

Socioeconomic roles of Holocene marine shell beads reveal the daily life of composite objects from East Kalimantan, Borneo

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ABSTRACT

Cultural objects composed of composite materials with differing physical properties are often differentially preserved in archaeological records favouring those materials less susceptible to taphonomic processes. Using microscopically observed wear patterns to decipher a model of socioeconomic roles for composite beaded objects, this study examines the rich marine shell bead assemblage excavated from Liang Jon in East Kalimantan, Borneo. Assessment of this 16,700-year sequence provides a unique context for discussing collection, transport, manufacture, and use of marine shell beads; spanning the biogeographical change associated with sea level rise 11,700 years ago creating the island of Borneo. Quantifying differences in bead wear patterning and distribution has revealed changes across 11,000 years of human occupation—detail seldom exposed in Island South East Asian archaeology. Results demonstrate marine species belonging to the families Nassariidae and Cypraeidae were targeted for the manufacture of beads. Whole shells and removed dorsa indicate some onsite manufacture occurred, while patterns of wear and residues including pigments, suggest most beads originated from different varieties of composite objects brought to the site and maintained in different contexts of daily life. Our model reveals a novel picture of Holocene social complexity broadly associated with dated rock art, providing a unique link between parts of the rich archaeological record at the Liang Jon, circumventing popular modes of ethnographic analogy less appropriate for this region.

1. Introduction

The manufacture of marine shell beads is representative of some of the earliest known human symbolic behaviours and a resilient cultural phenomenon following humanity's global expansion during the late Pleistocene (Bar-Yosef-Mayer et al., 2017; d'Errico et al., 2005, 2009; Henshilwood et al., 2004). Unlike other early shell ornaments, such as ostrich eggshell beads or engraved shells, marine shell beads occur in

many archaeological records across the world (Bar-Yosef-Mayer et al., 2017; Langley et al., 2018). The earliest marine shell beads (hereafter 'beads') are found in African and Mediterranean sites likely exceeding 100,000 years, and later spreading across Eurasia and into Island South East Asia (ISEA) (Bar-Yosef-Mayer et al., 2009; Jerardino and Marean, 2010; Sehassheh et al., 2021; Vanhaeren et al., 2006). In this latter region, our understanding of the complex socioeconomic roles of beads is hampered by small sample sizes and temporal disparity. Typically

Abbreviations: Holocene, Arkeologi; Manik-manik kerang laut, Ornament.

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recovered as isolated artefacts, the composite objects beads were once attached to have long perished due to the often plant-based nature of these technologies, presumably including basketry, clothing, fibre crafts, and other items of material culture made with organic components. The composite character of such objects leaves microscopic wear on beads as credible traces of object life history—key to modelling the socioeconomic role of beads. These roles, recognised as the systemic context of daily or even ritual use (Stiner et al., 2013:380; Stiner and Kuhn, 2003:65), are not well known in ISEA archaeology before the last few thousand years (Clark et al., 2018; Szabó, 2005). Due to its geographical positioning and strong maritime culture, ISEA has unparalleled evidence for early cultural adaptations, including the world's first known mariners voyaging from the now submerged shores of Sunda, reaching Sahul (the combined landmass of Australia, Tasmania, New Guinea, and the Aru Islands) by 65,000 years ago (Clarkson et al., 2017; Kealy et al., 2018; O'Connor, 2007) (Fig. 1a).

Colossal shifts in sea level and biogeography following the Last Glacial Maximum (LGM) around 18,000 years ago makes the present-day archipelago of Indonesia exceptional, particularly for the archaeology of marine materials exemplified by beads; with over 17,500 islands and ~80,000 km transitioning to the modern coastline over this period (Bird et al., 2005:2230; Marfai, 2011). Recovery of beads from at least twenty-six sites across ISEA (Fig. 1b) reveals regional longevity, with beads and other ornaments corresponding with some of the earliest evidence for human occupation (Brumm et al., 2020; Langley and O'Connor, 2019; Leavesley, 2007). Sea level rise and archipelago formation by the early Holocene, ~11,700 years ago stimulated regional change evident in archaeological records (Maloney et al., 2018:84; Ono et al., 2020; Reepmeyer et al., 2016; Samper-Carro et al., 2016; Shipton et al., 2020), with Neolithic expansions between 6000 and 4000 years ago seeing new socioeconomic contexts for beads (Bellwood, 2007:268;

Bulbeck, 2008:32; Datan and Bellwood, 1991:200; Lloyd-Smith et al., 2016:284, 286; O'Connor, 2015:90; Spriggs, 2011:253). The socioeconomic status of beads from earlier ISEA records, however, remains enigmatic beyond establishing human agency and bead antiquity (e.g. Francis, 1991; Indraningsih, 1985; Langley and O'Connor, 2019; Szabó, 2005).

Stiner et al. (2013:380; see also Stiner and Kuhn, 2003:65) note that archaeologists often focus on human agency and antiquity of beads at the expense of detail sensitive to shifting social roles, cautioning that while 'tempting to assign complex meaning ... beads usually are subsets of more intricate things ... even if the latter are not preserved' (Stiner et al., 2013:396). Rarely are beaded composite objects recovered leading researchers to draw comparisons from historical and ethnographic records (Hoop, 1932:133; Langley and O'Connor, 2019:88; Szabó, 2005:77). The analytical value of ethnographic analogy in Borneo is diminished by the extreme diversity of composite beaded objects produced by prehistoric, historic, and contemporary ISEA cultures and the complex successions and legacies of colonial rule (Aijmer, 2010; Taylor, 1994; Ruffner, 2018). In place of more recent historical and ethnographic records, rock art recorded across the Sangkulirang-Mangkalihat Peninsula (SMP) of East Kalimantan provides an exceptional record for analogy, where excavated shell beads—studied here for the first time—were recovered within a cultural landscape where directly dated rock art motifs depict a wide variety of material culture. This spatial and temporal proximity provides veracity for a 'type-level' analogy (Currie, 2016:88), with rock art possibly depicting beaded composite objects considered to be an important part of daily social and cultural life in the past.

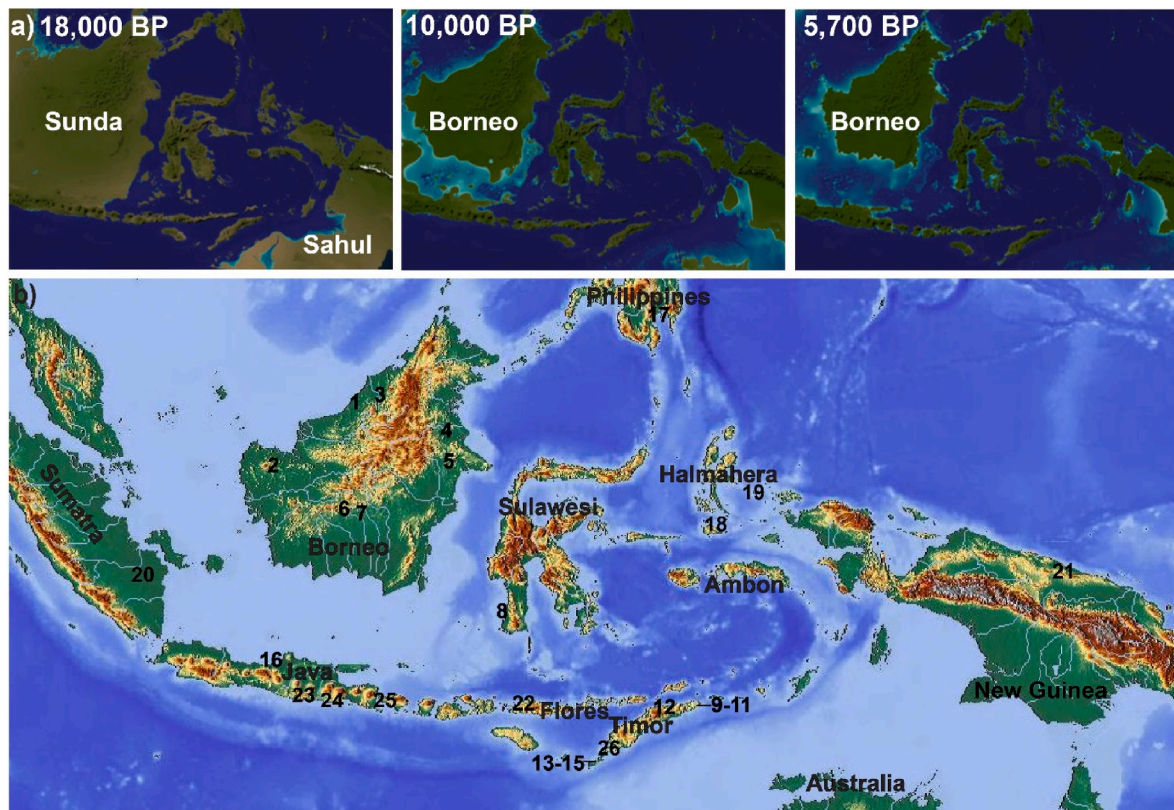


Fig. 1. a) Archipelago formation post Last Glacial Maximum (adapted from Sathiamurthy and Voris 2006). b) Archaeological sites with marine shell beads: (1) Niah Caves (2) Gua Sireh (3) Lubang Angin (4) Kimanis (5) Liang Jon (6) Diang Kaung (7) Diang Balu (8) Leang Bulu Bettue (9) Jeramalai (10) Matja Kuru (11) Lene Hara (12) Uai Bobo (13) Pia Hudale (14) Lua Manggetek (15) Lua Meko (16) Sodong (17) Kamauanan (18) Uattamdi (19) Golo (20) Medan Palembang (21) Watinglo (22) Liang Bua (23) Plawagan (24) Bojenegoro (25) Gilimanuk and (26) Camplong.

1.1. Study area

Located within the karst landscape of the SMP, Liang Jon is a limestone rockshelter situated ~1 km from the Marang River, approximately 167 km from Borneo's coast via a complex network of connected river systems and waterways (Setiawan et al., 2012). East Kalimantan forms the eastern promontory of the Sunda Shelf and after submergence of some 2.2M km² of land (the vast majority to the north, west, and south) island formation occurred by ~11,700 cal BP (Fig. 1a; Bird et al., 2005:2231).

In 2019 Maloney et al. (2022a) conducted systematic archaeological excavations at Liang Jon. Excavations revealed a rich cultural sequence covering the period from around 16,700 cal BP until the late Holocene, including a secondary human burial, feature 5A, of pre-Austronesian context, directly dated to 4231–3997 cal BP (Maloney et al., 2022a:12). Information on site excavation, stratigraphy, and chronology is reported in detail elsewhere (Maloney et al., 2022a). The stratigraphic profile including radiocarbon chronology and stratigraphic units (SU) inferred as Bayesian occupational phases is reproduced in Supplementary File A (see also Maloney et al., 2022a).

The cultural landscape surrounding Liang Jon provides a unique background to the archaeology of the site. The area boasts the earliest evidence in the world for successful surgical amputation at around 31 ka (Maloney et al., 2022b). Numerous caves and rockshelter sites containing rock art in the immediate landscape, including figurative motifs, dated to at least 40 ka (Aubert et al., 2018, 2019). A later occurring distinct rock art style depicts mulberry-coloured Datu Saman anthropomorphic figures (Fig. 2c), which are described as 'elegant, thread-like human figures ... usually portrayed with elaborate headdresses and an array of other objects of material culture ... depicted in narrative scenes ... engaged in enigmatic social or ritual activities' (Aubert et al., 2018:254). Ongoing research by AO confirms headdresses, tassels, basketry, and clothing can be discerned amongst these motifs, that are associated with a minimum U-series age estimate of 13.6 ka (Aubert et al., 2018:256) overlapping temporally with human occupation at Liang Jon (Maloney et al., 2022a). Datu Saman motifs are found at sites along the Marang River cultural complex, some within 9 km from Liang Jon (Fig. 2b), with many of these sites also containing more recent Neolithic motifs of geometric designs, including boats (Aubert et al., 2018).

2. Materials and methods

Beads uncovered during archaeological excavation were plotted in situ in 3D using a Leica MS60 Robotic Total Station. Beads not recovered in situ were recovered from residue dry-sieved using 1.5 mm screens, with 0.05 mm nylon sieves employed for delicate features such as the human burial/feature 5A. All beads were analysed using an Olympus DSX-1000 Digital microscope under various magnifications (30–560x) and lighting. Each bead was minimally handled using latex gloves and digital measurements were taken.

Taxonomic identifications were made using malacological reference collections housed at Queensland Museum that included Cypraeidae and Nassariidae—common families recovered archaeologically (e.g. Clark et al., 2018; Langley and O'Connor, 2015; Maloney et al., 2022a; O'Connor, 2010; Szabó, 2005). High levels of diversity amongst genera and species belonging to the families Cypraeidae and Nassariidae (e.g. Moretzsohn, 2014; Galindo et al., 2016), coupled with significant manufacturing modification and fragmentation of beads recovered from Liang Jon precludes unambiguous taxonomic identification.

Cypraeidae is distinguished based on morphological characteristics (Fig. 3) including non-existent spire, serrated aperture (teeth) with no operculum, glossy smooth exterior, and diversity in colour palette and pattern; while Nassariidae possess a distinct conical spire, an operculum aperture with a serrated margin, and exterior surfaces rough and comparatively monotone, retaining a glossy columella (Abbott,

1991:40–45, 64; Plate 3, 14 to 18; Coleman, 2002:126, 216; Dharma, 1988:55–65; Lorenz, 2017:51). Complete beads, with intact columellae, were distinguished from economic shell refuse and tools recovered from the site (Stiner and Kuhn, 2003:68; Stiner et al., 2013:382 Szabó, 2005:136). Economic shell refuse—exclusively fractured and calcined (98%) freshwater gastropods *Paludomus* spp. and *Sulcospira* spp.—is predominantly recovered in terminal Pleistocene deposits and four bivalve tool fragments of *Ctenodesma borneensis* have been previously identified (Maloney et al., 2022a).

Following Szabó (2005:135), beads were quantified using the minimum number of individuals (MNI), and number of identified specimens (NIS). A single constant and recurring diagnostic element, the columella, was used to produce MNI. NISP, inclusive of fragments without the columella, provides the absolute count. After Stiner et al. (2013:384), bead accumulation is further indexed to vertebrate NISP by division of shell bead MNI, by the sum of shell count and vertebrate NISP; giving 'standardised ornament abundance' (SOA). Minimum number of lithic flakes (MNF) and weights of economic shell refuse provide further comparative values, here compared using occupation phases aligned with stratigraphic units (SU) known from Liang Jon (Maloney et al., 2022a).

Three criteria establish beads as anthropogenic: (1) agency in their selection, transport, and accumulation; (2) distinction from taphonomic influence; and (3) manufacturing marks or wear (d'Errico et al., 2005:10; Langley and O'Connor, 2016:6; Stiner et al., 2013:384; Szabó, 2005:133–135; Vanhaeren et al., 2013:510–514). Although clearly variable in recognising 'worked' beads, experimental work on Indo-Pacific bead manufacture (Table 1) typically involves combinations of percussion and grinding to remove the dorsum (Clark et al., 2018:150; d'Errico et al., 2005:10; Langley and O'Connor, 2016:6; Szabó, 2005:132–133; Szabó and Ramirez, 2009:152; Vanhaeren et al., 2013:513). Grinding has been shown to form facets on worked edges and surfaces, within which, striae can be parallel or multidirectional (Alarashi, 2021:173). The directions and superimpositions of facets and striae have been linked to different manufacture techniques of grinding, with notable variability (Table 1). Latter stages of grinding can obscure previous wear traces, leaving an edge with pronounced rounding distinct from breakage patterns observed naturally (Alarashi, 2021:177; Szabó, 2005:130). Identifying collection contexts such as littoral shorelines, can be supported by traces of boring from marine invertebrate predation, and evidence of beach rolling (Stiner and Kuhn, 2003:69; Szabó, 2005:135; Szabó and Ramirez, 2009:152). Percussion can leave conchoidal or cone like scars with irregular edges (Stiner and Kuhn, 2003). This study recognises facets, striae, and rounding as likely manufacturing wear, independent of natural or taphonomic abrasion. Striae is described as parallel only when clearly discernible, or multidirectional, although there are complexities in these observations, for example where adjacent facets have both types of striae.

When distinct from littoral abrasion, regarding texture, gloss, and distribution, use wear can be distinguished by lustrous fine polish (Stiner et al., 2013:385). Such distinct polish is often a result of wear, rather than grinding or abrasion during manufacture, and is capable of obscuring traces of manufacturing wear (Langley and O'Connor, 2016:14; Szabó, 2005:242). Fine and lustrous polish on surfaces and modified edges, have been empirical linked to scenarios with one surface exposed and visual (unifacial), and the other affixed to material or objects, termed applique (Szabó and Ramirez, 2009:152; Vanhaeren et al., 2013:513). Others (e.g. Langley and O'Connor, 2016:6–7; Stiner et al., 2013:391) provide cases for bead stringing with muting of manufacturing marks on the modified dorsum opening, creating asymmetrical wear on margins, as well as lustrous polish on both surfaces (bifacial). For this study, microscopic observation of polish superimpositions overlying other wears, such as facets with striae, and rounding, was recorded as muting polish (Clark et al., 2018:150; Vanhaeren et al., 2013:511). Distributions of this muting polish are used to assess cases for likely stringing, with muting polish expected to be bifacial; or

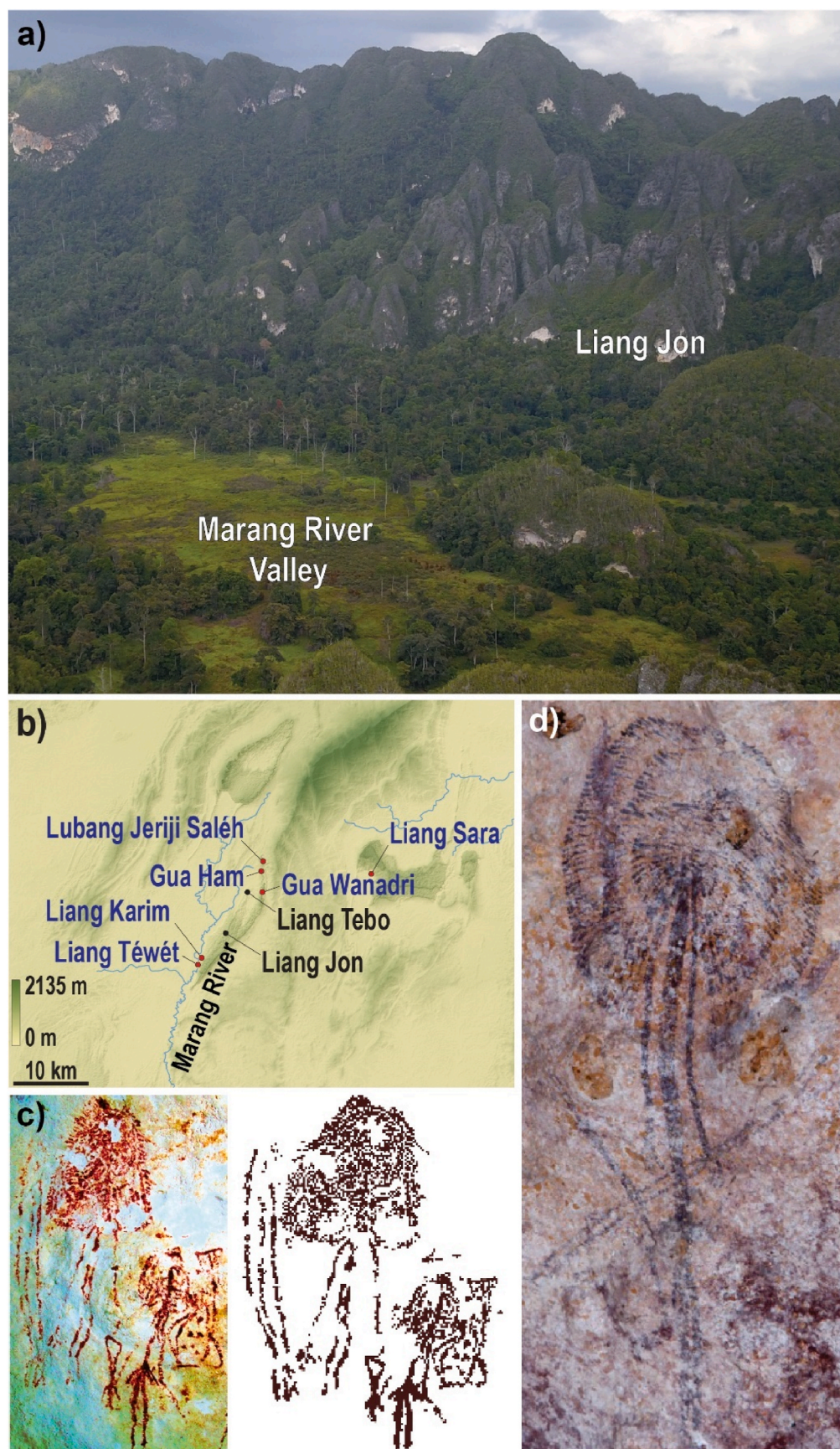


Fig. 2. a) Marang River valley showing characteristic conical karst towers and location of Liang Jon. b) Surrounding archaeological sites including those with Datu Saman figures (blue text). c, d) Examples of Datu Saman figures from Lubang Jeriji Saléh showing elaborately detailed composite objects such as headdresses, other accoutrements, and weaponry including spears. Rock art images by Adhi Oktaviana (2014).

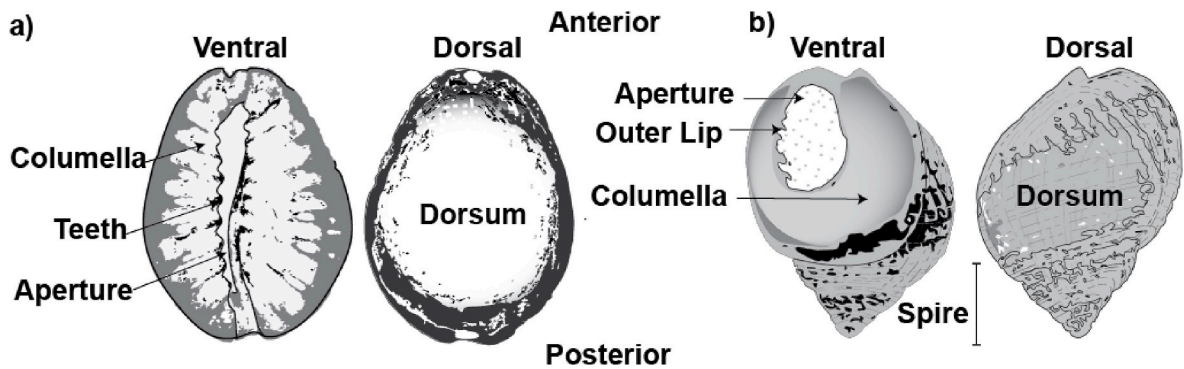


Fig. 3. Morphological characteristics of a) Cypraeidae and b) Nassariidae used for taxonomic identification.

Table 1
Experimental studies demonstrating empirical wear associated with shell bead manufacturing actions. Na = surface not worked.

Study	Identification	Actions	Dorsal Wear	Ventral Wear
Alarashi (2021)	Cypraeidae	Percussion Sawing Grinding Batch-grinding	Spire removal, random striae Long parallel striae Facet, long regular striae Facet, parallel striae	Random striae Long multidirectional striae Na
Stiner et al. (2013)	<i>Nassarius</i> spp. <i>Naticarius</i> spp.	Percussion Sawing	Removed aperture, cone fractures, rounding Na	Fine slit on lip margin
Clark et al. (2018)	Cypraeidae	Percussion/grinding	Parallel striae	Parallel striae, micro-flaking
Langley and O'Connor (2016)	<i>Oliva</i> spp.	Grinding Percussion Tapping	Parallel striae Localised crushing, multidirectional striae Micro-flaking	Na Na Na

applique, where muting polish is expected to be unifacial. Evidence provided by experimental works (Table 1) are used in this study to support cases for stringing or applique (Hoareau and Beyries, 2022) represented in the Liang Jon bead assemblage.

Colour and lustre of the exposed surfaces of beads can be modified when heated in controlled contexts; however, identification of deliberately burnt shell, charring hereafter, requires the exclusion of diagenetic and taphonomic processes (d’Errico et al., 2015). Colour gradients associated with charring are distinct from natural surface colour ranges, varying from light greys to blacks, and fully calcined powdery whites (Claassen, 1988:62–66; Stiner, 2005:51–52. Spennemann et al. (2004:16–17) linked Munsell Color Co (1992) colour values to experimentally controlled heating of Indo-Pacific molluscs, finding shell exposed for 5 min to temperatures of ~300° produced Munsell values between 10 YR 8/3.5 and 8/1 (greys and blacks) indicated deliberate charring without destruction to the shell matrix. Those exposed to higher temperatures (>700°) calcined and disintegrated after turning white (Spenneman, 2004:17). Further, d’Errico et al. (2015: 64–70) established distinct surface cracks coupled with a lack of burning signals on spatially contemporaneous shell as supportive evidence of deliberate charring. A combination of these surface and colour changes is used to identify anthropogenic charring.

Pigment and other residue staining were identified under high magnification digital light microscopy by the clear presence of colourful substances on the exterior of most shell layers, as well as more substantial residues collected inside internal shell structures. Vibrant red pigments (likely earth minerals/ochre) are visibly distinct from other residue exemplified by a black paste (respectively referred to as pigment and residue—the subject of a larger, ongoing program of analyses). The black residues from two beads were characterised in pilot work using portable Raman Spectrometry and Environmental Scanning Electron Microscopy (ESEM).

Portable Raman was undertaken using a Bruker Bravo™ handheld spectrometer. The instrument is equipped with two laser diodes (785 nm and 852 nm), operating at a maximum output of 100 mW with a spot size of ~0.7 mm, recording signal intensity at a spectral range of 300–3200

cm⁻¹ and a resolution of ~10 cm⁻¹. The dual-laser system enables sequentially shifted excitation, minimizing sample fluorescence in the spectrum by operating the two lasers at sequentially shifted wavelengths (<1 nm), during which the fluorescence bands and unwanted spectral artefacts remain at fixed positions while the positions of the Raman bands will shift slightly in response to the minor variations in excitation wavelength. During a single measurement the instrument collects six interferograms that are subsequently compiled into a single calculated spectrum. This enables the instrument software to identify and subtract unwanted fluorescence bands.

The portable Raman laser spot was targeted on the black residues and 2–4 measurements were taken on each artefact. The resulting interferograms were imported into Bruker OPUS software, converted to a single spectrum, and underwent the following data manipulations: Rubberband baseline subtraction (64 baseline points) and smoothing (13+ smoothing points) using the Savitzky-Golay algorithm (Savitzky and Golay, 1964). Each of the six interferograms and the calculated spectrum were screened to identify and disregard artificial spectral features due to signal saturation. Once satisfied with the calculated spectra for each sample, the band wavenumbers were tabulated and compared to reference spectra to verify mineral identifications using reference the Bruker Art and Archaeology reference library databases; RRUFF project database (Lafuente et al., 2015); in-house standards, and compiled data from literature.

ESEM was preformed using a FEI Quanta 600 F microscope equipped with a Bruker Quantax 200 silicon drift detector for X-ray energy dispersive spectrometry. The ESEM was operated in low vacuum mode and hyperspectral EDS data were collected at 10 kV.

Empirically distinct from taphonomic and beach rolling abrasion, wear is recorded within a uniform grid applying six relative sectors per complete bead surface (Fig. 4a, c; Stiner et al., 2013:385). Maximum length and width of complete shell beads were recorded (Fig. 4b, d), with maximum linear dimension (MLD) given in millimetres and mass measured in grams. Dimensions in millimetres of each complete beads modified dorsal margins were recorded, with length orientated to the same axis as bead length, and width orthogonal to this measure. These

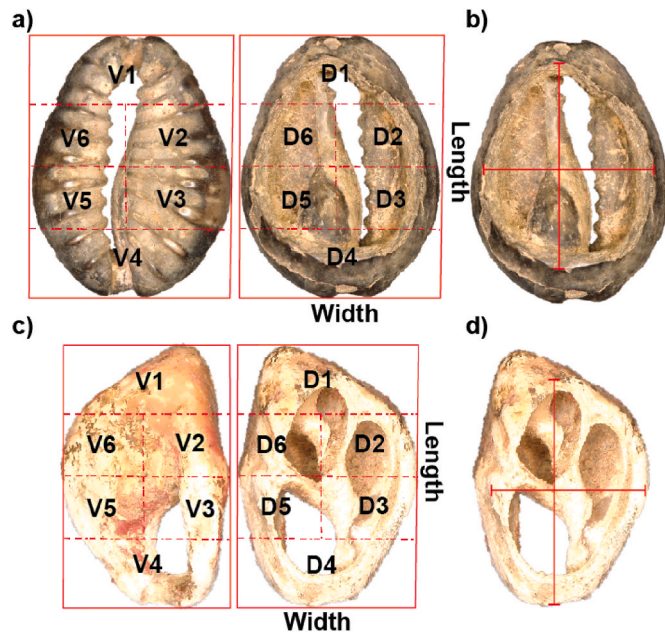


Fig. 4. a, c) Uniform grid for wear and residue distribution Cypraeidae and Nassariidae. b, d) Bead length and width dimensions of modified dorsal opening.

values facilitate calculation of the dorsum opening area with πab – where a provides dorsum opening length, and b width. Quantification of wear distribution per shell bead surface, creates an average dorsal and ventral value for wear observation, susceptible to statistical analyses for trends between taxon, surfaces, and occupation phases. To this end, frequency data obtained via these observations are tested using Wilcoxon signed rank, Kruskal Wallis, Chi squares, and general linear model tests in SPSS V.28 (Drennan, 2010:147,181), with all data provided in supplementary file B.

3. Results

Taxonomic identification is complicated by factors owing to anthropogenic modification obscuring defining dorsal features and natural variability in ventral structures (Christie et al., 2019:482). Comparison with reference material at the Queensland Museum, suggests most Cypraeidae as belonging to cf. *Monetaria annulus*, although beads being unidentifiable to genus or species level with confidence, family level identification is considered the most accurate for this study. The same applies for Nassariidae.

Overall, the Liang Jon assemblage consists of 120 complete shell beads, including 21 complete Cypraeidae and 99 complete Nassariidae beads, with 22 and 47 identifiable fragments respectively (Table 2). Additionally, four whole shells provide a total NISP value of 193 and MNI of 166 (Table 2) with one additional unidentifiable shell disc bead recovered from burial feature 5A.

Table 2

Bead frequency, with complete (comp), fragments (frag), whole, and NISP values per occupation phase (SU), including comparative artefact values.

SU	cal BP	Cypraeidae			Nassariidae			Beads			Artefact Values		
		comp	frag	whole	comp	frag	whole	NISP	MNI	SOA	Lithic (MNF)	Shell (kg)	Faunal (NISP)
		2	3		5			10	7	0.002	259	4.10	4105
2	7376–4100	8	10		43	10		71	61	0.003	2069	24.7	24,753
3	9427–7460	2	1		17	3	1	24	21	0.002	328	14.12	14,129
4	10744–9300	9	6	1	31	34	2	83	74	0.005	758	12.91	12,917
5	11938–10515		2		3			5	3	8.03	8833	6.23	6228
6	16985–12023									0	5134	1.02	1019
Bead Σ		21	22	1	99	47	3	193	166				

All Cypraeidae and Nassariidae beads, including fragments thereof, satisfy methodological criteria for human agency; being recovered from culturally stratified Holocene deposits of an inland rockshelter ~80 km from the coastal marine environments in which they can be found. In addition, anthropogenic wear independent of taphonomic and environmental abrasion coupled with distinct manufacturing wear, support human transport to the site.

Lack of significant difference between bead dimensions and respective depths—both in situ and stratigraphic—diminishes vertical movement as a major effect within the deposit (Table 3), where the chronostratigraphy is already notable for reasonable age depth ($r^2 = 0.657$, $p = 0.001$) (Maloney et al., 2022a:6). Fig. 5 demonstrates bead frequency generally tracks vertebrate NISP and lithic artefact MNF values, yet is clearly independent of refuse shell, indicative of bead accumulation being concurrent with Holocene site occupation litter and discard. Occupation intensity linked to bead frequency accumulation, is further supported by the SOA lacking significant change ($\chi = 24$, $p = 0.242$), suggesting beads were regularly brought to site and eventually discarded.

All complete beads and fragments thereof first appear in the sequence during SU5; associated with early Holocene age estimates between 11,938 and 10,515 cal BP, later peaking during SU2, between 7376 and 4100 cal BP (Table 2). All shell beads were intermixed amongst other artefacts within SUs; except for those recovered from the distinct and discrete 5A burial feature ($n = 14$) within SU2 (Maloney et al., 2022a:12, 17). These include Nassariidae and Cypraeidae beads as well as the only disc bead recovered at the site (Fig. 6a). A Cypraeidae bead fragment recovered from the burial was sampled for direct AMS dating, returning an age of 4975–4620 cal BP 95.4% (Beta-613434); calibrated in OxCal V4.4, with a Delta R correction of -164 ± 48 using Marine20 (Bronk-Ramsey, 2009; Heaton et al., 2020).

The ratio of Nassariidae to Cypraeidae shifts during SU2 ($\chi = 5.531$, $p = 0.019$), when Nassariidae is replaced as the dominant taxon throughout mid to late Holocene phases. The disc bead has minimal evidence for modification, with the central perforation lacking unambiguous wear, and may be foraminifera, which develop a calcareous ‘test’ or hole (Benzie and Pandolfi, 1991). The disc bead nonetheless satisfies the first criteria of human agency having been transported from a marine environment.

Table 3

General linear model tests of bead morphology against both depth (XU) and occupational phase (SU).

Length (mm) vs.	df	F	p
XU	45	1.01	0.465
SU	4	1.55	0.189
Width (mm) vs.	df	F	p
XU	40	0.809	0.769
SU	4	2.33	0.059
Mass (grams) vs.	df	F	p
XU	45	0.844	0.741
SU	4	0.538	0.708

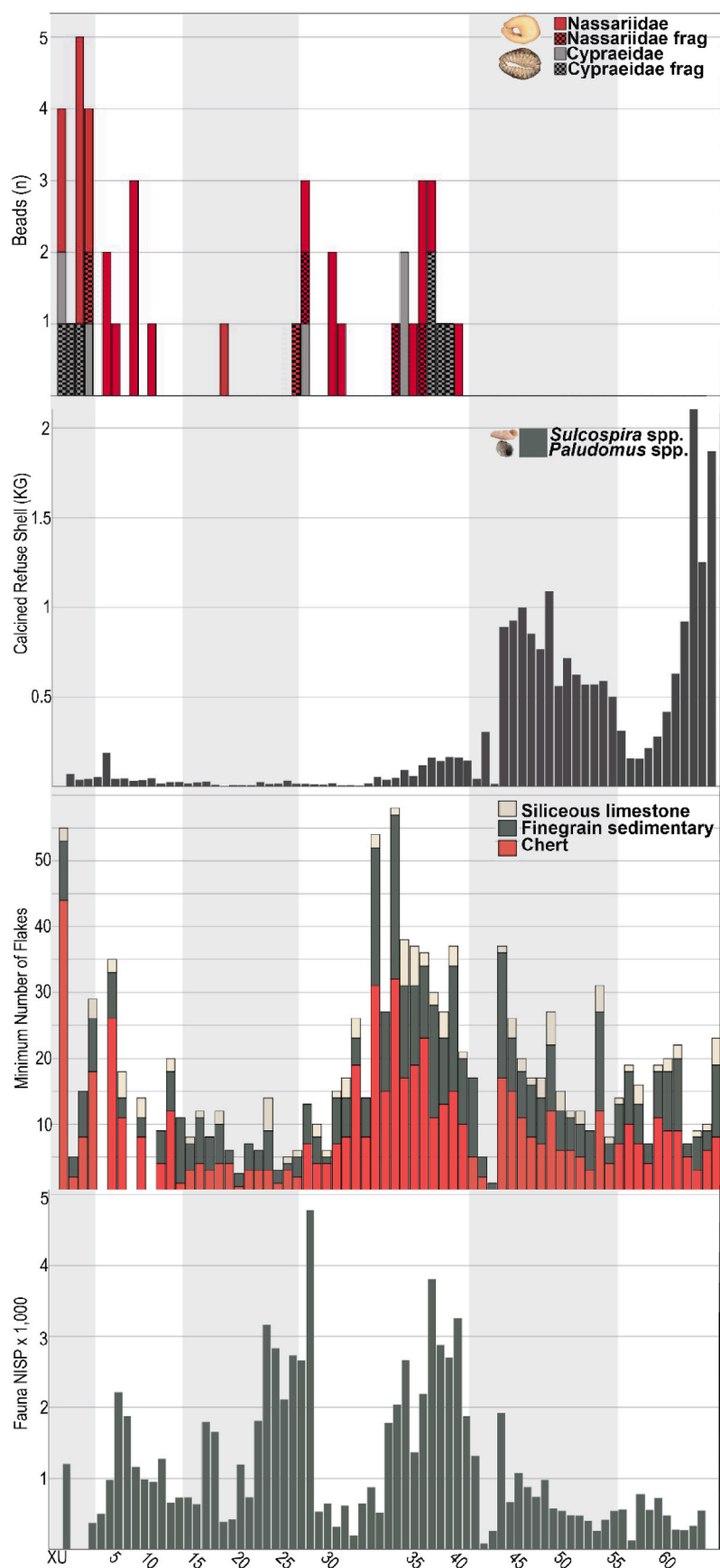


Fig. 5. Square C shell bead (complete and fragmented) accumulation shown against comparative artefact values and occupational phases (SUs, shown in grey).

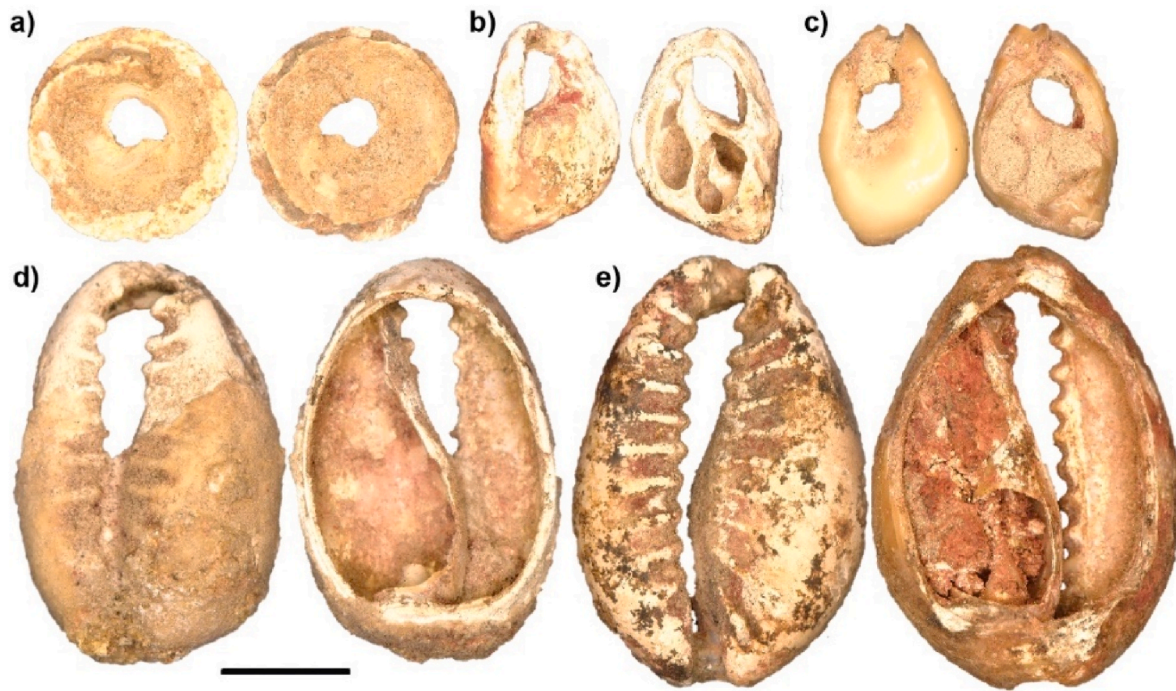


Fig. 6. Examples of shell beads recovered from human burial, feature 5A. a) Disc bead. b, c) Nassariidae. d, e) Cypraeidae. Scale bar 4 mm.

Frequency of all types of manufacturing wear changed significantly throughout occupational phases (Table 4), suggesting manufacture was dynamic, although with dorsal grinding modality. Technique/s of dorsal removal changed through time, seeing frequencies of parallel and multidirectional striae (Fig. 7a and b), as well as micro-flaking significantly shift across occupational phases (Table 4). Micro-flaking is most prevalent on Nassariidae (Fig. 7d). Facets with striae are unlike local cases of littoral action, breakage, or predation holes (Laimheheriwa, 2017:4; Morton and Chan, 2004:330); the latter observed on six Cypraeidae and ten Nassariidae beads, with a signal towards greater frequency amongst early Holocene beads ($\chi = 25.026$, $p = 0.015$). The distribution patterns of striae and rounding—suggestive of consistent grinding of dorsal surfaces as a regular manufacturing step in bead production—lacks strong signals of asymmetry on modified margins (Fig. 7); notably less clear on beads with superimposed lustrous fine polish (Cypraeidae 54.2%, Nassariidae 40.5%). Alongside these shifts, dimensions of modified dorsum openings also varied significantly on both species (Nassariidae: $Z = -8.319$, $p = 0.01$ | Cypraeidae: $Z = -2.914$, $p = 0.004$) (Fig. 8); a trend independent of bead dimensions (Table 3).

Charring with colour gradients towards darker grey to black surfaces—10 YR 8/3.5 to 10 YR 8/1—are identified on 37 Cypraeidae and 62 Nassariidae beads, each with surface heating cracks (Fig. 9a). Recovered in immediate proximity, charred and uncharred beads with lustrous polish occur directly adjacent to unburnt bivalve fragments (Fig. 10a). Of four bivalve tools and 53 bivalve fragments; none display surfaces indicative of charring, while freshwater shell refuse is consistently calcined white (98%) and confined to the late Pleistocene (Fig. 5).

Table 4

Wilcoxon Signed Rank test confirming manufacturing wear frequency changed significantly throughout occupational phases (SU).

Manufacture Wear	N	Mean Rank	Z	P
Facets	111	54	-9.182	0.01
Striae	59	29	-6.679	0.01
Rounding	87	41.5	-8.036	0.01
Multidirectional vs. Parallel striae	45	23.4	-4.335	0.01
Micro-flaking scars	13	7	-3.27	0.01

Frequency of surface cracks and observed charring colour gradients, both changed significantly throughout occupational phases (Cypraeidae: $Z = -3.998$, $p = 0.01$ | Nassariidae: $Z = -10.575$, $p = 0.011$).

Pigment staining was identified on the surfaces of 36 Nassariidae and 15 Cypraeidae beads, with pigment residues more than 1 mm in thickness embedded within the apertures of five Nassariidae and one Cypraeidae bead(s) (Fig. 9b). A further four Nassariidae retained dark residue within apertures with inclusions of fine web-like structures within their matrix (Fig. 9c). This latter dark residue was shown using portable Raman spectrometry and ESEM with EDS (Fig. 11) to be plant charcoal. Portable Raman spectroscopy revealed the black residue consists of a carbonaceous organic material with features at 1275–1350 cm^{-1} , ~1600 cm^{-1} , and 3000–3050 cm^{-1} that are characteristic of amorphous carbon. Note that band markers typical of manganese oxide or magnetite (Fe_3O_4) are absent, reinforcing the interpretation of organic material. While ESEM micrographs showed morphology consistent with plant charcoal, accordant with EDS and element mapping showing the chemical composition of the black residues is almost exclusively carbon. Both bead taxon (Nassariidae and Cypraeidae) have proportionately equal amounts of pigment staining and charcoal residue, yet pigment frequency changes relative to occupation phase (Cypraeidae: $Z = -3.355$, $p = 0.01$ | Nassariidae: $Z = -10.615$, $p = 0.01$), becoming more frequent in the occupational phases above SU3.

Evidence for bead manufacture within Liang Jon rock-shelter—inferred from the presence of both whole shells and dorsal debris—occurs between SU5 and SU2. Whole shells represent the transport of marine resources to the site for the purpose of bead manufacture or a type of unmodified ornamentation (Stiner and Kuhn, 2003:71); with two whole Nassariidae from SU4 charred without undergoing further modification (Fig. 10b). Removed dorsa, each retaining structural features, were exclusively Nassariidae ($n = 22$) found in SU4 ($n = 20$), SU3 ($n = 1$) and SU2 ($n = 1$). All dorsa show evidence of modification while lacking signals of lustrous polish (Fig. 10c), indicating on-site bead manufacture occurred only occasionally after the initial early Holocene period and supports lustrous polish being use related, independent of manufacture or taphonomic wear (Fig. 10c). Frequency data of both beads and fragments suggests most beads were manufactured elsewhere, being brought to the site as already

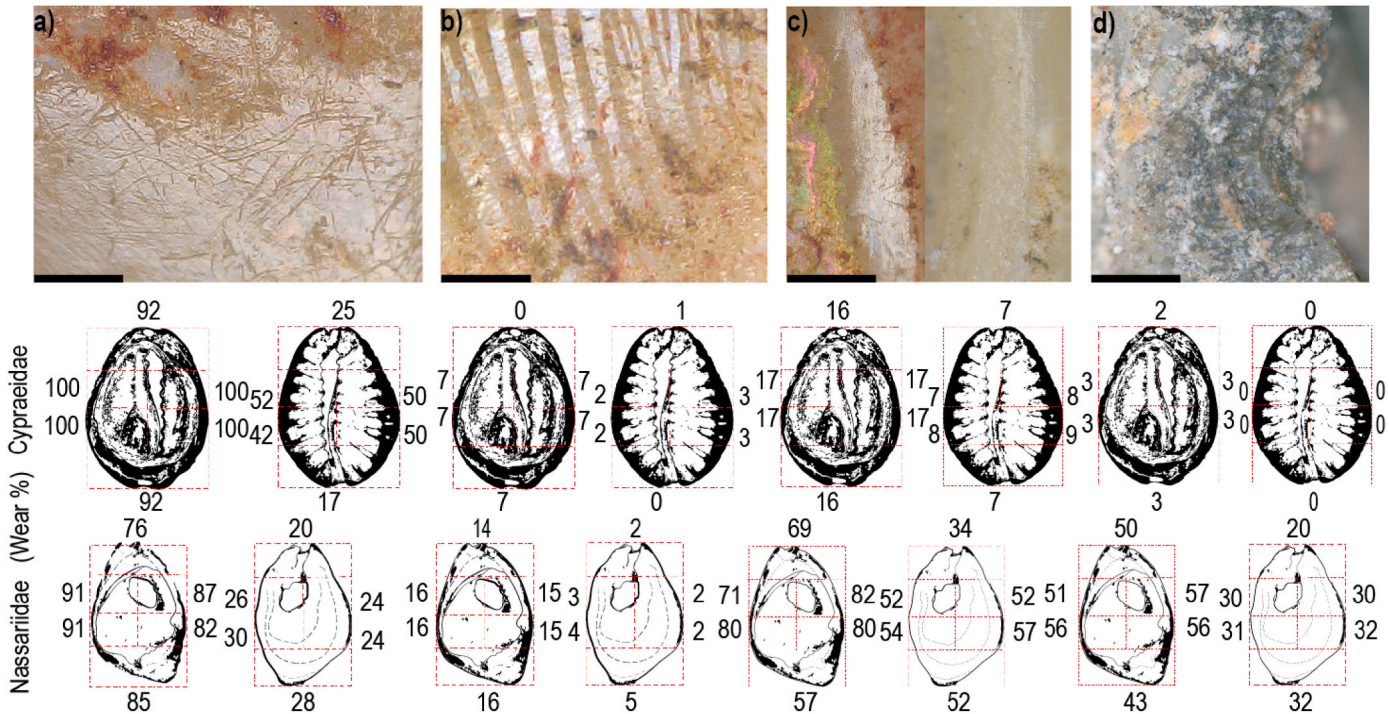


Fig. 7. Examples of manufacture wear and wear percentage (%) distributions across dorsal and ventral surface grids for each taxon. a) Facets with multidirectional striae. b) Facets exhibiting parallel striae. c) Rounding. d) Micro-flaking percussion. Scale bar 200 μ m.

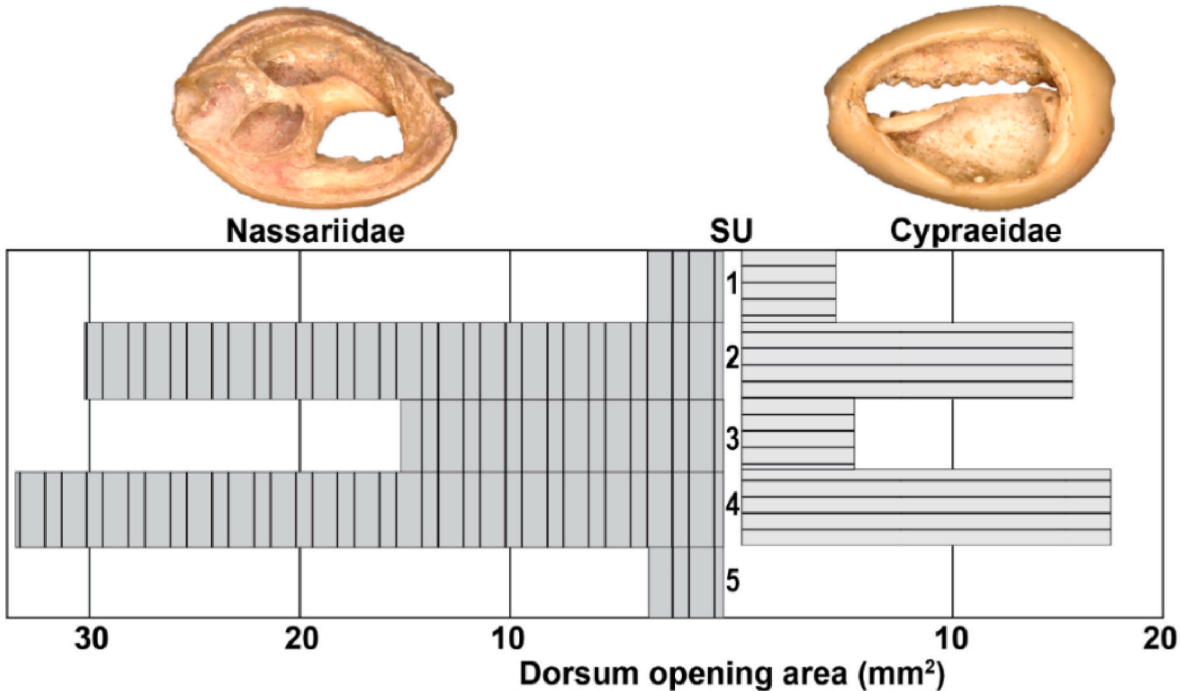


Fig. 8. Modified dorsal opening area across occupation phases (SU), excluding two Cypraeidae fragments from SU5 which lack modified dorsal openings.

constructed composite objects. Furthermore, the surface distribution of muting polish on complete beads, inferred as applique (unifacial) or stringing (bifacial) use wear, varies significantly throughout occupational phases (Applique: $Z = -5.609$, $p = 0.001$ | Stringing: $Z = -6.811$, $p = 0.01$) (Fig. 12), alongside other shifts through time in the pigments, residues, and charring.

4. Discussion

This study examined beads excavated from Liang Jon to decipher a model of socioeconomic roles related to bead manufacture and use, towards discussing how beads 'fit into the larger fabric of life' (ala Stiner and Kuhn, 2003:381). Documented variation amongst observed bead wears is considered reflective of cultural change(s) through time, occurring between occupational phases represented by each SU, inferred

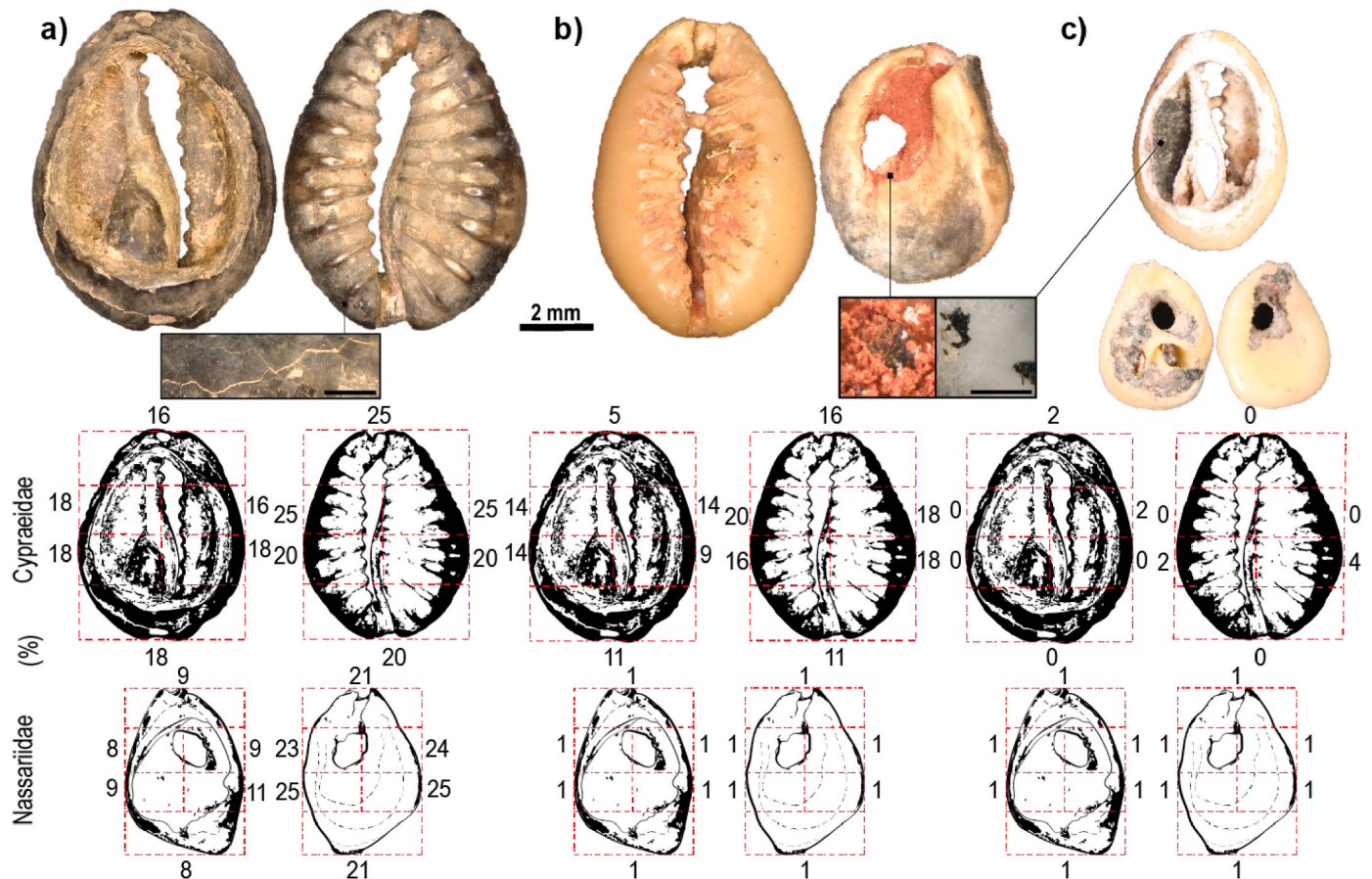


Fig. 9. Examples of a) charring, b) pigment, and c) residue with percentage (%) distributions across dorsal and ventral surface grids for each taxon. Bounded boxes showing heat cracking, pigment, and residue, scale bars 50 μ m.

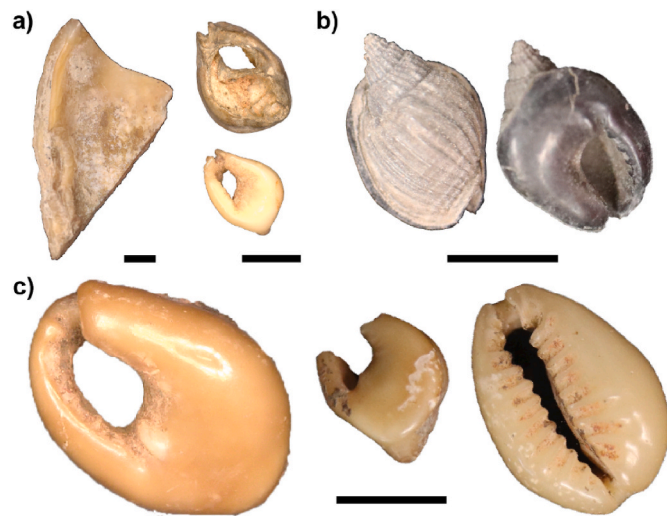


Fig. 10. a) Bivalve fragment with examples of charred and uncharred shell bead colour gradients from immediately adjacent units. b) Whole charred Nassariidae. c) Examples of lustrous fine polish. Scale bars 5 mm.

as shifting socioeconomic roles of composite objects, during the Holocene. Regionally populations were adapting to new socioeconomic contexts in response to early Holocene marine incursions, with new technologies, hunting strategies, burial practices, and rock art styles (Aubert et al., 2018; Bellwood, 2017:149; Maloney et al., 2022c; Piper, 2016) occurring contemporaneous to the initial occupation of Liang Jon

between 16,985 and 12,023 cal BP (Maloney et al., 2022a). The commencement of bead use and manufacture at Liang Jon, between 11,938 and 10,515 cal BP, is temporally congruent with Borneo coastlines resembling present distributions by 11,700 cal BP (Bird et al., 2005), while also occurring at a time when Datu Saman rock art was first being painted in Marang River valley sites surrounding Liang Jon, beginning around ~13.6k.

The Liang Jon bead assemblage suggests routine use and ornament maintenance within the site as the underlying cause of their accidental loss and intentional discard through time. Except for beads manufactured on-site, as evidenced by the presence of whole shells and removed dorsa occurring mainly during the early Holocene period, and beads recovered in the late Holocene burial feature, all were intermixed with other artefacts within SUs. Peaks of beads corresponding with flaked artefacts, faunal remains, and the SOA index trends support the case for beads being a part of regular social life at Liang Jon (Stiner et al., 2013:396), with documented uniformity in bead morphology being anthropogenic. The occurrence of beads in the human burial suggests an important role extending into complex ceremonial mortuary contexts.

Bead manufacturing and use wear distributions were not random, instead shifting through time, and tracking likely changes in the socioeconomic roles of beaded composite objects. Observations of manufacturing wear consist of grinding signals with facets showing mostly multidirectional striae, rounding on worked edges, and some instances of micro flaking. Although often obscured by later polish, these wears are congruent with empirical records of dorsa grinding (Table 1), with some instances of percussion or tapping to remove dorsa. Even with dorsal grinding modality, distribution and frequency of manufacturing wear changed significantly through time, as did the morphology of the modified dorsal opening. These documented trends

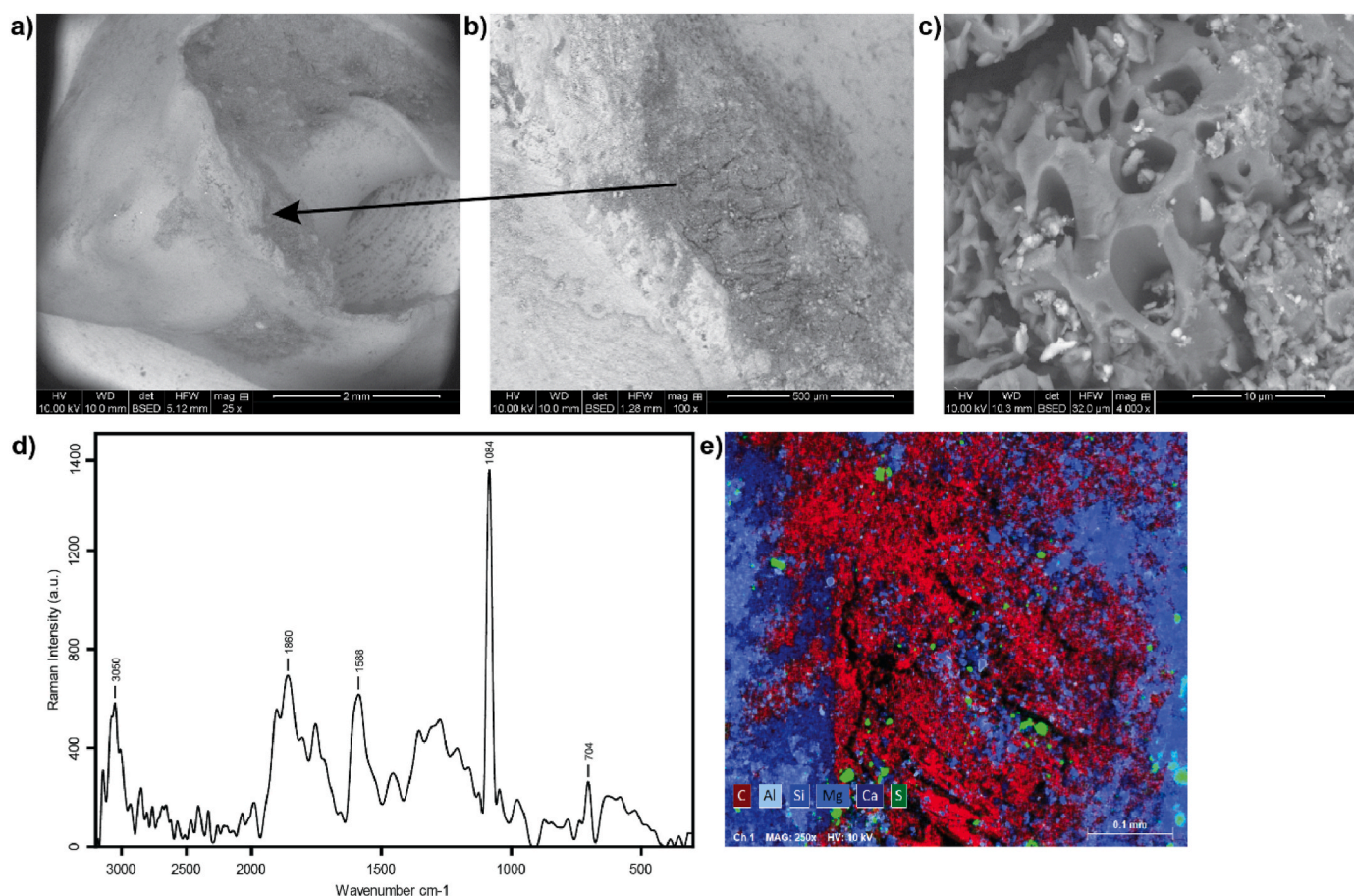


Fig. 11. a–c) ESEM backscattered electron micrographs of Bead 9 at 25x, 100x, 4000x magnification illustrating plant charcoal morphology. d) Raman spectrum of sample Bead 33. Bands at 1084 cm^{-1} and 704 cm^{-1} are attributed to CaCO_3 in the shell. Bands at ~ 1300 , ~ 1600 , and ~ 3050 are attributed to amorphous carbonaceous material. e) ESEM element map of residues in Bead 9 at 250x magnification showing the distribution of carbon (C) relative to proxy soil (Al and Si) and shell (Ca and Mg) chemistry.

confirm manufacture and maintenance were not only dynamic at Liang Jon, moreover, it is reasonably inferred to relate to variation in arrangements of shell beads in diverse composite beaded objects.

Bifacial distributions replaced an initial ventral surface modality in muting polish after the early Holocene. These wear distributions suggest strung objects likely became relatively more frequent than applique for both Cypraeidae and Nassariidae between 9427 and 7460 cal BP, peaking in the following occupation phase between 7376 and 4100 cal BP. The initial charring trend is mainly associated with applique wear, while at the same time, residues and pigments were becoming more common. This shift is coincident with bifacial wear increasing, particularly after 7376 to 4100 cal BP when beads and all other artefacts were at the highest discard values (Maloney et al., 2022a). These data support a model of change, seeing charred beads in applique arrangements (some manufactured on site) gradually replaced in popularity by strung objects with higher frequencies of pigment, including both red earth minerals (ochre) and black plant charcoal. The latter shift temporally overlaps with regional Neolithic expansion (Bellwood, 2007:268; Bulbeck, 2008:32), finding local support in observations of 'Austronesian' rock art in surrounding sites dated to 4k (Aubert et al., 2018:254), as well as pottery within the past few thousand years (Grenet et al., 2016:129; Plutniak et al., 2016:232).

While tempting, ethnographic analogy is resisted, owing to extreme diversity amongst historical beaded objects 'collected', often procured by coercion, from indigenous groups across Borneo (e.g. Aijmer, 2010; Ruffner, 2018; Taylor, 1994). While scant records exist to model composite beaded objects in the deep past, the Datu Saman rock art of the

study area provides an exceptional alternative, and perhaps more credible archaeological analogy (Currie, 2016:88), particularly given the ochre assemblage recovered at Liang Jon (Maloney et al., 2022a). This study demonstrates occupants of Liang Jon incorporated shell beads in their socioeconomic realm throughout the past 11,000 years. The use of pigment on beads coupled with the distribution of ochre throughout the site provides further credibility for inferential links to the locally painted Datu Saman figures; suggesting headdresses, tassels, basketry, and clothing depicted (Aubert et al., 2018:254; Fage et al., 2010:74, 99,121) as plausible composite objects for consideration—with shell beads revealing changing preferences and styles in ornamentation and arrangement.

5. Conclusion

It is likely that the bead assemblage recovered from Liang Jon was culturally filtered through trade networks along the Marang River, which conceivably links the site to the coastline along a ~ 167 km meander of waterways trailing SMP mountain valleys, connecting multiple cultural sites (Maloney et al., 2022a; Setiawan et al., 2012). The distance of this meander was stable throughout the Holocene, owing to the relatively steep peninsula coastline and Marang River biogeography (Bird et al., 2005; Kealy et al., 2018; Setiawan et al., 2012). Evidence for bead manufacture and maintenance at the site occurred mostly in the early Holocene, implying most beads were manufactured elsewhere. Arifin's (2004:249, 277–280; 2017:122) arguments for Holocene cultural networks recovered from Kimanis and other Upper Birang River

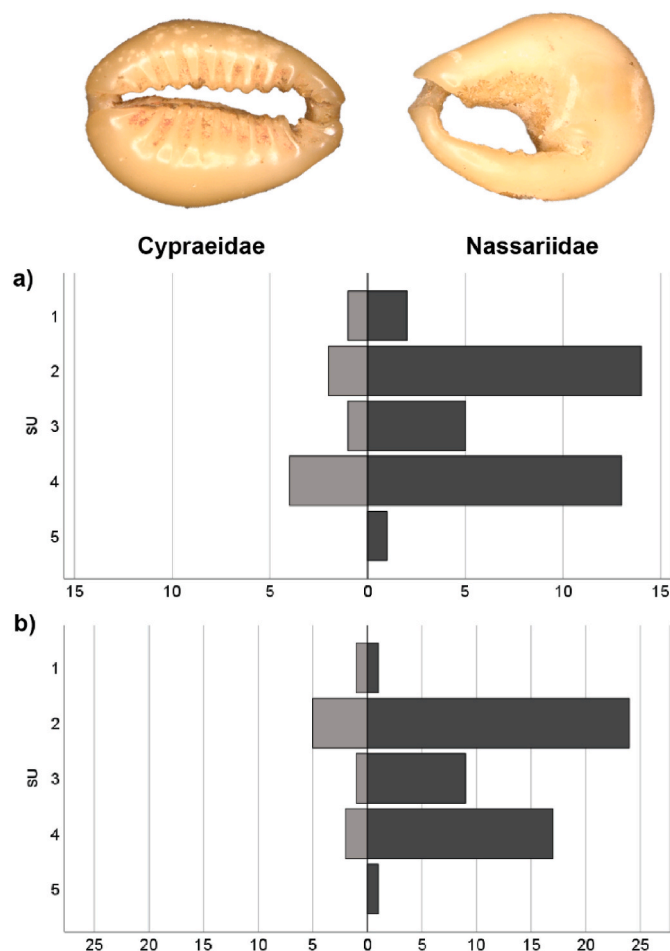


Fig. 12. Variation in a) applique and b) string polish use wear per taxon of complete beads (n) throughout occupation phases (SU).

Valley sites to the north, support the plausibility of beaded objects in similar scenarios for the Marang River, perhaps akin to Szabó's (2005:81–83,311) community of practice. Composite objects, in both applique and string arrangement, were a part of daily life for Liang Jons' site occupants, beginning during the early Holocene, and manifest evidence for shifts in socioeconomic roles, inferred from microscopically observed wear patterns.

Declaration of competing interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jas.2023.105840>.

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