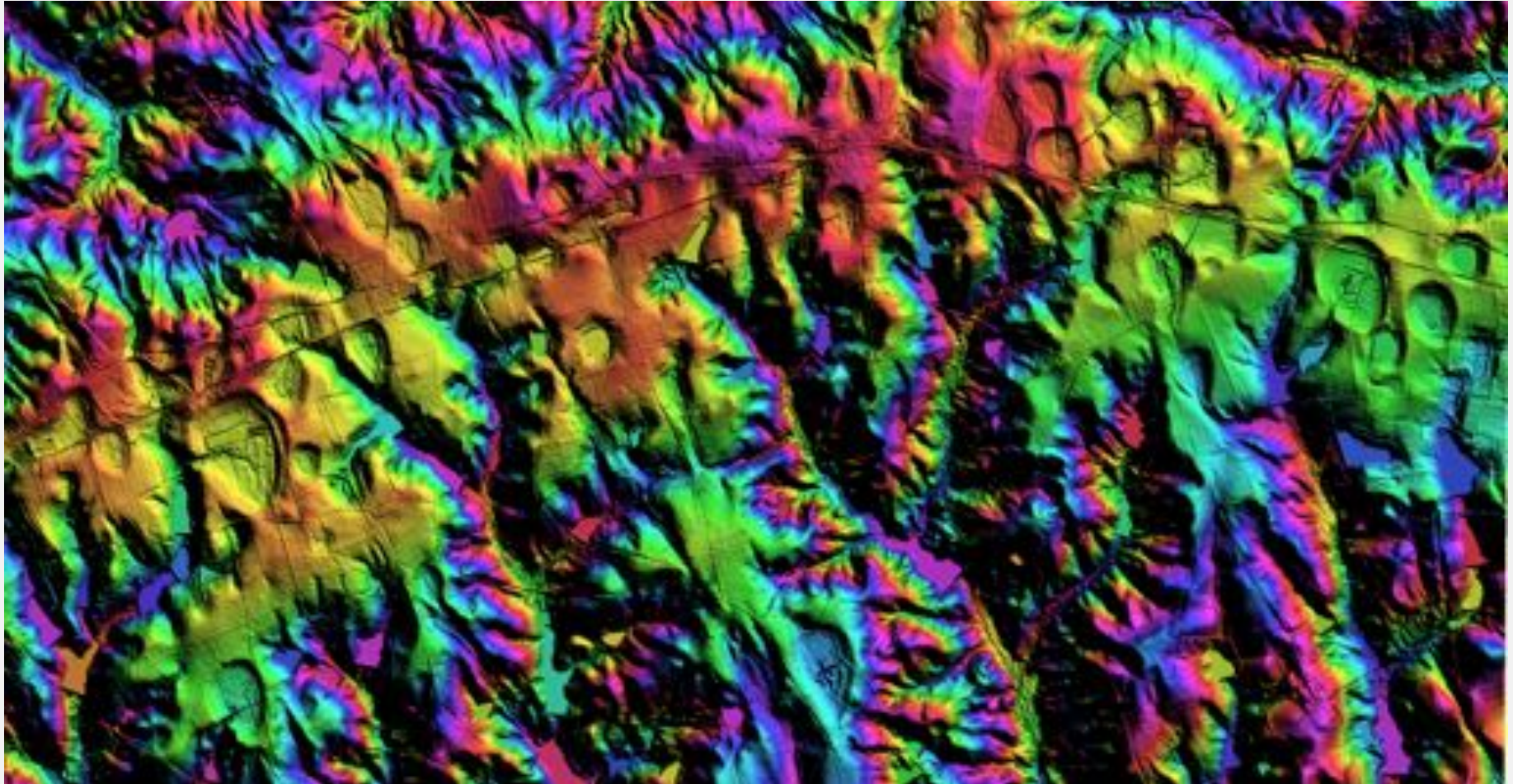


They Don't Build 'Em Like They Used To;

Examining LiDAR Of Modified Costal Terrace Surfaces Shows The Carolina Bay Landform To Be Robust When Threatened With Alteration By Gradualistic Processes



Paper 147-10
Michael E. Davias cintos.org

2015 GSA Annual Meeting
Baltimore, MD 1-4 November, 2015

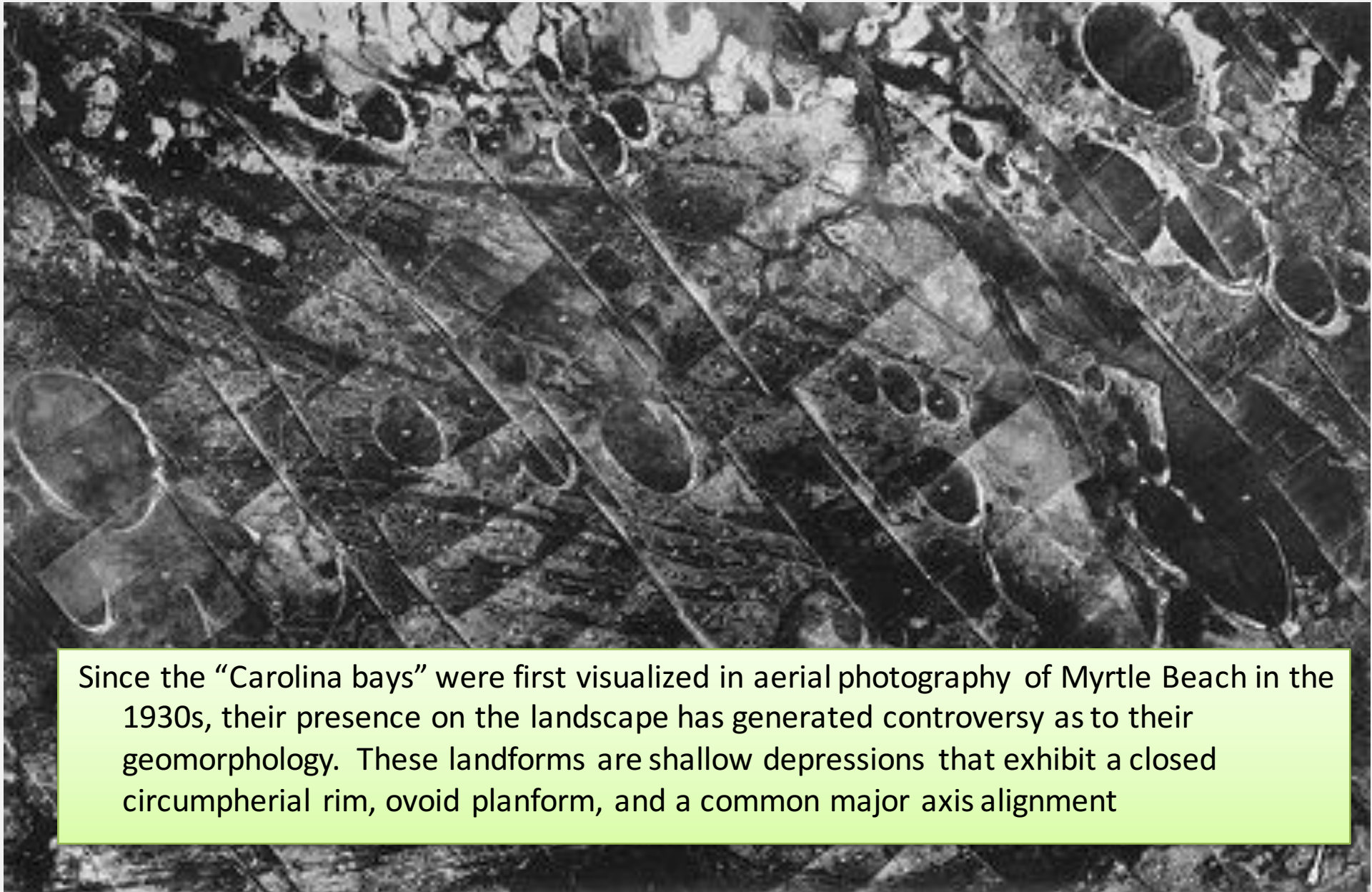
They Don't Build 'Em Like They Used To; Examining LiDAR Of Modified Costal Terrace Surfaces Shows The Carolina Bay Landform To Be Robust When Threatened With Alteration By Gradualistic Processes

Carolina bays exist in prodigious quantities on North America's Atlantic Coastal Plain. Research into the geomorphology of these enigmatic landforms is typically directed at easily recognized, hydraulically closed examples which show an affinity to undissected interfluvies on the coastal terraces. There may seem to be little reason to identify less wholesome examples; yet, a holistic assessment shows that erosional and accretionary processes are struggling to annihilate existent bays. Here we present LiDAR digital elevation maps to elucidate bays succumbing to erosion during the dissection of costal terraces of Cenozoic and Mesozoic age, yet leaving intriguing vestiges in terrace remnants at elevations over 200 meters above sea level. We also discuss Carolina bays inundated by fluvial and estuarine deposits, only to delicately project their ovoid planforms to the surface. Sheets of dune sands and aeolian loess have overridden and blanketed clusters of bays, yet they continue to offer evidence of their presence. Such findings suggest that once created, a Carolina bay's ovoid shape and orientation is deeply imprinted into the landscape, often revealing its presence despite the reworkings of host topography. While such processes apply to isolated bays, the findings are far more satisfying when demonstrated within a collection of co-aligned and identically shaped adjoining bays. Rather than being "wispy ephemeral" landforms, bay survival in hostile conditions supports a finding that they are very robust landforms. The temporal aspects of such alterations may provide constraints on the timing of bay creation. ^{14}C dating had long ago evaluated the age of organic deposits in cored Carolina bay basins to be older than 50 ka, the limit of that technology. The age of bays based on their existence on Cape Fear River terraces sets a - minimum date for bay formation at prior to the Illinoian glaciation - beyond the reach of OSL dating. Bays on a terrace remnant above the fall line in Virginia have been deemed by other workers to be far older, still. When attempting to date bay creation episodes, workers must discriminate between foundational rim deposits and those of subsequent gradualistic processes. Future research goals include application of $^{10}\text{Be}/^{26}\text{Al}$ isotopic burial dating techniques to the surfaces beneath these landforms.

Goals of Talk

- Carolina bays – a Hypothesis to test
- How I measure bays for the Survey
 - LiDAR
 - Overlays
- How old are the Carolina bays?
- Pristine bays on flat interfluvials
- Inundated bays & their persistence
 - Buried under meters of loess
 - Inundated on flood plains and in estuaries
- Eroded bays on terraces being dissected
 1. Headward stream erosion
 2. Lateral erosion
- All work product freely available @ cintos.org

Myrtle Beach, SC



Since the “Carolina bays” were first visualized in aerial photography of Myrtle Beach in the 1930s, their presence on the landscape has generated controversy as to their geomorphology. These landforms are shallow depressions that exhibit a closed circumpherial rim, ovoid planform, and a common major axis alignment

- ©Fairchild Aerial Surveys for the Ocean Forest Company: Aerial view taken in 1930 (12x8 km)

Myrtle Beach, SC

“No one has yet invented an explanation which will fully account for all the facts observed”

Douglas Johnson, 1942 *The Origin of the Carolina Bays*

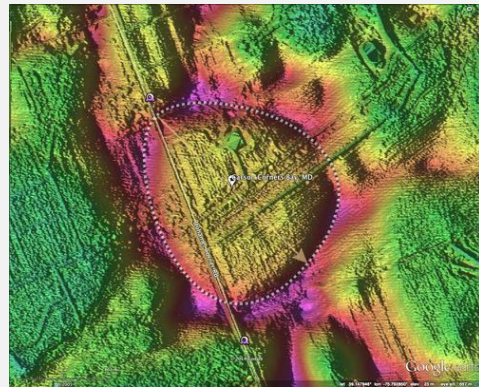
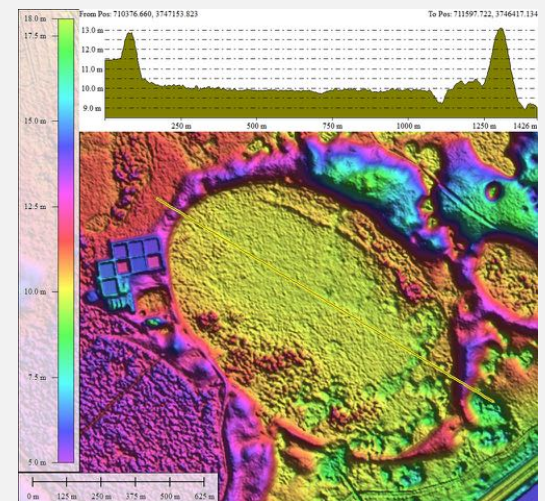
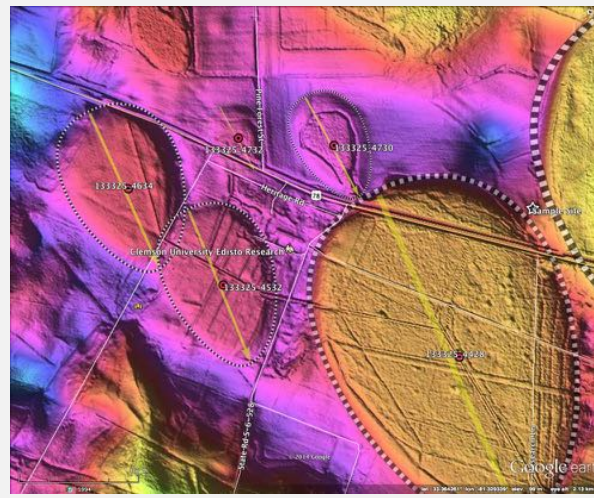
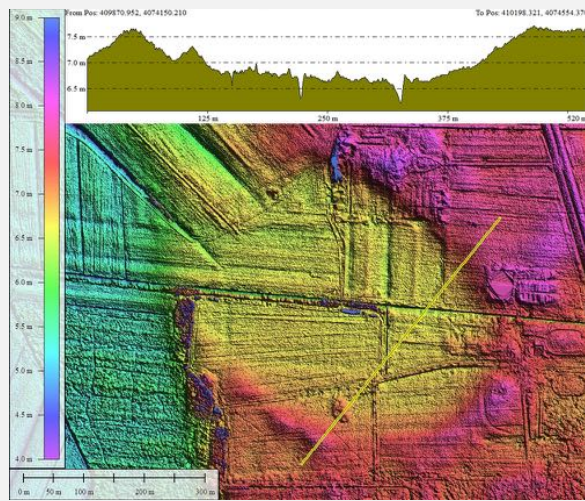
Over 70 years ago Douglas Johnson found the attempts being made to account for Carolina bays failing to adequately address “all the facts observed”. I find that to remain true. At Dr. Johnson’s direction, I invented a novel hypothesis:

Hypothesis

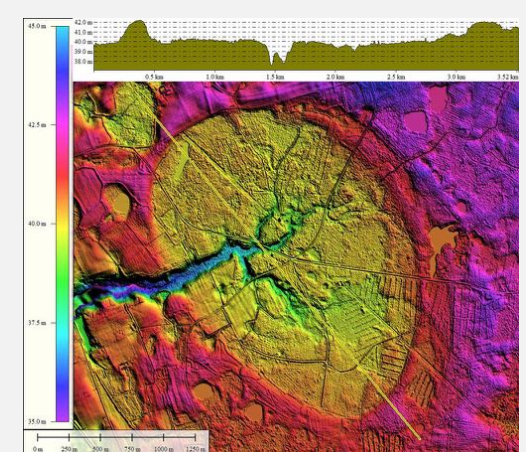
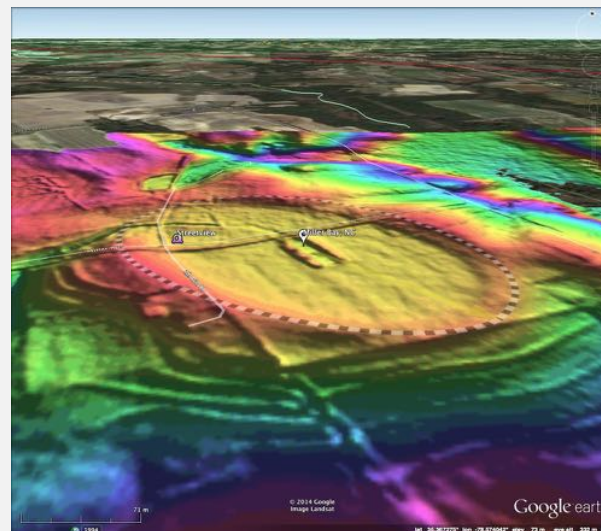
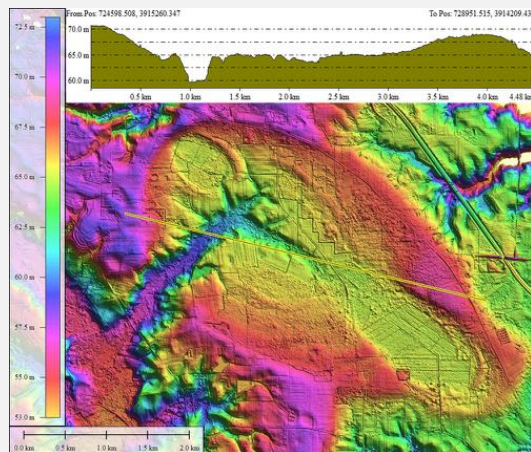
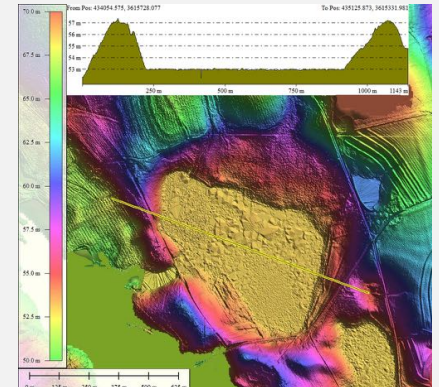
Carolina bays are not ephemeral, wispy landforms, but rather represent the surface topology of a sheet of unconsolidated quartzose grains, deposited during a Mid-Pleistocene cosmic impact event. With a planform and orientation controlled by arrival momentum robustly imprinted into the landscape, they have endured ongoing erosional and accretionary processes.

The hypothesis seems easily falsified

- “they don’t look that old”
- bay age analysis don’t supported singular event
- No impact crater is visible



Over the past 6 years I have catalogued tens of thousands of bays using LiDAR digital elevation maps. I can attest that the **only** gradualistic aspect of bays I see are the forces attempting to obliterate them.



This photo shows the interior of Antioch Bay, one of the finest examples of an unmolested bay.

Riddle of the Carolina Bays

BY KEVIN KRAJICK

AS FAST AS SHE CAN MANAGE, NORTH CAROLINA ZOOLOGY GRAD student Lisa Carwell, 24 years old and five feet tall, is hurdling fallen trees, busting through thick bushes and sprinting in thigh-deep water while grasping a butterfly net that's a lot longer than she is. Her eyes never leave the prey. "C'mere, buddy," she says, suddenly swinging like a major league batter at something small and airborne. Today she might get lucky and perhaps snag a rare insect never seen around here. Maybe even an unknown species. "You never know," she says.

"You never know" is a good motto for the Carolina bays, the locale for her hunt. The confusingly named bays are not ocean inlets; nor are they confined to the Carolinas, though that is where they lie thickest. They are eerie wetland depressions scattered across the Eastern coastal plain from southern New Jersey to northern Florida. Most of them are perfect ovals; they are ringed by ridges of sand as high and dry as their interiors are low and swampy; and all point the same way, north-west to southeast. They have long fueled weird local folklore, bewildered geologists and scared off most everyone else.

Today Carwell is inventorying butterflies, dragonflies and damselflies in bays—the first such study in a region settled for close to 300 years. That's because few biologists want to go in there: bays are often surrounded by, or even filled clear through with, impenetrable walls of shrubs and 12- to 30-foot-

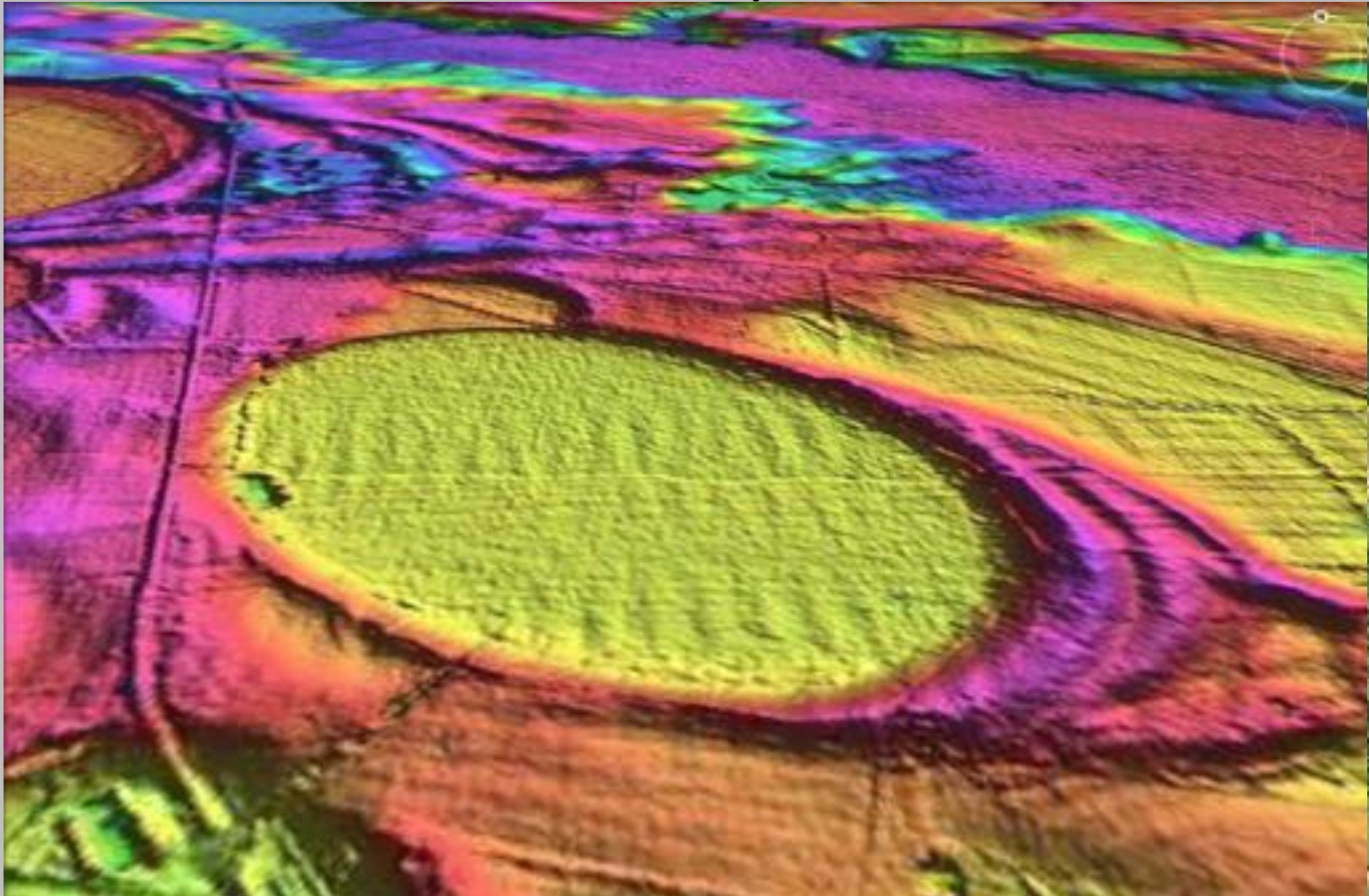
Article by Kevin Krajick, Smithsonian Magazine, September 1997

Antioch Bay, NC



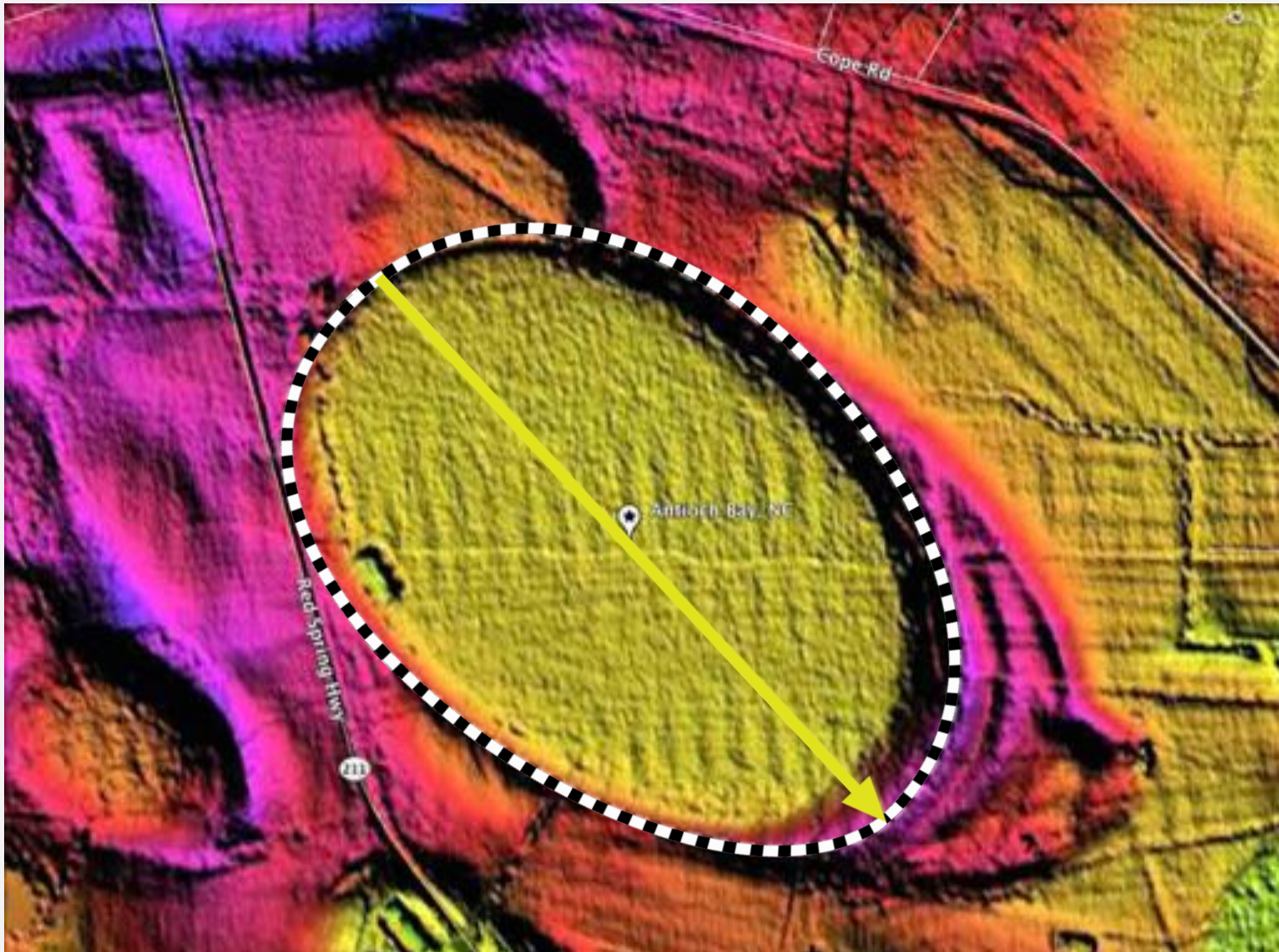
Here it is viewed from the air. Sadly, anthropological ditching, draining and logging has modified over 99% of these landforms.

Antioch Bay, NC



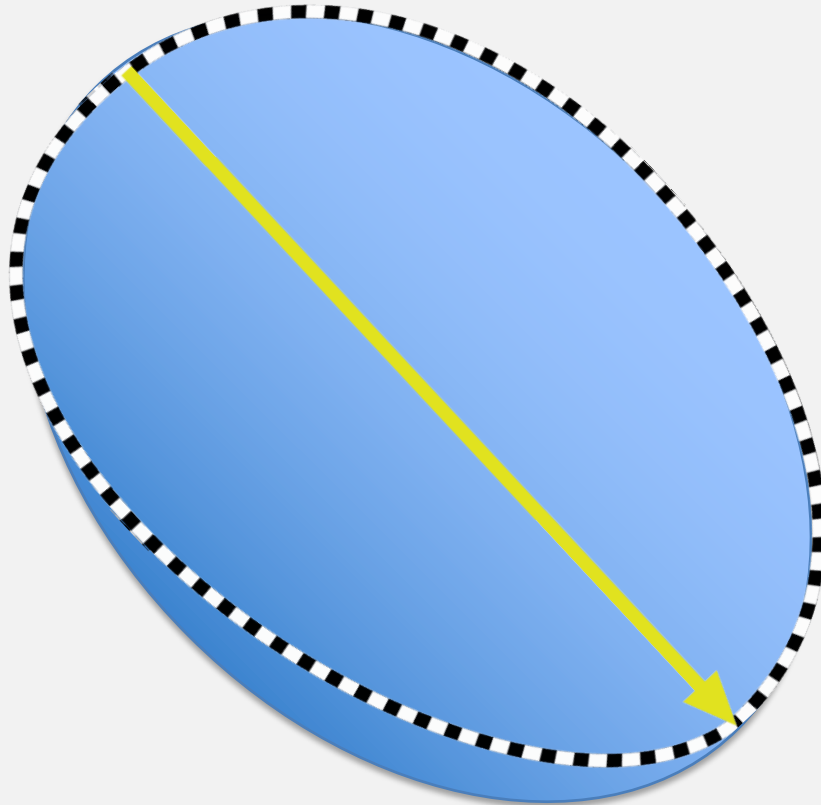
The topography of Antioch bay is apparent in the LiDAR, although I do exaggerate the relief 20x when generating these maps. I must call to your attention that the bay is not surrounded by a raised rim, but that across a significant extent it is sunken into the surrounding pediment.

bayCarolina Archetype Template



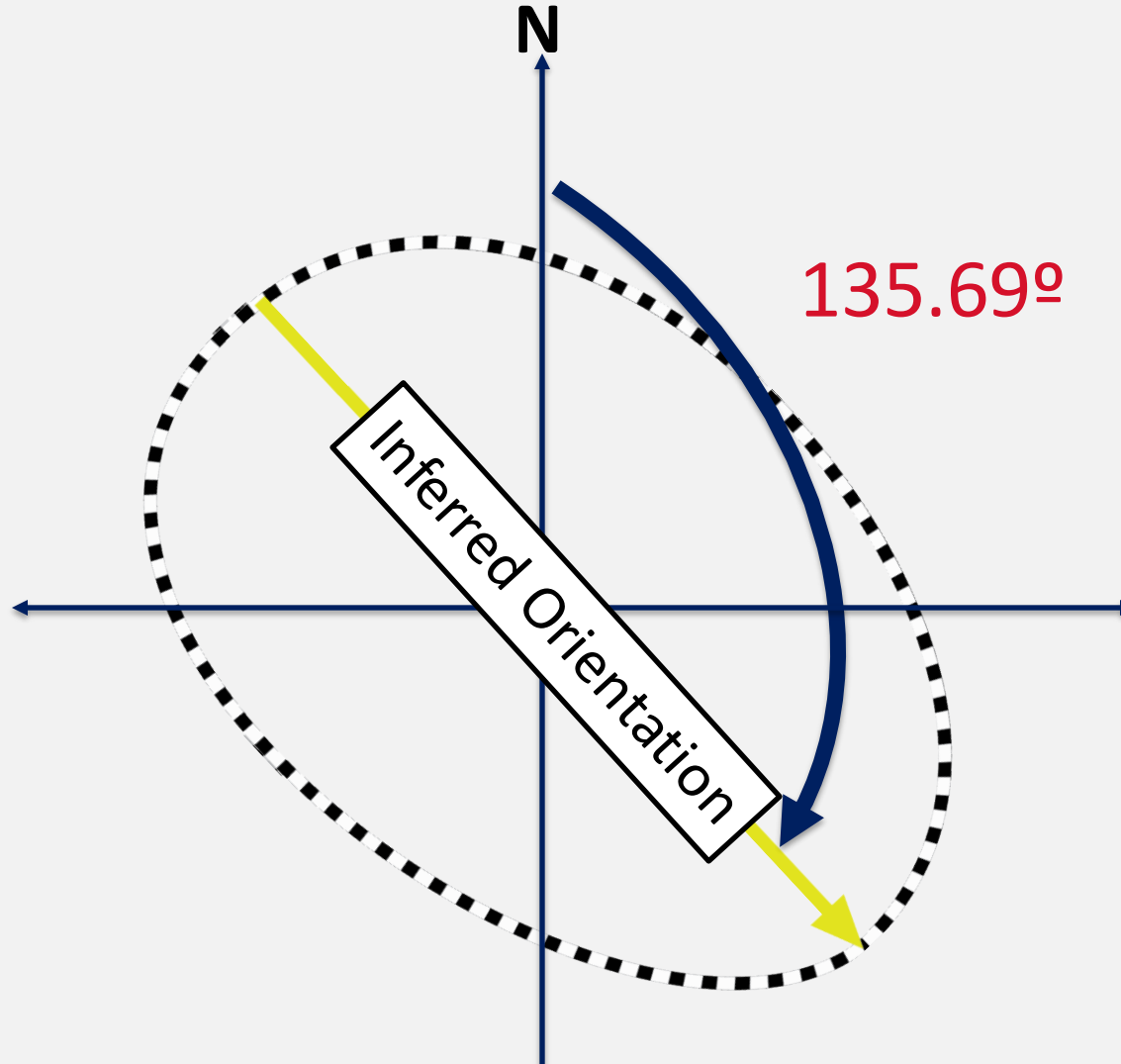
I use templates fit to the bays for measurement. This “bayCarolina” Archetype fits Antioch and 16,000 additional bays with great accuracy.

bayCarolina Archetype Template



Note it is NOT a pure oval, but is flattened on one side.

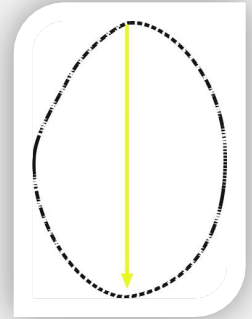
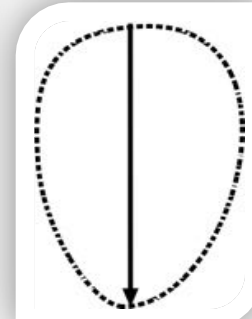
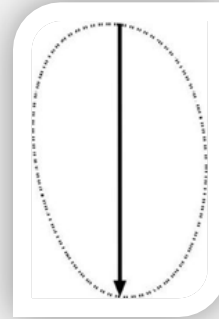
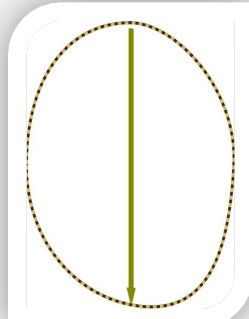
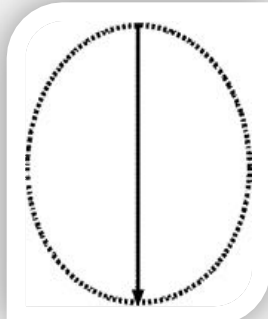
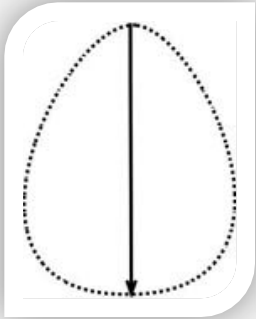
bayCarolina Archetype Template



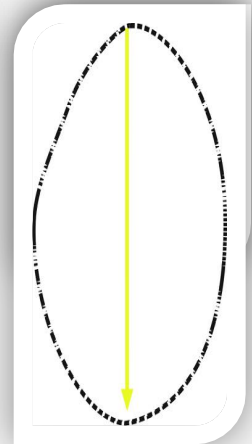
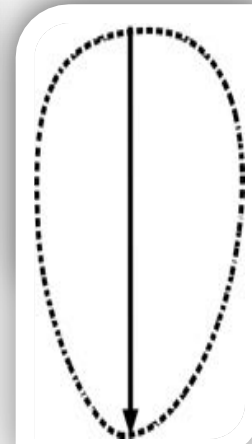
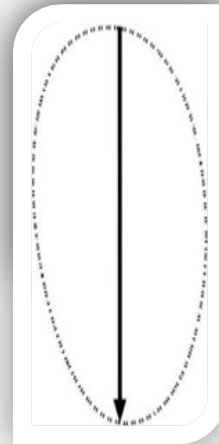
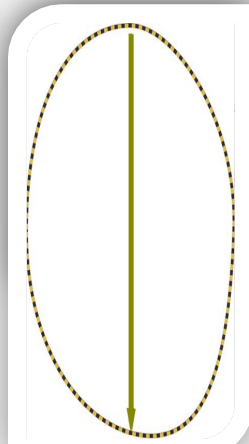
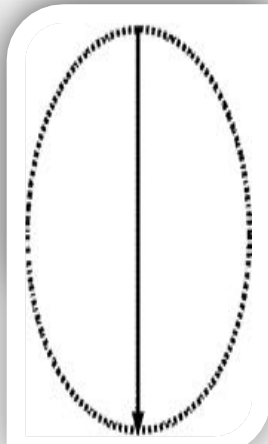
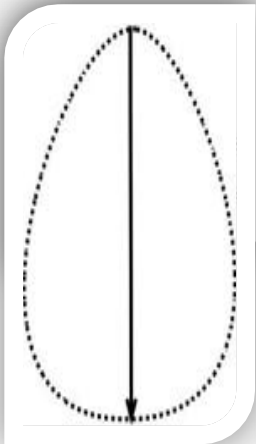
I track the orientation in degrees from North.

Taxonomy of landform Genus “Carolina Bay”

- Six tightly constrained archetypes as Species

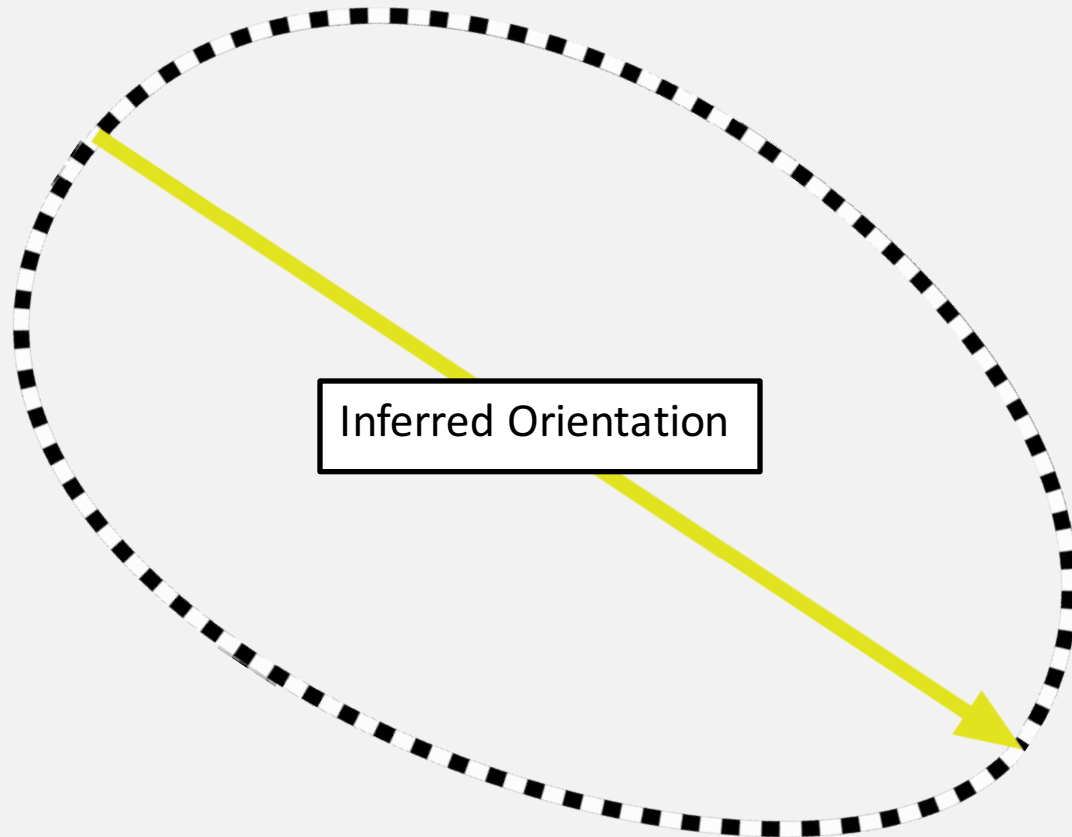


- Bell Oval Shore Carolina South West



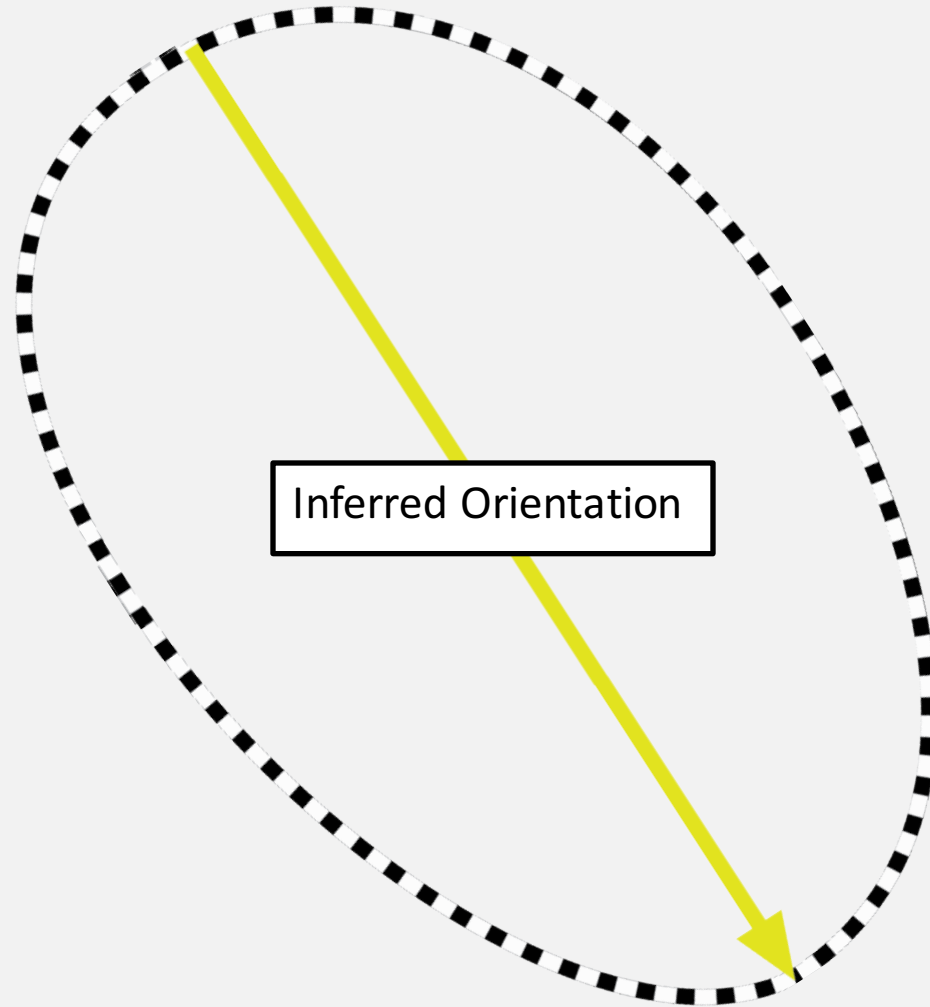
I have used **six templates** in the Survey, each is adhered to robustly within a given region. The templates can be shrunk or stretched...

bayCarolina Species



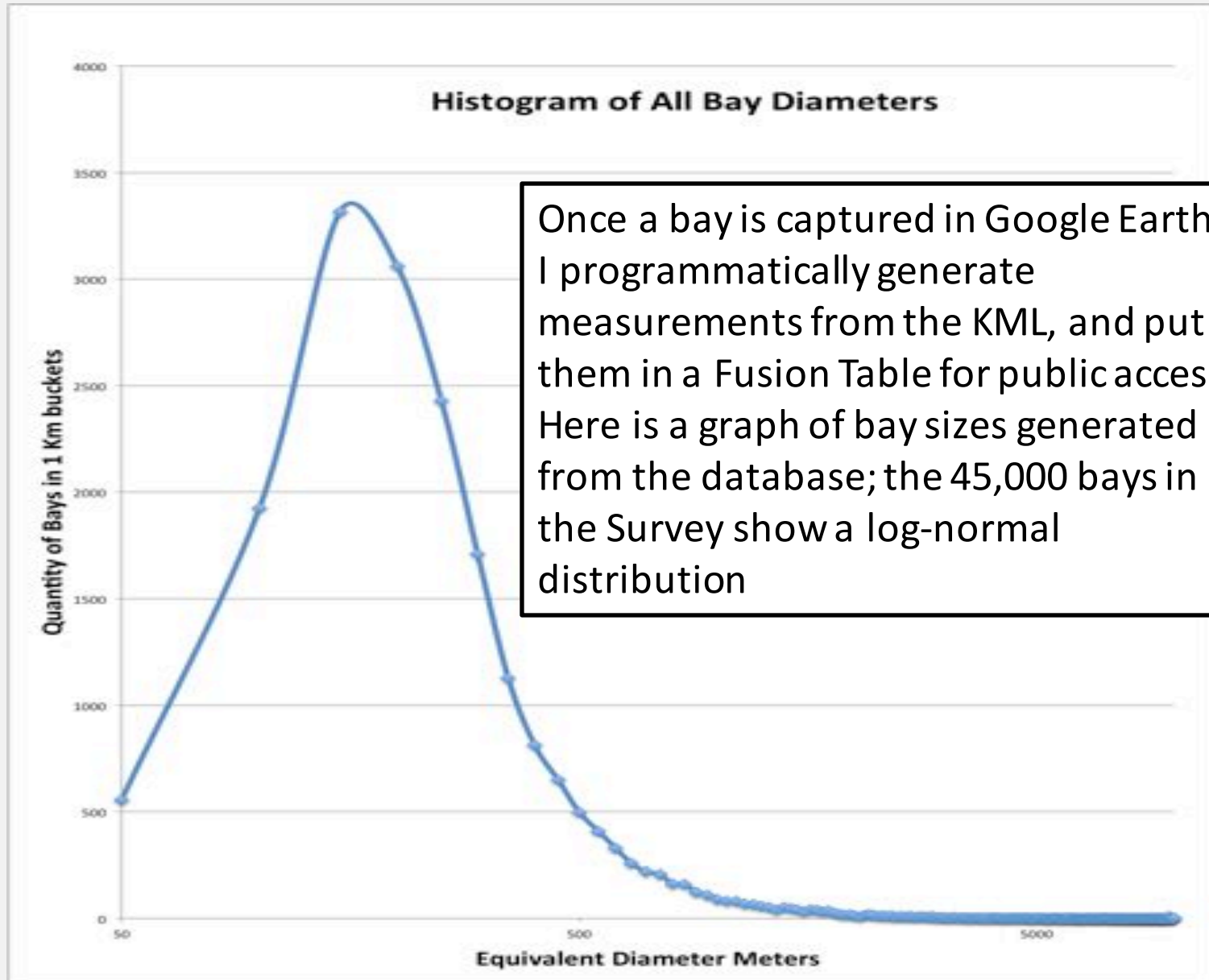
... and rotated to match.

bayCarolina Species



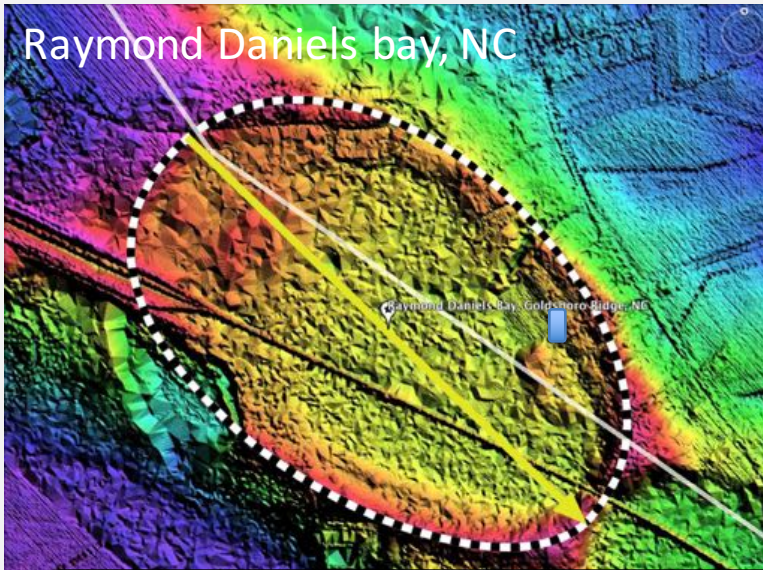
... and rotated to match.

Bay Sizes Exhibit Log-Normal Distribution

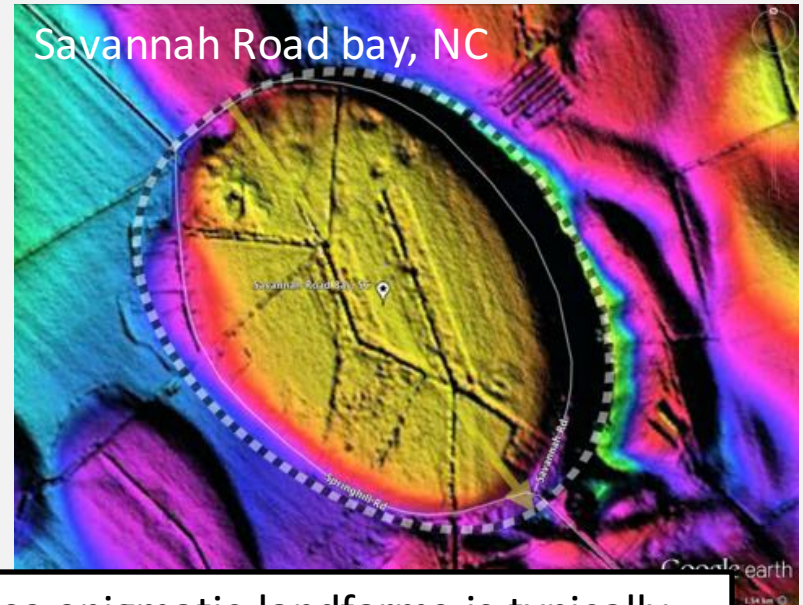


bayCarolina Species

Raymond Daniels bay, NC



Savannah Road bay, NC

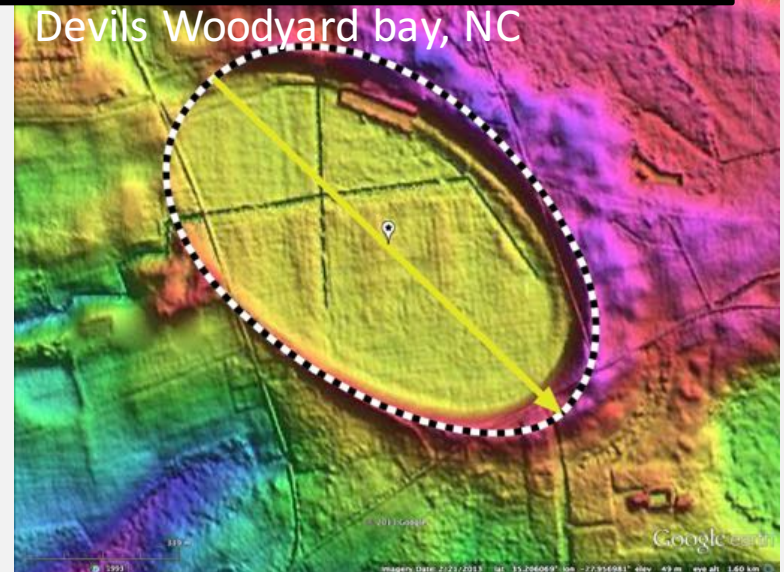


Research into the geomorphology of these enigmatic landforms is typically directed at easily recognized examples. There may seem to be little reason to identify less wholesome examples.

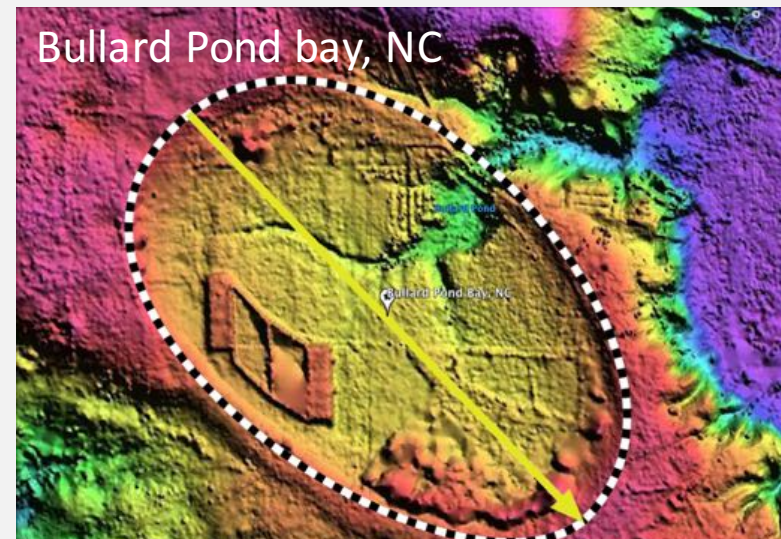
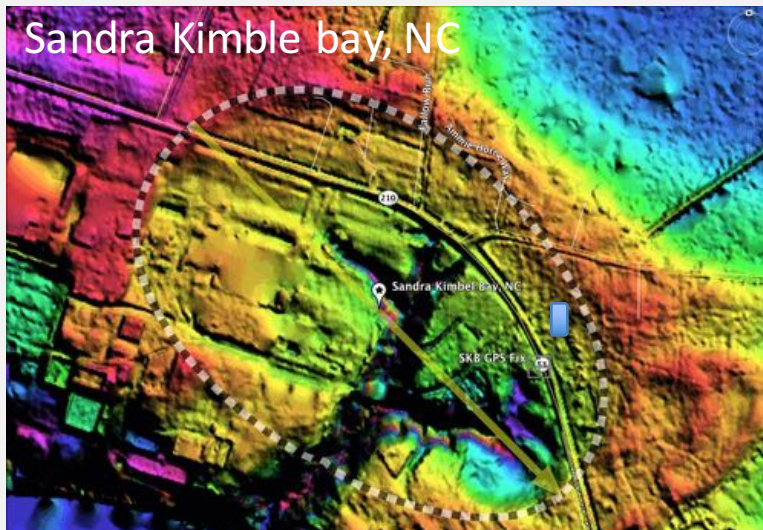
Antioch bay, NC



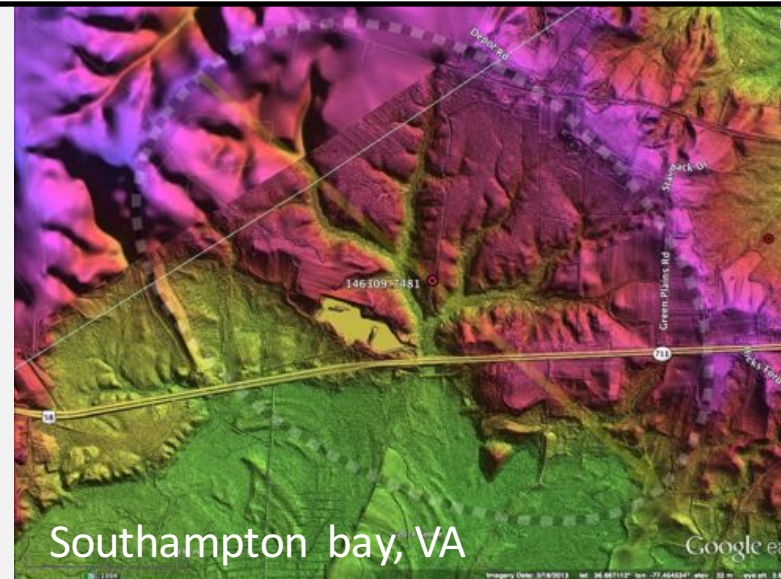
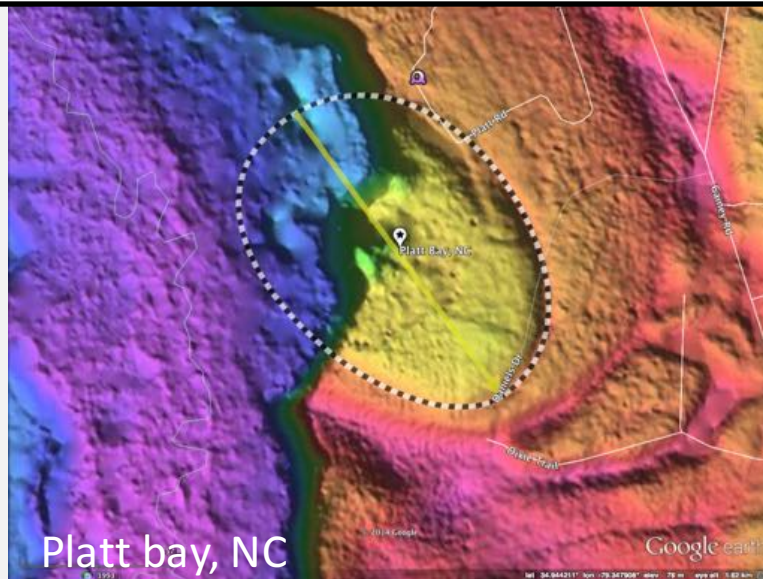
Devils Woodyard bay, NC



Heavily Eroded bay Carolina Species



..yet, a holistic assessment shows that erosional and accretionary processes are struggling to annihilate existent bays. ...most **heavily altered bays** are apparent only in the LiDAR – and correlating them with a template, as I do here, augments the assessment.



Age of the Bays

Age of the Bays

Results From Others

Age of the Bays

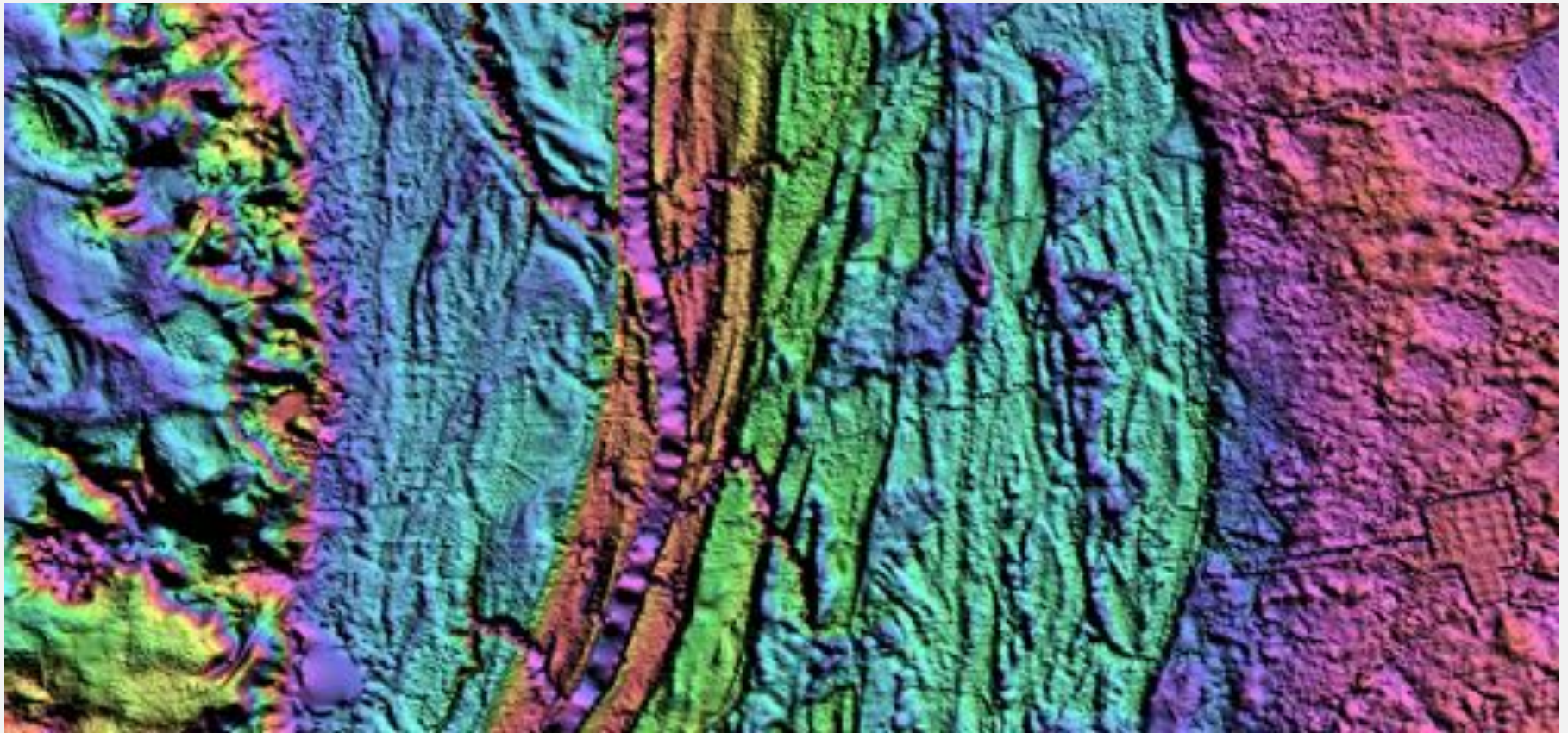
Pollen Chronology: Frey, 1955 – Pre-Illinoian?

“... the two lower organic layers in Singletary Lake (and other Carolina bays as well) antedate the Wisconsin Glacial... if the middle layer dates from the Sangamon, then the lowest layer might logically be associated with the Yarmouth.”

Frey, David G, 1955, A Time Revision of the Pleistocene Pollen Chronology of Southeastern North Carolina, Ecology, Vol 36, No. 4

Age of the bays

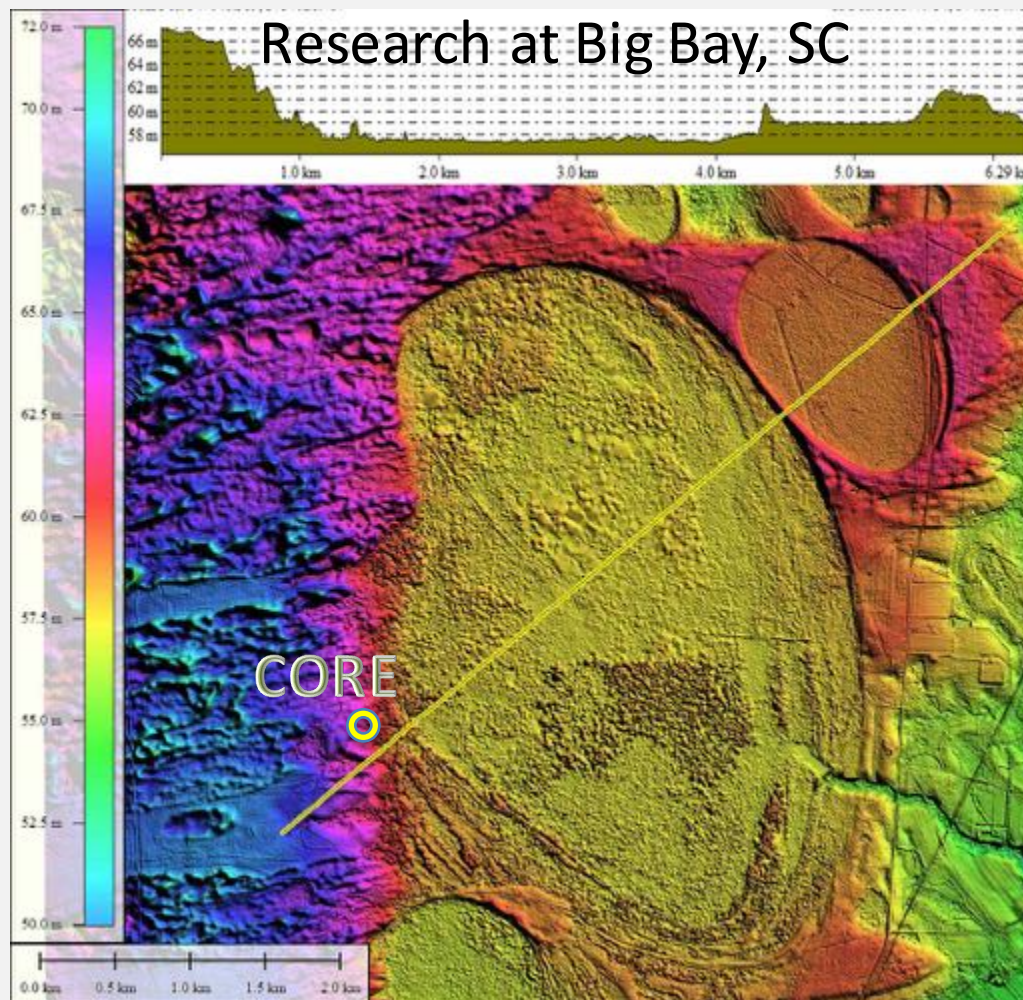
An examination of Terrace surfaces in the CFRV led **Soller** to pronounce Carolina bays to be of Middle Pleistocene in age. The current flood plain and the Wando terrace have none, but the older, higher, terraces do. The new Cosmogenic ^{26}Al - ^{10}Be burial analysis would better constrain those paving dates.



Soller, D. R., 1988; Geology and Tectonic History of Lower Cape Fear River Valley, Southeastern North Carolina, U.S. Geological Survey Professional Paper 1466-A

Age of the bays

Thom (1970)- suggested the bays were formed sometime during the mid to late Pleistocene



Big Bay is one of only 28 bays in my Survey over 5 kilometers. It has been the subject of several comprehensive dating exercises. Drained by a natural channel to the southeast, the bay floor has been receptive to the intrusion of a dune sheet. OSL Dating by Ivester tracked the progress of the encroaching dunes back as far as 73 ka at the surface, and 108 ka in nearby rim sands. A coring was taken 80 m from the leading edge of the dune. >>

It reached over 10 meters down to the **Pliocene Duplin Formation** beneath the organic rich bay fill, suggesting the bay could be 3 million years old. They report the usual >48,000 radiocarbon years for the sediment fill Five and a Half meters above the bay floor. Pollen assessment put the dating of a bay fill sample at MIS 5. Cosmogenic analysis anyone???

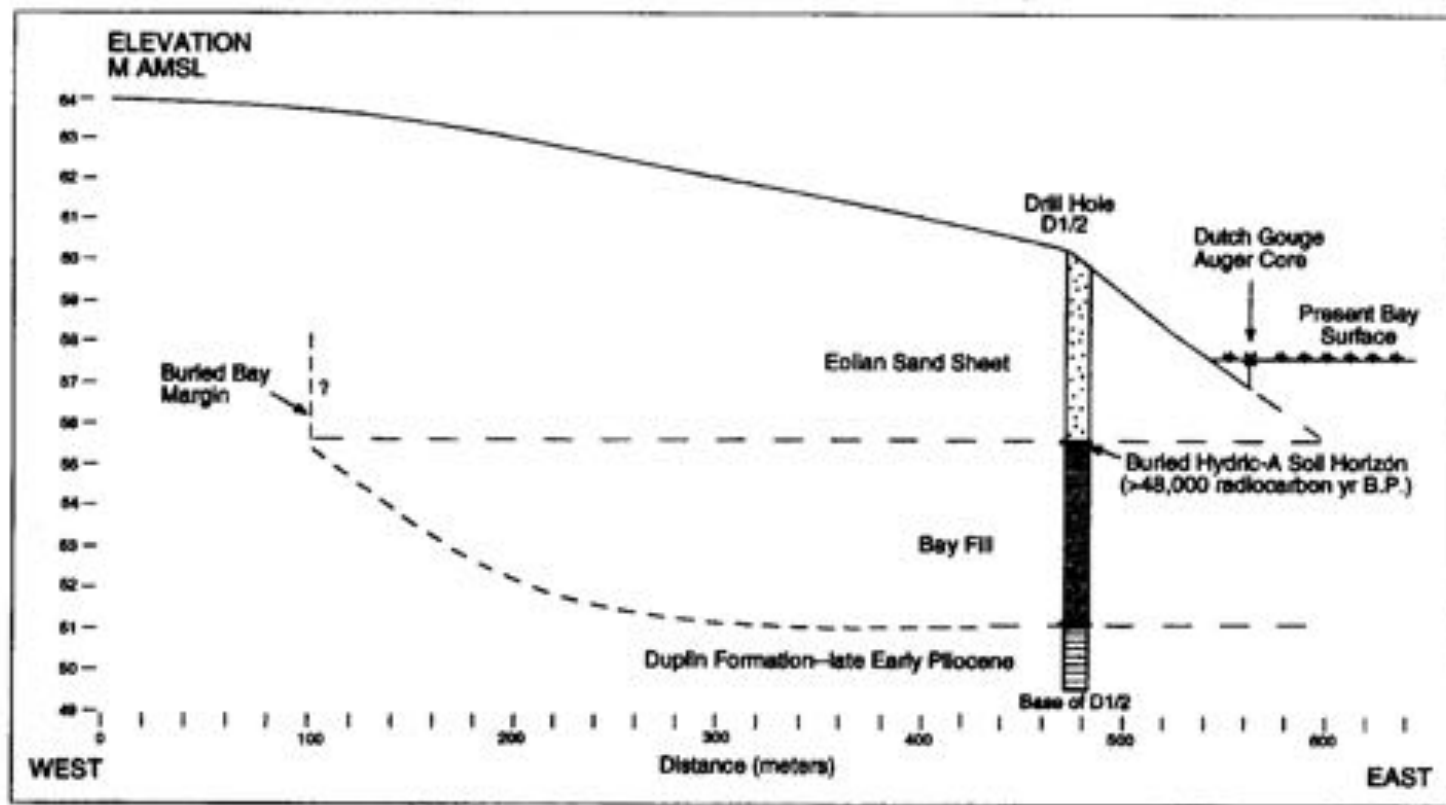
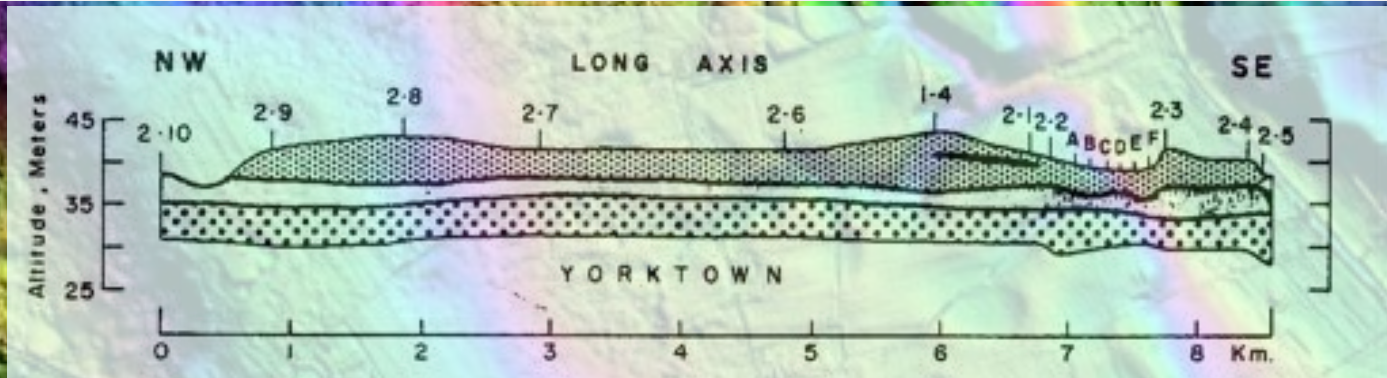


Figure 5. West-east schematic section through the western margin of Big Bay at drill hole D1/2 (see Figure 3 for location).

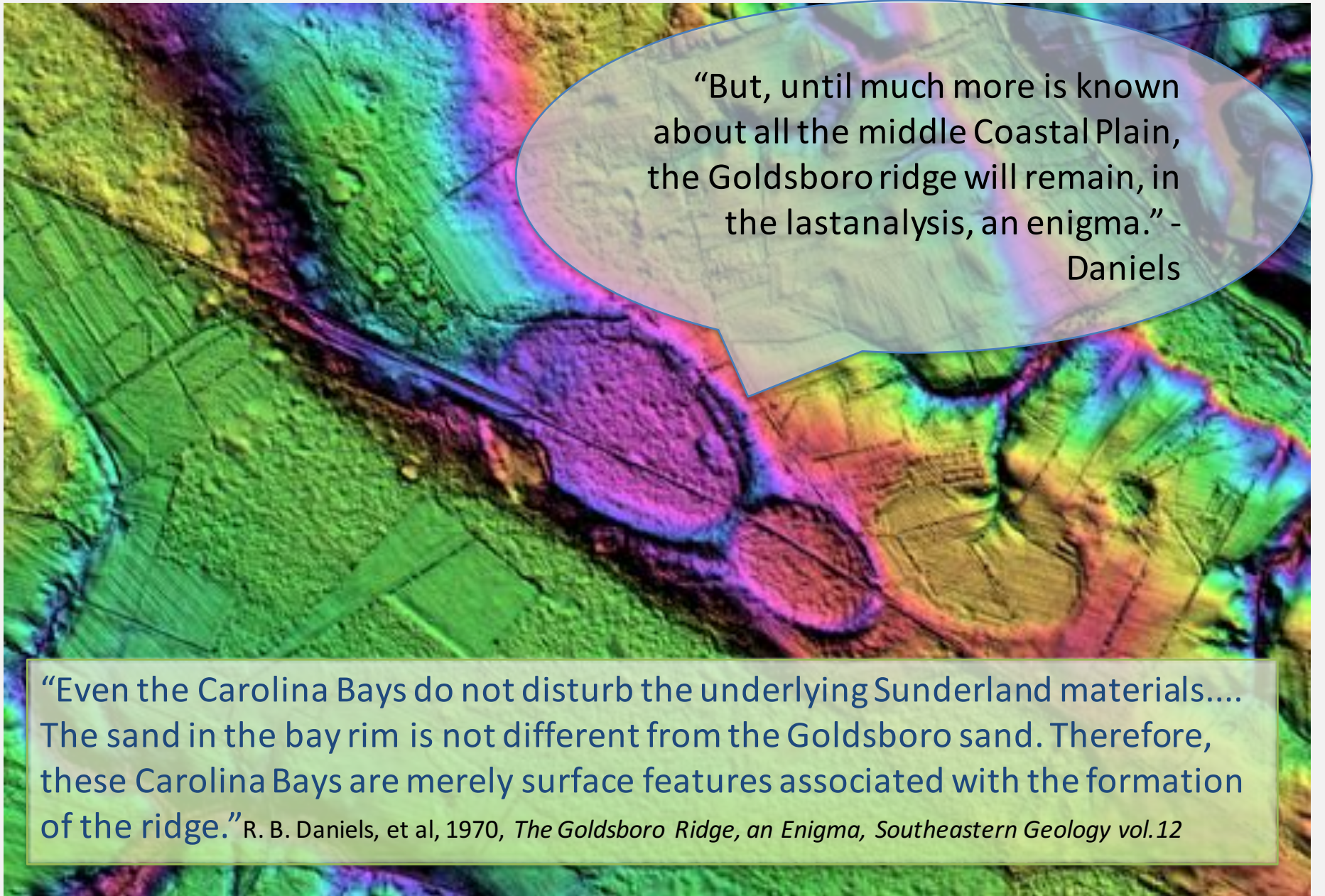
Mark Brooks, et al, 2001, *Pleistocene Encroachment Of The Wateree River Sand Sheet Into Big Bay On The Middle Coastal Plain Of South Carolina*, Southeastern Geology, Vol. 40, No. 4

Goldsboro Ridge, NC



40 years ago **Raymond Daniels** and his team performed the most extensive core fieldwork ever attempted on Carolina bays, at the Goldsboro Ridge. It was noted that the monotonous bulk sand deposit makes sharp unconformable contact with the antecedent surface,

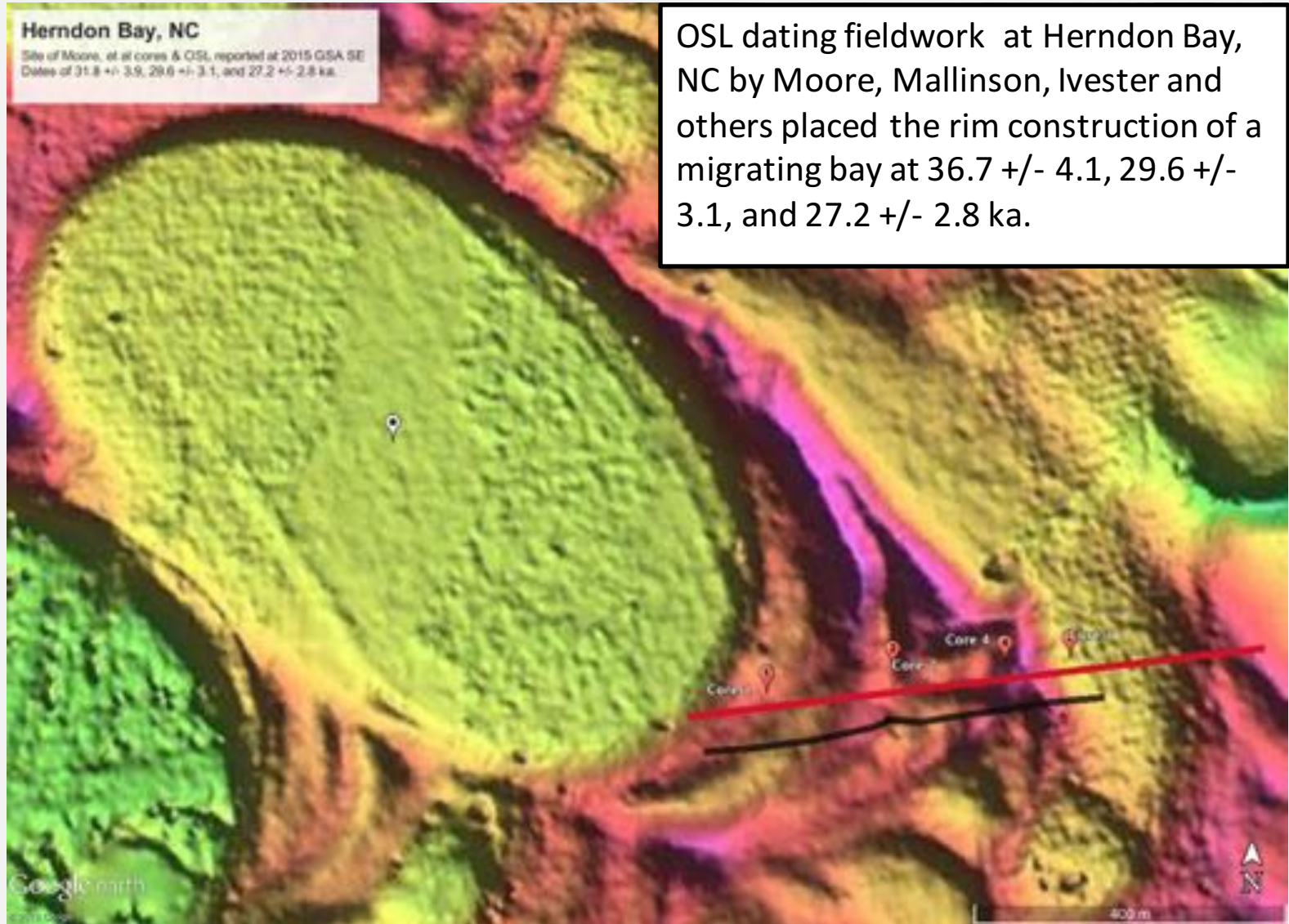
Goldsboro Ridge, NC



“But, until much more is known about all the middle Coastal Plain, the Goldsboro ridge will remain, in the last analysis, an enigma.” - Daniels

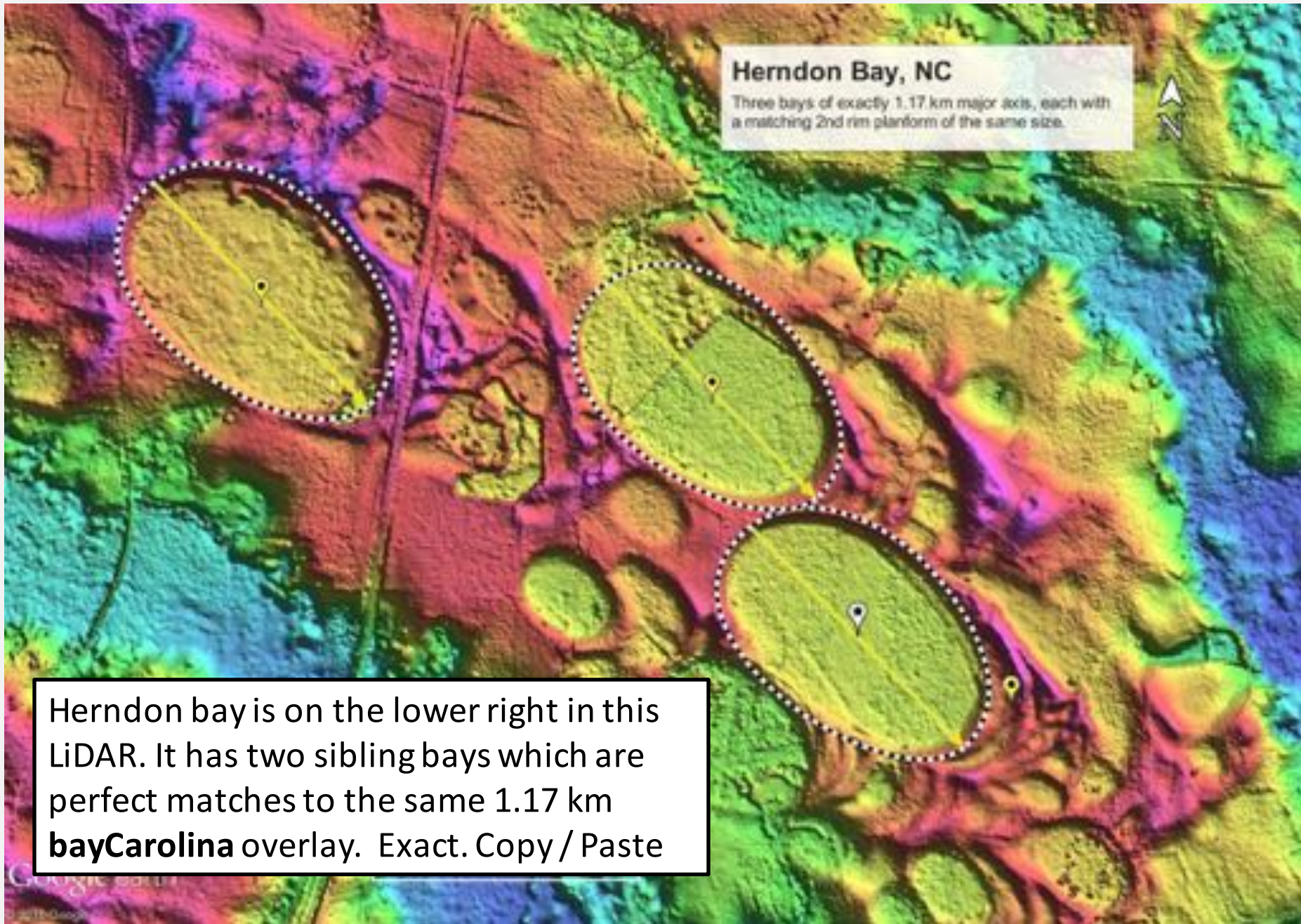
“Even the Carolina Bays do not disturb the underlying Sunderland materials.... The sand in the bay rim is not different from the Goldsboro sand. Therefore, these Carolina Bays are merely surface features associated with the formation of the ridge.” R. B. Daniels, et al, 1970, *The Goldsboro Ridge, an Enigma, Southeastern Geology* vol.12

Age of the bays

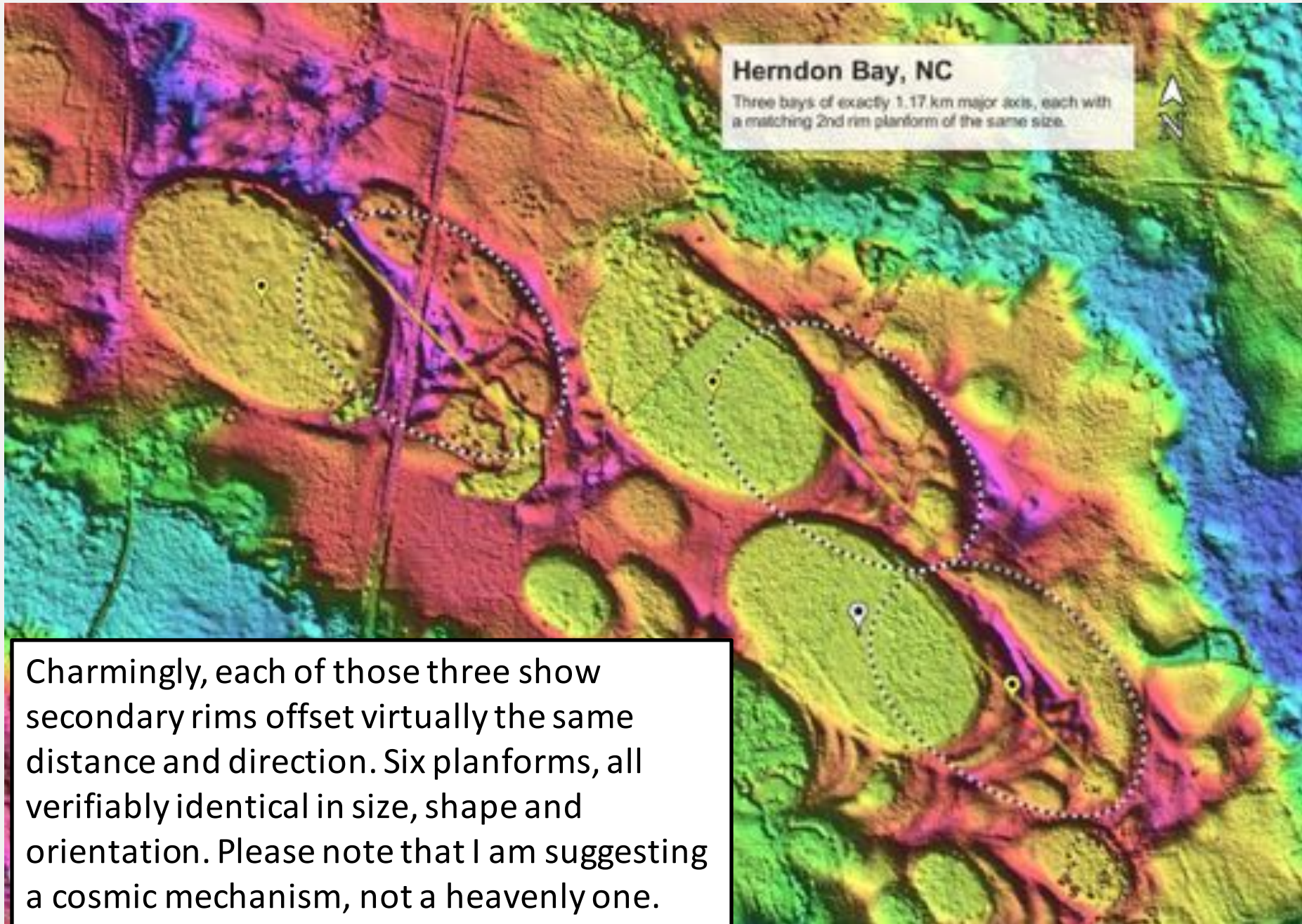


Moore, Brooks, Mallinson, Parham, Ivester And Feathers, *Rapid Scour, Sand Rim Construction, And Basin Migration Of A Carolina Bay In Southeastern North Carolina*, GSA Abstracts With Programs. Vol. 46, No. 3, P.96

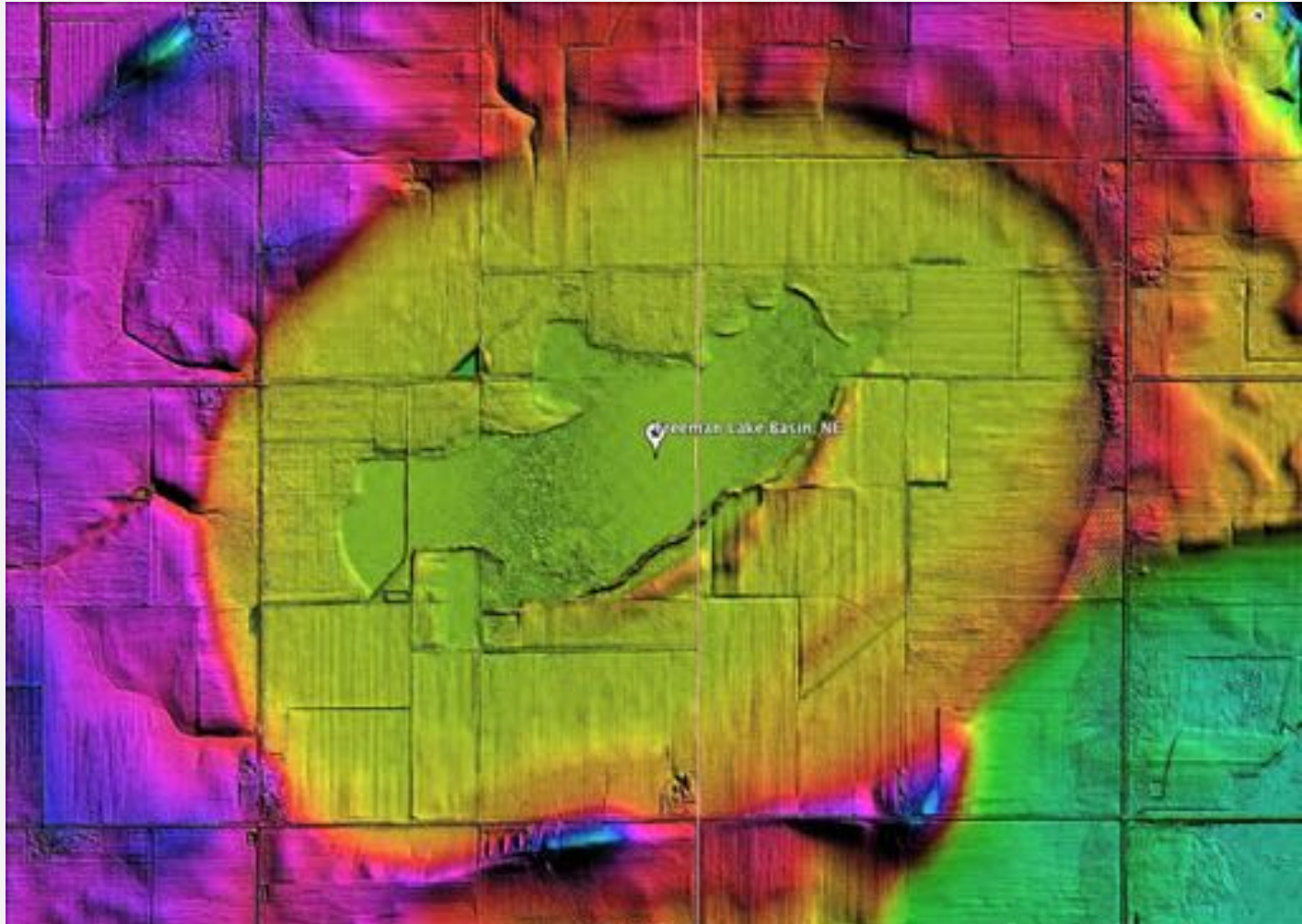
Age of the bays



Age of the bays

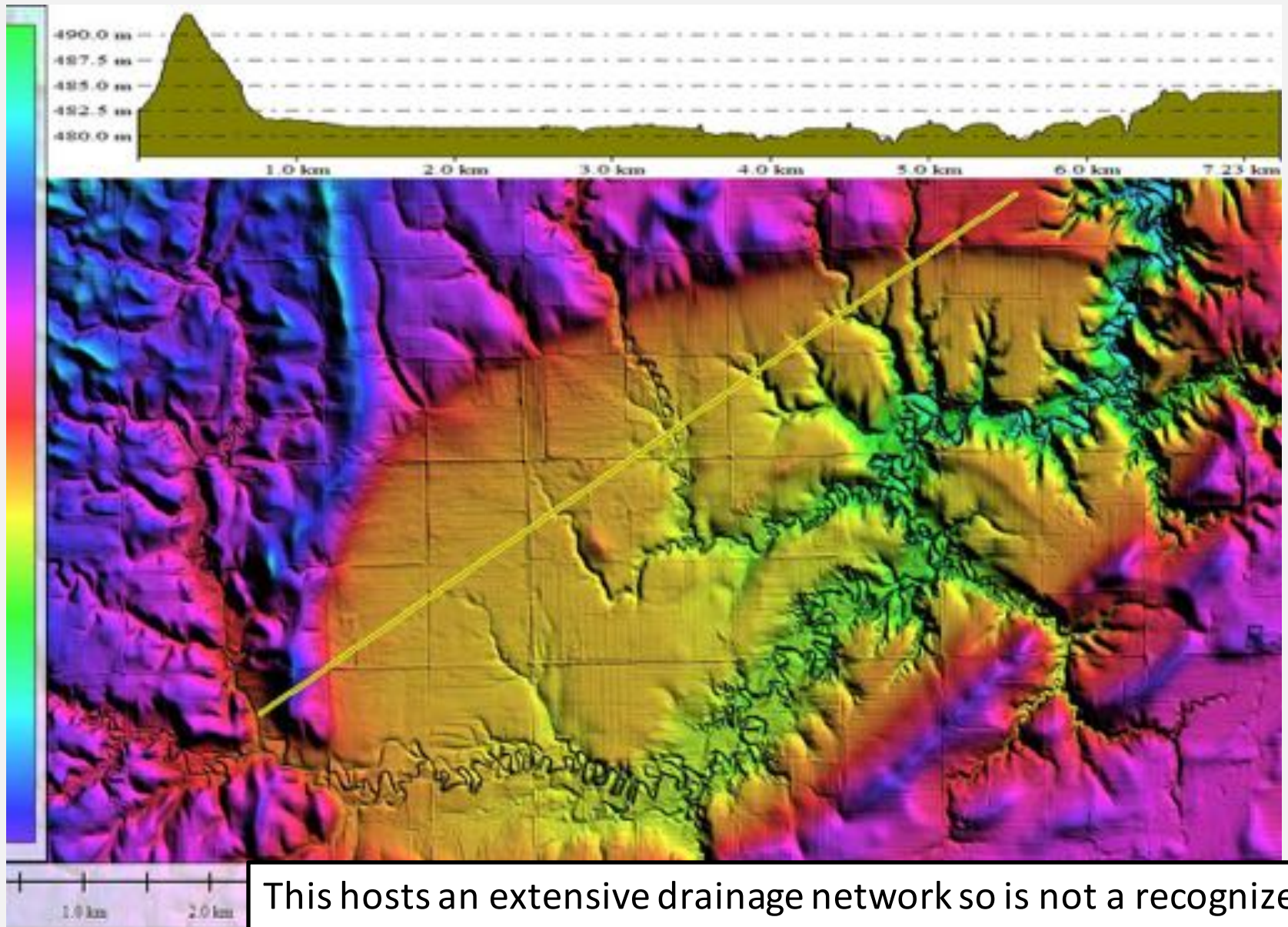


bayWest Freeman Lake Basin, NE



This is one of ~500 large “**Rainwater basins**” found in Nebraska. Zanner observed that these may have the same geomorphology as the Carolina bays. I think so, too.

bayWest Chelsea Bay, NE



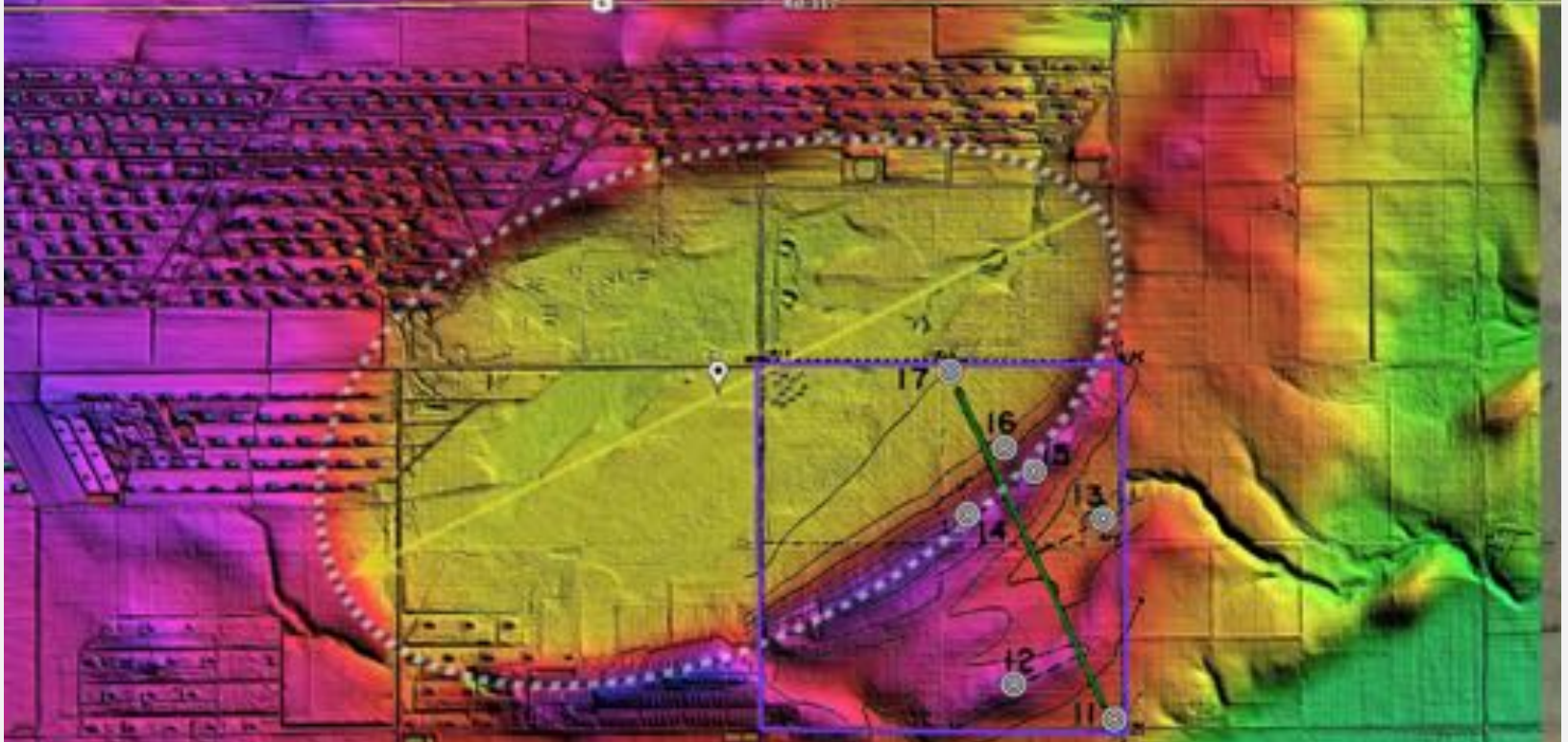
This hosts an extensive drainage network so is not a recognized Rainwater basin. But it matches the bayWest planform.

bayWest McMutrey Marsh, NE

McMutrey Marsh Bay, NE

Kuzila's core transects results show relief of rims is even sharper on antecedent surface found under 10 meter blanket of wind blow loess.

“These basins are palimpsest landforms created by the draping of a younger loess blanket over these underlying depressions .” - Zanner and Kuzila 2001



McMutrey Basin was one of the two locations that Kuizila (1994) examined using deep cores. Beneath 10 meters of well-provenanced Pleistocene glacial loess formations, he identified an antecedent coarse sand and gravel topography that projected through the loess. That base formation was not dated, but must have been over 500,000 years old. This is a good location to date with cosmogenic ^{26}Al - ^{10}Be burial dating techniques..

Burial Under Newer Sediments

**Burial Under Sediments
by
Eolian Sediments
or
Fluvial/marine Inundation**

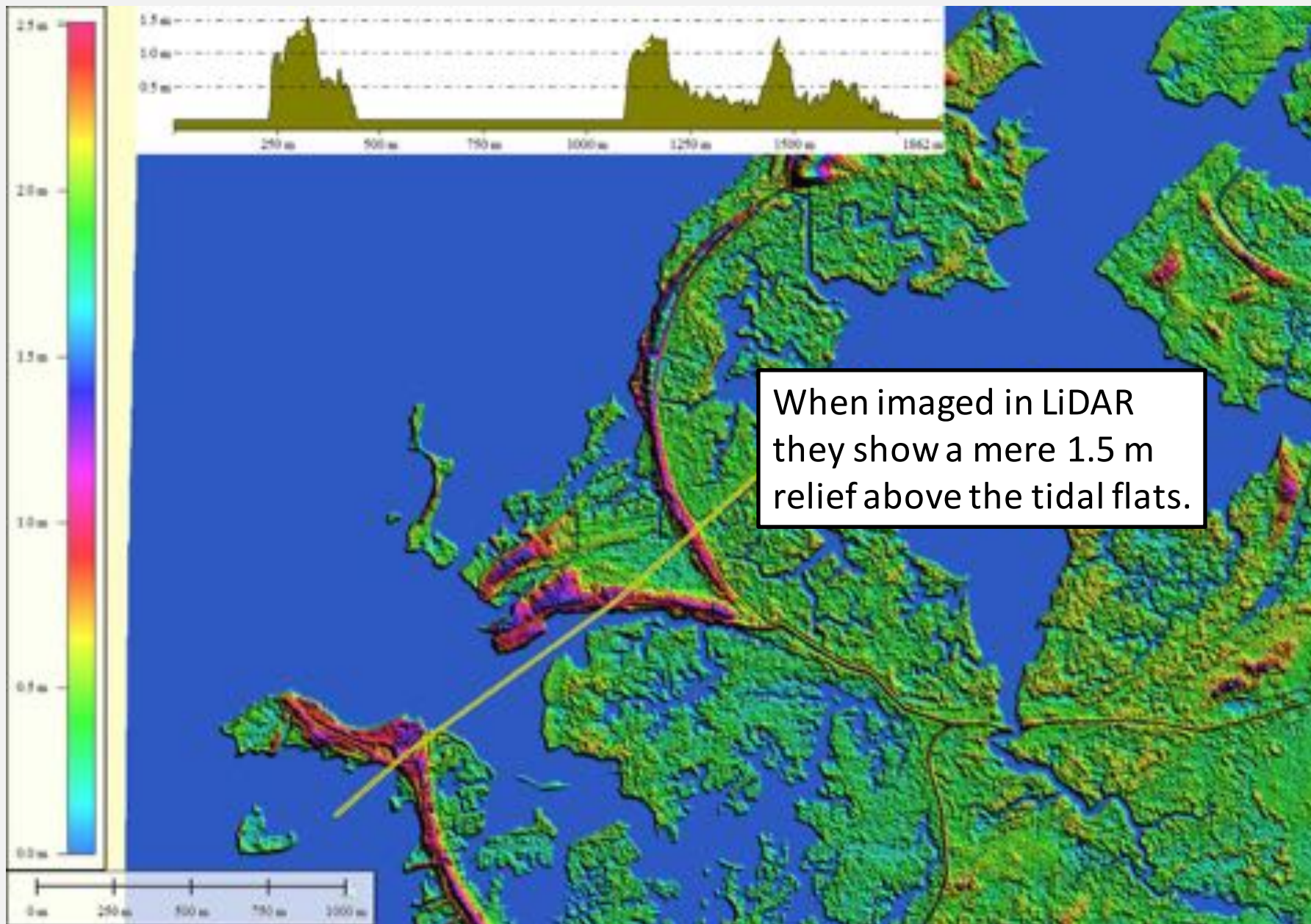
Chesapeake Bay, Rumbley, MD



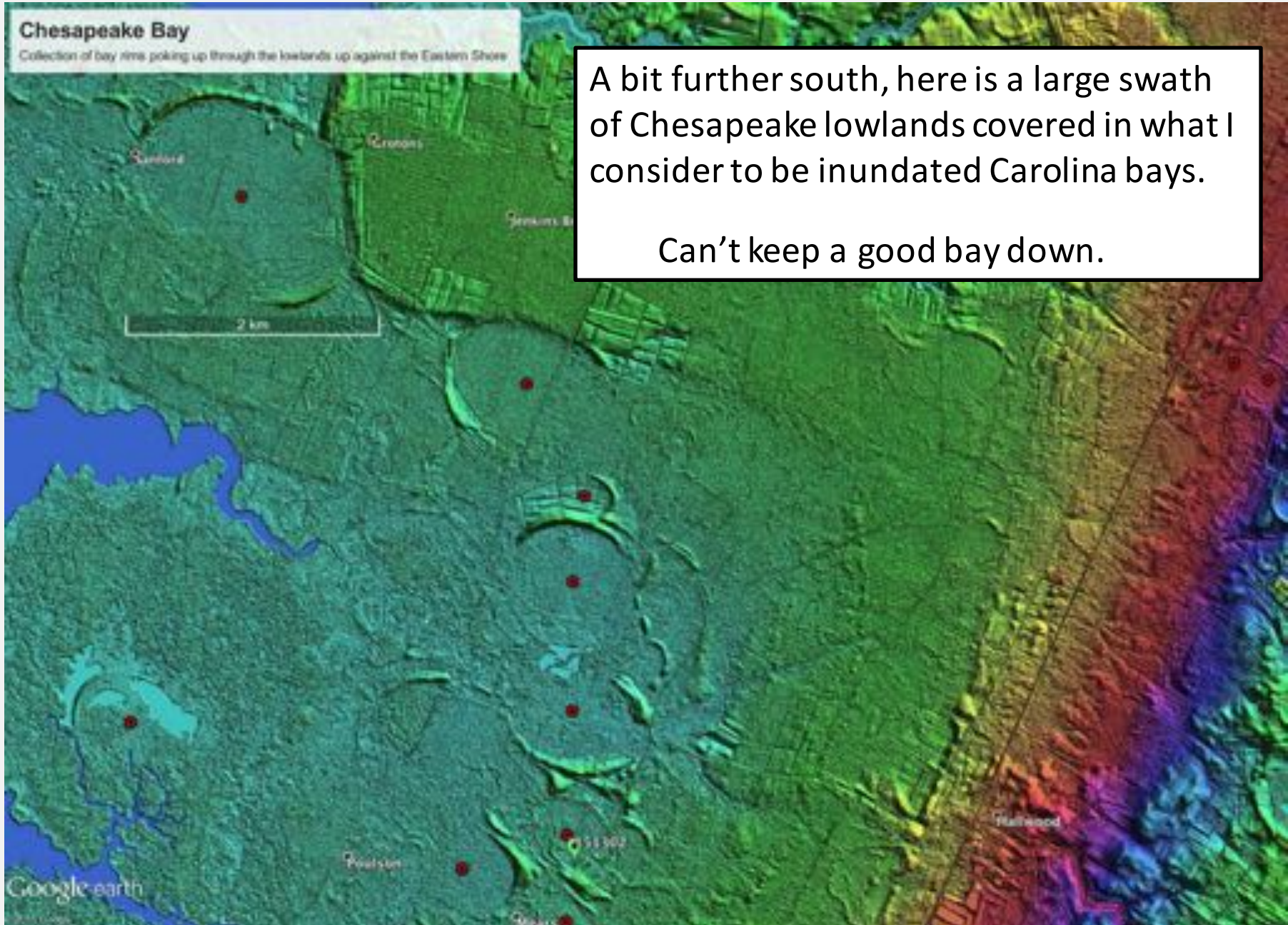
The numerous bays poking through the surface of Chesapeake Bay were thought by Cooke to have been formed by eddy currents *driven by the Earth's rotation*.

This plate is from his USGS Professional Paper 254.

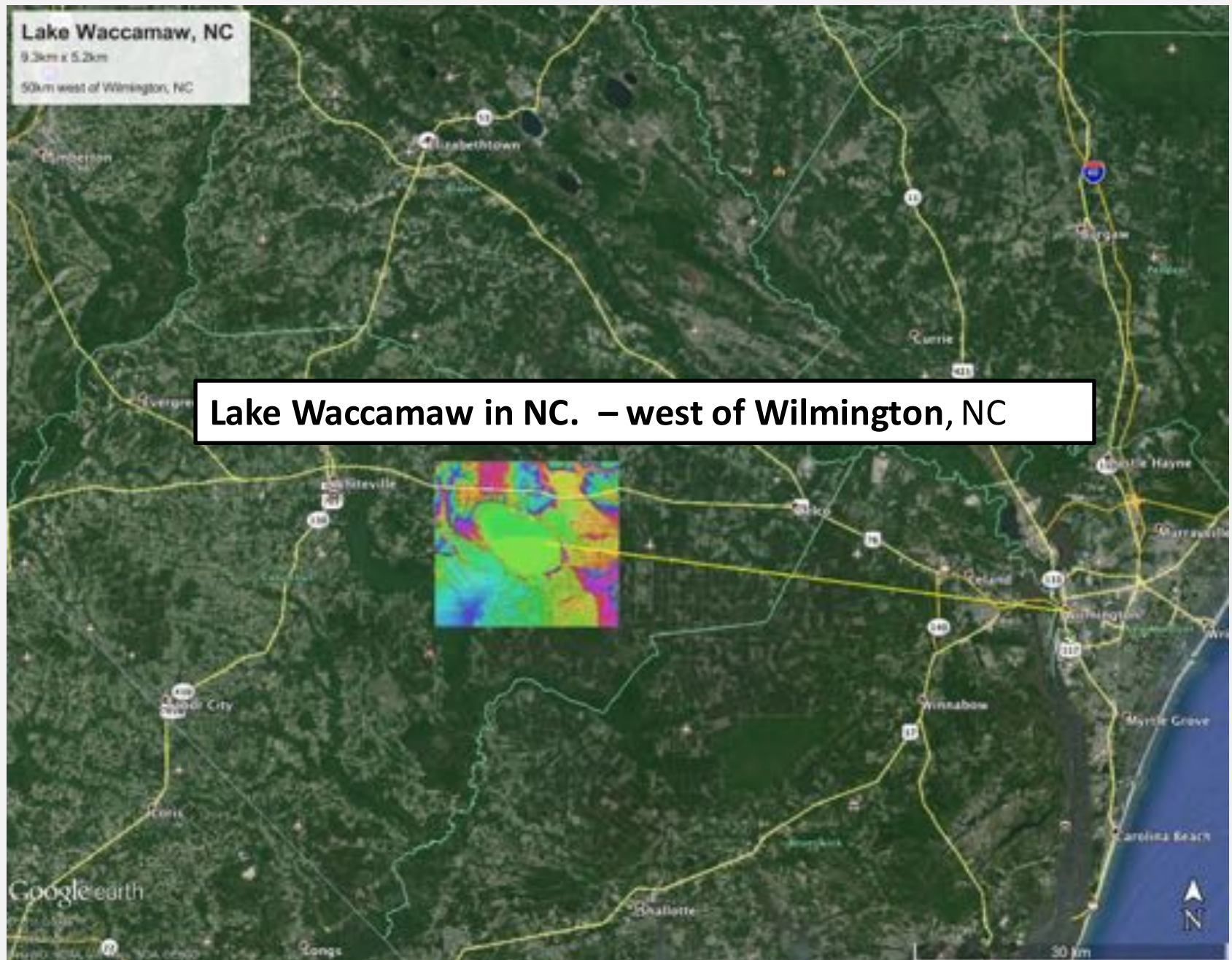
Chesapeake Bay, Rumbley, MD



Chesapeake Bay lowlands, Delmarva Peninsula, VA



Lake Waccamaw

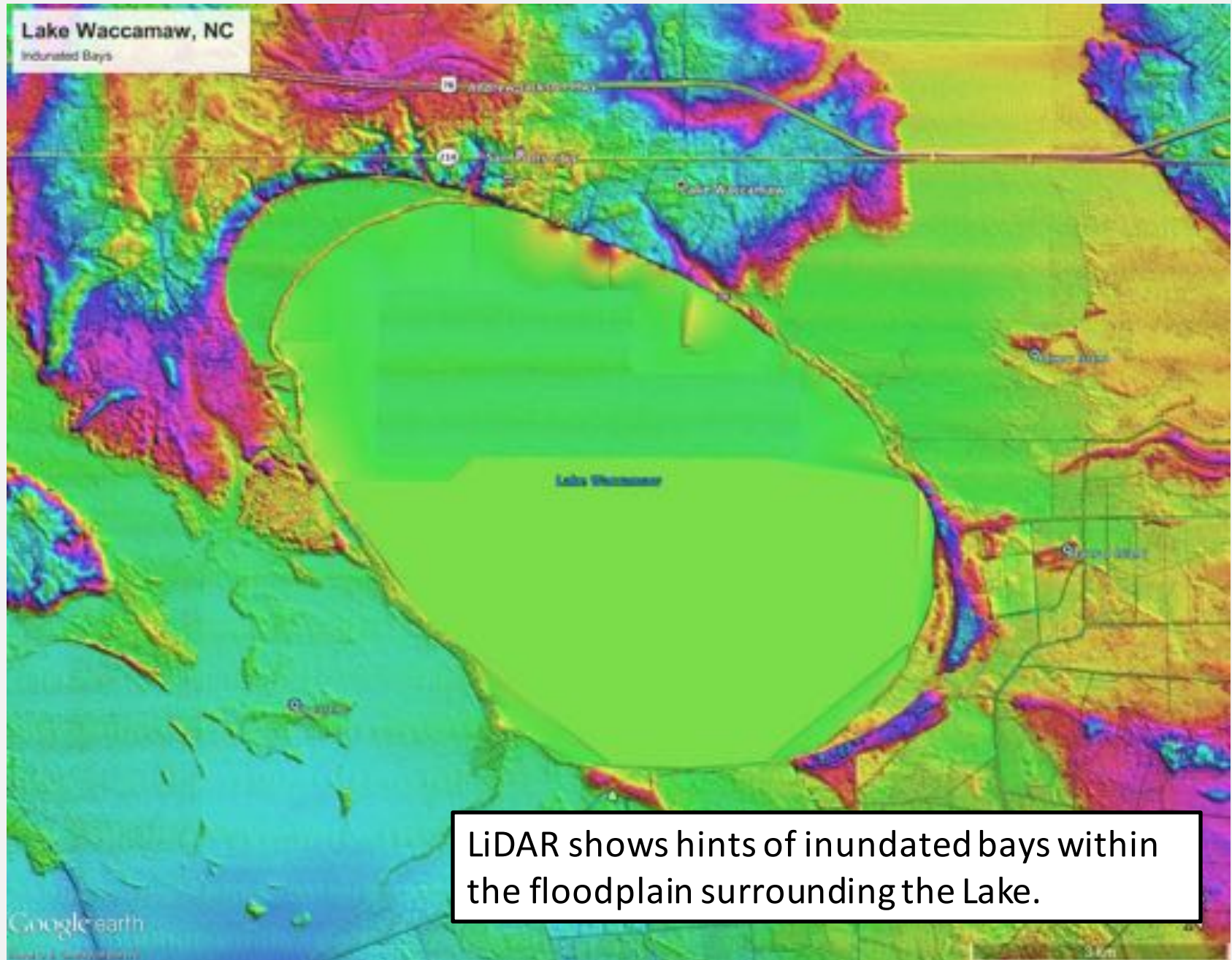


Lake Waccamaw



Lake Waccamaw in NC. – west of Wilmington.
In satellite imagery, the lake doesn't match the planform – but that is not my interest here..

Lake Waccamaw



Lake Waccamaw

Infrared photography reveals their true presence in a dramatic way. How long were these around as robust bays before being buried in flood plain deposits – and why are they not just “gone”.



Blythe Bay, NC



Blythe Bay, NC
WELLS, B. W., 1943. Blythe Bay, a record of
changing ocean levels. J. Elisha Mitchell Soc.
Soc. 59: 115-119.

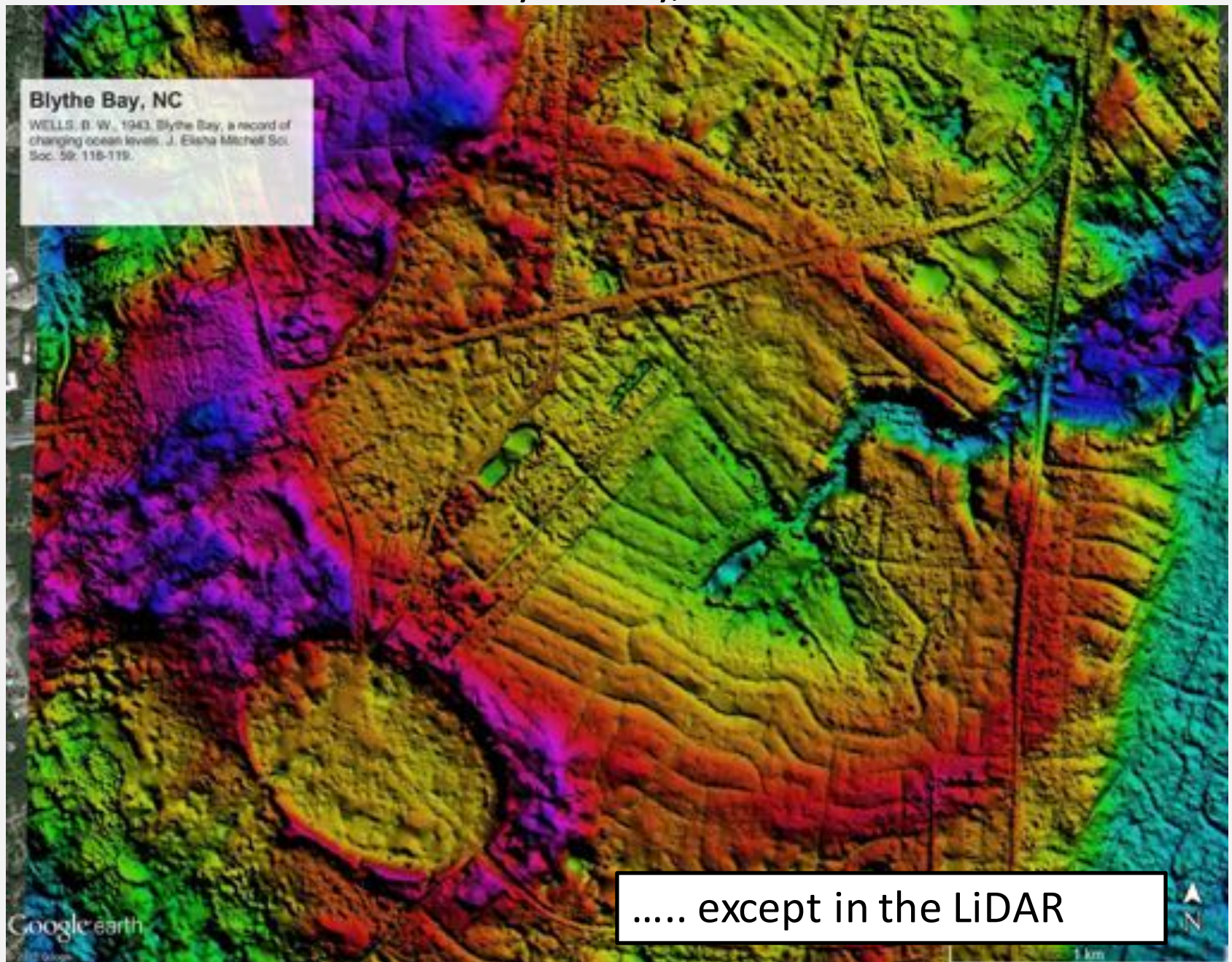
Blythe Bay in Wilmington NC. Wells reported on this bay back in the 1950s, illustrated with this photo, when the terrain was all farmland.

Blythe Bay, NC

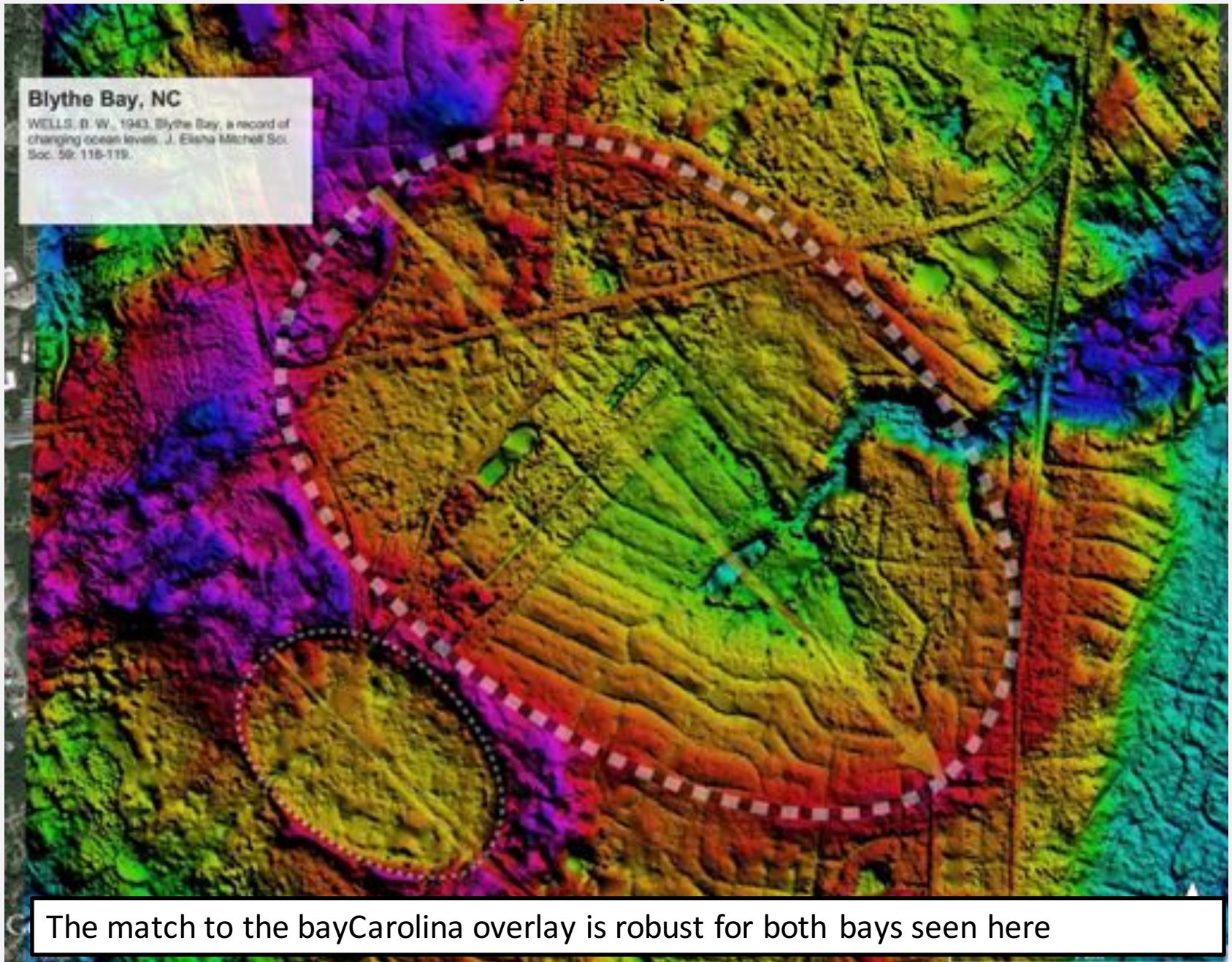


Today it is urban landscape, the bay mostly obscured...

Blythe Bay, NC

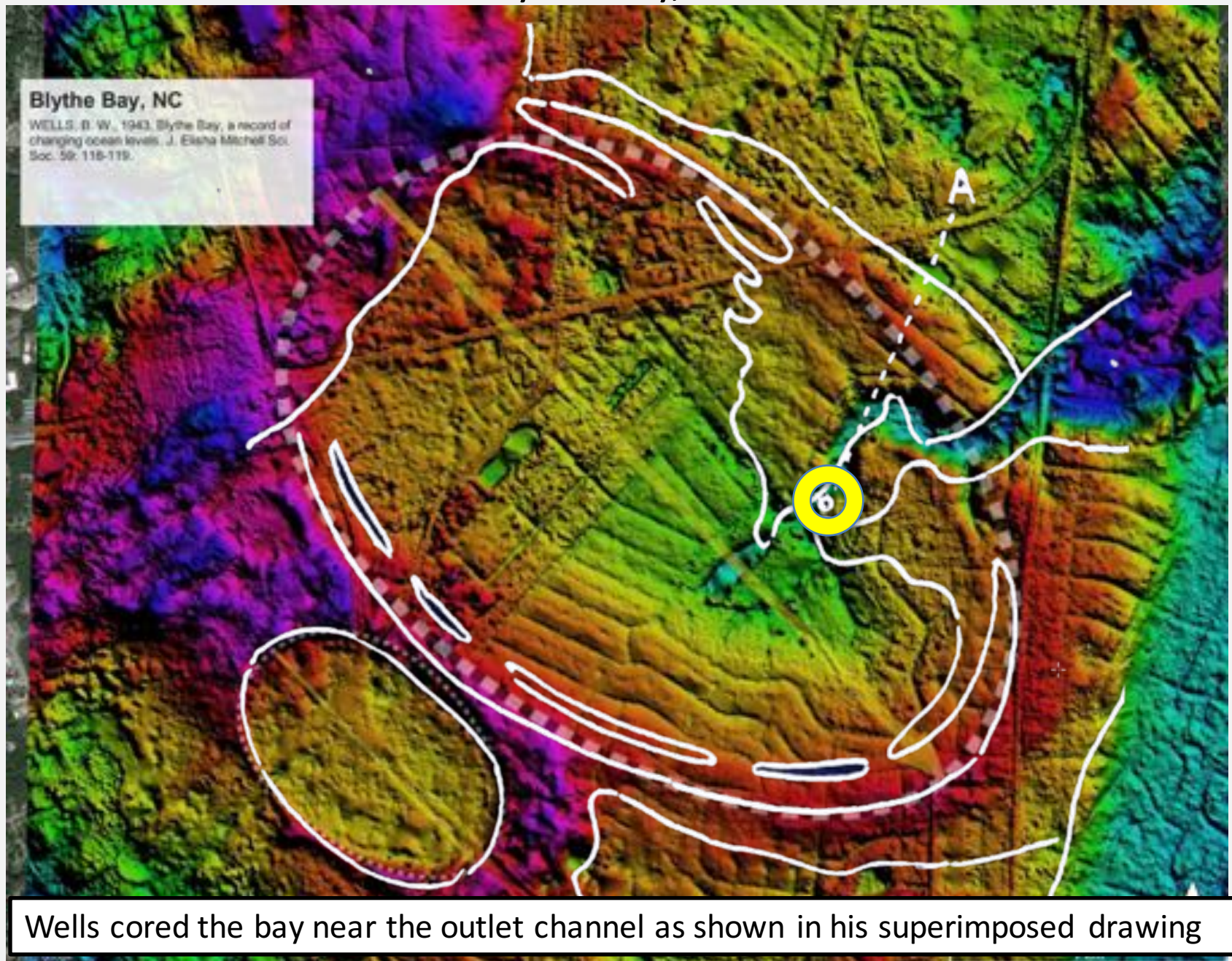


Blythe Bay, NC



The match to the bayCarolina overlay is robust for both bays seen here

Blythe Bay, NC



Wells cored the bay near the outlet channel as shown in his superimposed drawing

Blythe Bay, NC

First, “five and a half feet of peat developed”

Then, “with the rise of the sea ..., estuary tidal currents charged with fine sand silt and clay from the nearby mouth of the Cape Fear River became deposited over the peat to a maximum depth of seven and a half feet.”

BLYTHE BAY

silt and sand

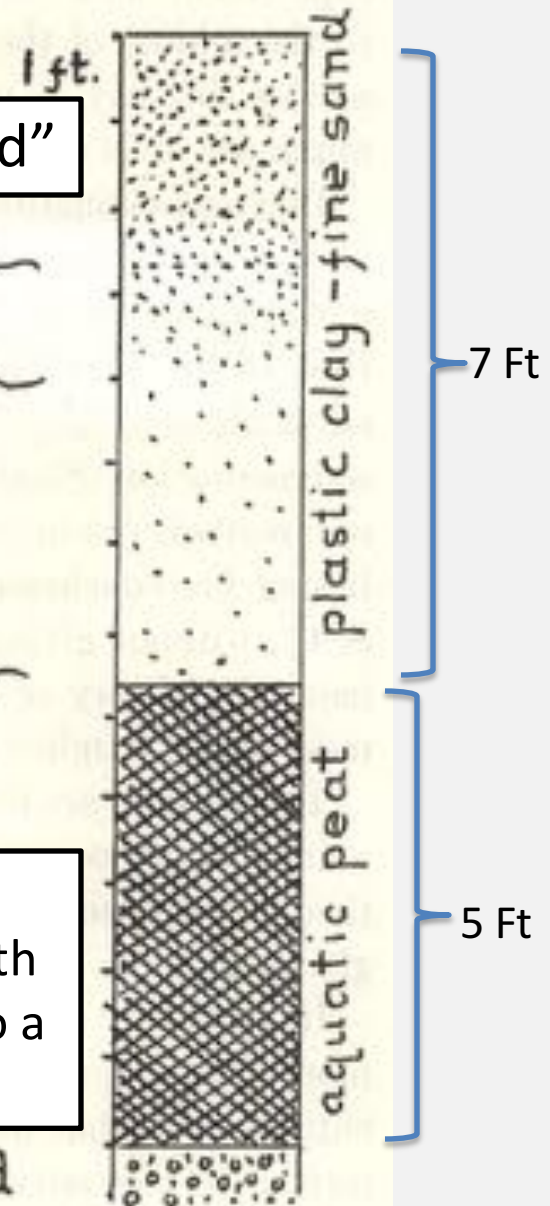
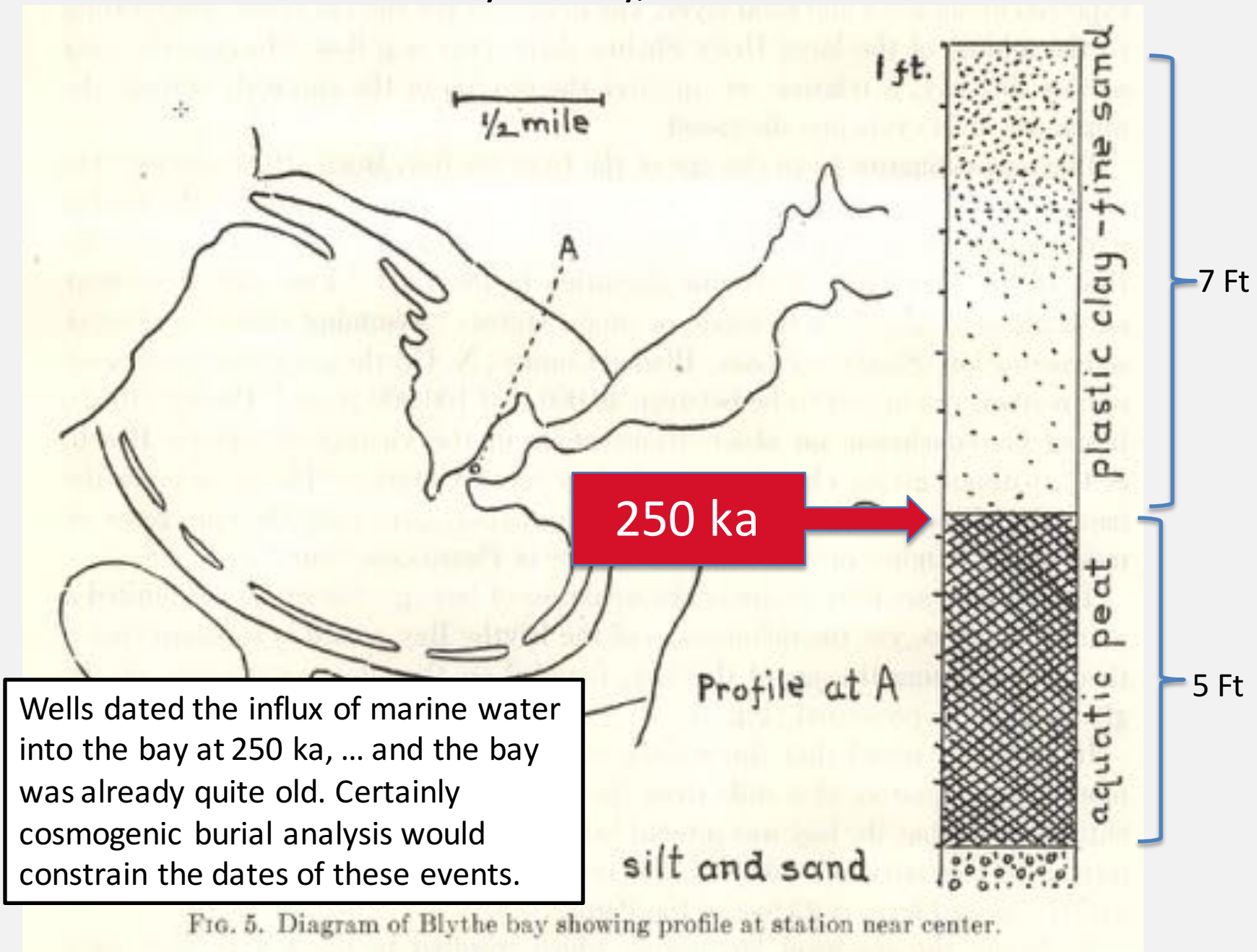


FIG. 5. Diagram of Blythe bay showing profile at station near center.

Blythe Bay, NC



Pee Dee River, SC

Here is an area of South Carolina along the Pee Dee River Estuary

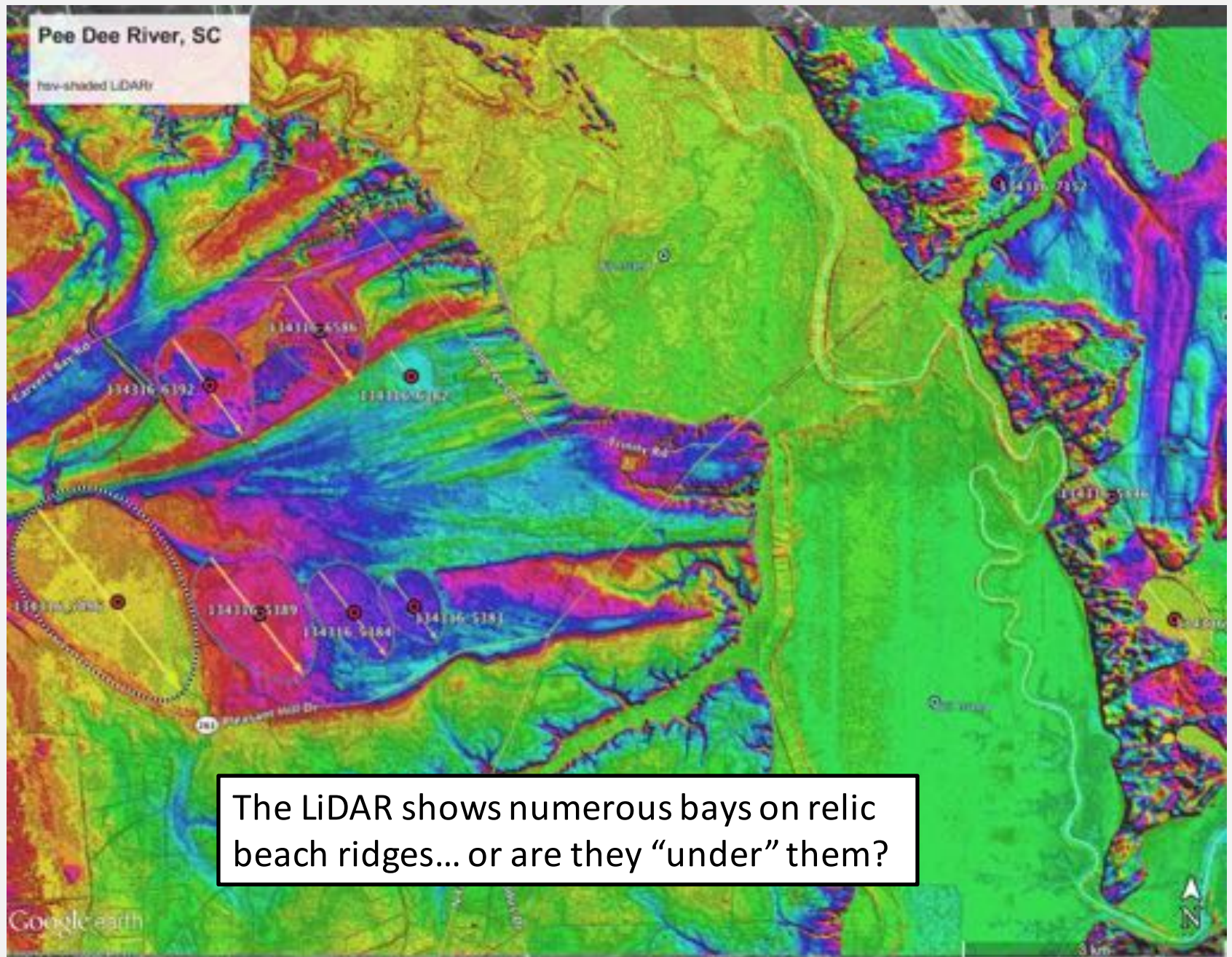
Google earth

20 km

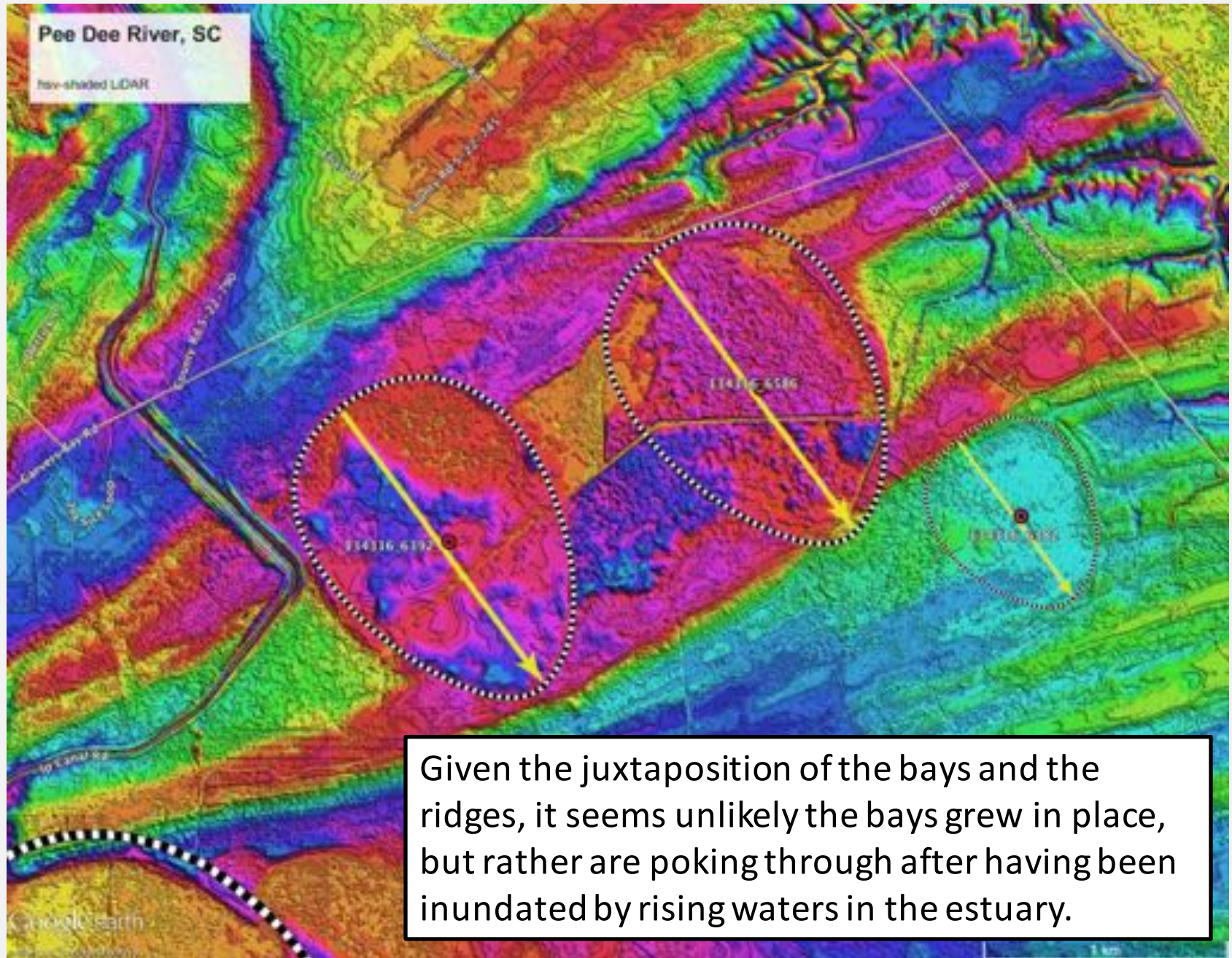
Here is an area of South Carolina along the Pee Dee River Estuary

Copyright © 2000
Data for 1990-1999
Image Limited

Pee Dee River, SC



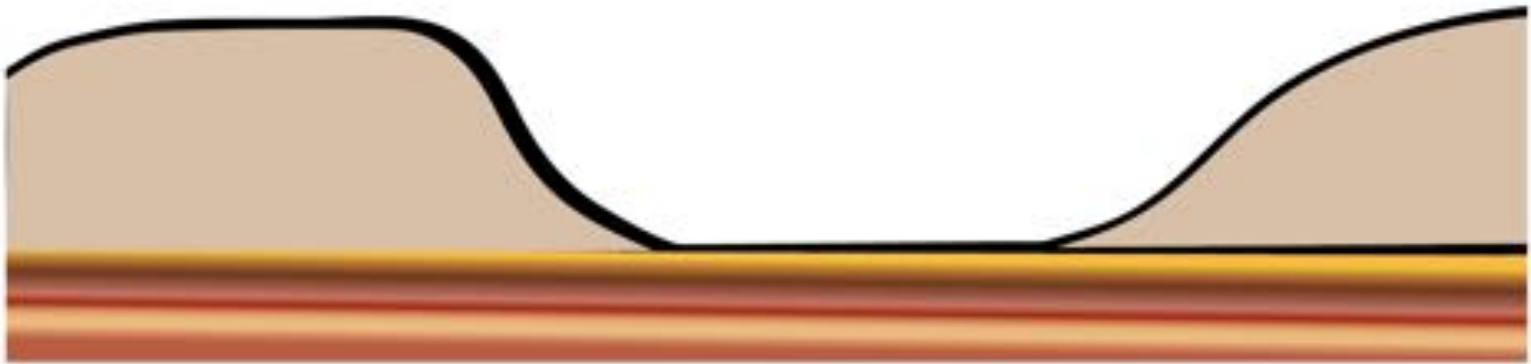
Pee Dee River, SC



Given the juxtaposition of the bays and the ridges, it seems unlikely the bays grew in place, but rather are poking through after having been inundated by rising waters in the estuary.

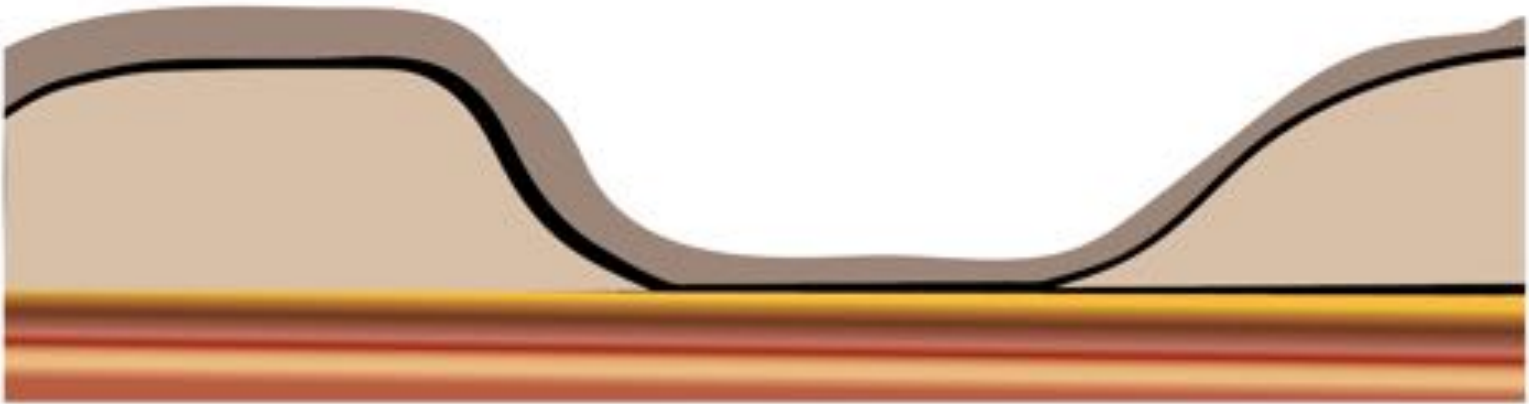
Keeping the Forces of Nature at Bay

Allow me to share a cartoon. Let's start with an antecedent surface, build a deposit with an embedded Carolina bay.



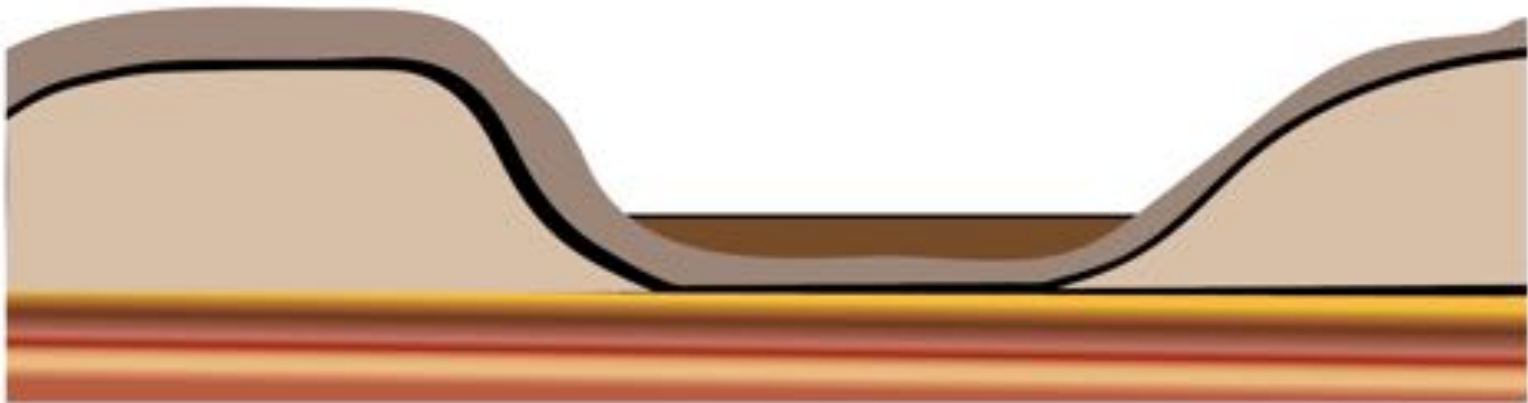
Keeping the Forces of Nature at Bay

... Cover with a sheet of eolian sand,



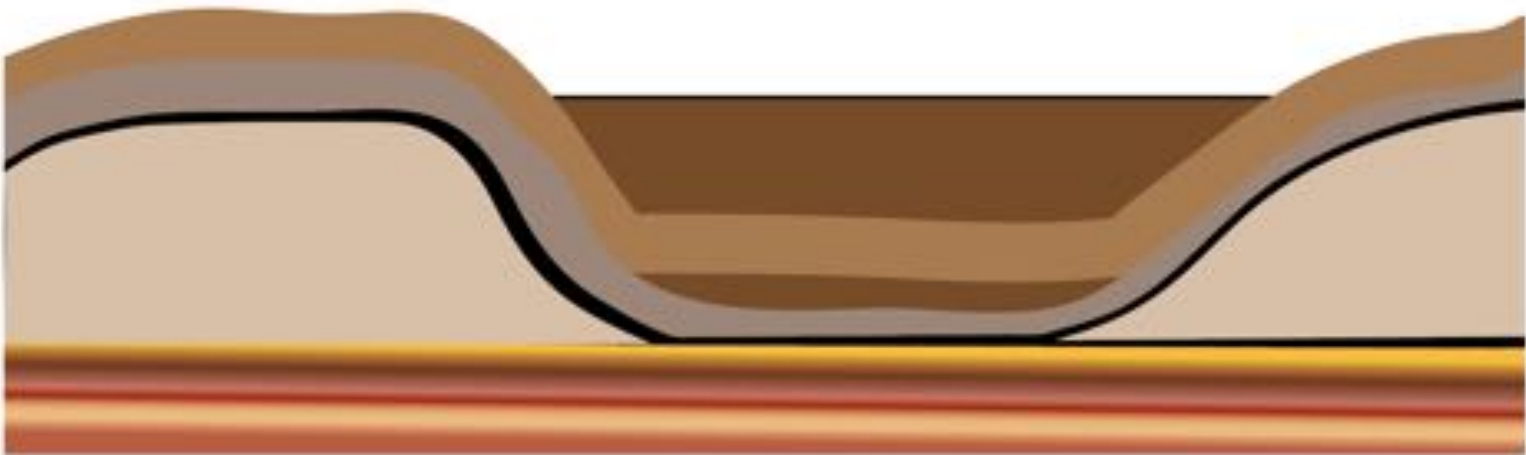
Keeping the Forces of Nature at Bay

... then hydrate and build a deep layer of peat.



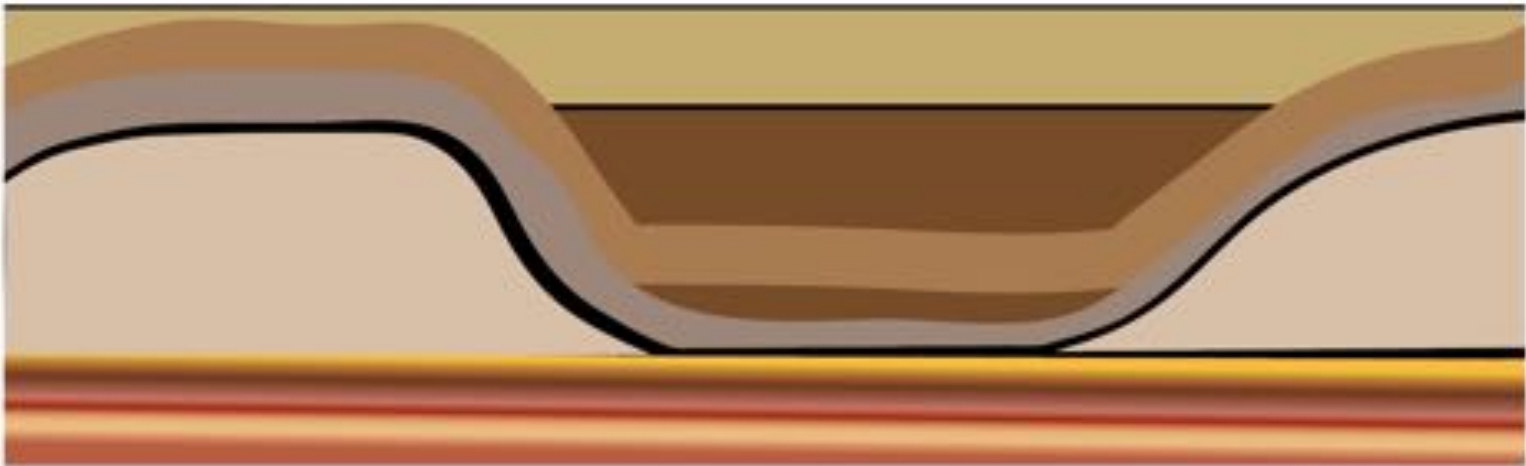
Keeping the Forces of Nature at Bay

Rinse & repeat with another eolian sheet, more peat...



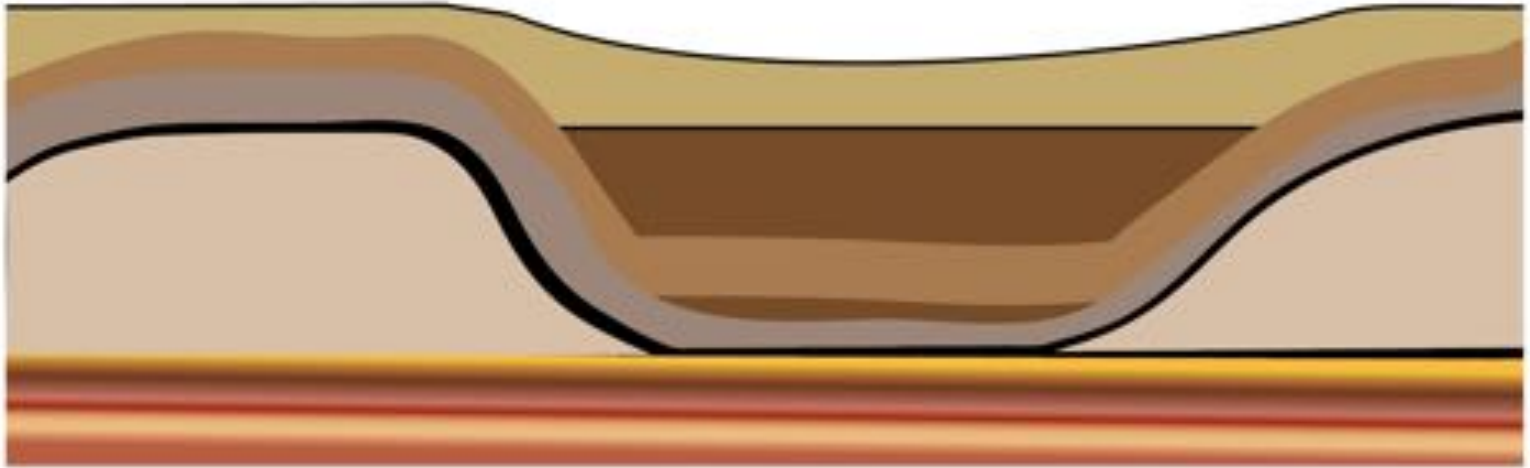
Keeping the Forces of Nature at Bay

Finally, lets fully inundate this in a **transitory** embayment, or flood plain environment.



Keeping the Forces of Nature at Bay

Eventually, the peat will **decompose** and compact. Voila! The original bay planform re-appears at the surface.
Think “**kettle hole**”.



Headward Erosion

Headward Erosion

GEOMORPHIC ELEMENTS AND SURFACE WATER FLOW PATHS

Kathleen Farrell discussed some interesting geomorphic elements at this year's Southeastern Meeting. She found "**Valley-Head basins**" that resembled Carolinas bays at the head of numerous streams ...

*"These **valley-head basins** may have steep, scarped walls, resembling sinkholes, or Carolina Bays, or a combination of the two."*

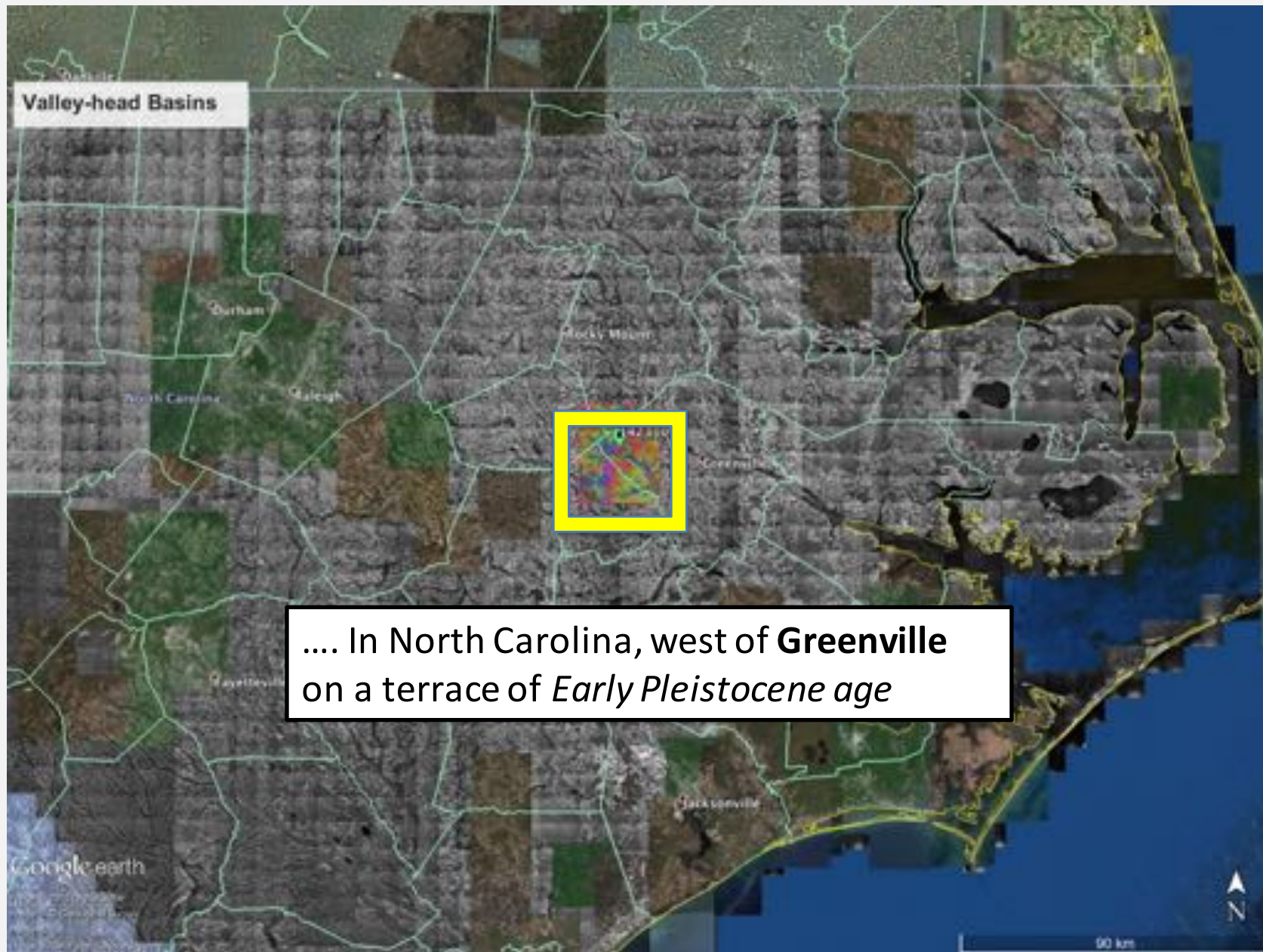
Located on

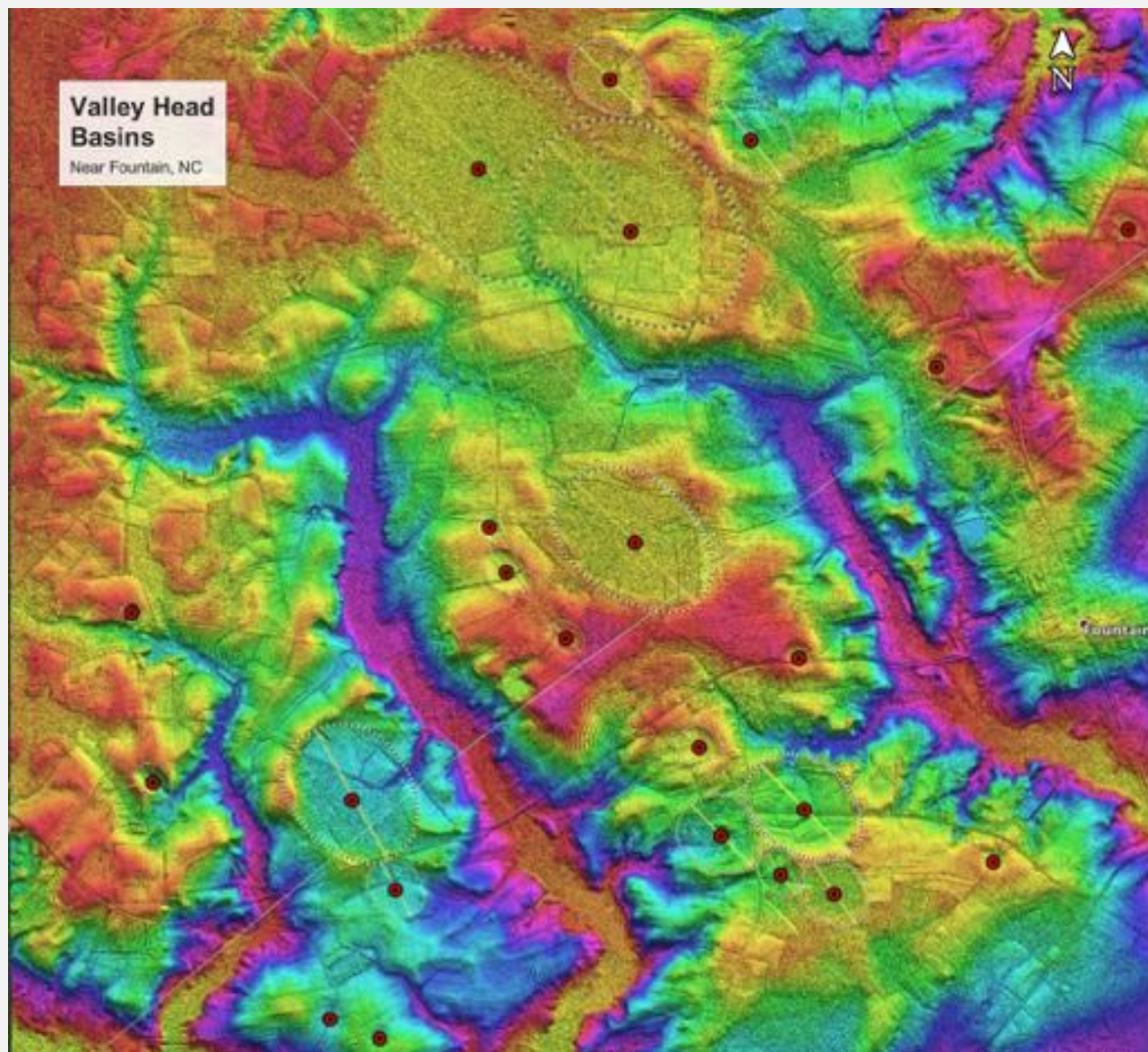
"Early Pleistocene terrace and shoreline surfaces"

Kathleen M. Farrell, North Carolina Geological Survey

GSA Southeastern Section - 64th Annual Meeting (2015) Paper No. 13-3

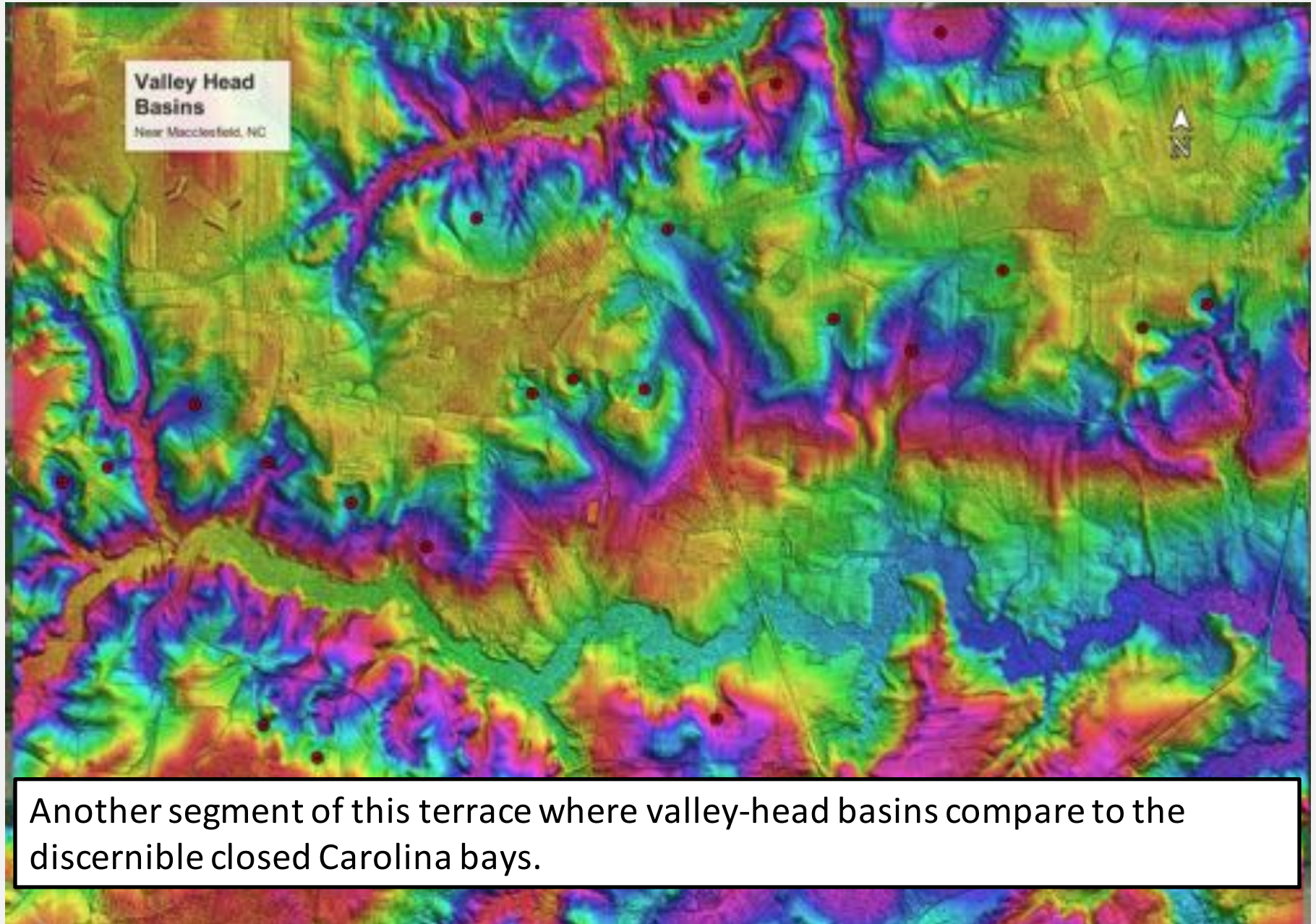
Valley-Head Basins, NC



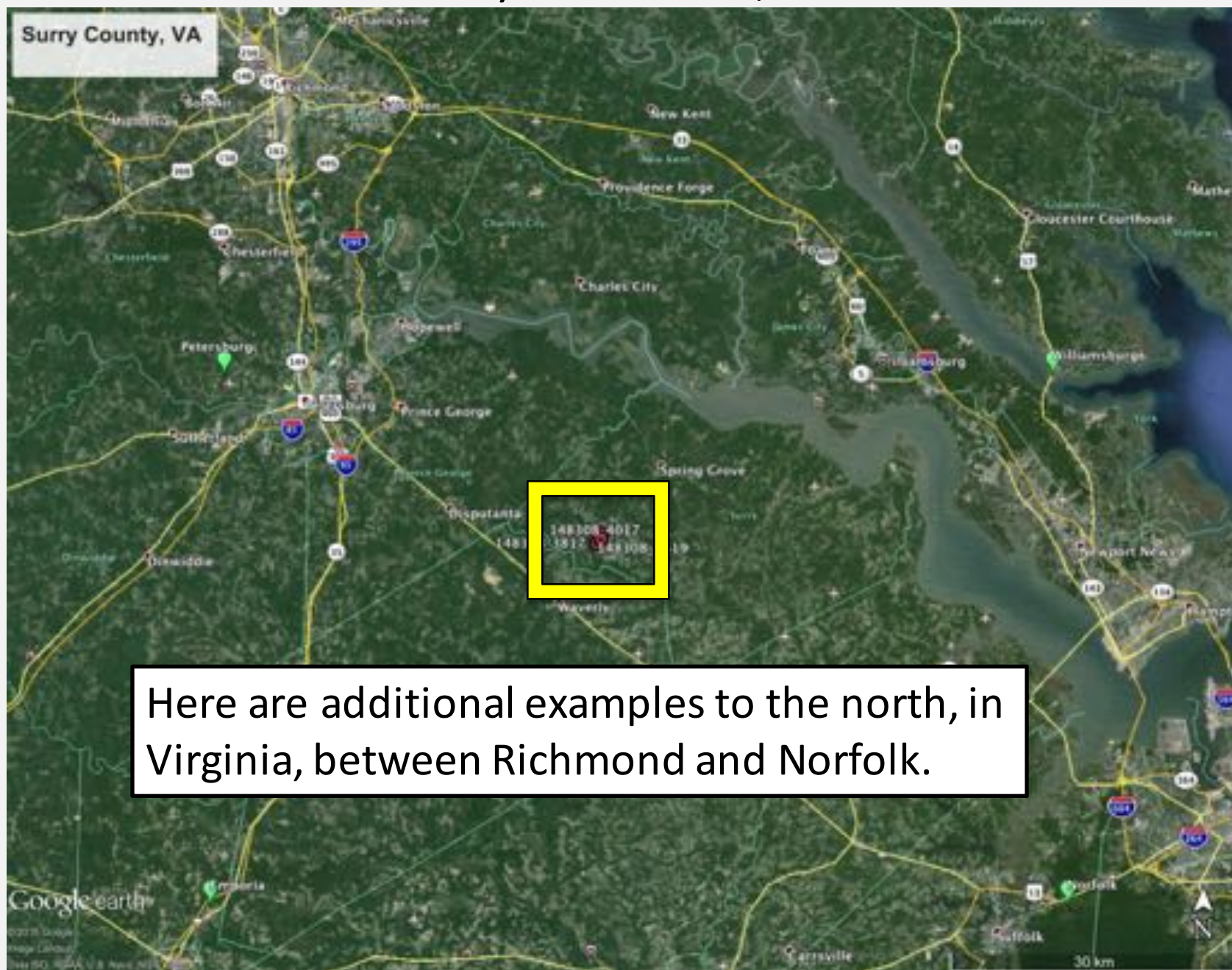


When those basins are compared to the discernible closed Carolina bays on the same surface, the LiDAR shows those valley head basins are indeed Carolina bays breached by headward erosion.

Valley-Head Basins, NC

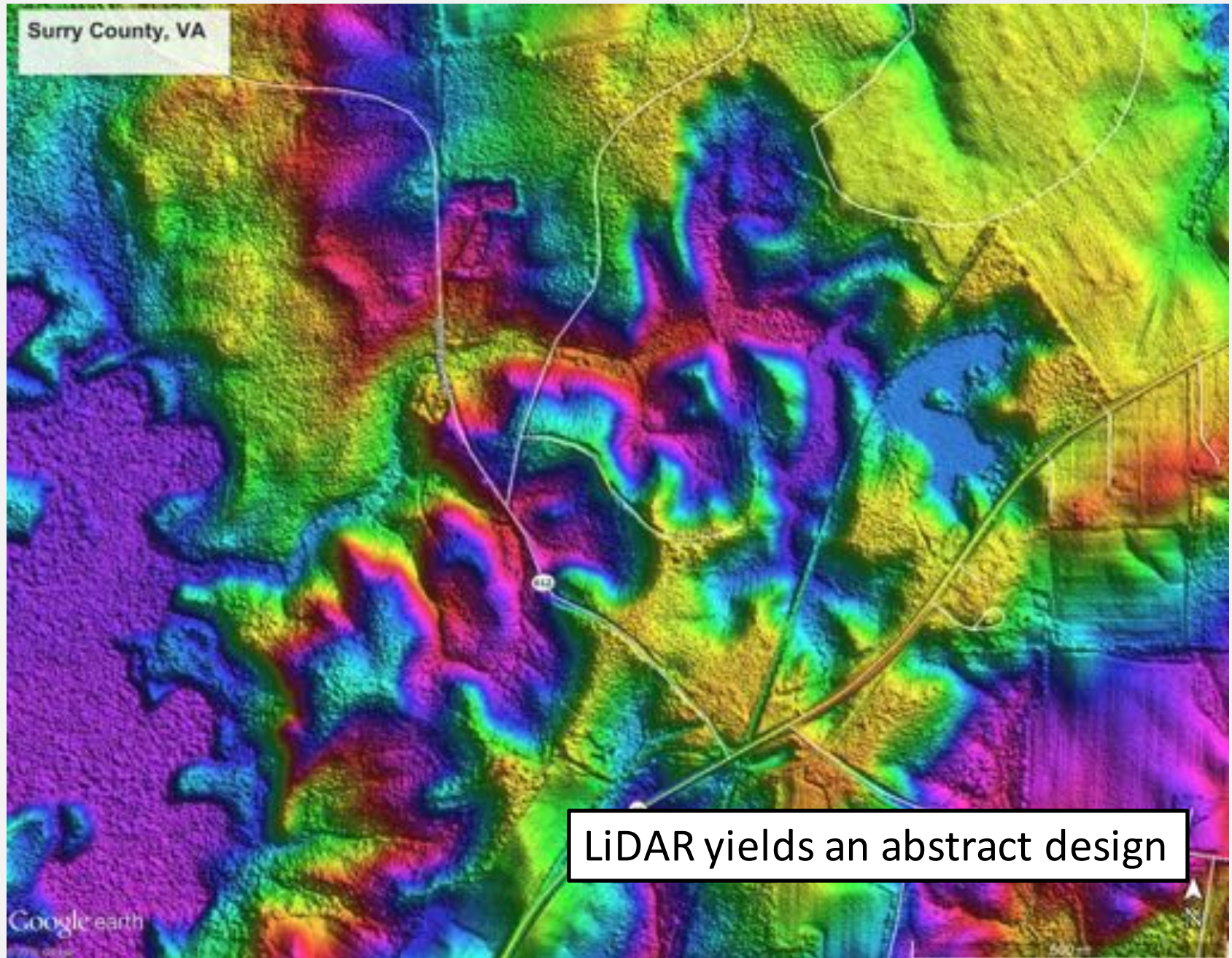


Valley-Head Basins, VA

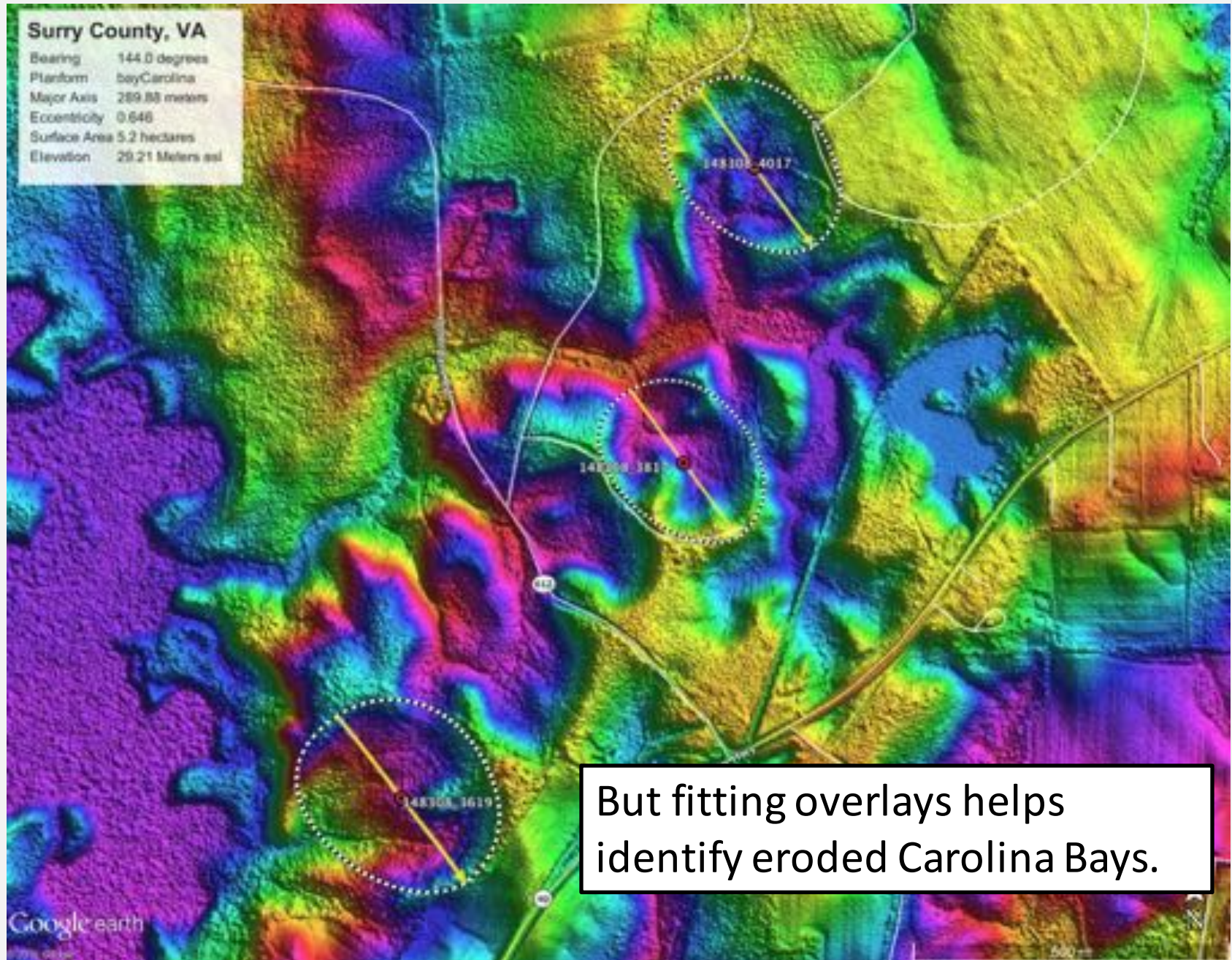


Here are additional examples to the north, in Virginia, between Richmond and Norfolk.

Valley-Head Basins, Surry County, VA

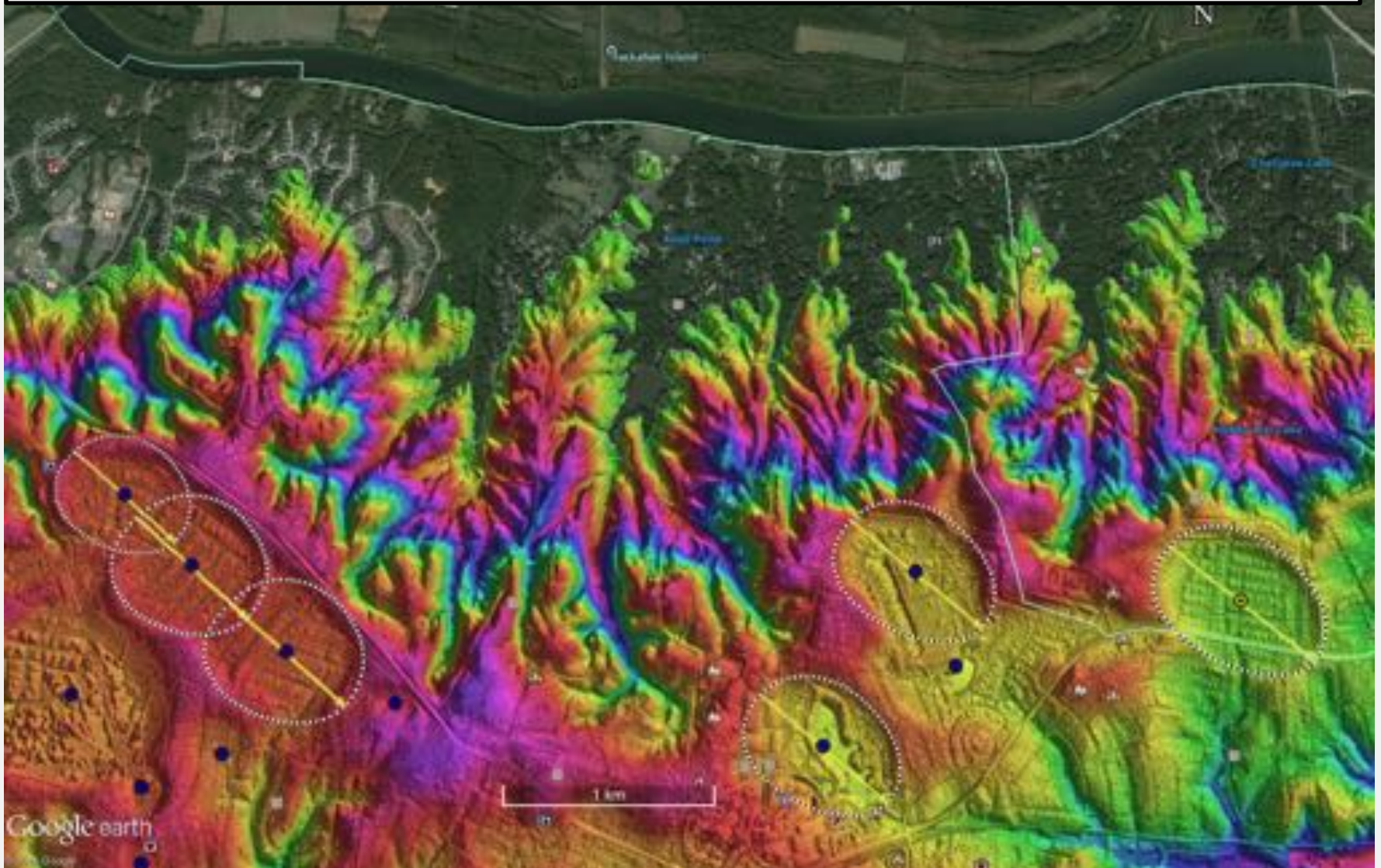


Valley-Head Basins, Surry County, VA



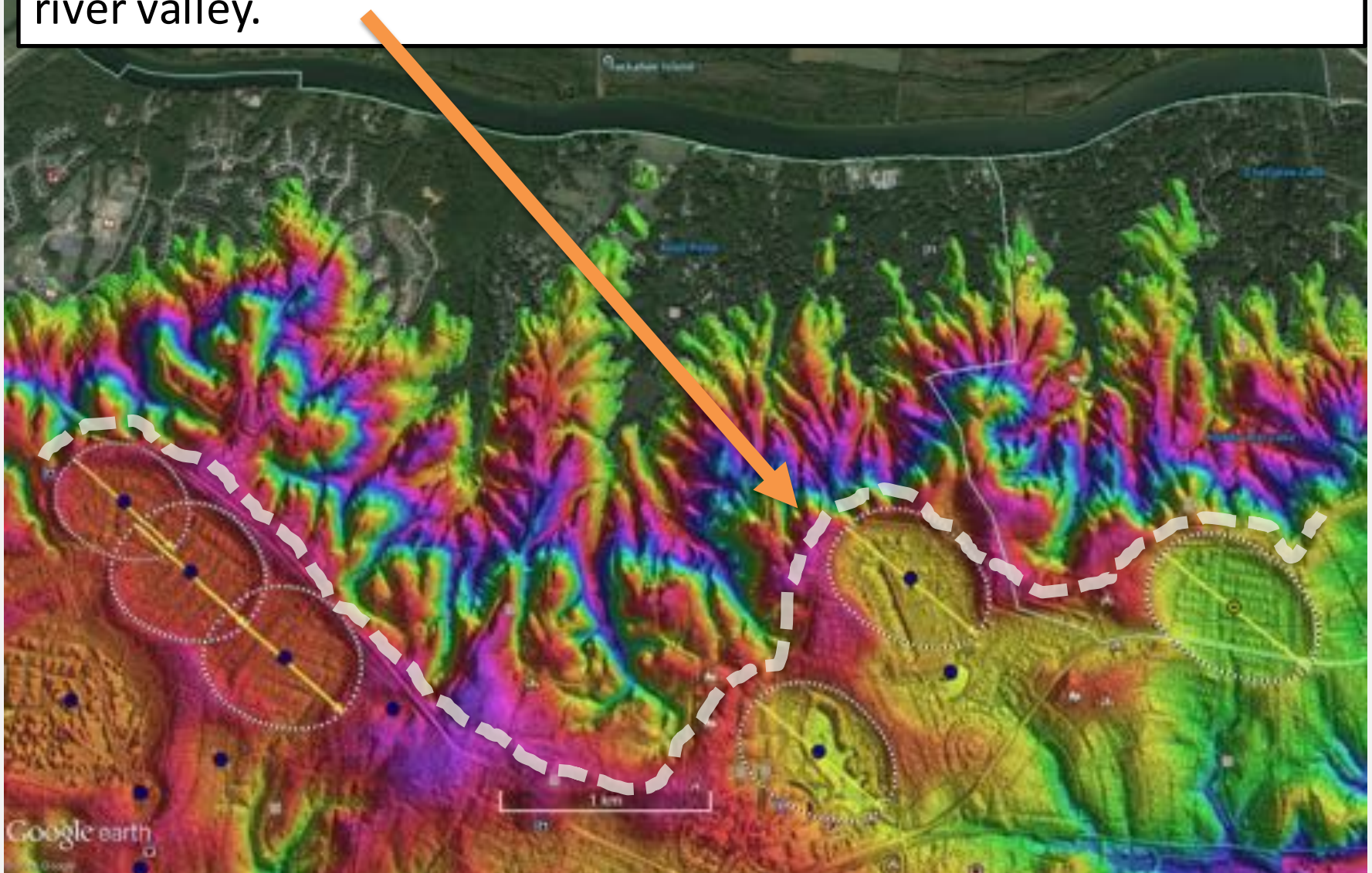
James River, Bon Air, VA

Further north, above the fall line, is the Late Tertiary **Bon Air Terrace**. On the Southern bank of the James River we see robust bay rims



James River, Bon Air, VA

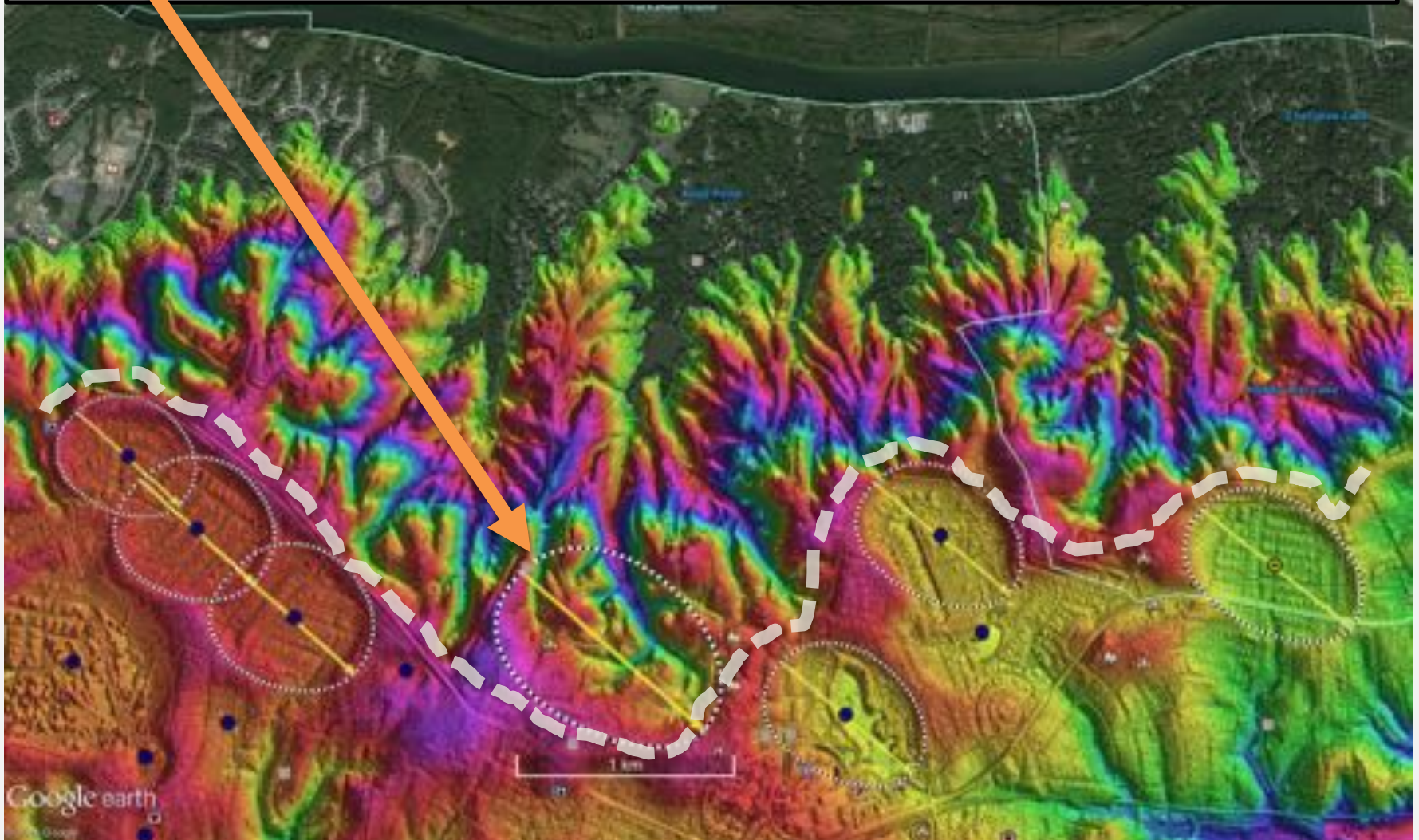
.... standing as a fortress, resisting the lateral expansion of the river valley.



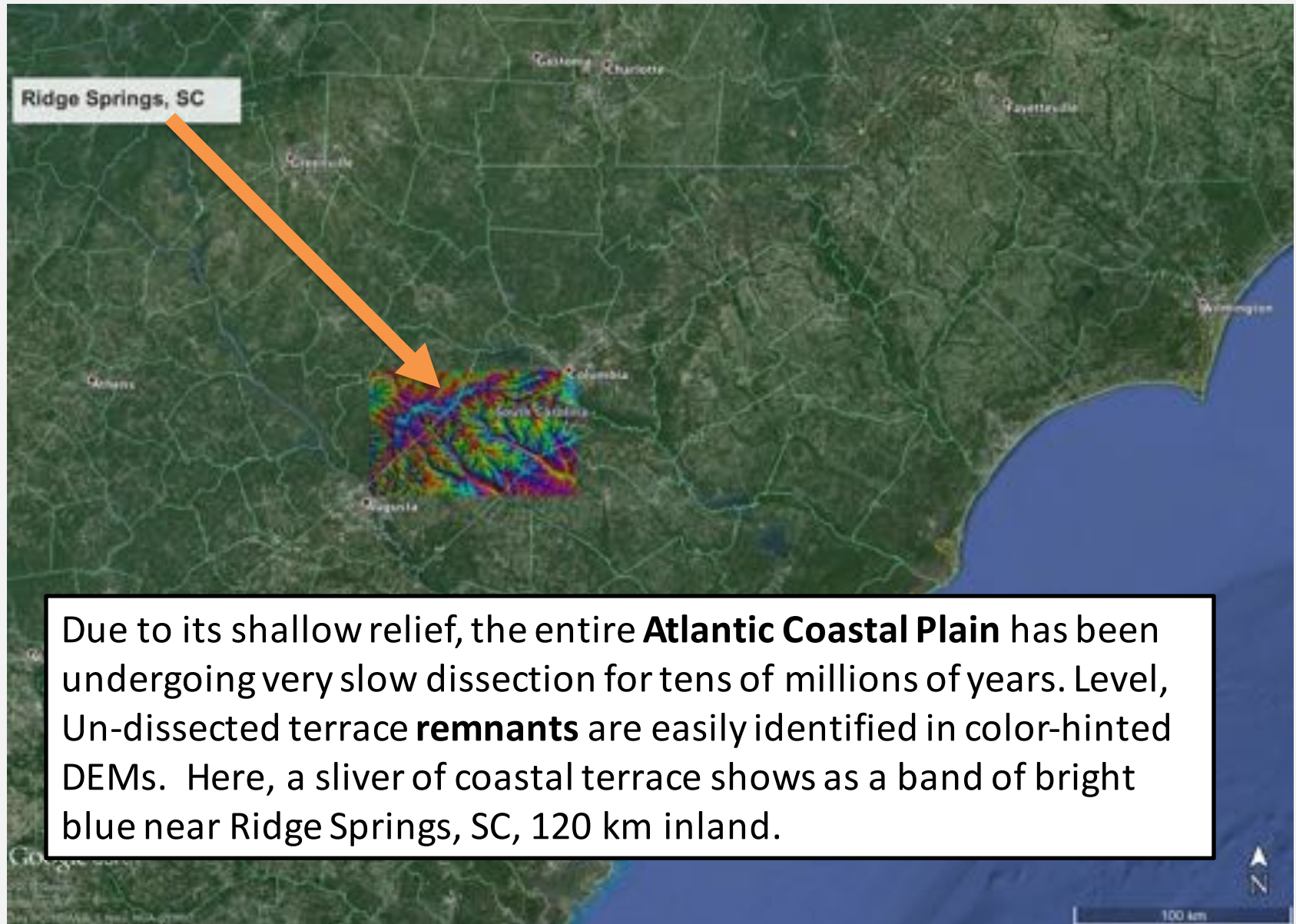
James River, Bon Air, VA

There are many compromised bays around the terrace;

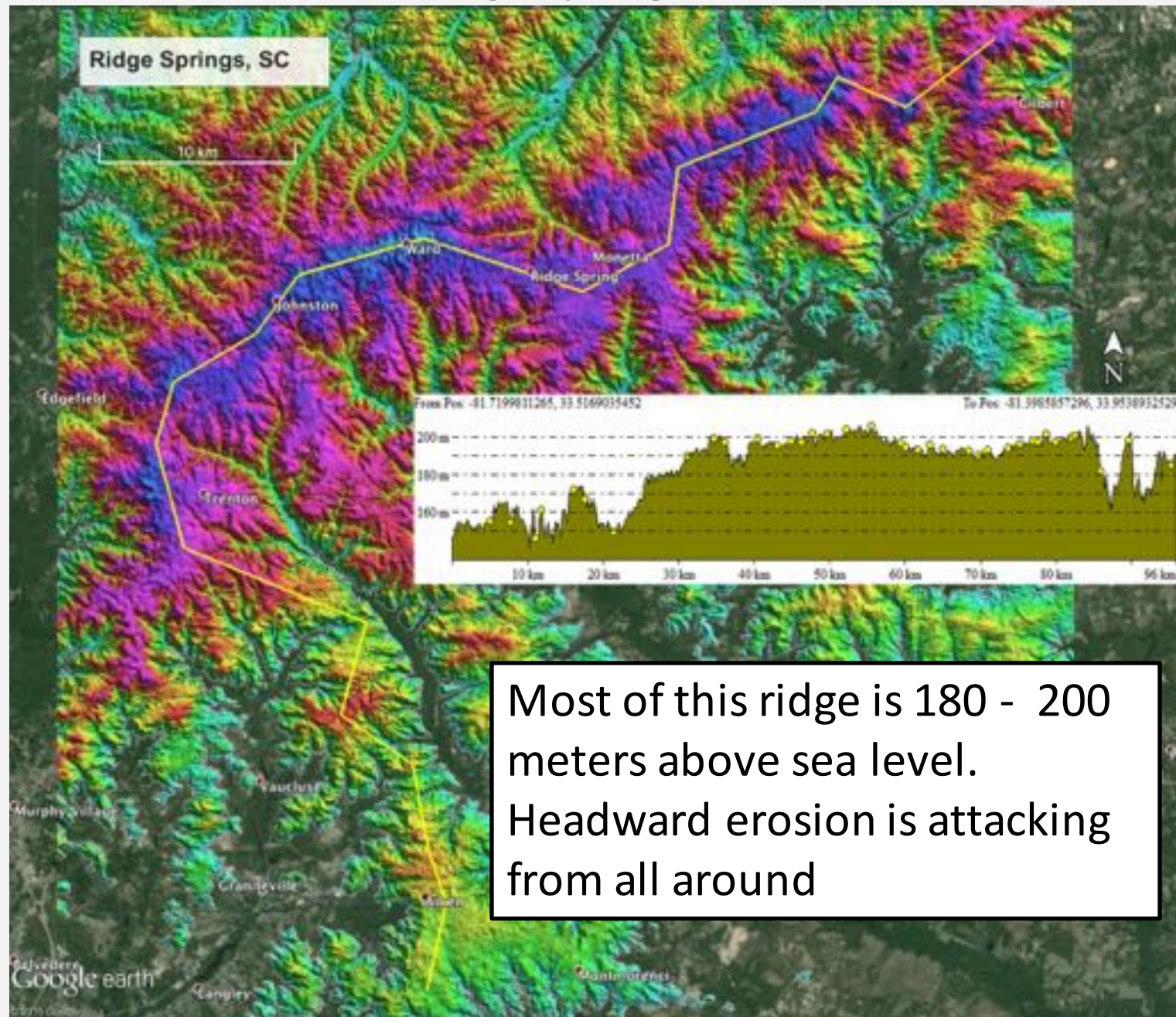
This bay at the center is recovered using the Overlay.



Ridge Springs, SC

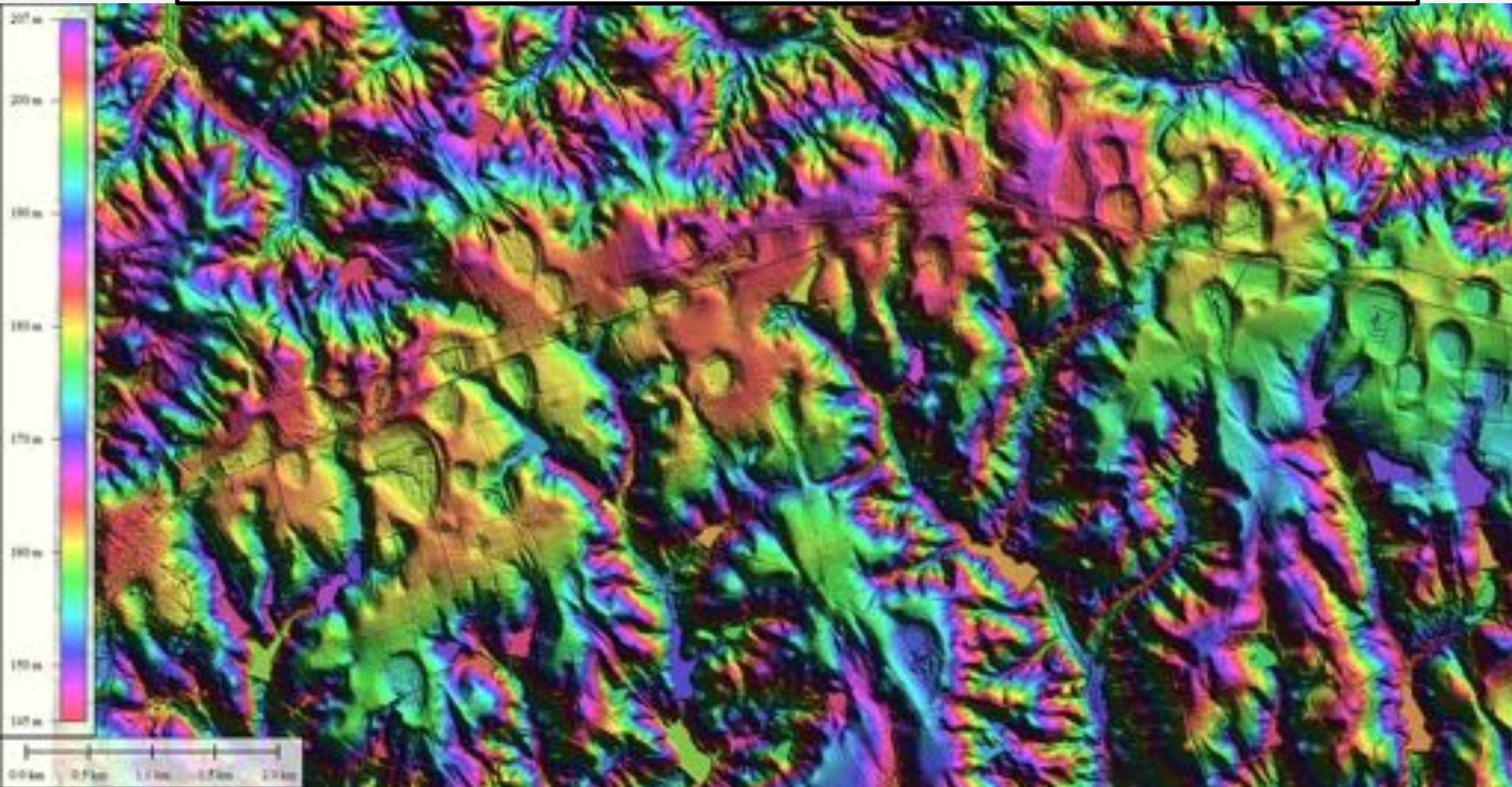


Ridge Springs, SC

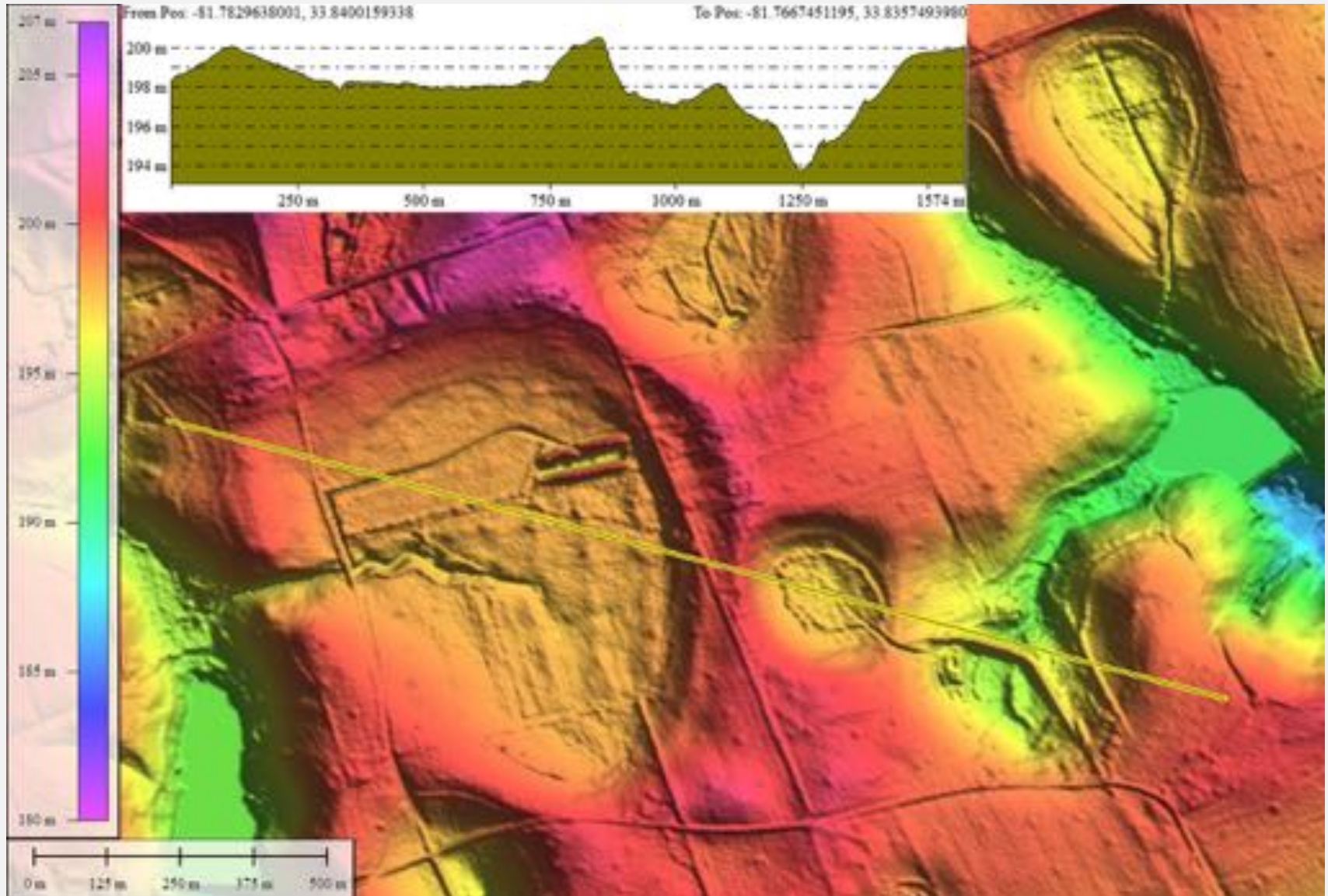


Ridge Springs, SC

The “**baySouth**” planform is crisply repeated along the entire broad ridge yet at the edges of the surviving terrace, “Valley-head basins” abound.



Ridge Springs, SC

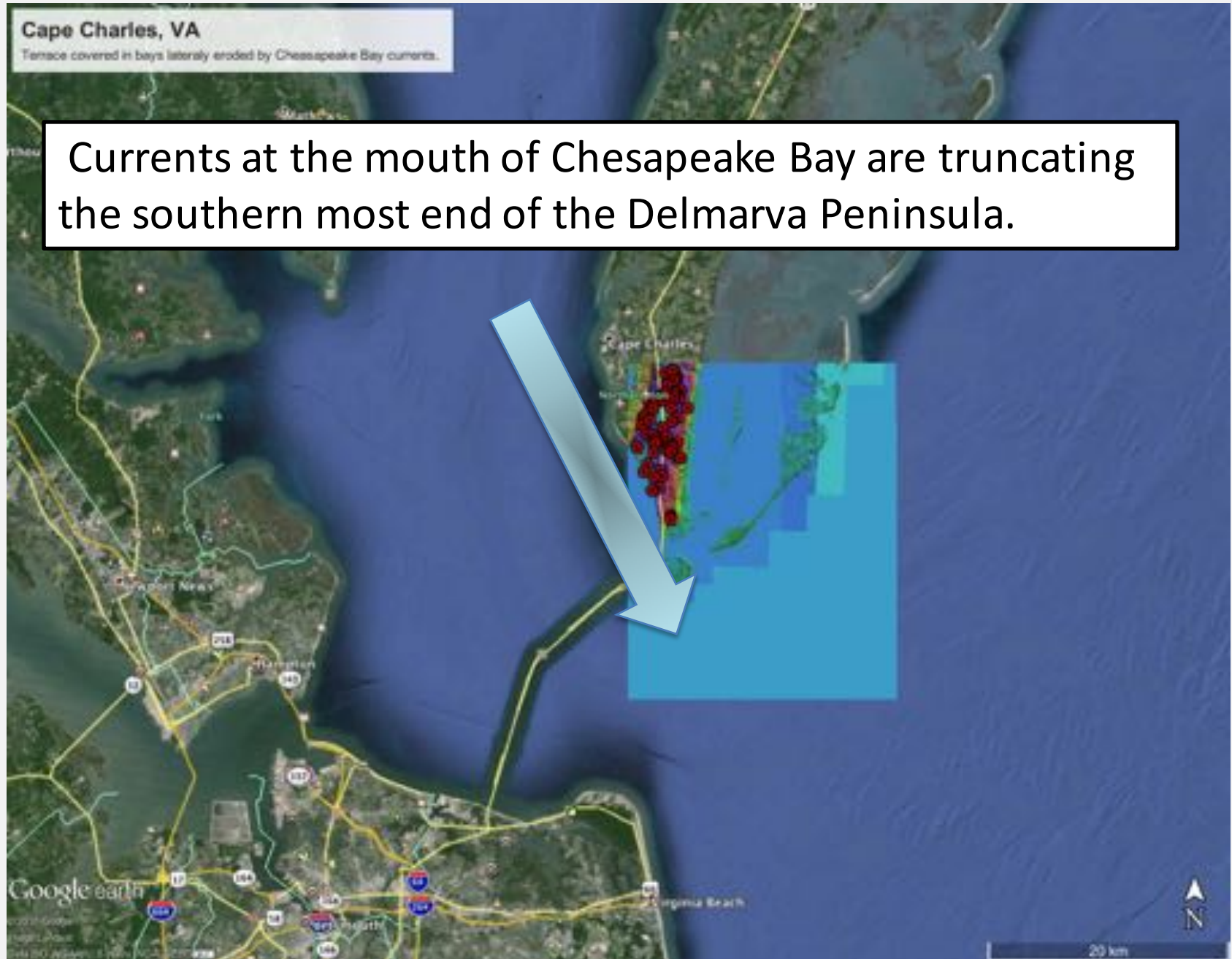


While shape **alone** is a good validation, it is **this** robust agreement of the shape and orientation of an eroded bay with adjacent well-formed sibling bays that confirms it.

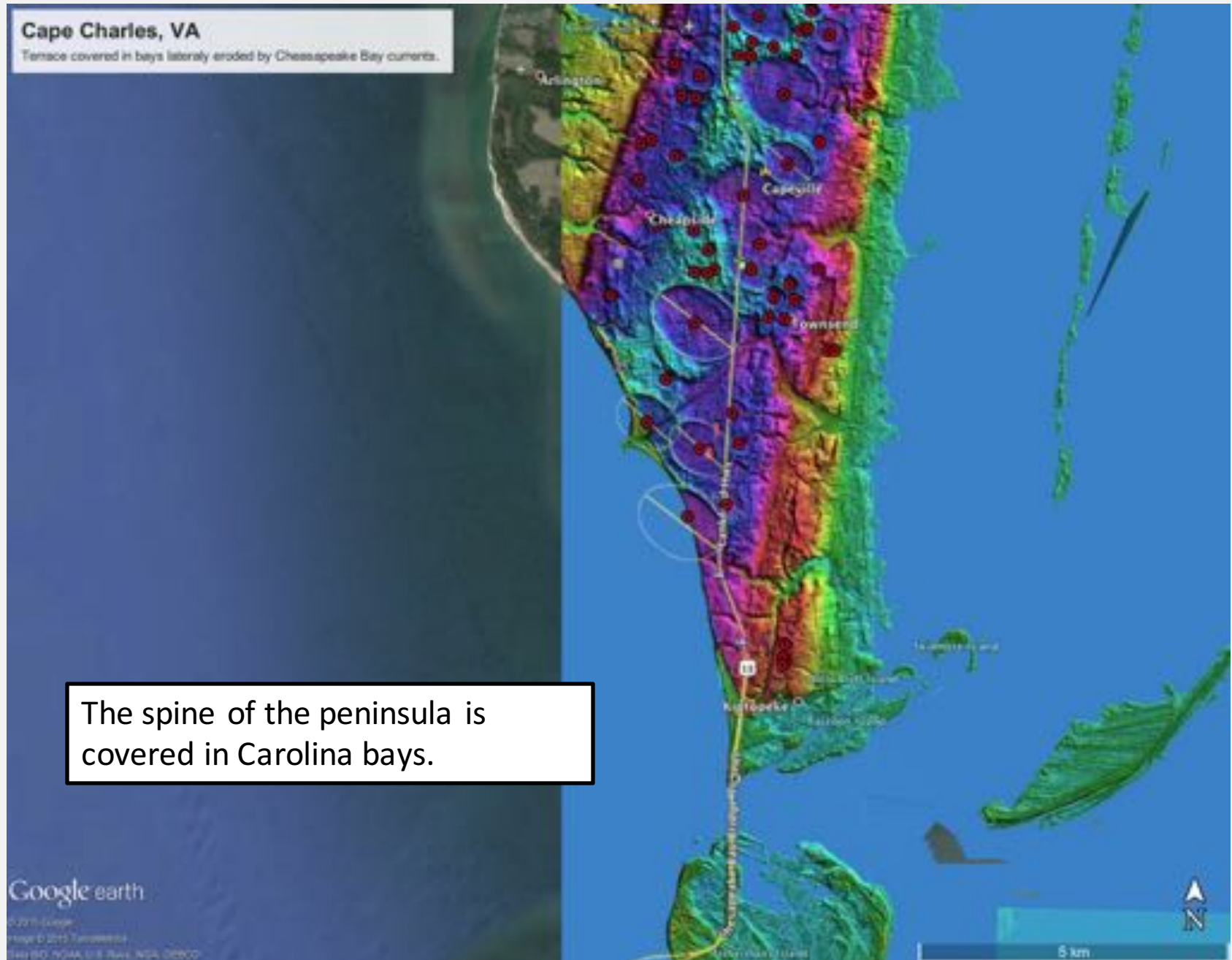
Lateral Erosion

Lateral Erosion

Cape Charles, VA



Cape Charles, VA

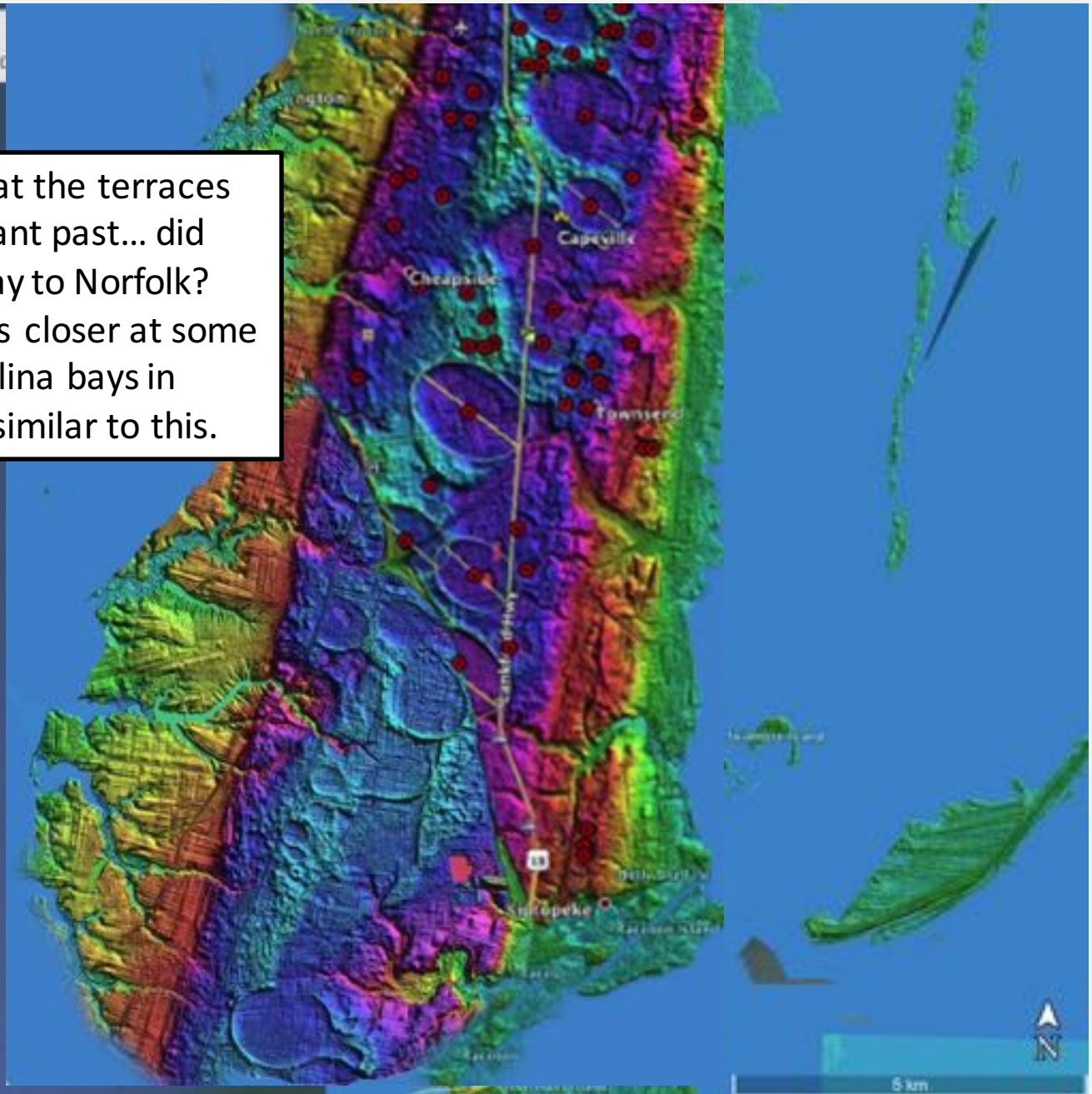


Cape Charles, VA

Cape Charles, VA

Terrace covered in bays laterally eroded by C

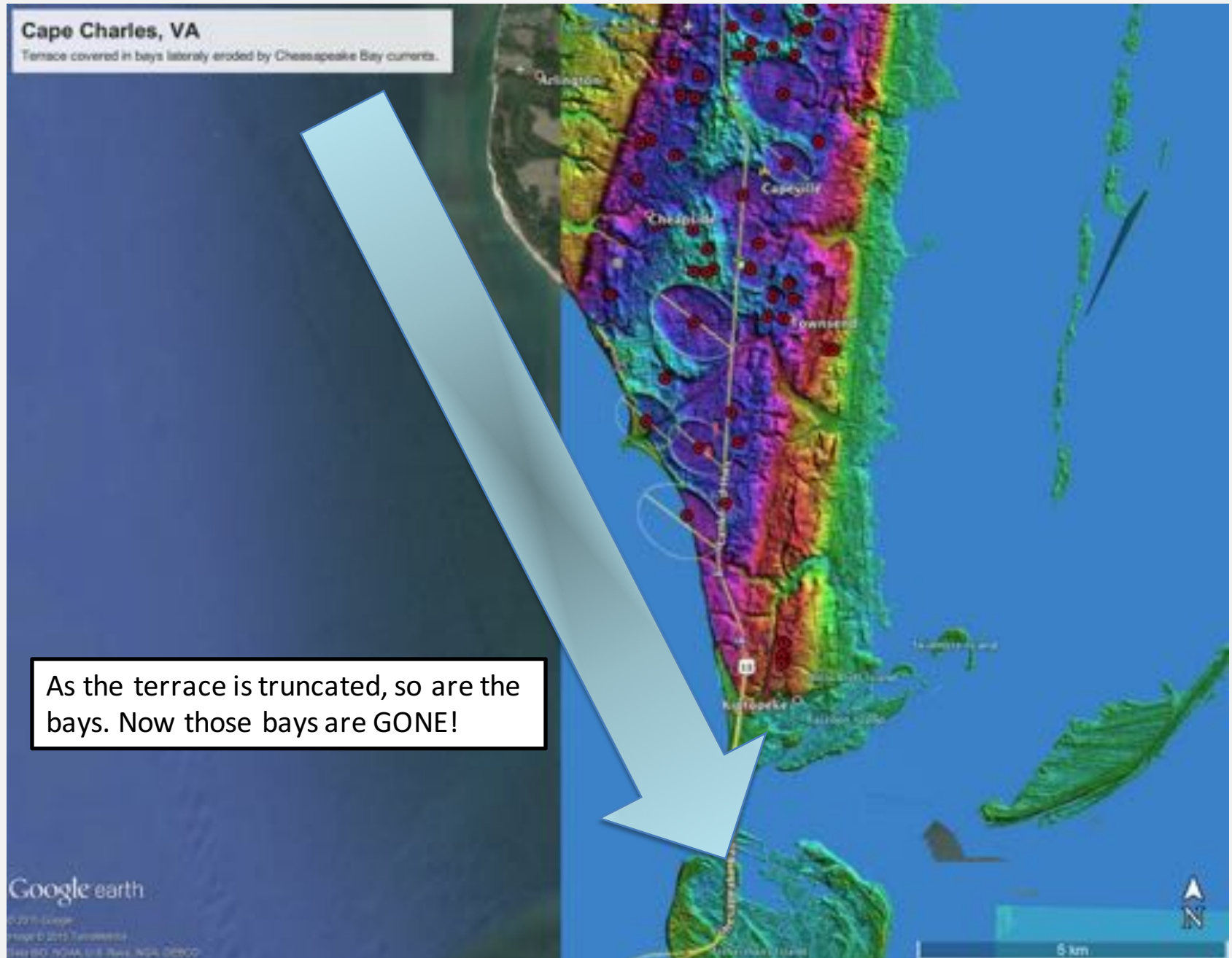
I speculate about what the terraces looked like in the distant past... did they extend all the way to Norfolk? Likely not, but perhaps closer at some point. There are Carolina bays in Norfolk at elevations similar to this.



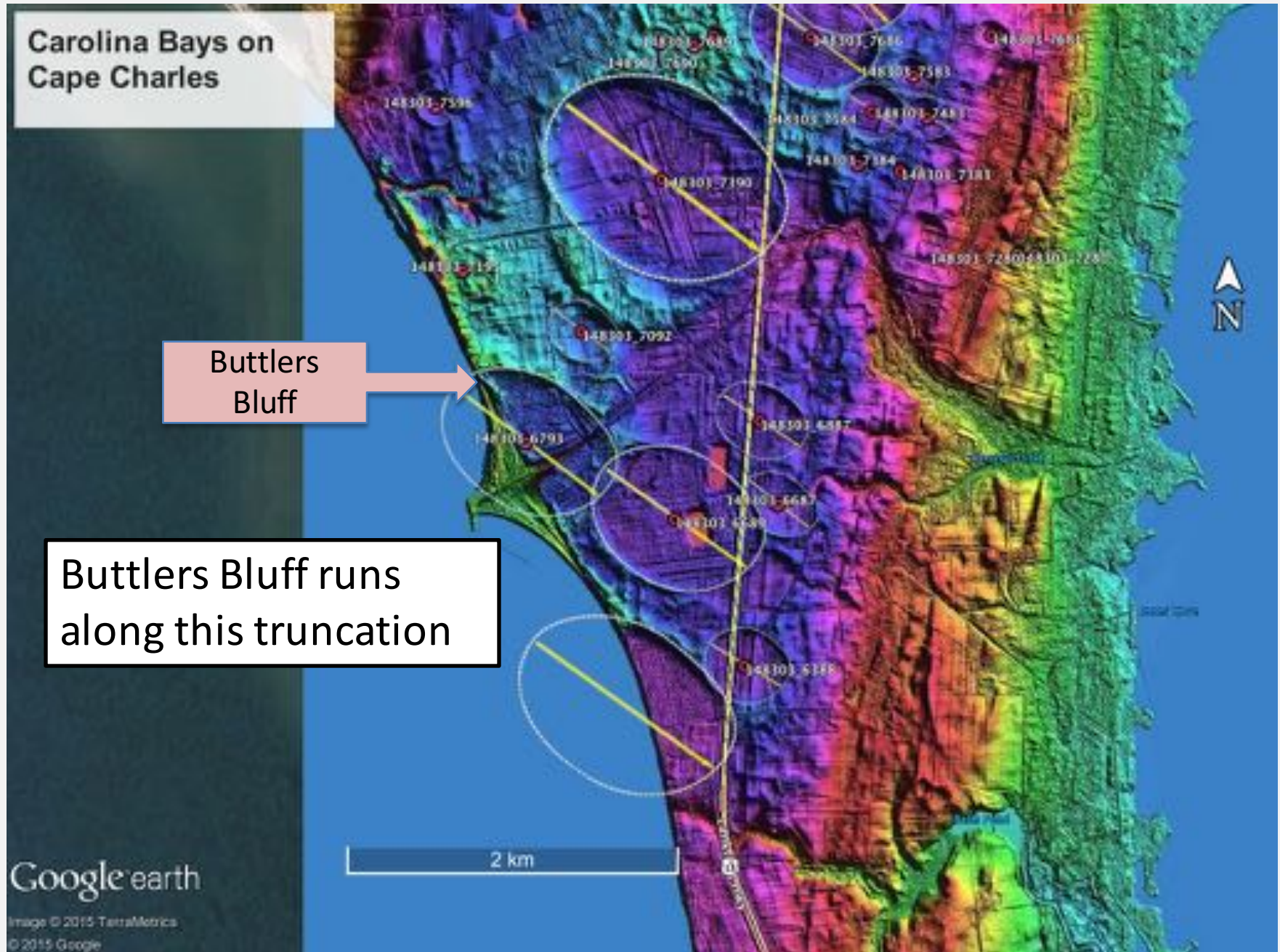
Google earth

©2015 Google
Image © 2015 TerraMetrics
Data (S): NOAA, U.S. Navy, NGA, GEBCO

Cape Charles, VA



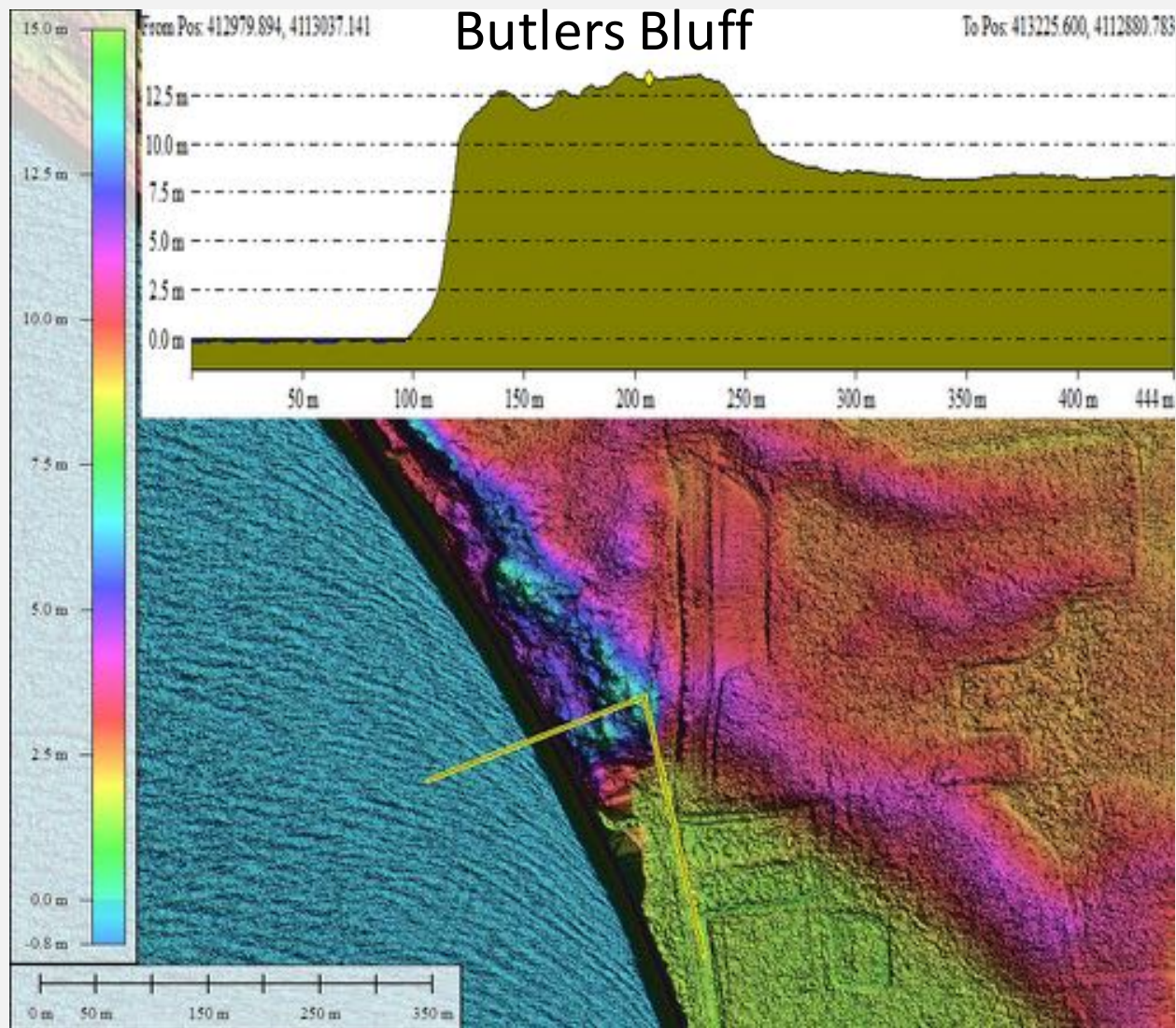
Cape Charles, VA



Butlers Bluff

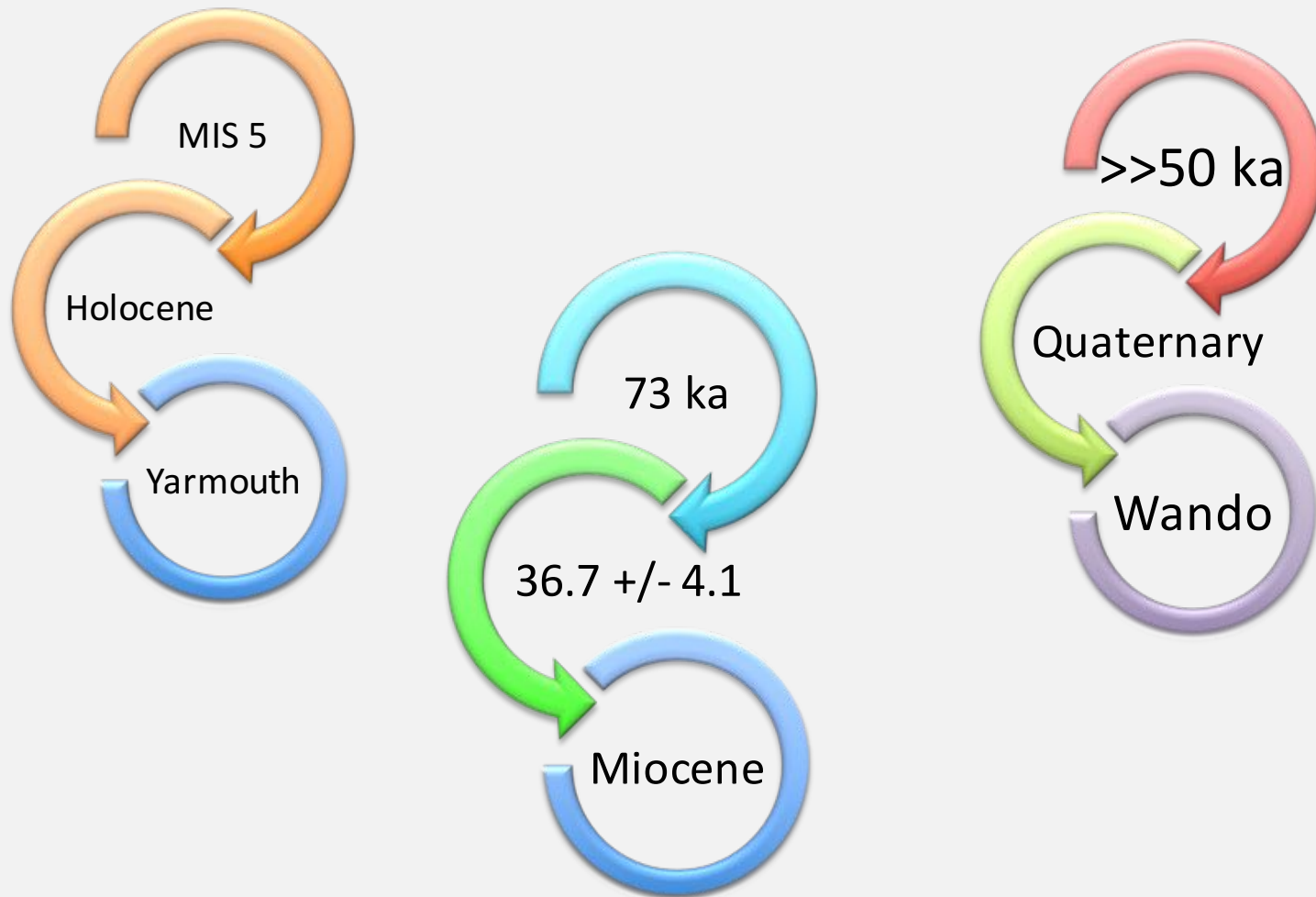
--- providing a unique access to the stratigraphy beneath a Carolina bay.





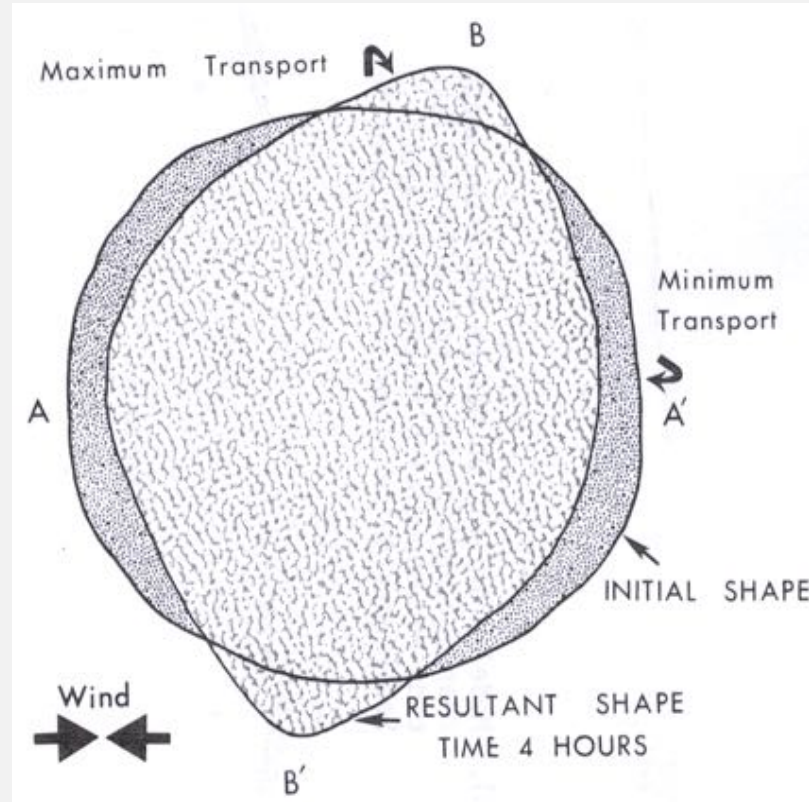
With a 10-meter exposure, no coring is necessary to extract samples for a cosmogenic analysis. ^{10}Be / ^{26}Al burial dating technology has already revolutionized our understanding of the North American Ice Sheet advances and can do the same thing for our costal terraces.

Dating: C¹⁴, OSL, Pollen



As for the current collection of Carolina bay origination dates , OSL and C14 can't reach back to the Mid Pleistocene. Perhaps they measure only gradualistic modifications.

Wind (Bidirectional!!!) and Wave



Which makes sense, since Kaczorowski's gradualistic demonstration mandates the presence of an antecedent water-filled circular depression, then he demonstrates surficial modification using an unrealistic alternating prevailing wind regimen. This eventually yields a planform which doesn't accurately represent any known Carolina bay.

Raymond T. Kaczorowski, 1977, *The Carolina Bays: A Comparison With Modern Oriented Lakes*, Coastal Research Div. USC, Technical Report No. 13-CRD

Summary

Carolina bays exhibit indications of great age as seen in erosion and modification, and they may well date to the Mid-Pleistocene.

Dissection of Costal terraces leaves Valley Head Basins

Inundation of Costal terraces leaves ghosts

No bays on Costal terraces truncated since Mid Pleistocene

Additional Deep Coring (10 m) is required

Cosmogenic ^{26}Al - ^{10}Be burial dating needed

References

- Brooks, M, et al, 2001, Pleistocene Encroachment Of The Wateree River Sand Sheet Into Big Bay On The Middle Coastal Plain Of SC, *Southeastern Geology*, Vol. 40, No. 4
- Moore, M, et al, 2015, Rapid Scour, Sand Rim Construction, And Basin Migration Of A Carolina Bay In SE NC, *GSA Abstracts With Programs*. Vol. 46, No. 3, p.96
- Cooke, 1940, Elliptical bays of South Carolina and the shape of eddies, *J. Geol.* 48:205-211
- Daniels, et al, 1970, *The Goldsboro Ridge, an Enigma, Southeastern Geology vol.12*
- Davias, 2013, A Proposed Taxonomy For Carolina Bay Circumferential Rim Planforms; Findings Of Robust Adherence To Distinctive Archetypes Is Supported By Lidar-Derived Digital Elevation Maps, *Geological Society of America Abstracts with Programs*. Vol. 45, No. 7, p.722
- Farrell, KM, *GSA SE Section - 64th Annual Meeting (2015)*, Paper No. 13-3
- Frey, David G, 1955, A Time Revision of the Pleistocene Pollen Chronology of Southeastern North Carolina, *Ecology*, Vol 36, No. 4
- Johnson, 1942 *The Origin of the Carolina Bays*, Columbia University Press, New York
- Kaczorowski RT, 1977, *The Carolina Bays: A Comparison With Modern Oriented Lakes*, Coastal Research Div. USC, Technical Report No. 13-CRD
- Kuzila, M.S. 1994. Inherited morphologies of two large basins in Clay County, Nebraska. *Great Plains, Research*. 4: 51-63
- Soller, D. R., 1988; *Geology and Tectonic History of Lower Cape Fear River Valley, Southeastern North Carolina, U.S.* Geological Survey Professional Paper 1466-A
- Thom, BG, 1970. Carolina Bays in Horry and Marion Counties, South Carolina, *Geological Society of America Bulletin*, 81:783-814.
- Wells, BW, 1943. Blythe Bay, a record of changing ocean levels, *J. Elisha Mitchell Sci. Soc.* 59, pp 118-119
- Zanner, CW, and Kuzila, MS, 2001, Nebraska's Carolina bays. *Geological Society of America Abstracts with Programs*, Vol. 33, No. 6, pp. 438