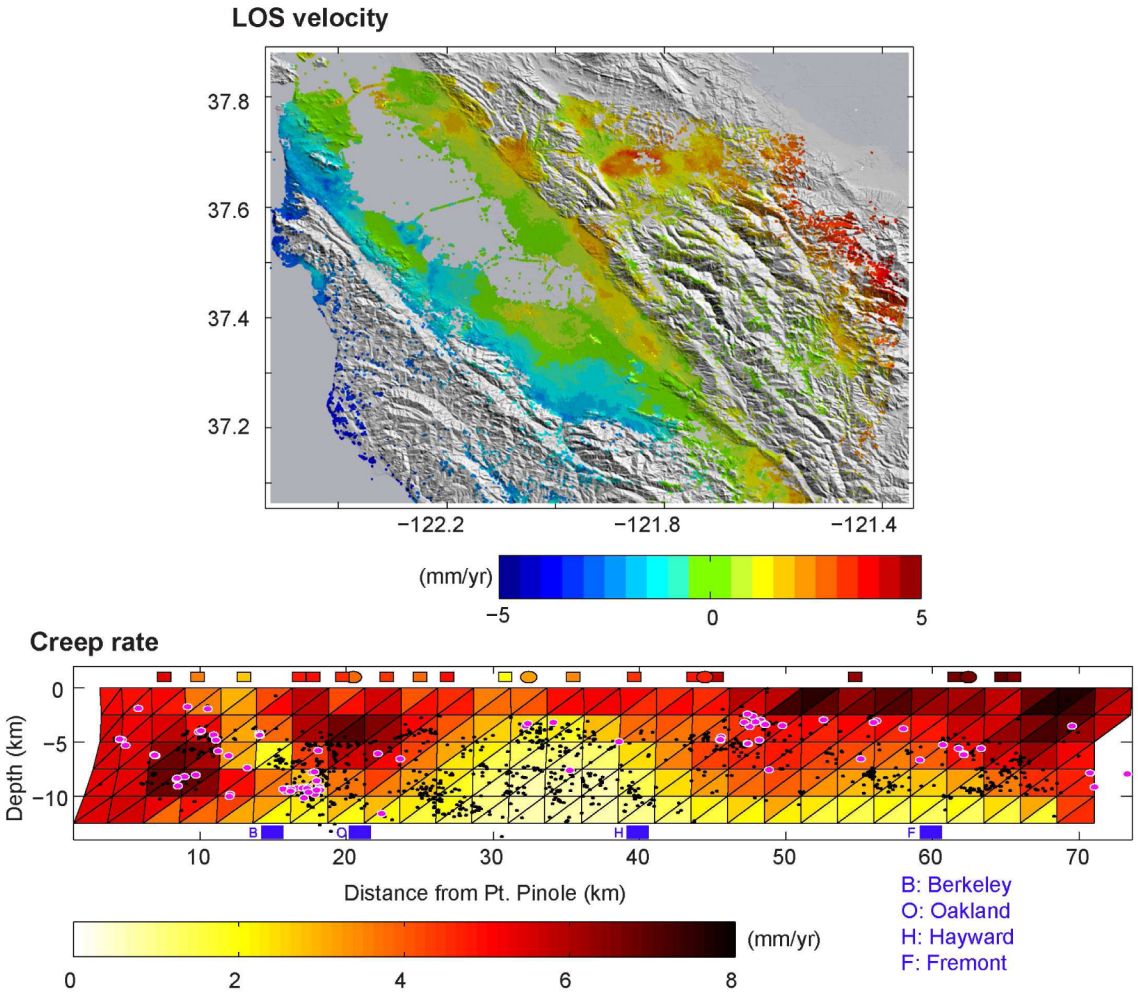
Berkeley Seismological Laboratory



Annual Report
July 2011 - June 2012

Chapter 1

Director's Report

1 Highlights

It is a great pleasure to present this year's Berkeley Seismological Laboratory (BSL) Annual Report. This is my first report as Director of the lab and it is exhilarating to see the wide range of BSL activities captured in these pages. The BSL today fosters both an active solid Earth research program and a cutting-edge geophysical observing facility. Spanning both of these realms, BSL provides an environment in which the extramural research program is strengthened and broadened by the facility, and the facility continues to push the boundaries of terrestrial observations in response to research needs. The contributions to this report are divided along these two lines. The research accomplishments are covered in Chapter 2, and progress in the development of our facilities is contained in Chapter 3. But first, I would like to highlight some of this year's activities.

The beginning of a new directorship provides an opportunity to reaffirm the BSL mission. After a review of the BSL's goals, priorities, and activities, we have developed the following mission statement consisting of four central tenets.

BSL's Mission: Sound science, serving society

Fundamental research: *Support fundamental research into all aspects of earthquakes, solid earth processes and their effects on society through the collection, archival and delivery of high quality geophysical data and through fostering a dynamic research environment that connects researchers across disciplines to geophysical observation systems.*

Hazard information: *Provide robust and reliable real-time data and information on Northern California earthquakes to government, public and private institutions, and to the public, in partnership with the US Geological Survey, CalEMA and other collaborating institutions.*

Broad education: *Enable the broad consumption of earthquake information and solid earth science through education and outreach to all sectors of society. Educate and train students at all levels through classes and research opportunities.*

Professional operation: *Create a productive professional working environment to enable efficient and robust operation and management of the geophysical facilities and career development of the staff and students.*

The basic research covered in Chapter 2 spans many topics in geophysics, seismology and tectonics. There are a total of 35 two-page summaries that range from micro-earthquake studies along the well-established San Andreas Fault to incipient faulting elsewhere; from aseismic slip on faults to great earthquake studies; from the structure of the deepest mantle to the properties of permafrost; from global seismic velocity structure to regional rheology. In addition to the two-page summaries, you will also find a list of publications and presentations about this research in Appendix I.

One of the exciting new developments during 2011-12 was a two-pronged effort to design and build a full prototype earthquake early warning system for California. This is being done thanks to generous funding by the Gordon and Betty Moore Foundation. In partnership with Caltech, the University of Washington and the USGS, we are now developing new algorithms to rapidly characterize the extent of faulting during large magnitude earthquakes. This will complement the current point-source methodologies that are the basis of the demonstration warning system that is running today. The second prong is the creation of BSL Earthquake Research Affiliates Program. It is designed to nurture partnerships between the BSL and the users of earthquake information. The program allows us to develop hazard products, including early warning, that are designed to fulfill the specific needs of private and public institutions and companies. The program currently has four members who are receiving earthquake alerts from the demonstration system. They are evaluating how their institution would respond to earthquake alerts in the future to reduce the impacts of earthquakes. You can find more information on the early warning effort in Chapter 2, Sections 20, 21, 22, 23, and 24.

The Gordon and Betty Moore Foundation has also funded our Tremorscope project. This project will in-

stall and operate a network of eight high-quality stations in the Cholame region south of Parkfield, CA, where seismic tremor has been found in the deep roots of the San Andreas fault zone. The network will be made up of four surface stations with broadband seismometers and accelerometers, and four borehole installations with geophones downhole, as well as digital broadband sensors and accelerometers. By the end of June 2012, all but two of the 8 stations were permitted, and the first two surface stations were installed and sending data. We evaluated data from these two sites to develop improvements to installation procedures before installing the other two surface sites. Over the next year, we expect to install and begin operating the remaining surface stations, as well as the borehole sites.

The BSL received significant funding from the USGS, in the framework of the American Recovery and Reinvestment Act (ARRA), to upgrade the recording systems at many of the Berkeley Digital Seismic Network (BDSN) broadband and borehole stations over the past three years. These upgrades are now completed at both our broadband and borehole stations. With the exception of two borehole sites installed under the auspices of Caltrans and several locations where we digitize other geophysical parameters such as electric and magnetic field strength, we now have new data loggers at all stations. All the broadband/strong motion sites now have some model of the Quanterra Q330 data logger, and the borehole sites have the 8-channel Basalt data logger.

In the last year, the BSL also completed work under the ARRA program to upgrade the Bay Area Regional Deformation (BARD) network's infrastructure, processing flow, and website. This included upgrading equipment at nearly half of the BARD GPS stations and installing six new stations (GASB, JRSC, MCCM, MNRC, PTRO, and WDCB), all co-located with BDSN seismometers. All BARD stations are now streaming data at 1 Hz. The upgraded receivers allowed us to make our real-time GPS data streams available more easily to the wider community. The real-time data streams also facilitate our in-house, real-time, high-rate processing of GPS data to produce station displacement estimates that can be used to inform real-time earthquake products, including Earthquake Early Warning systems. Daily processing and time-series generation for BARD backbone stations was re-established and the BARD webpage upgraded to provide more information (`http://earthquakes.berkeley.edu/bard`). More information about BARD can be found in Chapter 3, Section 5.

2 Facilities Review

The Berkeley Seismological Laboratory (BSL) is an Organized Research Unit (ORU) on the UC Berkeley campus. Its mission is unique in that, in addition to research and education in seismology, geophysics, and earthquake-related science, it is responsible for providing timely information on earthquakes to the UC Berkeley constituency, to the general public, and to various local and state governments, and private organizations. The BSL is therefore both a research center and a facility/data resource, which sets it apart from most other ORUs. A major component of our activities is focused on developing and maintaining several regional observational networks, and participating, along with other agencies, in various aspects of the collection, analysis, archival, and distribution of data pertaining to earthquakes, while maintaining a vigorous research program on earthquake processes and Earth structure. In addition, the BSL staff spends considerable time on public relations activities, including tours, talks to public groups, response to public inquiries about earthquakes, and an informational web presence (`http://earthquakes.berkeley.edu/`).

UC Berkeley installed the first seismograph in the Western Hemisphere at Mount Hamilton (MHC) in 1887. Since then, it has played a leading role in the operation of state-of-the-art seismic instruments and in the development of advanced methods for seismic data analysis and interpretation. Notably, the installation, starting in 1927, of Wood-Anderson seismographs at four locations in Northern California (BKS, ARC, MIN, and MHC) allowed the accurate determination of local earthquake magnitude from which a unique historical catalog of regional earthquakes has been maintained to this day, providing crucial input to earthquake probabilities studies.

Over the years, the then Berkeley Seismographic Stations (BSS) continued to keep apace of technological improvements. The first centrally telemetered network using phone lines in an active seismic region was installed by BSS in 1960. The BSS was the first institution in California to operate a 3-component "broadband system" (1963). It played a major role in the early characterization of earthquake sources using "moment tensors" and source-time functions. The BSS also made important contributions to the early definitions of detection/discrimination of underground nuclear tests and, jointly with UCB Engineering, to earthquake hazards work.

Starting in 1986, the BSS acquired four state-of-the-art broadband instruments (STS-1), while simultaneously developing PC-based digital telemetry. These two developments laid the groundwork for the modern networks we operate today. As telecommunication and computer technologies made rapid progress, in parallel with broadband instrument development, paper record reading was abandoned in favor of automated analysis of digital data. One paper-based helicorder does remain operational, primarily for the press and visitors to view.

Today, the BSL's networks can be divided into three

groups of instrumentation that are deployed at a total of 70 sites across central and northern California. The instrumentation types predominantly consist of broadband plus strong motion seismic, borehole seismic, and GPS, and are often co-located when appropriate. Data from all instrumentation streams continuously into the BSL's real-time monitoring system providing for earthquake notification and characterization, and also into the archive where it can be accessed immediately by researchers around the world for scientific study.

The Berkeley Digital Seismic Network (BDSN) is our regional seismic network of about 40 sites where both broadband and strong motion seismic instrumentation is installed. This network is the backbone of the BSL's operations, feeding the necessary data for real-time estimation of location, size and rupture parameters for earthquakes in central and northern California. This network has been steadily growing since the 1990's and consists of very high quality, low noise sites, making the data ideal for a range of research efforts. The array can be used to study local or global earthquake sources, and provides data for investigation of 3D crustal structure in California and its effects on regional waveform propagation, which in turn affect the intensity of ground shaking in larger earthquakes. Recent additions to the network include an ocean bottom seismometer in the Monterey Bay (MOBB) providing real-time data via an undersea cable (operated in collaboration with MBARI), and also the Tremorscope stations along the Cholame section of the San Andreas Fault just south of Parkfield.

The real-time data is also Berkeley's contribution to the California Integrated Seismic Network (CISN), which is a federation of networks that jointly provide all real-time earthquake information in the state. Since 1996, the BSL and the USGS in Menlo Park have closely cooperated to provide the joint earthquake notification program for Northern California. This program capitalizes on the complementary capabilities of the networks operated by each institution to provide rapid and reliable information on the location, size and other relevant source parameters of regional earthquakes. The real-time earthquake information is made available through the BSL's website (`http://earthquakes.berkeley.edu`).

The BSL's borehole networks represent the second grouping of instrumentation. The High Resolution Seismic Network (HRSN) was installed in 1987 and now consists of 12 operating sites. Additional borehole sites will soon be added as part of the Tremorscope project. These instruments have led to wide-ranging research into earthquake processes due to their high sensitivity, low noise, and proximity to micro-earthquakes, clusters and tremor sources along the highly studied Parkfield section of the San Andreas Fault. In the Bay Area, the Hayward Fault Network also includes 15 borehole instruments that have been installed progressively since the 1990s. Again, the goal of this network is to collect high signal-to-noise data for micro-earthquakes along the Hayward Fault to gain insight into the physics that govern fault rupture and its nucleation.

The third instrumentation type is GPS. The BSL operates the Bay Area Regional Deformational (BARD) Network consisting of 32 primary sites, 18 collocated with BDSN seismometers. All sites record with a 1 Hz sample rate and telemeter the data to BSL in real-time. Continuous GPS data tracks the motion of the tectonic plates and allows us to assess the strain buildup along faults as well as its release either through creeping episodes or through earthquakes. The application of GPS data feeds to real-time earthquake information is also a relatively new development. Very rapid processing now generates displacement waveforms that in turn support the development of improved real-time earthquake analysis methods for significant earthquakes.

The BSL's IT group is active in the development of new software for the collection, archival and real-time analysis of the various geophysical data streams that we collect. In 2009, the new AQMS seismic network software package was rolled out following a multi-year development effort by the BSL in collaboration with other CISN partners. This software provides all the real-time processing components needed by regional seismic networks and is now being rolled-out across the US. The development of real-time GPS processing software is a current area of focus for the lab along with development and implementation of earthquake early warning algorithms that can process the data quickly enough to provide alerts to people a few seconds to tens of seconds before shaking is felt.

Archival and distribution of data from the BSL and other regional geophysical networks is performed at the Northern California Earthquake Data Center (NCEDC), operated at the BSL in collaboration with USGS Menlo Park. The data reside on a mass-storage device (current holdings ∼60 TB), and are accessible online (`http://www.ncedc.org`). In addition to BSL network data, data from the USGS Northern California Seismic Network (NCSN), and other Northern California networks, are archived and distributed through the NCEDC. The NCEDC also maintains, archives and distributes various earthquake catalogs.

Finally, the field engineering team is responsible for maintaining our existing ∼70 geophysical observatories across Northern California, and designing and installing new sites. Of particular note is the completion in 2011 of the ARRA-funded upgrades. These urgently needed equipment upgrades replaced aging dataloggers at almost all BSL observatories, providing for more robust and more rapid transmission of data from the sites to the BSL real-time system. The group is now focused on the design and installation of the new Tremorscope borehole and surface stations just south of Parkfield along the

Cholame section of the San Andreas Fault.

All of these operations are supported by an operations and research staff of 10, an IT staff of 7, an engineering staff of 5, and an administrative support group shared with the Department of Earth and Planetary Science consisting of 7. In addition, there are currently 5 Postdoctoral Scholars and 14 PhD graduate students associated with the lab, along with 10 affiliated faculty.

Core University funding to our ORU provides salary support for one staff scientist (shared by three researchers), one IT staff member, one engineer, our operations manager, and two administrative assistants, and represents about one fifth of the total infrastructure support budget. The remaining support comes from extramural grants and contracts, primarily from the USGS, DOE, NSF, and the State of California, through its Emergency Management Agency (CalEMA). Currently, grants from the Gordon and Betty Moore Foundation contribute significantly to our operations as do the contributions from the members of our Earthquake Research Affiliates Program.

3 BSL Personnel News

Four new PhD graduate students joined the lab in the fall of 2011: Sierra Boyd, Cheng Cheng, Brent Delbridge, and Qingkai Kong. Also, Thomas Bodin, a new Miller Postdoctoral Fellow, and H. Serdar Kuyuk, a Postdoctoral Fellow, joined the lab. One PhD student, Aurelie Guilhem, graduated in December 2011. Her dissertation was titled "Analysis of unusual earthquake and tremor seismicity at the Mendocino Triple Junction and Parkfield, California." Postdoctoral Fellow Colin Amos also departed from the lab.

As usual, a stream of visitors spent various lengths of time at the lab. Jamie Barron, Morgan Guinois, Matthias Meschede, and Sergei Ventosa all visited from Institut de Physique du Globe de Paris, France, at various times. Simona Colombelli from the University of Naples spent 8 months at the lab working on earthquake early warning, and Jiajun Chong from the University of Science and Technology of China spent a summer working on waveform inversion in the Tibetan region.

The BSL staff remained mostly stable during this year following the significant changes of the previous few years. Administrative support continues to be provided through a shared services model with the Department of Earth and Planetary Science under the leadership of manager Judith Coyote. The IT and research staff also remained mostly stable. Tom Weldon left the research staff and we are pleased to welcome Clay Miller who joined the BSL as a Staff Research Associate.

Finally, in June 2012, Bill Karavas left the BSL. Bill was the lead engineer for the BSL networks for almost 20 years. During that time Bill led the effort to build the BDSN and much of the BARD network. He was also involved in supporting the borehole networks for the last few years. The quality of the BSL data, used by researchers around the world, would not be what it is without Bill's careful oversight of all engineering operations for the last two decades and we are very grateful to Bill for his efforts during that time.

4 Acknowledgements

I would like to thank our technical and administrative staff, scientists and students for their efforts throughout the year and their contributions to this annual report. Individual contributions to activities and report preparation are mentioned in the corresponding sections, except for the appendix sections, which were prepared by Jennifer Taggart.

I also wish to especially thank the individuals who have regularly contributed to the smooth operation of the BSL facilities: Mario Aranha, Doug Dreger, Aaron Enright, John Friday, Peggy Hellweg, Ivan Henson, Ingrid Johanson, Bill Karavas, Clay Miller, Josh Miller, Pete Lombard, Bob Nadeau, Doug Neuhauser, Charley Paffenbarger, Jennifer Taggart, Taka'aki Taira, Stephen Thompson, Bob Uhrhammer, Tom Weldon, and Stephane Zuzlewski, and, in the administrative office, Marion Banks, Matt Carli, Judith Coyote, Dawn Geddes, and Gretchen vonDuering. I also wish to thank our undergraduate assistants, Cora Bernard, Jennifer Taing and David Tang, for their contributions to our research and operations activities.

I am particularly grateful to Jennifer Taggart and Peggy Hellweg for their help in putting together this annual report and bringing it to completion.

The Annual Report of the Berkeley Seismological Laboratory is available on the web at `http://earthquakes.berkeley.edu/annual_report`.