South Georgia Rift Basin: Rift Initiation and Evolution (RIE) Assessment through Controlled Source Seismology

Camelia C. Knapp, James H. Knapp, David Heffner, Martins Akintunde, Olga Nedorub
Department of Earth and Ocean Sciences, University of South Carolina, Columbia, SC 29208
camelia@geol.sc.edu

The Eastern North American Margin (ENAM) has been identified as one of the primary focus areas for GeoPRISMS due to the complexity and regional extent of this mature Mesozoic passive margin rift system encompassing: (1) a large volume and regional extent of related magmatism, (2) a preserved complete stratigraphic column that records the post-rift evolution in several basins, (3) preserved lithospheric-scale pre-rift structures including Paleozoic sutures, and (4) a wide-range of geological, geochemical, and geophysical studies both onshore and offshore. The short-lived but most voluminous magmatic event associated with the initiation of rifting, the Central Atlantic Magmatic Province (CAMP), is one of the most significant magmatic events in North America.

The South Georgia Rift (SGR) basin is believed to be the largest and probably the most geologically complex Mesozoic graben of the ENAM (Popenoe and Zietz, 1977; Daniels et al. 1983; McBride et al. 1989) formed during crustal extension associated with the breakup of Pangea and later opening of the North Atlantic Ocean. The separation of the African and North American plates, the formation of the Atlantic Ocean and the associated zones of weakness in eastern North America have been stated as the initial events in the breakup of Pangea. Chowns and Williams (1983) and Swanson (1986) suggested that the formation of the Mesozoic basin was probably influenced by the presence or reactivation of these zones of basement weakness in the Southern Appalachians. McBride et al. (1989) and Petersen et al. (1984) have also described the basin to be a composite of smaller, Triassic basins. These basins, in most cases, appear to be bounded by high-angle normal faults some of which may have been reactivated in late Cretaceous and Cenozoic time as apparent reverse faults (Behrendt, 1986). Some of these sub-basins also contain interbedded basalt flows and diabase dikes and sills.

Tectonically induced rifting events also led to pronounced igneous activity within the SGR basin (Dietz and Holden, 1970). This igneous activity was characterized by the presence of surface basalt flows as well as the voluminous emplacement of diabase dikes and large-mafic and ultra-mafic intrusions (Daniels et al., 1983) as part of CAMP. These igneous deposits have been described by Phillips (1983) as normally magnetized materials, suggesting that they formed during the Late Triassic-Early Jurassic interval of predominantly normal polarity. Most radiometric ages for eastern North American Mesozoic basalt flows and diabase sills fall within the range of 180 – 200 million years (Phillips, 1983), thus supporting a Late Triassic-Early Jurassic age. The Jurassic ("J') basalt received considerable attention in the 1980's as a distinct, regional geologic marker that is widespread throughout the South Georgia Rift (SGR) basin, and that is either below or at the base of the Coastal Plain. One of our main interests in the "J" basalt reflector lies in its regional significance and potential to serve as seal for CO_2 storage in the underlying Triassic reservoir. The term originated from Schilt et al. (1983) based on seismic correlations with the Clubhouse Crossroads basalt flows (Figure 1) from three drill cores in South Carolina (Gohn et al., 1983, Gottfried et al., 1983). The age of the "J" basalt as determined by Lanphere (1983) on the Clubhouse Crossroads Basalt is early Middle Jurassic (184 Ma). Its emplacement resulted from the effects of pronounced igneous activity that is associated with the formation of the SGR basin and characteristics of the onset of sea floor spreading associated with continental margins (Holbrook and Kelemen, 1993). Also, it is known to be chemically similar to the Central Atlantic Magmatic Province (CAMP) basalt flows (Goldberg et al., 2010) and overlap with offshore basalt described seismically as "seaward-dipping reflectors (SDRs)". These SDRs were emplaced during the early opening of the Atlantic Ocean (Goldberg et al. 2010). The true geographical extent of the "J' horizon remains unknown in spite of previous efforts by Gottfried et al. (1983), McBride et al. (1989), and Chowns and Williams (1983) at delineating its areal extent. The postulated regional extent of the "J' basalt within the SGR was based on seismic correlations with limited and scattered drill-hole data.

Based on reanalysis of seismic and well data, Heffner et al. (in press) show the preserved extent of the "J"-horizon as being much more limited areally than previously reported and appears to correspond with the base of the Coastal Plain unrelated to the presence of basalt. This reinterpretation of the J-horizon has larger implications as to the timing of the opening of the Atlantic Ocean, and is also supported by re-processing and re-interpretation of the USGS' seismic reflection profile SeisData6 (Akintunde et al., in prep.).

The University of South Carolina has been funded by DOE to perform a feasibility study of geological storage of CO_2 within the Triassic sediments of the SGR basin (in South Carolina). Included in this ongoing effort are (1) acquisition of 240 km of 2-D seismic data (6 s two-way traveltime) (Fig. 1), (2) acquisition of a 6 km^2 3-D seismic data (Fall 2011), and (3) drilling and sampling of a borehole to ~4 km within the basin. These activities center around the Norris Lightsey deep well that provides lithological and petrophysical control down to ~3000 m. While these seismic data are most suitable for providing a good quality high resolution image of the SGR basin, the recording time is too short to provide reliable information from the lower crust and uppermost mantle.

Despite the panoply of controlled source seismic data recorded across the SGR basin (the majority of them being 6 s), there remain many critical questions that are suitable to address within the context of EarthScope targeting the lower crust/ upper mantle interaction. Some of these issues include: (1) the role of pre-existing structures/zones of weakness in the Triassic rifting including the style and timing of break-up and extensional deformation (orogenic belts, rheological heterogeneities, mechanical anisotropy of the mantle, thermal disturbances, and base-lithosphere pre-existing topography; Keranen & Klemperer, 2008), (2) the age of the CAMP basalts/diabase and how CAMP relates to the rift-drift transition of ENAM, (3) the controls on the architecture of rifted continental margins during and after breakup, (4) the nature, age, and geometry of the Brunswick anomaly that divides two different terrains with different orogenic imprints (Daniels et al., 1983), (5) the nature of the NE-trending SGR with NW-striking transfer faults, (6) the role of magmatic underplating in rift and post-rift evolution and relationship to slow lithospheric extension, in order to (7) better understand the regional SGR basin structure and asymmetric geometry and the role of a series of recognized transform faults and relationship to the suture zone shown now as the Brunswick anomaly. In addition, such an in-depth study can provide valuable information for the assessment of geohazards, in particular, the magnitude and frequency of rift-related earthquakes.

References

Akintunde. O. M., Knapp, C. C., Knapp, J. H., Heffner, D, Shafer, J., Reinterpretation of the "J" Basalt Reflector from Seismic Data Reprocessing across the Coastal Plain of Southeastern Georgia: Potential Implications for Long-term CO2 Sequestration, AAPG Bulletin, *in prep*.

Behrendt, J.C. (1986). Structural interpretation of multichannel seismic reflection profiles crossing the southeastern United States and the adjacent continental margin – Decollements, faults, Triassic(?) basins and Moho reflections, in Barangi, M., and Brown, L., eds., Reflection seismology: The continental crust: American Geophysical Union Geodynamics Series, v. 14, p. 201 – 214.

Chowns, T.M., and Williams, C.T., 1983, Pre-Cretaceous rocks beneath the Georgia Coastal Plain – Regional implications, in Gohn, G.S., ed., Studies related to the Charleston, South Carolina, earthquake of 1886 – Tectonics and seismicity: U.S. Geological Survey Professional Paper 1313, p. L1-L42.

Daniels, D.L., Zietz, I. and Popenoe, P. (1983). Distribution of subsurface lower Mesozoic rocks in the southeastern United States as interpreted from regional aeromagnetic and gravity maps, in Gohn, G.S., ed., Studies related to the Charleston, South Carolina, earthquake of 1886 – Tectonics and seismicity: U.S. Geological Survey Professional paper 1313, p. K1-K24.

Dietz, R. S. and J. C. Holden, 1970, Reconstruction of Pangaea: Breakup and dispersion of continents, Permian to present, Journal of Geophysical Research, 75, 4939, 1970.

Gohn, G.S., Houser, B.B., and Schneider, R.R., 1983b, Geology of the lower Mesozoic(?) sedimentary rocks in Clubhouse Crossroads test hole #3 near Charleston, South Carolina, in Gohn, G.S. ed., Studies related to Charleston, South Carolina earthquake of 1886 – tectonics and seismicity: U.S. Geological Survey Professional Paper 1313, P. D1-D17.

Goldberg, D.S., Kent, D.V., and Olsen, P.E., 2009, Potential on-shore and off-shore reservoirs for CO2 sequestration in Central Atlantic Magmatic Province Basalts (CAMP). PNAS, Vol. 107, 1327-1332.

Gottfried, D., Annell, C.S. and Byerly, G.R., 1983, Geochemistry and tectonic significance of subsurface basalts near Charleston, South Carolina: Clubhouse Crossroads test holes #2 and #3. In: Gohn, G.S. (Ed.). Studies

Related to the Charleston, South Carolina, Earthquake of 1886 – tectonics and Seismicity. United States Geological Survey Professional Paper 1313, p. A1-A19.
Heffner, D. M., Knapp, J. H., Akintunde, O. M., and Knapp, C. C., *in press*, Preserved extent of Jurassic flood basalt in the South Georgia Rift: a new interpretation o the J-Horizon, Geology, v. 40., doi:10.1130/G32638.1.
Holbrook, W.S. and Kelemen, P.B., 1993, Large igneous province on the United States Atlantic margin and implications for magmatism continental breakup. Nature, Vol. 364, P. 433-436.
Keranen, K. and Klemperer, S. L., 2008, Discontinuous and diachronous evolution of the Main Ethiopian Rift: Implications for development of continental rifts, Earth and Planetary Science Letters, v. 265, p. 96-111.
Lanphere, M.A. 1983, 40Sr/39Ar Ages of basalt from Clubhouse Crossroads test hole #2, near Charleston, South Carolina, Earthquake of 1886 – tectonics and Seismicity. United States Geological Survey Professional paper 1313, p. B1-B8.
McBride, J.H, Nelson, K.D., and Brown, L.D., 1989, Evidence and implications of an extensive Mesozoic rift basin and basalt/diabase sequence beneath the southeast Coastal Plain: Geological Society of America Bulletin, v. 101, p. 512-520.
Petersen, T.A., Brown, L.D., Cook, F.A., Kaufman, S. and Oliver, J.E. (1984). Structure of the Riddleville basin from COCORP seismic data and implications for reactivation tectonics: Journal of Geology, v. 92, p. 261-271.
Popenoe, P. and Zietz, I. (1977). The nature of the geophysical basement beneath the Coastal Plain of South Carolina and northeastern Georgia, in Rankin, D.W., ed., Studies related to the Charleston, South Carolina, earthquake of 1886 – A preliminary report: U.S. Geological Survey Professional Papwer 1028, p. 119-137.
Phillips, J.D., 1983, Paleomagnetic investigations of the Clubhouse Crossroads basalt, in Gohn, G.S. ed., Studies Related to the Charleston, South Carolina, earthquake of 1886 – Tectonics and Seismicity: U.S. Geological Survey Professional Paper 131, p. C1-C18.
Schilt, F.S., Brown, L.D., Oliver, J.E. and Kaufman, S., 1983, Subsurface structure near Charleston, South Carolina – results of COCORP reflection profiling in the Atlantic Coast Plain. In: Gohn, G.S. (Ed.), Studies Related to the Charleston, South Carolina, Earthquake of 1886 – Tectonics and Seismicity. United States Geological Survey Professional Paper 1313, p. H1-H19.
Swanson, M. T., 1986, Pre-existing fault control for Mesozoic basin formation in eastern North America, Geology, v.14, p. 419-422.

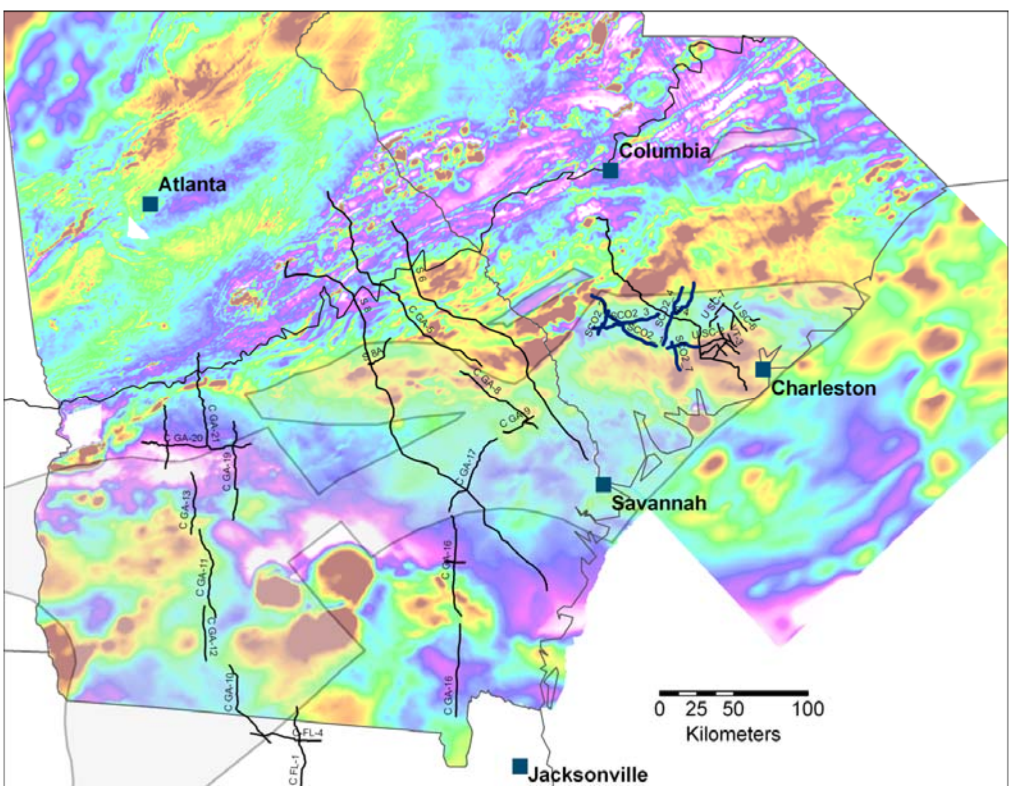

Figure 1. Location map of the South Georgia Rift (SGR) basin (light gray contour, after Chowns and Williams, 1983) in South Carolina and Georgia superimposed on the magnetic anomaly map. Existing deep seismic lines (USGS and COCORP) are shown as black lines together with newly acquired 2-D seismic lines (6 s TWT in bold) as part of the DOE CO_2 sequestration project.