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Where The Bays Are: Temporal Tale Of Carolina Bay Geomorphology

As Told In LiDAR By The Wando And Socastee Terraces

Abstract

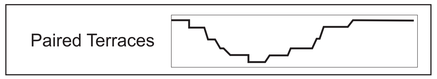
80 years after aerial photography revealed thousands of aligned oval depressions on the USA's Atlantic Coastal Plain, the geomorphology and ages of these "Carolina bays" remain enigmatic. Here, high-resolution LiDAR derived elevation maps[1] are used to examine Carolina bay landform distribution on terraces in the Cape Fear River Valley of North Carolina, in an attempt to identify and constrain their temporal distribution, which is of import to the gradualist vs. cosmic impact debate. The gradualist theory holds that bays were created episodically by katabatic winds during glacial periods, while an impact event would create all bays simultaneously.

The southeast flowing Cape Fear River has been incising its southwestern channel wall for over 2 million years, migrating up to 35 km laterally as its bed was tilted by the persistent tectonic uplift of the Cape Fear Arch. When combined with general regional uplift, a series of expansive and distinct unpaired fluvial terraces have been preserved, each created in turn during interglacial high stands of the Atlantic. This tableau provides a unique temporal index to the evolution of the coastal plain. Adjacent to the current-era flood plain is the Wando Terrace, considered by Soller (1988) to have formed during marine isotope stage (MIS) 5 interglacial ~80ka–135ka, based on uranium-series and amino acid methods. Continuing towards the Arch, Soller dated the Socastee Terrace at MIS 7 ~186ka–245ka, the interglacial preceding the Illinoian glaciation.

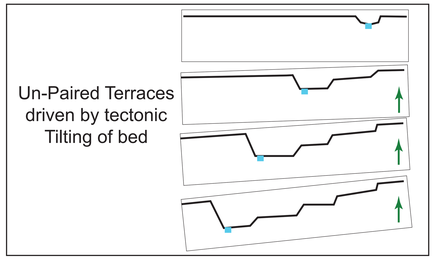
LiDAR elevation maps reveal a Socastee terrace populated with well-defined Carolina bays. Likewise, the successively older Penholoway, Waccamaw and Bear Bluff Terraces are rich in bays. In striking contrast, the LiDAR shows the Wando Terrace to be indisputably devoid of Carolina bay landforms. The absence of bays on the MIS 5 surface suggests a minimum age constraint for bay formation of ~135ka. Younger dates identified in the literature may depict reworking, not initial bay genesis. This finding is problematic for the gradualist theory, as the Wando surface should have offered a viable nursery during the last Glacial Maximum (MIS 2). The temporal data implies that if Carolina bays were created during a cataclysmic event, it must have occurred before MIS 5 and after MIS 7, thus during MIS 6, the Illinoian glaciation ~135ka–186ka.

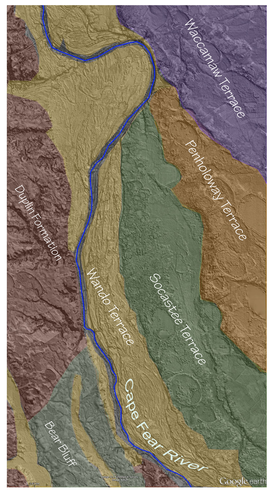
Terrace Evolution

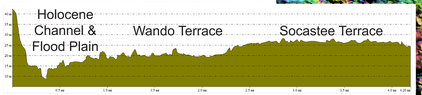
Paired Terraces are commonly found bordering fluvial channels, as the downward cutting action leaves shelves in the antecedent strata. Note that terraces are typically not paired directly across the fluvial channel, but arranged alternately along the river valley, based on meander position.

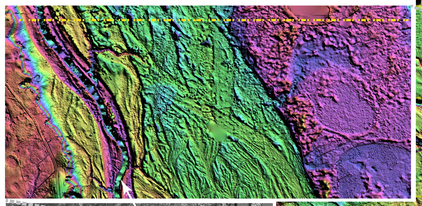


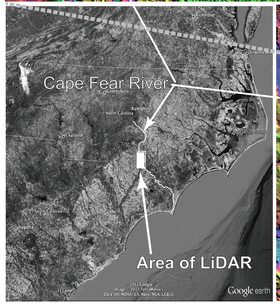
Un-paired terraces are far less common than the paired variety. To affect this outcome, the bed of the fluvial channel is gradually tilted, such that the downward cutting action is driven exclusively against one bank and away from the area of uplift. Terraces are abandoned sequentially as the river migrates laterally. The location of scarps between each succeeding terrace on the Cape Fear River Valley likely document the river's location at the oneset of down cutting in response to lowered sea levels during periodic continental ice ages.

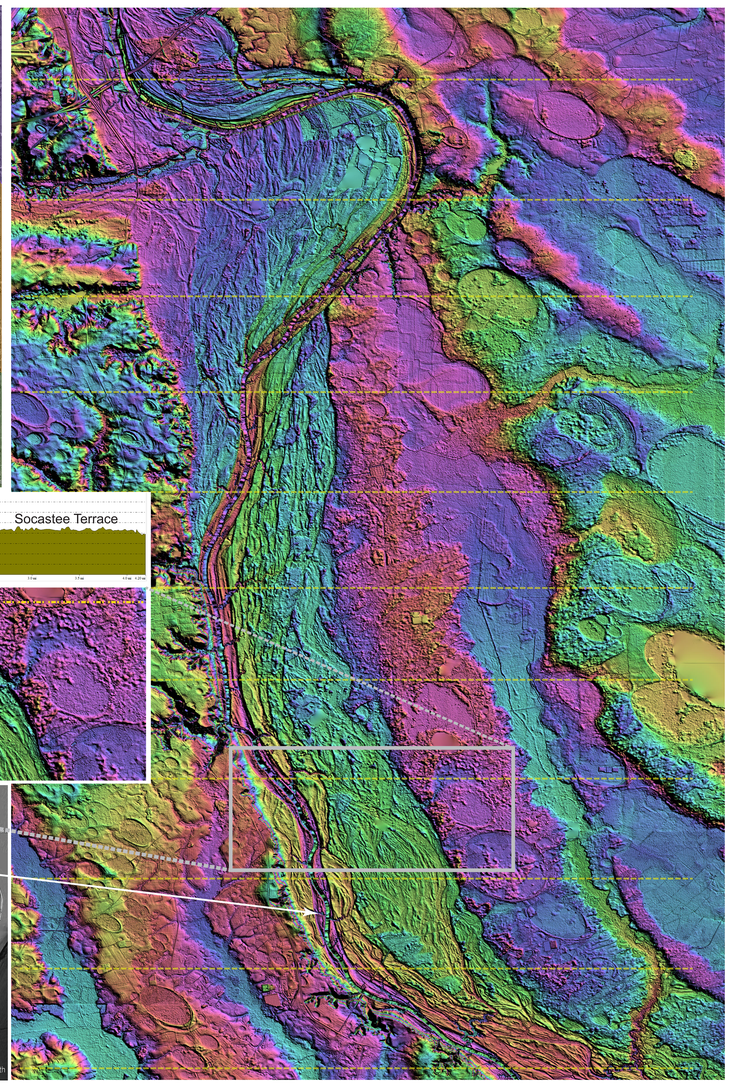






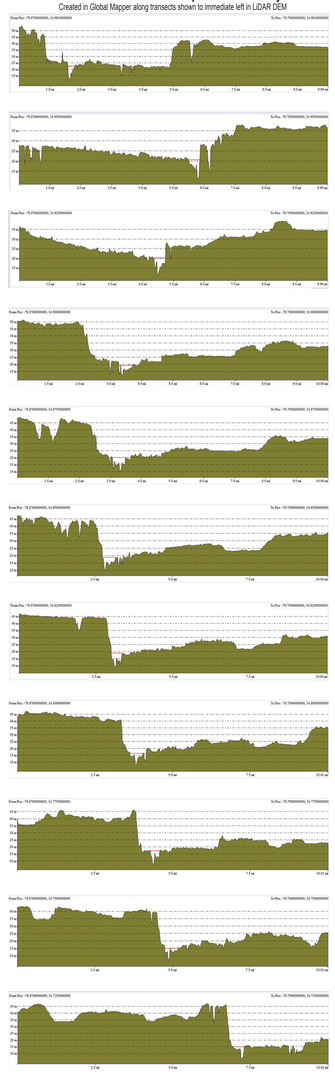






Elevation Profiles across Cape Fear River Valley

Created in Global Mapper along transects shown to immediate left in LiDAR DEM

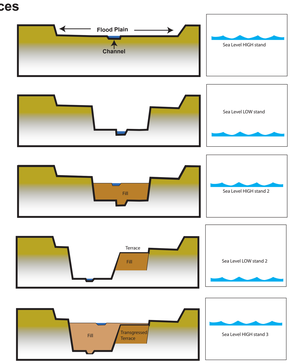


Evolution of Inundated Terraces

The Coastal Plain of the Carolinas has been subjected during the Pleistocene to a sequence of transgressions and regressions due to effects of sea level changes during glacially-driven high and low stands, as well to glacial-isostatic effects attendant to fore-bulge rise and fall. The graphics on the left illustrate how fluvial cut valleys are infilled during high stands. The de-glaciation leading into MIS-5 generated exceptional high stands, which in some areas inundated earlier high stand terraces. The Cape Fear River Valley terraces were mostly immune from this effect, as the combination of regional tectonic uplift and the local uplift seen along the Cape Fear Arch kept the MIS-5 Wando high stands from submerging the Socastee Terrace.

Closer to the coast, and away from the Arch, we see occasional instances of Carolina Bays existing on the Socastee Terrace Terraces being flooded and partially buried by Wando sediments. One example of this effect is seen near Lake Waccamaw, where shallow estuarine flooding of the Socastee terrace left ghost bays with little to no rim relief exposed above the transgressive Wando sediments, but the presence of the rim is clearly defined in infrared imaging.

Similarly, local flooding along tributaries across the Cape Fear River Valley has occasionally partially submerged Carolina Bays. Carolina bay landforms are actively morphing into ghost bays in the Chesapeake Bay along the western coastline of Virginia's Eastern Shore, likely caused by the relaxation of the Wisconsin Glaciation forebulge, allowing Holocene sediments to infill the enclosed basins.



Discussion

The Cape Fear River Valley is home to a vast number of Carolina bays, as is the entire surrounding region. Our Carolina Bay Survey[2] has identified over 1,150 Carolina bays within the USGS Elizabethtown 100K Quadrant surrounding our survey area. Within the LiDAR image displayed here, we have identified ~150. The absence of any Carolina bay landforms on the uniquely isolated Wando Terrace in the study area needs to be accounted for. The surface is composed of unconsolidated quartz sediments, and would normally be considered a good hosting surface for the development of wind-blown lake basins. The gradualistic evolution hypothesis for Carolina bay development presented by Kaczorowski (1977) is predicated upon the existence of a pre-existing water-filled depression. The extensive braiding across the surface should have provided the antecedent shallow basins required. The age of the Wando Terrace suggests its present surface existed throughout the Last Glacial Maximum of the late Pleistocene, MIS 2. The uniformitarian hypothesis holds that hurricane-force glacially driven winds would have carved those small water filled depressions into the classic Carolina bay planform.

The terrace age, and the lack of bays on the Wando were first noted by David R. Soller in his 1988 US Geological Survey Professional Paper. He mentioned the findings again in his chapter (with Mills) in The Geology of the Carolinas (1991), but recent Carolina bay age investigations by others have not referenced his findings, instead presenting bay sediment ages, which suggest episodic bay genesis across the past 100,000 years. Given a minimum age of 135 ka provided by Soller, sediments found to be more recent may simply represent reworking of bay rims and contents, rather than a validation of net new bay development. Many bay-fill carbon isotope dates have been found to be older than the range of the technology, >50ka.

Conclusions

These finding are problematic for the gradualistic hypothesis, and suggests the Carolina bays were generated during a single catastrophic event, occurring more recently than the formation of the Socastee Terrace, yet prior to the formation of the Wando Terrace. The author has speculated[2] on the provenance of the extensive surficial sand sheets seen across the coastal plain. Carolina bay depressions have evolved in these sand sheets, seemingly without deforming or altering the antecedent strata and paleosols they rest upon. The oriented ovoid bays are present in prodigious quantities and may represent diagnostic markers for these distinct sand deposits.

In an attempt to identify a universal mechanism for the materialization of these sand sheets, I proposed an aerial deposition, where the constituent quartz grains were mobilized and delivered as a "rain" of pulverized distal ejecta emanating from a remote cosmic impact. The bay depressions may be artifacts of voids in the ejecta blanket, frozen in time as the sand transited from liquefaction to lock-up, preserving an arrival vector in their orientation.

Using data from my LiDAR-augmented geospatial survey of 35,000 Carolina bays, I have noted systematically varying orientations and robust adherence to archetype planforms. A triangulation network, built using bay orientations and considering the Coriolis steering of trajectories, suggests a probable source impact site in the Saginaw bay area of Michigan. While such a catastrophic mechanism is unorthodox, the survey data and analysis suggests further research is warranted. Of primary interest should be age dating of deep, structural rim sediments, rather than surficial eolian or fluvial mantles.

Here, a minimum age constraint has been placed on the Carolina bays, with none found to be younger than Marine Isotope Stage (MIS) 6, the Penultimate Glaciation. In my catastrophic scenario, the presence an extensive continental ice sheet over Michigan is considered, further constraining the impact date to within the Penultimate Glacial Maximum, 135 ka to 145 ka.

Footnotes & References

1) Digital elevation map source data: U.S. Geological Survey National Elevation Data, 1/9 arc-sec

2) Carolina Bay Survey, http://Cintos.org/Survey

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