Imaging Granites, Other Plutons and Faults Associated with Continental Collision and Rifting Using Potential-Field, Seismic, and Well Data, South Georgia Rift Basin and Vicinity, South Carolina

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Abstract

Potential-field data, with its excellent spatial coverage, used in combination with seismic imaging, can help to illuminate basement and upper- to mid-crustal structures, especially igneous rock bodies associated with the Alleghanian orogeny and features attributed to subsequent continental rifting. The nature of the metamorphic and igneous basement rocks underlying coastal-plain sediments along the southern portion of the Eastern North American passive margin is poorly constrained. These rocks record the large-scale geologic processes responsible for the evolution of continental lithosphere spanning a Wilson cycle, including continental assembly, mountain building, continental rifting, and post-rift passive-margin evolution. In order to better characterize these rocks, maps and two-dimensional cross-section models, constrained by deep-well and seismic data, are being developed for the basement beneath the South Carolina Coastal Plain by forward and inverse modeling of the aeromagnetic and gravity fields. Exploratory data analysis and a quality assessment have been performed on gridded aeromagnetic data and land gravity data. A database of rock properties, including densities and magnetic susceptibilities, is being compiled from publications and ongoing lab analyses. Prior to inversion of the non-unique potential-field data, two-dimensional density/magnetic forward models are being developed with deep-well, seismic reflection and refraction data control, to better constrain inverse models.

Three crustal profiles traverse the South Georgia and Dunbarton rift basins, where interpretation is constrained by wells to basement, as well as 20 two-dimensional seismic reflection lines, and two seismic refraction surveys. The profiles are ideal because they cross major regional tectonic and geologic elements, including Paleozoic faults, Triassic rift basins, plutons, and mafic dikes, and because high densities and magnetic susceptibilities allow estimation of rock volumes, areal extent, and depth of mafic plutons associated with continental rifting and the Central Atlantic Magmatic Province (CAMP). The coastal-plain basement maps and profiles will also assist assessment of the potential for CO2 sequestration and geothermal-power generation in and near the rift basins.

Geologic Background

The rocks buried beneath the coastal plain of the Carolinas and Georgia record all of the major tectonic events responsible for shaping the eastern North American margin spanning a Wilson cycle: island arc accretion and continental collision around 290 Ma to form the super continent Pangea; continental rifting and the initiation of seafloor spreading beginning around 230 Ma; and the emplacement of CAMP, a large igneous province, around 200 Ma. This record consists of Paleozoic faults, sutures and granitic plutons; and Mesozoic mafic igneous intrusions and failed rift basins. Constraining the geometries, relative timing, and possible relationships among these features is a primary objective of this research.

Mapping the Buried Basement of the Coastal Plain

Because seismic and borehole data coverage in the coastal plain is sparse, potential field data, with its excellent spatial coverage of the southern Atlantic margin of eastern North America, can be used in concert with other geologic and geophysical constraints to develop a basement surface map including depth to basement and basement geology. The high density and magnetic susceptibility contrasts among metamorphic country rock, granitic plutons, mafic intrusions, and Triassic sediments permit, to the first order, the reliable modeling of the depth, thickness, and areal extent of intrusive rock bodies and major mid- to upper-crustal contacts or boundaries. Several two-dimensional cross-section forward models constrained by seismic refraction and reflection surveys as well as deep wells are being developed. Euler and Werner deconvolution will be used to invert the potential field data in three dimensions, allowing for mapping of the basement surface, structure, and geology.

These maps and models could help better resolve a variety of fundamental questions relating to Paleozoic accretion and orogenesis, as well as Mesozoic rift initiation and evolution. Numerical modeling estimates that a force of ~30 TeraN may be required to rupture strong, cold, continental lithosphere (Buck, 2004), but only ~3-5 TeraN are available from plate tectonics (Bott, 1991). Two mechanisms proposed to overcome this apparent paradox are pre-existing structure (Tommasi and Vauchez, 2001; Dunbar and Sawyer, 1989) and magmatism (Buck, 2004; Bialas *et al*., 2010). Although many rifts and passive margins formed by continental extension do appear to coincide with magmatism and/or occur along pre-existing crustal structures, the relative importance of these and other factors remain poorly understood (Shillington, 2012). Maps and models developed here could help locate and predict the shape of major crustal boundaries as well as igneous intrusions. Given recent reinterpretations of the J-Reflector (Hefner *et al*., 2012) raising questions about the connection between Clubhouse Crossroads Basalt and the Seaward Dipping Reflectors (SDRs) and the preserved areal extent of CAMP in the South Georgia Rift Basin, this project could also help to illuminate and better resolve the relationship among rifting, CAMP, and the SDRs.

Data

- Gridded aeromagnetic data set (Daniels, USGS)
- Land Gravity Data set (Howard, SCGS)
- 120-km-long seismic refraction profile (Luetgert, 1991)
- Database of 48 boreholes to basement (Howard, SCGS)
- Seisdata4 and SRS-7 2D seismic reflection profiles (Savannah River National Laboratory)
- Database of rock properties from literature review and lab measurements

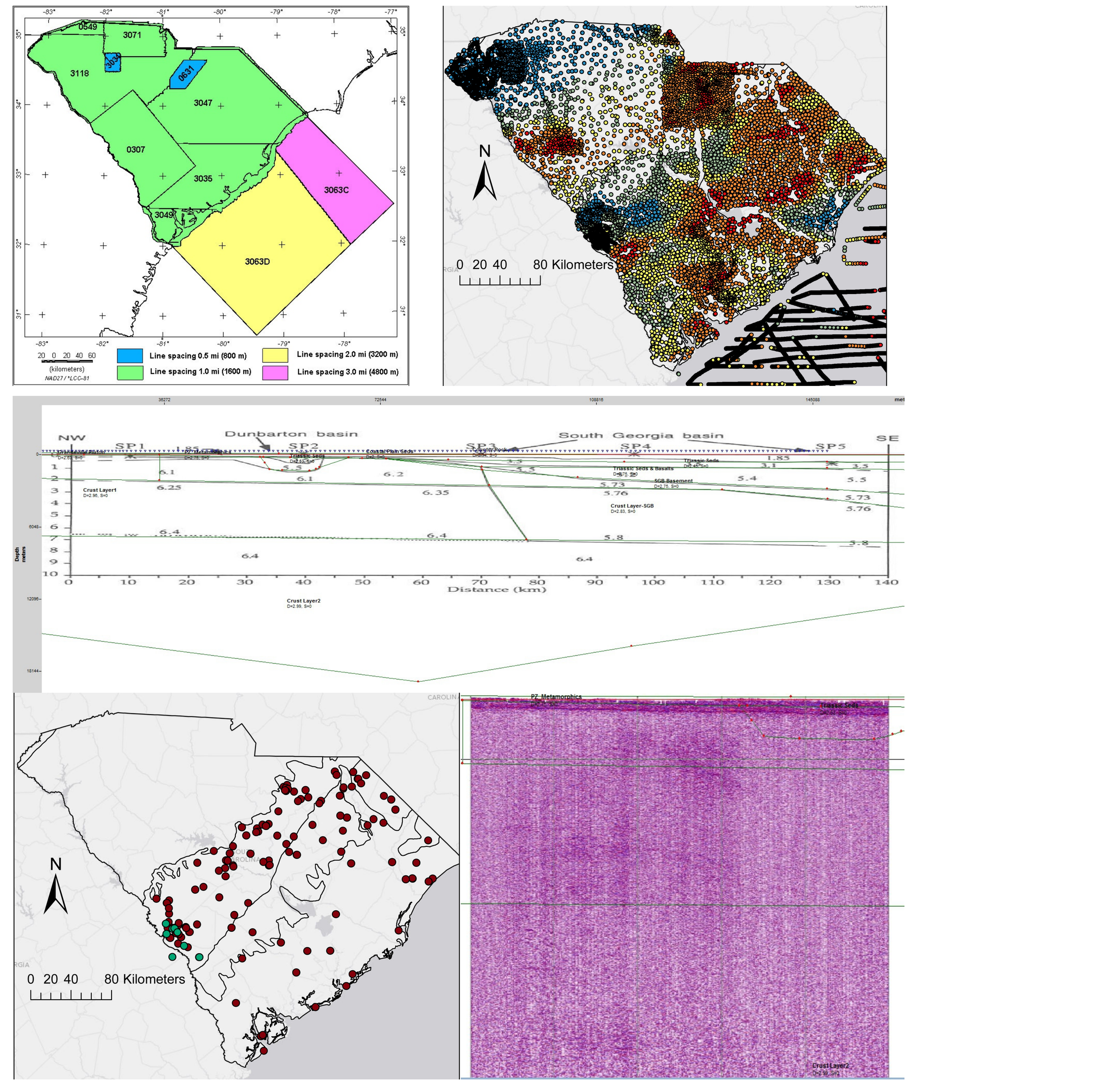


Figure 1: Top Left – A map showing the different USGS aeromagnetic surveys for South Carolina. The average flight line spacing is one mile. Top Right – A map showing the locations of land gravity stations in South Carolina. Average station spacing in the Piedmont is approximately 6 km, whereas the average station spacing in the Coastal Plain is 3 km. Middle – The initial Savannah River National Laboratory two dimensional forward model was calibrated using a 120-km-long seismic refraction survey profile (Luetgert *et al*., 1991). Major model blocks coincide with major crustal boundaries identified from the refraction experiment. Bottom Left – A map show the locations of boreholes to basement in South Carolina. The database was rich in the vicinity of the Savannah River National Laboratory, lending significant constraint on the initial 2D forward profile (Profile 1). Bottom Right – Profile 1 was also constrained by a ~35km seismic reflection profile, SRS 7. The seismic section is recorded in time down to 12 seconds. Prominent mid-crustal reflectors were used to define the shape of Crust Layer 1 under and adjacent to the Dunbarton Basin.

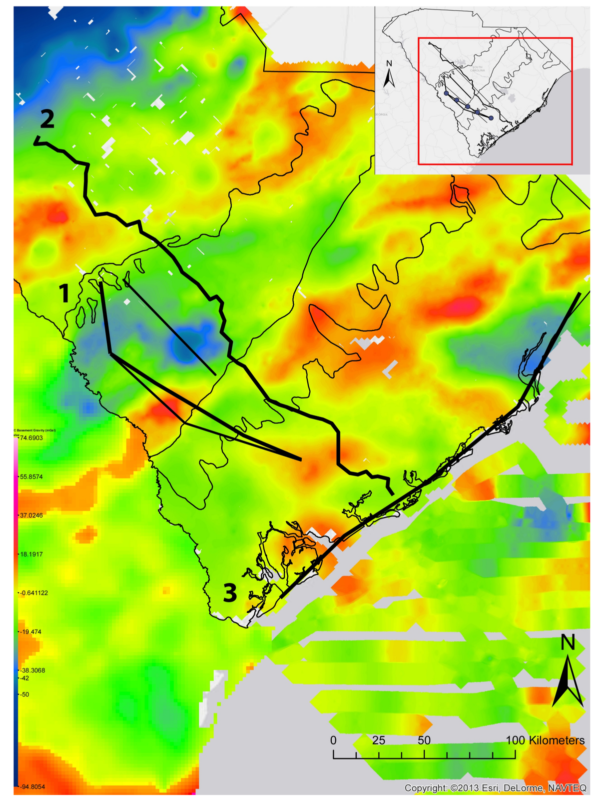


Figure 2: Gravity map of the study area, including the location of Profiles 1-3 and profile deviations. The inset shows the study area within South Carolina. The gravity lows are shown in blue. The gravity highs are shown in red.

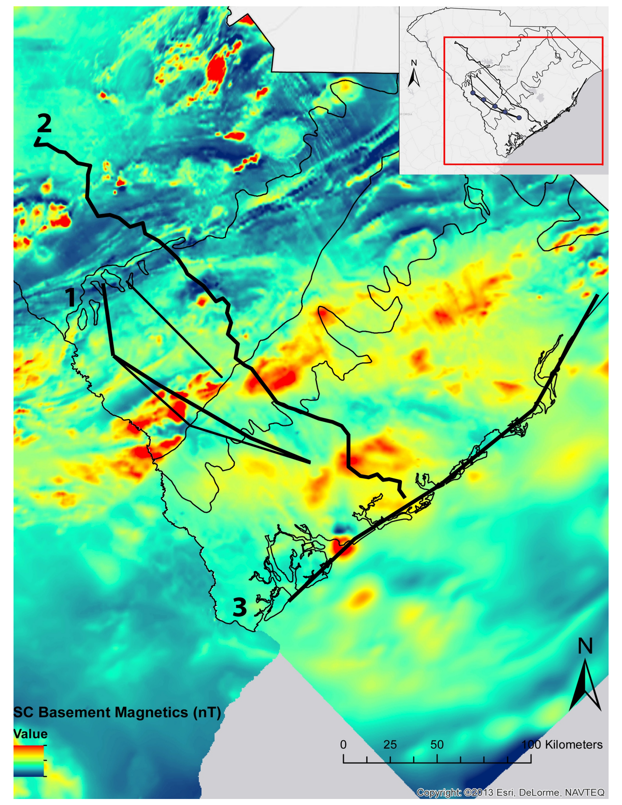
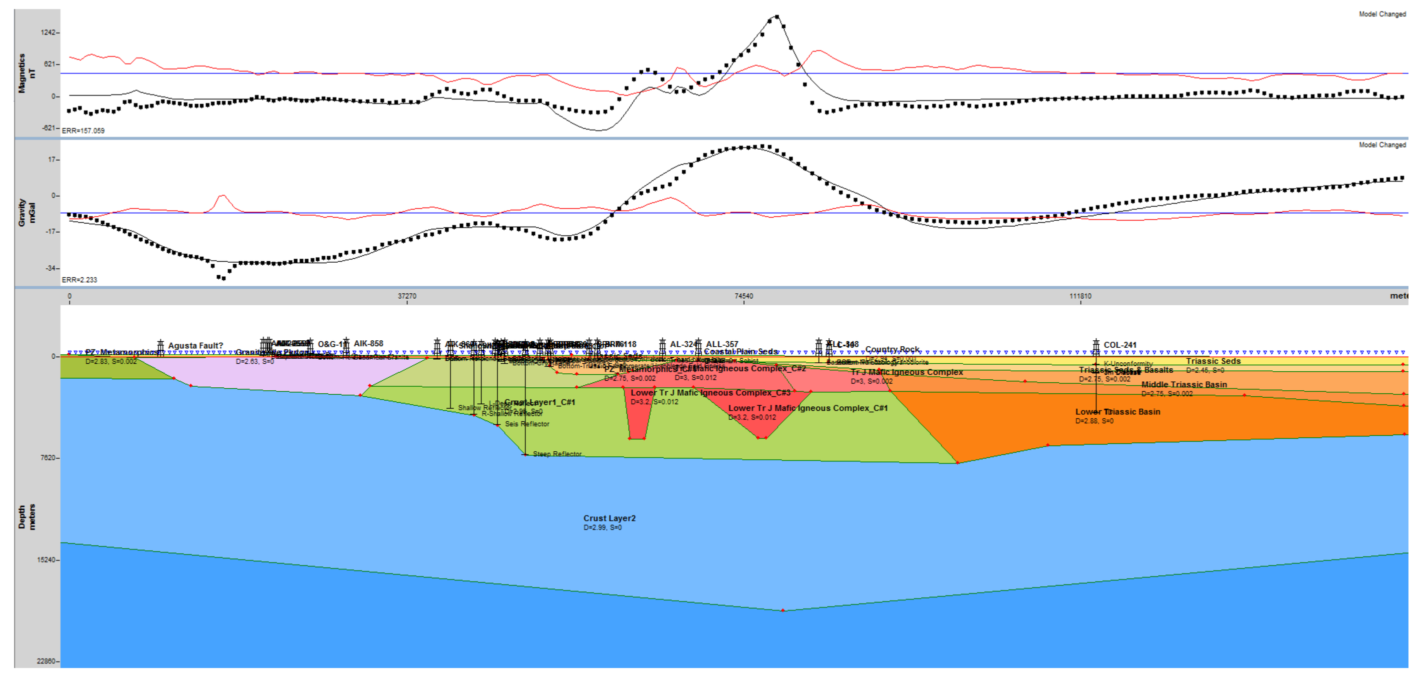


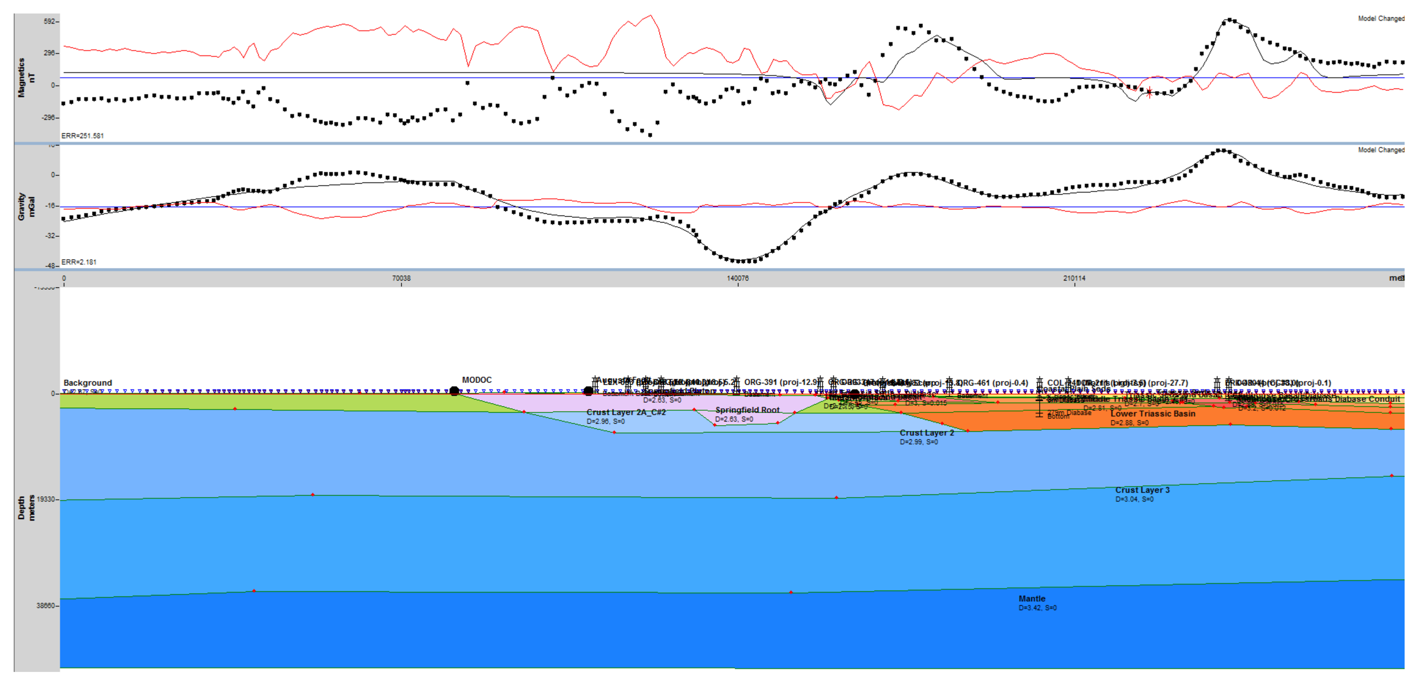
Figure 3: Magnetic map of the study area, with profile locations. The magnetic low intersecting Profile 1, shown in blue, is the Dunbarton Basin. The magnetic highs, shown in red, correspond to the interpreted mafic igneous intrusions.

2D Forward Model Profiles

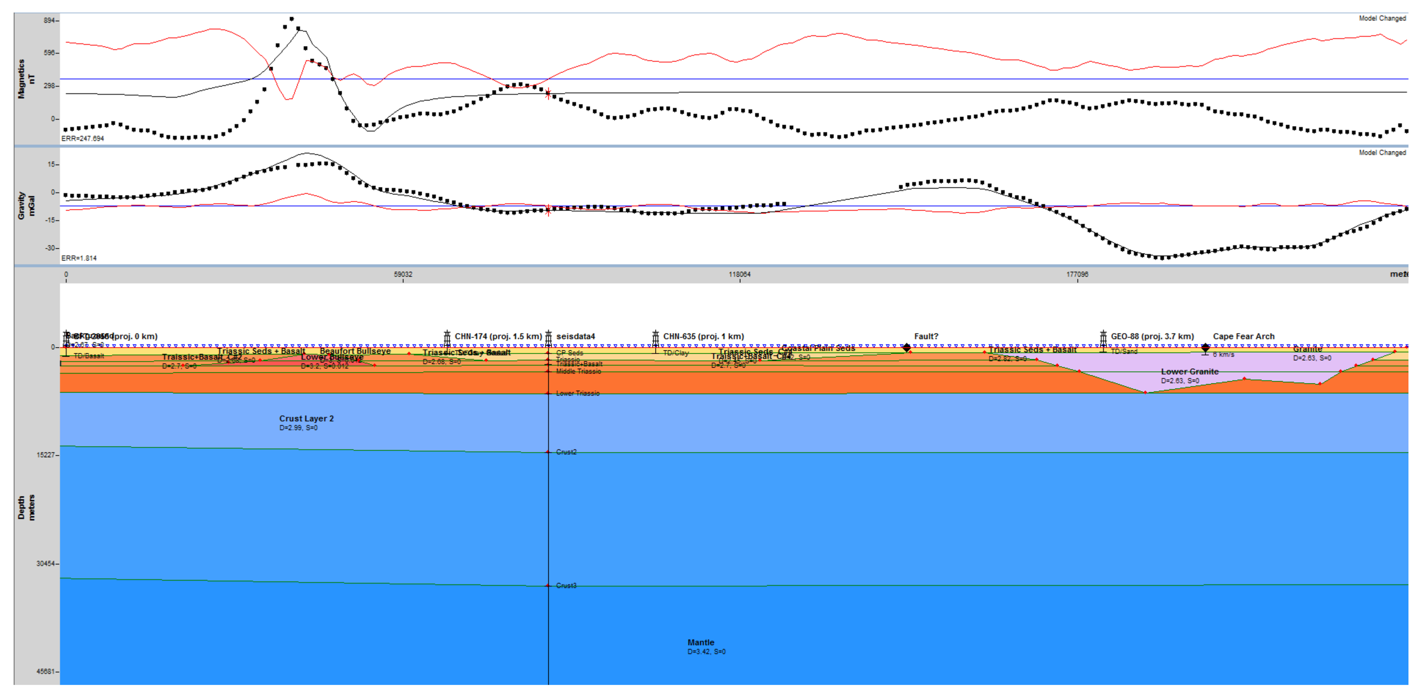
Profile 1 – Savannah River National Laboratory



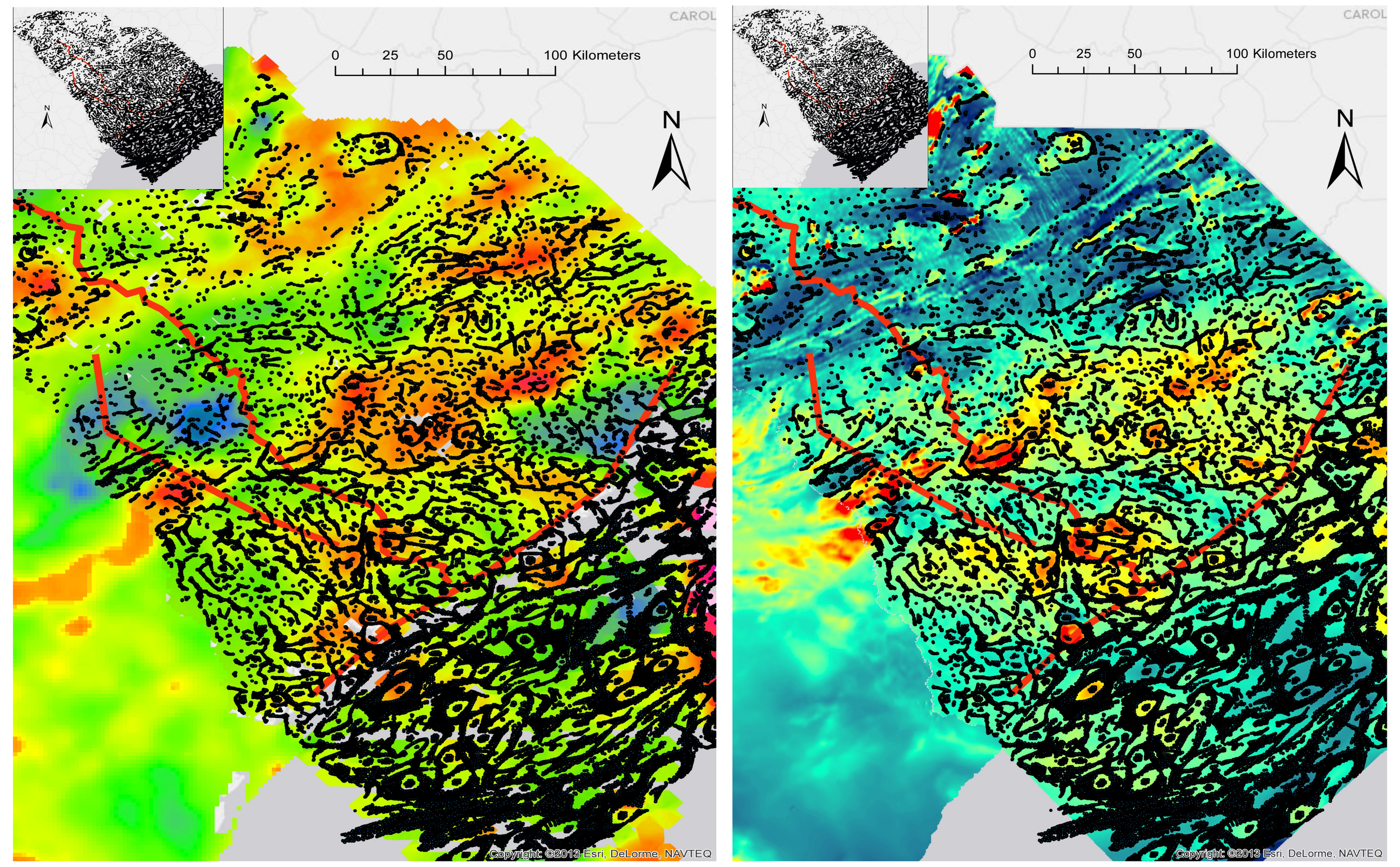
Profile 2 - Seisdata4

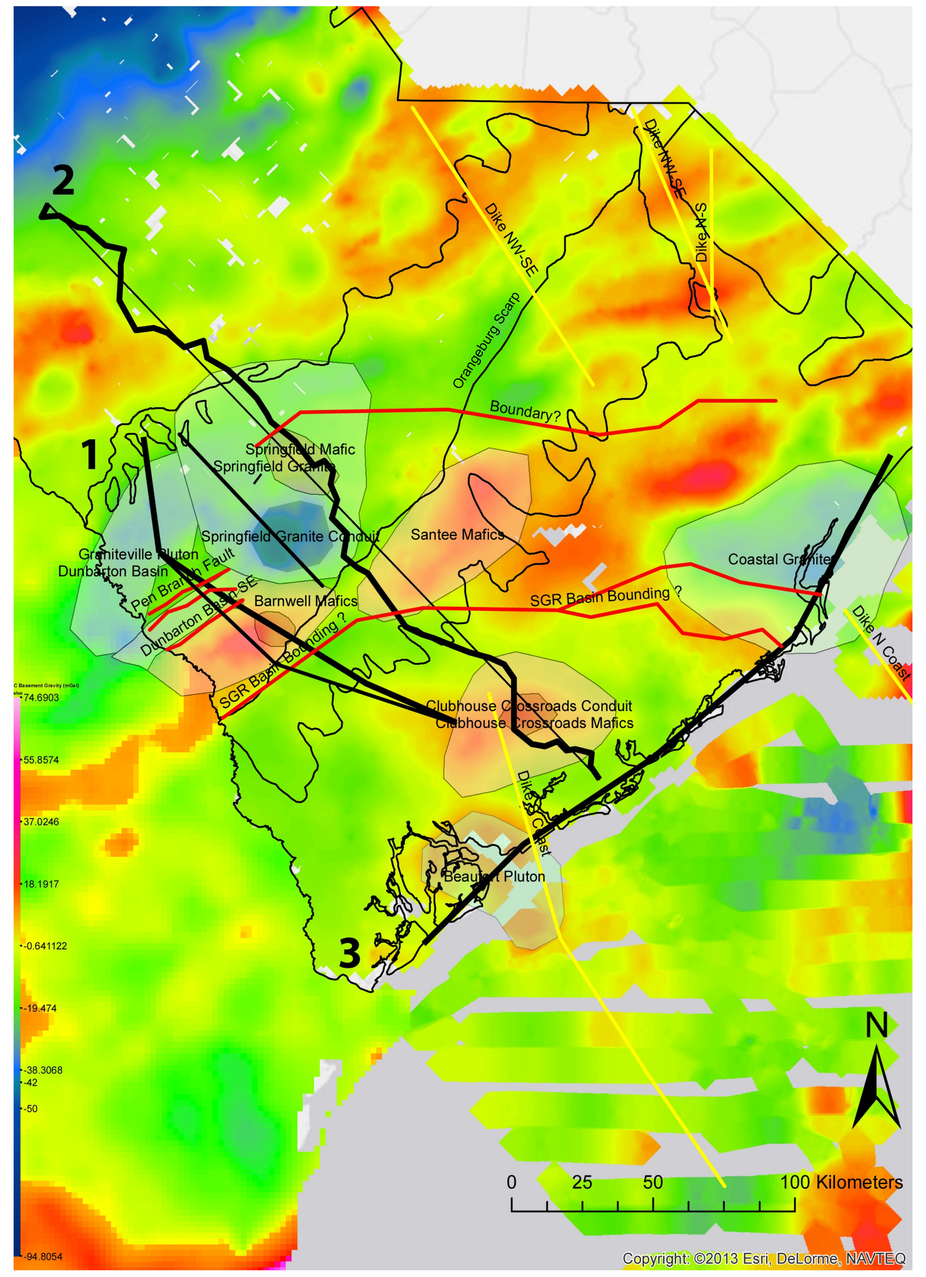


Profile 3 – Coastal Strike Line



Euler 3D Inversion Results and Basement Map





Profiles 1-3 and Inversion Maps: **Profile 1** traverses the Graniteville Pluton, Dunbarton Basin, Barnwell Mafics, and the SGR basin. The basin bounding fault of the SGR coincides with a major discontinuity in crustal velocity down to 8 km observed in the seismic refraction data, and corresponds to the topographical Orangeburg Escarpment. The Barnwell Mafics take the form of a laterally extensive sheet with 2 conduits down to 6 km. The Dunbarton Basin is a less than 1.5 km deep asymmetric down to the NW basin, bounded by the Pen Branch Fault. **Profile 2** is located parallel to the Seisdata4 2D seismic reflection profile. It traverses the Springfield Granite Pluton, Santee Mafics, the SGR basin, and the Clubhouse Crossroads Mafics. Based on the character of its gravity anomaly, the Springfield Granite represents one of the largest buried Granites on the eastern margin of North America. The Santee mafics are interpreted to be within the SGR basin or sub-basins, but could instead correspond to Gabbros within the metamorphosed Paleozoic Piedmont terranes. The Clubhouse Crossroads Mafics are models as laterally extensive thin sills or flows fed by a relatively shallow conduit. The USGS Clubhouse Crossroads boreholes confirm the existence of one of the few known Basalt flows within the SGR basin. **Profile 3** is strike oriented and traverses the Beaufort Pluton, the SGR basin, and a large coastal Granite. The magnetic anomaly associated with the Beaufort Pluton is consistent with a deep cylindrical conduit, which may have fed CAMP mafic sills and flows. The coastal Granite, has previously been interpreted as a sub-basin of the SGR (Talwani), but forward modeling suggests it is more likely a buried Paleozoic Granite outside of the basin boundary. The **Inversion Maps** above present the first known 3D inversion results for the SGR basin. The Euler 3D inversion of the magnetic field was performed with a structural index of zero and a uncertainty of 15%. Several coherent features and fabrics exist, including the boundaries of the Dunbarton Basin, a candidate for the N bounding fault of the SGR basin, the outlines of exposed and buried Granite intrusives, and the outlines of mafic units within and adjacent to the SGR basin. Several diabase dikes are also visible in the inversion results. These dikes appear to have at least two different strikes and exhibit crosscutting relationships. The **Structural Features Map** at left summaries interpretations made on the basis of the three 2D forward model profiles and the Euler 3D inversion results. The major features mentioned above are included along with the conduits where present for igneous bodies. Additionally, the faults bounding the Dunbarton Basin and potential basin bounding faults for the SGR basin are shown in red. Appearing in yellow are the major dikes identified from the inversion results. This map represents a synthesis of geologic and geophysical data and provides a first order constraint on major features of the buried basement of the southeast Atlantic margin of eastern North America.

Conclusions

- A major crustal boundary exists to the SE of profiles 1 and 2 line separating Triassic sediments from a structural high comprised of metamorphic rocks and mafic igneous intrusions. The boundary goes down to ~8 km depth, and could be the master normal fault bounding the South Georgia Rift Basin to the NW. This fault also coincides with the Orangeburg escarpment locally..
- With large gravity and magnetic contrasts we estimate 3D geometries for mafic intrusives CAMP? (Barnwell, Santee, Clubhouse Crossroads, Beaufort Pluton). Depths to intrusives ~400 m, thicknesses ~2 km, and conduits as deep as 6 km.
- We estimate geometries for the Graniteville Pluton and Springfield Granite (Depth to granite < 100 m, thickness ~ 2.5 km - 3.5 km, conduits to 6 km depth). We have also interpreted the coastal gravity low as a Coastal Granite, which has implications for the N boundary of the SGR basin.
- The Dunbarton Basin is a less than 1.5 km deep asymmetric down to the NW basin, bounded by the NE-SW striking, SE dipping Pen Branch Fault.

Future Work

- Given the study area and the regional scale of the Basement Mapping Project, the utilization of EarthScope and GeoPRISMS data and the development of partnerships are major objectives of the research effort.
- The acquisition of additional geophysical data, particularly regional seismic refraction experiments, is necessary because of the power of these data in constraining potential field forward models. The funded NSF and EarthScope SUGAR experiments by Shillington, Lizarralde, and Harder could be used for this purpose.
- Forward and inverse models will be extended from the initial focus on South Carolina to North Carolina and Georgia, where potential field data is equally rich, to develop a larger regional understanding of major geologic and tectonic elements.
- Acquisition of additional lab and field data to better constrain rock densities and magnetic susceptibilities, as well as rock ages is necessary to better illuminate issues related to rifting and passive margin evolution.

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