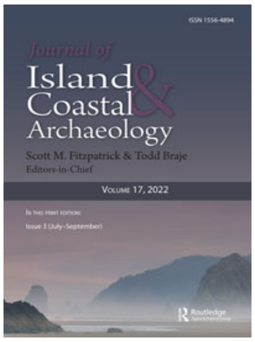

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Coastal landscape changes at Unguja Ukuu, Zanzibar: Contextualizing the archaeology of an early Islamic port of trade

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ABSTRACT

Unguja Ukuu, located on the Zanzibar Archipelago, eastern Africa, was an active Indian Ocean trading settlement from the mid-first millennium until the early second millennium AD. As part of recent archaeological excavations aimed at understanding the site's transregional trade networks, geoarchaeological analyses were undertaken to document the geomorphic context of the ancient settlement. Here, we outline the results of these field and laboratory studies to discuss patterns of anthropogenic sediment deposition. Unguja Ukuu's deep coastal stratigraphy appears to record progradation of an inhabited back-reef shore from the mid-seventh to the nineth centuries AD, perhaps in the wake of an earlier middle to late Holocene marine transgression. Excavations on the back-beach show that deposits associated with the ancient settlement include interlayered middens, paleofloors, and backshore sands and, in later phases, a peri-urban dump with dark-earth-type anthrosols developed on these deposits. Coastal progradation appears to have been driven in part by the accumulation of anthropogenic detritus and compaction of ancient surfaces. We hypothesize how the inherited, submerged relic Late Pleistocene geomorphology of the intertidal zone and later Holocene sediment supply from the hinterland may have supported the emergence of Unguja Ukuu as a trading locale, and possibly contributed to its decline in the early second millennium AD.

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Maritime trade; Swahili coast; archaeology of small islands; coastal geoarchaeology; settlement micromorphology

Introduction

For millennia, the Indian Ocean has been the maritime setting for a nascent form of globalization, with extensive trade and exchange networks operating between eastern

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Africa, Southern Arabia, South and Southeast Asia foreshadowing modern global shipping networks (Horton, Boivin, and Crowther 2021). These ancient maritime networks only functioned as well as the hubs and nodes—ports, trading settlements, and emporia—that linked them. Despite the obvious importance of such sites, relatively little is known about them and their interaction with the dynamic littoral environments in which they were located. To help understand how and why these nodes thrived or declined, it is important to know how the coastal landscape influenced the way traders undertook their commercial activities, or drove decisions, including mooring locations and investments of labor and capital by local communities and any central authorities. Similarly, from an environmental standpoint, it is crucial to know whether this commercialization had a physical effect on the coastline, anthropogenically modifying the landscape morphology or catalyzing change.

Archaeological evidence and historical accounts suggest that Unguja Ukuu, situated on the southern coast of Unguja (Zanzibar) Island, Zanzibar Archipelago (Figure 1), represents one of the earliest known nucleated trading settlements on the Swahili coast (Crowther et al. 2015; Fitton 2017; Fitton and Wynne-Jones 2017; Horton and Middleton 2000; Juma 2004; Sulas, Kristiansen, and Wynne-Jones 2019; Wynne-Jones et al. 2021). Building on existing archaeological work and comparative studies (Chami 1999; Chami and Msemwa 1997; Chittick 1966; Crowther et al. 2015, 2016, 2018; Faulkner et al. 2018; Fitton 2017; Fitton and Wynne-Jones 2017; Horton, Boivin, and Crowther 2021; Horton and Clark 1985; Horton and Middleton 2000; Juma 1996, 2004, 2017; Prendergast et al. 2017; Wood et al. 2017; Wynne-Jones et al. 2021), we employ geoarchaeological analyses allied with environmental assemblages and coastal landscape proxies to bring a new perspective to our understanding of Unguja Ukuu. The focus of this geoarchaeological research was to: (1) survey the geomorphic setting of the trading settlement and wider backshore area; (2) record and sample stratigraphy exposed in trenches to reconstruct on-site environmental and landscape change; and (3) assess geomorphic change (whether natural or human-made) of the Unguja Ukuu coast over the last millennium. We aimed to reconstruct the changing site environment and seek evidence for human–environment interactions to assess the relative importance of geomorphic versus anthropogenic drivers of coastal landscape change.

In this paper we report the geoarchaeological results and share insights from a reconnaissance survey of the settlement and its surrounding coastal landscape. We then articulate preliminary hypotheses linking the emergence and expansion of Unguja Ukuu's settlement with the geomorphic evolution of its adjacent coastline and hinterland, and the implications of this coastal change for the life of the trade port.

Social, geomorphic, and ecological setting

The Zanzibar Archipelago is a semi-autonomous region within the Republic of Tanzania, consisting of two main islands, Unguja (Zanzibar) and Pemba, and 44 smaller ones. Known today as the "Spice Island," Unguja was inhabited by foragers from at least 20,000 years ago prior to becoming an island (Kourampas et al. 2015; Prendergast et al. 2016; Shipton et al. 2016). By the mid-first millennium AD, the island was populated by farming societies that were actively involved in broader Indian Ocean trade and exchange

Figure 1. Unguja Island, Zanzibar Archipelago showing the location of Unguja Ukuu.

(Horton and Middleton 2000). During the early second millennium AD, existing trade links were cemented and new directions—for example, toward China—afforded avenues for economic development and expansion to eastern Africa's emerging cosmopolitan maritime society as evidenced by the increasing urban growth of the coastal settlements and trade ports (Fleisher et al. 2015). Over the years, the islands of the Zanzibar Archipelago witnessed numerous environmental and cultural changes as the region became a hub of maritime trade, cross-cultural interaction, and global exchange.

The southwestern coast of Unguja, where Unguja Ukuu is located, was shaped by early Holocene sea-level change with further modification by sediment aggradation, progradation, and erosion, which resulted in the formation of a macrotidal rias-and-

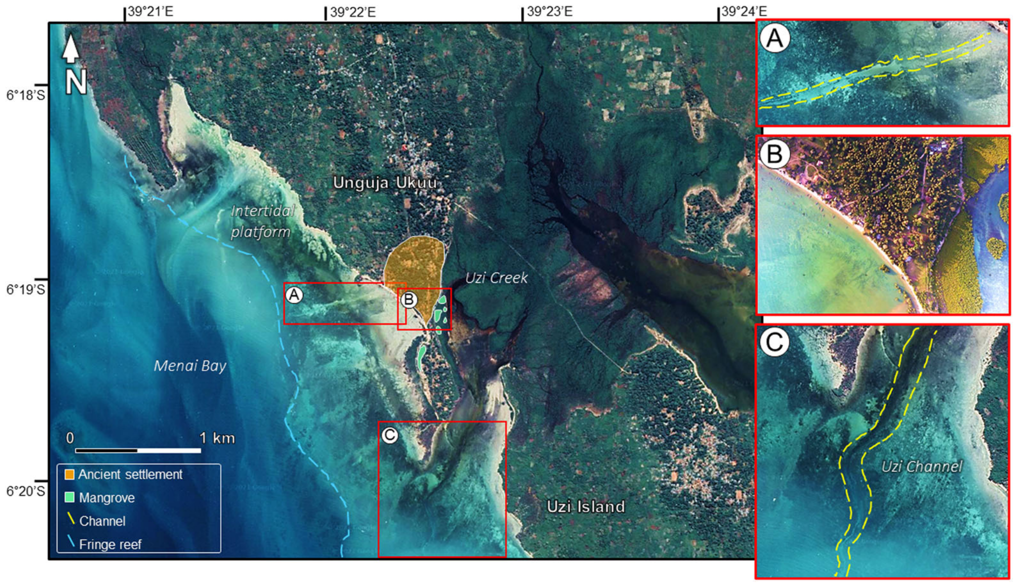

Figure 2. Satellite image of Unguja Ukuu and the surrounding landscape. In the insets: (A) the extent of the tidal channel leading to the settlement; (B) the satellite view of the settlement site; (C) the Uzi channel leading toward the creek. Source: Google Earth.

mangrove coastal environment. Compared to the east coast of the island where the soils are generally thin and poorly developed, the western coast has deeper, more fertile soils that were favored as locations for Iron Age settlements (Faulkner et al. 2018; Prendergast et al. 2017; Walshaw 2010).

The first millennium AD settlement of Unguja Ukuu (∼16 hectares) lies on the fringes of the present-day Kaepwani village, at the head of Menai Bay, nestled between the village, creek, and the shoreline. It is located behind the protective barrier of a shallow fringing back-reef platform, as well as the limestone islands of Miwi, Niamembe, and Uzi—the latter separated from Unguja Ukuu by a shallow intertidal platform (Figure 2). This is a macrotidal coast with mixed semi-diurnal tides, a mean springtide range of 3.3 m, and strong tidal currents (Horill et al. 2000). Late Pleistocene limestone that forms the bedrock (Arthurton 2003; Arthurton et al. 1999) is often exposed on coastal cliffs, low marine terraces (6–10 m above mean sea level [asl]), and as isolated outcrops under a cover of Pleistocene and Holocene backshore sands and soils (Figure 3). The coastal reaches of the submerged drainage network are incised through the limestone (Kourampas et al. 2015). Rias and coastal wetlands—creeks and tidal embayments fringed with mangrove—extend east of the modern town, at the mouths of NNW–SSE-trending valleys (Figure 3).

The western shore of Unguja Ukuu is an extensive, shallow back-reef shoreline; an intertidal shelf that stretches for about 2 km offshore to the fringing reef and is dissected by shallow channels, presumably formed by tidal currents. Notched cliffs, eroded in Pleistocene limestone, form short promontories and define an extensive 6–10 m asl terrace, presumably of Late Pleistocene age (Figure 3). This terrace and the backshore flats are covered with eolian sand drift and soils, of which two principal types can be distinguished: leached red sandy latosol, widespread along the coast and the main road that crosses the modern village. This soil has developed on eolian sands and limestone bedrock

Figure 3. (A) Composite photos of Menai Bay facing south-west from the beach; (B) Menai Beach from the intertidal zone, facing northeast toward the location of Trench UU14; and (C) fishing vessels beached and at anchor in Menai Bay at low tide, facing south-west toward Niamembe and Miwi Islands.

black organic soil (black/"dark earth" anthrosol) with abundant occupation debris (e.g., ceramics, charcoal, animal and plant remains, etc.) at and around the ancient settlement.

The coastal landscape east of the settlement is remarkably different; creeks and tidal embayments with extensive mangrove wetlands at the seaward end of shallow valleys predominate from about 6–7 km east of Unguja Ukuu (Figures 1 and 3). Three large creeks extend offshore across the shallow inner shelf as deeper channels. Two of these are confluent 4 km southeast of Unguja Ukuu and are forming the Pete Inlet, a deeper channel that traverses the entire inner shelf, from the east of Uzi Island to the reef front (Figures 1 and 3). This semi-submerged drainage network contributes terrigenous sediment from the hinterland (drainage catchment) to the inner shelf. Mangroves function as sediment traps and contribute large quantities of biogenic debris. Tidal currents and waves redistribute sediment along the shore with the tidal channel (partly filled with sediment) still visible on satellite images and at low tide (Figure 4).

Figure 4. Uzi Creek at Unguja Ukuu (to the east and south of Trench UU14).

Materials and methods

Building on earlier archaeological work, the 2011–2012 ERC-funded "Sealinks" project fieldwork at Unguja Ukuu included geoarchaeological reconnaissance that aimed to:

(1) assess late Holocene to recent geomorphic change on the Unguja Ukuu coast by means of landscape and environmental reconstruction;
(2) document the geomorphic context of the ancient settlement through coastal survey; and
(3) log and sample deposits exposed at two excavated archaeological trenches located in the backshore area of the site (UU11 and UU14).

Analyses were undertaken on the northern and western profiles of Trench UU14, which was situated at the coastal fringes of the early settlement ~10 m east of the ruins of a nineteenth-century house (Figure 5) and adjacent to Trench UU11 in which near-identical stratigraphy was exposed. Trenches were excavated using a single context recording system (and for "thicker" contexts further splitting into "spits") with dry sieving and, for the majority of lower contexts, a 100% flotation for optimal ecofact recovery. The trenches were excavated all the way to Pleistocene bedrock ~3.5 m below ground surface. The radiocarbon chronology on charred seeds for Trench UU14 has been published in Crowther et al. (2016, 2018) (Table 1) and the stratigraphy used throughout the results section has been resolved in Table 2.

Sedimentology

Sediment sampling included monolith bulk sampling of exposed stratigraphy of representative sections, each 2 cm. These were supplemented with undisturbed samples of selected layers, features, and interlayer boundaries. Sedimentological analyses including granulometry, geochemistry, and X-ray fluorescence (XRF), were undertaken on all

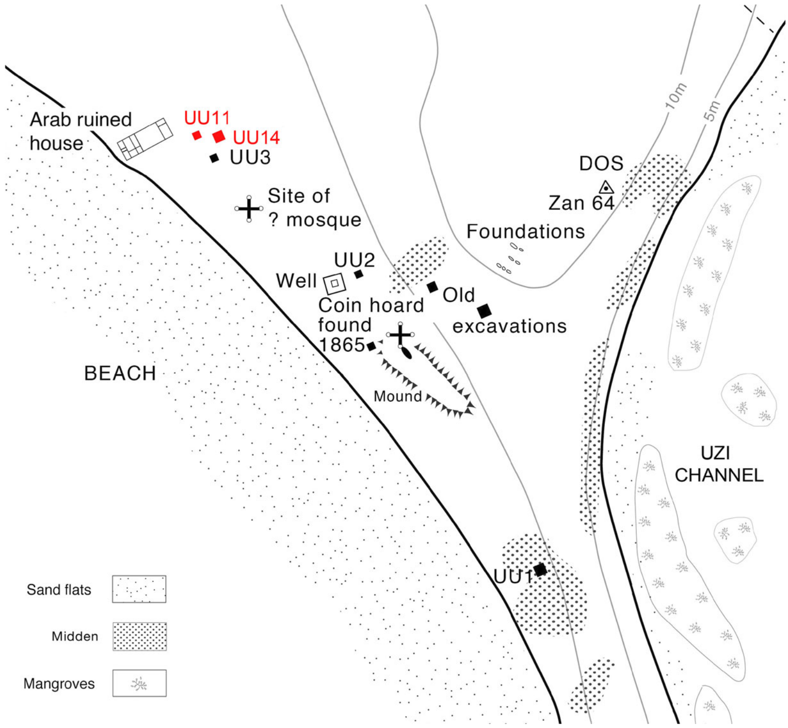

Figure 5. Site plan of Unguja Ukuu showing the location of Trench UU14.

Table 1. Radiocarbon dates on charred seeds from the trench UU14 (Crowther et al. 2016).

Site and trench (context)	Material, taxon	Laboratory no.	Treatment	$\delta^{13}C$	^{14}C years (BP)	Cal CE
UU14 (1404)	Charred seed, *Oryza sativa*	OxA-27520	RR	−24.74	1151 ± 26	885–990
UU14 (1417)	Charred seed, *Sorghum bicolor*	OxA-27518*	None	−10.08	1244 ± 27	715–890
UU14 (1417)	Charred seed, *Sorghum bicolor*	OxA-27519*	ABA	−8.99	1287 ± 25	675–860
UU14 (1417)	Charred seed, *Sorghum bicolor*	OxA-27698*	RR	−9.15	1226 ± 25	765–895
UU14 (1420)	Charred seed, *Sorghum bicolor*	OxA-29278	RR	−9.73	1317 ± 24	670–770
UU14 (1436)	Charred seed, *Oryza sativa*	OxA-28189	RR	−26.70	1265 ± 23	685–880
UU14 (1439)	Charred seed, *Sorghum bicolor*	OxA-29279	RR	−9.14	1232 ± 26	765–895
UU14 (1439)	Charred seed, *Triticum* sp.	OxA-29288	RR	−21.38	1305 ± 24	670–835
UU14 (1442)	Charred seed, *Sorghum bicolor*	OxA-28658	RR	−10.08	1314 ± 26	665–775
UU14 (1445)	Charred seed, *Oryza sativa*	OxA-27595	ABA	−24.76	1245 ± 22	765–890

samples. A Malvern Mastersizer 2000 was used to determine particle size distribution of the <2 mm size fraction. Dried subsamples were subjected to loss on ignition (LOI) analysis following standard protocols (Davies 1974; Heiri, Lotter, and Lemcke 2001).

Micromorphology

Undisturbed sediment blocks were extracted from selected layers, features, and inter-layer boundaries for micromorphology (e.g., Morley et al. 2017). In Trench UU14, blocks were removed in 6.5 × 10 × 4.5 cm polyurethane boxes. A total of nine blocks were extracted from lithostratigraphic interfaces, and the four most representative (see Figure 6 for locations of: MM5, MM6, MM7, and MM9) were selected for analyses.

Table 2. Stratigraphy of trench UU14.

Facies	Contexts	Description/*(Interpretation)*	Ages	Unit interpretation and association with archaeological phase
VII	1400	Accumulation of plastic, metallic, rubber artifacts in very loose, dark grayish sandy silt. Burning episodes and burrowing. *(Md)*		Peri-urban dump (with episodes of waste burning) and cassava farming on black earth soil. Archaeological Phase 10
	1402 + 1401	Cassava ditch cut (1402), filled with loose black organic soil (1401).		
VI	1403	Dark gray to black, cohesive to crumbly, lightly compacted, organics-rich sandy silt, with potsherds (abraded in basal layers), abundant bones, and limestone blocks. The upper parts are very organic, with mixed and abraded material culture. *(Md/Ps)*		Organics-enriched, diachronous anthrosol (black earth), growing on peri-urban midden. Heavily bioturbated. Archaeological Phase 8
	1404	Dark brown, cemented organics-rich silty sand (to sandy silt upwards), with bone (land mammals and fish), shells, and material culture. Accumulations of horizontal shell fragments in middle parts. *(Md/Pf)*	C14 date on charred seed, *Oryza sativa* OxA-27520: 885–990 cal CE	
	1415 + 1416	Small animal burrow of very loose and grayish sand with 1415 fill of 1416 cut.		Pit sequence
	1413	Sand pit feature associated with 1414 but of a lighter color and very loose.		
	1414	Large pit of loose, sand with some darker, more organic patches and lenses. The pit had well-defined edges at the top but was more dilute toward the bottom.		
V	1406	Shells and material culture in compacted, black organic silt. Shells and other platy objects lie flat on their surface. *(Pf)*		Peri-urban midden, exposed to relatively prolonged surface weathering and colluviation. Presence of well-defined paleofloors. Contexts associated with AP5a are supposed oxidized hearth or combustion features of bright orange coloring and organic character. Archaeological Phase 7 (contexts 1406, 1408, 1412) and 5a (contexts 1422, 1417, 1418, 1419)
	1408	Dense accumulation of shells in compacted, black organic silt. *(Md)*		
	1412	Black, organic sandy silt with rich accumulation of material culture. Compacted surface and horizontal arrangement of particles. *(Pf)*	Ceramic date on Yue pottery—ninth century AD.	
	1422	Compact, dark blackish, organic to bright orange sandy silt with diffuse boundaries and some material culture that looks to be oxidized by fire. *(Cf)*		

(*continued*)

Table 2. Continued.

Facies	Contexts	Description/*(Interpretation)*	Ages	Unit interpretation and association with archaeological phase
	1417	Orange to black silty sand rich with, often large, fragments of charcoal, marine shells, and potsherds. Fragments of charred sorghum grains are visible with a naked eye. Convex cross-section. *(Cf)*	3 x C14 dates all on charred seed, *Sorghum bicolor*: 1. OxA-27518*: 715–890 cal CE; 2. OxA-27519*: 675–860 cal CE; 3. OxA-27698*: 765–895 cal CE	
	1418	Loose to lightly cemented, organics-rich black clayey sand.		
	1419	Orange clayey sand. Circular in both profile and plan, with very diffuse boundaries. *(Cf)*		
IV	1420	Cemented silt with abundant shells. *(Md)*	C14 date on charred seed, *Sorghum bicolor:* OxA-29278: 670–770 cal CE	Dumping, burning, and other indeterminate practices—on peri-urban midden. Cementation caused potentially by percolation of material from the overlying contexts or from dissolved calcium carbonate from shells. Archaeological Phase 5
	1421	Loose and soft brown sand.		
	1425	Dark gray to black, very compact to cemented sand with abundant shells and other material culture. *(Md)*		
	1423	Loose black sands and dense shell accumulations (1423 N). Remaining spits similar to 1425. *(Md)*	17 (from midden)	
	1426	Sharp-based, lightly compacted dark gray organic sand with abundant shells. *(Md)*		
III	1447	Sharp-based black organic sandy loam with abundant charcoal. *(Cf)*		"Haphazard" occupation on the backshore. Dark layers are human-deposited floors and middens; white layers are eolian and storm wave-lain sand. Archaeological Phase 4 (contexts 1424, 1427–1431, 1433–1437) with 4a (contexts 1432, 1447, 1448), and 3 (contexts 1438–1440, 1442)
	1448	Sharp-based black organic sandy loam with abundant charcoal. *(Cf)*		
	1432	Black coarse sand. Hearth? *(Cf)*		
	1424	Yellow to white loose sand with more compacted orange staining.		
	1427	Clean white loose sand. *(Bs)*		
	1428	Dark brown, organics-rich sand with marine shells and material culture. Inclusions show evidence of marine corrosion. *(Md/Pf)*		
	1429	Pale, clean, yellow sand. *(Bs)*		
	1430	Dark brown, organics-rich sand with calcified inclusions.		
	1431	Loose, white clean sand. *(Bs)*		
	1433	Friable brown sand with large potsherds and corroded bone fragments.		

(*continued*)

Table 2. Continued.

Facies	Contexts	Description/*(Interpretation)*	Ages	Unit interpretation and association with archaeological phase
	1434	Yellow, darkening to firmer brown sand, with abundant bone, material culture, and rocks, most of which were very well-preserved but with some evidence of marine corrosion .		
	1435	Very loose, yellowish white sand with orange and olive mottling. *(Bs?)*	16	
	1436	Dark brown, organics-rich loose and moist mid to coarse sand with potsherds and bedrock limestone clasts.	C14 date on charred seed, *Oryza sativa* OxA-28189: 685–880 cal CE	
	1437	Loose, moist pale yellowish-white coarse sand. *(Bs)*		
	1438	Loose, yellowish coarse sand with some black organic inclusions.		
	1439	Ironized and organic medium to coarse sand with potsherds and other material culture, from loose and moist, very dark gray to blackish coarse sand passing up to pale yellowish-white sand with charcoal flakes and organic lenses. Iron oxide bands throughout.	C14 date on charred seed, *Sorghum bicolor* OxA-29279: 765–895 cal CE and on charred seed, *Triticum* sp. OxA-29288: 670–835 cal CE	
	1440	Brown sand with charcoal and bedrock clasts of coral rock.	14	
	1442	Brown coarse and friable sand with large quantities of well-preserved potsherds, metal objects, and bedrock clasts and packstone.	C14 date on charred seed, *Sorghum bicolor* OxA-28658: 665–775 cal CE	
II	1441	Pale, whiteish coarse sand with inclusions of clay. *(Bs?)*		Backshore with occupation episodes.
	1443	Very wet, whiteish, coarse sand with minor clay inclusions		Periphery of the earliest Unguja Ukuu settlement?
	1444	Organic, black clay with abundant charcoal.	13	Archaeological Phase 2
	1446	Mid-brown to gray clayey coarse sand with large pottery fragments and bedrock clasts.	12	
I	1445	Loose, friable, saturated, coarse pebbly sand with marine mollusks.	C14 dates on charred seed, *Oryza sativa* OxA-27595: 765–890 cal CE. Ceramic dates on turquoise-glazed ware/ Sasanian Islamic, ca. seventh–tenth century AD.	Fluvially supplied shore sediment. Archaeological Phase 2a
Bedrock	1449	Intensely karstified limestone (packstone/grainstone). Heavily eroded calcareous packstone (grain-supported rock containing micritic (lime mud) in its matrix)		Late Pleistocene bedrock. Archaeological Phase 1

Shaded in orange: also lithostratigraphic contexts with available micromorphological evidence. Key to context interpretation: Br: burial; Bs: beach sand; Cf: combustion feature; Md: midden; Pf: paleofloor; Ps: paleosol, Pt: pit.

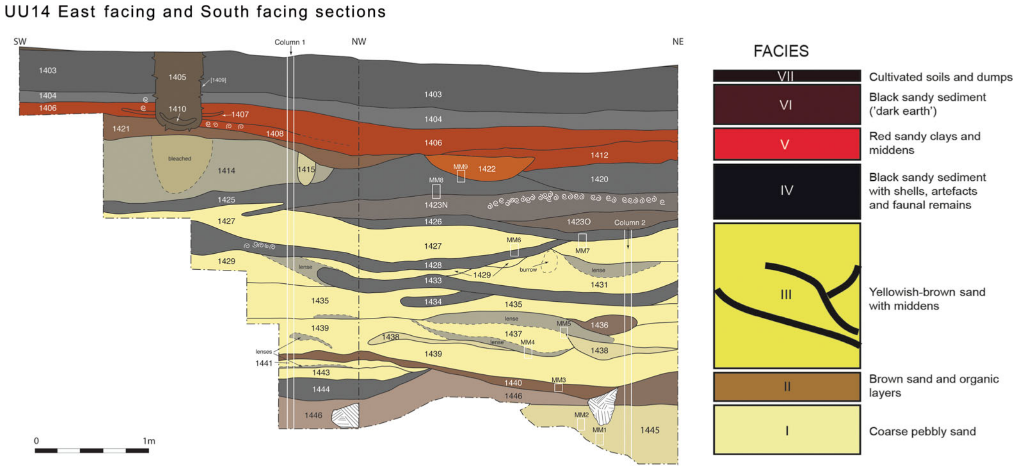

Figure 6. Composite drawing of UU14 north and west sections showing the location of micromorphological samples (MM1–9) and bulk sediment sample columns (columns 1 and 2).

Thin sections were manufactured at the University of Stirling Thin Section Laboratory following standard procedures (www.thin.stir.ac.uk). Four thin sections were examined under a polarizing microscope (100× to 400×) using plain polarized (PPL), cross polarized (XPL), and oblique incident light (OIL).

Results and interpretations

The Holocene stratigraphy represented in Trench UU14 was resolved into seven facies (I–VII), each representing similar environments of deposition (Figure 6; Table 2). Broadly speaking, the sediments comprise sandy units with variable organic content and anthropogenic inputs (Figure 6).

Bedrock: Late Pleistocene limestone (context 1449)

The Late Pleistocene bedrock at the base is a creamy white reef limestone with gastropods and bivalves. The limestone surface is intensely karstified and bioeroded, suggesting exposure on the foreshore prior to its burial. Although no absolute chronology is available, it is reasonable to assume correlation of this limestone with an elevated sea level during the last interglacial highstand (MIS5, broadly around 125,000 BP) (see Arthurton 2003; Arthurton et al. 1999). The marine terraces eroded on this limestone might relate to minor sea-level fluctuations (Kourampas et al. 2015).

Facies I: Coarse pebbly sand (context 1445)

The basal facies (context 1445) directly overlies bedrock (context 1449), comprising ~50–70 cm of light grayish brown, coarse pebbly quartz sand (to conglomerate, within bedrock scour hollows) draping limestone bedrock. Limestone and quartz pebbles (maximum ~4 cm) are well-rounded and abraded shallow-marine bivalves and gastropods are also present but in low numbers. This facies contains several large and well-preserved potsherds,

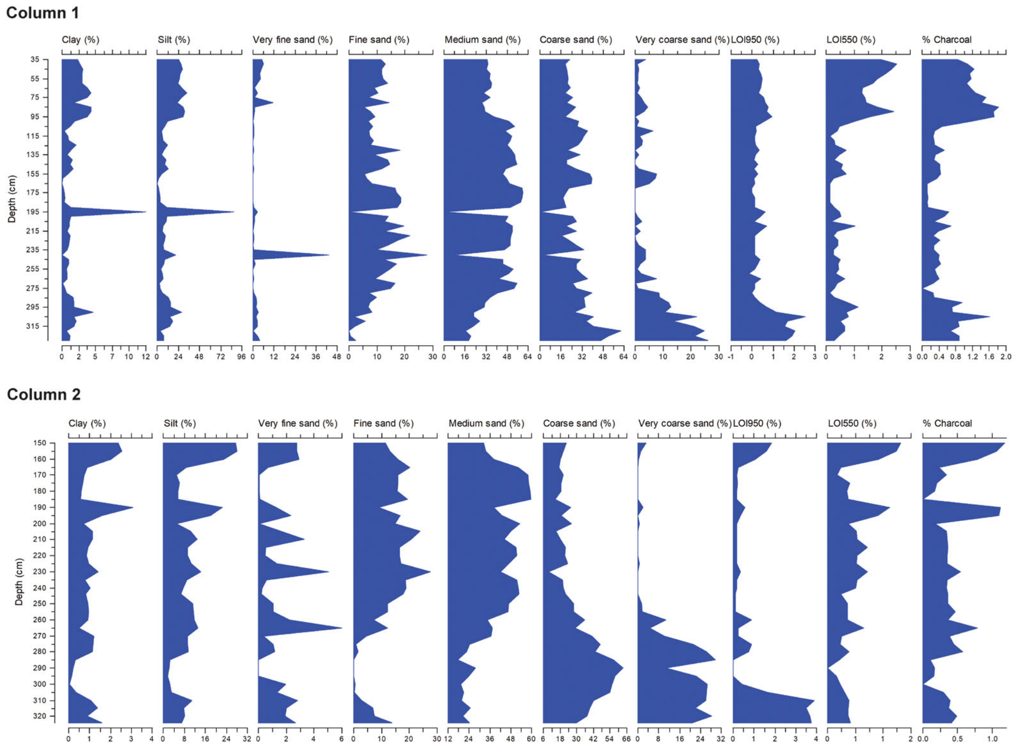

Figure 7. Results of sedimentological analyses in columns 1 and 2 showing sediment fractions and %LOI values.

including imported Turquoise Glazed wares (post mid-seventh century AD), that are generally better preserved and larger than the sherds in the overlying deposits.

Sedimentological analyses demonstrate that context 1445 is poorly sorted in the basal region with an increase in coarse sand up-profile (Figure 7). The %LOI values for organic matter and charcoal are generally low (mean organic matter = 0.64%, mean charcoal = 0.56%) but are moderately enriched in the lowest layers of both profiles (Figure 7). Unsurprisingly, the %LOI values for carbonates are highest in the layers immediately above the limestone bedrock (Facies I). Calibrated ^{14}C ages on charred seeds of *Oryza sativa* are AD 765–890 (Table 1), in reverse stratigraphic order relative to overlying contexts, suggesting vertical movement in the basal stratigraphy.

The high quartz content of this deposit, contrasting with the carbonate composition of the local bedrock, suggests a fluvio-deltaic origin with sediment supplied from the local creek and redistributed by coastal processes. The quartz grains that make up the bulk of the sediment may have been derived from older (e.g., Miocene) sediments recorded in the Unguja interior (Bron Sikat 2011; Stockley 1942). These sands were subsequently redeposited on the upper shoreline.

Facies II: Brown sand and organic layers (contexts 1446, 1444, 1443, and 1441)

Facies II is a ~0.6 m thick suite of heterogeneous, sandy, and organic-rich deposits with abundant material culture. Contexts include brown to gray, medium to coarse clayey

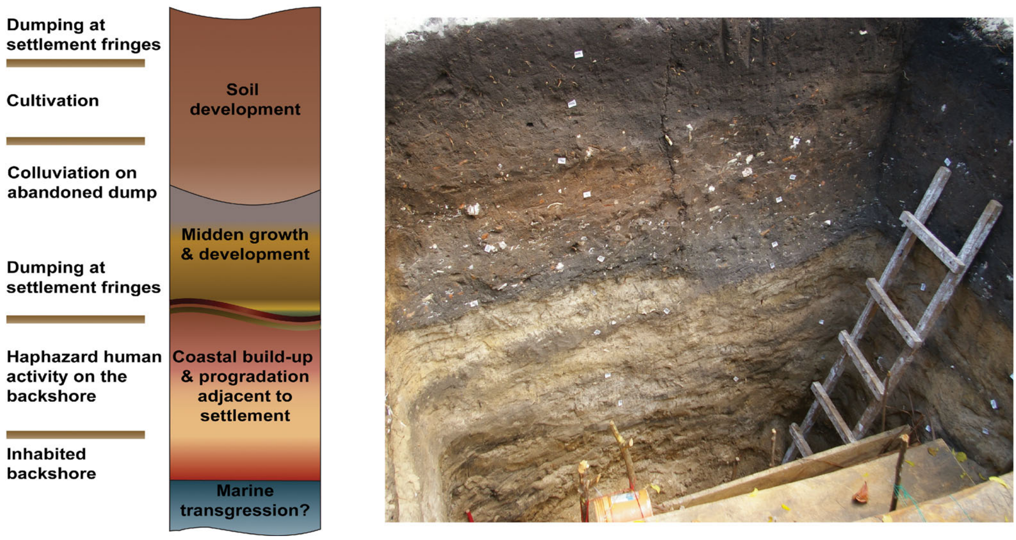

Figure 8. Photograph of the north section of Trench UU14 with a schematic representation of facies and the interpretations of the anthropogenic signatures in the sediments.

sands with low-angle lamination features (context 1446); black, organic-rich clays with abundant charcoal fragments (context 1444); A color to pale, coarse sand (contexts 1443/1441). Large unabraded potsherds, other cultural material, and limestone clasts are very frequent. Horizontal bands and localized patches of iron oxide impregnation are present throughout. Sedimentological analyses confirm the grain size variability of contexts 1444 and 1446 (Figure 7).

Facies II was deposited on a sandy beach frequented by humans. The sediments are dominated by marine sand variably intermixed with anthropogenic detritus. This facies represents human activity in a marginal backshore environment, with very little in the way of molluskan discard (minimum number of individuals (MNI) = 3).

Facies III: Yellow-brown sands with black, organic-rich shell bands (contexts 1442, 1440 to 1427, and 1424)

Facies III is highly heterogeneous, overlying a sharp, erosive surface. Alternations of two sub-facies (SF) are present. The sands of SFIIIa (e.g., context 1427, 1424, and 1429) consist of low-angle cross-beds/lenses (5–15 cm) of yellow to brown, generally well-sorted, medium to coarse sand with occasional marine shells, mammalian bone, and charcoal flakes. The lower interfaces are sharp and most likely erosive. Cultural material (e.g., pottery, metal objects) is abundant and well-preserved locally (e.g., context 1442). Low-angle and ripple cross-laminae are present, dipping predominantly landwards. The darker brown sandy layers within SFIIIa are richer in material culture and faunal remains.

Interstratified with these sandy beds are SFIIIb deposits: dark brown to black layers and lenses of densely packed marine shells, mammalian bone, charcoal, potsherds, and limestone clasts in an organic-rich clayey sand matrix (SFIIIb; contexts 1428, 1430, and 1432) (Figure 8). The lower interfaces are either diffuse (e.g., context 1434) or erosive (e.g., context 1436) and inclusions with long axes (e.g., shells, potsherds) are aligned sub-horizontally. A calibrated ^{14}C age on a charred seed of *Sorghum bicolor* from context 1442 is AD 665–775 (Table 1) and is the earliest date in this sequence.

Sedimentological analysis of SFIIIa indicates intra-unit variability. The lower part of 1442 is dominated by coarse sand with increasing proportions of fine sand, silt, and clay up-profile (Figure 7). More broadly, Facies III exhibits a fining upwards trend (Figure 7). Context 1431 (SFIIIb) is relatively clay- and silt-enriched, and a sharp spike in silt and clay is apparent within context 1429 (SFIIIb).

Micromorphology: MM5 (context 1437/lens), MM6 (boundary of contexts 1428/1427), MM7 (context 1424)

A thin section (MM5) from SFIIIa (UU14.5: Table 3, Figure 6), located at a depth of 220 cm, comprises moderately sorted, sub-angular to sub-rounded quartz sand (>90% quartz grains), with occasional to moderate quantities of fish bones and scales, and rare charcoal and other burning by-products (≤2–3%). Charcoal, where present, is in good condition with preserved cellular structure. Fine sediment matrix is limited to localized concentrations of clay and fine silt that contain silt-sized burned organics and amorphous phosphates. More densely packed domains with charcoal and phosphate-rich matrix are also present.

Thin section MM6, at a depth of 152 cm, straddles both SFIIIa and SFIIIb (Figure 9). Organic-rich context 1428 is heterogeneous and poorly sorted, with a variable intergranular matrix that is locally rich in amorphous charred organics and phosphates. Fish bones, clay aggregate grains, and charcoal are present throughout, but more abundant toward the upper contact with context 1427, where charcoal accounts for ~2–5% of the inclusions and recrystallized ash is present in small quantities. Fire-reddened intraclasts and a reworked fragment of well-compacted, organic-, and clay-rich sediment (possibly originating from a prepared floor or stabling surface) reflect proximity to the Unguja Ukuu settlement (Figure 9; Table 3). These reworked soil fragments and regions of closely spaced compacted sand grains near the 1428/1427 context boundary are consistent with the presence of a buried paleosurface (possibly a weakly developed soil horizon).

Thin section MM7 crosses the top of Facies III and the base of Facies IV. The upper surface of Facies III (UU14.7: context 1424; depth: 146 cm) consists of poorly sorted quartz sand with a well-developed fine matrix of clay and fine silt, often forming clay coatings and infillings around and between grains (Table 3). Fish bones and scales in various states of preservation are the dominant anthropogenic input, with charcoal, humified plant matter, and micro-traces of burning (silt-sized charred organics) in grain coatings and intergranular matrix. Despite intense bioturbation, micro-bedding is present in the form of horizontally aligned fish bones and closely packed grains in a fine micromass. The dark, organic-rich micromass is rich in charred organic silt, plant debris, and phosphates. Phosphates can also form circumgranular coatings, meniscus bridges, and pendants that cement the sediment.

Facies III records human habitation occurring on a sandy backshore environment. Sandy cross-beds were created by predominantly eolian processes, indicated by the well-sorted sands and general absence of shell fragments. Anthropogenic material was

Table 3. Thin section micromorphology of four sediment samples from Trench UU14.

Sample (contexts)	Description	Interpretation
UU14.9 (1425/1422); Facies IV/V		
Field	Brown organics-rich sand (1425), passing up into reddish brown, cemented organics-rich sandstone (1422). Abundant material culture, bones, shells.	Deposition of mainly unburned fish bone and scales, charred vegetable remains, ash, soot, and other burning by-products. Poorly preserved paleosurfaces developed between depositional episodes (fines-rich horizons at the 1425/1422 boundary). Other debris (e.g., burned bones) may have remained exposed for longer, resulting in the weathering and diminution (to S size). The depositional setting is consistent with intense fish exploitation and discard of by-products, perhaps in a near-settlement dump. Fish processing and other human habitation debris was comingled with wind-blown sand. *Post-deposition*: Illuviation of soot and P-rich fines and intense bioturbation (favored by high organic content?). Some of the illuviated fine organics may have originated in the (as yet unsampled) organics-rich LSU VI–VII further up-profile. P translocation and sediment cementation were sustained by dissolution of fish (and other faunal?) remains. These processes resulted in the development of an organics-and P-enriched, dark-earth-type anthrosol.
Lithology	Three units of moderately to poorly sorted granular sandstone, separated by subtle boundaries. The least well-sorted, most inhomogeneous, coarsest-grained sample of the set. Particle size peaks: 1000–1500 μm; 400–500 μm; 100–150 μm. **Mp:** 2 mm (bone); 1.3 mm (quartz). **C/Frd:** *Chitonic/gefuric* to *close porphyric* (1425/1422 boundary).	
Microstructure	*Granular + channel*. Also *horizontal lamination* (horizontally-lain fish scales/bones). **Porosity**: 35–45%	
Micromass	Brownish-yellow (1425) to orange-yellow (1422) (PPL), speckled to crystallitic (XPL), waxy orange, mildly rubified (OIL), with abundant charred organics (≤30% of micromass). Fe- and P-rich. Distributed unevenly; more abundant at ~1425/1422 boundary.	
Coarse minerals:	*Quartz* (G to mS; angular to mod. rounded, platy to oblong): Ab (> 90% of mineral grains). *Feldspars* (mainly microcline); *micas*, *hornblende*; *pyroxenes*; indet *metamorphic minerals*; *Pleistocene limestone* (S; commonly well-rounded): all ≤2%.	
Coarse biogenic and putative human inputs	**Faunal:** *Bone* fragments: angular to rounded; various sizes (G to mS). Predominantly *small vertebrates* (*fish*). Variable colors (from clear to yellowish) may suggest variable thermal histories across the slide. Very few, small (mS) burned bone fragments. Various states of preservation, with many fissured and dissolving particles. Ab: ≤ 10–20% locally. (Cm); locally defining microlamination; ≤ 1000 × 1500 μm; *Mollusk shell* fragments: vRr; rounded. (Figure 10). **Floral:** *Charcoal*: wood and fibrous; generally c-mS. Cm: ≤7–10% in lower unit; 2–5% in upper units; *Humified/uncharred plant tissue*: Cm.	
Pedofeatures	**Intraclasts and pedorelics:** Rubified particles of matrix-enclosed quartz (±other mineral) grains: *rip-up clasts*? <2%. **Interparticle fines:** Anisopachous grain coatings, bridges, pendents of, (1) *microcharcoal, calcite, and P(?)-rich clay*; (2) *limpid to crystallitic, moderately oriented, P-rich(?) clay*. Both vCm. Depositional sequence: (1) → (2) These fines cement the	

(*continued*)

Table 3. Continued.

Sample (contexts)	Description	Interpretation
	sediment. **Channel linings:** Orange-red, organics- and P-rich silty clayey linings, prob. made by arthropods. Cm. **Phosphatic**: Amorphous to microcrystalline P-ates, as interparticle fines/cement. Ab.	
UU14.7 (1424/1426); Facies III/IV		
Field	Yellow sand (1424), overlain by brown, organics-rich clayey sand with bone, shell, and material culture (1426).	Deposition of burned and unburned animal (predominantly fish) and vegetable remains, ash, soot, and other burning by-products, and diverse organic inputs and discarded ceramics (1428) on near-settlement backshore sands (1429) and overlain by such (1427 and 1424). Deposition was incremental, with development of poorly preserved paleosurfaces (fines-rich horizons in 1426). Deposition took place in a near-settlement dump, or at a site of intensive fish processing/consumption. Human habitation debris was comingled with wind-blown sand. *Post-deposition*: Illuviation of soot, P and ash-rich fines and intense bioturbation (perhaps favored by the high organic content of the sediment). These processes are linked with the evolution of a dark-earth-type anthrosol.
Lithology	Two units of well (~1424) to moderately (~1426) sorted medium/coarse quartz sand/sandstone. (~1426) is somewhat coarser-grained, notably more heterogeneous and richer in fines. Particle size peaks: 160–320 μm (~1427); 800–640 μm (~1428). **Mp:** 2.5 cm (coral limestone); 1.2 cm (ceramic); 0.3 cm (quartz). **C/Frd:** *Chitonic/gefuric* (~1427) to close *porphyric* (parts of 1426); *monic* locally (1427).	
Microstructure	*Granular* + *channel*. **Porosity**: 30–50% to 20–30% (matrix-rich parts of ~1426).	
Micromass	Brownish-yellow (PPL); speckled to calcite-crystallitic (XPL); very mildly rubified (OIL). P-rich(?) silty clay, with abundant charred organic silt (10–30% of micromass), calcite crystals (generally >50%; locally up to 70% of micromass), fS- bone fragments and other particles. Distributed unevenly: markedly more abundant in (~1424)/(~1426) boundary and within (~1426).	
Coarse minerals	*Quartz* (mainly mod. rounded, platy to oblong): Ab (≥90% of min. grains); *Pleistocene limestone*: angular to rounded, G to S (2–5%); *calcite-cemented sandstone* (one grain); *chert*; *feldspars* (mainly microcline); *micas*, *hornblende*; *pyroxenes*; indet *metamorphic minerals* (S; rounded): all ≤2%.	
Coarse biogenic and putative human inputs	**Faunal:** *Bone* fragments: predominantly *fish*: various states, from angular splinters to rounded, S-sized, fissured particles: Cm, but <3%. A few burnt fragments. Concentration of large (1–2 cm) fish bone fragments at base of (~1426); *Fish bones* ≤ 2.5 mm. *Mollusk* fragments: mainly angular, G to cS. Some are recrystallized and fissured (due to heating?). 1–2%; *Benthic foraminifera (Ammonium/Rotalia*-type): vRr. **Floral:** *Charcoal*: variable, wood, and fibrous. Angular to	

(*continued*)

Table 3. Continued.

Sample (contexts)	Description	Interpretation
	rounded, cS to fs. 2–3%; *Humified plant tissue:* Cm; *Phytoliths* (?) in micromass: Rr; *Calcite lozenge mosaics:* plant ash/tissue pseudomorhs?: Rr. **Amorphous Charred Organics:** Cm, especially in (∼1426); also in grain coatings/pendants and pore-filling micromass. **Artifacts:** *Ceramic* fragments: one cm-sized angular fragment (with Fe-depletion halo) at base of (∼1424). Many smaller rubified particles may also be ceramic fragments. Rr.	
Pedofeatures	**Intraclasts and pedorelics:** Rubified particles of micromass-enclosed quartz (±other mineral) grains: *rip-up clasts* ? <2%. **Interparticle fines:** Grain coatings, bridges, pendents of microcharcoal, calcite, and P(?)-rich clay. vCm. **Channel linings:** Brown to orange-red, organics-rich silty clayey linings to fillings. Made by arthropods. Cm. **Phosphatic**: Amorphous to microcrystalline P-ates in interparticle fines/cement. Ab. *Fecal pellets* (*ca.* 30 μm) of arthropod mesofauna in burrowed root remains: Rr; *Oblong aggregates* of organics-rich micromass + mineral grains (*ca.* 300 μm): mesofauna-made. Cm.	
UU14.6 (1428/1427); Facies III		
Field	Brown, organics-rich sand with a horizon of bivalve shells (1428), overlain by yellow sand (1427).	Deposition on the backshore, in close proximity to a settlement. Poorly sorted, fines-rich mid- section (top of 1428) records aggradation from burning by-products, food remains, artifacts, and reworked remains of trampled floors, oxisols, and sediments, probably consistent with the presence of an inhabited surface adjacent to a settlement. Compacted grain lines may be vestiges of this surface. Human inputs were comingled with windblown sand. Windblown sand was predominant in the upper part (1427) but human habitation debris also contributed to sediment accumulation here. *Post-deposition*: Illuviation of soot-rich silt, which may have happened pene-contemporaneously with human habitation, followed by much finer clay illuviation, perhaps after vegetation covered the (aggrading) overlying landsurface. Ash calcite present in the original sediment may have been
Lithology	Three units of very heterogeneous, moderately to poorly sorted, medium to coarse quartz sand to matrix-supported granular conglomerate. Subtle unit boundaries. Lower two units (∼1428) are darker-colored. The *ca.* 3 cm-thick middle unit (∼top 1428) is coarser grained, poorly sorted, and fines-rich. **Mp:** 1.2 cm (ceramic); 1.2 cm (limestone); 1 cm (reworked floor fragment). **C/Frd:** *Chitonic/gefuric* to *close porphyric* (∼top 1428).	
Microstructure	*Granular/channel*. Horizons of closely spaced grains in middle unit. **Porosity:** 40–50% in upper and lower units; *ca.* 30% in middle unit.	
Micromass	Variable abundance: <5% (lower ∼1428; 1427) to 10–20% (∼top 1428). Yellow silty clay (PPL), with abundant charred organics and amorphous organics (≤40–60% of micromass in ∼top 1428); speckled to calcite-crystallitic locally (XPL).	

(*continued*)

Table 3. Continued.

Sample (contexts)	Description	Interpretation
Coarse minerals	*Quartz*: Angular rounded (80–90%); *limestone* (mainly G; <5%); *feldspars* (<10–15%; mainly microcline); *micas*; *pyroxene*; indet *metamorphic minerals* (all <2%); "basalt/dolerite?" *volcanics* (<1%).	dissolved by percolating water. Pervasive mesofauna and plant root bioturbation.
Biogenic and putative human inputs	**Faunal:** *Bone:* mainly *fish*; splinters and fewer rounded fragments; S: 1–2%; *Mollusk shell* fragments: S to G. Micritized, fissured, with "soot" impregnation in fissures /dissolution pores. <2% to 2–10% (~top 1428). **Floral:** *Charcoal*: variable, including wood; angular and rounded; f-cS (max: 875 μm). <1% to 2–5% (~top 1428); Calcitic *pseudomorphs* of plant tissue: vRr; *Calcite rhombs* (after plant Ca-oxalate?): vRr; *Phytoliths:* vRr, in micromass-rich areas (esp. ~top 1428). **Amorphous Charred Organics:** Cm, esp. in ~ top 1428; also in bone and mollusk pores, grain coatings/pendants, and pore-filling micromass. **Feces:** Possible indet *coproliths*; cS. Rr. **Artifacts:** One angular fragment of quartz-tempered *ceramic* (1.2 cm); other multigrain rubified particles could also be ceramic fragments. Rr.	
Pedofeatures	**Intraclasts and pedorelics:** *Compacted paleofloor* clast (Figure 9): vRr; *Rip-up clasts:* angular, rubified (max. 300 μm): vRr; *Intraclasts* with charred organics-*rich* groundmass: Cm; *Red anthrosol* with granostriated groundmass: Rr; *Clay papule:* rounded, S. Cm. **Interparticle fines:** Anisopachous grain coatings, bridges, pendents, and cappings of organics- and P(?)-rich silty clay: Cm; Laminated, moderately-oriented silty clay without organics: Cm **Calcitic:** Microspar filaments/root channel linings: Rr. **Phosphatic:** Grain coating/bridging fines are P-rich (?). **Excremental:** Mesofauna pellets: Rr.	
UU14.5 (1437/lens); Facies III		
Field	Yellow sand.	Backshore, near foci of human activity. Background sediment was windblown sand, with which low quantities of human-induced debris were comingled. Denser-packed domains with charcoal and P-rich matrix may represent poorly preserved paleosurfaces. *Post-deposition*: Bioturbation by insects and plant roots. Illuviation
Lihtology	Three units of well to moderately sorted, medium quartz sand. Subtle unit boundaries. Particle size peaks: 400–500 μm; 100–200 μm. **Mp:** 1.5 cm	

(*continued*)

Table 3. Continued.

Sample (contexts)	Description	Interpretation
	(intraclast); 1000 μm (limestone). C/Frd: *Monic* to *chitonic/gefuric* (locally).	of fines (including organics and P), from settlement deposits higher up-profile.
Microstructure	*Granular (± channel)*. **Porosity**: 40–50%.	
Micromass	Very few fines ($\leq$5%!), locally in sub-horizontal domains. Yellow to brown (PPL), isotropic to weakly crystallitic (XPL), with charred organics and burned bone (fS).	
Coarse minerals	*Quartz*: angular, etched, to rounded, oblong to equidimensional. Ab (>85%); *mica*; *hornblende*; *pyroxenes*; *feldspar*, indet *metamorphic minerals*; *Pleistocene limestone* (rounded; S to G); indet isotropic particle (angular); all <2%.	
Biogenic content and putative human inputs	**Faunal:** *Bone*: predominantly *fish:* angular splinters: Rr; *fish scales/teeth* (Max: 70 mm): Rr; larger vertebrate bone (burnt): vR. Generally <1%. **Floral:** *Charcoal*: G to mS; 2–3%. **Amorhous Charred Organics:** Interlayered between grains; also in coatings/micromass (s). 1–2%; 5–10% locally. **Feces:** One possible particle (*ca*. 800 μm). **Siliceous Slag:** One particle (*ca*. 900 μm).	
Pedofeatures	**Intraclasts and Pedorelics:** *Rubified* intraclast: mod. rounded, organics-rich, with heat-fractured quartz grains 1.7 mm. Rip-up clast? vRr. **Interparticle fines:** Grain coatings, bridges, pendants, cappings of orange-brown, organics- and P(?)-rich clay. Rr. **Channel linings:** Orange-brown, organics-rich silty clay. Made by arthropods. Rr. **Phosphatic:** Globular pendants under charcoal, bone, and mineral grains (10-of-μm). R. (Figure 9). **Calcitic:** Linings/filaments of microspar in root channels. Rr.	

Mp: maximum particle size. **C/Frd:** coarse to fine-related distribution. **PPL:** plain polarized light; **XPL:** cross-polarized light; **OIL:** oblique incident light. Particle size classes: **G:** granules; **S:** sand; **s:** silt; **c:** coarse; **m:** medium; **f:** fine. *Relative abundance:* **vRr:** very rare; **Rr:** rare; **Cm:** common; **Ab:** abundant.

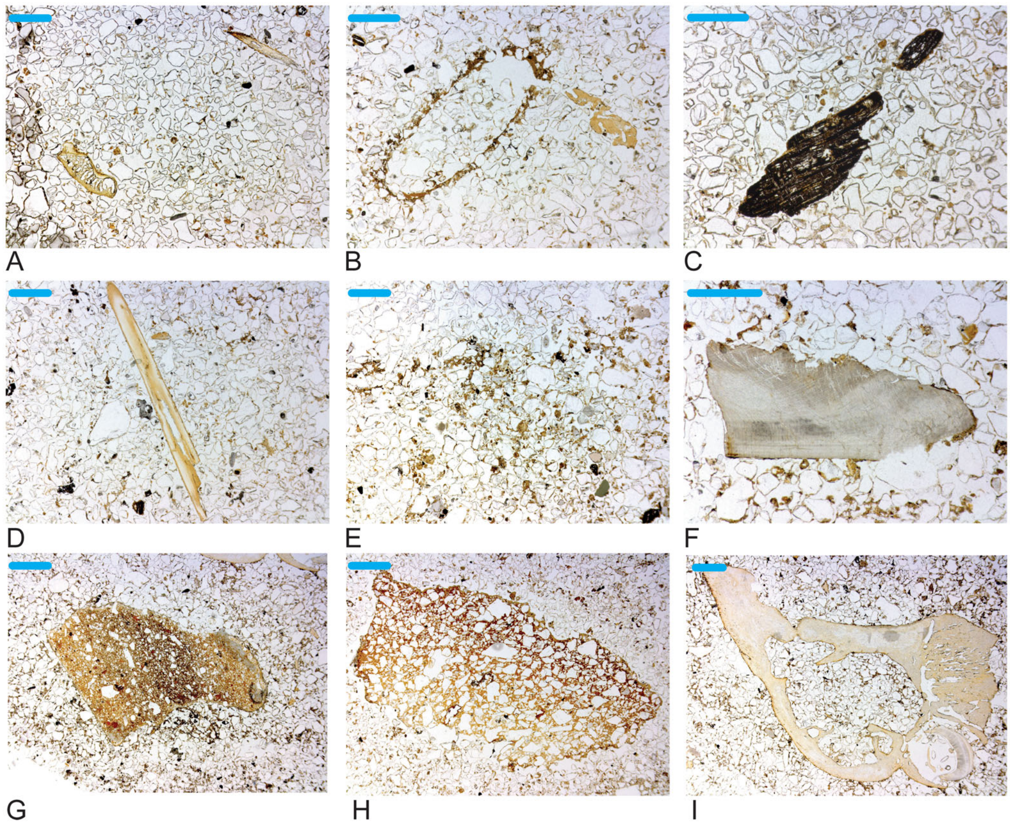

Figure 9. Selected microphotographs from Facies III: (A) general view of the SFIIIa matrix showing well-sorted quartz sand with occasional admixture of anthropogenic detritus, including weathered fish bone fragments. The fine matrix is limited and variable, with fine clay coatings on quartz sand grains; (B) Clay-lined burrow (arthropod?) partially infilled with quartz sand, and consistent with the partial remains of an ephemeral land surface. Weathered bone fragment (center right) shows some signs of partial dissolution and clay replacement/infilling; (C) Well-preserved, angular charcoal fragment with preserved cellular structure suggesting limited transport. Minor additions of clay and fine silt in the form of cappings and coatings; (D) Well-preserved bone splinter in poorly sorted sands with micro-charcoal and traces of clay infillings, all suggestive of a ground surface with anthropogenic inputs and possible disturbance; (E) Zone of clay matrix with fine microcharcoal and very small shell fragments, again supporting the presence of a land surface/incipient soil horizon forming on the back-shore; (F) Fish scale; (G) Probable ceramic fragment associated with a horizontal zone of fines-rich sediment; (H) Large fragment of fire-reddened (baked) clay with angular quartz sand, possibly reworked from a combustion feature (hearth?); (I) Large fish vertebra in an excellent state of preservation associated with a region of fine matrix. All microphotographs taken in plane polarized light (ppl); blue scale bar = 1 mm.

probably sourced from the local reworking of material from interstratified, organic-rich layers, or laterally by wind action. Dark, shell-rich layers are anthropogenic middens, formed through the processing, heating, and consumption of marine mollusks and fish, intermixed with other organic detritus. Reworked fragments of occupation surfaces (prepared floors?) support a scenario of human activity taking place at the margins of the Unguja Ukuu settlement.

At the micro-scale, compacted grain lines and horizontal concentrations of fine clay may be vestiges of ephemeral land surfaces. Anthropogenic detritus accumulating on the beach would have been subjected to deflation by wind action, resulting in the relative concentration of coarse debris (e.g., shell) as lag deposits before these middens were draped by beach sand. The sporadic occurrence of calcitic ash (often recrystallized) may record the presence of more abundant ash deposits, which dissolved by percolating water—a common occurrence in porous midden substrata (Villagran et al. 2011). We interpret the overall pattern of Facies III sedimentation as the result of the lateral migrations of small, *ad hoc* foci of food processing on the backshore environment, perhaps marginal to the main settlement.

Facies IV: Black sandy sediment with shells, bone, and artifacts (contexts 1426, 1425, 1423, 1421, 1420, and 1418)

Facies IV is separated from Facies III by a sharp, erosive, mainly convex surface of low relief (±5–10 cm) (Figure 8). This is the most conspicuous lithostratigraphic transition in trenches UU14 and UU11. Facies IV is formed of ∼60–70 cm of dark gray to black, variably cemented sand with abundant unabraded bone, marine shell fragments, and material culture (e.g., ceramics and glass beads). This facies is largely internally structureless, with poorly defined discontinuous horizons of sub-horizontal elongate/platy particles (bone, shell). Several centimeter-scale oxidized bands are also present (contexts 1417 and 1419).

Sedimentological analyses revealed that contexts 1426 and 1424, at the base of Facies IV, are enriched in clay and silt, and that the silt and clay content increase slightly in the upper part of this facies (Figure 7). Four radiocarbon dates on charred seeds of *Sorghum bicolor* were obtained from Facies IV: one on context 1420 and three on context 1417. The date from context 1420 is early, calibrating to AD 670–770, whilst three samples of *S. bicolor* from context 1417 produced calibrated dates in the range of: AD 675/715/765–860/890/895, respectively (Table 1).

Micromorphology: Top MM7 (context 1426) and bottom MM9 (context 1425)

Thin section MM7 intercepts the Facies III/IV interface. The base of Facies IV (context 1426; MM7; Figure 10) is formed of sub-rounded to sub-angular quartz sand with localized iron- (Fe) and manganese- (Mn) stained, clay- and silt-rich groundmass that contains abundant anthropogenic material where this fine matrix is present. Charcoal powder and microcharcoal are locally present in Facies IV, with ash surviving infrequently. Fine matrix-supported grains are sometimes present in localized horizontal/sub-horizontal zones, with clay coatings and infillings common in and around quartz grains.

The upper part of Facies IV (thin section MM9; ∼90 cm depth; UU14.9, context 1425), comprises centimeter-thick beds of sub-angular to sub-rounded quartz sand with variable quantities of fine clay matrix. In some locales this sand is phosphate-cemented. Abundant bone fragments with evidence of *in situ* fracturing, including fish vertebrae (Figure 10) and plant remains exhibiting variable thermal histories (Table 3), are present throughout. Horizontally aligned fish bones and scales account for some weakly

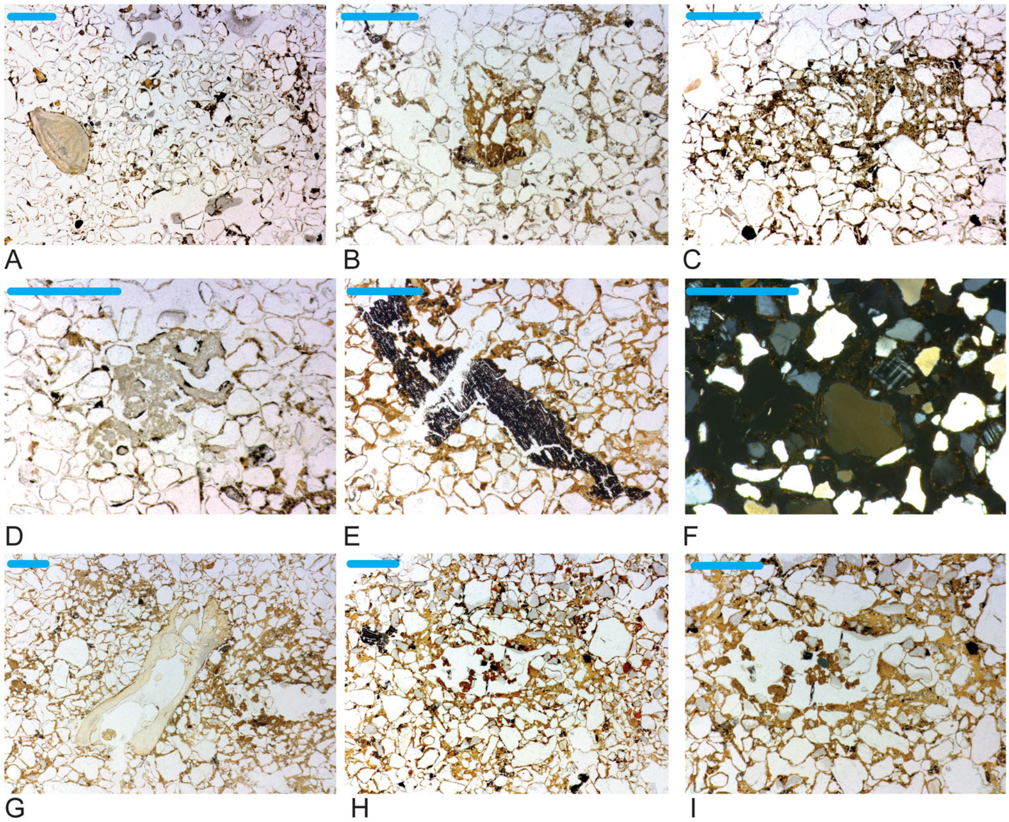

Figure 10. Selected microphotographs from Facies IV (A–G) and V (H–I): (A) Fish scale (center left) associated with an area of fine clay enrichment, including both clay coatings and void infillings. Clay and fine silt adhered to the outside edge of the fish scale suggesting original emplacement on a paleosurface or phosphatic cementation around the grain. Note that the sand grains are poorly sorted, suggesting dumping and/or disturbance of the sediments most likely by human activity; (B) Phosphatized clayey nodule located in an area enriched with fines. Very fine planar voids in this composite grain are consistent with a fragment of a trampled surface that has been redeposited; (C) Area enriched in speckled fine matrix (partially phosphatized) and matrix-supported sand grains. This dark matrix is rich in microcharcoal, small fragments of shell and bone, and is locally phosphate-rich, likely indicative of human activity on a developing soil surface. These types of phosphate-rich fines/cement have geopetal and meniscus morphologies, suggesting that they were deposited post-depositionally, from percolating water that had drained through habitation debris-enriched overlying deposits; (D) Rare occurrence of preserved ash, undergoing partial dissolution and phosphatization around the edges; (E) Large charcoal fragment with intact plant cellular structure in an area rich in fine clay matrix, coating grains, and infilling voids. Given the preservation state of the charcoal and its context, this area of the microstratigraphy is likely a buried soil that is partially disintegrating; (F) Weakly developed granostriated clays infilling void spaces and coating grains are indicative of swelling–contraction of the clays via wetting and drying; (G) Bone fragment, most likely fish vertebra, in a region of contiguous clay matrix rich in fine microcharcoal and exhibiting micro-planar voids suggesting trampling. The bone is undergoing partial dissolution at the upper end (phosphate dissolution); (H) Area strongly enriched in clay matrix, zones of which appear to have been thermally altered. The matrix contains a high frequency of microcharcoal and localized phosphatization, consistent with a well-developed midden. Relict midden paleosurface, likely to be relatively intact due to the presence of charcoal with preserved cellular structure; (I) Detail of clay matrix observed in H. All microphotographs taken in plane polarized light (ppl), except F, which is in cross polarized light (xpl); blue scale bar = 1 mm.

expressed lamination. Illuviated clay locally forms infills and coatings, and sometimes granostriated[1] b-fabrics are present. Two distinct types of illuviated fines are present: (1) poorly sorted, dark-colored silty clay with charred organic silt and calcite (probably ash-derived); and (2) sorted and moderately oriented amorphous phosphate and clays, consistently superimposed on the former, causing phosphatic cementation.[2]

The erosive surface on which Facies IV was deposited suggests an unconformity (the existence of depositional stratigraphic hiatus) of unknown duration. The sandy composition is most likely natural (geogenic) but contains significant additions of cultural detritus (food remains) locally cemented by phosphates, possibly derived from the dissolution of organic waste (mainly fish bone and scales). The preserved ash (Figure 10) indicates *in situ* burning, and clay-rich zones with organic-rich aggregates are consistent with activities occurring on a weakly developed sandy soil. The unabraded bone/shell fragments and microcharcoal with preserved cellular structure (Figure 10) suggest that deliberate dumping, rather than colluviation, was the dominant depositional process. Colluvial processes are likely to have contributed to the enrichment of sediment with occupational debris, however, ultimately resulting in an organic-enriched sediment that underwent incipient pedogenesis.

Facies V: Cemented reddish sandy clayey sediment and middens (contexts 1417, 1419, 1422, 1412, 1408, and 1406)

The interface with underlying Facies IV is diffuse (Figure 8) and in places, Facies V drapes densely packed shells. The bulk of this facies comprises ∼25–30 cm of reddish, cemented, poorly sorted sandy clay with angular fragments of ceramics, charcoal, bone, and shell in a matrix-supported fabric. Coarser particles decrease in size and frequency up-profile. The upper ∼10 cm are heterogeneous, with thin layers and lenses of densely packed, horizontally aligned marine shell, bone, and material culture in cohesive to cemented black organic silt (contexts 1412 and 1408; compacted 1406).

Micromorphology: Top of MM9 (context 1422/potential hearth?)

Facies V (sampled in thin section MM9) is a very poorly sorted quartz silt in an undifferentiated clay matrix, intermixed with finely divided charcoal powder. Some areas of the clay matrix have been thermally altered, occasionally revealing fine cracks suggestive of baking. Coarse inclusions are present, consisting mainly of bone, shell, and microcharcoal (Figure 10). Bone is often phosphatized and isotropic and occasionally is very pale, possibly due to calcination. Phosphates are also common in the fine matrix. Fines dominate the groundmass locally and fine planar voids are occasionally present. Sediment porosity is variable and heterogeneous.

We interpret the upper part of Facies V as midden deposit, representing at least three distinct episodes of discard on a paleosurface—possibly a trampled paleofloor (context 1406). Although bioturbation has largely homogenized the sediment, the presence of grading and laminations observed in the lower part of this facies suggests the reworking, by colluvial (surface wash) processes, of earlier dump deposits.

Facies V is a discontinuous midden, exposed to relatively prolonged phases of surface weathering and bioturbation. Much of the biogenic content is the product of intense fish processing at the settlement fringes. This anthropogenic detritus is comingled with wind-blown sand. Oxidized bands are likely the locally reworked remains of hearths and ashes, which are absent from the profile and likely dissolved by percolating water given the diagenetic features we observed in the sediments. The localized cementation of sediments is due to the presence of amorphous phosphate, likely originating from the dissolution of fish remains and other organic waste products. The abundance of clay coatings and infillings suggests that a significant proportion of these phosphates, clays, and fine-grained organics were illuviated down-profile.

Microstratigraphic investigation of context 1422 indicates reworking of a combustion feature, most likely a hearth, on a sandy substrate. Water percolating through sediments rich in bones, and possibly other animal residues, have produced conditions conducive to chemical modification of some organic inclusions and the localized cementation of the fine matrix. Reddening of the sediment is consistent with thermal alteration and indicates limited reworking since primary deposition.

Facies VI: Black sandy sediment (contexts 1404 and 1403)

Facies VI comprises ~40 cm of dark brown-black, organic-rich sands deposited on a moderately sharp surface (lower boundary). The basal ~15 cm (context 1404) are pale in color and cemented, transitioning to a crumbly black sandy silt up-profile (context 1403; Figure 8). The coarse fraction occurs less frequently and anthropogenic material is more abraded. The fine fraction and organic content both increase up-profile (Figure 8). The darker, organic-rich sediments contain a mixture of modern and archaeological material culture, the former including glass bottle fragments and metal. Bioturbation is intense, including roots, termite galleries, and arthropod burrows. A fining upwards trend is observed in the sand-sized fraction in contexts 1404 and 1403, with relatively high %LOI Organic (<2.5%) and %LOI Charcoal (<1.25%) values (Figure 7). The upper interface is a very sharp, erosive surface. One radiocarbon date, on a charred seed of *Oryza sativa*, was obtained from context 1404 and was calibrated to AD 885–990 (Table 1).

Facies VI is a dark organic soil ("dark earth") developing on occupational detritus at the periphery of Unguja Ukuu. This facies (and underlying Facies V) formed on the sediment of the adjacent midden. It is unclear whether this dark earth formed in waste dumped at the settlement margins or is the outcome of manuring and soil curation. The leached red sandy latosols observed during geoarchaeological survey, if representative of pre-settlement soils around Unguja Ukuu, would probably invite deliberate manuring (Juma 2004; Sulas and Wynne-Jones 2018). This inference is supported by the results of Fitton's geophysical survey, which showed traces of ridge-and-furrow farming in his Area B near the "neck" of the peninsula, which is thought to have delineated the limit of the harbor (Fitton and Wynne-Jones 2017). In any case, dark earth development is a diachronous process, probably involving several phases of deposition and pedogenesis (Arroyo-Kalin 2009). The admixture of modern objects and the sharp upper erosive surface (interpreted as a cultivation surface) suggest that this dark earth remained a significant agricultural resource for centuries after its inception. Unguja Ukuu's dark earth continues to support the growth of cassava, palm, and other tree crops.

Facies VII: Farming soil and marginal urban dumps (contexts 1402 to 1400)

Immediately below the modern ground surface, the dark earth is truncated by cassava ditches filled with loose black organic soil, seemingly derived from the dark earth. The surface layer (Trench UU14; context 1400) comprises very loose and bioturbated, dark gray sandy silt, densely packed with plastic, metal, and rubber objects forming the uppermost A-horizon of the dark earth that evidently still receives organic inputs from the modern village. Modern farming is, therefore, sustained by this anthropogenic soil representing long-term continuity in the landscape. The modern "overburden" is a mixture of windblown material and burned and unburned rubbish (an analogue for (inferred) earlier "dumps"), reflecting the changing uses of Unguja Ukuu's coastline. No radiocarbon dates were obtained for this facies.

Summary

The basal sands (Facies I) that overlie the basement limestone are coarse-grained with a high frequency of well-rounded quartz and limestone pebbles. These were likely deposited in a macrotidal foreshore setting, probably within the reach of spring tides. Overlying these are sands and paleosols with abundant plant and animal remains and material culture, deposited in permanently subaerial, backshore conditions, near to and—in later times—within the first millennium AD village (Facies II, III). Middens and paleofloors interstratified with backshore sands probably record superimposed sites of human activity (e.g., food processing) on the inhabited backshore. These sediments are truncated, above which are thick deposits of a ninth-century AD midden with abundant charred organics and phosphates (Facies IV, V). These are interpreted as dumps at the seaward fringes of the settlement. Soot, possibly resulting from burning inside sheltered structures (see Matthews et al. 1997), and microscopic inclusions of reworked fragments of floor crusts/trampled floors, suggest proximity of the settlement. The entire upper part of the profile, from the sharp surface upwards (Facies IV, V, and VI) seems to be the "dark earth." Each of these facies represents different pedostratigraphic horizons within this "dark earth" deposit.

Discussion

Environmental change and human activity on a Holocene back-reef shore

Unguja Ukuu's coastal stratigraphy records phases of late Holocene evolution of the macrotidal back-reef coast at the settlement fringes (Figure 8). The stratigraphy of UU14 and UU11 covers a narrow temporal window (~200–350 years) with high sedimentation rate, resulting in the deposition of 3.5 m of sandy units with anthropogenic detritus overlying the Late Pleistocene limestone bedrock (Figure 6; Table 2). The quartz sand in this sediment was supplied by Uzi Creek and subsequently reworked and redistributed by coastal and eolian processes.

The basal gravelly sands of Facies I were deposited in a moderate energy, creek-delta setting coinciding with a (poorly constrained) period of elevated mid-Holocene sea levels prior to 530 cal BP, inferred from the lateral shift of mangrove plant communities in

Unguja Ukuu and elsewhere on Unguja (Punwong, Marchant, and Selby 2013a, 2013b; Woodroffe et al. 2015). Gravel and sand supply was potentially augmented by ravine mouth progradation at or near modern sea level. Middle to late Holocene marine transgressions have been inferred from various sea-level proxies elsewhere on the East African coast (Jaritz 1977; Muzuka, Nyandwi, and Shaghude 2007; Ramsay and Cooper 2002), but regional correlations remain uncertain. Progradation of the Unguja Ukuu shoreline followed, with human activity in this area evidenced by artifacts and organic inputs in Facies II evidencing the proximity of the early settlement by the seventh century AD.

Interdigitated lenses of sterile eolian sand and organic-rich middens (Facies III) record *ad hoc* human activity (e.g., hearth construction), subsequently buried by wind-blown sand and tidal marine sediments and storm deposited sand. The proportional representation of incidental mollusk taxa is low in UU14 (367 MNI, 9.2%), but this may represent a minimum number given preservation conditions. Relative shifts in habitat representation through Facies I–III (with rising incidence of molluskan specimens up-profile) may indicate subtle shifts in the nature of mollusk harvesting and/or minor changes in the environmental/coastline structure (Faulkner et al. 2018).

A shift in the depositional dynamics is recorded in a switch to organic-rich sedimentation (Facies IV–VI) overlying an erosive paleosurface. The increase in anthropogenic detritus is consistent with increased activity at the coastal fringes of Unguja Ukuu from the mid-ninth century AD onwards. The prevalence of fish bone and combustion by-products suggest intensive fish consumption very near or within the ancient settlement (Prendergast et al. 2017). The increasing frequency of shell and a comparative broadening of the range of taxa and inferred habitat areas derived from Facies III, IV, and V reflect a lower degree of selectivity and increased dietary breadth. In these contexts, the increased representation of incidental taxa likely relates to foraging by-catch, although within Facies III it may relate to both behavioral and beach depositional processes (whilst fluvial processes may have contributed sediment to the wider shoreline). The exception to this is the landsnail taxa (representing forest habitat), particularly *Tropidophora zanguebarica*, which appears to increase in the higher density midden deposits as a result of increased human disturbance and waste disposal. Geophysical survey also showed that nearby areas were locales of industrial and midden-forming activity, probably related to harbor activities (Fitton and Wynne-Jones 2017). The increasing intensity of fish processing and consumption recorded in Facies IV and V is evidenced by the regular occurrence of phosphate cementation, derived from dissolving fish bone and other settlement waste.

Intermittent waste dumping and pedogenesis prior to and following abandonment of early Unguja Ukuu (twelfth–thirteenth century AD) is recorded in Facies VI, resulting in the development of an organic- and phosphate-rich dark-earth-type anthrosol on the backshore. Unguja Ukuu's dark earth appears to have developed diachronously, much like those in the American tropics (see Arroyo-Kalin 2009), through several phases of deposition and pedogenesis over the last ~1,000 years, primarily after abandonment, imparting a characteristic black/dark brown coloration on the upper parts of the stratigraphy (Figure 8). This dark earth represents one of the few recorded African examples (see Fairhead and Leach 2009) and continues to evolve, receiving organic inputs from the modern town and currently supporting cassava, palm, and other tree crops. Extensive remains of modern plowing are also recorded in the geomagnetic survey carried out by Fitton and Wynne-Jones (2017) who surveyed the area south of the settlement on Ras Makime peninsula and in our study area around trenches UU14 and UU11.

Anthropogenic forcing of coastal change

The interplay of a range of geomorphological processes, including coastal progradation and the seaward shift of the Unguja Ukuu shoreline, had important consequences for the configuration of Menai Bay head and, possibly, for Unguja Ukuu's viability as a trading settlement. Trench UU14 stratigraphy records rapid accumulation and progradation of the inhabited back-reef shore, possibly following an earlier Holocene marine transgression (inferred from the mangrove record; see Punwong, Marchant, and Selby 2013a). Coastal progradation since the later part of the first millennium AD has been recorded at other early East African coastal settlements, with shoreline migration ranging from 50 to 300 m at Kilwa and Kaole, on the mainland Tanzanian coast (Pollard 2009; Pollard and Ichumbaki 2017). Notwithstanding the limitations of our reconnaissance-scale sampling in the archaeological trenches and the influence of coastal processes that counteract the effects of progradation (e.g., sediment erosion, especially during storm surges; the complex interaction between creek sediment supply and tidal and longshore currents: Nyandwi and Muzuka 1991; Kairu and Nyandwi 2000), we suggest that sediment progradation prevailed along the Menai Bay coastline during the later phase of the first millennium settlement (seventh–tenth centuries AD).

At other eastern African sites, it has been suggested that this late Holocene coastal progradation was driven by subtle sea-level regression events (Muzuka, Nyandwi, and Shaghude 2007; Pollard 2009). However, mangrove records from Unguja Ukuu and Makomba Bay, also at Unguja Island (Punwong, Marchant, and Selby 2013a, 2013b), and a model-based reconstruction of the region's sea-level history over the past 12,000 years (Prendergast et al. 2016), do not support a Holocene fall in sea level (Figure 5). While this is certainly a factor, our results point toward geomorphological changes linked to terrestrial (and often marine) sedimentary input and some change in topography. Taken at face value, mangrove records from Unguja Ukuu appear to indicate a slow sea-level rise from the late first to the mid-second millennium AD (Figure 5), but these records may be complicated by settlement-induced sediment deposition, as we discuss below.

Sea-level drop is not, however, the only plausible driver of coastal progradation. The limited stratigraphic evidence from Unguja Ukuu documents remarkably high sedimentation rates in the backshore, and a succession of foreshore by backshore deposits (see stratigraphy section of this paper; Figure 6). In our view, this evidence, albeit limited, points strongly toward such a process of "normal," deposition-driven regression, contemporaneous with the flourishing of the first millennium AD settlement.

Since much of this shore-building sediment consists of various forms of habitation debris, coastal progradation appears to have been at least in part driven by human activity and the accumulation of anthropogenic detritus and surface compaction. The emergence of the trading village thus reshaped the Menai Bay shore in much the same way as ancient ports in the circum-Mediterranean modified the microtidal coastlines on which they developed (e.g., Marriner and Morhange 2006; Marriner, Morhange, and Goiran 2010).

In addition to the role of locally supplied anthropogenic debris, sedimentation on the Menai Bay shore and inner shelf may have been influenced by human activity in Unguja Ukuu's hinterland. As noted above, the minerogenic sediment fraction of the backshore environment was probably originally transported from the hinterland from where it was transported as alluvium prior to reworking by coastal processes. The land use history of Zanzibar in the later part of the first millennium AD, when coastal settlements like Unguja Ukuu and Fukuchani flourished, is virtually unknown (though see Marchant et al. (2018) and Walshaw and Stoetzel (2017) for regional reviews). For this reason, we extrapolate from the settlement pattern documented by systematic surveys in neighboring Pemba Island (Fleisher 2010; LaViolette and Fleisher 2009) with many small farming villages dotting the island's interior landscape. If the pattern of settlement in Unguja Island resembled that of Pemba at that time, it is reasonable to hypothesize that land clearance for settlement and farming in the Unguja interior would result in higher erosion rates and increase the supply of alluvial sediment delivery to the shore and inner shelf.

This hypothesis aligns with research that shows that the Iron Age transition in sub-Saharan Africa fundamentally altered, at near-continental scale, the landscape exploited by farming populations (Kay and Kaplan 2015). Such alteration may have resulted in widespread consequences for regional climate, hydrology, biodiversity, and ecosystem services that persist to the present (Kay and Kaplan 2015). Links between land-use intensification in the hinterland and increased sediment flux to the inner shelf (often with catastrophic ecological consequences), analogous to those postulated here for first millennium AD Zanzibar, are well-documented along the eastern African coast over the last century (e.g., Finn 1983). The presence of markedly higher concentrations of charcoal in post-AD 500 sediments from the Unguja Ukuu mangrove (Punwong, Marchant, and Selby 2013a) may reflect more frequent burning (in the course of agricultural landscape modification) not only at Unguja Ukuu, but also in the wider creek catchment (Figures 2 and 5). Settlement growth and economic intensification in the hinterland, well beyond the limits of Unguja Ukuu, or otherwise on a site of a much larger surface area than previously thought (as reported by Fitton and Wynne-Jones 2017), may have thus partially contributed to coastal progradation on the Menai Bay shore and hence written itself into a general pattern of geomorphic and ecological change as reported on the eastern African coast.

Settlement decline at the end of the first millennium AD

Increased terrigenous sediment flux to the Menai Bay shelf, likely occurring during periods of higher precipitation, might have reduced the depth of intertidal channels and inlets, forming sand or mud banks on the inner shelf platform. These processes would have reduced the navigability of the inner shelf, offshore from Unguja Ukuu (Fitton 2017). We suggest that as a result of both natural and anthropogenically forced processes, sediment deposition may have inhibited coral growth on the platform, especially in the channels on the inner shelf that represent extensions of the subaerial drainage. This could, in turn, have affected phytoplankton production and fish populations (see

Finn 1983), potentially impacting the subsistence strategies adopted by the inhabitants of Unguja Ukuu, although further analyses need to be performed to confirm this hypothesis. At the same time, reef/rock molluskan taxa contribute roughly 25–30% by MNI to the total assemblage economic taxa (Faulkner et al. 2018), which corroborates the interpretation about the dominance of the intertidal flat. Further dedicated geomorphological analyses to confirm this hypothesis are required.

It is widely accepted that increased terrestrial sediment supply and nutrient yields from anthropogenically modified coastal catchments represent a major threat to modern-day coral reefs (Perry et al. 2012). Our data suggest that a similar situation may have prevailed in the first millennium AD. Increased nutrient flows from Unguja Ukuu and its hinterland may have negatively impacted inner-shelf biota and, consequently, coral growth and carbonate productivity. Coastal progradation should also be taken into account which could have implications for the interpretation of ecological and sedimentary proxies of late Holocene sea levels.

The late Holocene depositional history of the Menai Bay shelf, and the patterns of land use in the settlement hinterland in the second half of the first millennium AD and during a period of rapid socioeconomic reorganization at the ~ first–second millennium boundary (which paved a path for the development of larger, more central commercial ports with often monumental architecture and urban structure by the mid-second millennium AD), may be critical for contextualizing the emergence and demise of Unguja Ukuu within a framework of environmental change. These important lines of evidence, however, remain undocumented. Piecing this history together would require establishing a program of offshore coring and sedimentological and paleocological analyses that were not originally part of our preliminary geoarchaeological reconnaissance.

Toward a unified assessment of coastal settlements in East Africa

Using an earth-science approach to investigate coastal settlements holds the potential to further illuminate the nature, degree, and directionality of human–environment interrelations at these sites (Anthony, Marriner, and Morhange 2014). Analysis of preserved sediment sequences using a multi-parameter approach strengthens environmental reconstructions against which cultural data can be scrutinized (Goldberg and Aldeias 2018). Here we have combined a suite of complementary datasets to reconstruct the archaeological landscape and coast-scape during the period of occupancy of Unguja Ukuu. We have been able to more confidently reconstruct the settlement history of the Unguja Ukuu backshore, from its early stages as a back-beach environment used for small-scale *ad hoc* activities, through to its transition into a major port of trade, albeit on a smaller scale than the later "stone towns."

The use of micromorphology in particular has afforded insights that would otherwise be undetectable at the field observation level. These data helped to identify the incipient beginnings of habitation on what is otherwise a natural landscape and disentangle subtle signals of land use change and the pedogenic processes that modified the sediment and its inclusions post-burial. The use of this technique in urban or peri-urban settings is thus far limited in sub-Saharan Africa (Shahack-Gross et al. 2004; Sulas and Madella 2012). However, micromorphology is a powerful tool for interrogating a stratigraphic sequence at a scale beyond the visible spectrum and allied with sedimentological analyses at Unguja Ukuu has been invaluable for identifying microfragments of anthropogenic detritus, which in their variable frequencies, record phases of activity at the site or in the near vicinity. By investigating the sediments at the micro-scale, we have been able to detect ephemeral or subtle changes in site or catchment environment. As such, we recommend the use of microstratigraphic analyses in future investigations of such coastal sites. This is particularly important where the timing of their formation—including their humble beginnings, possibly associated with *ad hoc* food processing on a back-beach environment—is critical to our understanding of wider-scale systems such as transoceanic trade.

Studying the geomorphic, sedimentary, and cultural history of Unguja Ukuu (and similar rias-and-mangrove harbors along the eastern African littoral) calls for the development of transdisciplinary research protocols in which field archaeologists with understanding of Earth and environmental sciences' sampling protocols and specialists working on finds and archaeometric analyses, synergize datasets throughout the study and compare them at different levels. Coastal and inner-shelf sediments in particular may hold records of human activity (settlement, port functions, land use) and geomorphic change (high-order sea-level change, shifts of the inhabited shoreline, erosion in the settlement hinterland) over the last two millennia. At Unguja Island and similar settings, a program of research that combines regional archaeological and geological/geomorphological surveying with coring along selected transects across the inner shelf may expand, refine, and ultimately test some of the hypotheses presented here.

Conclusions

Unguja Ukuu prospered in an ecologically liminal zone, hemmed in between the sandy back-reef shore of Menai Bay and the mangrove-banked creeks in the east. This landscape setting offered diverse economic resources near to the settlement. The rias-and-mangrove setting of Menai Bay head afforded shelter from monsoonal storms, navigable waterways across the shallow inner shelf to the shore, diverse dietary and other material resources from the mangrove habitat, and—potentially—connections between the shore and the island interior. This geomorphic configuration was crucial for the emergence of this farming, fishing, and trading settlement in the latter half of the first millennium AD.

Our results record snapshots of the late Holocene evolution of a macrotidal back-reef coastal system at the settlement fringes. Fluvial sediments, perhaps resulting from an earlier Holocene sea-level highstand, were covered by sandy beach facies and middens/dumps adjacent to the settlement from the mid-seventh century AD. The backshore activity area, which we investigated, was used for small-scale subsistence activities (such as middening), trade, and industrial waste (with the consumption of fish leaving a distinctive mark on the sediments' composition and microstructure), and may have accommodated other, currently unidentified, uses related to the port function of the site. This earlier urban heritage continued to shape Unguja Ukuu's soils in the long term, through periods of settlement decline and abandonment from the twelfth century AD onwards. A dark earth anthrosol continues to evolve on these archaeological deposits, supporting cultivation in and around the modern town. Dark anthropogenic soils, like those formed in Unguja Ukuu by rapid deposition of organic- and phosphate-rich settlement waste and prolonged tropical pedogenesis, may, therefore, be used as markers for undiscovered thatch-and-earth settlements on the eastern African littoral, alongside ceramic clusters and other artefactual evidence. The dark coloration of these anthrosols renders them readily identifiable on satellite images and other remote sensing datasets.

At Unguja Ukuu, and perhaps elsewhere on the eastern African coast, the first millennium human activities modified the shoreline as coastal sediments accumulated. Beach aggradation and progradation was driven by the deposition of settlement debris (food remains and other habitation waste, disintegrating thatch-and-earth structures, etc.). In addition, we hypothesize that an increase in land use at the settlement and agricultural intensification in the hinterland may have increased rates of terrigenous sedimentation to the inner shelf, contributing to rapid coastal progradation, and altering the coastal geography and ecological conditions of the inner shelf adjacent to Unguja Ukuu.

These processes might be implicated in the decline, and eventual abandonment of Unguja Ukuu at the turn of the second millennium AD—a period of regional socio-political and economic transformation of coastal African societies that marked the emergence of maritime Swahili culture (Fleisher et al. 2015). Although evoking an environmental causation of settlement abandonment would be too simplistic, the interaction of coastal villages and harbors with their dynamic landscapes—at present only coarsely delineated as working hypotheses—may have had a role in this regional reorganization of settlements, harbors, and trade flows.

Notes

1. Striated around grains.
2. Phosphate cementation, occurring widely in tropical islands, could be a useful parameter to study sea-level and/or paleoclimatic changes.

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Declaration of interest

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