2018

Re-Evaluation Of The Extent And Tectonic History Of The Helena Banks Fault Zone, Offshore South Carolina

Ahmet Postaagasi
University of South Carolina

RE-EVALUATION OF THE EXTENT AND TECTONIC HISTORY OF THE HELENA BANKS FAULT ZONE, OFFSHORE SOUTH CAROLINA

by

Ahmet Postaagasi

Bachelor of Geological Engineering
Ankara University, 2011

Submitted in Partial Fulfillment of the Requirements

For the Degree of Master of Science in

Geological Sciences

College of Arts and Sciences

University of South Carolina

2018

Accepted by:

James H. Knapp, Director of Thesis

Camelia C. Knapp, Reader

Andrew Leier, Reader

Cheryl L. Addy, Vice Provost and Dean of the Graduate School

ACKNOWLEDGEMENTS

I would first like to thank my thesis advisor Dr. James H. Knapp who gave me a great opportunity to do master with him. During my study, he always steered me in the right direction whenever he thought I needed it. Working with his guide and taking advantage of his experience were crucial for me. I gained great experience thanks to my advisor, Dr. James H. Knapp. Special thanks go to my committee members, Dr. Camelia C. Knapp and Dr. Andrew Leier whose lectures and advices moved me forward, and improve my thesis work. I also would like to thank my lab mates (Susie, Mac, Ross, Erin, Dawood, Ceren, David) to support throughout my time at the USC whenever I need. I would like to appreciate to my lovely wife, Ceren Postaagasi who always support me during my master's. A special thanks to Turkish Petroleum to give me both moral and material support.

ABSTRACT

The Helena Banks Fault Zone (HBFZ), first identified in the early 1980's offshore Charleston, S.C., was originally interpreted to be a major, high-angle, basin-bounding normal fault associated with Mesozoic rifting. Subsequent work suggests that (1) Mesozoic rift basins are not present on the continental shelf of South Carolina, (2) the HBFZ originated as a strike-slip fault within Paleozoic sedimentary rocks of the Suwannee Basin sequence, (3) a mafic intrusion inferred from aeromagnetic data is coincident with a broadly circular zone of highly-complex faulting along the north-eastward continuation of the HBFZ where (4) up to 300 m of local relief can be documented on the post-rift unconformity. These relations may indicate that the HBFZ served as a locus for magmatic intrusion in the upper crust, effectively stitching the fault where it appears to be inactive since Cretaceous time, in contrast to areas along strike to the southwest which may be currently seismically active. Analysis of 2D multichannel seismic reflection data, collected offshore from Charleston, is crucial to identify the continuation of the Helena Banks Fault Zone (HBFZ) in order to fully document both the lateral and vertical extent of the HBFZ, as well as re-evaluate the evidence for origin and evolution of the fault zone. According to Behrendt & Yuan (1987), the northeast-striking Helena Bank fault is approximately 110 km long strike-slip fault and trends between N68E and N77E, with a mostly N72E. Previous studies indicate that the HBFZ located 10m below the sea floor and also the most recent movement is during post-Miocene or

Pliocene time (Behrendt et al., 1981). The purpose of this research to find continuation of the Helena Banks Fault in the North-East direction and to analysis its' structure basing on interpretation of 102 seismic lines.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

HBFZ .... Helena Banks Fault Zone

HBFZ_1988 .... Helena Banks Fault Zone Mapped in 1988

HBFZ_2018 .... Helena Banks Fault Zone Mapped in 2018

J Horizon.. Top of the Paleozoic age

NA.. North America

PRU .... Post Rift Unconformity

CHAPTER 1

INTRODUCTION

Despite the fact that Behrendt et al. (1981) first identified the Helena Banks Fault on the seismic data as high angle reverse fault, 30km long and 12km offshore of Charleston and also the recent activities are Pliocene time acquired 10m below the sea floor, seismicity is unknown. Furthermore, the HBFZ is approximately 110km in length as a more complex strike slip fault zone, with comprising several echelon segment 10-40km long by Behrendt et al. (1983) and Behrendt & Yuan (1987). They proposed that the fault zone is basin boundary fault zone with a compressional reactivation of the Triassic(?) time into the Miocene or Pliocene.

Two earthquakes have occurred recently along the HBFZ. The recent offshore seismicity is 4.0 ML earthquake 2km depth in November 11, 2002 – 26km offshore from Kiawah Island, SC and 3.5 ML earthquake 3km depth November 8 in 2002 – 24km offshore from Kiawah Island, SC (Figure 1.1). The HBFZ would cause large damage earthquake in the future. It is important to note that possible earthquake, occurred by the activation of The Helena Fault, would cause Tsunami which will be dangerous along coastal cities of SC. The National Weather Services did a hypothetical scenario of an earthquake in 2011 and resulted possibly tsunami the Atlantic coast of Charleston, SC along the Helena Bank Fault. According to Hough et al. (2013), a tsunami is likely to be triggered by the wave, generated by the primary earthquake.

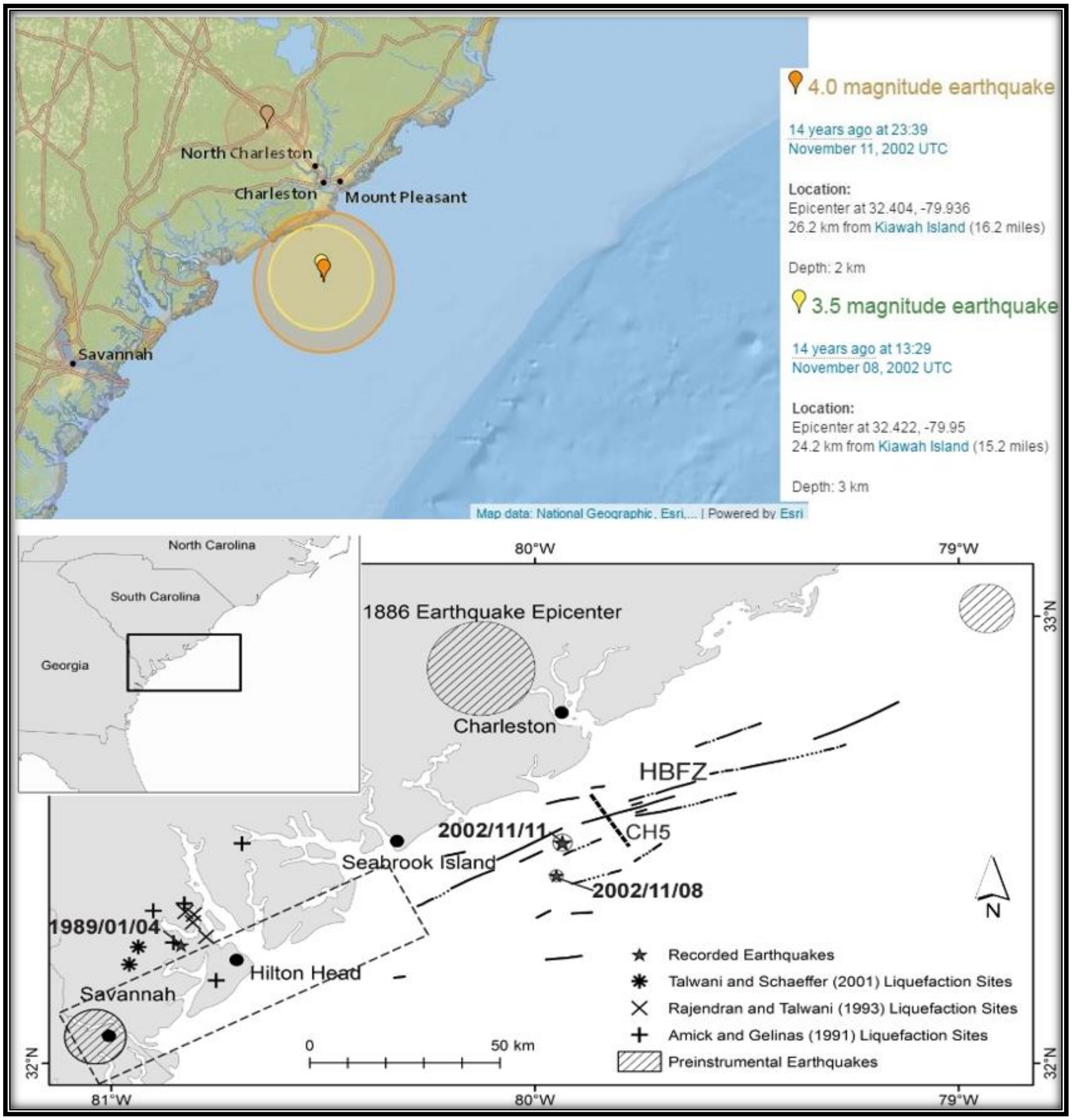

Figure 1.1 Location map of the earthquakes with the HBFZ [The two offshore stars in the bottom Figure (Derrick & Knapp, 2016; Behrendt et al., 1983) represent two earthquakes which are explained in the top Figure as 3.5 magnitude and 4.0 magnitude earthquakes around Kiawah Island along the HBFZ in November 2002].

CHAPTER 2

GEOLOGIC SETTING

The passive margin of central Eastern North America is formed in two stages (rifting and drifting) (Figure 2.1) like most passive margins (Withjack et al., 1998). According to most scientists (e.g., Manspeizer & Cousminer, 1988; Olsen et al., 1989), the transition from rifting to drifting was diachronous; rifting appeared during the Middle to Late Triassic and continued into the Early Jurassic (Withjack et al., 1998). During the Late Early to Early Middle Jurassic and until today, the separation of North America and Africa and then the creation of sea floor spreading in the Atlantic Ocean is directly connected to drifting (Klitgord & Schouten, 1986; Klitgord et al., 1988; Welsink et al., 1989).

They believed that the transition happened during a short time span between the Late Early Jurassic and Early Middle Jurassic whereas Klitgord et al. (1988) indicated that transition was not a perfectly synchronous event from the Carolina Trough to the Scotian Basin (Withjack et al., 1998). Withjack et al. (1998) propose that drifting started earlier in the south (~200 Ma) than in the north (~185 Ma). Furthermore, during the transition stage, the tectonic regime changed; normal faulting ended, reverse faults formed, thus rift-basin boundary faults had reverse displacements (Withjack et al., 1998).

The South Carolina Coastal Plain and Continental shelf are structured by Cretaceous through Holocene sediment, covering Precambrian and Paleozoic rocks and Triassic-Jurassic red beds and basalts, and six major depositional sequences (Figure 2.2), provided by Atlantic Margin Coring Program (AMCOR 6004 and 6005) appearing on the inner continental shelf of South Carolina (Idris & Henry, 1995). These Six major sequences are shown as a representative stratigraphic column for South Carolina (Figure 2.2).

Although no well control existed in the study area, the closest wells, taken from Boote & Knapp (2016), were analyzed. These wells are located approximately 220 km far away the study area. We can get deeper information from these wells (Figure 2.3). Red lines show PRU (Post rift unconformity). According to these wells Paleozoic age is seen under the PRU which is after approximately 1000 ft.

J horizons, upper cretaceous horizons and lower cretaceous horizons are picked from the location of the wells until the study area by using COST GE-1 well data information. Furthermore, these surfaces, taken from Almayahi & Knapp (2018), are created from these three horizons in two-way travel time in Figure 2.4. In the study area, Lower Cretaceous surface and Upper Cretaceous surface are seen little deformation on them. These surfaces are shown in Figure 2.5 in details. However, great deformation is seen on the J horizon by contrast with the other surfaces. (Figure 2.4).

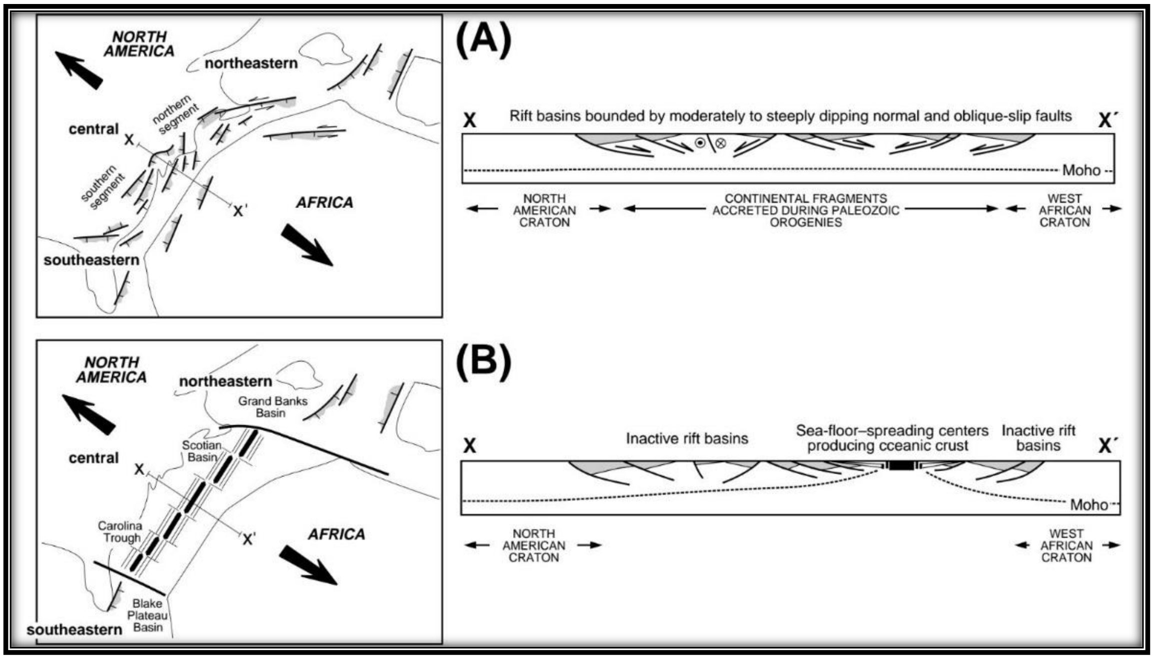

Figure 2.1 Two-stages model for evolution of passive continental margin of central eastern North America: (A) rifting during the Middle Triassic to Early Jurassic, and (B) drifting beginning during the Early to Middle Jurassic and continuing today. Drifting occurred later in southeastern (Blake Plateau Basin) and northeastern North America (Grand Banks Basin) (Taken from Withjack et al., 1998).

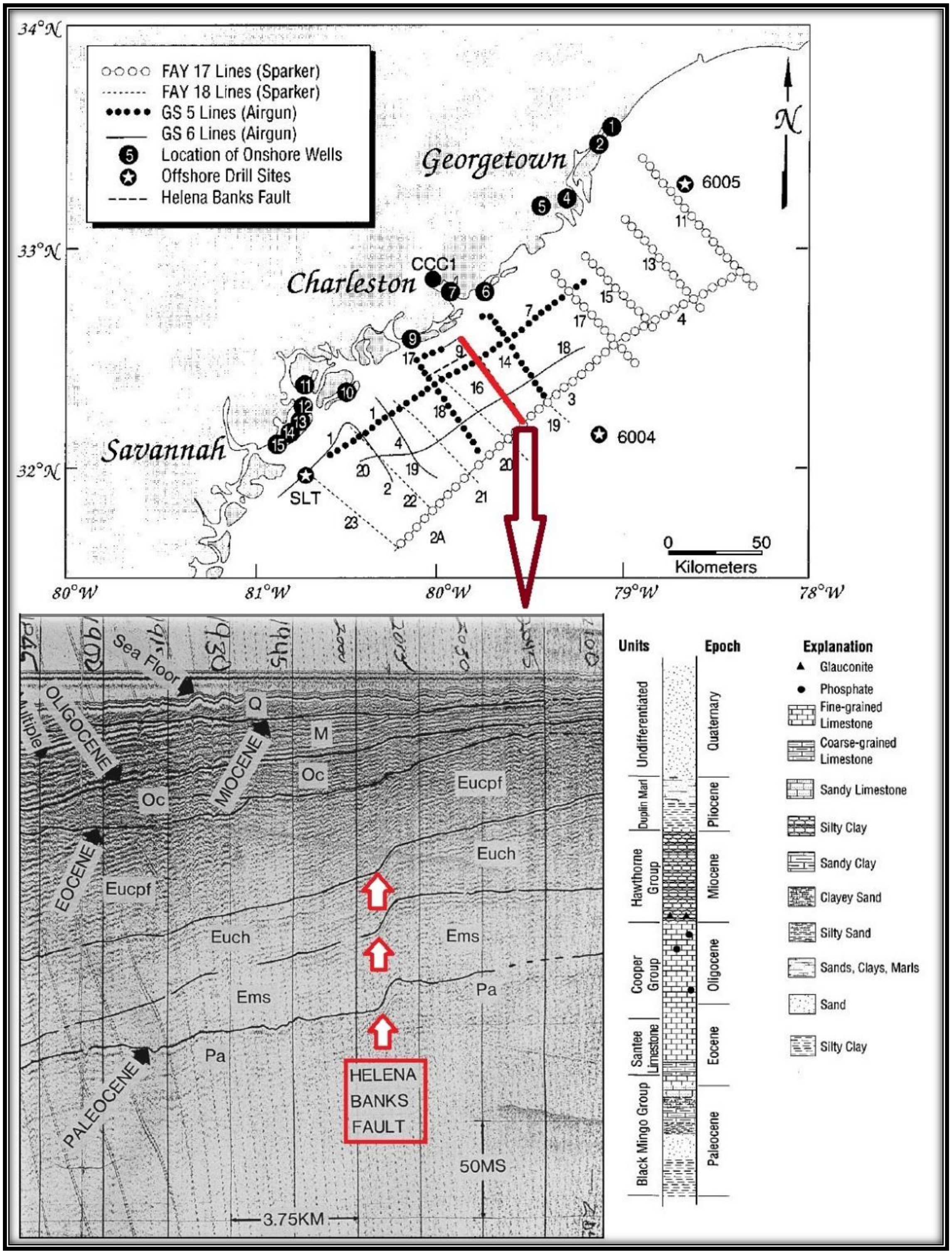

Figure 2.2 Interpretation of line 16 with stratigraphic column and location map [Pa: Paleocene, Ems: Middle Miocene (Santee Limestone), Euch: Harleyville Formation, Eucpf: Parkers Ferry Formation, Oc: Oligocene, M: Miocene, Q: Quaternary] (Modified by Idris & Henry, 1995).

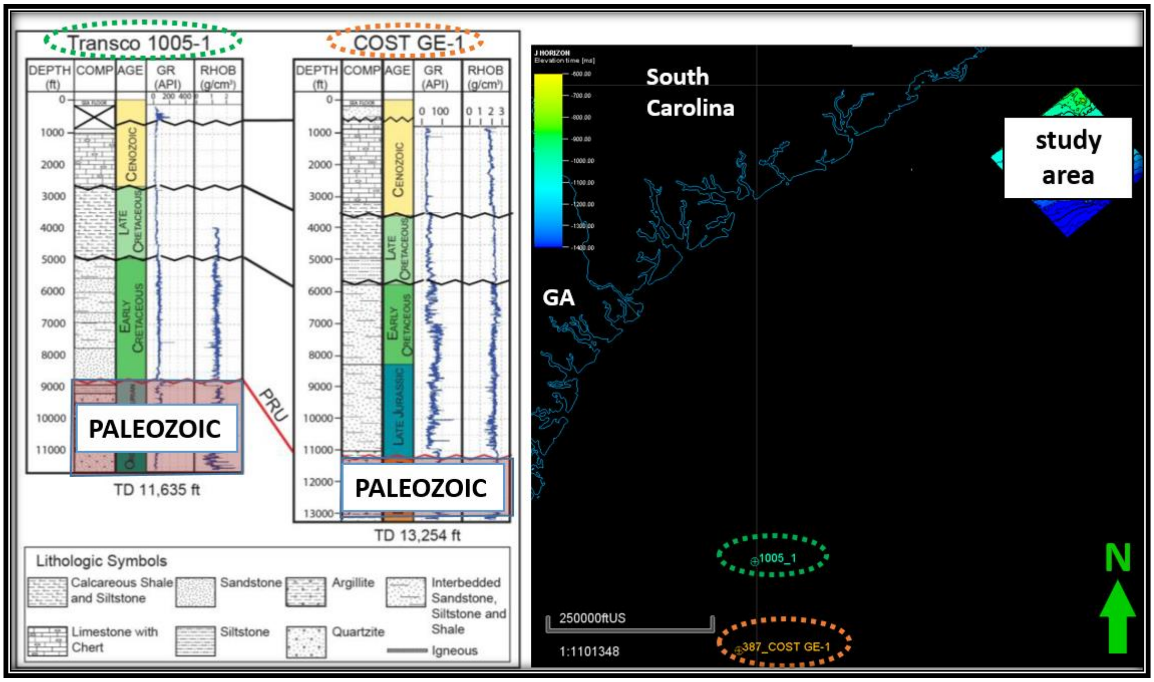

Figure 2.3 Well Controls and Their Location Map [Figure on the left is wells controls near the study area, these wells prove that under J horizon (post rift unconformatiy) is Paleozoic. Figure on the right shows the study area and the location of these well].

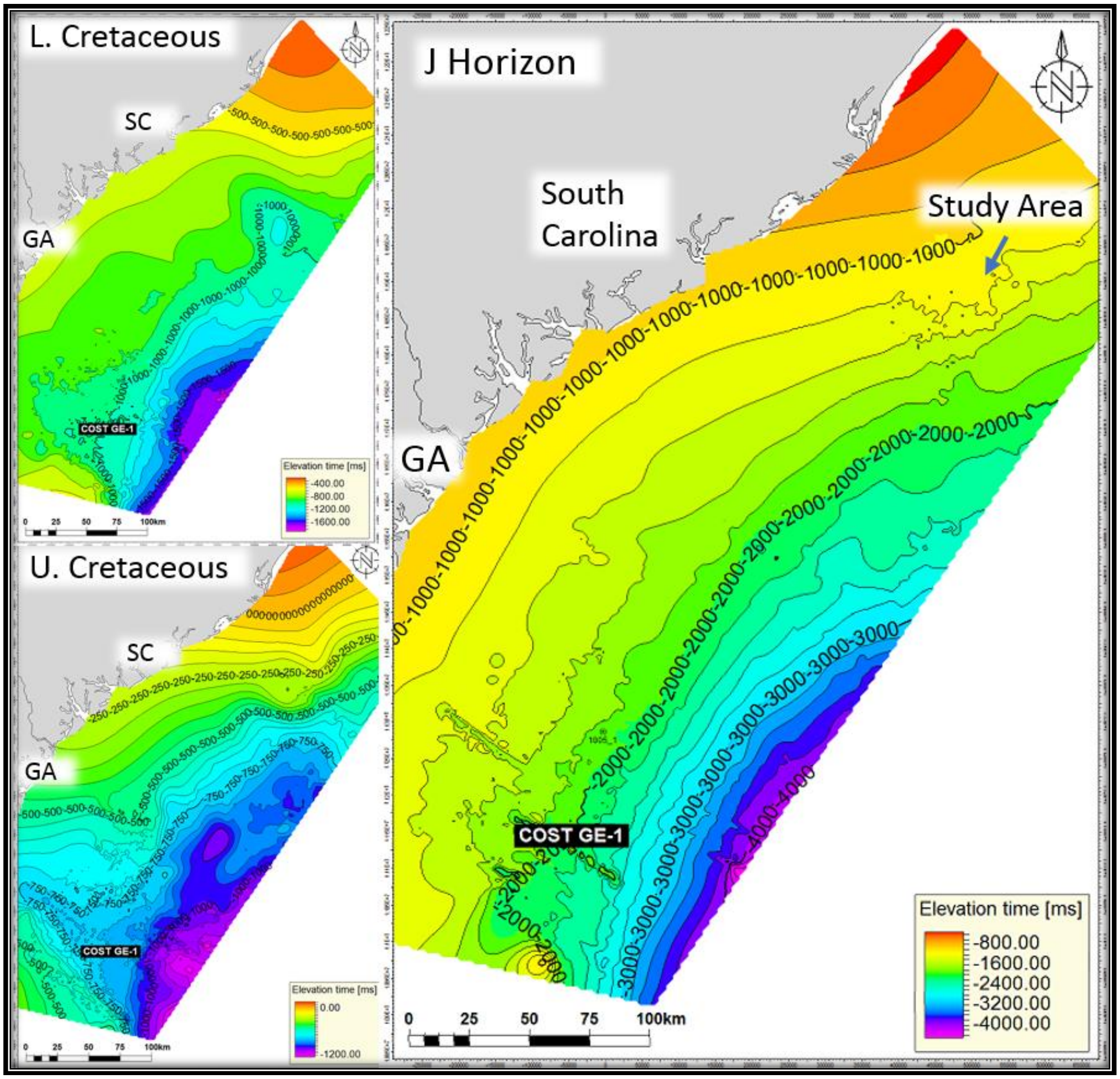

Figure 2.4 Surfaces for Lower Cretaceous, Upper Cretaceous and J horizon (They are created by using COST GE well log information in Figures, modified from Almayahi & Knapp (2018) in TWT. Right map is the J Post Rift surface that the deformation is seen in the study area).

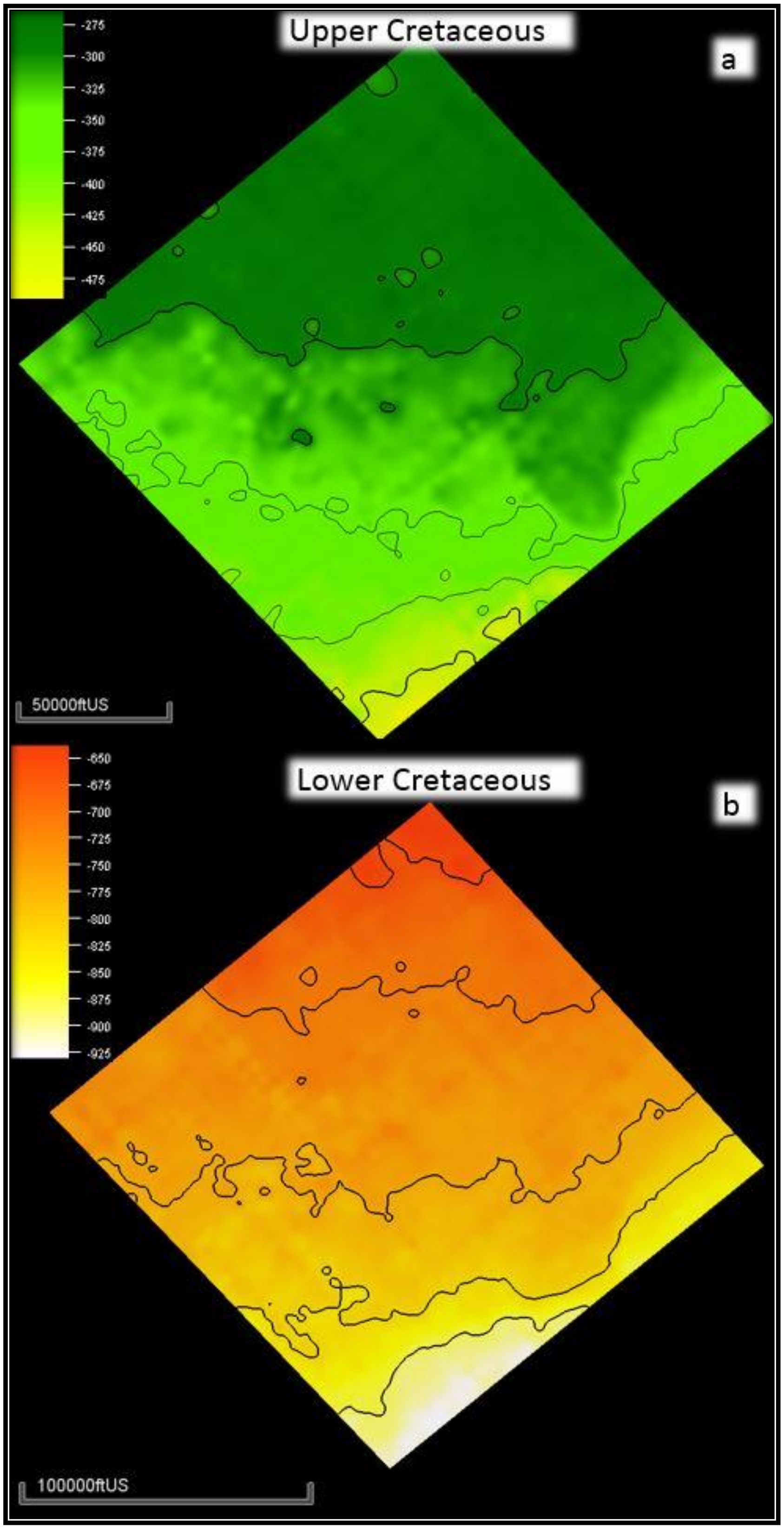

Figure 2.5 (a) Upper Cretaceous, (b) Lower Cretaceous Surfaces.

CHAPTER 3

STUDY AREA AND DATASET

The 2D Multichannel reflection data is collected by Bureau of Ocean Energy Management from offshore Charleston to South Carolina in August 1975. 49 composite seismic lines (each composite line consists of 2 seismic part, total is 98 seismic lines) are called as B-09-75-AT survey which have all the lines between GE-75-01 and GE-75-52 numbers. 26 seismic lines are in direction of Northwest-southeast while 23 lines are in direction of Northeast-southwest into approximately 3,550km^2 area (Figure 3.1). In addition to this survey, we work on the line in the B-05-86-AT survey that comprises two seismic lines, collected in October 1986. These two seismic lines (OSC-3 and OSC-3A) are in direction of Northwest-Southeast. As a result, using 2015 PETREL software and geographic information system (GIS), we have interpreted totally 102 2D multichannel seismic reflection profiles in our study area where is offshore South Carolina. Each seismic line is about to 50km long. Length of 102 seismic lines totally is approximately 50,000km long.

The datum information of data bases on World Geodetic System 1984 (WGS84) as the Navigation information. The purpose of collecting the data is acquired commercially with the aim of geological and geophysical exploration of gas and oil prospect in the United States outer continental shelf.

Figure 3.1 Location Map of the Study Area (The map shows location of 102 2D multichannel seismic reflection profiles offshore, South Carolina).

CHAPTER 4

HYPOTHESIS AND OBSERVATIONS

Helena Banks Fault Zone first was identified on the seismic data by Behrendt et al. (1981) Subsequent analysis that was maintained by Behrendt & Yuan (1987) and Yuan & Behrendt (1988) appears the HBFZ as a more complex structure, and it is mapped in 110km length and in 15km width. The fault zone, with several echelon segments is given in Figure 4.1. The red color indicates the HBFZ in direction of North-East also blue color shows our 98 seismic reflections (Figure 4.1). On these 2D multichannel seismic data, there is no interpretation about the HBFZ. Hence, it is possible to say that the HBFZ can be longer than previously thoughts (~110 km).

The aim of this study is to find the continuation of the HBFZ because no research has been done extensively related to its continuation. Moreover, we try to identify a high angle reverse fault in the study area even though they consider that dip slip fault system generally occurs in the extensional basin. Furthermore, the HBFZ is not appearing to be related to the Triassic rift basin structure, it would be reactivating Paleozoic fault. Therefore, by interpreting 102 seismic lines (each line approximately 50km long) in the study area, we focus on identifying the continuation of the Helena Banks Fault in NE-SW direction (Figure 4.1).

Identifying entire fault can be important to estimate potential seismicity in this area due to occurred two earthquakes in 2002 and possible tsunami in the future.

Activation of either the continuation of the Helena Banks Fault or itself can cause a possible earthquake or tsunami in the Atlantic coast of Charleston, offshore South Carolina.

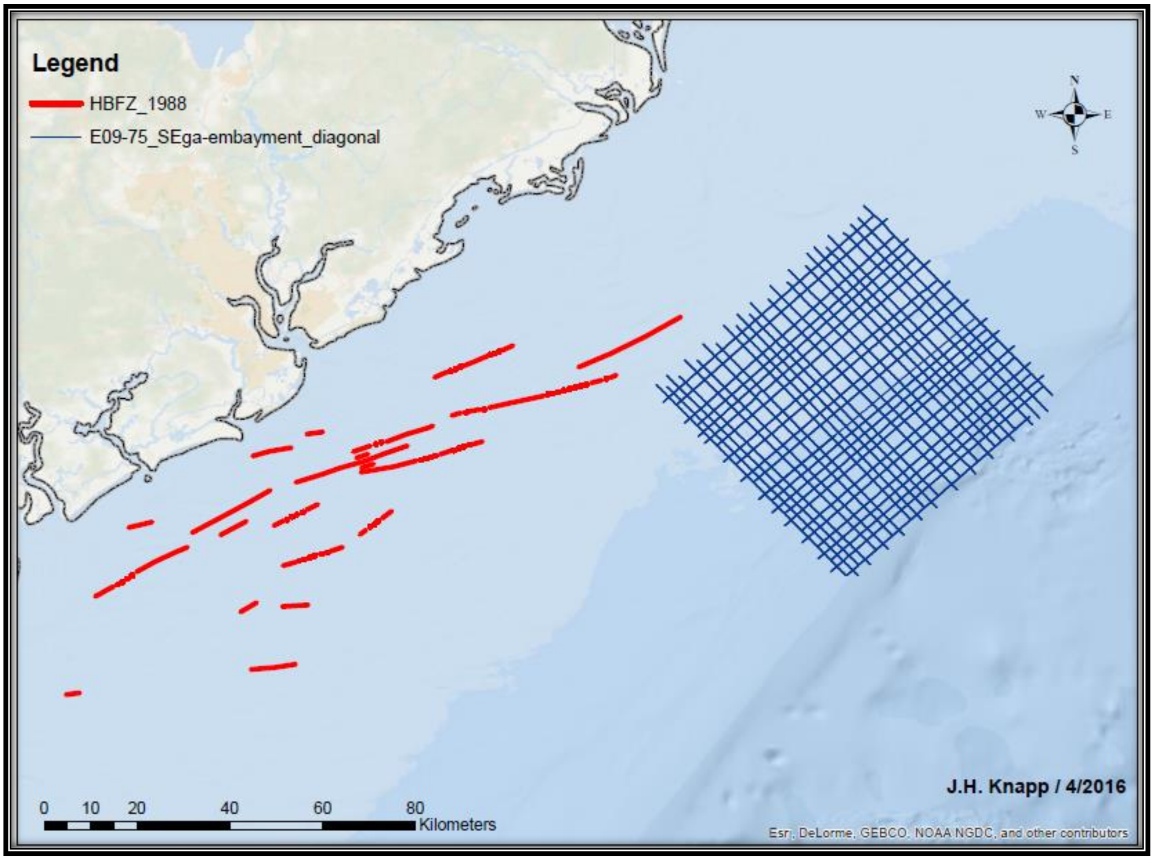

Figure 4.1 Map of the HBFZ with Seismic Lines (Red color is shown as Helena Banks Fault Zone, about to 110km long and 25km wide. The blue color as shape of square indicates 2D multichannel seismic reflection profile which consist of 98 seismic line in offshore South Carolina) (Knapp & Derrick, 2016).

CHAPTER 5

DISCUSSION

Northeast trending (N72ºE) the HBFZ in the 1886 earthquake meizoseismal area to the coast is high angle reverse fault, approximately 50km far away from the coast (offshore), and its displacement was 10m below the sea floor with recent reactivation late Miocene or Pliocene time (Behrendt et al., 1981). According to Behrendt & Yuan (1987), the previous studies indicate that the complicated structure of the HBFZ which is approximately 110km long, has probably some flower structures, and this idea supports the strike slip speculation.

Figure 5.1 which is interpreted by Derrick & Knapp (2016) prove that some parts of the HBFZ have flower structure. Likewise, it is possible to identify this flower structure on the seismic reflection data by using vertical exaggeration of 3:1 (Figure 5.2). Seismic line (black line) that cut through the Helena Banks Fault zone and its interpretation are given in Figure 5.2. Black line on the map represents composite line, consisted of OSC-3A and OSC-3. This composite line is important to understand the characteristic feature of the HBFZ and to compare them with faults on our study area. Interpreted faults is shown as three yellow dots on top of Figure 5.2, and these three faults are shown on the seismic line at the bottom. The faults come from approximately 2500 ms, and they cut through the J Horizon until Upper Cretaceous, similar to the fault shown in Figure 5.1. Likely, the possible flower structure was observed under and above the J reflector.

Using 98 seismic lines, surface for high amplitude J Horizon (also is known as PRU) was created to understand deformation on the J Horizon. While picking the horizon, the information that comes from the COST GE-1 well log was referred. In the Figure 5.3 (b), high gravity is seen in some parts of our study area on the gravity map. Likely, high magnetic is detected in the same part of our dataset. The circular/oval shapes in Figure 5.3 (c) gives information about high magnetic data. The area that has these circular shapes have high magnetic and high gravity anomalies These high magnetic and gravity anomalies are likely to indicate intrusive rocks. The deformation on the J horizon is not only associated with faulting, but also most likely associated with these circular shapes which show high magnetic and high gravity (Figure 5.3). The idea is that the HBFZ is mapped to the boundary of narrow Kiawah Triassic rift basin as a basin-boundary fault zone (Behrendt & Yuan, 1987). Likely, it is possible to say that the continuation of the HBFZ is a basin boundary of these high magnetic and high gravity anomalies, and these anomalies would exist due to mafic intrusion. Although, only one example of these basin boundary of the intrusion is given (Figure 5.4), high angle reverse separation of the HBFZ is seen on the lots of seismic reflection data as an intrusion boundary fault.

Several reflection profiles show that it is possible to follow horizons laterally right side and left side of the seismic line whereas reflectors cannot be followed in the middle part of the line due to complex structures. These complex structures also indicate high magnetic anomalies which means that the complex structure would be mafic intrusion (Figure 5.5). Relief on the J horizon can be identified due to intrusion, up to 300 m of local relief can be documented on the post-rift unconformity. Also, faulting is seen in this area which show relief on the J horizon (Figure 5.6). Basing on the age constraint, faulting (Paleozoic fault) is likely to be older than intrusion (Jurassic). Furthermore, The Migration pathway is needed to be occurred an intrusion, and Fault can be a perfect pathway for intrusion. There could be two possibilities about faulting in the area where intrusion occurred; these faulting could be either Helena Banks fault zone or different fault. However, it could not be possible that a single fault occurred in the area. Therefore, I am positive that this faulting seems to be HBFZ. On the other hand, it is hard to correlate these faults which are located on the area where intrusion happened with faults that I interpreted due to complex structure.

Displacement of sediments was measured by Behrendt et al. (1983) in order to find an evidence of faulting at depth. Furthermore, Behrendt et al. (1983) propose that movement on the Helena Banks Fault is seen notably greater on the reflections below J horizon than shallower reflections. Also, this argument is supported by Idris & Henry (1995). They indicate that the displacement of sediment decreases upward from on the Paleocene surface to on the shallowest Miocene reflector. Likewise, it is possible to see this larger displacement under the J horizon in our dataset whereas the smaller displacement is seen above the J horizon.

Although Behrendt & Yuan (1987) proposed the HBFZ as a compressional reactivation of an extensional Triassic(?) fault zone in some seismic profiles, it would be reactivation of the Paleozoic fault. The well controls near the study area prove that under J horizon(post rift unconformatiy) is Paleozoic age, Triassic age does not exist in our well logs.

We have generally interpreted reflection profiles which are roughly perpendicular (in direction of northeast-southwest) to the coastline. Because the identification of the HBFZ is straightforward in this direction. When we analyses these faults separately, it is possible to say that each fault can be high angle reverse fault, and some structures indicate positive flower structure which is also support typical strike-slip fault interpretation. Furthermore, in spite of the fact that we have realized a few small normal faults on some seismic lines, they do not appear to be related with the HBFZ, Triassic rift basins do not appear on the continental shelf. It is possible to see the small normal faults in the entire Atlantic margin.

In our dataset, faults, believed to be continuation of the HBFZ, are identified on the seismic GE-75-04A and GE-75-06 and GE-08A (Figure 5.7). Some of these fault is flower structure. And also interpreted fault is shown on seismic lines (GE-75-10, GE-75-12A, GE-75-14, GE-75-16) in Figure 5.8. Interpreted faults have same characteristics, therefore it is thought to be continuation of each other. These faults are seen between under the J horizon (older Paleozoic) and above the Upper Cretaceous (younger U. Cretaceous). It is likely to say that the faults are reactivation of Paleozoic fault. Also, these faults have high angle separation like faults in the HBFZ. Using vertical exaggeration of 3:1, the reverse character of the faults is determined. There are 25 interpreted faults, showing as yellow dots in Figure 5.9. After we have picked these faults with same characteristic of the HBFZ, we have drawn faults zone in our study area. The trend of fault zone is identified between N68^0 E and N77^0 E, with a mean of N72^0 E (Behrendt & Yuan, 1987). Likely, we have identified that the trend of the continuation of the HBFZ is between N66^0 E and N72^0 E. These faults appear to have same trend with Helena Bank faults zone that is shown in Figure 5.2. It is possible to say that the fault zone that we found would be the continuation of the HBFZ.

We tried to show the best interpretation in this research by using 2D seismic reflection data. According to our interpretation, length of the HBFZ was found as at least 140km whereas it had been found 110km in length in other studies (such as Yuan & Behrendt, 1988). Interpreted faults, given in Figure 5.9, is thought to be continuation of the HBFZ because these faults are same with the HBFZ in terms of age, trend and type of fault.

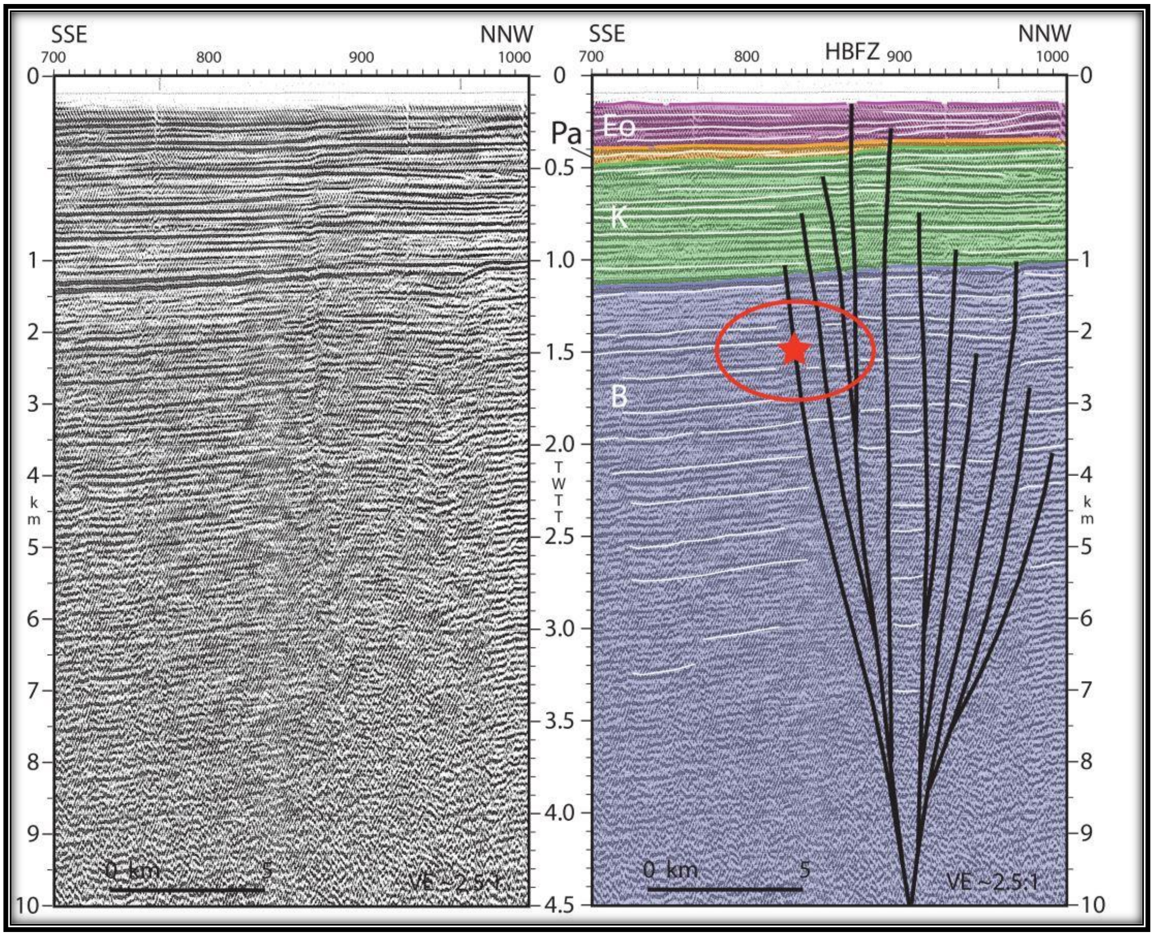

Figure 5.1 Flower structure fault on the CH5 seismic line (The CH5 seismic line shown flower structure fault a kind of strike slip fault. Marked the red stars on the fault in the seismic line would be create the earthquake in November 2002. Also, the stars are shown in left Figure) (Derrick & Knapp 2016).

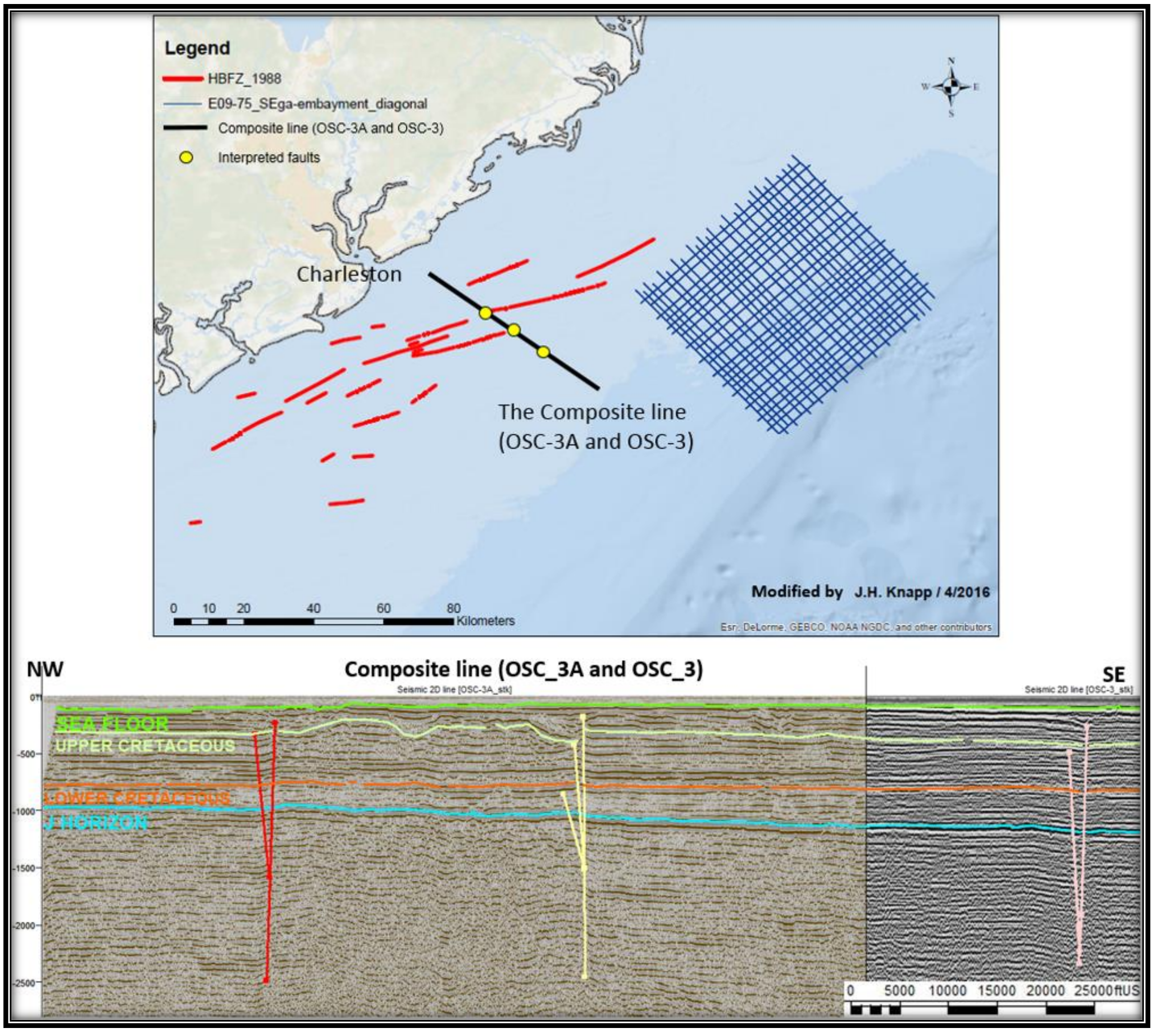

Figure 5.2 The composite line (OSC_3A and OSC_3) and its location map (Top map: location of the composite line. The bottom Figure shows that the composite seismic line which passes through on the Helena Banks Fault Zone. Left side of two faults in the seismic line on the fault zone and right. Right side fault has same feature with the HBF marked as point on the top map).

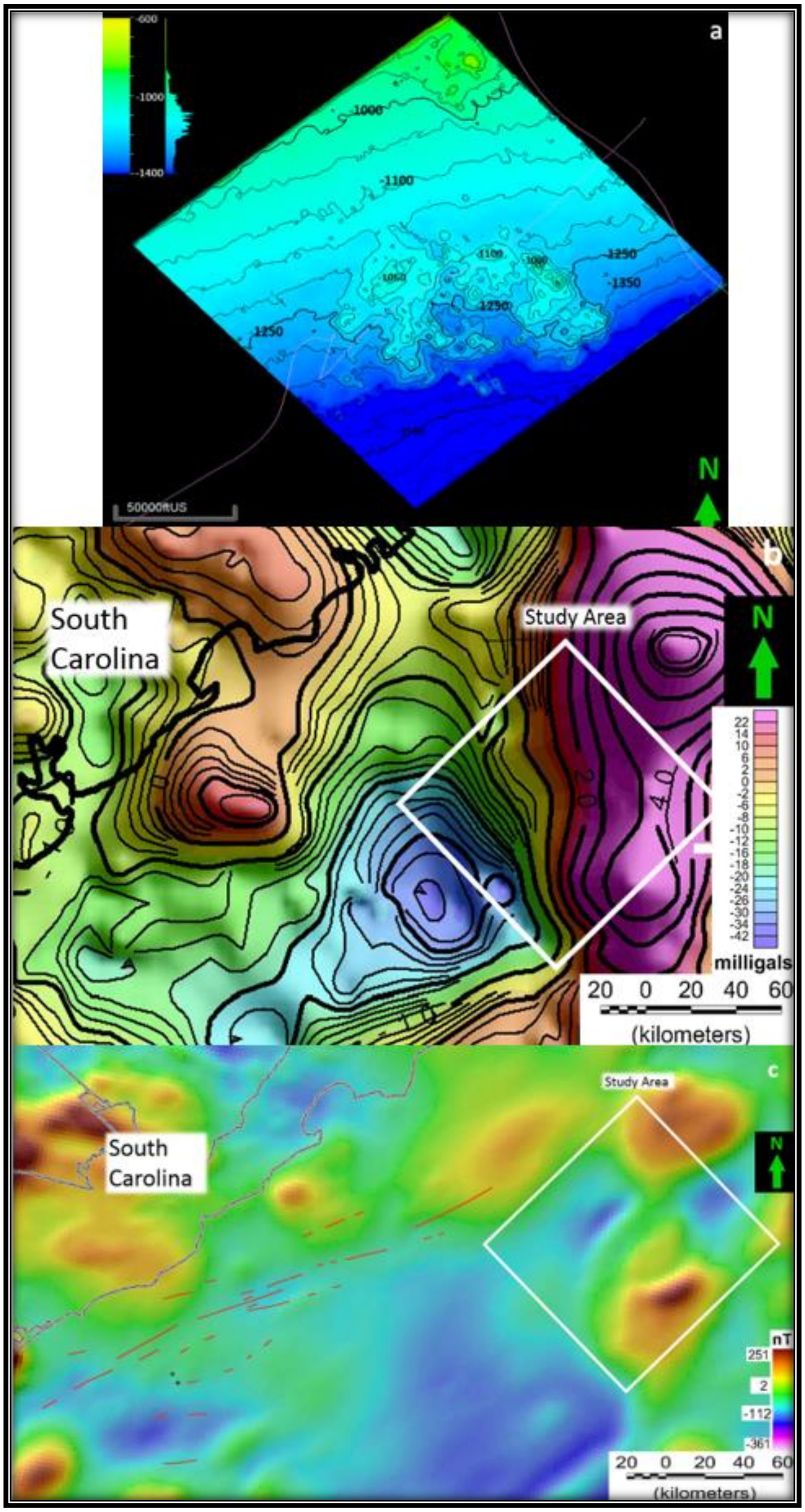

Figure 5.3 Surface map for J horizon, gravity map and aeromagnetic map of study area. (a) Surface for J horizon. (b) Gravity map of the study is modified from USGS map. (c) Aeromagnetic map of the study area.

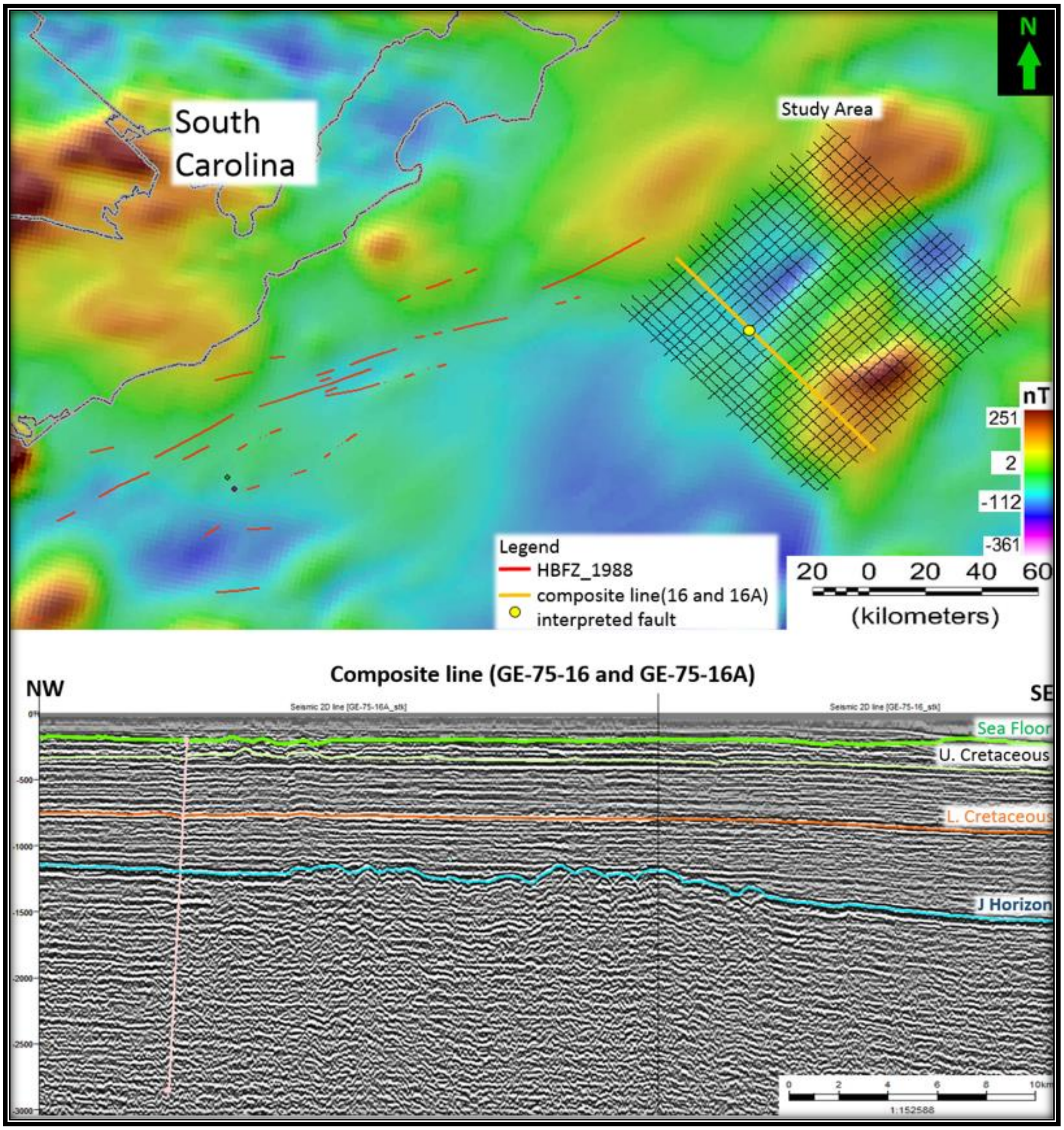

Figure 5.4 Composite line (GE-75-16 and GE-75-16A) and its location map (The continuation of the HBZF is shown on the composite line. The composite line shows the HBFZ is the basin boundary fault zone. The deformation on the J horizon mached with high magnetic anomalies which would be Paleozoic intrusion).

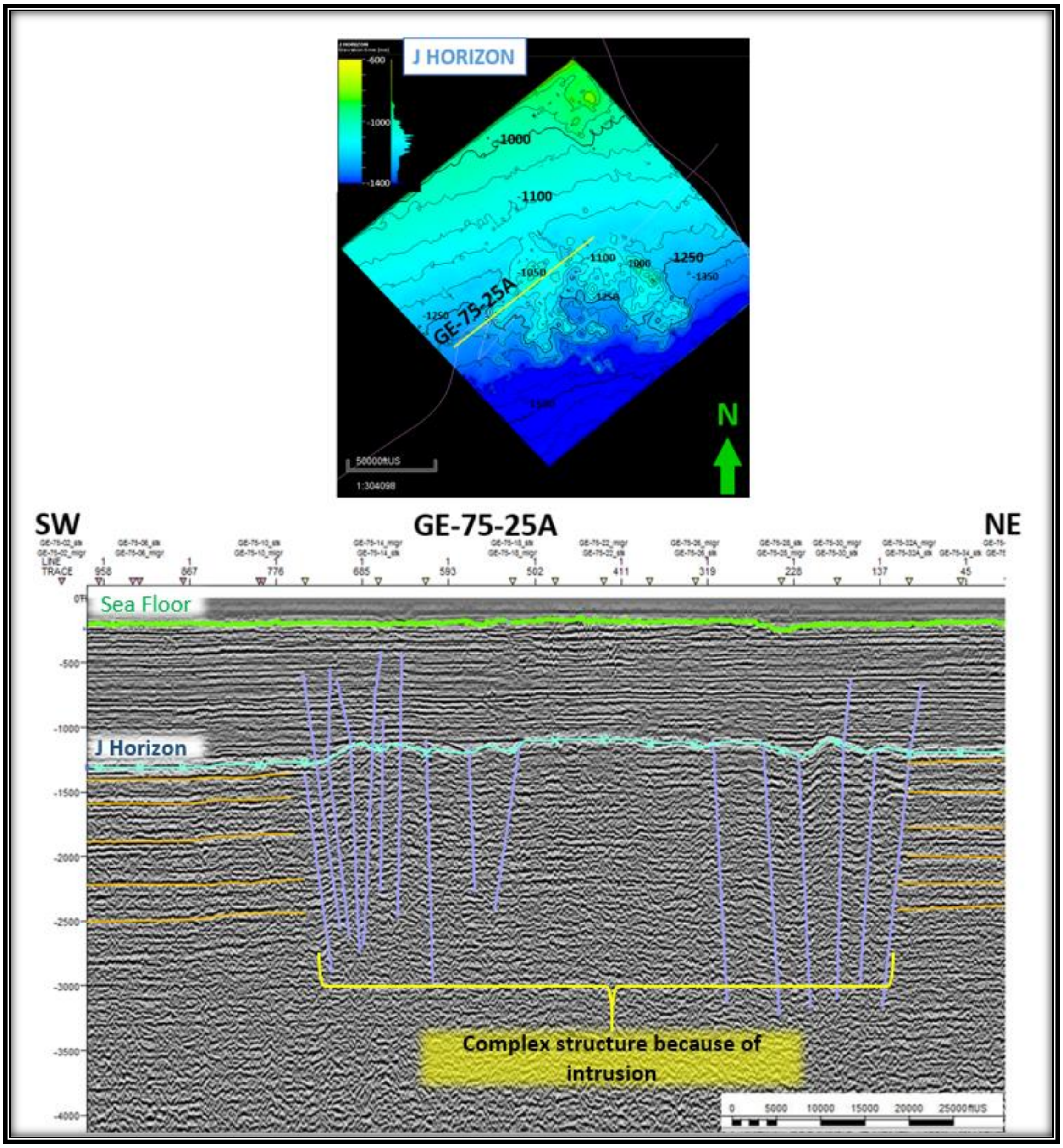

Figure 5.5 Appearance of relief on the J horizon and faulting.

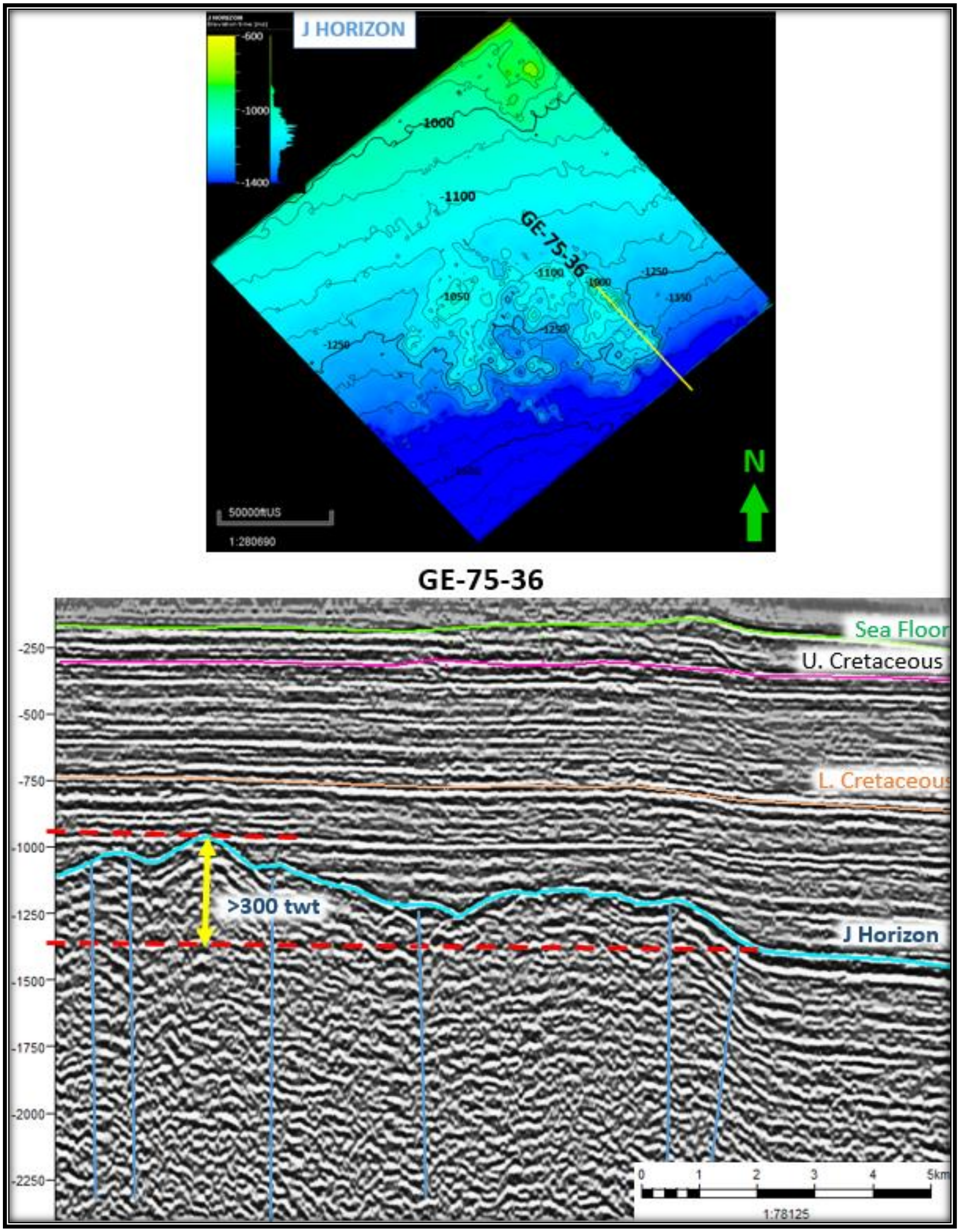

Figure 5.6 Great deformation on Post Rift Unconformity.

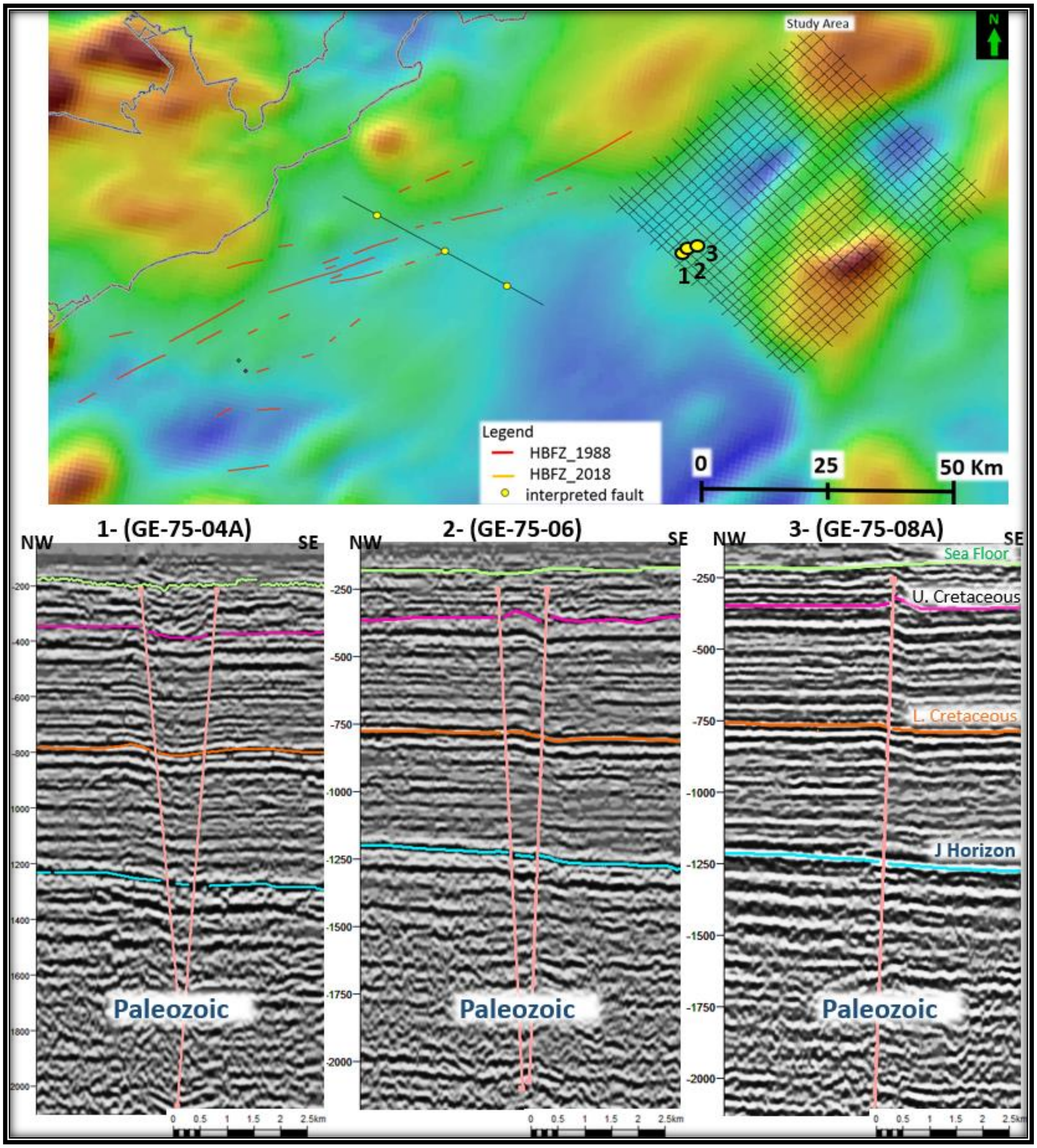

Figure 5.7 Interpreted faults and their location map 1 [Bottom Figures show interpreted Helena Banks Faults in lines GE-75-04A and GE-75-06 and GE-75-08A. Map shows location of these faults in the study area].

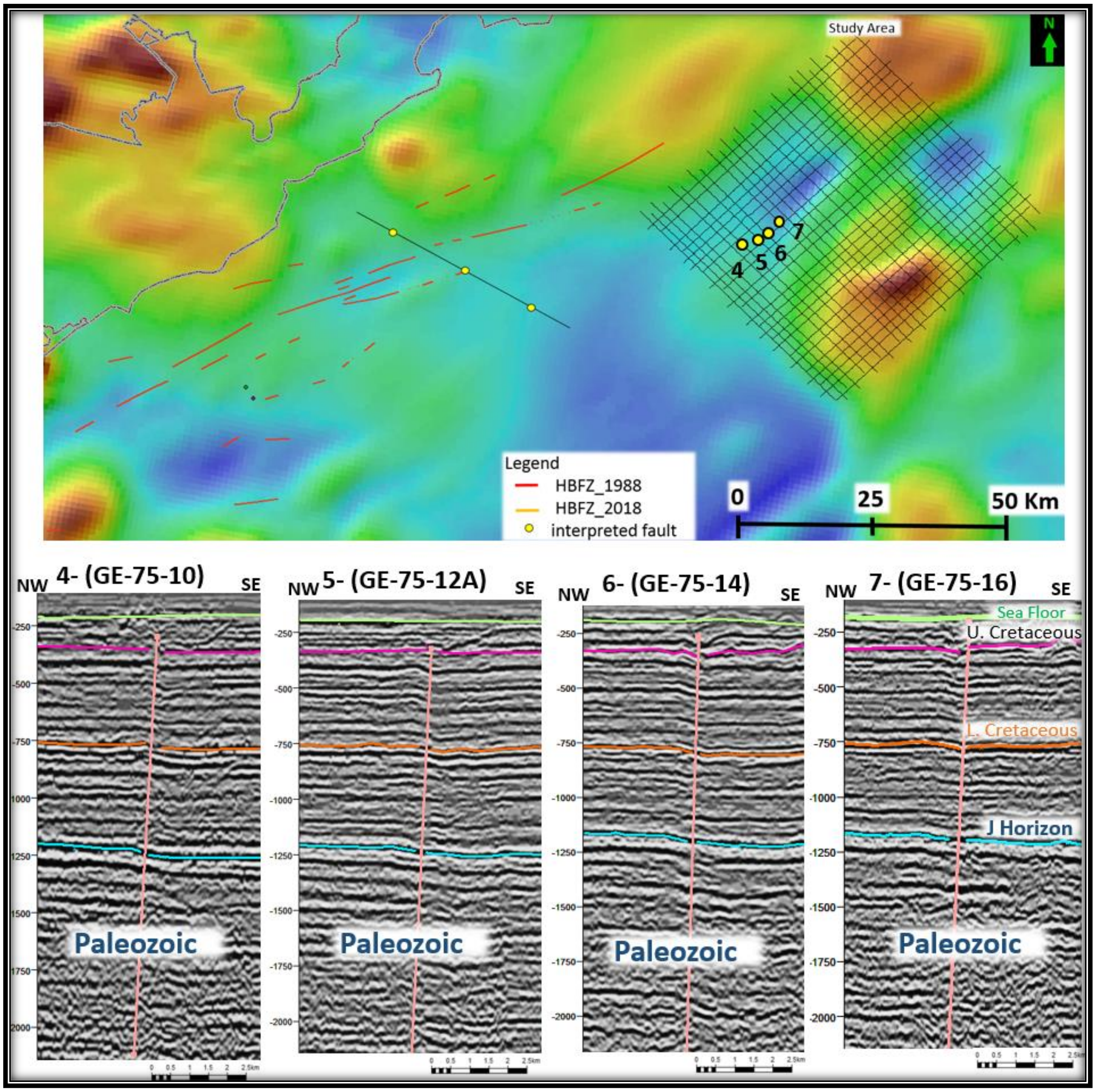

Figure 5.8 Interpreted faults and their location map 2 [Bottom Figures show interpreted Helena Banks Faults in lines GE-75-10 and GE-75-12A and GE-75-14 and GE-75-16. Map shows location of these faults in the study area].

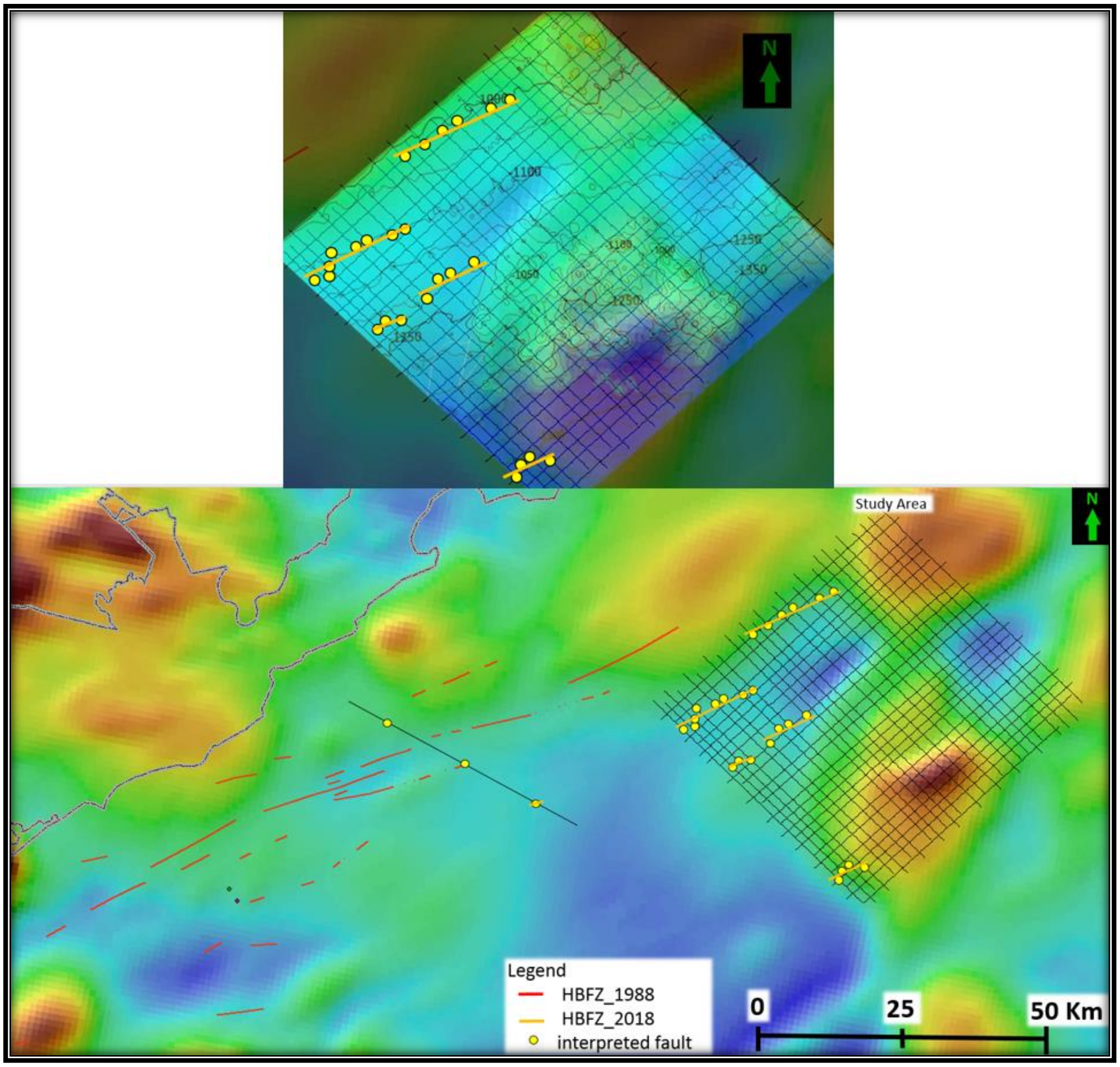

Figure 5.9 The continuation of the HBFZ (HBFZ_2018) (it is displayed by yellow lines with the HBFZ (HBFZ_1988) by red lines on aeromagnetic map). Top Figure shows aeromagnetic data together with J horizon deformation.

CHAPTER 6

CONCLUSIONS

The result of this study shows the continuation of the HBFZ (Figure 5.9). Comparing of age, type and trend of the fault, we conclude that these faults appear to be same faults with the HBFZ. Faults on our study are high angle reverse faults and some positive flower structure in direction of NE-SW. When we analyze faults separately, each fault has reverse separation, when we examine whole system, some parts of the fault system seem to have positive flower structures, supports the strike slip speculation. In other words, these fault systems appear strike-slip fault with oblique component of reverse fault. However, in the area where the intrusion is displayed, it is hard to pick faults due to complex structure.

Finally, Yuan & Behrendt (1988) mapped the HBFZ as a 110 km long fault zone, and it's given in Figure 5.9 with red color. However, we have mapped the continuation of the HBFZ in Figure 5.9 by yellow color. The length of the HBFZ is interpreted as an approximately 140km fault zone.

REFERENCES

Almayahi, D., & Knapp, J. H. (2018). Evaluation of CO2 Storage Potential in Offshore Lower Cretaceous Strata in Mid-South Atlantic Ocean, Southeast United States. Unpublished manuscript.

Behrendt, J. C., Hamilton, R. M., Ackermann, H. D., & Henry, J. V. (1981). Cenozoic Faulting in The Vicinity of the Charleston, South Carolina, 1886 Earthquake. Geology, 9(3), 117-122.

Behrendt, J. C., Hamilton, R. M., Ackermann, H. D., Henry, V. J. & Bayer, K. C. (1983). Marine Multichannel Seismic-Reflection Evidence for Cenozoic Faulting and Deep Crustal Structure Near Charleston, South Carolina. In Gohn, S.D., eds., Studies related to the Charleston, South Carolina, earthquake of 1886 – Tectonics and seismicity: USGS Professional Paper 1313, J1-J28.

Behrendt, J. C., & Yuan, A. (1987). The Helena Banks Strike-Slip (?) Fault Zone in The Charleston, South Carolina, Earthquake Area: Results from A Marine, High-Resolution, Multichannel, Seismic-Reflection Survey. Geological Society of America Bulletin, 98(5), 591-601.

Boote, S. K., & Knapp, J. H. (2016). Offshore Extent of Gondwanan Palezoic Strata in the Southeastern United States: The Suwannee Suture Zone Revisited. Gondwana Research, 40, 199-210.

Derrick, E. R. & Knapp, J. H. (2016). The Helena Banks Fault Zone, Offshore South Carolina: Cenozoic Reactivation on a Not-So-Passive Margin. Unpublished manuscript.

Hough, S. E., Munsey, J., & Ward, S. N. (2013). Reverberations on the Watery Element: A Significant, Tsunamigenic Historical Earthquake Offshore the Carolina Coast. Seismological Research Letter, 85(5), 891-898.

Idris, F. M., & Henry Jr, V. J. (1995). Shallow Cenozoic Seismic Stratigraphy and Structure: South Carolina Lower Coastal Plain and Continental Shelf. Geological Society of America Bulletin, 107(7), 762-778.

Mansperizer, W., & Cousminer, H. L. (1988). Late Triassic-Early Jurassic Synrift Basins of the U.S. Atlantic Margin. The geology of North America, 2, 197-216.

Olsen, P. E., Gore, P. J., & Schische, R. W. (1989). Tectonic, Depositional, and Paleoecological History of Early Mesozoic Rift Basins, Eastern North America. International Geological Congress Field Trip T351, American Geophysical Union, 174.

Kltgord, K. D., & Schouter, H. (1986). Plate Kinematic of the Central Atlantic. In the Western North Atlantic region, Decade of North American Geology, M, edited by Vogt, P. R. & Tucholke, B. E., Geol. Soc. Am., 351-378.

Klitgord, K. D., Hutchinson, D. R., & Schouten, H. (1988). US. Atlantic Continental Margin; Structural and Tectonic Framework. The Geology of North America, 2, 19-55.

Yuan, A., & Behrendt, J. C. (1988). High-Resolution Multichannel Seismic-Reflection Profiles Across the Helena Banks Strike-Slip Fault Zone Offshore of the Charleston, South Carolina, Earthquake Area.In Miscellaneous Field Studies Map MF-2056, Department of The Interior Geological Survey. Retrieved from https://pubs.usgs.gov/mf/2056/plate-1.pdf

Withjack, M. O., Schlische, R. W., & Olsen, P. E. (1998). Diachronous Rifting, Drifting, and Inversion on the Passive Margin of Central Eastern North America: An Analog for Other Passive Margins. AAPG Bulleetin, 82(5), 817-835.

Welsink, H. J., Dwyer, J. D., & Knight, R. J. (1989). Tectono-Stratigraphy of the Passive Margin Off Nova Scotia. In Tankard, A. J., & Balkwill, H. R. eds., Extensional tectonics and stratigraphy of the North Atlantic margins: AAPG Memoir, 46, 215-231.