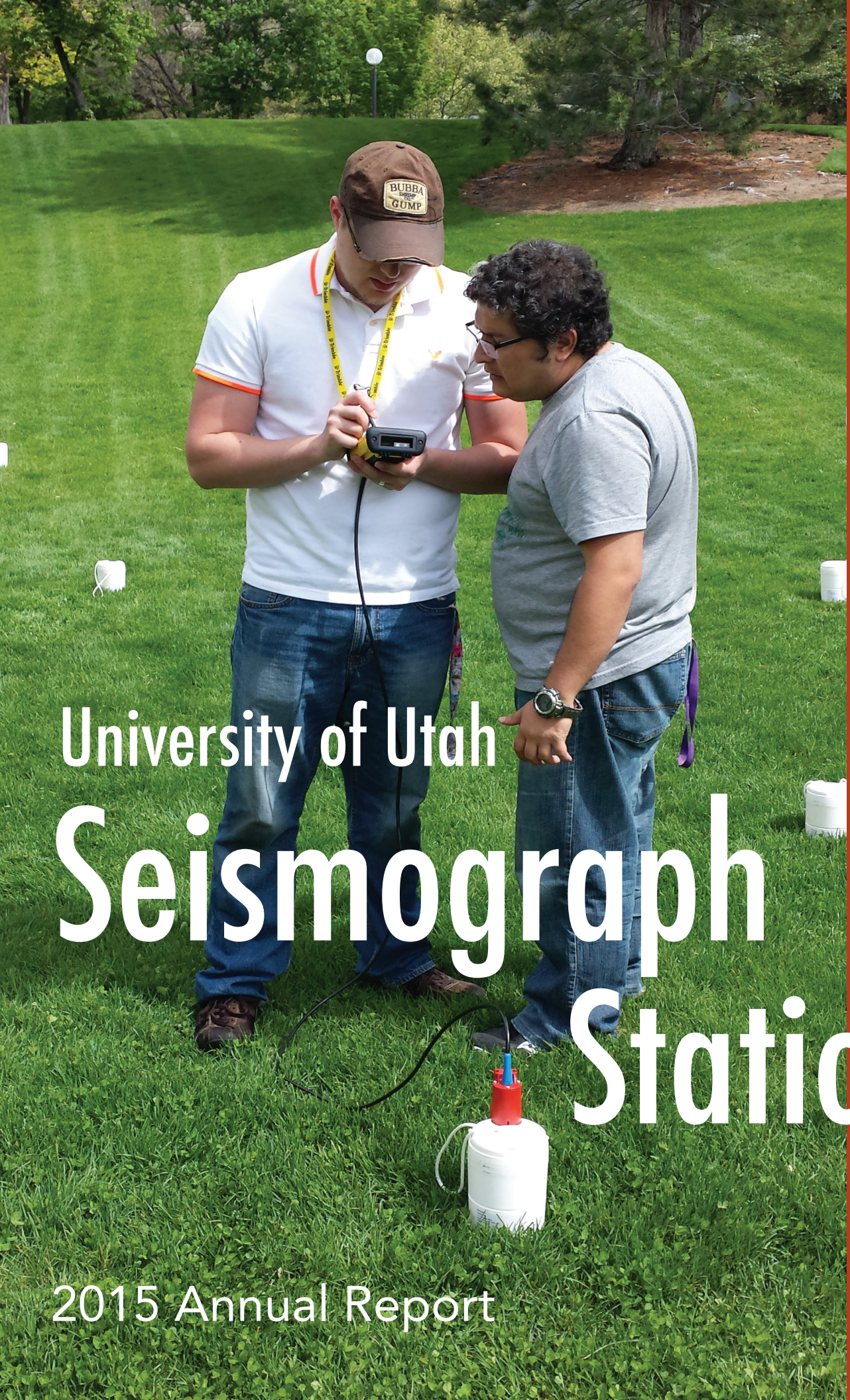


University of Utah Seismograph Stations

2015 Annual Report

Cover photo: Post-doctoral research scientist, Oner Sufri, looks on as undergraduate student, Kyler Goddard, calibrates a Nodal geophone during a practice deployment of the sensors on the University of Utah campus (photo by Sheryl Peterson).

Inside front cover: Cactus in bloom near station LCMT (Little Creek Mountain, UT). Photo by David Drobeck.

University of Utah
Seismograph Stations

115 South 1460 East, Room 211
Salt Lake City, UT 84112-0102
(801) 581-6274
www.quake.utah.edu

University of Utah Seismograph Stations
2015 Annual Report

Dear Friends,

2015 has been another vibrant and productive year for the University of Utah Seismograph Stations (UUSS). Our long-standing partnership with the United States Geological Survey (USGS) was extended with a new, 5-yr cooperative agreement from the USGS Earthquake Hazards Program. This award ensures that earthquake monitoring in Utah will continue to operate with state-of-the-art equipment and software at least through 2020. Congratulations to the UUSS staff for all their hard work on the USGS proposal, it was truly a team effort.

The legacy of UUSS in earthquake monitoring and research was recognized in 2015 as two former UUSS Directors received prestigious awards for career accomplishments. Research Professor Emeritus Dr. Walter J. Arabasz received the 2015 Alfred E. Alquist Special Recognition Medal from the Earthquake Engineering Research Institute, while Professor Emeritus Dr. Robert B. Smith received the 2015 Paul G. Silver Award from the American Geophysical Union. Congratulations to Walter and Bob for the leadership and service they have provided to the seismological community over the last several decades.

UUSS developed a new monitoring capability in 2015 with the acquisition of nearly 50 new wireless seismographs. The instruments were purchased in collaboration with Dr. Fan-Chi Lin and other University of Utah geoscientists, and will allow for the imaging of shallow Earth structure at a very small scale as well as the detection of small aftershocks that follow regional earthquakes. Please look inside to read about one of the first experiments carried out with the new instruments.

We expect great new things in 2016 as well. Keep an eye out for an updated UUSS web page and expanded social media presence. We also look forward to a celebration of the 50th anniversary of UUSS, in April 2016.

Dr. Keith D. Koper
Director

Nodal Geophones Enhance Seismic Monitoring and Research Capabilities

In 2015, the University of Utah purchased 48 Nodal Seismic instruments for use in various seismological studies. The instruments measure ground movement in three different directions (north-south, east-west, and vertical). Unlike older versions of these types of instruments, these are wireless and are completely self-contained. Each instrument has a seismometer, data-logger, battery, and data-storage all contained in a waterproof casing that is about the size of a quart jar (see below, and cover photo). This allows for freedom to configure the instruments in a way to best gather data that will address science goals.

During 2015, the instruments were used in 3 major projects. In May and then again in July 2015, the University of Utah Nodal instruments were deployed at the Dugway Proving Grounds to record a series of simulated truck bombs in conjunction with the Defense Threat Reduction Agency. In November 2015, all 48 University of Utah instruments, as well as instruments borrowed from the University of Texas El Paso and additional instruments from the manufacturer, Fairfield Nodal, were deployed in Yellowstone National Park. In all, 133 seismometers collected data for two weeks in the Upper Geyser Basin of Yellowstone, focusing on the area around Old Faithful (see related article). Following the Yellowstone experiment, the University of Utah instruments were deployed for a month in southern California for a project to study the San Jacinto fault.

These new seismic instruments are enabling University of Utah seismologists to collect large volumes of high quality seismic data that we can use to better understand the processes that are occurring beneath our feet. The Nodal instruments are proving to be a great way to instigate collaboration between the University of Utah Seismograph Stations and other organizations in order to foster integrative approaches to solving earth science related problems. The instruments will also allow flexibility for aftershock studies and for characterizing other seismic sources that might be of interest.

Importantly, these Nodal seismic instruments are proving to be a great educational tool that can be and have been used for small projects during classes in the Department of Geology and Geophysics. Having a readily available instrument pool teaches students valuable lessons on how to plan, execute, and process data from a seismic experiment.

We already have plans to purchase additional instruments and look forward to future projects that are already planned and ones that are still being thought up including future work looking at potential geothermal systems in Utah and the Denali Fault in Alaska.

Faculty and students hold a practice deployment of Nodal geophones on the University of Utah campus (below). Closer view of a geophone (inset).

Dr. Walter J. Arabasz Honored

Dr. Walter J. Arabasz, Research Professor Emeritus and former UUSS Director, was presented with the Earthquake Engineering Research Institute (EERI) 2015 Alfred E. Alquist Special Recognition Medal April 2, in Boston, Massachusetts.

The Alquist Medal is presented annually to an individual, company, or organization that has made substantial contributions to the field of seismic safety and earthquake risk reduction, having directly affected the seismic safety of the general population.

Dr. Arabasz was recognized for his contributions to advancing seismic safety in the United States, particularly in the State of Utah, and for bridging the fields of education, seismology and public policy.

Dr. Arabasz receives the 2015 Alfred E. Alquist Special Recognition Medal presented by EERI President, Mary C. Comerio. Photo courtesy of Marshall Lew (EERI).

A research professor in the University of Utah Department of Geology and Geophysics from 1983–2010, Dr. Arabasz was appointed director of the University of Utah Seismograph Stations in 1985, a position he held until his retirement from university in 2010.

Dr. Arabasz was a founding member of the Utah Seismic Safety Commission, and from 1997 to 2001 served as commission chairman. During his tenure, he assisted in the development and implementation of the "Strategic Plan for Earthquake Safety in Utah."

Dr. Arabasz served as a member of the National Earthquake Hazards Reduction Program's Advisory Committee on Earthquake Hazards Reduction - a committee that advises Congress and other federal agencies on science public policy and management issues.

Prior to receiving the Alquist medal, Dr. Arabasz was the recipient of the following honors:

2008 Western States Seismic Policy Council Lifetime Achievement Award in Earthquake Risk Reduction, for extraordinary commitment, level of service, and contribution of the application of earthquake risk reduction to public policy.

2007 U.S. Geological Survey John Wesley Powell Award, for significant contributions in advancing national earthquake monitoring and earthquake safety.

Automatic Earthquake Tweets

In the fall of 2015, UUSS implemented automatic Twitter updates for significant earthquakes in Utah and Yellowstone. The tweets include earthquake date and time, latitude, longitude, depth, and a description of the earthquake location in relation to nearby cities or towns. Earthquakes that have been reviewed by a seismologist are tweeted automatically under the new system.

With the addition of tweets to pre-existing means of disseminating earthquake information such as press releases, phone calls to public agencies, and website updates, we are able to reach a broader audience.

UUSS also tweets links to quarterly earthquake seismicity and network operations reports for Utah and Yellowstone.

For the latest earthquake updates:

@UUSS_Quake_Info

Report Examines What Utah Could Encounter During a Major Wasatch Fault Earthquake—and What Can Be Done Now to Improve Disaster Resiliency

Over three quarters of Utah residents live along the Wasatch Front, adjacent to the most active segments of the Wasatch fault extending from Brigham City to Nephi. More than three quarters of the state's economy is also concentrated in this area.

Of the several hundred earthquakes occurring in the Wasatch Front region, most are magnitude 2 or less on the Richter scale. Of greatest concern is a large surface-faulting earthquake—the kind of earthquake the Wasatch fault produces along its most active segments roughly every 300 years.

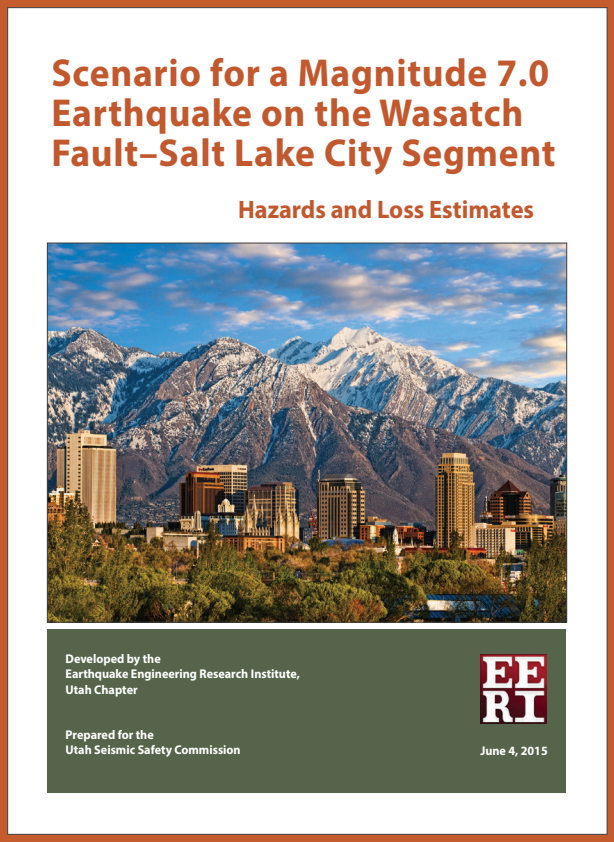
A report released in 2015 presents a credible scenario of what Utah will likely face in the aftermath of such a large magnitude earthquake on the Salt Lake City segment of the Wasatch fault. Specifically, the report warns of the "long-term impacts on Utah's economy" and suggests that full recovery, both for the state and for residents, will take much longer than many realize.

Commissioned by the Federal Emergency Management Agency the report was developed by a committee of professionals from the Utah Earthquake Program (see graphic below right) working in partnership under the auspices of the Utah Chapter of the Earthquake Engineering Research Institute. Dr. Kristine L. Pankow, Associate Director of the University of Utah Seismograph Stations served as committee chair.

The report was prepared for the Utah Seismic Safety Commission (USSC), the advisory group to Utah's governor and state legislature as well as the general public, on seismic policy issues in Utah.

The report provides background on the fault, geological conditions of the surrounding area, and loss estimations based on Hazus modeling. Factors affecting response and recovery are also discussed. The report concludes with nine recommendations intended as a catalyst for efforts, both public and private, that will help increase disaster resiliency and enable the state and its residents to better prepare to withstand, respond, and recover from a large magnitude earthquake on the Wasatch fault.

Following the presentation of the report to the USSC in July, it was released to the general public. In September, it was presented by the USSC to Utah Lieutenant Governor, Spencer J. Cox. A link to the report is available at www.ussc.utah.gov



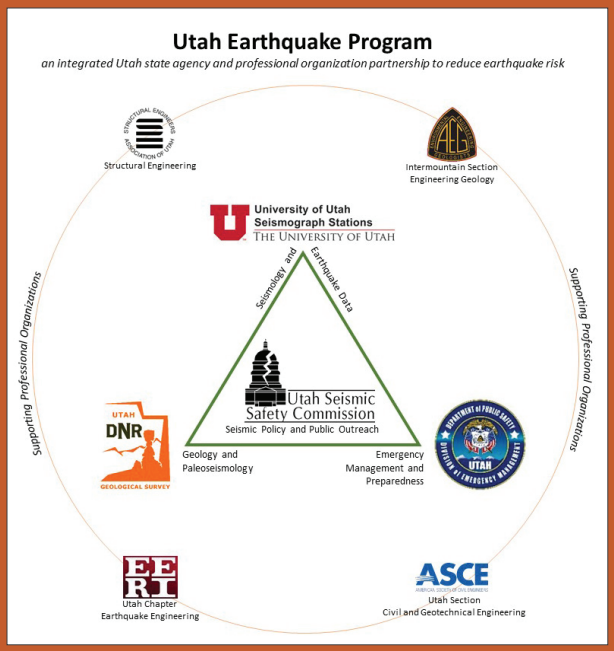


Image credit: Utah Earthquake Program (Utah Division of Emergency Management, University of Utah Seismograph Stations, and the Utah Geological Survey)

Dr. Robert B. Smith Honored

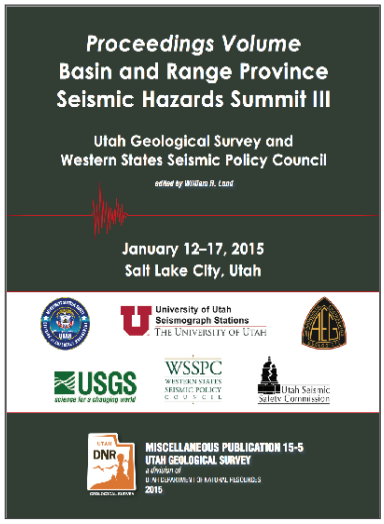
Former UUSS Director, Dr. Robert B. Smith received the Paul G. Silver Award in December from the American Geophysical Union (AGU) for original and creative scientific research throughout his distinguished academic career. Dr. Smith was the first Silver Award recipient to be recognized for outstanding contributions in multiple sections of the AGU including seismology, tectonophysics and geodesy.

Dr. Smith's career has focused on the earthquakes and volcanoes of Yellowstone, the structure and evolution of the lithosphere, and the structure of the mantle and crust of the western U.S. He was instrumental in the development of a number important geophysics initiatives, including: the creation of the University Navistar Consortium (UNAVCO) in the 1980s, formation of the Incorporated Research Institutions for Seismology (IRIS) in 1984, and he cofounded the National Science Foundation EarthScope program focused on developing seismic and GPS infrastructure for understanding the structure and active tectonics of North America.

In addition to serving on the Advisory Board of the Seismological Society of America, Dr. Smith was instrumental in founding the Yellowstone Volcano Observatory in 1990 and he served several years as a member, and first chair, of the Science Advisory Council for the Southern California Earthquake Center.

Dr. Smith has mentored generations of young scientists, and collaborated with colleagues around the world. He has also given time and effort to public education and outreach, and to educating emergency response authorities, and politicians on earthquake and volcano hazards.

Basin and Range Province Seismic Hazard Summit III



In January, subject matter experts in the fields of geology, seismology, geodesy, engineering, emergency management, and seismic hazard policy gathered in Salt Lake City for the Basin and Range Province Seismic Hazards Summit III (BRPSHS III). The summit is the third in a series, convened approximately once per decade, to review recent research related to earthquake hazards, and to consider its implications for policy-making and reducing earthquake hazards in the Basin and Range Province – an area that covers portions of Nevada, Utah, Arizona, New Mexico, Idaho, California, Oregon, Texas, and Mexico.

The summit was convened by the Utah Geological Survey (UGS) and the Western States Seismic Policy Council. UGS scientists William Lund and Steve Bowman chaired the summit. Event co-sponsors included the University of Utah Seismograph Stations, Utah Division of Emergency Management, U.S. Geological Survey, Intermountain Section of the Association of Environmental and Engineering Geologists, Utah Seismic Safety Commission, Utah Professional Geologists Licensing Board, and the Utah Professional Engineers and Land Surveyors Licensing Board.

UUSS contributions to the summit proceedings included:

- A keynote address by Dr. Keith Koper, "Earthquake Early Warning in the Intermountain West."
- A poster presentation of research by Dr. Walter Arabasz, Dr. Jim Pechmann, and Relu Burlacu titled, "A Uniform Moment Magnitude Earthquake Catalog for the Utah Region (1850-2012) an Estimation of Unbiased Recurrence Parameters for Background Seismicity."
- Dr. Jim Pechmann moderated one of the seven technical sessions and was co-author for the talk "Numerical Simulations of Wasatch Fault Earthquakes," and for the poster presentation,"Paleoseismology of the Northern Segments of the Great Salt Lake Fault."
- Dr. Keith Koper and Dr. Kris Pankow assisted in leading a field trip on the concluding day of the summit: "Salt Lake City's Earthquake Threat and What is Being Done About It." Participants visited several sites around the Salt Lake Valley, including the UUSS Rio Tinto Earthquake Information Center.

Reports on the proceedings of BRPSHS III and the two preceding summits can be found on the UGS website at:

http://www.geology.utah.gov/hazards/earthquakes-faults/utah-earthquake-working-groups/basin-and-range-province-seismic-hazards-summit/

Seismo Tea - a weekly geophysics seminar

Brewed by:
Dr. Jamie Farrell (Spring Semester)
Dr. Amir Allam (Fall Semester)

Date	Speaker	Affiliation	Title/Topic
Jan 28	Jamie Farrell	University of Utah	Recent studies on Yellowstone swarms, deformation, and unusual hydrothermal signals
Feb 4	Hsin-Hua Huang	University of Utah	Yellowstone magmatic system from the upper crust to the mantle plume
Feb 9	Phil Wannamaker	University of Utah	Subduction Arc and Backarc Processes of the Western U.S. from Magnetotelluric Arrays
Feb 19	Yao Yao	University of Utah	Scientific Visualization and its applications in seismology
Feb 25	Dimitri Zigone	University of Southern California	Multi-scale noise-based imaging of the San Jacinto Fault Zone environment
Mar 4	Keith Koper	University of Utah	Lateral Heterogeneity in Earth's inner core
Mar 11	Emily Wolin	Northwestern University	Seasonal and diurnal variations in long-period noise at SPREE stations: the influence of soil characteristics on shallow stations' performance
Mar 25	Kevin Seats	Stanford University	Observations of time-lapsed relative velocity changes at Yellowstone using ambient seismic noise
Apr 1	Jared Stein	University of Utah	Discriminating mining induced seismicity from natural tectonic earthquakes in the Wasatch Plateau region of central Utah
Apr 8	Amir Allam	University of Alaska Fairbanks	Combining geophysical, geological, and geodetic techniques to understand the interplay between Earth structure and earthquakes
Apr 15	Paul Okubo	USGS Hawaiian Volcano Observatory	Seismological applications at the active Hawaiian volcanoes
Apr 23	Josef Dufek	Georgia Institute of Technology	Fluid Mechanics of Pyroclastic Density Currents
Oct 9	Amir Allam	University of Utah	Velocity contrast and 15km vertical Moho offset across the Denali fault, Alaska, from double-difference tomography and fault zone head wave analysis
Oct 23	Keith Koper	University of Utah	"Backprojecting the April 2015 M7.8 Nepal Earthquake"
Oct 30	Marianne Karplus	University of Texas at El Paso	"Temporary Seismometer Deployment and Aftershock Distribution of the April 2015 M7.8 Nepal Earthquake"
Nov 6	Larry Brown John Hole	Cornell University Virginia Polytechnic Institute and State University	IRIS Webinar: "Aftershock Imaging with Dense Arrays (AIDA): Lessons from the Mw 5.8 Virginia Earthquake of 2011"
Nov 20	Kris Pankow	University of Utah	"The Science Behind the Utah Earthquake Scenario Report"
Dec 11	Yao Yao	University of Utah	"P- and S-wave Slowness Anomalies in the Mantle"

Publications

Peer Reviewed Journal Papers

Chambers, D., K. D. Koper, K. L. Pankow, and M. K. McCarter (2015). Detecting and characterizing coal mine related seismicity in the Western U.S. using subspace methods, *Geophys. J. Intl.,* **203,** 1388–1399.

Gal, M., A. M. Reading, S. P. Ellingsen, L. Gualtieri, K. D. Koper, R. Burlacu, H. Tkalcic, and M. A. Hemer (2015). The frequency dependence and locations of short-period microseisms generated in the Southern Ocean and West Pacific, *J. Geophys. Res. Solid Earth,* **120,** 5764–5781, doi:10.1002/2015JB012210.

He, X., S. Ni, L. Ye, T. Lay, Q. Liu, and K. D. Koper (2015). Rapid seismological quantification of source parameters of the 25 April 2015 Nepal earthquake, *Seism. Res. Lett.,* **86,** 1568–1577.

Huang, H.-H., F.-C. Lin, B. Schmandt, J. Farrell, R. B. Smith, and V. Tsai (2015). The Yellowstone magmatic system from the mantle plume to the upper crust, *Science,* **348,** doi:10.1126/science.aaa5648.

Koper, K. D., and R. Burlacu (2015). The fine structure of double-frequency microseisms recorded by seismometers in North America, *J. Geophys. Res. Solid Earth,* **120,** 1677–1691, doi:10.1002/2014JB011820.

Pyle, M. L., K. D. Koper, G. G. Euler, and R. Burlacu (2015). Location of high-frequency P-wave microseismic noise in the Pacific Ocean using multiple small aperture arrays, *Geophys. Res. Lett.,* **42,** 2700–2708.

Reports

Burlacu, R., P. M. Roberson, J. M. Hale, K. J. Goddard, K. D. Koper, J. C. Pechmann, and K. L. Pankow (2015). *Earthquake Activity in the Utah Region Preliminary Epicenters October 1–December 31, 2014,* Quarterly Report, University of Utah Seismograph Stations, Salt Lake City, Utah, 33 pp.

Burlacu, R., P. M. Roberson, J. M. Hale, K. J. Goddard, K. D. Koper, J. C. Pechmann, and K. L. Pankow (2015). *Earthquake Activity in the Utah Region Preliminary Epicenters January 1–March 31, 2015,* Quarterly Report, University of Utah Seismograph Stations, Salt Lake City, Utah, 31 pp.

Burlacu, R., P. M. Roberson, J. M. Hale, K. J. Goddard, N. S. Mohammad Jamaal, K. D. Koper, J. C. Pechmann, and K. L. Pankow (2014). *Earthquake Activity in the Utah Region Preliminary Epicenters April 1–June 30, 2014,* Quarterly Report, University of Utah Seismograph Stations, Salt Lake City, Utah, 36 pp.

Burlacu, R., P. M. Roberson, J. M. Hale, K. J. Goddard, K. D. Koper, J. C. Pechmann, and K. L. Pankow (2014). *Earthquake Activity in the Utah Region Preliminary Epicenters July 1–September 30, 2014,* Quarterly Report, University of Utah Seismograph Stations, Salt Lake City, Utah, 33 pp.

Farrell, J., R. Burlacu, P. M. Roberson, J. M. Hale, K. J. Goddard, K. D. Koper, R. B. Smith, J. C. Pechmann, and K. L. Pankow (2015). *Earthquake Activity in the Yellowstone Region Preliminary Epicenters October 1–December 31, 2014,* Quarterly Report, University of Utah Seismograph Stations, Salt Lake City, Utah, 20 pp.

Farrell, J., R. Burlacu, P. M. Roberson, J. M. Hale, K. J. Goddard, K. D. Koper, R. B. Smith, J. C. Pechmann, and K. L. Pankow (2015). *Earthquake Activity in the Yellowstone Region Preliminary Epicenters January 1–March 31, 2015,* Quarterly Report, University of Utah Seismograph Stations, Salt Lake City, Utah, 20 pp.

Farrell, J., R. Burlacu, P. M. Roberson, J. M. Hale, K. J. Goddard, K. D. Koper, R. B. Smith, J. C. Pechmann, and K. L. Pankow (2015). *Earthquake Activity in the Yellowstone Region Preliminary Epicenters April 1–June 30, 2015,* Quarterly Report, University of Utah Seismograph Stations, Salt Lake City, Utah, 18 pp.

Farrell, J., R. Burlacu, P. M. Roberson, J. M. Hale, K. J. Goddard, G. Bobetich, A. Mokhtar, K. D. Koper, R. B. Smith, J. C. Pechmann, and K. L. Pankow (2015). *Earthquake Activity in the Yellowstone Region Preliminary Epicenters July 1–September 30, 2015,* Quarterly Report, University of Utah Seismograph Stations, Salt Lake City, Utah, 18 pp.

Pankow, K., W. J. Arabasz, R. Carey, G. Christenson, J. Groeneveld, B. Maxfield, P. W. McDonough, B. Welliver, and T. L. Youd (2015). *Scenario for a Magnitude 7.0 Earthquake on the Wasatch Fault–Salt Lake City Segment: Hazards and Loss Estimates,* Earthquake Engineering Research Institute, Utah Chapter, Salt Lake City, Utah, 53 pp.

Wong, I., W. Lund, C. DuRoss, P. Thomas, W. Arabasz, A. Crone, M. Hylland, N. Luco, S. Olig, J. Pechmann, S. Personius, M. Petersen, D. Schwartz, R. Smith, and S. Bowman (2015). Earthquake Probabilities for the Wasatch Front region in Utah, Idaho, and Wyoming, *Final Tech. Rept.,* U.S. Geol. Surv. Award Nos. G11AP20010, G11AP20004, G13AP00003, G13AP00002, and G10AC00058, 520 pp.

Other Scientific Publications

Koper, K. D. (2015). *Geophysics,* in Encyclopedia Britannica 2015 Book of the Year, Encyclopedia Britannica, Inc., pp. 226–227.

Koper, K. D., Dalton, C. A., Ampuero, J.-P. (2015), A Global Array of Broadband Arrays, whitepaper for NSF workshop on Future Seismic and Geodetic Facility Needs in the Geosciences, Leesburg, VA, May 4-6, pp. 1-2.

National and International Presentations

Basin and Range Province Seismic Hazards Summit III, January 12-17, Salt Lake City, UT:

Arabasz, W. J., J. C. Pechmann, and R. Burlacu (2015). A uniform moment magnitude earthquake catalog for the Utah region (1850–2012) and estimation of unbiased recurrence parameters for background seismicity, in *Proc. Basin and Range Province Seismic Hazards Summit III,* W. R. Lund (Editor), Utah Geological Survey Miscellaneous Publication 15-5.

Dinter, D. A., and J. C. Pechmann (2015). Paleoseismology of the northern segments of the Great Salt Lake fault, Utah, in *Proc. Basin and Range Province Seismic Hazards Summit III,* W. R. Lund (Editor), Utah Geological Survey Miscellaneous Publication 15-5.

Hylland, M., B. Carey, C. DuRoss, J. Johnson, K. Koper, K. Pankow (2015). Salt Lake City's earthquake threat and what is being done about it - field trip guide, Basin and Range Province Seismic Hazards Summit III, Utah Geological Survey, pp. 1-21.

Koper, K. D. "Earthquake Early Warning in the Intermountain West," Basin and Range Province Seismic Hazards Summit III, January 13, 2015, Salt Lake City, UT.

Roten, D., K. B. Olsen, and J. C. Pechmann (2015). Numerical simulations of Wasatch fault earthquakes, in *Proc. Basin and Range Province Seismic Hazards Summit III,* W. R. Lund (Editor), Utah Geological Survey Miscellaneous Publication 15-5.

Seismological Society of America Annual Meeting, April 21-23, Pasadena, CA:

Batchelor, C. E., K. D. Koper, and K. L. Pankow (2015). Characterization of seismic swarms in Utah, ***Seismol. Res. Lett.*** **86,** 681.

Dinter, D. A., and J. C. Pechmann (2015). Paleoseismology of the northern segments of the Great Salt Lake fault, Utah, *Seismol. Res. Lett.* **86,** 672.

EarthScope National Meeting, June 14-17, Stowe, VT:

Farrell, J., and F.-C. Lin (2015). Imaging the Yellowstone magmatic system using surface waves from ambient noise cross-correlation (abstract).

Huang, H.-H., F.-C. Lin, B. Schmandt, J. Farrell, R. B. Smith, and V. C. Tsai (2015). The Yellowstone magmatic system from the mantle plume to the upper crust (abstract).

Linville, L., K. Pankow, D. Kilb, and J. Rubinstein (2015). Enhancing seismicity catalogs for basins in the central United States (abstract).

26th International Union of Geology and Geophysics General Assembly, June 22-July 2, Prague, Czech Republic:

Koper, K. D., and R. Burlacu (2015). Location of P-wave microseism sources via back-projection of large aperture seismic array data, in *Proc. 26th International Union of Geology and Geophysics General Assembly*.

Pankow, K. L., J. R. Stein, D. Chambers, and K. D. Koper (2015). Discriminating seismic sources (mining-induced seismicity, fluid injection induced seismicity, and tectonic earthquakes) in Central Utah, USA, in *Proc. 26th International Union of Geology and Geophysics General Assembly*.

34th International Conference on Ground Control in Mining, July 28-30, Morgantown, WV:

Stein J., K. L. Pankow, K. D. Koper, and M. K. McCarter (2015). Discriminating mining induced seismicity from natural tectonic earthquakes in the Wasatch Plateau region of central Utah, in *Proc. 34th International Conference on Ground Control in Mining,* July 28-30, Morgantown, WV.

Chambers, D. J. A., M. K. McCarter, K. D. Koper, and K. L. Chambers, D. J. A., M. K. McCarter, K. D. Koper, and K. L. Pankow (2015). Application of regional subspace detection to identify mining related seismicity, in *Proc. 34th International Conference on Ground Control in Mining,* July 28-30, Morgantown, WV.

Chambers, D. J. A., K. D. Koper, K. L. Pankow, and M. K. McCarter (2015). Subspace detection to detect small mining events: A comparison of catalogs, in *Proc. 34th International Conference on Ground Control in Mining,* July 28-30, Morgantown, WV.

Geological Society of America Annual Meeting, November 1-4, Baltimore, MD:

Farrell, J., R. B. Smith, H.-H. Huang, F.-C. Lin, W.-C. Chang, and C. M. Puskas (2015). Recent discoveries of Yellowstone's magmatic plumbing system, seismic swarms and their relationship to current deformation, Geological Society of America, Abstracts with Programs, 47(6), 7.

Puskas, C. M., C. M. Meertens, W.-L. Chang, J. Farrell, and R. B. Smith (2015). A history of geodesy in Yellowstone National Park and the legacy of Robert B. Smith, Geological Society of America, Abstracts with Programs, 47(6), 4.

American Geophysical Union Fall Meeting, December 14-18, San Francisco, CA:

Farrell, J., and F-C. Lin (2015). Imaging the Yellowstone magmatic system using multi-component ambient noise cross-correlation and tomography, Abstract V31E-3071.

Huang, H.-H., F.-C. Kin, B. Schmandt, J. Farrell, R. B. Smith, and V. C. Tsai (2015). The Yellowstone magmatic system from the mantle plume to the upper crust, Abstract V24C-08.

Koper, K., J. Hale, R. Burlacu, K. Goddard, A. Trow, L. Linville, J. Stein, D. Drobeck, and M. Leidig (2015). Dense Seismic Recordings of Two Surface-Detonated Chemical Explosions, Abstract S52B-03.

Liu, Q., K. D. Koper, R. Burlacu, S. Ni, and F. Wang (2015). Observations of teleseismic body waves (P,SV,SH) in

microseisms recorded by a large aperture array in China, Abstract S41B-2757.

Smith, R. B., J. Farrell, and C. M. Puskas (2015). Mantle-crust volcanics and geodynamics of the Yellowstone hotspot from seismic and GPS imaging and earthquake swarm magmatic interaction, Abstract V33-08.

Wang, Y., F.-C. Lin, and J. Farrell (2015). Rayleigh wave tomography of Mount St. Helens, Washington from ambient seismic noise, Abstract S41A-2705.

Additional Presentations:

Chambers, D. J. A., J. M. Wempen, M. K. McCarter, K. L. Pankow, and K. D. Koper (2015). Correlation of newly detected mining induced seismicity with subsidence in a Wyoming mining district, in *Proc. 2015 SME Annual Conference and Expo,* February 15-18, Denver, CO, pp. 192–198.

Q&A:

Can We Predict Earthquakes?

No. We cannot predict the precise time, location, and size of earthquakes in the U.S. In order to predict earthquakes there has to be an adequate history of repeated earthquake cycles and/or extraordinary instrumental observations. Long-term forecasts (on scales of years or decades) are becoming common for well-studied earthquake zones. The Chinese have correctly predicted some earthquakes, evacuated cities and saved lives. They have also had large earthquakes occur with no predictions and have predicted earthquakes that never occurred.

Visitors

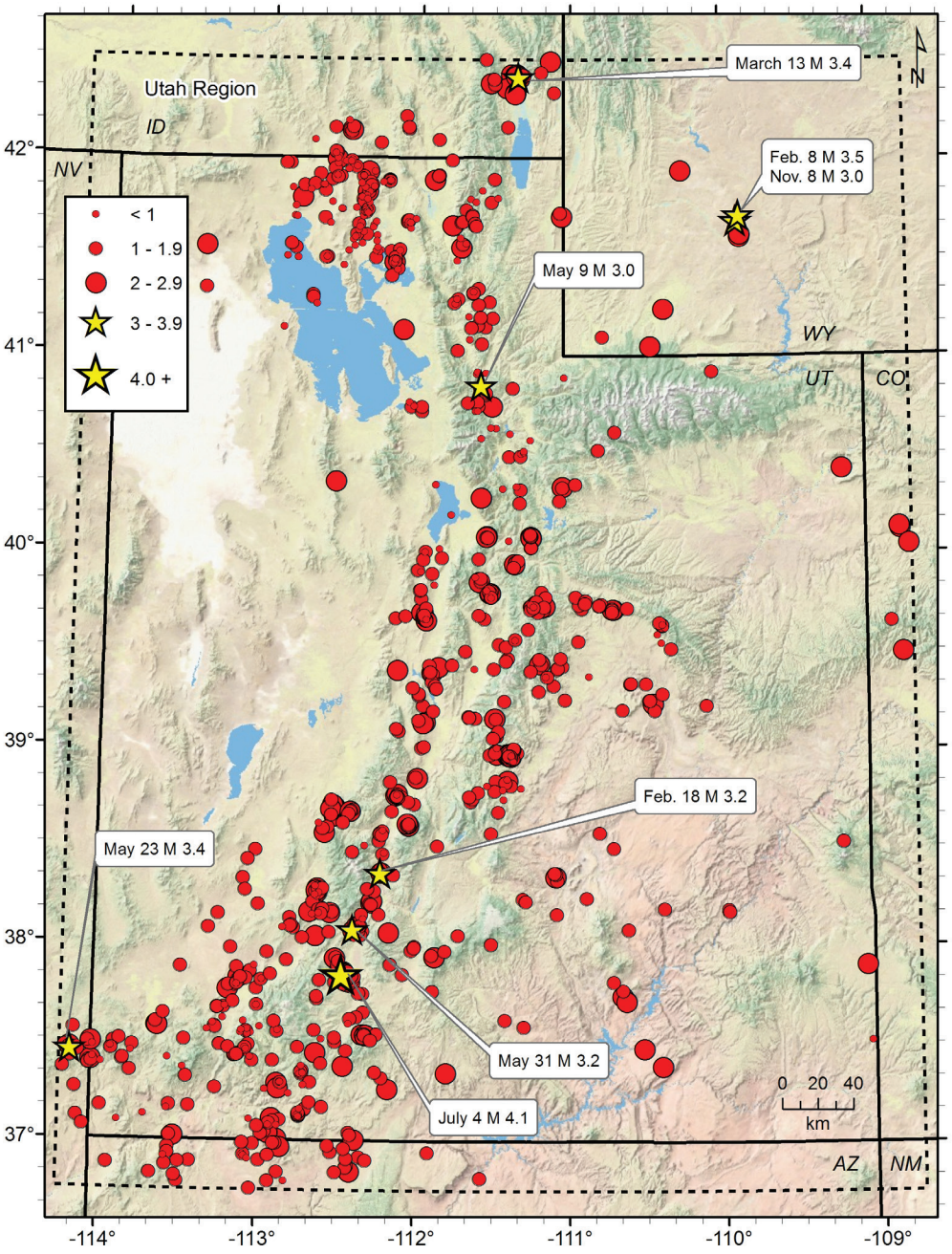
Liu Qiaoxia, visiting scholar from the Geophysical Exploration Center, China Earthquake Administration, Zhengzhou, China, spent 12 months working with Dr. Keith Koper. Liu's visit concluded with a poster presentation of her research, "Observations of Teleseismic Body Waves (P,SV,SH) in Microseisms Recorded by a Large Aperture Array in China," in December at the 2015 Annual Meeting of the American Geophysical Union in San Francisco, CA.

In April, UUSS hosted Dr. Paul Okubo, Research Geophysicist with the U.S. Geological Survey Hawaiian Volcano Observatory. During his stay, Dr. Okubo presented "Seismographic Network Applications at Active Hawaiian Volcanoes."

Representatives from the US Department of Energy and the Yellowstone Volcano Observatory visited in September. Also in September, UUSS hosted a guest lecture by Dr. Ross Stein (right), "Introducing Temblor, a web and mobile app to help people understand their seismic risk."

Seismicity of the Utah Region
January 1, 2015 - December 31, 2015

During the twelve-month period January 1 through December 31, 2015 the University of Utah Seismograph Stations located 1,039 earthquakes within the Utah region. The total includes one earthquake in the magnitude 4 range, seven earthquakes in the magnitude 3 range, and 128 earthquakes in the magnitude 2 range. Earthquakes of magnitude 3.0 or larger occurring in 2015 are plotted as stars (see map below).



M_L 3.5	Feb 8 17:54 MST	25 mi WNW of Green River, WY
M_L 3.2	Feb 18 21:35 MST	14 mi N of Circleville, UT
M_L 3.4	Mar 13 10:55 MST	5 mi SE of Georgetown, ID

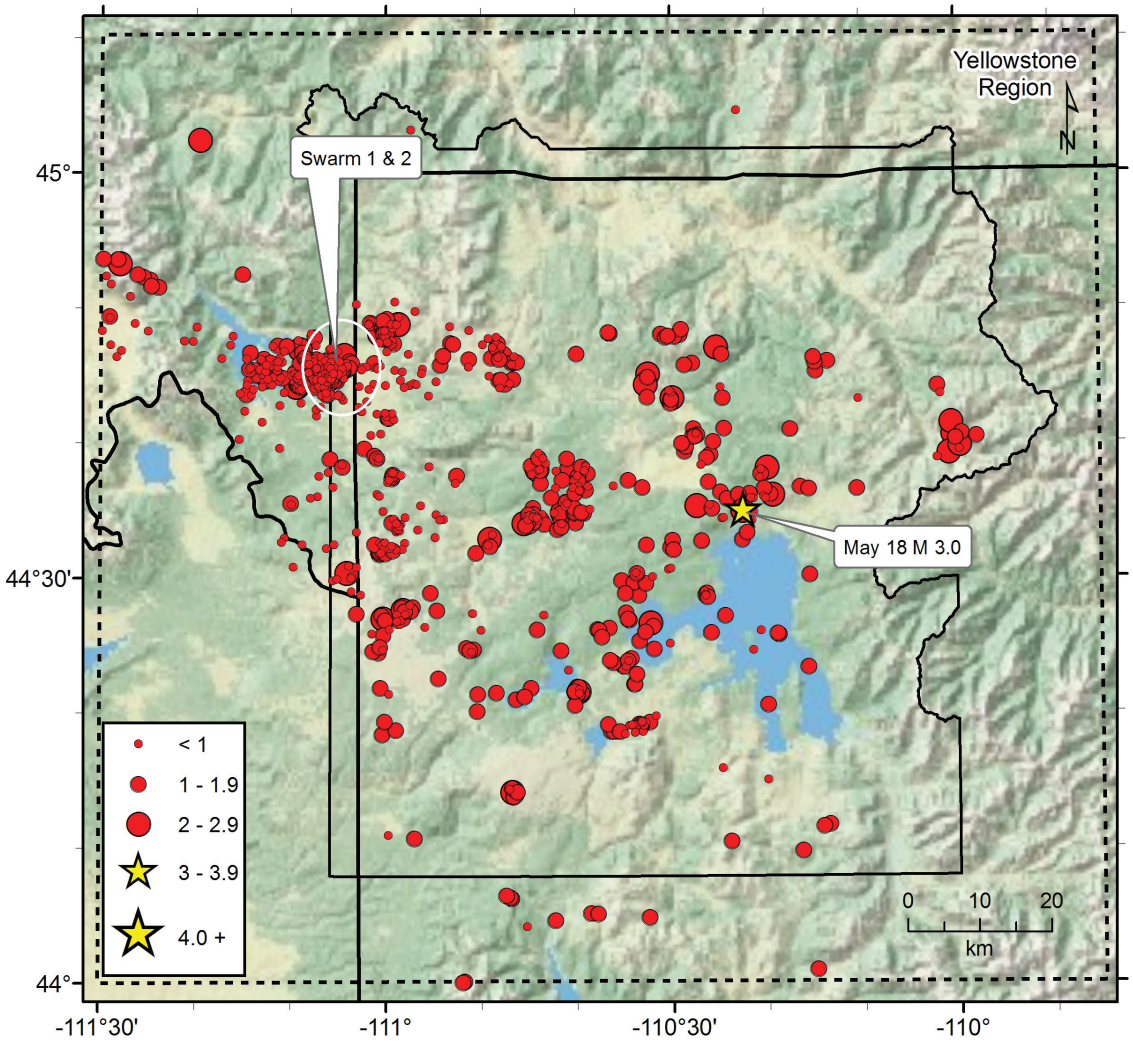
M_L 3.0	May 9 11:41 MDT	11 mi SW of Coalville, UT
M_L 3.4	May 23 23:14 MDT	21 mi ESE of Caliente, NV
M_L 3.2	May 31 09:07 MDT	10 mi SW of Circleville, UT

M_W 4.1	Jul 4 10:00 MDT	2 mi NW of Panguitch, UT
M_L 3.0	Nov 8 19:55 MST	25 mi WNW of Green River, WY

Seismicity of the Yellowstone National Park Region
January 1, 2015 - December 31, 2015

During the twelve-month period January 1 through December 31, 2015 the University of Utah Seismograph Stations located 1020 earthquakes within the Yellowstone National Park region—which reflects a relatively low rate of earthquakes for the area. The total includes one earthquake in the magnitude 3 range, and 34 earthquakes in the magnitude 2 range. Earthquakes of magnitude 3.0 or larger occurring in 2015 are plotted as stars (see map below).

There were two significant swarms in 2015 (indicated by ovals on map below). Both swarms occurred in the Hebgen Lake area, just west of the Yellowstone National Park boundary. The first swarm occurred 6.4 miles north of West Yellowstone, MT from January 21-22 and consisted of 136 earthquakes. The second swarm occurred 6.8 miles north of West Yellowstone, MT from November 7-10. This swarm contained 87 earthquakes. In addition to these two largest swarms, there were 9 other swarms in and around the Yellowstone region during 2015. Overall, swarm seismicity constituted 37% of the total seismicity for 2015. A swarm is a series of earthquakes clustered in space and time with no outstanding main shock.



M_L 3.0	May 18 17:00 MDT	3 mi NE of Lake, WY, YNP

Site Maintenance at Station KNB

One of four UUSS stations installed in a mine shaft or cave, station KNB (Kanab, UT) is located near Utah's Coral Pink Sand Dunes. The site, owned by the Utah Schools and Institutional Trust Lands Administration (SITLA), was initially built and operated by Lawrence Livermore National Laboratories. Subsequent use of the cave was granted to UUSS, and in September 2008 data transmission was restarted at the site—now part of the UUSS regional seismic network (service log entries and photos by Corey Hatch).

160CT15

East component of broadband sensor stuck at the rail. Used Guralp breakout box to recenter, but sensor reacted completely screwball. Looks like north component is now stuck too. Will have to return with another sensor. Installed new lighting inside cave: 100ft, ten-position contractor-grade string lights using 100W CFLs (actual 23W each), with new power switch inside first door. Also cleaned up extension cord routing to equipment in rear, plug strip at breaker box, and floor in front room -ch

270CT15

Swapped out bad broadband sensor which had two components stuck at the rail. Old sensor: Guralp CMG-3T S/N T3650. New sensor: Trillium 120PA S/N 002085. Palm pilot showed proper activity on all three channels. Also replaced conduit blocking material at bulkhead (second door). Yanked old, wet rag and installed 2in pink foam plug at both sides. And finally, scrambled up rock wall to inspect repeater site. All looked good -ch

Cave entrance (above left); (above, top to bottom): steel door at mouth of the cave; cave shaft; installed seismic equipment; cave shaft looking toward entrance; repeater site above the cave.

Collaboration with Boise State University

From June 5 through 8, a Boise State University field crew led by Dr. Lee Liberty successfully collected 14.5 km of surface wave and P-wave reflection and refraction data (seismic data) along several east-west lines in downtown Salt Lake City (Brophy et al., 2015). The equipment that they used consisted of an accelerated weight drop source and a land streamer with 48 geophones mounted on a fire hose.

The primary objectives of the NEHRP-funded project were to (1) test the capabilities of the new land streamer equipment, (2) measure V_S30 (near-surface shear wave velocities) along the profiles, and (3) identify and characterize active faults in the downtown Salt Lake City area, especially the southernmost extent of the Warm Springs fault (part of the Wasatch fault zone). UUSS and Utah Geological Survey (UGS) personnel helped Dr. Liberty define the scientific goals of the project and design the seismic experiment. Further UUSS-UGS collaborative involvement in the project is expected.

During operations, a van pulls the trailer and the land streamer forward by a few feet and stops (below left). Then, the accelerated weight drop source on the trailer (below right) is activated lifting up the steel plate beneath the trailer and slamming it back down onto the pavement. The seismic waves generated by the steel plate hitting the road reflect and refract off the geologic layers below the road surface, and are recorded by the geophones (seismometers) in the land streamer (photos by Jim Pechmann).

Q&A:

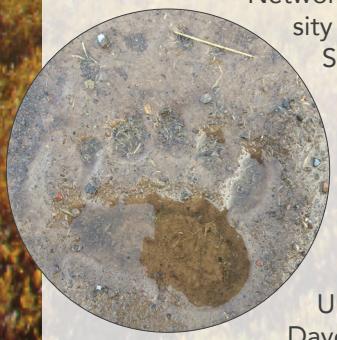
Will the Ground Open Up During an Earthquake?

Although it makes for great action-adventure movies—in reality, the ground does not open up and swallow people (a commonly feared myth). Open ground cracks may form during an earthquake—related, for example, to landsliding or ground slumping. But such fissures are open gaps (they don't "swallow") that a person could stand in.

Hawks Rest Revisited... Almost

On September 15, University of Utah Seismograph Stations employees Dave Drobeck and Jamie Farrell, along with U.S. Forest Service packer Chris Hart traveled by horseback approximately 25 miles one way to the U.S. Forest Service Hawks Rest backcountry ranger cabin. The purpose of this trip was to move the recently installed Hawks Rest seismic station (YHR) from inside a radio repeater building and bury it in a better quality seismic vault some distance away to lessen the amount of wind noise that is recorded by the instrument. The seismometer is located on Hawks Rest Peak just outside the SE corner of Yellowstone National Park near the confluence of the Yellowstone and Thorofare Rivers. It is co-located with a U.S. Forest Service radio repeater site.

The Hawks Rest station is part of the Yellowstone Seismic Network that is operated by the University of Utah Seismograph Stations. Seismic data from this station are telemetered approximately 50 miles via an RF link from Hawks Rest to Mt. Washburn, YNP, and then uploaded to the Internet for recording at the UUSS data center at the University of Utah.



Unfortunately, due to a snowstorm, Dave and Jamie were never able to make it from the cabin up to the top of Hawks Rest to complete the work and on September 18, they had to ride the 25 miles back out. The job is tentatively scheduled to be completed sometime in the fall 2016—weather permitting.

Clockwise from above left: A bear track sighted along the trail; Chris Hart leads the group into the backcountry; Jamie Farrell prepares equipment for storage; Dave Drobeck relaxes after a long day; the U.S. Forest Service Hawks Rest Patrol Cabin serves as home base during the trip (photos by Dave Drobeck and Jamie Farrell).

Upper Geyser Basin Seismic Imaging

In early November, the University of Utah, in conjunction with Yellowstone National Park and the University of Texas El Paso, installed 134 seismometers in and around Old Faithful Geyser in the Upper Geyser Basin of Yellowstone National Park. All together, there were 17 people involved in the project—nine from the University of Utah, two from the University of Texas El Paso, two from Fairfield Nodal, and four from Yellowstone National Park. The project was led by Dr. Jamie Farrell, Dr. Bob Smith, and Dr. Fan-Chi Lin at the University of Utah and included help from six students. The instruments used were new Fairfield Nodal geophones recently purchased by the University of Utah and the University of Utah Seismograph Stations as well as geophones borrowed by the University of Texas El Paso and Fairfield Nodal.

The two main goals of this project are to 1) image the shallow velocity structure of the Old Faithful area for use by the Park Service for engineering purposes, and 2) to record and identify hydrothermal signals that will allow us to better understand how hydrothermal systems work and how different features within the geyser basin are related and interact with each other.

The instruments were installed on November 2 and ran continuously until they were removed November 13. In total, over 4 terabytes of data were collected over the 13 day project period.

Project team members from the University of Utah (above) standing in front of Old Faithful Geyser: Andy Trow, Eli Workman, Sin-Mei Wu, Dr. Jamie Farrell, and Dr. Fan-Chi Lin; Dr. Farrell programs a Nodal geophone (left).

Left to right: a U.S. Forest Service pack mule appears less than amused as it is prepped for the trip; Hawks Rest above the Upper Yellowstone River (photos by Dave Drobeck and Jamie Farrell).

Faculty

Dr. Keith D. Koper

- Director
- Professor of Geology and Geophysics

Dr. Kristine L. Pankow

- Associate Director
- Research Associate Professor of Geology and Geophysics

Dr. James C. Pechmann

- Research Associate Professor of Geology and Geophysics

Dr. Jamie M. Farrell

- Research Assistant Professor of Geology and Geophysics

Dr. Walter J. Arabasz

- Emeritus Director
- Emeritus Research Professor of Geology and Geophysics

Full-time Staff

William Blycker	Systems Administrator
Valeriu Burlacu	Research Manager
David Drobeck	Seismograph Technician
Mark Hale	Earthquake Information Specialist
Corey Hatch	Seismic Network Engineer
Martha Knowlton	Administrative Manager
Sheryl Peterson	Communications Specialist
Paul Roberson	Earthquake Information Specialist
Jon Rusho	Seismic Network Engineer
Katherine Whidden	Research Seismologist

Part-time Staff

Greg Bobetich	Student Analyst
Kyler Goddard	Student Analyst
Gordon Johansen	Field Assistant
Afiq Mokhtar	Student Analyst
Barry Morse	Station Attendant
Peter O'Neill	Field Assistant
Jared Stein	Research Assistant
Marcela Torres	Exhibit Coordinator
Ken Whipp	Electronics Technician

Top to bottom: on the road to station ICU (Indian Springs Canyon, UT) near St. George; view from station RDMU (Red Mountain, UT) near Vernal; looking northeast at Frisco Peak near station PSUT (Pine Springs, UT) in southwestern Utah; station PCCW (Pine Creek, Cokeville, WY). Photos by Corey Hatch.

Committee Service

Dr. Keith D. Koper

- Vice-chair, Utah Seismic Safety Commission, 2010–present.
- Member, US Air Force Seismic Review Panel, 2011–present.
- Member, Editorial Advisory Board, EOS Transactions of the American Geophysical Union, 2010–present.
- Member, Global Seismographic Network (GSN) Review Panel, Incorporated Research Institutions for Seismology (IRIS), 2015
- Member, External Review Committee for Energy and Climate, Lawrence Livermore National Laboratory (LLNL), 2015

Dr. Kristine L. Pankow

- Chair, Utah Earthquake Scenario Committee, Earthquake Engineering Research Institute (EERI) - Utah Chapter, 2014–present.
- Voting Member, Utah Mine Safety Technical Advisory Council, 2011–present.
- Intermountain West Regional Coordinator for Committee on National Implementation and Committee on Comprehensive Catalog, Advanced National Seismic System (ANSS), 2010–present.

Dr. James C. Pechmann

- Member, Program Committee, 2015 Basin and Range Province Seismic Hazards Summit III, Utah Geological Survey and Western States Seismic Policy Council, 2013–2015.
- Member, Utah Quaternary Fault Parameters Working Group, Utah Geological Survey, 2003–present.
- Member, Utah Ground-Shaking Working Group, Utah Geological Survey, 2003–present.
- Member, Working Group on Utah Earthquake Probabilities, Utah Geological Survey, 2010–present.

Dr. Walter J. Arabasz (Emeritus)

- Member, Working Group on Utah Earthquake Probabilities, Utah Geological Survey, 2010–present.
- Member, Working Group on a "Scenario for a Magnitude 7.0 Earthquake on the Wasatch Fault—Salt Lake City Segment," Earthquake Engineering Research Institute (EERI), Utah Chapter, 2014–2015.

Dr. Keith Koper during a quarterly meeting of the Utah Seismic Safety Commission.

Graduate Student Affiliates

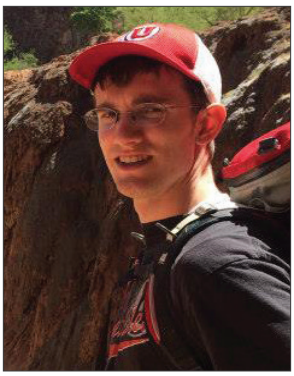
Earthquake swarms are defined as clusters of events that occur closely in space and time and do not exhibit a clear mainshock, in contrast to foreshock-mainshock-aftershock sequences. Swarms are especially common within the seismically active region of the Intermountain West. Of the ~1,500 earthquakes detected and located by the University of Utah Seismograph Stations (UUSS) each year, a fraction of these earthquakes occur in swarms. The source mechanism of swarms in Utah is not well understood, one hypothesis is that stress is induced by the propagation of either hydrothermal or magmatic fluids. To characterize this potential relationship, as well as the spatial and temporal characteristics of seismic swarms in Utah, I am using waveform correlation methods to detect small events in a 2003 Marysvale Volcanic Province swarm sequence that were missed in routine UUSS earthquake cataloging. This work will apply waveform correlation to single-component as well as three-component stations over time to better understand the event propagation of these types of swarm sequences. I am also using a subspace method to detect events in this swarm and will document the differences between these two detection methods.

Chase Batchelor
MS - Geophysics

My research was focused on applying subspace detection methods to detect mining related seismicity in the western United States. My work was published in the Geophysical Journal International (doi:10.1093/gji/ggv383). I successfully defended my thesis in the summer of 2015 and accepted a job offer with the National Institute of Occupational Safety and Health (NIOSH) in the Office of Mine Safety and Health Research (OMSHR).

Thesis: Application of Subspace Methods to Detect and Characterize Coal Mine Related Seismicity in the Western United States

Derrick Chambers
MS - Mining Engineering
2015 Graduate

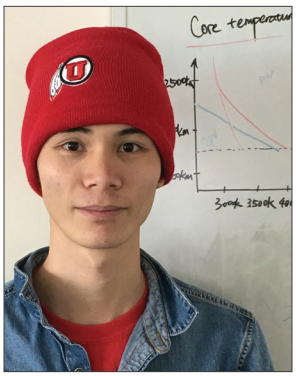


I'm working on enhancing seismicity catalogs in sedimentary basins in the central U.S. where active fluid extraction/injection occurs. We are hoping to find new source zones through automated template searching that aren't represented in current catalogs. These new templates, combined with local cataloged events can then be used to generate high-resolution time histories of event families–leading to a better understanding of how each basin responds to fluid injection.

Lisa Linville
PhD - Geophysics

My research is about the energetic earthquake swarm that began in March 2014 and continued through the present, near Challis, Idaho. This swarm is adjacent to the Lost River Fault, which produced the damaging M6.9 Borah Peak earthquake in 1983 and the earlier study indicated that the relocations of more than 100 events in 2014 outlined a NW-SE trend similar to the strike of the Lost River Fault. My job is to use template-based seismic detection methods to find more small events during the swarm activity, then do the location and relocation for them to better characterize the fault system in this relatively sparsely instrumented yet hazardous region.

Guanning Pang
PhD - Geophysics



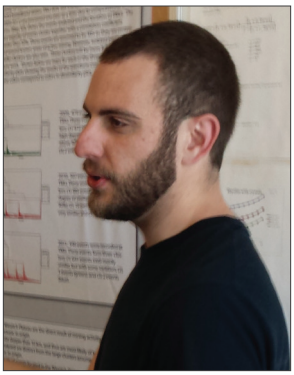
To elucidate the understanding of the natural seismicity of the Milford, Utah area, induced seismicity sources needed to be separated from the seismic catalog. This was achieved by locating the events close to the quarry and the discriminating the blasts based on the time of day in which they occurred. To increase the efficiency of analyzing the data of the quarry and other areas, a program was created to review the location and time of day in which an event occurred. The quarry area was compared to surrounding areas of seismicity and it was concluded that the quarry's seismicity was composed of 61 blast events and 3 naturally occurring events.

Stephen Potter
MS - Geology

I have just finished a research project centered on cataloging different seismic source types in the Wasatch Plateau region of Central Utah. The main focus was to discriminate mining induced seismicity resulting from the many nearby underground coal mines from the naturally occurring earthquakes also taking place in the region. In order to do this, I used a combination of methods including event relocation, waveform cross-correlation, and spectral analysis. The result of this research is a catalog of seismic events sorted by source type for a complicated area of Utah seismic activity.

Thesis: Seismic Source Discrimination in the Wasatch Plateau Region of Central Utah

Jared Stein
MS - Geophysics
2015 Graduate



Undergraduate Student Affiliates

Greg Bobetich	BS-Geophysics
Kyler Goddard	BS-Geophysics 2015 Graduate
Afiq Mokhtar	BS-Geophysics

Kyler Goddard (left), presents, "Microseisms from the Great Salt Lake" during the Geology and Geophysics spring student poster session in April. Dr. Jim Pechmann looks on as Chase Batchelor (above) shares her presentation, "Characterization of Seismic Swarms in Utah" with a colleague. Jared Stein (not pictured) presented, "Discriminating mining induced seismicity from natural tectonic earthquakes in the Wasatch Plateau region of central Utah."

Earthquake Exhibit

"Earthquakes in the Intermountain West" is a traveling educational exhibit funded by the State of Utah and maintained and administered by UUSS. The exhibit tells Utah's earthquake story including the history of earthquakes in the region, the science behind them, and how to prepare for future earthquakes. The list and map below show public schools and other organizations that hosted exhibit displays during the year:

Beacon Heights Elementary - Salt Lake City

Beehive Elementary - Kearns

Bonneville Elementary - Salt Lake City

Cook Elementary - Syracuse

Franklin Elementary - Provo

Kennedy Junior High - West Valley City

Lincoln Elementary - Salt Lake City

MasterControl, Inc. - Salt Lake City

Meadowlark Elementary - Salt Lake City

Mountain View Elementary - Salt Lake City

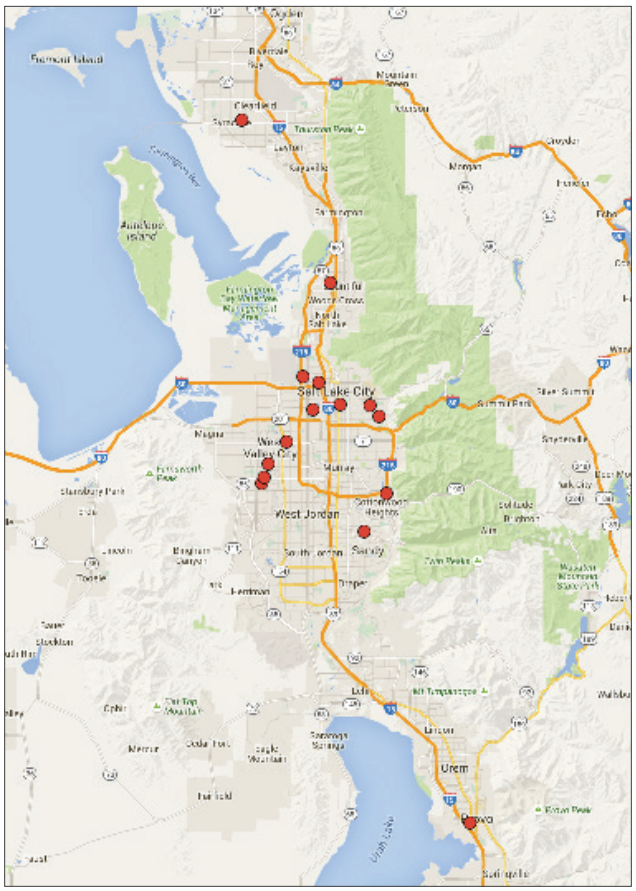
Silver Mesa Elementary - Sandy

Utah State Fairgrounds - Salt Lake City

West Bountiful Elementary - West Bountiful

West Lake Junior High - West Valley City

Western Hills Elementary - Kearns



Outreach Presentations and Interviews

Kamloops Exploration Group, Kamloops, British Columbia	Mar 5
SciFi Friday Podcast, Utah Educational Network	Mar 27
Career Fair, Box Elder Middle School	Mar 27
The Deseret News	Apr 8
KSL 1160 News Radio	Apr 17
LDS 13th Ward Relief Society, Salt Lake City, Utah	May 12
Rocky Mtn. Section Meeting, Geological Society of America	May 21
Office of the Lieutenant Governor, State of Utah	Sep 21
OSHER Lifelong Learning Institute, University of Utah	Sep 30
Department of Geological Sciences, Brigham Young University	Oct 8
Timpanogos Club	Oct 22
Nakama Research Seminar, University of Utah	Nov 6
Science Day, University of Utah	Nov 7
Jordan High School	Dec 8 & 9
Canyon Rim Academy	Dec 10

Earthquake Information Center Tours

UUSS provided 14 tours of the Rio Tinto Earthquake Information Center to groups from various educational institutions and community organizations. Each tour gives an overview of Utah's earthquake threat as well as UUSS network operations and the role that UUSS plays in earthquake response.

UUSS Funding—Calendar Year 2015

40% — **U.S. Geological Survey—Earthquake Hazards Program**

Regional and urban seismic monitoring and research along the Wasatch Front urban corridor and Intermountain Seismic Belt

36% — **State of Utah**

Earthquake monitoring, research, education and outreach in the Utah region

15% — **U.S. Geological Survey—Volcano Hazards Program**

Earthquake monitoring and research in the Yellowstone National Park region

9% — **Other**

National Science Foundation

- Using EarthScope Transportable Array Data to better characterize induced seismic sequences

U.S. Department of Energy
University of Utah Energy and Geoscience Institute

- Analysis of structurally controlled geothermal systems in the Eastern Great Basin Extensional Regime, Utah
- Frontier Observatory for Research in Geothermal Energy (FORGE)

Utah Department of Public Safety

- Traveling educational earthquake exhibit

National Institute for Occupational Safety and Health
University of Utah Department of Mining Engineering

- Monitoring and research on mining-induced seismicity in Utah coal mines and graduate student training

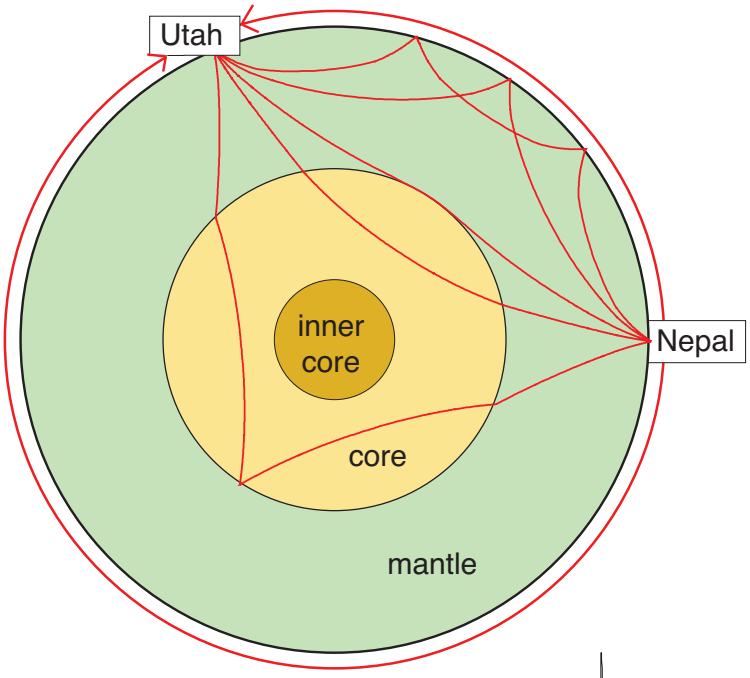
Utah Department of Public Safety

- Traveling educational earthquake exhibit

Additional revenue from:

- Production of seismic data products
- Consulting
- Individual research grants

Partners and Sponsors



Types of Seismic Waves

Pdiff A P wave that diffracts around Earth's core.

PP A P wave that bounces once on the underside of Earth's surface.

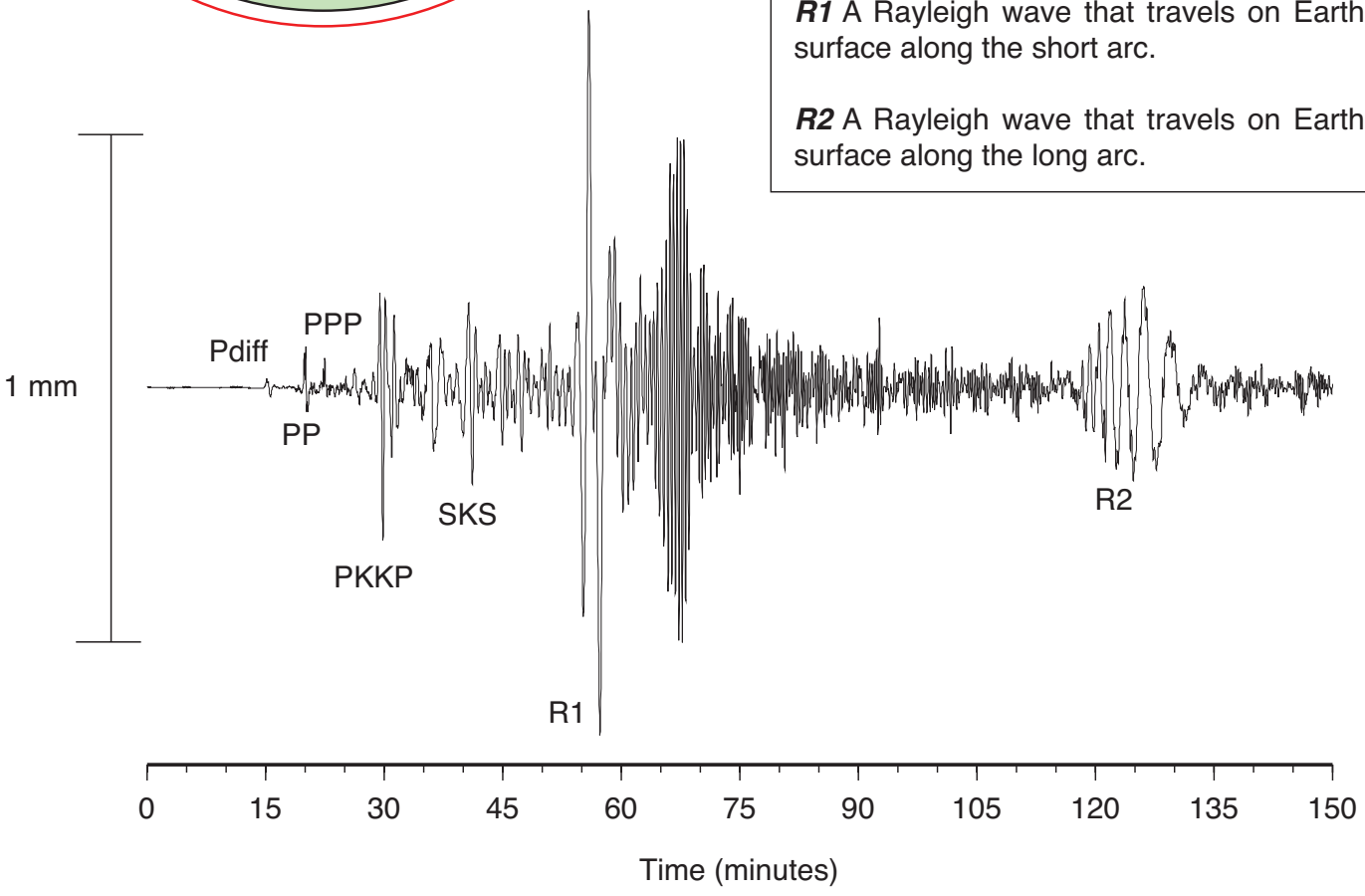
PPP A P wave that bounces twice on the underside of Earth's surface.

PKKP A P wave that bounces once on the underside of the core-mantle boundary.

SKS A wave that travels as an S wave in the mantle and a P wave in the core.

R1 A Rayleigh wave that travels on Earth's surface along the short arc.

R2 A Rayleigh wave that travels on Earth's surface along the long arc.



A devastating M7.8 earthquake struck Nepal on April 25, 2015. Although the epicenter was over 12,000 km away from Utah, UUSS recorded a variety of seismic waves from this event. The seismogram shown here was recorded in Zion National Park. Codes for different types of waves are explained in the inset, and the corresponding ray paths through the Earth are shown in red. P waves are body waves that vibrate in the direction of propagation, S waves are body waves that vibrate perpendicular to the direction of propagation, and Rayleigh waves are surface waves that have elliptical particle motion.

University of Utah
Seismograph Stations
The University of Utah