

91st Annual Meeting of the Eastern Section of the Seismological Society of America



November 3-5th, 2019
The Ohio State University
Columbus, OH



Acknowledgements

The work of many people made this meeting possible and we are grateful for their contributions. These people include:

Field Trip Leaders: Derek E. Sawyer, W. Ashley Griffith, and Curtis Coe.

Banquet Guest Speaker: Brad Lepper.

Budget and planning: Daniel Pradel, Derek E. Sawyer and W. Ashley Griffith.

Abstract Submission web and logistics support: Rikki Anderson, Nan Broadbent.

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Program: Christine Goulet and Daniel Pradel.

Student Grant coordination: Oliver Boyd.

Jesuit Seismological Society Award Committee.

Many thanks to all the session chairs!

Daniel Pradel and Christine Goulet
Planning Committee Chairs

Many thanks to our generous sponsors!



General Information

Welcome to Columbus, Ohio!

With a population of about 900,000, Columbus is Ohio's most populous city and the state capital. The city's Scioto Mile is a string of parks on both sides of the Scioto River, with a huge interactive fountain and trails. On the west bank, the COSI science center offers hands-on exhibits and a planetarium. Downtown, the Columbus Museum of Art includes American and European paintings and a sculpture garden. The German Village area has restored brick houses built by 1800s settlers. More at www.experiencecolumbus.com.

A great way to experience Columbus is to rent a bicycle, as there are numerous bicycle trails along the rivers, bike-friendly communities, and connections to the hundreds of miles that form the state's bicycle trail network (www.ohiobikeways.net).

The meeting will take place in the Columbus campus of the Ohio State University (OSU). The 1760 acre campus is located about 2 miles north of downtown and hosts about 61,000 students.

Fans of Bob Dylan may consider attending his concert on Nov. 4 at 8PM at the OSU Mershon Auditorium (www1.ticketmaster.com/event/05005725D85860E7).

Field trip to Serpent Mound Crater and Serpent Mound Monument

The field trip is on Sunday Nov. 3. If you have registered, please meet in the Blackwell Inn lobby at 7:45AM, the bus will leave at 8:00 AM sharp. Lunch will be provided and we will return to the hotel around 5:30 PM.

Serpent Mound Crater is an impact structure several kilometers in diameter that was formed about 320 Million Years ago by a hypervelocity meteorite impact. During the site visit we will stopping at several locations to observe the ring graben and central uplift, then stop at a lab where recently obtained rock cores are stored locally (Links: en.wikipedia.org/wiki/Serpent_Mound_crater and impactcraters.us/serpent_mound_ohio). Additionally, we will visit the famous Serpent Mound Monument a Native-American earth structure built around 300 BCE that depicts a long snake (about 420m long) that is about to eat an egg (Links: en.wikipedia.org/wiki/Serpent_Mound and www.ancient-origins.net/ancient-places-americas/great-serpent-mound-ohio-largest-earthen-effigy-world-001594)



Banquet Presentation: Native-American Earthmounds of Ohio

Dr. Brad Lepper is a Curator of Archaeology for the Ohio History Connection. In addition, he has occasionally been a Visiting Professor of Sociology and Anthropology at Denison University. His primary areas of interest include North America's Ice Age peoples, Ohio's magnificent mounds and earthworks, and the history of Archaeology. Noteworthy research includes excavation of the Burning Tree mastodon and discovery of the Great Hopewell Road, featured in a documentary that was first broadcast on PBS in 1998.

Information for Speakers:

Oral Presentations will be 25 minutes long with 5 minutes for questions. Please make note of the session and time for your presentation. Equipment for PowerPoint presentations will be available. The most efficient way to load your presentation on the computer is to bring a USB stick with your PowerPoint file and load it on the meeting PC during a break before your session.

Information for Poster Presentations:

Tape (blue painters' tape) for the hanging of posters, up to approximately 4 ft wide by 3 ft high, will be made available. Please be near your posters during the Monday afternoon session and during parts of the coffee breaks.

Information for Session Chairs:

There will be a microphone at the lectern. A total of thirty minutes is allotted to each presentation, including questions and change-over time. However, it is also important to stimulate discussion on each presentation if there are no immediate audience questions after talks that finish on time.

Meeting Website:

www.seismosoc.org/inside-eastern-section/annual-meeting

SRL Abstracts:

Abstracts for meetings of the Eastern Section, SSA will be published electronically.



Meeting Venue:

The Blackwell Inn (theblackwell.com) is located on the campus of the Ohio State University at:

2110 Tuttle Park Place

Columbus, Ohio 43210

For reservations: 866-247-400 (note: we have a limited number of rooms at a discounted rate are available by phone under "OSU Civil Engineering Department")

Other less convenient options (about 40-minute walk away) include:

- Marriott Columbus University Area at 3100 Olentangy River Rd, Columbus, OH 43202. Phone: (614) 447-9777)
- Holiday Inn Express & Suites Columbus University Area at 3045 Olentangy River Rd, Columbus, OH 43202. Phone: (614) 447-1212
- Hilton Garden Inn Columbus-University Area at 3232 Olentangy River Rd, Columbus, OH 43202. Phone: (614) 263-7200

Travel Information to and from Columbus International Airport (CMH):

The Blackwell Inn and Ohio State University campus is located about 9 miles from Columbus International Airport, which is served by numerous airlines. Taxis, Uber and/or Lyft are the most convenient form of transportation to the campus and hotel.

Contacts:

Daniel Pradel, OSU, pradel.1@osu.edu

Christine Goulet, SCEC, USC, CA, cgoulet@usc.edu

Meeting at-a-glance

	Sunday, November 3	Monday, November 4	Tuesday, November 5
	Field trip (8:00-17:00 or so), lunch provided	Coffee and posters (8:00-8:30)	Coffee and posters (8:00-8:30)
AM Session 1 (8:30-10:00)		Welcoming remarks	Oral Session T1
		Oral Session M1	
Break and posters (10:00-10:30)		Break and posters	Break and posters
AM Session 2 (10:30-12:00)		Oral Session M2	Oral Session T2
Lunch (12:00-13:00)		Catered lunch	Catered lunch Business Meeting (12:30-13:00)
PM Session 1 (13:00-14:30)		Oral Session M3	Oral Session T3
Break and posters (14:30-15:00)		Break and posters	Break and posters
PM Session 2 (15:00-16:30)		Oral Session M4	Oral Session T4
		Posters	Closing remarks
Evening events	Icebreaker Reception (18:00-20:00) Board Meeting (private, 20:00-21:30)	Banquet and Jesuit Society Award's Dinner (18:30-20:30)	

Locations:

- Sunday: Blackwell Inn
- Monday: Pfahl 140 (next to the Blackwell Inn)
- Tuesday: Ohio Union (lectures in the US Bank Conference Theater and posters/meals in the Ohio Staters Traditions Room)

Program

Student presentations are denoted with ** before the title; first author name is in **bold**

Sunday, November 3	
8:00 AM Field trip: meet at 8:00 AM in lobby of Blackwell Inn – return around 5:00 PM	
6:00 PM Registration opens - at Icebreaker location	
6:30 PM Icebreaker Reception	
Monday, November 4 Lectures and posters in Pfahl 140	
8:00-8:30 Coffee and registration	
8:30-10:00 Welcoming remarks and Session M1: Seismicity and Earthquake Source (Chair: Goulet)	
8:30	WELCOMING REMARKS. <i>GOULET, Christine and PRADEL, Daniel</i>
9:00	**INSIGHTS FROM AFTERSHOCKS OF THE 30 NOVEMBER 2017 DOVER, DE, EARTHQUAKE. PEARSON, Karen , <i>LEKIC, Vedran, PRATT, Thomas, WAGNER, Lara, ROMAN, Diana, KIM, Won-Young.</i>
9:30	**SEGMENTATION OF THE EASTERN REELFOOT RIFT MARGIN: REINTERPRETATION OF THE NORTHEASTERN REELFOOT RIFT FAULT GEOMETRY AND SEISMIC POTENTIAL. MARLOW, Christopher , <i>POWELL, Christine, COX, Randel.</i>
10:30-11:00 Break and Posters	
10:30-12:00 Session M2: Seismicity and Earthquake Source (Chair: Pradel)	
10:30	A NEW, PRELIMINARY EVALUATION OF THE ADAMS MILL FAULT. COUNTS, Ronald.
11:00	**IS THE AFTERSHOCK AREA A GOOD PROXY FOR THE MAINSHOCK RUPTURE AREA? NEO, Jing Ci , <i>HUANG, Yihe, YAO, Dongdong, WEI, Shengji.</i>
11:30	**THE EFFECTS OF EPISODIC TREMOR AND SLIP EVENTS ON FAULTS IN THE WRANGELLIA SEGMENT OF THE CASCADIA SUBDUCTION ZONE. CANNON, Kasey , <i>FURLONG, Kevin.</i>
12:00-1:00 Lunch	
1:00-2:30 Session M3: Triggered and Induced Seismicity (Chair: Jaumé)	
1:00-1:30 Poster Session	
1:30	EARTHQUAKE SWARMS AND SLOW SLIP ON A SLIVER FAULT IN THE MEXICAN SUBDUCTION ZONE. BRUDZINSKI, Mike , <i>FASOLA, Shannon, HOLTKAMP, Stephen, GRAHAM, Shannon, CABRAL-CANO, Enrique.</i>
2:00	HYDRAULIC FRACTURE INJECTION STRATEGY INFLUENCES THE PROBABILITY OF EARTHQUAKES IN THE EAGLE FORD SHALE PLAY OF SOUTH TEXAS. FASOLA, Shannon , <i>BRUDZINSKI, Mike, SKOUMAL, Robert, LANGENKAMP, Teresa, CURRIE, Brian, SMART, Kevin.</i>
2:30	**FACTORS INFLUENCING THE PROBABILITY OF HYDRAULIC FRACTURING INDUCED SEISMICITY IN OKLAHOMA. RIES, Rosamie , <i>BRUDZINSKI, Michael, SKOUMAL, Robert, CURRIE, Brian.</i>
3:00-3:30 Break and Posters	
3:30-5:00 Session M4: Triggered and Induced Seismicity (Ebel)	
3:30	TRIGGERED AND INDUCED SEISMICITY IN EAST ASIA. PENG, Zhigang , <i>LEI, Xinglin.</i>
4:00	SEISMIC AND LIQUEFACTION HAZARD MAPS FOR THE CHARLESTON, SOUTH CAROLINA, AREA. CRAMER, Chris , <i>JAUME, Steven, LEVINE, Norman.</i>
4:30	SEISMICITY INDUCED BY HYDRAULIC FRACTURING IN THE CENTRAL AND EASTERN UNITED STATES. BRUDZINSKI, Michael , <i>SKOUMAL, Robert, RIES, Rosie, FASOLA, Shannon, FRIBERG, Paul, CURRIE, Brian.</i>
6:30-8:30 Banquet Dinner	
JESUIT SEISMOLOGICAL ASSOCIATION AWARD BANQUET PRESENTATION: “NATIVE-AMERICAN EARTHMOUNDS OF OHIO”, Bradley T. Lepper - Curator of Archaeology for the Ohio History Connection	

Tuesday, November 5	
Ohio Union (lectures in the US Bank Conference Theater and posters/meals in the Ohio Staters Traditions Room)	
8:00-8:30 Coffee and registration	
8:30-10:00 Session T1: Instrumentation and Data Processing (Chair: Peng)	
8:30	COHERENT PROCESSING OF RASPBERRY SHAKE DATA FROM THE WASHINGTON D.C AND BOSTON AREAS. PULLI, Jay , KAFKA, Alan .
9:00	RECENT RESULTS OF SEISMIC NETWORK MONITORING IN THE CENTRAL VIRGINIA SEISMIC ZONE. CHAPMAN, Martin , BEALE, Jacob , GUO, Zhen , WU, Qimin .
9:30	RELATIONSHIP BETWEEN INSTRUMENTAL GROUND-MOTION PARAMETERS AND FELT INTENSITY IN CENTRAL AND EASTERN UNITED STATES. KIM, Won-Young , GOLD, Mitchell .
10:00-10:30 Break and Posters	
10:30-12:00 Session T2: Site Response (Chair : Goulet)	
10:30	CORRECTION FACTORS FOR GROUND-MOTION SITE RESPONSE IN THE CENTRAL UNITED STATES. WANG, Zhenming , CARPENTER, Seth , WOOLERY, Edward .
11:00	SITE RESPONSE FROM DEEPLY BURIED ROCK LAYERS IN THE ILLINOIS BASIN REVEALED BY S-WAVE H/V. CARPENTER, S. , WANG, Z. , WOOLERY, E. , HICKMAN, J.
11:30	ES-SSA Business Meeting
12:00-1:00 Lunch	
1:00-2:30 Session T3: Imaging and Machine Learning (Chair: Carpenter)	
1:00	IMAGING SUBSURFACE GEOLOGIC STRUCTURES NEAR CHARLESTON, SOUTH CAROLINA WITH NEW HIGH-RESOLUTION AIRBORNE MAGNETIC SURVEY DATA, PREVIOUS SEISMIC-REFLECTION PROFILES, AND BASEMENT SAMPLE ANALYSES. SHAH, Anjana , PRATT, Thomas , HORTON, JR, J. Wright .
1:30	**DETECTING LITHOSPHERIC DISCONTINUITIES BENEATH THE MISSISSIPPI EMBAYMENT USING S WAVE RECEIVER FUNCTIONS. SAXENA, Arushi , LANGSTON, Charles .
2:00	**PREDICTING TIME TO EARTHQUAKE WITH NEURAL NETWORK AND OTHER MACHINE LEARNING METHODS. BAI, Yongsheng , ZHA, Bing , WEI, Jianli , YILMAZ, Alper , SEZEN, halil .
2:30-3:00 Break and Posters	
3:00-4:30 Session T4: Ground Motion Hazard and Historical Observations (Chair: Brudzinski)	
3:00	REMAPPING CHARLESTON: USING HISTORICAL INFORMATION TO UPDATE SEISMIC SITE CONDITIONS IN AN URBAN SETTING. JAUME, Steven , DESILETS, Reagen , LEVINE, Norman .
3:30	SEISMIC HAZARD IN STE. GENEVIEVE, MO FROM GRAVITY, SEISMIC REFRACTION, AND SHEAR WAVE VELOCITY OBSERVATIONS. CRAMER, Chris , RAHMAN, Md. Jabir , PATTERSON, Gary .
4:00	HISTORIC ACCOUNTS OF ANIMAL REACTIONS BEFORE AND DURING EARTHQUAKES IN NORTHEASTERN NORTH AMERICA EBEL, John .
4:30	STUDENT PRESENTATION AWARDS. PENG, Zhigang CLOSING REMARKS. PRADEL, Daniel
4:45 Adjourn	

Posters (Alphabetical order of title)

- **2-D AND 3-D DYNAMIC EARTHQUAKE SIMULATIONS FOR THE CASCADIA MEGATHRUST.**
RAMOS, Marlon, HUANG, Yihe.
- **A GROUND MOTION MODEL FOR ARIAS INTENSITY AND CUMULATIVE ABSOLUTE VELOCITY BASED ON THE NGA-EAST DATABASE.** **FARHADI, Ali**, PEZESHK, Shahram.
- **A STATISTICAL STUDY OF THE NEW MADRID SEISMIC ZONE.** **ZHANG, Yixin**, HORTON, Stephen, LANGSTON, Charles, POWELL, Christine.
- **AN EFFICIENT REPEATING SIGNAL DETECTOR THAT USES MACHINE LEARNING TO IMPROVE DETECTION OF INDUCED SEISMICITY.** **CHIORINI, Sutton**, SKOUMAL, Rob, BRUDZINSKI, Michael.
- **AN EMPIRICAL GROUND-MOTION PREDICTION MODEL FOR SMALL-TO-MODERATE INDUCED EARTHQUAKES IN CENTRAL AND EASTERN UNITED STATES.** **FARAJPOUR, Zoya**, PEZESHK, Shahram.
- **DEVELOPING DATA-DRIVEN STOCHASTIC SEISMOLOGICAL PARAMETERS OF CENA FROM THE NGA-EAST DATABASE.** **NAZEMI, Nima**, PEZESHK, Shahram, ZANDIEH, Arash.
- **MICROEARTHQUAKE DETECTION WITH ULTRA-DENSE SEISMIC ARRAY IN NORTHERN OKLAHOMA.** **LI, Chenyu**, ZHAI, Qiushi, LI, Zefeng, PENG, Zhigang.
- **STRESS DROP VARIATION OF DEEP-FOCUS EARTHQUAKES BASED ON EMPIRICAL GREEN'S FUNCTIONS.** **LIU, Meichen**, HUANG, Yihe, RITSEMA, Jeroen.
- BASELINE ASSESSMENT OF THE IMPORTANCE OF CONTRIBUTIONS FROM REGIONAL SEISMIC NETWORKS TO THE PACIFIC TSUNAMI WARNING CENTER'S OPERATIONS.** **SARDINA, Victor**, KOYANAGI, Kanoa, WEINSTEIN, Stuart.
- DEPTH TO BASEMENT ACROSS THE PENNSYLVANIA PORTION OF THE APPALACHIAN BASIN USING SEISMIC REFLECTION DATA.** **NYBLADE, Andrew.**
- EXTRACTING RELIABLE CORE PHASES IN THE WEST-CENTRAL BRAZIL USING AMBIENT SEISMIC NOISE.** **SHIRZAD, Taghi**, AFRA, Mahsa, ASSUMPÇÃO, Marcelo, BRAUNMILLER, Jochen.
- NATURAL SEISMICITY OBSERVATIONS IN AND AROUND THE EASTERN KENTUCKY ROME TROUGH FROM A TEMPORARY SEISMIC NETWORK.** **CARPENTER, N.**, HOLCOMB, A., WANG, Z., WOOLERY, E., HICKMAN, J.
- RASPBERRY SHAKE, EQ1, AND RESEARCH-GRADE SEISMOGRAPHS: PROS AND CONS OF DIFFERENT TYPES OF SEISMOGRAPHS FOR EDUCATION, CITIZEN SCIENCE, AND EARTHQUAKE MONITORING IN NEW ENGLAND AND TEXAS.** **KAFKA, Alan**, FINK, Kristi.
- RAY-THEORY BASED ANALYSIS OF THE P/S RATIO BEHAVIOR WITHIN VERTICAL GROUND MOTIONS.** FRID, Michael.
- SEISMIC AND LIQUEFACTION HAZARD MAPS FOR DYER COUNTY, NORTHWESTERN TENNESSEE.** **CRAMER, C.**, VAN ARSDALE, R., ARELLANO, D., PEZESHK, S., HORTON, S., WEATHERS, T.
- THE MODERNIZATION OF THE OHIO SEISMIC NETWORK.** **FOX, Jeff.**
- USGS WORKING GROUP ON IMPLEMENTATION OF ATLANTIC AND GULF COASTAL PLAIN SITE RESPONSE MODELS IN SEISMIC HAZARD ANALYSES.** **BOYD, Oliver**, MILLS, Sarah, MCNAMARA, Dan, CHAPMAN, Martin, THOMPSON, Eric, REZAEIAN, Sanaz.

Abstracts

Abstracts are organized by alphabetical order of the first author's last name.

****PREDICTING TIME TO EARTHQUAKE WITH NEURAL NETWORK AND OTHER MACHINE LEARNING METHODS**

BAI, Yongsheng, ZHA, Bing, WEI, Jianli, YILMAZ, Alper, SEZEN, halil.

Accurate earthquake prediction is still in great challenge for scientists in recent year, but a lot of progress have been made for it, for example, some researchers, like Los Alamos National Laboratory (LANL) in USA, have already simulated earthquake in man-made environments, which is also called laboratory earthquake. It can mimic the stresses, strains, temperature and other physical conditions where the rocks are susceptible to form faults in the crust. They collected a large number of data during the experiments and tried to find a scientific and precise model to predict when earthquake will occur. This paper is a work in this effort. We joined a Kaggle competition in which LANL provided training and testing acoustic data of the strains measured in the faults, and used various neural network and other machine learning methods to train the prediction model with feature extraction on raw data, which leads to less input data but more accuracy for prediction. Our models are based on Long Short Term Memory (LSTM), Convolutional Neural Networks (CNNs), Multilayer Perceptron (MLP), Random Forest (RF) and Light Gradient Boosting (LGB), and the predictions on the time to quake are quite well for such large data sets, in particular for the testing data which are randomly selected from different sources. The study shows that it is possible to monitor the strain level of real faults or rocks in various depth with sensors and predict earlier and more accurately about the time of earthquake, and is beneficial for saving more lives and reducing property losses.

USGS WORKING GROUP ON IMPLEMENTATION OF ATLANTIC AND GULF COASTAL PLAIN SITE RESPONSE MODELS IN SEISMIC HAZARD ANALYSES

BOYD, Oliver, MILLS, Sarah, MCNAMARA, Dan, CHAPMAN, Martin, THOMPSON, Eric, REZAEIAN, Sanaz.

Past and present research on earthquake ground motions along the Atlantic and Gulf Coastal Plains show significant frequency-dependent deviations relative to other areas in the Central and Eastern United States (CEUS). Ground motions have been shown to be strongly correlated with sediment thickness, where greater thickness leads to higher attenuation and lower ground motion amplitudes at short periods, but higher ground motion amplitudes at longer periods. With the recent implementation of basin depths for select areas in seismic hazard analyses for the western United States, a USGS working group has been formed to consider whether a sediment thickness model can be constructed for the Atlantic and Gulf Coastal Plains and successfully implemented in CEUS seismic hazard analyses. Many existing sediment thickness datasets have been gathered by our working group to date, and one Coastal Plain Fourier site response model was recently published with another specific to the Atlantic Coastal Plain presented at recent meetings. In addition to the challenge of constructing a sediment thickness map, properly converting Fourier spectral amplification to response spectra will need to be resolved. Because this potential improvement to our hazard analyses for the CEUS may lead to very different estimates of hazard relative to current models, we will also need to estimate the lingering uncertainties for consideration by the user community. We aim to decide if and how coastal plain amplification will be implemented in the National Seismic Hazard Model (NSHM) by the end of 2020, the deadline by which refereed articles and reports need to be published in order to be considered for inclusion into the 2023 NSHM update.

EARTHQUAKE SWARMS AND SLOW SLIP ON A SLIVER FAULT IN THE MEXICAN SUBDUCTION ZONE

BRUDZINSKI, Mike, FASOLA, Shannon, HOLTKAMP, Stephen, GRAHAM, Shannon, CABRAL-CANO, Enrique.

The Mexican subduction zone is an ideal location for studying subduction processes due to the short trench-to-coast distances that bring broad portions of the seismogenic and transition zones of the plate interface inland. Using a recently generated seismicity catalog from a local network in Oaxaca, we identified 20 swarms of earthquakes ($M < 5$) from 2006 to 2012. Swarms outline what appears to be a steeply dipping structure in the overriding plate, indicative of an origin other than the plate interface. This steeply dipping structure corresponds to the northern boundary of the Xolapa terrane. In addition, we observed an interesting characteristic of slow slip events (SSEs) where they showed a shift from trenchward motion toward an along-strike direction at coastal GPS sites. A majority of the swarms were found to correspond in time to the along-strike shift. We propose that swarms and SSEs are occurring on a sliver fault

that allows the oblique convergence to be partitioned into trench-perpendicular motion on the subduction interface and trench-parallel motion on the sliver fault. The resistivity structure surrounding the sliver fault suggests that SSEs and swarms of earthquakes occur due to high fluid content in the fault zone. We propose that the sliver fault provides a natural pathway for buoyant fluids attempting to migrate upward after being released from the downgoing plate. Thus, sliver faults could be responsible for the downdip end of the seismogenic zone by creating drier conditions on the subduction interface trenchward of the sliver fault, promoting fast-slip seismogenic rupture behavior.

SEISMICITY INDUCED BY HYDRAULIC FRACTURING IN THE CENTRAL AND EASTERN UNITED STATES

BRUDZINSKI, Michael, SKOUMAL, Robert, RIES, Rosie, FASOLA, Shannon, FRIBERG, Paul, CURRIE, Brian.

We have investigated seismicity potentially associated with hydraulic fracturing (HF) in several areas of the Central and Eastern United States to improve our understanding of the phenomena. In our study, we utilized multi-station template matching to lower the detection threshold and improve the completeness of seismicity catalogs. We also collected all publicly available information on timing and location of HF-related well stimulations and saltwater disposal to evaluate relationships with recorded seismicity. While rare, we found that HF induced seismicity with magnitudes greater than 2.0 more often than generally assumed and was the dominant source of seismicity in some areas. In areas of Ohio, Oklahoma, and Texas, >90% of the seismicity was correlated with HF wells, and in a few cases >30% of the HF wells were correlated with seismicity. This includes >600 earthquakes with M 2.0-4.0 best explained by being induced by HF. Detailed investigations of seismicity induced by HF indicate that the maturity of nearby faults played a key role in the types of seismicity produced. In addition, we found several trends that suggest the probability of induced seismicity is influenced by the injected volume, injection rate, number of laterals on the well pad, stratigraphic interval stimulated, depth of the stimulation, and viscosity of the injected fluid. Finally, we have begun to explore strategies for estimating the probability seismicity will exceed a threshold magnitude during stimulation, including use of the seismogenic index.

****THE EFFECTS OF EPISODIC TREMOR AND SLIP EVENTS ON FAULTS IN THE WRANGELLIA SEGMENT OF THE CASCADIA SUBDUCTION ZONE**

CANNON, Kasey, FURLONG, Kevin.

The potential for a large megathrust earthquake on the Cascadia Subduction Zone has driven many studies of the seismic hazards in the region. One part of this system that was discovered in Cascadia is a new form of seismic activity known as Episodic Tremor and Slip (ETS) events. These events appear to occur adjacent to and down-dip of the main megathrust locking zone, and therefore their occurrence may change the stress conditions on other faults in the region, such as the main megathrust fault or nearby crustal faults. In order to appraise how the ETS events may affect these faults, we considered an ETS event to act as a moderate sized earthquake (consistent with its observed slip characteristics) and analyzed its effects on the coulomb stress conditions. After analyzing the resulting stress maps of the subduction zone interface for three styles of ETS events, we found that all events increased the stress conditions on the locked patch of the megathrust fault, loading the area where the magnitude 9.0 earthquake is expected to occur. Additionally, the resulting stress maps for the regional crustal faults showed that if the ETS event was sufficiently far from the crustal fault no significant change would be seen in stress conditions. For upper-plate faults that are closer to the ETS slip, there was a change in Coulomb stress conditions on those faults. The magnitude of that effect was very dependent on the orientation of the crustal faults.

NATURAL SEISMICITY OBSERVATIONS IN AND AROUND THE EASTERN KENTUCKY ROME TROUGH FROM A TEMPORARY SEISMIC NETWORK

CARPENTER, N., HOLCOMB, A., WANG, Z., WOOLERY, E., HICKMAN, J.

The Rome Trough, a northeast-trending graben system extending from eastern Kentucky northeastward across West Virginia and Pennsylvania into southern New York, is part of a larger failed rift system and contains a thick sequence of sedimentary rocks. The oil and gas potential in one formation deep in the trough, the Cambrian Rogersville Shale, is being tested. A temporary seismic network was deployed in the Rome Trough of eastern Kentucky (EKRT) from mid-2015 through May, 2019 to characterize natural seismicity as testing of the Rogersville Shale occurs. The first three years of seismicity observations detected and located using traditional algorithms has been compiled and is the focus of this presentation.

Consistent with the long-term seismicity patterns in the USGS ANSS catalog, very few earthquakes occurred in the crust beneath the EKRT, where only six events were recorded. None of these events was associated with Rogersville Shale oil and gas test wells, or shallower ongoing waste water disposal. Outside of the EKRT, earthquakes are diffusely distributed in zones extending into southern Ohio to the north, and into the Eastern Tennessee Seismic Zone to the south. The focal depths of most (> 85 percent) events was less than 25 km, but several earthquakes occurred in the mid-to-lower-crust at anomalous depths of 34 km or greater. P-axes from nine first-motion focal mechanisms indicate the state of stress across the EKRT is generally consistent with regional stress. However, the only focal mechanism determined for a deep earthquake, ~30 km west of the EKRT, shows that predominantly normal-style faulting occurred.

SITE RESPONSE FROM DEEPLY BURIED ROCK LAYERS IN THE ILLINOIS BASIN REVEALED BY S-WAVE H/V

CARPENTER, N., WANG, Z., WOOLERY, E., HICKMAN, J.

Quantifying the response of shallow layers to incident seismic waves is needed for predicting the effects of strong earthquake shaking and such calculations require determination of the local S-wave velocity structure. For engineering purposes, S-wave velocity profiles are typically determined to depths of 30 m or through just the unlithified sediment layers. At seismic stations within the Illinois Basin, however, S-wave H/V observations derived from local and regional earthquake recordings reveal at least one large impedance contrast hundreds of meters beneath the base of the sites' measured velocity profiles; resonances from these impedance contrasts—1 to 3 Hz—are within the frequency band of engineering concern. The estimated depths of the layers correspond approximately with the tops of large coalbed gas- or oil-bearing reservoirs in Pennsylvanian or Upper Mississippian sandstones in the basin, and may be sources of unmodeled site-response hazard in the event of a strong earthquake: at most sites, the resultant amplifications are similar to or greater than those from the shallow sediment layers in published S-wave velocity structures. The influence of these layers on the site responses at Illinois Basin stations along the Ohio River is unclear, as resultant peak frequencies coincide with the base-mode resonance frequencies of the soil columns at these sites.

In this presentation, the S-wave H/V curves and the theoretical 1-D site responses derived from Thomson-Haskell propagator matrices and published S-wave velocity structures will be compared. Also, estimated depths to the large impedance contrasts will be compared with nearby well data to attempt identification of the formation(s) responsible for the 1 to 3 Hz S-wave resonances.

CORRECTION FACTORS FOR GROUND-MOTION SITE RESPONSE IN THE CENTRAL UNITED STATES

CARPENTER, Seth, WOOLERY, Edward.

Although the time-weighted average of shear-wave velocity for the top 30 m of soils and rock, V_{s30} , has been used as one of the key parameters to account for site response in earthquake engineering, it is not appropriate, particularly for the central and eastern United States, because V_{s30} does not correlate with site resonance. Site resonance is the main concern for many urban locations in the central and eastern United States, which are often underlain by soft sediments overlying hard bedrock, resulting in significant impedance contrasts. Two physics-based parameters—the fundamental (i.e., base mode) resonance frequency, f_0 , and its peak amplification, A_0 —have been identified as paired proxies that capture the characteristics of site resonance. The fundamental resonance frequency and its peak amplification can be determined from (1) horizontal-to-vertical spectral ratios (HVSr) of earthquake S-waves, (2) 1-D site-response analysis (e.g., SHAKE or DEEPSOIL), or (3) simplified one-layer sediment over bedrock. We propose using f_0 and A_0 as correction factors to modify the design response spectrum to account for site resonance. Furthermore, we propose substituting the fundamental resonance period, T_f (i.e., $1/f_0$), for T_s —i.e., $T_s = T_f$ —and A_0 for the site coefficient F_a —i.e., $F_a = CAA_0$ (C_A is a constant). The proposed design response spectrum is determined by:

$$T_0 = 0.2T_s, T_s = 1/f_0;$$

$$SDS = CAA_0S_s, S_s \text{ is short-period response acceleration};$$

$$S_a = SDS (0.4 + 0.6T/T_0) \text{ for } T \leq T_0;$$

$$S_a = SDS \text{ for } T_0 < T \leq T_s;$$

$$S_a = SDS T_s/T \text{ for } T_s \leq T.$$

We also developed modification factors for the fundamental resonance frequency and its peak amplification to account for soil nonlinear response to different levels of input ground motion.

RECENT RESULTS OF SEISMIC NETWORK MONITORING IN THE CENTRAL VIRGINIA SEISMIC ZONE

CHAPMAN, Martin, BEALE, Jacob, GUO, Zhen, WU, Qimin.

A twenty-five station temporary seismic network operated in central Virginia from April 2017 through November 2018. A total of 457 earthquakes were located, 400 of which are aftershocks of the Mw 5.7 August 23, 2011 Mineral earthquake. The aftershock sequence is persistent and stable. The general pattern of hypocenters is not appreciably different from that of the immediate (August 25 – December 31, 2011) aftershocks. The rupture zone of the mainshock remains an aftershock shadow, and most of the activity forms a distinctive halo at depths less than 6.2 km, above and to the north-northeast of the mainshock rupture zone. The majority of the 47 well-constrained focal mechanisms are reverse, and the nodal planes trend North to Northwest, consistent with a maximum horizontal stress trending approximately N70E, whereas the mainshock rupture plane (also reverse) strikes N30E. The great majority of these aftershocks are shallower than the mainshock rupture. The rate of aftershocks observed during the study period is within a factor of two of that predicted by Omori's Law, using parameters determined from the early aftershock sequence in 2011. The results establish that the aftershock spatial distribution is temporally stationary, and that the stress field responsible for the early aftershocks at shallow depths is also temporally persistent. Currently, the most active part of the central Virginia seismic zone outside the 2011 Mineral aftershock area is centered approximately 60 km to the southwest, in Buckingham County, a historically active region, and possibly the site of a pre-historic shock of significant size.

**AN EFFICIENT REPEATING SIGNAL DETECTOR THAT USES MACHINE LEARNING TO IMPROVE DETECTION OF INDUCED SEISMICITY

CHIORINI, Sutton, SKOUMAL, Rob, BRUDZINSKI, Michael.

Induced seismicity has become a major issue with the increase in both hydraulic fracturing and disposal of the leftover wastewater. Although regulatory management strategies such as traffic light systems aid in mitigating the impact of induced seismicity on society, they do not forecast when or where future cases of induced seismicity are likely to occur. Detecting earthquakes prior to reaching regulatory thresholds is a challenge for both operators and regulators, such that advanced methods for detection are needed. Previous methods to identify induced seismicity include Matched Filter Analysis (MFA; Caffagni et al., 2016), Fingerprint and Similarity Thresholding (FAST; Yoon et al., 2015) and Fast Matched Filtering (FMF; Beauce et al. 2017). While all these methods are effective, they require long computation times or heavy computational requirements and multiple sensors to produce viable results. We recently developed a computationally efficient Repeating Signal Detector (RSD), which utilizes a form of machine learning to identify similar waveforms in continuous seismic data using a single seismometer. Instead of relying on a priori templates, RSD identifies repeating signals above a specified signal-to-noise threshold and then grouping based on frequency and time domain characteristics, resulting in a significantly faster processing time than other current approaches. Recent work has also focused on distinguishing repetitive cultural noise from repetitive seismicity, as both types signals can be confused by automatic detection methods. We will discuss recent efforts to apply RSD in areas of induced seismicity that employ strategies to limit repetitive noise.

A NEW, PRELIMINARY EVALUATION OF THE ADAMS MILL FAULT:

COUNTS, Ronald.

The Adams Mill fault is a high-angle reverse fault that thrusts Cambrian crystalline basement over unconsolidated gravel deposits near the original entrance of the Smithsonian National Zoological Park in downtown Washington, D.C. Multiple ages that range from the Cretaceous to the early Pleistocene have been assigned to the footwall gravel since the early 20th century, but none were based on radiometric methods. In 2016, a trench was dug through the fault on National Zoo property to characterize the fault's trend and to collect samples for luminescence dating. Infrared stimulated luminescence dating revealed the gravel was deposited 451 ± 34 ka. This age represents a maximum age for the Adams Mill fault, which could be significantly younger than the gravel.

Other known faults in the immediate area include one identified in an excavation near 18th and California streets and a fault inferred from boreholes drilled at Lafayette Park. All three locations lie along the same trend. The exposed faults at Adams Mill Road and 18th Street were formerly characterized as small and localized, but recent USGS mapping shows them as a single continuous fault, extending from the National Zoo and into East Potomac Park where it connects with the Stafford Fault system. The Lafayette Park drilling indicated displacement increases with depth, suggesting

multiple slip events have occurred. Evidence of multiple slip events combined with deformation younger than 500,000 years would classify the Adams Mill fault as a capable fault according to Nuclear Regulatory Commission guidelines. There are many historic, unreinforced masonry buildings and structures along the fault trend, including the East Wing of the White House and Washington Monument, that are highly vulnerable to seismic shaking. Although the fault is not part of an active fault system and is currently considered to have a low probability for modern slip, it poses an extremely high risk to the Washington D.C. metropolitan region.

SEISMIC AND LIQUEFACTION HAZARD MAPS FOR THE CHARLESTON, SOUTH CAROLINA, AREA

CRAMER, Chris, JAUME', Steven, LEVINE, Norman.

A previously developed community velocity model and liquefaction probability curves for the local geology in a three county area around Charleston, South Carolina, have been used to generate detailed seismic and liquefaction hazard maps for nine quadrangles. Hazard maps with the effects of local geology have been generated for a resolution of 500 m, expanding the pilot study done on the Charleston quadrangle in 2014. Additional products include a database of M7 time histories (series) for the engineering foundation geology of Cooper Marl at the surface and a comparison of 1886 M7 alternative source model scenario hazard maps with the intensities observed in the 1886 earthquake. The database of time histories is for use by the engineering community in site-specific evaluations in the Charleston area and has been generated at their request with their input. The 1886 earthquake intensities have been converted to ground motions using an update to the Ogweno and Cramer (2017) CENA ground motion to/from intensity correlation equations and then compared with the varying source based scenario hazard maps. The goal is to see if differences between alternative sources for the 1886 earthquake can be resolved by the intensity observations converted to ground motions. Obviously, the seismic hazard in the Charleston area is high due to its proximity to the 1886 earthquake source. PGA probabilistic hazard is reduced by about 50% from the USGS B/C boundary hazard maps and PGA M7.0 scenario hazard ranges from 0.4 g near the source to less than 0.2 g at greater distances. Liquefaction hazard varies with surface geology with younger sediments showing higher hazard than older sediments. The probability of moderate to severe liquefaction varies from greater than 90% to less than 20 %.

SEISMIC AND LIQUEFACTION HAZARD MAPS FOR DYER COUNTY, NORTHWESTERN TENNESSEE

CRAMER, C., VAN ARSDALE, R., ARELLANO, D., PEZESHK, S., HORTON, S., WEATHERS, T.

A five-year seismic and liquefaction hazard mapping project for five western Tennessee counties began in 2017 under a Disaster Resilience Competition grant from the U.S. Department of Housing and Urban Development to the State of Tennessee. The project supports natural hazard mitigation efforts in the counties of Lake, Dyer, Lauderdale, Tipton, and Madison. The county seismic hazard maps for Lake County in northwestern Tennessee were completed in early 2018 and similar maps for Dyer County were completed in 2019. Additional geological, geotechnical, and geophysical information has been gathered in Lake and Dyer Counties to improve the base northern Mississippi Embayment hazard maps of Dhar and Cramer (2017). Information gathered includes additional geological and geotechnical subsurface exploration logs, water table level data collection and measurements, new measurements of shallow and deep shear-wave velocity (Vs) profiles, and the compilation of existing Vs profiles in and around the counties. Improvements are being made in the 3D geological model, water table model, the geotechnical liquefaction probability curves, and the Vs correlation with lithology model for Lake and Dyer Counties. Resulting improved soil response amplification distributions on a 0.5 km grid will be combined with the 2014 U.S. Geological Survey seismic hazard model (Petersen et al., 2014) earthquake sources and attenuation models to add the effect of local geology for Lake and Dyer Counties. Resulting products will be similar to the Memphis and Shelby County urban seismic hazard maps recently updated by Cramer et al. (2018).

SEISMIC HAZARD IN STE. GENEVIEVE, MO FROM GRAVITY, SEISMIC REFRACTION, AND SHEAR WAVE VELOCITY OBSERVATIONS

CRAMER, Chris, RAHMAN, Md. Jabir, PATTERSON, Gary.

Several historic buildings in Ste. Genevieve, MO survived the 1811-1812 New Madrid earthquakes with seemingly minimal damage, including a brick building (Old Brick House). We completed a gravity, refraction, and Multi-Channel Analysis of Surface Waves (MASW) surveys around the town to better understand the sediment thickness over the limestone bedrock. The relative gravity survey consists of 73 closely-spaced stations and provides sediment depth estimation beneath the historic district. Five independent refraction profiles serve to constrain the density contrast

between bedrock and overburden and help constrain the sediment thickness. MASW measurements constrain the V_s gradient in the sediments. Sediment depths range from 25 to 50 m within an uncertainty of 5 m. Older historic buildings seem to be over the shallower depth to bedrock areas. Scenario earthquake models using the velocity gradient in sediments, the depth to competent bedrock, and the 2014 USGS national seismic hazard model provide estimates of peak ground acceleration (PGA) from 1/5th to 1/4th g for the New Madrid M7.5, M7.3, and M7.7 earthquakes. Equivalent hard-rock PGA estimates range from 0.05 to 0.07 g. This suggests that the damage from the 1811-1812 earthquakes could have been more extensive as suggested by recent engineering investigations inside the historic buildings and historical 1811-1812 accounts from the New Bourbon region around Ste. Genevieve.

HISTORIC ACCOUNTS OF ANIMAL REACTIONS BEFORE AND DURING EARTHQUAKES IN NORTHEASTERN NORTH AMERICA

EBEL, John.

There is great interest among the general public in animal reactions to earthquakes, primarily because many people believe that animals engage in unusual behavior before earthquakes occur. In my recently published book *New England Earthquakes: The Surprising History of Seismic Activity in the Northeast*, I included many accounts of the reactions of animals to the strong historic earthquakes that took place in northeastern North America. Animal reactions are found in many historic accounts. Animals that reportedly reacted to the earthquakes include dogs, cats, cattle, horses, chickens, turkeys, and “brute beasts”. Some accounts from ships in harbors or offshore indicate that fish jumped from the water in large numbers during earthquake shaking, and one report stated that dead fish were seen on the ocean surface immediately following the 1755 M6.3 Cape Ann, Massachusetts earthquake. There are a few reports that suggest that some animals did not react to the earthquake shaking that was experienced by nearby human observers. Some of the historic accounts are very general in nature, such as that dogs barked due to the earthquake. Other accounts are quite specific, where the timing of the sensation of the ground shaking by human observers relative to the reaction of their animals is precisely stated. In almost all of the accounts, the animals reacted to the earthquake shaking and not prior to the shaking. An account of the 1727 M5.6 earthquake at Newburyport, Massachusetts suggests that dogs may have become agitated just before the P wave was experienced, and something similar is contained in a newspaper account of one of the M5.5 earthquakes at Ossipee, New Hampshire in 1940. There is only one report of dog becoming agitated and barking several hours before an earthquake, the 1982 M5.8 Miramichi, New Brunswick earthquake. The historic accounts from the northeast provide almost no evidence that animals behave in an unusual way before strong earthquakes.

****AN EMPIRICAL GROUND-MOTION PREDICTION MODEL FOR SMALL-TO-MODERATE INDUCED EARTHQUAKES IN CENTRAL AND EASTERN UNITED STATES**

FARAJPOUR, Zoya, PEZESHK, Shahram.

Induced seismicity refers to seismic events caused partially or completely by human (anthropogenic) activities. Since 2009, the average number of earthquakes with magnitude 3 and more has jumped and has been much higher than the typical average of 25 earthquakes per year.

Accordingly, the recent report by the U.S. National Academy of Sciences on 2013, incidents of induced and triggered earthquakes associated with energy production have increased in recent years. In the past several years, there have been many small seismic events in Arkansas, Ohio, Oklahoma, and Texas which have been related to wastewater disposal associated with oil and gas production.

For seismic hazard evaluation, scientists are looking at both tectonic and man-made earthquakes. A key component of the seismic hazard evaluation is ground motion models (GMMs). In this study, we consider an extensive database, containing more than 46,000 horizontal-component recorded ground motions, which is well-recorded ground motion data sparse at close distances. Additionally, we work on response spectra and peak ground motions for the shallow focal depth events of M 3–6 within hypocentral distances of less than 200 km considering induced seismicity events for Central and Eastern US. The ground-motion database for this study collected from IRIS, Gupta et al. (2017), and other available sources. The proposed GMPEs applied to soft-to-rock site conditions for VS30 ranging in 150-800 m/s. We propose a “mixed effect” regression for regression analysis. A comprehensive residual analysis considering inter-event and intra-event components of strong motion variability with respect to the distance, magnitude, and site

condition are considered. The suggested functional form takes into account differences in the earthquake occurrences, source, wave propagation, and site-response characteristics.

****A GROUND MOTION MODEL FOR ARIAS INTENSITY AND CUMULATIVE ABSOLUTE VELOCITY BASED ON THE NGA-EAST DATABASE**

FARHADI, Ali, PEZESHK, Shahram.

From engineers' point of view, three characteristics of strong ground-motion including the amplitude, frequency content, and duration are of great importance. In practice, more than one ground-motion parameter is required to fully describe these characteristic features of strong ground motion. In central and eastern North America (CENA), researchers have developed several ground-motion models (GMMs) to predict intensity measures (IMs) such as PGA (peak ground acceleration) and SAs (spectral accelerations). These IMs describe the amplitude and the frequency content of the ground motion. Therefore, there is a need to develop GMMs for predicting duration related ground motion parameter in CENA. To this end, we performed mixed-effects regression on the NGA-East database to establish a GMM for duration related IMs including Arias Intensity (AI) and cumulative absolute velocity (CAV).

The proposed model has a simple functional form with four independent parameters including the magnitude, source-to-site distance, average shear wave velocity of the top 30 meters, and the style of faulting. AI and CAV can be obtained from the time integration of acceleration time histories. These IMs are well correlated with damage potential of geotechnical and structural systems because they reflect the cumulative effects of ground motion duration and intensity.

HYDRAULIC FRACTURE INJECTION STRATEGY INFLUENCES THE PROBABILITY OF EARTHQUAKES IN THE EAGLE FORD SHALE PLAY OF SOUTH TEXAS

FASOLA, Shannon, BRUDZINSKI, Mike, SKOUMAL, Robert, LANGENKAMP, Teresa, CURRIE, Brian, SMART, Kevin.

We investigated the recent increase in seismicity rate in 2018 in the Eagle Ford shale play of south Texas that grew to 33 times higher than previous years and how hydraulic fracturing (HF) contributed. We compared times and locations of HF wells with a catalog of seismicity we enhanced with waveform correlation. Over 200 HF wells had seismicity nearby during operation with ~90 earthquakes larger than magnitude 2.0 indicating seismicity from HF is more common in the Eagle Ford shale play than previously thought. We found that HF injection strategies affect the probability of earthquakes. Seismicity was twice as likely when operators inject into multiple well laterals simultaneously compared to when they inject into multiple well laterals one lateral at a time. Simultaneous lateral injection was three times more likely to produce seismicity compared to when injection occurs into a single lateral alone. Of the ~2400 HF-induced earthquakes we identified, a MW 4.0 on 1 May 2018 is one of the largest reported in the United States, and it occurred ~10 km from the largest (MW 4.8) earthquake in south Texas previously thought to be due to fluid extraction. This study demonstrates that faults in this area are capable of producing felt and potentially damaging earthquakes due to ongoing operational activities.

THE MODERNIZATION OF THE OHIO SEISMIC NETWORK

FOX, Jeff.

Low seismicity rates combined with smaller magnitude events pose specific challenges to the understanding of the seismotectonics and hazards in the eastern United States, and particularly Ohio. Until recently, the infrastructure needed to detect lower-magnitude (<~2.5Mb) events was not available in Ohio. The Ohio Seismic Network's (OhioSeis) poor station density, lack of telemetry, and non-ideal interior locations of the earlier seismic instruments made earthquake detections difficult. Efforts to modernize the capabilities of the Ohio Seismic Network began in 2012, when 25 Transportable Array (TA) broadband stations were first deployed. In 2015, OhioSeis implemented the Earthworm system, making use of TA stations fed from the Incorporated Research Institutions for Seismology (IRIS) wave server for earthquake notifications, alerts, and automated locations throughout the state. Since 2016, seismologists with the Ohio Department of Natural Resources (ODNR) Division of Geological Survey have worked to modernize OhioSeis stations, upgrading from older instruments to modern broadband (120s – 100Hz) seismometers in below-ground vaults. In 2019, OhioSeis implemented the ANSS Quake Management System (AQMS) to handle archiving, alerts, detections, and analysis. All OhioSeis stations are now sending data in real time to the IRIS Data Management Center

under network code 'OH'. The ODNR Division of Geological Survey now oversees a network of 38 seismic stations, providing a model for state-run seismic monitoring throughout the Midwest.

RAY-THEORY BASED ANALYSIS OF THE P/S RATIO BEHAVIOR WITHIN VERTICAL GROUND MOTIONS

FRID, Michael.

Vertical ground motions have been traditionally neglected in seismic-hazard analysis, because they were believed to have minor effects on civil structures. Specifically, the vertical site-response and the physical parameters which affect it are still poorly understood. In recently-published vertical GMPEs, the site-response component is represented only by SV dependent parameter (i.e. Vs30). However, several studies have shown that - depending on magnitude, distance, and other site conditions, the P-wave contribution to the vertical component of ground motion, specifically at high frequencies, could be as large as that of the SV-wave or even larger. In this study, we hypothesize that the site-response component in vertical GMPEs can be better estimated by combining P- and S- related site parameters. However, such combination can only be obtained once their relative contribution to the vertical ground motion is properly understood and well-defined. This topic has not been fully explored before and hence represents a significant knowledge-gap in the current ability to characterize vertical site-response.

In order to examine the relative contribution of P- and SV- waves on the vertical ground motion component, an analytical algorithm was developed. It allows us to calculate and present all the possible direct wave-fronts that leave a point-source and meet at a single recording point. The calculation takes into account the geometrical setting as well as the frequency-dependent attenuation and is a function of a number of independent variables, such as the thickness of the overlying soil layer, the velocity ratio, and the source-to-site distance. The computed data allows us to establish the pure separated P and S amplitudes and their ratio in the frequency domain as function of specific physical properties. This study is expected to facilitate an improved understanding of the relative contribution of P- and S- wave types to the vertical ground motion.

RELATIONSHIP BETWEEN INSTRUMENTAL GROUND-MOTION PARAMETERS AND FELT INTENSITY IN CENTRAL AND EASTERN UNITED STATES

KIM, Won-Young, GOLD, Mitchell.

We attempt to determine the relationship between instrumental ground-motion parameters and felt intensity in central and eastern United States (CEUS) using the newly available observed community decimal intensity (CDI) data that are the basis to generate USGS community internet intensity map (CIIM) and improved high-sample rate broadband waveform data. Despite obvious success of the ground motion prediction and intensity prediction equations to aid generating realistic ShakeMaps and to assess hazard tolls, the regression relationship between the Modified Mercalli (MM) intensities in the range of 2 to 5 (II – V), and the corresponding peak ground velocity (PGV) values show a spread of about two orders of magnitude around the mean. We obtained 740 CDI – PGV pairs out of 57,000 CDI values from 20 earthquakes with magnitude greater than 4 and 2,130 PGV measurements, due to sparse and uneven distribution of seismic stations and population density. Using the unbiased CDI – PGV pairs, we obtained regression relation of $MMI = 1.76 \log_{10} PGV [cm/s] + 5.78$. We modeled the CDI – PGV pairs to determine a regional scale adjustment by using the local site conditions.

REMAPPING CHARLESTON: USING HISTORICAL INFORMATION TO UPDATE SEISMIC SITE CONDITIONS IN AN URBAN SETTING

JAUME, Steven, DESILETS, Reagen, LEVINE, Norman.

Mapping surface geology with respect to seismic site conditions in a historic urban area like Charleston, South Carolina provides unique challenges. Human modification of the land surface began almost immediately upon the founding of the city in 1680 and the filling of tidal marsh with man-made materials was well advanced by the time of the 1886 earthquake. By the time modern geological surface mapping began in the Charleston quadrangle (circa-1980s) extensive areas of reclaimed land already existed both on the Charleston Peninsula and in the vicinity of the former Charleston Navy Base. In addition, the City of Charleston's attempts to preserve the historic building fabric of the city has limited redevelopment, which also limits the distribution of new geotechnical borings. In recent years we have begun compiling and digitizing historical maps, older (pre-CPT/SCPT) geotechnical reports, and other historical information in order to "peel back" the man-made surface and see more clearly what lies beneath. Some the most

valuable materials in this endeavor are the 1949 Halsey Map of the original outline of the Charleston peninsula, the 1919 USGS topographic map of the Charleston quadrangle, and historic geotechnical and engineering reports from the City of Charleston archives. These materials better document the original boundary between extremely low VS (< 100 m/sec) Holocene tidal marsh deposits and the firmer (VS ~200 m/sec) Quaternary Silver Bluff and Wando Formations. They also allow us to recognize errors in existing surface maps (e.g., man-made fill mislabeled as a Quaternary unit) and previously unrecognized zones of firm ground in otherwise deep Holocene marsh deposits. This work also helps make better sense of previous microtremor site amplification results, which appear to be more sensitive to the thickness of Holocene marsh underlying the artificial fill than the presence of the artificial fill itself.

RASPBERRY SHAKE, EQ1, AND RESEARCH-GRADE SEISMOGRAPHS: PROS AND CONS OF DIFFERENT TYPES OF SEISMOGRAPHS FOR EDUCATION, CITIZEN SCIENCE, AND EARTHQUAKE MONITORING IN NEW ENGLAND AND TEXAS

KAFKA, Alan, FINK, Kristi.

The Texas Educational Seismic Project (TX-ESP), and the Boston College Educational Seismology Project (BC-ESP), share a collaborative mission to turn real-world phenomena into teachable moments for students of all ages and socio-economic backgrounds. In pursuit of our mission, both TX-ESP and BC-ESP use seismology as a medium for inviting students into the world of scientific research and for promoting inquiry-based learning through investigation of earthquakes recorded by classroom seismographs. Seismographs-in-schools programs, which grew out of efforts to enhance science education through seismology, resulted in many seismic stations operating in schools (and now in other public venues). As these seismographs-in-schools programs developed, an inevitable question was raised: Are the educational seismographs used in these programs only suitable for educational purposes focused on large, globally-recorded, earthquakes, or could they also serve as additional instruments for monitoring smaller earthquake seismicity in regional settings? The recent development of the low-cost “Raspberry Shake” (RS) seismograph, which has an instrument response in the frequency range necessary for regional monitoring, provides opportunities for RS seismographs to serve as additional stations for regional seismic monitoring. Here we explore the extent to which the RS seismograph compares with the EQ1 educational seismograph and with more expensive, research-grade seismographs commonly used for regional seismic networks and global monitoring. We find that the affordability, flexibility, and technical capability of the RS is well suited for recording both regional earthquakes and more distant global earthquakes, thus enabling an opportunity for students of all ages and socio-economic backgrounds to monitor and study earthquakes “in their own back yard” as well as across the globe.

****MICROEARTHQUAKE DETECTION WITH ULTRA-DENSE SEISMIC ARRAY IN NORTHERN OKLAHOMA**

LI, Chenyu, ZHAI, Qiushi, LI, Zefeng, PENG, Zhigang.

There is a surge of ultra-dense seismic array deployment in recent years, mainly because of the development of portable sensors and increasing need of more complete seismicity and detailed structure in many regions. Ultra-dense seismic arrays generally have hundreds to thousands of stations that cover a few to tens of kilometers. The IRIS Oklahoma Community Wavefield Experiment (YW network) is a recent example of such ultra-dense array, which includes more than 360 nodal sensors in Northern Oklahoma and is recorded continuously from June – July 2016. Here we apply a recently developed local similarity method to the 5-10 Hz filtered waveforms. This method measures the mean cross-correlation of waveforms at each station to its neighboring stations and uses the resulting stacked cross-correlation function to detect new events. Using this method, we find 21 tremor-like long-duration, long-period events that are likely generated by nearby train (Li et al, 2018) as well as more than 3000 earthquake-like signals. Next we compare the timing of our newly detected events with those listed in the Oklahoma Geological Survey (OGS) catalog and the template-matched catalog of Oklahoma (Skoumal et al., 2019). Among the 378 events in OGS catalog during the recording period, 318 of them are detected by the local similarity method, and 954 out of 1687 events on the template-matched catalog are detected by local similarity. Furthermore, we find that most of the known earthquakes within 30 km from the array could be detected by local similarity. Our next step is to further distinguish between teleseismic, regional and local events in all the new detections, and obtain more detailed spatial distribution of local events during the study period. We plan to incorporate beamforming and time-shifting from predicted travel times in the local similarity method to obtain coarse locations of these events, and then pick station-wise arrival times around the detections and further relocate them.

****STRESS DROP VARIATION OF DEEP-FOCUS EARTHQUAKES BASED ON EMPIRICAL GREEN'S FUNCTIONS**

LIU, Meichen, HUANG, Yihe, RITSEMA, Jeroen.

We estimate stress drops of Mw 6.0-8.2 global deep-focus (> 350 km) earthquakes using teleseismic P-wave and S-wave waveforms and an empirical Green's functions approach. We estimate the corner frequency assuming Brune's source model and calculate the stress drop assuming a circular crack model. The P-wave and S-wave stress drops range between 0.06 to 3300 MPa and between 0.35 to 540 MPa, respectively, and do not depend on event depth. Based on the analysis of P waves, the median of our stress drops estimates is about four times higher than the median stress drop of shallow earthquakes with the same magnitude estimated by Allmann and Shearer (2009). This suggests that the shear strength of deep faults in the mantle transition zone is on average four times higher than the shear strength of faults in the crust.

****SEGMENTATION OF THE EASTERN REELFOOT RIFT MARGIN: REINTERPRETATION OF THE NORTHEASTERN REELFOOT RIFT FAULT GEOMETRY AND SEISMIC POTENTIAL**

MARLOW, Christopher, POWELL, Christine, COX, Randel.

We investigated the magnitude potential of the ERRM extending from Covington, Tennessee, to Dyersburg, Tennessee. This region contains Quaternary and Holocene age folds and scarps as well as concentrated seismic activity. Previous research on the ERRM's faults has been limited in spatial resolution, thereby leading to significant interpolation of fault geometries and lengths between control points. We assert this is a significant gap in understanding, as the most statistically significant predictor of the M potential of a fault is its length. To better interpret the ERRM fault geometries, we utilized publicly available aeromagnetic data. Data filtering consisted of both reduction-to-the-pole and the horizontal-gradient-method (HGM). The HGM was used to detect magnetic contacts assumed to be due to faults. We then integrated previous data sets with our interpreted faults to create a rank-ordering system based on corresponding geologic and geophysical evidence of faulting. Our results indicate that this section of the ERRM consists of 13 fault segments which vary in strike and length from 270 - 087° and 7.5 - 41.5 km, respectively. We used assumed fault widths of 10, 14, 15, 19, 28, and 32 km to calculate a range of fault areas for each fault. We used the CEUS relation of M magnitude to fault area to generate a range of possible magnitudes for each interpreted fault. For the minimum fault areas, the M potential ranged from 6.2 - 7.0, and for the maximum fault areas, the M potential ranged from 6.7 - 7.5. Based on the correspondence of modern seismicity, Holocene activity, and tectonic geomorphic indicators of active tectonism, we interpret each fault to be seismically active. Our results indicate that the M potential along this section of the ERRM supports previous work in this region. However, we recognize that our study area does not capture all of the seismogenic faults along the ERRM, and further research is required.

****DEVELOPING DATA-DRIVEN STOCHASTIC SEISMOLOGICAL PARAMETERS OF CENA FROM THE NGA-EAST DATABASE**

NAZEMI, Nima, PEZESHK, Shahram, ZANDIEH, Arash.

The fundamental idea of this project is to obtain a set of self-consistent stochastic seismological parameters for Central and Eastern United States (CENA). We are using median 5% damped pseudo-spectral acceleration (ROTD50) with rupture distances (Rrup) less than 500 km from the NGA-East database and the point source stochastic model (Boore, 2003) to determine seismological parameter that minimize the residuals over the usable frequencies of the data using a genetic algorithm. The largest Vs30 value for the database is 2000 m/s. The final product of this study is a set of well correlated seismological parameters compatible with single and generalized additive and multiplicative double corner frequency models.

Parameters obtained in this study include a frequency dependent tri-linear geometric spreading model, site kappa for very hard rock in CENA, frequency dependent quality factor, eight magnitude dependent parameters of generalized additive and multiplicative double corner frequency model (Boore et al., 2014), and magnitude dependent point-source correction factor (also known as pseudo depth). The double corner frequency can easily be converted to single corner frequency model and a magnitude dependent stress drop parameter and corner frequency, which has the same entity of being data-driven and self-consistent.

The final objective of this research is to develop an updated hybrid empirical ground motion model to map the ground motion of the higher magnitudes from a richer database by scaling the ground motion in the target region (CENA) by the ratio of stochastic over empirical ground motion obtained in a target region.

****IS THE AFTERSHOCK AREA A GOOD PROXY FOR THE MAINSHOCK RUPTURE AREA?**

NEO, Jing Ci, HUANG, Yihe, YAO, Dongdong, WEI, Shengji.

Large earthquakes are usually followed by sequences of small earthquakes, exhibiting a mainshock-aftershock pattern. The locations of aftershocks are often observed to be on the same fault plane as the mainshock and used as proxies for its rupture area. However, there has been limited research on how well aftershock location actually approximates mainshock rupture area. Furthermore, recent developments in earthquake relocation techniques have led to great improvements in the accuracy of earthquake locations. Hence, we investigate this assumption using slip distributions of 12 $M_w \geq 5.4$ mainshocks and relocated aftershocks of 12 $M_w \geq 5.4$ mainshocks in California. We calculate the area enclosed by the aftershocks, normalized by the mainshock rupture area derived from slip contours. We find that overall, the ratios of aftershock areas to mainshock rupture areas lie within a range of 0.5 to 5.5, with most values larger than 1. Using different slip inversion models for the same earthquake can have a large impact on the results, but the ratios estimated from the relocated catalogs and Advanced National Seismic System (ANSS) catalog have similar patterns. The ratios for earthquakes in Southern California fall between 0.5 and 3, while earthquakes in Northern California exhibit a wider range of ratios from 1 to 5.5. We also investigated the possible relationship between the aftershock area and Coulomb stress change, stress drop and afterslip. Our results show that both Coulomb stress changes and stress drops are correlated with aftershock areas, indicating that static stress change is a primary aftershock triggering mechanism. Extensive afterslip may account for the large aftershock areas of the Loma Prieta mainshock.

DEPTH TO BASEMENT ACROSS THE PENNSYLVANIA PORTION OF THE APPALACHIAN BASIN USING SEISMIC REFLECTION DATA

NYBLADE, Andrew.

Induced seismicity as a result of hydraulic fracturing and the subsequent wastewater disposal process has been a concern in recent years. Although typically small magnitude events, these induced earthquakes can reach magnitudes large enough to cause damage to nearby structures. The majority of induced seismic events occur within old basement faults below the target formation. While most induced seismicity has occurred in the central United States, there are several instances of induced events occurring in the Appalachian Basin such as the magnitude 2.3 Lawrence County, PA event in 2016 and the magnitude 4.0 Youngstown, Ohio event in 2011.

Using 2D seismic reflection data (courtesy of Geophysical Pursuit, Inc.) and basement well logs, this study aims to measure depth to basement across the Pennsylvania portion of the Appalachian Basin. Current depth to basement estimates in Pennsylvania suffer due to a lack of data, particularly in the northeast and southwest portions of the state. Tying the newly acquired seismic reflection data with existing basement-penetrating well bores produces a more resolved image of the Precambrian basement structure across the commonwealth. This allows operators and government entities to better evaluate risk of induced seismicity from wastewater injection and hydraulic fracturing.

****INSIGHTS FROM AFTERSHOCKS OF THE 30 NOVEMBER 2017 DOVER, DE, EARTHQUAKE**

PEARSON, Karen, LEKIC, Vedran, PRATT, Thomas, WAGNER, Lara, ROMAN, Diana, KIM, Won-Young.

The M_w 4.2 earthquake near Dover, DE, in November 2017 represented an opportunity to evaluate seismicity in a passive margin setting, motivating a rapid deployment of instruments in order to record aftershocks. Within 24 hours of the main shock, personnel from the University of Maryland, the Department of Terrestrial Magnetism of the Carnegie Institution for Science, the Lamont-Doherty Earth Observatory, Lehigh University, and the USGS mobilized to install a mix of instruments in the epicentral area.

Using template-matching, we detect several dozen aftershocks, all with magnitudes ≤ 1.5 , and locate a subset of them using a site-specific 1D model. The 1D model is based on receiver function modeling refined by modeling waveforms to 5 sec period of the largest aftershock at the closest deployed temporary broadband station. The locations of the aftershocks allow us to identify the fault structures of the immediate region. Using three-component waveforms filtered at 1 – 5 Hz, we perform moment tensor inversion for larger aftershocks to determine moment magnitude and assess focal mechanism variability. We discuss the aftershock productivity and locations in the context of East Coast seismicity.

TRIGGERED AND INDUCED SEISMICITY IN EAST ASIA

PENG, Zhigang, LEI, Xinglin.

It is well known that large earthquakes can trigger other earthquakes at nearby (aftershocks) and long-range distances (remote triggering). In addition, naturally occurring cyclic loadings (e.g., atmospheric pressure changes, solid earth tides, and annual variations in water storages) are also capable of modulating seismicity at depth (both microearthquakes and deep tectonic tremor). In recent years, a growing number of studies have shown that human activities (e.g., reservoir impoundment, fluid injections) are capable of reactivating fault movements and induce small to moderate-size earthquakes. The anthropogenic stress perturbations can be similar or larger than those naturally occurring stress changes. In this presentation, we first define the terms “triggered” and “induced” earthquakes. Next, we summarize recent observations of triggered and induced seismicity in East Asia. For triggered seismicity, we focus on remotely triggered earthquakes around Tibet and intraplate regions in China, as well as triggered deep tectonic tremor along major plate boundary zones. For induced earthquakes, we present updated results associated with reservoir-induced seismicity in the past two decades in China and other countries. In addition, we introduce recent observations of moderate-size earthquakes in southern Sichuan Basin, likely induced by ongoing shale-gas development, deep salt mining, and disposal of wastewater. A systematic comparison of triggered and induced seismicity in these regions can provide new insight on physical mechanisms of fault reactivation and earthquake nucleation, as well as possible ways to reduce seismic hazard associated with anthropogenic activities.

COHERENT PROCESSING OF RASPBERRY SHAKE DATA FROM THE WASHINGTON D.C AND BOSTON AREAS

PULLI, Jay, KAFKA, Alan.

Raspberry Shake (RS) seismographs have gained wide acceptance over the past two years as an inexpensive, IoT solution for seismic monitoring. There are nearly 2000 installed RSs across the globe. These “Shakes” are providing additional coverage for existing seismic networks, educational experiences for students in schools, and citizen science seismographs for the interested public. Many of these Shakes are installed in homes and are subject to noise sources that are usually avoided. But where RSs are densely distributed their sensitivity, bandwidth, and interstation coherence enable the application of seismic processing that is normally used for quiet networks. Here we demonstrate coherent processing for Shake networks around the Washington D.C. & Boston areas.

There are 15 Shakes operating around the Washington D.C. area. The geometry is near-ideal for coherent processing of teleseismic body and surface waves. The network routinely records global earthquakes above M6. The Feb. 22, 2019 Ecuador earthquake (M7.5) provides a test case for coherent processing. The event was 4600 km south of the network. Frequency-wavenumber (fk) processing of the P-wave data results in a back-azimuth estimation that is in error by only 0.1 deg. There are few local earthquakes but the western portion of the network includes a number of small quarries. Rg waveforms provide an efficient means of detection and localization and is a test case for data processing in noisy areas.

There are 26 Shakes in southern New England. Most are in schools and other public venues as part of the Boston College Educational Seismology Project. This greater station density, and a higher rate of seismic activity, provides an excellent test case for coherent processing. Combining fk solutions from this and the DC network, along the 650 km baseline, enables global event location and other types of coherent processing for teaching concepts of seismology for students and citizen scientists of all ages.

****2-D AND 3-D DYNAMIC EARTHQUAKE SIMULATIONS FOR THE CASCADIA MEGATHRUST**

RAMOS, Marlon, HUANG, Yihe.

There is ample geologic evidence to support the occurrence of multiple M>8 and larger earthquakes along the Cascadia megathrust for the last ~10 kya. Coseismic subsidence was observed along the Pacific Northwest coastline during the most recent event in 1700 A.D. However, because there are no modern seismic recordings of megathrust earthquakes for this subduction zone, most rupture simulation efforts to date have focused on how stochastic or kinematic on-fault slip parameterizations borrowed from other megathrust events (e.g., Tohoku, Maule) affect tsunami hazard or predict ground motions. Geodetic observations, on the other hand, are readily available above the Cascadia megathrust and suggest varying degrees of locking, or slip deficit.

We take geodetic inversions for slip-rate deficit and convert them to slip by assuming megathrust recurrence intervals constrained by paleoseismic data. We then go one step further and use these kinematic slip parameterizations to derive initial shear stress levels on the megathrust as initial input into our dynamic rupture simulations. Furthermore, we build upon previously designed 2D dynamic rupture models (Ramos and Huang, 2019) that incorporate an abruptly positive to negative stress drop from the base of the locked to transition regions of the fault.

****FACTORS INFLUENCING THE PROBABILITY OF HYDRAULIC FRACTURING INDUCED SEISMICITY IN OKLAHOMA**

RIES, Rosamiel, BRUDZINSKI, Michael, SKOUMAL, Robert, CURRIE, Brian.

Injection induced seismicity became an important issue over the past decade, and while much of the rise in seismicity is attributed to wastewater disposal, a growing number of cases have identified hydraulic fracturing as the cause. A recent study identified regions in Oklahoma where $\geq 75\%$ of seismicity from 2010-2016 correlated to several hundred hydraulic fracturing (HF) wells. To identify factors associated with increased probability of induced seismicity, we gathered publicly available information about the HF operations in these regions including: injected volume, number of wells on a pad, injected fluid (gel vs. slickwater), vertical depth of the well, proximity of the well to basement rock, and the formation into which the injection occurred. To determine the statistical strength of the trends, we applied logistic regression for continuous factors and odds ratios for binary data. We see no trend with total injected volume in Oklahoma, in contrast to strong trends observed in Alberta and Texas, but we note those regions have many more multiwell pads that would lead to larger cumulative volumes in local areas. We found a $\sim 50\%$ higher probability of seismicity with the use of slickwater compared to gel. We found a strong relationship where older formations showed higher probability of seismicity, which was primarily due to well depth. Well depth produced the strongest relationship, increasing from $\sim 10\%$ to $\sim 60\%$ probability from 1.5 to 5.5 km. However, no trend was seen in the depth to basement parameter, suggesting that critically stressed faults are not restricted to the basement in our study region. We interpret the strong absolute depth relationship to be a result of increasing formation overpressure in deeper portions of the basin that lower the stress change needed to induce seismicity.

BASELINE ASSESSMENT OF THE IMPORTANCE OF CONTRIBUTIONS FROM REGIONAL SEISMIC NETWORKS TO THE PACIFIC TSUNAMI WARNING CENTER'S OPERATIONS

SARDINA, Victor, KOYANAGI, Kanao, WEINSTEIN, Stuart.

The Pacific Tsunami Warning Center's core mission consists in saving lives and minimizing property damage through the issuance of timely, effective tsunami warnings and threat messages. For this purpose the center relies primarily on the analysis of near-real-time seismic data streams provided by established networks such as the Global Seismic Network (GSN), but also by an increasing number of stations contributed by regional seismic networks (RSN) from around the world. We used the theoretical computations of the detection time of the first arriving P wave as a proxy to highlight the areas where RSN contributions have the greatest operational impact. To this aim, the P wave detection times computed for the GSN provided a baseline to isolate the contribution of the RSNs in the form of spatially distributed detection time gains. Inspection of the resulting global maps reveals detection time gains of more than 3 m for Hawaii, Alaska, the east and west coasts of the United States, South America, New Zealand, the southwest Pacific, Australia, and the Sunda Arc. Despite higher density of GSN baseline stations across the US west coast and the eastern Caribbean, contributions from regional seismic networks still result in detection time gains of more than 2 m. These gains in earthquake detection speed correlate well with the continuous increase in the number of stations ingested into the PTWC system, and the gradual reduction of the operational median response time to under 6 m from origin during the last 5 years. These results allow us to conclude that fulfillment of the PTWC's international and domestic tsunami warning responsibilities turns both impossible and unsustainable without the support of the regional seismic networks contributing data to PTWC's daily operations.

****DETECTING LITHOSPHERIC DISCONTINUITIES BENEATH THE MISSISSIPPI EMBAYMENT USING S WAVE RECEIVER FUNCTIONS**

SAXENA, Arushi, LANGSTON, Charles.

Detection of the lithosphere-asthenosphere boundary (LAB) beneath the Central and Eastern US, a cratonic interior, using converted phases remains a challenging problem. The problem becomes even more difficult for Mississippi Embayment (ME), where reverberations from the shallow unconsolidated sediments interfere with the converted phases. However, recent findings in the ME have alluded to a thinned lithosphere beneath the New Madrid Seismic

Zone, and higher upper mantle temperatures compared to the surrounding region. To understand the upper mantle structure of the ME, we use Sp receiver functions (SRF). We use data from a dense station coverage of Northern Embayment Lithospheric Experiment recently deployed under EarthScope FlexArray and other permanent networks. We first investigate the dependence of signal to noise ratio of the SRF on the stacking methods using several synthetic seismograms. We then calculate common depth points Sp stacks for the observed data following the same techniques. Our results indicate a continuous and broad Sp phase corresponding to a negative velocity gradient across 60 to 90 km. Based on the inferred depths, we speculate this gradient to be a mid lithospheric discontinuity (MLD) rather than a LAB. Other studies have also found a similar discontinuity within the lithosphere below this region. We attribute compositional and thermal changes for the origin of the MLD.

IMAGING SUBSURFACE GEOLOGIC STRUCTURES NEAR CHARLESTON, SOUTH CAROLINA WITH NEW HIGH-RESOLUTION AIRBORNE MAGNETIC SURVEY DATA, PREVIOUS SEISMIC-REFLECTION PROFILES, AND BASEMENT SAMPLE ANALYSES

SHAH, Anjana, PRATT, Thomas, HORTON, JR, J. Wright.

The Charleston seismic zone, SC, is home to earthquakes that are typically <Mw3 but is also the site of the 1886 ~M7 earthquake. This largest historical earthquake east of the Appalachian Mountains did devastating damage to the city of Charleston. The 1886 earthquake occurred before modern seismic monitoring, so the causative fault is unknown. Recurrence rates from paleoliquefaction data have been estimated, but causative faults and corresponding event magnitudes also remain unknown. Modern earthquakes observed near Summerville do not clearly define a single fault slip plane, but rather a diffuse tabular body of seismicity. The presence and distribution of optimally oriented faults which may generate a large earthquake are also poorly known. Improved maps of subsurface faults within the region are needed to address these questions and assess earthquake risk.

In June-July 2019 we collected airborne magnetic and radiometric data over the Charleston seismic zone to better image and model subsurface structures. These data, flown with 400-m flight line spacing, provide a 4-fold improvement over legacy airborne data collected in the 1950s to 1970s. Analyses of the legacy magnetic data have indicated features related to Paleozoic orogenies, accreted terranes, and Mesozoic rifting. Near Charleston and Summerville they image flood basalts, dikes, and probable intrusions emplaced during Mesozoic rifting. We apply filtering and derivative approaches to the new data to map possible faults that offset these features and/or related magnetic contacts. Analyses of preliminary data suggest NE- and E-oriented anomalies that likely represent Paleozoic and Mesozoic structures, respectively. Additional narrow N- to NNW-oriented anomalies suggest Jurassic dikes. Further analyses of processed data and comparisons to previous seismic reflection and seismicity data will be used to better map subsurface faults within the region, especially those that are candidates for seismic activity.

EXTRACTING RELIABLE CORE PHASES IN THE WEST-CENTRAL BRAZIL USING AMBIENT SEISMIC NOISE

SHIRZAD, Taghi, AFRA, Mahsa, ASSUMPÇÃO, Marcelo, BRAUNMILLER, Jochen.

Ambient seismic noise has been shown to be a powerful tool for extracting empirical Green's functions (EGFs) in aseismic regions. Recently, noise analysis has been expanded to extract seismic core phases through cross-correlation of long windows of raw data with signal coherence enhanced by selecting appropriate stacking procedures. In this study, we present core phases (e.g., PcP) beneath the Pantanal, Chaco and Paraná Basins, in west-central Brazil, obtained from ambient seismic noise analysis. Currently, little is known about the nature and thickness of the D'' boundary in the northwestern part of South America due to a lack of suitable earthquake source-receiver configurations that could sample the entire D'' beneath the whole continent. Ambient noise offers a unique way to study the D'' beneath South America. We used up to three years of continuous data recorded by 73 broadband stations of the (permanent) BL and BR and (temporary) XC networks. For data processing, we applied the usual time and frequency domain normalizations to suppress the influence of instrument irregularities and earthquake signals. After the cross-correlation process, we implemented a new stacking method based on the uniform distribution of energy around a station pair to compensate for the non-random distribution of noise sources. This method produced identifiable PcP phases on the EGFs. Comparison between the PcP and D'' travel times indicates that the average thickness of the D'' varies between 150 to 170 km beneath west-central Brazil.

****A STATISTICAL STUDY OF THE NEW MADRID SEISMIC ZONE**

ZHANG, Yixin, HORTON, Stephen, LANGSTON, Charles, POWELL, Christine.

The New Madrid Seismic Zone (NMSZ), which is known for its frequently occurring seismicity in an intraplate area, has several fault system models based on the existing earthquake locations and focal mechanisms and rheology models. These studies identified fault planes mostly by visual inspections, which are based on earthquake catalogs and geological evidence. In this study, we used the Optimal Anisotropy Dynamic Clustering (OADC) method to statistically identify fault planes in the NMSZ. This method is more rigorous and separates large thick clusters of hypocenters into discrete fault planes and reveals hidden faults by using high-quality earthquake locations. Before input to the OADC, we relocated earthquakes in the NMSZ catalog between 2000-2019 using a double-difference method (hypoDD). The input data, P and S wave arrival times differences, were determined from catalog arrival time picks and separately from seismic waveform cross-correlation. Dynamic clustering of the relocated earthquakes revealed several small fault planes within the larger fault segments of the NMSZ. To further constrain the results of the OADC method, we determined the focal mechanisms by using both P- and S- wave polarities and their waveform amplitudes for each event that is recorded by a sufficient number of stations. The improved fault system model can provide more insight into the faulting mechanism of the NMSZ.