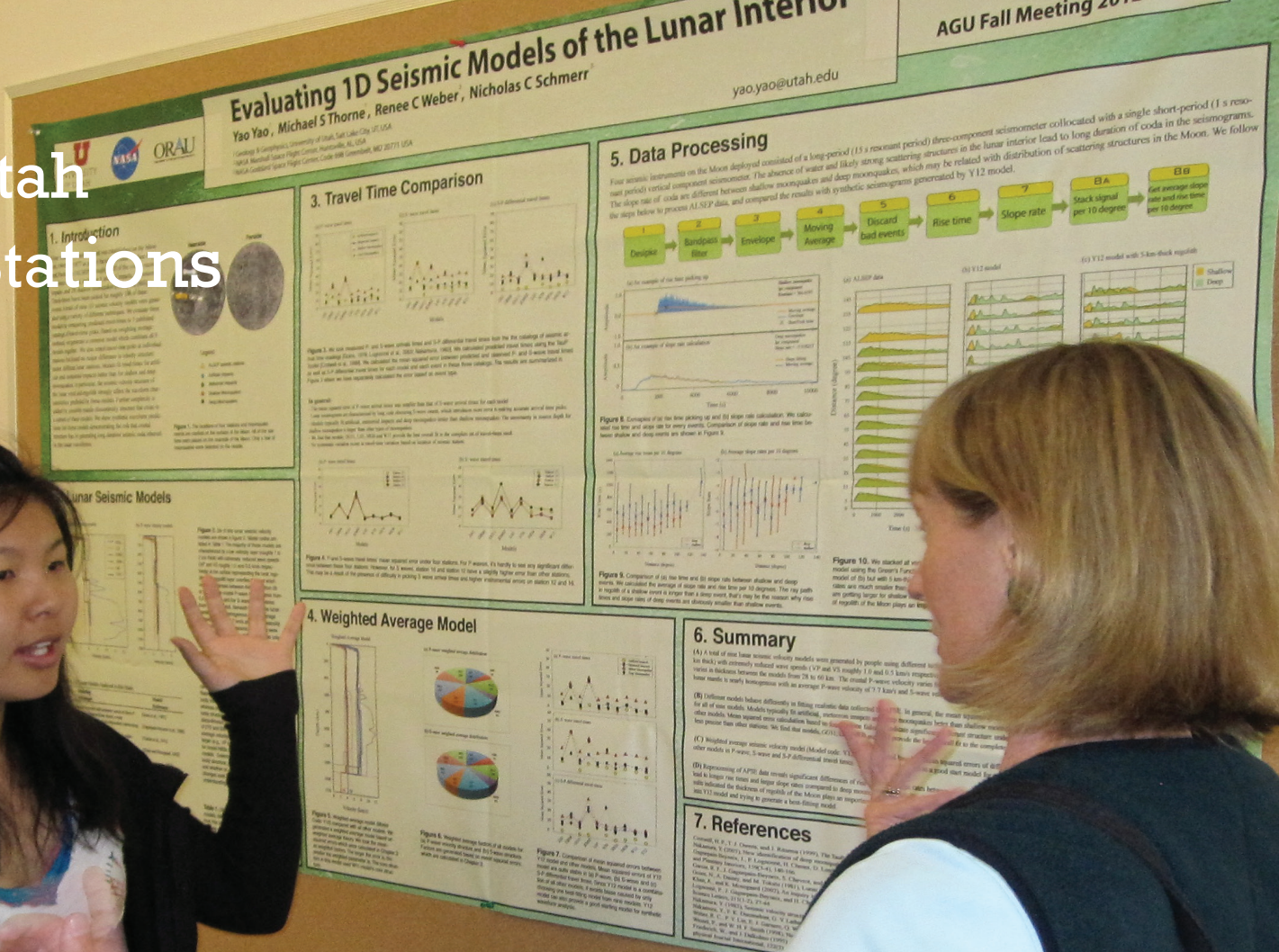


University of Utah Seismograph Stations



2013 Annual Report



University of Utah Seismograph Stations (UUSS) had another busy year in 2013.

The professional highlight was hosting the annual meeting of the Seismological Society of America (SSA), April 17-19, at the Salt Palace Convention Center in downtown Salt Lake City. The SSA is the world's premier scientific society dedicated to the study of earthquakes. UUSS personnel served on the organizing committee, led a Town Hall Meeting, moderated several of the scientific sessions, and contributed to 12 scientific presentations. For some UUSS students, it was the first time attending a professional meeting and they were excited to meet scientists whom they had previously known by reputation only.

During 2013 UUSS detected and located about 6,000 earthquakes in the Intermountain West. This region includes all of Utah and Yellowstone National Park, as well as parts of Arizona, Colorado, Idaho, Montana, and Wyoming. Although none of the earthquakes were large enough to cause significant damage, careful documentation of these events allows us to better define the locations of active faults and to estimate seismic hazard in the region more precisely. The geologic record clearly indicates that magnitude 6.5-7.5 earthquakes have repeatedly occurred along the Wasatch fault in areas of Utah that are now densely populated.

In addition to earthquakes, our seismic network often observes other "exotic" sources of seismic energy. Such a source occurred on the evening of April 10, 2013 when the northeastern wall of the Bingham Canyon, Utah open-pit copper mine collapsed in two distinct landslides separated by about 90 minutes. The combined episode was the largest non-volcanic

landslide to occur in North America in modern times. Seismic waves were well recorded thousands of kilometers away from the mine, and at least 16 tiny earthquakes were triggered by stress changes associated with the landslide. Owing to rigorous geotechnical monitoring, the mine operators were able to accurately predict the timing of the landslide and so avoid casualties.

A second exotic seismic source occurred on July 31 at 7:30 p.m. (local time) when the Steamboat Geyser in Yellowstone National Park erupted, sending water 200-300 feet in the air. Signals recorded at a nearby seismometer showed energy lasting for over two hours as steam poured out of vents following the initial eruption. Notably, acoustic energy from the eruption was recorded by one of the infrasound stations located in the park.

In 2014 the students, faculty, and staff of UUSS will continue to monitor earthquake activity in the Intermountain West and to raise awareness of the seismic hazard in the State of Utah. Academic research will focus on a range of topics including the rupture properties of large earthquakes, earthquake swarm and aftershock sequences, seismicity induced by mining and other anthropogenic activities, as well as producing better images and models of the geological structure beneath Utah and Yellowstone.



*Keith D. Koper
Director, UUSS*

Cover Photo: Graduate student Yao Yao discusses her research poster with attendees at the spring student poster session.

University of Utah Seismograph Stations

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Image courtesy of the University of Utah



Image courtesy of the University of Utah



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Research Notes

Annual Meeting of the Seismological Society of America

Salt Lake City was host to the 2013 Annual Meeting of the Seismological Society of America (SSA), held April 17-19 at the Salt Palace Convention Center. SSA provides an annual opportunity to share and discuss current seismological research with colleagues from around the world.



Dr. Keith Koper and Oner Sufri visit with Dr. Victor Tsai of the California Institute of Technology.

Scientists and students affiliated with UUSS made significant contributions to the meeting proceedings. UUSS Director Dr. Keith Koper participated as technical program committee co-chair, with Dr. Jim Pechmann and student Christine Gammans who served as program committee members. UUSS Associate Director Dr. Kristine Pankow served as a member of the Student Award subcommittee.

Dr. Koper co-chaired two oral sessions: “Intermountain West Earthquake and Volcano Characterization and Related Hazards”, and “Oceanographic and Atmospheric Signals in Seismology.” A third oral session was co-chaired by Dr. Kris Pankow, “Triggering of Seismic and Volcanic Events”.

UUSS scientists and students contributed to a total of seventeen talks and poster presentations during the meeting’s technical proceedings. Jamie Farrell was recognized with a 2013 SSA Student Presentation Award for excellence in both content and presentation of his invited talk: “Crustal Velocity Structure and Seismicity of the Yellowstone Volcanic System from Automated Waveform Analysis of Body Waves, 1984-2011.”

A public town hall meeting, “Utah Earthquakes and You - It’s Personal,” was held in conjunction with the Great Utah ShakeOut, to educate attendees about earthquake preparedness. The meeting, held at the Radisson Hotel Salt Lake City Downtown, involved presentations from seven participants, including Dr. Walter Arabasz, “Utah’s Earthquake Threat - the Big Picture and the Long View,” and Dr. Jim Pechmann, “How Strong Will the Ground Shaking be During the ‘Big One’ - and Other Future Earthquakes”.



Jamie Farrell, Tex Kubacki, Lisa Linville, and Meagan Boltz.

Dr. Arabasz also participated as a co-speaker with program committee co-chair Ivan Wong in a luncheon address: “The Big One Will Hit during This Luncheon (or Not)—Utah Earthquake Probabilities

and Public Policy Making.” The address highlighted the key challenge of how to motivate a constant, long-term level of preparedness before Utah’s next large earthquake.



Dr. David Wald of the U.S. Geological Survey and Dr. Kristine Pankow discuss ShakeCast Implementation with Mike Ellis and Josh Sletten of the Utah Dept of Transportation.

An open house and tour of the Rio Tinto Earthquake Information Center on the campus of the University of Utah was conducted by UUSS personnel, as part of a field trip for visiting SSA scientists.



Dr. Kristine Pankow discusses a poster with Dr. Debbie Kilb of the Scripps Institution of Oceanography and Lisa Linville.

Salt Lake Valley Seismic Noise Study

Dr. Fan-Chi Lin, University of Utah Assistant Professor of Geology and Geophysics, partnered with UUSS to conduct a preliminary seismic noise study in and near the Salt Lake Valley.



Dr. Fan-Chi Lin looks on as technician Dave Drobeck activates a Nodal Seismic geophone system using a handheld computer.

In November, six Nodal Seismic geophones and four broadband seismometers, some of which were co-located with broadband seismometer, were deployed in the area (all with on-site digital recording.) Passive seismic data from these instruments was gathered over a two-week period. The data will be analyzed along with data from nearby permanent stations to determine if empirical Green's functions between each station pair can be extracted using a



Close-up view of a Nodal Seismic geophone which houses a sensor, datalogger, and a Global Positioning Satellite clock.



Dr. Lin poses with newly installed Nodal Seismic geophone.

noise cross-correlation method. From the analysis Dr. Lin hopes to learn more about the noise wavefield in the Salt Lake Valley.

If robust surface wave signals can be extracted by noise cross-correlation, Dr. Lin will conduct a second, more ambitious study involving a dense temporary array which will allow the construction of a high-resolution 3D basin model beneath the Salt Lake Valley to improve understanding of fault structure and seismic wave propagation in the area.

Dr. Lin, joined the faculty of the University of Utah

Department of Geology and Geophysics in 2013. He received his PhD from the University of Colorado at Boulder and recently completed a post-doc at the California Institute of Technology

Annual Meeting of the American Geophysical Union

A handful of UUSS scientists and students traveled to San Francisco, CA to attend the 2013 Annual Meeting of the American Geophysical Union (AGU), held December 9-13.



Katherine Whidden, J. Mark Hale, Dr. Kris Pankow, and Lisa Linville meet for dinner with former UUSS staff members, Fabia Terra and Sue Nava at AGU.

During the meeting proceedings, a total of five scientific presentations were delivered by UUSS attendees: Dr. Kristine Pankow, Katherine Whidden, and students J. Mark Hale, Kevin Kwong, and Lisa Linville. Overall, UUSS personnel contributed to a total of ten presentations made during the meeting's technical proceedings.

Conferences such as AGU allow earth scientists to keep abreast of advances being made in current research. Dr. Pankow believes the conference also provides an important opportunity to network with other scientists and former colleagues. "Dinner at

AGU with both current and past UUSS folks was a nice chance to connect. Thanks to Fabia for showing us a local's pick for restaurants in Chinatown."

Spring Student Poster Session

Students from the Department of Geology and Geophysics had an opportunity to hone their presentation skills by sharing their research during the spring semester student poster session.



Students Oner Sufri (far left) and Yao Yao (far right) present their research at the spring student poster session.

The event was co-sponsored by Conoco Phillips and the University of Utah Student Chapter of the American Association for Petroleum Geologists (AAPG). The forty participating students were each assigned a station on one of the three upper floors of the Frederick Albert Sutton building. Visitors were given 45 minutes to listen to presentations on each floor.

Christine Gammans, Kevin Kwong, Oner Sufri, and Yao Yao all presented research posters in the Seismology/Structural Geology Group.

Visiting Scientists and Guests

In early September, UUSS received a visit from Lingling Ye, a PhD student from the University of Cal-

ifornia Santa Cruz. Ye traveled to the University of Utah to study a new technique for inferring the rupture properties of large earthquakes with Dr. Keith Koper.

Nuclear-Test-Ban Treaty Science and Technology Conference

The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) has organized for the last seven years the Science and Technology conference series. The 2013 edition, hosted by the city of Vienna, Austria, has brought together more than 750 participants from 100 countries. The conference, whose main declared goal was to "build and strengthen its relationship



Opening ceremony at the CTBT Science and Technology 2013 Conference at the Hofburg Imperial Palace in Vienna, Austria. Photo courtesy of www.ctbto.org

with the broader science community in support of the CTBT," has benefitted by the presence of distinguished keynote speakers, like Hans Blix, former Director General of the International Atomic Energy.

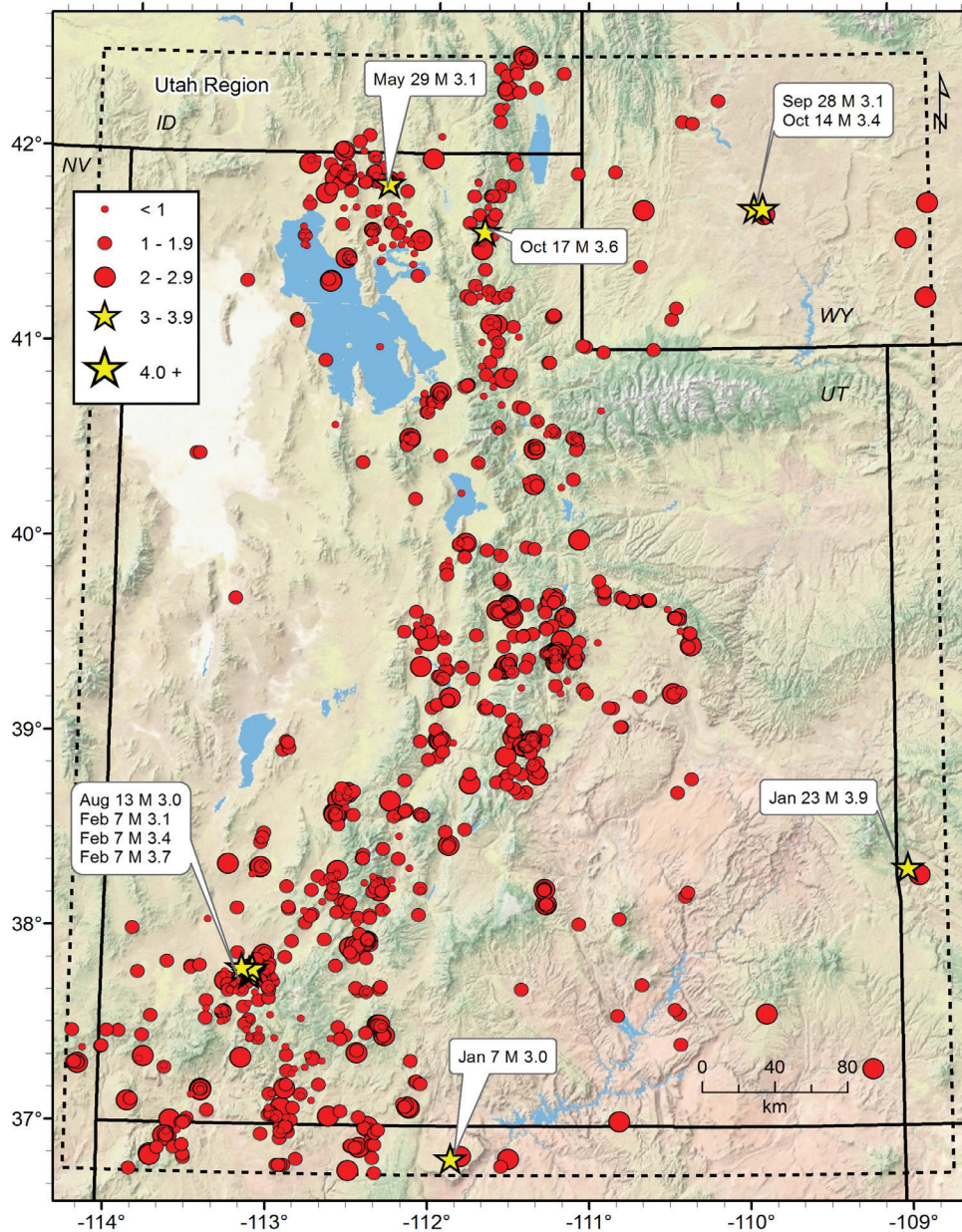
Relu Burlacu participated with a poster (with co-authors Keith Koper, UUSS, and Stephen Arrowsmith, LANL) that focused on ambient noise recorded at ~400 USArray TA infrasound stations. The UUSS presence at the conference represented an opportunity to develop a strong relation with the CTBT community and to continue our commitment of being actively involved in the nuclear monitoring research.

First Full Year of Operations for Earthquake Monitoring System

The ANSS Quake Monitoring System (AQMS) has been implemented into the UUSS operations in the last quarter of 2012, after a period of comprehensive testing, and has been continuously running during the year 2013. Together with the operation and maintenance of more than 200 seismic stations, the AQMS is part of the UUSS advanced infrastructure that forms the Utah regional seismic network and provides high quality earthquake related data and data products in agreement with the ANSS performance standards. Built around an Oracle database, the AQMS system allows direct access to all recorded seismic events, for post-processing or statistic analyses of the seismic activity in Utah and Yellowstone.

At UUSS, AQMS has evolved into a complex system of hardware and software components. Currently, we manage two operational redundant systems—each having both a real-time and a post-processing machine—at the University of Utah location, and a third system at our hot site in Richfield, Utah, part of the UUSS continuity of operations plan. We operate two additional AQMS systems for testing and implementation of new software solutions, configuration

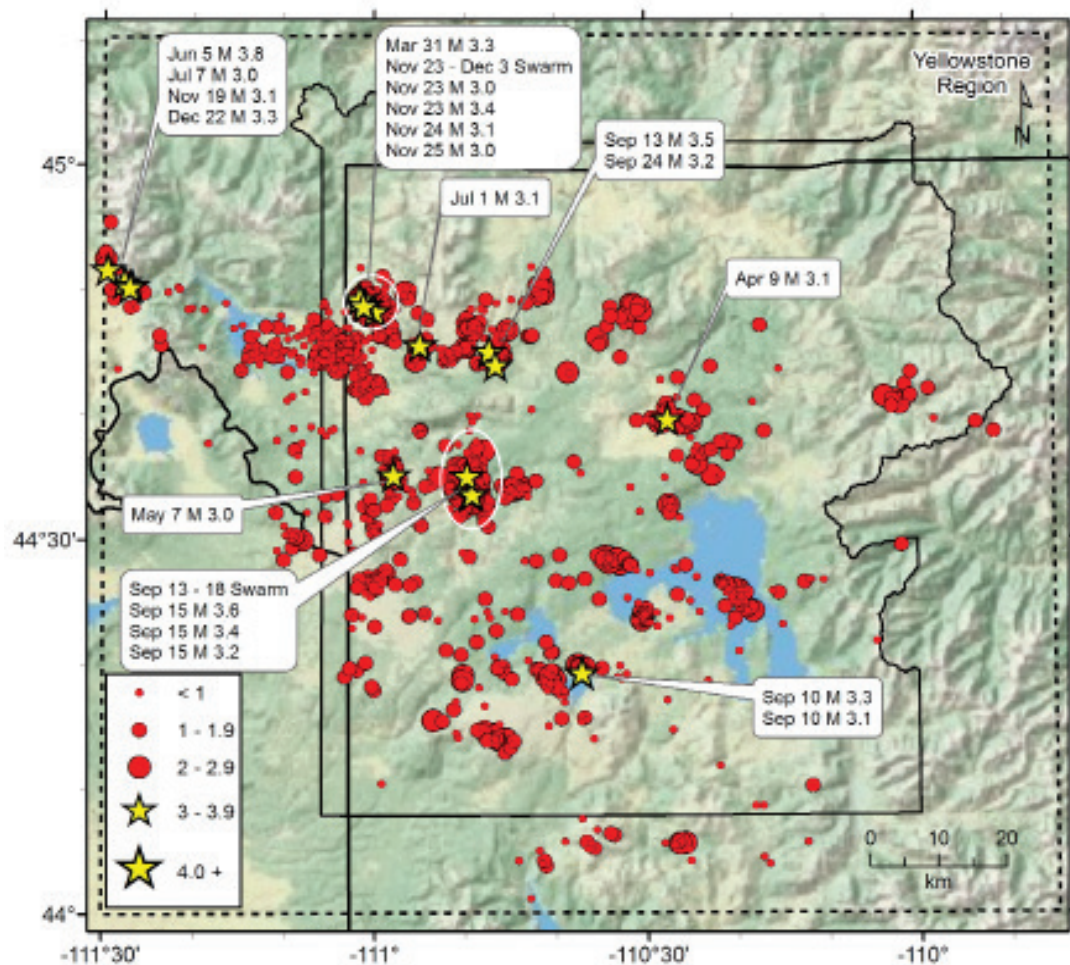
Seismicity of the Utah Region January 1, 2013 - December 31, 2013



During the twelve-month period January 1 through December 31, 2013 the University of Utah Seismograph Stations located 1546 earthquakes within the Utah region. The total includes 10 earthquakes in the magnitude 3 range, and 135 earthquakes in the magnitude 2 range. Earthquakes of magnitude 3.0 or larger occurring in 2013 are plotted as stars (see map at left).

| | | |
|-----------|---------------------|---------------------------------|
| M_L 3.0 | Jan 7 08:36 MST | 22 mi WSW of Page, AZ |
| M_W 3.9 | Jan 23 21:46 MST | 14 mi WSW of Uravan, CO |
| M_L 3.1 | Feb 7 12:29 MST | 5 mi WNW of Enoch, UT |
| M_L 3.4 | Feb 7 13:02 MST | 6 mi W of Enoch, UT |
| M_L 3.7 | Feb 7 19:47 MST | 6 mi W of Enoch, UT |
| M_L 3.1 | May 29 07:32 MDT | 11 mi WNW of Garland, UT |
| M_L 3.0 | Aug 13 23:47 MDT | 9 mi W of Enoch, UT |
| M_L 3.1 | Sep 28 02:54 MDT | 24 mi WNW of Green River, WY |
| M_L 3.4 | Oct 14 18:03 MDT | 27 mi WNW of Green River, WY |
| M_L 3.6 | Oct 17 10:19 MDT | 8 mi ENE of Paradise, UT |

Seismicity of the Yellowstone National Park Region January 1, 2013 - December 31, 2013



During the twelve-month period January 1 through December 31, 2013 the University of Utah Seismograph Stations located 1954 earthquakes within the Yellowstone National Park region - which reflects a relatively normal rate of earthquakes for the region. The total includes 19 earthquakes in the magnitude 3 range, and 143 earthquakes in the magnitude 2 range. Earthquakes of magnitude 3.0 or larger occurring in 2013 are plotted as stars (see map at left).

There were two significant earthquake swarms in 2013. The largest swarm occurred beneath the Lower Geyser Basin from September 13-18 and consisted of 229 earthquakes (indicated by an oval on map at left). The next largest occurred 13 mi NNE of West Yellowstone, MT from November 23 – December 3 and consisted of 213 earthquakes (indicated by a circle on map at left). In addition to these two largest swarms, there were numerous smaller swarms in the Yellowstone region. Overall, swarm seismicity constituted 59% of the total seismicity for 2013. A swarm is a series of earthquakes clustered in space and time with no outstanding main shock.

| | | | | | |
|-----------|---------------------|--------------------------------------|-----------|---------------------|--------------------------------------|
| M_L 3.3 | Mar 31 10:41 MST | 11 mi NNE of West Yellowstone, MT | M_L 3.2 | Sep 15 05:11 MDT | 8 mi N of Old Faithful, YNP |
| M_L 3.1 | Apr 9 03:33 MDT | 8 mi NNW of Fishing Bridge, YNP | M_L 3.6 | Sep 15 09:53 MDT | 6 mi N of Old Faithful, YNP |
| M_L 3.0 | May 7 07:22 MDT | 8 mi SE of West Yellowstone, MT | M_L 3.2 | Sep 24 04:24 MDT | 4 mi W of Norris Junction, YNP |
| M_L 3.8 | Jun 5 20:09 MDT | 23 mi NW of West Yellowstone, MT | M_L 3.1 | Nov 19 19:32 MST | 24 mi NW of West Yellowstone, MT |
| M_L 3.1 | Jul 1 04:49 MDT | 12 mi NE of West Yellowstone, MT | M_L 3.4 | Nov 23 13:47 MST | 11 mi NNE of West Yellowstone, MT |
| M_L 3.0 | Jul 7 12:42 MDT | 21 mi NW of West Yellowstone, MT | M_L 3.0 | Nov 23 16:03 MST | 11 mi NNE of West Yellowstone, MT |
| M_L 3.3 | Sep 10 06:46 MDT | 14 mi SE of Old Faithful, YNP | M_L 3.1 | Nov 24 00:18 MST | 12 mi NNE of West Yellowstone, MT |
| M_L 3.1 | Sep 10 06:57 MDT | 14 mi SE of Old Faithful, YNP | M_L 3.0 | Nov 25 14:10 MST | 11 mi NNE of West Yellowstone, MT |
| M_L 3.5 | Sep 13 6:56 MDT | 5 mi NW of Norris Junction, YNP | M_L 3.3 | Dec 22 14:39 MST | 22 mi NW of West Yellowstone, MT |
| M_L 3.4 | Sep 15 05:10 MDT | 7 mi N of Old Faithful, YNP | | | |



“Planning is imperative and would not be possible without the information generated by the University of Utah Seismograph Stations, the Utah Geological Survey and structural engineers.”

Bob Carey
Utah Division of Emergency Management

“Walter Arabasz, a University of Utah professor emeritus, stressed the likelihood of a massive earthquake is roughly the same as the risk of heart disease. Though city and state governments have enacted measures toward emergency preparedness, the panel is worried. Any earthquake-proof buildings or emergency responses have not been tested yet. They insist individual action will be key. *‘Our vulnerability is increasing every year,’ Arabasz said. ‘Invariably, there’s a terrible price to pay. We need to build resilient communities and take common sense measures.’*”

“Seismologists Warn Utah is Unprepared for the Big One: Town Hall Meeting -Food, Water Storage, Medical Kits and Plan to Escape are Needed.”
DJ Summers, The Salt Lake Tribune, April 18, 2013, updated 4/21/2013

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Bahavar, M., A. R. Hutko, C. M. Trabant, K. D. Koper, R. E. Anthony, and R. C. Aster (2013). The new IRIS DMC noise toolkit, Abstract S11A-2310.

Farrell, J., R. B. Smith, S. Husen (2013). The Yellowstone magma reservoir is 50% larger than previously imaged, Abstract V41B-2778.

Hale, J. M., S. Arrowsmith, R. Burlacu, C. Hayward, K. L. Pankow (2013), Infrasound observations of the massive landslide at Bingham Canyon Copper Mine, Abstract S23B-2489.

Kwong, K. B., K. D. Koper, H. Yue, and T. Lay (2013), Reconciling short-period and broadband source models of the Mw 8.7 Indian Ocean earthquake of 11 April 2012, Abstract S43A-2472.

Linville, L. M., K. L. Pankow, D. L. Kilb, A. A. Velasco, C. Hayward (2013), Dynamic triggering potential of large earthquakes recorded by the EarthScope U.S. Transportable Array using a frequency domain detection method, Abstract S44B-02.

Pankow, K. L., S. R. Ford, T. M. Kubacki, K. D. Koper, K. M. Whidden, J. R. Moore, M. K. McCarter (2013), Bingham Canyon landslide: Force history analysis and identification of induced earthquakes, Abstract NH14A-02.

Whidden, K. M., L. Rudzinski, G. Lizurek, K. L. Pankow (2013), Regional, local, and in-mine moment tensors for the 2013 Rudna Mine collapse, Abstract S21B-2396.

Whittaker, S., M. S. Thorne, K. D. Koper, and N. C. Schmerr (2013), Broadband array observations of the D" discontinuity, Abstract DI51A-2270.

Ye, L., T. Lay, H. Kanamori, and K. D. Koper (2013), Energy release of the 2013 Mw 8.3 Sea of Okhotsk earthquake and deep slab stress heterogeneity, Abstract S41C-01.

Yue, H., T. Lay, J. T. freymueller, K. Ding, L. A. Rivera, N. A. Ruppert, and K. D. Koper (2013), Super-shear rupture of 2013 Jan 05, Mw 7.5, Craig, Alaska earthquake, Abstract S33E-07.



Other Presentations

Arabasz, W. J., "Utah's Earthquake Threat—the Big Picture and the Long View," (invited presentation) Utah Earthquakes and You—It's Personal, Town Hall Meeting, Seismological Society of America, Salt Lake City, UT, April 17, 2013.

Arabasz, W. J., "Utah Earthquake Probabilities and Public Policy Making," (invited presentation),

Public Policy Luncheon, Annual Meeting of the Seismological Society of America, Salt Lake City, UT, April 18, 2013.

Arabasz, W. J., "A Revised Earthquake Catalog and Unbiased Seismicity Rate Calculations for Background Seismicity in the WGUEP Region," meeting of the Working Group for Utah Earthquake Probabilities, Salt Lake City, UT, September 12, 2013.

Koper, K. D., "Rupture Imaging of Recent Giant Earthquakes", (invited presentation), Northwestern University, Evanston, IL, January 11, 2013.

Koper, K. D., "Using Seismology to Observe Ocean Storms and Storminess", (invited presentation), National Academy of Sciences Workshop on Observations of Sea-Level Rise and Storminess in California, Irvine, CA, June 20, 2013.

Koper, K. D., "Microseisms from Superstorm Sandy Recorded in North America by the Transportable Array", (invited presentation), IUGG Joint Assembly, Gothenburg, Sweden, July 25, 2013.

Pankow, K. L., "Bingham Canyon Rock Avalanche" (invited presentation with Jeff Moore), Distinguished Lecture Series, University of Utah Department of Geology and Geophysics, Salt Lake City, UT, October 24, 2013.

Pankow, K. L., "Bingham Canyon Rock Avalanche" (invited presentation with Jeff Moore), Rio Tinto Kennecott, South Jordan, UT, December 3, 2013.

Pechmann, J. C., "How strong will the ground shaking be during the 'big one' —and other future earthquakes," (invited presentation) Utah Earthquakes and You—It's Personal, Town Hall Meeting, Seismological Society of America, Salt Lake City, UT, April 17, 2013.

Pechmann, J. C., Discussion of "NOVA: Japan's Killer

Quake," (invited presentation), Natural History Museum of Utah Science Movie Night, Salt Lake City, UT, June 11, 2013.

Pechmann, J. C., "Preliminary Comparison of Geodetic and Geological/Seismological Moment Rates in the WGUEP Wasatch Front Region", (invited presentation), Meeting of the Working Group on Utah Earthquake Probabilities, Salt Lake City, UT, September 12, 2013.

Research Projects

A Unified Earthquake Catalog and Background Seismicity Rates for the Wasatch Front and Surrounding Utah Region

This project represents one aspect of collaborative efforts by a Working Group on Utah Earthquake Probabilities, organized under the auspices of the Utah Geological Survey and the U.S. Geological Survey. Dr. Walter Arabasz, with assistance from Dr. Jim Pechmann and Relu Burlacu, extensive continued work was carried out on the construction and analysis of a unified earthquake catalog, 1850–2012, and the calculation of seismicity rates for the Wasatch Front and surrounding Utah region. The seismicity analyses involve more thorough and rigorous treatment of the earthquake record, magnitude estimates, and magnitude uncertainties than previously attempted.

During 2013, major work focused primarily on four aspects of the project: (1) the refinement of the methodology for the estimation of unbiased earthquake recurrence parameters; (2) the assessment of magnitude uncertainties associated with multiple magnitude types—in their original scales, in their conversion to moment magnitude, and in their combination to achieve best-estimate values of moment magnitude; (3) the completion of the final unified earthquake catalog, including a "declustered" ver-

sion from which secondary events (foreshocks and aftershocks) have been removed; and (4) the construction of background earthquake recurrence models ($M < 6.75$), specified by unbiased seismicity-rate parameters, for both the Wasatch Front region and the Utah region as a whole.

Bingham Canyon Landslide

UUSS seismologists and others are analyzing the April 10, 2013, Bingham Canyon Mine landslide using seismic, acoustic, and photographic data. The research team consists of UUSS staff members Dr. Kris Pankow, Dr. Keith Koper, Katherine Whidden, and Mark Hale; UU Mining Engineering graduate student Tex Kubacki, Dr. Jeff Moore (UU Geology and Geophysics), Dr. Kim McCarter (UU Mining Engineering), and Sean Ford (Lawrence Livermore National Laboratory).

Research avenues are related to the analyses of induced earthquakes, reconstructing the source time history, and modeling of the infrasound data. Initial work was presented at the AGU 2013 Fall Meeting in San Francisco and published in the January 2014 issue of GSA Today.

Dynamic Earthquake Triggering

Continuing work with UU Geology and Geophysics graduate student Lisa Linville and collaborators from Scripps and the University of Texas El Paso, Dr. Kris Pankow continues to analyze data from the National Science Foundation Transportable Array (TA) to identify dynamically triggered earthquakes. As part of this work, Lisa Linville has developed a new frequency domain earthquake detection algorithm and has shown that there is no convincing case that 12 $M > 8$ earthquakes occurring from 2007–2012 triggered earthquakes across the TA Array. Work is continuing on analyzing $M > 7$ earthquakes. Using the larger catalog of dynamically triggered earthquakes from this study, together with properties of the seis-

mic waves generated by the teleseisms, the goal is to understand the physics behind dynamic earthquake triggering.

An M 4.8 Earthquake in the Upper Mantle Beneath the Wind River Range, Wyoming

On Sept. 21, 2013, a rare continental upper mantle earthquake of M_w 4.8 occurred beneath the Wind River Range of western Wyoming. This event is being analyzed by Dr. Jim Pechmann, Dr. Keith Koper, Katherine Whidden, and Dr. Kris Pankow of the UUSS in collaboration with Dr. Bob Herrmann (St. Louis



University), Dr. Harley Benz (U.S. Geological Survey), and Dr. Fan-Chi Lin and Dr. Dave Chapman (UU Geology and Geophysics). Results to date indicate a depth of 70 to 85 km below the surface, a strike-slip focal mechanism with a small reverse component, and a stress drop of 100 to 130 bars.

Magnitudes to Moment Magnitudes

Dr. Jim Pechmann and Katherine Whidden continued their work on empirical relations between mo-

ment magnitude (M_w) and the magnitudes in the UUSS instrumental earthquake catalog for the Utah region: local magnitude (M_L) and coda magnitude (M_C), which is calibrated against M_L . These relations are two of the eighteen magnitude conversion relations developed for the Working Group on Utah Earthquake Probabilities earthquake catalog project, but are the most important in terms of their impact on the best-estimate moment magnitudes in the catalog. The M_w - M_L data are consistent with a nonlinear relation, as expected based on theory and on data from California. Nevertheless, the relations between M_w and both M_L and M_C are well approximated by linear relations with slopes less than one over the magnitude range 3 to 6.

Local Utah Earthquakes

UU Geology and Geophysics graduate student Christine Gammans completed her MS thesis on the 2011 M_w 4.5 Tushar Mountains earthquake. In collaboration with Dr. Kris Pankow, Dr. Keith Koper, Dr. Jim Pechmann, Katherine Whidden, and Dr. John Bartley (UU Geology and Geophysics), Christine relocated aftershocks, determined first-motion focal mechanisms, and determined source durations for the mainshock and one of the larger aftershocks using the empirical Green's function technique. From the analysis, it seems plausible that the mainshock occurred on a low-angle normal fault and that the majority of aftershocks occurred on a secondary fault plane.

Mining-Induced Seismicity (MIS)

Dr. Kris Pankow has been working with UU Mining Engineering graduate students Meagan Boltz, Tex Kubacki, Derrick Chambers, and Jared Stein to improve three-dimensional locations of MIS. Results

from these studies will then be used to compare to geotechnical models, mine operation plans, and In-Sar images, and to discriminate between MIS and tectonic earthquakes.

Kris is also working with Katherine Whidden to determine moment tensors for MIS. This year they have focused on a mine collapse in Poland where there were differing interpretations of the cause of the seismic event. Combining efforts with Polish scientists and using seismic data from in-mine, above-mine, and regional distances, they concluded that the seismic energy was generated by a collapse in the mine.

The Relation of University of Utah Local and Coda Infrasond from Small Earthquakes

UU Geology and Geophysics graduate student Mark Hale (also a UUSS seismic analyst) completed his MS thesis on the generation of infrasond from small earthquakes in the Intermountain Region in collaboration with UUSS Seismic Network Manager Relu Burlacu, Dr. Kris Pankow, and collaborators from Southern Methodist University and Los Alamos National Laboratory. Mark concluded that it was uncommon to detect infrasond generated by small earthquakes. There was a minimum ground motion threshold found for all detections, but exceeding this ground motion did not guarantee an infrasond detection.

Analysis of Storm-Induced Seismic Energy Recorded Across North America

Detection and Location of Mining-Induced Seismicity

Imaging the Rupture Properties of Large Earthquakes in Pakistan, the South Shetland Islands, and the Indian Ocean

Committee Service

Dr. Keith D. Koper

- Vice-chair, Utah Seismic Safety Commission, 2010-present.
- Member, US Air Force Seismic Review Panel, 2011-present.
- Co-chair, Program Committee, 2013 Annual Meeting, Seismological Society of America, 2012-2013.
- Member, Editorial Advisory Board, EOS Transactions of the American Geophysical Union, 2010-present.
- Co-chair, Workshop on Arrays in Global Seismology, Incorporated Research Institutions for Seismology (IRIS), Raleigh, North Carolina, May 15-16, 2013.
- Co-organizer, Session on Array Seismology, International Association of Seismology and Physics of the Earth's Interior (IASPEI), Gothenburg, Sweden, July 25, 2013.

Dr. Kristine L. Pankow

- Member, Board of Directors, Earthquake Engineering Research Institute (EERI) - Utah Chapter, 2013-present.
- Voting Member, Utah Mine Safety Technical Advisory Council, 2011-present.
- Intermountain West Regional Coordinator, Advanced National Seismic System (ANSS), 2010-present.
- Member, Utah Ground-Shaking Working Group, Utah Geological Survey, 2003-present.

Dr. James C. Pechmann

- Member, Program Committee, 2013 Annual Meeting, Seismological Society of America, 2012-2013.
- Member, Utah Quaternary Fault Parameters Working Group, Utah Geological Survey, 2003-present.
- Member, Utah Ground-Shaking Working Group, Utah Geological Survey, 2003-present.
- Member, Working Group on Utah Earthquake Probabilities, Utah Geological Survey, 2010-present.

Dr. Walter J. Arabasz

- Member, Working Group on Utah Earthquake Probabilities, Utah Geological Survey, 2010-present.
- Chair, Update Steering Committee, Pajarito Fault System (PFS) External Review Project, Los Alamos National Laboratory, 2011-2013.
- Chair, Participatory Peer Review Panel, Ground-Motion Model Review Project (2004, 2006), Electric Power Research Institute (EPRI), Palo Alto, California, 2012-2013.



People

Faculty

- Dr. Keith D. Koper
Director
Associate 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. Walter J. Arabasz
Emeritus Director
Emeritus Research Professor
of Geology and Geophysics

Full-time Staff

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

Part-time Staff

- Jamie Farrell
Postdoctoral Research Associate
- Gordon Johansen
Field Assistant
- Barry Morse
Station Attendant
- Wesley O'Keefe
Field Assistant
- Peter O'Neill
Field Assistant
- Sheryl Peterson
Staff Specialist
- Marcela Torres
Exhibit Coordinator
- Ken Whipp
Electronics Technician



Internships

Kevin Kwong—Cross-Correlation of Ambient Infrasonic Noise from Arrays in Utah

Kevin's summer internship was at the Air Force Research Laboratory at Kirtland Air Force Base in Albuquerque, New Mexico. As a Space Scholar working under Dr. Eli Baker, Kevin focused on cross-correlating noise from infrasound arrays in Utah to test whether atmospheric Green's functions could be recovered. This type of research attempts to advance nuclear test monitoring capabilities.

Derrick Chambers—Mining Seismicity Research

Derrick's internship took place at the National Institute for Occupational Safety and Health (NIOSH) Office of Mining Safety and Health in Spokane, Washington. Derrick participated in mining seismicity research by writing programs to mine seismic data, process seismic traces, and convert file formats.

New Endeavors

Recent MS graduate Christine Gammans accepted a position with Chevron Corporation in Houston, TX.

Undergraduate Students

- Derrick Chambers BS-Mining Engineering
- Shaz Mohammad Jamaal BS-Geoscience
- Eli Workman BS-Geoscience
- Yeou Hui Wong BS-Geoscience

Graduate Students

- Meagan Boltz MS-Mining Engineering
- Jamie Farrell (Staff) PhD-Geophysics
- Christine Gammans MS-Geophysics
- J. Mark Hale (Staff) MS-Geophysics
- Kevin Jensen MS-Geophysics
- Kevin Kwong MS-Geophysics
- Tex Kubacki MS-Mining Engineering
- Lisa Linville MS-Geophysics
- Sheryl Peterson (Staff) MPC-Communication (Weber State University)
- Jared Stein MS-Geophysics
- Oner Sufri PhD-Geophysics
- Stefanie Whittaker MS-Geophysics

Fellowships and Scholarships

- Shaz Mohammad Jamaal
Dean's Scholarship - UU College of Mines and Earth Sciences
Geology and Geophysics Scholarship - UU Dept of Geology and Geophysics
- Yeou Hui Wong
Dean's Scholarship - UU College of Mines and Earth Sciences
Geology and Geophysics Scholarship - UU Dept of Geology and Geophysics

Awards

- Jamie Farrell
2013 SSA Student Presentation Award
Seismological Society of America (SSA)
- Yeou Hui Wong
2012-2013 Outstanding Undergraduate in Geophysics
UU Department of Geology and Geophysics
- Sheryl Peterson
Management Essentials Certificate
UU Department of Human Resources

Graduate Degrees

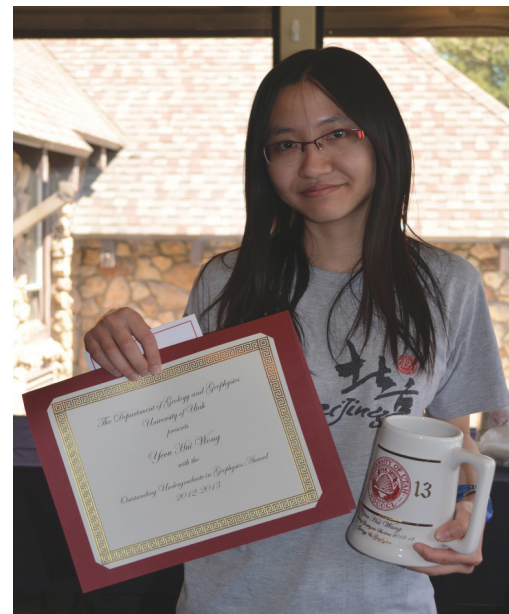
Jamie Farrell PhD - Geophysics
Thesis: *"Seismicity and Tomographic Imaging of the Yellowstone Crustal Magmatic-Tectonic System"*

Christine Gammans MS - Geophysics
Thesis: *"Low-Angle Normal Faulting Within the Basin and Range-Colorado Plateau Transition Zone During the January 3, 2011 Circleville, Utah Earthquake Sequence"*

J. Mark Hale MS - Geophysics
Thesis: *"Infrasound Signal Characteristics of Small Earthquakes"*

Kevin Jensen MS - Geophysics
Thesis: *"SPdKS Analysis of Ultra-Low Velocity Zones Beneath the Western Pacific"*

Kevin Kwong MS - Geophysics
Thesis: *"Imaging the Rupture Properties of the Great 2012 Indian Ocean Intraplate Earthquakes"*



Yeou Hui Wong, 2012-2013 Outstanding Undergraduate in Geophysics

From the Field

Mountain Top Upgrades

Seismic data generated at stations throughout the State of Utah and Yellowstone National Park is often transmitted to UUSS headquarters via mountain top relay sites.



Mountain tops are chosen as they allow a direct line-of-sight radio path to the seismograph station or a repeater site. They also provide a controlled environment for all requisite equipment and a connection to the internet via the State Microwave Network. Such mountain tops are used by many entities for various communication needs, and UUSS is no exception.

Data digitized at various station sites is transmitted via radio signal to nearby mountain tops where it is routed to the internet in a fairly straightforward manner. However, data from legacy analog-telemetered stations is digitized at the mountain top itself - a process that requires additional equipment at the mountain top site.

In principle, seismic data from several analog stations may arrive combined at a single VHF antenna/radio pair. Such data must be separated into its constituent components. This is accomplished by audio

discriminators which separate out discrete carrier tones from as many as eight different stations. A 16bit analog-to-digital converter digitizes the discriminated data, and a terminal server then packages the serial data for forwarding over the internet.

One mountain top site located in southern Utah (pictured below and left) was upgraded with a discriminator and digitizer to improve data integrity for station ICU. Before this upgrade, ICU was only repeated at this mountain top before the signal embarked on a 100-mile radio shot to the closest mountain top with digitizing capabilities.

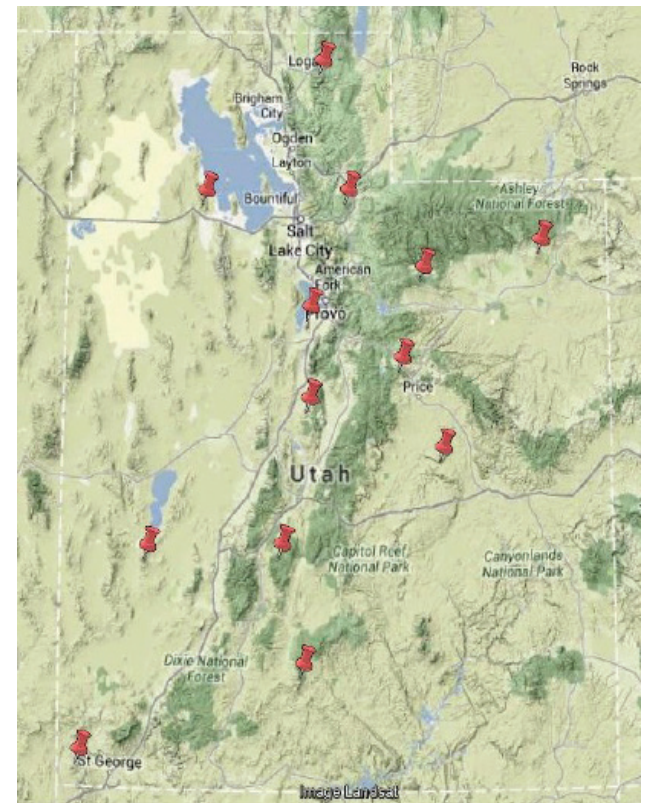


Beginning in the summer of 2013, a program of upgrades was carried out at all mountain tops to improve reliability and serviceability. These upgrades included minimally the addition of:

- A battery back-up uninterrupted power supply (UPS) for protection against brownouts and short blackouts,
- An industrial-grade Ethernet switch to improve data reliability,
- Web-Relay power cyclers to remotely reboot/cycle the digitizers and discriminator racks, and

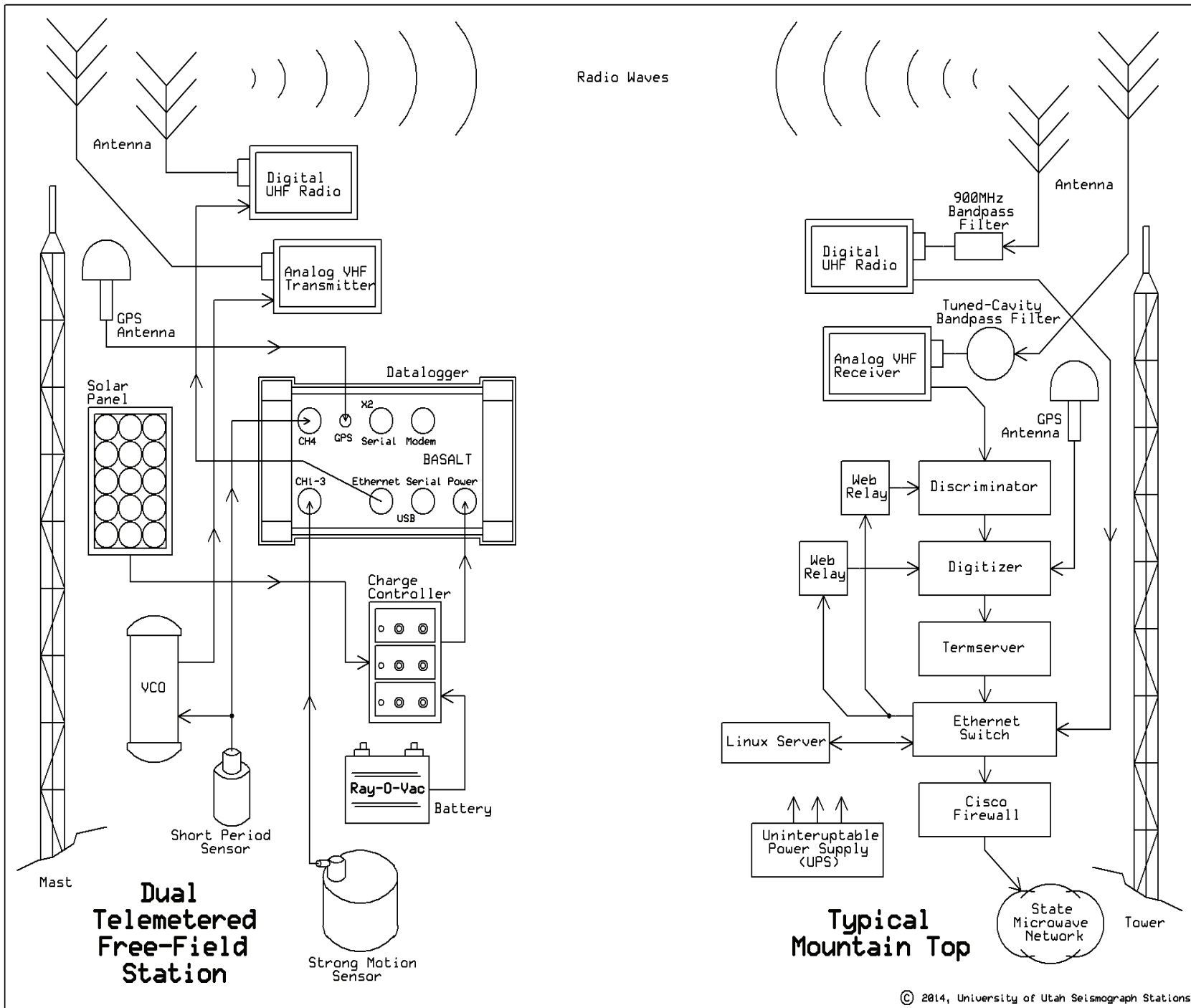
- A Linux server to locally collect and store seismic data, especially from analog short period stations. There are occasional outages in the State Microwave Network. Digital stations can backfill some missing data once the network has been restored, but data from analog stations is irretrievably lost during an outage without collection and storage at mountain tops.

Other incidental changes were made at all sites, such as adding tuned-cavity bandpass filters, changing and organizing cables, remounting equipment, etc.



Locations of UUSS mountain top sites throughout Utah.

(Next page) Schematic illustrates the flow of data from a typical field seismograph station to a typical mountain top site on its way to UUSS headquarters via the State Microwave Network.



© 2014, University of Utah Seismograph Stations

Network Changes

Stations Removed

RIV (Riverton Public Works Bldg - Salt Lake County, UT)

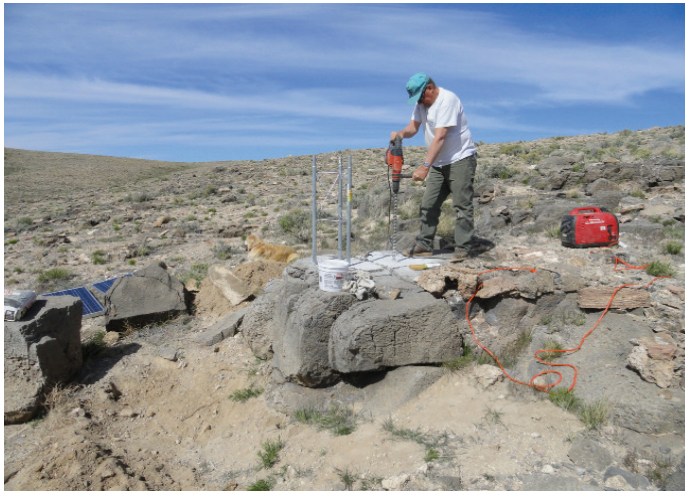
GMV (Granite Mountain Vault - Salt Lake County, UT)

HFSU (Holladay Fire Station, Salt Lake County, UT)

Stations Installed

SWUT (Soap Wash - Millard County, UT)

QOGD (North Ogden - Weber County, UT)



Installation of Broadband Station SWUT (Soap Wash, UT)

This site was selected to fill a gap in geographic broadband station coverage. Additionally, the site was chosen for good quality bedrock contact, safety from vandalism, and line-of-sight radio telemetry. Initial construction was completed in two days with five technicians. After a period of at least one month to allow for concrete to cure, a second trip was made to emplace the sensors and recording electronics.

Above: A Luna moth spotted near the station site. Clockwise from upper left: Field assistant Gordon Johansen drills holes to install triangular tower for holding solar panel, radio antenna, and Global Positioning Satellite (GPS) antenna; electronics technician Ken Whipp and field assistant Pete O'Neill excavate seismometer vault; view of completed solar/telemetry tower; completed installation with datalogger and radio located in visible barrel, seismometer buried in a similar barrel nearby.

Education and Outreach

Seismologists Share Expertise at Natural History Museum of Utah

Scientists from UUSS contributed their expertise in several capacities for the Natural History Museum of Utah during 2013.

In May, Katherine Whidden trained museum docents on earthquake facts prior to the opening of the traveling exhibit “Nature Unleashed: Inside Natural Disasters”. The exhibit ran from May 25 - December 8. Katherine was also on hand to attend the exhibit’s press event. Later she, Dr. Kris Pankow, and Dr. Jim Pechmann each spent a few hours as “Scientist in the Spotlight” - discussing their research and answering questions from exhibit guests.



[Photos courtesy of The Natural History Museum of Utah]

Dr. Jim Pechmann was the guest scientist in June at Science Movie Night - a monthly public event sponsored by the museum in partnership with the Utah Film Center and the Salt Lake City Library. Following a showing of, “Japan’s Killer Quake,” an excellent 53-minute NOVA documentary about the 2011 mag-

nitude 9.0 Tohoku, Japan earthquake, Dr. Pechmann addressed the following questions for the audience:

(1) Why did seismologists underestimate the maximum magnitude for earthquakes off the east coast of Japan? (2) How big are the biggest earthquakes expected to occur in Utah’s Wasatch Front Region (and how do we know)?, and (3) How strong will the ground shaking be during Utah’s ‘big one’--and other future earthquakes?



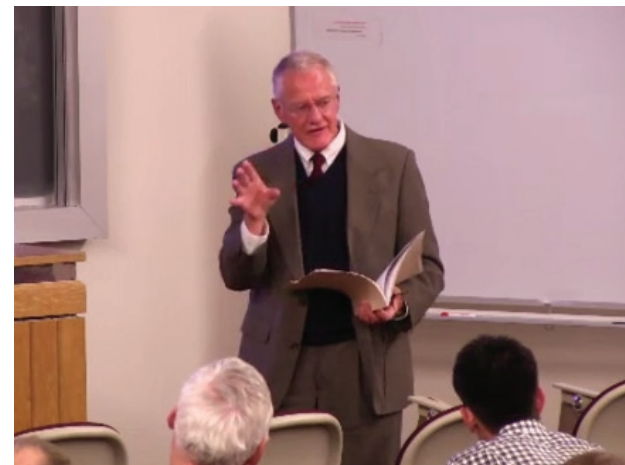
Dr. Pechmann concluded the event by answering questions from audience members who ranged from school children to university professors.

Katherine Whidden, Dr. Kris Pankow, Dr. Keith Koper, and Dr. Jim Pechmann also staffed a booth at the museum’s preparedness fair in September. They answered questions from attendees about Utah earthquakes and earthquake safety. They also performed several demonstrations such as using slinkies to illustrate the differences between P and S waves, and using blocks to show different faulting types. A resonant frequency demonstration was also conducted to show how different types of earthquakes (big and far away versus small and nearby) affect buildings of different heights.

Former UUSS Director Featured at EERI’s “Meet the Mentors”

On November 6, 2013 the Utah Chapter of the Earthquake Engineering Research Institute (EERI) spon-

sored a “Meet the Mentors” event on the University of Utah campus, inviting two of Utah’s distinguished earthquake professionals to share their experience and wisdom with students and younger colleagues.



Dr. Walter J. Arabasz, Research Professor Emeritus of Geology and Geophysics and former director (1985–2010) of the University of Utah Seismograph Stations, was a featured speaker along with Dr. T. Leslie Youd, Professor Emeritus of Civil and Environmental Engineering at Brigham Young University.

Dr. Arabasz and Dr. Youd each summarized their career highlights, shared professional and personal insights, and offered suggestions to audience members on how to make a difference in seismic safety. An extended question-and-answer period followed.

During his career Dr. Arabasz has been extensively involved in national and state public policy-making for seismic monitoring and earthquake risk reduction. Related awards include the Utah Governor’s Medal for Science and Technology in 1996; the U.S. Geological Survey’s John Wesley Powell Award in 2007; and the Western States Seismic Policy Council Lifetime Achievement Award in Earthquake Risk

Reduction in 2008. Since his retirement in 2010, he has continued to work part-time at the University of Utah Seismograph Stations and has chaired or co-chaired three peer-review panels relating to seismic hazard analyses for nuclear facilities. He's also completing a major revision of Utah's earthquake catalog as a member of a Working Group on Utah Earthquake Probabilities.



Seismo Tea Brings Students and Faculty Together

Seismo Tea is a weekly informal discussion session that provides a relaxed atmosphere for graduate students to present their research before professional scientists and receive constructive feedback. As research topics are discussed students learn to critique and provide feedback on the research of others. Seismo Tea also provides students the opportunity to gather feedback from scientists outside their thesis committee and to seek advice regarding career choices.

Kevin Kwong was the Seismo Tea student chair during spring semester. Guest presenters included Helena Buurman, a Postdoctoral Research Fellow in Volcano Seismology at the University of Alaska Fairbanks Geophysical Institute, who shared her work

on volcano seismicity in Alaska. A second guest speaker was Dr. Tea Godoladze, Deputy Director of the Institute of Earth Sciences at Ilia State University in the country of Georgia, who presented her work on seismicity and crustal structure in the Caucasus. In addition to these invited presentations, graduate students Oner Sufri, Christine Gammans, and Tex Kubacki presented talks related to their thesis research. The group also discussed the February 2013 North Korea nuclear test, and the February meteor explosion that occurred in Russia.

Stefanie Whittaker was the fall semester student chair for Seismo Tea. Included in the semester presentations were Dr. Kris Pankow and Dr. Jeff Moore who shared their research on the April 2013 landslide at the Kennecott Utah open-pit mine. A talk was given by Dr. Fan-Chi Lin on seismic interferometry. Dr. Keith Koper, Dr. Jim Pechmann, and Mark Hale talked about an abnormally deep seismic event that occurred in Wyoming, and graduate students Lisa Linville and Stefanie Whittaker shared their masters thesis research in preparation for presenting at the 2013 Fall Meeting of the American Geophysical Union. At one of the weekly meetings, time was provided for students to query faculty members on suggestions for employment opportunities available following graduation.

UUSS Director Assists Utah Seismic Safety Commission

UUSS Director Dr. Keith Koper serves as vice-chair of the Utah Seismic Safety Commission (USSC), a 15-member group dedicated to the review and assessment of earthquake-related hazards and risks to the state of Utah and its inhabitants. Each calendar quarter the USSC has a public meeting during which legislative and outreach activities related to seismic hazards are discussed. A particular focus in 2013 was obtaining seed funding from the State of Utah to do rapid visual screening of schools as a precursor to

formal seismic assessment. On November 13, USSC members traveled to Las Vegas, Nevada for a joint meeting with the Nevada Earthquake Safety Council.

Utah Public Information Officer Conference

Katherine Whidden and Sheryl Peterson represented UUSS at the 2013 Utah Public Information Officer (PIO) Conference in St. George, Utah, September 24-25.



Conference presentations addressed diverse topics designed to give PIOs practical insights for better serving the public by providing information during times of crisis. Presentations also gave attendees a look at what goes on behind the scenes as agencies deal with events that impact public safety.

Notable presentations included: Rio Tinto Kennecott Spokesperson Kyle Bennett who shared recommendations for crisis planning gleaned during the Spring 2013 landslide at Kennecott's Bingham Canyon Mine; Frank Fania, PIO from the Aurora, CO Police Department who presented his insights from the city's recent theatre shooting incident; and Burea Chief of Public Information for the Boston Police Department, Cheryl Fiandaca, who shared advice from her experience with the recent Boston Marathon bombing.

Katherine Whidden had the following comments on the experience. "The conference was a wonderful opportunity to learn about how other PIOs have overcome challenges in efficiently getting informa-

tion to the public during crises.”

“A theme that came up frequently was the importance of social media, especially Twitter, as a tool to quickly disseminate information. Cheryl Fiandaca of the Boston Police Department was especially persuasive about the effectiveness of Twitter in her talk about the Boston Marathon bombing. The agency relied on Twitter to get information out when phones, Facebook, and other websites were overloaded.”

“The conference inspired us to move forward with implementing automatic earthquake tweets, currently a work in progress. We believe this will help us get earthquake information out more efficiently and allow us to better serve the people of Utah.”

In the Classroom

UUSS Director and Associate Professor of Geophysics Dr. Keith Koper was back in the classroom spring semester 2013, teaching a course entitled “Signal/Image Processing.” Three undergraduate geophysics majors and seven M.S. geophysics students were enrolled, including several with UUSS affiliations: Christine Gammans, Tex Kubacki, Kevin Kwong, Stefanie Whitaker, and Eli Workman.

Rio Tinto Earthquake Information Center Tours

Earthquake Information Specialists Paul Roberson and Mark Hale conducted 15 tours of the Earthquake Information Center in 2013 for various organizations including university-sponsored classes and clubs. Each tour gives an overview of Utah’s earthquake hazard as well as UUSS network operations and the role that UUSS plays in earthquake response.

Earthquake Exhibit Tours the State

“Earthquakes in the Intermountain West” is a traveling educational exhibit funded by the State of Utah and maintained and administered by UUSS. The exhibit tells Utah’s earthquake story including

the history of earthquakes in the region, the science behind them, and how to prepare for future earthquakes. Exhibit Coordinator Marcela Torres reports that in 2013, exhibit displays were hosted by the following public schools and organizations:

- Beacon Heights Elementary – Salt Lake City
- Canyon Elementary – Spanish Fork
- Canyon View Junior High – Huntington
- Centennial Middle School - Provo
- Cook Elementary - Syracuse
- Delta Airlines - Salt Lake City
- Discovery Gateway – Salt Lake City
- Driggs Elementary - Salt Lake City
- Elk Meadows Elementary - South Jordan
- Emery County Library – Castle Dale
- Emery County Library – Elmo
- Emery County Library – Orangeville
- Entheos Academy – Kearns
- Foothill Elementary - Brigham City
- Foxboro Elementary – North Salt Lake
- Grand County Public Library – Moab
- Granger Elementary – Salt Lake City
- Hillside Middle School – Salt Lake City
- Iron Springs Elementary – Cedar City
- Kanab Elementary – Kanab
- Kearns Jr. High - Kearns
- Larsen Elementary – Spanish Fork
- Majestic Elementary – West Jordan
- Municipal Elementary - Roy
- North Point Elementary - Lehi
- Oak Hills Elementary - Bountiful
- Redwood Elementary – Salt Lake City
- Riverview Elementary - Spanish Fork
- South Summit Elementary – Kamas
- Thunder Ridge Elementary – Saratoga Springs
- Union Middle School – Sandy
- Valley View Elementary - Pleasant Grove
- Westside Elementary - Springville

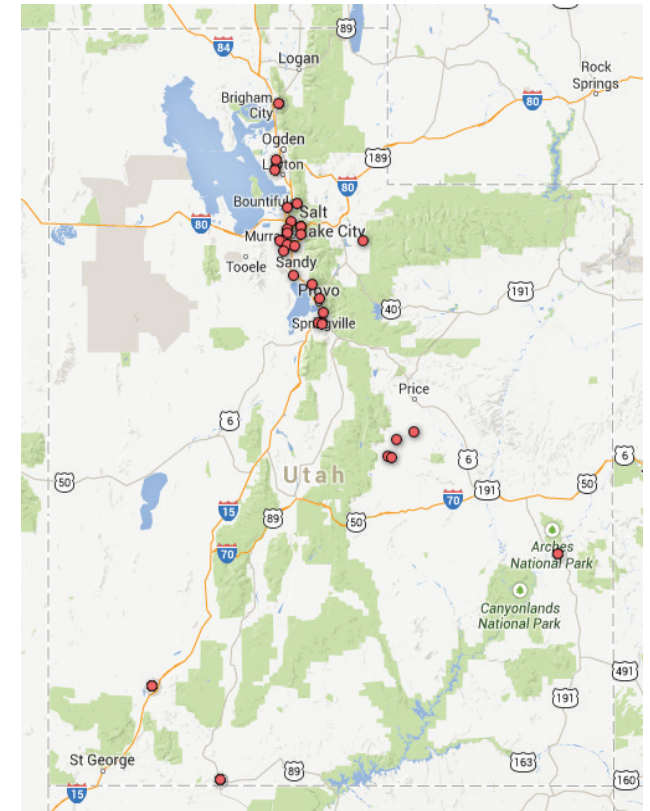
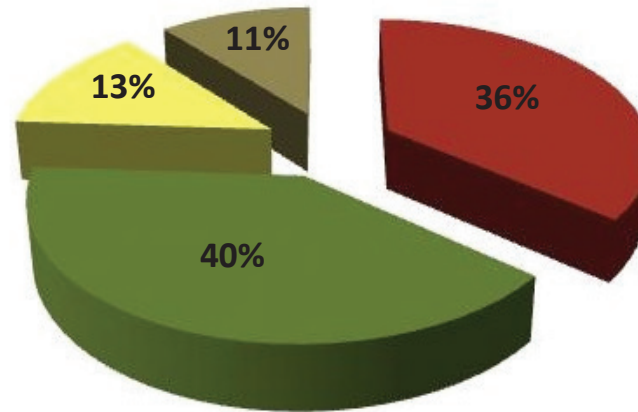


Exhibit destinations throughout the state in 2013.

Financials

UUSS Funding January 1 - December 31, 2013



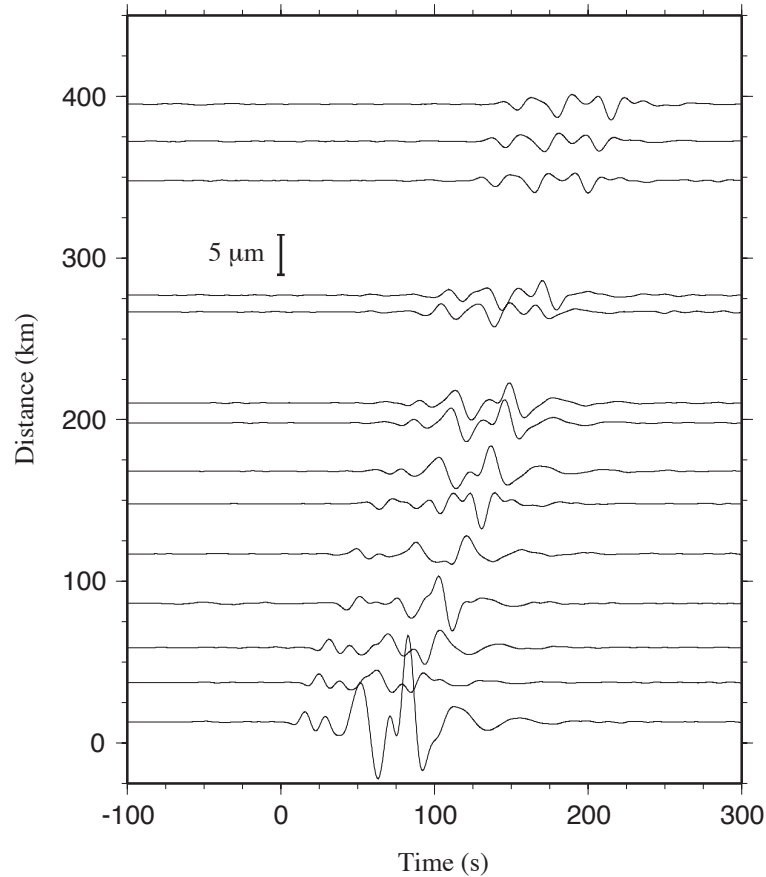
| | |
|---|---|
| <ul style="list-style-type: none"> State of Utah | Earthquake monitoring, research, education and outreach in the Utah region. |
| <ul style="list-style-type: none"> U.S. Geological Survey—Advanced National Seismic System | Regional and urban seismic monitoring and research along the Wasatch Front urban corridor and Intermountain Seismic Belt. |
| <ul style="list-style-type: none"> U.S. Geological Survey—Volcano Hazards Program | Earthquake monitoring and research in the Yellowstone National Park region. |
| <ul style="list-style-type: none"> U.S. Geological Survey | Maintenance of a continuous GPS network to monitor strain accumulation across the Wasatch Fault. |
| <ul style="list-style-type: none"> U.S. Department of Energy Southern Methodist University Los Alamos National Laboratory | Collaborative infrasound seismic research. |
| <ul style="list-style-type: none"> Utah Department of Public Safety | Traveling educational earthquake exhibit. |
| <ul style="list-style-type: none"> National Institute for Occupational Safety and Health University of Utah Department of Mining Engineering | Monitoring and research on mining-induced seismicity in Utah coal mines and graduate student training |
| <ul style="list-style-type: none"> National Science Foundation | Collaborative research of dynamic earthquake triggering using the US Array. Location and characterization of ambient seismic noise using the US Array. |
| <ul style="list-style-type: none"> Additional revenue from: <ul style="list-style-type: none"> Production of seismic data products Consulting Individual research grants | |



Rio Tinto



Utah Broadband Vertical Component Data



April 10, 2013 Bingham Canyon, Utah Landslide

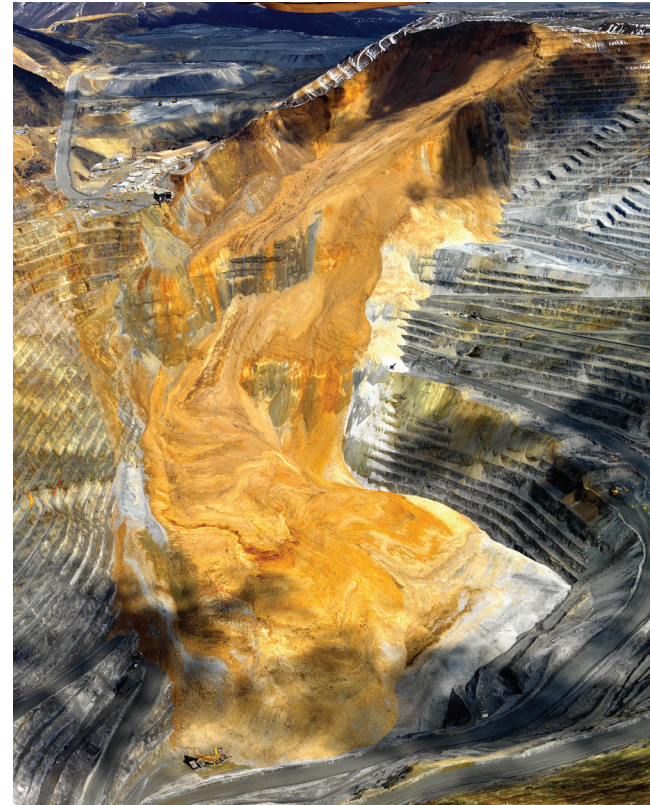


Figure courtesy of Rio Tinto Kennecott

The left panel shows ground motion recorded by UUSs seismometers from the massive landslide that occurred in the Bingham Canyon, Utah, copper mine on April 10, 2013. The ground motion becomes smaller and arrives later as the distance between the mine and the seismometer increases. The nearest station recorded a peak displacement of just over 10 micrometers (μm). A picture of the Bingham Canyon open-pit copper mine, after the landslide, is shown on the right. The mine had been evacuated prior to the landslide and so there were no casualties.