Rare pre-Columbian settlement on the Florida Gulf Coast revealed through high-resolution drone LiDAR

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Edited by Christopher B. Rodning, Tulane University, New Orleans, LA, and accepted by Editorial Board Member Elsa M. Redmond October 4, 2019 (received for review July 5, 2019)

Drone-mounted, high-resolution light detection and ranging reveals the architectural details of an ancient settlement on the Gulf Coast of Florida without parallel in the Southeastern United States. The Raleigh Island shell-ring complex (8LV293) of ca. 900 to 1200 CE consists of at least 37 residential spaces enclosed by ridges of oyster shell up to 4 m tall. Test excavations in 10 of these residential spaces yielded abundant evidence for the production of beads from the shells of marine gastropods. Beads and other objects made from gulf coastal shell were integral to the political economies of second-millennium CE chiefdoms across eastern North America. At places as distant from the coast as the lower Midwest, marine gastropods were imported in raw form and converted into beads and other objects by craftspeople at the behest of chiefs. Bead making at Raleigh Island is exceptional not only for its level of production at the supply end of regional demand but also for being outside the purview of chiefly control. Here we introduce the newly discovered above-ground architecture of Raleigh Island and outline its analytical value for investigating the organization of shell bead production in the context of ancient political economies. The details of shell-ring architecture achieved with drone-mounted LiDAR make it possible to compare the bead making of persons distributed across residential spaces with unprecedented resolution.

shell rings | LiDAR | Mississippian | craft production

The largest and most complex pre-Columbian societies of North America imported a variety of raw materials and objects to support a political economy of ritualized power (1, 2). Among the imports to ancient cities such as Cahokia were the shells of gastropods from the Gulf of Mexico, which craftspeople fashioned into engraved cups, gorgets, and beads (3). How shell was supplied to places hundreds of kilometers from gulf sources is poorly known due to limited evidence of production from coastal settlements (4–6). A newly discovered site on Raleigh Island on the northern Gulf Coast of Florida provides an unprecedented opportunity to document source-side production of shell beads. High-resolution, drone-mounted light detection and ranging (LiDAR) of Raleigh Island reveals the architectural details of a shell-ring complex that housed shell bead making from ca. 900 to 1200 CE, when polities of the Mississippian Era arose across eastern North America. With the spatial controls provided by LiDAR, research can proceed on the source-side organization of shell bead production as a contributing factor in the rise of regional political economies.

Background

Raleigh Island is located within the Lower Suwannee National Wildlife Refuge of north gulf coastal Florida and is under the jurisdiction of the US Fish and Wildlife Service (USFWS; Fig. 1*A*). The elongated island of ∼30 ha is a remnant of an Ice Age parabolic dune (7) that is now surrounded on all sides by extensive intertidal marsh. Located at the south end of the Suwannee Sound, Raleigh Island is part of an open-water estuarine biome with once-extensive oyster reefs and beds, aggraded tidal flats, and offshore sand shoals that support seagrass.

Archaeological sites on Raleigh Island were registered with the state of Florida in 1991 with little detail. The scope and complexity of its shell rings went unnoticed at the time. In response to the *Deepwater Horizon* oil spill in April 2010, USFWS dispatched archaeologists to inventory refuge land for sites that were vulnerable to impact. Brief reconnaissance of Raleigh Island at that time revealed a complex of rings arrayed along the western end of the island. Investigations since then by the Lower Suwannee Archaeological Survey of the University of Florida (8), under permit with USFWS, has established that the rings date from ca. 900 to 1200 CE, they cluster in 4 cases to form cloverleaf-like compounds of 6 to 12 rings each, the interior of each ring contains organic midden and numerous pits and postholes, and the artifacts of each ring include abundant waste debris from the manufacture of disk-shaped beads from the whorls of lightning whelk shell (*Sinistrofulgur sinistrum,* nee *Busycon sinistrum*).

The shell architecture of Raleigh Island is without parallel in the greater Southeast. Open-access LiDAR data for Raleigh Island and vicinity (9) enable reasonably accurate projections of the topography of mounded shell (Fig. 1*B*), but many architectural details are obscured for lack of sufficient light penetration through generally thick forest cover. Likewise, dense understory prevented

Significance

An unexpected discovery made during the environmental impact surveys after the *Deepwater Horizon* oil spill of 2010 was the remains of an ancient village on the northern Gulf Coast of Florida. Drone-mounted LiDAR reveals a complex of 37 rings of oyster shell, and archaeological testing shows that each of the households occupying the rings produced large numbers of beads from the shells of marine gastropods. Shell beads were integral to the political economy of chiefdoms in eastern North America, but archaeologists have very little knowledge about bead making at the source of the shells. The Raleigh Island village of AD 900 to 1200 is unprecedented in its architecture, its scale of bead production, and its place in regional geopolitics.

Author contributions: T.E.B. and K.E.S. designed research; T.E.B., K.E.S., E.N.B., and R.K. performed research; T.E.B., K.E.S., A.M.A.Z., E.N.B., and B.W. analyzed data; and T.E.B. and K.E.S. wrote the paper.

The authors declare no competing interest.

This article is a PNAS Direct Submission. C.B.R. is a guest editor invited by the Editorial Board.

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1911285116/-/DCSupplemental.

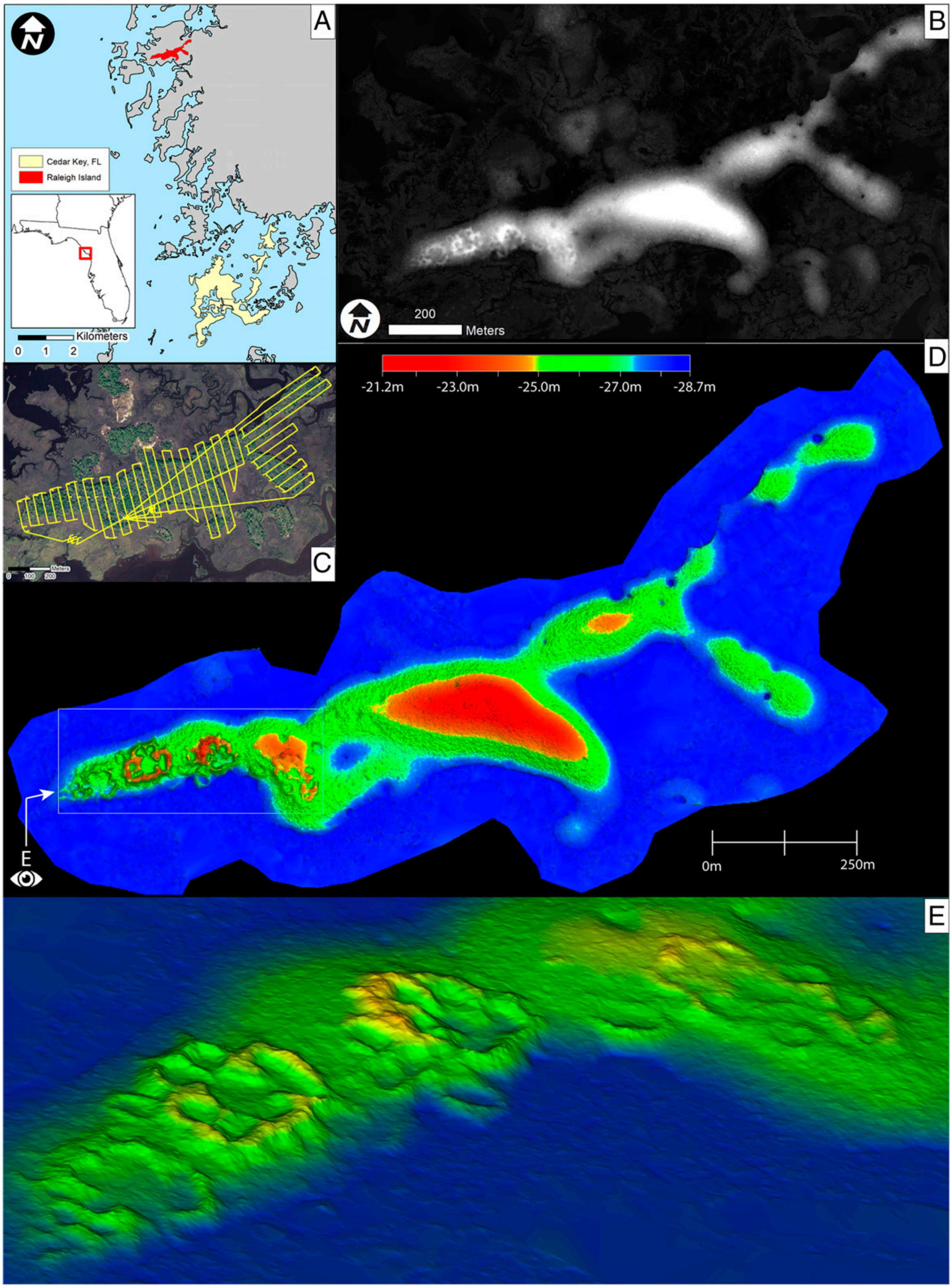

Fig. 1. Location of and prior geospatial information available for Raleigh Island and results of unmanned drone survey missions. (*A*) Location of Raleigh Island along the Gulf Coast of Florida. (*B*) A DEM derived from LiDAR data publicly available from NOAA. The ring complex is visible at the western terminus of the island; however, detail is lacking and in-depth spatial analysis would be difficult or impossible, given missing structural elements and the coarse-grained nature of the data. (*C*) Flight paths of *GatorEye* drone mission for Raleigh Island. (*D*) DEM created from the high-resolution LiDAR data generated by drone survey. (*E*) 3D mesh overlay of shell ring complex on Raleigh Island. Height ramp altered and elevation stretched by factor of 1.5 for visual aesthetic.

comprehensive surface mapping with on-the-ground surveying instruments (e.g., Total Station). In 2018, a drone was deployed at Raleigh Island with LiDAR instrumentation capable of penetrating dense forest canopies and understory for the derivation of high-resolution bare-earth models. Methods and results of the drone flights follow.

Drone-Mounted LiDAR Mapping

The drone LiDAR mapping system, part of the University of Florida's GatorEye Unmanned Flying Laboratory (www.speclab.org/gatoreye.html) multimodal drone-sensor suite, consists of a DJI Matrice M600 Pro Hexacopter carrying a Velodyne laser scanner payload integrated by Phoenix LiDAR Systems. The Hexacopter is capable of ~20-min flights while carrying the mapping system. The laser scanner is a VLP-16 Puck lite that sweeps 16 lasers, offset by 2°, about a central scanning axis oriented in the direction of flight. The combined pulse repetition rate for the scanner is 300 kHz, with each outgoing pulse capable of producing 2 detected returns, enabling penetration through gaps in vegetation to sample ground elevations. Each laser pulse is georeferenced via a postprocessed kinematic Kalman filter solution of the scanner trajectory, integrating dual-frequency Global Navigation Satellite System and Inertial Measurement System observations, corrected against a base station located at the island center whose position was calculated using Trimble Centerpoint RTX to within 1 cm. Per point accuracy of the resulting point cloud was on the order of 3 cm root mean square error.

Three flights were conducted over the study island, each lasting ~14 min. Flights followed the terrain at a height above ground level of 50 m. A north-to-south grid transects approach was used, with 50 m between transects (Fig. 1*C*), and with a flight speed of 8 m/s. The resulting point density was 1,000 to 1,500 points/m^2. All north–south flight lines were merged, and then ground points were identified at a very fine resolution, using the archaeology setting of LASTools lasground_new software (10). We then created a 0.25-m-resolution Geotiff raster digital elevation model (DEM), which was used for all subsequent analyses (Fig. 1 *D* and *E*).

Shell Ring Architecture

Observed in a bare-earth DEM derived from LiDAR are a minimum of 37 shell rings distributed across 4 clusters, labeled in Fig. 2*A* as groups 1 to 4. The number of rings in each group varies from 6 (group 2) to 12 (group 1). Each of the individual rings encloses a flat area of variable size, but large enough in most cases to accommodate a dwelling and outdoor activity space for several people, hereafter referred to as living space. The height of shell walls enclosing circular living spaces varies from less than 1 to nearly 4 m. One exceptional living space is the large rectangular enclosure of group 2. In the comparison of ring groups that follows, we exclude this exception but note for now the possibility that it enclosed public architecture or space.

Using a combination of functions in ArcGIS, the area of living space for each ring was calculated from the DEM of LiDAR data (Fig. 2*B* and *SI Appendix*, Table S1). Excluding the large rectangular enclosure, the area of living space among 36 rings varies from 23.11 to 136.22 m^2 and averages 75.71 m^2 with a SD of 27.14 m^2. Each of the 4 clusters of rings includes small and large enclosures, but some nonrandom tendencies in the distributions bear mentioning. Most notably, the rings of group 1 express the smallest average (56.67 m^2) and greatest variance (cv = 0.51) of any group. They are also the most numerous (n = 12) of the groups and have the least amount of topographic relief among its shell walls. Rings in each of the other 3 groups express averages ranging from 78.30 to 94.11 m^2 with moderate to slight variances (cv = 0.17 to 0.29). Similar to those of group 1, the rings of group 4 (n = 10) have relatively low shell walls.

To test for nonrandom patterning in the size distribution of rings by group, a 1-way ANOVA test was conducted comparing average living space per ring. The results show significant difference at the 0.05 level among the means of each ring group (F [1,35] = 6.85; P = 0.01). Post hoc comparisons using the Tukey HSD (Fig. 2*C*) test indicated significant pairwise differences at the $P < 0.05$ level between groups 1 and 2 (P = 0.03) and between groups 1 and 4 (P = 0.03). The remaining pairwise comparisons show no significant differences.

In qualitative terms, variation among ring groups is most pronounced in the topographic relief of shell walls, as noted earlier. The subtle relief of some rings went unnoticed until the LiDAR data of drone flights were processed. This is particularly the case for rings in groups 1 and 4, which express 1 m or less of topographic relief. In contrast, the shell walls of rings in groups 2 and 3 reach heights up to 4 m that obscure line-of-sight between adjacent rings. Although total living space in each group does not vary appreciably, the amount of shell comprising walls does. We have yet to excavate the walls of any of the rings, but suspect that they accumulated in stages, as they did in older, Late Archaic rings in the region. If so, the low-relief rings in groups 1 and 4 may have been shorter-lived than those with greater relief in groups 2 and 3. It may be significant that rings in the former groups are more numerous than those in the latter groups, indicative perhaps of serial occupation of short-lived rings.

Another dimension of variation among ring groups is the contiguity of rings. Each group has a core of 5 or more rings whose shell walls converge into a cloverleaf plan. Each group also has between 1 and 5 outlier rings whose relatively low shell walls do not converge into a consistent pattern. Groups 1, 2, and 3 each have 5 contiguous rings (counting the rectangular form of

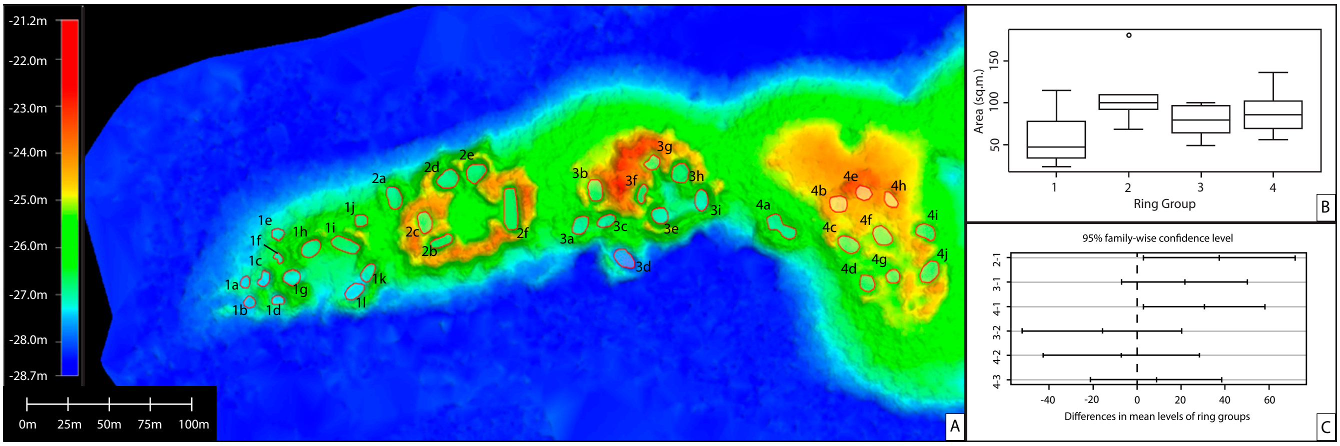

Fig. 2. Characterization of living areas and their spatial properties. (*A*) Location and alphanumeric designation of 37 living areas identified within the 4 ring groups. (*B*) Box-plot derived from living area means organized by ring group. (*C*) Results of Tukey post hoc comparisons between each ring group.

group 2), whereas group 4 has 9 contiguous rings. Outlier rings vary from 1 to 5, but all are emplaced to the west of the contiguous rings. The only exception is a ring to the north of the group 1 cluster, which may actually be a western outlier of group 2 but in closer proximity to the group 1 cluster. Group 4 deviates from the others in having not only a much greater number of contiguous rings but also 1 in the center of the cluster; the other groups have what amounts to an open area at the center, much like a central plaza or courtyard. Overall there appears to be an architectural grammar to ring clusters and associated outlier rings.

The subsurface of each ring consists of anthropogenic soil (i.e., midden) rich in artifacts, food remains, and features. Test excavations to date consist of a series of 25 shovel tests (30 × 30-cm in plan) across all groups and seven 1 × 2-m units, 1 in each group and 4 in group 2. Fig. 3*A* shows the profiles of test units in adjacent rings of group 2 against a cross-section of the shell walls that enclose these rings and the overlying canopy on the north side of the group. All excavations into the living spaces of rings exposed organic, anthropogenic soil (midden) extending ~60 to 70 cm below the surface (Fig. 3 *B* and *C*). Contained in midden were abundant and diverse vertebrate faunal remains (mostly fish), some oyster and clam shell, numerous sherds of pottery, and the technology and byproducts of making shell beads from marine gastropods. Pit features and occasional post holes were detected at the base of the midden in all excavation units. The artifacts, food remains, pits, and postholes all point to habitation within rings. Excavations thus far are inadequate to infer anything about the size and form of habitation structures (i.e., houses), how long they were occupied, and how they relate to other features in rings, such as pits. Houses aside, the oyster shell of enclosing walls presumably accumulated gradually during the occupational span of rings as oyster was consumed, but we cannot rule out that walls were erected quickly from extant oyster shell deposits.

Finally, the rectangular enclosure in group 2 stands apart from all others not only in shape but also in size. With more than 180 m^2 of living space, this enclosure could have housed multiple small structures or a much larger public structure, or have simply been open public space. It is not unusual for villages and towns of pre-Columbian communities of the Southeast to include at least 1 public building or common space among an assemblage of domestic structures. Future subsurface testing will aim to resolve this issue.

Shell Ring Chronology

Despite the unprecedented details of Raleigh Island shell architecture, we had assumed before excavation that the rings were constructed during the Late Archaic Period, when shell rings with topographic relief were prevalent (11). The recovery of pottery sherds dating exclusively to the last millennium dispelled that assumption. Ten AMS assays of wood charcoal from rings in each of the groups confirm the late age of the complex. *SI Appendix*, Fig. S1 provides the probability distributions of the

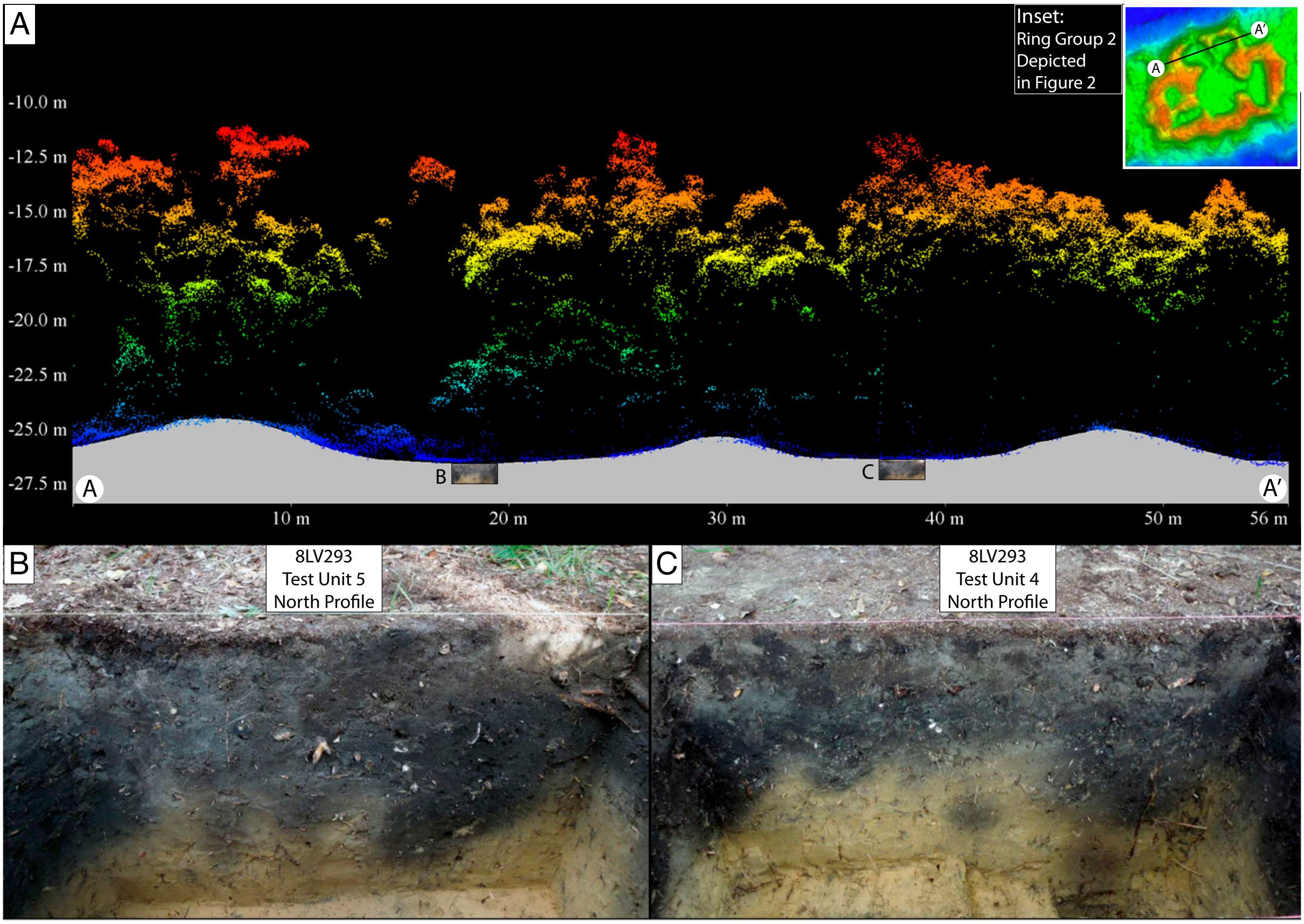

Fig. 3. Cross section of living areas 2d and 2e of ring group 2, with test unit profiles showing dense anthropogenic midden identified. (*A*) Cross-section showing upper- and lower-story returns as well as ground hits from drone LiDAR. Ground surface is depicted in gray. Test unit profiles are to scale in their correct location. (*B*) Test Unit 5 profile, excavated to a depth of 105 cm below datum (cmbd). (*C*) Test unit 4 profile, excavated to a depth of 105 cmbd.

calibrated ages of these samples, plus a summed probability distribution for the entire group of assays. The full range of calibrated ages at 2-sigma spans more than 4 centuries (778 to 1220 cal CE), but Bayesian modeling of a single phase sequence reduces that span by more than a century, ca. 900 to 1200 cal CE.

The summed probability distribution of AMS age estimates is bimodal in shape, and thus possibly indicative of a 2-phase sequence of occupation of the rings. Additional AMS assays are needed to substantiate this assessment, but if a 2-phase model holds up, we suspect that the earlier occupation was concentrated at the west end of the complex, in the area of group 1. The test unit in 1 ring of this group produced the only substantial evidence for a pottery type (Swift Creek Complicated Stamped) that does not postdate ca. 900 CE. If an early age for group 1 holds up to additional dating, a trend toward prolonged use of rings over time may be born out in the greater topographic relief of rings in groups 2 and 3.

Shell Bead Production

All of the seven 1 × 2-m excavation units within rings of Raleigh Island yielded abundant evidence for the manufacture of disk-shaped shell beads. The evidence includes the raw material of beads; namely, the outer whorls of lightning whelk, bead blanks struck from whorls, bead preforms that are partially or fully drilled, stone drills and the byproducts of making them, stone anvils for making drills, and stone abraders for shaping beads (Fig. 4). Data are insufficient to calculate the scale of bead production in the rings, but enough are available to assert that output was high and that the occupants of all rings participated in production. Although test excavations outside of the confines of rings are limited to date, none has yielded evidence for bead making.

Shell bead production goes back millennia in eastern North America (12), but was intensified during the first half of the second millennium CE, the era of so-called Mississippian chiefdoms (13, 14). Shell beads of various forms were sewn on clothing and strung into necklaces and bracelets. They may have been available to everyone, although we presume that the value of shell beads increased with distance from the source, and thus may have been a medium of economic wealth and political power far to the interior of the continent. One elaborate burial at the Mississippian city of Cahokia, for instance, involved the use of more than 25,000 shell beads on a garment believed to be a cape in the form of thunderbird (15). Shell in general was regarded as a powerful medium by Native Americans of the contact period. The shell of lightning whelk held particular significance for mimicking the cycle of the sun in its sinistral spiral (16, 17). The overwhelming majority of disk and tubular beads at sites of the Mississippian Period were fashioned from lightning whelk.

Fig. 4. Sample of the artifact types recovered during excavations on Raleigh Island. (*A*) Outer whorls of lightning whelk shell used as raw material for bead production. (*B*) Limestone abrader used to shape shell beads into their final form. Note the characteristic groove on the pictured specimen. (*C*) Chert cobbles used to flake stone or serve as raw material for tools. (*D*) Limestone tablet with usewear indicative of an "anvil" for bipolar stone-tool reduction. (*E*) Lightning whelk shell beads in various stages of manufacture. (*F*) Chert microlithic drills used to bore the holes in shell bead blanks.

Lightning whelk shells were imported in raw form to Cahokia, where evidence for on-site manufacture of beads is abundant (18–20). Starting in the 11th century CE, craft production at Cahokia became more centralized over time, with most exotic goods regulated by elite residences by the late 13th century (21). However, not all Mississippian towns of the interior imported whole shell even as they consumed tens of thousands of shell beads. Whether in raw form or as finished products, the majority of lightning whelk shells likely originated from the estuarine waters of the Gulf Coast, where they abound. Lightning whelk also inhabit the southeastern Atlantic, but are eclipsed in numbers by knobbed whelk (*Busycon carica*), which were the taxon of choice for disk-bead making at a 14th century site on the Georgia coast (6). Recent morphometric analysis to identify sources of shell imported to Mississippian centers of the interior suggest that the most common source was lightning whelk from the eastern Gulf of Mexico (22).

While much is known about bead production and consumption at large political centers such as Cahokia, comparatively little is known about bead production near sources of shell (23, 24). Raleigh Island is unusual for its abundance of evidence for shell bead production, a testament to the elevated scale of manufacture at the supply end of a wide network of demand. Moreover, the onset of shell bead production at Raleigh slightly predates the emergence of Mississippian chiefdoms, and thus could have been among the earliest suppliers of beads for nascent chiefdoms. A chiefly political economy predicated on the acquisition of nonlocal goods such as shell beads may have been stimulated by entrepreneurs at Raleigh Island. At the same time, growing demand for beads among chiefdoms may have contributed to the intensification of bead production at Raleigh Island and beyond.

A promising avenue for research at Raleigh Island presents itself in the intersection of architecture and shell-bead making. Spatial controls over the living spaces of inhabitants at sites of the Gulf Coast are virtually nonexistent, precluding investigations into the relationships of individuals or households to society at large and their participation in regional economies. Conversely, the shell rings of Raleigh Island lend themselves to comparisons across households. Was shell bead production segmented among households, or did each manage production independently? Did households compete among themselves to meet regional demand for beads? Were any households experimenting with innovations to improve the efficiency or output of production? Raleigh Island holds unlimited potential to address these and related questions.

Conclusion

High-resolution, drone-mounted LiDAR reveals architectural details of a complex of shell rings with no parallel in the archaeological record of the last millennium CE. Although the shell rings of Raleigh Island may have ancestral roots in the Late Archaic tradition of the Southeast, no such architecture is known for the centuries leading up to and ushering in the Mississippian Era of the second millennium CE. Given the existence of a few shell rings in the Lower Suwannee region that postdate the heyday of Late Archaic rings by as much as 3,000 y, we suspect that those of Raleigh Island are indicative of a reinvented tradition. Insofar as shell bead production at Raleigh Island was geared toward an emerging political economy of Mississippian chiefdoms throughout the Southeast, its inhabitants would appear to have embraced both ancient and novel forms of cultural expression. Based on the architectural details afforded by high-resolution LiDAR, research into this cultural development can proceed with unprecedented spatial controls.

Data Availability. LiDAR data used in this project are available online at www.speclab.org/gatoreye.html, and use restrictions are described there. Archaeological data are forthcoming in a technical report, and when completed will be available online at http://lsa.anthro.ufl.edu.

ACKNOWLEDGMENTS. We are grateful to the staff of the USFWS for their ongoing support and stewardship of Raleigh Island and the sites around it, as well as members of the Laboratory of Southeastern Archaeology that aided in the excavations of the shell ring complex. Drone mapping by the *Gatoreye* team and excavation costs were funded through the Hyatt and Cici Brown Endowment for Florida Archaeology.

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