THE CAROLINA BAYS: AN INVESTIGATION OF NORTH AMERICA'S POST LAST- GLACIAL MAXIMUM ENVIRONMENT (LGM)

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Abstract—Buried beneath the East Antarctic Ice Sheet is a mountain range similar to the European Alps whose age estimates range from 35 to 500 million years. Expeditions during the International Polar Year are seeking to reveal the sub-glacial topography of the range and obtain hints to solve the mystery of their formation. The tools they are using include a combination of ice-core samples and ice penetrating RADAR.

During the Last Glacial Maximum (LGM), North America's Laurentide Ice Sheet, reached its maximum extent approximately 20,000 years ago. Its south-easternmost margin penetrated deeply into Pennsylvania. There is no evidence that this or other glaciations went further, but it is believed that evidence for the harsh climatic conditions that prevailed during each glacial episode can be seen in topographical features that remain visible far to the South. Prominent among the features often attributed to glacial climate are numerous elliptically shaped, shallow depressions called collectively Carolina Bays, hypothesized to have been formed by "blow outs" of loose sediment by the strong, sustained winds characteristic of glacial epochs.

Approximately 13,000 years ago, the Laurentide Ice Sheet's retreat was interrupted by a return to glacial climatic conditions that persisted for over 1,000 years. The events precipitating the dramatic, millennial long climatic cooling, known as the Younger Dryas (YD), remain both a mystery and the subject of debate. It has recently been hypothesized that a fragmented comet or asteroid might have simultaneously initiated the YD and formed the Carolina Bays. However, Carbon 14 dating and pollen analysis indicates an earlier genesis. While this research does indicate the bays were formed during prior glacial epochs, the bays also appear to be repositories of a significant amount of materiel considered evidence of an extraterrestrial impact including carbon and magnetic spherules and nanodiamonds.

If created during or before the LGM, the bays would have experienced episodic post-formation modification due to cold, dry, windy periods alternating with warm, moist and calmer climatic conditions. In this event, Carolina Bays would episodically fill with wind-blown or water-borne sediment or water.

To understand the processes that created the bays, it is helpful to probe their interior structure. Analogous to the Gamburtsev mountain research, sedimentary core samples and a ground penetrating RADAR survey were used to probe the interior of the bay to collect evidence consistent with either the terrestrial or extraterrestrial formation theory. We also used soil processing techniques to extract carbon spherules and magnetic material from soil samples taken from Sandra Kimbel Bay. These samples were taken by the Younger Dryas Impact Study team from the Undergraduate Research Experience in Ocean, Marine, and Polar Science (URE OMPS) in the summer of 2008. By analyzing these extractions we built data charts that represented the characteristics of Sandra Kimbel Bay. The data charts were then compared to previous studies conducted on the Carolina Bays and their correlation to the Younger Dryas period. The research paper contains an in-depth summary of the investigation of theories on how and when the Carolina Bays were formed.

Keywords: katabatic winds, periglacial, Carolina Bay, nano diamond, carbon spherule, Ground Penetrating RADAR, slurry, epoch, stratigraphy

I. INTRODUCTION

There has been a debate going on about how the Carolina Bays were formed. Carolina Bays are shallow ponds and wetlands that dot the Coastal Plain from Delaware to Florida. Numbering in thousands, these elliptical, shallow depressions are most numerous in the Carolinas and occur individually and in groups with some bays appearing to have encroached upon neighbors. There are two pending theories about the formation of the bays. (1)The Carolina Bay depressions were formed due to a fragmented asteroid or comet impact precipitating the Younger Dryas climate change[6]. This caused a mass extinction of many species on the planet; species that include mammoths, saber toothed cats, and the earliest known human civilization, the Clovis people. In addition to causing a massive extinction, the YD is also believed to be the event that caused of the formation of many of the Carolina Bays.

(2) On the contrary, other scientists credit the formation of the bays to natural events that happened after the Last Glacial Maximum (LGM) about 20,000 years ago. Due to the massive coverage of ice during the LGM, the land free of ice in continental North America would have become "cold deserts" because of the lack of moisture, resulting from the massive ice sheets containing all the water in a frozen state. Consequently, scientists believe that it was hurricane-force winds that created the bays. Katabatic winds would have resulted in the wind blowing and traveling down the edge of the glacier, which would be miles tall, reaching hurricane speeds. The strong winds would have blown the lighter material on top of the hard dry surface because of the lack of vegetation from the lack of moisture in the land and create the depressions leading to dunes that would look very similar to what are known as Carolina Bays [5].

Rockyhock Bay has features of a bay that was here before the YD onset, and according to carbon 14 dating and pollen analysis done by D. Whitehead [3], the bay is older than the Younger Dryas. Soil sediment sampling and coring are methods used to examine the stratigraphy of the bay, and are used to search for changes in different layers of the bay. Also Ground Penetrating RADAR (GPR) is a device used to view the different layers of a bay, to search for multiple rims. With the combination of coring, soil processing, and GPR surveying, our team was able to get a better understanding of the stratigraphy of the bay.

II. Procedure

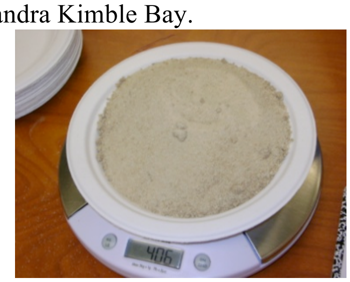
A. Materials

In order to get successful results, certain materials were needed to get process the soil samples. (Fig. 1)

- NDB Super Magnet
- Hefty Ziploc Bags
- 20µ Coffee Filters
- 3 Gallon Buckets
- 2 Liter Buckets
- 45x & 180x Microscope
- 3 kg & 10g. Scale

B. Soil Sampling

Soil analysis was performed to detect and extract impact related markers such as carbon spherules, magnetic grains, charcoal, and glass-like carbon. Before the process was started, soil samples at specific depths were weighed on a scale to the amount of 400 grams (as shown in Fig.2 below), then poured into a large bucket. The procedure used for soil sampling consisted of two parts, including extraction of carbon spherules, glass-like carbon, charcoal, and extraction of magnetic material. Each part was done meticulously and repeated for accurate results. Samples used were taken from Sandra Kimble Bay.



(Fig. 2)

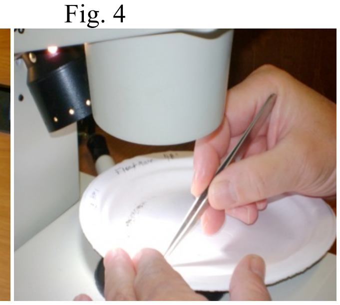
C. Extraction of Carbon Spherules, Glass-like Carbon, and Charcoal

Carbon spherules have a low specific gravity, which causes them to float. Therefore, a floatation procedure was used to separate them. The bucket of sediment was filled with ample water for dilution, and the slurry, a mixture of water and sediment, was agitated to free the floating material. The water carried any floating material that was drained into a filter. All the excess water was transferred into another bucket. The water was then added back to the slurry. The process was repeated until all floating material had been drained into the filter. The floating fraction was placed on a plate to dry (Fig. 3). After drying, the floating fraction was examined under the microscope, where the carbon spherules were identified. After observation, the carbon spherules were counted and analyzed (Fig. 4).

NOTE: This process was repeated for each soil sample at each depth. All materials extracted were placed in a vial and catalogued.

Fig. 3

Fig. 4



D. Extraction of Magnetic Materials

Magnetic materials are denser and sink to the bottom with the slurry, beneath water. In order to extract the magnetic fraction, a super magnet was used.

The excess water was added back to the slurry, and the slurry was agitated to loosen the magnetic fraction. The magnet was placed into a sealed Hefty bag, and the bag was stretched tightly over the magnet, alleviating air pockets that would lessen the strength of the magnet. Then the magnet was placed into the slurry and moved slowly through the mixture (Fig 5). The magnetic fraction drawn onto the magnet (Fig. 6) was released into a small bucket of clean water by withdrawing the magnet from the bag (Fig. 7). The magnetic grains were released into clean water. This step was repeated until minimal additional grains were extracted from the slurry.

Fig. 5

Fig. 6

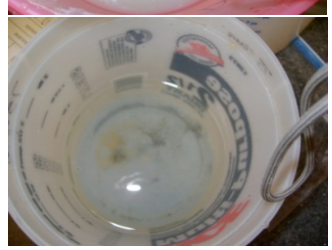


Fig. 7

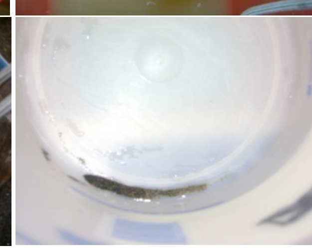


Fig. 8

Next, the magnetic fraction had to be separated from the excess dirt. The magnet and Ziploc bag was immersed into the bucket of magnetic fraction and extracted only the magnetic fraction. The clean magnetic fraction was released into another clean bucket of water. The water was drained from the clean magnetic fraction, leaving little moisture in the bucket so that the magnetic fraction could dry. (Fig. 8)

To make sure the entire magnetic fraction had been extracted, the slurry was dried, and the grains were poured over a dry bag stretched tightly over the magnet to draw any excess magnetic fraction that had been left behind. The magnetic fraction, if any, was then released into a clean bucket of water, separated from any excess dirt, and dried.

Next, the entire magnetic fraction was compiled together onto one plate, then weighed (Fig. 9) and catalogued.

Fig.9

Fig. 10

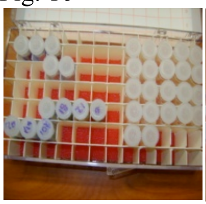


Fig. 11

E. Analysis of Individual Soil Samples

From the samples processed, carbon spherules and magnetic material were extracted. Carbon spherules are shown below in Fig. 12 from 120" inches below the surface. Carbon spherules were extracted from each depth with the exception of 36" inches. Carbon spherules found were a dark gray and black color and varied in size (Fig. 13 & Fig. 14).

Fig. 12

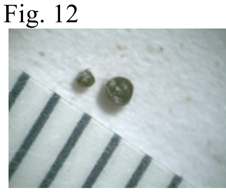


Fig. 13

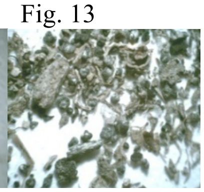
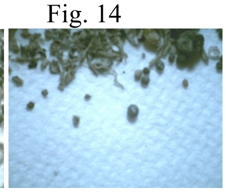


Fig. 14



Magnetic material was also found. Although there were no magnetic spherules found, there was a magnetic spheroid (Fig. 15) found at the depth of 120" inches below the surface. There were many magnetic grains found at various depths.

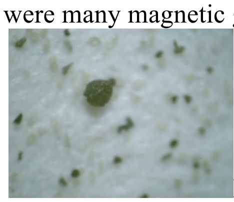


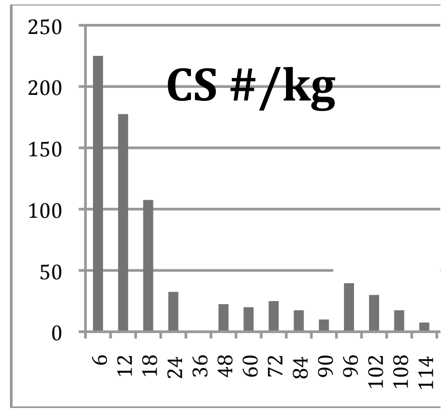
Fig. 15

The following tables represent the amounts of carbons spherules and magnetic material extracted at each depth that was processed. The dispersal of both carbon spherules and the magnetic grains found were not consistent with other studies performed on the Carolina Bays. Our results pertaining to carbon spherule extractions may have been affected by recent forest fires. The significance of the carbon spherules found would be maximized if there is a presence of nanodiamonds within them, a factor that would contribute to the impact theory [6].

There were also two peaks in the magnetic grains found. As seen in the chart representing magnetic material, the most grains were found at 72 and 120 inches below the surface. The reasoning for the dispersal of the magnetic material was also unclear. Magnetic grains may have been present due to the natural background of the soil, rain of magnetite, local mineralogy, or possibly extraterrestrial background. The significance of the magnetic grains found would be maximized if there is a presence of high levels of iridium, which would also contribute to the impact theory. This process would require an Scan Electron Microscope and was not able to be performed on the magnetic grains. It will be a part of future work.

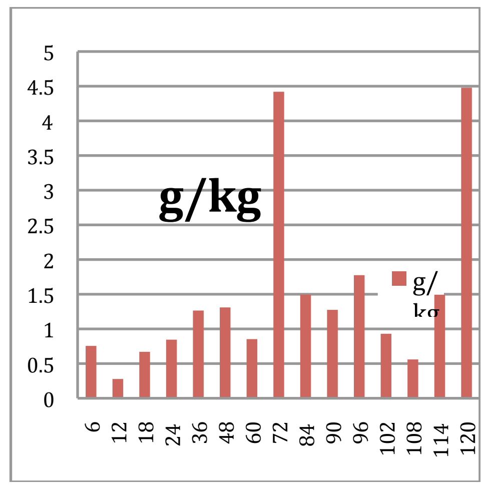
CARBON SPHERULE DATA

Depth	CS/kg
6	225
12	177.5
18	107.5
24	32.5
36	0
48	22.5
60	20
72	25
84	17.5
90	10
96	39.6
102	30
108	17.5
114	7.5
120	13.3



MAGNETIC MATERIAL DATA

Depth	g/kg
6	.755
12	.278
18	.670
24	.845
36	1.265
48	1.310
60	.853
72	4.420
84	1.495
90	1.275
96	1.775
102	.930
108	.560
114	1.493
120	4.478



The results taken from Sandra Kimbel Bay were compared to results from a previous study done on the Younger Dryas Boundary research sites.

The maximum number of carbon spherules found in the Carolina Bays in the YD study was 1,458, and the minimum number of carbon spherules found was 142. Carbon spherules extracted during the research on Kimbel Bay equaled slightly over one tenth of the maximum number of carbon spherules and slightly under one tenth of the minimum number of carbon spherules found in the study on other Carolina Bays.

The maximum number of grams per kilogram of magnetic material found in the study about the Younger Dryas research sites was 17, and the minimum number of grams per kilogram of magnetic material found was 0.5. The maximum number of grams of magnetic material extracted during the research on Sandra Kimbel Bay was over seventy percent less than the maximum from the research in the previous study, and the minimum number of grams extracted was approximately twenty percent less than the magnetic material extracted in the previous study.

COMPARISON OF YD STUDY AND SKB STUDY

	Min CS/kg	Max CS/kg	Min Mag. g/kg	Max Mag. g/kg
YD Study	142	1458	0.5	17
SKB Study	0	225	.278	4.478

III. ROCKY HOCK BAY

In order to get a more in-depth understanding of the features and stratigraphy of the bays, our team investigated at Rocky Hock Bay in Edenton, North Carolina. The site had been previously studied in research done by Donald Whitehead. In the previous study, research results were based off radio carbon dating and pollen analysis [3]. Our research data was gathered through Ground Penetrating Radar (GPR) surveying and core sampling.

Whitehead's research correlates with the data we gathered from Rockhock Bay. Whitehead [3] documented that the bay was elliptical in shape and that its orientation of the long axis is northwestern to southeastern, which is proven to be true by satellite images. (Fig. 16) One contrast in our research is that Whitehead gathered his data from a belt transect extending from the southeast margin of the bay, while our data was gathered from a transect at the center of the bay, closer to the northwestern portion of the bay (Fig. 17).Whitehead describes the soil as peat, which is a highly organic material found in marshy or damp regions, composed of partially decayed vegetable matter. [3]. This study on Sandra Kimble Bay also found that the top layer of soil was peat. In the Whitehead study [3], he notes that the layer of the brown fibrous peat was found beneath surface to 2.10 meters, which was not seen in our expedition at Rocky Hock. After ~1-1.5 meters, we were able to see the layer of peat dissipate into more sandy textured sediment.

Fig. 16

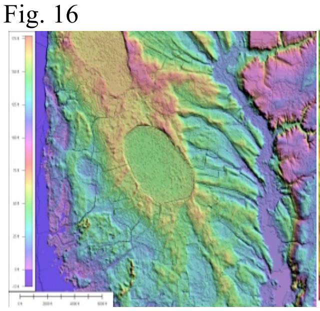
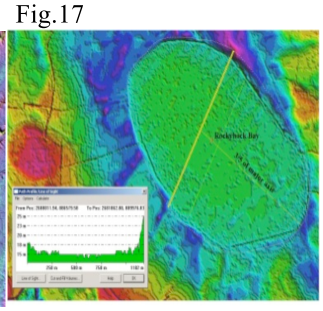


Fig.17



Beneath the layers of peat, we found two iron layers ~3 inches apart (Fig 18), showing evidence of a former lake. Evidence of a shallow lake was also mentioned in Whitehead's explanation of vegetation found inside the bay.

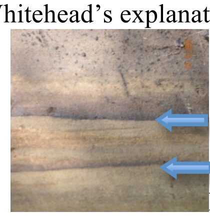


Fig. 18

According to Whitehead [3], a depth of 2.5 meters corresponds to an age of approximately 11,000 years, but is only half the total depth of the bay. This provides evidence that the Carolina Bay depressions were formed prior to the advent of the Younger Dryas event.

IV. GROUND PENETRATING RADAR (GPR)

The Ground Penetrating RADAR provides an image of what is beneath the surface in high resolution. GPR transmits microwave electromagnetic energy into the ground, creating an image based on variations in the round trip time it takes for the reflected energy to return.

GPR can be used not only on terrain similar to Rockyhock Bay, but can also be used to determine the depths of polar ice sheets.

A. Location

Rockyhock Bay, Edenton, NC

A compacted dirt road provided a path for a GPR survey along the bay's semi-minor axis. The survey consisted of a quarter mile transect running from the middle of the bay to its outer rim. The GPR location was recorded every 100 feet with GPS..

The results from the GPR showed an iron layer that appears to be a second rim in the Rockyhock Bay. (Fig. 19- 29)

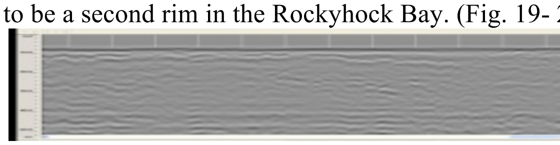


Fig. 19

Fig. 20

Fig. 21

Fig. 22

Fig. 23

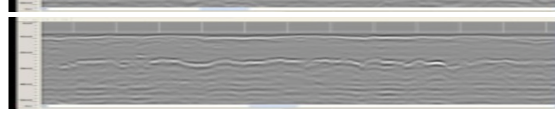


Fig. 24

Fig. 25

Fig. 26

Fig. 27

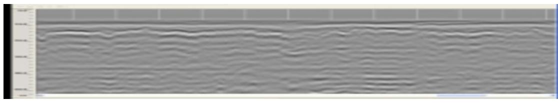


Fig. 28


Fig. 29

The images show the iron layer as the bright strip steadily rising as we get closer to the edge of the bay. The reason we believe that this is a second rim is because of its features. It steadily rises and shows a depression in the middle of the bay. In the Fig. 30, a full image of the GPR reading shows the entire reading as one image, providing a clearer picture of the composition of the layers of the bay.
NOTE: The GPR used a frequency of 400 MHz

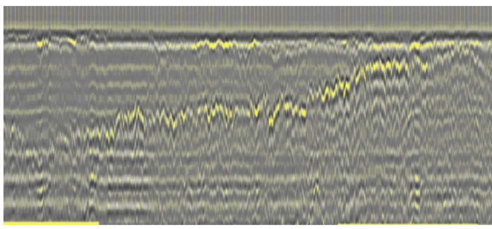


Fig. 30

V. Coring

Coring is the process of obtaining a vertical soil sample in order to get a profile of the soil sediments to a desired depth. This effort's soil sampling went as deep as 112 inches and got soil samples at six inch intervals. Samples were taken from the center of the bay as well as at the rim of the bay. However, because of time, the processing of the soils samples taken from Rockyhock Bay were not analyzed. It will be completed as a future work.

VI. Conclusion

The research project was conducted from an objective point of view in efforts to find evidence to narrow the possibilities of the formation of the bays and to understand the environment since the Last Glacial Maximum. The two theories in question remain: 1) The Carolina Bays were formed as a result of extraterrestrial impact by an asteroid or comet. 2) The Carolina Bays were formed by blowouts from strong winds during the last glacial maxim when winds reached hurricane speeds frequently. The data gathered can be used to support both theories and further research must be conducted to understand the relation of the results to a particular theory. Neither of the two theories can be proved or disproved with the amount of information available from the samples of Kimbel Bay.

However, the data gathered from Rockyhock Bay appears to supports the second theory. Our GPR scans only viewed 2.5 meters beneath the surface (roughly 98 inches). By viewing the scan, we cannot see the bottom of the bay. Also, the iron layer was roughly 2 meters below the surface. According to Whitehead [3], anything that low is approximately 9,000 years (about 11,000 years if he used calibrated carbon-14 dating), and we did not see any indication of the bottom of the bay from our hole. This means that Rockyhock Bay has been around since before the Younger Dryas.

Carbon spherules in previous studies on the Carolina Bays have been found carrying nano diamonds which are very rare on Earth but are found in meteorites and extraterrestrial impact sites. The only other known explanation for nano diamonds are from volcanic origin [2] which can be eliminated from the possibilities on the samples taken from Sandra Kimbel Bay. The carbon spherules found at Sandra Kimbel Bay were dispersed throughout the samples in such a way that they do not confirm the impact theory. Carbon spherules were more prevalent closer to the surface at depths of 6-12 inches below the surface. This factor allows the possibility of materials found in the bay's sediment to be windblown. Carbon spherules have been found in one of four modern forest fires, confirming that they can be produced by intense heat in high-stand wildfires.

On the contrary, magnetic material was found in the most quantity at the lowest depth which was 120 inches below the surface at Kimbel Bay. No magnetic spherules were found in the samples taken from Kimbel Bay. There was a magnetic spheroid found at the depth of 120 inches below the surface. Why this phenomenon is structured in such a way is unknown at the current time.

Our primary aim was to present evidence to form a better understanding of the environment after the Last Glacial Maximum. This evidence would represent the changes that took place on Earth and serve as a record and model of the consequences of either natural events or extraterrestrial events that affected human civilizations.

VII. Future Work

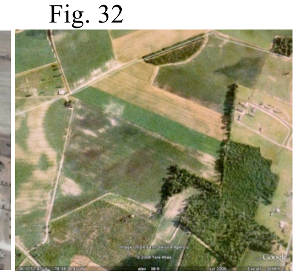
The soil samples analyzed within the team's current research were taken from Sandra Kimbel Bay in the year 2008. These samples have been analyzed for magnetic and carbon spherules. In the future, the team will have the carbon spherules examined through a Transmission Electron Microscope (TEM) for nano diamonds.

Ample data was gathered from the team's expedition at Rocky Hock Bay. Coring samples were taken from the center of the bay as well as the rim of the bay. In the future, these samples will be analyzed for markers such as carbon spherules, magnetic spherules, glass-like carbon, and other materials that would provide a more in-depth understanding of the Carolina Bays.

Future bays to be studied include Lester Lane Bay (36º 15' 47. 24" N, 76º 34' 30. 92" W) shown below in Fig. 31 and Maraton Bay (36º10'54.52" N, 76º38'43.73" W) in shown below in Fig. 32.

Fig. 31

Fig. 32



VIII. Acknowledgement

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References

[1] Grant, John A., Brooks, Mark J., Taylor, Barbara E., "*New constraints on the evolution of Carolina Bays from ground-penetrating radar*" in Geomorphology, 22, 1998, 325-345.

[2] R.B. Firestone, A. West, J.P. Kennett, L. Becker, T.E. Bunch, Z.S. Revay, P.H. Schultz, T. Belgya, D.J. Kennett, J.M. Erlandson, O.J. Dickenson, A.C. Goodyear, R.S. Harris, G.A. Howard, J.B. Kloosterman, P. Lechler, P.A. Mayewski, J.Montgomery, R. Poreda, T. Darrah, S.S. Que Hee, A.R. Smith, A.Stich, W. Topping, J.H. Wittke, and W.S. Wolbach, "*Evidence for an extraterrestrial impact 12,900 years ago that contributed to the megafaunal extinctions and the Younger Dryas cooling*", in PNAS , vol . 104 no. 41, 2007, pp 2-4

[3] Whitehead, Donald, "*Late-Pleistocene Vegetational Changes in Northeastern North Carolina*," in *Ecological Monographs*, 51(4), Ecological Society of America, 1981, pp. 451–471.

[4] Bennett. S.H. Nelson J.B., "*Distribution and Status of Carolina Bays in South Carolina"* in *Nongame and Heritage Trust Publications,* Vol. 1. South Carolina Wildlife and Marine Resources Department, Columbia SC 1991, pp 88.

[5] Johnson, D.W, "*The Origin of Carolina Bays",* in *Columbia University Press*, New York ,1942,pp 341

[6] Prouty, W.F., "*Carolina Bays and their Origin*" in Geology Society of America, ed. 63, Bull 1952, pp 167-224

[7] Kaczorowski, R. T., "*The Carolina Bays: a Comparison with Modern Oriented Lakes Technical Report*" no. 13-CRD, Coastal research Division, Department of Geology, University of South Carolina, Columbia, South Carolina.1977, pp.124