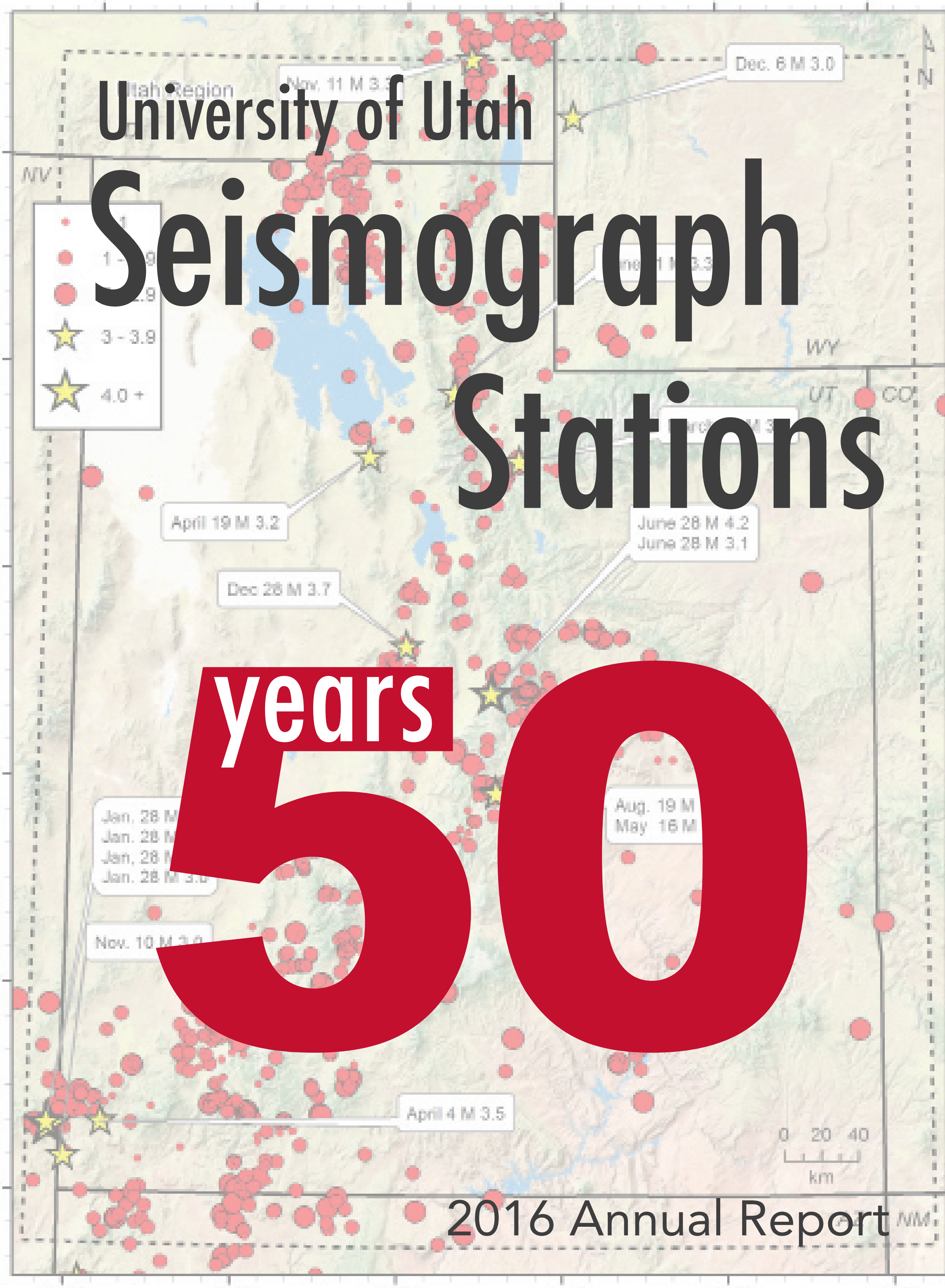
University of Utah

Seismograph Stations

years 50



2016 Annual Report

Inside front cover: A sego lily in bloom near station HDU (Hyde Park, UT). Photo by David Drobeck.

University of Utah Seismograph Stations

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Dear Friends,

In April of 2016 the University of Utah Seismograph Stations (UUSS) celebrated the 50th anniversary of its creation as an organizational unit within the University of Utah. We celebrated this milestone with a party honoring the founding director, Dr. Ken Cook, and the unveiling of a new historical display just outside the Rio Tinto Earthquake Information Center. The ceremony was well attended by current and former UUSS employees, colleagues in the College of Mines and Earth Sciences, representatives of sister agencies in the Utah Earthquake Program, members of Dr. Cook's family, and many other friends of UUSS. Here's to another 50 years of reducing the risk from earthquakes in Utah through research, education, and public service.

2016 was also a year of transition for UUSS. Our administrative manager, Martha Knowlton, retired after 14 years of service. We will miss Martha's attention to detail, professionalism, and strong work ethic. UUSS communications specialist Sheryl Peterson, who has worked in various capacities for UUSS since 1989, also left in the fall of 2016. Sheryl's competence, cheerfulness, and organizational skills will serve her well as she pursues a new career as director of advancement operations at Southern Virginia University. We will also miss Katherine Whidden, a research scientist, student mentor, and the UUSS public information officer, who left in 2016 (ending a five-year stint with UUSS) to travel the country in an RV with her husband, John. In other news, Cindi Meier, who worked at UUSS during 1994-1999, agreed to return as our new full-time administrative officer. In 2016, we also welcomed Dr. Hao Zhang to UUSS as a post-doctoral research scientist focusing on the detection and location of sequences of very small earthquakes.

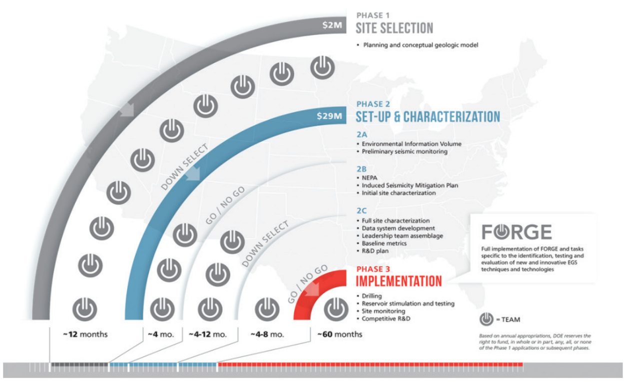
We look forward to an exciting new year in 2017. I encourage you to visit our revamped web page at quake.utah.edu to stay up-to-date on our new initiatives and products as well as to find out about the latest seismic activity in Utah. You can also follow UUSS on Twitter with the handle @UUSS_Quake_Info.

Dr. Keith D. Koper
Director

Enhanced Geothermal System

Natural geothermal systems contain permeable hot rocks thousands of feet below the ground through which fluids are conducted. When conditions are right, these fluids are carried to the Earth's surface and the energy can be harnessed to produce electricity. When conditions are not ideal for these natural systems to function, (i.e. rocks are not very permeable and contain little water), they can be enhanced by injecting fluids into the rocks - thereby increasing the permeability of the fluid pathways.

The Frontier Observatory for Research in Geothermal Energy (FORGE) proposes the development of a national subsurface research facility where scientists and engineers will develop, test, and accelerate breakthroughs in Enhanced Geothermal System (EGS) technologies. Sponsored by the US Department of Energy (DOE), FORGE is an effort to produce viable, clean, domestic sources of energy.



The FORGE subsurface laboratory will yield a fully instrumented research site to enable a commercial pathway for EGS technologies.

The FORGE project is divided into three phases:

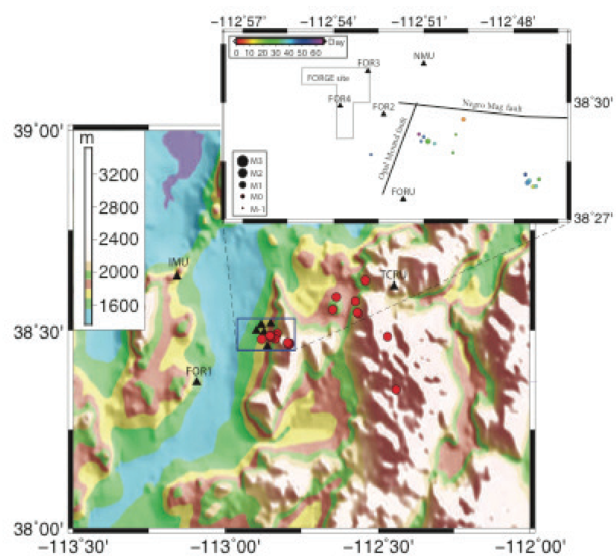
Phase 1: Site Selection
Phase 2: Set-Up & Characterization
Phase 3: Implementation

During Phase 1 (completed in spring 2016), five research teams from national laboratories and the University of Utah performed site selection and developed conceptual geological models at five potential locations. These locations included: Snake River Plain, Idaho; Newberry Volcano, Oregon; Fallon, Nevada; West Flank of Coso, California; and Milford, Utah. Following Phase 1, two groups, Sandia National Laboratory (location Fallon, Nevada) and the University of Utah (location Milford, Utah), were selected to continue to Phase 2.

The University of Utah (UU) FORGE group is led by the research team of Dr. Joseph Moore, Dr. Phillip Wannamaker, and Dr. John McLennan, all from the University of Utah Energy and Geoscience Institute (EGI), and Dr. Rick Allis of the Utah Geological Survey. A number of supporting organizations have partnered with the UU FORGE group including the University of Utah Seismograph Stations (UUSS), which will lead the seismic mitigation and monitoring efforts.

The area for the proposed Utah site, 10 miles north of Milford, Utah in eastern Beaver County, has been extensively explored for geothermal prospects and was first developed beginning in the 1970s. The site is ideal in meeting the requirements for temperature, depth, and rock needed for successful implementation of the FORGE project. The area is also a renewable energy hub. In addition to the existing geothermal Blundell power plant, there is a wind farm and a solar array.

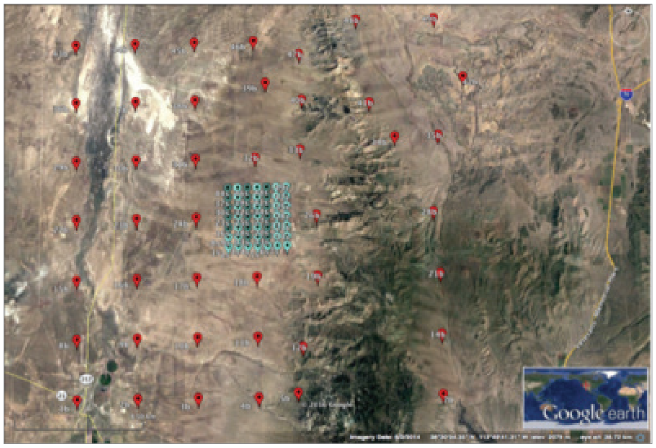
Phase 2 of the project began in October 2016 and is divided into three subtasks as illustrated in the info graphic at left. Subtask 2A involves environmental information gathering and preliminary seismic monitoring. In November 2016, UUSS installed a five-station broadband telemetered seismic network on and near to the proposed Utah FORGE site. With this network the detection threshold will be lowered, such that earthquakes as small as magnitude zero can be reliably detected and located. To date, there have been no earthquakes detected below the proposed drill site.



Map of seismic network (black triangles) and earthquakes detected during Phase 2A from November 10, 2016 through January 20, 2017 (red circles). Blue box, region enlarged in the inset image. Stations beginning FOR are part of network installed for the FORGE project. Stations TCRU, IMU, and NMU are part of the UUSS regional seismic network. Inset image, shows location of Utah FORGE footprint, nearby faults, and earthquakes, as a function of time from the installation of the network.

Seismicity is concentrated to the east in the Mineral Mountains and to a region just north of Milford.

In addition to the broadband network, a temporary deployment of 93 three-component Nodal seismometers was deployed over the proposed study area for 30-days beginning mid-December 2016. The purpose of this array is to further lower the detection threshold and to provide data that can be used to determine seismic velocity models of the subsurface.

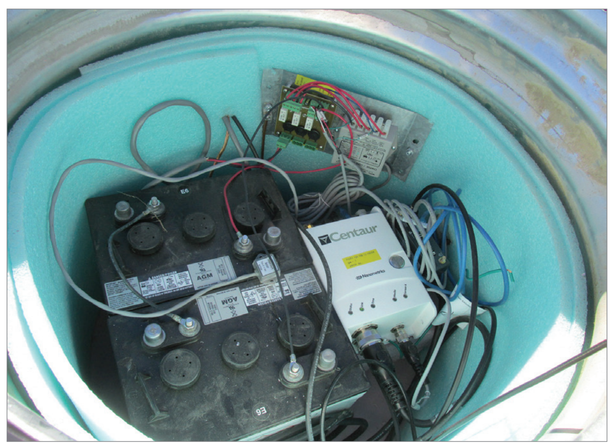


Location of the Nodal seismic instruments deployed in December and early January. There are two grids. The internal grid roughly centered on the proposed drill site has a spacing of ~600m. The outer grid ~4km.

During Phase 2B, which will take place in 2017, site characterization and permitting will continue, a test hole will be drilled to verify subsurface conditions, and an Induced Seismic Mitigation Plan will be developed. At the end of Phase 2B, DOE will select the group responsible to build FORGE.

For general FORGE information, visit: https://energy.gov/eere/forge/forge-home.

Utah FORGE project information can be found at: http://www.forgeutah.com.



At right: A view of the wind and solar farm west of station FOR2.

Technician assistant Peter O'Neill excavating seismometer vault for station FOR1.

FOR1, inside of the electronics enclosure, showing charge control electronics, batteries, and data-logger.

Completed station FOR1: solar panel in background; charging electronics, batteries, surge protection, data-logger, and cell modem for telemetry are in culvert section at left side, GPS antenna for timing is mounted to exterior of the culvert, cell modem antenna is mounted in the center of the lid, broadband seismometer is in similar culvert section completely buried under the adjacent pile of dirt to the right.

UUSS Launches Updated Website

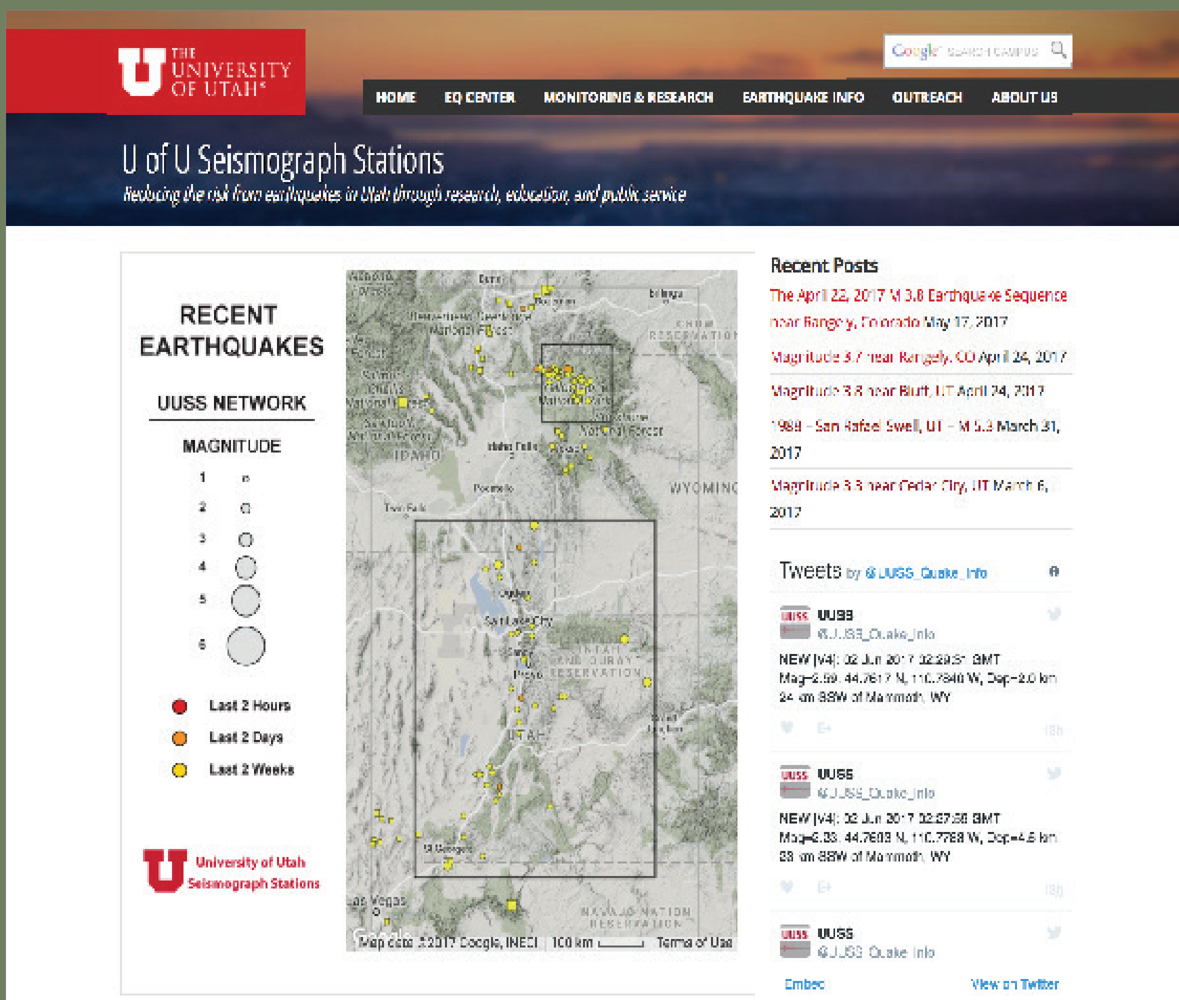
A second priority during 2016 was a major redesign of the UUSS website. The new website was rolled out on April 4, 2016. In this work, we leveraged code provided by the Pacific Northwest Regional Seismic Network.

Key features of the new webpage include modern, zoomable earthquake maps with links to the USGS Event Pages, new zoomable station maps with links to webicorders, dynamic updating of station information, easy access to recent posts and press releases.

The new website also provides access to UUSS Twitter posts. UUSS automatically tweets information for events with magnitudes larger than 2.5, as well as news and other information.

Most of the content featured on the older website version has already been ported to the new site, such as links to UUSS publications, outreach services, and other earthquake information.

While much has been accomplished, this will be a work in progress. We will continue to add content and adjust the layout for optimal usage.



quake.utah.edu

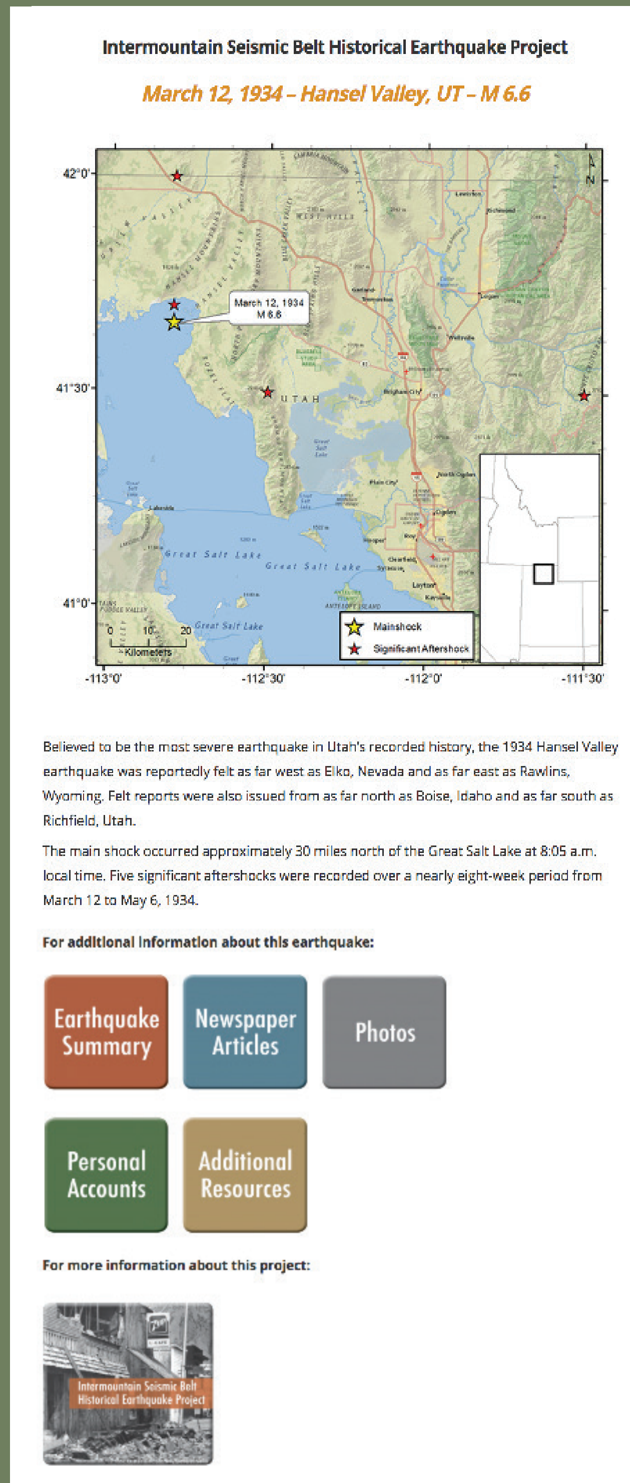
An ongoing effort is fully porting the information that was part of "Personalizing the Earthquake Threat," now titled "Intermountain Seismic Belt Historical Earthquake Project." Information for one or two historical earthquakes will be added, as blog posts, to the new website on a monthly basis. Information for the following historical earthquakes has already been ported:

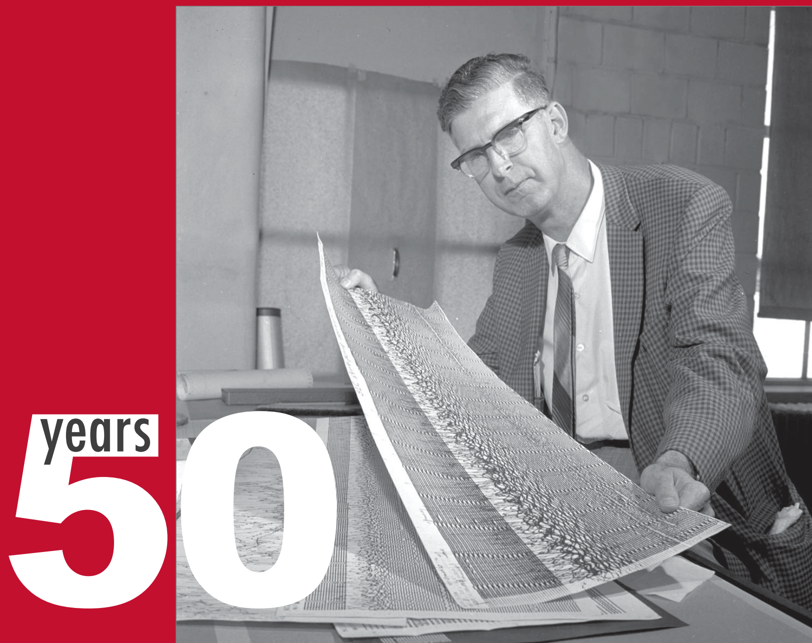
- 1915 M 5.0 Provo, UT
- 1934 M 6.6 Hansel Valley, UT
- 1959 M 5.7 Kanab, UT
- 1975 M 6.1 Yellowstone Nat'l Park, WY
- 1988 M 5.3 San Rafael Swell, UT

Historical earthquake blog posts include links to photographs, personal accounts, newspaper articles and other resources. Posts are also linked to a webpage that gives an overview of the project and a table and map of all 48 featured historical earthquakes.

The project is designed to personalize the earthquake risk to current residents of the Intermountain Seismic Belt (ISB) by presenting evidence of the impact to people and places from past ISB earthquakes.

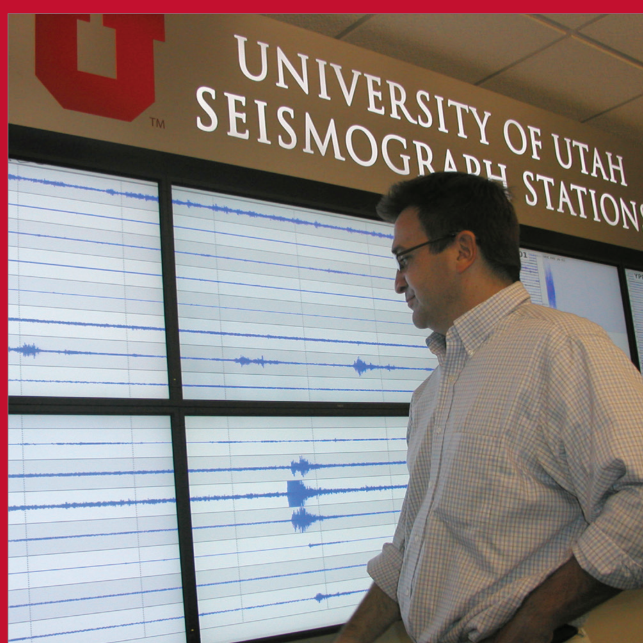
The purpose of the project is to promote a better understanding of earthquakes in this region and to motivate individuals to prepare for future ISB earthquakes.





Paper seismograms such as those being examined by Dr. Kenneth L. Cook above, typify the era of the University of Utah Seismograph Stations from 1962 to 1974 when seismographs operated in specially constructed small buildings and recordings were made in darkened vaults on photographic paper. The records were developed on-site and then mailed by station attendants to the University of Utah campus for analysis.

Paper seismograms were replaced by digital in the 1980s. UUSS retired its remaining drum recorders in 2009 and now displays real-time digital waveforms such as those being examined by current UUSS director, Dr. Keith D. Koper below, in the Rio Tinto Earthquake Information Center.



Dr. Walter J. Arabasz, Honored by the Seismological Society of America

Dr. Walter J. Arabasz, Research Professor Emeritus of Geology and Geophysics and former director of the University of Utah Seismograph Stations, was presented with the Seismological Society of America (SSA) 2015 Frank Press Public Service Award for his extraordinary public service in modernizing, expanding and promoting seismic monitoring for public safety in the United States. The award was presented during the SSA annual meeting in Reno, Nevada, April 20–22, 2016.

The Frank Press Public Service Award is presented each year to an individual, group of individuals, or organization that has made outstanding contributions to the advancement of public safety or public information relating to seismology.

Dr. Arabasz began his career at the University of Utah in 1974 and was appointed director of the University of Utah Seismograph Stations in 1985, a position he held until his retirement from university in 2010.

He played a leading role in motivating the Utah State Legislature to create the Utah Seismic Safety Commission and in helping to build an effective state earthquake program.

Walter Arabasz (right) with Utah Governor Gary Herbert (then Lieutenant-Governor) in June 2007 at the centennial celebration of seismographic recording at the University of Utah.

During a 15-year period leading up to congressional authorization of the Advanced National Seismic System (ANSS) in 2000, Dr. Arabasz was a key player in laying the groundwork for and shaping the vision of the ANSS. He then worked to implement elements of the ANSS in Utah, in the Intermountain West region, and nationally. He has served on the national Advisory Committee on Earthquake Hazards Reduction, providing guidance and oversight to the National Earthquake Hazards Reduction Program.

Of particular note in his award nominations was Dr. Arabasz's efforts following the 2007 Crandall Canyon, Utah mine collapse. Dr. Arabasz assisted experts on both the state and national levels to reach a better understanding of the circumstances of the collapse and the implications for the larger issue of mine safety. He also assisted the media and public in gaining a greater awareness and understanding of mining-induced seismicity.

ComCat

Loading the UUSS catalog into the USGS Comcat has been a major priority for UUSS during 2016. We have created and are implementing a viable plan for importing all pre-AQMS parametric and waveform data into the UUSS AQMS databases. Steps we have completed include: accumulating and organizing parametric data (picks and trigger files) for all events in the catalog into event directories in a common data structure; quality control of the catalog by recreating the catalog using the files retrieved from archive (all discrepancies were investigated); inspection and quality assessments of the spreadsheet that contained all ML magnitude data; and development of python programs to export the ML data for each event from the excel spreadsheet to the event directory with the other parametric data. We are also collecting and performing quality control analysis for all available waveform data. Steps related to waveform retrieval have included: retrieving data from tape archives; converting the old UW1 format to mseed; adding location codes and accounting for channel mapping changes; and correcting sample rate issues related to older data and block size issues for storing the mseed. These data will be loaded into a new expanded CWB combined with newer data for use as an AQMS waveserver. Other efforts include relocating the catalog using the velocity models implemented in AQMS. While this step provides improved locations, the main purpose is to use a constant datum (sea level) for the catalog. Any events that do not meet current location standards or events with large changes in location are being reprocessed.

Most of the pieces are now in place to start loading the data into the AQMS database and assign eventIDs. Since we do not have database administrator on staff, we are currently in discussions with Alan Walter and Paul Friberg about developing code necessary for this last key step.

Seismograph Stations Reaches 50-year Mark

The centennial of the installation of the first seismographs on the University of Utah campus by Dr. James E. Talmage was celebrated on June 29, 2007. April 2016 brought another milestone—the 50-year anniversary of the founding of the University of Utah Seismograph Stations (UUSS).

On April 11, 1966, the University of Utah Board of Regents recognized the Seismograph Stations as an organizational entity in formally appointing Dr. Kenneth L. Cook as its first director, a position he held until 1976.

The term "University of Utah Seismograph Stations" originally referred to a small group of seismographic installations with onsite photographic recording. In 1962 the University operated stations on campus, in Price, and at Dugway; data from a fourth station owned by Utah State University in Logan were incorporated. Attendants at the remote stations routinely mailed paper seismograms to the University for analysis and interpretation. Data added from three other stations in Utah during the mid-to-late 1960s enabled a skeletal statewide seismographic network to emerge.

During Governor Calvin L. Rampton's term of office (1965–1977), Dr. Cook served on two advisory bodies to the governor. Persuaded that seismic monitoring was vital to the welfare and safety of the people of Utah, Governor Rampton initiated state funding to the University of Utah Seismograph Stations in 1971 and helped establish this funding as a line-item appropriation from the Utah State Legislature beginning in 1972.

A number of significant changes over the past 50 years have contributed to an evolution in the character of UUSS. These include changes both in technology and in motivations for seismic monitoring. Regional earthquake monitoring has long been prompted by damaging earthquakes. In the 1960s, the monitoring of underground nuclear tests became important. In the 1970s, there was a growing interest in earthquake research and in earthquake prediction. The 1980s brought the added need to serve emergency management and earthquake engineering. Since 2000, UUSS has been involved in multipurpose seismic monitoring as part of an Advanced National Seismic System.

In 1974, a major transformation of the University of Utah's seismograph network began under the direction of Drs. K. L. Cook, R. B. Smith, and S. H. Ward (director, 1976–1980). Onsite-recording installations were superseded by a regional telemetered seismic network involving radio, microwave, and telephone telemetry. In early 1974, there were two telemetered stations in the UUSS network. By the end of 1975, an additional 25 telemetered stations were added to form a regional network with continuous centralized recording on the University campus that covered much of the Wasatch Front area (recording was on multi-channel film recorders). Geographic coverage expanded to other parts of the Utah region with a total of nearly 60 stations operating by the end of the 1970s.

Under Dr. Robert B. Smith (director, 1980–1985), digital seismic recording of the UUSS regional seismic network began in January 1981. Also, a local seismic network in the Yellowstone National Park region, originally installed by the U.S. Geological Survey, was integrated into UUSS operations and research.

Multi-year efforts by Dr. Walter J. Arabasz (director, 1985–2010) to foster a strong state earthquake program and to help achieve congressional authorization of an Advanced National Seismic System (ANSS) resulted in access to state and federal funds for improved seismic monitoring and enabled significant modernization and statewide expansion of the UUSS regional seismic network. In 2000, in advance of the 2002 Salt Lake City Winter Olympics, UUSS began implementing a real-time earthquake information system together with the integration of urban strong-motion monitoring into the UUSS regional seismic network. Further growth followed major increases in state funding in 2007 and in ANSS funding in 2009. In 2009, UUSS moved its network operations into seismically-hardened, state-of the-art facilities in the Frederick Albert Sutton building on the university campus, and the Rio Tinto Earthquake Information Center was inaugurated.

Since, 2010, Dr. Keith D. Koper (director, 2010-present) has overseen the implementation of a state-of-the-art ANSS Quake Monitoring System to detect and locate seismicity in the Utah and Yellowstone regions. As of April 2016, UUSS maintains and operates 237 seismic stations (ANSS network codes: UU [194 stations], WY [28 stations], and NP [15 stations]). As a member of the Utah Earthquake Program, UUSS collaborates with state agencies and professional partners to better understand Utah's earthquake threat and to advise policy makers (both state and federal) regarding seismic-related safety issues.

Now in its 51st year of operations, UUSS continues to pursue a mission of reducing the risk from earthquakes in Utah through research, education, and public service.

Notes:

1) "Historical Review of Earthquake-Related Studies and Seismographic Recording in Utah" by Walter J. Arabasz, in Earthquake Studies in Utah 1850 to 1978, Special Publication of the University of Utah Seismograph Stations and the Department of Geology and Geophysics, University of Utah, July 1979, pp. 33-56.

2) "Seismographic Centennial, June 29, 1907–June 29, 2007: Commemorating the centennial of the installation of the first seismographs in Utah by Dr. James E. Talmage and celebrating 100 years of earthquake recording at the University of Utah" by Walter J. Arabasz, University of Utah Seismograph Stations, July 2007, 12 pp.

Display Recognizes UUSS Founding and Honors First Director

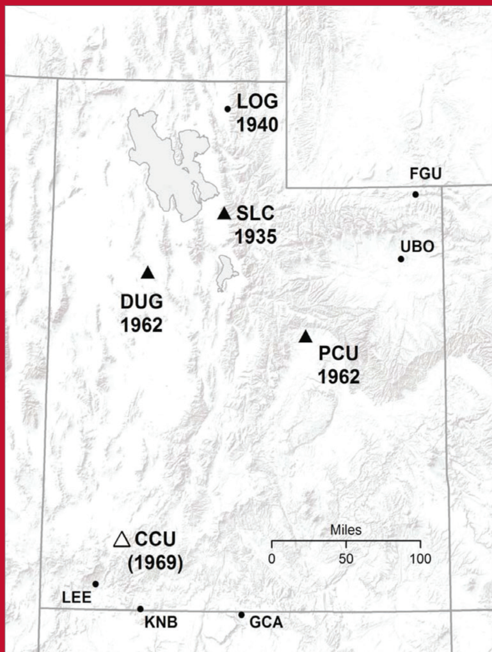
In conjunction with the UUSS 50th Anniversary celebration in April 2016, a display was installed in the first floor lobby of the F.A. Sutton Building on the university campus. The display recognizes the founding of UUSS in April 1966, and honors Dr. Kenneth L. Cook, first director of UUSS.

Artist's rendering of the display that recognizes the founding of UUSS in April 1966, and the first UUSS director, Dr. Kenneth L. Cook.

Kenneth L. Cook (B.S. physics, Massachusetts Institute of Technology, 1939; Ph.D. geology and physics, University of Chicago, 1943) was a distinguished scientist and educator, acclaimed as the "Father of Utah Geophysics." After early career work in geophysical exploration with the U.S. Bureau of Mines and the U.S. Geological Survey, Dr. Cook joined the faculty of the University of Utah in 1952, becoming Professor of Geophysics in 1955. He developed and expanded the Department of Geophysics, which he headed from 1952 until 1968, when the department was merged into a combined Department of Geology and Geophysics. He retired in December 1981 but remained active as professor emeritus until his death in 1996.

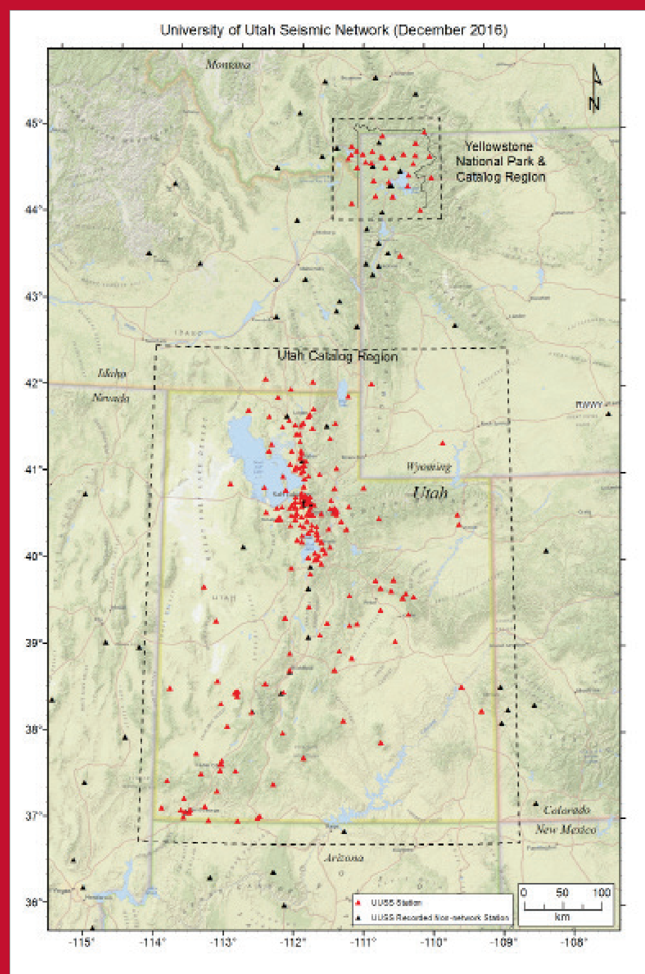
Dr. Cook's teaching and pioneering research in exploration and solid earth geophysics of the Earth's crust and upper mantle were wide-ranging—from the use of gravity, magnetic, electrical resistivity, and regional seismic refraction techniques to seismology, tectonics, and the correlation of strain and tilt with earthquakes. More than 60 graduate theses in geophysics (13 Ph.D., 48 M.S.) were completed under his direct supervision. The breadth and distinction of his scientific engagement were reflected by his active membership in more than a dozen national and international professional societies and organizations.

From a celebration commemorating the 50th anniversary of the founding of the University of Utah Seismograph Stations held April 8, 2016 at the Frederick Albert Sutton Building on the University of Utah campus. (Left to right beginning at top) Sign points arriving guests to the Frederick Albert Sutton Building; UUSS Seismic Network Manager, Valeriu Burlacu, gives a tour of the Rio Tinto Earthquake Information Center; attendees gather in the lecture hall prior to the program; Carla Rae Cook shares remembrances of her father, UUSS founding director, Dr. Kenneth L. Cook; Dr. Jim Pechmann (left) visits with former UUSS staff members (l to r) Erwin McPherson and Bill Richins and spouse; buffet line in the Sutton Building confluence.



When the "University of Utah Seismograph Stations" (UUSS) formally began in April 1966, the University operated three seismographic stations: SLC, DUG, and PCU (solid triangles); a fourth station was later added in Cedar City (CCU, open triangle). Station LOG, owned by Utah State University, transmitted paper seismograms to the University of Utah for analysis from 1963 to 1976. Non-UUSS stations operating in the Utah region in 1966 (dots) included two stations operated at dam sites by the U.S. Bureau of Reclamation (FGU, GCA) and three stations sponsored by the Department of Defense for nuclear test monitoring (UBO, LEE, KNB).

50 years



As of December 2016, UUSS maintained and operated 237 seismic stations. ANSS network codes: UU (194 stations), WY (28 stations), and NP (15 stations).

Presentations

Seismological Society of America Annual Meeting, April 20-22, Reno, NV:

Batchelor, C. E., K. D. Koper, and K. L. Pankow, and R. Burlacu (2016). Waveform correlation detection methods as applied to Utah seismic swarms, *Seismol. Res. Lett.* **87 (2B),** 574.

Hale, J. M., K. L. Pankow, S. J. Arrowsmith, B. Stump, C. Hayward (2016). Infrasound scaling characteristics from small earthquakes in the Utah region, *Seismol. Res. Lett.* **87 (2B),** 535.

Linville, L., K. Pankow, D. Kilb (2016). Lowering template magnitudes using frequency domain array processing in regions of induced seismicity, *Seismol. Res. Lett.* **87 (2B),** 527.

Pang, G., K. D. Koper, and R. Burlacu (2016). Application of template-based seismic detection methods to recent seismicity near the M6.9 1983 Borah Peak, Idaho earthquake, *Seismol. Res. Lett.* **87 (2B),** 574.

Pechmann, J. C., Y. Zeng, P. A. Thomas, and M. D. Petersen (2016). Comparison of geodetic and geological/seismological moment rates for the Wasatch Front region, Utah, *Seismol. Res. Lett.* **87 (2B),** 459.

Rusho, J., C. Hatch, D. Drobeck, and K. Pankow (2016). Waveform recovery enhancements in the Utah network, *Seismol. Res. Lett.* **87 (2B),** 524.

Stein, J. R., K. L. Pankow, K. D. Koper, and D. Chambers (2016). Discriminating seismic sources (mining-induced seismicity, fluid injection induced seismicity, and tectonic earthquakes) in Central Utah, USA, *Seismol. Res. Lett.* **87 (2B),** 543.

Zhang, H., S. van der Lee, C. Bina, and Z. Ge (2016). Rupture mechanism of the May 24, 2013 M_W8.3 Sea of Okhotsk deep-focus earthquake, *Seismol. Res. Lett.* **87 (2B),** 543.

Geological Society of America Annual Meeting, September 25-28, Denver, CO:

Zhang, H., S. van der Lee, E. Wolin et al. (2016). Distinct crustal structure of the North American mid-continental rift from *P*-wave receiver functions, Geological Society of America, Abstracts with Programs, 48(7), doi: 10.1130/abs/2016AM-287598.

American Geophysical Union Fall Meeting, December 12-16, San Francisco, CA:

Earle, P., M. R. Perry, J. R. Andrews, M. M. Withers, M. Hellweg, W. K. Kim, B. Shiro, M. E. West, D. A. Storchak, K. L. Pankow, V. A. Huerfano Moreno, L. S. Gee, and C. J. Wolfe (2016). Populating the Advanced National Seismic System Comprehensive Earthquake Catalog, Abstract S53A-2821. Pang, G., K. D. Koper, R. Burlacu, and M. Stickney (2016). High-resolution imaging of recent seismic swarms in the Challis, ID region, Abstract S53A-2811.

Farrell, J., F-C Lin, A. A. Allam, R. B. Smith, M. S. Karplus (2016). Using a large N Geophone Array to identify hydrothermal seismic sources in the Upper Geyser Basin of Yellowstone National Park, Abstract S53C-04.

Koper, K. D., J. C. Pechmann, R. Burlacu, K. L. Pankow, J. Stein, J. M. Hale, P. Roberson, M. K. McCarter (2016). Magnitude based discrimination of man-made seismic events from naturally occurring earthquakes in Utah, USA, Abstract S31A-2721.

Smith, R. B., J. Farrell (2016). The Yellowstone crustal magmatic system: What we know and what we don't know, Abstract V43G-01.

Zhang, H., S. van der Lee (2016). A N-S fossil transform fault reactivated by the March 2, 2016 Mw 7.8 southwest of Sumatra, Indonesia earthquake, Abstract S53A-2807.

Additional Presentations:

Farrell, J., F-C Lin, R. B. Smith, S-M Wu (2016). The 2015 Upper Geyser Basin seismic imaging experiment, The 13th Biennial Scientific Conference on the Greater Yellowstone Ecosystem, October 4-6, Grand Teton National Park, Wyoming.

Farrell, J. F-C Lin, S-M Wu, R. B. Smith (2016). The 2015 Upper Geyser Basin seismic imaging experiment, The 2016 Biennial Meeting of the Yellowstone Volcano Observatory, May 10-11, Mammoth Hot Springs, Wyoming.

Farrell, J., R. B. Smith (2016). What do we know about earthquakes at Yellowstone: An overview of swarms, magnitudes, fault interactions, earthquake families, and why we can't find LPs, The 2016 Biennial Meeting of the Yellowstone Volcano Observatory, May 10-11, Mammoth Hot Springs, Wyoming.

Gal, M., A. Reading, S. Ellingsen, K. Koper, R. Burlacu, H. Tkalcic, and S. Gibbons (2016). Three component microseism analysis in Australia from deconvolution enhanced beam forming, European Geosciences Union General Assembly, April 17-22, Vienna, Austria.

Koper, K. D. (2016). ML-MC: A possible depth discriminant for small seismic events recorded at local distances, Los Alamos National Laboratory, September 15, Los Alamos, New Mexico.

Koper, K. D. (2016). Time-scale heterogeneity in Earth's inner core, Tokyo Technology Earth Life Science Institute, February 10, Tokyo, Japan.

Publications

Peer Reviewed Journal Papers

Arrowsmith, S., C. Young, S. Ballard, M. Slinkard, and K. Pankow (2016). Pickless event detection and location: The waveform correlation event-detection system (WCEDS) revisited, *Bull. Seism. Soc. Am.*, **106,** 2037–2044, doi:10.1785/0120150179.

Gal, M., A. M. Reading, S. P. Ellingsen, K. D. Koper, R. Burlacu, and S. J. Gibbons (2016). Deconvolution enhanced direction of arrival estimation using 1- and 3-component seismic arrays applied to ocean induced microseisms, *Geophys. J. Inter.,* **206,** 345–359, doi:10.1093/gji/ggw150.

Koper, K. D., J. C. Pechmann, R. Burlacu, K. L. Pankow, J. Stein, J. M. Hale, P. Roberson, and M. K. McCarter (2016). Magnitude based discrimination of man-made seismic events from naturally occurring earthquakes in Utah, USA, *Geophys. Res. Lett.,* **43,** 10638–10645, doi:10.1002/2016GL070742.

Lay, T., L. Ye, C. J. Ammon, A. Dunham, and K. D. Koper (2016). The 2 March 2016 Wharton Basin M_W 7.8 earthquake: High stress drop north-south strike-slip rupture in the diffuse oceanic deformation zone between the Indian and Australian Plates, *Geophys. Res. Lett.,* **43,** 7937–7945, doi:10.1002/2016GL069931.

Lay, T., L. Ye, K. D. Koper, and H. Kanamori (2016). Assessment of teleseismically-determined source parameters for the April 25, 2015 M_W 7.9 Gorkha, Nepal earthquake and the May 12, 2015 M_W 7.2 aftershock, *Tectonophysics,* doi:10.1016/j.tecto.2016.05.023.

Liu, Q., K. D. Koper, R. Burlacu, S. Ni, F. Wang, C. Zou, Y. Wei, M. Gal, and A. Reading (2016). Source locations of teleseismic P, WV, and SH waves observed in microseisms recorded by a large aperture seismic array in China, *Earth Planet. Sci. Lett.*, **449,** 39–47, doi:10.1016/j.epsl.2016.05.035.

Moore, J. R., M. S. Thorne, K. D. Koper, J. R. Wood, K. Goddard, R. Burlacu, S. Doyle, E. Stanfield, and B. White (2016). Anthropogenic sources stimulate resonance of a natural rock bridge, *Geophys. Res. Lett.,* **43,** 9669–9676, doi:10.1002/2016GL070088.

Velasco, A. A., R. Alfaro-Diaz, D. L. Kilb, and K. L. Pankow (2016). A time-domain approach to identify small earthquakes within the Continental U.S. recorded by the USArray and regional networks, *Bull. Seism. Soc. Am.*, **106,** 1825–1835, doi:10.1785/012040310.

Whidden, K. M. and K. L. Pankow (2016). Shear waves from isotropically dominated sources: Comparison of the 2013 Rudna, Poland and 2007 Crandall Canyon, Utah mine collapses, *Bull. Seism. Soc. Am.*, **106,** 2037–2044, doi:10.1785/0120160018.

Ye, L., T. Lay, H. Kanamori, and K. D. Koper (2016). Rapidly estimated seismic source parameters for the 16 September 2015 Illapel, Chile M_W 8.3 earthquake, *Pure Appl. Geophys.,* **173,** 321–332, doi:10.1007/s00024-015-1202y.

Zhang, H., S. van der Lee, and Z. Ge (2016). Multiarray rupture imaging of the devastating 2015 Gorkha, Nepal earthquake sequence, *Geophys. Res. Lett.,* **43,** 584–591doi:10.1002/2015GL066657.

Zhang, H., S. van der Lee, E. Wolin, et al. (2016). Distinct crustal structure of the North American mid-continental rift from *P*-wave receiver functions, *J. Geophys. Res.* **121,** 8136–8153, doi:10.1002/2016JB013244.

Reports

Burlacu, R., P. M. Roberson, J. M. Hale, G. Bobetich, A. Mokhtar, K. D. Koper, J. C. Pechmann, and K. L. Pankow (2016). *Earthquake Activity in the Utah Region Preliminary Epicenters October 1–December 31, 2015,* Quarterly Report, University of Utah Seismograph Stations, Salt Lake City, Utah, 31 pp.

Burlacu, R., P. M. Roberson, J. M. Hale, G. Bobetich, A. Mokhtar, K. D. Koper, J. C. Pechmann, and K. L. Pankow (2016). *Earthquake Activity in the Utah Region Preliminary Epicenters January 1–March 31, 2016,* Quarterly Report, University of Utah Seismograph Stations, Salt Lake City, Utah, 30 pp.

Burlacu, R., P. M. Roberson, J. M. Hale, G. Bobetich, A. Mokhtar, K. D. Koper, J. C. Pechmann, and K. L. Pankow (2016). *Earthquake Activity in the Utah Region Preliminary Epicenters April 1–June 30, 2016,* Quarterly Report, University of Utah Seismograph Stations, Salt Lake City, Utah, 31 pp.

Burlacu, R., P. M. Roberson, J. M. Hale, J. Stanley, A. Parapuzha, K. D. Koper, J. C. Pechmann, and K. L. Pankow (2016). *Earthquake Activity in the Utah Region Preliminary Epicenters July 1–September 30, 2016,* Quarterly Report, University of Utah Seismograph Stations, Salt Lake City, Utah, 30 pp.

Farrell, J., R. Burlacu, P. M. Roberson, J. M. Hale, G. Bobetich, A. Mokhtar, K. D. Koper, R. B. Smith, J. C. Pechmann, and K. L. Pankow (2016). *Earthquake Activity in the Yellowstone Region Prelim-*

inary Epicenters October 1–December 31, 2015, Quarterly Report, University of Utah Seismograph Stations, Salt Lake City, Utah, 17 pp.

Farrell, J., R. Burlacu, P. M. Roberson, J. M. Hale, G. Bobetich, A. Mokhtar, K. D. Koper, R. B. Smith, J. C. Pechmann, and K. L. Pankow (2016). *Earthquake Activity in the Yellowstone Region Preliminary Epicenters January 1–March 31, 2016,* Quarterly Report, University of Utah Seismograph Stations, Salt Lake City, Utah, 14 pp.

Farrell, J., R. Burlacu, P. M. Roberson, J. M. Hale, G. Bobetich, A. Mokhtar, K. D. Koper, R. B. Smith, J. C. Pechmann, and K. L. Pankow (2016). *Earthquake Activity in the Yellowstone Region Preliminary Epicenters April 1–June 30, 2016,* Quarterly Report, University of Utah Seismograph Stations, Salt Lake City, Utah, 15 pp.

Farrell, J., R. Burlacu, P. M. Roberson, J. M. Hale, J. Stanley, A. Parapuzha, K. D. Koper, R. B. Smith, J. C. Pechmann, and K. L. Pankow (2016). *Earthquake Activity in the Yellowstone Region Preliminary Epicenters July 1–September 30, 2016,* Quarterly Report, University of Utah Seismograph Stations, Salt Lake City, Utah, 16 pp.

Other Scientific Publications

Arabasz, W. J., J. C. Pechmann, and R. Burlacu (2016). A uniform moment magnitude earthquake catalog and background seismicity rates for the Wasatch Front and surrounding Utah region, Appendix E in *Working Group on Utah Earthquake Probabilities, Earthquake probabilities for the Wasatch Front region in Utah, Idaho, and Wyoming*, Utah Geological Survey, Misc. Publ. 16-3, 126 pp. and 10 electronic supplements, http://ugspub.nr.utah.gov/publications/misc_pubs/mp-16-3/mp-16-3.pdf.

Koper, K. D. (2016). *Geophysics,* in Encyclopedia Britannica 2016 Book of the Year, Encyclopedia Britannica, Inc., p. 170.

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 (2016). Earthquake probabilities for the Wasatch Front region in Utah, Idaho, and Wyoming, Utah Geological Survey, Misc. Publ. 16-3, 164 pp. (excluding appendices), http://ugspub.nr.utah.gov/publications/misc_pubs/mp-16-3/mp-16-3.pdf.

Visitors

Wenying Li, an undergraduate from the University of Science and Technology in China, visited UUSS for two months during the summer of 2016. During her visit she used global seismic data to study the high frequency rupture processes of a pair of Mw 7.5 earthquakes that occurred in Papua, New Guinea in 2015.

Q&A:

Where is the Safest Place to be in an Earthquake?

In an open field, where nothing can fall on you. Earthquakes do not injure or kill people; buildings and falling objects do. If you are indoors, when you feel the ground start to shake, take cover immediately under a table or sturdy piece of furniture, placing a barrier between falling objects and yourself. Do not attempt to use the stairs or an elevator or run out of the building.

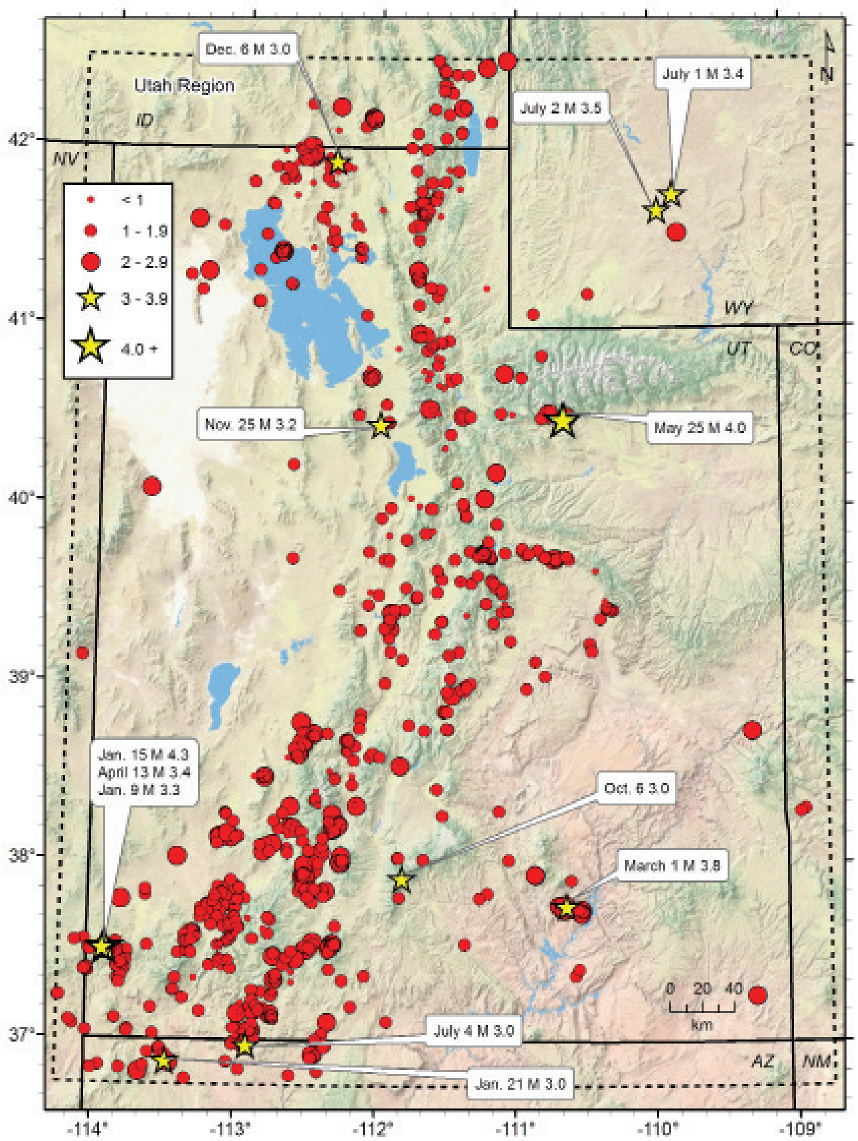
Seismo Tea - a weekly geophysics seminar

Brewed by:
Elizabeth Berg (Spring)
Dr. Amir Allam (Fall)

Date	Speaker	Affiliation	Title/Topic
Jan 29	Chris Rollins	California Institute of Technology	Estimating postseismic and interseismic deformation in Southern California using 3D elastic, viscous and frictional models.
Feb 8	Gerard Schuster	King Abdullah University of Science & Technology	Hominid Seismology at Olduvai Gorge, Tanzania
Feb 19	Sin-Mei Wu	University of Utah	February 6, 2016 ML 6.4 Mei-Nong Earthquake in Taiwan
Feb 26	Colton Lynner	University of Arizona	Constraining sub-slab mantle dynamics
Mar 11	Yao Yao	CGG Veritas - Houston, TX	P- and S-wave Slowness anomalies in the mantle: implications for iron spin transition
Mar 25	Jim Pechmann	University of Utah	Paleoseismology of the Northern Segments of the Great Salt Lake Fault, Utah
Mar 28	Cliff Thurber	University of Wisconsin–Madison	Laguna del Maule volcanic field, Chile: A caldera in the making?
Apr 8	Cole Richards Jake Reitman Sam Clairmont	University of Utah	Physical Mineral Characteristics of Fault Zones as a Function of Distance from the Principal Slip Survace (Richards); Earthquake Focal Mechanisms and Seismic Hazard in Southern California (Reitman); Precariously Balanced Rocks: Determining the Earthquake History of the Wasatch and Hurricane Fault Zones of Utah (Clairmont)
Aug 26	Yen-Yu Lin	California Institute of Technology	Evidence for Non-Self-Similarity of Microearthquakes Recorded at a Taiwan Borehole Seismometer Array
Sep 30	Jamie Farrell	University of Utah	Using a large N geophone array to identify hydrothermal seismic sources in the Upper Geyser Basin of Yellowstone National Park
Oct 7	Kris Pankow	University of Utah	The Utah FORGE Project
Oct 21	Amir Allam	University of Utah	The Predictive Power of Fractal Faults
Oct 28	Jim Pechmann Kris Pankow	University of Utah	2016 Italy Earthquakes
Nov 2	Trevor Irons	University of Utah	Society of Exploration Geophysicists (SEG) Nuclear Magnetic Resonance characterization of hydrologic properties
Nov 11	Jeff Moore	University of Utah	Structural Dynamics of Rainbow Bridge
Nov 14	Jonathan Delph	Rice University	The Inversion of Multiple Datasets: A Necessity for Constraining the Velocity Structure of the Lithosphere
Dec 2	Hao Zhang	University of Utah	A cascade rupture of the 2016 M_w 7.8 New Zealand earthquake from teleseismic P waves

Seismicity of the Utah Region
January 1, 2016 - December 31, 2016

During the twelve-month period January 1 through December 31, 2016 the University of Utah Seismograph Stations located 1,141 earthquakes within the Utah region. The total includes two earthquakes in the magnitude 4 range, 10 earthquakes in the magnitude 3 range, and 120 earthquakes in the magnitude 2 range. Earthquakes of magnitude 3.0 or larger occurring in 2016 are plotted as stars (see map below).



M_L 3.3	Jan 9 16:06 MST	13 mi WSW of Enterprise, UT
M_L 4.3	Jan 15 15:37 MST	12 mi WSW of Enterprise, UT
M_L 3.0	Jan 21 17:10 MST	17 mi SSE of St. George, UT
M_L 3.8	Mar 1 12:07 MST	53 mi E of Escalante, UT

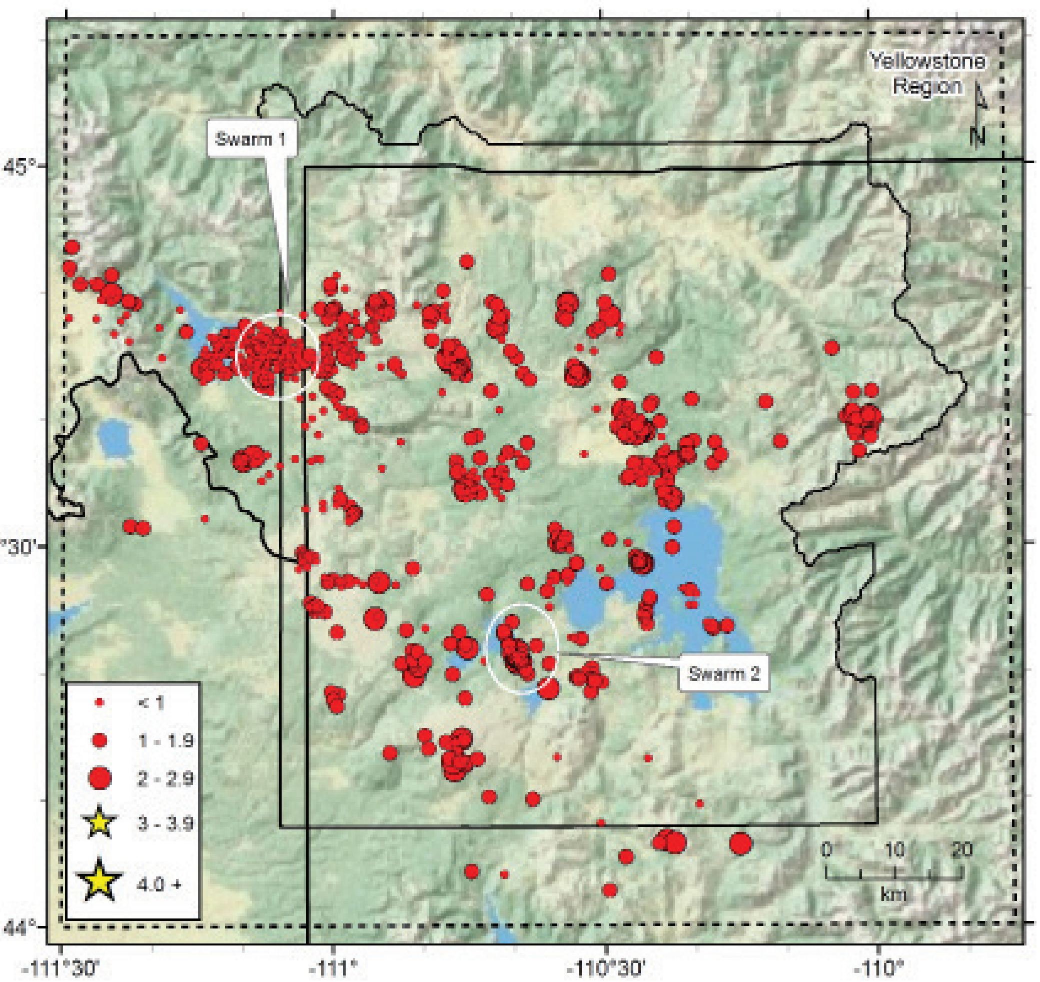
M_L 3.4	Apr 13 17:42 MDT	13 mi SW of Enterprise, UT
M_L 4.0	May 25 07:01 MDT	26 mi NW of Duchesne, UT
M_L 3.4	Jul 1 17:38 MDT	24 mi WNW of Green River, WY
M_L 3.5	Jul 2 16:14 MDT	26 mi W of Green River, WY

M_L 3.0	Jul 4 22:10 MDT	4 mi E of Colorado City, AZ
M_L 3.0	Oct 6 11:20 MST	15 mi WNW of Escalante, UT
M_L 3.2	Nov 25 08:45 MST	4 mi SW of Bluffdale, UT
M_L 3.0	Dec 6 21:29 MST	15 mi W of Clarkston, UT

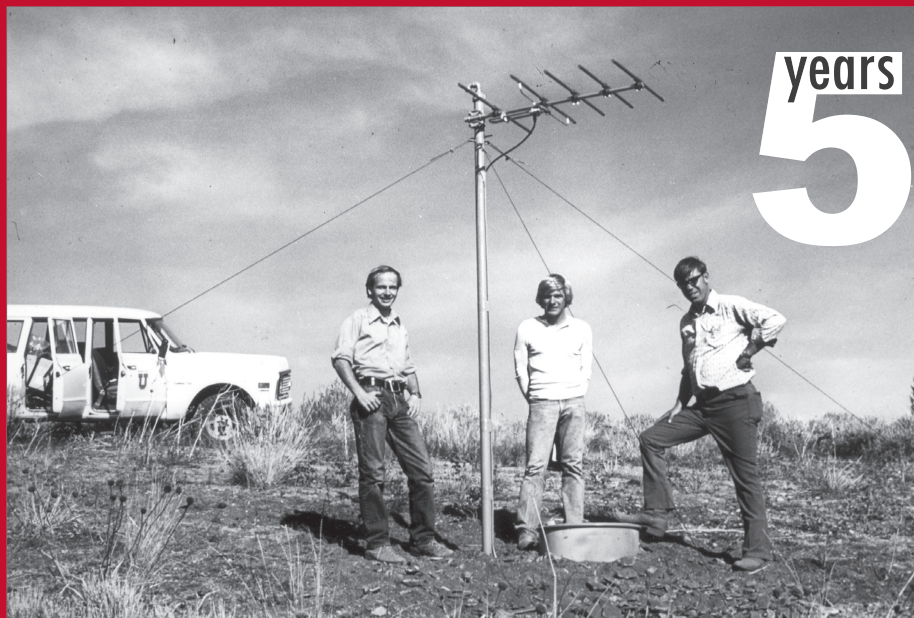
Seismicity of the Yellowstone National Park Region
January 1, 2016 - December 31, 2016

During the twelve-month period January 1 through December 31, 2016 the University of Utah Seismograph Stations located 917 earthquakes within the Yellowstone National Park region—which reflects a relatively low rate of earthquakes for the area. There were no earthquakes in the magnitude 3 range during 2016. The total includes 66 earthquakes in the magnitude 2 range.

There were two significant swarms in 2016 (indicated by ovals on map below). The first swarm occurred in the Hebgen Lake area 6.5 miles north of West Yellowstone, MT from September 24-26 and consisted of 49 earthquakes. The second swarm occurred near Shoshone Lake 6 miles southwest of West Thumb, Yellowstone National Park from November 23-26. This swarm contained 64 earthquakes. In addition to these two largest swarms, there were 8 other swarms in and around the Yellowstone region during 2016. Overall, swarm seismicity constituted 24% of the total seismicity for 2016. A swarm is a series of earthquakes clustered in space and time with no outstanding main shock.



years 50



The practice of burying seismic monitoring equipment in barrels is still used today—as is radio telemetry, though supplemented with other transmission modes such as microwave and Internet. Most stations are reached by truck, but remote stations may be accessed by helicopter. Laptop computers assist today's field technicians.

Imaging the Upper Geyser Basin in Yellowstone National Park Using Dense Seismic Deployments

In November 2016, the University of Utah, in collaboration with the National Park Service and the University of Texas at El Paso, installed a dense seismic array centered on Old Faithful Geyser in Yellowstone National Park. The goals of this project are to image the shallow velocity structure beneath and around Old Faithful in order to identify areas of shallow, active hydrothermal activity as well as to learn more about these hydrothermal systems, in particular Old Faithful. This project was a continuation of a similar study that was conducted in November of 2015. This past year, the University of Utah installed seismometers at 518 different locations around the Upper Geyser Basin. This project was a "mini Transportable Array" experiment where instruments were deployed in dense grids with ~20 meter spacing using ~100 instruments. These dense grids ran continuously for ~24-48 hours then were picked up and moved to different locations in order to cover the entire area of interest with a dense grid. A subset of 33 instruments were installed and left in there locations for the entire two week time period to provide a backbone network to tie the different dense grids together.

In addition to recording passive seismic data and hydrothermal signals, we also did an active seismic experiment where we struck a sledgehammer against a metal plate on the ground to produce seismic sources that were recorded throughout the array. In total, we produced 337 individual seismic sources throughout the array that will help us image the very shallow velocity structure of the Old Faithful area.

The field work for this experiment included 3 faculty members, 2 post docs, and 4 students from the University of Utah and 1 faculty member and 2 students from the University of Texas at El Paso. Having students involved in field deployments using these state-of-the-art seismic instruments provides valuable field experience that will aid them in their professional advancement.

Photos (at right) show the installation of Nodal seismometers around Old Faithful by University of Utah Seismograph Stations seismologist Jamie Farrell and Yellowstone National Park employees. Photos by Robert B. Smith.

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

Dr. Hao Zhang

- Postdoctoral Research Associate in Earthquake Seismology

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
- Gordon Johansen — Field Assistant
- Afiq Mokhtar — Student Analyst
- Cindi Meier — Administrative Assistant
- Barry Morse — Station Attendant
- Peter O'Neill — Field Assistant
- Arvind Parapuzha — Student Analyst
- Julian Stanley — Student Analyst
- Ken Whipp — Electronics Technician

Near station LCMT (Little Creek Mountain, UT) in Washington County. 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, Board of Directors, Incorporated Research Institutions for Seismology (IRIS), 2016–present.
- Member, External Review Panel, Geophysics SCEC5, National Science Foundation, 2016.
- Member, External Review Panel on Signal Analysis, US Department of Energy: Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), and Sandia National Laboratory (SNL), 2016.

Dr. Kristine L. Pankow

- Member, Utah Mine Safety Technical Advisory Council, 2011–present.
- Member, Review Panel, National Earthquake Hazards Reduction Program (NEHRP), 2016.
- Intermountain West Regional Coordinator for Committee on National Implementation, Committee on Comprehensive Catalog, and Organizing Committee: NetOps Workshop, Advanced National Seismic System (ANSS), 2010–present.

Dr. James C. Pechmann

- Reviewer, Bulletin of the Seismological Society of America, 2016.
- Reviewer, National Science Foundation, 2016.
- 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, 2010–2016.

Dr. Walter J. Arabasz (Emeritus)

- Member, Working Group on Utah Earthquake Probabilities, Utah Geological Survey, 2010–2016.

Near station BEI (Bear River Range, ID). Photos by Corey Hatch.

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
2016 Graduate

Thesis: Waveform Correlation Detection Methods Applied to the 2003-2004 Seismic Swarm in the Marysvale Volcanic Province of central Utah

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

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

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

By analyzing the continuous data, using subspace detectors, a more complete catalog for the years 2010-2016 has been created for the area near Milford, UT. This improved catalog allows a better understanding of the characteristics of seismicity in the area. Further research will be conducted to locate these newly detected events to allow further analysis to be continued on the data sets. The areas of focus include the Roosevelt Hot Springs region and an area located just northeast of Milford, UT.

Stephen Potter
MS - Geology

The Wasatch Plateau region of Central Utah contains multiple sources of seismic activity caused by a complicated mix of extensional tectonics and a long history of coal mining induced seismicity. This mixture has made it difficult to study this region effectively in terms of regional structure, seismic hazard, and mine planning. Using a catalog of 6,402 events recorded at UUSS broadband seismic station SRU between mid-1998 and the end of 2011, this study aims to identify seismic event types in this region through a cumulative approach of methods.

Jared Stein
MS - Geophysics
2016 Graduate

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

My research is investigating a potential geothermal play near Milford, Utah. I am detecting and locating small seismic events in order to characterize potential seismic swarms in the area. Seismic swarms are clusters of events that occur closely in space and time and exhibit no clear mainshock. Swarm like behavior has been known to be caused by migrating hydrothermal and magmatic fluids in the subsurface. This is why understanding seismicity near geothermal energy sources can help identify successful targets for energy production. I was able to collect my own dataset in July with the new Nodal instruments owned by the UUSS. The photo is from the summer when Jamie Farrell and myself set up the month long experiment.

Andy Trow
MS - Geophysics

Less than 35 miles from downtown Salt Lake City and only a few minutes from station SNUT (Stansbury North, UT). Behind the locked gate (top left) is a large bay, currently dry due to lake level. "I like the picture because it represents a distinctive facet of the many faces of Utah," says photographer Corey Hatch.

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 and science of earthquakes in the region, 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:

American Fork Hospital - American Fork

Canyon View Junior High - Orem

Carl Sandberg Elementary - West Valley City

Crestview Elementary - Layton

Elk Run Elementary - Magna

Heritage Elementary - Layton

Hillcrest Junior High - Murray

Orem Community Hospital - Orem

Salem Junior High - Salem

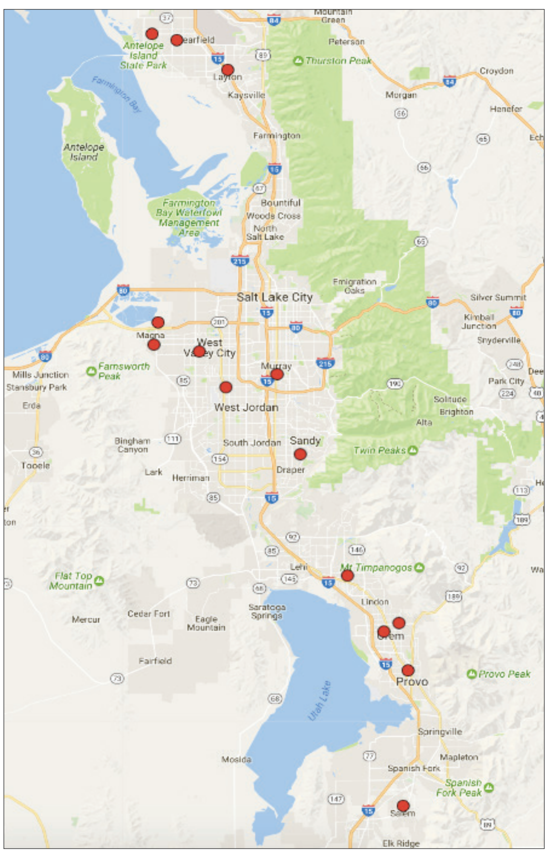
Sunrise Elementary - Sandy

Syracuse Arts Academy, North Campus - Syracuse

Utah Valley Hospital - Provo

West Point Elementary - West Point

Westbrook Elementary - West Jordan



Outreach Presentations and Interviews

Herriman Amateur Radio Club	Jan 9
"Earthquakes in Utah: When, Where, Why, How?" Highland Park Elementary 4th Grade	Jan 15
Salt Lake Arts Academy	Feb 1
Salt Lake Center for Science Education	Feb 18
"A big earthquake is coming- but when, and how bad will it be?" Salt Lake Tribune - Trib Talk	Apr 21
Salt Lake County Amateur Radio Emergency Services	Apr 27
"Earthquakes: Public Perception vs. Reality" Utah Earthquake Resiliency Workshop–Earthquake Engineering Research Institute, Utah Chapter	Apr 27
Interview on Recent Earthquakes KSL Television	May 25
"Earthquakes in Utah: When, Where, Why, How?" Granite Peaks Endoscopy	Jun 1
"The Yellowstone Hotspot: One of the World's Largest Volcanoes" Utah Field House of Natural History	Jun 16
Teleseismic S waves in Microseisms Science News	Aug 24
Speed Date: Shake, Rattle, and Roll Natural History Museum of Utah	Sep 28
"The Yellowstone Hotspot: One of the World's Largest Volcanoes" Park City Rotary Club	Nov 29
Seismic Events in North Korea Interview with Eva Botkin-Kowacki of Christian Science Monitor	Dec 16
Induced Seismicity Interview with Geoff Smith of Utah Public Radio	Dec 19

Earthquake Information Center Tours

UUSS provided 27 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 2016

38% — 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

14% — U.S. Geological Survey—Volcano Hazards Program

Earthquake monitoring and research in the Yellowstone National Park region

12% — 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)

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

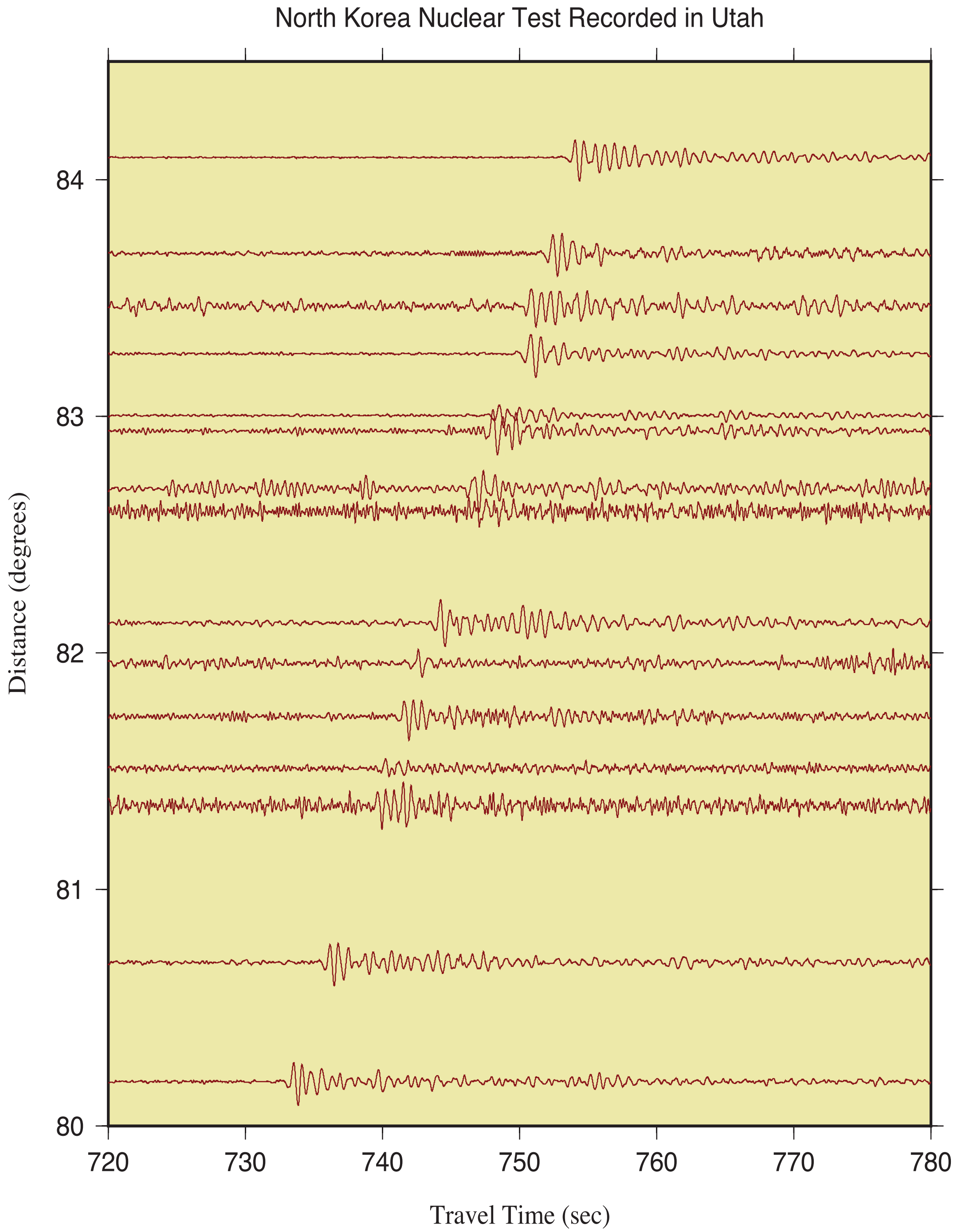
Utah Department of Public Safety

- Traveling educational earthquake exhibit

Additional revenue from:

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

Partners and Sponsors



On September 9, 2016, North Korea conducted its fifth test of a nuclear weapon. The explosion occurred at the Punggye-ri Test Site and had a yield estimated at 20-30 kilotons of TNT equivalent. Seismic waves generated from the test were observed worldwide and a magnitude of 5.3 mb was assigned by the United States Geological Survey. The figure shows P waves from the North Korea nuclear test recorded by15 broadband seismometers in Utah. Distance is measured in degrees, where one degree is equivalent to 111.19 kilometers. Time is measured in seconds after the origin time of the explosion. It takes 12-13 minutes for P waves from the Punggye-ri Test Site to reach Utah. The peak-to-peak amplitudes of the P waves recorded in Utah are about 20 nanometers.

University of Utah
Seismograph Stations
THE UNIVERSITY OF UTAH