The IRIS Proposal, 1991-95

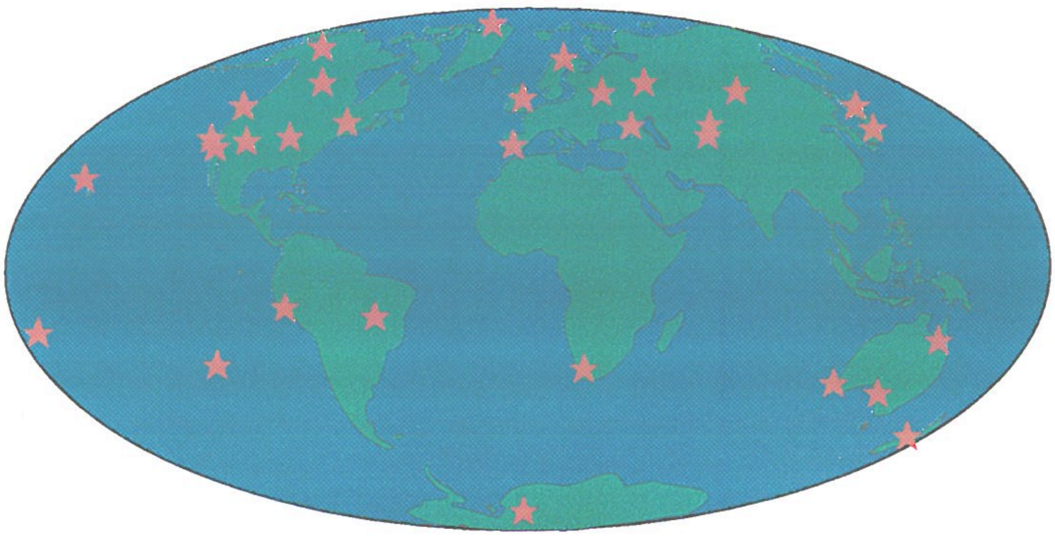
Understanding the Earth's Dynamics and Structure

Strategy and Implementation Plan

the Global Seismic Network

the Program for Array Studies

the Data Management System



I. Introduction

Objectives of the IRIS Program

The IRIS Consortium is composed of 70 universities with research programs in seismology. It was created to provide the new generation of seismic instrumentation needed to image, in detail, the interior of the Earth and further our understanding of the earthquake process. The goals of the IRIS Program include the completion of the following projects:

- A Global Seismographic Network of 128 modern, very broadband, standardized, digital seismic stations with a spacing of 2000 km around the world. They are to provide real-time telemetry of the data to the IRIS data archive.
- Modern portable seismic (PASSCAL) instruments, composed of 1550 field recording units with a total of 6000 recording channels, with ancillary sensors and field computer support.
- A Data Management System for the collection, archiving, and timely distribution of the new seismic data to the research community.

The IRIS research facility will meet the experimental needs of over 1000 research geophysicists and geologists at over 70 universities across the nation. It will also assist colleagues in government research, and in other countries. The facility is a key part of the new Global Geosciences initiative in the NSF.

Our primary source of motivation is the great contribution which seismology can make, given adequate data, to our understanding of the Earth. Seismology can probe the internal structure, from the shallow crust to the inner core, and reveal the complex processes involved in earthquake ruptures, volcanic eruptions, and underground explosions. High quality observations are critical to this ability. Current data acquisition systems, using antiquated technology, desperately need to be upgraded and replaced.

The IRIS Consortium has completed an initial 5-year program that focused on development of hardware and software for the Global Seismographic Network (GSN), the Program for Array Studies (PASSCAL), and the Data Management System (DMS). Prototype implementation of these key facilities is now complete. Scientific discoveries are already being made with the new high quality data. These discoveries, many of which are described in Section II of this proposal, serve as promising harbingers of the scientific returns anticipated.

The IRIS Consortium also responds to new opportunities consistent with the program's objectives. For example, IRIS developed a program to deploy modern instrumentation in the Soviet Union; and, following the 1989 Loma Prieta earthquake, IRIS created a special initiative to coordinate the planning of the university research community in the field of earthquake research. Our earthquake initiative is directed at maintaining coherence between the IRIS instrumentation programs and national earthquake monitoring networks which are under the oversight of the U. S. Geological Survey.

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Summary

The Earth's deep interior remains a major scientific frontier. Inaccessible for direct observation beyond a few kilometer's maximum drilling depth, the Earth's crust, mantle and core are studied primarily through seismic wave illumination. Modern seismological imaging, along with geophysical fluid dynamical modeling and geochemical observations, will revolutionize our views of the Earth's interior structure and associated geodynamical processes.

The IRIS program's first five years has seen significant advances in our understanding of Earth dynamics and structure. It has also witnessed the training of a new generation of research scientists. Seismic tomographic methods, some using digital data from the IRIS Global Seismographic Network and Passcal arrays, have greatly improved our images of the Earth. Intriguing insights into the heterogeneity of the inner core have resulted from the analysis of free oscillation splitting. There is striking evidence for the existence of new mantle discontinuities, and the absence of others proposed earlier, as suggested from stacking and averaging of global digital data. The installation of temporary broadband stations has provided new constraints on the anisotropy of the uppermost mantle and the history of the continental lithosphere. These, and many other discoveries, have been made using modern, broadband, digital global and portable seismic stations which form the new observational basis for scientific progress.

The implementation of the IRIS instrumentation program for 1991-95 is critical to our continuing understanding of the Earth. It will offer high resolution, high capability access to the Earth's interior, and to the earthquake process. It will be, in effect, the Earth scientists' counterpart to the telescope facilities shared by astronomers. Just as advances in telescope technology are essential for progress in space science, the instrumentation and networks proposed are vital to the health of seismology, and all the Earth sciences.

Background

The IRIS consortium was founded in 1984 by 22 universities to serve as a national focus for the development, deployment, and support of modern digital seismic instrumentation. Now in its fifth year of funding by the National Science Foundation, it has a membership of 70 institutions, and has begun to deploy instruments and support facilities developed under this first phase of IRIS activity.

The purpose of the IRIS program is to provide national facilities for the study of the dynamics and structure of the Earth's interior. These instruments make possible enormous qualitative and quantitative strides in our ability to resolve details of geophysical significance, in imaging the Earth's internal structure, and in the patterns of seismicity for tectonic activity.

The cornerstones of the IRIS program are the instrumentation programs.

> The goal of the *Global Seismographic Network* (GSN) is to contribute to the establishment of at least 128 modern, very broadband, standardized, digital seismic stations with a spacing of 2000 km around the world, and providing real-time telemetry of the data to the IRIS data archive.
>
> The *Program for Array Studies of the Continental Lithosphere* (PASSCAL), has the goal of establishing a national resource of about 6000 channels of high performance portable digital seismic recording.

The *Data Management System* (DMS), the third basic element of the IRIS program, has the goal of providing the community with timely, convenient access to seismic data from the two programs. It will archive and distribute GSN and PASSCAL data, and facilitate data exchange and standards.

The Data Management System has benefitted enormously from technological advances in data storage, data processing, and networking, and has evolved into a functional archive and service center for members of the scientific community needing seismic data.

Science Plans for GSN and PASSCAL were prepared in community-wide workshops in 1984, and have served as both the science rationale, and the operating plan for IRIS in its first five years of funding. This proposal is prepared in the context of these original plans. We assert that the scientific rationale, the examples, and the program plans contained there remain valid today. We also assert that achievements of IRIS during its first five years have followed these original plans quite well, except for timing, which was affected by a lower than originally anticipated level of funding.

The 1984 IRIS Science Plans

Plan for a New Global Seismographic Network

PASSCAL: Program for Array Studies of the Continental Lithosphere

Accomplishments of the IRIS Program 1985-90

The Global Seismographic Network: The GSN has developed two lines of standardized stations employing very-broadband (VBB) sensor technology. Network operating facilities are now in place at the U.S. Geological Survey Albuquerque Seismological Laboratory, and the IRIS/IDA headquarters at Scripps Institution of Oceanography of the University of California, San Diego. By the end of 1990, 31 VBB stations will have been installed, returning data to the IRIS archive.

Through the *Eurasian Seismic Studies Program (ESSP)*, a cooperative effort of IRIS, the U. S. Geological Survey, and the Institute of Physics of the Earth in Moscow, and funded by DARPA, at least 13 stations are to be established in the Soviet Union. IRIS operates the ESSP program because of its role in establishing near-uniform global coverage of digital seismic stations, and in fostering new experiments in array and network seismology and data telemetry, using state-of-the-art instrumentation.

The Program for Array Studies: Passcal has developed a line of 6-channel, standardized, portable dataloggers to serve as the backbone of the national capability. The first of several planned Instrument Centers has been established at the Lamont-Doherty Geological Observatory, with 90 dataloggers now in place. The instruments have been used in a variety of experiments since the first delivery in August, 1989.

Prototypes for a second line of compatible, less expensive, 3-channel dataloggers have been ordered. These should play a major part in experiments where number and density of sensors are critical, and will support individual investigators and educational programs.

The rapid deployment of Passcal instruments following the 17 October 1989 Loma Prieta earthquake has emphasized the role of portable instruments in providing badly needed capabilities for dense deployment and rapid response within the National Earthquake Hazard Reduction Program.

Field experiments during the past year have demonstrated the capability of these instruments in several very different applications: (1) Recording of offshore airgun shots in a crustal refraction profile; (2) Recording of teleseisms on a 1500 km array of 3-component stations; (3) Participation in teleseismic studies of crustal structure in Kenya; (4) Testing of a tight 2-D array for monitoring the propagation of high frequency regional phases; (5) Rapid response deployment of instruments for recording aftershocks of the Loma Prieta earthquake.

Workstations for field support and data management of Passcal data have been developed, based on SUN hardware. These computers are incorporated routinely as an essential part of Passcal data acquisition programs.

The formidable, practical difficulties of managing portable instruments and data flow in the field have been greatly reduced by the hardware and software standardization, and the existence of a central support organization.

The Data Management System: The IRIS Data Management System manages data flow from the Data Collection Centers (DCC) to the archive, followed by distribution to the scientific community. It includes nodes for data collection at Albuquerque Seismological Laboratory and the University of California, San Diego, and a central archive at the Center for High Performance Computing of the University of Texas, Austin. Through Internet, it extends to the data users, and to European users via the ORFEUS data center in the Netherlands. The archive is unique in the world in its commitment to archiving all GSN and FDSN *continuous* data streams at 20 sps. It has been functional for over six months, and is now handling user requests in excess of the estimates made in a 1986 design study for the steady-state load on a fully implemented GSN.

Through dial-up and telemetry facilities at certain GSN sites, the DMS collects major-event waveforms in near-real-time, and provides this information to the community through the GOPHER software interface.

Special datasets from important earthquakes and from field deployments of Passcal instruments have been compiled and are distributed upon request.

The DMS is a focus for the support and distribution of application and utility software.

Cooperating Agencies and Organizations: These programs have been carried out through the participation of a variety of agencies and research institutions, and of many individual scientists from the member Universities.

The U.S. Geological Survey (USGS) is a partner with IRIS in the implementation of the GSN. IRIS members of the IRIS University Network operate stations and networks in cooperation with the USGS U. S. National Network and the National Earthquake Hazards Reduction Program.

Internationally, IRIS is a member of the Federation of Digital Seismographic Networks, in which national programs for deployment of VBB digital instrumentation are coordinated.

USGS provides earthquake information and digital data that complement the continuous data archive and distribution services of the IRIS DMS.

The Eurasian Seismic Studies Program (ESSP) involves the cooperation of the USGS, the (Soviet) Institute of Physics of the Earth, the Defense Advanced Research Projects Agency (DARPA), and a number of University participants.

IRIS facilities are implemented through subcontract to Universities. At present, such efforts are in place at the University of California, San Diego, the University of Texas, Austin, Columbia University, and Lawrence Berkeley Laboratory.

Oversight and Management: Governance of IRIS is in the hands of Committee members from the research community. IRIS is managed through a small staff with headquarters in Arlington, Virginia. Each member institution has one representative on the IRIS Board of Directors, which has legislative control of the Consortium. The Executive Committee, representing the Board of Directors, makes overall policy, and Program Standing Committees provide regular input by the research community into the program operations.

The IRIS Plan for 1991-95

Authorization: In this proposal, IRIS requests funding authorization for the five year period through 1995.

Scientific Justification: The scope and strategy of the IRIS plan arises out of the critical role played by modern facilities in the cutting-edge of scientific research, reaching across a broad spectrum of interests. The *IRIS Science Review: Impact*, a companion volume to this Proposal, contains essays and examples which illustrate in some detail this critical role. The larger importance of the IRIS facilities is expressed by the *Report of the Workshop on Continental Dynamics: CD/2020*. This study by a representative group of all Earth sciences, urged the importance of 3-dimensional geophysical studies of the whole Earth in understanding the processes which shaped the evolution of the continents. Along with the study of the Earth's surface environmental change, the questions underlying continental dynamics are among the most fundamental ones now being addressed. These involve, in different ways, all of the Earth science specialties, from geochemistry to geology, to geophysics.

Acquisition of detailed direct data on the mantle/continent system dominates the list of needs by the large community studying continental dynamics. The IRIS facilities are designed to serve these needs.

Funding for most experimental projects, particularly those requiring the deployment of arrays, falls outside the scope of IRIS. Within the NSF, the Seismology Program and the Continental Dynamics Program have responsibility for funding scientific initiatives which require the use of the IRIS facilities.

Programmatic Justification: A major justification for use of a centralized organization is the need for standardization. The availability of large amounts of data is not in itself an advancement, unless these data can be efficiently brought to bear on scientific problems. Individual seismic traces are of limited interest; it is often necessary to work with data sets with a large number of traces. Without some assurance of technical quality and uniformity, the data users would be faced with an impossible job. Furthermore, no individual or small organization could manage the task. By moving the technical facilities and support costs for the science to a central operator, the incremental cost to the individual PI's is more rationally based on their specific manpower and scientific needs.

The IRIS principal goals for this period are to complete the basic IRIS facility as defined by the 1984 proposal, to make continued improvements in its service functions, and to promote cutting-edge scientific research into the dynamics and structure of the Earth, using seismic observational tools.

The required facilities are:

- A global network of 128 Very Broad Band stations, adequately sited at low-noise sites in a broad distribution, 80% funded by IRIS, with 20% of the coverage from other networks.
- Data collection and data management facilities for the data recorded by these stations, and by a similar number of national and regional VBB stations.
- Establishment of real-time data collection and telemetry from a significant subset of the network.
- 6000 channels of total capacity in a pool of 1550 portable array instruments, with sensors and support equipment for the recording of signals from artificial sources, and from earthquakes in a number of experimental configurations.
- Provision of ancillary hardware and software to bring the data from both the global stations and the portable instruments quickly to the scientific laboratory.

Cost: The estimated five year cost of the IRIS program is about $87 million, of which 63% is for the capital acquisition costs of the basic facilities. Most of the remainder is for essential operating and maintenance activities.

Schedule: We strongly advocate the completion of the IRIS facilities in the next five years.

Why is this important?

1. The successful, complex, technical and logistical development of the past 5 years is designed for implementation in a full-scale program now. It is not technically appropriate for a program which would still be acquiring equipment 15 years from now.

2. Renewed emphasis on the National Earthquake Hazards Reduction Program requires expanded facilities which well exceed the needs envisioned in the 1984 IRIS plans.

3. Standardization requires that the facilities be brought up to strength quickly. Drawn-out programs lead to continual development, the antithesis of standardization.

4. Both the GSN and PASSCAL are integrated systems, together with the Data Management System. They should be complete.

    Uniform global coverage of GSN stations defines the design goals and the state of the art for a global imaging system.

    The most important imaging studies of crust, the mantle, and of earthquake sources, will require state of the art array performance. This requires 3-component data on a dense, 2-dimensional sensor array, as stated in the original 1984 PASSCAL Plan.

5. For both the imaging and earthquake source applications of the GSN, some of the most significant science comes from special events which are quite rare, one per decade or less. Delayed deployment means lost scientific opportunity.

    The very largest earthquakes are in this category. Large deep-focus events are rare, yet important for understanding the dynamics of the mantle. In the newly developed study of "slow" earthquakes, rare, large events represent an opportunity for some novel insights into the processes of plate dynamics.

IRIS Facilities: 5 year buildup

Five year total			Out yr. annual
	capital	operations	operations
GSN	$32.1m	$10.2m	$3.0m
Passcal	$21.4m	$10.8m	$3.7m
DMS	$1.8m	$7.7m	$2.1m
Administration	$0.2m	$3.3m	$0.7m
Total	$55.4m	$32.0m	9.4m

For the period of buildup, capital costs dominate the total costs.

Beyond the capital development of the facilities, most of the costs are for facilities operation: maintenance, routine upgrades, training, data distribution, and documentation.

The service goals of IRIS will involve efforts in communications, science planning, software, and other areas where coordination and professionalization of technical tasks can greatly increase the productivity of the scientific community.

IRIS development efforts will continue, although with a minor budgetary impact. Some flexibility is provided for continued technical development aimed at capabilities needed in later years.

Funding Alternatives: We request full funding for the three major IRIS facilities. However:

> ....Every new instrument added to the global network is important to the data acquisition needs of the science.
>
> ....Every new lot of 50 portable instruments provides an array which will be kept busy acquiring information about the Earth's interior and earthquake sources.

Funding at lower levels than requested will result in loss of many benefits of rapid implementation as stated above .

At funding levels below those of this proposal, proportionally fewer instruments will be available in five years.

> At $12 million per year, the GSN would achieve 70 stations in five years, and PASSCAL would have about 3300 channels... half the planned capacity.
>
> At $7.5 million per year, in 15 years the current IRIS funding would asymptotically approach 60 GSN stations and 3000 Passcal channels. At this point the cost of maintenance and operation would force the annual capital investment to zero. This budget option is clearly unwise because only about a 50% implementation of the facility would be achieved and so slowly that the instrumentation would be obsolete before completion of the 15 year program.

Initiatives outside the basic NSF support:

In its effort to promote seismic instrumentation in support of the needs of the community, IRIS becomes involved in initiatives which are not stated priorities of its facilities program with NSF. In order to insure that the priority facilities efforts are not diluted by new initiatives, such programs are undertaken only with supplemental support, and with the involvement of an interested constituency.

The Eurasian Seismic Studies Program: This will be a continuation of the support, now in its third year, from DARPA. The authorization request in this proposal includes an estimated $25M for the Eurasian Seismic Studies Program, which is funded through NSF, but not with NSF funds. The goals of this program are:

- Growth to 20 GSN stations in the USSR and its territories, while funding continues. Contraction will be required if the additional funding is reduced or eliminated.
- The array efforts in the Northern Caucasus and Kirghizia will be sustained near current levels.
- Completion of plans to implement data telemetry by satellite communications from the stations for data exchange between US and USSR data centers.
- Training of Soviet scientists and technicians in the operation and use of the facilities. Conversion to near 100% Soviet operational responsibility. Fostering of student and scientist exchange between the two countries through joint research and scientific meetings.
- Promotion of basic seismic research in areas of nuclear verification and nuclear nonproliferation.

The Committee on Earthquake Research: The newly appointed IRIS Committee on Earthquake Research has been given a two year lifetime and asked to devise (from the IRIS perspective) a national scientific strategy and justification for basic research in earthquake science. This effort is to adopt the entire scientific community's perspective, with the involvement of both university and government scientists. The strategy must involve the entire nation and include both tectonically active regions and stable cratonic regions. Initially it will be financed by the central office, but may seek incremental funding to carry out the needed study.

Ocean Science Initiatives: IRIS works closely with the coordinators of several new initiatives involving marine seismology. These entail a cost and scope which is comparable to the current IRIS plan, with a scientific constituency and funding offices outside of the Earth Sciences Division. Because of this, IRIS cannot incorporate these initiatives wholly within the present proposal which is concerned primarily with programs initiated in 1984. These programs include (1) reuse of the Guam-Japan marine undersea cable for scientific purposes, (2) the Ocean Seismic Network, for 20 seismic stations down ocean floor boreholes in the late 1990's, (3) the RIDGE program (4) the MARGINS program and (5) the EDGE program.

Education

Access to modern instrumentation and modern seismological data is the central goal of the IRIS program. This is critical to training students for advanced degrees in the Earth sciences. The decline in funding for earthquake science during the past five years has jeopardized educational programs in this field, while the decline in the fortunes of oil exploration companies has reduced student participation in related seismological research.

Yet rekindled interest in earthquake hazard studies, the increasing importance of monitoring nuclear nonproliferation pacts, the need for shallow geophysical imaging in waste management and cleanup, the drive to close the gap between long-term geodetic and short-term seismic measurements for global change, and other geophysical studies, demand a reinvestment in the geophysical research and teaching technologies. The efficient use of modern seismic instrumentation, the technologies for managing large data sets, and the long-term telemetry of remote global data dictates a need for qualified young scientists.

Few students are attracted to disciplines where research is stunted by obsolete equipment. With modern equipment, even small undergraduate projects can make significant scientific contributions. For instance, the study described in section II.32 of the *IRIS Science Review: Impact* was an undergraduate senior project that used a one-day deployment of five Passcal instruments. IRIS programs which offer modern tools to Earth scientists, touching virtually all universities in the U.S. with seismology interests, will excite cutting-edge interest in advanced technical education.

IRIS seeks greater involvement in outreach activities designed to improve the quality of high school and college-level science education, and the desire of students for careers in science.

About the IRIS Consortium

IRIS is a non-profit consortium of research institutions founded in 1984 for the purpose of developing and operating modern seismological facilities, for the distribution of data, and the promotion of research.

From the founding group of 22 Universities, membership has now grown to 70 Institutions (*Figure 1*).

Institution	*Director*
University of Alaska	Nirendra N. Biswas
University of Arizona	Terry C. Wallace, Jr.
Arizona State University	Chris Sanders
Boise State University	John R. Pelton
Boston College	John Ebel
California Institute of Technology	Hiroo Kanamori
University of California, Berkeley	Thomas V. McEvilly
University of California, Los Angeles	Paul M. Davis
University of California, San Diego	John A. Orcutt
University of California, Santa Barbara	William A. Prothero, J
University of California, Santa Cruz	Thorne Lay
Carnegie Institution of Washington, DTM	Paul G. Silver
University of Colorado, Boulder	Carl Kisslinger
Colorado School of Mines	Thomas M. Boyd
Columbia University	Paul G. Richards
University of Connecticut	Vernon F. Cormier
Cornell University	Bryan L. Isacks
University of Delaware	Susan McGeary
Georgia Institute of Technology	Leland T. Long
Harvard University	Adam M. Dziewonski
University of Hawaii at Manoa	Daniel Walker
University of Illinois at Urbana Champaign	Wang-Ping Chen
Indiana University	Gary L. Pavlis
Indiana University Purdue University at Fort Wayne	Dipak Chowdhury
University of Kansas	Ross A. Black
Lawrence Berkeley Laboratory*	E. L. Majer
Louisiana State University	Vindell Hsu
Massachusetts Institute of Technology	Thomas H. Jordan
Memphis State University	Jer-Ming Chiu
University of Michigan	Larry Ruff
Michigan State University	Kazuya Fujita
Michigan Technical University	Gordon E. Frantti
University of Minnesota	Francis R. Schult
University of Missouri	Joseph Engeln
University of Nevada, Reno	James Brune
University of New Orleans	Abu K.M. Sarwar
New Mexico Institute of Mining and Technology	John Schlue
New Mexico State University	James Ni
State University of New York at Binghamton	Francis T. Wu
State University of New York at Stony Brook	Dan M. Davis
University of North Carolina	Christine A. Powell
Northern Illinois University	Philip Carpenter
Northwestern University	Seth A. Stein
Oregon State University	John Nabelek
Pennsylvania State University	Shelton S. Alexander
Princeton University	Robert A. Phinney
Purdue University	Lawrence W. Braile

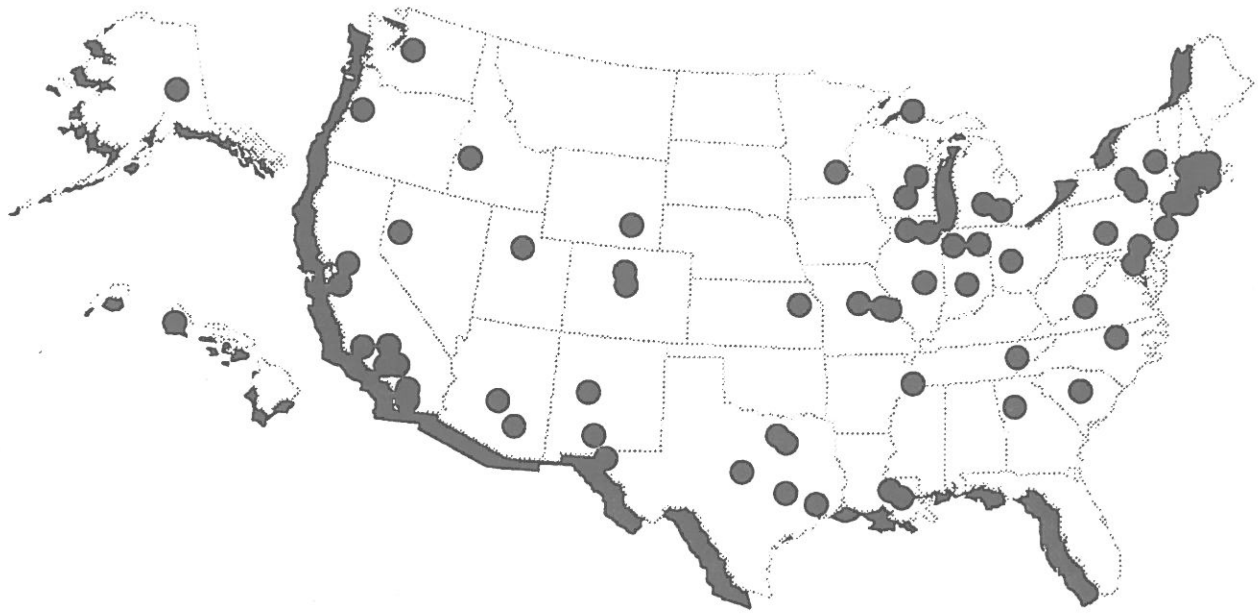


Figure 1. The IRIS Consortium—1990 Member Institutions

Rensselaer Polytechnic Institute	Steven Roecker
Rice University	Alan R. Levander
Saint Louis University	Brian J. Mitchell
San Diego State University	Steven M. Day
University of South Carolina	Pradeep Talwani
University of Southern California	Ta-Liang Teng
Southern Methodist University	Eugene T. Herrin
Stanford University	George A. Thompson
University of Tennessee	Richard T. Williams
Texas A&M University	Melvin Friedman
University of Texas at Austin	Arthur E. Maxwell
University of Texas at Dallas	George McMechan
University of Texas at El Paso	G. Randy Keller, Jr.
University of Utah	Robert B. Smith
Virginia Polytechnic Institute	J. Arthur Snoke
University of Washington	Robert S. Crosson
Washington University, St. Louis	Douglas Wiens
University of Wisconsin, Madison	Clifford H. Thurber
University of Wisconsin, Oshkosh	John Karl
Woods Hole Oceanographic Institution	G. Michael Purdy
Wright State University	Benjamin H. Richard
University of Wyoming	Scott B. Smithson
Yale University	Jeffrey J. Park

* Associate Member

IRIS Governance

IRIS Officers are elected by the Board of Directors on a two year rotation:

John Orcutt	Chairman
Paul Richards	Vice Chairman
Jeffrey Park	Secretary
Richard Williams	Treasurer

IRIS is governed by the *Executive Committee* of the Board of Directors, elected by the Board of Directors, with two year rotation.

John Orcutt	Larry Braile
Paul Richards	Paul Silver
Thorne Lay	Gary Pavlis
Clifford Thurber	Jeffrey Park

Program oversight is provided by the *Standing Committees*, appointed by the Executive Committee.

Standing Committee for the Global Seismographic Network:

Sean Solomon (chairman)	Jonathan Berger	Emile Okal
Don Forsyth (new chairman)	Stephen Grand	Charles Langston
Art Lerner-Lam	Don Helmberger	Kazuya Fujita
Robert Massé (ex officio, USGS)		

Standing Committee for the Program for Array Studies:

Larry Braile (chairman)	Tom Owens	Anne Trehu
Walter Mooney	David Okaya	Robert Smith
Paul Silver	David Simpson	

Standing Committee for the Data Management System:

E. R. Engdahl (chairman)	Shelton Alexander	Keith Nakanishi
William Menke	J. Bernard Minster	John Nabelek
Arch Johnston	Toshiro Tanomoto	Steve Malone
Cliff Frohlich		

The *Committee for the Eurasian Seismic Studies Program* was appointed in June 1990, to maintain oversight of the ESSP and liaison with the Standing Committees.

Paul Richards (chairman)	Charles Archambeau
Paul Silver	Jonathan Berger
Terry Wallace	David Simpson

The *Committee on Earthquake Research* was established June 1990, to coordinate a national plan for research in the field of earthquake science. Membership of this committee is currently being determined.

Since the founding of IRIS in 1984, the following members of the community have served as officers or committee members:

K. Aki	PASSCAL Standing Committee
Don L. Anderson	Executive Committee
Shelton Alexander	Executive Committee, Vice Chairman, DMC S.C. Chairman
Milo Backus	Data Management Standing Committee
Gilbert Bollinger	Corporate Secretary; PASSCAL Standing Committee
Larry Braile	Executive Committee, PASSCAL Standing Committee Chair
Rhett Butler	GSN Standing Committee
Robert Crosson	Data Management Standing Committee
F. A. Dahlen	GSN Standing Committee
Gregory Davis	PASSCAL Standing Committee
Adam Dziewonski	Executive Committee, GSN Standing Committee Chairman
William Ellsworth	PASSCAL Standing Committee
Freeman Gilbert	Executive Committee
Eugene Herrin	GSN Standing Committee
David James	PASSCAL Standing Committee
Lane Johnson	Data Management Standing Committee, Chairman
Hiroo Kanamori	GSN Standing Committee
Ken Larner	PASSCAL Standing Comm.; Data Management Stand. Comm.
Thorne Lay	Executive Committee; GSN Standing Committee
Alan Levander	Data Management Standing Committee

Peter Malin	PASSCAL Standing Committee
Robert Massé	GSN Standing Committee
Thomas V. McEvilly	Executive Committee, Chair; GSN Standing Committee
George McMechan	PASSCAL Standing Committee
William Menke	PASSCAL Standing Committee
Robert Meyer	PASSCAL Standing Committee
Brian Mitchell	Corporate Treasurer; GSN Standing Committee
John Orcutt	Executive Comm. Chair; Data Management Standing Comm.
Gary Pavlis	Corporate Treasurer, DMC Standing Committee
Robert Phinney	Exec. Comm., Chairman; PASSCAL Stand. Comm. Chairman
Larry Ruff	Data Management Standing Committee
Selwyn Sacks	PASSCAL Standing Committee
David Simpson	PASSCAL Standing Committee
Robert Smith	Executive Committee, PASSCAL Standing Committee
Stewart Smith	President
Seth Stein	Executive Committee
Fumiko Tajima	Data Management Standing Committee
Ta-liang Teng	Executive Committee, GSN Standing Committee
Clifford Thurber	Executive Committee; Corporate Secretary
Terry Wallace	GSN Standing Committee
John Woodhouse	Data Management Standing Committee

IRIS Management

IRIS is managed by a small professional staff:

Corporate Office:

Robert A. Phinney	President
Gregory E. van der Vink	Director of Planning; ESSP Program Manager
Elizabeth McDowell	Manager of Administration
Deanna Mann	Administrative Assistant

Program Managers:

Rhett Butler	Global Seismic Network
James Fowler	Program for Array Studies
Timothy Ahern	Data Management System

Technical Staff:

B. Sue Schoch	Senior Database Programmer
Rebecca Wofford	System Manager

IRIS Centers

IRIS facilities programs are carried out at field centers under subaward or other joint agreement.

Operations and Data Collection Center for the Global Seismographic Network
U. S. Geological Survey, Albuquerque Seismological Laboratory

Operations and Data Collection Center for the IRIS/IDA stations of the GSN
University of California, San Diego

Technical Management of the Eurasian Seismic Studies Program
University of California, San Diego

The IRIS Data Management Center
University of Texas Institute of Geophysics and Center for High Performance Computing, Austin

The Passcal Instrument Center
Lamont-Doherty Geological Laboratory, Columbia University

The SierraSeis Users Group Support Center
Lawrence Berkeley Laboratory, University of California

IRIS University Projects

Where possible, IRIS makes use of capabilities at member Universities to provide services and functions needed by the instrumentation and data services efforts. For the period 1985-90, the following efforts at member Universities were funded wholly or in part by IRIS.

University of Arizona	TUC Station, IRIS University Network
California Institute of Technology	PAS station, IRIS University Network Historical USSR Seismogram Project
University of California, Los Angele	PASSCAL Bus Interface project PASSCAL Instrument Bench Testing South Pole Gravimeter Station
University of California, San Diego	Historical USSR Seismogram Project IRIS/IDA Network, ESSP Program
University of California, Santa Barbara	PASSCAL Instrument Evaluation Loma Prieta aftershock monitoring
University of California, Santa Cruz	Loma Prieta aftershock monitoring
Carnegie Institution of Washington, DTM	Archean-Proterozoic Transect
University of Colorado	USSR Program: Data analysis and Kirghiz tight array
Columbia University	Loma Prieta aftershock monitoring and dataset preparation. USSR Program: Caucasus network Retrieve software development: DMC.
Harvard University	HRV Station: IRIS University Network
University of Indiana	USSR Program: Kirghiz tight array
University of Missouri, Columbia	PASSCAL Nevada Passive Experiment
University of Nevada, Reno	Nevada Passcal Experiments
New Mexico Institute of Technology	Instrument Field Evaluation
Oregon State University	COR Station, IRIS University Network
Purdue University	PASSCAL Ouachita Experiment
Rensselaer Polytechnic Institute	USSR Program: Kirghiz tight array
Rice University	Brooks Range Profiling Experiment
University of South Carolina	USSR Program: Kirghiz tight array
St. Louis University	CCM station, IRIS University Network
Stanford University	PASSCAL SGR Instrument Support PASSCAL Nevada Active Experiment
Texas A & M University	Instrument Field Evaluation
University of Texas, Austin	DMC Interim Database Development
University of Texas, Dallas	PASSCAL Ouachita Experiment
University of Texas, El Paso	PASSCAL Ouachita Experiment
University of Utah	Zplot Program, PASSCAL Nevada Active Experiment
University of Washington	GOPHER software development
University of Wisconsin - Madison	Instrument Field Evaluation
University of Wisconsin - Oshkosh	PASSCAL Nevada Active Experiment
University of Wyoming	PASSCAL Nevada Active Experiment

In addition, the U. S. Geological Survey, Menlo Park, has been an active sponsor and organizer of PASSCAL field experiments, both programs funded by IRIS and other programs involving USGS and IRIS Universities.

IRIS Agreements and Cooperative Projects

Memorandum of Understanding with the U. S. Geological Survey for joint support and operation of the Global Seismographic Network.

Memorandum of Understanding with the GEOSCOPE network for cooperation at the Kipapa (KIP) station; pending agreement for data exchange.

Memorandum of Understanding with the Geological Survey of Canada (GSC) for operation of the GSN station at Alert, and for exchange of data.

Membership in the Federation of Digital Seismic Networks, under the auspices of the Internation Commission on the Lithosphere (ICL) and the International Association of Seismology and Physics of the Earth's Interior (IASPEI), to promote standards and data exchange among broad-band digital networks. IRIS has agreed to archive FDSN continuous data.

Participation in the NASA Earth Observing System, for satellite transmission of ground station data.

Joint initiative with the Earthquake Research Institute, University of Tokyo to reuse the Guam-Japan undersea cable for geoscience.

Joint protocol with the U. S. Geological Survey and the Institute of Physics of the Earth, USSR Academy of Sciences, implementing the Eurasian Seismic Studies Program.

Cooperative Project with the ORFEUS network regarding data exchange.

Working liaison with several other countries, including Japan, Italy (Mednet), Germany (Grafenburg).

IRIS foreign liaison for the establishment of most GSN stations is handled by the USGS and U. C. San Diego, as a part of their network operations.

At this time, mid-1990, a working prototype of IRIS's planned facilities is in operation, based on the developmental work of the past five years. It already provides data and services to the Earth science community. We are proud to summarize it here as proof of the support that full IRIS facilities can provide for research on the Earth's interior.

- 21 VBB (Very Broad Band) GSN stations are now operating, including 5 in the Soviet Union. By the end of 1990, this number will rise to at least 30.
- Data from these stations, as well as data from 25 other stations, are archived in the IRIS Data Management Center in Austin, TX. The current archive runs from the beginning of 1988 to the current date, minus 60 days.
- The scientific community has access to the DMC via Internet, through which it may make requests for data from the archive, extract status information from an online bulletin board, and make specialized requests to the staff for assistance in obtaining data anywhere in the world.
- The GOPHER service provides data in near real time for 150 significant earthquakes, obtained from 5 GSN stations equipped with a dial-up interface.
- Customized data products for important events are prepared for general distribution, and include as complete as possible a set of continuous data over a several day period. Currently available global data are: the Armenian earthquake, the Macquarie Islands earthquake, the Loma Prieta earthquake, and the 20 June 1990 Iran earthquake and aftershocks.
- The following pre-packaged PASSCAL data sets are available: (1) the US/USSR Joint Verification Experiments, (2) the 1986 Ouachita experiment, (3) the 1986 Basin and Range active source experiment, (4) the 1988-89 Basin and Range passive source experiment, (5) a preliminary 1989 Loma Prieta aftershock dataset. Data sets from most currently active PASSCAL experiments will also appear for distribution 6 months after the close of operations.
- 90 6-channel RefTek PASSCAL dataloggers are now available for use in field experiments, along with sensors, cables, field computers, and training service. Preliminary letter proposals are invited for the use of these instruments. Serious requests, based on confirmed funding for a project, should be made by October 30 of each year for including in annual scheduling, although requests may be entertained at any time, based on availability.
- The DMS distributes and supports utility software to facilitate standardized access to and exchange of data. (1) RDSEED, for reading the GSN exchange format media, (2) Retrieve, for interacting with the DMC archive, (3) various format conversion utilities, (4) ZPLOT, for display of seismic trace gathers. It also distributes, with limited support, the following analysis packages: (1) SAC, the Seismic Analysis Code, written at LLNL, (2) AH, the analysis package written at Lamont, and (3) SierraSeis, a commercial reflection seismic processing package with, IRISeis enhancements for use of PASSCAL data.

Information about these services is available through the IRIS/DMS Bulletin Board: telnet *128.83.149.25*, login *bulletin*, password *board*, or Tim Ahern, DMS Program Manager, 512-471-0404. PASSCAL scheduling inquiries should be made to Jim Fowler, PASSCAL Program Manager, 703-524-6222.

Other opportunities for participation:

In addition to these services, IRIS encourages the participation by members of the scientific community in a variety of ways. In general, participation is open to all members of the research community, except for service on the Executive Committee, which is limited to members of the IRIS Board of Directors.

- IRIS supports University initiatives to operate their own "design goal" digital seismographic stations. The IRIS University Network now includes sites at Harvard, Cathedral Caves, Pasadena, Corvallis, and (1990) Tucson. This support is in the form of supplemental funding to help achieve full design goals, standardization, and data availability. Proposals are evaluated on a yearly basis, following a 1 July deadline.
- Universities planning to purchase PASSCAL instruments or other hardware compatible with PASSCAL EQUIPMENT for their own use are urged to participate in an IRIS resource-sharing plan, in which the standard maintenance services of an Instrument Center are made available for the University-owned equipment.
- IRIS conducts an annual Workshop in March. It supports the participation of one representative from each member institution, and welcomes all interested participants, particularly those from government, industry, and foreign countries.
- IRIS is considering the issue of long-term research priorities in the area of earthquake science. Indi-

viduals who wish to play a role in this process are encouraged to inquire.

- In December, 1990, IRIS will elect new members to the Executive Committee, which will then appoint new members to the Standing Committees for GSN, PASSCAL, and DMS. Individuals who are interested in involvement in program planning and oversight are encouraged to inquire.
- IRIS is preparing Requests for Proposal, for issuance in the last quarter of 1990, for the following projects:

Operation of a second PASSCAL Instrument Center.

Five year agreement for the operation of the Data Management Center archive.

Inquiries about these opportunities should be made to the IRIS President, Dr. R. A. Phinney, 1616 N. Fort Myer Drive, Arlington, VA 22209, phone 703-524-6222, fax 703-527-7256, or to the relevant program manager.

II. Proposal

Scientific Motivation

The Basic Objective of Seismology: Understanding the Dynamic Earth System

The Earth is a vast and remarkably complex dynamic system, with only a thin surface veneer directly accessible to man. Its evolution, often manifested by volcanic eruptions and earthquakes, continues to reshape the planet's surface, creating new mountains and ocean basins. The atmosphere, hydrosphere, and biosphere are intimately linked to the internal Earth system by progressive degassing of the interior, recycling of elements concentrated by surface processes into the Earth's interior, and catastrophic surface motions driven by deep-seated processes. Fortunately, our ability to understand and quantify this internal dynamic system is not restricted to observing surface processes. Despite the Earth's nearly viscous behavior for long-time-scale processes, the materials comprising the terrestrial interior behave elastically on short time scales. These materials transmit elastic waves throughout the interior.

Seismology is the study of elastic waves in the Earth. Seismologists try to determine both the material properties of the Earth's interior, and the nature of various sources of seismic waves. Both internal Earth structure and seismic sources reveal fundamental aspects of the dynamic Earth system. Hence, seismology, together with other geophysical disciplines such as geodynamics, mineral physics, gravity, geodesy and geomagnetism, can expose the configuration and dynamics of the otherwise inaccessible Earth system.

Imaging the three-dimensional structure of internal material properties at all depths inside the Earth, from shallow crust to inner core, is a basic objective of seismology. The internal Earth structure can be determined by exploiting the fundamental nature of waves traveling in a solid material: its elastic properties control the propagation speed of compressional and shear waves, and in tandem with density, determine the reflection of wave energy at internal Earth discontinuities. Its internal friction governs the dissipation of wave energy. These material properties provide constraints on the chemical and thermal structure at depth, which in turn reflect the dynamic processes that have operated in the past, and continue to take place.

Seismological images of the interior expose hidden mineral and petroleum resources, suggest crustal deformations that occurred billions of years ago, define the configuration of upper mantle convection, and may even constrain the inner core's deformation. No other geophysical discipline can extract such detailed information about the Earth's internal structure.

While structural variations reflect long-term deformations in the Earth system, earthquakes, the sources of seismic waves reveal instantaneous motions of the system. The majority involve sudden strain release accompanying sliding of rock masses on a buried fault. earthquakes of this type are direct responses of the lithosphere, the Earth's brittle outer layer, to long-term motions in the planet. To the extent that seismic waves transmit with little (or at least predictable) distortion, it is possible to recover detailed information about the seismic source, such as the asymmetries in radiation associated with rupture of a geologic fault. Seismological analysis can determine the direction of faulting, even at great depths , as well as spatio-temporal variations in slip on the fault , and total energy release during faulting. Very slow fault motions can also be detected, bridging the fields of seismology and geodesy.

Other sources of seismic waves, such as underground explosions, volcanic magma motions, landslides, surface impacts, and the earthquake sources that give rise to tsunamis, can all be studied using seismological procedures. This provides a basis for studying rapid geological phenomena shaping the environment in which we live. This basic research has the direct corollary benefit of providing the data and the expertise for monitoring nuclear test treaties.

Elements of Modern Seismology: Theory and Technology

The decade of the 1980's has witnessed tremendous advances in technical and theoretical aspects of seismology. Many of these advances arise from the explosion of computing power, and its role in the improved acquisition, storage, analysis, and modeling of digital seismic data. Advances in theoretical seismology have kept pace with the growth of technical capabilities, so that seismologists have been able to develop increasingly sophisticated techniques for analyzing data, and for modeling Earth structure and earthquake properties.

Seismology has undergone a fundamental change in outlook. The data needed in any particular investigation

will be a collection of many seismic traces, from arrays of sources, and arrays of receivers. A single two-day experiment to image the Loma Prieta Fault zone using a marine airgun source and onshore arrays of portable instruments, might collect 10^6 traces, or 10^{10} bytes of information. The task is similar in scope and concept to modern astronomical or medical imaging technologies.

Technical advances relevant to seismology have come in many areas. Improvements in computer speed, storage technology, graphics capability, and networking have all enhanced the power of seismologists' primary tools for data analysis. Recent developments in the design and construction of seismometers have yielded a new generation of "very broad band" sensors, which respond faithfully to Earth vibrations ranging over five decades of frequency. Similarly, analog-to-digital converters (digitizers) are able to convert the 140db of dynamic range of ground motion amplitude into computerized form. Advances in other areas such as satellite telemetry and computer networking facilitate the rapid transmission and exchange of seismic data.

During this period, seismologists have refined existing algorithms, and created entirely new techniques for analyzing and modeling seismic data. The theory of elastodynamics provides a quantitative formalism to calculate the excitation and propagation of seismic waves in the Earth from any specified deformational force. Given accurate recordings, or seismograms, of ground motion produced by the passage of these waves, powerful techniques of linear inverse theory can be used to extract information about the source and transmitting medium. Inverse techniques have been developed to model seismic waves with vibration periods ranging from fractions of a second (high frequency strong motions) to nearly an hour (whole Earth free oscillations). A host of seismological algorithms has been developed for inverting seismic data for images of internal Earth structure on scales ranging from tens of meters to thousands of kilometers. In addition, seismic sources varying in energy release by factors as much as 10^{20} have been studied, ranging from minor rock bursts in mines, to great earthquake ruptures involving more than 20 meters of slip over 1000-kilometer long faults.

The technological and theoretical tools are in place for a new revolution in Earth sciences—the transition from the kinematic model of plate tectonics which has unified the field for the past 25 years, to a fully dynamic model of the Earth system, involving the solid Earth and its fluid envelopes. Seismology is poised to make major contributions to this effort, but modern observational facilities which can provide the necessary seismic data, are vitally important. This proposal is for continuation of the effort initiated by the IRIS consortium: to modernize and standardize seismic instrumentation in a global network of permanent facilities, and to acquire the new generation of portable array instruments needed for high resolution analysis of the Earth system.

Earth Structure

Given suitable data, seismological analysis procedures can be used to study internal Earth structure over an immense range of scales. Data from global networks can be accumulated to study the entire planet's radial layering and lateral heterogeneity.

Figure 1 shows the rich complexity of the wavefield apparent in a stack of digital seismograms recorded by

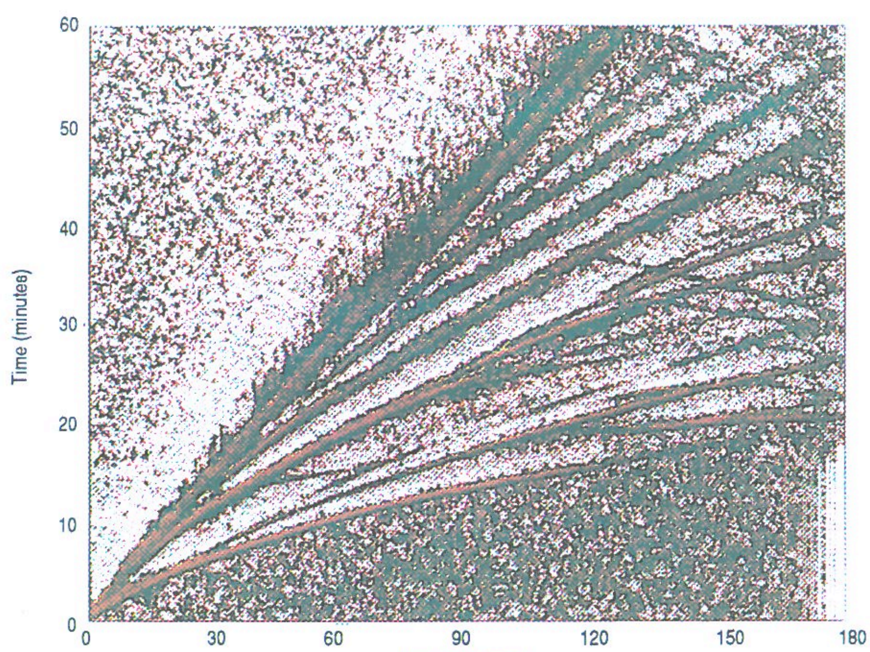


Figure 1. Standard record section of GDSN vertical data (1980-84)

the GDSN. In the past, seismological analysis has primarily exploited the travel times and waveforms of only the direct compressional (P) and shear (S) body waves, the surface waves and the frequencies of seismic free oscillations. Modern digital data has begun to open new research opportunities in using the entire waveform to understand both elastic and anelastic layering of the Earth. The advances still to be made are many, as preliminary global stacking has revealed the global existence of a radial velocity discontinuity near 530km depth in the upper mantle transition zone. This is in conjunction with intermittent occurrence of other discontinuities in both the upper and lower mantle. Such features could not be detected by conventional seismic analysis, and a further study of their nature will require much more high-quality data.

The lateral variations in reflectors in the mantle are likely to be associated with chemical and thermal heterogeneity in the system. Low resolution images of large-scale heterogeneity in the mantle and inner core have been produced using the first generation of digitally-recorded seismic data. *Figure 2* shows an example of long wavelength variations in P velocity structure near the base of the mantle. These were obtained by seismic tomography, the inversion procedure for imaging three-dimensional structure. The clear correlation between lower mantle, low velocity heterogeneity and surface locations of mantle plumes is quite striking, but are these causally linked? Only higher resolution imaging can answer this, along with similar questions concerning the configuration of the mantle convective regime. Attainment of the necessary resolution requires improved seismic data, as well as denser spatial sampling.

Separating the effects of thermal versus chemical heterogeneity continues to be a problem in the interpretation of the dynamical significance of the mantle's seismological images. Possible solutions include imaging of seismic attenuation and anisotropy heterogeneity, endeavors which are presently in a state of relative infancy. Attenuation is thermally activated in the Earth, while anisotropy arises from intrinsic material properties e.g. flow-induced preferred orientation of mineral crystals. When the imaging of these properties is extended throughout the mantle with greater resolution than the preliminary mappings available today, new aspects of the dynamic Earth system will be revealed.

Detailed imaging of crustal and lithospheric structure can be performed with higher resolution than we can ever expect to achieve for whole Earth structure.

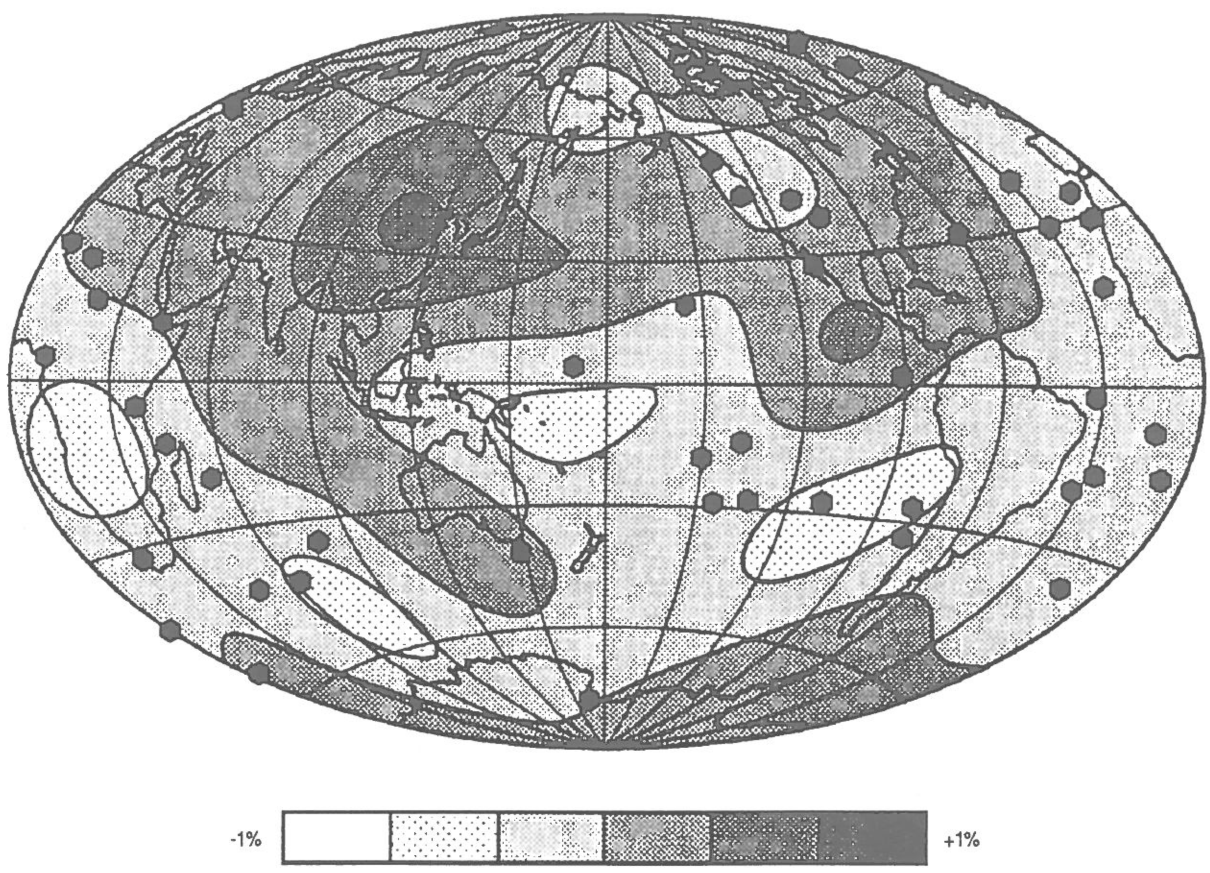


Figure 2. P-wave velocity anomalies of a depth of 2750 km inferred from a large data set of ISC travel times. 80% of the surface hot spots (black dots) fall in areas where the anomaly is negative.

The corresponding details of the shallow dynamic system and its complex history can be revealed in great detail. New seismological procedures involving two dimensional surface arrays, as well as occasional three dimensional arrays with borehole sensors, are required to resolve the three dimensional structure at depth. *Figure 3* shows the high resolution tomographic image of the structure beneath the caldera of the Medicine Lake, CA, volcano. The high velocity plug in the western portion of the caldera may indicate an intrusive mass of sills and dikes. Preliminary attenuation heterogeneity studies have also been performed in this region.

Reflection profiling based on industry techniques became a significant tool for looking at the continental crust in the mid-1970's, with the COCORP program in the US, and the BIRPS program in the UK. More recent applications of these technologies have become greatly diversified in approach. The use of the marine airgun as a source gives particularly good results, and permits detection of long-offset signals at distances from 30-200km which can determine crustal velocities. The joint Canadian-US project GLIMPCE, in the Great Lakes, produced the striking crustal cross section of the Grenville Front shown in *Figure 4*.

High resolution imaging of active fault zones offers a new understanding of the faulting process. *Figure 5* shows an anomalous low velocity zone crossing the San Andreas fault south of the nucleation zone for the previous Parkfield earthquakes. The nucleation zone is characterized by a high-velocity anomaly. Understanding the relation between geological heterogeneity imaged by tomography, and the nature of slip heterogeneity during faulting, is one of the exciting frontiers in seismology. This knowledge could contribute immeasurably towards accurately evaluating earthquake hazards.

Imaging the lithospheric heterogeneity under the tectonically active regions of western North America looks on a larger scale (*Figure 6*). The lateral variations in velocity structure reflect chemical and thermal variations that are direct manifestations of mantle dynamic processes associated with surface tectonics. Higher resolution imaging of P and S velocity structure, anisotropy and attenuation, will reduce the ambiguity in interpreting these structures, and will help bridge the seismological and geodynamical approaches to the study of the lithosphere.

Seismic Sources

As our knowledge of Earth structure has become increasingly refined, so too has our understanding of the various sources producing seismic waves in the Earth. Digital data are now available from a global network. These new data have transformed the routine analysis of earthquake sources from a mere cataloging of locations and magnitudes, into a complete description of the equivalent body force system, or moment tensor, for all events with magnitudes greater than 5. An example of this remarkable advance is shown in *Figure 7* (Harvard CMT solutions for Jan. 1990), where the significant seismicity for a one month period is plotted. These earthquake source mechanisms, determined by inversion of digital waveforms of long period body and surface waves, provide a current catalog of global faulting. This is an instantaneous picture of brittle failure processes in the surface dynamic system.

The ability to determine routinely the basic quadrupole representation of fault mechanisms is a tremendous advance of the 1980's. The recovery of more physically detailed faulting processes for large events should also become routine. It is now possible to use

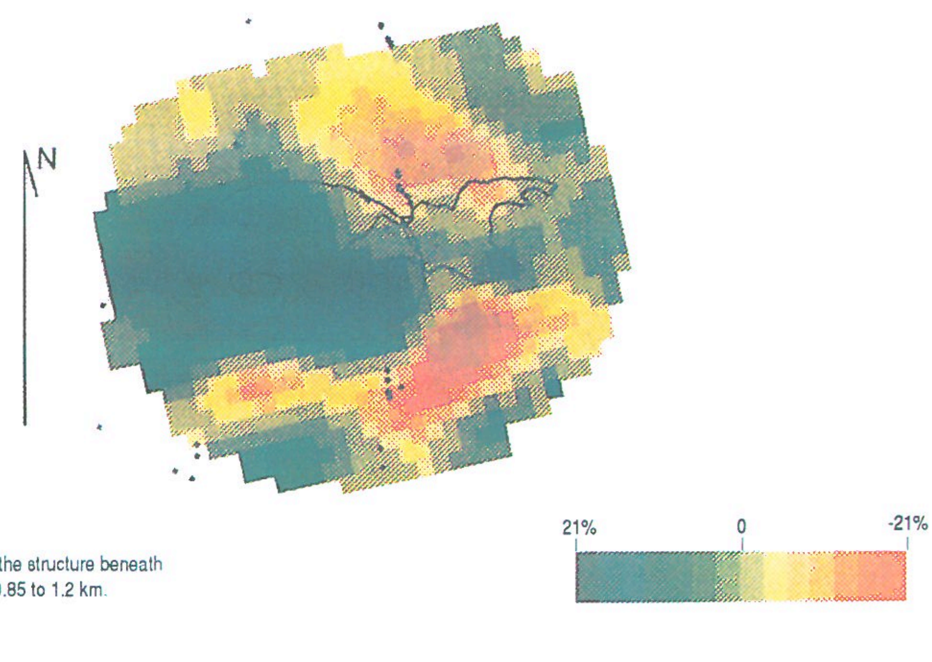


Figure 3. Tomographic inversion for the structure beneath Medicine Lake volcano: depth range -0.85 to 1.2 km.

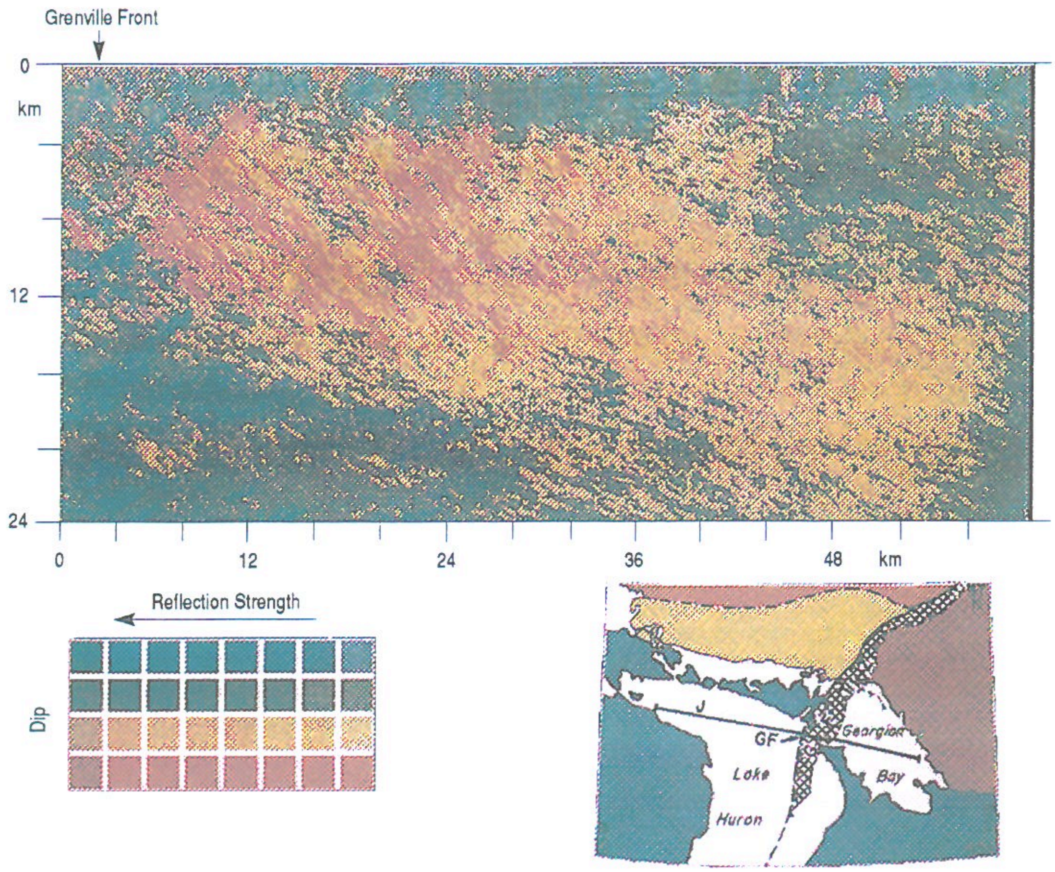


Figure 4. Seismic reflection image of the Grenville Front, from the GLIMPCE marine multichannel experiment.

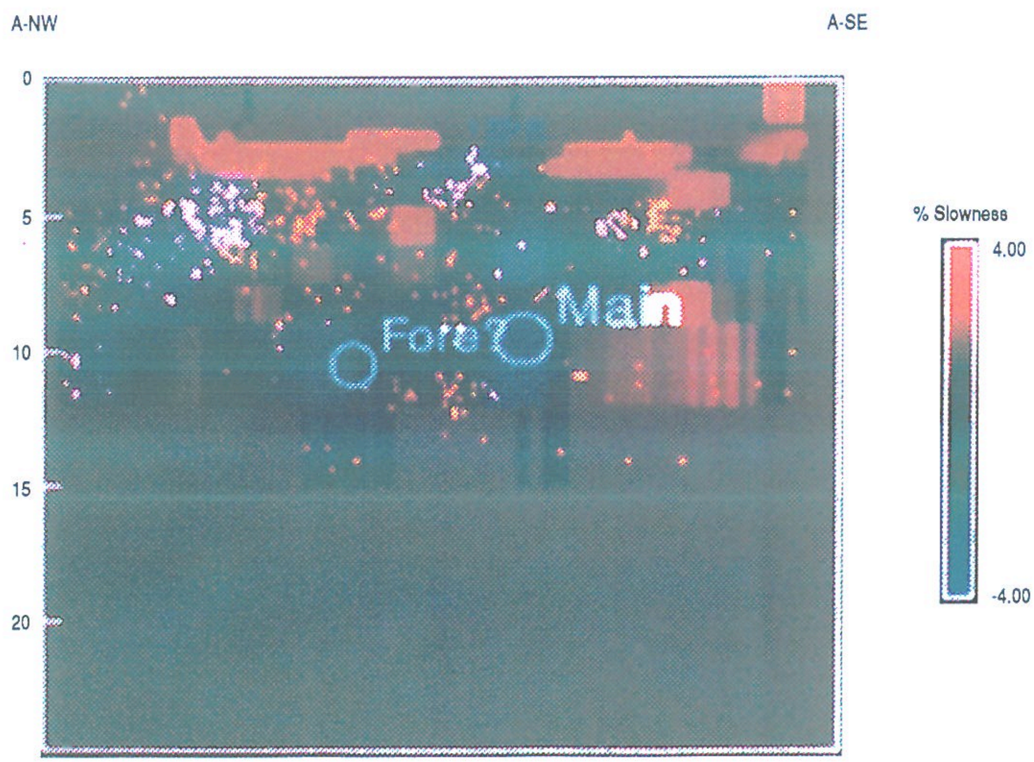


Figure 5. Microearthquake epicenters and velocity structure along the San Andreas Fault at Parkfield, CA, determined from a downhole high sensitivity network.

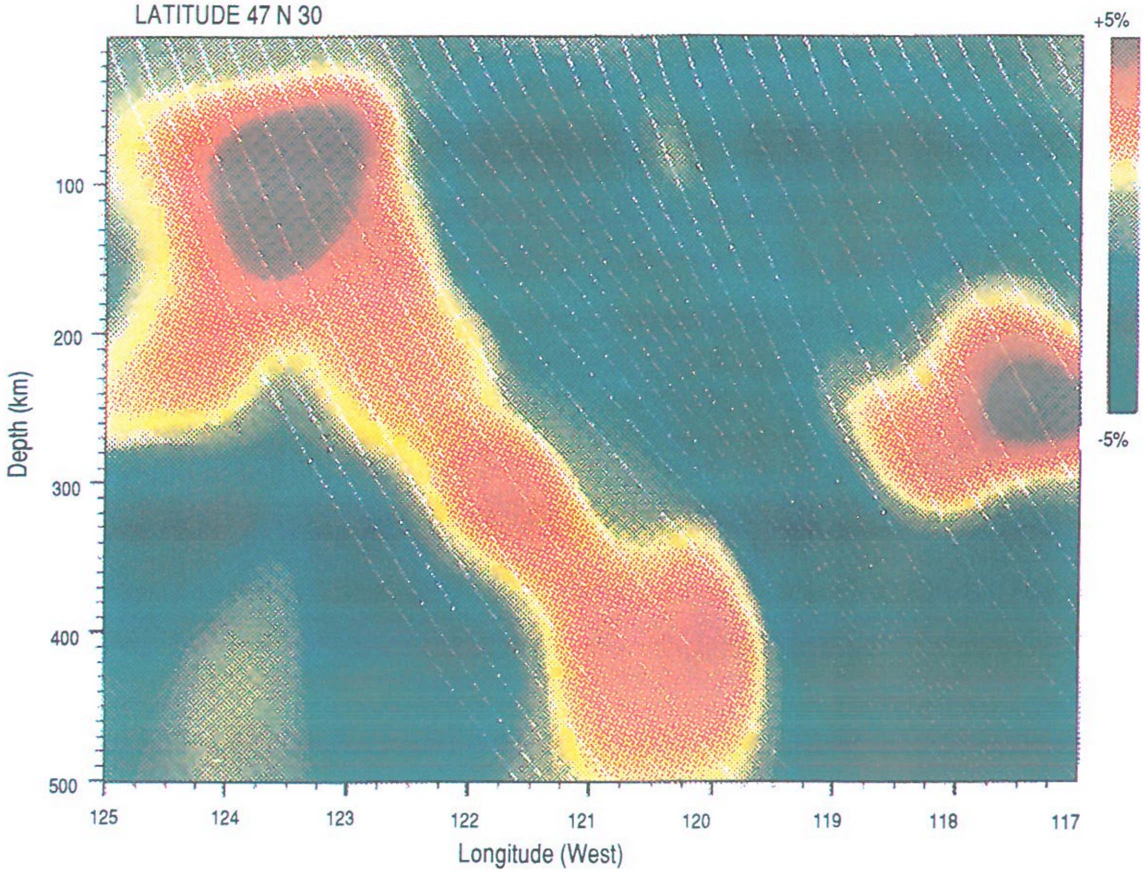


Figure 6. Tomographic image of the descending Juan de Fuca slab under western Washington.

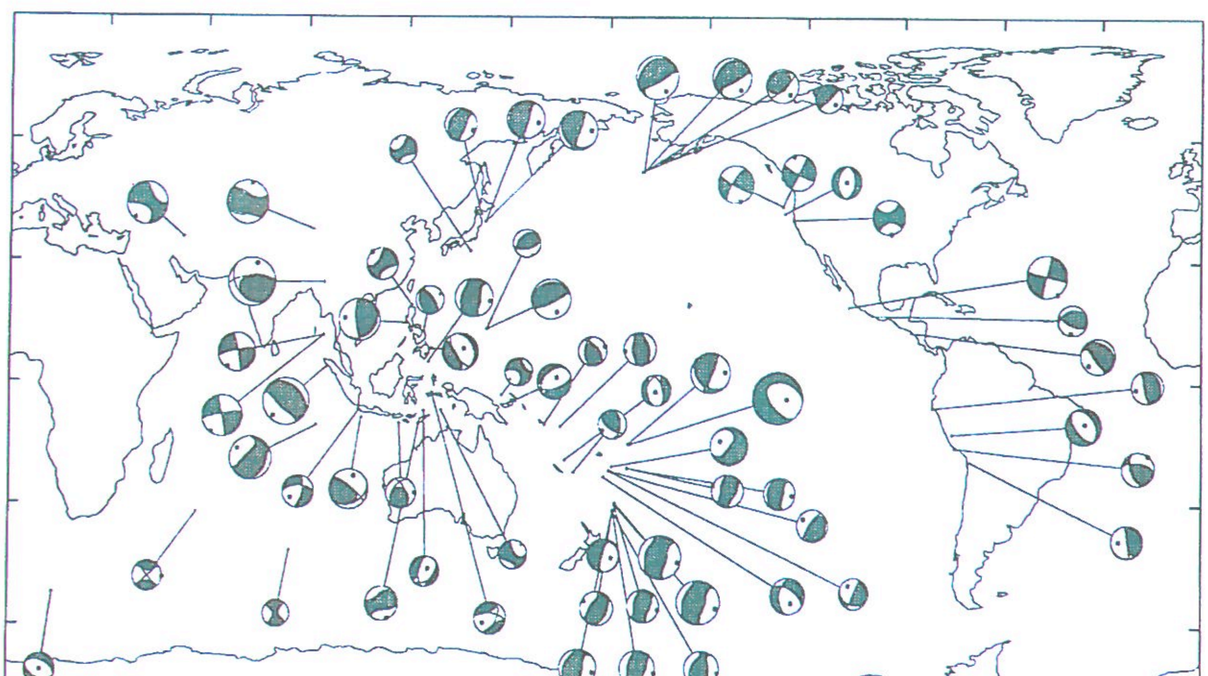


Figure 7. 65 centroid moment tensor solutions for January 1990.

high-resolution inversion techniques to characterize the spatio-temporal history of slip on a large earthquake's fault plane. This requires a substantial number of broadband seismic recordings for each event. The October 17, 1989 Loma Prieta earthquake, which caused $10 billion damage in Northern California, was well-recorded by the new generation of very broadband digital sensors. *Figure 8* shows the results of inversion of the teleseismic body wave data to determine the fault orientation, slip history, and depth extent of this rupture. The results of teleseismic signal analysis are compatible with the aftershock seismicity, which defines the fault plane as a southwestward dipping surface in the San Andreas system, as well as with geodetic modeling, which constrains the depth extent and total moment of faulting.

High resolution imaging of the slip history in earthquake ruptures is a major frontier in the study of faulting. It is recognized that the faulting process is highly heterogeneous, with a given fault failing either with highly variable slip, or with regular, characteristic events. The slip distribution on each fault appears to have strong spatial variations, which are linked in a complex fashion to preshock and aftershock seismicity. The new tools for analyzing broadband data are rapidly increasing our understanding of faulting, but we are still far from being able to describe the earthquake cycle more fully, and from forecasting large damaging events.

In addition to conventional earthquake ruptures that spread over the fault surface at a few kilometers per second, there is a continuum of events with slower rupture velocities. Those events with rupture velocities of a few hundred meters/second do not excite body waves strongly, and can be detected only at long periods. Searching for such 'silent' earthquakes is a new research direction requiring extensive coverage of the Earth. *Figure 9* shows the results of a systematic search through continuous IDA gravimeter recordings to detect time intervals in which a significant number of the Earth's free oscillations are excited, thereby flagging a long-period 'event.' Correlation of these intervals with the record of seismicity links most 'events' with ordinary earthquakes, but a few statistically significant periods of mode excitation are observed which are associated with either an unexpectedly small earthquake or no event at all. The former cases, called 'slow' events, are found to occur most often on oceanic transform faults, while some of the latter cases may be accelerated creep events, or silent earthquakes. Understanding these anomalous ruptures and quantifying their role in the surface dynamic system is an emerging research area.

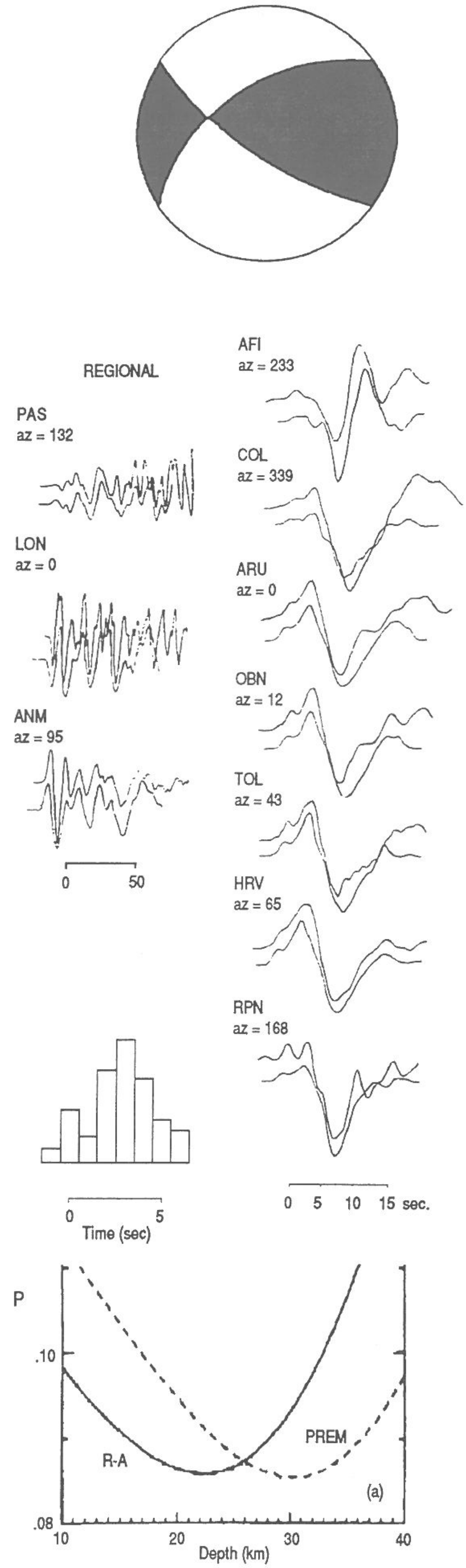


Figure 8. Loma Prieta focal mechanism determined by matching regional and teleseismic broadband wave forms. The solution includes an estimate of the surface duration (5 secs.) and the depth (22 km).

In addition to earthquake faults, seismic waves are excited by other natural or man-made sources. Investigations of seismic waves from a variety of 'exotic' sources, such as landslides, volcanic eruptions, and atmospheric sources (meteorites, shuttle flybys) have been studied using new broadband digital recordings. The most widely-studied man-made sources include underground nuclear explosions, quarry blasts, and sources used in mineral exploration. In every case the principles are the same: analyze the seismic recordings to extract information about the source process, and relate that to the causal mechanism. The societal ramifications of this capability are extensive, ranging from practical procedures for monitoring nuclear testing and nonproliferation treaties, to hazard warning capabilities for volcanic eruptions and tsunamis. In every instance, it is a combination of high quality data and sophisticated seismic inversion capabilities which enables the source to be understood.

Seismological Frontiers

The preceding sections should clarify some of the directions in which seismological research is headed. To meet these new opportunities in the study of earthquakes and Earth structure, *we propose the completion within 5 years of the three prime components of the IRIS facility:* the Global Seismic Network, the PASSCAL array, and the Data Management System. This goal is realistic and within our reach, for it requires a level of funding commensurate with projections made at the inception of the IRIS program. Remarkably, the proposed level of funding is rather modest compared to the $250 million support provided for Project VELA-Uniform in the 1960's (in 1960's dollars!).

The scientific tasks for the seismological community will be substantial so that full advantage can be made of these new facilities' capabilities. We must

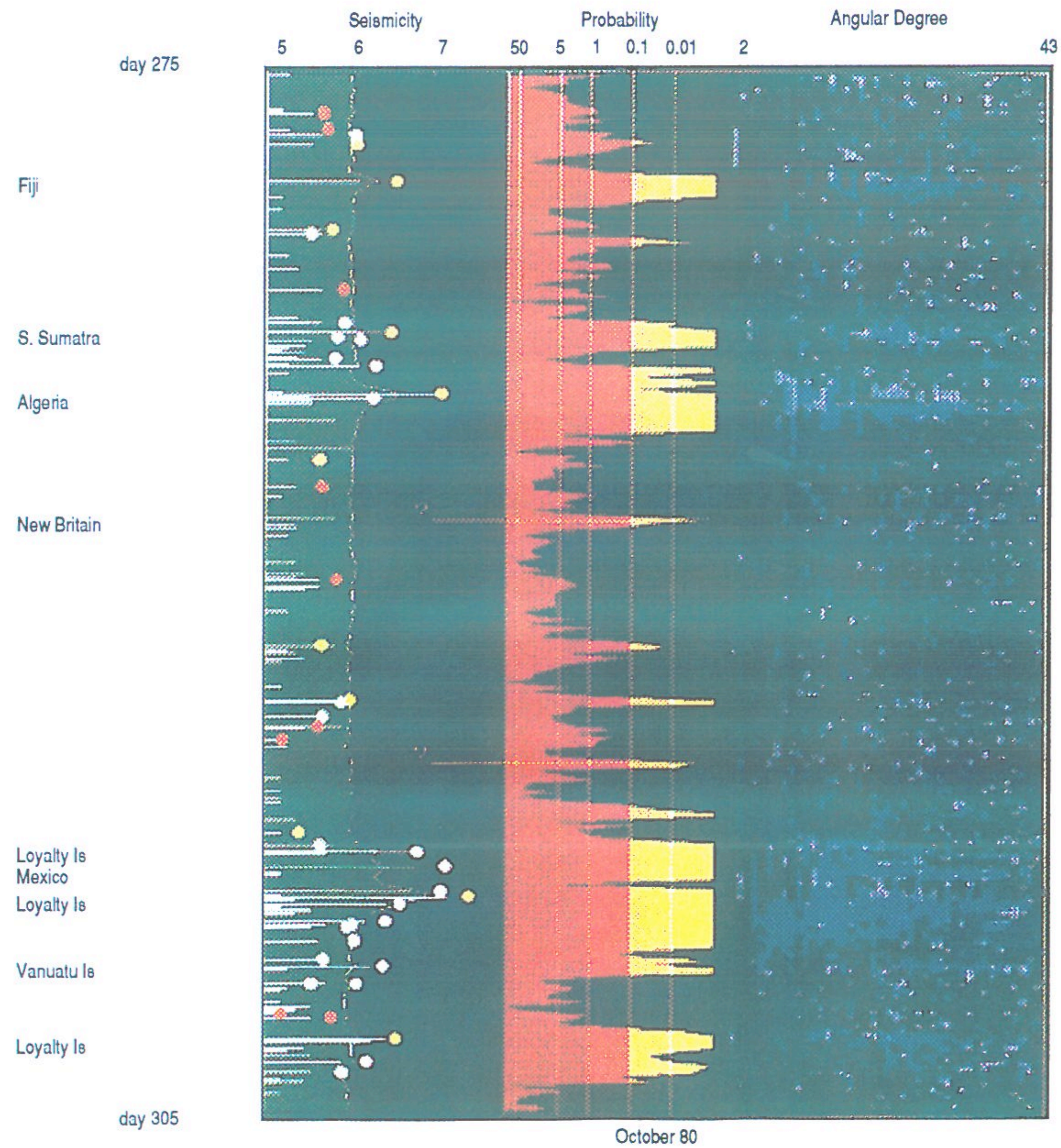


Figure 9. Inventory of "slow" seismic events, as determined from the excitation of fundamental normal modes 2-43, for a 3 day period.

prepare ourselves, our students, and our geological colleagues for the scientific potential of the IRIS facilities. Training in the use of modern digital instrumentation, the analysis and modeling of digital data, and effective strategies for array deployments or global data "gathers" must not be neglected.

At the same time, we must push further into the frontiers of seismology. We can anticipate significant progress in certain technical, theoretical, and practical aspects, and can expect other advances not yet envisioned. In the area of technology, two key areas are ocean-bottom deployments, and telemetry. For adequate, uniform global coverage with high-quality sites, it is essential that the GSN eventually include a number of ocean-bottom borehole sites. An IRIS/JOI joint working group has already made great strides in this direction, with a borehole site north of Hawaii planned for a re-entry test in 1991. Improvements in telemetry will bring us closer to "real-time seismology", enabling us to characterize major seismic events rapidly (on the order of minutes), and initiate appropriate responses. Forms of response would include informing the public, media, and emergency officials about earthquakes or possible tsunamis. Portable array instrumentation for aftershock studies could be rapidly deployed. Understanding new observations at very low and very high frequencies will require significant theoretical and methodological efforts, like those faced by the astronomical community when new gamma ray or radiotelescope facilities are developed. We must also learn how to use effectively new capabilities for extremely dense array coverage in active and passive imaging studies. These will produce sharper images of the Earth's interior than ever before possible.

Purpose

In the early 1960's the establishment of the World Wide Standard Seismograph Network (WWSSN) of analog instrumentation revolutionized global seismology. The breakthrough improvements in earthquake mechanisms and source locations provided by the WWSSN data were critical for validating the seafloor spreading hypothesis and the plate tectonics paradigm. In the 1970's the first digital seismic stations were installed for a Global Digital Seismograph Network. This was accomplished through upgrading several of the WWSSN sites with digital recording, by the deployment of the Seismic Research Observatory (SRO) borehole systems, and the International Deployment of Accelerometers (IDA). The data from these digital networks were basic to the first tomographic studies of the Earth, yielding three-dimensional images of Earth structure which linked the seismic velocity field with mantle dynamics and other geophysical phenomena. However, both of these networks — boons to the science of their time — are now inadequate for providing further progress.

The need for a new Global Seismographic Network of modern instrumentation was recognized and proposed in the 1984 Science Plan for a New Global Seismographic Network. This was written by the seismological community at the start of the IRIS program. The scientific justification for a new GSN has increased since then, as the community has developed and refined many new tools for Earth study using modern digital stations. A series of short essays illustrating this appears in the second part of this proposal, *IRIS Science Review: Impact*.

The examples described in Section 2 provide a glimpse of the potential that can be realized by the fully-implemented GSN. The objectives of the GSN program are unchanged from our 1984 goals:

- 128 very broad band, high dynamic range, digital seismic stations, uniformly distributed with 2000 km spacing about the Earth.
- Real-time telemetry of the data to the IRIS Data Archive

This five-year proposal primarily addresses the completion of the first goal for global coverage. This is within our reach, even using seismic stations deployed only on land, as illustrated in *Figure 10*. In achieving global coverage, the efforts of other nations and other programs within the U.S. government toward global

Global Coverage with 128 Land Sites

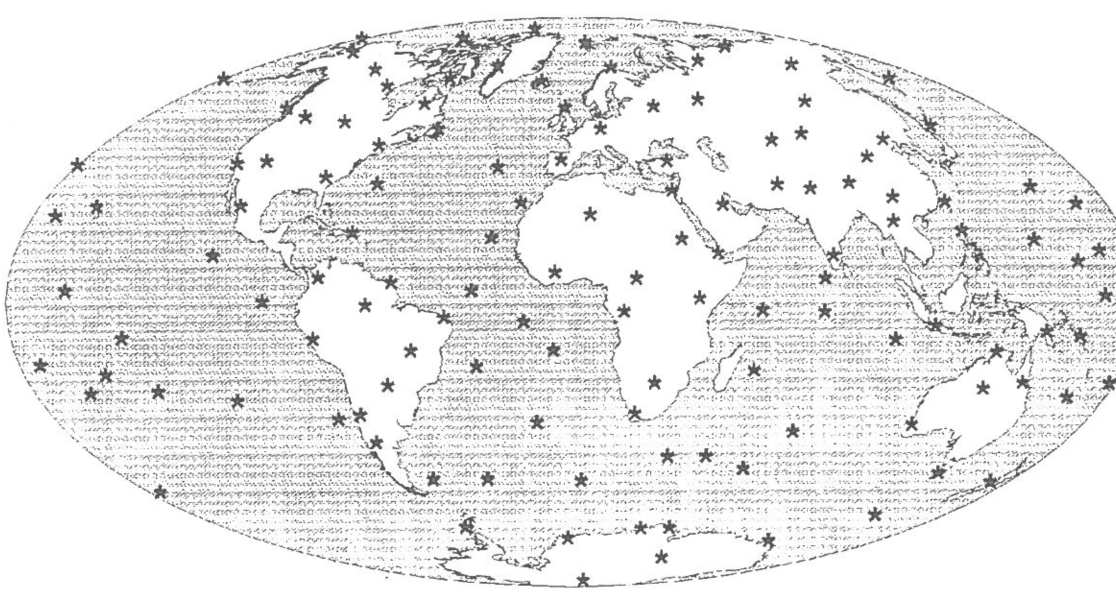


Figure 10. A 128 station Global Seismographic Network, including the contribution of seismic stations from many nations, can be installed within five years. Although coverage can be improved with sites on or beneath the sea floor, a 128 station network with reasonable coverage can be installed on the continents and on islands. The configuration shown includes French, Canadian, Japanese, German, and Chinese Network sites as well as sites from the U.S. Air Force GTSN program. These national and international efforts are an important complement to IRIS's siting efforts, and provide about 20% of the global coverage. To provide the coverage shown, a 100 station IRIS Global Seismographic Network is required.

siting, are expected to result in about 20% of the coverage of the Earth. The remaining 80% must come from IRIS's efforts — 100 stations.

The goal of global, real-time telemetry of the data is important, but cannot be realized within the coming five years. Nonetheless, IRIS is progressing toward this by working with NASA for telemetry on the Earth Observing System satellites scheduled for launch at the end of the decade.

To serve the scientific needs the new GSN has certain minimum requirements.

Broad frequency bandwidth is required to measure the high-frequency motions near the earthquake, as well as the long-period free oscillations of the Earth.

High dynamic range is required to capture on scale the vibrations of small local events and the truly great, magnitude 9+ earthquakes.

Low-noise station siting is required to bring the vast numbers of small and intermediate size earthquakes as well as the larger ones into the network's focus. Even the largest earthquakes require low-noise sites for extending the signal time windows necessary for studying the detailed splitting of the Earth's normal modes.

Timely, rapid access to data is required to react to, and study seismicity as it happens.

Broad, uniform global coverage is needed for resolving the details of the structure of the Earth and for analyzing the distribution and attributes of seismic phenomena.

Accomplishments of the GSN Program, 1985-90

By the end of 1990, the IRIS GSN will have installed or upgraded 31 seismic stations with very broad band (VBB) seismometers at sites noted in *Figure 11*. The goal in this past five year effort has been to provide for broad coverage in ways that minimize cost. In accomplishing this, IRIS GSN has emphasized the installation of modern VBB seismometers. Many of the sites do not presently have data loggers which meet our high-dynamic-range (24-bit) design goal. Or, they do not possess auxiliary seismometers to measure high-frequency (> 8 Hz) motions or strong-ground motions (> 0.1 g) where the need is appropriate. These sites will require further upgrade during the next five years.

The next phase of the GSN will involve costlier installations: low-noise sites, boreholes on oceanic islands, completely new installations, and installations based upon distribution rather than convenience.

IRIS has worked to develop strong international ties through the Federation of Digital Seismographic Networks (FDSN). In the spirit of FDSN cooperation IRIS

IRIS Global Seismographic Network

1990

Figure 11. In its first five years the IRIS Global Seismographic Network has established seismic stations on all of the continents and on islands of the Pacific Ocean. Sites which are underlined indicate installations in the latter half of 1990. The seismic station in Hawaii — KIP, Kipapa — is a cooperative venture between France's Project Geoscope and IRIS.

and France's Project GEOSCOPE jointly operate the seismic station on Oahu, Hawaii — KIP. Also in the same spirit of cooperation, the IRIS seismic station at ALE, Alert in northernmost Canada, provides data to both IRIS and the Geological Survey of Canada.

Within the United States IRIS has encouraged University participation in the GSN through its support of the IRIS University Network. This program augments funds raised by an IRIS member University which is trying to establish a seismic station meeting GSN design goals. Access to IRIS funds is based upon yearly, competitive proposals to the GSN. Four sites are currently a part of the University Network: Harvard, MA; Cathedral Caves, MO; Pasadena, CA; Corvallis, OR; and a site at Tucson, AZ, will be installed in early 1991.

IRIS works in cooperation with the U.S. Geological Survey in establishing the new Global Seismographic Network. IRIS and the USGS have expanded the capabilities of the Data Collection Center at the USGS Albuquerque Seismological Laboratory to handle the increasing volume of GSN data. The USGS has worked closely with IRIS in testing seismometers and developing the design goal seismic station processor for the GSN. Trained installation teams and network maintenance facilities will expand and service the GSN. Within the United States all IRIS GSN sites will become elements of the U.S. National Seismic Network being installed by the USGS over the next few years.

IRIS GSN has continued funding the Project IDA network of long-period gravimeters, and has encouraged and funded the installation of VBB seismometers at many of the IDA sites. The IRIS/IDA group at the University of California at San Diego — which possesses supplemental instrumentation funds from the private Cecil and Ida Green Foundation —has become an active force in the installation of the Global Seismographic Network, and has developed a version of the PASSCAL data logger for use as a GSN station processor. Six of the original IDA stations have been upgraded to GSN specifications. Four seismic stations were established in the Soviet Union by IRIS/IDA in 1988, and two more sites will be completed in 1990. The IRIS/IDA group has established IRIS Data Collection Centers in La Jolla, CA, and in Obninsk, USSR, and has linked the two centers by satellite telemetry.

While telemetry of data from all GSN stations remains a long-term goal, implementation in the near term is based upon special opportunities. Working with NSF Polar Programs, IRIS is seeking some available bandwidth on an ATS satellite operated by NSF for telemetry to the South Pole base, and oceanographic ships for the IRIS polar GSN sites at the South Pole and northernmost Canada. Working with NOAA, IRIS has received permission to use the GOES satellites to transmit very long-period data (0.1 sps) from five GSN sites in North America and the Pacific. As part of the ESSP, an experimental quasi time-division multiplexing system is planned for deployment in the Soviet Union. The system will utilize standard C-Band INTELSAT IBS circuits, sharing them by as many as 40 stations. This system, available on all INTELSAT regions, promises to offer affordable two-way communications between the stations and the central DMS.

IRIS is currently evaluating — and plans to install during the coming five years — systems available for transmitting low-data-rate, state-of-health information from GSN sites not accessible by telephone dial-up. At sites with telephone access, IRIS has been providing the most modern modem equipment for direct telephone access to the data for the user and the IRIS Data Management Center.

Oceanic sites are essential for global coverage, but present obvious difficulties. In addition to the problems of operating instruments on the sea floor, islands tend to be extremely noisy. Recognizing the importance of good oceanic sites for global coverage, IRIS GSN has funded a study of island borehole drilling costs, and is prepared to provide the low-noise, island borehole sites demanded by the community. Toward the longer range goal of siting seismometers on or beneath the sea floor, IRIS is working with the U.S. scientific community in an initiative (the Ocean Seismic Network) to install seismometers in boreholes of the Ocean Drilling Program, and with the Japanese and U.S. scientific communities to re-use sections of the Trans-Pacific Cable for geoscientific observatories.

Five Year Plan — The Goal: An Installed 100 Station IRIS Network

A Global Seismographic Network is a major facility, like a telescope or a ship. The capital and installation costs are substantial, but when completed the operation and maintenance costs are much less. A Global Seismographic Network serves the broad scientific community — it is an international resource for seismologists of all nations. It is a facility which serves large and small Universities alike.

IRIS is committed to a global network of 128 design goal seismic stations uniformly spaced at about 2000 km. It is evident that the U.S. scientific community cannot achieve this undertaking alone, given that resources for Earth sciences are scarce. To stretch these scarce resources while strengthening international ties, IRIS will continue to coordinate its plans with those of other nations. Of 128 potential sites shown in *Figure 10*, about 20% of the site coverage can be met from the coverage of other networks, leaving about 100 sites globally to be met by IRIS. IRIS continues to encourage the financial participation of its member Universities toward establishing design goal GSN sites operated by the member institution. The final global network configuration will depend upon international negotiations and site surveys yet to be concluded, and upon gains in establishing permanent ocean bottom stations which may compensate for certain island coverage.

IRIS has developed a detailed *Technical Plan for a New Global Seismographic Network* with the U.S. Geological Survey which formulates with great specificity how the GSN will proceed — this *Technical Plan* is included in Section 3 of this proposal. The implementation of the Technical Plan is dependent upon funding. Under modest funding, IRIS will continue to make modest increments each year to the GSN. However, a rapid science return on the Network investment is ensured by deploying the full 100 station network within five years. This course is sought in this five-year authorization, since an accelerated program not only benefits the science, it is more cost effective. By accelerating deployment, the GSN can take advantage of lower cost, bulk procurements, leading to greater standardization of the Network's hardware with lower long-term maintenance costs. Efficiencies are further achieved by using site preparation and installation teams full-time without slack periods.

Network maintenance facilities for the GSN are co-located with the IRIS/USGS and IRIS/IDA Data Collection Centers in the Albuquerque, New Mexico, and La Jolla, California, respectively. They are fully operational at this time and are capable of flexible growth towards meeting the needs of the Network. Maintenance is the key to the network's long-term viability. Providing for proper maintenance of the seismic stations after they are installed is as important as their deployment. The attached *Technical Plan* discusses maintenance issues in detail.

The schedule for station installation is set by a combination of expediency, and the need for better global coverage. In establishing a foundation network shown in *Figure 11* during the past five years, IRIS has emphasized occupying and improving existing sites. During the development phase of its design goal station processor, IRIS elected to deploy state-of-the-art broadband seismometers with available good data loggers, rather than waiting to deploy full design goal systems. The consequences of these actions — though good decisions — are twofold. As many of the "easier" sites have already been established, the cost per station for site preparation and installation will rise as more difficult, remote seismic stations are established. Among the existing stations of the foundation network, nearly two-thirds require additional data logger upgrades to bring them into design specifications. Furthermore, most sites do not yet have seismometers to record, in a triggered mode, either high-frequency seismic energy outside of the bandwidth of the Streckeisen seismometer, or strong-ground motion sensors in active earthquake areas.

Succinctly stated, there is no reason — save for funding — that restrains the U.S. Earth science community from having an installed, operational 100 station Global Seismographic Network within 5 years. Starting nearly from scratch, the 150 station World Wide Standard Seismograph Network was installed over the same time frame in the early 1960's. The science section of this proposal has made a strong case for the kind of data that truly global, uniform coverage can provide. IRIS GSN has spent five years laying the best possible foundation for a bold and rapid but orderly network deployment, with modest funding. Design goal instrumentation has been developed, network deployment teams are trained and experienced, data collection facilities are in place, and network operation and maintenance centers are operational. The stage is set.

The PASSCAL program was born in 1983 and 1984 as an outgrowth of several key studies by the National Academy of Sciences. These studies helped launch the workshops that defined requirements for a new generation of standardized portable seismic instruments for studying the continental lithosphere. IRIS has overseen the big step of converting the scientific community's needs into a concrete, operational reality. This puts us on the threshold of a new era in the study of the Earth's interior.

Purpose

Beginning with the familiar example of Galileo and the telescope, history has taught that major advances in science are triggered whenever fundamentally new data become available. In this century, the Mariner images of Mars revolutionized scientific discourse, which had been based on the inadequate resolution of Earth-based telescopes. PASSCAL instruments make it possible to conduct seismic experiments now that would have been impossible only a year ago. As the number of instruments that are available increases, the feasibility of new experiments will increase accordingly. There is little question that the new data acquired in the process will lead to new discoveries about the internal workings of the Earth, the nature of earthquakes, and wave propagation within the Earth.

There are five key elements to PASSCAL facilities that make the data we can collect fundamentally new.

- The large number of digital instruments
- The high bandwidth, dynamic range and resolution of the data collected
- Multicomponent, multipurpose sensor technology
- The flexibility and portability of the PASSCAL instruments
- Standardization of hardware, calibration, and data formats

While older instruments embodied some of these features, the combination of all of them in the PASSCAL instruments will vastly increase the capabilities applicable to a large number of seismological and structural-tectonic problems. Two distinct capabilities arise from the large number of instruments. Data from dense deployments employing hundreds of instruments will yield an improved resolution of subsurface geologic features, approaching the length scales mapped by geologists at the surface. For example, the difference between the roughly 10 kilometer resolution possible with current lithospheric tomography, and the potentially-achievable 1 kilometer (or better) resolution is the difference between a fuzzy image of a lithospheric structure and a sharp one that can be correlated with the geology. In addition, a larger number of instruments will permit determination of earthquake locations, focal mechanisms, and rupture mechanisms far more precisely than is now possible. A significant qualitative breakthrough occurs because enough sensors would be available to sample the wavefield without spatial aliasing at frequencies up to 30 Hz. This opens the full range of powerful wavefield processing methods, which have been so important in reflection imaging techniques (e.g. migration and waveform inversion). These methods were hitherto used only for seismic exploration data. PASSCAL facilities allow these methods to be applied to a wider frequency band and on a larger spatial scale. Extension of coherent wavefield processing methods to the study of earthquake sources and teleseismic signal propagation will be a significant step forward.

The digital nature of the recordings allows large data sets to be analyzed rapidly with modern, computer-based methods. The large bandwidth, wide dynamic range, and high resolution of the instruments permits a variety of sizes and types of sources to be observed in a single experiment. This capability is essential in large multi-disciplinary experiments, which may consist of several simultaneous experiments.

Versatile three-component sensors allow all aspects of ground motion to be recorded, so that both P and S waves and their polarizations can be studied. While previous vertical-component deployments have often treated the Earth as an acoustic (fluid) body, the recording of both P and S waves on three-components will permit more realistic elastic (solid) models of the Earth. Additional special-purpose sensors, such as accelerometers, enable experiments directed towards engineering and near-field source studies. Finally, in the past five years, low-power, broadband sensors, which can record ground motion faithfully with periods ranging from 20 ms to 20 s, have become commercially available. These sensors open new frontiers for imaging deep Earth structure with portable arrays.

The flexibility of the instruments, owing to their programmability and portability, simplifies interdisciplinary studies. The possibility of simultaneous recording of artificial sources and teleseisms, for example, will encourage coordination between studies of lithospheric and crustal structure, and studies of the earthquake process. Other disciplines, such as exploration seismology and earthquake engineering, can benefit from the array. PASSCAL instruments can be used to augment existing regional seismic networks with short-term deployments of broadband standardized digital recorders.

Standardization will have substantial benefits. Quantitative intercomparison of results from different experiments will be possible. The PASSCAL support organization will be able to maintain calibration and quality control, and by establishing PASSCAL standards, encourage the expansion of the standard technologies into other branches of seismology and Earth science.

Standardization of hardware and software makes it possible for data to be available for analysis within hours of acquisition. Just a few years ago, university investigators would spend the better part of a year post-processing uncalibrated, nonstandard data to prepare it for analysis.

A natural question is: why do we need thousands of channels of seismic instruments? First, we need to perform new types of experiments. The many possibilities include:

(1) Refraction and wide-angle reflection: Wavefield continuation methods now make it possible to determine simultaneously velocity structure and to image the reflection (turning point) levels of these signals. Full use is made of the recorded wavefield, not just of the arrival times and amplitudes.

(2) Travel-time analysis: Standard methods of analyzing refraction time anomalies (time term) or teleseismic P-wave anomalies are equivalent to the tomographic methods first used widely in medical imaging. Larger numbers of stations improve the resolving power of this technique.

(3) Reflection profiling: Reflection studies have always been conducted using dense-array methods e.g. COCORP profiling. The number, flexibility, and portability of the PASSCAL instrumentation will permit near-vertical reflection studies at a variety of scales, and with the areal deployments which permit 3-dimensional imaging. Extensive use of explosive sources for certain studies will also enhance the depth of sensitivity relative to vibroseis methods. Finally, calibrated 3-component measurements can potentially provide more complete constraints on the physical properties of crustal rocks by examining P and S reflection amplitudes simultaneously.

(4) Network studies of local and regional earthquakes: With the network treated as an array, this kind of earthquake data will be equivalent to controlled source data, and could be processed by wavefield and tomographic methods to yield not only detailed velocity and structural models, but also dynamical images of the sources themselves. Studies of this type are underway using the aftershock data set collected above the Loma Prieta fault zone.

In addition, innovative experimental programs are aided by the ready availability of this flexible instrumentation. Some detailed examples are given in *IRIS Science Review: Impact*, including core-mantle boundary structure studies using portable, broadband arrays; using 2-D, 3-component arrays in Eurasia to observe P-to-S converted phases from deep earthquakes in the Hindu-Kush; or beamforming portable array data to image mantle discontinuities. Other types of projects will emerge as the creative energy of the community is unleashed with these new facilities.

Demand is the second major justification for a large number of channels. The best evidence is demand for the current year. By the end of this year IRIS-PASSCAL will have supported 15 experiments conducted by 18 different member institutions. In 1989, the available instruments were in the field for a total of 175 instrument-months out of an available total of 225. For 1990, the projected total is 537 instrument-months out of a total of 600. Given the need for maintenance, service, and preparation work at the Instrument Center, these represent close to 100% of possible utilization. The demand is there, and needs to be filled. It is likely to grow even larger.

A factor of particular importance is the prospect of longer-term deployments of arrays (about 100 instruments) which need to record a large number of earthquakes, and require several weeks to one year in service. Examples are:

Linear arrays deployed over ~1500km aperture to record teleseisms and surface waves for the purpose of mantle and core imaging.

Converted-wave imaging of the crust and upper mantle requires an array of ~100 instruments spaced at 500m intervals, which is shifted along line in a series of 1 month teleseismic recording sessions.

Detailed monitoring of a critical earthquake source zone can productively utilize hundreds of instruments for a year or more.

The demand for these capabilities will grow faster than the capacity. It is particularly noteworthy that nearly half of the rapid growth of demand experienced during the first year of PASSCAL availability, has been from investigators whose projects were not being principally supported by the NSF Earth Sciences Division. The community being served, therefore, is a broad one, and growing.

Nature of the PASSCAL Facilities

The flexibility provided by the PASSCAL instrument has important benefits to the infrastructure of the science beyond the capabilities it can provide to fuel innovative projects. This topic has several aspects.

1. The PASSCAL facilities provide support for both large-scale experiments with many people and

large budgets, as well as small scale experiments. Thus the facilities can support both "big science" and "little science," and geologic questions on many scales can be addressed. This capability promotes the overall health of the seismological community, as both are important to the long-term health of science.

2. The PASSCAL facilities have an important role in education. They are important in graduate education for building exciting new frontiers for Earth science in general. These facilities are also important for undergraduate education because, as long as the pool of instruments is sufficiently large, any member institution can borrow instruments to teach an undergraduate field geophysics class. Few universities can justify funding such instrument acquisitions independently.
3. The PASSCAL facilities will provide an important resource for the basic research in earthquake science mandated by Congress through the National Earthquake Hazards Reduction Program. The next generation of seismic data needed to further our understanding of the nature of earthquakes will come from IRIS facilities (both GSN and PASSCAL).
4. The PASSCAL facilities promote cooperation between competing institutions because all share a common base of instrumentation. The PASSCAL facilities will expand the pool of scientists who can collect state-of-the-art data. Any of our 70 member institutions have an equal right to PASSCAL instruments provided they can work within scheduling constraints.

Accomplishments of the PASSCAL program, 1985-90

PASSCAL has taken the instrument needs given in the 1984 Program Plan, and completed an operational prototype for the full PASSCAL facility. This involved the following steps:

- Produce a formal set of engineering requirements
- Issue an RFP to construct prototype instruments meeting this requirements. Selection of Refraction Technology of Dallas from a number of bidders.
- Construction and delivery by Ref Tek of 7 prototypes, including timing system, playback unit.
- Field and bench testing of the prototype instruments.
- Incorporation of design improvements, including smaller size and addition of disk unit.
- Purchase, in two lots, of 90 production instruments.
- Development and purchase of software to permit the use of Sun workstations as field computers. Testing of field computers under a number of experimental conditions.
- Requested bids from universities for the operation of the first PASSCAL Instrument Center. Selection of Lamont-Doherty Geological Observatory of Columbia University. Start-up of the Instrument Center in August 1989, on receipt of the first production instruments.

The transition of IRIS from hardware and software engineering to a service role involved several field experiments. These experiences educated IRIS and the scientific community about the practical issues of using large numbers of instruments: experiment planning, data acquisition, data preprocessing, and analysis. Much of this work was funded by IRIS to promote this smooth transition.

- Interim lithospheric active imaging experiments in the Ouachita Mountains (1986) and the Basin and Range (1986).
- Interim lithospheric passive imaging experiment in the Basin and Range (1988-89).
- The Archean-Proterozoic Transect experiment (1989), using passive recording of teleseisms to look at upper mantle structure under a 1500 km array.
- The West Greenland Archean onshore-offshore experiment (1989), the first use of the production instruments.
- The rapid deployment of the new production instruments for aftershock recording following the Loma Prieta earthquake (1989).
- Teleseismic array recording in the Kenya Rift (KRISP) experiment (1990).
- Testing of a tight 3-component passive array at Pinon Flat, CA, for study of high frequency regional wave propagation and high frequency site effects.

IRIS appreciates the cooperation and patience of these investigators in serving as beta testers of the prototype PASSCAL operation. It has been an essential step in detecting and rectifying the expected list of small, but vexing bugs in the hardware and software.

As a consequence of the high performance and 6-channel capacity of the PASSCAL datalogger, the unit cost of $15,000 becomes a disadvantage to experimenters who need to maximize the number of sensors in the field, at somewhat lower flexibility and performance. In late 1989, manufacturers were requested for quotes on prototypes for an instrument with 3-components and a substantially lower price. The vendor selected, Ref Tek, offered an economy model of the 6-channel PASSCAL instrument with 3 channels, and less flexibility in the manipulation of data streams. Otherwise, the 3-component "simple instrument" fits well into the existing PASSCAL technology, and will become the preferred instrument for many investigators. With a system price of less than $6,000, it will make a more attractive instrument for educational institutions. The prototypes are scheduled for delivery in late 1990.

Pending the large-scale acquisition of the 3-component simple instrument, PASSCAL has partially supported an interim facility at Stanford University equipped with 200 Seismic Group Recorders. In cooperation between Stanford, the U.S. Geological Survey, Menlo Park, and IRIS, these operational instruments, if used, are being maintained to provide a large number of geophone channels for current refraction/reflection experiments.

Finally, the PASSCAL facility moved into operational status in spring, 1990. It is now engaged in providing the present complement of 90 6-channel instruments, along with sensors, field computers, and supporting equipment, for the use of funded Principal Investigators.

While moving into full operation, PASSCAL continues to upgrade the functionality of the system. Evaluation of GPS technology for 1ms timing is under way. A number of portable broad-band sensors are in delivery, for testing under field conditions. A 24-bit digitizer has been developed by Ref Tek and Hewlett-Packard for optional incorporation into the instrument. Work funded under the Eurasian Seismic Studies Program has demonstrated a number of elements of a possible telemetered PASSCAL array system.

The current PASSCAL facility may be considered an operational prototype of the full facility proposed in 1984, which we now propose to complete by 1995.

The Five Year Goal: Diversity, Activity, Innovation, Excitement

The scientific frontiers which can be addressed by PASSCAL arrays are characterized by *diversity*. The influx of young scientists into this field in anticipation of PASSCAL capability brings fresh *activity*, *innovation*, and *excitement*. It is the IRIS responsibility to provide the capability.

The PASSCAL facility may, like the GSN, be compared to a ship or a telescope. Instruments are deployed in arrays of 20 to 500, and function as an integral data collection system. Each experiment is planned by a team of investigators from several institutions, and several disciplines. Their scientific goal is to focus on a new, important target, and to apply innovative techniques in advancing our detailed understanding of how the Earth works. The team is to, in effect, design and build a new experimental system out of the building blocks provided by the PASSCAL program.

PASSCAL experiments, then, are a partnership between IRIS and the scientific team. The team organizes and funds its effort through one of several possible channels. IRIS, through its basic NSF facility support program, provides the equipment and the infrastructure of technical knowledge and oversight so that the needs of the scientific groups can be met.

Unlike the GSN, which has established a framework for global coverage, there is no inherent size for the PASSCAL facilities. We have established a target of 6000 channels of total capacity: approximately 450 6-channel instruments, and 1100 3-channel instruments. Much of the scientific rationale for numbers of this scale is given above, and in the *IRIS Science Review: Impact* which follows this Proposal. This goal, however, is aimed at achieving a level of scientific health and productivity in the Earth science community, and in particular, providing facilities which can significantly advance the goals of the *Continental Dynamics Program.*

At this time, there are active communities needing arrays for the following kinds of application:

Crustal imaging, using mixed reflection and refraction techniques, extending the capabilities of narrow-angle reflection imaging to 3-components and wide angle, permitting imaging of physical properties as well as reflectivity. Duration: 4 weeks. Need: 500-3000 channels.

Upper mantle profiling, with deployments which depend mostly on earthquake signals, supplemented by explosions. Duration: 6 months per deployment: Need: 200 broad-band instruments.

Earthquake hazards, fault studies, with tens of clusters of instruments, each cluster a tight array. Duration: a year or more. Need: ~400 channels.

For the US community to be marginally functioning in this arena, there should be two projects in place each year in the above categories. The mantle imaging and earthquake studies can be expected to tie up 2000 channels full time. Then, in addition to the needs in crustal imaging, there are many individual investigators with innovative projects to be carried out with arrays of 50-100 channels for smaller scale problems.

Substantial growth in demand is anticipated in areas of practical application; for example:

- Unified instrumentation of buildings and sites for earthquake engineering studies
- Aquifer mapping using a small reflection experiment with engineering source
- Installations to monitor time-dependent hydrologic phenomena, in aquifer drawdown, water reservoir management, hydrocarbon extraction.
- Subsurface site assessment of the top 100m with an area array, exploiting surface wave tomography, refraction, and noise data.
- Quicklook rapid deployment 15 channel tight array for reaction to seismic activity.

While funding for such instrumentation may eventually come from other sources, IRIS needs to provide the capability for innovation.

Implementation Plan:

The PASSCAL program has passed through a development and testing phase. An instrument exists that achieves the design goals outlined in the original 1984 IRIS proposal. The PASSCAL instrument is a reality, and we are prepared to complete this essential geophysical facility.

Equipment Acquisition

Data Loggers: There are presently two versions of the PASSCAL instrument: a six channel and a three channel recorder. Both are made by the same manufacturer. The cost per channel for the two different versions is comparable, but there are trade-offs in flexibility and performance versus modularity. Details of differences in these two versions of the instrument are spelled out in technical discussions in Section 3.II: Status and Plan for the Program for Array Studies. Present plans are to acquire approximately equal numbers of total channels of both versions of the instrument, as follows:

Instrument	Number	Channels
6-channel dataloggers	450	2700
3-channel dataloggers	1100	3300

Sensors: A flexible facility demands several different sensor models. Portable sensors fall into three general categories:

Exploration geophones, with f_0 ranging from 4.5 Hz to 50 Hz, usually cabled in linear arrays.

Short-period seismometers, with f_0 around 1 or 2 Hz.

Broad-band, or intermediate-period seismometers, with response between 20 sec and 20 Hz.

For many applications, 3-component strings of exploration geophones and 3-component, 2 Hz seismometers are most suitable, relatively inexpensive, and easy to deploy. Enough of these will be acquired to serve each instrument, along with extender cables, as needed.

Broadband force-balance instruments are now the preferred technology for high dynamic range recording of signals in the longer period range. They function on the same principles as the Streckeisen STS-1 VBB instruments used by the GSN to cover the frequency range from the Earth's normal modes to 10 Hz. To achieve price and portability, they are not intended for performance in the normal mode range from 1 to 10 mHz. They are in high demand for several reasons:

(1) Broadband sensors can produce the better-quality data needed for undistorted waveforms in crustal imaging experiments.

(2) Large numbers are needed for the arrays which will map mantle structure at the resolution needed for geological significance.

(3) Broadband sensors are a powerful tool for looking at local and regional earthquakes and determining their rupture mechanisms.

(4) Many broadband sensors are likely to be deployed in arrays that run for many months at a time. This will lead inevitably to scheduling demands that require enough sensors to support multiple deployments.

In the presently available technology, they are still too expensive to afford in quantities of 1000's, and they are not portable in the same sense that a geophone is portable. Each site must receive a significant fraction of a day's effort of preparation.

We propose a compromise target for the PASSCAL facilities of 270 (3-component) broadband sensors. This would allow multiple experiments of a reasonable scale to be running at any given time, while working within practical fiscal bounds. Acquiring these seismometers is planned for as early as possible in the five year period, in order for the critical teleseismic array experiments to be fielded soon.

Field Computers

The 1984 IRIS proposal projected a need for field computers for quality control and initial data processing to support field programs with PASSCAL instruments. At that time it was projected that one field computer could support from 50 to 100 instruments, depending on the nature of the experiment. That projection has turned out to be remarkably accurate and remains as the working figure used in our budget estimates. An important development for the future of the program, however, is that the cost of required computer hardware has fallen dramatically in the past 5 years, and the net cost of this portion of the facility has been reduced drastically.

It is now widely recognized that software development is more costly and difficult than funding hardware. IRIS will continue to support efforts to upgrade the field computer software, and to add the high performance functionality required to deal with large gathers of data.

The field computer with the IRIS developed software, and the IRIS-supported SierraSeis package, is indistinguishable from a SUN workstation used at a university for research. All development and support of the field computers, then, is immediately available elsewhere for use on workstations.

Instrument Centers

IRIS has adopted a policy of contracting with member universities to provide service support for PASSCAL instruments. This benefits the infrastructure that supports the science's health by increasing technical support within the university community. The first such facility was established at Lamont-Doherty Geological Observatory in May, 1989. Experience has shown that no single instrument center in a university setting can support more than 100 6- channel instruments without significantly interfering with the institution's normal research activities. Beyond this, the facilities' impact on space and personnel may be too great for most university groups.

IRIS strongly prefers to house the Instrument Centers in member universities. It is an opportunity to rebuild capability and instrumentation awareness in the university community. Budget estimates are based on this assumption, with a new Instrument Center for each additional 600 channels.

The Lamont-Doherty Instrument Center has developed software, documentation, training, and deployment techniques, in addition to participating in routine equipment maintenance and management of the equipment. As a first approximation, these R&D functions at Lamont will serve for the entire PASSCAL Program. It is possible that the proposal process for selecting the new centers will generate some novel R&D activity at those locations.

The second Instrument Center will be put up for proposals in late 1990, and will be specialized for the maintenance of the 3-channel simple instruments to be acquired in 1991. Other Instrument Centers may be similarly specialized. For example, a center in California might manage a rapid response array for earthquake aftershock response.

Equipment Upgrades

The major developments for the PASSCAL instruments are complete. Several related technologies are advancing at a rapid rate and will have important impacts on the facilities. Therefore, the instruments will require some upgrades in the next 5 years. The upgrades will probably need to consist of the following:

Sensors. New commercial sensors are likely to be introduced that significantly improve upon the current generation of sensors. The timetable for these developments is unpredictable as shown by the example in recent years. Five years ago, there was no broadband sensor that was conveniently portable. Now, there are good candidates.

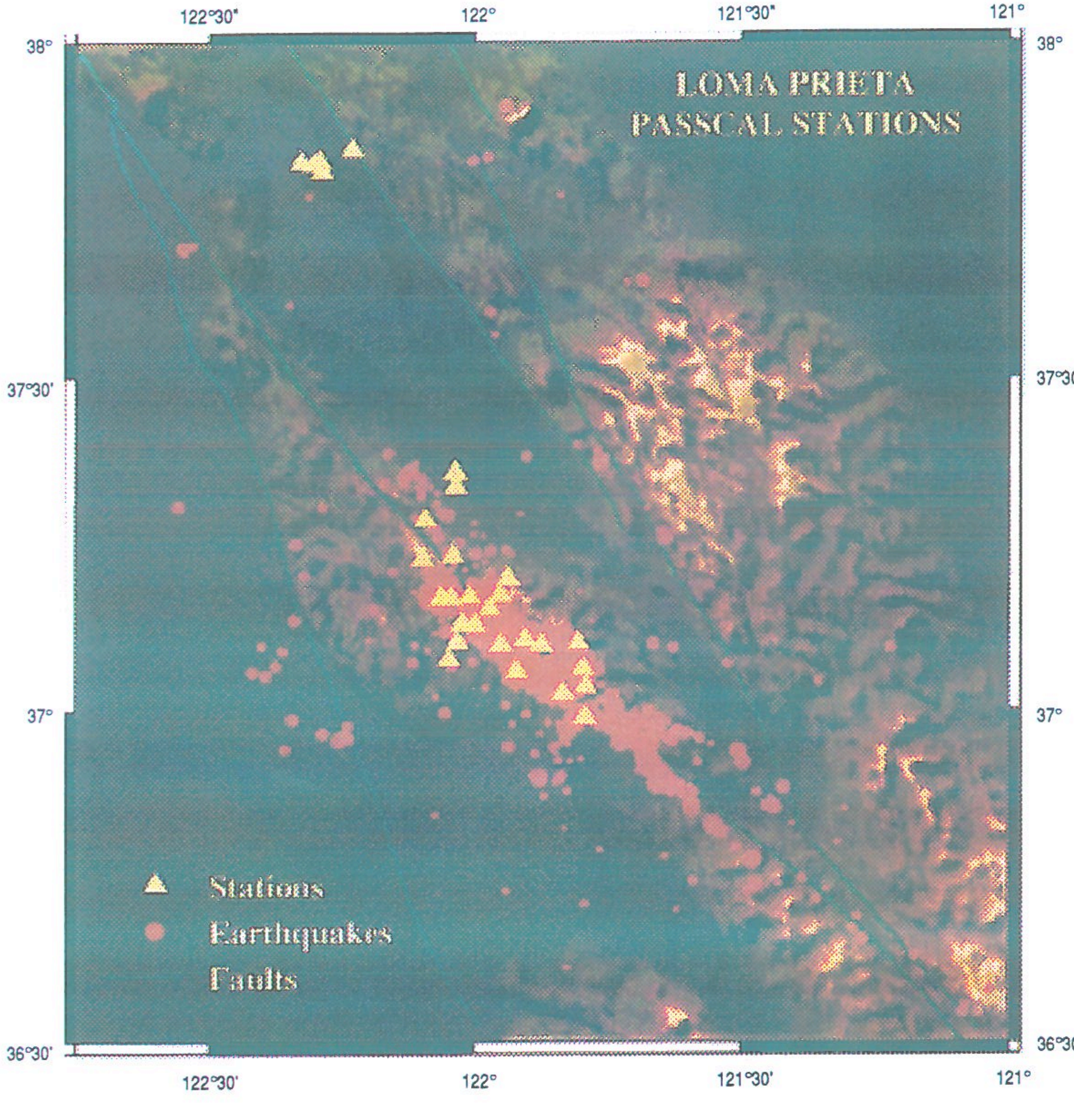
Timing-system conversion from OMEGA to Global Positioning System satellite clocks will probably resolve problems that have kept OMEGA as a marginal timing method.

Equipment for automated diagnostic and status testing of instruments is needed at the Instrument Center(s) to manage efficiently the large number of instruments.

Telemetry: a general solution to the desire for telemetry remains elusive, due to difficulties in obtaining and using radio frequencies. However, specific innovations can be useful. The ESSP array projects have developed a local telemetry network out of existing hardware with only minor enhancements. Direct telephone or cellular phone access can provide services in some areas. Low data rate satellite services for transmitting state of health are an attractive option.

Upgrade of a subset of instruments from 16-bit to 24-bit encoders.

Field computers. Developments in computer hardware have advanced at a rapid rate. Most computer equipment is now obsolete within five years. Funds will need to be directed to field computer upgrades.



Locations of PASSCAL stations deployed to record aftershocks of the Loma Prieta earthquake. The 1407 epicenters shown are for events October 20-21 of magnitude 1.0 to 4.4 recorded on at least one of the PASSCAL instruments.

Purpose

Digital seismology, a concept since at least 1958, was vigorously taken up by industry in the late 1960's. However, the lack of funding for serious academic facilities, and the applied perspectives of agency programs, have led to many years of fragmentation of R&D efforts in digital seismology. Investigators commonly spent months or years converting data from different sources into a form usable for research.

The quantum jump in both the quality and quantity of digital data, made possible by the GSN and PASSCAL programs, can be fully exploited only if individual scientists can easily access this greatly expanded data set in a timely fashion. The DMS's primary purpose is to ensure that such access will take place.

The obsolescence of the analog World Wide Standard Seismographic Network (WWSSN) led to the organization of the IRIS/GSN Program. This became an opportunity to employ the kind of data management needed if the new digital data acquisition technology were to be of any use.

IRIS has addressed this issue by organizing a Data Management System (DMS) as an equal partner with the GSN and PASSCAL programs. Standardization and compatibility of all three programs has been a basic goal of the IRIS effort over the past five years. The DMS has emerged as a smaller, more functional and less expensive system than could have been anticipated even five years ago. This has only been possible because of the unprecedented growth of the technology needed to handle the IRIS data. As a consumer and not a developer of this technology, IRIS has been building the DMS right at the limit of what is available and affordable.

The Continuous Archive: a unique capability

The IRIS DMS has undertaken the archiving and distribution of continuous 20sps data from global broadband seismographic stations. The need for continuous data was stated in the 1984 GSN Program Plan, and has been reiterated regularly by the Standing Committees. Other global networks, as well as the USGS, which is an IRIS partner in the GSN, have elected to develop event archives. The event CDROMs distributed by the USGS capture events listed over M5.5 in the PDE bulletin, and are a convenient tool for many researchers.

The continuous archive is not only unique, but serves data needs which cannot be met by compiled event-oriented products. These include (1) rapid access to a dynamically maintained archive; (2) access to regional and local earthquakes for powerful new studies of earthquake dynamics; (3) extended free oscillation time windows, excited by large or unusual events such as the slow earthquakes on oceanic transforms; (4) unanticipated phenomena.

The continuous archive thus complements the data products available elsewhere, and provides the greatest flexibility to the researcher. It has become feasible for network operators in the FDSN to deposit their continuous data in the IRIS DMS. The IRIS DMS archive then provides a single access point for data in a truly global sense. IRIS must guarantee that the data are readily available on a global basis, which will be increasingly important in the coming five years.

Figure 12, (following page), shows the architecture of the IRIS Data Management System.

Acronyms in the Data Management System	
DCC	Network Data Collection Center: one at UCSD and one at USGS, Albuquerque.
DMS	The IRIS Data Management System: includes all networked elements from the DCC's to the archive to the user terminal.
DMC	The Data Management Center: the IRIS facility in Austin, TX, which houses the archive.
UTIG	The University of Texas Institute of Geophysics
CHPC	The Center for High Performance Computing, University of Texas, Austin.
DBMS	The Database Management software resident on the IRIS SUN node at CHPC. May be the "prototype" or the "interim" package.
archive	The mass store at CHPC on which the data resides. Also refers to the data itself.
SEED	The standard format for data recorded at seismic stations, adopted by the FDSN.
FDSN	The Federation of Digital Seismographic Networks.

The heart of the DMS is the data archive, which is the official library of all IRIS data. The network Data Collection Centers (DCC) and the users complete the

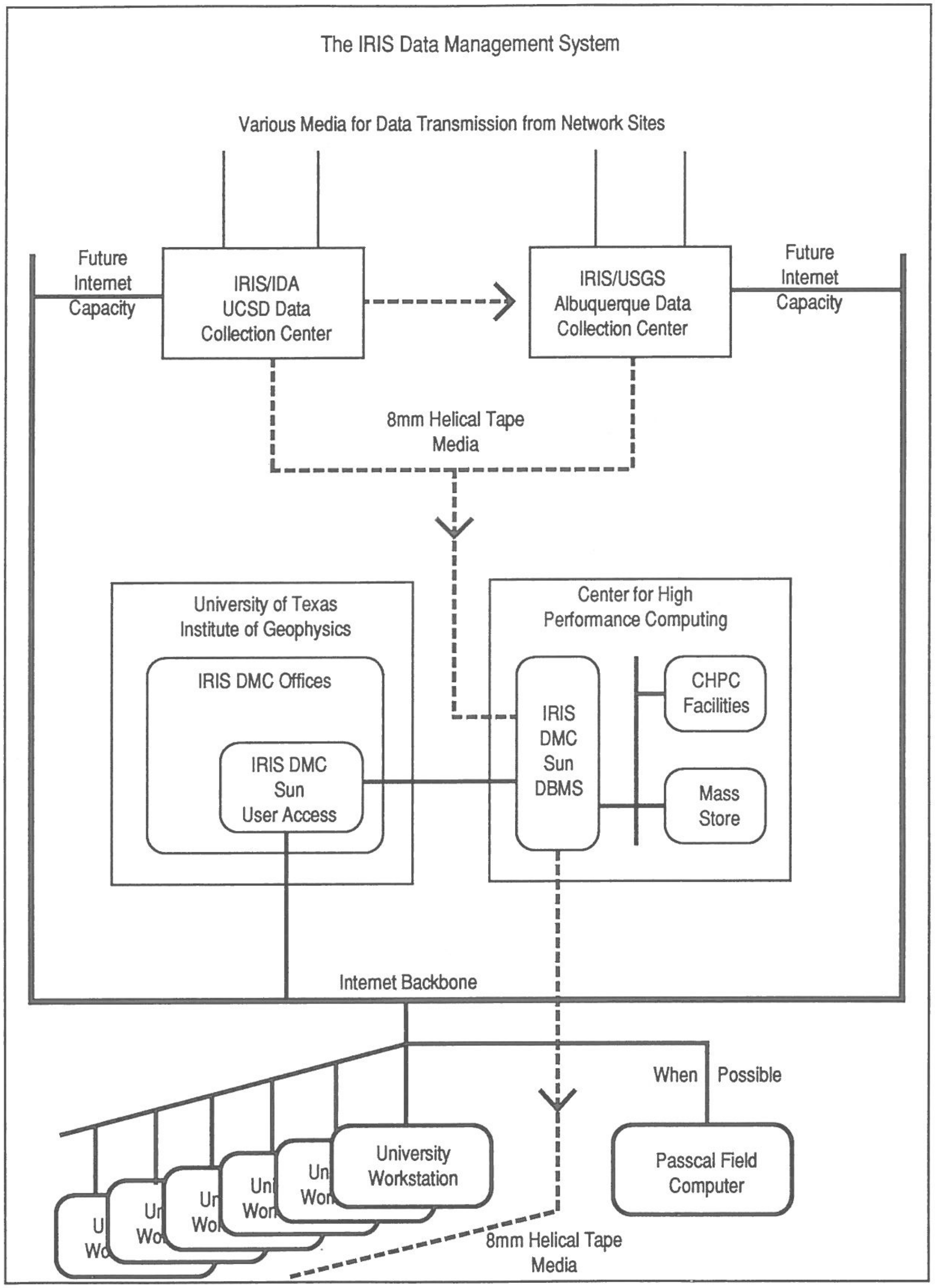

The IRIS Data Management System
Various Media for Data Transmission from Network Sites
Future Internet Capacity
IRIS/IDA UCSD Data Collection Center
IRIS/USGS Albuquerque Data Collection Center
Future Internet Capacity
8mm Helical Tape Media
University of Texas Institute of Geophysics
IRIS DMC Offices
IRIS DMC Sun User Access
Center for High Performance Computing
IRIS DMC Sun DBMS
CHPC Facilities
Mass Store
Internet Backbone
When Possible
University Workstation
Passcal Field Computer
8mm Helical Tape Media

Figure 12.

DMS by network connections and data paths to the archive. The DMS is ultimately responsible for the integrity and maintenance of all the data. It provides rapid, effective methods for obtaining data. The IRIS DMS central archive is currently housed at the Data Management Center (DMC) at the Institute of Geophysics, University of Texas at Austin.

Enormous advances during the past five years in computer speeds, mass storage technology, and networking have made the DMS possible. New technologies for digital storage on video tape will make it possible to store physically on six cartridges one year's continuous GSN data from a 128 station network. Inexpensive high capacity commercial satellite links in the coming decade may connect the data acquisition point, the data archive, and the user.

Utility is the leading performance criterion for the entire IRIS program, but particularly so for the DMS. Users need to obtain a response to requests for information in a minute or less, to obtain sample waveform data in minutes, and to obtain multi-gigabyte data in one day. Individual scientists have individual preferences. Many problem-driven data requests (e.g. the retrieval of all P_{diff} phases from an particular portion of the core-mantle boundary) can best be addressed by interrogating the archive directly. Other users would prefer to store a large fraction of the global data set locally. Others may wish to reprocess data sets from previous active-source array deployments. Many researchers favor accessing data in near-real time for rapid determination of the source parameters of important earthquakes. The DMS should provide the services that practicing seismologists would like to take for granted.

The large data volumes demand common standards. Just as the combination of data into a single network demands hardware and data format standards, so must members of the scientific community cooperate in access and data exchange, and with utility and applications software.

The DMS is well positioned for simplifying many routine, but time-consuming, data-handling tasks performed by IRIS member institutions. IRIS has adopted the SEED (Standard Exchange of Earthquake Data) data format for archival and distribution of earthquake data. PASSCAL data are available in the industry-standard SEGY format for artificial source data. The DMS functions as a clearing house for software to format-convert, display and process data. The DMS software includes SierraSeis, sold at a discount to IRIS members, and the freely-distributed SAC and AH programs, written by researchers at Lawrence Livermore National Lab and Lamont-Doherty Geological Observatory, respectively.

The central archiving and distribution system for IRIS data can also serve in this same capacity for data sets collected by other network operators, including networks in the Federation of Digital Seismic Networks (FDSN). This can be accomplished without a significant additional burden for the DMS, and provides seismologists with convenient access to this larger data set. At present, IRIS receives data from Project GEOSCOPE (France), ORFEUS (Western Europe), and the Geological Survey of Canada (GSC); negotiations for data exchange are underway with POSEIDON (Japan), MEDNET (Italy), the Grafenberg Array (Erlangen, West Germany) and other non-U.S. operators of broadband stations. In return, IRIS agrees to provide access to the DMS archive for foreign seismologists.

Accomplishments of the IRIS Data Management System, 1985-90

In the past five years, the IRIS DMS has evolved from design studies to a working data system. The DMS archive receives data from GSN and other global fixed stations after initial processing at the Data Collection Centers (DCC) at UC San Diego, and the Albuquerque Seismic Lab. Data from field experiments using PASSCAL instruments are received from the principal investigators with appropriate documentation, after a delay not intended to exceed six months. The archive, physically located in the mass store at the Center for High Speed Computing (CHPC) at UT Austin, contains global data from 1988 through the first few months of 1990, along with several PASSCAL data sets.

The development of the DMS has been carried out by a core group of IRIS employees in the DMC: Tim Ahern, the Program Manager, Sue Schoch, Senior Database Programmer, and Becky Wofford, the System Manager. The design principles were finalized by the Standing Committee for the DMS, after considering recommendations of the early design studies. Scientists and programmers at universities including the University of Texas, Columbia University, and the University of Washington, provided a number of key software packages needed for the DMS. The design has emphasized modularity, portability, expandability, and independence of mass storage hardware.

Access to the data in the mass store requires a database management system (DBMS), which provides inquiry and retrieval services. The DBMS resides on a SUN computer system with 4Gb of local disk storage, which has access to the large mass store at the CHPC. An "interim" DBMS has been in use since October, 1989, permitting the retrieval of specified station-channel-time windows. The user interface is accessible through Internet. Small data sets are supplied directly over Internet, and large data sets are mailed as half-inch tape or tape cartridge.

For the past two years network-architecture DBMS, designed to provide full, rapid functionality, has been under development at the DMC for the past two years. Based on the product DB-Vista, its prototype is now in beta test by a number of university users. When the evaluation of the prototype is completed in late 1990, the design will be finalized, and the essential software tools of the IRIS archive will be complete. A window-based user interface is being designed, and should be available by the end of 1990.

Most of the archive's development has involved parallel efforts. The system has been created to minimize cross-dependency among different elements. Initial loading of data began in mid-1989, and continues now, with the delay between receipt of data from the field and archiving now greatly reduced. The initial shakedown period required solving a number of minor problems with implementing SEED format compatibility.This year's switchover from the interim DBMS to the prototype is a clean one.

The IRIS DMS is designed for portability to a wide variety of data storage systems, from traditional mass store hardware to new jukebox technologies. In this way IRIS can take full advantage of technological advances in mass storage. After completing evaluation of the prototype DMS in late 1990, IRIS will issue a request for proposals from institutions wishing to serve as the permanent home of the IRIS data archive.

Data being received at the archive come from the two Data Collection Centers:

- U.S. Geological Survey, Albuquerque Seismological Laboratory - Data from the DWSSN, SRO, ASRO, China Network.
- University of California, San Diego, Institute of Geophysics and Planetary Physics - Data from IRIS/IDA GSN installations, original IDA gravimeters, and stations in the Soviet Union.

While the DCC's are organized under the DMS, they are operated in connection with GSN network operations of the USGS and UCSD. Their cooperation in guaranteeing data quality, and in expediting data flow, has been extremely important.

The DMS archive currently holds over 45 Gbytes of seismic data, mostly collected over the last two years by several dozen fixed global stations. The current data flow is greater than 200 Mbytes/day, and is increasing rapidly as new GSN stations are installed, both at new sites and existing fixed-station sites. The volume of PASSCAL data to be archived is also growing rapidly. The initial weeks of the Loma Prieta aftershock deployment generated more than 2 Gbytes from 25 instruments operating at 200 samples/s in triggered mode. The projected data flow from the completed GSN and PASSCAL programs is roughly 1 Tbyte/yr, or 3 Gbyte/day.

The IRIS DMS contains the GOPHER system, written at the University of Washington. Upon receipt of an NEIC earthquake bulletin for an 'interesting' event, GOPHER accesses a set of broadband seismic stations by dialup modem, and downloads data windows containing the initial body wave phases (on the VBB channels), and surface wave phases (on the LP channels). These data are made available to outside users by remote login (dialup or internet) to the DMS computer. The GOPHER system allows simultaneous access to data from multiple users, unlike the individual GSN stations, whose dialup ports allow only one interrogator at a time. GOPHER proved its usefulness after the October 17, 1989 Loma Prieta event by allowing researchers rapid viewing of records from stations PAS (Pasadena, Calif), ANMO (Albuquerque, NM) and HRV (Cambridge, Mass.). The short data windows obtained by GOPHER are saved online, allowing perusal of earlier 'interesting' events. For example, records from station PAS from an August, 1989 M=5 foreshock of the Loma Prieta event were available for rapid comparison with the main shock.

The DMS operates a bulletin board through its internet node. It provides access to the DBMS for data requests and the GOPHER system for dial-up data. It supplies information on status of the archive, custom data products, PASSCAL data, and supported utility software.

PASSCAL data, along with a data report, are supplied to the DMS by the scientific team which organized the particular experiment. Currently, distribution is in the form of SEGY records. Future software development for the field computer will permit earthquake data recorded on PASSCAL arrays to be put in SEED format and managed as earthquake data.

DMS has assumed a role in the distribution of useful utility and applications software. It fully supports the SEED format reader and the PASSCAL field computer utilities for field operations, and is responsible for documenting this software. It acts as a distributor for ZPLOT, a screen/plotter package for seismic gathers, developed at the University of Utah; for the Seismic Analysis Code (SAC), developed at Lawrence Livermore; the AH package, developed at Lamont; and the SierraSeis reflection processing package.

The Five Year Goals:

- Grow in capacity as networks and arrays grow
- Maximize service, convenience, and responsiveness
- Archive worldwide continuous VBB data
- Achieve a high level of quality control
- Develop the means to manage earthquake data from arrays

The present DMS functions well with the current influx of data from IRIS and other facilities. The software is designed to port readily to other platforms, to make use of newer options in mass storage, and to handle data volumes and user requests at the level for which the GSN and PASSCAL are planned. During the coming five years, the DMS's principal task is the upgrading and revision required to accommodate the data flow, while at the same time improving convenience, service, and responsiveness.

Toward the end of 1990, the Standing Committee will evaluate the status of the DMS, and make recommendations regarding its conversion from the current prototype status to "Version 1.0". This is expected to involve:

1. Issuance of an RFP to institutions wishing to host the operational DMS.
2. Selection of a site.
3. Selection of the mass storage method to be used for the operational system.
4. Possible installation of satellite data link for data transfers from DCC's to DMS.

In the operational DMS, effort will be divided between the service function and the continuing task of improving responsiveness and convenience. Within the latter area, some of the tasks are:

1. Enhancement of the user interface to provide more seismologically oriented tools.
2. Exploration of efforts for transmitting very large datasets directly to users. Improvements in the Internet as well as the capabilities of the KU-band satellite service used by the U.S. National Seismic Net provide plausible paths to speeding up data access.
3. Upgrading the GOPHER service to take advantage of the increase in the number of dial-up stations and the advent of telemetered stations in the USSR and the USA. The goal would be to reduce the reaction time in the case of major earthquakes to approach the minimum determined by travel times in the earth.
4. Development of the browse capability. The ability for a user to conduct unrestricted, random browse of the full archive for waveforms or gathers of waveforms, is a requirement which exceeds present or anticipated hardware capabilities. However, considered as part of the normal process for scanning for a particular subset of data, a structured browse capability appears feasible, involving the preparation of intermediate online data sets to be browsed.

During the next five years, more and more VBB stations installed by member countries of the Federation of Digital Seismographic Networks (FDSN) will be coming on line. As this happens, the IRIS DMS will, in accordance with our agreement with the FDSN, accept and archive continuous data from the new stations. This will eventually consolidate the design goal stations of the FDSN into a single 128 station Global network. This will involve specific bilateral agreements with these networks to insure that the facilities and services of the DMS archive can be used by their national scientists as technical limitations permit.

During the past five years, the startup of the new GSN network facilities included the development of Data Collection Centers at U.C. San Diego, and at the USGS Albuquerque Seismological Laboratory. At this point, IRIS has formally put the coordination of DCC operations and procedures under the Program Manager for the Data Management System. This permits adequate oversight of data flow and quality control through the entire path between the return of data to the DCC to the DMS archive, and to the user. For the upcoming year, the Standing Committee, the DMS, and the DCC operators will agree upon requirements and procedures for quality control through the system.

Some participation is planned by university research groups to assist in the quality control process. The active research groups engaged in working with many earthquakes from global networks are more likely to uncover subtle problems with data quality, than are the personnel at the DCC who review the data as a routine function. Agreements are planned for formalizing this process with about two institutions, to ensure that the data in the archive will be reviewed by seismologists interested in basic research outside the DCC.

One of the most important new types of seismic data will be that acquired by arrays of broadband PASSCAL instruments. Such deployments could more than double the number of effective stations which must be archived. A number of critical software links need to be developed. The experimenter must use the field computer for event association and creation of edited event gathers, with software having real-time access to information from the National Earthquake Information Center (NEIC). The resulting gathers must be archived in the DMS. Such array experiments would be even more useful, since the event waveform data will provide many types of information. These data may be of great interest to the larger research community, though perhaps not to the original experiment designer.

The advent of the U. S. National Seismic Network (USNSN), will allow IRIS and the USGS to maximize the use of data collected in the US for earthquake hazard monitoring purposes. In the next few years, the USNSN will likely be joined by a number of high-performance digital broadband networks operated by universities on a regional or local basis. By the same token, the global stations of the GSN have an established role in the real-time response to earthquakes within the US. IRIS is committed to developing mechanisms for data exchange with the national facilities under the aegis of the U. S. Geological Survey, and for making optimum use of complementary capabilities. These arrangements will depend on the technology, the funding, and the institutional arrangements which emerge along with the new generation of regional and local monitoring networks. An example is the recently concluded arrangement between IRIS and the Caltech TERRASCOPE network, in which IRIS DMS acts as the primary archive for continuous data from the network, but a port of the IRIS DBMS at the Caltech site is available for local use in data management.

The IRIS DMS provides support for standard utility and application software. This role has involved software for which DMS can fill a void. The support of the SEED reader, and of format conversion utilities, is the most obvious. The limited support for the existing AH and SAC analysis packages relieves the authors of an unsought service burden. The SierraSeis Support Center at Lawrence Berkeley Laboratory has provided a widely used common package for work with PASSCAL data on individual work stations. The tools of 'standard' seismological analysis have grown more sophisticated. It is often assumed that seismologists possess a wide array of software packages for data processing and synthetic seismogram generation. Although true in principle, in practice researchers expend considerable effort seeking appropriate codes from their colleagues, or writing code to accomplish standard tasks. Ancillary to its function as a source for seismic data, the IRIS DMS already offers much data-handling software. Additional effort will be necessary. A powerful workstation environment for the analysis of large, complex, multitrace, 3-component datasets will be necessary in the very near future. The IRIS DMS, in consultation with the Standing Committee, will explore options for bringing the needed software to the users. The DMS bulletin board will continually be augmented to help the community exchange and standardize widely used software, such as raytracing and modeling codes.

In this Proposal, the budgets for the DMS range between \$1.7m and \$2.2m per year, representing only about 12% of the IRIS program's total five year cost They will be less capital intensive than the GSN and PASSCAL programs during 1991-95. The DMS budget levels increase only slightly with the number of GSN and PASSCAL instruments, since much of the cost is a fixed base. For the DMS, most functionality is available "off the shelf" from hardware and software developed for totally different applications. Most of our development efforts are incremental, and require a small professional staff to maintain the DMS at a state of the art condition.

Purpose

The Eurasian Seismic Studies Program (ESSP) is a joint US-Soviet research program in seismology. IRIS and the US Geological Survey represent the United States, and the Institute of the Physics of the Earth of the Soviet Academy of Sciences represents the Soviet Union. The purpose of the ESSP is to provide facilities and data that will permit a practical understanding of seismic properties of the crust and continental lithosphere, signal and noise propagation and characteristics, and the properties of seismic sources. IRIS operates the ESSP program because of its direct contribution towards establishing near-uniform global coverage of digital seismic stations, and for its role in fostering new experiments in array and network seismology and data telemetry using state-of-the-art instrumentation.

The funding for the ESSP is provided by a Congressional appropriation to the nuclear monitoring budget of the Defense Advanced Research Projects Agency (DARPA); it is transmitted through the NSF, which administers it under the terms of the Cooperative Agreement with IRIS. As such, it falls under the 5-year funding authorization which we request in this proposal, although the funds are not provided out of the NSF budget.

US seismologists have long sought access to data from stations in the Soviet Union. These data would enable the study of a variety of continental tectonic processes exemplified in Eurasian structures. The data would also provide even coverage of the Earth in a global array. For many years, requests by US seismologists for Soviet data were turned down. But in 1987 the Natural Resources Defense Council (a private organization) was permitted to place temporary seismic stations in Kazakhstan. This was part of an experiment to examine the verifiability of treaties limiting nuclear weapon testing. Sensing a change in Soviet policy, IRIS approached the Soviet Academy of Sciences. Soviet permission, and US funding for the ESSP were obtained by April 1988, and the first deployment of IRIS instruments in the USSR occurred in August-September 1988.

Support to IRIS for the ESSP comes mostly from organizations concerned with the program's technical contributions to public policy issues concerning nuclear explosion monitoring and earthquake hazards mitigation. IRIS views these contributions as both a strength of the program, and as an opportunity for its member institutions to supply objective technical information on important issues of public concern. IRIS, however, assumes no position on policy issues.

Accomplishments of the Eurasian Seismic Studies Program: 1988-90

Under the ESSP, four broadband GNS stations in the USSR are now sending data back to the US on a routine basis. Detailed plans and funding are in place for growth to thirteen stations by the end of 1991; and it is expected that about 20 stations will eventually operate in the USSR.

With the IRIS instrument deployments of 1988, the process of studying Soviet earthquakes with broadband data is only just beginning. As contributors to the global broadband array, IRIS Soviet stations are being used to study many events teleseismically, including the Loma Prieta earthquake of October 1989. They are particularly crucial for the study of the 20 June 1990 M7.7 Iran earthquake and its strong aftershocks. A principal scientific result from the ESSP so far is the discovery that Lg-wave amplitudes are far more stable than amplitudes of other regional waves, or of teleseismic P-waves. Now, greatly improved estimates of Soviet underground nuclear explosion yields can be obtained.

In addition to these installations in the USSR, IRIS is setting up two regional networks and a small aperture array. This was a result of a request from the Soviet side in 1989 for modem telemetered networks in Armenia and Kirghizia, both identified as regions of earthquake hazard. Under this initiative, plans are being executed by the University of California, San Diego (UCSD), to install a telemetered regional network near Frunze, Kirghizia. This array will be quite similar to the network now operated in Anza, California. With 10 stations, each recording at 100 samples per second, the Kirghizia network is likely to generate important new data for studying earthquake source processes. Embedded within this network, UCSD is also installing a small aperture (2 km across), 25 station broadband array that is designed to study the phenomena of seismic wave scattering by shallow crustal heterogeneities. Several other IRIS members are involved in the research plan for this array, which addresses fundamental aspects of wave field coherence. The initial plan for a regional network to study seismicity in Armenia has been modified due to political instabilities in the area. The Lamont-Doherty Geological Observatory will instead install telemetered stations in a network near Kislovodsk, on the northern edge of the Caucasus.

Installation and operation of the Soviet stations are performed by the two current network operators for the Global Seismographic Network: the University of California, San Diego, and the U.S. Geological Survey, Albuquerque Seismological Laboratory. The data are transmitted from the stations to the ESSP Data Collection Center at the Central Seismological Observatory, Obninsk (near Moscow), where the data will undergo quality control, duplication, and transmission to the US DCC. Until mid-1990, data were transmitted by 9–track magnetic tape within the Soviet Union and internationally, resulting in delays of 6 weeks to 3 months before receipt in the DMS archive. At this time, telephone line telemetry is in place for the four original stations, and an international satellite will soon carry the data to the San Diego DCC.

The ESSP entails various agreements on reciprocity with the Soviets. In particular, VBB stations in the US are designated exchange stations, and their data are sent to the Soviet side.

The principal institutional partners in the ESSP along with IRIS are the U.S. Geological Survey and the Institute of Physics of the Earth, Moscow. The instrument under which the international program takes place is "Seismological Studies and Data Exchange: Project number 02-09-15 under the U.S. - USSR Agreement on Cooperation in the Field of Environmental Protection".

Five Year Plan — The Goal: Completion and Integration of Facilities

In June 1990, the Executive Committee of IRIS took action to appoint a Committee on the ESSP. Its task was to consider the future structure and mission of the ESSP. The Committee will be responsible for presenting a fully worked out long-term strategy. The plans given here represent a conservative consolidation of present tasks, on the assumption of level funding which after a period of 4-5 years, will eventually decrease.

1. The principal element of the ESSP is the extension of the GSN into the Soviet Union. Based on the spacing in the GSN siting plan, about 10 stations would be required. Given the current importance of the new stations to verification research, about 20 stations are regarded as a desirable target. We expect this to be reached with the 1991 or 1992 funding, although the final installation may lag by as much as a year.
2. In keeping with the integrated nature of the IRIS GSN, the Soviet GSN stations are to be managed within IRIS as a subset of the GSN, and the Data Collection paths brought under the oversight of the DMS.
3. The special funding and the fact that such a large land area falls in one country makes it possible to plan for continued conversion of the GSN stations to telemetry: in-country transmission to Obninsk, followed by the international satellite link to the US.
4. The array and network projects in the Caucasus and Kirghizia are in the midst of a 2-3 year implementation period, a vital period of prototype operation. This is necessary so that the optimum siting, design, and operation under the often difficult practical constraints can be established.

For all elements of the ESSP, including the GSN stations, the Data Collection Center, and the array/network operations, a critical goal is to help Soviet personnel to operate, maintain, and creatively use these facilities to the fullest extent. This will require continued exchange of US and Soviet scientists and technicians between each country, as well as the continued provision of hardware and software.

At a higher level, IRIS seeks to reduce barriers to scientific communication, and increase collaboration between US and Soviet scientists. Soviet seismology must be actively brought into the mainstream of the international community. In addition to the working visits described above, IRIS hopes to use the IRIS workshop to organize other scientific events in furthering these goals.

In the US, the ESSP has enabled university and government scientists to research seismic sources and crustal wave propagation to generate information needed for nuclear testing limitation, and nuclear nonproliferation treaties.

Scientific Planning: The Committee on Earthquake Research

The need for a national earthquake research plan was underscored by the recent magnitude 7.1 Loma Prieta earthquake, and its aftermath, of 17 October 1989. Several billion dollars of property damage and dozens of deaths resulted from an earthquake 30 times smaller than the 1906 San Francisco earthquake. Funding for basic earthquake science research and engineering has declined in recent years, so that much work on earthquake hazards can no longer continue, and new ideas cannot be explored. For example:

- The U.S. Geological Survey is barely able to continue the basic function of monitoring earthquake activity. Seismographic networks can no longer be maintained,and resources are unavailable for upgrading equipment that is seriously outdated and incapable of supporting modern research.
- Research on earthquake hazard reduction has been curtailed. Strategies to limit damage cannot be fully developed.
- New ideas cannot be pursued. As a result, graduate education in earthquake science and engineering is faltering, and young scientists and engineers are turning away from careers in earthquake studies.

This deterioration is particularly distressing given the consequences. A major earthquake in the United States could kill thousands of people, cause more than a hundred billion dollars worth of property loss, and have a significant negative impact on our national security. As seen in Armenia in 1988 and Mexico City in 1985, major earthquakes are second only to war for inflicting catastrophic losses. The future cost to the Federal and State Governments will be immense. Less than 20% of the residents in earthquake prone areas have any kind of earthquake insurance. Consequently, the Government will pay the cost of the damage through disaster assistance and lost tax revenue, as well as the cost of damage to Federal and State property.

The recent earthquake in California serves as an example of an area in which progress has been made in basic research. This earthquake was *forecast* based upon the historical record of earthquakes along this segment of the fault, and estimates of strain buildup. The Marina District and the Nimitz Freeway had been identified as areas where ground motion would be amplified due to water-saturated soils.

The U.S. Geological Survey estimates that in the next 30 years there is a 50% probability of a magnitude 7 earthquake in the San Francisco Bay region. There is a 60% probability of a magnitude 7.5 to 8 earthquake along the southern San Andreas Fault, and a 50% probability of a magnitude 6.5 to 7 earthquake on the San Jacinto fault in southern California. It is almost a certainty that at least one of these earthquakes will occur in California in the next 30 years. Earthquake danger, is not restricted to California, however.. The largest earthquakes to occur in the United States, with magnitudes of 8.6, 8.4, and 8.7, were centered in New Madrid, Missouri in 1811-1812. Damaging earthquakes historically have occurred in Alaska, Utah, Hawaii, the Pacific Northwest, Nevada, South Carolina, central Mississippi, and the northeastern U.S. earthquakes will occur again in these places.

This is a critical time for rebuilding the national effort. Because of enhanced public interest, there is now an opportunity to greatly strengthen the National Earthquake Hazards Reduction Program (NEHRP). Unfortunately, the academic seismology community lacks a clear National plan to direct the pursuit of additional funding in this field. The USGS needs a strong partnership with the academic sector to help in its mandate as a national focus for earthquake studies. In Congressional Hearings held by Federal and State Governments after the Loma Prieta earthquake, it was clear that these legislative bodies were receiving incomplete and conflicting information on the role of earthquake research. To help correct this, the Executive Committee of IRIS recommended the formation of a Committee on Earthquake Research (CER), on 10 May 1990. The CER, which must be approved by the Board of Directors, has two purposes:

- Provide accurate information to Congress regarding earthquake science.
- Establish within the seismological community a consensus national scientific plan and strategy on the basic research needed to support the needs of the NEHRP.

IRIS will cover the cost of the meetings of the CER. The formal membership of the CER has not yet been determined and the committee will develop liaison relationships with the U.S. Geological Survey and State organizations such as RESCU (Research in Earthquake Science in California Universities). It is intended that the CER complement and provide the larger National context for other planning activities of agencies and regional and state groupings.

IRIS Facilities: Their role in earthquake hazards research

The basic IRIS program already provides, in prototype, some facilities and services required in a modernized, strengthened NEHRP.

The rapid deployment of PASSCAL instruments for aftershock monitoring and site safety studies after the Loma Prieta earthquake produced a data set of unprecedented quality and dynamic range. PASSCAL plans to dedicate a fraction of its next group of instruments for rapid response to an earthquake or earthquake alert. This will require advance coordination of the CER, the Instrument Center, and the agencies and universities who have on-site responsibility in areas of high risk.

Access to GSN data through the GOPHER dial-up capability made obtaining information about the Loma Prieta source possible within hours. Accurately knowing the source dynamics of a major earthquake within minutes could significantly improve the post-earthquake responses of emergency service, public response and earthquake scientists' activities. This capability requires widely distributed global stations. Planned installations of dial-up hardware in the GSN and upgrading of the GOPHER service will make this information available. It will require more coordination among the different institutions involved in providing information to identify mechanisms through which rapid determinations could be implemented.

The new U.S. National Seismic Network represents the framework for the modernized monitoring effort required by a strengthened NEHRP. This effort must include modernized regional and local digital networks. Since operating these networks and using the data will involve the University community in a significant way, IRIS must assist University groups with technical issues and in developing data acquisition, exchange, and archiving that meets the standards of the DMS. Moreover, the stations of the IRIS University Network also have a role in the USNSN. A significant effort to integrate the USGS, IRIS, and University programs will be needed. The present complementary roles and capabilities of the USGS and IRIS data services provide a basis for this closer integration.

The agreement with the Caltech TERRASCOPE network for data integration from their VBB regional stations into the IRIS Data Management System, is an example of IRIS/University coordination.

The IRIS Consortium receives its charter and legitimacy from the scientific community: the member institutions, the faculty, staff, and students at these institutions, and members of the scientific community working in government or industry. The constituency goes well beyond specialists in seismology to students of the geology, geophysics, and geochemistry of the Earth. The initiative by 22 Universities to form IRIS in 1984 was the consequence of a long, gradual decline in the facilities available for seismology, and a total lack of new investment in state of the art digital technology.

The basis for the 1984 IRIS Proposal was a series of panel reports which made a case for the great importance of reinvestment in seismic observing systems. The period since then has characteristically seen numerous new initiatives, expressing in proposal form the strength of the commitment by the scientific community to a new level of capability in solid Earth geophysics. This brief digest provides a review of this history... a family tree for the IRIS Consortium.

Panel Reports and Recommendations 1977-84:

These reports from the National Academy of Sciences/National Research Council reflected the urgency of reversing the decline in technological investment in solid Earth geophysics by developing a new generation of seismic instrumentation.

1. *Global Earthquake Monitoring (1977)*, report by the Committee on Seismology, National Academy of Sciences/National Research Council (NAS/NRC).

   "Global seismic networks are as basic to seismology as the telescope is to astronomy and the accelerator is to physics. Without this instrumentation, seismologists are "blind" to subsurface Earth processes and properties and the very survival of the science would be threatened. Support of a modern global network of seismic stations is clearly in the national interest."

2. *Seismographic Networks (1983)*, report by the Committee on Seismology, NAS/NRC.

   "It is essential to maintain a global data base that is uniform for years or even decades."

3. *Effective Use of Earthquake Data (1983)*, report by the Committee on Seismology, NAS/NRC.

   "...the development of a coordinated national effort in the collection, storage, and dissemination of digital earthquake data to assure that our most advanced technology is used effectively in seismological research and engineering applications."

   "The data problems in seismology are of such key importance for achieving potential scientific advances and so changeable with time that continued vigilance will be needed to ensure that new developments in technology are implemented in a timely manner, enabling United States scientists and engineers to stay at the forefront of modern seismology."

4. *Opportunities for Research in the Earth Sciences (1983)*, report by the Board on Earth Sciences, NAS/NRC.

   "...the power of digital data for the solution of major problems that have been previously unapproachable."

   "A large array of portable digital seismographs is needed to define heterogeneities of the lithosphere... "

5. *Research Briefings (1983)* for the Office of Science and Technology Policy (OSTP), the National Science Foundation, and Selected Federal Departments and Agencies; Committee on Science, Engineering, and Public Policy (COSEPUP) of the NAS/NRC. .

   "Closely spaced arrays of up to 1000 seismic instruments are required to sample the lithosphere on a scale comparable to its geological heterogeneity."

6. *Seismological Studies of the Continental Lithosphere (1984)*, report by the Committee on Seismology, NAS/NRC.

   "...that long-range coordinated field programs on specific geological problems be started immediately"

   "Arrays of 1000 instruments are required to study the lithosphere... controlled source (explosives, vibrators, etc.) and earthquake source recording."

As a consequence, the seismological community organized national workshops to develop plans for the new generation of instrumentation. These plans were then incorporated into the 1984 IRIS Proposal to the National Science Foundation.

7. *Plan for a New Global Seismographic Network* (1984).

   "The core of this initiative is a ten year, $80M plan to design, deploy, and operate a global network of some 100 seismic stations, telemetered via satellites to data centers around the world."

8. PASSCAL: *Program for Array Studies of the Continental Lithosphere* (1984).

   "PASSCAL is a major new initiative to conduct high-resolution studies of the continental lithosphere, using 1000 matched multi-channel portable digital seismographs."

Cooperative Scientific Initiatives, 1985-present:

Since 1985, the collective wisdom of the community has been increasingly directed toward organizing and seeking funding for multi-disciplinary, multi-institutional efforts. In a 1989 national workshop sponsored by the National Science Foundation, the U.S. Geological Survey, and the Department of Energy, the common scientific basis for these new programs was clarified, under the topic of Continental Dynamics. Among many issues, the report emphasizes the key role played by modern geophysical data in addressing the most important scientific problems:

9. CD/2020, *A National Program for Continental Dynamics* (1990).

   "Continental Dynamics is the growth of traditional geology and geophysics to a unified exploration of the Earth beneath our feet, *animated by vast improvements in the kind and quality of data, and made coherent by a new generation of theory and modeling*. Research will increasingly

   —be interdisciplinary, requiring coordination of efforts in geophysics, geology, and geochemistry.

   —be critically dependent on the ability to mobilize high technology tools, for acquisition of data in the field, for study of materials in the laboratory, and for modeling of systems on the computer.

   —require three-dimensional study of the subsurface to depths of hundreds of km by geophysical means, direct measurement of plate motions, detailed monitoring of earthquakes and of deformation near plate boundaries, and instrumentation and sampling of the subsurface through drilling."

Closely allied to IRIS in its approach, and of major significance for modern dynamical studies of crustal deformation and earthquakes, is the use of GPS satellite technology for measuring and monitoring crustal deformation:

10. *The University NAVSTAR Consortium* (UNAVCO) (1985), organizes and coordinates member university efforts to purchase, maintain, and deploy GPS systems. Although smaller in scale and more informal, UNAVCO is very similar to IRIS in its purposes and methods of operation, and the geodetic technology is particularly complementary to seismic technology in its contribution to continental dynamics.

The disciplinary interface between the oceans and the continents has increasingly become the subject of intense interest. It has become evident that seismic networks and arrays belong in the oceans as well as on land; for studies of plate collisions, of the upper mantle, of the core-mantle boundary, the shoreline is an arbitrary inconvenience. Through a series of planning workshops, both problem-focused and technology-focused possibilities have been brought to the attention of both the solid Earth and the ocean science communities. Efforts are being made to raise funding for these initiatives, at least in part through traditional funding sources for ocean science. IRIS appreciates their close relation with the GSN and PASSCAL programs, and plans to establish more formal working relationships when a secure funding and program are in place.

10. *The Ocean Seismic Network* (1989), *Proceedings of a Workshop*, A. Dziewonski and M. Purdy. A plan to install about 15 broad-band seismic stations on the ocean floor by occupying ODP holes. This initiative is a natural extension of the IRIS GSN, and has received initial support from ODP with the selection of a planned test hole north of Oahu. IRIS has agreed, with JOI, to provide modest support for the efforts of the organizers.

11. *The EDGE Program* (1987—) is a geologically oriented effort to mobilize available multi-channel reflection ship time for study of US continental margins under conditions which minimize the cost of ship time to the project. Following regional workshops, EDGE has begun a series of reflection profiling efforts on the nearshore portion of US continental shelves. PASSCAL instruments are generally scheduled into these projects for onshore recording of offshore airgun shots.

12. *The RIDGE Program,* a multi-disciplinary effort in the marine community for the detailed study of oceanic ridges, is being funded. RIDGE and IRIS plan to collaborate in the deployment of GSN sites on Iceland and the Azores in 1992 or 1993.

13. *The MARGINS Program,* a multi-disciplinary effort modeled on the lines of RIDGE for detailed study of continental margins is at a somewhat earlier stage of organization. As a probable organizer of large field experiments, MARGINS is expected to be a frequent user of PASSCAL instruments for land-based recording.

14. A workshop convened in 1989 by M. Talwani and W. Mooney considered the issue of development of arrays of inexpensive ocean-bottom seismometers which could extend the reach of PASSCAL - type array studies to the offshore. If funded, this development would, like the Ocean Seismic Network, form a natural extension of the IRIS facilities to the offshore. We await developments.

All of these initiatives broaden the IRIS constituency to include a large community of marine geophysicists. For the time being, however, it is prudent for IRIS to limit its areas of direct program management to its current programs, and to encourage these new initiatives through cooperation, resource sharing, and the like.

The flavor of these newer initiatives differs from that of the NAS/NRC panel reports of a decade ago. These initiatives are organized for the purpose of carrying out specific scientific programs of appreciable scope, and represent a cooperative research style which is relatively new to the Earth Sciences. In most cases, IRIS stands as a resource for facilities and technology, available to help any group. In Section 2 of this Proposal, we describe three examples of this genre which have arisen among students of the continents, and which will be clients for the IRIS facilities: (1) A program to study continental accretion in the Alaska Panhandle (ACCRETE); (2) A transect across the southern Sierra Nevada; (3) A program to image the upper mantle on a transect crossing North America.

United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VA 22092

TAKE PRIDE IN AMERICA

In Reply Refer To:
Mail Stop 905

July 20, 1990

Dr. Robert Phinney
President, Incorporated Research Institutions
for Seismology
1616 N. Fort Myer Drive
Xerox Building, Suite 1440
Arlington, Virginia 22209

Dear Bob:

Thank you for the opportunity to see a draft of your proposal to the National Science Foundation (NSF), The IRIS Proposal, 1991-1995. I want you in IRIS, as well as the reviewers of your proposal, to know that the Geological Survey (USGS) strongly supports the IRIS effort.

Over the last several years, IRIS and the USGS have made important strides in learning to work together toward common scientific and programmatic goals. We in the USGS, both as individual scientists and as an agency responsible for supporting and directing research, see very significant opportunities for enhancing this cooperation in the future.

Your proposal indicates five areas of cooperation with the USGS. The cooperation between us is somewhat different in each of these areas. Thus, I would like to comment briefly on each.

<u>The Global Seismographic Network</u>

As an agency with a history of supporting global seismic networks with marginally adequate or inadequate resources, we greatly welcome the capital investments for global instrumentation made by the IRIS program to date and envisioned in the proposal for the next 5 years. Understanding of the appropriate roles for IRIS, its component universities, and the USGS in the installation and operation of the new Global Seismic Network (GSN) has taken a fair amount of sorting out. We our pleased with the Technical Plan, now basically complete, which describes these roles. We see the new National Seismograph Network (NSN), which we are installing with support from the Nuclear Regulatory Commission (NRC), as being compatible in terms of recording system and complimentary in terms of station distribution to the GSN. As we have discussed with you over the last year, the requirements for resources to begin installation of the NSN in

Fiscal Year 1990, exacerbated by increased fixed costs for ongoing programs, necessitated deferring some maintenance on existing global stations this year. We view this decision as a strategic move which will result in an overall greatly improved data resource available to the seismological community in the future. This temporary redirection does not indicate a fundamental decision on our part to abandon global networks. Indeed our intent is to resume the previous level of maintenance on global networks as soon as we either can complete the initial installation phase of the NSN or as we can identify additional funds for this work. We appreciate your understanding of our reasons for making this management decision.

The Program for Array Studies(PASSCAL)

The USGS has worked together with IRIS on several individual imaging experiments and on studies of aftershocks of the 1989 Loma Prieta earthquake. We are generally quite pleased with the manner in which this work has developed and look forward to further cooperation in the future.

The Data Management System

One of the two IRIS Data Collection Centers is operated by the USGS at the Albuquerque Seismic Lab. In our view, this arrangement is working well.

The Eurasian Seismic Studies Program

This project, funded by the Defense Advanced Research Projects Agency, has been stressful for all concerned over the last several years. We are pleased that operational lines of the project now seem to have been worked out.

The IRIS Role in Earthquake Hazards Research

We believe that there may be a useful role for IRIS in coalescing thinking within the university earth science community about needed directions in research within the National Earthquake Hazards Reduction Program. Therefore, we are prepared to work with you as appropriate to explore this aspect of your planned activity.

In sum, we are pleased with the continuing development of working relationships between IRIS and the USGS. We are looking for further opportunities to improve positive communication. One possibility that merits consideration would be for the USGS to have a liaison representative to the IRIS executive committee.

Thank you again for the opportunity to review the proposal.

Sincerely yours,

Rob

Robert L. Wesson
Chief, Office of Earthquakes,
Volcanoes, and Engineering

III. Review of IRIS Budgets 1986-90

Summary

The IRIS Program received its first funding in 1985, with a $200,000 grant to start up the headquarters operation. The funding for 1986-90 is described in the table.

Total NSF funding: 1986-90 *by category*	1986	1987 15 mo	1988	1989	1990	Total
Operating & Development Budgets	1678.8	2655.0	2495.2	2895.7	2752.4	12477.1
Capital Budgets	296.2	145.0	2504.8	2104.3	2147.6	7197.9
by Program						
GSN	433.0	1044.8	1827.7	1885.0	1790.5	6981.0
Passcal	811.7	891.8	1832.0	1851.7	1768.4	7155.6
DMS	605.6	569.8	1019.0	709.3	881.2	3784.9
Central Office	124.7	293.6	321.3	554.0	459.9	1753.5
Total	1975.0	2800.0	5000.0	5000.0	4900.0	19675.0
Total, 5 yrs: $19675k						

All amounts are shown in thousands of dollars. The table reflects final budget figures for the Programs, based on the final decision for the NSF award each year.

This presentation deals with the annual NSF award levels and the IRIS budget categories. Actual expenditures differed from budgeted amounts principally due to the delay of expenditures or payments past the end of the budget year; consequently, an account of annual expenditures can differ substantially in detail, although the totals over the five year period agree closely.

The actual award levels have fallen substantially below the most pessimistic estimates of program funding, owing to the circumstance that total NSF funding in Earth Sciences did not grow as rapidly as was anticipated at the time the "Continental Lithosphere" programs were initiated in 1985. A number of technical factors have made it possible to largely complete the developments in technology called for in the 1984 Program Plans at lower cost than originally estimated.

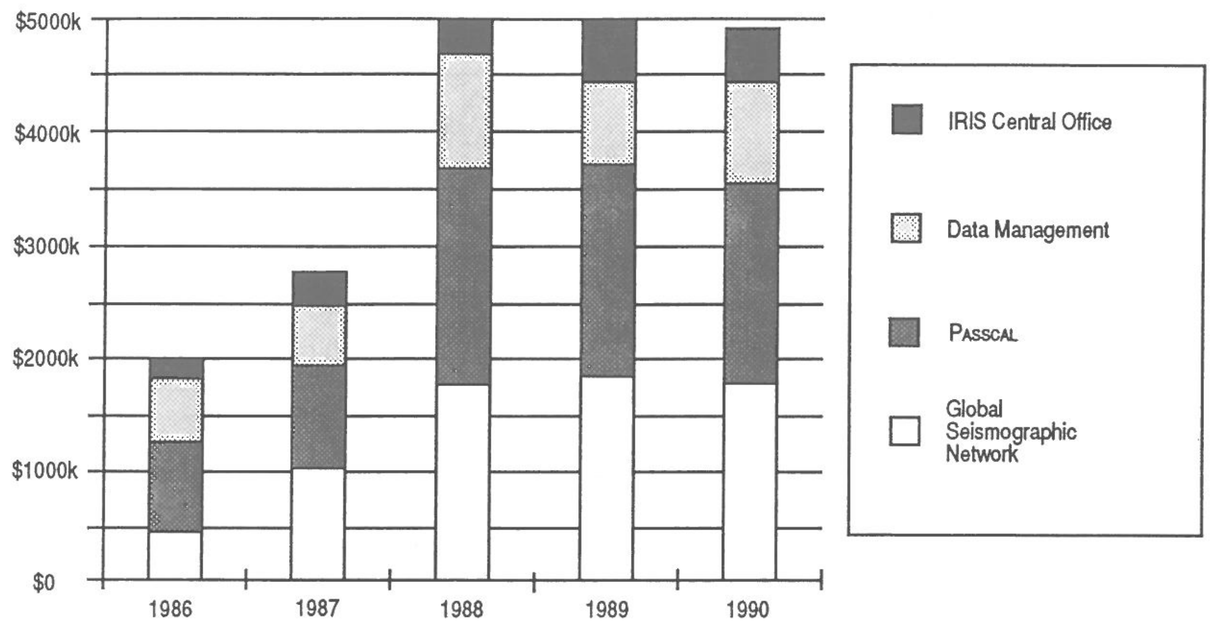
The 1987 budget covered a 15 month fiscal year, from 1 October 1986 to 31 December 1987, which arose in the course of changing the fiscal year to a calendar year.

These budgets differ significantly in category and emphasis from the proposed budgets for 1991-95. The past five years have been a period of development. The next five years are to be a period of implementation of the new technologies just developed.

The funding for the Eurasian Seismic Studies Program, from the Defense Advanced Research Projects Agency, is not included in these analyses, but will be discussed separately. The only point where the NSF budgets show an impact of this funding is in the cost of the Central Office, which has been partly supported with ESSP funds in 1989 and 1990.

Budget management is based on the autonomy of the three program areas plus the central office. Each program manager prepares an annual budget plan with the advice of the Standing Committee. These requests are adjusted by the President and the Executive Committee to fit within the award level for the year. The program managers are responsible for staying within budget, and report to the Standing Committees and the Executive Committee during the course of the year. Funds to meet the needs of a large contract, such as the first procurement of production models of the GSN station processor, are frequently carried over into a

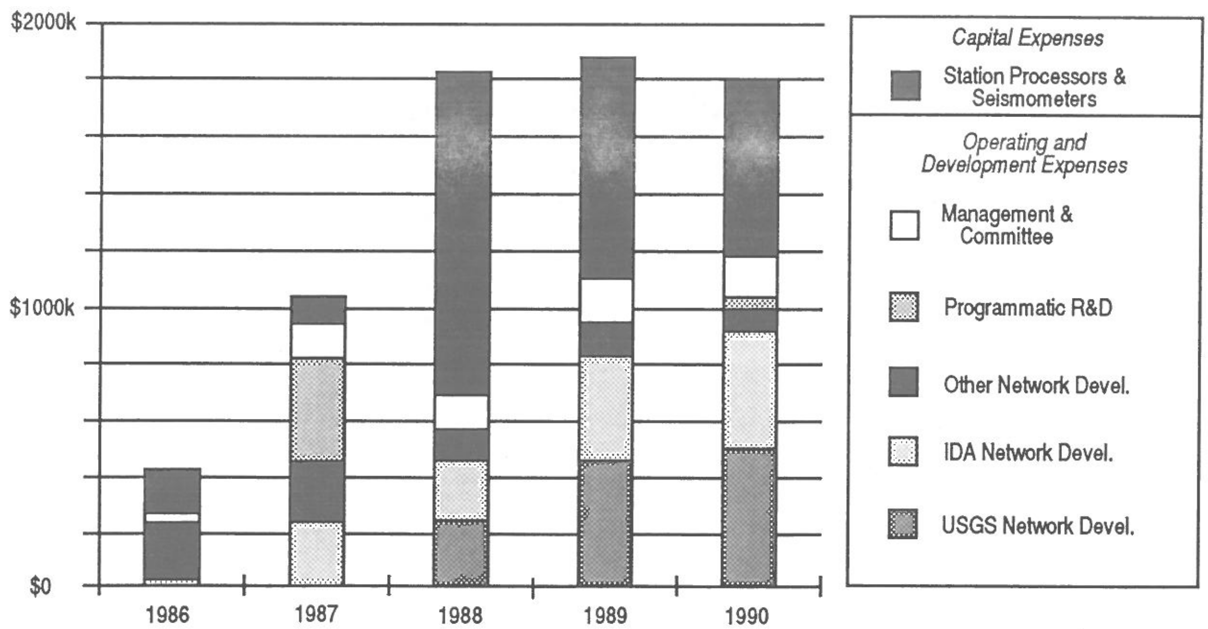
IRIS Budgets 1986-90



following year, to insure the availability of enough cash to meet the contract obligation.

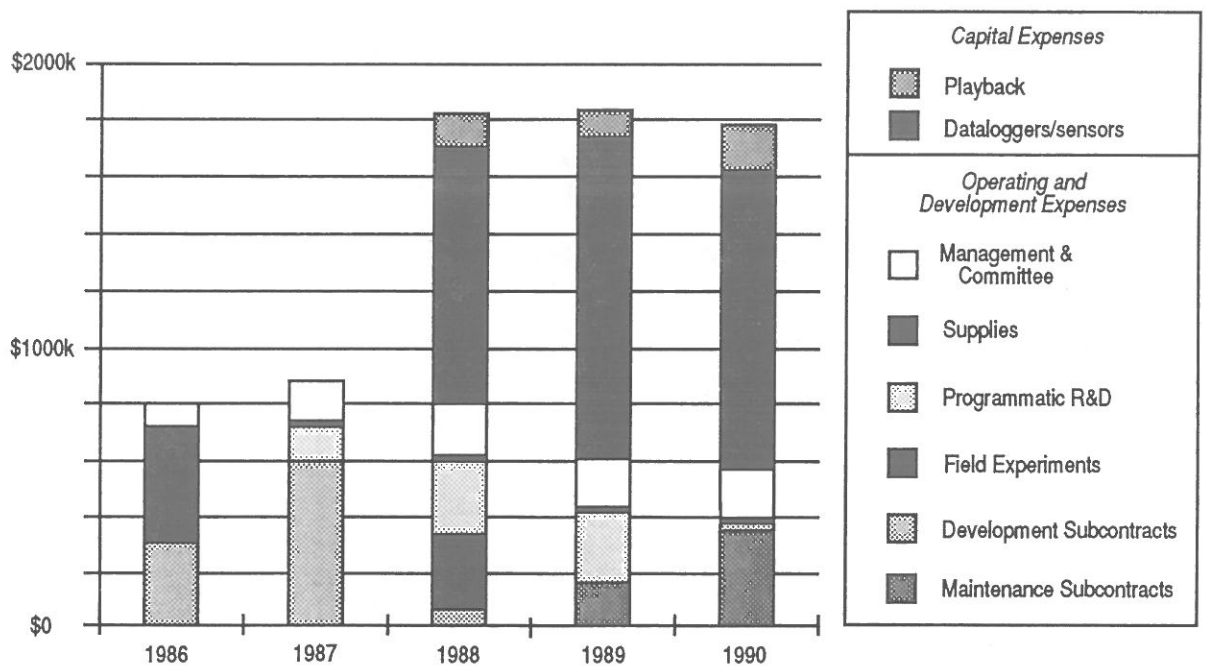
The budget category *Management and Committee* for each program includes the salary and benefits of the program manager, staff travel and travel for the Standing Committee, along with a small amount for supplies and services. In 1989 and 1990, the cost of the IRIS workshop was distributed among the programs as well as the Eurasian Seismic Studies Program. The total cost for the workshop came to $110k.

The Global Seismographic Network	1986	1987 15 mo	1988	1989	1990
Operating and Development Budget					
USGS Network Development			249.8	460.0	501.7
IDA Network Development	30.0	245.0	200.0	369.7	425.0
Other Network Devel.	200.0	220.0	123.5	124.0	75.0
Programmatic R&D		350.0			40.0
Management & Committee	50.0	139.8	136.2	181.3	148.8
Capital Budget					
Station Processors/ Seismometers	153.0	90.0	1118.2	750.0	600.0
Total	433.0	1044.8	1827.7	1885.0	1790.5
Total, 5 yrs: 6981.0					



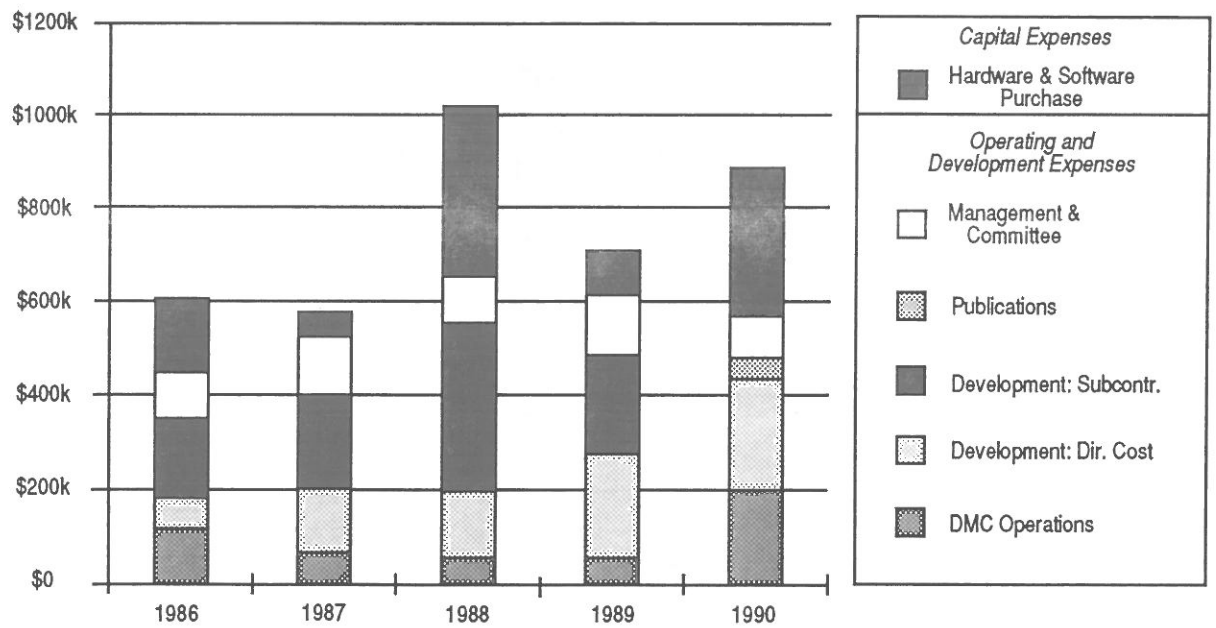
1. USGS Network Development included the upgrading of the Albuquerque Seismological Laboratory Data Collection Center to handle the anticipated large increase in data volume, as well as the cost of installing upgrades to DWSSN and ASRO stations.
2. IDA Network Development included development and installation costs for IRIS-3 dataloggers and Streckeisen STS-1 sensors at existing IDA accelerometer sites, along with support for the IDA network.
3. Other Network Development consisted of a variety of smaller projects: in particular, the cooperative upgrading of US University sites as well as the continuation of the South Pole site.
4. The IRIS-2 datalogger development shows up as Programmatic R&D in 1987.
5. Funds for station processors and seismometers: 1988 and part of 1989 funding was used to pay for equipment to upgrade existing sites. The remainder of the 1989 funding and the 1990 funding are being used to pay for the first production order of ten IRIS-2 standard dataloggers which are being delivered during 1990.

PASSCAL		1986	1987 15 mo	1988	1989	1990
Operating and Development Budget						
Maintenance Subcontracts					150.0	325.0
Development Subcontracts		320.0	600.0	65.0		40.0
Field Experiments		370.0		250.0		
Programmatic R&D			150.0	300.0	275.0	
Supplies		05.0		20.0	27.0	35.0
Management & Committee		116.7	141.8	170.4	173.1	158.8
Capital Budget						
Dataloggers & sensors				886.6	1126.6	1062.1
Playback				140.0	100.0	147.5
Total		811.7	891.8	1832.0	1851.7	1768.4
Total, 5 yrs:	**7155.6**					



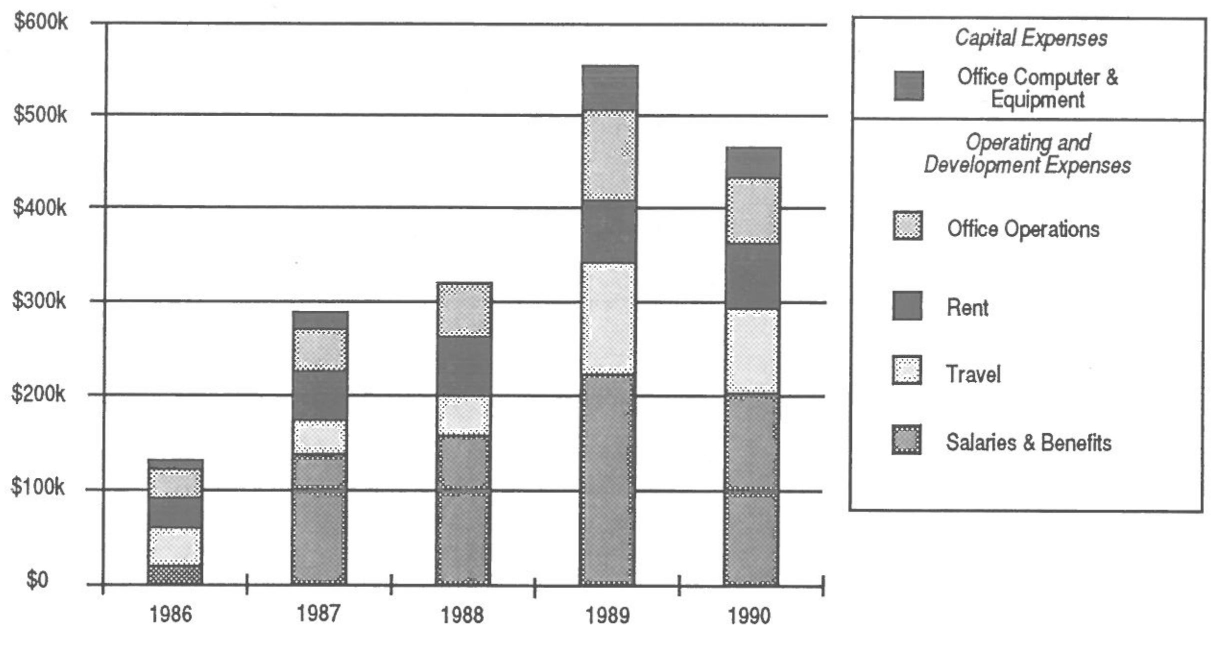
1. Funding for field experiments in 1986 and 1988 represents the only expenditures for field programs as originally envisioned in the 1984 Program Plan.
2. Development subcontracts were let for different kinds of testing and evaluation; however, the bulge in 1987 represents the principal datalogger development program at Ref Tek.
3. The start-up of the Lamont Instrument Center in 1989 shows as a new increasing ramp under Maintenance.
4. The acquisition of field equipment has proceeded as rapidly as possible ever since the initial availability of PASSCAL dataloggers in 1988. These costs are approximately half for dataloggers and half for sensors, cables, timing, and support hardware.

The Data Management System		1986	1987 15 mo	1988	1989	1990
Operating and Development Budget						
DMC Operations		108.0	73.8	50.0	50.0	196.0
Development: Direct		70.0	125.0	138.0	245.5	240.0
Development: subcontracts		165.0	200.0	365.0	195.0	
Publications						40.0
Management& Committee		122.6	131.0	108.0	133.0	91.2
Capital Budget						
Hardware & Software Purchase		140.0	40.0	358.0	85.8	314.0
Total		605.6	569.8	1019.0	709.3	881.2
Total, 5 yrs:	**3784.9**					



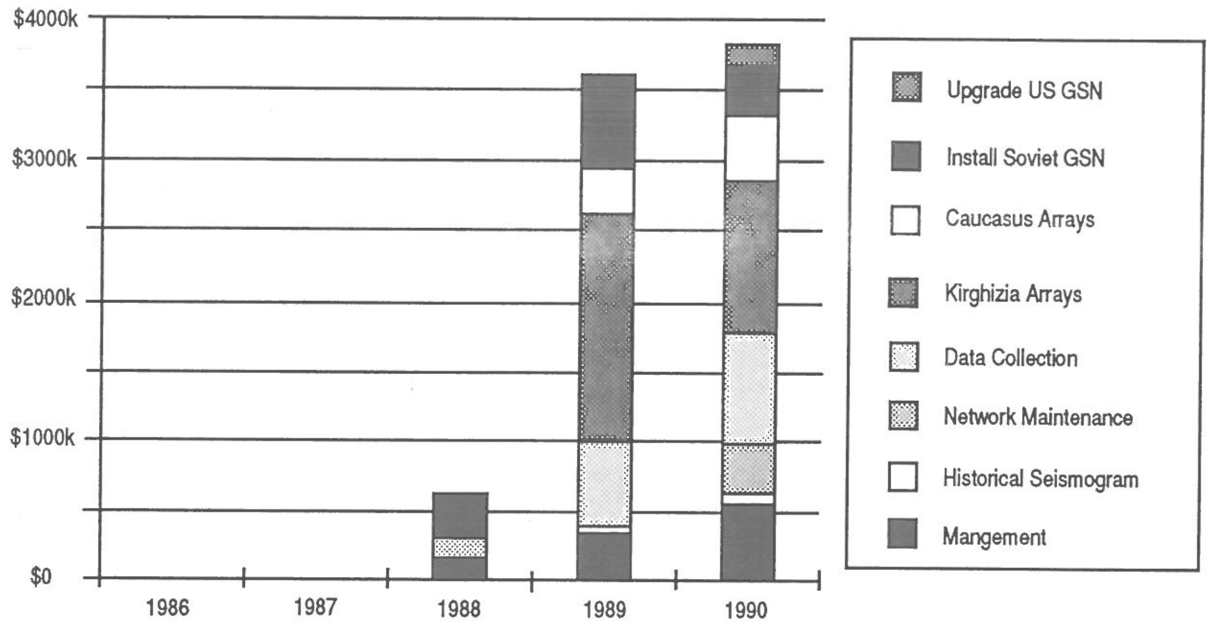
1. The period 1986-88 was devoted to design studies and preliminary experiments in data distribution. Since 1989, the effort to engineer and produce a working DBMS at the Austin DMC has been carried out largely in-house by IRIS staff: see the growth of the direct cost development work and the phasing out of major subcontractor effort.
2. The subcontractor development work consisted principally of: 1986: Preliminary DMS Design Study by Science Horizons Inc; 1987: DMS Design Study by TASC; 1987-88: writing of the PASSCAL field computer software; 1988-89: completion of field computer software, writing of the interim DMBS, writing of the GOPHER software.
3. DMC operations now represent a growing element in the program, beginning with the effective startup of the "interim" DBMS in fall of 1989.
4. The hardware purchased for the DMC consists largely of off-the-shelf Sun systems with appropriate peripherals. The 1990 purchase includes the acquisition of a prototype for a stand-alone mass storage system. The capital budget also includes the initial procurements of PASSCAL field computers.
5. The 1988 capital budget includes $150k for the SierraSeis processing system, for use on the field computers and for licensing to IRIS members.

The IRIS Central Office		1986	1987 15 mo	1988	1989	1990
Operating and Development Budget						
Salaries & Benefits		17.6	140.0	158.3	219.1	200.9
Staff & Execom travel		42.1	42.0	40.0	125.0	95.0
Rent		27.0	46.6	63.0	66.0	66.0
Office Operations		34.8	50.0	58.0	102.0	74.0
Capital Expenses						
Office Computer & Equipment		3.2	15.0	02.0	41.9	24.0
Total		124.7	293.6	321.3	554.0	459.9
Total, 5 yrs:	**1753.5**					



1. Salary costs in 1987 and 1988 showed basically 2 FTE's: for the President and the Administrator. The increase for 1989 and 1990 reflects part of the cost of adding a Director of Planning.
2. The decrease in 1990 is a result of the partial offset of Central Office costs by funding from the Eurasian Seismic Studies Program. The long-term evolution of the Central Office cost is slightly upward, driven principally by the administrative burden of dealing with an increasing volume of purchasing and contracting.
3. The increasing cost of travel hits this budget particularly, to cover the costs of 4-5 Executive Committee meetings each year, as well as substantial Presidential travel.

Eurasian Seismic Studies Program	1986	1987 15 mo	1988	1989	1990
Upgrade US GSN Stations					150.0
Install Soviet GSN Stations			365.0	690.8	360.0
Caucasus Array Program				326.6	475.0
Kirghizia Array Program				1636.8	1090.0
Data Collection Facilities			150.0	613.2	803.0
Network Maintenance					360.0
Historical Seismogram Project				50.0	100.0
Management			120.0	314.5	510.0
Total			635.0	3631.9	3848.0
Total, 5 yrs: 8114.9					



1. Upgrading US stations of the IRIS University Network is a new task for 1990, in order to assure that the US can send reciprocal data to the Soviets.
2. Installing and operating new GSN stations in the Soviet Union has been a basic priority for the ESSP. The budget figure combines equipment and installation, although the 1990 stations equipment has been furnished directly by DARPA, and does not appear in this budget. The three-year budget supports the installation of 13 stations, of which perhaps 9 will be in by the end of calendar 1990.
3. Capital equipment represents about 2/3 of the Kirghiz array cost, and about half of the Caucasus Array cost shown here. Both array programs have incorporated local telemetry in the technology. The Kirghiz facility will have a 10 station regional network and a 25 element tight array. The Caucasus Array will have 18 elements, deployed with both tight and wide aperture spacings.
4. The Data Collection costs include the capitalization and operation of a Soviet DCC at Obninsk, the capitalization and operation of the IDA DCC at San Diego, and the support of a satellite link between the two locations.
5. The Historical Seismogram project, has undertaken to optically scan an unusual library of Soviet broadband analog recordings which goes back several decades.
6. Management costs as shown include an IRIS management charge and overhead charged by U. C. San Diego.

Proposed Budgets 1991-95

Summary

The IRIS Consortium requests program and funding authorization for a five year program of seismic instrumentation facilities. Funding authorization is requested for $122,799,000. This figure includes $25,000,000 of non-NSF funding for the Eurasian Seismic Studies Program, and includes an assumed 4% annual inflation. Unless otherwise stated, all budget tables are given in constant 1991 dollars.

The budget is based on building the Global Seismographic Network and the Program for Array Studies up to the design strength recommended in the 1984 Program Plans and IRIS Proposal. It is also based on several reports by the National Academy of Sciences/ National Research Council in the period 1980-84.

Program Element	Capital budget	Operating budget	Total	Comments
Global Seismographic Network (GSN)	$32,057k	$10,230k	$42,288k	Facilities implementation for 1984 baseline program of 100 stations.
Program for Array Studies (PASSCAL)	$21,350k	$10,798k	$32,148k	Facilities implementation for 1984 baseline program of 6000 channels of portable instruments.
Data Management System (DMS)	$1,750k	$7,730k	$9,480k	Facilities implementation for 1984 baseline program of support for GSN and PASSCAL.
Central Office	$200k	$3,265k	$3,465k	Administration and Communications
Eurasian Seismic Studies Program	{$6,075k}	{$18,963k}	{$25,038k}	Special program, begun in 1988. Funding from DARPA.
Committee for Earthquake Research	none	included in Central Office		Special initiative, begun in 1990. Costs <$100k.
Total	**$61,432k**	**$50,987k**	**$112,419k**	
Total, computed for 4% inflation			**$120,220k**	

These plans assume a five year period of enhanced capital purchase of facilities, followed by an indefinite period (~10 years) of operations at a lower budget baseline. The projected operational cost is shown in each of the following budget charts as a 1996 budget, and totals $9.5m per year for the entire program.

Funding at levels below this request will have a straight forward impact on the number of instruments which can be acquired in five years, or, alternatively, on the number of years required to achieve the design goals. Two such alternatives are shown at the end of this section. Funding at the $12m level per year would mean a period of 8 years to reach the design goals. Funding at the $7.5m level per year could never achieve the design goals, and would require a reassessment of these goals downward by nearly 50%.

IRIS Five Year Budget Plan 1991-95

National Science Foundation funding

first of six pages

All figures in thousands of dollars: Zero Inflation Assumption.

1. Summary by Program	1991	1992	1993	1994	1995	Continuing operating budget 1996
Global Seismographic Network	7,801	8,177	8,553	8,929	8,828	2,963
Program for Array Studies	4,130	5,864	6,716	7,453	7,985	3,673
Data Management System	1,735	1,911	1,726	1,859	2,250	2,064
Central Office	633	683	683	733	733	733
	14,298	16,635	17,678	18,975	19,795	9,433

2. Summary by function	1991	1992	1993	1994	1995	1996
Operating Expenses	4,639	5,690	6,601	7,717	8,752	9,468
Capital Expenses	9,934	11,220	11,352	11,532	11,318	240
	14,298	16,635	17,678	18,975	19,795	9,433
		Five Year Total			87,381	
		Five Year Capital		63%	55,357	

3. Global Seismographic Network *Detailed GSN worksheet on the fourth budget page.*

	1991	1992	1993	1994	1995	1996
Operating Expenses						
Network Operations & Maint.	1021.3	1397.5	1773.8	2150.0	2512.8	2687.5
Programmatic R&D	100.0	100.0	100.0	100.0	100.0	100.0
Management incl. Committee	175.0	175.0	175.0	175.0	175.0	175.0
Capital Expenses						
Site Works & Installations	3182.5	3182.5	3182.5	3182.5	2955.1	0.0
Seismometers & Dataloggers	3019.9	3019.9	3019.9	3019.9	2804.2	0.0
Spare Parts Depot Inventory	302.0	302.0	302.0	302.0	280.4	0.0
Total	7800.7	8176.9	8553.2	8929.4	8827.6	2962.5
		Five Year Total			42,288	
		Five Year Capital		76%	32,057	

4. Program for Array Studies *Detailed PASSCAL worksheet on the fifth budget page.*

	1991	1992	1993	1994	1995	1996
Operating Expenses						
Instrument Centers	740.0	1088.3	1553.2	2060.1	2586.8	3113.5
Programmatic R&D	175.0	200.0	200.0	250.0	250.0	200.0
Quick Response	100.0	100.0	100.0	100.0	100.0	100.0
Management & Committee	175.0	250.0	255.0	255.0	260.0	260.0
Capital Expenses						
Dataloggers, timing, storage	1560.0	2400.0	2700.0	2850.0	2850.0	0.0
Sensors, cables	1139.5	1456.0	1478.1	1488.1	1488.1	0.0
Playback	240.0	370.0	430.0	450.0	450.0	0.0
Total	4129.5	5864.3	6716.2	7453.1	7984.8	3673.5
		Five Year Total			32,148	
		Five Year Capital		66%	21,350	

continued on next page

5. Data Management System

Detailed DMS worksheet on the sixth budget page.

	1991	1992	1993	1994	1995	1996
Operating Expenses						
Data Management Cntr	647.5	739.3	772.1	871.6	975.8	1022.7
Data Collection Center	350.0	367.5	385.9	405.2	425.4	425.4
Programmatic R&D	75.0	82.5	90.8	99.8	109.8	120.8
Publications & Visitors	40.0	90.0	95.0	100.5	106.6	113.2
Management & Committee	172.0	182.0	182.0	182.0	182.0	182.0
Capital Expenses						
Facility Maintenance	200.0	200.0	200.0	200.0	200.0	200.0
Mass Storage	250.0	250.0	0.0	0.0	250.0	0.0
Total	**1734.5**	**1911.3**	**1725.8**	**1859.1**	**2249.6**	**2064.1**
		Five Year Total			9,480	
		Five Year Capital		18%	1,750	

6. Central Office

	1991	1992	1993	1994	1995	1996
Operating Expenses						
Number of FTE:	*5*	*6*	*6*	*7*	*7*	*7*
Salaries:	375.0	425.0	425.0	475.0	475.0	475.0
Rent & Operating Costs (*)	148.0	148.0	148.0	148.0	148.0	148.0
Staff Travel	75.0	75.0	75.0	75.0	75.0	75.0
Board of Directors & ExecComm.	80.0	80.0	80.0	80.0	80.0	80.0
Committee on Earthquake Res.	30.0	30.0	30.0	30.0	30.0	30.0
IRIS Workshop	120.0	120.0	120.0	120.0	120.0	120.0
Newsletter	40.0	40.0	40.0	40.0	40.0	40.0
Capital Expenses						
Computer Equipment	40.0	40.0	40.0	40.0	40.0	40.0
Total Central Office	**908.0**	**958.0**	**958.0**	**1008.0**	**1008.0**	**1008.0**
Charge to						
Eurasian Seismic Studies Program	275.0	275.0	275.0	275.0	275.0	275.0
Net cost to NSF budget.	**633.0**	**683.0**	**683.0**	**733.0**	**733.0**	**733.0**
		Five Year Total			3,465	
		Five Year Capital		6%	200	

continued on next page

The budget for the Eurasian Seismic Studies Program is included in the overall authorization request to NSF.
Funding for the ESSP is obtained from the DoD, and is transmitted to IRIS via the NSF.
It is not included in the totals for the NSF Program budget, above.

7. Eurasian Seismic Studies Program

	1991	1992	1993	1994	1995	1996
Operating Expenses						
IRIS Central Office	275.0	275.0	275.0	275.0	275.0	275.0
IRIS Data Management Cntr	300.0	350.0	400.0	450.0	500.0	500.0
USA matching GSN stations	150.0	175.0	200.0	200.0	200.0	200.0
Caucasus Network/Array	550.0	550.0	550.0	500.0	350.0	350.0
Soviet visiting scientists	120.0	120.0	120.0	120.0	120.0	120.0
Programmatic R&D	100.0	100.0	150.0	150.0	150.0	150.0
Subcontracts for Operations						
USSR GSN stations	360.0	500.0	500.0	500.0	500.0	500.0
US Data Collection Cntrs	315.0	345.0	400.0	400.0	400.0	400.0
Obninsk Data Collection Cntr	195.0	195.0	195.0	195.0	195.0	195.0
Telemetry Services	330.0	430.0	430.0	430.0	430.0	430.0
Kirghizia Network/Array	350.0	350.0	350.0	350.0	300.0	250.0
Overhead	341.0	400.4	412.5	412.5	401.5	390.5
Capital Expenses						
New GSN stations	1,300.0	1,000.0	750.0	750.0	750.0	0.0
Telemetry	300.0	300.0	300.0	275.0	350.0	0.0
Total ESSP	4986.0	5090.4	5032.5	5007.5	4921.5	3760.5
		Five Year Total			25,038	
		Five Year Capital		24%	6,075	

continued on next page

GSN Recommended Five Year Budget Plan	1991	1992	1993	1994	1995	1996
	All Amounts in thousands of dollars					
Number of Sites at year start	*31*	*45*	*59*	*73*	*87*	*100*
New Sites Installed	*14.00*	*14.00*	*14.00*	*14.00*	*13.00*	*0.00*

Cost Parameters

GSN Management	175.0	
Programmatic R&D	100.0	
Operation and Management		
Yearly cost per installed site	26.9	$K/sta/yr
Spare Parts Depot Inventory Cost Factor:	.1	x equipment installed each year

Site to be installed by 1995	69	Average Cost/Site	
Site Works & Installation	15685.0	227.3	(includes doing upgrades
Seismometers & Data loggers	14884.0	215.7	in background)

	1991	1992	1993	1994	1995	1996
Operations						
GSN Management	175.0	175.0	175.0	175.0	175.0	175.0
Programmatic R&D	100.0	100.0	100.0	100.0	100.0	100.0
Operation and Maintenance	1021.3	1397.5	1773.8	2150.0	2512.8	2687.5
Total Operating Cost	**1296.3**	**1672.5**	**2048.8**	**2425.0**	**2787.8**	**2962.5**
Capital Equipment						
Site Works & Installation	3182.5	3182.5	3182.5	3182.5	2955.1	.0
Seismometers & Data loggers	3019.9	3019.9	3019.9	3019.9	2804.2	.0
Spare Parts Depot Inventory	302.0	302.0	302.0	302.0	280.4	.0
Total Capital Equipment	**6504.4**	**6504.4**	**6504.4**	**6504.4**	**6039.8**	**.0**
Total	**7800.7**	**8176.9**	**8553.2**	**8929.4**	**8827.6**	**2962.5**

Global Seismographic Network budget plan for 1991-95
Designed for a total of 100 IRIS stations by 1995
Figures for 1996 show operational cost for 100 stations

IRIS Five Year Budget Plan 1991-95

fifth of six pages

PASSCAL Recommended	Five Year Budget Plan	1991 Qty	1991	1992 Qty	1992	1993 Qty	1993	1994 Qty	1994	1995 Qty	1995	1996
		All Amounts in thousands of dollars										
Operations	Salaries & benefits		105k		175k		175k		175k		175k	175k
	Staff Travel		35k		40k		45k		45k		50k	50k
	Committee Travel		35k		35k		35k		35k		35k	35k
Total Operations			**175k**		**250k**		**255k**		**255k**		**260k**	**260k**
Subcontracts	Instrument Centers (*)		650k		944k		1,367k		1,827k		2,306k	2,785k
	Insurance		40k		69k		112k		158k		206k	253k
	R&D/Methodology		100k		100k		100k		100k		100k	100k
	SierraSEIS Support		50k		75k		75k		75k		75k	75k
	Software Development		75k		100k		100k		150k		150k	100k
	Quick Response		100k		100k		100k		100k		100k	100k
Total Subcontracts			**1,015k**		**1,388k**		**1,853k**		**2,410k**		**2,937k**	**3,413k**
Total Operations & Subcontracts			**1,190k**		**1,638k**		**2,108k**		**2,665k**		**3,197k**	**3,673k**
		Qty		Qty		Qty		Qty		Qty		
Capital Equipment	PASSCAL Instruments	*60*	960k	*75*	1,200k	*75*	1,200k	*75*	1,200k	*75*	1,200k	
	Simple Instruments	*100*	600k	*200*	1,200k	*250*	1,500k	*275*	1,650k	*275*	1,650k	
	Aux Recorders	*23*	115k	*39*	195k	*46*	230k	*50*	250k	*50*	250k	
	Field Computers	*5*	125k	*7*	175k	*8*	200k	*8*	200k	*8*	200k	
	2 Hz Sensors	*100*	11k	*200*	15k	*250*	17k	*275*	17k	*275*	17k	
	1 Hz Sensors	*60*	270k	*75*	338k	*75*	338k	*75*	338k	*75*	338k	
	Broadband Sensors	*45*	675k	*56*	844k	*56*	844k	*56*	844k	*56*	844k	
	Cables	*120*	120k	*150*	150k	*150*	150k	*150*	150k	*150*	150k	
	Shipping cases,etc	*160*	64k	*275*	110k	*325*	130k	*350*	140k	*350*	140k	
Total Capital Equipment			2,940k		4,226k		4,608k		4,788k		4,788k	
Total PASSCAL (Annual)			4,130k		5,864k		6,716k		7,453k		7,985k	3673k
Cumulative Total Capital Equipment			2,940k		7,165k		11,774k		16,562k		21,350k	
Cumulative Total PASSCAL			4,130k		9,994k		16,710k		24,163k		32,148k	
Total Equipment Available	PASSCAL 6-ch Instruments	*150*		*225*		*300*		*375*		*450*		
	Simple 3-ch Instruments	*100*		*300*		*550*		*825*		*1100*		
	Total Channels	*1200*		*2250*		*3450*		*4725*		*6000*		

PASSCAL budget plan for 1991-95. Designed to build to 6000 channels in 5 years.

Figures for 1996 show operational cost for 6000 channels.

IRIS Five Year Budget Plan **1991-95**

sixth of six pages

DMS Recommended Five Year Budget Plan	1991	1992	1993	1994	1995	1996
	All Amounts in thousands of dollars					
Number of GSN	40	60	80	100	120	120
# of Passcal channels	1200	2400	3600	4800	6000	6000
Data Volume (Gbyte/yr)	274	475	675	876	1077	1077
Number of staff	5	6	6	7	8	8
Operations						
Salaries: Base	250.0	300.0	300.0	350.0	400.0	400.0
Benefits	62.5	75.0	75.0	87.5	100.0	100.0
Travel Staff	40.0	50.0	50.0	50.0	50.0	50.0
Committee	32.0	32.0	32.0	32.0	32.0	32.0
Supplies & Services	95.0	109.3	125.6	144.5	166.2	191.1
Publications	40.0	40.0	40.0	40.0	40.0	40.0
Visitor support	0.0	50.0	55.0	60.5	66.6	73.2
Total Operations	519.5	656.3	677.6	764.5	854.7	886.3
Subcontracts						
IDA/UCSD DCC	350.0	367.5	385.9	405.2	425.4	425.4
DMC host inst. support	190.0	190.0	190.0	190.0	190.0	190.0
Hardware Maintenance	50.0	55.0	60.5	66.6	73.2	80.5
Software maintenance	100.0	110.0	121.0	133.1	146.4	161.1
Software development	75.0	82.5	90.8	99.8	109.8	120.8
Total Subcontracts	765.0	805.0	848.1	894.6	944.8	977.8
Total Operating costs	1284.5	1461.3	1525.8	1659.1	1799.6	1864.1
Capital equipment						
Maintenance of facility	200.0	200.0	200.0	200.0	200.0	200.0
Mass Storage	250.0	250.0	0.0	0.0	250.0	0.0
Total Capital Equipment	450.0	450.0	200.0	200.0	450.0	200.0
Total	1734.5	1911.3	1725.8	1859.1	2249.6	2064.1

Data Management System budget plan for 1991-95

Designed for recommended GSN and PASSCAL strength

Notes to Budget Plan

0. *General*

0.1 This Budget Plan is based on a program which completes the installation of 100 GSN stations, and the acquisition of 6000 channels of PASSCAL equipment by the end of 1995 Unless otherwise noted, all figures are presented in constant 1991 dollars, at zero inflation.

0.2 The budget column for 1996 is not a part of the current request, but is given to illustrate the cost of operating a facility that consists of 100 GSN stations and 6000 channels of portable seismometers. Most 1996 budgets show zero capital investment, since the 10% replacement/maintenance cost is built into operating expenses (see 2.1).

0.3 All budget figures assume zero inflation. An estimate of the total cost, corrected for 4% inflation, is given in the first page of this section.

2.2 The consequences of running at a lower budget level, and stretching out the period of capital investment, are subsequently discussed. There are two kinds of consequences:

- A steady state level of support below $7m would make it impossible to maintain and operate the full design facility, regardless of timing.
- The time scale for technological change would then be shorter than the time scale for capital investment in the IRIS facilities. The notion of a standardized technology is more difficult to maintain.

1. *Summary by Program:*

1.1 This budget summary includes only funds requested from NSF. The separate funding for the Eurasian Seismic Studies Program is included in the overall authorization request. It can be found on the first page of this section, and is presented as an itemized budget under ¶7.

1.2 The balance between the three operating programs has run close to 40/40/20 over the first five years of IRIS operations. As the data flow and number of instruments increase, the proportion required for Data Management decreases. This is because of the relatively small cost of mass storage relative to fixed support cost. The GSN will take fractionally more than PASSCAL during the next five years, since all of the logistically difficult, expensive GSN sites have been deferred up until now.

1.3 The Data Collection Centers (DCC) for the GSN have been administratively put under the Data Management System. The DMS budget includes support for the IRIS/IDA DCC at the University of California, San Diego. Operating support for the IRIS/USGS DCC at Albuquerque is provided by the USGS under the terms of the Memorandum of Understanding.

2. *Summary by Function:*

2.1 Operating expenses are an integral part of the capital investment. The individual program budgets contain an operations and maintenance line, which includes 10% of the installed capital base for modernization, replacement, and maintenance. It is a well-established figure in current high technology, required to maintain capability at a steady state. Thus, about $6 million of the IRIS systems' operating cost in the out years past 1995, is based on this estimate.

3. *The Global Seismographic Network*

3.1 In addition to the budget summary (¶3), a more detailed worksheet for the GSN budget is presented on the fourth budget page. The major costs are formula-based. The annual capital investment cost is proportional to the number of stations to be installed, and the annual maintenance cost is proportional to the total installed base. Detailed calculations are given in Section 3 of this proposal, in the *GSN Program Plan.*

3.2 The recommended GSN budget is based on the assumption that the GSN stations installed by the end of 1995 reach a total of 100. This will require 69 new stations, or about 14 per year. An average per-station cost is adopted for both site preparation, and for instrumentation. The actual schedule for implementation of stations will result from detailed negotiations normally required with the host institution and country, and from the annual recommendations by the GSN Standing Committee. Siting will be in accordance with the *GSN Technical Plan* (in Section 3 of this proposal).

3.3 The site preparation costs for new stations are unpredictable, and can vary from less than $50k to upward of $350k. The seismological community has asked IRIS to do its best to optimize (1) global distribution of sites, including oceanic and southern hemisphere areas and (2) very low noise sites. Although most island sites cannot be expected to have low noise, they will still be very costly. The preferable low noise sites away from the ocean are deep mines, not necessarily used, but accessible. Where these are lacking, it may eventually be necessary to go to borehole instruments.

3.4 Stations will be installed and maintained by the network operation centers at the USGS, Albuquerque Seismological Laboratory, and the University of California, San Diego. The station siting plan in the Technical Plan calls for approximately a 2:1 ratio between USGS and UCSD sites. Under the terms of the Memorandum of Understanding between IRIS and the USGS, the USGS will fund network maintenance for its complement of stations. Since this amount, as well as the actual IRIS funding, is determined annually, the authorization request in this proposal includes full maintenance costs, independent of network operator.

3.5 For each year that new stations are installed, a capital investment is made in spare parts inventory of 10% of the new station capital increment.

3.6 Management includes the salary, benefits, and travel of the Program Manager; travel and incidental expenses of the Standing Committee; and other incidental costs.

4. *Program for Array Studies (PASSCAL)*

4.1 In addition to the budget summary (¶4), a more detailed worksheet for the PASSCAL budget is presented on the fifth budget page. The major costs are formula-based. The annual capital investment cost is proportional to the number of instruments to be acquired, and the annual maintenance cost is proportional to the total installed base. Further information is given in Section 3 of this proposal, in the *PASSCAL Program Plan.*

4.2 The recommended PASSCAL budget assumes that 6000 channels of datalogger capacity are acquired by the end of 1995. This will involve acquiring about 1200 channels per year, in a combination of 6-channel and 3-channel dataloggers. Costs for the capital equipment are based upon currently established purchase prices.

4.3 Management includes (1) salary, benefits, and travel of the Progam Manager, who also serves as IRIS Chief Engineer on behalf of the other Programs; (2) travel and incidental expenses of the Standing Committee; (3) other incidental costs; and (4) the salary, benefits and travel, beginning in 1992, of a Manager for Instrument Centers.

4.4 The principal operating cost, for Instrument Centers, is based on the assumption that a new center will be required for each 600 channels. It is based on the current experience with the first Instrument Center at Lamont. Costs include about 2 FTE personnel, travel, overhead, supplies, test equipment, service and training equipment. The Lamont Instrument Center also serves as a national focal point for incremental engineering and software development, quality control and standards, and carries about 4 FTE.

The Instrument Center budget includes allowance for the cost of replacement and incremental upgrading of the equipment stock.

4.5 The Quick Response is a reserve to support the rapid deployment of portable instruments in the event of a significant earthquake in this country. It is based on the cost of the Loma Prieta deployment, but does not include extended operation of the stations or preparation of the data for distribution.

4.6 Programmatic R&D is described in the PASSCAL Program Plan, in Section 3. Technical issues regarding the performance of portable instruments often strongly depend on local ground and noise conditions. Actual field deployments might be needed to determine the design of arrays for innovative applications. The normal practice would be to use this funding to increment a planned, funded experiment.

5. *Data Management System (DMS)*

5.1 In addition to the budget summary (¶5), a more detailed worksheet for the DMS budget is presented on the sixth budget page. Further information is given in Section 3 of this proposal, in the *DMS Program Plan.*

5.2 The cost structure for the Data Management Center is unlike that of the other Programs. It consists of:

- A fixed salary and facility cost, required for maintenance of the DMC.
- Incremental cost of salary, supplies, and incidentals, dependent on the service load to the community.
- Incremental cost of mass storage.

Continuing increases in the density, and decreases in the cost of mass storage, plus similar improvements in network capacity, will largely offset the increase in input and output to the DMC associated with GSN growth and PASSCAL. The overall fractional growth of DMS cost is therefore much less than the other programs.

5.3 Programmatic R&D represents the cost of essential software development to facilitate user access to, and interface with, data from the IRIS facilities. It is probably a factor of five or ten less than the cost of professional quality software for seismic data manipulation in a modern workstation environment, and represents a minimum allowance for basic functionality.

5.4 Some capital reinvestment is shown to maintain the DMC equipment's hardware capability at state of the art level, and capable of response to the increased load.

5.5 The detailed budget breakdown for DMC costs shows a mixture of IRIS direct costs, with the subcontract to the host institution for space and other support. This reflects the current arrangement with the University of Texas Institute for Geophysics. A competitive selection will be conducted in early 1991 to determine the host institution and program management plans for the next five years. The line-by-line breakdown from that point would reflect the arrangement with the newly selected host. In particular, much of the direct salary charge to IRIS could move to the host institution subcontract.

5.6 Management includes the salary, benefits, and travel of the Program Manager; travel and incidental expenses of the Standing Committee; and other incidental costs.

5.7 The Data Collection Center at the University of Califonia, San Diego, is now administered under the IRIS DMS. The budget shows a prorated fraction of the full expense of operating this DCC, based on the IRIS/IDA stations not covered by the Eurasian Seismic Studies Program. The DCC operations at Albuquerque are covered by the USGS under the Memorandum of Agreement.

6. *Central Office*

6.1 This budget shows all direct costs of operating the office in Arlington, VA, including salaries and services which are not readily attributable to the costs of the major programs. It is direct charged in lieu of an overhead calculation, and amounts to approximately a 4.3% management charge on the operations of the programs. At the 1990 level of funding, the Central Office burden is approximately 7%.

6.2 The gross cost to the NSF of the Central Office is reduced by a charge to the Eurasian Seismic Studies Program.

6.3 The 1991 staff consists of: (1) President of IRIS; (2) Director of Planning; (3) Business Manager; (4) Bookkeeper and Purchasing; (5) Administrative Assistant. Staff increases are assumed, based on the increasing load of handling a growing total budget.

6.4 Travel and incidental support is budgeted for the following:

- Staff: President and Director of Planning. This includes a higher proportion of foreign travel than seen in the Program budgets.
- Board of Directors and Executive Committee: The BOD meets annually at the December meeting–one per member institution. The 7 person Executive Committee (Execom) meets at least five times per year, joined by Standing Committee chairmen and special invitees.
- The Committee on Earthquake Research is given a basic budget for 4 meetings per year. It is expected that expansion of the CER would be associated with supplemental funding for special activities.
- The IRIS Workshop is held annually to encourage the seismological community to communicate on technical and scientific questions regarding the new generation of technology. One representative from each member institution is given travel support, and attendance is open to others who respond to the Announcement. The Workshop has been held at resort locations: Alta, UT, and Hilton Head, SC, during off-season, where the atmosphere of a workshop can be obtained at reasonable cost.

6.5 Starting fall, 1990, the IRIS Newsletter is to be produced with professional assistance out of IRIS headquarters, with Dr. G. van der Vink, as Editor. It will have a regular quarterly schedule, with feature articles and special departments designed to communicate the services and activities which are connected with IRIS. It will be distributed without cost upon request. The current mailing list of 750 is to be expanded to about 2000, by a special review of interested scientists in seismology and related branches of earth science, here and in other countries. The mailing list will also include people in government, the media, and education, who have some interest in IRIS.

7. *The Eurasian Seismic Studies Program*

7.1 The ESSP was funded in 1988-90 by DARPA. Continued funding at about the level of $5 million per year is anticipated and much of the capital investment in this program has already been made. Consequently, the period 1991-95 is a transitional one, in which stations, telemetry, and networks are to be fully completed. The program is to become purely operational, with the goal of integrating Soviet scientists and engineers into the routine operations of the facilities, and lessening the need for US effort.

7.2 The ESSP was funded with the goal of obtaining rapid installation of state-of-the-art seismic stations in the USSR, including near-real-time service. This has been inherently more costly per station than the rest of the GSN, although it may not prove to be so when compared with costs of installing more difficult stations elsewhere in the world.

7.3 Through 1990, the ESSP has completed the installation of 7 GSN stations, and obtained funding for 6 additional GSN stations and two arrays. A Soviet Data Collection Center has been installed at Obninsk, and appropriate facilities for the US end of the link have been added to the UCSD DCC. Through 1995, the goal is to install approximately 7 additional GSN stations in the USSR and several additional stations in other locations worldwide, in collaboration with the Soviets. Two sites at Soviet Antarctic stations have been jointly agreed to.

7.4 For the arrays in Kirghizia and the Caucasus, the goal is to complete the installation of the funded facilities, to stabilize operations, and to move the Soviets into maximum operational responsibility for these facilities.

7.5 Adminstratively, it is planned to simplify the ESSP in the light of the existing structure and programs of IRIS.

- Installation and operation of GSN stations will be under the programmatic oversight of the GSN Program Manager, advised by the Standing Committee.
- Administration and oversight of Data Collection Center functions will come under the DMS Program Manager, with the advice of the Standing Committee.
- Operation of the networks will be done by subcontracts overseen by the PASSCAL Program Manager.

7.5 Charges are made to the ESSP for IRIS incremental costs associated with the Central Office, and with the increased archive in the Data Management Center.

7.6 The ESSP includes provision for transmission of data from US VBB stations to the Soviets. These "matching" stations are being provided by upgrading existing sites in the IRIS University Network, and in the US National Seismic Network.

7.7 Operational costs for telemetry principally include the service costs of the satellite links or common carrier being employed. An annual cost of nearly $200k is associated with the Intelsat link from Obninsk to San Diego. Future capital and operational costs for telemetry are hard to estimate, as cost and availability are improving rapidly. The estimates in this budget are substantially less than current retail cost for complete US-supplied telemetry, but are not very well constrained.

Budget Alternatives

If the IRIS Proposal is given a reauthorization for the five year period 1991-95, but at a lower level than requested, or if actual funding comes in at a lower level than requested, IRIS is prepared to construct a revised Budget Plan in accordance with such figures. Here we present two alternative budgets, and discuss the programmatic consequences, of different funding levels.

IRIS 5yr Plan

	5 yr sum	op cost	#inst	# yrs to goal
GSN	42288	2963	100	
Passcal	32148	3673	6000ch	
DMS	9480	2064		
Central Office	3365	713		
Total	**$87381k**	**$9433k**		**5**

In the proposed IRIS 5 year plan, an average of $18m per year is required for 5 years, at which point the design goals of 100 GSN stations and 6000 PASSCAL channels are reached. The annual operational cost for this complement after 5 years would be $9.5m. The scientific importance of implementing the IRIS facilities at full strength in five years has been taken up at several points in this Proposal.

Alternative A

	5 yr sum	op cost	#inst	# yrs to goal
GSN	29471	2318	76	
PASSCAL	20919	2490	3360ch	
DMS	8678	1943		
Central Office	2750	620		
Total	**$61818k**	**$7370k**		**8**

If IRIS is funded for 5 years at about $12m per year, then the facilities are built to 60-70% of design goal. At that point, they could be operated for $7.4m per year, or built up to design goal in 3 additional years (8 total), at which point the operating cost would be $9.5m per year. The 8 year scenario is viable, in that the out year operating cost would be less than the annual budget during the period of capitalization. Adding the effects of inflation would probably stretch the time of full implementation to 10 years, although the scenario is still feasible.

Alternative B

	5 yr sum	op cost	#inst	# yrs to goal
GSN	14734	1646	51	
PASSCAL	14943	1951	2130	
DMS	7552	1772		
Central Office	2200	500		
Total	**$39429k**	**$5869k**		**17**

Alternative B involves a 5 year funding period of $6.5m per year. At that point, the GSN is up to only half strength, while PASSCAL is up to only one third strengh. By linear extrapolation, it would take a total of 17 years to achieve design strength. However, the curve for operating cost would exceed the annual budget level shortly after the five year point, and system capitalization would terminate.

At funding levels such as illustrated in Alternative B, several consequences would be felt:

- As shown, operating costs would limit ultimate facilty growth to about half of the design goal for the IRIS facilities.
- The long time scale for implementation leads to a situation where successive 3-year cadres of new instruments would end up with new technology

increments, and the network/array facilities would never in any sense be standard. There would be a possible decade's difference in technology between instruments in the same network. This would complicate the maintenance, training, standardization, and retrofitting problem, and add significantly to the maintenance overhead.

- It is unlikely that a 50 station GSN would come close to meeting the scientific requirements for imaging convection and geodynamical tracers in the deep earth. The 50 station GSN would have a distribution skewed toward the easy locations, the upgrades of existing sites. The obsolescence of many existing vaults would lead to a generally poorer signal to noise performance.
- 2200 PASSCAL channels, as a national facility for the entire university community, would be equal to the capacity of a single state-of-the-art reflection crew. Meeting needs in high resolution mantle imaging in active and passive experiments, as well as contibuting to the earthquake hazards issue, would be severely restricted.
- The research community, and IRIS, would be forced to reassess the goals established in 1984.

Alternative B would represent a serious retreat from the vision of 1984, as reiterated in the short essays of Section 2 in this Proposal.

In general, at lower levels of funding, the different overheads take up a larger proportion of the budget. The Central Office must operate at a minimum of $450k, regardless of how small the facilities, and would need to go to only about $750k for the full design goal program. The DMS also has an established capitalization for most of its facilities, and a fixed minimum support cost of about $800k per year. It is designed to service the data flow from the design goal program.

As a final comment, it should be noted that the gross estimate for an IRIS ten year facilities buildup made in the 1984 plan, $110 million, is remarkably close to the current estimate for the ten year buildup. This is $21 million spent on development during 1985-90, and $87 million cost for acquiring and operating the design level of facilities during 1991-95.