02/19/2003

An Impact Crater in Northeast South Carolina Inferred from Potential Field Data

Pradeep Talwani*, Eric Wildermuth, and Chris D. Parkinson

Department of Geological Sciences, University of South Carolina, 701 Sumter St., Columbia SC 29208.

* Corresponding author: talwani@geol.sc.edu

Abstract

A comparison of recently acquired gravity data with aeromagnetic data for northeastern South Carolina revealed the presence of coincident circular anomalies near Johnsonville. These ~11 km diameter circular lows meet the geophysical criteria for those associated with buried complex impact craters. Within the magnetic low is a northwest-southeast structure enclosed by two concentric "moat-like" lows to its northeast and southwest. The pattern of surface streams passing above the structure is also consistent with the interpretation of a buried impact crater. Fortuitously, a drill core was available from a borehole drilled within these lows. The core includes ~10 m of Paleozoic crystalline Piedmont basement. Petrographic analysis of basement samples from the core revealed indications of shock metamorphic textures, including ballen texture in quartz, and transformation of some feldspar grains to diaplectic glass, supporting the interpretation of the existence of a buried impact crater.

Keywords: Impact Crater, South Carolina, Potential Field, Shock Metamorphism

Introduction

Although over 50 meteorite impact craters have been identified in North America, from Alaska to Chicxulub, Mexico, until now none have been reported from the southeastern Atlantic states. Due to the possible contribution of meteorite impacts to Earth's history, and their rarity, the discovery of a new impact crater and its time of formation are of great interest to the broader scientific community. Because of their antiquity, any evidence of their existence is likely to be preserved in the subsurface, and can be inferred from geophysical and geomorphological data, but definitive confirmation can be provided only by petrographic examination of the affected rocks.

Comparison of recently acquired detailed gravity data (1 mGal contour interval) with aeromagnetic data for northeastern South Carolina revealed the existence of coincident ~11 km wide circular lows. Detailed analyses of these anomalies show that they meet the geophysical criteria for evidence of a buried impact crater (Pilkington and Grieve, 1992; Grieve and Pilkington, 1996). Fortuitously, a borehole (MRN-78) drilled for groundwater studies is located within the anomaly. This borehole is one of the few that have penetrated the basement underlying the wedge of sedimentary rocks in eastern South Carolina (Figure 1). It was cored ~350 m through the Coastal Plain sediments and ~10 m into the underlying metamorphic basement. Biostratigraphic examination revealed that the age of the sedimentary rocks below the surface increases from ~30 Ma to 90 Ma. Layer(s) of underlying ~200 Ma age (Hames et al., 2000) basalt flows encountered in neighboring wells were missing in MRN-78. Initial examination of the sedimentary section in the core revealed anomalous fossil assemblages when compared with nearby Coastal Plain boreholes (L. Edwards, Pers. Comm., 2002) The cores were also examined for petrographic evidence of shock metamorphism of the underlying basement rocks. Meteorite craters are known to influence surface features. Drainage networks may extend radially from the rim of the crater while removal of debris occurs within the crater (Grant and Schultz, 1993). Hence, we carried out a geomorphological examination of the drainage pattern in the vicinity of the potential field lows.

Synthesis of potential field, geomorphologic and petrographic data strongly suggest the presence of a buried impact crater at a depth of ~0.5 km below the Coastal Plain near Johnsonville in northeast South Carolina.

POTENTIAL FIELD DATA OF THE JOHNSONVILLE AREA

Detailed gravity data were acquired with a station spacing of 1 to 3 km. The aeromagnetic data were acquired with a flight spacing of 1.6 km (1 mi.) and at a flight elevation of 152.4 m (500ft.) above mean terrain (Popenoe and Zietz, 1977). The data were gridded with a cell size of 1km (Smith and Wessel , 1990).

In both regional (20 nT contour interval) aeromagnetic and the detailed (1 mGal contour interval) Bouguer gravity maps of northeast South Carolina we noticed a nearly circular anomaly low located to the east of Johnsonville. Typically many sources contribute to the observed potential field anomalies. In order to isolate the structures associated with the potential field lows we analyzed the data with the following filtering techniques. The magnetic anomaly data were reduced to the pole (RTP), a procedure that shifts the anomalies caused by induced magnetization to positions above their sources (Hildenbrand et al., 2001). The circular low to the east of Johnsonville can be seen in the regional RTP aeromagnetic anomaly map (Figure 1) and is well defined in the enlarged view (Figure 2). We have labeled it the Johnsonville low. The resulting RTP magnetic anomaly and Bouguer anomaly data were then analytically continued to a surface equivalent to the node spacing of the gridded data set (1 km) above the terrain. These upward continued data were subtracted from the RTP magnetic and Bouguer anomaly data to obtain the corresponding residual anomaly maps (Figures 3a and 3b). The anomalies in these maps are then primarily due to shallow crustal sources and also outline the Johnsonville low. The magnetic data were also analyzed by matched bandpass filtering, which is a frequency domain filtering method that calculates the contribution of selected depth intervals to the total magnetic field (Spector and Grant, 1970). These depth intervals are related to slope segments in the energy spectrum for any given data set. The matched filtered RTP magnetic data due to a depth slice of the top ~ 0.5 km is shown in Figure 4a. We note that the shallow matched filtered RTP magnetic map mimics the RTP residual magnetic anomaly map reinforcing our interpretation of a shallow source for the Johnsonville low. The Johnsonville low is absent on the matched filtered RTP magnetic map corresponding to a layer with a maximum depth of 2.4 km (Figure 4b). This indicates that the source of the circular low lies in the top ~500 m. Comparison of the residual magnetic and residual gravity and the matched filtered magnetic anomaly maps (Figures 3a, 3b, and 4a) reveals the following:

[1] The three maps have coincident 11-12 km wide circular lows centered at ~ 33.82° N and 79.36° W. The near perfect circular low in the magnetic maps (Figures 3a and 4a) is elongated along a NW-SE direction in the gravity anomaly map (Figure 3b).

[2] In both the magnetic maps (Figures 2 and 3a), the circular 100 nT low contains within it a ~3 km wide, ~7 km long 20 nT northwest trending feature which is surrounded by concentric "moat-like" lows to its northeast and southwest.

[3] In both the residual magnetic maps (Figures 3a and 4a) and regional magnetic map (Figure 1) we note that the circular low disrupts the regional NE-SW Appalachian trend of magnetic highs.
[4] The amplitude of the gravity anomaly, ~3 mGal for a circular feature ~11 km wide is conformable with those of terrestrial impact structures (Figure 13; Grieve and Pilkington, 1996).
[5] When compared with the magnetic anomaly maps (Figures 3a and 4a), there is an absence of a corroborative moat structure of lower values within the circular gravity low which is elongate NW-SE along the course of the Great Pee Dee river (Figures 3b and 6).

We also examined other circular magnetic anomalies in the SCCP. We found that they did not display coincident gravity anomalies. Most of the other circular anomalies in the SCCP consist of magnetic high signatures. The Johnsonville low was the *only* example of a feature with coincident, circular gravity and magnetic lows in the SCCP, i.e. the Johnsonville low is unique.

DISCUSSION OF THE POTENTIAL FIELD DATA

The coincident circular gravity and magnetic anomaly lows that disrupt the regional magnetic anomaly pattern and their shallow source and amplitude of the gravity anomaly satisfy the potential field criteria for a buried complex (diameter > 4 km) terrestrial impact crater (e.g., Pilkington and Grieve, 1992; Grieve and Therriault, 2000). We infer the diameter of the crater to be ~11 km based on the change of the gradient surrounding the circular lows. Two dimensional modeling (see below) and matched filtered data indicate that the circular lows are not associated with a deep buried geological body (such as a pluton) but are due to a shallow buried structure in the top one kilometer. We interpret the ~3 km wide NW-SE trending axial high (in the magnetic maps) to be associated with the rebound of the cavity floor and collapse of the transient rim forming the 'moats'. The small depth to diameter ratio of the lows, the amplitude of the gravity anomaly for the inferred width of the crater and the moat structure within the magnetic low, which is interpreted to be associated with rim collapse are other observations that fulfill criteria for potential field anomalies of buried impact craters. Hereafter, based on the potential field data, we refer to the inferred structure associated with the Johnsonville low as the Johnsonville Impact Crater (JIC).

TWO-DIMENSIONAL STRUCTURAL MODEL

Figure 5 shows a two-dimensional structural model obtained to match the residual gravity and reduced to the pole (RTP) magnetic data along a 25 km, NE-SW line passing through the site of a borehole, MRN-78 (Figure 2). In developing the structural model whose calculated gravity and magnetic signature match the observed gravity and magnetic data, we used the following constraints. The matched filtered data suggest that the causative structure lies within the top 1 km. The borehole MRN-78 (33.86°N, 79.33°W) penetrated ~350 m of sediments and bottomed in the Piedmont basement rocks consisting of gneisses and schists. Three neighboring deep wells in the area that penetrated the Coastal Plain bottomed out in 200 Ma basalts and red beds (baked sediments associated with the basalt flows which overlie the basement rocks, Figure 1). The Mesozoic basalts are observed both directly (well data) and indirectly (RTP aeromagnetic data) in the SCCP. The locations and elevations of the flows at these wells are as follows: DOR-211, 33.16°N, 80.52°W, -574 m; FLO-274, 33.86°N, 79.77°W, -305 m; BRK-644, 33.40°N, 79.93°W, -520 m (The deepest borehole in the South Carolina Coastal Plain at Lodge, S.C., total depth 3.8 km, 33.01° N, 80.93°W penetrated several basalt flows varying in thickness from less than one meter to over 100 m). The basalt flows are also present in the observed RTP aeromagnetic data (Figure 1). So in our structural model we include a thin layer of basalt (ρ = 2.8 g/cc, k = 0.005) overlying the metamorphic basement rocks (ρ = 2.7 g/cc, k = 0.0014) outside the crater. Examination of the core from well MRN-78 indicates that the top ~350 m of sediment lying above the basalt flows is comprised of sands and shales (ρ = 2.4 g/cc, k = 0.0). We have modeled this Coastal Plain sedimentary wedge as such. Below the basalt layer lies metamorphic basement material with little to no magnetization. The last element of our model is comprised of fractured reduced density material (ρ = 2.6 g/cc, k = 0.0) infilling the interpreted crater. The density contrast between the fractured crater fill and metamorphic basement is ~0.1 gm/cc. The density contrast between the interpreted basalt flows and the crater fill is ~0.2 gm/cc. These density relationships provide the anomalous low gravity signature for the Johnsonville anomaly, whereas, the magnetic low signature of the Johnsonville low is attributable to the absence of basalt over the interpreted crater location. Based upon the lack of impact textures in the top ~400 m of sediments, we infer that the meteorite impact destroyed the thin layer of basalt that may have been present and penetrated the underlying basement material prior to the deposition of the Coastal Plain sediments.

GEOMORPHOLOGICAL OBSERVATIONS

The spatial configurations of rivers and streams in the vicinity of the inferred JIC show interesting patterns. The NW-SE elongation of the residual gravity anomaly low lies along the path of the Great Pee Dee River (Figure 6). We suggest that the cause of the larger lateral dimensions of the gravity anomaly is due to continued erosion by the Great Pee Dee River. Although the general drainage direction in the region is NW-SE, several streams flow into the JIC from other directions, including a stream that flows northward opposite of the regional drainage pattern. Also, the Lynches River changes its southeasterly course ~20 km from the crater and flows easterly into it. A similar abrupt diversion of the York and James Rivers was noted by Poag (1999) as they flowed into the Chesapeake Bay Impact Crater. The Great Pee Dee and the E-W flowing Lynches Rivers have narrow channels as they enter and exit the JIC. However, they appear to anastomose and pond within the crater itself. The bow-shaped anastamosing pattern is located in the northeast moat structure - the depression between the central magnetic high and the rim of the putative crater, suggesting a causal association. Ponding occurred in the moat structure leading to the development of the observed swampy material at that location. The Little Pee Dee River flows along a curved path parallel and to the northeast of the rim of the crater suggesting a causal relationship. There appears to be an intriguing spatial association of the river geomorphology with the inferred location of the crater. The outline of the inferred crater (at depth) is coincident with a circular depression at the surface. The observed pattern of stream flow is along radial directions into the circular depression which encloses within it a small raised NW-SE structure. Rivers flow in and out of the circular depression from different directions along straight paths and pond and anastamose within it, although we can not prove a causal association. These surface features, 350 m above the inferred location of impact, suggest that the drainage pattern that formed at the time of the impact was preserved through time as sediments were deposited. Talwani and Weems (2001) noted a similar correspondence between subsurface structures (inferred from potential field data) and shallow structures (< 100 m) inferred from biostratigraphic data. We interpret the geomorphological data as providing additional, albeit circumstantial, evidence for the JIC.

Thus, the available gravity, magnetic and geomorphologic data all strongly supports the inference of a buried impact crater near Johnsonville, South Carolina. However, definitive identification of an impact origin must be based on petrographic evidence.

PETROGRAPHIC DATA

We next sought petrographic evidence for the impact crater in the core recovered from borehole MRN-78. The core comprises 10 m of post-Miocene surficial sediments, 338 m of Late Cretaceous shallow marine clastic sediments, 8 m of saprolite (highly weathered basement rocks), and 9 m of the Piedmont crystalline basement. Core of the Miocene and Cretaceous sedimentary rocks is 3.5 cm diameter; whereas the basement is 10 cm diameter core. The Piedmont basement rocks are predominantly schists and gneisses with a strongly developed subhorizontal foliation. The foliation is cross-cut by 1-10 cm wide zones of lithic microbreccia. Preliminary petrographic examination was performed on 9 rock sections selected from the topmost 0.7 m of the basement core, in order to determine if the rocks exhibited shock metamorphism as a result of the impact event. Unfortunately, the location of the borehole was near the inferred rim and at least 5 km from the center of the crater. At this distance the velocity of the shock waves associated with the impact attenuate to near seismic velocities, thus impeding the development of commonly observed shock textures associated with shock metamorphism. The most widely and completely documented indicator of shock metamorphism is the occurrence of planar microstructures in tectosilicates, particularly quartz (e.g., Stoffler, and Langenhorst, 1994). These are subdivided into planar fractures (PFs) and planar deformation features (PDFs). Unambiguous planar microstructures in quartz - PFs and PDFs have not, so far been detected in the core samples. The apparent lack of these diagnostic features may be because of attenuation of shock waves when they reached the well location from the center of the crater. Also, the shock propagation in rocks is highly irregular and that shock pressures may vary by a factor of two or more over distances of millimeters in rock that was supposedly uniformly shocked (e.g., Grady, 1977). However, petrographic examination revealed some subtle, and strongly suggestive indications of shock metamorphism (Figure 7). They comprise: [1] highly kinked and warped biotite grains in the gneiss, many of which have lost their pleochroism: [2] recrystallization of feldspar xenocrysts in mineral glass within microbreccia (Figure 7a), [3] pseudomorphic transformation of some plagioclase grains (up to 1 mm across) to isotropic diaplectic glass and the development of 'chessboard' patterns (Figure 7b) and [4] development of ballen texture quartz with reduced birefringence, typical of impactites (cf. Carstens, 1976; Bischoff and Stoffler, 1984; Grieve et al., 1996) (Figure 7c). Even on the scale of a thin-section these textures are sporadic.

In summary, these features provide generally supportive petrographic indications of shock metamorphism related to elevated post-shock temperatures and very rapid cooling.

AGE OF THE IMPACT CRATER

Based on biostratigraphic mapping of the Coastal Plain, the sediments immediately below the ~10 m post-Miocene cap are Maastrichtian (~ 69 Ma) in age (Self-Trail,2002) and those overlying the basement (and saprolite) are ~90 Ma in age (Christopher et al., 1999). Three deep wells in the area neighboring MRN-78 bottomed out in 200 Ma basalts and red beds. The unconformity marked by the Cretaceous sediments overlying the basalt flows represents a long period of regional erosion in the SCCP. We infer that the meteorite impact destroyed the thin layer of basalt that may have been present and subsequent erosion removed the shattered pieces of basalt. We consider that common impact textures usually preserved in the stratigraphic record were lost during the period of erosion. These observations allow us to constrain the age of the JIC between 200 and 88 Ma. We anticipate that further geochronological studies using samples of the basement rocks will allow us to better constrain the age of the impact.

CONCLUSIONS

Analysis of circular gravity and magnetic anomalies strongly suggest the presence of a buried impact crater, ~11 km wide, to the east of Johnsonville, South Carolina. The river geomorphology data are spatially consistent with the inferrence of a buried crater and provide intriguing, albeit circumstantial evidence for a causal association. Initial petrographic analysis of crystalline core samples obtained from within the crater show some evidence of shock metamorphism, weakly supporting the interpretation of a buried impact crater. Indirect geologic constraints suggest that the crater was formed in the interval 200-90 Ma. Further geophysical and petrographic studies are expected to refine these conclusions.

ACKNOWLEDGMENTS

We are grateful to Joe Gellici of the South Carolina Department of Natural Resources and Bill Clendenin, State Geologist, of the South Carolina Geological Survey for providing access to core samples from the Brittons Neck borehole. We thank Tom Hildenbrand for discussions regarding the potential field data. We also thank Peter Schulz for his suggestions concerning the manuscript. We also thank an anonymous reviewer and Ray Christopher for clarifying the biostratigraphic data.We benefited greatly fromdiscussions with Gene Yogodzinski and Jim Knapp of the University of South Carolina, Wylie Poag and Dave Prowell of the U.S.G.S. All potential field maps were generated using the Generic Mapping Tool - GMT (Smith and Wessel, 1990). An earlier version of this manuscript benefited greatly from reviews by two anonymous reviewers.

REFERENCES

Bischoff, A. and Stoffler, D., 1984. Chemical and structural changes induced by thermal annealing of shocked feldspar inclusions in impact melt rocks from Lappajdrvi crater, Finland: Journal of Geophysical Research Supplement, v. 89, p. B645B656.

Carstens, H., 1975. Thermal History of impact melt rocks in the Fennoscandian shield:Contributions to Mineralogy and Petrology, v. 50, p. 145-155.

Christopher, R.A., J.M. Self-Trail, D.C. Prowell and G.S.Gohn, The stratigraphic importance of the late Cretaceous pollen genus *Sohipollis* gen.nov. in the coastal plain province, *South Carolina Geology,41*, 27-44,1999.

Grady, D., 1977. High strain rate studies in rock: Geophysical Research Letters, v. 4 , p. 263-266.

Grant, J. A. and Schultz, P. H., 1993. Degradation of selected terrestrial and martian impact craters: Journal of Geophysical Research, v. 98, p. 11025-11042.

Grieve, R. A. F. and Pilkington, M., 1996. The signature of terrestrial impacts: J. Australian Geology and Geophysics, v. 16, p. 399-420.

Grieve, R. A. F. and Therriault, A., 2000. Vredefort, Sudbury, Chicxulub: Three of a kind?: Annual Reviews in Earth and Planetary Sciences, v. 28, p. 305-38.

Grieve, R. A. F., Langenhorst, F., and Stoffler, D., 1996. Shock metamorphism of quartz in nature and experiment: 11. Significance in geoscience: Meteoritics, 31, 6-35.

Hames, W.E., P.R. Renne and C.Ruppel,New evidence for geologically instantaneous emplacement of earliest Jurassic Central Atlantic magmatic province basalts on the North American margin,*Geology,28*, 859-862, 2000.

Hildenbrand, T. G., Stuart, W. D., and Talwani, P., 2001. Geologic structures related to New Madrid earthquakes near Memphis, Tennessee, based on gravity and magnetic interpretations: Engineering Geology, v. 62, p. 105-121.

Pilkington, M. and Grieve, R. A. F., 1992. The geophysical signature of terrestrial impact craters: Rev. Geophysics, v. 30, p. 161-181.

Poag, C. W., 1999. Chesapeake Invader: Discovering America's Giant Meteorite Crater. Princeton Univ. Press. Princeton, N. J., I 10- 111.

Popenoe,P.,and I. Zeitz The nature of the geophysical basement beneath the Coastal Plain of South Carolina and northeastern Georgia, in *Studies related to the Charleston, South Carolina earthquake of 1886-Apreliminary Report,* edited by D.W.Rankin, *Geological Survey Prof. Paper 1028, 119-137, 1977.*

Self-Trail,J.M., Trends in late Maastrichtian calcareous nannofossil distribution patterns, Westen North Atlantic margin, *Micropaleontology, 48*, 31-52,2002.

Smith, W. H. F. and Wessel, P., 1990. Gridding with continuous curvature splines in tension: Geophysics, v. 55, p.293-305.

Spector, A. and Grant, F. S., 1970. Statistical models for interpretating aeromagnetic data: Geophysics, v. 35, 293-202.

Stoffler, D. and Langenhorst, F., 1994. Shock Metamorphism of quartz in nature and experiment: 1. Basic observation and theory: Meteoritics, v. 29, p. 155-18 1.

Talwani, P. and Weems, R., 2001. Neotectonic activity in the Charleston, South Carolina, region, GSA Abstracts with Programs, v. 33, no. 6, p. A-346.

FIGURE CAPTIONS

Figure 1. Observed reduced to the pole (RTP) aeromagnetic anomaly map for a portion of the South Carolina Coastal Plain (SCCP). The region of higher magnetic values in the center of the figure is interpreted as Mesozoic basalt flows associated with rifting as also evidenced by tholeiitic basalt encountered in multiple deep boreholes (black triangles). Johnsonville, SC, well MRN-78, and the inferred crater lie within the Johnsonville study area (black rectangle). Johnsonville is labeled with a gray triangle. All data were gridded with an increment of 1 km.

Figures 2. Observed RTP aeromagnetic anomaly map of the Johnsonville study area. White and red triangles denote the city of Johnsonville, SC and well MRN-78, respectively. Dashed lines represent the interpreted crater perimeter and central uplifted zone caused by post-impact basement rebound. A and A' are end points of a profile which potential field data were extracted to generate a structural model (Figure 5).

Figures 3a,b. The circular low to the east of Johnsonville, SC (white triangle) in both the residual RTP magnetic anomaly (a) and residual gravity anomaly (b) maps. The NW-SE axial magnetic high within the circular low is interpreted to be associated with central uplift from post-impact basement rebound. Well MRN-78 lies within the perimeter of the anomaly and is labeled with a red triangle. A and A' are end points of a gravity and magnetic structural model that passes through the center of the anomaly and well MRN-78, and is shown in Figure 5.

Figures 4a, b. Matched bandpass filtered anomaly maps from residual RTP aeromagnetic data corresponding to a depth slice of ~500 m (a) and ~2.4 km (b). The outline of the Johnsonville low from Figures 2 and 3a is replotted on the two figures. It outlines a coincident low for the shallow depth slice but not the deeper slice, indicating a shallow source (~500 m).

Figure 5. Structural model generated from residual gravity and RTP aeromagnetic data along NE-SW profile AA' through the center of the Johnsonville anomaly and constrained by well MRN-78. Coastal Plain sediments (blue dashed pattern, ρ = 2.3 g/cc, k = 0.00), intercalated basalt flows and red beds (crosses, ρ = 2.8 g/cc, k = 0.005), reduced density and susceptibility crater material (gray, ρ = 2.6 g/cc, k = 0.0003), and metamorphic basement (red, ρ = 2.7 g/cc, k = 0.0014). This model represents a depression within the basement material at a depth to ~900 m. Basalt flows above the depression are absent due to the inferred meteorite impact event.

Figure 6. Location map of the Johnsonville potential field anomaly in the Coastal Plain of South Carolina (dashed circle). The inner ellipse is interpreted as a central uplifted region due to post-impact basement rebound. Deep well MRN-78 lies within the interpreted perimeter of the crater at the northeastern boundary. Note the radial pattern of streams flowing into the crater.

Figure 7. Petrographic indications of shock metamorphism in the MRN-78 core samples. [a] Partial pseudomorphic transformation of plagioclase grain in lithic microbreccia by isotropic (black areas) diaplectic glass (sample # 18; cross-polarized light). [b] Zoned K-feldspar xenocryst within brownish devitrified glass (sample # 21; plane-polarized light). [c] 'Ballen' texture quartz (Qz) with spheroidal grains of brown, non-pleochroic biotite (Bi) (sample # 3A; plane-polarized light).

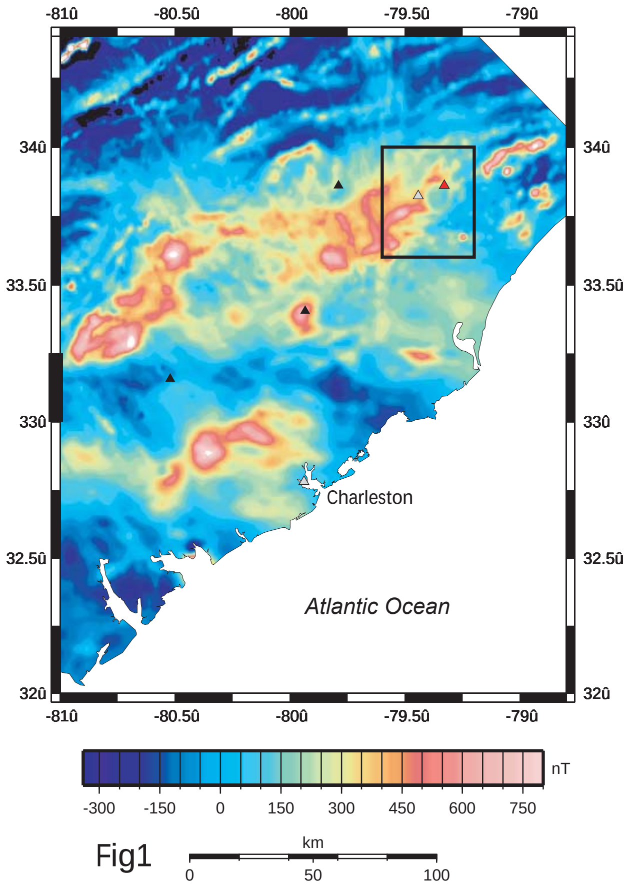

Fig1

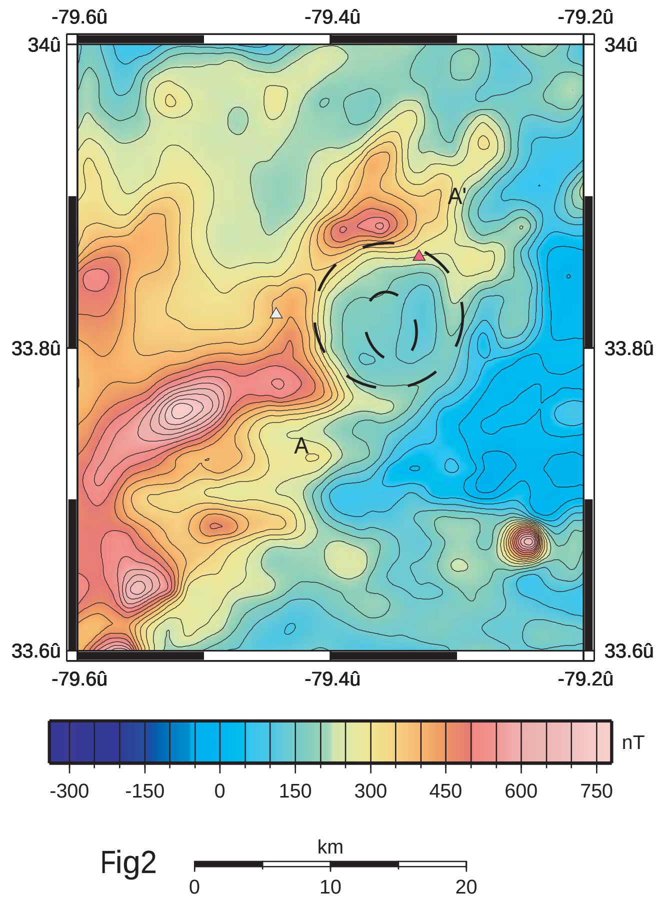

Fig2

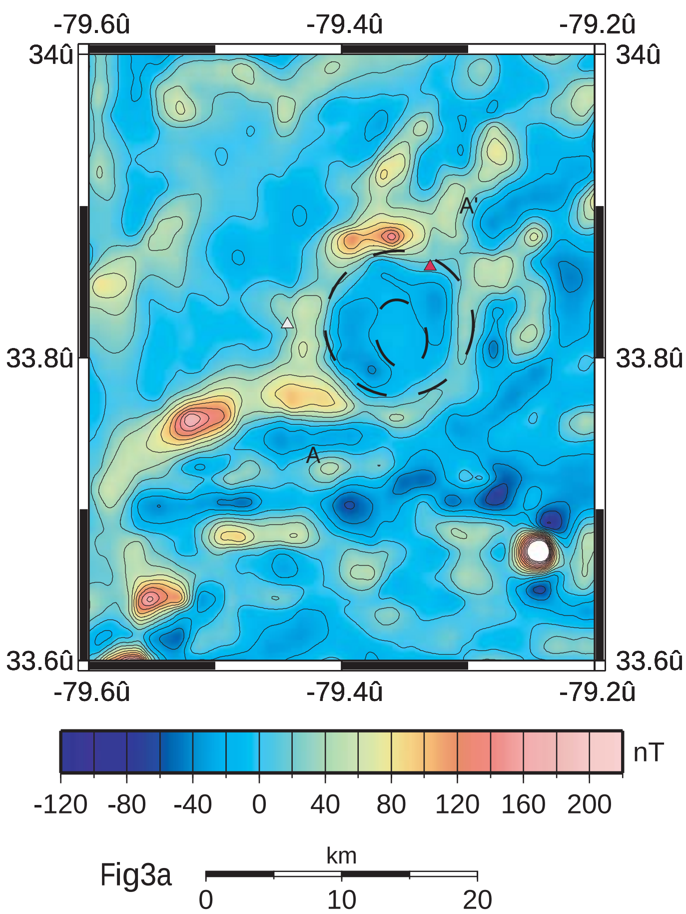

Fig3a

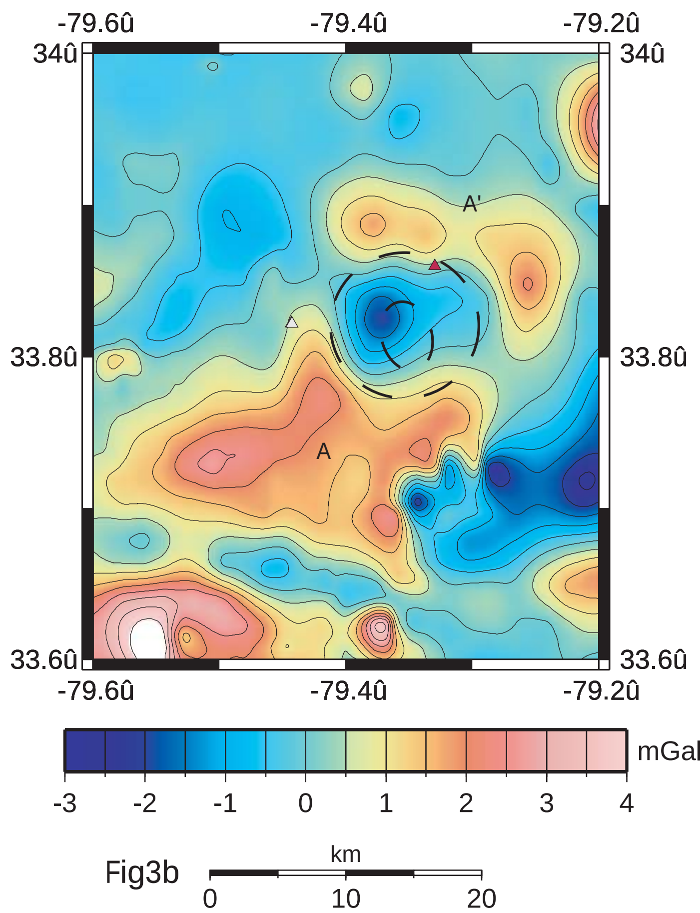

Fig3b

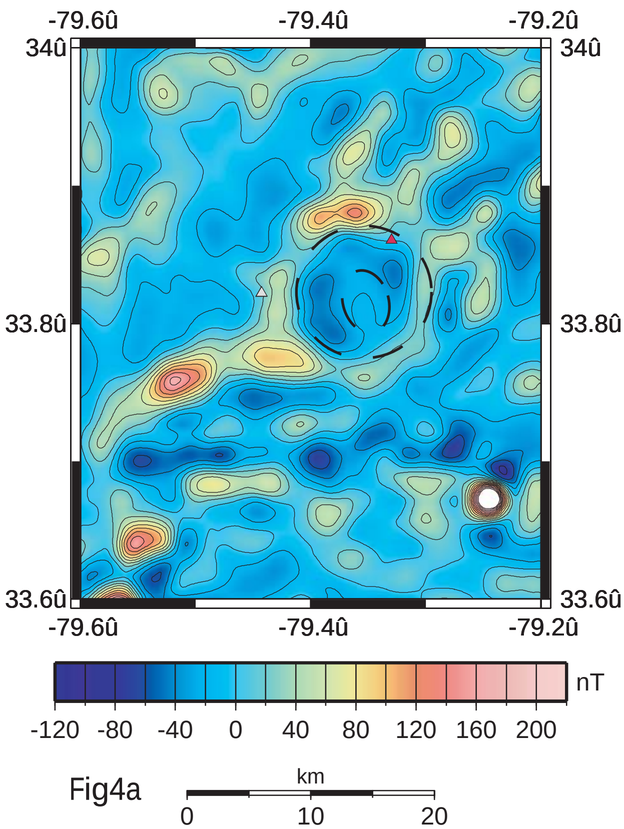

Fig4a

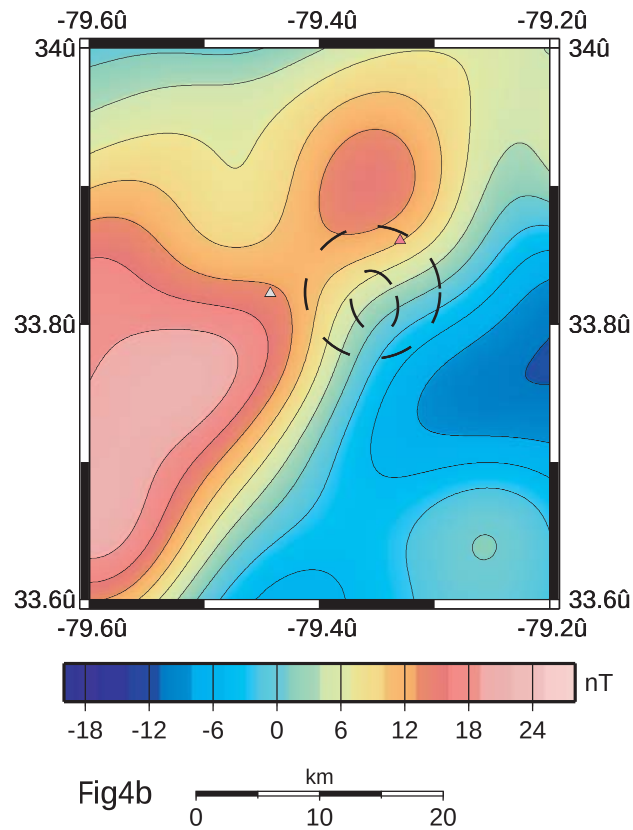

Fig4b

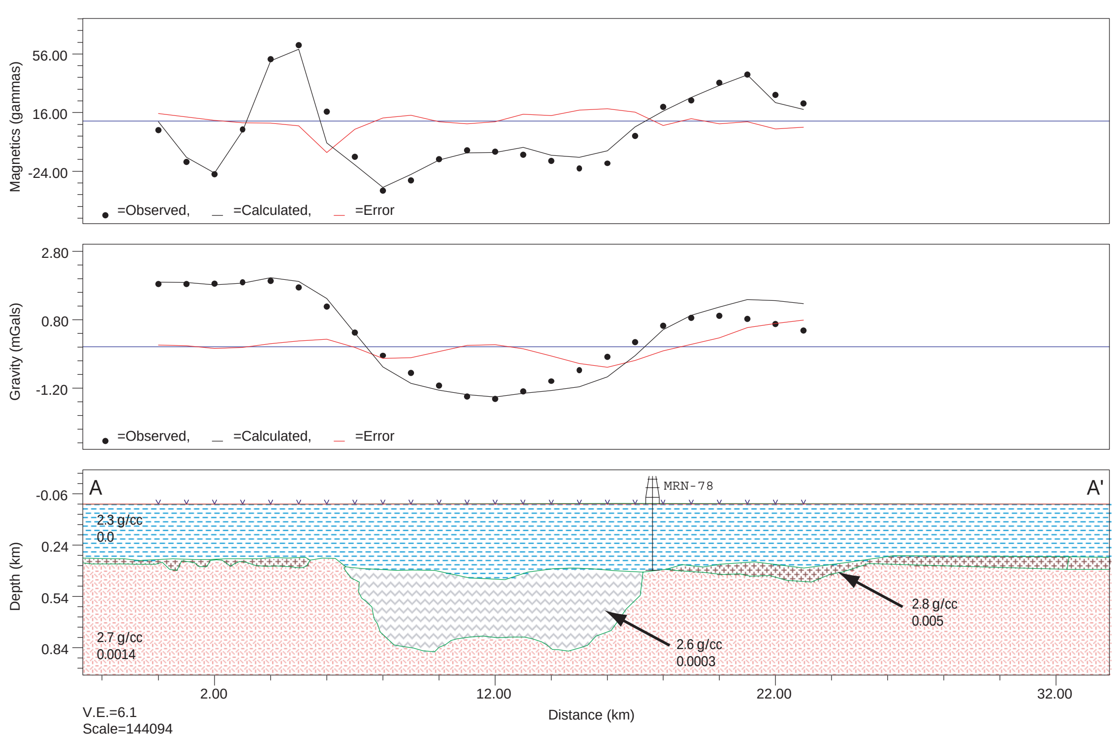

Fig5

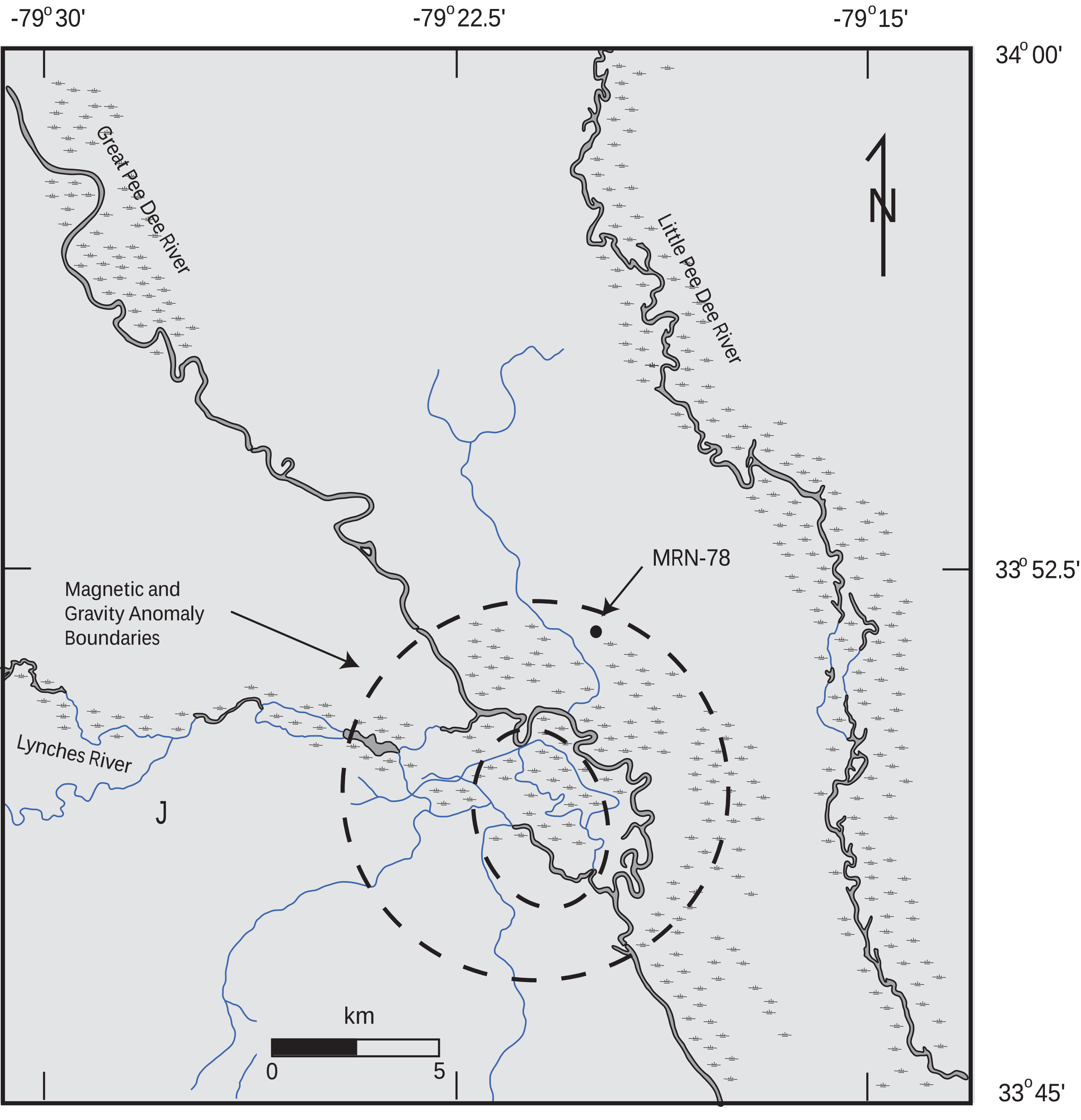
-79° 30'
-79° 22.5'
-79° 15'
34° 00'
33° 52.5'
33° 45'
N
Great Pee Dee River
Little Pee Dee River
Lynches River
J
MRN-78
Magnetic and
Gravity Anomaly
Boundaries
km
0
5

Fig6

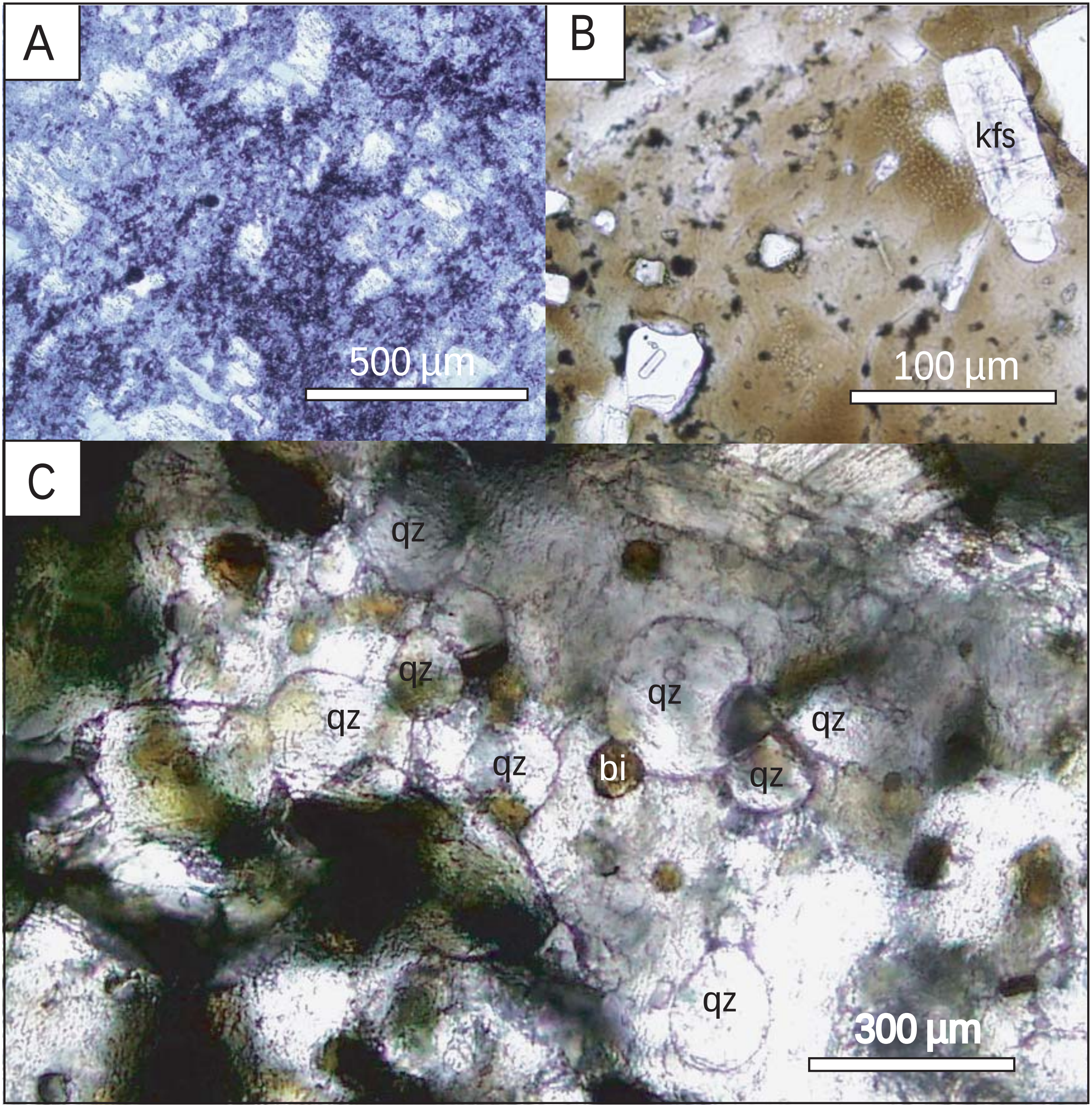

Fig7