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Experiment to Determine Hypocenters and Focal Mechanisms of Earthquakes Occurring in Association with Imaged Faults near Summerville, South Carolina

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Abstract

An 8-station temporary seismic network was operated in the epicentral area of the 1886 "Charleston", South Carolina, earthquake, from August 7, 2011 through August 30, 2012. The objective of the project was to collect data for testing the hypothesis that modern seismicity in the Summerville, South Carolina area is occurring in association with Cenozoic-Mesozoic faulting previously imaged on seismic reflection profiles. The data collected are from 134 earthquakes with duration magnitudes in the range -1.8 to 2.6. The data provide much greater depth constraint on hypocenter location and focal mechanisms than was possible in the past. Results to date indicate that the earthquakes occurred in a west-dipping, N-S-trending tabular zone. Concentrations of shallow earthquakes in the depth range from 1 to 5 km near the Ashley River form hypocenter alignments that intersect the location of an imaged fault (Chapman and Beale; 2008, 2010a). On-going work will apply double-difference location techniques combined with focal mechanism determination to further investigate the spatial relationship between seismicity and geologic structure.

Introduction

The lack of understanding concerning the geologic source of the 1886 "Charleston", South Carolina, shock is reflected in the uncertainties associated with the source representation in the current national seismic hazard maps. Recent discoveries have shed some light on this problem (Chapman and Beale; 2008, 2010a) but progress is hampered because of the absence of a permanent seismic monitoring network with capability to collect data necessary for addressing the science questions.

Residents of Summerville, South Carolina continue to feel earthquakes, 127 years after the "Charleston" earthquake. The most strongly-felt recent examples were a magnitude 3.6 shock on December 16, 2008, and a magnitude 3.2 shock on August 29, 2009. Here we report some early results obtained from the on-going analysis of data collected from a one-year, focused data collection experiment involving the temporary deployment of a seismic monitoring network in the Summerville area. The objective of the data collection effort was to test the hypothesis that the modern earthquakes are occurring on faults previously imaged with seismic reflection profile data (Chapman and Beale, 2008, 2010a). Testing this hypothesis and thereby advancing our understanding of neotectonics near Charleston requires hypocenter location and focal mechanism determination capability greatly exceeding the virtually non-existent current ANSS capability.

Background

Our previously published work (Chapman and Beale; 2008, 2010a) describes results obtained by reprocessing and interpreting seismic reflection profiles collected in the epicentral area of the 1886 earthquake. The initial work (Chapman and Beale, 2008) imaged previously un-recognized Mesozoic-Cenozoic faulting that may be directly related to the 1886 shock, using data from a reflection profile collected by Virginia Tech

in 1981. Further work involved reprocessing of the remaining short seismic reflection profiles in the immediate epicentral area (Chapman and Beale, 2010a). That effort imaged a structural basin within a zone of early Mesozoic extensional faulting. Cenozoic-Mesozoic faults were imaged within this structural basin and along its northwestern boundary, at locations in close proximity to modern seismicity located since the 1970's by the USGS and the University of South Carolina (Chapman and Beale; 2010a, 2010b, 2010c; Beale et al., 2010).

A major potential field anomaly with high magnetic total intensity and positive Bouguer gravity values includes the epicentral area of the 1886 shock. Modeling of the potential field indicates that the upper crust beneath the seismically imaged extensional faulting and structural basin is comprised largely of mafic rocks to a depth of at least 4 km (Chapman and Beale, 2010a). The northwestern margin of this magnetic high passes through Summerville as a very sharp gradient in the total intensity field. Four of the five instances of imaged Cenozoic-Mesozoic faulting are in close proximity to this gradient, and Chapman and Beale (2010a) infer that the gradient marks a major crustal-scale fault zone. Some modern earthquakes occur in the vicinity of this magnetic gradient.

Seismic Network Deployment

The project described here was motivated by the spatial correlation of faults imaged on the reflection profiles with epicenters located by the University of South Carolina permanent seismic network that previously operated in the area. It appears that many of the earthquakes located in years past have a high probability of being associated with the imaged faults. The focal depth control of the network that operated in past years was insufficient to provide data for an unequivocal assessment of the relationship, if any, between the imaged faults and the modern seismicity. In addition to accurate hypocenter depth, well-constrained focal mechanisms are needed for geological interpretation. This required the deployment of a local network of stations, sited with particular attention to the collection of the necessary data.

A network of eight 3-component, short-period stations was installed in the Summerville area, and collected continuous data from August 7, 2011 through August 30, 2012. The instruments were Sercel L22, 2-Hz, 3-component, seismometers in combination with Ref Tek 130 high-dynamic range digital acquisition units, provided by the IRIS/PASSCAL instrument center, Soccoro, New Mexico. Absolute time was provided by GPS receivers. The 100 sample/sec data were recorded and stored on-site in flash memory, and retrieved by periodic visits to the stations. The seismometers were buried in shallow holes. The instruments were huddle-tested prior to deployment to insure that channel gains and polarities were consistent among the instruments. The temporary stations were augmented by 3 permanent ANSS stations in the area (Figure 1). The network provided data that to date have allowed the location of 134 earthquakes with duration magnitudes ranging from -1.8 to 2.6 (Figure 1). The data collected by the experiment are archived at the IRIS Data Center under seismic network code XY, and are available for download at http://www.iris.edu/SeismiQuery/month_f2.html.

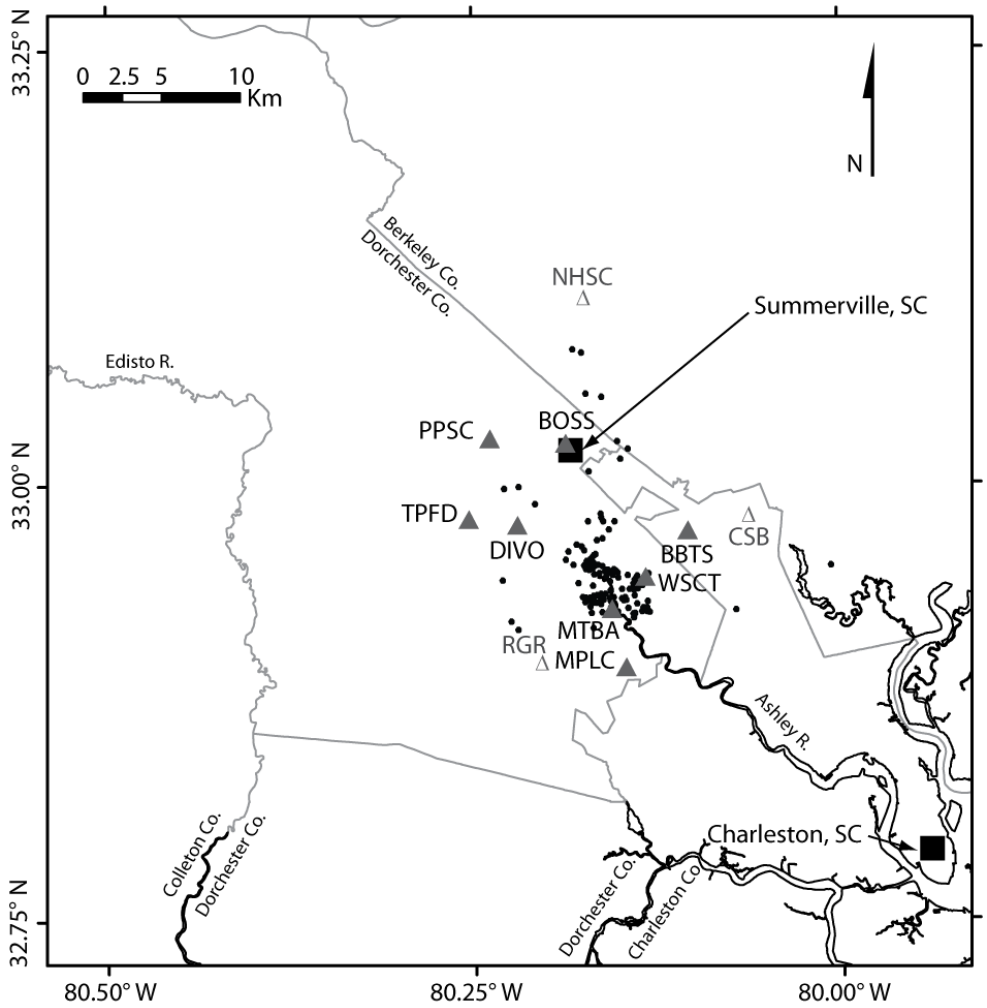


Figure 1. Map of the study area near Summerville, South Carolina. Shaded triangles show the locations of 8 temporary seismic stations deployed in this study. The open triangles show the locations of three permanent seismic stations operated by ANSS in the vicinity of Summerville that contributed additional data. The small filled circles show the epicenters of earthquakes that occurred during the project period.

Results to Date

Figure 2 shows the earthquake epicenters determined by the temporary deployment during the study period as well as the locations of Cenozoic-Mesozoic faults imaged from reflection profiles in the area (Chapman and Beale; 2008, 2010a). The majority of the earthquakes are concentrated near the Ashley River along the southeastern half of seismic profile VT3 and near the imaged location of fault F1, described in detail by Chapman and Beale (2008, 2010a). Note: Fault F1 in Figure 2 is referred to as Fault C by Chapman and Beale (2008). Other earthquakes have occurred to the north and west of

the cluster of events at the Ashley River, close to the locations of faults imaged on seismic profiles near the magnetic gradient. Figure 3 compares the epicenters of the earthquakes located with the temporary deployment with the epicenters of events with magnitudes greater than 2.0 derived by the University of South Carolina for the period from the late 1970's through 2004. The hypocenters of the older events plotted in Figure 3 are taken from the Southeastern U.S. Seismic Network Bulletins, available online at http://www.geol.vt.edu/outreach/vtso/anonftp/catalog/. Figure 3 shows that the earthquakes recorded by the temporary deployment are representative of the longer term seismicity of the study area.

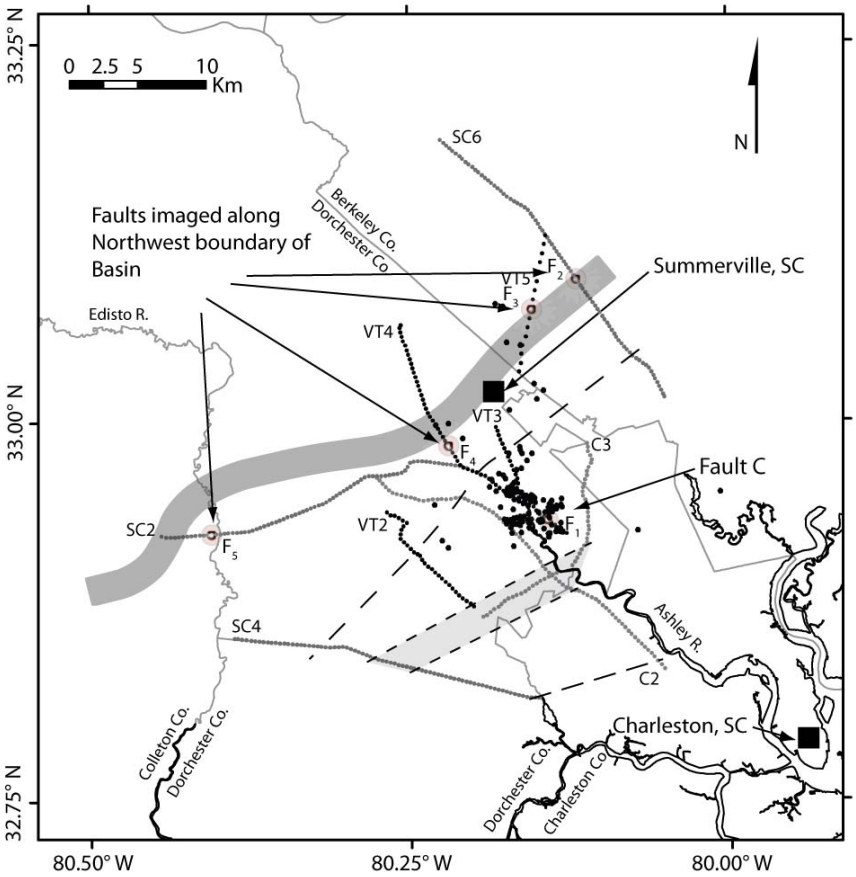


Figure 2. Map of the study area near Summerville, South Carolina, showing the locations of seismic reflection profiles SC2, SC4, VT2, VT3, VT4 and VT5, and 5 locations of Cenozoic-Mesozoic faulting imaged on them, indicated by F1 through F5 (Chapman and Beale; 2008, 2010a). The thick shaded line passing through Summerville and associated with faults F2, F3, F4 and F5 marks the location of a prominent magnetic gradient. The dashed lines to the southeast of Summerville indicate the margins and central trough of a faulted extensional basin imaged by the seismic reflection data (Chapman and Beale; 2008, 2010a). *Modified from Chapman and Beale (2010a).*

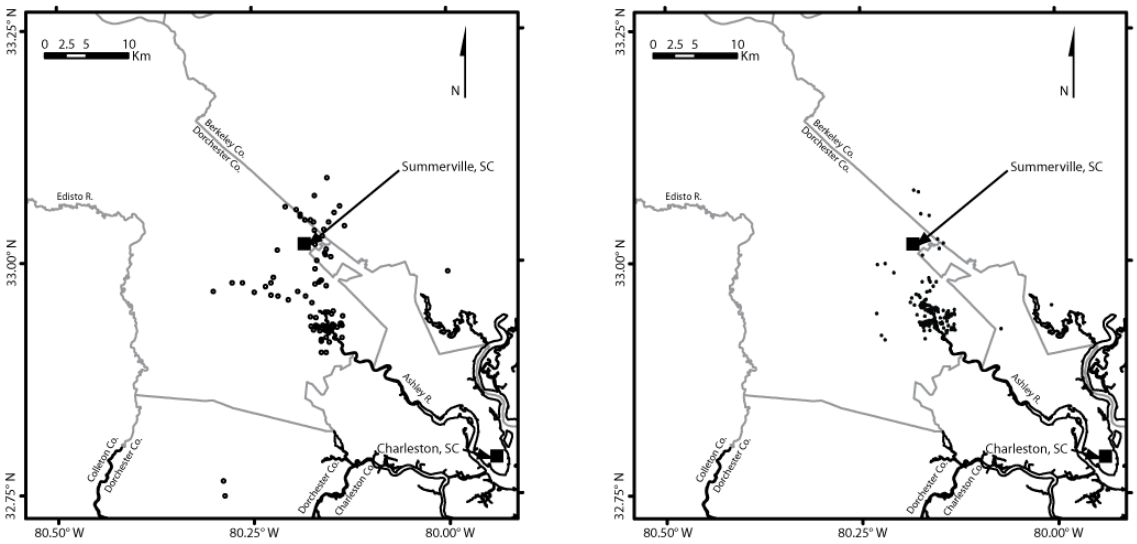


Figure 3. (left) Epicenters of earthquakes occurring from 1977 to 2005 with magnitudes greater than 2.0. (Right) Epicenters of earthquakes occurring from August 7, 2011 through August 30, 2012 located using the temporary instrument deployment.

Figure 4 compares the hypocenters of the pre-2006 earthquakes determined by the permanent network with those determined by the recent temporary deployment. In both cases the hypocenters are projected onto vertical planes trending East-West and North South. The depth sections shown in Figure 4 reveal two main features: 1) the hypocenters located by the recent deployment exhibit much smaller vertical dispersion than the older hypocenters and 2) the results from the recent deployment suggest a broad tabular distribution of hypocenters and the possibility of a North-South striking, West - dipping zone of seismicity. The majority of the recent events occur at depths between 3 and 5 kilometers, although some events occurred as shallow as approximately 1 km, which coincides with the base of the Coastal Plain sediments. This contrasts with the broad depth distribution determined for the pre-2006 earthquakes. The recently determined hypocenters suggest that within this broad tabular volume there is structural complexity: the data show linear/planar trends and two tight clusters of activity that may indicate stress concentrations along short fault segments. For example, the majority of the recent shocks are in a small volume beneath the Ashley River that consists of two short linear alignments of epicenters trending approximately parallel to the river and roughly perpendicular to it (Figure 2). The short alignment trending N70E roughly perpendicular to the Ashley precisely intersects the location of the fault imaged on seismic profile VT3, (F1 in Figure 2) and referred to as Fault C by Chapman and Beale (2008). The results shown here are preliminary and the data will be subjected to extensive analysis involving double-difference location techniques. However, it is clear at this point that the project deployment has produced an important data set with geologically meaningful resolution.

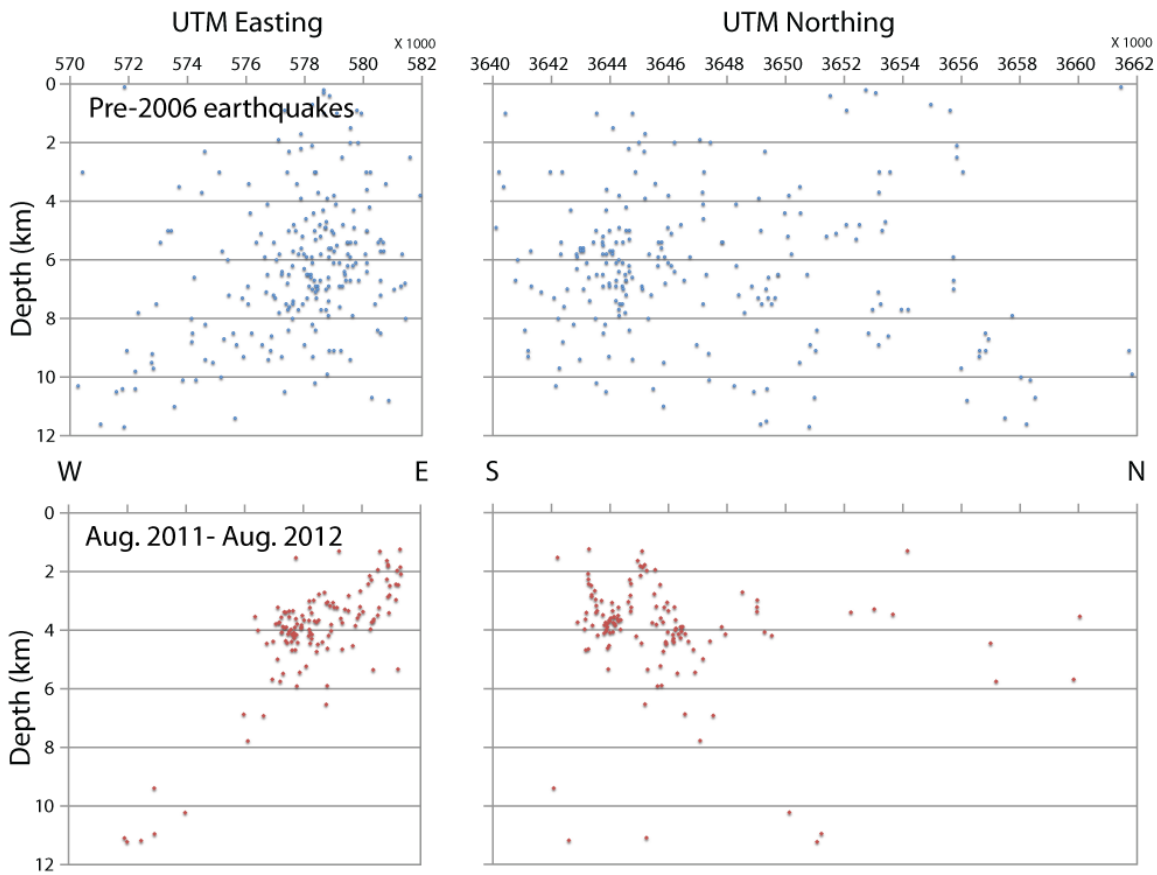


Figure 4. Hypocenters projected onto vertical planes trending W-E (left) and S-N (right). (Upper) Blue symbols show hypocenters of earthquakes with magnitudes greater than 2.0, occurring prior to 2006 and located by the University of South Carolina seismic network. (Lower) Red symbols show hypocenters located by this project.

Figure 5 shows the recently located hypocenters in perspective plots looking North and East. Hypocenters systematically deepen to the west, defining a west-dipping seismic zone. However, it appears that this broad zone features complex faulting in the vicinity of the Ashley River (described above). The East-Looking view in Figure 5 shows evidence of high-angle faulting at shallow depths along two short trends, one of which intersects the location of Fault C, described by Chapman and Beale (2008, 2010a), and shown as F1 in Figure 2.

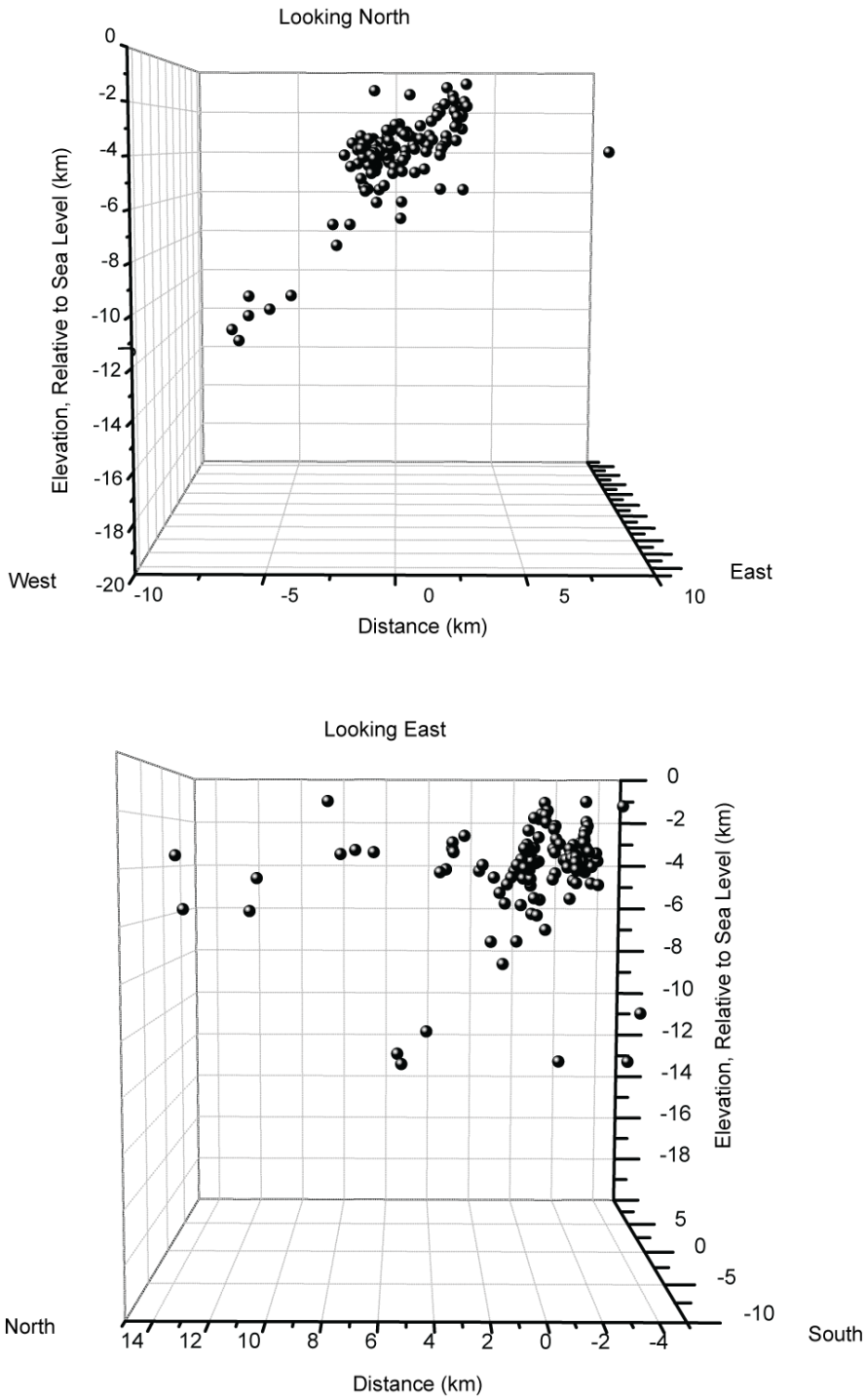


Figure 5. (Top): Perspective plot of recent hypocenters, looking North. (Bottom) Perspective plot of recent hypocenters, looking East.

The collection of data for well-constrained focal mechanism determination was another objective of the project. On-going work is making use of both P-wave first motion polarities and S and P wave amplitude ratios. Figures 6 and 7 shows focal mechanism results for 5 events. The figures are lower-hemisphere projections showing P wave polarity and the resulting nodal planes and P,T and B mechanism axes, for all

consistent mechanisms (no errors), derived using the grid-search program FOCMEC (Snoke et al. 1984). The mechanisms in Figures 6 and 7 are numbered 1 through 5, and the corresponding epicenters are indicated in Figure 8.

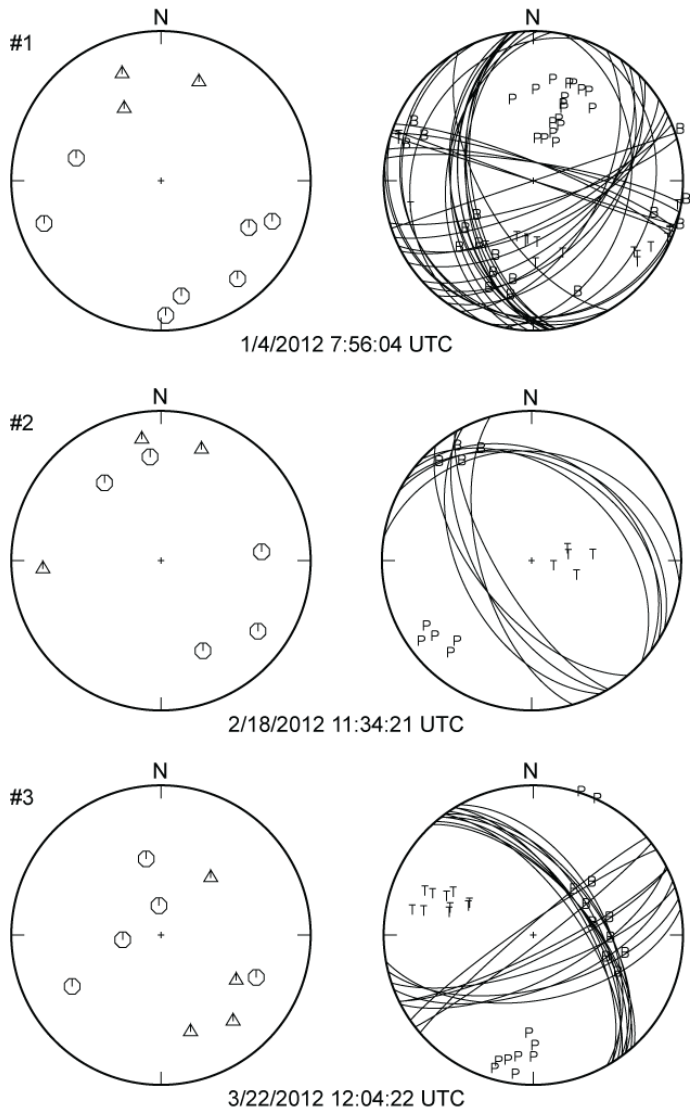


Figure 6. Example focal mechanism solutions for earthquakes recorded by this project. The solutions are lower-hemisphere projections. Circles indicate compressional P wave arrivals; triangles indicate dilatational P wave arrivals. Lines show nodal plane orientations and P, T and B axes are indicated, for all solutions satisfying zero polarity errors. Event numbers refer to Figure 8.

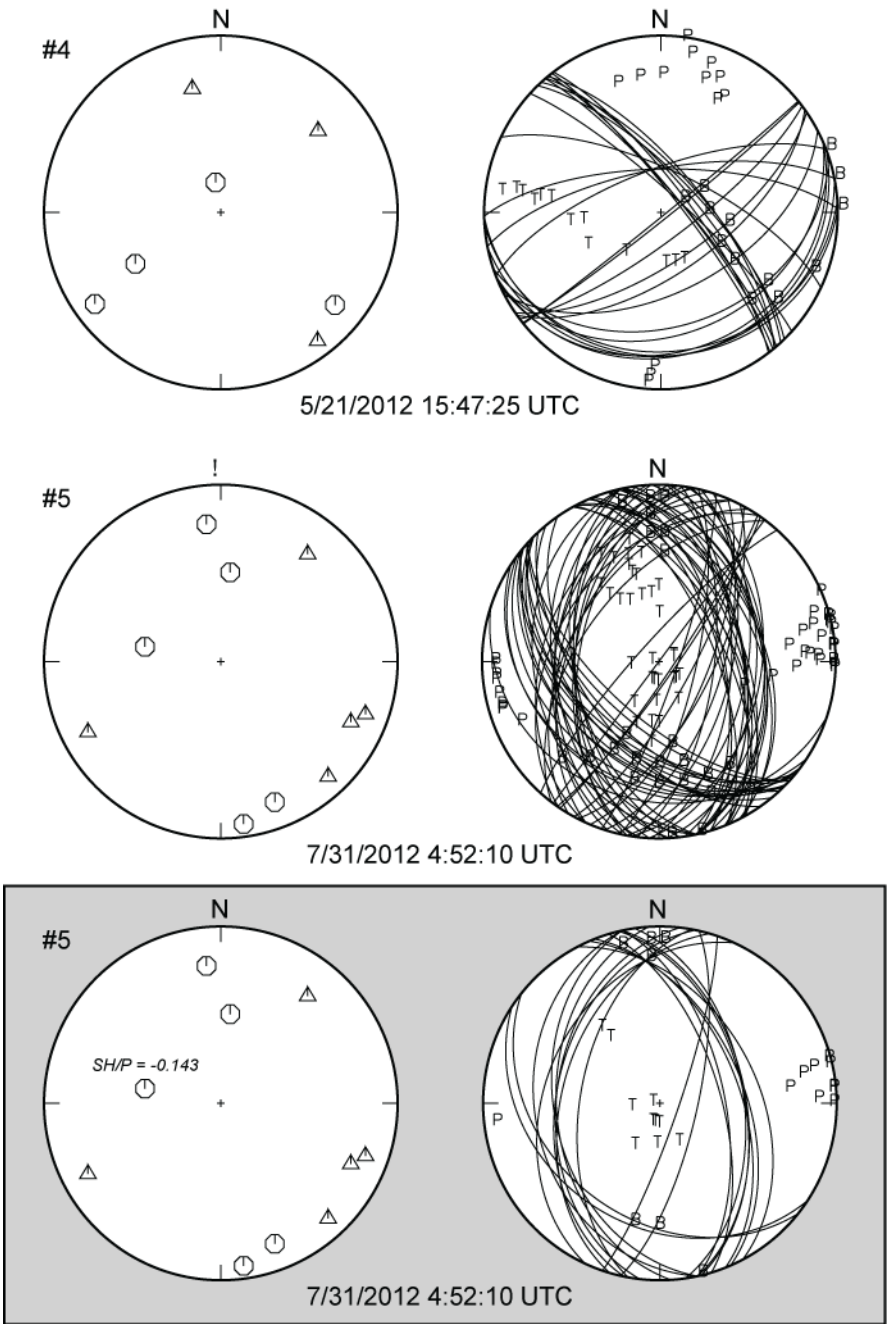


Figure 7. Example focal mechanism solutions for earthquakes recorded by this project. The solutions are lower-hemisphere projections. Circles indicate compressional P wave arrivals; triangles indicate dilatational P wave arrivals. Lines show nodal plane orientations and P, T and B axes are indicated, for all solutions satisfying zero polarity errors. Event numbers refer to Figure 8. Note two solutions are shown for Event #5. The lower plot indicates the added constraint provided by SH/P amplitude ratios, from a single station.

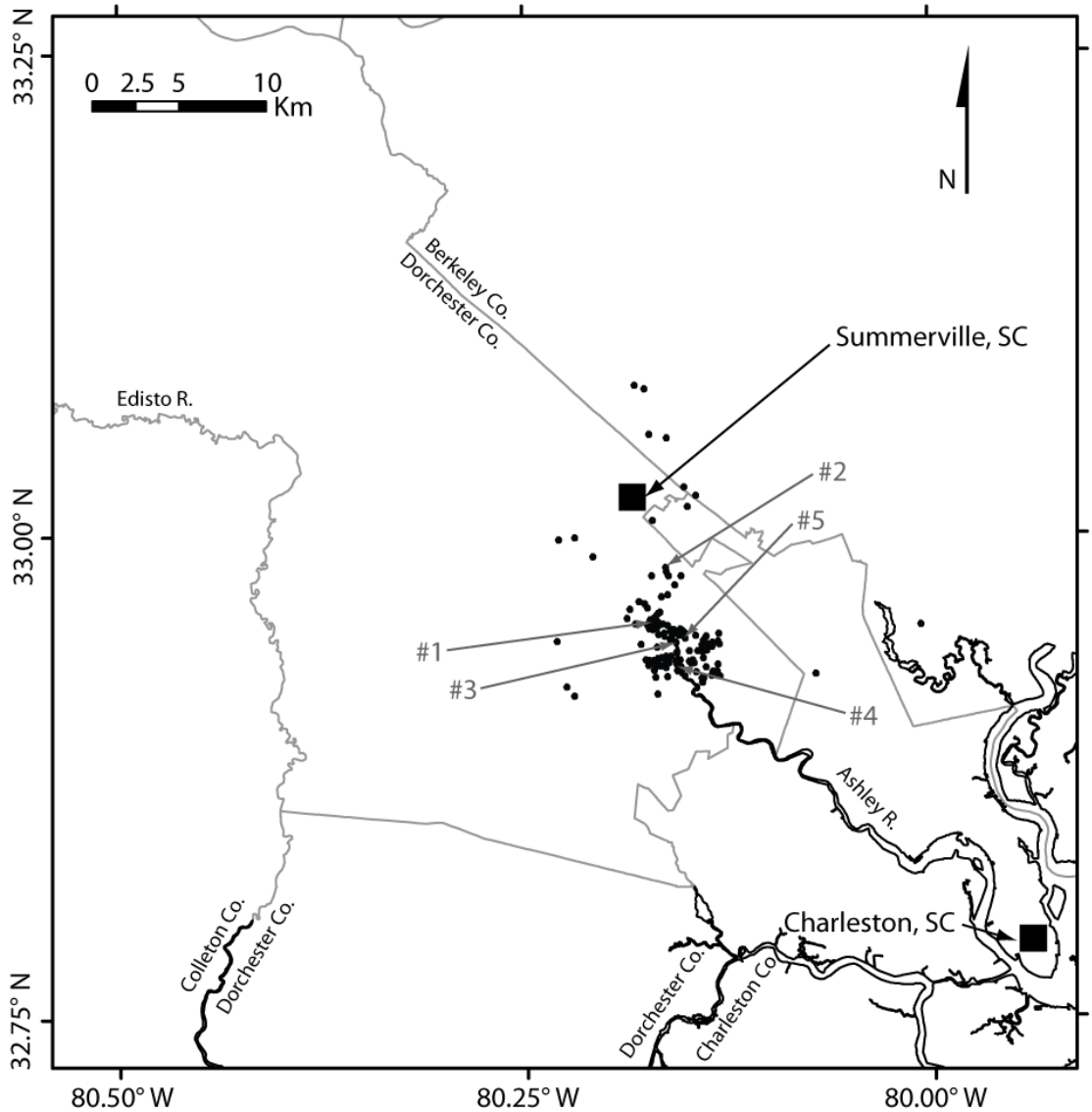
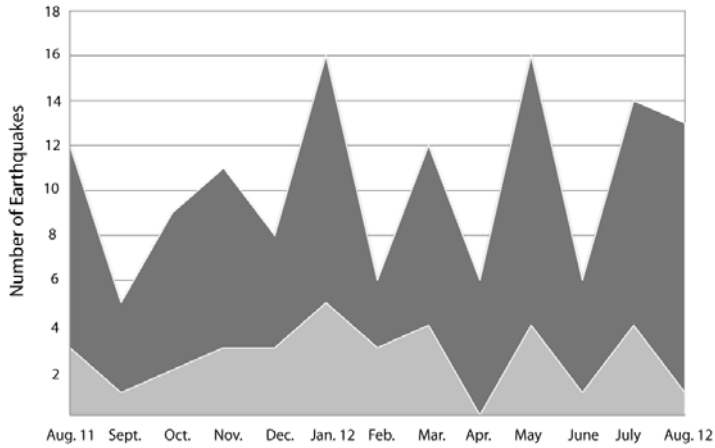


Figure 8. Small circles show epicenters of earthquakes located by this project. Numbered arrows indicate epicenters of earthquakes with focal mechanism solutions shown in Figures 6 and 7.

The focal mechanisms show sub-horizontal P axes that trend from N-S to E-W. The results from event #5 show that amplitude ratio information adds substantial constraint to the mechanism, in addition to that provided by the P wave polarities. The focal mechanism analysis now underway with the collected data set involves locating the earthquake hypocenter, and then rotating the 3-component data to obtain the radial and transverse horizontal components. Amplitudes of P, SV and SH arrivals are measured on the vertical, radial and transverse components, and the observed amplitudes are corrected for transmission across the major velocity discontinuity at the base of the coastal plain sediments, as well as the free-surface effect. The SH/P, SV/P and SV/SH amplitude ratios will be used, in conjunction with P wave polarity, to constrain focal mechanisms for as

many events as possible. The resulting nodal plane orientations will be compared with spatial trends observed in the hypocenter locations.

Figure 9 shows the number of events detected and located per month during the project period, as well as the cumulative Log N versus M frequency/magnitude recurrence relation. The detection capability of the temporary network and the seismicity rate appear to have been stable throughout the project period, with complete detection for events with duration magnitude greater than approximately 1.0.



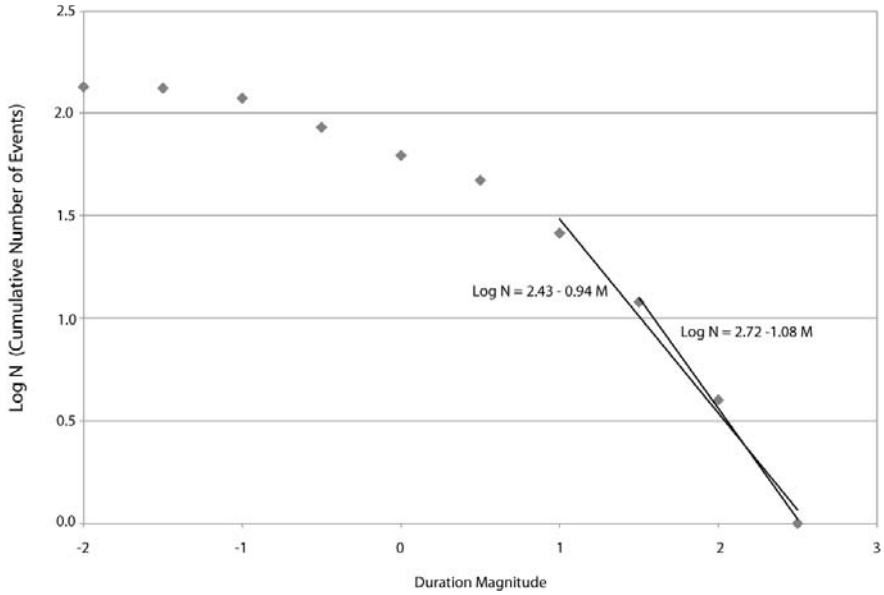


Figure 9. (Top) Number of earthquakes detected by this project, per month (dark grey): number of earthquakes per month with magnitude greater than 1.0 (light grey). (Bottom) Number of earthquakes detected (log base 10) greater than a given duration magnitude, plotted versus magnitude.

Conclusions

An 8-station network of 3-component short-period seismographs was operated in the epicentral area of the 1886 "Charleston", South Carolina, earthquake, from August 7, 2011 through August 30, 2012. The objective of the data collection experiment was to test the hypothesis that modern seismicity in the Summerville, South Carolina area is occurring in association with Cenozoic-Mesozoic faulting previously imaged on seismic reflection profiles. The data collected are from 134 earthquakes with duration magnitudes in the range -1.8 to 2.6. The data provide much greater depth constraint on hypocenter location and focal mechanisms than was possible in the past. Results to date indicate that the earthquakes occurred in a west-dipping, N-S-trending tabular zone. Concentrations of shallow earthquakes in the depth range from 1 to 5 km near the Ashley River form hypocenter alignments that intersect the location of an imaged fault (Chapman and Beale; 2008 and 2010a). On-going work will apply double difference location techniques and focal mechanism determination to further investigate the spatial relationship between seismicity and geologic structure.

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