Foundations of Portable Seismology: The Program for Array Seismic Studies of the Continental Lithosphere (IRIS-PASSCAL)

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IRIS Workshop 2018
Outline

• Field Seismology Before PASSCAL
• Origins of PASSCAL
• Early PASSCAL experiments
• PASSCAL Science (a small sampling!)
Field Seismology in the 1980’s –
still using helicorders for some experiments
Field Seismology in the 1980’s –
Assortment of digital recording
Varying formats
Data not usually shared, archiving ad hoc
Limited recording capacity (event triggered)
Late 1970’s and Early 1980’s - Reports from the National Academy helped lead to the development of the IRIS Consortium
The Original IRIS Proposal to NSF
(the ‘Rainbow Proposal’)
December, 1984
1984 IRIS ‘Rainbow’ Proposal

Proposal for a ten-year program for the implementation of four major national facilities for seismology:

- **A Global Digital Seismic Array**
  featuring real-time satellite telemetry from *one hundred* modern seismographic observatories

- **A Mobile Array**
  comprised of *one thousand* portable digital seismographs to be used for studies of the continental lithosphere

- **Central Data Management and Distribution Facilities**
  to provide rapid and convenient access to the data sets for the entire research community

- **A Major Computational Facility**
  capable of supporting the analyses of these new data
The PASSCAL program was an important part of the original IRIS Proposal

Passcal

Program for Array Seismic Studies of the Continental Lithosphere

Introduction

In a major departure from the traditional single-investigator approach to research support, the seismological community came together in 1984 in a national consensus movement to create a consortium of research universities for the purpose of implementing, through a cooperative approach including industry and government agencies, a set of initiatives for critically needed national facilities necessary to support seismological research in the coming decades. IRIS, the Incorporated Research Institutions for Seismology, a consortium of the leading research universities in the field, was formed to implement this national plan. The IRIS proposal (McEvilly and Alexander, 1984) has emerged from this effort representing the collective request from the U.S. seismological community for a set of modern research tools, the tools, or national facilities, will serve the national science as primary data sources well into the next century. Replacement of the present vintage equipment with state-of-the-art instrumentation and data management systems is a necessary step in achieving a major improvement in our ability to understand the earth's structure.

Our knowledge of the earth's interior is now limited by data quality and quantity. Theory and analytic techniques are in a sense the tools of the future, but the data are needed today. Theory can be used to construct a model of the earth, but the model is a hypothesis which can be tested only through comparisons with observations.

The IRIS effort has the dual goals of improving the state of the art in the technique of earthquake data collection and analysis, and developing the microseismic network distributed across the country. The development of a network of high quality microseismic stations is necessary for understanding the structure, composition, and processes operating in the upper mantle and the subducting slabs, as well as for detecting and locating the origins of significant seismic events. The network of microseismic stations must be distributed across the country in order to provide a statistically meaningful database for understanding the tectonic processes acting on the Earth.

In the 1986 AGU Spring Meeting, marks the first anniversary in the operational life of the IRIS Consortium. It was a year ago that planning began in the AGU headquarters building in Washington, D.C., for a consortium for which we were preparing. In the year since, we have looked at the data that were collected, and now we are beginning to think about how we can expand the project during the next few years. Space was limited, but we are still working at a rate of 1000 or more stations per year. We are now looking at how we can expand the project during the next few years. We are also looking at how we can expand the project to include new scientific areas such as the study of the earth's interior, the study of the lithosphere, and the study of the atmosphere.

The Current IRIS Program

Until October 1985, the physical existence of IRIS was limited to a small desk at the AGU headquarters building in Washington, D.C., with an electronic mail system that linked key members of committees across the country. Without the latter it is difficult to imagine how the enterprise could have functioned during those early days. Space was limited, but we are still working at a rate of 1000 or more stations per year. We are now looking at how we can expand the project during the next few years. Space was limited, but we are still working at a rate of 1000 or more stations per year. We are now looking at how we can expand the project during the next few years. Space was limited, but we are still working at a rate of 1000 or more stations per year. We are now looking at how we can expand the project during the next few years. Space was limited, but we are still working at a rate of 1000 or more stations per year. We are now looking at how we can expand the project during the next few years.
Portable Array Studies (PASSCAL)

Instrument Development

The PASSCAL Science Plan spelled out in detail the need for an advanced portable seismograph system. This system would be digital, with high dynamic range; it would be portable and micro-powered, and most importantly, it would be flexible and modular so as to be able to adapt to changes in technology that are likely to occur over the lifetime of the instrument. Since the plan is to make a major national commitment through the purchase of 1000 instruments, it is clear that we should not freeze in place the technology available at this particular point in history. The rapidly changing field of mass storage illustrates the most obvious example of this problem, but comparable changes in encoder technology, timing systems, and virtually every other part of the system are very likely over the next decade. To avoid this, a plan was made for a modular communications “bus” approach to design. With this concept the seismic instrument functions as a local computer, with each module having an

Smith, EOS, 1986
1984

**PASSCAL**

Program for Array Seismic Studies of the Continental Lithosphere

10-Year Program Plan

Incorporated Research Institutions for Seismology

December, 1984

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Bob Phinney, First chair of PASSCAL Standing Committee

Jim Fowler, founding manager for PASSCAL program. Started as IRIS Chief Engineer in 1984.

Photo credit: Craig Jones

Photo from PASSCAL web page
PASSCAL Timeline

1984 – IRIS Incorporated
1986 – Ouachita Experiment
1986 – Basin and Range Experiment
1986 – Issue RFP for new instrument
1987 – Issue contract to develop a new instrument
1989 – First PASSCAL instrument center opened at Lamont
1989 – Loma Prieta – first aftershock deployment (RAMP)
1990 – receive first broadband sensors
1991 – Tibet broadband experiment (1st BB experiment to produce SEED data)
1991 – Stanford PASSCAL instrument center established – active source and RAMP
1992 – Rocky Mountain Front experiment – first experiment with over 25 broadband
1995 – first GPS clocks on REF TEKs
1998 – New PASSCAL Instrument Center at New Mexico Tech, closed LDEO and Stanford instrument centers
1999 – first TEXAN instrument
2002 – new data acquisition systems developed
2003 – USArray starts
PASSCAL Oachita Experiment, 1986

Paleozoic continent-ocean transition in the Ouachita Mountains imaged from PASSCAL wide-angle seismic reflection-refraction data

400 seismic group recorders (SGR) from Amoco. Each recorded data from a string of geophones on digital cassettes. Overlapped COCORP line.

Keller et al, Geology, 1989
The 1986 PASSCAL Basin and Range Lithospheric Seismic Experiment

Array analysis of the large-aperture array of the 1988–89 PASSCAL Basin and Range Passive-Source Seismic Experiment

George E. Randall and Thomas J. Owens
Department of Geological Sciences, University of South Carolina, Columbia, SC 29208, USA

Randall and Owens, 1994

Catchings et al, 1988
Lamont PASSCAL Instrument Center (PIC), 1989 - 1998

Art Lerner-Lam

Bob Busby

Noel Barstow

Paul Friberg

http://www.columbia.edu/cu/record/archives/vol20/vol20_iss19/record2019.21c.gif

Photo credit: Bob Busby
Loma Prieta 1989 – 1st RAMP (aftershock) deployment

Heidi Houston, Thorne Lay, Susan Schwartz, David Simpson and Ornella Bonamassa deploying PASSCAL instruments.

- This was the second overall deployment of the new PASSCAL equipment.
- Data collected in triggered mode using STA/LTA.

Photos from Susan Schwartz
Loma Prieta 1989 – 1st RAMP (aftershock) deployment

EMPIRICAL GREEN’S FUNCTION ANALYSIS OF LOMA PRIETA AFTERSHOCKS

BY S. E. HOUGH, L. SEEBER, A. LERNER-LAM, J. C. ARMBRUSTER, AND H. GUO

Fig. 2. Initial P-wave arrivals for events 38 and 02 recorded at station WAWA. The amplitude of the smaller event, which is used as empirical Green’s function, is amplified by a factor of 5. The two events are observed to be significantly different in magnitude but to have very similar waveform complexity.
1991 Stanford PASSCAL Instrument Center
Established – Active Source and RAMP

Probing the Archean and Proterozoic Lithosphere of Western North America
Timothy J. Honeck and Alan Levander, Rice University
Catherine M. Swanson, G. Randy Keller, Kate C. Miller, and Steven H. Harland, University of Texas at El Paso
Andrew H. Gromass and Ron M. Chowes, University of British Columbia, Vancouver
Michael J.A. Burney, University of Alberta, Edmonton
Eugene D. Humphrey, University of Oregon

Lithospheric P-wave velocity model along the Deep Proterozoic crust extending from southern New Mexico to Edmonton, Alberta. Three crustal domains and two mantle domains have distinct seismic velocity structures. The mantle structure beneath the Proterozoic terranes of the southern Rocky Mountains/Cordillera plateau has low velocities similar to that of a spreading ridge, whereas the mantle beneath the Archean Wyoming and Hareno Province is somewhat faster than that of the North American crust as a whole. The transition from slow to fast velocity occurs over a distance less than 220 km to the vicinity of the surface contact separating Archean crust from Proterozoic island arc terranes at the Canadian Shield. The two Archean provinces have distinctly different crustal thicknesses and velocities. In particular the Wyoming province is characterized by a thick (>20-25 km) high-velocity mid-lower crust.
Tibet – 1st major Broadband experiment 1991-92
Tom Owens and Francis Wu, PIs

Demonstrated that very high-quality broadband data could be obtained at temporary sites in extreme environments.
Data of interest to scientists beyond the PIs on the project

11 stations - 10 STS2, 1 Guralp CMG3-ESP
330 mb hard disks, data download by hard disk or exabyte tape
Data stream 1 – 5 sps triggered, Data stream 2 – 40 sps triggered, Data stream 3 – 1 sps continuous
OMEGA clocks

Photo credits: Left, Francis Wu; Center Lupei Zhu.
Tibet – 1st major Broadband experiment 1991-92

McNamara, Owens, Silver, Wu, JGR, 1994
McNamara, Walter, Owens, Ammon, JGR, 1997

Owens, Randall, Wu, Zeng, BSSA, 1993
Rocky Mountain Front 1992. 30 Broadband stations
Lerner-Lam, Humphreys, Grand, PIs

Omega clocks, 200 mb disks, triggered and low rate continuous

Photo credits: Anne Sheehan
Omega clocks, 200 mb disks, triggered and low rate continuous

Exabyte drive to download data to exabyte tape in the field. Epson controller for DAS.

Photo credits: Anne Sheehan
Rocky Mountain Front 1992. 30 Broadband stations

Found Rockies are not compensated by a simple Airy-type root, require significant compensation in the mantle

Crustal thickness from receiver functions

Mantle structure from teleseismic S-wave tomography

Sheehan, Abers, Lerner-Lam, Jones, JGR, 1995

Lee and Grand, JGR, 1996
1993 Cascadia Experiment
PI Nabelek, OSU

69 broadband sites
44 stations simultaneously
Spacing 4 km

Nabelek et al., One-pager from IRIS Proposal, 1995
Li and Nabelek, 1999
1993 Cascadia Experiment
PI Nabelek, OSU

69 broadband sites
44 stations simultaneously
Spacing 4 km

Image of Cascadia Subduction zone from teleseismic converted phases

Nabelek et al., One-pager from IRIS Proposal, 1995
Li and Nabelek, 1999
1993 Cascadia Experiment
PI Nabelek, OSU

69 broadband sites
44 stations simultaneously
Spacing 4 km

Bostock et al., 2002
The loss of signal from the continental Moho in the mantle forearc is attributed to mantle serpentinization by fluids released from the subducting plate.
1998 New Mexico Tech PASSCAL Instrument Center Established

Mission:
Provide state-of-the-art, low power portable seismic instrumentation and deliver basic field expertise and data management tools in support of portable array seismic experiments worldwide.
Attenuation Tomography

Dehydration reactions explain changes in seismic velocities seen within subducting crust.

Decollement at base of the Himalaya.
Observations of Antipodal PKI1KP Waves: Seismic Evidence for a Distinctly Anisotropic Innermost Inner Core

Fenglin Niu (Department of Earth Science, Rice University), Qi-Fu Chen (Institute of Earthquake Science, China Earthquake Administration)

Studies of the seismic structure of the inner core using body waves that propagate through the inner core, such as PKI1KP, are always hindered by contamination from mantle heterogeneities. A common approach in eliminating mantle anomalies is to use differential travel time or relative amplitude between PKI1KP and a reference phase, which travels along a very close ray path to PKI1KP in the mantle. Waves reflected at or refracted above the inner-core boundary (ICB), PKiKP and PKPbc, have been frequently employed to study the top ~400 km of the inner core [e.g., Niu and Wen, 2001; Creager, 1992]. On the other hand, no such reference phase has been identified as suitable for modelling the deeper part of the inner core [Breger et al., 2000]. As the result the seismic structure of the deeper ~800 km of the inner core is less constrained compared to the top ~400 km of the inner core. We found that PKI1KP is an ideal reference phase to PKI1KP for deciphering seismic structure at the centre of the earth, as the two have very similar ray paths in the mantle (Figure 1a).

We found clear PKI1KP arrivals from two deep-focus
Details of Tremor Observed by a Dense Seismic Array

PASSCAL Today
46 different experiments in 2017
48 different experiments in 2018

Examples of 2017/18 experiments –
Mexico RAMP
Alaska Amphibious Array
Education – Geophysics classes
Totten Glacier
Rutford Ice Stream
Induced seismicity – CO, TX, OK
Patagonia
Mongolia
SHIRE New Zealand
Seismic study of post-fire flash floods
FLUME 2.0
Dead Sea wide angle
Summary –

PASSCAL has allowed us to do research on tectonic process on every continent, at every type of plate boundary, and a tremendously broad range of scales.

Much of what we now know about collisional processes in orogens, modes of rifting, and the cycling of melt and volatiles in subduction zones comes from PASSCAL experiments.

PASSCAL is guided by the community to address the major seismological science targets of today and tomorrow, even as those targets become more broad in nature.
Thank you to the many people who provided slides and information!

- Francis Wu
- Bob Busby
- Susan Schwartz
- Randy Keller
- Steve Harder
- Susan Beck
- Ken Creager
- Lara Wagner
- Art Lerner-Lam
- Paul Passmore
- Tom Owens
- Karen Fischer
- Steve Roecker
- Craig Jones
- Peter Molnar
- Kent Anderson
- Bob Woodward
- Marcos Alvarez
## Equipment Inventory as of March 31, 2018

Table 6: Equipment inventory at the end of Q1, 2018

<table>
<thead>
<tr>
<th>Inventory</th>
<th>Data loggers</th>
<th>All-in-one</th>
<th>Sensors</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>3-Ch Data logger</td>
<td>6-Ch Data logger</td>
<td>1-Ch &quot;Texan&quot;</td>
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<tr>
<td>PASSCAL</td>
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<tr>
<td>Total</td>
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<td>253</td>
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