UNIVERSITY OF UTAH SEISMOGRAPH STATIONS

ANNUAL REPORT 2019

Cover photo: UUSS technician Wesley O'Keefe working on seismic equipment.

UNIVERSITY OF UTAH
SEISMOGRAPH STATIONS

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University of Utah
Seismograph Stations
2019 Annual Report

TABLE OF CONTENTS

DIRECTOR'S MESSAGE

2019 was an exciting year for the University of Utah Seismograph Stations. We welcomed new students and staff, had an earthquake sequence widely felt in the Salt Lake Valley, and were involved in several interesting research projects.

We welcomed several new faces to our team. Dr. Ben Baker joined us as a research scientist and co-taught a new course "Statistical Applications to Earthquake Seismology" with associate director Kris Pankow, to great student reception. We also gained full-time communications specialist Rebecca Sumsion. UUSS brought on two postdoctoral research associates: Dr. Maria Mesimeri and Dr. James Holt. They've been a great contribution to important research projects.

At the beginning of the year, there was excitement in Bluffdale, Utah, at the south end of the Salt Lake Valley where an earthquake sequence took place between February – April. The event generated a lot of public interest since the sequence occurred in a densely populated area. UUSS received a lot of media attention and we participated in several interviews for local news networks and newspapers.

We're proud of the many graduate and undergraduate students we have working for us. 2019 brought a lot of opportunity for great student-led research projects. Research projects included investigating the fault location of the Bluffdale sequence, earthquakes that occurred around the Utah FORGE seismometer deployment and an intriguing swarm near the San Rafael Swell.

We are excited to announce that we joined the International Seismological Centre and are looking forward to the exposure this opportunity will provide. UUSS also joined in celebrating the 25th anniversary of the Utah Seismic Safety Commission at the state capitol.

2019 closed with the annual American Geophysical Union fall meeting. UUSS had a strong representation and were included in several presentations. I'm proud of the work we do and look forward to more opportunities in 2020.

Make sure to follow us on social media: @uussquake on Twitter and Instagram and @UUSeismographStations on Facebook.

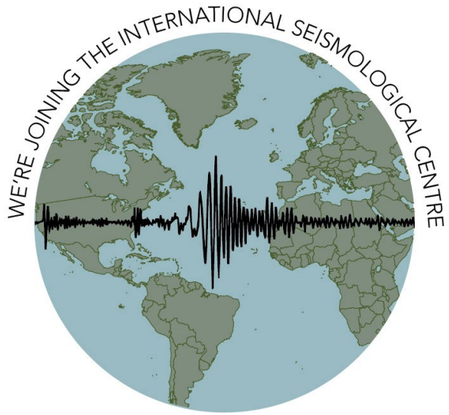
Best Wishes,

Keith D. Koper, UUSS Director

Top left: equipment located at the west end of Salt Lake Valley
Top right: UUSS Director Keith Koper talks to reporters about the Bluffdale, Utah, earthquake sequence.
Middle left: UUSS personnel at the 2019 Fall BBQ on Oct. 2.
Middle right: Alysha Armstrong, Avery Conner, and Maria Mesimeri at the Fall Geology and Geophysics open house.
Bottom left: Daniel Wells, Monique Holt, Jonathan Voyles, and Maria Mesimeri helping out at the College of Mines and Earth Sciences "U Rock the Earth" Day.
Bottom right: nodal seismometer to help monitor seismicity at the FORGE site near Milford, Utah.

UUSS JOINS ISC

The University of Utah Seismograph Stations (UUSS) is excited to announce it was recently invited to become a formal Member-Institution of the International Seismological Centre (ISC).



The ISC is a non-governmental, non-profit international organization which maintains extensive information about earthquakes and other seismic events from around the world. ISC members strive to collect, archive, and process seismic station and network bulletins and prepare and distribute the ISC bulletin – the definitive summary of the world's seismicity.

Since its inception in the 1960s, the ISC has provided invaluable data used by thousands of seismologists worldwide. The current ISC mission is to maintain the ISC bulletin, the International Seismographic Station Registry, and the IASPEI Reference Event list. ISC also maintains several other important catalogs, contacts, and datasets.

The UUSS is honored to join the ISC. It joins 68 other research and operational organizations in 50 countries that support the ISC. Other ISC Members in the United States include NEIC/USGS, and IRIS. The invitation to join comes as a great recognition of the important work of the UUSS on a national, and now international, scale.

AWARDS

Kris Pankow, Associate Director
Outstanding Faculty Research 2018–2019
University of Utah
Department of Geology and Geophysics

Jon Rusho, Seismic Network Engineer
2019 Excellence in Safety Award
University of Utah
College of Mines and Earth Sciences

Jonathan Voyles, Undergraduate Student
Outstanding Student Presentation Award, Seismology
American Geophysical Union Meeting, 2019

Thure Cerling (left), Chair of the Department of Geology and Geophysics, presents Kris Pankow (right) with the Outstanding Faculty Research award.

PERSONNEL

Faculty

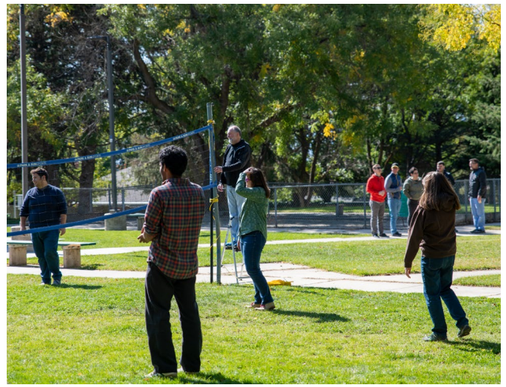
Dr. Keith D. Koper
Director
Professor of Geology and Geophysics

Dr. Kristine L. Pankow
Associate Director
Research 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
Research Professor Emeritus of Geology and Geophysics
[Past UUSS Director, 1985–2010]



Full-Time Staff

Dr. Ben Baker	Research Scientist
William Blycker	Systems Administrator
Relu Burlacu	Research Manager
Mark Hale	Earthquake Information Specialist
Corey Hatch	Seismic Network Engineer
Dr. James Holt	Postdoctoral Research Associate
Cindi Meier	Administrative Officer
Dr. Maria Mesimeri	Postdoctoral Research Associate
Wesley O'Keefe	Seismograph Technician
Arvind Parapuzha	Seismograph Technician
Paul Roberson	Earthquake Information Specialist
Jon Rusho	Seismic Network Engineer
Rebecca Sumsion	Communications Specialist
Dr. Hao Zhang	Postdoctoral Research Associate

Part-Time Staff

Barry Morse	Station Attendant
Sheryl Peterson	Communications
Katherine Whidden	Research Scientist

Graduate Students

Monique Holt	Ph.D. Candidate
Guanning Pang	Ph.D. Candidate
Daniel Wells	Ph.D. Student
Amy Record	MS Geophysics

Undergraduate Students

Alysha Armstrong
Avery Conner
Boe Ericksen
Nicholas Forbes
Miles Haynes
Barrett Johnson
Jonathan Voyles

Pictured above: UUSS Staff and students attend the annual UUSS Fall BBQ on Oct. 2, 2019.
Pictured Left: Ben Baker, James Holt, and Mark Hale at the 2019 Fall BBQ.

STUDENT RESEARCH

Monique Holt
Ph.D. Candidate Geophysics

Monique researched seismic discrimination, or using seismic data to distinguish between earthquakes and underground explosions. She worked on developing a new method of discrimination using the amplitude and duration of the seismograms generated by small seismic events recorded at small distances.

Guanning Pang
Ph.D. Candidate Geophysics

Guanning published his work on the 2017–2018 Maple Creek earthquake sequence in Yellowstone National Park. He also worked on inner core heterogeneity mapping using International Monitoring System array data. Guanning also mentored Barrett and Avery in two Utah earthquake sequences dynamics.

Daniel Wells
Ph.D. Student Geophysics

Daniel primarily worked on the FORGE project performing ambient noise tomography using four different nodal geophone arrays combined with permanent seismometers. He used a combination of eikonal tomography and ellipticity measurements to generate a 3D velocity model for part of Southern Utah.

Amy Record
MS Geophysics

Amy's research focused on defining and characterizing earthquake sequences in south-central Utah using several clustering techniques. The goal was to assess the influence of fluids in the upper crust on earthquake generation in this area.

Monique Holt presents at the 2019 American Geophysical Union Fall Meeting

Alysha Armstrong
Senior – Geoscience-Geophysics

Alysha's work included performing high-precision relative relocation of mining-induced seismicity to improve catalog locations and identify previously uncatalogued events, the goal was to better understand relationship between mining operations and nearby seismicity. She was also involved investigating the spectral differences of quarry blasts and earthquakes in northern Utah.

Avery Conner
Senior – Geoscience-Geophysics

Avery researched an earthquake sequence in the San Rafael Swell Region of Utah. She refined event locations in order to establish a potential fault structure, and detected more earthquakes associated with the sequence. Through this research, Avery plans to learn more about tectonic structures present in the San Rafael Swell, as well as determine if the 2019 sequence is linked to a 1988 M_L 5.2 earthquake.

Boe Ericksen
Senior – Geoscience-Geophysics

Boe utilized various seismic stations located in Utah, Wyoming, and surrounding states to locate earthquakes. He also monitored mining operation blasts in the state of Utah, teleseism events, or background noise.

Nicholas Forbes
Senior – Geoscience-Geophysics

Nicholas used Nodal and Lake-Bottom seismometer arrays to generate a dataset, based on event detection methods, of earthquakes in the Yellowstone Lake region. Using this data, Nicholas work will hope to further characterize seismicity in the Yellowstone Plateau volcanic field as well as potentially image hydrothermal features located on the bottom of Yellowstone Lake.

Barrett Johnson
Senior – Geoscience-Geophysics

Barrett researched the Bluffdale, UT earthquake sequence. Using waveform cross-correlation methods to calculate differential travel times, Barrett worked to relocate the initial earthquake locations with a cluster-based relative relocation algorithm, GrowClust. The results will allow him to determine if the sequence occurred on the Wasatch fault, illuminate the complex nature of the tectonic setting surrounding the Bluffdale region, and make more precise earthquake hazard assessments moving forward.

Jonathan Voyles
Senior – Geoscience-Geophysics and Geological Engineering

Jonathan worked on the M_L–M_C depth-based discrimination at local distances project for three years. During that time, he tested M_L–M_C on a new catalog of explosions in Utah, simulated what mechanisms are driving the M_C depth-dependence using high-performance computing, and tested M_L–M_C using machine learning methods.

EXCITING DEVELOPMENT OF SAN RAFAEL SWELL RESEARCH

From March 13, 2019 to May 28, 2019, there were over 180 small earthquakes that occurred on the edge of the San Rafael Swell. It's an area that is usually seismically quiet. The sequence caused enough interest that Avery Conner, Geology and Geophysics student and UUSS student researcher, was assigned to head up the research.

The project turned out to be more than Conner was expecting. She was thrilled to participate in real-time research as an undergraduate. And as data and the scope of the project grew, it also included a field of particular interest to Conner.

At the start of the research, Conner entered the earthquake data into GrowClust, a program that uses information from multiple seismograph stations to better calculate a more accurate position for each earthquake. Originally, the earthquakes appeared to be two separate clusters. But with the relocated earthquake information from GrowClust, the data revealed a well-resolved fault plane. The fault plane was steep, almost vertical at about 87 degrees.

Next, Conner used the waveforms of the located earthquakes as templates to identify more earthquakes that didn't originally register in the system. Conner estimated they would discover two to three times the original number of earthquakes. This process actually revealed an additional 1,505 earthquakes, eight times the original amount for a total of 1,694 earthquakes. These earthquakes were also added to the GrowClust program to provide an even better resolution for the fault plane.

With the earthquakes spreading from the bottom to the top of the fault plane (first earthquake being near the bottom of the fault, and the rest of the earthquakes generally moving up and outward as the sequence went on), it led Conner and associates to think about the possibility of there being some fluid flow. Based on the evidence and the decision to label the earthquakes as a swarm, they believe there is potential that magma is moving around.

Conner was thrilled that not only did the project grow data wise, but it also connected to theories of magma flow. Conner has a particular interest in volcano seismology and plans to attend a PhD program in Oregon to further her studies.

"When I started at UUSS," Conner said. "I was just so happy to get a chance to work with real data and with people who are actually doing research, that I was happy to take any research opportunity that came my way. It was extremely fortunate that it ended up being super relevant to what I really want to study."

Conner presented "The 2019 Earthquake Sequence in the San Rafael Swell Region of the Colorado Plateau, Utah" Conner, A.; Koper, K.D.; Pang, G.; Burlacu, R.; Pechmann, J.C.; at the American Geophysical Union, Fall Meeting 2019.

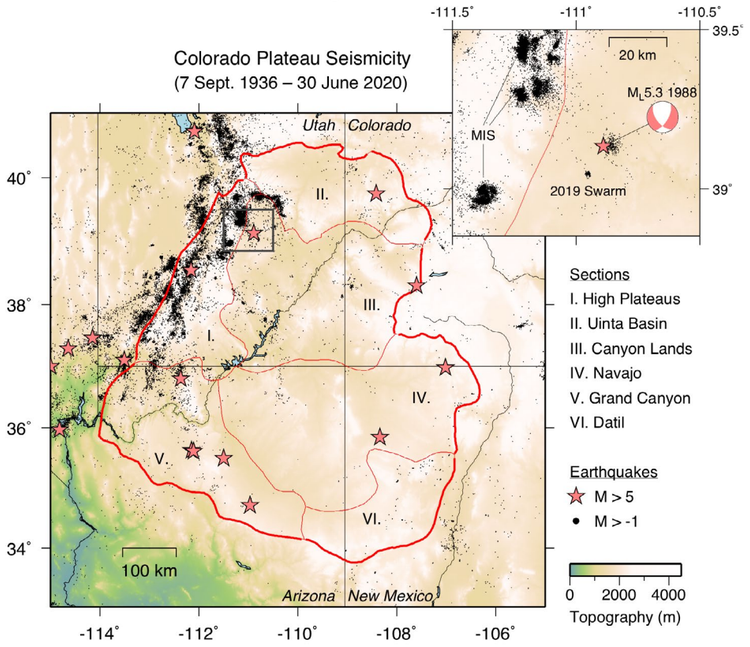


Figure of the San Rafael Swell earthquakes created by Keith Koper. The star is the first earthquake and the square was the largest earthquake.

ODD EVENT FEEDS VOLCANIC THEORY AND HELPS PROJECT

On April 14, 2019, one of the weirdest earthquakes in Utah occurred. The M4.1 in central Utah had some strange characteristics, but what really struck as an odd coincidence was the timing and help it provided in relation to Utah's Frontier Observatory for Research in Geothermal Energy (FORGE).

In spring 2019, Maria Mesimeri, Post Doctoral Research Associate in Seismology, was busy deploying an array of 151 nodal seismometers to monitor seismicity at FORGE near Milford, Utah. The nodes were ready to go before the injections were scheduled to begin in April and May.

Then on April 14, 30 km away from the FORGE site, the M4.1 earthquake occurred. Mesimeri was able to gather more information on the M4.1 than would have been possible just one month before, because of the recently deployed nodes.

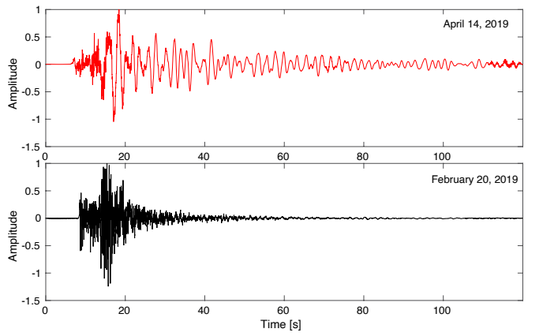
The M4.1 was an extremely shallow event, only 1 km in depth. Usually such shallow depth is indicative of an explosion or mine collapse, but those possibilities were ruled out through the data. The UUSS cataloged 19 events in addition to the mainshock within the first three days, causing the events to be labeled as the M4.1 Black Rock, Utah sequence. Mesimeri was able to analyze and detect the sequence waveforms to find even more events. She concluded that the M4.1 was not a tectonic event but was related to a volcanic field in the area because it was shallow and unusual in waveform.

Unfortunately, the data was not as conclusive in determining the exact nature of the volcanic field, but it opened the path to possible future research in the area to better understand what is going on.

One key takeaway for Mesimeri, was the benefit the sequence provided for her research with FORGE. She was able to use the events of the M4.1 sequence to practice detecting extremely small events which would be more in line with geothermal injections. It also gave her the opportunity to test out algorithms they intended to use with FORGE: the frequency-domain array-based detection algorithm, the local similarity-based detection algorithm, and the algorithm based on the envelope of stacked subarrays.

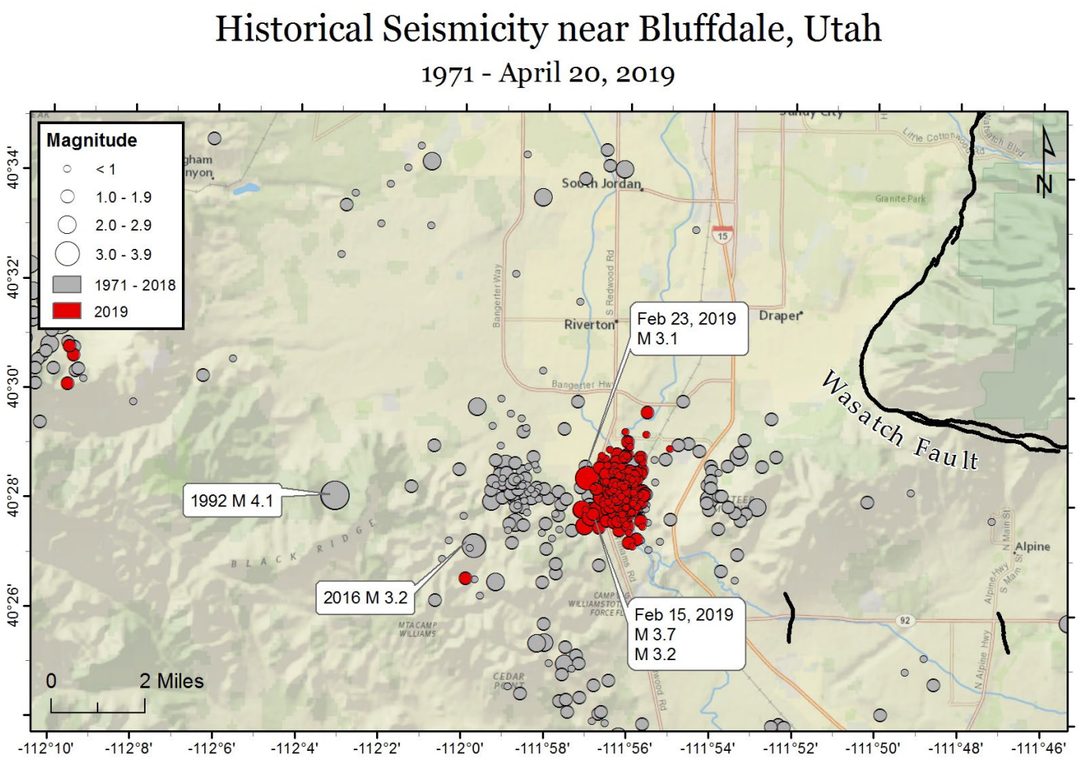
The algorithms showed promising results. As shared in her abstract for the AGU 2019 fall meeting, Mesimeri wrote: "Preliminary results show that the implemented algorithms surpass the permanent network's detection capability. For the first two hours following the mainshock we are able to at least double the number of detections compared to routine process."

Mesimeri presented "Detecting aftershocks using a dense N-array: the case of the 2019 M4.1 Black Rock, Utah sequence" Mesimeri, M.; Pankow, K. L.; at the American Geophysical Union, Fall Meeting 2019.



Pictured top left: Daniel Wells, Santiago Rabade, Maria Mesimeri, and Hao Zhang deploy an array of 151 nodal seismometers at the Utah FORGE site.
Figure above: waveform comparison. Top waveform is the April 14, 2019 M4.1 earthquake.

BLUFFDALE RATTLED BY EARTHQUAKE SEQUENCE



Between Feb. 13 – April 20, the Bluffdale area, located at the south end of the Salt Lake Valley, experienced quite the earthquake sequence. The mainshock was an M3.7 that occurred on February 15, 2019 at 5:09 am MST.

13 foreshocks proceeded the M3.7 mainshock. The foreshocks included an M3.2 also on Feb. 15, that occurred seven minutes before the mainshock at 5:02 am MST. The two M>3.0 events were widely felt, with the M3.7 reaching over 9,000 felt reports.

The sequence went on to include 177 aftershocks, including 11 aftershocks of M2.0 and larger. The largest aftershock was an M3.1 event that occurred on Feb. 23.

The 2019 Bluffdale earthquakes were within an east-west trending band of seismicity across the southern end of the Salt Lake Valley that has had earthquakes off and on. Since 1962, five earthquakes of magnitude 3.0 or greater have occurred within 16 miles of the epicenter of the M3.7 mainshock, including an M4.1 in 1992 and M3.2 in 2016.

The sequence occurred in a densely populated area which led to a lot of news coverage throughout the spring, especially when there were felt events. The sequence also brought up concerns about the sequence possibly occurring on the Wasatch Fault and what that would mean for future hazard assessment. This led to a research project headed by Barrett Johnson to better define the fault the sequence occurred on.

SCIENTIFIC AND PERSONAL DISCOVERIES FROM RESEARCH

Seismicity is a common occurrence in Utah, but it's typically uncommon for that seismicity to be widely felt. However, on Feb. 15, 2019, there was an M3.7 earthquake near Bluffdale, at the southern tip of Salt Lake county. There were over 9,000 felt reports and a lot of buzz within Utah about the long discussed "big one."

Geology and Geophysics UUSS student analyst turned researcher, Barrett Johnson, was assigned with the task of answering the question "If the M3.7 occurred on the Wasatch Fault, what did that mean for future hazard assessment?" In addition to answering questions about the fault, Johnson found some answers to questions of his own.

Johnson entered data from 13 foreshocks and 178 aftershocks into the GrowClust program to relocate the earthquakes using relative locations. This gave a finer picture of the fault structure where these earthquakes occurred. The fault was determined to be antithetic, oppositely dipping to the Wasatch Fault.

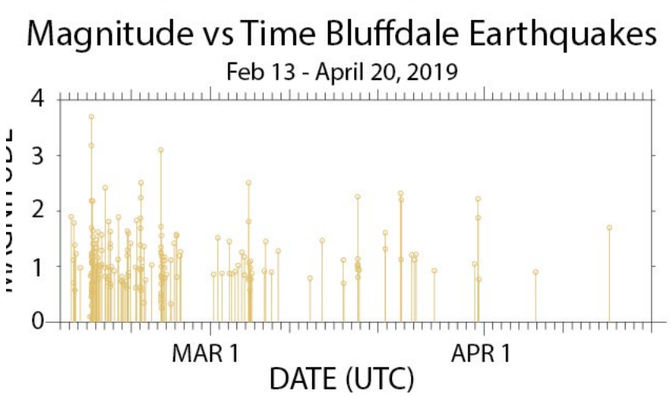
To make the picture even more clear, Johnson took 36 earthquakes from a smaller 2017 Bluffdale sequence and also put them into GrowClust. Then, using the waveforms from the 2017 and 2019 earthquakes, Johnson used a detection algorithm to find 517 previously undetected events. By adding the newly detected earthquakes to the relocation algorithm, Johnson was able to confirm the subsurface architecture with higher resolution.

Throughout the process, Johnson was able to answer more than "if the M3.7 occurred on the Wasatch Fault." As Johnson turned to research in addition to his student analyst duties, he was able to answer his own questions about what to focus on as he moved forward in his education.

"I was pleasantly surprised," Johnson said, "Before, I didn't really see the connection between the network with what is done outside of the network — research. By becoming a part of both aspects, I see the connection that is made. But what ultimately stood out to me is seeing everything I'm using in the classroom apply to what we're doing in research. Understanding the principles behind techniques we're using was fascinating. Graduate school then became the next logical step."

Johnson plans to receive a masters and PhD from the University of Washington to pursue plans to work within a seismic network and continue to conduct research.

Johnson presented "High resolution relocations of the 2019 Bluffdale, Utah, earthquake sequence" Johnson, B.N.; Koper, K.D.; Pang, G.; Burlacu, R.; and Pechmann, J.C.; at the American Geophysical Union, Fall Meeting 2019.



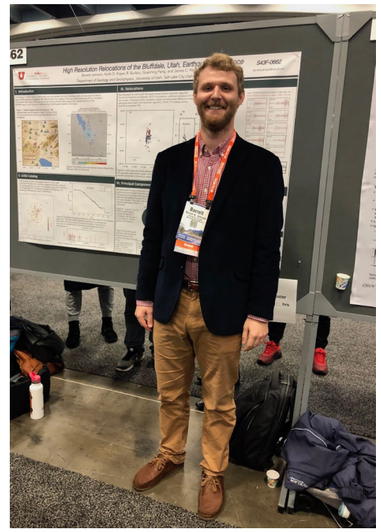
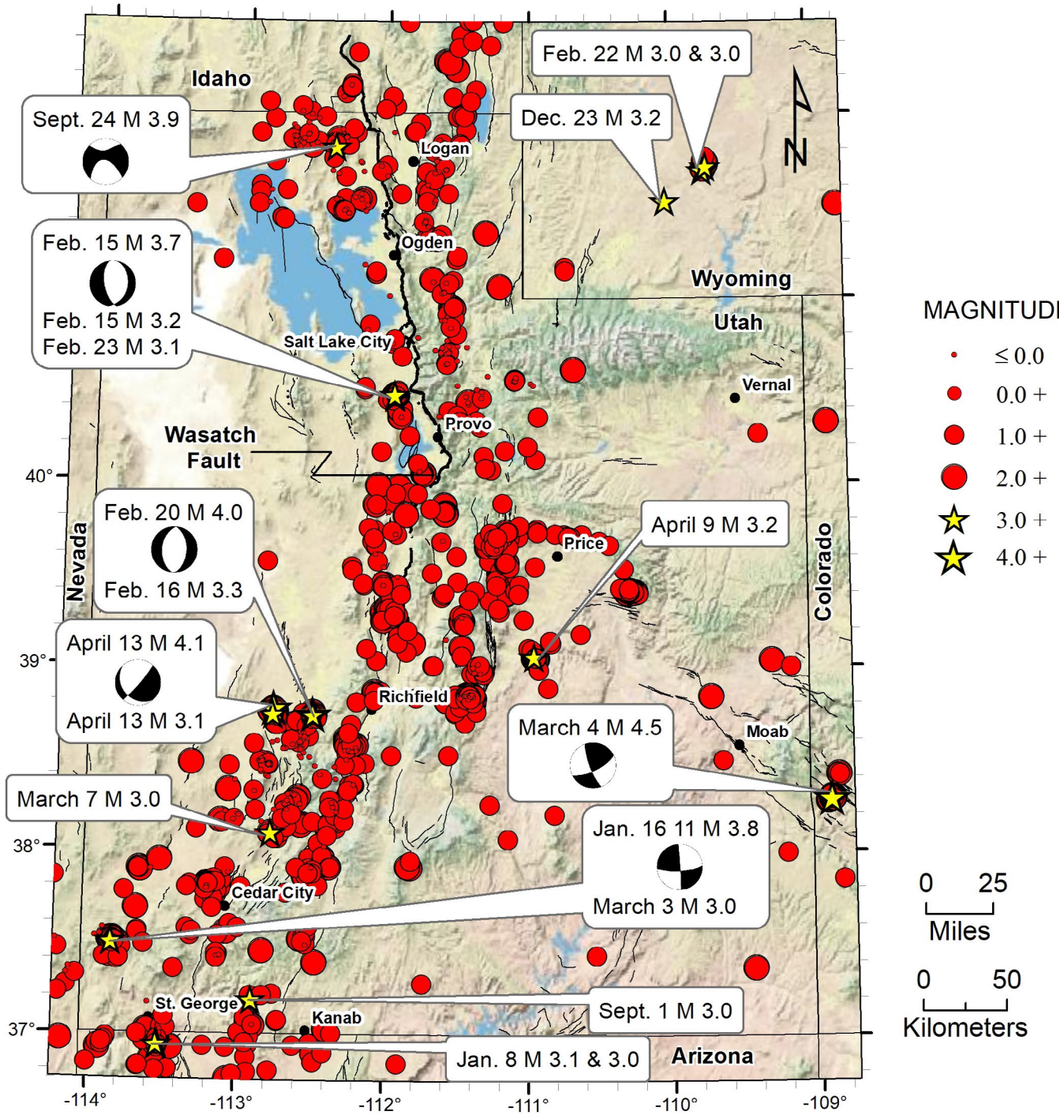


Figure top left: historical seismicity near Bluffdale, Utah.
Figure above: Magnitude vs Time of the 2019 Bluffdale Earthquakes
Pictured right: Barrett Johnson presents his poster at the American Geophysical Union Fall Meeting 2019.

SEISMICITY IN THE UTAH REGION

During the 12-month period Jan. 1, 2019 through Dec. 31, 2019, the University of Utah Seismograph Stations (UUSS) located 2,325 earthquakes within the Utah region. The total includes 3 earthquakes in the magnitude 4 range, 16 earthquakes in the magnitude 3 range, 278 earthquakes in the magnitude 2 range, 1533 earthquakes in the magnitude 1 range, and 495 below the magnitude 1 range. Earthquakes of magnitude 3.0 or larger occurring in 2019 are plotted as stars (see map below).

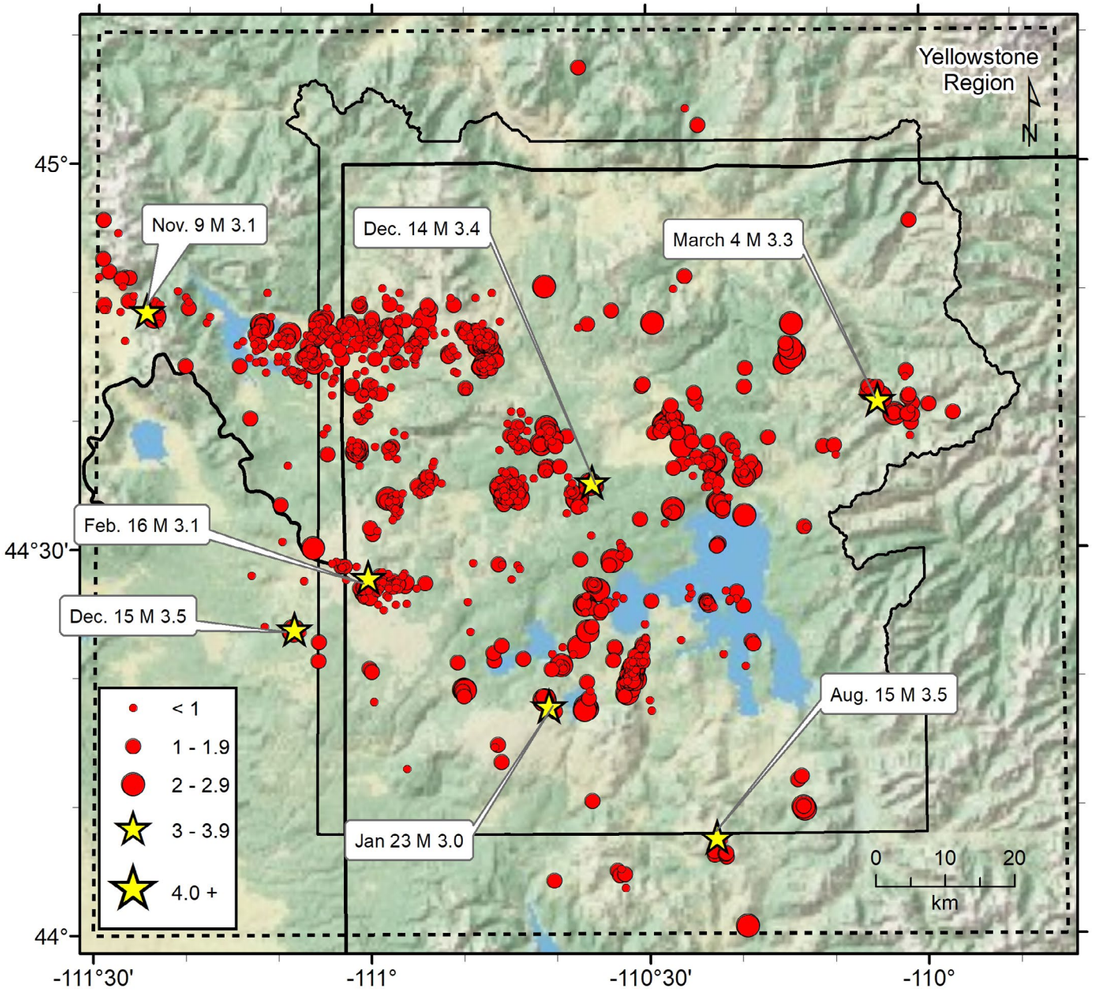
EARTHQUAKES BETWEEN JAN. 1, 2019 – DEC. 31, 2019 IN THE UTAH REGION



SEISMICITY IN THE YELLOWSTONE REGION

During the 12-month period Jan. 1, 2019 through Dec. 31, 2019, the University of Utah Seismograph Stations (UUSS) located 1,218 earthquakes within the Yellowstone National Park region. The total includes zero earthquakes in the magnitude 4 range, 7 earthquakes in the magnitude 3 range, 76 earthquakes in the magnitude 2 range, 434 earthquakes in the magnitude 1 range, and 701 earthquakes below the magnitude 1 range. Earthquakes of magnitude 3.0 or larger occurring in 2019 are plotted as stars (see map below).

EARTHQUAKES BETWEEN JAN. 1, 2019 – DEC. 31, 2019 IN THE YELLOWSTONE REGION



COMMITTEE SERVICE

Dr. Keith D. Koper

- Member of University of Utah Faculty Senate, 2019–present
- Member of AGU Aki Award Subcommittee, 2019–present
- Member/Chair of SSA Richter Award Subcommittee, 2018–present
- Member of U.S. Air Force Seismic Review Panel, 2011–present
- Vice-Chair of Utah Seismic Safety Commission, 2010–present
- Member of EOS editorial advisory board, 2010–present
- Member of AGI Critical Needs Working Group, 2019–Present
- Review panel, Dept. of Earth Sciences and Cntr. for Earthquake Information at Univ. of Memphis, 2019
- Member of Advisory Committee on Earthquake Hazard Reduction, 2019
- Member of DOE external review panels on Signal Analysis for LANL, LLNL, and SNL, 2019
- Chair of departmental merit review committee (Utah), 2019
- Member of departmental undergraduate affairs committee (Utah), 2019

Dr. Kristine L. Pankow

- Guest Editor, Journal of Seismology Special Issue: Induced seismicity: observations, modeling, monitoring, discrimination, and risk management strategies, 2019–present
- NIC representative to ANSS Steering Committee (non-voting), 2019–present
- Powell Cntr. Working Group, Future Opportunities in Regional & Global Seismic Monitoring, 2018–present
- ANSS NIC Working Groups: Member, Large Magnitude Working Group, 2018 – 2019
- Utah Mine Safety Technical Advisory Council, July 1, 2011 – present
- Member, ANSS National Implementation Committee (NIC), 2010–present
- ANSS Regional Coordinator, Intermountain West (IMW) region, 2010–present;
- University of Utah GG Department Executive Committee, 2009–2010, 2015–2017, 2018–2019
- University of Utah GG Department Merit Review Committee, 2009–2012, 2017–2019
- Utah Geological Survey, Ground Shaking Working Group, 2003–present
- Session Co-Chair, National and Regional Earthquake Centers: Highlights and Challenges, IASPEI, July 2019
- Session Co-Chair, New Frontiers in Global Seismic Monitoring and Earthquake Research, SSA, 2019
- Schubert Review Panel, SHADOW Project, Sandia National Laboratory, 2019
- Special Topics GEO 5920/6920/7920: Statistical Applications to Earthquake Seismology, Fall 2019

Dr. James Pechmann

- Member, Western States Seismic Policy Council Program Committee, 2019 – present
- College Council, 2018 – present
- Participant, Utah Geological Survey, Basin and Range Province Earthquake Working Group, 2018 – present
- Member, Utah Quaternary Fault Parameters Working Group, Utah Geological Survey, 2003 – present
- Member, Utah Ground Shaking Working Group, Utah Geological Survey, 2003 – present
- Reviewer, Seismological Research Letters, 2019
- Reviewer, Journal of Geophysical Research, 2019
- Alternate CMES Career-Line Faculty Representative on the Academic Senate, University of Utah, 2019

SEISMO TEA

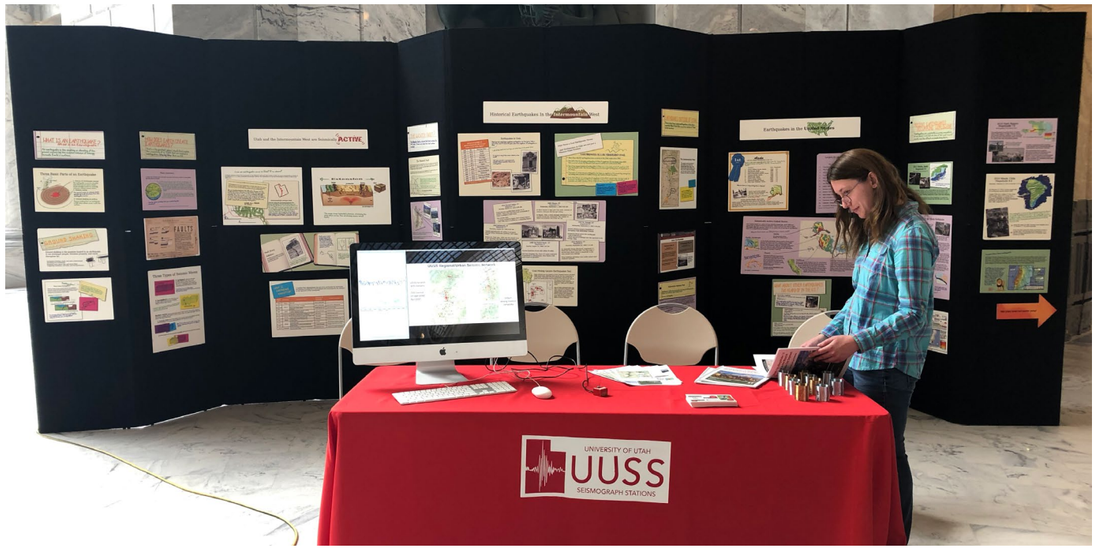
Date	Name	Lecture
Jan. 23	James Holt	Calculating Moment Magnitude (Mw) for Small to Moderate-Size Earthquakes in Utah from Sg/Lg Spectra
Feb. 6	Kostas Gkogkas	Inversion of Love Waves from Ambient Noise Arrays: Application in the Mygdonia Basin Area (Northern Greece)
Feb. 27	Pablo Ampuero	Fast rupture of the 2018 Mw 7.5 Palu, Indonesia Earthquake
Mar. 21	Hongrui Qui	Temporal Changes of Seismic Velocities in the San Jacinto Fault Zone
Mar. 27	Maria Mesimeri	Modeling Earthquake Swarms: Occurrence patterns, Evolution Mechanism and Possible Triggering
April 8	Jeffrey Johnson	Infrasound from Snow Avalanches and Volcanoes
Sept. 4	Kevin Mendoza	ANXCOR: Ambient Noise X (cross) Correlation
Sept. 11	Surya Pachhai	Probabilistic estimation of elastic and anelastic structure of the inner core using free-oscillations of the Earth
Sept. 18	Elizabeth Berg	Shear Velocity Model of Alaska via Joint Inversion of Rayleigh Wave Ellipticity, Phase Velocities, and Receiver Functions across the Northern US Array
Sept. 25	Doug Wehyer & Dallan Coons	Instrumenting a Coal Pillar to Analyze Velocity Changes Due to Changes in Stress
Oct. 16	Geohazards Research Group	Beyond Vibrating Arches: Modal Analysis of Desert and Alpine Landforms Using Ambient Seismic Monitoring
Oct. 23	Jonathan Voyles	A New Catalog of Explosion Source Parameters in the Utah Region with Application to ML–MC Based Depth Discrimination at Local Distances
Oct. 30	Jamie Ward	Inferring the Sharpness and Structure of the African LLVP Boundaries from Slowness-Backazimuth Measurements of Multipathing
Nov. 6	Jim Rutledge	Moment Tensors for Small Hydro-Fracturing Sources
Nov. 20	Guanning Pang	Inner Core Small-Wavelength Scale Structure from PKiKP Coda
Dec. 4	Various	Presentation Practice for AGU

Left: Jonathan Voyles gives a presentation during Seismo Tea. Right: Geology and Geophysics Open House attendees test out the seismometer in the Earthquake Information Center.

PRESENTATIONS

Date	Personnel	Location	Topic
April	Jim Pechmann	Bluffdale Preparedness Fair	Utah Seismicity and the 2019 Bluffdale Earthquakes
April	Kris Pankow	U.S. Geological Survey Science Center, Menlo Park, CA	Re-evaluating remote dynamic triggering by first establishing background seismicity rates
April	Kris Pankow	University of Utah, Department of Chemical Engineering	Seismic Monitoring at the Utah Frontier Observatory for Research in Geothermal Energy
April	Jamie Farrell	Yellowstone Geothermal Monitoring Meeting, Bozeman, MT	Geothermal Monitoring using Seismic and GPS
May	Jamie Farrell	West Yellowstone public lecture, West Yellowstone, MT	Earthquake Activity in and Around Yellowstone: Using Seismology to Better Understand the Yellowstone Volcanic and Geothermal System
May	Jamie Farrell	Yellowstone National Park Interpreter Training, Old Faithful, YNP	Old Faithful and the Upper Geyser Basin: Using Seismology to Better Understand the World's Most Famous Geyser
July	Keith Koper	Utah Seismic Safety Commission, Utah State Capitol	2019 Bluffdale Earthquakes
Aug.	Jamie Farrell	Earthquake Lake Visitor Center, Cameron, MT	60th Anniversary of 1959 Hebgen Lake M 7.3 Earthquake
Aug.	Jamie Farrell	Natural History Museum of Utah public lecture, Salt Lake City, UT	An Update on the Status of the Yellowstone Volcanic System and its World Famous Geysers
Oct.	Keith Koper	School of Mines, Golden, CO	Forensic Seismology in the Western U.S.
Oct.	Jamie Farrell	Park City Rotary, Park City, UT	
Nov.	Jamie Farrell	Weber State University, Ogden, UT	

Jamie Farrell gives a presentation at the Natural History Museum of Utah to a full house.



Avery Conner helps with the traveling exhibit at the Utah Seismic Safety Commission 25th Anniversary Mtg, July 11, 2019.

SPONSORS

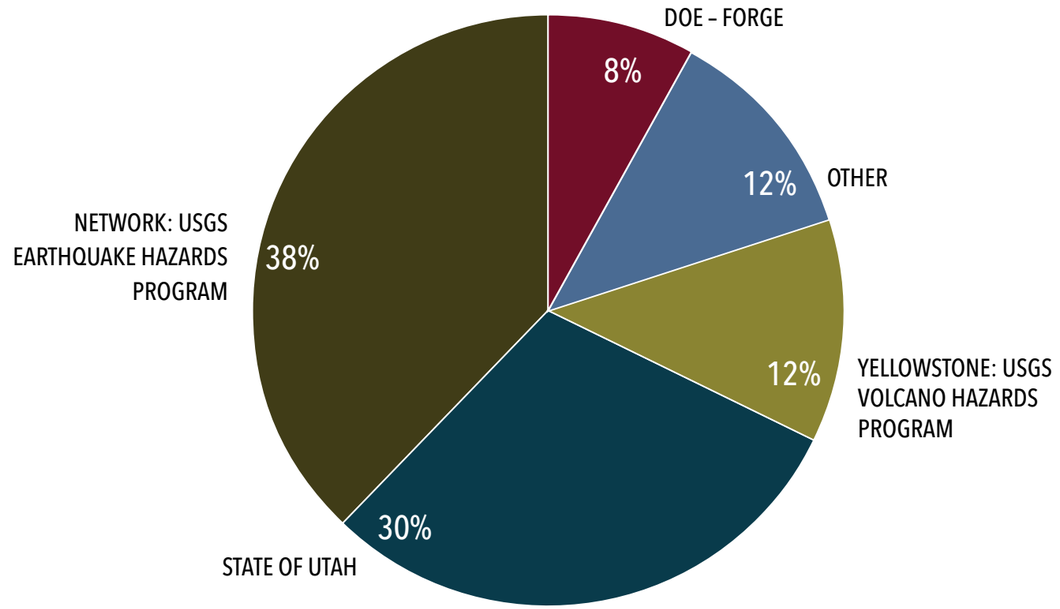
University of Utah
- College of Mines and Earth Sciences
- Department of Geology and Geophysics
- Department of Mining Engineering
- Energy and Geoscience Institute

Advanced National Seismic System
Air Force Research Laboratory
Arizona Geological Survey
Brigham Young University, Idaho
Idaho National Laboratory
International Seismological Centre
Lawrence Livermore National Laboratory
Montana Bureau of Mines and Geology
National Science Foundation
National Strong Motion Project
Northern Arizona University
Plate Boundary Observatory
RioTinto
Sandia National Laboratory
State of Utah
University of Nevada, Reno
U.S. Bureau of Reclamation
U.S. Department of Energy
U.S. Geological Survey
Utah Department of Public Safety
Utah FORGE
Utah Geological Survey
Yellowstone National Park

ADDITIONAL OUTREACH

- The UUSS gave 15 tours of the RioTinto Earthquake Information Center.
- Sent the traveling earthquake exhibit to 5 events.
- Numerous media interviews (e.g. NPR, KSL, etc.)
- Numerous contributed articles (e.g. Yellowstone Caldera Chronicles)
- Staff and students attended and helped at multiple events for the university and other government associations including:
- Department of Geology and Geophysics Open House
- College of Mines and Earth Sciences "U Rock the Earth"
- Utah Seismic Safety Commission 25th Anniversary
- National Earthquake Program Managers Meeting
- Bluffdale Preparedness Fair

FUNDING



U.S. Geological – Survey Earthquake Hazards Program 37.58%

- Regional and urban seismic monitoring: Wasatch Front and neighboring Intermountain West region

State of Utah 29.82%

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

U.S. Geological Survey – Volcano Hazards Program 12%

- Operational and maintenance of the Yellowstone regional seismic network and earthquake information system

U.S. Department of Energy – FORGE 8%

- Enhanced geothermal system concept testing and development at the Milford City, Utah FORGE site

Other 12%

Utah Department of Public Safety **.08%**

- Intermountain West earthquakes, a traveling educational exhibit

U.S. Department of Energy **.08%**

- Structurally controlled geothermal systems in the Eastern Great Basin Extensional Regime, Utah

Sandia National Laboratory – Department of Energy **3.45%**

- Geophysical monitoring and characterization of the Utah Region

Air Force Research Laboratory **4.15%**

- Evaluation of ML-MC as a possible depth discriminant at local distances

National Science Foundation **4.73%**

- Collaborative research: capitalizing on earthscope transportable array data to better characterize induced seismic sequences .43%
- Mapping fine scale structure in earth's inner core with a global array of seismic arrays 2.86%
- The origin and propagation of shallow water microseisms: a study at Yellowstone Lake 1.01%
- Rapid: seismic deployment in response to 2018 Kilauea eruption and summit explosions .42%

ABSTRACTS, PUBLICATIONS, & REPORTS

ABSTRACTS

Seismological Society of America Annual Meeting, Miami, Florida, April 23–26, 2019

Forbes, N. M., K. D. Koper, R. Burlacu, and P. Jewell, Seismic Monitoring of Mass Wasting Events Following the 2017 Brian Head Wildfire in Southern Utah.

Koper, K. D., J. Farrell, R. Burlacu, and R. A. Sohn, A Multidisciplinary Study of Shallow Water Microseisms in Yellowstone Lake.

Liberty, L. M., J. St Clair, G. Gribler, G. N. McDonald, and J. C. Pechmann (2019). Shallow shear-wave velocities for downtown Salt Lake City: Relationships with surface topography, basin depth and earthquake site amplification.

International Union of Geodesy and Geophysics, General Assembly, Montreal, Canada, July 8-18, 2019

Pankow, K., K. Koper, R. Burlacu, J. Pechmann, J. Farrell, J. Holt, and K. Whidden (2019). The University of Utah Seismograph Stations regional earthquake center, 27th IUGG General Assembly, July 8-18, 2019, Montreal, Canada, Abstract IUGG19-1906.

Koper, K. D., and R. Burlacu (2019). Synoptic Study of Double-Frequency Microseisms Recorded by the Transportable Array in Alaska, 27th IUGG General Assembly, July 8–18, 2019.

American Geophysical Union Fall Meeting, San Francisco, California, December 9 – 13, 2019

Albert, S. and K. L. Pankow (2019). Comparison of wind noise reduction systems for use in temporary infrasound deployments (abstract, S41E-0581), 2019 Fall Meeting, AGU, San Francisco, CA, December 2019.

Armstrong, A. D., G. G. Euler, K. D. Koper, and W. S. Phillips (2019). Investigation of the spectral nature of quarry blasts and earthquakes at local distances in Northern Utah, abstract S11E-0412, fall AGU, San Francisco, CA

Baker, B. (2019). Expediting the UUSS's Response to the Soda Springs, Idaho Aftershock Sequence, 2019 AGU Fall Meeting, Dec. 9–13, 2019, San Francisco, California, https://www.essoar.org/doi/10.1002/essoar.10503692.1

Baker, B. and K. L. Pankow (2019). Teaching machine learning to seismologists: Lessons learned (abstract, ED23D-04), 2019 Fall Meeting, AGU, San Francisco, CA, December 2019.

Berg, E. M., A. A. Allam, R. Burlacu, K. D. Koper, and K. L. Pankow (2019). Iterative deterministic and Bayesian seismic imaging of the Wasatch fault zone, Utah, incorporating earthquake and ambient noise waveforms (abstract, S14A-06), 2019 Fall Meeting, AGU, San Francisco, CA, December 2019.

Conner, A., K. D. Koper, G. Pang, R. Burlacu, and J. C. Pechmann (2019). The 2019 earthquake sequence in the San Rafael Swell region of the Colorado Plateau, Utah, 2019 AGU Fall Meeting, Dec. 9–13, 2019, San Francisco, California, Abstract S41H-0642.

Farrell, J., K. D. Koper, S. Rabade., N. Forbes, R. Burlacu, and R. A. Sohn (2019). Towards a better understanding of shallow water microseism generation in Yellowstone Lake, Yellowstone National Park, Fall Meeting of the American Geophysical Union, San Francisco, CA, December 9–13, 2019.

Koper, K. D. (2019). The importance of regional seismic networks in monitoring nuclear test-ban treaties, Fall Meeting of the American Geophysical Union, San Francisco, CA, December 9–13, 2019.

Johnson, B. N., K. D. Koper, G. Pang, R. Burlacu, and J. C. Pechmann (2019). High resolution relocations of the 2019 Bluffdale, Utah, earthquake sequence, 2019 AGU Fall Meeting, Dec. 9-13, 2019, San Francisco, California, Abstract S43F-0662.

Mendoza, K., B. Baker, and K. L. Pankow (2019). ANXCOR: Ambient noise cross correlation with Python (abstract, NS21A-01), 2019 Fall Meeting, AGU, San Francisco, CA, December 2019.

Mesimeri, M. and K. L. Pankow (2019). Detecting aftershocks using a dense N-array: The case of the 2019 M4.1 Black Rock, Utah sequence (abstract,

S41H-0630), 2019 Fall Meeting, AGU, San Francisco, CA, December 2019.

Pankow, K. L. and D. L. Kilb (2019). Spatial and temporal characteristics associated with remote dynamic earthquake triggering (abstract, S13D-0463), 2019 Fall Meeting, AGU, San Francisco, CA, December 2019.

Pang, G., S.-M. Wu, K. D. Koper, and G. G. Euler (2019). Regional variation of fine-scale structure of Earth's inner core, Fall Meeting of the American Geophysical Union, San Francisco, CA, December 9–13, 2019

Shelly, D. R., K. M. Whidden, K. L. Pankow, J. I. Walter, X. Chen, K. Mayeda, and W. R. Walter (2019). Addressing "the magnitude problem" for small earthquakes: exploring the coda envelope technique for moment magnitude estimation in Oklahoma (abstract, S53C-0512), 2019 Fall Meeting, AGU, San Francisco, CA, December 2019.

Voyles, J. R., Pitarka, A., Koper, K. D., & Holt, M. M. (2019). Simulated Effects of Shallow Crustal Heterogeneity, Surface Topography, and Seismic Source Depth on Coda Wave Generation for Magnitude-Based Depth Discrimination. AGUFM, 2019, S11E-0417.

Wells, D. E., K. L. Pankow, F. C. Lin, and B. Baker (2019). Ambient noise tomography across southern Utah combining multiple geophone deployments and broadband data (abstract, S11D-0365), 2019 Fall Meeting, AGU, San Francisco, CA, December 2019.

Zhang, H. and K. L. Pankow (2019). Bayesian SPAC tomography with a dense nodal array (abstract, S14A-05), 2019 Fall Meeting, AGU, San Francisco, CA, December 2019.

Other Abstracts

Koper, K. D., and R. Burlacu, Synoptic Study of Double-Frequency Microseisms Recorded by the Transportable Array in Alaska, 27th IUGG General Assembly, July 8–18, 2019.

Pankow, K. L., M. Mesimeri, and J. Moore (2019) Seismic monitoring at the Utah Frontier Observatory for Research in Geothermal Energy, Geothermal Research Council Annual Meeting, Palm Springs, CA.

Pankow, K. L., J. Rutledge, J. Moore, and J. McLennan (2019). Seismic monitoring at the Utah Frontier Observatory for Research in Geothermal Energy, Third Schatzalp Workshop on Induced Seismicity, Davos, Switzerland.

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Pankow, K., M. Mesimeri, and J. Moore (2019). Seismic monitoring at the Utah Frontier Observatory for Research in Geothermal Energy: Proceedings of the Geothermal Resources Council, v. 43

Moore, J., J. McLennan, R. Allis, K. Pankow, S. Simmons, R. Podgorney, P. Wannamaker, and W. Rickard (2019). The Utah Frontier Observatory for Research in Geothermal Energy (FORGE): An international laboratory for enhanced geothermal system technology development: Proceedings, 44th Workshop on Geothermal Reservoir Engineering, Stanford University, CA February 11- 13, 12 p.

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Holt, M. M., K. D. Koper, W. Yeck, S. D'Amico, Z. Li, J. M. Hale, and R. Burlacu (2019), On the portability of ML-MC as a depth discriminant for small seismic events recorded at local distances, Bull. Seismol. Soc. Am., 109, 1661–1673.

Linville, L., K. L. Pankow, T. Draelos, C. J. Young, and S. Alvarez (2019). Leveraging longterm seismic catalogs for automated real-time event classification, Geophys. Res. Lett., 46, 3643-3651, doi:10.1029/2018GL081119.

Pang, G., K. D. Koper, J. M. Hale, R. Burlacu, J. Farrell, and R.B. Smith (2019), The 2017-2018 Maple Creek earthquake sequence in Yellowstone National Park, USA, Geophys. Res. Lett., 46, 4653-4663, doi:10.1029/2019GL082376.

Pankow, K. L., M. Stickney, J. Y. Ben-Horin, M. Litherland, S. Payne, K. D. Koper, S. L. Bilek, and K. Bogolub, (2019). Regional Seismic Monitoring in the Eastern Intermountain West, Seism. Res. Lett., 91, 631-646, doi.1785/0220190209.

Schmandt, B., C. Jiang, and J. Farrell (2019), Seismic perspectives from the western U.S. on magma reservoirs underlying large silicic calderas, J. Volcanol. Geotherm. Res., 384, 158-178, doi:10.1016/j.volgeores.2019.07.015.

Wu, S. -M., F. -C. Lin, J. Farrell, and A. Allam (2019), Imaging the deep subsurface plumbing of Old Faithful geyser from low-frequency hydrothermal tremor migration, Geophys. Res. Lett., 46, 7315-7322, doi:10.1029/2018GL081771.

Ye, L., T. Lay, H. Kanamori, and K. D. Koper (2019), Reply to: Comment by Rodrigo Cienfuegos on "Rapidly Estimated Seismic Source Parameters for the 16 September 2015 Illapel, Chile, Mw 8.3 Earthquakes" by Lingling Ye, Thorne Lay, Hiroo Kanamori, and Keith D. Koper, Pure Appl. Geophys., 176, 2753, doi:10.1007/s00024-019-02214-3.

Zhang, H., K. L. Pankow, and W. Stephenson (2019). A Bayesian Monte-Carlo inversion of spatial auto-correlation (SPAC) for near surface Vs structure applied to both broadband and geophone data, Geophy. J. Intl., 217, 2056-2070, https://doi.org/10.1093/gji/ggz136.

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Burlacu, R., P. M. Roberson, J. M. Hale, N. Forbes, B. Johnson, K. D. Koper, J. C. Pechmann, and K. L. Pankow (2019), Earthquake Activity in the Utah Region Preliminary Epicenters October 1 – December 31, 2018, quarterly report of Univ. Utah Seismograph Stations, pp. 1–33.

Burlacu, R., P. M. Roberson, J. M. Hale, N. Forbes, B. Johnson, K. D. Koper, J. C. Pechmann, and K. L. Pankow (2019), Earthquake Activity in the Utah Region Preliminary Epicenters January 1 – March 31, 2019, quarterly report of Univ. Utah Seismograph Stations, pp. 1–45.

Burlacu, R., P. M. Roberson, J. M. Hale, N. Forbes, B. Johnson, K. D. Koper, J. C. Pechmann, and K. L. Pankow (2019), Earthquake Activity in the Utah Region Preliminary Epicenters April 1 – June 30, 2019, quarterly report of Univ. Utah Seismograph Stations, pp. 1–35.

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Farrell, J., R. Burlacu, P. M. Roberson, J. M. Hale, N. Forbes, B. Johnson, K. D. Koper, R. B. Smith, J. C. Pechmann, and K. L. Pankow (2019), Earthquake Activity in the Yellowstone Region Preliminary Epicenters October 1 – December 31, 2018, quarterly report of Univ. Utah Seismograph Stations, pp. 1–18.

Farrell, J., R. Burlacu, P. M. Roberson, J. M. Hale, N. Forbes, B. Johnson, K. D. Koper, R. B. Smith, J. C. Pechmann, and K. L. Pankow (2019), Earthquake Activity in the Yellowstone Region Preliminary Epicenters January 1 – March 31, 2019, quarterly report of Univ. Utah Seismograph Stations, pp. 1–17.

Farrell, J., R. Burlacu, P. M. Roberson, J. M. Hale, N. Forbes, B. Johnson, K. D. Koper, R. B. Smith, J. C. Pechmann, and K. L. Pankow (2019), Earthquake Activity in the Yellowstone Region Preliminary Epicenters April 1 – June 30, 2019, quarterly report of Univ. Utah Seismograph Stations, pp. 1–15.

Farrell, J., R. Burlacu, P. M. Roberson, J. M. Hale, N. Forbes, B. Johnson, K. D. Koper, R. B. Smith, J. C. Pechmann, and K. L. Pankow (2019), Earthquake Activity in the Yellowstone Region Preliminary Epicenters July 1 – September 30, 2019, quarterly report of Univ. Utah Seismograph Stations, pp. 1–18.

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Arabasz, W.J. (2019). Revised historical catalog for the Utah Region, 1850-June 1962: University of Utah Seismograph Stations Report, Excel Workbook with catalog database, online at https://quake.utah.edu/earthquake-information-products/earthquake-catalogs/revised-historical-earthquake-catalog-for-the-utah-region-1850-june-1962.

Pankow, K. L., S. Potter, H. Zhang, A. Trow, A. S. Record, (2019). Micro-seismic characterization of the Utah FORGE Site, (eds.) R. Allis and J. Moore, Utah Geological Survey Misc. Pub. 169-G, doi:10.34191/MP-169.

Trow, A. J., K. L. Pankow, Y. Wang, F. C. Lin (2019). Local ambient noise tomography over the FORGE Utah site, (eds.) R. Allis and J. Moore, Utah Geological Survey Misc. Pub. 169-G, doi:10.34191/MP-169.


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