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Reprocessing and Interpretation of an Industry Seismic Reflection Profile Across the South Georgia Rift in the Epicentral Area of the 1886 Charleston, SC Earthquake

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Abstract

The seismic reflection data collected in the epicentral area of the Charleston earthquake, and to the northwest across the South Georgia Rift in South Carolina, are interpreted to indicate that the 1886 shock occurred in an extensive fault zone located between Summerville and Charleston. The western boundary of this fault zone is marked by a prominent gradient in the potential field. Cenozoic deformation is observed on every seismic reflection profile crossing the potential field gradient in the epicentral area. The zone of active faulting extends to the south and east of Summerville, and includes a synclinal structure lying between Summerville and the Atlantic coast. Cenozoic faults are imaged in the interior of this feature, southeast of Summerville along the Ashley River, and 17 km to the south in the vicinity of Rantowles, South Carolina. Modern seismicity is concentrated at the location of an imaged fault in the trough of the synclinal structure, beneath the Ashley River a few kilometers to the southeast of Summerville. In all likelihood, the 1886 rupture involved one or more of these seismically imaged faults.

The Cenozoic-Mesozoic faults and modern seismicity near Summerville are associated with a major potential field anomaly that extends across South Carolina at Latitude 37.7N within the South Georgia Rift. The seismic reflection data and modeling of the potential field show that, in the vicinity of Summerville, this potential field anomaly is due to a high percentage of mafic volcanic rocks in the upper 4-5 km of the crust. The early Mesozoic volcanism was associated with the crustal extension responsible for the fault zone imaged near Summerville. On the basis of data from the seismic profiles, we propose that the entire zone marked by this potential field anomaly is similar in structural character to the epicentral area of the 1886 earthquake near Summerville.

The Summerville area is in the interior of the South Georgia Rift. The Seisdata4 reflection profile images the northwestern boundary of the rift between Branchville and Bamberg, South Carolina. The seismic data show that the rift boundary is a major extensional fault zone that is in many respects similar to that observed in the interior of the rift near Summerville. The similar character of reflections and the association of the rift boundary faulting with a positive potential field anomaly suggest a very similar seismotectonic setting.

Introduction

The 1886 Charleston earthquake was the most damaging and costly earthquake in eastern United States history. It killed at least 100 people and it more or less wrecked the port city. Because of the modern urbanization of the epicentral area, another shock of similar size in the same general vicinity will produce a disaster on the scale of the 1994 Northridge, California earthquake. Paleoseismic evidence indicates that the return period of potentially damaging shocks in coastal South Carolina is on the order of 500 years. Yet, the geological setting of the 1886 shock remains poorly understood, resulting in uncertainties of source representation in the national seismic hazard maps.

This study investigated the upper crustal structure of the South Georgia Rift, in the vicinity of the epicenter of the 1886 shock, using an industry seismic reflection profile. Seisdata4 is the longest seismic reflection profile collected to date in the epicentral area of the 1886 shock. Several other shorter seismic profiles were collected by non-industry research groups during the period 1977 through 1981, with support from the U.S. Geological Survey and the U.S. Nuclear Regulatory Commission.

Our previously published work describes results obtained by reprocessing and interpreting the shorter 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 is probably 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. That effort imaged a structural basin within a zone of extensive extensional faulting. Cenozoic-Mesozoic faults were imaged within this structural basin and along its northwestern boundary, at locations in close proximity to instrumentally located modern seismicity (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 Seisdata4 profile is located to the south of the shorter reflection profiles and crosses the Mesozoic extensional fault zone and potential field anomaly. It provides additional constraint on the structural geometry (Beale et al., 2010). Of great importance is the fact that the Seisdata4 profile extends well to the northwest of the epicentral area and, in the vicinity of Branchville, South Carolina, the profile crosses a second major potential field anomaly remarkably similar to that in the epicentral area of the 1886 earthquake. This second major potential field anomaly is spatially close to the boundary of the South Georgia Rift inferred on the basis of well data. As will be discussed below, major faulting imaged on Seisdata4 in association with this feature is here interpreted to mark the actual structural boundary of the rift.

The Seisdata4 profile was acquired in 1981 by Seisdata Services, Inc., using 96 channels, with 70 meter geophone group intervals. The sample interval was 4 msec. The

source sweep was a 48-12 Hz down-sweep, lasting 24 seconds. The data were recorded with an 8 second listen time. The profile is owned by Geophysical Pursuit, Inc., Houston, Texas. Virginia Tech acquired the uncorrelated field traces, including the Vibroseis source sweeps, and the complete set of observer and survey notes. Virginia Tech obtained permission from the owners of these data to reprocess the entire data set and to publish the scientific results. The profile had previously been described in publication only in the form of line drawings from brute stacks (Behrendt, 1985, 1986). Beale et al. (2010) described some preliminary results of our reprocessing of approximately 1/4 of the profile located to the south of Summerville.

We describe below the results of reprocessing the entire Seisdata4 profile, with emphasis on geological features of significance to earthquake hazard assessment. We begin by briefly reviewing our previous work, and then focus on the southeastern end of the Seisdata4 profile and the information it provides on the nature of the early Mesozoic extensional fault zone and associated structural basin in the Summerville-Charleston area that hosted the 1886 earthquake. We then shift to the northwest, where SeisData4 clearly images major extensional faulting comprising the structural boundary of the South Georgia Rift. As we will show, that area is remarkably similar, in term of structural framework, to the epicentral area of the 1886 shock.

Background

A schematic outline of the South Georgia Rift is shown in Figure 1. It lies buried beneath the southeastern United States Atlantic Coastal Plain sediments in parts of South Carolina, Georgia, Florida and Alabama. It is understood on the basis of scattered well data, potential field interpretation and a few seismic reflection profiles. Mesozoic rift-complex lithology distinguishes this terrane from the largely metamorphic crystalline rocks of the Paleozoic Appalachian Piedmont province to the north, and from Paleozoic felsic rocks of the inferred relic African "Suwannee Terrane" of Florida (Daniels et al., 1983, Chowns and Williams 1983, Thomas et al., 1989, McBride 1991). The seismic reflection data in Georgia and Northern Florida indicate that the South Georgia Rift is a complex terrane of grabens and intervening structural highs (McBride, 1991). The basement is comprised of an extensive sequence of basalt flows and /or diabase sills with intervening clastic sediments (McBride et al. 1989, McBride 1991). This characteristic rift-complex lithology defining the South Georgia Rift is present in the epicentral area of the 1886 earthquake, as demonstrated by drill cores and seismic reflection data near Summerville, South Carolina (see Gohn, 1983a, for a summary, and Gohn, 1983b, for detail on the lithology of Mesozoic basalt and clastic sediments encountered in the Clubhouse Crossroads core holes near Summerville).

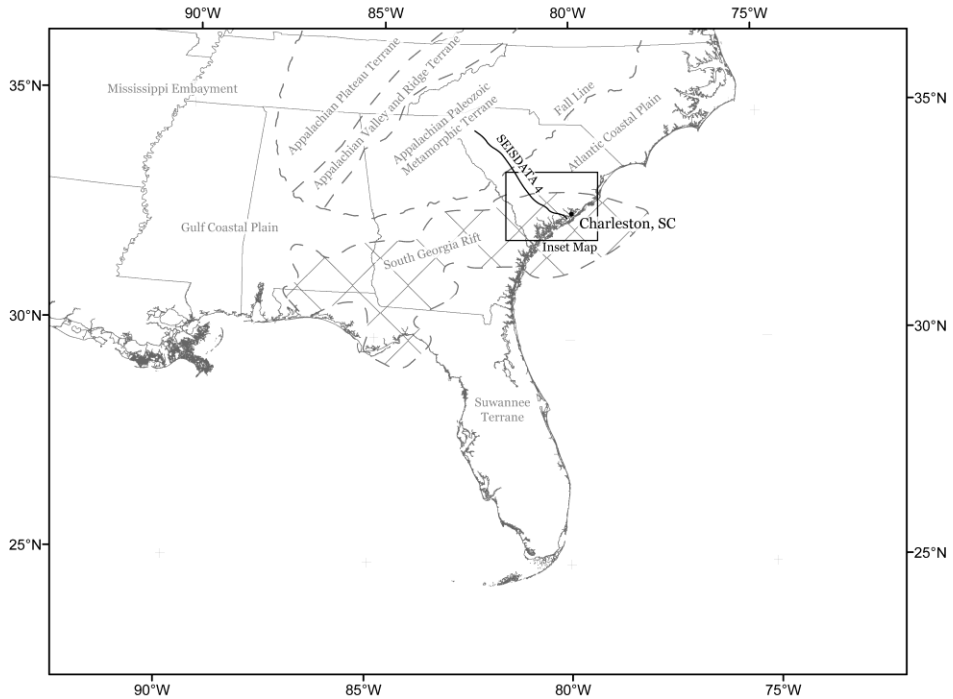

Figure 1. Physiographic/geologic provinces and geologic terranes in the southeastern United States. The approximate extent of the South Georgia Rift is taken from Daniels et al. (1983). The study area is within the rectangle that includes Charleston, South Carolina. The location of reflection profile Seisdata4 is indicated by the thick line.

Figure 2 shows magnetic total intensity and Bouguer gravity, along with the locations of wells that have penetrated through Cretaceous and younger Atlantic Coastal Plain sediments. In Figure 2, blue filled circles indicate the locations of wells that bottomed in crystalline rocks lithologically similar to those exposed in the Appalachian Piedmont province. The red filled circles show the wells that bottomed in mafic volcanic rocks or clastic sedimentary rocks similar to those found in exposed Mesozoic basins throughout the Appalachian region (e.g., rocks of the Newark Supergroup). The red circles are the basis for inferring the extent of the South Georgia Rift in the study area.

Figure 3 shows the study area in more detail. Seismic reflection profiles are indicated, as are wells penetrating into the basement and the total intensity magnetic anomaly contours (from Daniels, 2005). Figure 3 shows the epicenters of modern earthquakes (M>2) determined by the University of South Carolina seismic network (1977-2005). Figure 3 also shows that the modern seismicity is spatially associated with a prominent magnetic "high". Note that Seisdata4 crosses another prominent magnetic and gravity high in the vicinity of 33° 15' N, 80° 50' W, near Branchville, South Carolina (indicated in Figure 2). That area is in the vicinity of the boundary of the South Georgia Rift, as inferred by Daniels et al. (1983) on the basis of the well data similar to that shown in Figure 2.

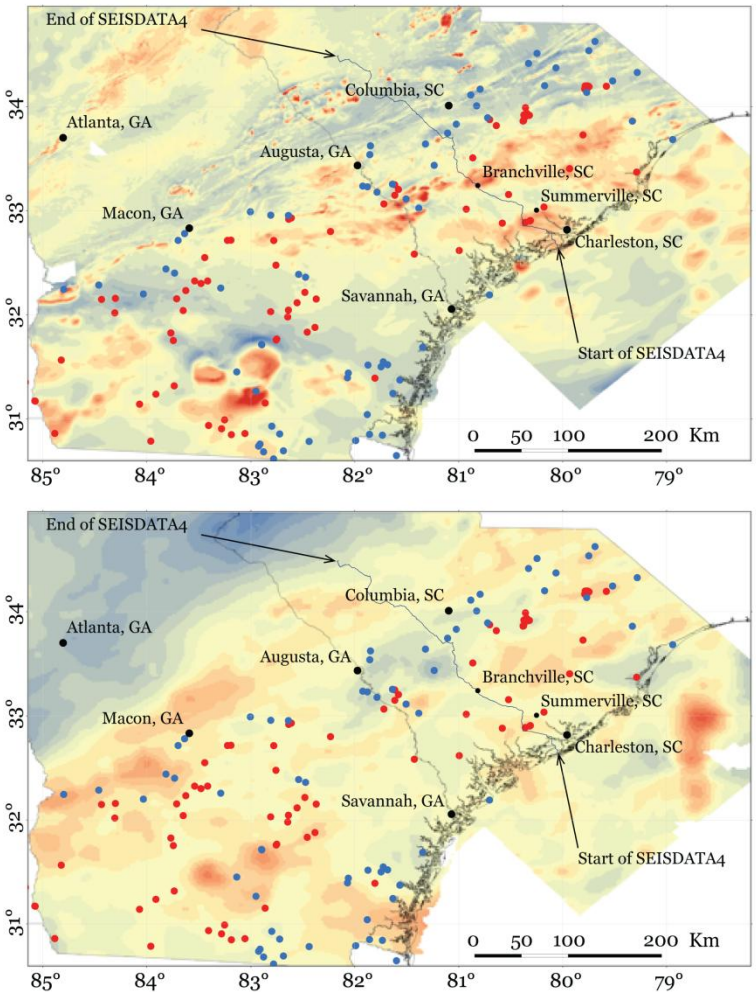

Figure 2. ***Upper***: Magnetic total intensity (red color is high intensity). ***Lower:*** Bouguer gravity (positive anomaly is colored red). The blue circles show the location of wells penetrating the Coastal Plain sediments and bottoming in crystalline rocks interpreted as similar to those exposed in the Appalachian Piedmont to the north and west. The red circles show the location of wells penetrating the Coastal Plain sediments and bottoming in mafic volcanic rocks or clastic sedimentary rocks similar to those encountered in exposed Mesozoic basins throughout the Appalachian region. The location of the Seisdata4 reflection profile is indicated by the solid line. Note the positive potential field anomalies in the vicinity of Summerville and Branchville, SC.

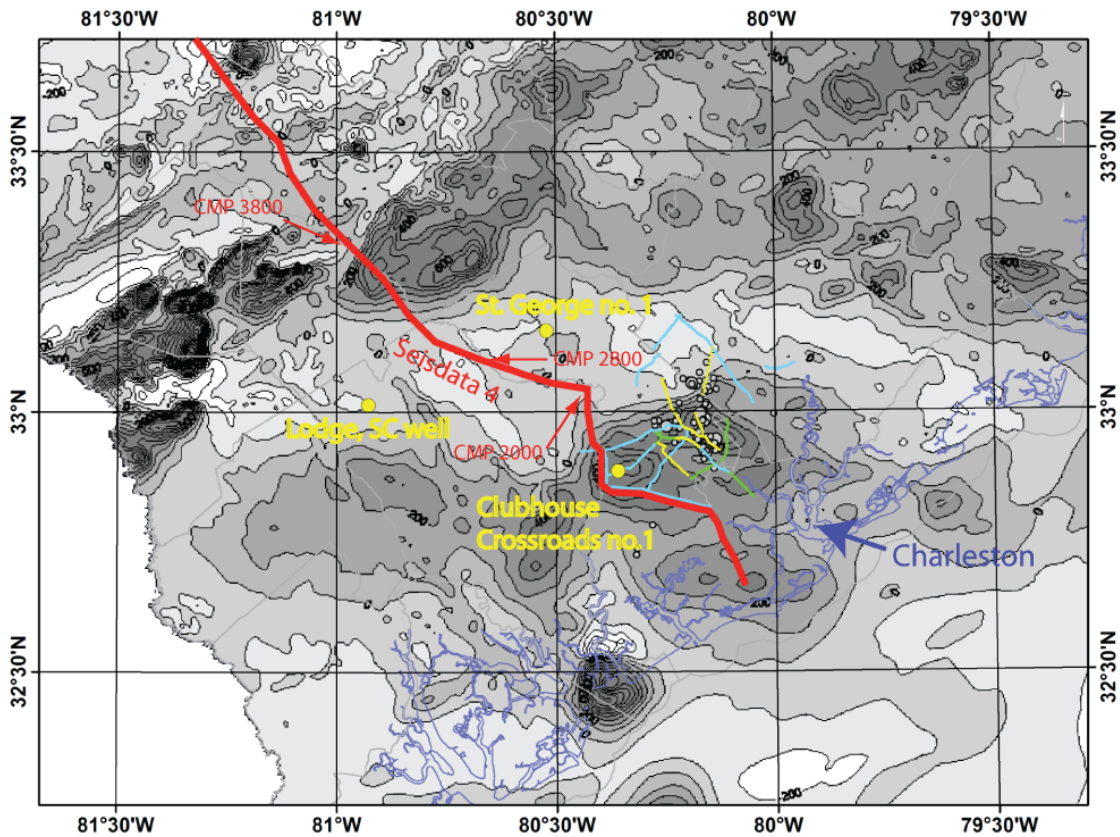

Figure 3. Contours show the total intensity magnetic anomaly (nanoteslas) in South Carolina and offshore (Daniels, 2005). The red line shows the location of the Seisdata4 reflection profile. Yellow circles show the locations of wells penetrating into the basement. Thin yellow lines show the locations of Virginia Tech seismic profiles VT-1, VT-2, VT-3, VT-4 and VT-5, described in detail by Chapman and Beale (2010a). Thin blue lines show USGS seismic reflection profiles (Chapman and Beale, 2010a). Thin green lines show COCORP reflection profiles (Chapman and Beale, 2010a). Open circles show instrumentally located earthquake epicenters determined by the University of South Carolina seismic network (M>2, 1977-2005).

Figure 4 is adapted from Chapman and Beale (2010a) and shows a detailed map of the epicentral area of the 1886 earthquake with the locations of seismic reflection profiles indicated, including Seisdata4. The figure shows the locations of Mesozoic-Cenozoic faulting imaged on the reflection profiles and described in detail by Chapman and Beale (2010a), and the location the magnetic gradient separating high values southeast of Summerville from low values to the northwest. Modern seismicity is clearly associated with the faulting imaged on profile VT-3 (indicated by F_c) and also occurs in proximity to the faulting imaged at three locations on profiles SC6, VT-4 and VT-5 where those profiles cross the magnetic gradient in and around Summerville (indicated by F_{mg} in Figure 4). Dashed lines indicate the extent of the structural basin described by

Chapman and Beale (2010a), with the shaded area marking the trough of the structural basin.

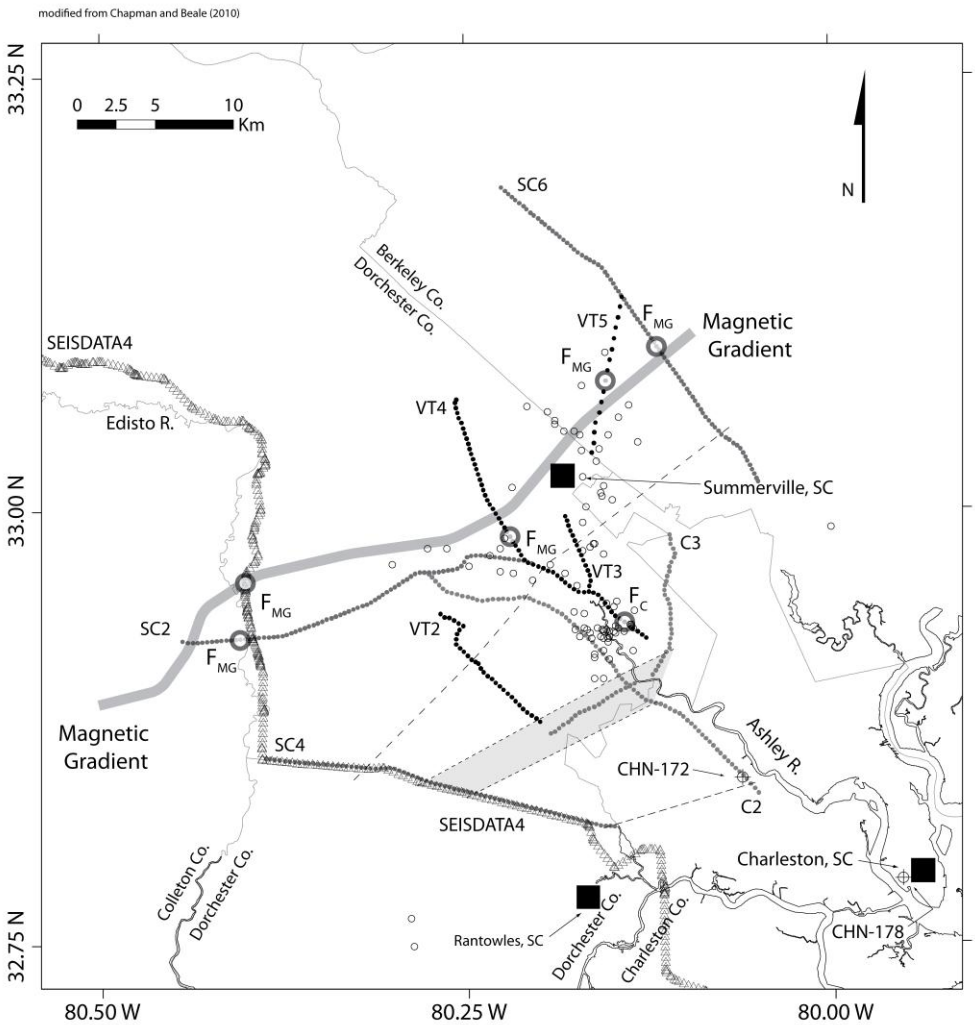

Figure 4. Detail map of the epicentral area of the 1886 earthquake showing notable locations of imaged Cenozoic faulting. The locations of short seismic profiles are shown as small filled circles. The Seisdata4 profile stations are shown by triangles. The magnetic gradient marking the northwest margin of the imaged Mesozoic fault zone/extensional basin is shown by the thick grey line passing just northwest of Summerville. The two long-dashed lines show the northwestern and southeastern flanks of the basin were B reflectors exhibit pronounced dip to the southeast and northwest, respectively. The trough of the basin is indicated by the NE-SW trending shaded area outlined by short-dashed lines. Earthquake epicenters (M>2, since 1977) are shown by small open circles. Locations of imaged Cenozoic faults in association with the magnetic gradient are shown by large circles labeled "Fmg". The Cenozoic fault imaged on VT3 in the basin interior is labeled "Fc". Additional faulting imaged on profile Seisdata4 is discussed in the text.

The extensional feature that is schematically indicated in Figure 4 was recognized by Chapman and Beale (2010a) from our reprocessing of all the VT reflection profiles, as well as our examination of the stacked record sections of the COCORP and SC profiles that are also indicated in Figure 4. Seismic profiles VT-1, VT-3, VT-4, VT-5, SC-10, and COCORP-2 (indicated as C2 in Figure 4) show a zone of highly reflective Mesozoic rocks beneath the early Jurassic "J" reflector that marks the unconformity separating the lower Mesozoic rift-complex volcanic rocks and clastic sedimentary rocks from Cretaceous and Tertiary Coastal Plain sediments in the area near Summerville. The reflectors below the "J" reflector have been referred to as the "B" reflectors by previous workers, and they are discussed in detail in Chapman and Beale (2008, 2010a). The western margin of this reflective zone of bright "B" reflections is observed on profiles VT-4 and VT-5, and coincides with a steep gradient in the total intensity magnetic anomaly map, which separates a prominent paired magnetic high and low anomaly that extends east-west almost entirely across South Carolina (Figures 2 and 3). In the study area near Summerville, the "B" beds deepen and brighten to the southeast into the zone of high magnetic intensity. This deepening is due to early Mesozoic extensional faulting (Chapman and Beale 2010a). With the exception of Seisdata4, only COCORP-2 (C-2 in Figure 4) is long enough to provide some insight into the extent and structure of this extensive lower Mesozoic fault zone between Summerville and Charleston. The southeastern extent of the faulting associated with major Mesozoic extension is not constrained by the short reflection profiles shown in Figure 4, and the southeastern-most dashed line in Figure 4 marks the point where "B" reflectors merge with the "J", forming the southeastern margin of a synclinal trough that we have referred to in our previous publications as "extensional basin". The southeastward extent of the faulting and structural complexity associated with the crustal-scale Mesozoic extension in this area is better represented by the longer Seisdata4 profile discussed below.

Seisdata4 in the 1886 Epicentral Area

Figure 5 is another map showing the location of the southeastern part of the Seisdata4 profile with distinct sections of the profile and reference locations indicated to facilitate description. Also shown in Figure 5 is the location of COCORP profile C2, approximately 17 km to the north, along the south side of the Ashley River, in the epicentral area the 1886 earthquake. Figures 6 and 7, respectively, show C2 and the southeastern section of Seisdata4 between common mid-points CMP 1400 and CMP 200. The reflection at 0.7 seconds is the "J" reflector, due to the impedance contrast at the unconformity marking the top of the Mesozoic section over much of the 1886 epicentral area. On C2 (Figure 6) the underlying B reflectors gradually deepen along the profile from the northwest end of the profile to a point northwest of Ft. Dorchester (shown by the northwestern-most dashed line in Figure 4). At that point, they deepen abruptly. The faulting on line VT-3 to the north of C2 on the opposite side of the Ashley River (F_c in Figure 4) projects on line C2 to the center of a synclinal basin defined by the B reflections. These "B" reflectors shallow further to the southeast toward the end of the C2 profile, defining a severely faulted basin of at least 17 km lateral extent along the C2 profile.

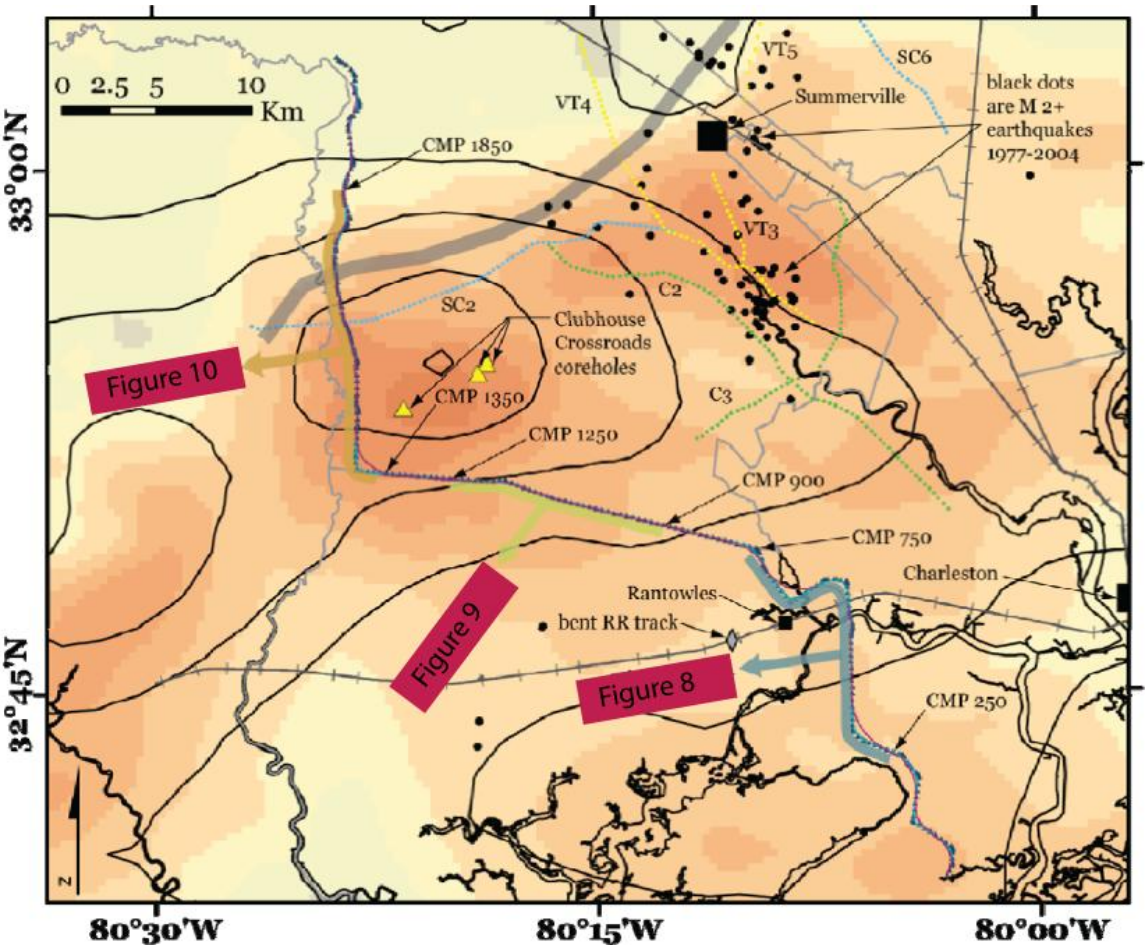

Figure 5. Potential field map of the 1886 earthquake epicentral area. Colored contours show total intensity magnetic anomaly (dark-large values: light-small values). The solid line contours show Bouguer gravity anomaly values, with largest values spatially associated with large magnetic anomaly values. The thick grey line shows the location of the magnetic gradient separating a zone of low intensity to the northwest from the magnetic high to the southeast. Small filled circles show epicenters of earthquakes with magnitudes greater than 2.0 in the 1977-2004 time period. Colored dots show the station locations of several seismic reflection profiles re-processed and described by Chapman and Beale (2008, 2010a). Sections of profile Seisdata4 described in the text are indicated by the thick colored lines, with arrows referring to figures showing the stacked record sections (modified from Buckner, 2011).

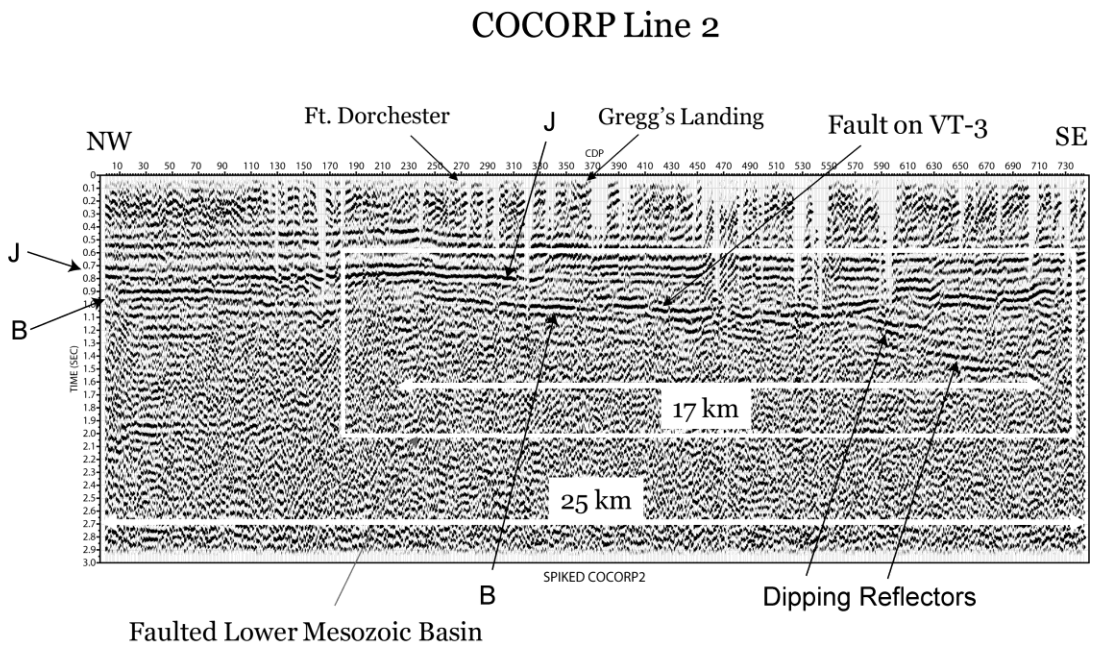

Figure 6. COCORP reflection profile C2 collected along the southern side of the Ashley River. J and B reflections from the Lower Mesozoic section are indicated. The locations of Fort Dorchester, Gregg's Landing and the projected location of Fault C of profile VT3, (Fc in Figure 4) and described by Chapman and Beale (2008, 2010a) are indicated. Note the image of an extensive syncline-shaped structural feature involving the Lower Mesozoic section (adapted from Buckner, 2011).

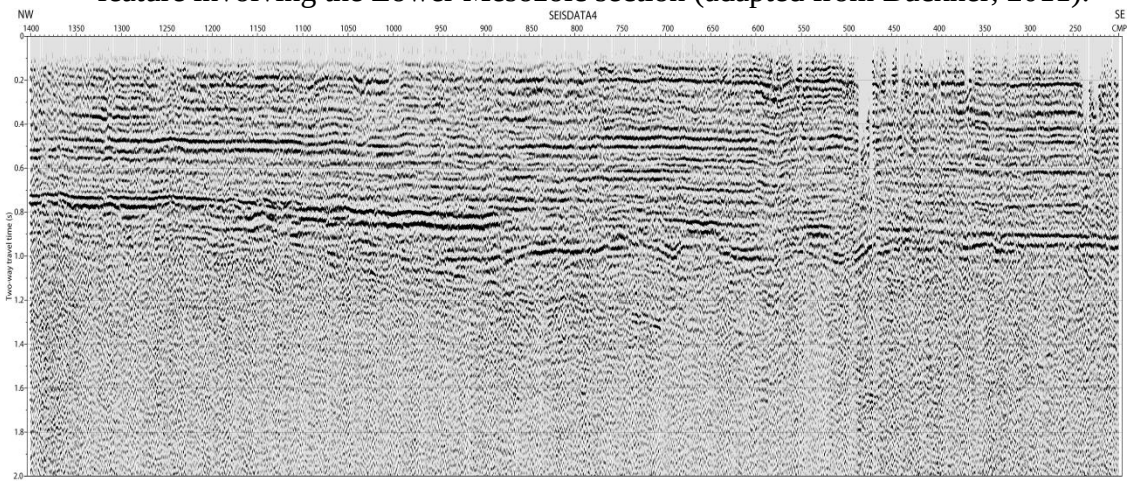

Figure 7. The southeastern section of Seisdata4 between CMP 1400 and CMP 200 (see Figure 5 for locations). Note the similarity of the deformation involving the Lower Mesozoic section on C2 and Seisdata4 profiles which are separated by approximately 17 km (adapted from Buckner, 2011).

Cenozoic Faulting associated with Mesozoic Crustal Extension Between Summerville and Charleston

Figure 7 shows a very similar synclinal structure on Seisdata4 between common mid-points (CMP) 1250 and 750. Faulted B units (inter-bedded early Mesozoic volcanic and clastic sedimentary rocks) apparent between 1.0 and 1.2 seconds on Seisdata4 extend well to the southeast of CMP 750, to the southeastern end of the profile (CMP 0). The "J" reflector, due to the impedance contrast at the unconformity between the coastal plain sediments and the underlying higher velocity lower Mesozoic units at approximately 0.9 to 1.0 seconds, is disrupted by faulting on Seisdata4 to the southeast of CMP 1250. Velocity analysis of Seisdata4 (Buckner, 2011) indicates that the Jurassic basalt, encountered at the unconformity in the Clubhouse Crossroads coreholes (Figure 5), is present to the northwest of CMP 1000 on Seisdat4 but absent to the southeast, in the zone of tectonic deformation to the southeast of CMP 1250. The absence of the basalt unit at the unconformity in that area was inferred by previous investigators (Hamilton et al., 1983) on the basis of the shorter SC4 reflection profile that was co-located with Seisdata4 between CMP 1350 and 750 (Figure 5).

The similarity of Seisdata4 with profile C2 to the north is striking. Between CMP 350 and 1150, the B units are clearly faulted. Between CMP 450 and 900, the profile shows much diffracted energy, which we attribute to the truncation of volcanic units due to faulting as observed on profile VT3 (Chapman and Beale, 2008, 2010a). Disruption of the shallow coastal plain sediments is apparent at several locations. Several processing steps were applied to these data (described by Buckner, 2011) including a thorough velocity analysis to clean up the shallow section. It is clear that the extensional basin imaged to the north by the shorter reflection profiles extends to the south and is crossed by Seisdata4. It is important to note that Seisdata4 images a series of southeast dipping reflections that can be traced to 2.0 seconds two-way time on the southeastern end of the profile, corresponding to a depth of approximately 4 km. We interpret those reflections to be caused by inter-bedded lower Mesozoic volcanic and sedimentary rocks.

Figure 8 shows the reprocessed shallow section (to 1 second two-way time) of Seisdata4 between CMP 750 and 250, east of Rantowles, SC. This part of the profile is shown as the blue line in Figure 5. The reflection from the Cretaceous-Lower Mesozoic post-rift unconformity is weak, discontinuous and apparently disturbed by faulting on this section of the profile, particularly between CMP 600 and 300. The overlying Cretaceous and Cenozoic sediments show disruption and evidence of faulting. Refraction velocity analysis (Buckner 2011) found a relatively low velocity of 4,200 m/s for the Mesozoic section on the southeastern end of the profile, in contrast to velocities of 5,500 m/s to the west of CMP 1000. This is interpreted to indicate that the early Jurassic basalt unit encountered at the Cretaceous-Lower Mesozoic unconformity in the Clubhouse crossroads wells (Figure 5) is present on Seisdata4 to the west of CMP 1000, but absent to the east. This is likely due to the tectonic deformation obvious on the profile to the east of CMP 1250.

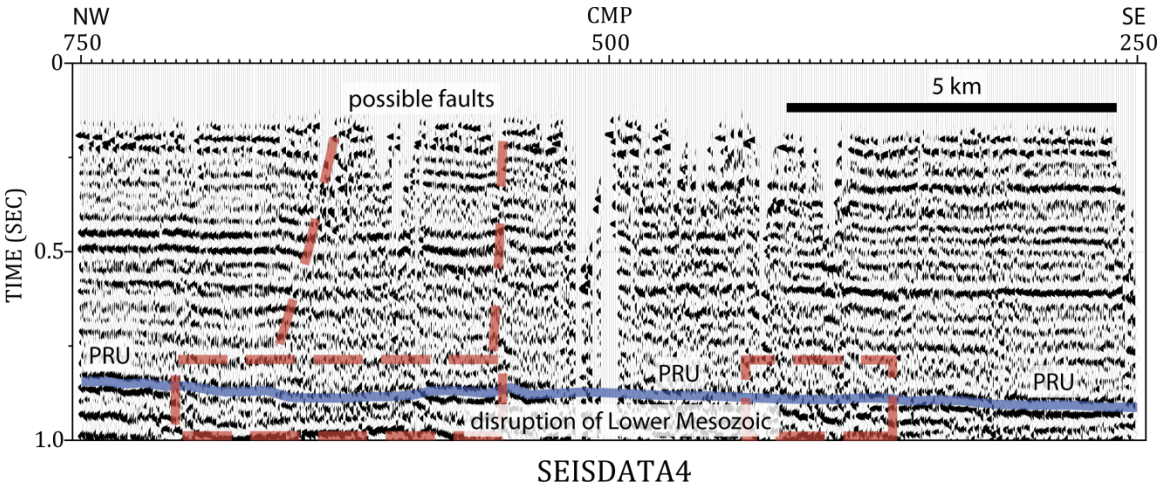

Figure 8. Reprocessed section of Seisdata4 profile between CMP 750 and 250, to the east of Rantowles, SC. Refer to the blue line in Figure 5 for location. The dashed lines indicate interpreted faults affecting the Cretaceous and Cenozoic sediments and the lower Mesozoic section. The J reflection due to the impedance contrast at the unconformity between Cretaceous sediments and the lower Mesozoic section (labeled PRU for "post-rift-unconformity") is shown by the blue line. Figure adapted from Buckner (2011).

Figure 9 shows the reprocessed section of Seisdata4 profile between CMP 1250 and 900, to the west of Rantowles, SC (refer to the green line in Figure 5 for location). Three faults affecting the Cretaceous and Cenozoic coastal plain sediments are interpreted along this part of the profile. To the northwest of CMP 1000 on Seisdata4, the J reflection is due to the unconformable contact of Cretaceous sediments and an early Jurassic basalt unit encountered in cores at the Clubhouse crossroads drill sites (Figure 5). The bright reflection terminates at CMP 900, and the basalt is apparently absent to the southeast.The fault interpreted at CMP 1180 on Seisdata4 was previously noted by Hamilton et al. (1983) on the shorter, co-located, seismic profile SC4 which they named the Drayton Fault. SC4 was obtained along the same road as Seisdata4, and the two profiles are co-located between CMP 1350 and 750 on Seisdata4 (Figure 5). The image obtained by reprocessing Sesidata4 provides much better resolution of this feature than was previously available, and it shows that the Cenozoic faulting is not confined to a single fault, but to a series of faults with minor deformation along this section of the profile.

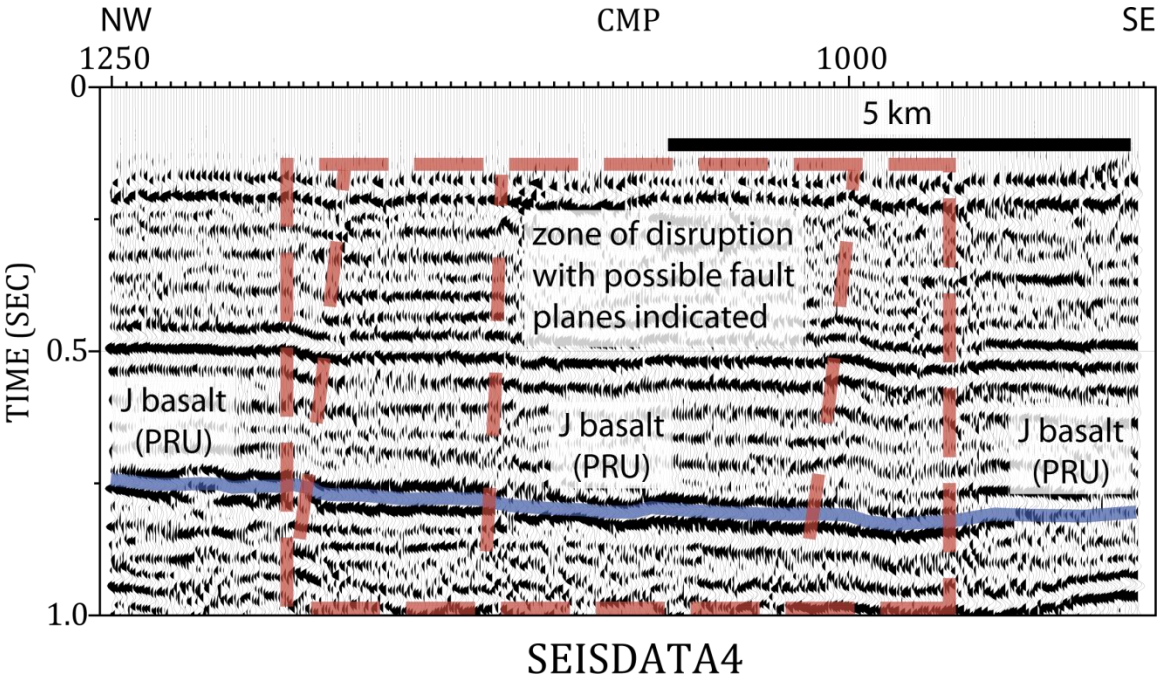

Figure 9. Reprocessed section of the Seisdata4 profile between CMP 1250 and 900, to the west of Rantowles, SC. Refer to the green line in Figure 5 for location. The dashed lines indicate three interpreted faults affecting the Cretaceous and Cenozoic coastal plain sediments. The J reflection due to the impedance contrast at the unconformity between Cretaceous sediments and the lower Mesozoic section (labeled PRU for "post-rift-unconformity") is shown by the blue line. Figure adapted from Buckner (2011).

Cenozoic faulting along the Magnetic Gradient Marking the Northwest Margin of the Zone of Crustal Extension Between Summerville and Charleston

Figure 5 shows that the trend of the Seisdata4 profile changes from northwest to due north in the vicinity of the Edisto River (CMP 1400). This north-south section of the profile to the southwest of Summerville has high-quality data and crosses the prominent gradient in the magnetic field. This section exhibits the best-resolved evidence of Cenozoic deformation on Seisdata4 in the epicentral area of the1886 shock.

Figure 10 shows the reprocessed Seisdata4 profile from CMP 1350 to 1850 (refer to Figures 3 and 5 for location: the section under discussion is shown as a brown line in Figure 5). At CMP 1780 there is a monocline down-to-the-south fold that involves the Tertiary-Cretaceous coastal plain units as well as the lower Mesozoic section. The location of this inferred fault of Seisdata4 is indicated in Figure 4 by F_{mg}. This general style of Cenozoic deformation, resolved here as folding, exists along this section of the profile from CMP 1780 to 1500. The reflectors in the vicinity of 0.5 seconds two-way time are clearly involved. However, the shallowest reflection, resolvable at approximately 200 ms, shows less deformation. Overall, the tectonically deformed section of the profile shows clear evidence of a general down-to-the-south displacement between several high angle faults, as interpreted in Figure 10.

The north-south trending section of Seisdata4 crosses the magnetic gradient, which is coincident with the location of the observed deformation. Faulting at the magnetic gradient, near this part of Seisdata4, was also noted by Hamilton et al. (1983) on adjacent profile SC2 (indicated by F_{mg} on that profile in Figure 4). The deformation observed on this section of Seisdata4 is similar to that noted by Chapman and Beale (2010a) on other profiles that cross the magnetic gradient in the study area, particularly, VT4 and VT5, which are shown for comparison in Figures 11 and 12, respectively. Modern seismicity occurs in close proximity to the magnetic gradient a few kilometers to the northeast of this section of Seisdata4, in and around Summerville (Figure 4 and Figure 5). Chapman and Beale (2010a) interpreted the magnetic gradient as being the seismically active northwestern fault-bounded margin of the zone of major early Mesozoic crustal extension between Summerville and Charleston.

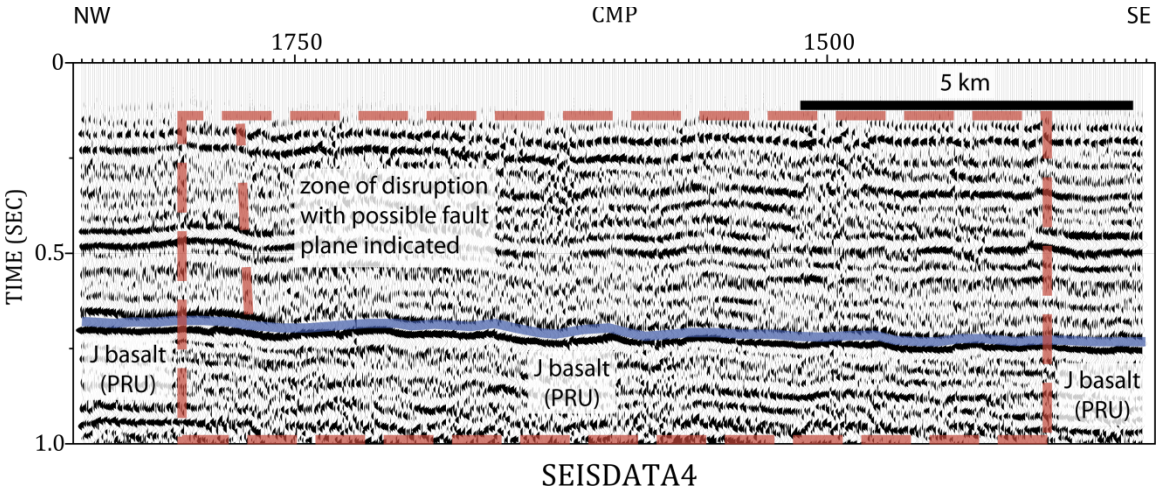

Figure 10. Reprocessed Seisdata4 profile between CMP 1350 and 1850. This section trends north-south, parallel to the Edisto River. Refer to Figures 3, 4 and 5 for location. The dashed red lines indicate interpreted faults affecting the coastal plain sediments. This section of Seisdata4 crosses the magnetic gradient, and deformation similar in style to that previously noted on other seismic profiles crossing the gradient in the study area is observed here as well. Note the zone of folding and general down-to-the-south deformation pattern. The unconformable contact between the Cretaceous and younger coastal plain sediments and the lower Mesozoic section (labeled "PRU") is indicated by the blue line. In this section of Seisdata4, this bright reflection is caused by the presence of a lower Jurassic basalt at the unconformity.

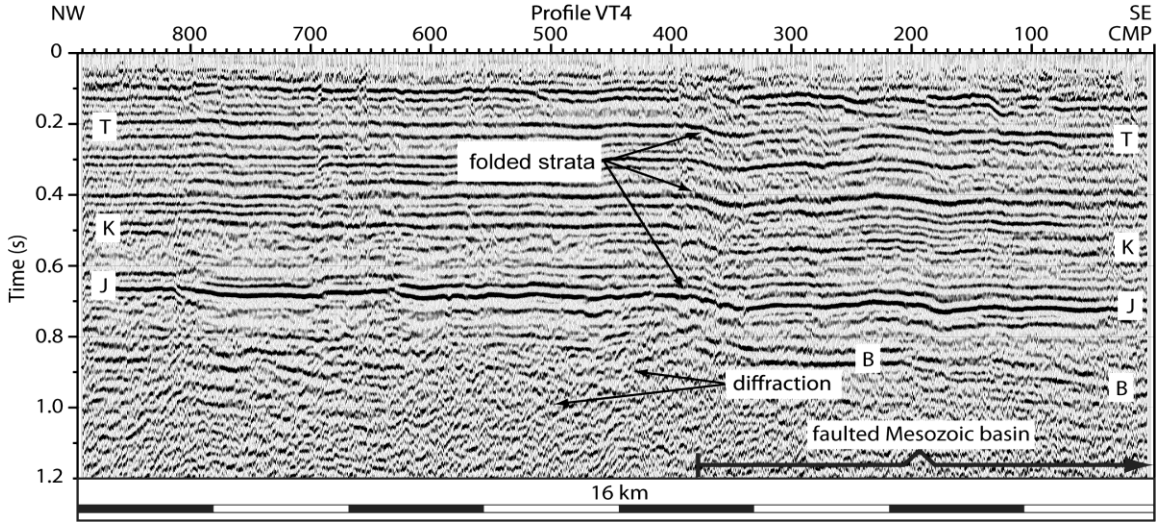

Figure 11. Profile VT-4 showing folding of Cenozoic sediments indicative of reactivation of Mesozoic faults in the vicinity of the magnetic gradient (see Figure 4 for location). Note that the B beds deepen to the southeast. This is interpreted to indicate young (Cenozoic) faulting at the northwestern margin of the zone of Mesozoic extension and associated structural basin defined by the B reflectors. Reflections labeled T and K are within the Tertiary-Cretaceous sediments. Reflection J is the top of the lower Mesozoic section. Adapted from Chapman and Beale (2010a).

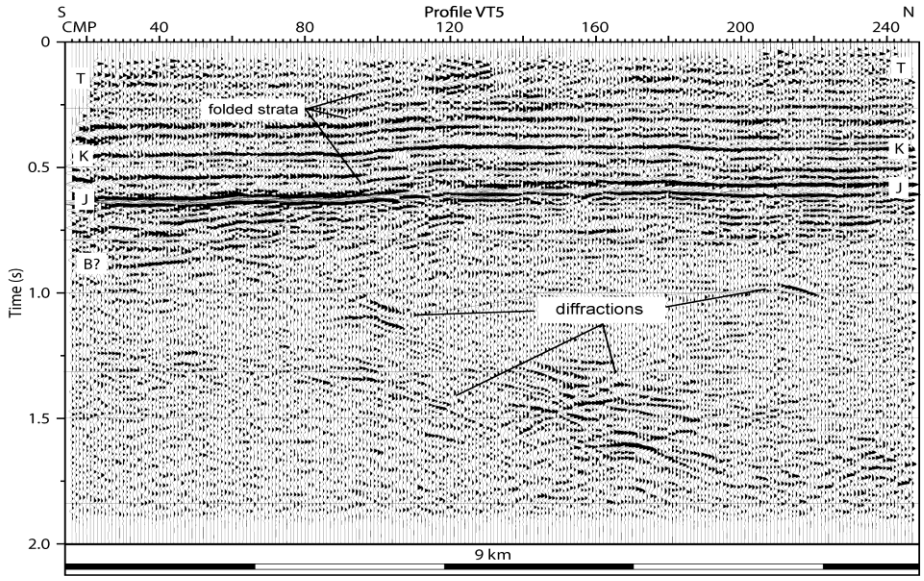

Figure 12. Monocline fold on profile VT-5, along the magnetic gradient to the north of Summerville is analogous to that observed on VT-4 and Seisdata4 (See Figure 4 for location). Note that the beds on the south end of VT-5 are down-to-the-south, consistent with the sense of motion shown in Figure 11 for VT-4, and Figure 10 for Seisdata4 . All profiles suggest that faults at the margin of the Mesozoic zone of extension have been reactivated in a down-to-the-southeast sense in the Cenozoic. Adapted from Chapman and Beale (2010a).

The Broad Structure of the South Georgia Rift in the Study Area and the Northwest Rift Margin

CMP 0-1000

Figure 13 shows the reprocessed Seisdata4 profile between CMP 0 and 1000. Referring to Figure 5 for location, this section extends from the southeastern end of Seisdata4 to a point to the northwest of Rantowles, approximately 3 km west of CMP 900 indicated on Figure 5. As discussed above, this section of the profile shows much tectonic disruption of the reflection from the Cretaceous-lower Mesozoic unconformity at approximately 1.0 second two-way time, as well as several zones of apparent Cenozoic faulting described in detail above. We interpret the upper 2.0 seconds of this profile to indicate the presence of Mesozoic rift sedimentary rocks as well as an abundance of interbedded volcanic rocks that contribute to an average total intensity magnetic anomaly of approximately 300 nT. Bright reflectors between 1.0 and 1.5 seconds probably are due to the impedance contrasts between mafic units and clastic sedimentary rock. Below approximately 2.0 seconds, the data are poor, with only sporadic indications of coherent reflections. We speculatively interpret the top of a tectonically extended crystalline basement on the basis of a few discernible reflections below 2.0 seconds two-way travel time, shown schematically as dashed lines in Figure 13.

CMP 1000-2000

Figure 14 shows the reprocessed Seisdata4 profile between CMP 1000 and 2000. Referring to Figure 5 for location, this section extends from a point to the northwest of Rantowles, approximately 3 km west of CMP 900 as indicated on Figure 5, to the point west of Summerville where the Edisto River changes trend from north-south to east-west (See Figure 3). There is a 90 degree bend in the profile in the vicinity of CMP 1400, were the profile encounters the Edisto River southwest of Summerville . As discussed above, this section of the profile crosses the prominent gradient in the magnetic field, where we interpret Cenozoic compressional reactivation of high-angle Mesozoic extensional faults between CMP 1500 and 1800. We have interpreted the basement faults to dip to the northwest on the basis of the geometry of deep reflections in the 1.5 to 2.0 second time interval. Three such faults are schematically shown by the dashed lines in Figure 14. These faults would have experienced down to the northwest extension in the Triassic, but are interpreted to have been reactivated in a compressional sense during the Cenozoic on the basis of down-to-the-southeast displacement of Cretaceous-Cenozoic reflectors shallower than 1.0 second two-way time (see discussion above). We speculatively interpret the top of a tectonically extended crystalline basement (shown schematically as dashed lines) on the basis of some coherent reflections below 2.0 seconds two-way travel time. The brightness, and apparent thickness of the B reflections between CMP 1800 and 1100 in general (and between CMP 1600 and 1200 in particular) on this section of the profile indicates the presence of large impedance contrasts between Mesozoic sedimentary rocks and a massive volume of mafic volcanic rocks. This is supported by the high magnetic intensity: modeling by Chapman and Beale (2010a) indicates that most of the shallow crust above 2.0 seconds two-way time (approx. 4 km) in this section of the profile is comprised of mafic material. The western boundary of this shallow block of mafic material corresponds to the inferred faulting near CMP 1700.

CMP 1800-2800

Figure 15 shows the section of the Seisdata4 profile from CMP 1800 to CMP 2800. See Figure 3 for the locations of CMP 2000, 2800 and 3800. This section of the profile is to the northwest of the magnetic high between Summerville and Charleston, and the magnetic intensity is approximately constant in the range 0 to -150 nT. This indicates much less mafic material in the shallow crust than along sections of Seisdata4 to the southeast. The B units between 1.0 and 1.5 second two-way time from CMP 1800 to 2600 exhibit less deformation than on sections of Seisdata4 to the south and east previously discussed. We speculatively interpret the top of a tectonically extended crystalline basement (shown schematically as dashed lines) on the basis of some coherent reflections below 2.0 seconds two-way travel time. The rather bland character of most of this section of the profile changes abruptly near the northwestern end in the vicinity of CMP 2700.

CMP 2800-3800

Figure 16 shows the section of the Seisdata4 profile from CMP 2800 to CMP 3800. See Figure 3 for the locations of CMP 2000, 2800 and 3800. This section of the profile crosses the magnetic and gravity high in the vicinity of Branchville, SC (shown on Figure 2) and exhibits the highest level of shallow Mesozoic extensional deformation the authors have seen in the study area. The positive potential field anomaly between CMP 3700 and 3200 is similar in scale and intensity to that previously discussed to the southeast of Summerville, indicating an abundance of mafic rock at shallow depth. The reflection due to the Cretaceous-lower Mesozoic unconformity shallows to less than 0.5 seconds two-way travel time on the western end of the profile. This reflection is intensely disturbed by faulting all along this section of Seisdata4. Bright, southeastward-deepening, reflections analogous to the B reflections previously discussed in connection with the synclinal extensional structure to the southeast of Summerville are apparent along this section of Seisdata4. However, the geometry of the reflections clearly indicates major down-to-southeast displacement between CMP 3700 and CMP 2800 on a scale not seen to the south and east of Summerville. These reflections are interpreted, here as elsewhere along Seisdata4, as due to the impedance contrasts between mafic volcanic rocks and clastic sedimentary rift-facies rocks. Examples of this type of lithology were encountered in the Lodge well (Figure 3) located to the south of this section of the profile (Chapman and Beale, 2010a), and Figure 2 shows that wells bottoming in rift-facies sedimentary rocks and mafic volcanic rocks are nearby. Reflections of this character are present in the near-surface at CMP 3600, but this reflective sequence rapidly thickens and deepens to at least 2.0 second two-way time beneath CMP 2900 (approximately 4.0 km) over a lateral distance of 20 km. This southeastward deepening of the B reflections, their truncation in many places, and the intense diffracted energy, indicates that this section of Seisdata4 images a major Mesozoic extensional fault zone beneath the coastal plain sediments. We interpret this section of the Seisdata4 profile as imaging the northwest structural margin of the South Georgia Rift, located at the surface in the vicinity of CMP 3700. The characteristic B reflections that are visible on Seisdata4 all the way from CMP 0 (southwest of Charleston) to CMP 3700 (just northwest of Branchville), are absent to

the northwest of CMP 3700. From that point to the northwest end of the reflection profile near Greenville, SC, Seisdata4 images crystalline rocks of the Appalachian Piedmont.

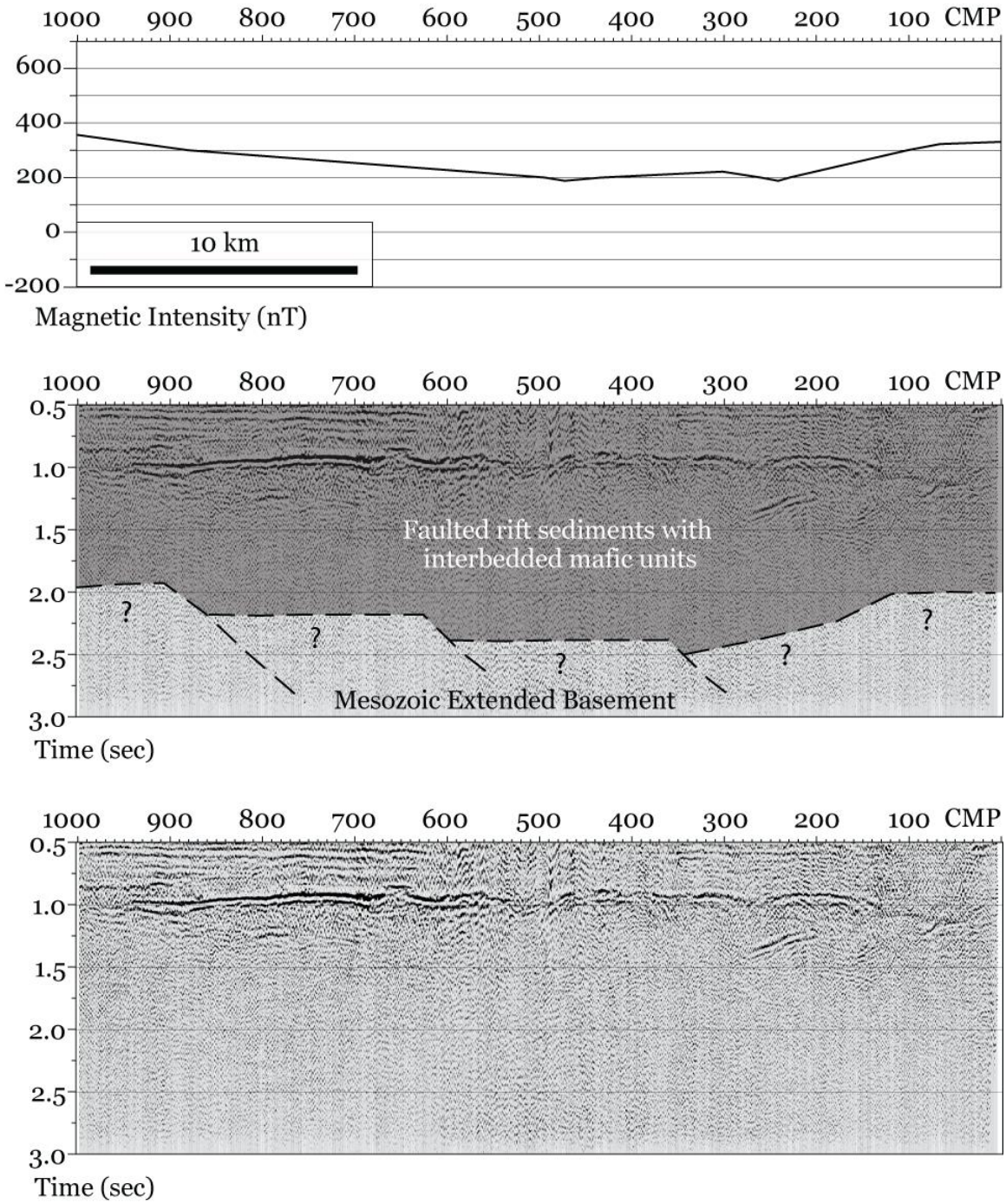

Figure 13. **Top:** Total intensity magnetic anomaly along the Seisdata4 profile (nanoteslas) between CMP 0 and CMP 1000. **Middle:** stacked record section of the reprocessed Seisdata4 profile, with an interpretation of the configuration of the basement structure of the South Georgia Rift. **Lower:** un-interpreted record section. Refer to Figure 5 for CMP locations.

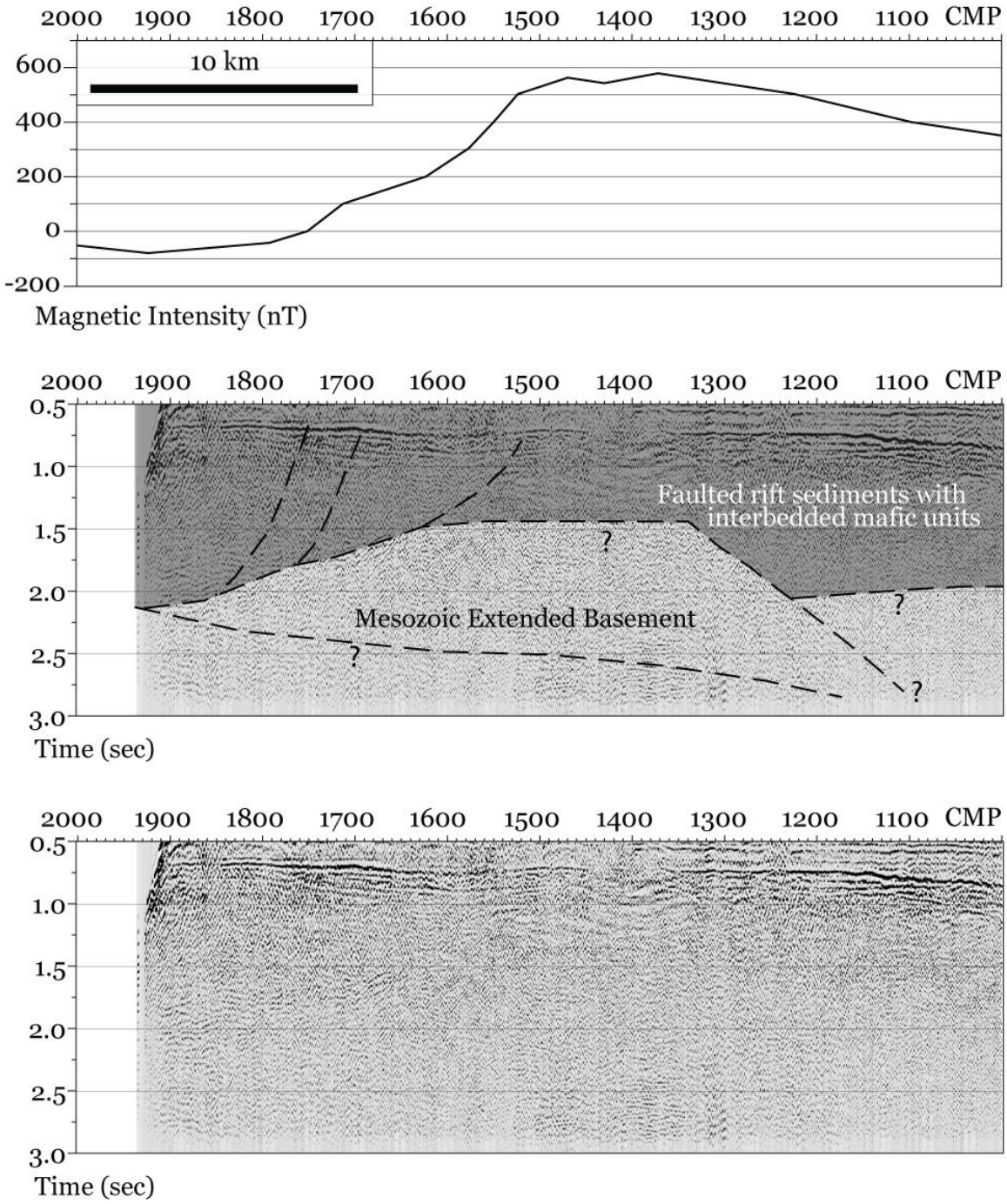

Figure 14. **Top:** Total intensity magnetic anomaly along the Seisdata4 profile (nanoteslas) between CMP 1000 and CMP 2000. **Middle:** stacked record section of the reprocessed Seisdata4 profile, with an interpretation of the configuration of the basement structure of the South Georgia Rift. **Lower:** un-interpreted record section. Refer to Figure 5 for CMP locations.

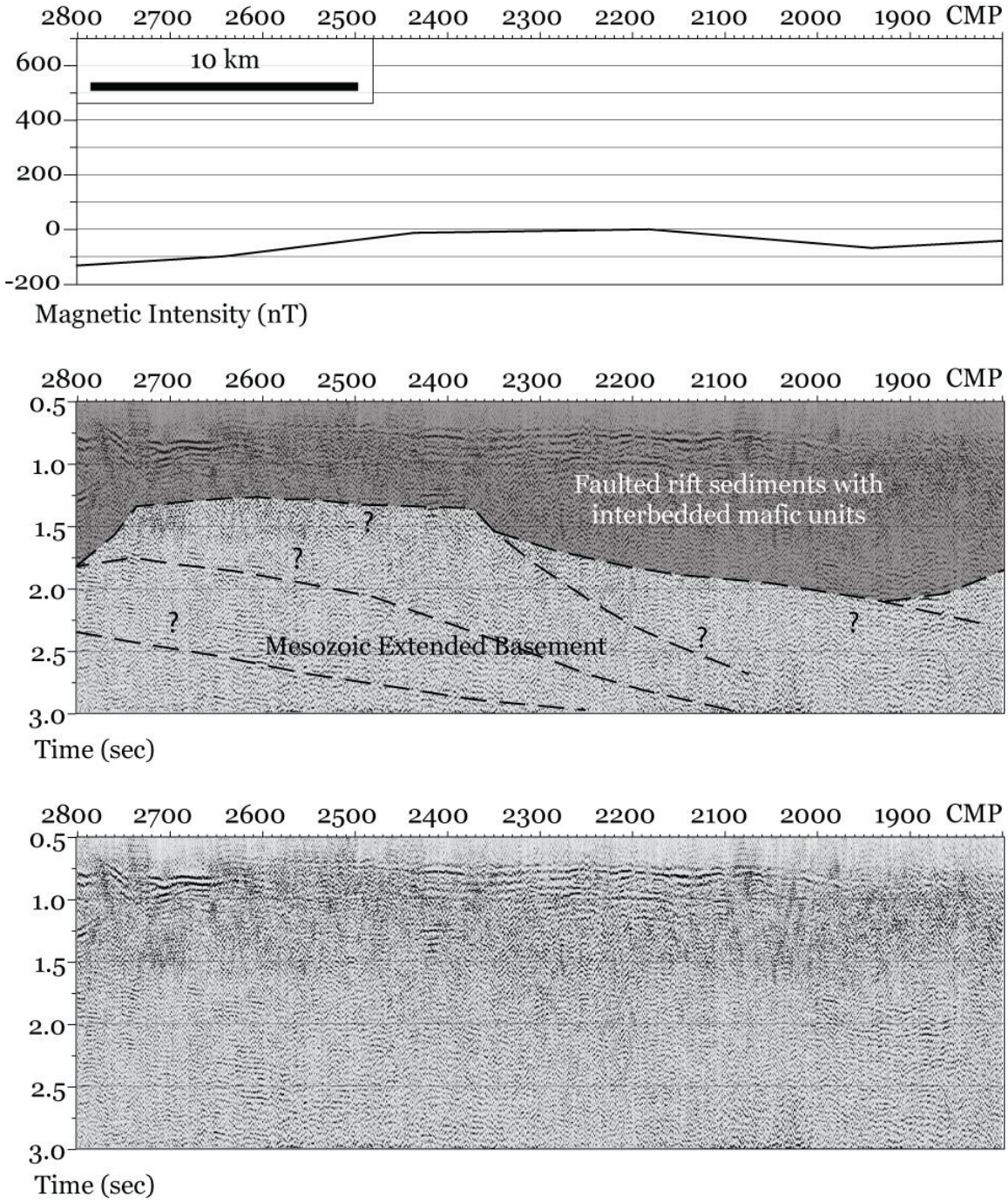

Figure 15. **Top:** Total intensity magnetic anomaly along the Seisdata4 profile (nanoteslas) between CMP 1800 and CMP 2800. **Middle:** stacked record section of the reprocessed Seisdata4 profile, with an interpretation of the configuration of the basement structure of the South Georgia Rift. **Lower:** un-interpreted record section. Refer to Figure 3 for CMP locations.

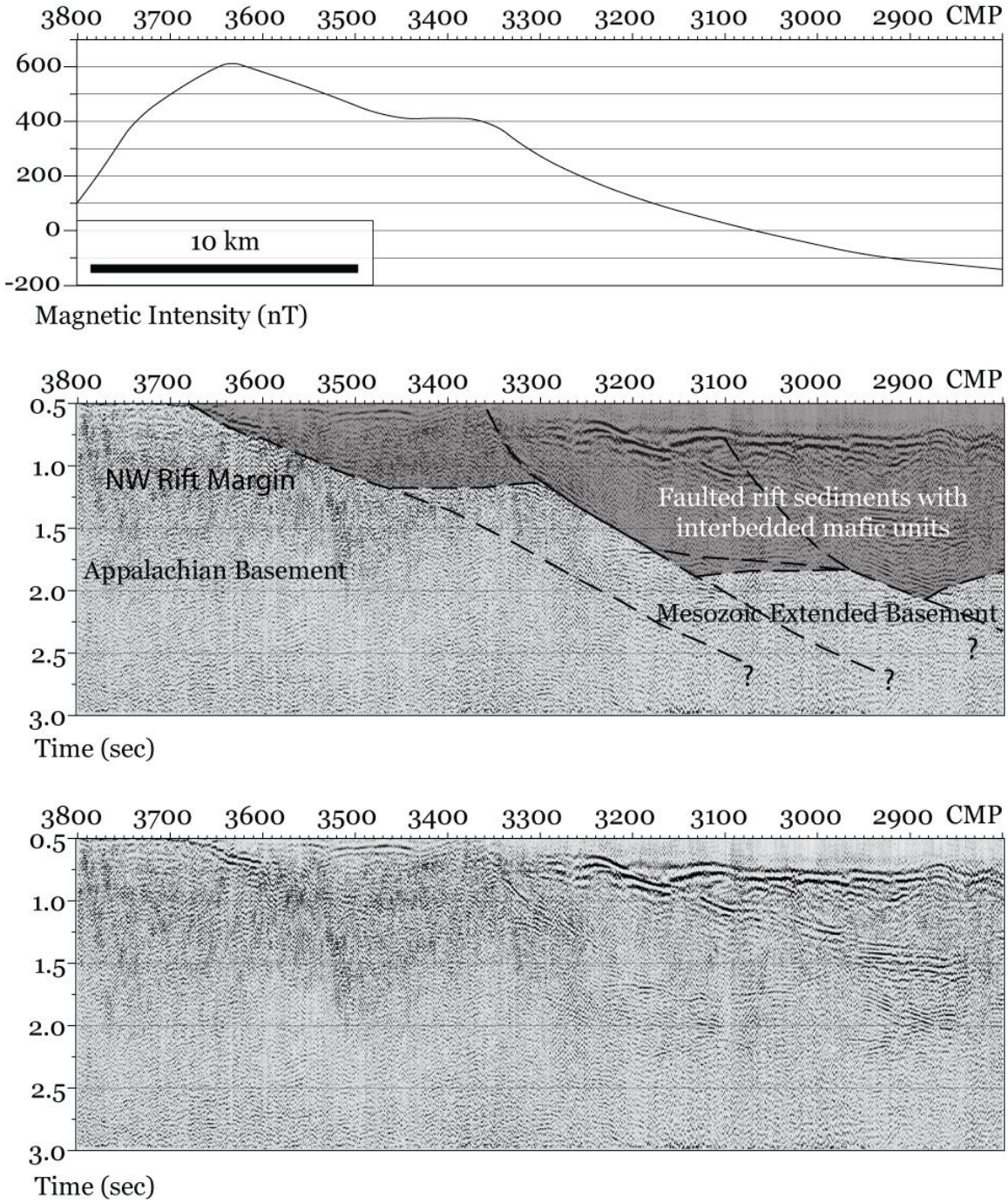

Figure 16. **Top:** Total intensity magnetic anomaly along the Seisdata4 profile (nanoteslas) between CMP 2800 and CMP 3800. **Middle:** stacked record section of the reprocessed Seisdata4 profile, with an interpretation of the configuration of the basement structure of the South Georgia Rift. **Lower:** un-interpreted record section. Refer to Figure 3 for CMP locations.

Conclusions

The seismotectonic setting of the 1886 Charleston earthquake is largely defined by modern compressional reactivation of early Mesozoic extensional faults in the South Georgia Rift.

The seismic reflection data collected in the study area are interpreted to indicate that the earthquake occurred in an extensive fault zone located between Summerville and Charleston. The western boundary of this fault zone is marked by a prominent gradient in the potential field. Cenozoic deformation is observed on every seismic reflection profile crossing the potential field gradient in the epicentral area. The zone of active faulting extends to the south and east of Summerville, and includes a synclinal structure lying between Summerville and the Atlantic coast. Cenozoic faults are imaged in the interior of this feature, immediately southeast of Summerville along the Ashley River, and 17 km to the south in the vicinity of Rantowles, SC. Modern seismicity is concentrated at the location of an imaged fault in the trough of the synclinal structure, beneath the Ashley River a few kilometers to the southeast of Summerville. In all likelihood, the 1886 rupture involved one or more of these seismically imaged faults.

The Cenozoic-Mesozoic faults and modern seismicity near Summerville are associated with a major potential field anomaly that extends across South Carolina at Latitude 37.7N within the South Georgia Rift. The seismic reflection data and modeling of the potential field show that, in the vicinity of Summerville, this potential field anomaly is due to a high percentage of mafic volcanic rocks in the upper 4-5 km of the crust. The early Mesozoic volcanism was associated with the crustal extension responsible for the development of the fault zone imaged near Summerville. On the basis of data from the seismic profiles, we propose that the entire zone marked by this potential field anomaly may be similar in structural character to the epicentral area of the 1886 earthquake near Summerville. In other words, the anomaly should be regarded as marking an east-west trending zone of major crustal-scale extensional faults that may be reactivated in the modern stress regime.

The Summerville area, and the potential field anomaly discussed above, is in the interior of the South Georgia Rift. The Seisdata4 reflection profile images the northwestern boundary of the rift near 33.31N 80.94W, between Branchville and Bamberg, South Carolina. The seismic data show that the rift boundary is a major extensional fault zone that is in many respects similar to that observed in the interior of the rift near Summerville. The similar character of reflections and the association of the rift boundary faulting with a positive potential field anomaly suggest a very similar seismotectonic setting.

The seismic hazard assessment issues concerning the locations of future earthquakes like the 1886 shock in the southeastern U.S. can best be addressed by seismic network monitoring, reflection profiling and paleoseismic investigations in Summerville and elsewhere along the potential field anomaly trending east-west across the state of South Carolina at the latitude of Summerville, and to the northwest, along the major fault zone forming the structural boundary between the Appalachian Piedmont province and the South Georgia Rift.

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