

IRIS Newsletter

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National Science Foundation funds IRIS-2000

After a comprehensive, year-long review, the National Science Board (NSB), the governing body of the National Science Foundation, accepted the recommendation of the NSF Director to expand support of the IRIS Consortium for the next 5 years - 1996-2000.

The IRIS-2000 proposal was submitted to NSF Earth Sciences Division, Instrumentation and Facilities Program, in August 1995. It was initially reviewed by seventeen *ad hoc* mail reviewers. A Special Emphasis Panel of six experts then met in October and submitted a consensus report of their review and recommendations. The proposal was also reviewed by the standing panel of the Instrumentation and Facilities Program at its October meeting. The wrap-up stage of the external review process was a summing up by NSF staff of the concerns expressed in review in the form of eleven questions that were formally submitted to IRIS. All major programs at NSF require approval by the National Science Board and, as the final stage of review, the full IRIS-2000 package of reviews and recommendations was presented to this body in July, 1996.

With solid support from NSF over the next five years, the primary responsibility of IRIS will be to continue to operate and expand the Global Seismographic Network, the PASSCAL portable instrument pool and the Data Management System and proceed with a modest program of proposed initiatives such as telemetry and shallow imaging, as outlined in the IRIS-2000 proposal and prioritized by the membership of the Consortium. NSF has also expressed

its strong encouragement for expanded IRIS participation and leadership in programs of education and outreach in the Geosciences.

The funding profile recommended by the National Science Board authorizes a step increase in funding for FY97, from the current average of approximately \$8M per year to \$12.5M per year. Support for capitalization of the Global

research and monitoring related to a Comprehensive Test Ban Treaty. NSF and IRIS are working with the USGS, our partner in operation of the GSN, to ensure a similar increase in internal USGS funding for their participation in the GSN.

The NSB recommendation also approves non-NSF funding of up to \$31.5M. This authorization allows IRIS to seek outside support of proposed initiatives primarily in ocean bottom seismology and the expansion of selected GSN stations to more versatile geophysical observatories capable of accurate and continuous geodetic, geomagnetic, gravity and barometric measurements.

In funding the IRIS Consortium and its programs for the next five years, NSF gives a clear statement of the confidence it has in the seismology community, through IRIS, to continue to lead the development of programs and facilities for the support of exciting and vigorous scientific research. To all of you who participated in the development of the IRIS-2000 proposal, the Consortium extends its sincere thanks. To those of you who will make use of the resources that IRIS provides, we invite your continued advice and encouragement. •

RESOLVED, that the National Science Board approves the making by the Director, at his discretion, of a grant, contract, or other arrangement with the Incorporated Research Institutions for Seismology, in the amount not to exceed \$60,400,000 of National Science Foundation funds and not to exceed \$31,500,000 through Interagency or other Agreements, under the direction of Dr. David W. Simpson, for a period of 60 months.

Resolution adopted by the National Science Board - July, 1996

Seismographic Network through the Department of Defense ended in 1996. The increased NSF funding in FY97 represents a commitment by NSF to enhance its support for the operation of IRIS facilities, primarily the GSN and DMS, because of their contribution to

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Quantifying the Recovery of Global Teleseismicity

Michael Wyession, Washington University

The current configuration of plate boundaries, continents and islands results in a limited teleseismic sampling of global seismicity. Using a simple algorithm, this geographical sampling as a function of distance can be quantified, as shown in Wyession [1996]. Because seismic investigations of different regions within the Earth require recordings of teleseismic phases that have very particular distance ranges, this quantification can be a useful tool in the selection of existing data or the placement of future temporary arrays.

The ability to recognize which geographical regions receive different seismic phases becomes especially relevant with respect to the proliferation of PASSCAL deployments of broadband instruments. Experiments are being planned to investigate particular regions within the Earth with particular seismic phases. For example, the Missouri-to-Massachusetts (MOMA) array had a mapping of core-mantle boundary structure using core-diffracted waves as one of its objectives. MOMA was guaranteed to record many good P_{diff} and S_{diff} arrivals because of its geographical placement in relation to the seismicity of the southwest Pacific rim, which dominates global seismicity. The MOMA station locations receive on average 53% of the world's large earthquakes in the $100^\circ - 140^\circ$ range, which is good for receiving P_{diff} and S_{diff} . This is much better than the 30% expected for an average geographic location. This can be demonstrated by the following technique.

We start with a database representative of global seismicity. We use all events (5250) in the National Earthquake Information Center catalog for an arbitrary 20-year period (1963-1992) with $m_b \geq 5.7$. This magnitude was chosen because we found it to be a minimum for providing good teleseismic core phases. Other values would work just as well. We then compute the number of these earthquakes that would be recorded under ideal conditions in particular distance ranges for each point on the globe (we actually use a $1^\circ \times 1^\circ$ grid). So, for instance, we determine where on Earth would be the best place

to record the most P_{diff} waves by showing where you would be $100^\circ - 140^\circ$ from the most large earthquakes.

In the article on MOMA in this issue by Fischer et al., the P_{diff} data shown span about $105^\circ - 120^\circ$, and Figure 1 shows a map of the percentages of global seismicity recorded in this distance range. The two geographical ranges that record the most earthquakes in this range are the southern Atlantic Ocean (extending up into central Africa) and northeastern North America. MOMA was ideally suited to record P_{diff} and S_{diff} waves.

The same analysis can be applied to

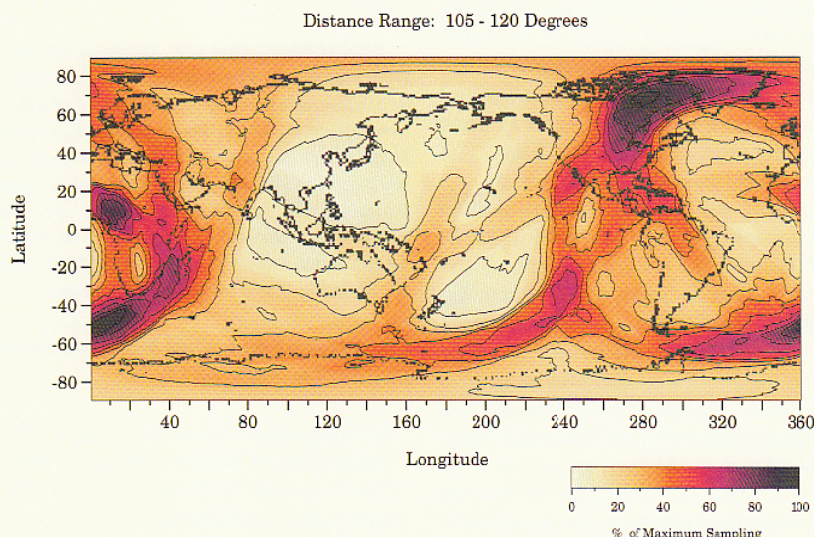


Figure 1. A geographical sampling map for the $105^\circ - 120^\circ$ range, corresponding to a good distance to record core-diffracted P_{diff} and S_{diff} phases. Values shown are the percentage of earthquakes that would be recorded at a given location, in relation to the maximum value, which occurs in the southern Atlantic Ocean. We use the data base of 5250 large ($m_b \geq 5.7$) earthquakes during 1963-1992, taken from the National Earthquake Information Center catalogs.

This issue's bannergram: The bannergram on this issue's cover is the vertical velocity record of a mine collapse near the Ural mountains on January 5 1995. The event was recorded at the Arti (ARU) GSN station in the Ural Mountains. The record was passed through a 0.2 to 0.6 Hz bandpass filter. On page 2 is a synthetic seismogram in red of the same event, and on page three are both the observed data (in black), and the synthetic seismogram (in red). The inversion indicates a dipolar compressional source consistent with a mine collapse. Because standard discrimination methods indicate that this magnitude 4.4 seismic event was not created by an earthquake, it has considerable interest among the nuclear monitoring community.

any distance range, and in Wyss [1996] the images such as Figure 1 are given in terms of 20° distance ranges ($0^\circ - 20^\circ$, $20^\circ - 40^\circ$, etc.). We show two more examples here for particular phases. Many investigations of the core-mantle boundary rely on studies of the S_{cd} and P_{cd} phases, which are refracted by a velocity increase at the top of D'' . These phases arrive between the S and S_{cs} (or P and P_{cp}) in roughly the $70^\circ - 90^\circ$ range, which corresponds to the geographical sampling region shown in Figure 2. Studies like Lay et al., (1996) have taken advantage of the good sampling by western North American stations. Studies like Weber [1993] utilized the good sampling in Europe. However, the latter region of good sampling also extends across Europe into the Middle East, which has not been utilized for this phase. Antarctica is also ideal for recording in the $70^\circ - 90^\circ$ distance range.

Studies of the inner core rely heavily on the differential phases of the DF and BC branches of PKP. The distance range required is from 145° , where PKP-BC begins, to at least 152° , where PKP-BC begins to diffract around the inner core. A geographic sampling map for the $145^\circ - 175^\circ$ distance range is shown in Figure 3. Unlike the previous examples, however, the best station sites for these phases are not on land. While much of eastern South America and western Africa receive large numbers of PKP-BC phases, many more are received in the mid-Atlantic region. Should a MELT-style linear array ever be installed across the mid-Atlantic ridge, it would also be ideal for providing a high-resolution examination of one particular region of the inner core, guaranteed to record many earthquakes at the necessary distances.

The same application can also be used in a reciprocal sense, where we look at the strengths of digital networks in particular distance ranges. We can take

the existing network of IRIS stations and examine the teleseismic strengths of individual stations, or even the network as a whole, in being able to record earthquakes at different distances. Figure 4 shows the percentage of global seismicity recorded by a network of 97 digital stations reporting to IRIS (including GSN stations, the GTSN in the southern hemisphere, and the China network), plotted with respect to an average network. The zero line represents the average number of earthquakes recorded as a function of distance by an evenly distributed network. It is a function of the planet's spherical geometry. For example, we would expect many fewer earthquakes to be recorded in the $170^\circ - 180^\circ$ range than for the

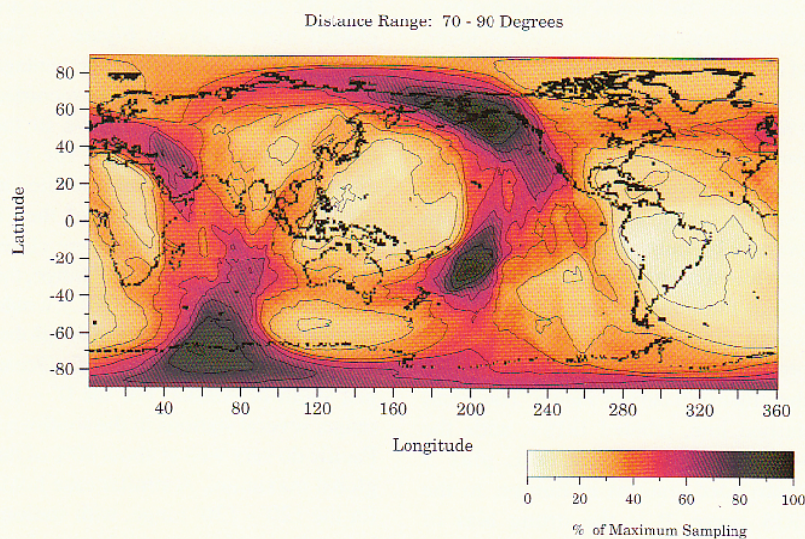


Figure 2. Same as Figure 1, but shown for the $70^\circ - 90^\circ$ range, corresponding to the distance required to examine D'' using S_{cd} and P_{cd} phases.

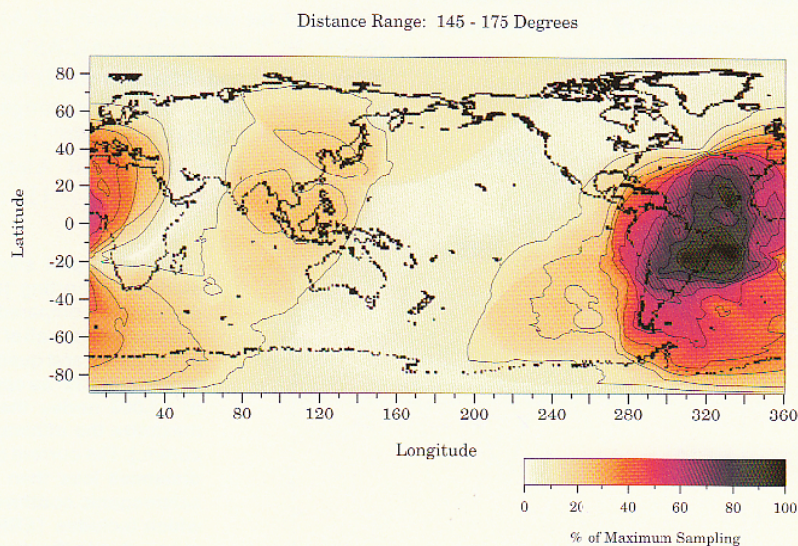


Figure 3. Same as Figure 1, but for the $145^\circ - 175^\circ$ distance range, corresponding to the distances needed to examine core structure using the different branches of PKP.

80° - 90° range because of the much smaller planetary surface that this range allows. This global average was obtained for a grid of 40,002 nodes that maximizes the minimum distance between nodes, providing a near-1.0° spacing between all adjacent nodes [N. Sloane, pers. comm.]. The values of the curves represent the mean number of earthquakes, as a percentage of the total seismicity that would be recorded by a network station compared to the mean of an ideally global network. A value of +1% means that the network recorded 1% more of the global seismicity in a particular distance range than the ideally global network. The performance of IRIS is never better or worse than average by more than 1%, a sign that it provides a reasonably global sampling. While there are regions of better and worse coverage, the IRIS network provides a more even distribution than the other two curves shown. The small dashed line, labeled IRIS+, adds the stations of TERRASCOPE plus 5 contributed stations in Europe, to the IRIS curve. It is the strong bias of Californian stations that biases the shape of the curve, giving it large values in the 70° - 120° distance range. The large-dashed line in Figure 4, labeled OBS, is for a proposed set of permanent ocean-bottom seismometers. These sites were

chosen to bolster the existing network and provide a more global coverage. It is encouraging that the strengths and weaknesses of the geographical sampling of these sites very nicely complement those of the existing IRIS stations; in particular, in the 50° - 75° and 130° - 150° ranges.

We can also look to see how individual stations fare as a function of distance. The 132 stations used in Figure 4 are plotted individually in Figure 5. The vertical axis is now given as a percentage of the number of earthquakes recorded by a particular station relative to the best location on the Earth for that distance range. No station is located at the very best place for any of the 18 distance ranges, but several are close. For example, for the 80° - 90° range, the station in College, Alaska (COL), would receive 90% of the arrivals of the global maximum, which is in the Pacific Ocean just south of Alaska. For the 0° - 10° range, several stations in the southwest Pacific do very well at about 80% of the global maximum. A similar case holds for the 120° - 130° range, with stations in southern Africa receiving at about 70% of the maximum. For some of the other distance ranges there are one or two stations that clearly do better than the rest of the network: Guam (GUA) for 20° - 30°, Casey, Antarctica (CASY), Adak (ADK) and Afiamalu (AFI) for 60° - 70°; Rarotonga (RAR) for 70° - 80°; Flin Flon (FFC) and Alert (ALE) for 100° - 110°;

Godhaven (GDH) and Santo Domingo (SDV) for 110° - 120°; Namibia (TSUM) for 130° - 140°; Sondre Stromfjord, Greenland (SFJ) for 140° - 150°; and Brasilia (BDFB) and Dimbroko (DBIC) for 160° - 170°; and Pitinga, Brasil (PTGA) for 170° - 180°. The network as a whole is far below average for recording antipodal phases. The hat-like structure formed from many similar profiles (low at both ends, large in the middle) results from the preponderance of Californian stations. This type of analysis can be used to quantify the number of events expected to be recorded by a given station (or locations) over a given time period, and would therefore be important information for the proposal of a PASSCAL deployment that is geared toward the passive recording of particular teleseismic phases.

While the quantifications shown here are enlightening, their usefulness only goes so far. No information is provided about the azimuthal distribution of the received earthquakes (though an attempt at this was made by Wyss et al. [1996]). It may not be sufficient just to record lots of a particular phase - broad geographical coverage may be more important, as with tomographic studies. Additional constraints may also be required, such as the distribution of three-dimensional paths for studies of inner core anisotropy. This approach also gives no indication of the number of useful data that can actually be recorded (e.g., island stations are noisier

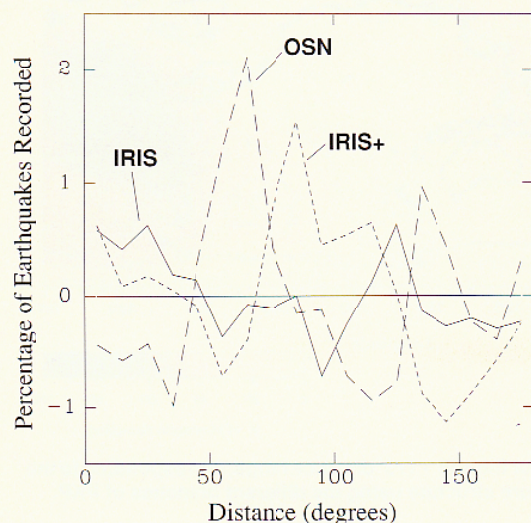


Figure 4. A plot showing how well the global network of digital stations (reporting to IRIS) records teleseismicity at a range of distances, compared to an average value. The average that is subtracted from all of the curves is a result of the spherical geometry of the Earth, and quantifies the increase in surface area for distance ranges near 90° as opposed to 0° or 180°. It is determined from a grid of 40,002 nodes that cover the globe in such a manner as to maximize the minimum distance between nodes [N. Sloane, pers. comm.]. The current network (solid line) does better than average at distances less than about 50°, due to the many stations in the seismogenic southwestern Pacific regions. The short-dashed line, which includes TERRASCOPE stations, does well in the 70° - 120° range, due to the many stations in North America. The dashed line is a set of 25 proposed ocean bottom sites that would complement the land-based network [R. Butler, pers. comm.]; this does a good job of compensating for the weaknesses of the current network.

than continental stations), or value judgements about the politics of site selections (many non-unique land stations will still cost much less than one uniquely-located ocean bottom station). Nonetheless, many digital seismometers will be deployed in upcoming years, both permanent and temporary, so it is important to know what we can expect these stations to receive in the way of teleseismicity.

Acknowledgments: I thank N. Sloane (Bell Labs) for providing his models of global node spacings, and R. Butler for providing a list of proposed OBS sites.

References:

Lay, T., E. J. Garnero, C. J. Young, and J. B. Gaherty, Scale-lengths of shear velocity heterogeneity at the base of the mantle from S wave differential travel times, *J. Geophys. Res.*, submitted, 1996.

Fischer, K. M., M. E. Wyssession, T. J. Clarke, M. J. Fouch, G. I. Al-eqabi, P. J. Shore, R. W. Valenzuela, A. Li, J. M. Zaslów, The 1995-1996 Missouri to Massachusetts Broadband Seismometer Deployment, *IRIS Newsletter*, 1996.

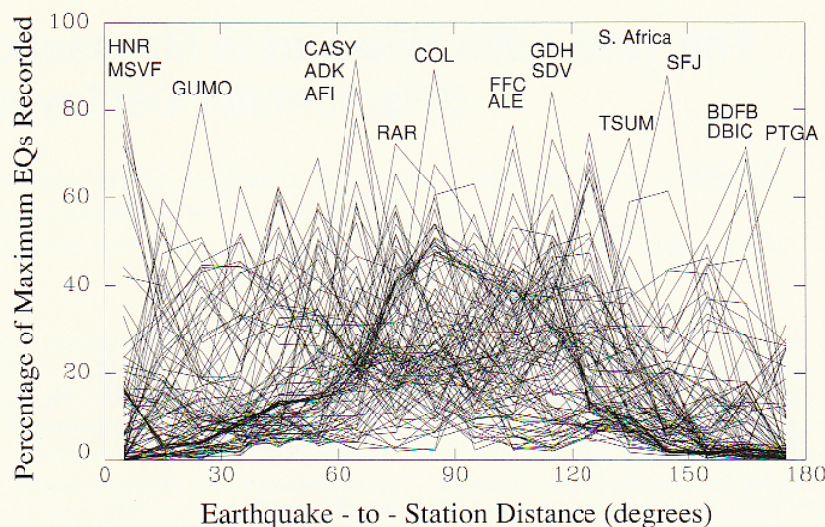


Figure 5. Similar to Figure 4, only now showing the profile for each station of the IRIS "network" separately. The values are the number of earthquakes recorded by a given station normalized as a percentage of the number of earthquakes received by the best location for each distance. The hat-shaped often-repeated profile is from the many stations in California. The stations that are labelled are the ones that do appreciably better at particular distances than the rest of the network.

Weber, M., P and S wave reflections from anomalies in the lowermost mantle, *Geophys. J. Int.*, 115, 183-210, 1993.

Wyssession, M. E., How well do we utilize global seismicity, *Bull. Seismol. Soc. Amer.*, in press, 1996. •

Defense Terminates Science Program

Stan Dickinson

Air Force Office of Scientific Research

Dated 22 January 1996, the Department of Defense Comptroller has issued a program decision that removes funding for seismology from the Air Force's budget plans for the Office of Scientific Research and the Phillips Laboratory Geophysics Directorate. The decision immediately affects fiscal year 1997, beginning 1 October 1996; no reinstatement of funding is anticipated in the out years.

Thus ends an era of significant Defense investment in scientific investigations in seismology engendered by nuclear weapon testing and the monitoring of treaties promulgated to control or prohibit nuclear tests. The recognition that

seismic research is essential to detecting and identifying nuclear detonations is in its 40th year. Air Force budgets supporting detection research predate that by about 10 years. During a large part of that era, the science of seismology has been the beneficiary of \$4-6 million per year in grants and contracts managed by AFOSR and the Geophysics Laboratory.

On the eve of the end of an era, it is fitting to recall the influence of Defense support. Especially high on any list of reminiscences is Bill Best supporting "his kids" with DARPA funds. Those "kids" are now the movers and shapers of the seismology enterprise. The impact of science on rendering underground tests transparent is well documented.

The ultimate result, the recently drafted CTBT, stands as a singular monument to the success of seismic investigations. However, there is much more to relate: in the lexicon of Washingtonese, the 'dual use' of results from seismic research are legend. Plate tectonics, wavelets, Earth structure, Earth dynamics, the Global Seismographic Network, the IRIS Data Management System, technological advances in single station operations and array analyses: all of these create an encyclopedia of accomplishment in large measure deeply rooted in the science supported by the Defense Department.

It has been a proud, productive era of discovery. •

The 1995-1996 Missouri to Massachusetts Broadband Seismometer Deployment

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Data collected by the Missouri to Massachusetts (MOMA) broadband seismometer deployment are now beginning to enhance resolution of several fundamental aspects of mantle velocity structure: the seismic character of the core-mantle boundary, the detailed structure of the upper mantle beneath the eastern United States, and the properties and extent of subducting lithospheric slabs. In the MOMA experiment, 18 portable broadband seismometers were deployed in a roughly linear array between the

permanent IRIS/GSN stations at Cathedral Caves, Missouri (CCM), and Harvard, Massachusetts (HRV) (Figure 1); 16 of the instruments were borrowed from the IRIS/PASSCAL program. The array spanned a wide variety of tectonic provinces including the Illinois Basin, the Appalachian Plateau and Range, and the Triassic rifts and older orogenic structures of New York and New England.

Because of limitations on instrument availability, array deployment occurred in two phases between January and

March of 1995, and the stations remained in place through March of 1996. Station spacing was roughly 90 km and stations were located on a variety of public and private lands. All sensors (7 Guralp CMG-3T's and 11 Streckeisen STS-2's) were sited in sub-surface vaults, and most vaults extended to local bedrock, except in areas such as the Illinois Basin where shallow, stable rock of any kind was in short supply. Extensive drainage trenches and pipes were installed in several vaults to prevent recurrent flooding. Figure 2 shows a

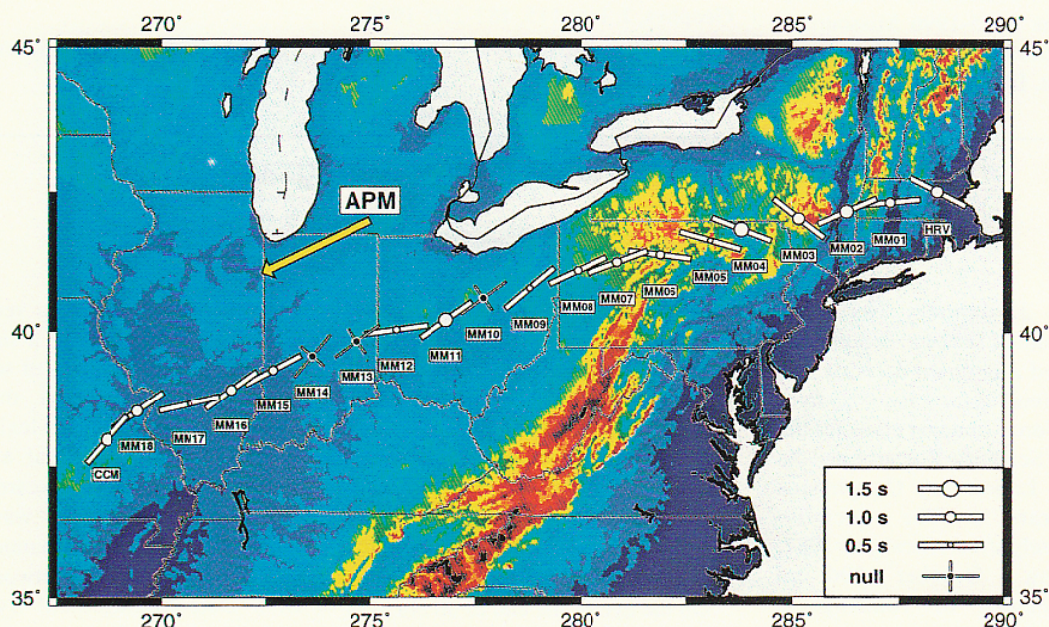


Figure 1. The stations of the MOMA array and IRIS/GSN stations CCM and HRV with shear-wave splitting parameters determined for teleseismic SKS, SKKS, and PKS phases from roughly 25% of the MOMA dataset. Colored shading indicates topography. Values shown for fast directions and splitting times are weighted averages of individual shear-wave splitting measurements. Fast directions are shown by the azimuth of the bar plotted at the station; splitting times are represented by circles scaled to the magnitude of the splitting time. Stations marked by crosses are those at which no shear-wave splitting has yet been resolved, and the directions of these crosses represent the average backazimuth and its corresponding perpendicular direction of unsplit phases. The yellow vector indicates the absolute motion of the North American Plate. The shift in fast direction pattern between MM07 and MM05 coincides with the eastern margin of the thick continental root imaged in shear-wave velocity models [Grand, 1994; van der Lee, 1995].



Figure 2. View of MM04 (LeRaysville, PA). The black box contained the DAS, SCSI disk, and two marine batteries. The sensor was located in a buried vault roughly 8' behind the solar panels. The photo also shows Brown University students Matthew Fouch, Julie Zaslow and Aibing Li (right to left) in the process of demobilizing the station. MM04 was located in a field behind the LeRaysville Cheese Factory which made it a very popular stop on array maintenance trips.

typical station configuration. Data were collected by Reftek 72A-08 DAS's in continuous streams at 20 sps and 1 sps; the 1 sps stream was used primarily for efficient data quality checks. External timing was provided by a mix of GPS and Omega clocks. Two stations (MM05 and MM06) were equipped with experimental communication units that permitted DAS's to be accessed via local telephone lines. These units were effective in monitoring station status and data quality, and proved very useful during

the severe weather of the 1995-1996 winter.

Analyses of MOMA data have begun at each of the three participating institutions. One particular goal of the array design was to densely sample the central- and circum-Pacific core-mantle boundary (CMB) with phases such as P_{diff} , S_{diff} , PKP, SKS, SKKS and SPdKS. Because of the distribution of global seismicity, the MOMA stations recorded roughly twice as many earthquakes in the 100° - 140° distance range as the average global station

location. The better resolution of radial and lateral variations in P- and S-wave velocity structure afforded by these broadband records should help to address several questions regarding the nature of the CMB. Is CMB heterogeneity primarily chemical or thermal in origin? Does the CMB contain the signature of subducted slab material or nascent mantle plumes? Is the CMB partially molten or anisotropic?

The ability of the MOMA array to achieve a new level of resolution of the CMB is demonstrated by the core-diffracted P (P_{diff}) arrivals for the Kermadec earthquake of July 3, 1995 (Figure 3a). Core-diffracted waves experience a dispersive effect that, like surface waves, is a result of the radial structure of the mantle; the high frequencies sample close to the CMB and the lower frequencies sample higher into the mantle. However, unlike surface waves, core diffracted phase dispersion is very small and hard to measure. A long linear array with stations at distances of more than 100° and sharing a common azimuth is required to accurately determine the dispersion. The dispersion appears in Figure 3a as the change in slope (slowness) of the arrivals as a function of frequency. The Kermadec earthquake is a good example of southwest Pacific seismicity recorded by the MOMA array. The distance range for this event is 104.9° - 120.5° , but the azimuth range is only 54.6° - 55.7° . Figure 3b shows the dispersion

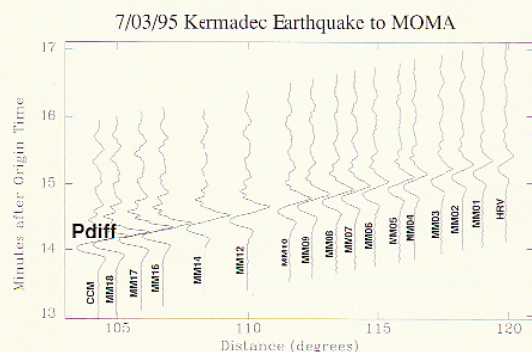


Figure 3a. Vertical component record section containing P_{diff} arrivals for the Kermadec earthquake of July 3, 1995.

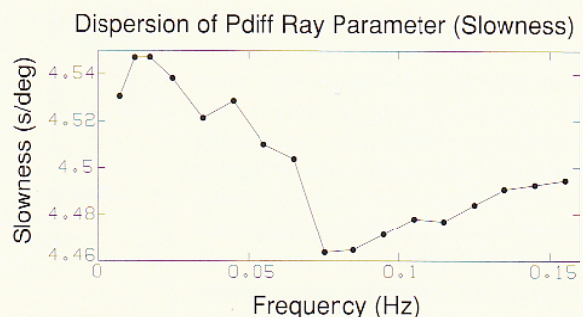


Figure 3b. Dispersion of P_{diff} slowness for the Kermadec earthquake.

of the P_{diff} slowness for the Kermadec earthquake. With 17 stations going into the determination of these slownesses, the standard error is very small. The P_{diff} times are not yet corrected for mantle heterogeneity along their upswing paths (they all share the same downward mantle path), so the absolute slowness values are biased by trans-U.S. crust and mantle structure. However, the frequency effects along these mantle paths are of second order compared to the CMB dispersion, so the shape of the curve in Figure 3b is robust. It is interesting to note that there is a slowness minimum at mid-frequencies. While synthetic modeling remains to be done, early indications are that this trend is compatible with an increase in velocity at the top of D", with slower velocities above and below. This result is in agreement with the model of D" found using the amplitude decay of S_{diff} waves from the same earthquake [Wyssession et al., 1996], as well as for a nearby eastern Pacific region using triplicated S_{dS} waves [Garnero et al., 1993].

MOMA records for the August 23, 1995 Marianas earthquake illustrate potential resolution of different aspects of CMB structure (Figure 4). The SKS phase from this event is followed by an SP_{dKS} arrival which represents the coupling of SKS to P_{diff} . The move-out of SP_{dKS} relative to SKS is sensitive to P-wave velocities at the base of the mantle near the point where SKS either enters or exits the core. SP_{dKS} phases observed in long-period waveforms provide evidence for a thin (<40 km) very slow layer just above the core in the central-Pacific [Garnero and Helmberger, 1996]. This low velocity layer may represent a zone of partial melt [Williams and Garnero, 1996]. Initial modeling of the broadband SKS and SP_{dKS} phases in Figure 4 with reflectivity synthetic seismograms shows that the data are not well-matched by a standard PREM CMB structure, but are consistent with a very thin and slow layer at the base of the mantle just

to the east of the Marianas trench [Zaslow et al., manuscript in prep.]. Another intriguing development in the study of CMB structure is the growing evidence from S_{diff} and ScS phases for CMB anisotropy (most likely with a vertical symmetry axis). For instance, Kendall and Silver [1996] argue for shear-wave splitting of 3-9 s and anisotropy at an average strength of 1.8% in the CMB beneath the Caribbean. In contrast, the relative timing of the SH_{diff} and SV_{diff} waveforms in most of the Figure 4 records rules out splitting of more than 1-2 s, indicating that anisotropy in the north central-Pacific CMB region sampled by these data probably varies from weak to non-existent. Further modeling of data for this earthquake and other events recorded by MOMA stations should aid in mapping variations in the strength of CMB anisotropy and in determining the thickness and lateral extent of a low

velocity boundary layer between the mantle and core.

The MOMA array also recorded numerous large intermediate- and deep-focus earthquakes in Central and South America, and these data should help to pin down the geometry and extent of lithospheric slabs subducting beneath the Caribbean and South America. For instance, intermediate-focus earthquakes in Colombia generated clear body-wave phases that largely miss the lithosphere currently subducting beneath South America, but travel through a slab-like high-velocity anomaly that has been imaged in the lower mantle beneath the Caribbean [cf. Grand, 1994]. The MOMA records contain strong ScS S and $sScS$ -sS travel-time anomalies that are consistent with the existence of a subducted slab to great depth in the lower mantle, and they also manifest large variations in amplitude and waveform complexity.

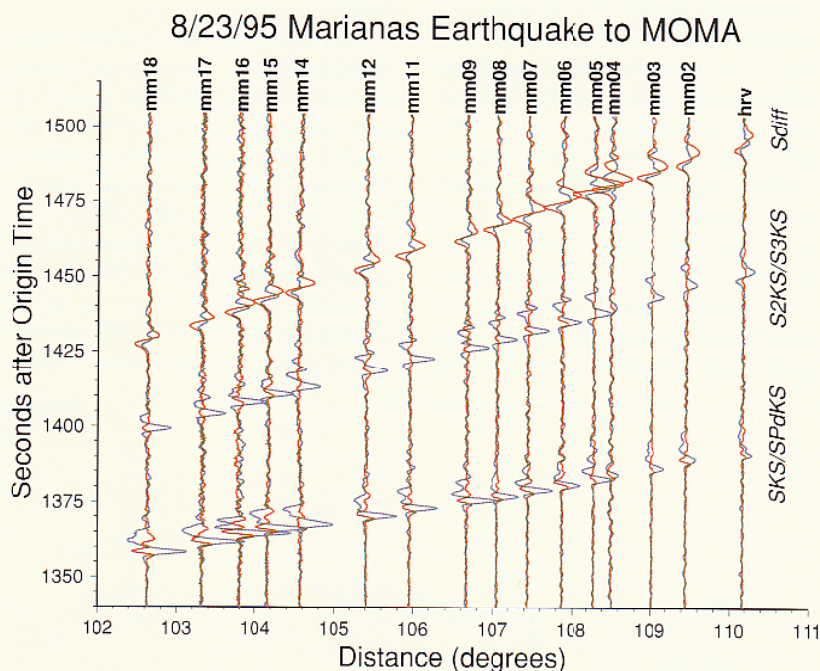


Figure 4. Horizontal component record section for the Marianas earthquake of August 23, 1995 (depth = 595 km). Radial component is plotted in blue; transverse component is plotted in red.

We plan to model body waveforms from these and other South and Central American events using reflectivity, CORE [Clarke, 1993], and Fourier method synthetic seismograms in order to enhance resolution of the width and dip of the lower mantle Caribbean slab anomaly and clarify its interaction with the CMB.

Finally, broadband waveforms recorded by the MOMA array will also enhance models of mantle structure beneath eastern North America. Studies now underway include receiver function analysis and inversion of body-wave seismograms using the CORE method to constrain crustal structure and mantle discontinuity depths, inversion of fundamental and higher mode surface waves to image upper mantle heterogeneity, and shear-wave splitting analysis. Better constraints on the radial and lateral distribution of seismic anisotropy in continental regions of the upper mantle would shed light on the dynamics of deep continental deformation, in particular the degree of coupling between thick continental roots and the surrounding mantle. Images of upper mantle shear-wave velocity structure contain high velocities to depths of more than 300 km beneath the interior of the North American continent [Grand, 1994; van der Lee, 1995], and the eastern margin of this fast continental root intersects the MOMA array in the vicinity of MM07-MM04. This major transition in mantle structure coincides with a shift in the pattern of observed shear-wave splitting fast directions obtained from teleseismic core phases (SKS, SKKS, PKS, etc.) [Fouch et al., 1996] (Figure 1). Core phases recorded at stations from MM07 to the west yielded fast directions that are roughly parallel to each other (the average 95% confidence limit for fast direction is $\pm 15^\circ$) and that lie within 20° of the direction of absolute plate motion determined from the HS2-NUVEL1 plate motion model. In contrast, from

MM06 east to HRV, fast directions follow a more variable rotating pattern. These splitting measurements are in general consistent with the findings of previous studies over length scales of ~ 100 km [Barroul et al., 1996; Levin et al., 1996], but the more densely spaced MOMA stations in northern Pennsylvania, southern New York and New England document a much stronger variation in fast direction orientation than is apparent in earlier work. To better resolve the distribution of anisotropy with depth, we are investigating splitting in Ps conversions from crustal and upper mantle discontinuities through modeling of radial and transverse component receiver function stacks. We plan to synthesize core phase and Ps splitting results to distinguish between models in which anisotropy is primarily produced by lithospheric deformation and models in which anisotropy is also caused by asthenospheric flow around the margin of a mechanically strong continental root.

Acknowledgments. We would like to thank the many people at IRIS who made this experiment possible, and special thanks go to Carl Ebeling, Paul Friberg, Sid Hellman, Bob Busby and the entire staff of the PASSCAL Instrument Center at Lamont-Doherty Earth Observatory for their assistance with the field deployment and data management. We would also like to recognize the many private and public land owners who allowed us to build stations on their property, and Tom Owens and Francis Wu for their helpful advice. Funding for this project was provided by the National Science Foundation.

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National Academy of Sciences Begins Study on *The Science of Earthquakes*

Charles Meade, National Research Council

Recent earthquakes in California and Japan have demonstrated the devastating consequences of seismicity in large urban areas. Together, the Loma Prieta, Northridge, and Kobe earthquakes resulted in approximately 5100 deaths, \$130 billion in property damage, and incalculable social disruption. Unfortunately, these were not unusual seismic events. Throughout the world each year, there are approximately 17 earthquakes with magnitudes greater than that of Loma Prieta (6.9). Similar or larger earthquakes near U.S. cities are certain to occur in the future.

Over the past 20 years, scientific research on earthquakes has contributed greatly to our understanding of these seismic hazards. Networks of seismographs have recorded the locations and frequencies of earthquakes, along with detailed measurements of strong ground motion close to seismic sources. The evolving field of paleoseismology has provided new data on earthquakes with extremely long recurrence intervals. Multi-disciplinary research efforts across a wide range of fields are utilizing new technologies to study the physical processes associated with earthquakes. These include remote sensing and geodesy to measure ground deformation, high performance computers for detailed modeling, and laboratory measurements on mineral properties.

Two recent government reports have called attention to the disparity between the state of knowledge regarding earthquake processes and the level of seismic mitigation efforts. One of these studies (*Reducing Earthquake Losses*, Office of Technology Assessment) characterizes this problem as the "implementation gap." Solving the problem, the report concludes, will require important policy decisions regarding the balance of federal support for earthquake science research. The

second study (*Strategy for National Earthquake Loss Reduction*, White House Office of Science and Technology Policy), outlines a new strategy for interagency coordination on earthquake research and mitigation. It is notable that neither of the studies assesses the contributions of earthquake science to date, nor do they articulate a future role for scientific research.

To address this problem, the National

Academy of Sciences has initiated a study entitled *The Science of Earthquakes* to strengthen the role of scientific research in seismic hazard mitigation strategies and to enhance the interface between earthquake scientists and engineers. This study has two principal goals. First, it will produce a primary reference document incorporating a consensus review of the scientific understanding of earthquake processes. This information was conspicuously absent in the recent OTA and OSTP reports, and it is clearly needed to establish the role of scientific research in a new national earthquake policy. For users of earthquake

information, such a document could be an important reference for assessing the credibility and applicability of research results. Also, by framing the important research problems, the document would be valuable to the community of scientists. At present the field of earthquake science extends beyond the boundaries of seismology, and there is a need to integrate the efforts of the many researchers outside of the Earth sciences and the concerns of hazard mitigation. Finally, by strengthening and organizing the work of the research community, such a document would contribute to the ongoing efforts to enhance the interface between earthquake scientists and engineers.

Second, the study will strive to engage a broad cross section of scientists and engineers in an ongoing dialog to articulate the roles and responsibilities of earthquake science and engineering in the national effort to reduce earthquake losses. It is intended that this process will produce a "feedback" effect. As the engineering community learns of the results of earthquake science, it can refine its requests for data products to support mitigation efforts. At the same time, as scientists begin to understand the needs of the engineering community, research efforts can be shifted to more rewarding areas.

To begin a review of accomplishments of earthquake science, the committee is seeking input and participation from a broad cross-section of the research community. A web page has been set up at <http://www2.nas.edu/eqsci> to provide updated information on the study and to provide a public forum for discussion and input regarding the committee's work. The committee is also convening a Union session on the Science of Earthquakes at the Fall meeting of the American Geophysical Union. Symposia at future professional meetings are being planned. •

Committee on the Science of Earthquakes

Thomas H. Jordan, Chair	MIT
Gregory Beroza	Stanford
C. Allin Cornell	Stanford
C.B. Crouse	Dames & Moore
James Dieterich	US Geological Survey
Arthur Frankel	US Geological Survey
David D. Jackson	UC, Los Angeles
Arch Johnston	Memphis State
Hiroo Kanamori	CalTech
James Langer	UC, Santa Barbara
Marcia McNutt	MIT
James R. Rice	Harvard
Barbara A. Romanowicz	UC, Berkely
Kerry Sieh	CalTech
Paul Somerville	Woodward-Clyde
	NRC Staff
Charles Meade	Study Director

PASSCAL High Resolution Equipment Demonstrated at IRIS Workshop

With funding from the Department of Energy, Office of Basic Energy Sciences, IRIS has embarked in a new direction with the purchase of a 60-channel high resolution seismograph system manufactured by EG&G Geometrics. The instrument is equipped with a roll-along switch, cables with 5m takeouts, and 40 Hz geophones for high-resolution shallow reflection profiling, and with cables with 33m takeouts and 4.5 Hz geophones for fixed spread crustal recording. The Geometrics has an LCD screen display and some internal processing capability which permit a near real-time view of the data being collected, making it an excellent educational, as well as research, instrument. Delivered in late November 1995, the new instrument has been in almost continuous use, and is currently scheduled through the autumn of 1996. A second instrument, also purchased with DOE funding, will be available for field use in the fall of 1996.

The instrument has now been used in a variety of seismic reflection and

refraction investigations of the shallow subsurface including a tomography experiment in west Texas conducted by UTEP, a 3-D reflection investigation of the Wasatch Fault on the University of Utah campus, and a 2 D transmission tomography and reflection experiment in an open pit copper mine in New Mexico by Rice. US Geological Survey seismologists have used the equipment in reflection investigations of shallow faulting in Portland, Oregon, and for reflection/refraction investigations of groundwater resources and groundwater flow paths in Flagstaff, Arizona. Future projects include investigations of shallow faulting in the San Francisco Bay region by the USGS, and tracking deeper faults to the surface in the Tucson Basin, Arizona by the University of Arizona.

The different surveys have utilized a variety of sources ranging from weight drops and sledge hammers, to 12 and 8 gauge shotguns, to small dynamite (0.5-1.0 kg) charges.

At the recent IRIS Annual Workshop

at Blaine, Washington, an IRIS/USGS demonstration of the new Geometrics seismograph drew about 35 observers. Using a 12 gauge shotgun source provided by the USGS, participants were able to map a 70m deep reflector in the survey area. Also at the Blaine Workshop, Tom Pratt of the USGS held a High Resolution Seismic Imaging Special Interest Group (SIG). Discussion focused on several key issues related to shallow investigations. These included the design criteria for a new portable simple instrument (the "Walkman" seismograph) for active source seismology and shallow imaging applications, the availability of seismic reflection processing systems for the IRIS community, the purchase of horizontal component geophones for shear wave recording and sources for the high resolution seismic system, and the possibility of IRIS' acquisition of a ground penetrating radar unit to complement the Geometrics unit.

Alan Levander, Rice University



Bill Stephenson of the U.S.G.S. demonstrates the use of a shotgun source in Shallow Seismic Profiling.



Data acquisition recorder for the new IRIS shallow imaging system.

Eighth Annual IRIS Workshop



Participants at the Eighth Annual IRIS Workshop*

The Eighth Annual IRIS Workshop was held June 19-23, 1996 at the Inn at Semi-ah-moo, on Puget Sound near Blaine, Washington. More than 200 IRIS members, friends and family attended the Workshop and joined in the activities. The wonderful weather, serenity of Puget Sound and surrounding beach life, with Mount Baker in the distance made Semi-ah-moo an ideal setting. The Inn provided the ultimate in ambiance, service and accommodations - together a wonderful blend for scientific exchange and conversation, as well as relaxation.

The Workshop was preceded by a two day Short Course on The Use of Relational Databases in Seismology at the IRIS Data Management Center in Seattle. On the trip from Seattle to Blaine, about 20 Workshop attendees joined in a fieldtrip led by Brian Atwater and Steve Malone, visiting sites of paleoseismic evidence for prehistoric earthquakes in the Puget Sound and Seattle area. On arrival at Semi-ah-moo a demonstration of the new IRIS multi-channel, high-resolution equipment was held for those interested in seeing the field set-up for collecting a typical shallow imaging profile.

Scientific Sessions

Pacific Northwest/Cascadia - The first technical session of the IRIS workshop was devoted to the tectonics and structure of the Pacific Northwest.

The first two talks provided the tectonic setting and geologic evidence for giant thrust earthquakes along the Cascadia subduction zone. Roy Hyndman presented an elastic strain model for the subduction zone based on geodetic data and thermal modeling to define the extent of the locked and partially locked part of the subduction zone. The zone is wide in the northern part off the Washington coast and narrow but closer to the coast off southern Oregon and northern California. If the whole modeled locked zone slipped in one earthquake it could have a 25m slip and generate a $M_w=9$ earthquake. Brian Atwater followed with a description of the geologic evidence for great megathrust earthquakes over the past 3500 years including the most recent event of 300YBP. A comparison of the buried marshes and soils along the Washington coast with those observed at the sites of recent large earthquakes (Alaska, Peru) is consistent with the latest event being a very large ($M_w=8+$) earthquake.

John Nabelek explored the detailed geometry of the deeper part of the descending Juan de Fuca plate slab. A review of several different types of seismological investigations points out details of the slab geometry along strike. In particular, recent receiver function studies using arrays of broadband seismographs shows an undulation of the slab. As a transition from the detailed

structure of the subduction zone to crustal tectonics, Gene Humphreys used an interesting approach by discussing what the Cascadia subduction zone does not do. He suggests that the subduction zone provides a window through which North America can escape. Pacific - North America relative motion is partially accommodated by distributed deformation throughout eastern California and the Basin and Range province. The northern part of this deformation must step back to the west to merge with the continental margin in a sequence of structures consistent with this model.

Separate presentations covering the crustal structure in the Cascadia forearc and under Puget Sound were given by Anne Trehu and Thomas Pratt. In the first case, several major PASSCAL type refraction, wide-angle reflection lines image the major crustal structures both parallel and perpendicular to the Cascade range as well as on- and off-shore. In the second case a series of marine reflection profiles in the Puget Sound provide direct evidence for shallow crustal faults in Neogene sedimentary rocks.

The final talk of this session by Chris Fox described the developing hydroacoustic technology to locate small shallow submarine earthquakes using the Navy's SOSUS arrays. At least two swarms of earthquakes along the Juan de Fuca ridge recently have been detected and located in near real-time

providing information for cruises to the swarm site to confirm sea floor volcanic eruptions. This technology may provide the capability to significantly improve earthquake catalogs of the ocean basins.

Western North American Margin – This session provided the opportunity to synthesize what has been learned about the structure and dynamics of the western margin from a remarkably large number of seismic reflection and refraction investigations along and within the western margin of North America. These experiments have been conducted since the mid 1980's, by groups from the United States and Canada, with the goals of investigating the geologic signatures resulting from the plate tectonic processes shaping North America's western margin. These studies have improved the resolution of crustal features by orders of magnitude, have probed the structure of the margin throughout the entire crust and into the uppermost mantle, and in the process imaged the crustal architecture along transects through the margin. Seismic reflection/refraction investigations have now been conducted from the Salton Trough, at the southeastern end of the



Opening Reception*

San Andreas transform fault, along the length of the San Andreas to the Mendocino Triple Junction, throughout the Cascadia subduction zone, in the Queen Charlotte strike-slip system and the accreted terranes of southeastern Alaska, in the southern Alaska and Aleutian subduction zones, and across the Bering-Chukchi Sea.

Advances in tomographic imaging using teleseismic signals, coupled with the utilization of teleseismic data from fixed seismograph arrays and portable PASSCAL instruments, have allowed a similar increase in resolution of the 3-D structures within the mantle which both drive the plates and result from collision, subduction, and transpression. Although less geographically extensive than the active source investigations, these mantle studies are exciting as they allow us, for the first time, to associate the causes of crustal deformation, seen in the active source experiments, with mantle behavior. The most detailed upper mantle studies have come from analysis of the teleseismic data recorded on the California and Cascadia short period earthquake networks, however, the deployment of dense PASSCAL arrays has also contributed significantly to the images of the upper mantle being constructed for the western margin.

The session included overviews of the plate tectonic development of the western US strike slip and subduction system, the seismic imaging experiments which have refined thinking

about strike-slip and subduction kinematics and dynamics, recent experiments to image the accreted terranes and island arcs in Alaska, and ended with an historical review of the western margin as the proving ground for theories of the earthquake source.

Joann Stock emphasized the roles that Farallon fragmentation and subsequent microplate accretion have played in development of the western strike slip system, which was complemented by Tom Brocher's discussion of microplates and detachments imaged by San Andreas transform system experiments. George Zandt in turn described mantle imaging of the Cascadia subduction zone and the California strike-slip system, noting both the gross similarities and pronounced local differences in the seismic images of the two regimes and attributing the differences to smooth laminar flow in the subduction environment and convective instability in the subduction free, transform regime. Greg Beroza provided an historical overview of development of earthquake source theory from Reid's elastic rebound theory through modern satellite investigations of strain accumulation, underscoring the importance of the western margin database and the interplay between the parallel developments in understanding of the earthquake source, earthquake occurrence, and regional tectonics.

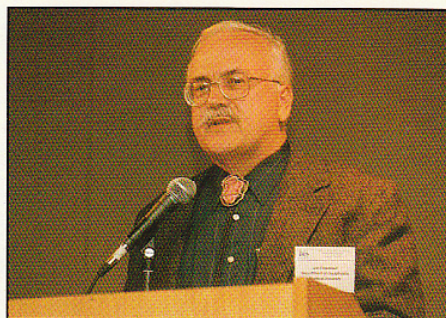
Bob Butler described the modern



Poster Session*

tectonist's view of western North America as a collage of exotic terranes of variable size, some of which are far traveled along the western margin. Ron Clowes described the Canadian transect extending from the Pacific Ocean basin across the Cascadia subduction zone and the Canadian Rockies to Calgary. This is the first integrated active source seismic endeavor to understand the entire western margin as a single tectonic entity, and one which encompasses a large number of the far traveled terranes. Sue McGeary provided an overview of early results from three experiments in Alaska designed to investigate details of terrane accretion and continental construction, the structure of island arcs, and continental orogenesis.

Potpourri of Scientific Issues – The third scientific session provided a radial trip from the crust to the core, beginning with deformation and structure in the continents, and proceeding through the mantle to the core. Chris Marone led off with a look at failure at the earthquake source from the perspective of experimental rock mechanics. While friction laws have been developed to explain most of the observations under controlled conditions in the lab, there are still major challenges in scaling these results to the size and complexity of natural fault systems. The evolution of continents, from island arcs to cratons, was the subject of a talk by Doug Nelson. He showed how recent seismological studies have led to revised views of the development of continental lithosphere and discussed types of combined geophysical experiments that could lead to further understanding of continental evolution. Craig Bina described the complex chain of phase changes that occur in the transition zone of the upper mantle and their influence on seismic velocity and changes in density. Thorne Lay and Michael Wyssession showed how recent data have improved the resolution of structure in the deep mantle and the core, especially the complex region near the core-mantle boundary. The session ended with a presentation



Speaker, Jon Claerbout*

by Xiadong Song of recent work with Paul Richards on how decade-scale temporal changes in travel times provide evidence for rotation of the inner core. This type of slow temporal changes in Earth properties points out the need for stable, long-term observations in seismology.

Posters, SIGS, Talks and Trips

In addition to the scientific sessions, the Workshop included opportunities for informal discussion around posters and computer demonstrations and in SIGs (Special Interest Groups). Poster displays and demonstrations were as popular as ever - with an increasing demand for more display area. Posters described a wide variety of projects based on the use of IRIS facilities and provided platform for discussion of future projects. Demonstrations of the facilities provided by PASSCAL and the DMS helped new members and students become familiar with the resources available from these IRIS programs. SIGs were held on portable instrumentation, shallow imaging and western US structure and seismicity. Evening sessions included an exploration of "Future Directions for Research and Funding in Seismology", with representatives from NSF and the USGS, and a discussion of recent developments in monitoring a Comprehensive Test Ban Treaty.

This year saw the

introduction of meal-time speakers to the Workshop. Jon Claerbout from Stanford showed how innovative use of command scripts for developing graphical presentation of results can aid in "Making Scientific Computation Reproducible". Dan Kohn from Teledesic provided a fascinating view of how, early in the next century, broadband global satellite systems may be able to collect and transmit data from remote field stations, at costs low enough to make it possible to collect continuous real time data from seismic stations anywhere in the world.

Although the late snowmelt on Mt. Baker detoured one scheduled field trip, hikers were not disappointed by the substitute trek, judging from their tired smiles. The other field trip by boat around the San Juan Islands proved a restful interlude - but unfortunately, no whales! Dave Engebretson from nearby Western Washington University provided an illustrated introduction to the boat trip along with lively commentary from the bridge as the cruise progressed.

Program Chairs for the Workshop were Alan Levander, Steve Malone and Gene Humphreys. •

* Photographs courtesy of Michael Hasting, Naval Air Weapons Station, China Lake, CA. For copies of these and other photographs, you may contact Michael Hasting at the following: mike@geowiz.chinalake.navy.mil



San Juan Island Boat Trip*

IRIS Consortium Member Logo

As you know, the web is quickly becoming the interface of choice in the science community for gathering important information and data acquisition. We hope by now you have had a chance to view our ever-expanding web site. Many of you have a link to our site on your home pages already. We now have a special IRIS Consortium Member logo that we would like to offer to those members with web sites. You can use it on your page to signify your membership and/or as a button to link to the IRIS home page. You can download the logo from this site:

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We sincerely hope that you choose to use this logo on your site and, in exchange, let us know your site address so we can add you to our site list. •

Deborah Barnes, Webmaster, IRIS DMC

IRIS Employee News

Rhett Butler was a member of the US delegation to the Conference on Disarmament ad hoc Group of Scientific Experts (GSE) meetings in February, May, and August in Geneva, Switzerland, as an Observer for the US Arms Control and Disarmament Agency.

Gregory van der Vink has been elected a Delegate to the British-American Project, sponsored by the Royal Institute of International Affairs at Chatham House and the Paul H. Nitze School of Advanced International Studies at Johns Hopkins University. Greg has also been appointed to the AGU Committee on Public Affairs. •



The IRIS Newsletter is published quarterly by The IRIS Consortium. Please address your letters or inquiries to:

IRIS Newsletter

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The Incorporated Research Institutions for Seismology (IRIS) is a consortium of over 80 research institutions with major commitments to research in seismology and related fields. IRIS operates a facilities program in observational seismology and data management sponsored by the National Science Foundation. Major funding for IRIS programs is provided by the National Science Foundation through its Division of Earth Sciences and the Air Force Office of Scientific Research.

The IRIS Newsletter welcomes contributed articles. Articles should be less than 1000 words and four figures. Please send articles or requests for submission of articles to the address listed above.

Executive Editor: David Simpson (simpson@iris.edu)
Production Editor: Anne DeLaBarre Miller (anne@iris.edu)

New PASSCAL Datasets Available

Antarctic Crustal Profile

PASSCAL Data Set 96-010: Uri ten Brink and Jie Zhang, USGS and WHOI

New England Broadband Experiment

PASSCAL Data Set 96-009: Vladimir Levin and William Menke, Lamont Doherty Earth Observatory

Mendocino Array Experiment

PASSCAL Data Set 96-008: Bruce Beaudoin, John Hole, and Simon Klemperer; Stanford University

Seismic Explosion Experiment at Landers

PASSCAL Data Set 96-007: Y.G. Li and Keiti Aki, University of Southern California

Landers After Shocks

PASSCAL Data Set 96-006: Y.G. Li and William H.K. Lee, University of Southern California, USGS

PMP Reflections Beneath the San Bernadino Mountains, CA, from Landers After Shocks

PASSCAL Data Set 96-005: Tom Henyey and Y.G. Li, University of Southern California

For more information please refer to the IRIS DMC electronic bulletin board (telnet [iris.washington.edu](http://www.iris.washington.edu) userid = bulletin password = board) or World Wide Web Server (<http://www.iris.washington.edu/datasource.html>) •

GSN Update

Seven new GSN sites have been installed since the last Newsletter.

The IRIS/IDA team (University of California, San Diego) has completed two borehole sites at EFI, Mt. Kent, Falkland Islands, in the South Atlantic and at CMLA, Cha de Macela, Azores, in the North Atlantic and a new vault site at RAYN, Ar Rayn, Saudi Arabia. The RAYN site currently uses only STS-2 sensors, but will be upgraded later with a borehole KS54000 system.

The IRIS/USGS team (Albuquerque Seismological Laboratory) has completed three new vault sites at CASY, Casey, at an Australian base in Antarctica; SFJ, Sondre Stromfjord, Greenland; and KMI, Kunming, China. The SFJ site is a cooperative joint station with the German GEOForschungsNetz (GEOFON). The KMI site is cooperative joint station with the New Chinese Digital Seismographic Network (NCDSN). IRIS/USGS also completed a new borehole installation at COLA, College International Geophysical Observatory, Alaska; replacing the COL site which has been closed. •

Calendar

1996

- Oct. 14-18 AAAS and Intl. University of Kyrgyzstan: Mountain Research - Challenges and Directions for the 21st Century Bishkek
- Nov. 10-14 Society of Exploration Geophysicists Denver, Colorado
- Dec. 15-19 American Geophysical Union, Moscone Center San Francisco, CA
- Dec. 16 IRIS Board of Directors Meeting Yank Sing Restaurant, San Francisco, CA

New Members

IRIS welcomes as a new member, Texas Tech, Harold Gurrola, Representative. IRIS also welcomes as new foreign affiliate members: University of British Columbia, Michael Bostock, Representative; University of Otago, Helen Anderson, Representative; and Institute of Geophysics, Beijing, PRC, Gowgwei Zhou, Representative. •

IRIS Board of Directors Meeting

***MONDAY* December 16, 1996**

The Annual Reception and Meeting of the IRIS Board of Directors will be held during the AGU meeting in San Francisco.

Note – because of changes in the AGU schedule, the meeting will be held on Monday evening, not the traditional Tuesday.

The location is Yank Sing Restaurant, 427 Battery Street, a short walk from the Moscone Center. The reception will begin at 6:00PM and feature traditional Chinese dim sum and a cash bar. The Annual Meeting will start at 7:15PM and include a report of IRIS activities, election of new Executive Committee members and other business. A formal announcement of the meeting will be sent to all institutional representatives on the Board of Directors. •

An IRIS DMS Short Course

A short course on Synthetic Seismograms using the Direct Solution Method (DSM) will be taught by Phil Cummins of ANU on December 13 and 14 at Stanford University. Students will learn the theory as well as gain hands-on practical experience at running a code that they can take home with them. Interested Parties can learn more about the course through the WWW at

URL=<http://www.iris.washington.edu/FORMS/dms.shortcourse.html>

Registration is available through the WWW at

URL = <http://www.iris.washington.edu/FORMS/register.form.html>

or contact the IRIS DMC at (206) 547-0393 or kris@iris.washington.edu to have a registration form faxed to you. The hands on portion of the course will be limited to 20 people so early registration is advised. The deadline for registering is **November 15, 1996.** •

High Resolution Seismic Reflection Short Course

A two day short course on high resolution seismic reflection techniques, given by Don Steeples, will be held in the San Francisco area on December 13-14, 1996 prior to the Fall AGU Meeting. It is designed for PT's who have little or no experience in this area, but who would like to utilize the new PASSCAL multi-channel reflection acquisition system. In order to provide maximum "hands-on" experience, the course will be limited to 20 students. A limited amount of financial support will be available for attendees. Registration requests should be submitted by filling in the form on the PASSCAL Web site (<http://www.iris.edu/passcal/course.form.html>). For further information contact Jim Fowler at the IRIS Headquarters (jim@iris.edu). •



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