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Early Aboriginal pottery production and offshore island occupation on Jiigurru (Lizard Island group), Great Barrier Reef, Australia

Sean Ulm[a,*,1], Ian J. McNiven[b,1], Glenn R. Summerhayes[c,d,e], Pei-hua Wu[c,2], Magdalena M.E. Bunbury[a], Fiona Petchey[f,a], Quan Hua[g,d], Robert Skelly[h], Ariana B.J. Lambrides[a], Cassandra Rowe[i], Kelsey M. Lowe[d], Christian H. Reepmeyer[j,a], Cailey Maclaurin[a], Katherine G.P. Woo[a], Matthew Harris[a], Sarah B. Morgan[a], Kayla L. Turner-Kose[a], Sarah A. Slater[a], Joshua D. Connelly[a], Michael C. Kneppers[a], Katherine Szabó[h], Andrew Fairbairn[d], Simon G. Haberle[k], Felicitas Hopf[k], Robert Bultitude[l], Jeremy Ash[b], Stephen E. Lewis[m], Robin J. Beaman[n], Javier Xavier Leon[o], Matthew C. McDowell[b,p], Martin Potter[q], Benjamin Connelly[r], Chris Little[s], Scott Jackson[q], John McCarthy[t], Luke D. Nothdurft[u], Jian-xin Zhao[v], Michael I. Bird[i], Matthew W. Felgate[w], Brian Cobus[x], Walmbaar Aboriginal Corporation RNTBC[y]

[a] *Australian Research Council (ARC) Centre of Excellence for Australian Biodiversity and Heritage, College of Arts, Society and Education, James Cook University, PO Box 6811, Cairns, Queensland, 4870, Australia*
[b] *Australian Research Council (ARC) Centre of Excellence for Australian Biodiversity and Heritage, Monash Indigenous Studies Centre, Monash University, Clayton, Victoria, 3800, Australia*
[c] *Archaeology Mātai Whaipara Takata, School of Social Sciences Te Puna Pāpori, University of Otago, PO Box 56, Dunedin, 9054, New Zealand*
[d] *School of Social Science, The University of Queensland, Brisbane, Queensland, 4072, Australia*
[e] *Archaeology and Natural History, College of Asia and the Pacific, Australian National University, Canberra, Australian Capital Territory, 2601, Australia*
[f] *Waikato Radiocarbon Dating Laboratory, The University of Waikato, Hillcrest Road, Hamilton, 3240, New Zealand*
[g] *Australian Nuclear Science and Technology Organisation, Locked Bag 2001, Kirrawee DC, New South Wales, 2232, Australia*
[h] *Monash Indigenous Studies Centre, Monash University, Clayton, Victoria, 3800, Australia*
[i] *Australian Research Council (ARC) Centre of Excellence for Australian Biodiversity and Heritage, College of Science and Engineering, James Cook University, PO Box 6811, Cairns, Queensland, 4870, Australia*
[j] *Commission for Archaeology of Non-European Cultures, German Archaeological Institute, Dürenstraße 35-37, 53173, Bonn, Germany*
[k] *Australian Research Council (ARC) Centre of Excellence for Australian Biodiversity and Heritage, Archaeology and Natural History, College of Asia and the Pacific, Australian National University, Canberra, Australian Capital Territory, 2601, Australia*
[l] *Geological Survey of Queensland, Department of Natural Resources, Mines and Energy, PO Box 15216, City East, Queensland, 4002, Australia*
[m] *Centre for Tropical Water and Aquatic Ecosystem Research, James Cook University, Townsville, Queensland, 4811, Australia*
[n] *College of Science and Engineering, James Cook University, PO Box 6811, Cairns, Queensland, 4870, Australia*
[o] *School of Science, Technology and Engineering, University of the Sunshine Coast, Locked Bag 4, Maroochydore DC, Queensland, 4558, Australia*
[p] *Australian Research Council (ARC) Centre of Excellence for Australian Biodiversity and Heritage, School of Natural Sciences, University of Tasmania, Private Bag 55, Hobart, Tasmania, 7001, Australia*
[q] *School of Communication and Creative Arts, Deakin University, 221 Burwood Highway, Burwood, Victoria, 3125, Australia*
[r] *Maptek Pty Ltd, 63 Conyngham Street, Glenside, South Australia, 5065, Australia*
[s] *School of Engineering and Built Environment, Griffith University, 170 Kessels Road, Nathan, Queensland, 4111, Australia*
[t] *College of Humanities, Arts and Social Sciences, Flinders University, GPO Box 2100, Adelaide, South Australia, 5001, Australia*
[u] *School of Earth and Atmospheric Sciences, Queensland University of Technology, GPO Box 2434, Brisbane, Queensland, 4001, Australia*
[v] *School of Earth and Environmental Sciences, The University of Queensland, Brisbane, Queensland, 4072, Australia*
[w] *College of Arts, Society and Education, James Cook University, PO Box 6811, Cairns, Queensland, 4870, Australia*
[x] *PO Box 886, Cooktown, Queensland, 4895, Australia*
[y] *Walmbaar Aboriginal Corporation RNTBC, 24 Flierl Street, Hope Vale, Queensland, 4895, Australia*

* Corresponding author.
E-mail address: sean.ulm@jcu.edu.au (S. Ulm).
[1] Equal first authors.
[2] Deceased.

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ABSTRACT

Aboriginal manufacture and use of pottery was unknown in Australia prior to European settlement, despite well-known ceramic-making traditions in southern Papua New Guinea, eastern Indonesia, and the western Pacific. The absence of ancient pottery manufacture in mainland Australia has long puzzled researchers given other documented deep time Aboriginal exchange networks across the continent and the close proximity of pottery-bearing Lapita and post-Lapita maritime communities in the western Pacific with ocean-going watercraft and sophisticated navigation abilities. We report the oldest securely dated ceramics found in Australia from archaeological excavations on Jiigurru (Lizard Island Group) on the Great Barrier Reef, northeast Australia. Comprehensive radiocarbon dating and Bayesian modelling constrains ceramic deposition to between 2950–2545 cal BP and 1970–1815 cal BP. This timing overlaps with late Lapita and post-Lapita ceramic traditions of southern Papua New Guinea. Geological characterisation of the sherds strongly suggests local manufacture as the vessels belong to three temper and clay groups locally sourced to northeast Australia, and most likely to Jiigurru. The oldest occupation layers date to 6510–5790 cal BP, making Jiigurru the earliest offshore island occupied on the northern Great Barrier Reef. The results demonstrate that northeast Australian First Nations communities had sophisticated canoe voyaging technology and open-sea navigational skills and were intimately engaged in ancient maritime networks, connecting them with peoples, knowledges, and technologies across the Coral Sea region.

1. Introduction

Pre-European manufacture and use of pottery by the Indigenous peoples of Australia (Aboriginal peoples across the mainland and Melanesian Torres Strait Islanders in the northeast) is unknown ethnographically. The apparent absence of pottery in Australia, as noted by early and more recent European observers, both reflected and was used to support, racist social evolutionary hierarchies characterising Aboriginal societies as lacking cultural complexity (Abbie, 1951; Franklin, 2020).

Southeast Asian pottery appears across a wide area of northern coastal Australia over the past 400 years associated with Makassan maritime industrial activities (Clayton, 2023; Macknight, 1976; Taçon et al., 2010; Urwin et al., 2023; Wesley et al., 2014) and is reported as far east as the Wellesley Islands in the southeast Gulf of Carpentaria (Oertle et al., 2014). Pre-European pottery of local Indigenous manufacture in Australia is only known in Torres Strait where 24 sherds have been reported. In western Torres Strait, locally made pottery largely dates to between 1700 and 1500 cal BP, with several sherds as old as 2600–2100 cal BP at Mask Cave (McNiven et al., 2006; Wright and Dickinson, 2009). In eastern Torres Strait, pottery appears to be of southern New Guinea origin and dates to 2200–1700 cal BP (Carter, 2001, 2002; see also Wright et al., 2019). The Torres Strait ceramics mostly post-date the end of the Lapita era (McNiven et al., 2006), although it is broadly accepted that the earliest sherds are likely associated with late Lapita which dates to 2600–2550 cal BP at Caution Bay (David et al., 2011; Shaw et al., 2022; Skelly et al., 2014:471; see Fig. 1 and Supplementary Table S11 and Fig. S5 for chronological details and updated age calibrations). As Skelly et al. (2014:471) note in relation to the c.2600 cal BP Mask Cave ceramic sherds, Lapita is the only ceramic tradition of this age known from this part of the Pacific.

The absence of Lapita sites along Australia's eastern seaboard has long perplexed Pacific and Melanesian archaeologists (Lilley, 2019), especially in the context of growing archaeological evidence of Lapita pottery traditions from neighbouring Papua New Guinea and its islands. The northeast Australian coastline appears to have been within reach of ceramic-making seafaring groups in Near Oceania (e.g. New Guinea and Solomon Islands) with sophisticated watercraft and navigation technologies (Dousset and Di Piazza, 2021; Irwin, 1992:143). Various explanations have been proposed for the absence of early ceramic use by Aboriginal Australians, ranging from incomplete archaeological sampling and failed settlement attempts, to the possibility of Pacific groups avoiding Australia altogether because it was already populated (despite examples of Lapita peoples co-habiting for centuries alongside existing local peoples in Near Oceania) (Clark and Bedford, 2008; Felgate, 2007; Green, 1978; McNiven et al., 2011; Spriggs, 1997).

1.1. The history of Lapita in Oceania

The islands of the western Pacific were peopled in the great Lapita voyages originating from the islands of eastern Papua New Guinea c.3300 cal BP (Denham et al., 2012; Kirch, 2017), demarcated in the archaeological record by distinctive ceramics and shell technologies, introduced plant species, and domesticates like dog, pig, and chicken. Within the space of a few centuries, Lapita peoples and their descendants had settled a vast area extending from Solomon Islands eastwards into Remote Oceania and Vanuatu, New Caledonia, Fiji, Tonga, and Samoa, a distance exceeding 5000 km (Fig. 1). Lapita voyaging and settlement of the Pacific is one of humanity's great maritime settlement accomplishments, setting the stage for the subsequent Polynesian occupation of far-flung Hawaiʻi, Rapa Nui (Easter Island), and Aotearoa (New Zealand) (Bedford et al., 2019; Kirch, 2017; Sefton et al., 2022).

Until recently, mainland Papua New Guinea yielded no Lapita sites (e.g. Allen, 1972; Bulmer, 1978; Irwin, 1985; Vanderwal, 1973); although a single sherd had been found near Aitape, on the north coast (Terrell and Schechter, 2007). In contrast to Australia, later ceramic wares in mainland Papua New Guinea are common, and many communities continue to make and use pottery today (May and Tuckson, 1982). Just over a decade ago, extensive excavations undertaken at Caution Bay revealed well-stratified deposits containing large pottery assemblages dating to between 2900 and 2600–2550 cal BP, associated with Lapita (David et al., 2011, 2013, 2019, 2022; McNiven et al., 2011, 2012a, 2012b; Richards et al., 2016). These discoveries not only pushed back the known antiquity of pottery manufacture in mainland New Guinea by some 900 years, but they also expanded the distribution of Lapita much farther west. Additional pottery sherds attributed to Lapita have been recovered from archaeological sites in the Kouri Lowlands, c.300 km northwest of Caution Bay (see Skelly and David, 2017; Skelly et al., 2014, 2016), and the Massim islands off the southeast tip of mainland Papua New Guinea (Negishi and Ono, 2009; Shaw et al., 2020, 2022) (Fig. 1).

1.2. The discovery of pottery on Jiigurru

In 2006, pottery sherds were discovered on the surface of an intertidal lag deposit in the Jiigurru lagoon. All of these sherds were rounded and worn down by coastal processes (Lentfer et al., 2013; Tochilin et al., 2012). Attempts to date the sherds directly using luminescence techniques were inconclusive. Dickinson's (2014) initial analysis of the composition of the sherds and Tochilin et al.'s (2012) dating of zircon in the sherds suggested that most, if not all, the sherds were likely to have been locally manufactured.

Here we report on the discovery of a large, temporally constrained, assemblage of ceramic sherds recovered from the South Island Headland Midden (SIHM), a terrestrial deposit on Jiigurru, dating to the late Lapita/immediate post-Lapita period. This study emphasises the sedimentary history and chronological modelling of the site, while details about the mollusc, bone, urchin, stone and shell artefact assemblages will be presented elsewhere. Results further emphasise that northeast Australian First Nations people were not isolated or geographically constrained, as once conceived; rather people were deeply connected by way of movement between places and sharing of knowledges across the Coral Sea region.

2. Background: Jiigurru environmental, archaeological and ethnographic contexts

Prior to post-glacial sea-level rise, the islands of Jiigurru were conspicuous mountains on a broad coastal plain some 20 km west of the glacial low-stand coastline on the outer edge of the exposed continental shelf. With Late Pleistocene sea-level rise, Jiigurru would have been surrounded by water by at least 10,000 years ago. By the time Jiigurru was first occupied c.6500 years ago, it was c.30 km from the contemporary mainland coast (Fig. 2).

The present-day northern Great Barrier Reef has a north-south trending line of granite continental islands comprising Jiigurru, North Direction Island, and South Direction Island. These islands are situated approximately 33 km off Cape Flattery on the mainland coast and 93 km northeast of Cooktown. The islands of Jiigurru surround a deep (c.10 m) lagoon, and comprise Lizard Island, the largest island at 10 km^2 in area, Palfrey Island, South Island, Osprey Islet and Bird Islets. The most extensive reef development is from South Island across to Bird Islets and adjacent to Coconut Beach on the southeast windward margin of Jiigurru. Today the reef flat and reef crest adjacent to the South Island Headland Midden are broadly characterised by coral, calcified algae, and sparse coral, rubble, and algae on sand (Hamylton et al., 2014). These benthic habitats support diverse faunal communities such as reef fish, sharks, chiton, urchin and molluscan species including clams (e.g. *Hippopus hippopus* and *Tridacna* spp.), top shell (*Rochia nilotica*), conchs (Strombidae), cone snails (Conidae), and nerites (Neritidae). Terrestrial fauna are limited across the islands, with only small-bodied mammals (e.g. black flying fox [*Pteropus alecto*]), snakes and lizards (e.g. large yellow spotted monitor [*Varanus panoptes*]) reported. The bird population is

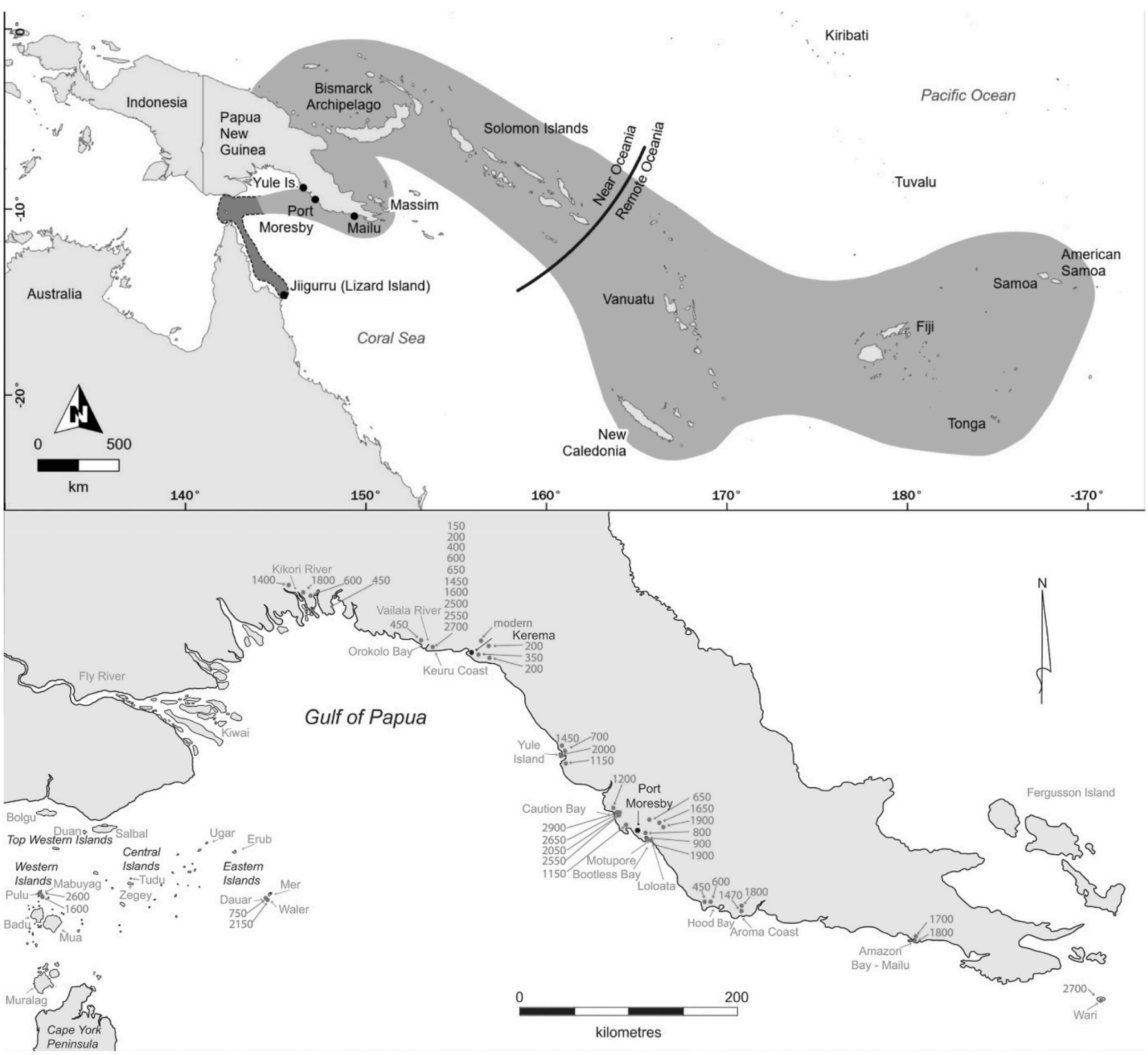

Fig. 1. Top: Map of known Lapita cultural area showing the location of Jiigurru (Lizard Island Group) (after David et al., 2011). Dashed extension of the Lapita cultural area into Torres Strait and northeast Australia indicates possible Lapita distribution or influence (after Shaw et al., 2022). Bottom: Median onset ages for pre-nineteenth century ceramic sites in the Coral Sea region. Median calibrated ages have been rounded to nearest 50 years. Only sites with published radiocarbon chronologies are included (Supplementary Table S11).

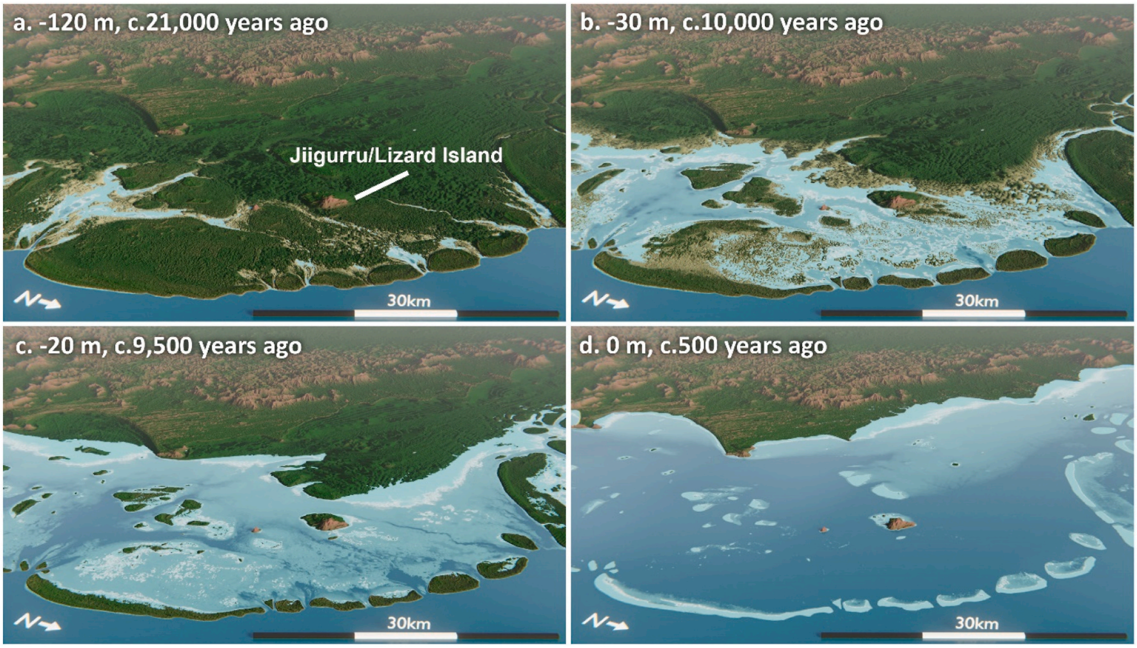

Fig. 2. Visualisation of sea-level rise on Jiigurru (Lizard Island Group) since the Last Glacial Maximum. By at least −30 m (10,000 years ago), Jiigurru would have been surrounded by water. Islandisation may have occurred slightly earlier, allowing for several metres of post-glacial marine transgression sediments, reflected in this modern surface. Note that islands identified in (b) and (c) include topographic features from Holocene reef-growth. However, the general pattern reflects landforms created during the last interglacial period. Bathymetric data from Beaman (2017) (see also Supplementary Fig. S7).

more diverse, with a range of visiting and resident land and shore birds (Smith, 1987). There are permanent freshwater sources on Lizard Island, including one documented by Lieutenant James Cook in August 1770 on the northern extent of Watson's Bay (Beaglehole, 1962), but freshwater is also accessible from seasonal springs across the interior and around the rim of many islands in the group.

Jiigurru's vegetation is dominated by *Themeda australis* and *Arundinella nepalensis* grasslands, intermixed with small areas of closed forest types (e.g. semi-deciduous notophyll vine forest) as well as shrubby heath characterised by *Thryptomene oligandra*. Isolated sclerophyll woodlands feature *Acacia crassicarpa*, *A. humifusa* and *Eucalyptus tessellaris*. Permanently wet central low-lying areas are dominated by *Pandanus* species. The coastal and brackish regions are vegetated by diverse mangroves, dune and strand communities (Proske and Haberle, 2012; Lentfer et al., 2013). Jiigurru is positioned within the Tropical Aw climatic classification based on the Köppen scheme (Peel et al., 2007).

Geologically, Jiigurru (Lizard Island, along with Palfrey and South Islands) forms the Lizard Island Granite group comprising outcrops of leucocratic biotite-muscovite granite (Bultitude, 1993:46–55; Bultitude and Champion, 1992:28, 32, 35–36; Domagala et al., 1997; Garrad and Bultitude, 1999:272; Geological Survey of Queensland, 2015; Lucas and Keyser, 1965:8; Morgan, 1964:7) within the Cooktown Supersuite of granites that also take in Barrow Point on the adjacent mainland. The Cooktown Supersuite is one of a series of distinctive granite formations outcropping in Torres Strait and along eastern Cape York Peninsula and northern sections of the Great Barrier Reef (Bain and Draper, 1997).

Jiigurru is a place of high importance to the Traditional Owners from the Guugu Yimithirr nation and stories passed down from the Elders tell of the islands being a place of ceremony, initiation, gathering, deliberations, and a place for knowledge to be passed down to young men (Phillip Baru, Dingaal Elder, pers. comm., 2020). Trips to the islands for initiation were believed to have lasted for several months during the recent past. According to Phillip Baru (pers. comm., 2020), Dingaal families also travelled to Jiigurru to access foods such as wild yam, shellfish, fish, and turtle. During the eighteenth and nineteenth centuries, European mariners noted structures ('huts'), canoes, hearths, and scatters of shell, fish and turtle remains on Jiigurru (Beaglehole, 1962; Macgillivray, 1852).

McNiven (2021, 2022) identifies Jiigurru as the southern extent of a series of nineteenth century ethnographically-known voyaging and exchange networks that indirectly connected coastal communities of eastern Cape York Peninsula and Torres Strait (Australia) and the southern mainland coast and adjacent islands of Papua New Guinea to form the Coral Sea Cultural Interaction Sphere (CSCIS) (Fig. 3). In addition to the two-way movement of objects, these exchange networks provided opportunities for the two-way movement and sharing of ideas by coastal communities between New Guinea and Australia. While use of certain ethnographic objects such as bamboo smoking pipes across the CSCIS reveal broad-scale sharing of ideas, restricted use of certain objects to either Cape York Peninsula and Torres Strait (e.g. shell-handled spearthrowers) or Torres Strait and New Guinea (e.g. dog-tooth necklaces) indicates shared knowledge did not always result in shared uptake of ideas and/or objects. Geographical differences in the distribution of ethnographic objects reveal the operation of social and cultural selection in object uptake. As such, object distributions may change through time as selection processes similarly change.

2.1. Archaeological research

Archaeological research commenced on Jiigurru in the 1970s when Beaton (1973) and Specht (1978) conducted surveys of Lizard Island and recorded numerous site types (e.g. middens, stone arrangements). More than a decade later, Mills (1992) completed an extensive survey of Lizard Island, recording 21 middens, four stone arrangements, and two art sites, and completed the first excavations on the island (Site 17 Freshwater Bay Midden; Site 18 Gecko Shelter). The Site 17 Freshwater Bay Midden (Lizard Island) was re-excavated in 2009 by Lentfer et al. (2013) and outcomes suggested the island was first occupied by 3656 cal BP, with an observed increase in the intensity of site use over the past ~1500 years.

In 2012, Ulm and McNiven, in partnership with Aboriginal Traditional Owners, established a new research program to consider the deep time history of Jiigurru more broadly. This project extended preliminary findings of ceramic earthenware sherds in the intertidal zone of

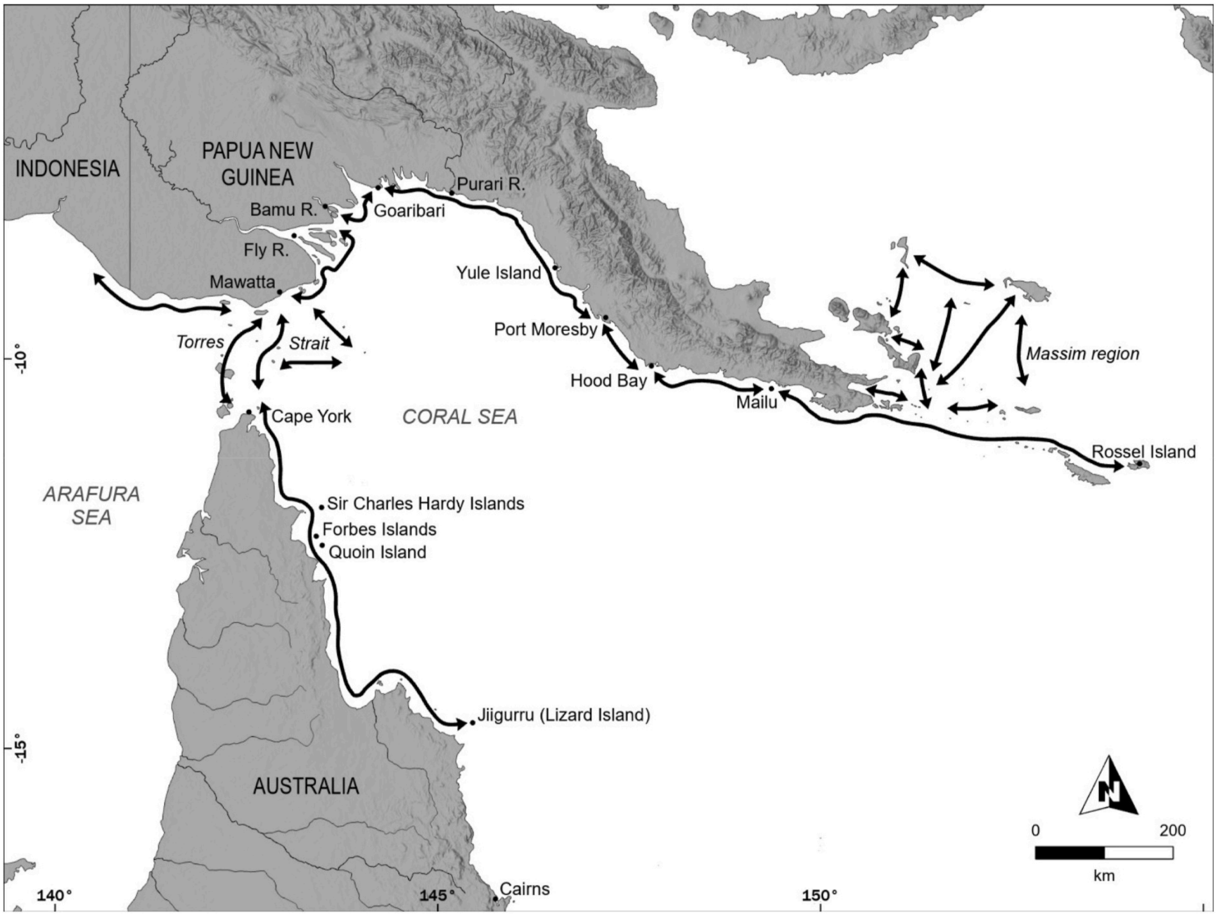

Fig. 3. Connections across the coral sea cultural interaction sphere (ESRI, 2022; after McNiven, 2021).

Mangrove Beach by Matthew Felgate and Jim Specht (2006–2010) (Tochilin et al., 2012). Further excavations were undertaken at the Mangrove Beach Intertidal Site and new excavations were conducted at the nearby Site 3 Mangrove Beach Headland Midden (Ulm et al., 2019; Lambrides et al., 2020), the latter extending the known use of Jiigurru to the past 4000 years. Subsequent fieldwork included excavations on South Island (South Island Headland Midden, reported here), and extensive surveys of Lizard, Palfrey, South, and North Direction Islands, and the recording of stone arrangements (Fitzpatrick et al., 2018) and art sites (Arnold, 2020) (Fig. 4).

3. Methods

3.1. Excavation methods

A 1 m × 1 m excavation (Square A) was undertaken at the South Island Headland Midden across three field seasons between 1–22 July 2017, 26 September–14 October 2017 and 1–29 September 2018. The excavation square was positioned on a flat area on the crest of the headland (Figs. 5 and 6). Excavations proceeded in shallow, arbitrary excavation units (XUs) within stratigraphic units (SUs), averaging 20.5 mm in depth and 13.4 kg in weight. Excavation ceased at 243 cm below ground surface and well below the deepest cultural objects at 195 cm (Supplementary Table S1). In the lower sections of the deposit, sediments with cultural materials (e.g. shell) were separated from sediments without obvious cultural materials by subdividing XUs into parts 'a' and 'b', respectively. Each part was a continuous, discrete area within its respective XU (rather than multiple patches). Only part 'a' subdivisions (termed Series A) are analysed for this paper. Information on part 'b' subdivisions is presented in Supplementary Data. pH readings and Munsell Soil Color® chart tests were completed in the field on dry sediments from each XU. A local site datum was established 226 cm east of the central east margin of Square A. Eight elevations (including the four corners and centre-point) were recorded at the beginning and end of each XU, using an autoset level and stadia rod. Plan view photographs were taken at the completion of each excavation unit. Single pieces of charcoal and selected shells suitable for radiocarbon dating and fragile cultural objects (e.g. ceramic sherds) were plotted in three dimensions and bagged separately for precise provenance and protection. Section drawings and photographs were made of all sides of the square after cleaning at the end of the excavation. In addition, photographs were regularly taken to record the excavations in progress and the general site context. A total of 2279.6 kg (1711.25 L) of material was excavated. All midden materials were dry-sieved through 2.3 mm mesh on site. Sediment samples were collected from each XU, from the material that passed through the 2.3 mm sieve. Materials retained in the sieve were double-bagged for laboratory sorting, identification, and analysis. Each bag (sieve materials, sediment samples, and plotted objects) was assigned a unique Field Specimen (FS) number. The pit was backfilled with the sieved sediments supplemented with local beach sands.

3.2. Ground penetrating radar (GPR)

A ground penetrating radar (GPR) survey was undertaken to characterise the depth and extent of subsurface cultural deposits. GPR data were collected using a Geophysical Survey Systems, Inc. (GSSI) SIR-3000, 400 MHz antenna and a model 620 survey wheel. Transects were spaced every 0.5 m, and 16-bit data were collected with a 40 ns time window, 512 samples/scan and with 25 scans/m. The data were processed (including a time zero correction and bandpass filter) and

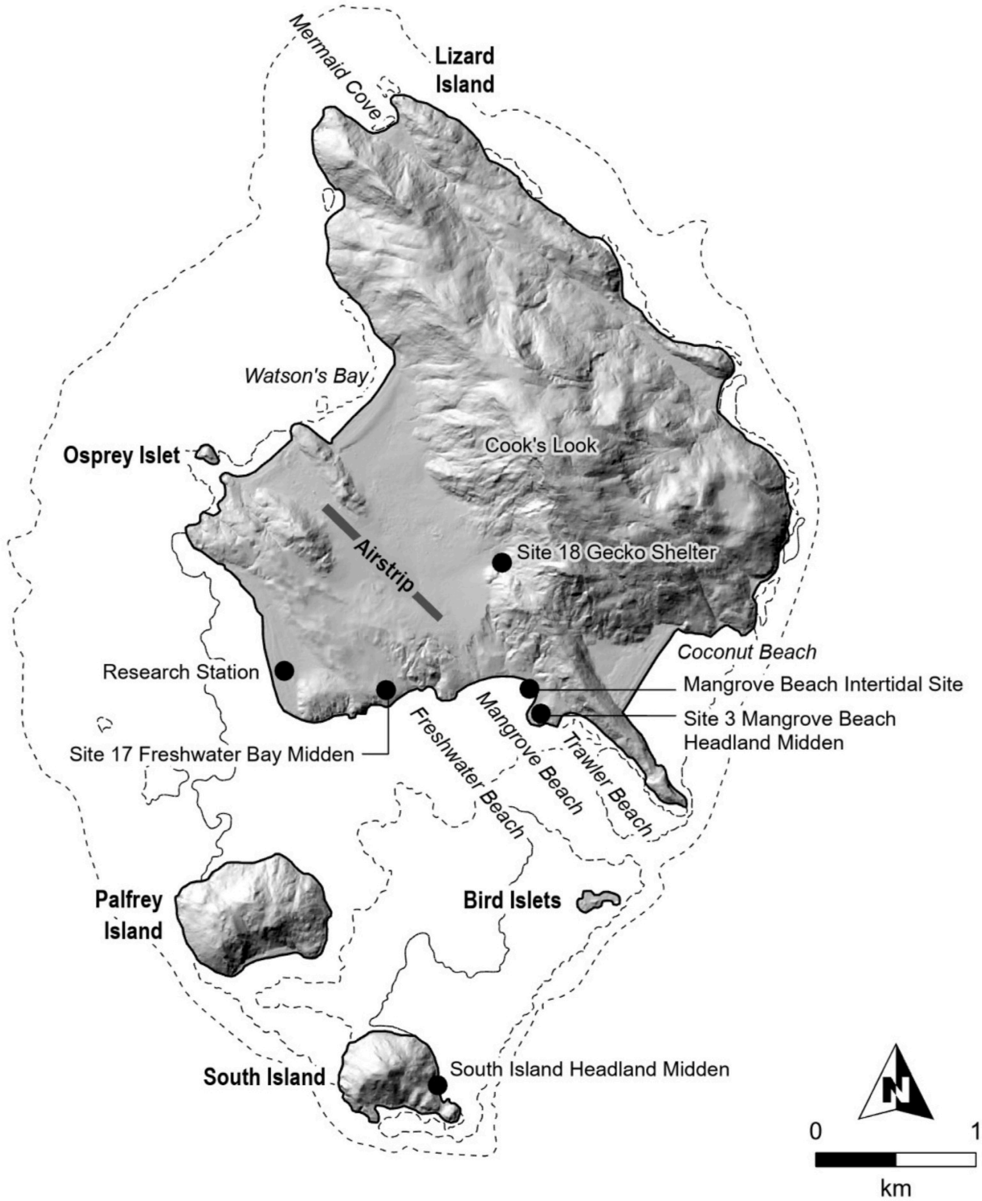

Fig. 4. Jiigurru (Lizard Island Group), showing the location of archaeological sites and places mentioned in text. The dotted line shows the extent of the reef platform (State of Queensland - Department of Resources, 2020).

converted into slice maps using GPR-SLICE v7.0. The hyperbola fitting function was used to estimate the relative dielectric permittivity (RDP), which is derived from the two-way travel time to depth. This function helped in creating the amplitude time slice-maps and provided an estimated depth for the features identified in the data (Goodman and Piro, 2013). In GPR Slice, the GPR data were georeferenced using Geocentric Datum of Australia (GDA) 94 Zone 55 and topographical corrections were made using total station points collected on the site. These data were used to create the three-dimensional and volume renderings. The geophysical grid covered a 7 m × ~10 m area (0.007 ha), including the location of the 1 m × 1 m excavation square. Mapping and cartography were completed in ESRI ArcGIS 10.6.1. Any processed GPR images not used in GPR Slice were exported as JPEGs and georeferenced to GDA 94 Zone 55. Fifteen amplitude slice maps were recreated from the GPR data, converted to real-world coordinates using GDA 94 Zone 55 in GPR Slice, and then exported as a georeferenced JPEGs into ArcGIS. An Overlay Analysis was employed to combine the amplitude time-slices into ~1 m.

GPR data were corrected for topography in GPR Slice and horizon detection used to calculate the volume of the shell deposits. The auto-detect function was used to assist in locating the appropriate energy pulses at specified depths. Horizon 1 represented the ground surface layer, and Horizon 2 represented the base of the shell midden. This function permits the detection of the peak + or peak – of the pulse. After detecting the base of the shell deposits, the files were manually fitted because some of the layers detected by the software had deviated off course. 3D volume was calculated using Open GL.

3.3. Radiocarbon (^{14}C) dating and chronological modelling

Accelerator mass spectrometry (AMS) radiocarbon age determinations on marine shell and charcoal were undertaken at the University of Waikato Radiocarbon Dating Laboratory. Samples were pre-treated following standard AMS protocols (UCI KCCAMS Facility, 2011a, 2011b). When possible, single charcoal fragments were identified to taxa prior to dating. Charcoal was pretreated with 1M HCl at

Fig. 5. South Island Headland Midden. Top left: General view across Blue Lagoon towards South Island in top left (Photograph: Sean Ulm). Top right: View across excavation to Blue Lagoon and reef flat (Photograph: Ian J. McNiven). Bottom left: Excavation in progress (Photograph: Sean Ulm). Bottom right: Terrestrial laser scanning of final sections in progress (Photograph: Ian J. McNiven).

80 °C for 1hr; 1M NaOH at 80 °C for 30 min; 1M HCl at 80 °C for 1hr; 80 °C, MilliQ™ water for 5 min (pH > 5), sonicated, then dried at 80 °C. Charcoal samples were converted to CO_2 in sealed quartz tubes by oxidation at 800 °C overnight, using pre-baked CuO wire (JT Baker) and silver wire to absorb any SO_x and NO_x produced. All shell samples were identified to species. Shells were sampled using a Dremel® 3000 Rotary Tool fitted with a diamond wheel to take c.10 mm-long and c.4 mm-wide samples parallel to the margin of each shell. This sampling strategy is designed to avoid seasonal ^{14}C variation by sampling across multiple growth increments (Culleton et al., 2006; Hogg et al., 1998; Petchey et al., 2008). Shell samples (<3 mm fragments, 35–45 mg) were etched in 0.1M HCl at 80 °C to remove ~45% of the surface, then dried. Cleaned shells were then tested for recrystallization by Feigl staining (Friedman, 1959) to ensure either aragonite, or a natural aragonite/calcite distribution, was present in the shell. Two samples of *Anadara antiquata* (Wk-46099, Wk-46100) from XUs 40 and 43 respectively, were abandoned owing to mixed calcite/aragonite response on Feigl staining. CO_2 was collected from shells by reaction with 85% H_3PO_4 under vacuum at 70 °C for c.30 min. Cryogenically separated CO_2 was reduced to graphite with H_2 at 550 °C using an iron catalyst. $\delta^{13}C$ was measured either on a LGR Isotope analyser CCIA-46EP or a Thermos Scientific MAT252 IRMS. Pressed graphite was analysed at the Keck Radiocarbon Dating Laboratory, University of California, Irvine, on a NEC 0.5 MV 1.5SDH-2 AMS system (Beverly et al., 2010).

Radiocarbon ages were calibrated using OxCal (v.4.4) (Bronk Ramsey, 2009a). Terrestrial radiocarbon ages were calibrated using IntCal20 (Reimer et al., 2020) acknowledging the influence of the southward penetration of the Inter-Tropical Convergence Zone (Hogg et al., 2013; Hua et al., 2012).

ΔR values for the northern Great Barrier Reef are similar for the period 5500–0 cal BP. However, significant ΔR variations have been documented for the interval 7000–5500 cal BP (Hua et al., 2020). Consequently, we calculated weighted mean ΔR values for the northern Great Barrier Reef for these two periods to use in age calibration of marine radiocarbon ages. For the period 5500–0 cal BP, 15 ΔR values derived from U-Th dated corals and known-age shells from the northern Great Barrier Reef reported in Hua et al. (2020), and three ΔR values based on U-Th dated corals from the South Island Headland Midden determined in this study were used (see Supplementary Tables S3–S5). Coral samples were inspected using a scanning electron microscope for the presence of meteoric calcite and other diagenetic alteration prior to U-Th dating. U-Th samples were dated using a Nu Plasma multi-collector-inductively coupled plasma-mass spectrometer (MC-ICP-MS) at the Radiogenic Isotope Facility at The University of Queensland (Zhou et al., 2011; Clark et al., 2014). Paired ^{14}C measurement of the coral samples was carried out using the VEGA AMS Facility at the Australian Nuclear Science and Technology Organisation (Hua et al., 2001; Fink et al., 2004). ΔR values and associated uncertainties were calculated using the online *deltar* software (Reimer and Reimer, 2017) and Marine20 data (Heaton et al., 2020). The weighted mean ΔR value relative to Marine20 for the northern Great Barrier Reef for 5500–0 cal BP is −197 ± 56 years ($n = 18$). For the 7000–5500 cal BP period, seven ΔR values reported in Hua et al. (2020) and two values from Magnetic Island (Lewis et al., 2012) derived from U-Th dated corals were used for the calculation. The weighted mean ΔR value relative to Marine20 for the northern Great Barrier Reef for 7000–5500 cal BP is −38 ± 158 years ($n = 9$). In both ΔR calculations, the uncertainty associated with the weighted mean value is the larger of the error of the mean and the standard deviation.

The onset of occupation and deposition of ceramics was modelled in

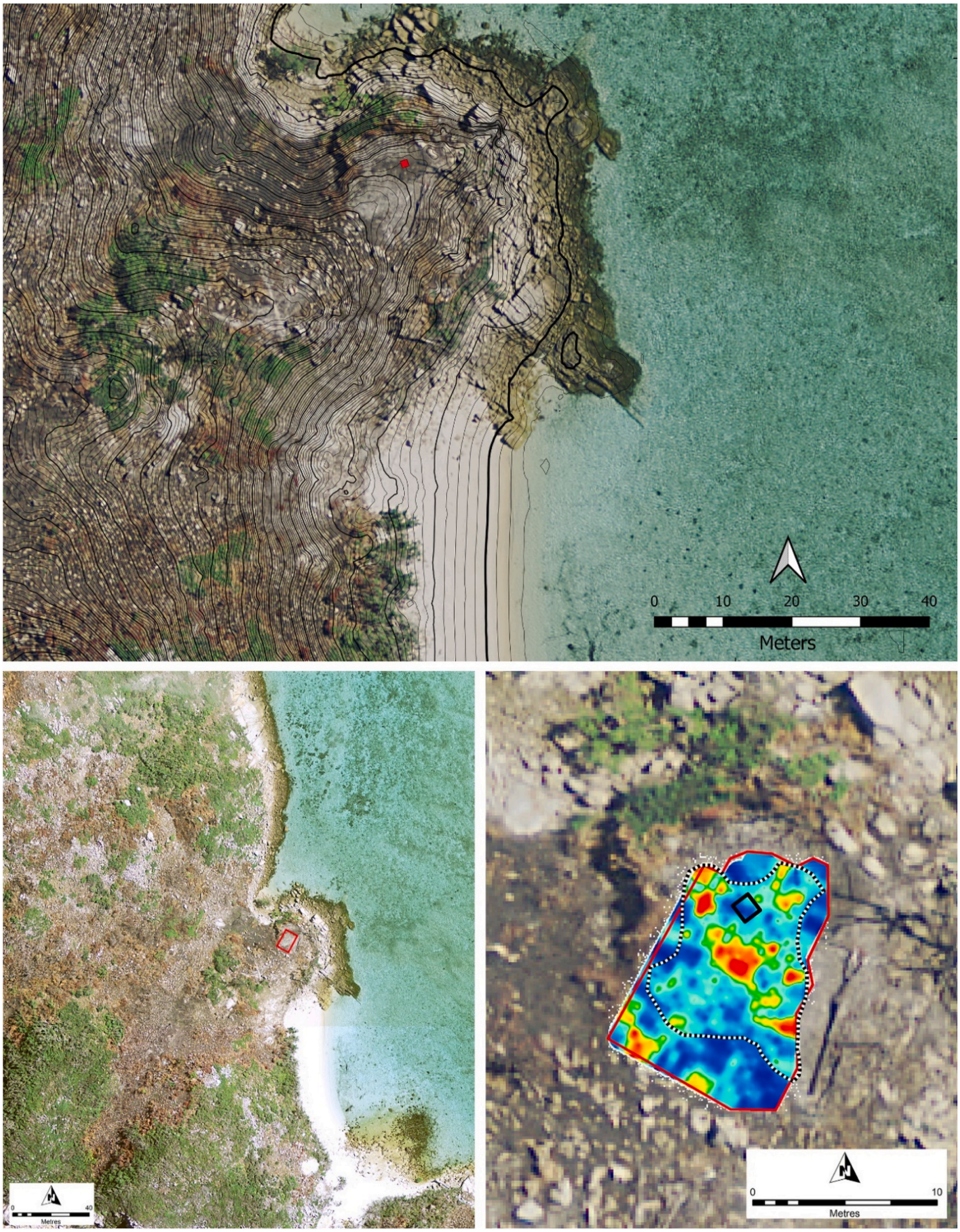

Fig. 6. Top: Orthophotograph of site and immediate context (20 cm contour intervals). The thick black line is the median sea level (0 m). Red square shows the position of the Square A excavation. Bottom left: General site context. Red square encloses the area of the geophysical survey grid. Bottom right: Site plan showing excavation and geophysical grid. The black square shows the position of the Square A excavation. The red outline encloses the area of the geophysical survey grid. Higher GPR reflections are shown in yellow and red; weaker reflections are shown in blue. Note that the geophysical survey was conducted after Square A was backfilled. The dotted black line shows the boundary of the shell deposit as interpreted from the geophysical data. © State of Queensland (Department of Natural Resources, Mines and Energy) [2017, 20203]. Based on or contains data provided by the State of Queensland Department of Natural Resources, Mines and Energy) [2017, 20203]. In consideration of the State permitting use of this data you acknowledge and agree that the State gives no warranty in relation to the data (including accuracy, reliability, completeness, currency or suitability) and accepts no liability (including without limitation, liability in negligence) for any loss, damage or costs (including consequential damage) relating to any use of the data. Data must not be used for direct marketing or be used in breach of the privacy laws.

OxCal (v.4.4) (Bronk Ramsey, 2009a, 2017) using *Highest Probability Distributions* (HPDs) obtained from multiple ^{14}C dates within a Bayesian framework (Bronk Ramsey, 2009a). The reliability and accuracy of HPDs depend upon two key factors: the overall distribution of the ^{14}C data, including the contextual information associated with the ^{14}C dates, and the inherent characteristics of the data, such as the probability of a particular sample being an outlier (Schmid et al., 2018).

The HPDs were modelled using the OxCal (v.4.4) platform (Bronk Ramsey, 2009a). To ensure precise data entry, we employed the OxCalparser program, which facilitated the construction of robust Bayesian Outlier models within the OxCal framework (Schmid et al., 2018). The modelled HPDs are presented for both 1σ (68.3%) and 2σ (95.4%) confidence intervals. Unless explicitly noted, results discussed in this paper are based on the 95.4% confidence interval.

We modelled 51 ^{14}C dates using Bayesian *Outlier models*, which identify and downweigh dates that are inconsistent with the surrounding data. We used the *General t-type Outlier model* for identified short-lived materials, including 37 marine shell (*Rochia nilotica*, *Anadara antiquata*) and 10 identified short-lived charred *Pandanus* nutshell fragments (Polydrupe *Pandanus* endocarp, identified following Fairbairn and Florin, 2022). This model assumes that short-lived samples (with a lifespan of less than 10 years) should be extremely close to the date of sedimentation and are modelled in a Student-t distribution. A small proportion, however, can be older or younger than their contexts. Thus, samples are given a 5% prior probability of being an outlier within this distribution (Bronk Ramsey, 2009b). We used the *Charcoal Plus Outlier* model for four unidentified charcoal samples. This model assumes that in most of the cases the outliers are older (inbuilt age or reworked material) than their dates of deposition, but they can occasionally be intrusive, which are drawn from an exponential distribution towards younger ages ages (Dee and Bronk Ramsey, 2014). Samples were given a 100% prior probability of being an outlier within this distribution. We ran each model multiple times, and modelled ages were rounded to the nearest five years to avoid spurious precision (Bunbury et al., 2022; Hamilton and Krus, 2018). We modelled the ^{14}C dates into eight *Phases*, unordered groups of events, bracketed by *Boundaries* within a *Sequence*, an ordered group of events. *Boundaries* represent either a hiatus in the age ranges of samples or a change in the intensity of deposition. Initially, we modelled all ^{14}C dates and then removed seven outliers in the analysis, which are clearly intrusive materials within the stratigraphic sequence: one marine shell age (Wk-49180) is c.1500 years younger than other marine samples above and below in the matrix; three short-lived charcoal samples (Wk-47859, Wk-47858, Wk-47856) are significantly younger than marine shells above and below in the matrix. These are most likely not in situ samples, as tiny charcoal samples can easily move through the matrix; and three marine shell dates (Wk-48799, Wk-50062, Wk-50061) are much older than other surrounding shell and charcoal dates.

A Bayesian age-depth model was created using the *rbacon* software (Blaauw and Christen, 2011) with the same calibration data and marine radiocarbon reservoir correction (ΔR) values used for the phase modelling. The same radiocarbon ages employed in the phase modelling were also used for the age-depth modelling. This analysis facilitates confirmation that the site chronology is robust.

3.4. Ceramic analysis methods

Metric and non-metric observations for each sherd were recorded following Rice (1987), which included maximum length and thickness, weight, surface inspection for weathering patterns and modification, interior and exterior colour with a Munsell Soil Color® chart, vessel part, identification of vessel forming techniques, and basic petrography.

All sherds were photographed and examined under low-powered microscopy to characterise diversity in sherd temper. Seven sherds representing the observed diversity were selected for compositional analysis. These sherds were made into thick sections and carbon-coated for analysis. Compositional analysis included both temper (non-plastic inclusions) and ceramic matrix analyses, undertaken using a Hitachi TM3030 Scanning Electron Microscope with a Bruker QUANTAX 70 Energy Dispersive X-Ray Spectrometer (SEM-EDS) (Froh, 2004; Vilgalys and Summerhayes, 2016). Calibration of the beam to a copper standard was conducted at the beginning and end of each analysis session, and geological standards were analysed as further standards (Anorthite NMNH-137041, Hornblende NMNH-143965, Ilmenite NMNH-96189, Rhyolite glass NMNH-72854). A working distance of 8–8.5 mm optimised the production of high-resolution micrographs, operating on 15 kV Extra High Tension (EHT) accelerating voltage for EDS. Mineral composition data were analysed manually with known standard mineral compositions with the aid of Deer et al. (1992).

Eight samples of beach sands from different contexts around Jiigurru were analysed with the SEM-EDS for comparison with temper used in the sherds (Supplementary Fig. S4).

3.5. Particle size analysis

Particle size analysis (PSA) aids in understanding the processes of site sediment deposition (the presence of wind or water deposition, for example, degree of weathering, and/or influence by people). The technique also assists with an accurate description of the excavated deposit and facilitates comparison with other sediments and/or sites. PSA of the <2.3 mm excavated sediment was carried out to characterise the sediments making up the deposit. The analysis employed laser diffraction using a Malvern Mastersizer 2000 with Hydro MU attachment housed at the Fenner School of Environment and Society, Australian National University. Pre-treatment of 2.5 cc subsamples included 10% HCl to remove carbonates, 30% H_2O_2 to remove organic matter, the addition of Calgon to disperse aggregates, and an additional 30 s of ultrasonic dispersal directly prior to measurement (Blott and Pye, 2012; Bowman and Hutka, 2002; Switzer and Pile, 2015).

3.6. Charcoal and pollen analysis

Charcoal analysis is used to reconstruct long-term variations in fire occurrence, applied in conjunction with the sedimentology and archaeology to examine the linkages between burning and anthropogenic activities. Studies of charcoal deposition following modern fires, as well as theoretical models of particle transport, suggest that macroscopic particles (>125 μm) are less able to be carried aloft, transported only short distances from a fire source before settling, to provide a local fire reconstruction (Whitlock and Larsen, 2002). A 1.25 cc subsample of the <2.3 mm excavated materials from every excavation unit was bleached and sieved at 125 μm and 250 μm. The total quantity of charred particles was ascertained in each size fraction by counting under a stereo microscope.

Pollen analysis involved thoroughly homogenising samples before taking 10 cc subsamples which were dispersed in Calgon and sieved through 125 μm screen mesh. Processing then followed standard HCl, KOH and acetolysis methods (Faegri and Iversen, 1989) and included addition of *Lycopodium* marker grains to calculate concentrations of pollen (Stockmarr, 1971). Lithium polytungstate was used at a specific gravity of 2.0 to further concentrate pollen in the samples (Caffrey and Horn, 2013). All samples were mounted in glycerol and examined at × 400 using a Zeiss Axiophot compound light microscope. Analysis aimed to count c.300 pollen grains per slide to represent variability.

3.7. Magnetic susceptibility

Magnetic susceptibility measures how easily a material can be magnetised in the presence of a magnetic field (Thompson and Oldfield, 1986). It effectively detects magnetic minerals present in soils and sediments, the presence of which can be due to both cultural and natural processes such as fires, pedogenesis or chemical weathering (Dalan and

Banerjee, 1998; Ellwood et al., 1997; Herries and Fisher, 2010; Linford et al., 2005). Samples ($n = 167$) from the <2.3 mm sediment samples of every XU of Square A were packed in non-magnetic Althor P-15 boxes (5.28 cc volume). Magnetic susceptibility measurements were carried out using a Bartington Instruments MS2B sensor, with repeat measurements taken for each sample and averaged. Mass and volume low-field magnetic susceptibility (χ and K) measurements were obtained, as well as dual frequencies (460 and 4600 Hz) for the frequency dependence of susceptibility (χfd). Frequency dependence represents the difference between the measured magnetic susceptibilities at low and high frequency and is expressed either as a relative loss of susceptibility ($\chi fd = \chi 460Hz - \chi 4600Hz$), or a percentage loss of the low frequency value ($\chi fd\% = \chi 460Hz - \chi 4600Hz/\chi 460Hz * 100$) (Dearing et al., 1996; Maher, 1986). The measurement of χfd% shows the contribution of ultrafine or superparamagnetic (SP) grains (>0.03 μm) (Dearing et al., 1996). Increases in χfd% accompanying increases in magnetic susceptibility suggest an increase in the percentage of SP grains, indicative of burned or well-developed soils (Dalan and Banerjee, 1998; Dearing et al., 1996).

3.8. Sequential loss on ignition

Sequential loss on ignition (LOI) was used to estimate the moisture, organic and carbonate content of sediments (e.g. Beaudoin, 2003; Dean, 1974; Heiri et al., 2001; Wang et al., 2011). In compliment to PSA and establishing physical sediment properties, LOI generates a baseline organic and inorganic chemistry profile in the assessment of site stratigraphy. Subsamples of wet sediment (10 g) from the <2.3 mm material were oven dried for 24 h at 105 °C until a constant dry weight was achieved. Organic matter was then oxidised for 4 h at 550 °C to carbon dioxide and ash. Carbon dioxide was evolved from carbonate at 1000 °C for 4 h, leaving oxides (Heiri et al., 2001). The weight loss during the reactions was recorded by weighing the samples before and after heating. The weight loss on ignition was then converted to a percentage value.

4. Results

4.1. Cultural deposits and stratigraphy

South Island Headland Midden is located on South Island within the Jiigurru group (Fig. 4). Excavations revealed a 195 cm thick deposit of cultural materials (e.g. shell, bone, artefacts) resting on sediments without obvious inclusion of cultural materials (Figs. 5, 7–10; Supplementary Figs S2, S9). Sediments are sand and silt dominated, with a very minor clay component (Fig. 10). Sand-to-silt proportions alternate in three broad phases; majority sand is present from 2.5 cm to 74 cm depth, distinguished by a medium to coarse grain size, incorporating a very coarse sand texture between 57 and 72 cm. Coarse granulation is concurrent with a plateau in magnetic susceptibility readings. Greater silt combines with finer sands to a depth of 166 cm. Sands then increase to the base of the profile, maintaining finer texture. Particle size distributions do not appear to have influenced other physical sediment properties (see below). Water content is consistent throughout the profile, with percentage organic remains only pronounced at the surface (the upper 12 cm). All sediments are mildly alkaline. Pollen was not preserved below the surface of the site, which contained grasses, Eucalyptus, Sapindaceae and Terminalia. The cultural deposit is dominated by reef-dwelling mollusc taxa *Rochia nilotica* (Top Shell), *Conomurex luhuanus* (Strawberry Conch), *Tridacna* spp. (Giant Clam), and *Lambis lambis* (Spider Conch). It also contains large quantities of chiton, urchin, fish and turtle bone, and occasional fragments of charcoal, including charred food plant remains (mainly *Pandanus* endocarp [nutshell]), flaked stone, terrestrial fauna bone and shell artefacts, and ceramic

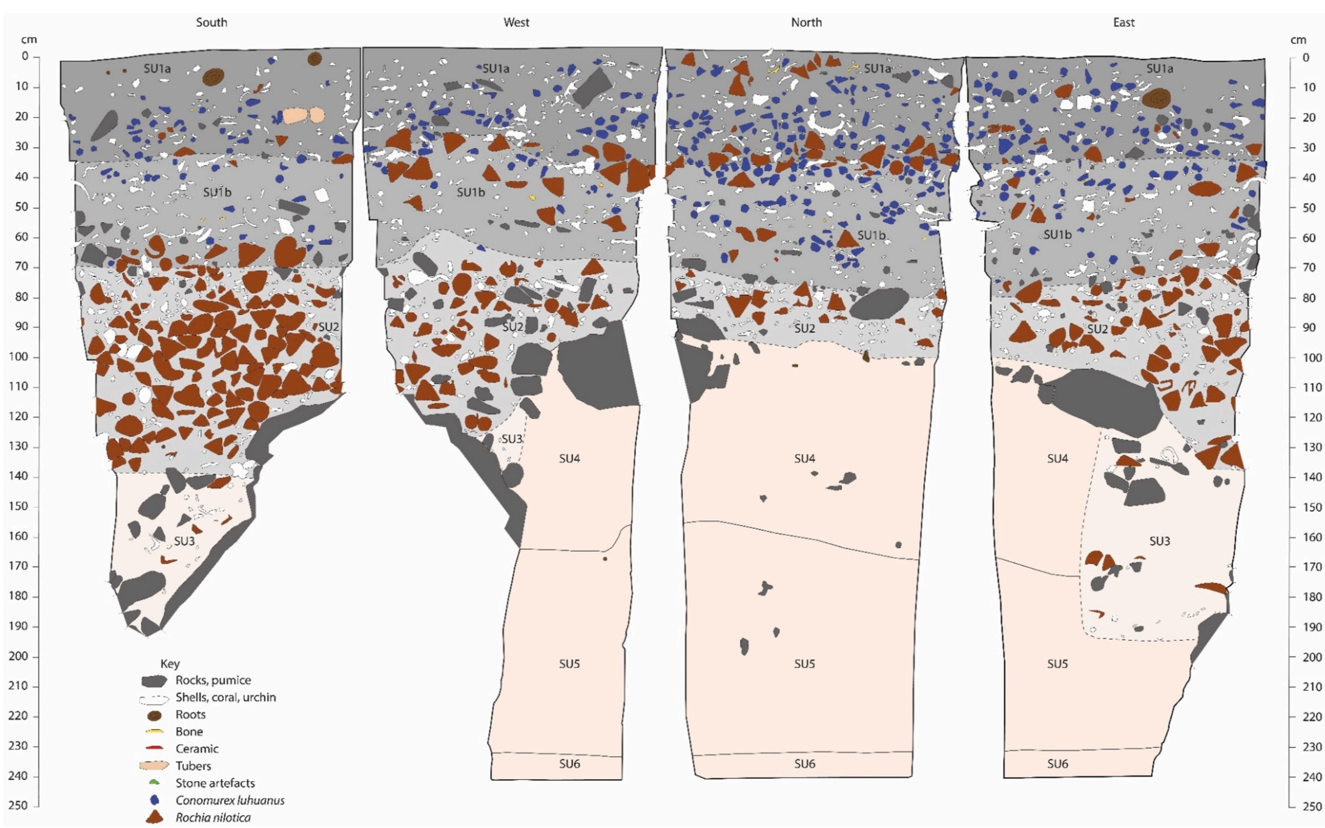

Fig. 7. South Island Headland Midden. Section drawing, showing major stratigraphic units. Note that only a single ceramic sherd is visible (i.e. at the base of SU1b on the North section).

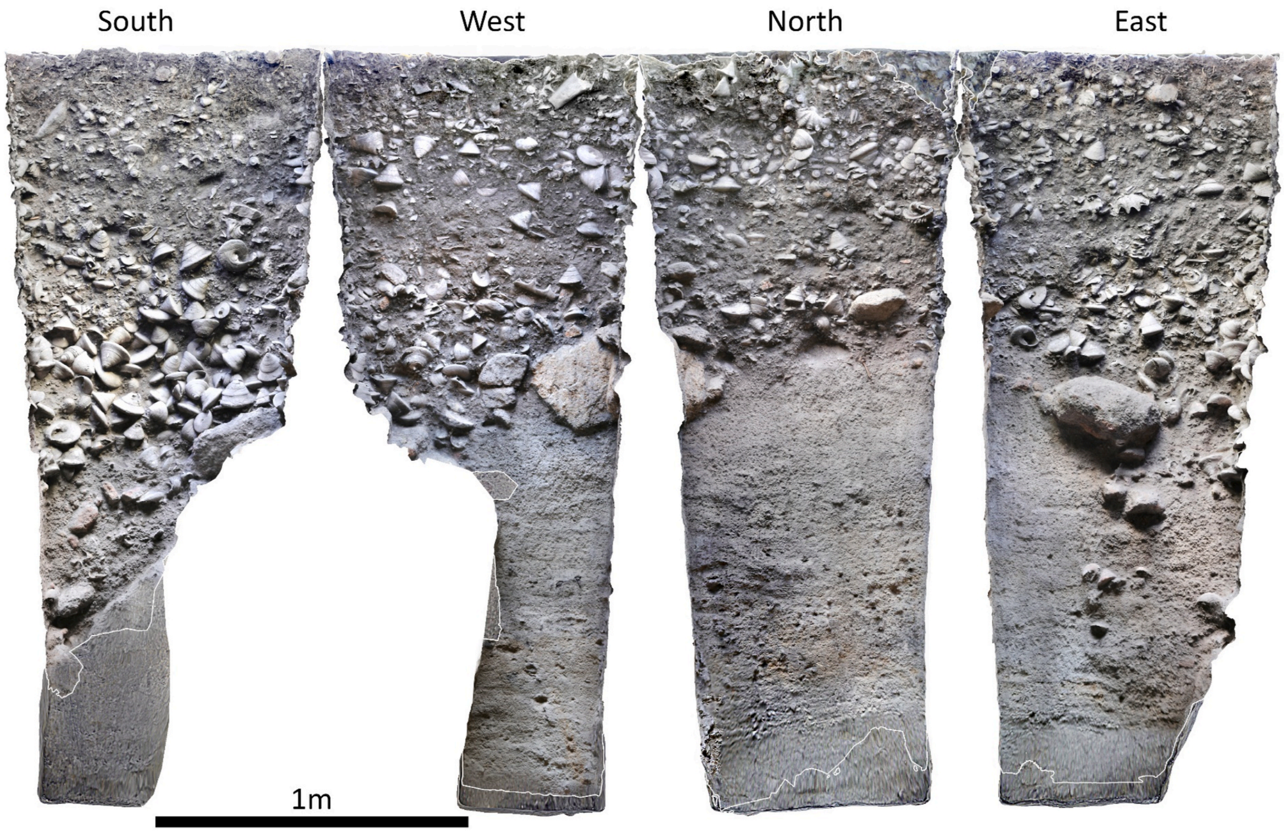

Fig. 8. South Island Headland Midden. Renders of section faces derived from orthographic renders from photogrammetry and reprojections of spherical images from laser scanner (dataset extents delineated by thin white line, with photogrammetry in central part of trench and top and bottom edges which were not fully captured by photogrammetry augmented from laser scans).

sherds. No stylistically diagnostic objects (e.g. decorated pottery, stone axes, shell artefacts, engraved bones) or floral (e.g. banana) or faunal (e. g. pig, chicken) material that can be linked to Melanesian ethnicity have been identified in the assemblage.

The sequence can be divided into six main stratigraphic units (SUs) (Fig. 7). SU1 extends from the surface to a maximum depth of 79 cm, dipping to the northeast. This unit comprises very dark gray (7.5 YR 3/1) sandy sediments and dense shell, including *C. luhuanus*, *R. nilotica* and *Tridacna* spp. Grass and tree roots decrease with depth, with the boundary between SU1a and SU1b demarcating the base of the root zone. SU2 extends down to a maximum depth of 139 cm, dipping to the southeast. Cultural material dominated by *R. nilotica* occurs in a very dark gray (7.5 YR 3/1) to dark gray (7.5 YR 4/1) silty-fine sand matrix, with concretion of sediments towards the base of the unit. SU3 contains the deepest cultural material in the southeast extremity of the square, extending to 195 cm. It appears to fill a void in the original ground surface, with dominant pinkish gray (7.5 YR 6/2) mixed particle sediments. The magnetic susceptibility correlates well to the dense cultural deposit with magnetic enhancement occurring in the upper layers of SU1-SU3. The magnetic susceptibility decreases further down, indicating that dense cultural sediments (shell midden) and burning are likely indicators of this increase (Supplementary Table S9).

SU4, SU5 and SU6 contain no discernible cultural materials. SU4 has a similar elevation to SU3 across the north, northeast and northwest areas of the square. Sediments grade from dark gray (7.5 YR 4/1) to pinkish gray (7.5 YR 7/2). SU5 extends to a maximum of 233 cm, with occasional rock inclusions in sediments grading from pink (7.5 YR 7/3) to very pale brown (10 YR 8/3). SU6 extends from a minimum of 233 cm, blending silt and sands with occasional small rock inclusions in a very pale brown (10 YR 8/3) sandy matrix. The depth of the unit was not determined. The excavation ceased at 243 cm below the ground surface.

Geophysical investigations identified contrasts associated with the depth of the shell deposits and the underlying granite bedrock of the island. These anomalies were particularly notable in the topographically lower areas of the site and where the headland slopes towards the lagoon (Fig. 9). The dielectric properties of the radar energy increased as the radar energy encountered the dense shell deposits and the granite bedrock and were weaker in the sand deposits. The horizon detection function was used to detect subsurface layers based on the changes in radar energy or dielectric properties. Three stratigraphic layers were defined based on the dielectric properties/radar energy. The first was the shell deposit, followed by a sand layer below the shell, and then the granite bedrock (see Supplementary Fig. S8). Note bedrock was not visible in all profiles, mainly on the edge of the headland where granite outcrops the site surface. The maximum depth of the GPR survey reached 2.98 m, with the upper 1.5–2 m characterised by shell midden deposit. The average depth of shell deposits across the site was 1.941 m, and the volume of the estimated shell was 136 m^3. The thickness and location of the shell midden varies, with most concentrated in the northern half of the survey area. The GPR data revealed several circular to oblong high amplitude reflections in the time slices in the mapped lower layers of the area surveyed. Given their size, shape and intensity, these reflections represent natural features, primarily the underlying granite or bedrock of South Island.

4.2. *Ceramic assemblage*

The ceramic assemblage comprises 82 highly fragmented sherds with a combined weight of 202.3 g (Supplementary Table S10; Fig. 11). All sherds were recovered from between 41.7 cm and 81.9 cm below the surface, with 78 recovered between 60 cm and 80 cm. Nineteen sherds were plotted in situ before removal across XUs 35–40. Sixteen of these

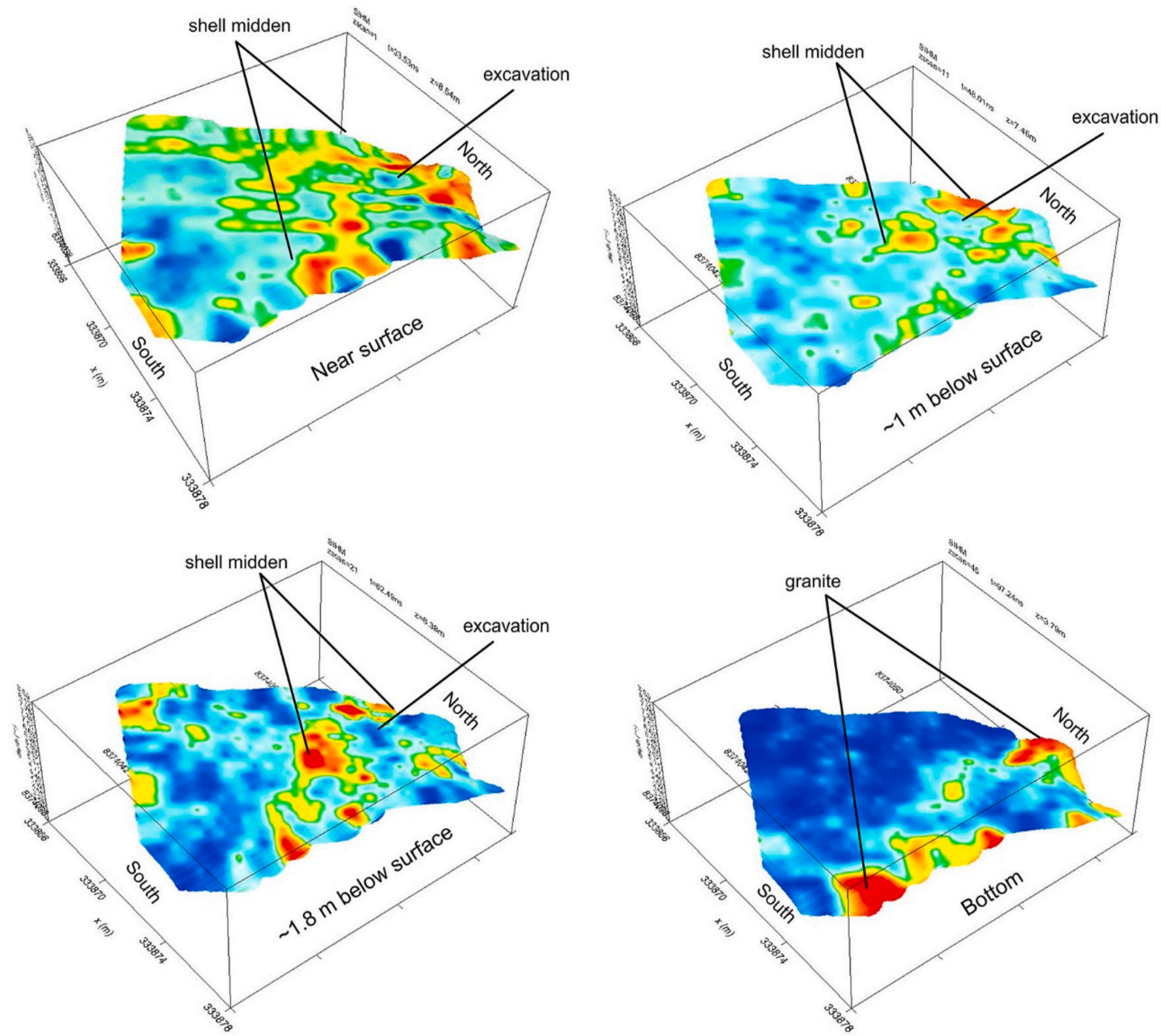

Fig. 9. Ground-penetrating radar results showing 3D images of topographically corrected GPR data showing changes of the subsurface deposits with depth. Higher GPR reflections are shown in yellow and red; weaker reflections are shown in blue. See Fig. 6 for location of the geophysical survey grid.

sherds were oriented flat, or nearly flat, indicating the stratigraphic integrity of the deposit. The sherds are distributed in a dense shell deposit comprising interlocking large reef shellfish species dominated by *R. nilotica*, limiting post-depositional movement within the deposit. The average length of the sherds is 17.7 mm (SD = 9.3) and their thickness averages 5.1 mm (SD = 2.0). Only 18 fragments weigh more than 2 g, 14 pieces weigh 1–2 g, and the remaining 50 pieces weigh less than 1 g. Three refit sets were identified in XU36 (FS95, FS196, FS197, FS198, FS199), XU37 (FS103, FS104) and XU38 (FS108).

One rim, four neck, and one rim and neck sections are present in the assemblage. The sherds are too small to reveal information about vessel form. The two rim sherds (FS106/1, FS112) are flat lipped and incurving with a concave neck section. We estimate the orifice of FS112 is >20 cm, however, given the rim sherd comprises less than 3% of the total rim, this is only an approximation. Both rim sherds display surface decoration, comprising parallel diagonal lines incised on the lip-top.

Red-slip (a common characteristic of Lapita ware) was identified on two sherds (FS87/2, FS93/1; see Fig. 11(b)) and a further sherd (FS93/10) displayed an indeterminate red pigmentation on the exterior surface not attributable to oxidising firing. This may suggest a surface modification with red paint; however, the preservation of the sherd does not allow for definitive confirmation. Approximately 20% of the sherds display surface weathering. The ceramics were likely to have been fired in an oxidising environment at low temperatures. The clay colour is yellowish-brown with a slight reddish hue (10YR 6/6 to 2.5Y 6/1). The interior is slightly more reddish than the exterior.

The assemblage is primarily characterised by a single temper type. Temper mineral compositions contain quartz, calcareous sand, and K-feldspar, alongside the accessory mineral mica (both muscovite and biotite are present), plagioclase (albite and andesine), magnetite, and ilmenite (Table 1). The quartz and K-feldspar are sometimes present as intergrowth. The composition of quartz, K-feldspar, and mica indicate that the geological source rock is granite. The coarse texture of the quartz (≥2 mm coarse) supports this conclusion. The presence of calcareous sand suggests that the temper sands were collected at a beach, probably locally at Jiigurru where calcareous sand is also found (see below). This calcareous sand is made up of coral and shell detritus, with some of the organic structure visible in the electron images (Supplementary Material Figs S3A-G). There is, however, an exception in the assemblage; Sherd FS196 does not contain calcareous sand and has additional unknown accessory minerals, suggesting a different temper type for this sherd. However, the minerals are consistent with a local source and the absence of calcareous inclusions reflects temper variation in local manufacture.

Quartz is the dominant temper type, followed by calcareous sand, feldspar and mica aplastics (see Table 1). All these minerals are readily

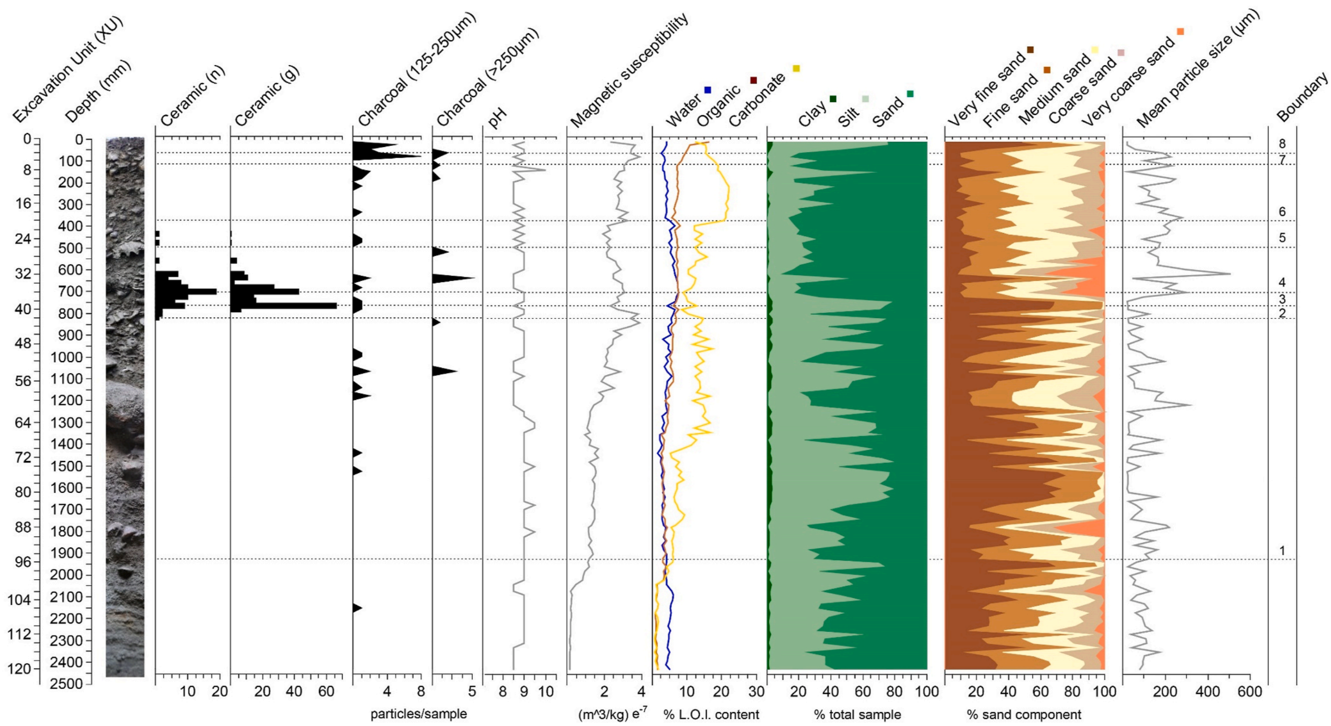

Fig. 10. Deposit characteristics and distribution of ceramics, Series A. See Supplementary Table S8 for raw data. Horizontal dotted-lines represent the approximate chronostratigraphic boundaries defined by the Bayesian modelling.

available in the local environment. Aplastic sizes are fine-to-medium, with a few sherds ($n = 13$) showing substantial amounts (≥40% mass) of relatively large rounded quartz grains. Overall, temper showed significant rounding (aplastic rounding index = 0.3) indicating that temper sources derive from coastal contexts. The presence of calcareous inclusions in the pottery supports this inference.

The sherds contain a high proportion of temper (≥40%). The roundness of the temper grains suggests beach sand was added to the clay rather than the inclusions being natural to the clay itself. The quantity of temper used is greater than that used in Papua New Guinea south coast assemblages, although the quantities used are not unusual in low-fired ceramics. Manufacture could have been the result of paddle and anvil or coil manufacturing. There are no coiling fractures to confirm coil methods were used although the opportunities for identifying a coiling fracture in a small highly fragmented assemblage are limited. Two sherds have possible paddle impressions (FS84/4, FS100/6) and two sherds have dimple impressions (FS113, FS73/1), however, both manufacturing methods involve the use of paddles.

The clay texture of all samples was analysed under x2000 magnification. The findings show similarity across samples, with each containing tiny clay minerals of mica (fibrous minerals, see Supplementary Figs S3H-J). Calcium oxide (CaO) is around 3% weight in all samples. The only different clay texture is that of FS196 in which clay mineral-sized mica is not as abundant (Table 2). The compositional analysis indicates the clay sources were collected from a geologically similar setting area to the tempers, again, parsimony pointing to Jiigurru.

Based on the chemical composition derived from the geochemical analysis, the ceramics fall into three groups with up to three different clay sources likely to have been used to produce the pottery (Table 3).

Analysis of eight representative samples of beach sands from around Jiigurru provides comparative data to the temper analysis. Quartz is found in all samples, with calcareous inclusions found in all but two samples. K-Feldspar (orthoclase) is found in three samples, while K-Feldspar (microcline) is found in one. Plagioclase Feldspar (andesine) is also found in one sample (Table 4, Supplementary Figs S3K-R). In sample 60 it is easily seen that quartz is embedded into the K-Feldspar. Such intergrowths were also identified in the ceramic samples as well as in local geological reports (Bultitude and Champion, 1992:24, 25). Minerals identified in the sands by Bultitude and Champion (1992:28) include zircon, ilmenite, apatite, mica (muscovite and biotite), and tourmaline. No mica or apatite was identified in the beach sands, however, they are documented on Jiigurru and both mica and ilmenite are found in the pottery.

These sands, like those identified in the pottery, originate from a granitic base. Jiigurru granite is a subvolcanic intrusion (Bultitude and Champion, 1992:12). While a low number of small outcrops of granite with mineralogy similar to Jiigurru occur on the eastern mainland coast of Cape York Peninsula at least 90 km from Jiigurru (Bain and Draper, 1997; Bultitude, 1993; Lucas and Keyser, 1965), the combination of temper and clay analyses and similarity to both local beach sands and geology support the conclusion that people collected local beach sand and clay sources to make pottery.

4.3. Chronology

Occupation of the site commenced at 6510–5790 cal BP with rapid deposition of c.108 cm of cultural deposit within c.800 years (Fig. 12, S1, Table 5, S2). After a period of low accumulation between 6360 and 5600 cal BP and 5745–4930 cal BP, another rapid cultural deposition event is centred on c.5000 cal BP. The land surface dating to 4950–4485 cal BP was then exposed for c.2000 years with little or no cultural deposition before a dramatic change in site use commenced at c.2950–2545 cal BP, marking the beginning of a c.1500 year-long more-or-less continuous period of occupation. Significant time-averaging of deposits is evident between 76.4 cm (Wk-46554, XU40) and 82 cm (Wk-48805, XU42). Radiocarbon ages on marine shell in this zone of the deposit exhibit a left-skewed distribution indicating strong representation of older shells relative to younger shell ages at these depths. This pattern clearly indicates mixing of younger shells and older shells, most likely explained by the incorporation of younger shell into an older deposit, for example by trampling (Sanchez et al., 2022). Ceramic deposition occurred onto this older surface, commencing 2950–2545 cal

Fig. 11. Ceramic sherd selection. (a) Body sherd (FS100/6, XU37); (b) body sherd with red-slip on margin (FS93/1, XU36); (c) rim sherd with lip-top decoration (FS112, XU39); (d) rim sherd with lip-top decoration (FS106/1, XU38); (e) body sherd (FS118, XU40); (f) body sherd (FS93/10, XU36); (g) body sherd (FS97, XU36) (Photographs: Steve Morton).

BP and terminating 1970–1815 cal BP. This ceramic horizon therefore had a maximum longevity of 630–1085 years. Trampling, as a frictional force exerted on the site surface (Micó et al., 2024), is further evident in the shift in sediment particle size distribution, notably the displacement of finer size particles. Very coarse sands distinguish the onset of change in site use, retained with ceramic deposition onto this older surface. The surface and near-surface deposits dating to the past few centuries. No artefacts manufactured from European materials (e.g. glass) were found on the site.

The result of the *rbacon* age-depth modelling is shown in Supplementary Fig. S1 and Table S7. The posteriors of the accumulation rate and memory effect are in good agreement with their priors (see Supplementary Fig. S1, middle and right diagrams in top panel, respectively). This, together with a stationary distribution for Markov Chain Monte Carlo (MCMC) iterations with little structure among neighbouring iterations (Supplementary Fig. S1, left diagram in top panel), indicates that the age-depth model is reasonable. The age-depth model indicates the sequence covers the past c.7000 years with a hiatus at

Table 1
Mineral composition and geochemistry of selected ceramics from the South Island Headland Midden (unit: %).

Field Specimen #	83/3	91	196	108	110/1	113	115
Object #	na	1	6	1	na	2	4
XU	32	35	36	38	39	39	39
Temper Type	Ca + Qtz + Kfs	Ca + Qtz + Kfs	Qtz + Kfs	Ca + Qtz + Kfs	Ca + Qtz + Kfs	Ca + Qtz + Kfs	Ca + Qtz + Kfs
Grain Size	very fine to very coarse	very fine to very coarse	very fine to very coarse	very fine to very coarse	very fine to very coarse	very fine to very coarse	very fine to very coarse
Grain Shape	subangular to rounded	subangular to rounded	subangular to rounded	subangular to rounded	subangular to rounded	subangular to rounded	subangular to rounded
Calcareous	11.58	59.20		31.28	5.52	7.37	14.14
Quartz	54.88	35.63	75.59	60.00	68.51	85.79	81.15
K-feldspar	22.56	4.02	9.45	6.66	14.92	6.32	3.14
Plagioclase (total)		0.57			4.42		
Albite		0.57					
Andesine					4.42		
Mica (total)	10.98	0.57	0.80		6.63	0.53	1.57
Muscovite	10.37	Accessory	0.80		6.63	0.53	0.52
Biotite	0.61	0.57					1.05
Magnetite				1.03			
Ilmenite				1.03			
Clay Minerals			9.45				
Rusty Clay?			4.72				

Table 2
Clay geochemistry of selected ceramics from the South Island Headland Midden (unit: weight %).

Spectrum	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	FeO	Clay Source	Temper Type
FS91	0.38	1.72	39.06	45.10	2.12	2.75	1.55	7.65	1	Ca + Qtz + Kfs
FS108		1.51	41.35	43.96	0.96	3.67	1.43	8.72	1	Ca + Qtz + Kfs
FS113	0.37	1.20	41.06	46.17	0.68	4.00	1.87	5.66	1	Ca + Qtz + Kfs
FS115		1.36	40.46	47.26	1.16	2.50	1.87	6.49	1	Ca + Qtz + Kfs
FS110/1	1.08	2.11	33.87	47.72	1.73	2.72	1.60	10.11	2	Ca + Qtz + Kfs
FS196	0.20	2.42	32.30	50.27	1.86	2.58	1.05	9.48	2	Qtz + Kfs
FS83/3	0.80	0.74	46.66	44.59	1.14	3.04		4.29	3	Ca + Qtz + Kfs

Table 3
Clay source groups, based on the chemical composition derived from the geochemical analysis.

Group	Description
Clay Source 1	Comprises sherds FS91, FS108, FS113, and FS115, contains 0.4 wt % of Na_2O, 1.5 wt % of MgO, 40 wt % of Al_2O_3, 45 wt % of SiO_2, and 6–8 wt % of FeO.
Clay Source 2	Comprises sherds FS110/1 and FS196, contains 2 wt % of MgO, 33 wt % of Al_2O_3, 50 wt % of SiO_2, and 10 wt % of FeO. The weight % of Na_2O is quite different in these two sherds which might further distinguish the clay source of these two sherds.
Clay Source 3	Comprises sherd FS83/3, contains 0.8 wt % of Na_2O, 1 wt % of MgO, 46 wt % of Al_2O_3, 44 wt % of SiO_2, and 4 wt % of FeO. Of note is that TiO_2 is absent.

c.70–73 cm. Although the *rbacon* age-depth and OxCal phase models did not show the same modelled age for each radiocarbon date, they were similar. Both analyses demonstrate a robust chronological sequence for the site.

5. Discussion

5.1. Ceramic manufacture and use at Jiigurru

We interpret our results as demonstrating that Aboriginal people manufactured pottery on Jiigurru between 2950–2545 cal BP and 1970–1815 cal BP. The archaeological evidence does not point to outsiders bringing exotic pottery or pottery technology directly to Jiigurru, nor does genetic evidence suggest any sustained direct contact with peoples from pottery manufacturing locales to the north (Wasef et al., 2021). Nevertheless, there is evidence for the movement of people and ideas throughout the Coral Sea region during late Lapita and post-Lapita times. A Lapita seafaring expansion along the south coast of Papua New Guinea after 2900 cal BP has been confirmed with finds at Caution Bay near Port Moresby, Galley Reach c.25 km farther to the west, and the Vailala River region c.240 km farther again to the west (see David et al., 2011, 2012; McNiven et al., 2011, 2012a; Sand et al., 2022; Skelly et al., 2014). Pieces of pottery dating to the late Lapita period also reached the islet of Pulu off Mabuyag in Torres Strait suggesting widespread

Table 4
Composition of beach sands from Jiigurru analysed using the scanning electron microprobe. Locations of samples shown in Supplementary Fig. S4.

Sample	Quartz	Zircon	Calcium Carbonate	K-Feld Orthoclase	K-Feld (Microcline)	Plag Feld (Andesine)
O	x	x				
3	x		x			
4	x		x	x		
5	x		x			x
6	x		x	x		
14	x		x			
51	x		x	x		
60	x				x	

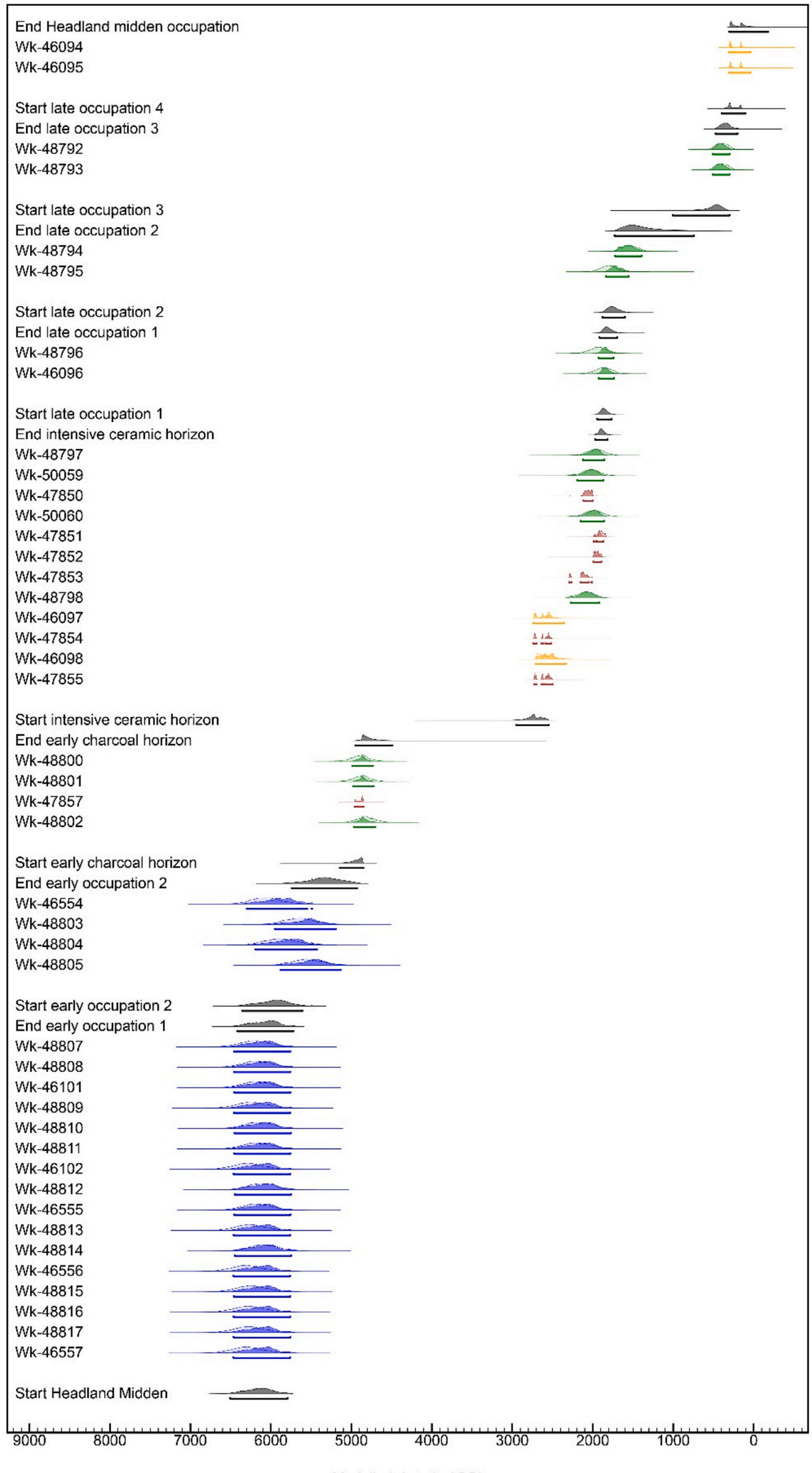

Fig. 12. *Highest Probability Distributions* of the South Island Headland Midden sequence using OxCal (v.4.4) (Bronk Ramsey, 2009a). Brown HPDs are identified charcoal samples (Polydrupe *Pandanus* endocarp). Orange HPDs are unidentified charcoal samples. Blue and green HPDs are marine shell samples with $\Delta R = -38 \pm 158$ years and -197 ± 56 years, respectively. Gray HPDs represent boundaries, which are listed in Table 5. OxCal code is provided in Supplementary Table S6.

seafaring connections emanating from the Lapita expansion (McNiven et al., 2006; see also David et al., 2011; Shaw et al., 2022). Widespread seafaring connections continued after the Lapita period as illustrated by obsidian reaching the Gulf of Papua from west Fergusson Island 900 km northeast by sea between 2300 and 1900 cal BP (Skelly et al., 2014, 2016). Genetic studies point to movement of Papuan people into Remote Oceania c.2700–2200 cal BP (Lipson et al., 2018; Posth et al., 2018), which is perhaps indicative of broader inter-regional movements throughout the Coral Sea region. We argue that the similar chronology for the Jiigurru ceramics suggests that the movement of peoples and

Table 5
Highest Probability Distributions of events at the South Island Headland Midden using OxCal (v.4.4) (Bronk Ramsey, 2009a). Dark gray shaded areas represent the duration of events in years. CI = confidence interval.

Boundary	Description	Material Dated	Outliers	Age (cal BP)		Age (cal BP)	
				68.3% CI Age Range (cal BP)	68.3% CI Age Range (cal BP)	95.4% CI Age Range (cal BP)	95.4% CI Age Range (cal BP)
Start early occupation 1	Early occupation. Abundant marine shell dominated by *Rochia nilotica*. No ceramics.	Marine shell	Wk-49180	6320	5955	6510	5790
End early occupation 1				6295	5885	6420	5715
Start early occupation 2	Abundant marine shell dominated by *Rochia nilotica*. Few ceramic sherds ($n = 5$) likely derived from higher in sequence.	Marine shell	Wk-47859	6155	5755	6360	5600
End early occupation 2				5515	5095	5745	4930
Start early charcoal horizon	Abundant marine shell dominated by *Rochia nilotica*. Occasional ceramic sherds likely derived from higher in sequence. Earliest secure sample of charcoal is dated to 4332 ± 17 BP (Wk-47857)	Marine shell and charcoal	Wk-47858, Wk-47856	4970	4855	5145	4845
End early charcoal horizon				4875	4725	4950	4485
Duration early charcoal horizon – intensive ceramic horizon in years				1940	2220	1655	2315
Start intensive ceramic horizon	Abundant marine shell. 73 pieces of ceramics and abundant charcoal.	Marine shell and charcoal	Wk-48799, Wk-50062, Wk-50061	2815	2620	2950	2545
Duration intensive ceramic horizon in years				715	935	630	1085
End intensive ceramic horizon	Abundant marine shell. Occasional ceramic sherds.			1930	1855	1970	1815
Start late occupation 1	Abundant marine shell. Few ceramic sherds.	Marine shell		1910	1820	1945	1760
Duration late occupation 1				0	60	0	135
End late occupation 1				1880	1770	1920	1695
Start late occupation 2	Abundant marine shell. No ceramic sherds.	Marine shell		1835	1690	1880	1595
End late occupation 2				1675	1275	1730	740
Duration late occupation 2 – late occupation 3 in years				665	1205	145	1275
Start late occupation 3	Abundant marine shell. No ceramic sherds.	Marine shell		575	355	1005	300
End late occupation 3				425	295	475	200
Start late occupation 4	Abundant marine shell. No ceramic sherds.	Charcoal		340	150	400	100
End occupation	Abundant marine shell. No ceramic sherds.			300	80	305	−185

ideas across the Coral Sea incorporated Jiigurru. Although the small Jiigurru ceramic assemblage recovered to date does not exhibit any of the classic characteristics of Lapita – dentate-stamped designs – the chronology of the assemblage, dating between 2950–2545 cal BP and 1970–1815 cal BP, overlaps with late Lapita (2900 and 2600–2550 cal BP) and post-Lapita occupation across southern Papua New Guinea (David et al., 2011, 2013, 2019, 2022; McNiven et al., 2011, 2012a, 2012b; Shaw et al., 2022; Skelly et al., 2014). Furthermore, Lapita ceramic assemblages across the western Pacific are diverse and do not simply comprise dentate-stamped sherds. In fact, Lapita assemblages are dominated by plain undecorated sherds and Summerhayes (2019) notes that dentate-stamping decreases in complexity and ceases to be used altogether in the late Lapita period. At Caution Bay, only 10 of the 295 sherds (3.4%) from the Lapita assemblage of Tanamu 1, dating to 2800–2750 cal BP, exhibit comb dentate stamping (David et al., 2022), while none of the nearly 9000 sherds from the late Lapita to immediate post-Lapita levels of Moiapu 3 dating to 2630–2410 cal BP is comb dentate-stamped (David et al., 2013). Whether late Lapita and post-Lapita in age, or singularly post-Lapita in age, the Jiigurru pottery is, nevertheless, clearly associated with Lapita cultural influences diffusing down the Queensland coast through exchange networks, with both continuity in ceramic technology (low-fired earthenware) and characteristic manufacture from local materials. The local manufacture of Jiigurru ceramics is consistent with findings in the western Pacific, where petrographic analyses of Lapita pottery have confirmed that long-distance transfer of vessels was rare and that pots were usually made with local raw materials (Dickinson, 2006).

The Jiigurru sherds are from thin-walled vessels. Thin-walled vessels require less clay in manufacture than their thick-walled counterparts, and are lighter to transport, although maximum vessel size is limited because walls need to be thicker to make larger pots. Rice (1987) notes that thin-walled vessels heat and cool more evenly and are therefore resistant to thermal shock and are less likely to crack during manufacture and use. Rice (1987) also notes that cooking with thin-walled vessels requires less fuel than thicker pots. As no carinated sherds are present in the Jiigurru assemblage, the thin-walled sherds could indicate that the vessel form/s are plain globular pots (with either everted rim or outcurving rim), which usually thicken at the rim/neck/shoulder and gradually thin toward the base. However, as the sample size is quite small and the pieces highly fragmented, this would need further investigation to confirm. The low number of sherds suggests that not many pots were ever made. As pots made for cooking tend to be numerous at sites and result in thousands of sherds, it would suggest that the pots were not part of everyday cooking but had more restricted use. Whether that restricted use was related to cooking and/or use for other materials can be tested through future residue studies.

The context of the ceramics at Jiigurru is different from that at Caution Bay and elsewhere in the Pacific where pottery appears stratigraphically as a disjunction with previous occupation (e.g. accompanying distinctive Lapita ceramics across the western Pacific are domesticates like dog, pig, and chicken and unique shell technologies). Conversely, at Jiigurru, pottery is deposited as one of many events in a long-term occupation sequence that commenced >3000 years before the appearance of pottery, and which continued after the end of the pottery-making period up to the present, with a continuity of marine-focussed exploitation throughout.

5.2. Earliest offshore island occupation on the Great Barrier Reef

The maximum age for occupation of Jiigurru at c.6500 years ago makes the South Island Headland Midden the oldest offshore island site on the northern Great Barrier Reef and one of only a few sites with significant deposits dating prior to 4000 years ago. The earliest dates for Aboriginal occupation of the Great Barrier Reef are at Nara Inlet 1 (a non-basal age of 8150 ± 80 BP, 9398–8656 cal BP, Beta-27835, charcoal, SHCal20) and Border Island 1 (6440 ± 90 BP, 7165–6315 cal BP, Beta-56976, marine shell) in the Whitsunday Island Group (Barker, 2004) and Yindayin Rockshelter (5881 ± 31 BP, 6500–5740 cal BP, ANU-55324, marine shell) on Stanley Island at Princess Charlotte Bay (Wright et al., 2023). Nara Inlet 1 was not an island at the time of first occupation and was connected to the mainland by land bridges before sea-level rise caused insulation. Sea-level reconstruction shows that Jiigurru became an island with rising post-glacial sea-levels around 10, 000 years ago and by 6500 years ago was c.30 km offshore (Fig. 2 and Supplementary Fig. S6). The presence of people on Jiigurru c.6500 years ago demonstrates that Aboriginal watercraft voyaging technology and open-sea navigational skills were sophisticated at this time, with a minimum water crossing of 14 km of island-hopping required to reach Jiigurru. As in the ethnographic past, Jiigurru may have been too small to accommodate permanent settlement by a resident community and was most likely occupied seasonally by coastal peoples with territory extending across the islands, reefs and adjacent mainland. Archaeological evidence of use of marine resources on Jiigurru (North Queensland) and Border Island (Central Queensland) dating to 6500–6000 years ago indicates that the entire Great Barrier Reef was within voyaging reach of Aboriginal peoples over the past 6500 years and possibly since formation of the reef in the Early Holocene. The findings provide further support for continuous use of Sea Country across the transgression, with people continuously adjusting their relationships with Country as landscapes and seascapes changed (McNiven, 1991; Ulm, 2011).

Cultural deposition at the site c.4950–4485 cal BP co-occurs with changes in island environments. Palaeoecological data from Jiigurru demonstrate increasingly open vegetation communities incorporating high frequencies of landscape burning, including diversity in fire type (Lambrides et al., 2020; Proske and Haberle, 2012; see also charcoal accumulation, Fig. 10). Enhanced site use and ongoing occupation from c.2950–2545 cal BP coincides with further shifts in the spatial extent of the island's vegetation communities, and the species present within them. Plant disturbance indicators (e.g. Cyclosorus ferns, woody Acacia species) become abundant within the past 3000 years, forest understorey taxa decline, and rainforest-swamp vegetation contracts (Lentfer et al., 2013; Proske and Haberle, 2012).

5.3. Coral Sea Cultural Interaction Sphere

Historical and ethnographic records concur that prior to European settlement of Australia in the late eighteenth century, neither Aboriginal peoples nor Torres Strait Islanders made or used pottery. In terms of northeast Australia, the closest ethnographically known pottery-making and pottery-using communities are located along the Gulf of Papua on the south coast of Papua New Guinea. Pottery manufacture is unknown ethnographically for Indigenous communities along the south coast of West Papua (Indonesia) (Pétrequin and Pétrequin, 2020). Archaeological evidence for pottery manufacture and use in Torres Strait between 2600 and 700 cal BP and Jiigurru within the period 2950–1815 cal BP indicates that Indigenous peoples of northeast Australia had ceramic traditions in the pre-ethnographic past. The striking overlap in the dates for ceramics in Torres Strait, Jiigurru, and the south coast of Papua New Guinea suggests that pottery traditions in all three regions are related and have ancestral links back to the earliest Lapita ceramics in the Bismarck Archipelago of northeastern Papua New Guinea 3300–3000 years ago. Such chronological overlaps coupled with the shared tradition of hand-made, low-fired earthenware supports the view that the Jiigurru pottery was not an isolated, independent development but part of a broader inter-regional tradition of cultural sharing and exchange.

Direct links between Jiigurru and the south coast of Papua New Guinea and further afield between 3000 and 2000 years ago are plausible given sailing modelling (Dousset and Di Piazza, 2021). That is, multidirectional multiday voyaging across the Coral Sea was not only feasible, but well within the technological and navigational capabilities of Pacific seafarers 3000 years ago. Furthermore, historical (textual and pictorial) records indicate voyaging by Torres Strait Islanders (a Melanesian people) for hundreds of kilometres down the east coast of Cape York Peninsula, with oral histories extending voyaging ranges 600 km south to Jiigurru (McNiven, 2015; McNiven and Russell-Cook, 2020). Curiously, historical evidence of these southern sojourns is not reflected genetically; that is, preliminary genetic analysis of Cape York Peninsula Aboriginal peoples reveals no recent Papuan admixture (Wasef et al., 2021). Although Cape York Aboriginal peoples do reveal genetic influences from New Guinea expressed in morphology (e.g. Brace, 1980; Macintosh and Larnach, 1973), such influences are thought to reflect earlier gene flow during periods of lower sea levels when the Australian and New Guinea landmasses were joined (Wasef et al., 2021; Wright et al., 2018; cf. McNiven, 2021).

Prior to the Jiigurru ceramic finds, the southern-most known pottery traditions occurred in Torres Strait. Ceramic sherds excavated archaeologically in the Meriam Islands of eastern Torres Strait recalibrated to 2200–1700 years ago (Supplementary Table S11) and sourced to the nearest pottery-making communities of the south coast of Papua New Guinea over 200 km to the north, represent the only direct archaeological evidence for ceramic trade between communities in Australia and New Guinea. In contrast, McNiven et al. (2006) argue that locally made pottery at Mask Cave in western Torres Strait dating to 2600 years ago may represent an influx of Papuan peoples, or at the very least a transfer of pottery making skills (Wright and Dickinson, 2009).

Our research suggests that Aboriginal peoples of Jiigurru shared in the Lapita-inspired tradition of pottery making and use through chains of information flow and exchange that extended for hundreds of kilometres between coastal communities along the east coast of Cape York Peninsula, into Torres Strait, and farther north to the south coast of Papua New Guinea (see also Shaw et al., 2022). It is likely that such knowledge sharing and movement occurred between coastal groups and was enhanced by both terrestrial and maritime exchange networks.

The findings presented here are consistent with the operation of a large-scale Coral Sea Cultural Interaction Sphere over the past 3000 years, characterised by long-distance maritime exchange networks with multidirectional interactions, complex alliance systems, and the selective movement of objects and ideas (McNiven, 2021, Fig. 3). In addition to a shared tradition of pottery manufacture and use, a preliminary study of the stylistic characteristics of Jiigurru stone arrangements attributed most to Aboriginal authorship, but noted that some arrangements exhibited cultural affinities with areas across the Coral Sea, including Papua New Guinea and Solomon Islands (Fitzpatrick et al., 2018).

The presence of pottery on Jiigurru more than 2500 years ago points to the likelihood of finding more pottery, perhaps including Lapita, on the vast and archaeologically unknown northeast Queensland coastline. Why ceramics ceased to be a part of these long-distance Coral Sea social networks along the mainland Queensland coast and not the southern Papua New Guinea coast over the past 2000 years is a question for future research.

6. Conclusion

The pottery sherds at Jiigurru and the antiquity of offshore island occupation demonstrated in this study open a new chapter in Australian, Melanesian, and Pacific archaeology and point to a deep history of cultural interaction across the Coral Sea. In some ways, pottery finds of the past 20 years dating to between 3000 and 2000 years ago on the south coast of Papua New Guinea, Torres Strait, and Jiigurru, echo the implications of the emerging discovery and understanding of the Lapita cultural complex across Island Melanesia in the 1950s and 1960s. That is, founding populations of many nation states of Remote Oceania in the southwest Pacific (e.g. Vanuatu, New Caledonia, Fiji, Samoa, Tonga) were bearers of Lapita pottery, a tradition which developed in Near Oceania in eastern Papua New Guinea before it began spreading eastwards. Golson (1961:176) referred to Lapita linkages across Remote Oceania as a 'community of culture', an archaeologically constructed connection that resonated, and continues to resonate across all Lapita nations in Near and Remote Oceania, both culturally and politically, down to the present (see also Bedford et al., 2010:44; cf. Terrell, 2014). The Jiigurru pottery finds now extend the shared historical bonds of the legacies of Lapita culture to embrace Aboriginal Australia as part of a community of cultures across the Coral Sea.

Ongoing analyses of the large cultural assemblage from the South Island Headland Midden will provide opportunities to investigate whether occupation and resource use changed with ceramic manufacture and use. The findings challenge racist and colonialist stereotypes of Aboriginal communities as lacking complexity and innovation and contribute to a robust and nuanced understanding of the deep knowledges and complex technologies of Indigenous Australians. Most importantly, the Jiigurru pottery evidence reveals the capacity of archaeology to shed profound new insights into Australia's history and the international reach of First Nations communities over thousands of years prior to the commencement of British invasion in 1788.

Author contributions

S.U. and I.J.M. developed the collaboration framework for the research with Traditional Owners, obtained funding, designed the study, directed the excavations and laboratory and specialist analyses, and wrote the first draft with specialist contributions from other authors. S. U., I.J.M., A.B.J.L., K.M.L., C.H.R., C.M., M.H., M.P., B.C. and C.L. undertook excavations and field data collection. G.R.S. and P.W. conducted ceramic compositional analyses. R.S. and C.H.R. analysed the ceramic assemblage. F.P. and Q.H. performed the AMS ^{14}C dating. J-x.Z. and L.D. N. performed the U/Th dating of corals. Q.H. and S.U. undertook ΔR calculations. M.M.E.B., Q.H. and F.P. undertook Bayesian modelling. A. B.J.L. supervised laboratory sorting and analysed fish bones. C.H.R. undertook site mapping. C.M., S.B.M., K.L.T-K., S.A.S., M.C.K., K.G.P.W., K.S., A.B.J.L. and S.U. analysed excavated assemblages. I.J.M. and J.D.C. analysed stone artefacts. R.B. and M.I.B. conducted and advised on geological investigations. A.F. undertook archaeobotanical identifications. M.C.M. undertook terrestrial faunal identifications. R.S. analysed ceramic chronologies of sites in the region and made the map in Fig. 1 (bottom). M.H. made the maps in Fig. 1 (top) and Figs. 3 and 4. I.J.M., S. U. and J.A. created the section drawing in Fig. 7. K.M.L. undertook geophysical studies of the site. C.R., S.G.H., F.H. and J.X.L. performed sediment analyses. S.E.L. and R.J.B. modelled sea-level changes. M.P., B. C., C.L., S.J. and J.M. undertook terrestrial laser scanning, photogrammetry and visualisation. M.W.F. provided specialist information and unpublished materials on previous archaeological investigations on Jiigurru. Walmbaar Aboriginal Corporation RNTBC and B.C. provided approvals to undertake the research. Walmbaar Aboriginal Corporation RNTBC participated in the excavation and provided funding. All authors provided comments and revisions.

Code availability

The OxCal code used to generate the Bayesian age model for the site is provided in full in the Supplementary Data, together with information about the program and version used.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All primary data relevant to the interpretations discussed in the manuscript are detailed in the supplied Supplementary Data.

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Appendix A. Supplementary data

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