Reprint of

IRIS Seismology Program Marks 20 Years of Discovery

By R. Aster, B. Beaudoin, J. Hole, M. Fouch, J. Fowler, and D. James. 2005.
EOS, Transactions of the American Geophysical Union 86(17):171.

IRIS Seismology Program Marks 20 Years of Discovery

PAGES 171–172

The year 2004 marked the twentieth anniversary of the Incorporated Research Institutions for Seismology (IRIS) Consortium and its four core programs: the Program for Array Seismic Studies of the Continental Lithosphere (PASSCAL), the Global Seismic Network (GSN), Education and Outreach (E&O), and the Data Management System (DMS).

IRIS activities (www.iris.edu) are supported principally through the U.S. National Science Foundation's (NSF) Earth Sciences Instrumentation and Facilities Program, and through the community efforts of IRIS's more than 150 member institutions in the United States and abroad. The consortium provides fundamental capabilities for the exploration of the Earth's interior through the collection and distribution of seismographic data. PASSCAL is the IRIS facility program dedicated to seismographic data collection associated with temporary deployments using highly portable instrumentation.

The founding vision for PASSCAL was to provide a state-of-the-art pool of flexible, low power, and portable seismic instruments to the research community to advance broad understanding of Earth structure and processes. Over the past 20 years, PASSCAL has supported over 500 diverse research projects around the globe (Figure 1), including 69 distinct deployments during 2004. PASSCAL facilitates planning, training, fieldwork, and data archival for scientists from member and affiliated institutions. Its operations are supported through the PASSCAL Instrument Center at the New Mexico Institute of Mining and Technology, in Socorro, New Mexico. Research projects are funded to individuals or teams of scientists through a range of sources, notably by a variety of NSF programs and by the U.S. Department of Energy (DOE).

PASSCAL has free and open instrument use and data distribution policies (www.iris.edu/about/PASSCAL), with data distribution facilitated through the IRIS Data Management Center (DMC), hosted by the University of Washington (www.iris.edu/about/DMC/dms.htm). The PASSCAL data archive at the IRIS DMC (Figure 1) presently amounts to approximately 10 Tb.

The explosion of high-quality seismological data during the past few decades, spurred by IRIS and other U.S. and global efforts, represents an enormous new volume of observations spanning research interests ranging from deep mantle and core processes to the very near surface. Portable seismology deployments have evolved from single-institution efforts employing a handful of individually designed instruments to deployments of many hundreds of standardized instruments operated by institutional partnerships with professional support provided by the PASSCAL program.

The range of uses for PASSCAL instruments has evolved from early pioneering large-scale deployments consisting of tens of instruments in the 1980s to projects spanning the full range of spatial (from tens of meters to thousands of kilometers) and seismic frequency (from

megahertz to hundreds of hertz) scales. Below is a representative list of publications associated with this body of work; a more comprehensive list of PASSCAL and other IRIS-associated citations can be found at http://www.iris.edu/about/publications.htm.

Recent research ranges from large-scale imaging of the crust and mantle to addressing fundamental processes in a variety of tectonic regimes, including subduction zones [e.g., *Bostock et al.,* 2002], stable cratons [e.g., *Carlson et al.,* 2000], hot spots [e.g., *Wolfe et al.,* 2003], continental collision zones [e.g., *Kind et al.,* 2002], and continental rifts [e.g., *Wilson et al.,* 2005]. Controlled-source surveys using vibroseis and/or explosion sources have facilitated fine-scale source imaging of active fault systems such as the San Andreas [e.g., *Li et al.,* 2004], basins [e.g., *Lutter et al.,* 2004], and deep continental roots [e.g., *Gorman et al.,* 2002]. Access to data sets incorporating increasingly larger numbers of high-quality instruments has also furthered data processing methodologies [e.g., *Hole et al.,* 2001].

A key result of PASSCAL-supported science during the past 20 years has been the illumination of lithospheric complexity on a range of scales, bringing into focus a number of key questions regarding continental evolution [e.g., *Humphreys and Dueker,* 1994]. The uncovered wealth of fine structure associated with processes such as small-scale mantle convection and crustal delamination [e.g., *Zandt et al.,* 2004] has produced strong motivation for larger, denser experiments and increasingly interdisciplinary research groups, and has provided impetus for the NSF's EarthScope initiative [*Hornberger et al.,* 2001] (www.earthscope.org).

Along with PASSCAL's enhanced capability for supporting ever-larger seismograph deployments, it has also increasingly supported new avenues of research in areas including volcano seismology and infrasound [e.g., *Johnson et al.,* 2004], the cryosphere, and general ocean/ice hydroacoustic and seismic phenomena [e.g., *MacAyeal et al.,* 2004].

The principal challenge for PASSCAL in meeting future research community needs is to continue to evolve its combination of professional expertise and instrumentation capabilities to support innovative applications, while accommodating higher resolution experiments employing greater numbers of instruments. PASSCAL-supported science has also provided natural links to undergraduate and graduate internship programs for young scientists (e.g., www.iris.edu/about/ENO/internship.htm).

An Overview of the PASSCAL Facility

The original PASSCAL seismographs were acquired with NSF funding over a 12-year period beginning in 1988 and, thanks to an original vision of flexible use and design, saw nearly continuous deployment for over a decade. However, heavy use and improving technology eventually made them difficult to maintain and ripe for replacement. Over the past four years, hundreds of these first-generation PASSCAL data loggers have been replaced with new units (see Table 1), through funding from DOE's National Nuclear Security Administration's Nonproliferation and Verification Research and Development account. The capabilities of this newly upgraded community resource are summarized below.

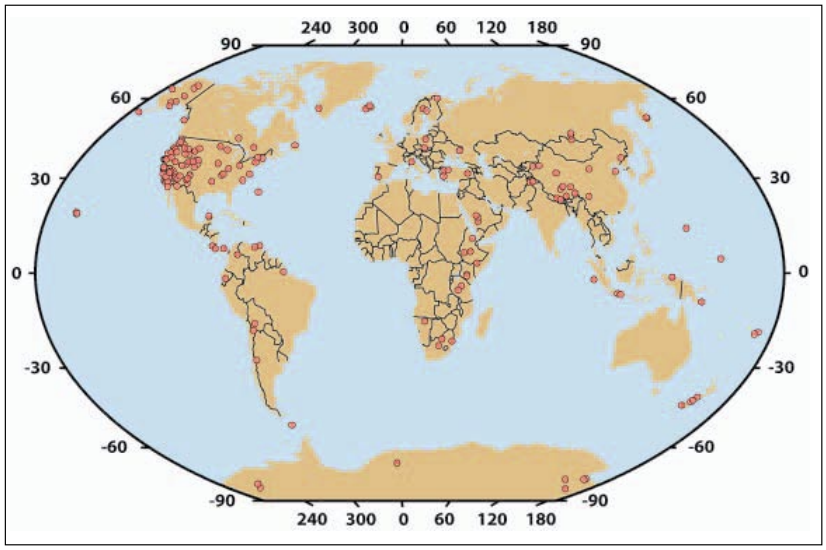

Fig. 1. Global map of PASSCAL deployments with data archived at the IRIS Data Management Center, 1986–2004.

Data acquisition systems. PASSCAL supports a variety of three-channel data loggers that are commonly used for earthquake source and/or seismic imaging studies, and occasionally in controlled source experiments. These recorders are typically solar powered and feature low-power consumption (1 W), reusable data media (compact flash or microdrives), and/or external data storage with present capacities of up to 20 Gb, dynamic ranges of ~135 dB (22–23 bits), and temperature-compensated crystal oscillators synchronized to a duty-cycled external GPS receiver/clock. Data are readily incorporated into Standard for the Exchange of Earthquake Data (SEED) format to facilitate permanent archival at the IRIS DMC.

PASSCAL hosts a large inventory of single-channel seismographs for controlled-source experiments. A compact configuration (each unit consists solely of a geophone and a ~2-kg recorder the size of a large tin can) facilitates efficient and inconspicuous deployments of many hundreds of channels. Sampling rates range from 1000 to 25 Hz, and up to 1000 preset programmed data windows are available.

Development is currently under way for a next-generation single-channel instrument that will expand memory capacity to 256 Mb, as well as improve programming download efficiency. This capability is jointly managed between PASSCAL and a collaborative pool of identical instruments owned and maintained by the University of Texas at El Paso.

For small-scale (typically controlled source) surveys, PASSCAL supports four 60-channel engineering seismographs for either standalone or combined use. These systems utilize cabled geophones, are externally triggered, and feature 24-bit recording at sampling rates up to 4000 Hz. Engineering seismographs have frequently been employed in teaching and in overlapping research/teaching activities, such as the Summer of Applied Geophysical Experience (SAGE) [*Jiracek et al.,* 2000].

Sensors. A seminal seismological development during the PASSCAL era has been the wide availability of low-power (~1 W), active portable broadband (0.008–50 Hz) seismometers. PASSCAL also supports a variety of passive seismometers (1–2 Hz low-end corner frequency) in configurations compatible with all appropriate data acquisition systems (Table 1). Controlled-source surveys are carried out with geophones with low-end corner frequencies ranging from 4.5 to 40 Hz.

Telemetry. Telemetry significantly reduces the need for site visits, greatly improves data retrieval rates and system state-of-health information, and facilitates more rapid data analysis. However, it also imposes special site and power requirements. While experiments in very remote locales will likely continue to rely on on-site data storage and retrieval for some time, PASSCAL is implementing telemetered systems where feasible and as new communication technologies become available. The PASSCAL Instrument Center supports a variety of point-to-point and satellite telemetry systems in association with the Scripps Institution of Oceanography at the University of California, San Diego.

EarthScope Activities

IRIS, along with the UNAVCO geodetic consortium and a Stanford University—U.S. Geological Survey (USGS) team, is one of the three facility partners in EarthScope, an NSF Major

Research Equipment and Facilities Construction (MREFC) project in Earth sciences. IRIS's principal responsibilities within EarthScope are the design, procurement, maintenance, and deployment of USArray, a continent-spanning deployment of seismometers and magnetotelluric instrumentation. IRIS maintains USArray portable field instrumentation through the USArray Array Operations Facility at the PASSCAL Instrument Center.

USArray incorporates (1) 2400 PASSCAL-like "flexible" array portable teleseismic, local earthquake, and controlled-source seismographs (Table 1) for use by investigators through support from peer-reviewed grants; (2) a systematically deployed 400-element, ~75-km spacing "transportable" telemetered broadband teleseismic array that will occupy 2000 sites spanning the continental United States and Alaska; and (3) a 100-element permanent telemetered broadband network installed in association with the GSN and USGS that will serve as a long-term reference for the portable arrays and as a component of national seismic monitoring.

USArray is currently receiving delivery of the first phase of this new facility, and is deploying the first footprint of the transportable array, and the DMC is presently archiving and freely distributing data in real time.

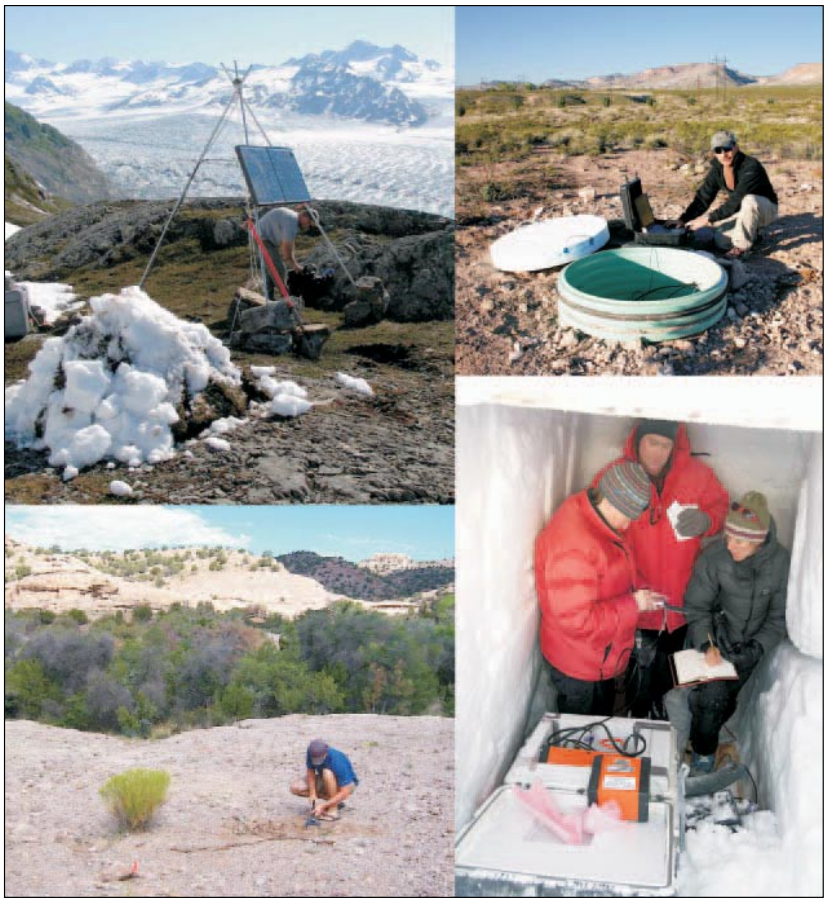

Fig. 2. Recent representative PASSCAL projects in the field. Clockwise from upper left: Columbia Glacier passive seismic recording (Dan McNamara, U.S. Geological Survey); EarthScope USArray Transportable Array station Y22C at New Mexico Institute of Mining and Technology near Socorro, New Mexico (Marcos Alvarez, IRIS Consortium); SOUTHBERG seismic vault on iceberg C16, McMurdo Sound, Antarctica (Doug MacAyeal, University of Chicago); Arizona Source Phenomenology Experiment, active source recorder deployment (Travis Glen, Southern Methodist University and Bill Walter, Lawrence Livermore National Laboratory, U.S. Department of Energy).

Acknowledgments

PASSCAL instrumentation has been funded through the Instrumentation and Facilities Program of NSF's Earth Sciences Division, with additional equipment provided through the Air Force Office of Scientific Research, DOE's Office of Nonproliferation Research and DOE's Office of Basic Energy Sciences. The facilities of the IRIS Consortium are supported by NSF under Cooperative Agreement EAR-0004370. This manuscript was improved by comments from IRIS consortium staff, PASSCAL Instrument Center staff, and members of the IRIS PASSCAL standing committee.

References

Bostock, M., R. Hyndman, S. Rondenay, and S. Peacock (2002), An inverted continental Moho and the serpentinization of the forearc mantle, *Nature, 417*, 536–538.

Carlson, R. W., et al. (2000), Continental growth, preservation and modification in southern Africa, *GSA Today, 20,* 1–7.

Gorman, A., et al. (2002), Deep Probe: Imaging the roots of western North America, *Can. J. Earth Sci., 39,* 375–398.

Hole, J. A., R. D. Catchings, K. C. St. Clair, M. J. Rymer, D. A. Okaya, and B. J. Carney (2001), Steep-dip seismic imaging of the shallow San Andreas Fault near Parkfield, *Science, 294*, 1513–1515.

Hornberger, G., et al. (2001), Review of Earthscope Integrated Science: Committee on the Review of EarthScope Science Objectives and Implementation Planning, Board on Earth Sci. and Resour., Div. on Earth and Life Stud., Natl. Res. Counc., Natl. Acad. Press, Washington, D. C.

Humphreys, E. D., and K. G. Dueker (1994), Western U.S. upper mantle structure, *J. Geophys. Res., 99*, 9615–9634.

Jiracek, G. R., W. S. Baldridge, S. Biehler, L. W. Braile, J. R. Ferguson, B. J. Gilpin, and D. L. Alumbaugh (2000), SAGE: Learning geophysics by immersion, *Leading Edge, 19*, 986–990.

Table 1. Inventory of PASSCAL and USArray Instrumentation[a]

Instrumentation	*PASSCAL*	*EarthScope USArray Flexible*	*EarthScope USArray Transportable*
Three-channel seismographs	540	400	400
One-channel seismographs	850[b]	2000	-
Sixty-channel cabled seismographs	4	-	-
Broadband seismometers	370	200	400
Intermediate period seismometers	120	-	
1–2 Hz seismometers	160	200	
4.5 Hz seismometers	>850	>2000	
40 Hz seismometers	>240		
Telemetry support	80 sites	up to 200 sites	400 sites

[a]PASSCAL as of January 2005; USArray scheduled by 2008.
[b]Includes instruments owned and maintained by the University of Texas at El Paso.

Johnson, J. B., R. C. Aster, and P. R. Kyle (2004), Volcanic eruptions observed with infrasound, *Geophys. Res. Lett.*, 31, L14604, doi:10.1029/2004GL020020.

Kind, R., X. Yuan, J. Saul, D. Nelson, S. Sobolev, J. Mechie, W. Zhao, G. Kosarev, J. Ni, U. Achauer, and M. Jiang (2002), Seismic images of crust and upper mantle beneath Tibet: Evidence for Eurasian plate subduction, *Science, 298,* 1219–1221.

Li, Y.-G., J. E. Vidale, and E. S. Cochran (2004), Low-velocity damaged structure of the San Andreas Fault at Parkfield from fault zone trapped waves, *Geophys. Res. Lett., 31,* L12S06, doi:10.1029/2003GL019044.

Lutter, W., et al. (2004), Upper crustal structure from the Santa Monica Mountains to the Sierra Nevada, Southern California: Tomographic results from the Los Angeles Regional Seismic Experiment, phase II (LARSE II), *Bull. Seismol. Soc. Am., 94,* 619–632.

MacAyeal, D., et al. (2004), SOUTHBERG: An in situ investigation of the seismic symphony of Iceberg C16, Ross Sea, Antarctica, *Eos Trans. AGU, 85*(47), Fall Meet. Suppl., Abstract C33D-08.

Wilson, D., R. Aster, M. West, J. Ni, S. Grand, W. Gao, W. S. Baldridge, S. Semken, and P. Patel (2005), Lithospheric structure of the Rio Grande rift, *Nature, 433,* 851–855.

Wolfe, C. J., P. G. Okubo, and P. M. Shearer (2003), Mantle fault zone beneath Kilauea volcano, Hawaii, *Science, 300,* 478–480.

Zandt, G., H. Gilbert, T. Owens, M. Ducea, J. Saleeby, and C. Jones (2004), Active foundering of a continental arc root beneath the southern Sierra Nevada in California, *Nature, 431,* 41–46.

Author Information

R. Aster, New Mexico Institute of Mining and Technology, Socorro, New Mex.; B. Beaudoin, IRIS PASSCAL Instrument Center, New Mexico Institute of Mining and Technology, Socorro; J. Hole, Virginia Polytechnic Institute and State University, Blacksburg; M. Fouch, Arizona State University, Tempe; J. Fowler, IRIS Consortium, Washington D.C.; and D. James, Department of Terrestrial Magnetism, Carnegie Institution of Washington, D.C.

For additional information, contact R. Aster; E-mail: aster@nmt.edu.