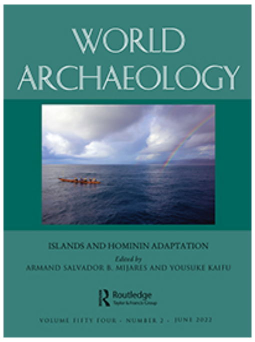

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Terminal Pleistocene emergence of maritime interaction networks across Wallacea

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ABSTRACT
The crossing of the Wallacean islands and settlement of Sahul by modern humans over 50,000 years ago, represents the earliest successful seafaring of our species anywhere in the world. Archaeological research throughout this vast island archipelago has recovered evidence for varied patterns in island occupation, with accumulating evidence suggesting a significant change in cultural activities and interaction amongst island communities following the LGM. New forms of technology such as shell fish hooks and adzes appear alongside standardised forms of shell beads, indicating that these technological innovations were accompanied by shared styles of personal ornamentation. Simultaniously, obsidian from a single, off-island source is found in the archaeological assemblages on at least four islands. We explore these implied spheres of interaction across Wallacea, with a focus on the terminal-Pleistocene/early-Holocene cultural materials and customs linking the south-eastern Wallacean islands of Alor, Timor, and Kisar, and other parts of greater Wallacea and Near Oceania.

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Introduction

Modern humans embarked on the world's first great maritime journey from the Pleistocene continent of Sunda (the greater Asian mainland) to Sahul (Australia, New Guinea, Misool and the Aru Islands) over 50,000 years ago. In the process they settled Wallacea, the archipelago of thousands of islands lying between these two continental landmasses (Figure 1). Archaeological records show modern humans occupied the larger islands of Wallacea, from Sulawesi in the north-west to Flores and Timor in the south and south-east, at least 45,000 years ago (Aubert et al. 2014, 2019; Hawkins et al. 2017; Sutikna et al. 2018). By 35,000 years ago the small islands of Talaud, lying between Mindano and Sulawesi, and Gebe, between Halmahera and New Guinea, had been settled (Tanudirjo 2001; Ono, Soegondho, and Yoneda 2009; Bellwood 2019;). The Philippines (excluding Palawan), variously considered its own region or grouped with Wallacea depending on interpretations of Wallace's Line (Figure 1; Dickerson et al. 1928), presented many of the same challenges for hominin colonisation

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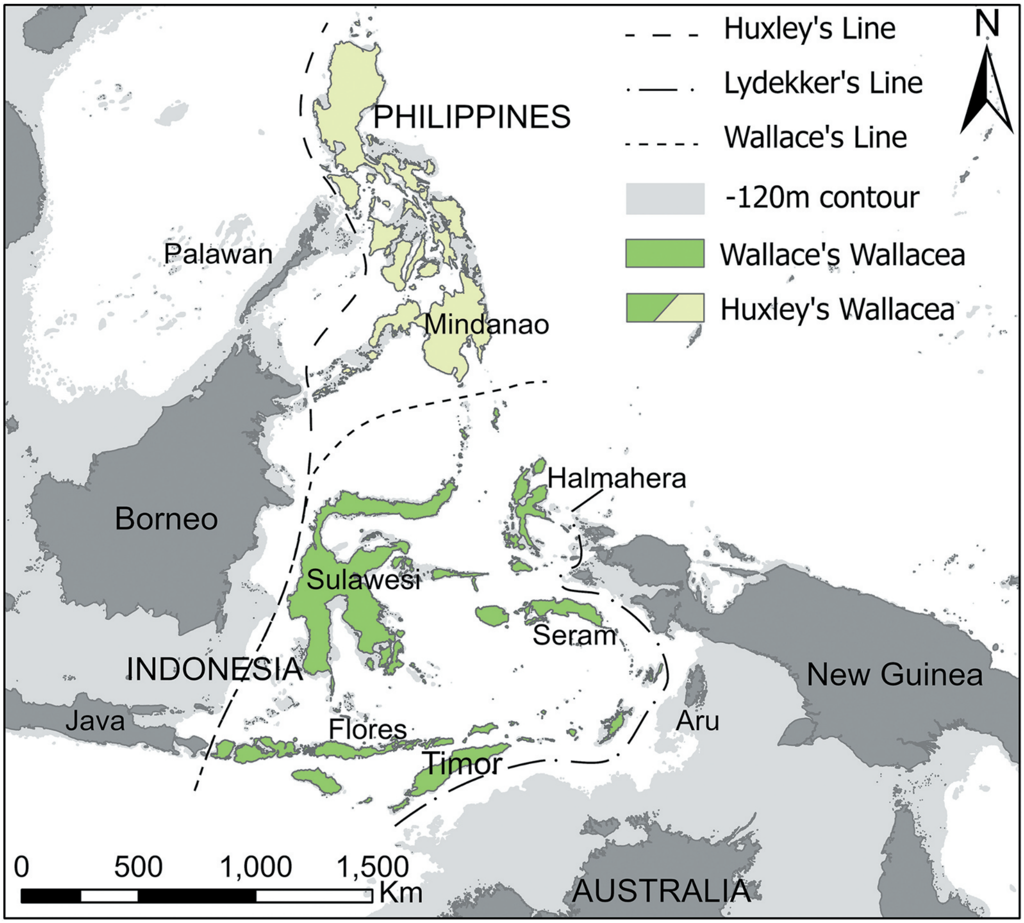

Figure 1. Map showing extent of Sunda and Sahul continental shelves (light grey) boardered by Lydekker's line to the east and Wallace's and Huxley's lines to the west. The islands of Wallacea as per Wallace's line are shown in dark green, while the Philippine islands included under Huxley's modification to Wallace's line are shown in light green.

and have produced a similar archaeological record to the rest of Wallacea; with arrival on the island of Ilin dated to at least 32,000 years ago (Pawlik et al. 2014; Pawlik and Piper 2018).

These maritime migrations must have involved competent seafaring technology and flexible economies as the new settlers were able to cross strong ocean currents and prevail on islands which had little in the way of terrestrial faunal prey (O'Connor, Ono, and Clarkson 2011; Roberts et al. 2020; Shipton, O'Connor, and Kealy 2021). After initial settlement, it appears that these island societies were stable, as there is no evidence for major cultural changes or inter-island material transfers for tens of millennia following initial colonisation (Moore et al. 2009; Shipton et al. 2019). However, at the end of the last glacial phase this changed dramatically. New forms of technology appear throughout the archipelago and obsidian from a single, as yet unidentified, off-island source is found in the archaeological assemblages on at least four islands (Reepmeyer et al. 2019), marking the onset of the world's earliest maritime network. Coincident with these changes, new highly standardised forms of shell beads appear, indicating that these technological innovations were accompanied by shared styles of personal ornamentation (Langley et al. in press).

Here we briefly outline the archaeological evidence for settlement in Wallacea and then focus on the major changes in technology and evidence for inter-island connectivity beginning in the terminal Pleistocene. We also explore the spheres of interaction implied by the occurrence of similar items of technology across the broader archipelago and Oceania. In doing this we build on and update an earlier effort by Bulbeck (2022) to examine cultural transmission and interaction zones using material culture traits. However, our focus is somewhat different to Bulbeck's being constrained to the Pleistocene/early Holocene and to cultural materials and customs mostly linking the southeastern Wallacean islands of Alor, Timor, and Kisar with each other and other parts of Wallacea.

Overview of the Wallacean archipelago

Wallacea is a major biogeographic transitionary zone, situated betwixt the continental landmasses of Sunda and Sahul, but having never been connected by land to either. Thus, all flora and fauna found on the islands, including hominins, must have arrived by crossing the oceans (Figure 1). Bounded on the east by Lydekker's line; which marks the eastern limit of oriental biota, and the west by Wallace's/Huxley's line; which marks the western limit of Australasian biota (Figure 1), the Wallacean islands contain a depauperate mixture of animals shared with, or diverged from, animals in Sunda and Sahul, including both marsupial and placental mammals (Simpson 1977). The size of the islands and their proximity to the Sunda or Sahul continental shelf influences the diversity and abundance of fauna that arrived and the duration of their successful colonisation, as per the equilibrium theory of island biogeography (MacArthur and Wilson 1967). Some 'good swimmer' taxa such as the stegodons, an extinct genus of proboscidean, travelled east from the Sunda mainland reaching as far as the island of Timor (Hooijer 1975; Louys, Price, and O'Connor 2016). Others such as the Komodo dragon (*Varanus komodoensis*) and marsupial phalangers (or cuscus), moved west out of Sahul until halted by Wallace's Line (Hocknull et al. 2009; Kealy et al. 2019). Only rodents and humans (Sunda dispersers) however, managed to cross both Wallace's/Huxley's and Lydekker's Lines (Figure 1), making it all the way across the Wallacean archipelago to reach Sahul.

As past sea level changes impacted these critical variables of island size and isolation (Kealy, Louys, and O'Connor 2016), the timing of these arrivals and successful/failed colonisations were further impacted by island profile and geographic location. A characteristic feature of the Wallacean islands are their high relief topography and steep bathymetric profile. Thus, while a few Wallacean islands combined with other islands during sea-level low stands, the size of most islands did not change as dramatically with sea level transgression and regression in contrast to much of Sunda and Sahul (e.g. Wurster and Bird 2014; Williams et al. 2018). The Wallacean islands also have marked variability in precipitation and vegetation. Those in the north receive higher rainfall and, prior to clearance for cash crops, had denser forest cover, whereas the southern islands are significantly drier and may have supported more open landscapes at times in the past. This variability in climate across the broad latitudinal range of the Wallacean archipelago has further implications when considering the arrival and survival of colonising animals and people.

Lower Pleistocene occupation of western Wallacea and the Philippines

Fossils and material remains left by archaic hominins dating back to the Middle and Early Pleistocene up to one million years ago have been found on islands in Wallacea (Brumm et al.

2010; Sutikna et al. 2016, 2018; van den Bergh et al. 2016; Ingicco et al. 2018; Tocheri et al. 2022), but are limited to the three large islands just to the east of Huxley's Line; Flores, Sulawesi, and Luzon (Figure 1). These large islands are notable for supporting medium to large-sized terrestrial prey species in the Pleistocene, such as rhinoceros and stegodon on Luzon, and stegodons, large land turtles, and Komodo dragons (*Varanus komodoensis*) on Flores and Sulawesi. In particular, the large islands of the Philippines and Sulawesi, close to the Asian mainland, are distinct for their diversity of medium-large endemic mammals such as dwarf buffalo (*Bubalus* spp.) and a variety of suids (Louys et al. 2021).

The early hominins who reached these islands seem to have utilised the large terrestrial game for their subsistence (Brumm et al. 2010; van den Bergh et al. 2016; Ingicco et al. 2018; Sutikna et al. 2018; Tocheri et al. 2022). Although at sites such as Liang Bua, small terrestrial species such as murids constitute the majority of the faunal assemblage, and may also have been prey (Tocheri et al. 2022, 49). That these early hominins did not succeed in onward eastern migration, even to islands on which large prey species were available, such as Timor and Sumba (Louys, Price, and O'Connor 2016; Turvey et al. 2017), suggests that they had limited maritime abilities and that the settlement of the larger western islands resulted from incidental rather than purposive sea crossings (Leppard 2015a and b; Shipton, O'Connor, and Kealy 2021; T.D'Cunha, Montenegro, and Field 2021).

Modern human settlement of the Wallacea Archipelago

Colonisation and settlement of Wallacea by modern humans in the Late Pleistocene was of an entirely different order. Modern humans successfully colonised the length and breadth of Wallacea, reaching Sahul by at least 50,000 years ago (Clarkson et al. 2017; Tobler et al. 2017). This maritime migration must have involved sea-faring technologies, craft, and versatile economic strategies, as the new settlers utilised the broad spectrum of resources encountered on the different islands. Two primary maritime routes through Wallacea were proposed by Birdsell in 1977 on the basis of the number and length of water passages between islands, and the size and height of target islands; a northern route through Sulawesi, the Maluku islands, to Papua; and a southern route crossing from Bali to Lombok, through the Nusa Tenggara archipelago to Timor, and across to Northern Australia (Birdsell 1977). While modelling efforts have suggested the northern route as most parsimonious for successful landfall in Sahul (Kealy, Louys, and O'Connor 2018; Norman et al. 2018), intensified field exploration over the past decade has failed to resolve either as the route of first passage. It is likely that the early colonists did not move onward in a unidirectional or least cost way, but rather that islands in proximity where currents and winds were favourable were visited and settled, regardless of whether this moved populations eastward. In this scenario modern human populations may have utilised both routes simultaneously.

Settlement of islands on the northern and southern route would have required markedly different subsistence strategies and technologies. The northern islands had some large to medium sized terrestrial game, at least in the west, while the drier southern islands were depauperate in terms of terrestrial prey species, at least by the time of modern human arrival. Although the largest of the southern islands, Timor and Flores, once had giant fauna such as stegodons, it appears that these were extinct prior to ca. 47,000 years ago when modern humans reached the islands (Louys, Price, and O'Connor 2016; Tocheri et al. 2022). The extinction of these larger species left just bats, snakes, lizards, and rodents as potential terrestrial prey, necessitating a focus on marine resources (O'Connor, Ono, and Clarkson 2011; Roberts et al. 2020).

Technological, social and demographic changes in the Terminal Pleistocene

Following the end of the glacial phase major technological, social, and demographic changes occured in Wallacea. About 16,000 years ago obsidian from an as yet unknown source makes its first appearance in archaeological assemblages in the southern Wallacean islands of Alor (Tron Bon Lei), Timor (Hatu Sour, Laili, Bui Ceri Uato, Matja Kuru, Asitau Kuru, Lene Hara), Atauro (Arlo), and Kisar (Here Sorot Entapa) (Figure 2). At about the same time new technology in the form of fishhooks, and standardised items of personal decoration also appear in the archaeological sequences of these islands. Ground shell adzes emerge in the record in the following millennia, a technology ethnographically recorded as used in the production of dugout canoes; watercraft that would have enabled the voyaging necessary to sustain this inter-island obsidian exchange network (Shipton et al. 2020a).

Obsidian and obsidian movement in the southern Wallacean islands

The earliest record of obsidian use in Wallacea comes from Makpan Cave on the volcanic island of Alor and is bracketed by dates of 40,000 and 22,000 years ago (Kealy et al. 2020). Bubog 1 on Ilin Island in the Philippines (at *ca*. 33–28 thousand years ago; Neri 2015; Pawlik 2021) and Tron Bon Lei shelter in Alor (at 22,000 BP; Samper Carro et al. 2016), also preserve early evidence of obsidian use. While the Bubog obsidian is thus far unsourced, obsidian artefacts with the same chemical signature have been recovered from the Ille cave and rockshelter site on Palawan, dated to 12,000 BP as well as undated artefacts from Alegria on Cebu (Neri 2015; Pawlik 2021), suggesting the presence of a Philippine obsidian exchange network involving at least three islands in the terminal Pleistocene (Figure 2).

An obsidian source locality has been identified on Alor, known as Kulunan, located approximately 15 km east of Tron Bon Lei. It is the dominant source exploited in the earliest levels of Tron Bon Lei (Reepmeyer et al. 2016), however, after a chronostratigraphic hiatus between *ca*. 18,000 and 12,000 years ago, a second and third source appear in the assemblage known as 'Group 1' and 'Group 2' which remain unsourced. One of these sources ('Group 1') has also been found in assemblages on Timor, Atauro, and Kisar, meaning it must be an exotic import to at least three of these four islands (Reepmeyer, O'Connor, and Brockman 2011; Reepmeyer et al. 2016, Reepmeyer et al. 2019). 'Group 1' obsidian is unlikely to derive from the islands of Timor, Atauro, or Kisar due to their geology. The fact that it only appears in the Tron Bon Lei sequence in the terminal Pleistocene, coincident with its appearance in the other island records, has been argued to indicate that it was also likely an import to Alor (Reepmeyer et al. 2019).

The Asitau Kuru site (formerly Jerimalai) at the eastern tip of Timor-Leste (Figure 2) dates to *ca*. 45,000 cal. BP. The exotic 'Group 1' obsidian first appears at Asitau Kuru *ca*. 17,000 years ago (Reepmeyer, O'Connor, and Brockman 2011; Shipton et al. 2019), although the dating of its first appearance, based on bracketing radiocarbon dates, deserves finer resolution. 'Group 1' obsidian artefacts were also found in the late Pleistocene levels of Laili in central-north Timor-Leste (Figure 2) (Hawkins et al. 2017). Notably, no obsidian was recovered from the inland sites of Uai Bobo 1 and 2 (Glover 1986). The lack of obsidian in these inland Timor sites is perhaps because this resource was directly linked to maritime exchange, and so only readily available to coastal communities (Reepmeyer et al. 2019). The VOC *dagh-register* of Joannes de Hartog who visited neigbouring Wetar Island (see Figure 2(a)) in 1681 emphasises the lack of 'communication or intercourse' between inland and coastal groups on the island (translated by Hägerdal 2019, 202–3). If

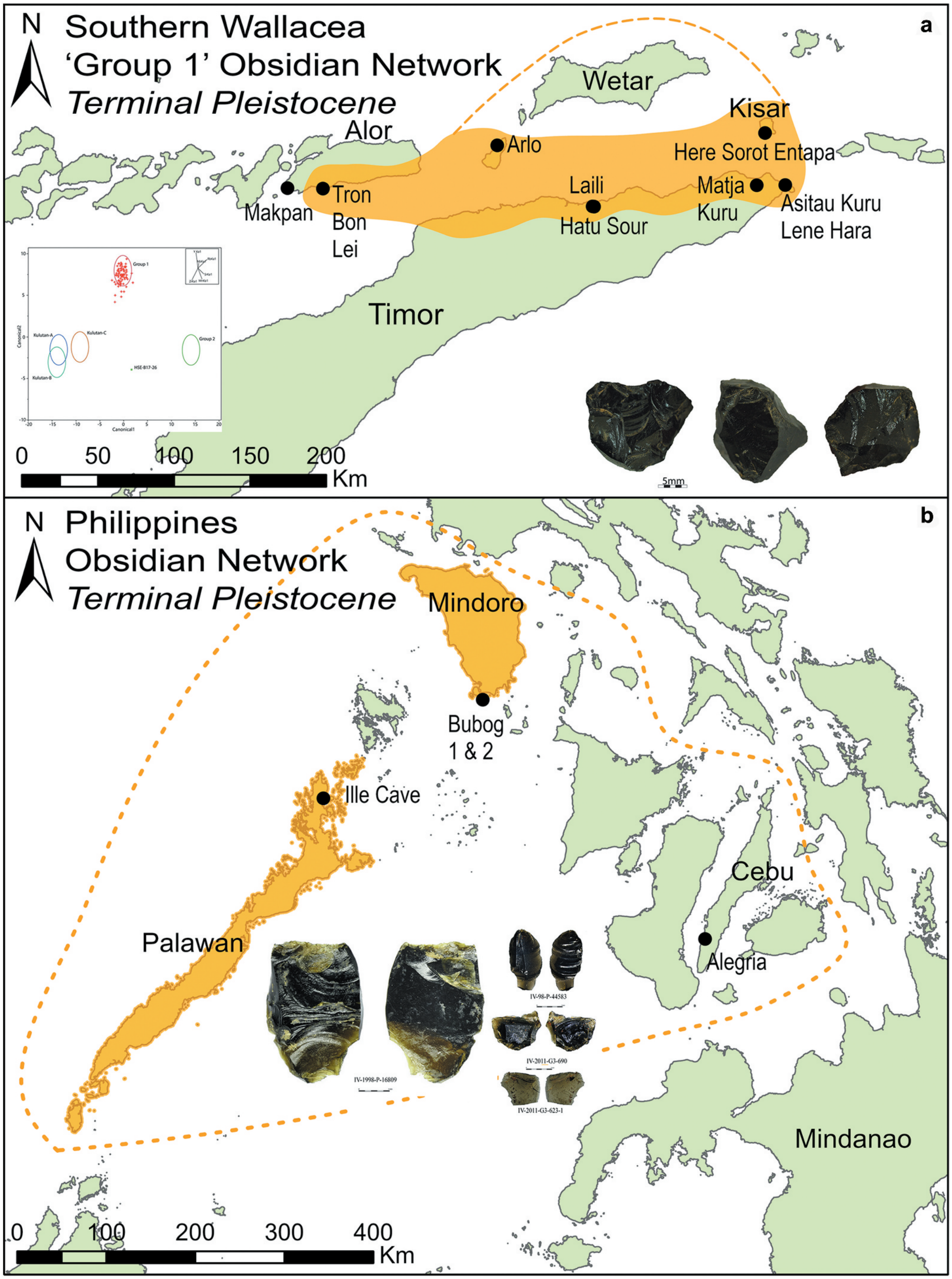

Figure 2. Terminal Pleistocene obsidian networks in Wallacea. a) The southern Wallacean 'Group 1' network incorporating the islands of Alor, Atauro, Timor, and Kisar. Graph inset from Reepmeyer et al. (2019: fig. 6), photo inset from Maloney et al. (2018): Figure 4). b) The Philippine island network incorporating the islands of Palawan and Ilin (Mindoro). Photo inset from Neri et al. (2015):Figure 3). The dotted line indicates possible extent of the networks.

widespread, such a division would account for the lack of obsidian movement from the coast into inland areas of the islands.

On the small island of Kisar to the northeast of Timor, occupation begins *ca.*16,000 years ago at Here Sorot Entapa (HSE) rockshelter (O'Connor et al. 2019). The HSE lithic assemblage is comprised of chert, quartz, and the exotic 'Group 1' obsidian, the latter found from the earliest level until about 9,500 cal. BP, when a chronostratigraphic hiatus occurs in the sequence (Reepmeyer et al. 2019). When the record recommences *ca.*4900 years ago, the exotic 'Group 1' obsidian is absent, the lithics are dominated by quartz, and pottery appears (O'Connor et al. 2019). It would seem that obsidian transport, at least to Kisar, had ceased by the late Holocene.

We currently do not know the location of the 'Group 1' source nor the extent of its movement throughout the archipelago. Geological assessment and the fact that 'Group 1' is found in greatest proportions in the east, suggests that it most likely derives from one of the volcanic islands to the east of Alor in the Banda Arc. Geological survey of the region in 1937 recorded notable obsidian outcrops in central-east Wetar island (Heering 1941). Other candidate islands are Romang and Damar as their geology is thought to be of similar age and origin to that of Wetar (Agustiyanto et al. 1994).

Fish hooks and intensification of maritime resource exploitation

Other significant changes in the archaeological records of the southern Wallacean sites coincide with the initial appearance of 'Group 1' obsidian. Carefully made single piece shell fish hooks of a variety of types and sizes are found in the archaeological assemblages of Kisar, Alor, and Timor from at least 16,000 cal BP (Figure 3) (O'Connor, Ono, and Clarkson 2011; O'Connor et al. 2017b, 2019;

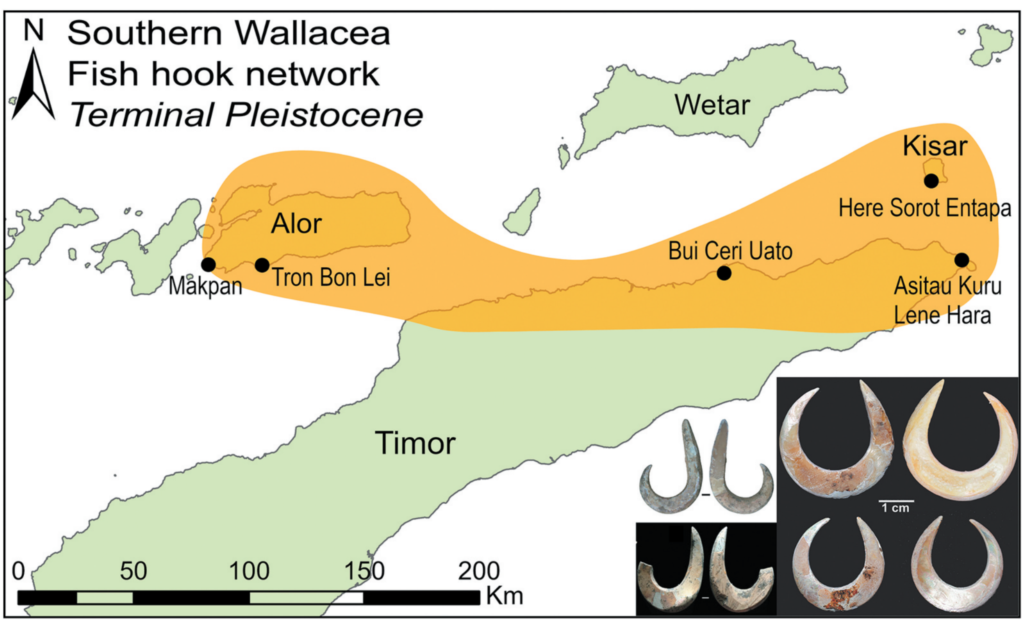

Figure 3. Shell fish hook network incorporating the islands of Alor, Timor, and Kisar during the terminal Pleistocene. Photo insets for jabbing hooks from Langley et al. (2021: fig. 8) and O'Connor et al. (2019: fig 7), and rotating hooks from O'Connor et al. (2017b: fig. 7).

Langley et al. 2021). Although fish remains occur from the time of earliest settlement in Makpan and Tron Bon Lei on Alor, and Asitau Kuru on Timor (O'Connor, Ono, and Clarkson 2011; O'Connor et al. 2017b; Samper Carro et al. 2016, 2018; Shipton et al. 2019; Kealy et al. 2020), no fish hooks have been found in these initial occupation levels. The appearance of fish hooks in these sites coincides with a step up in the intensity of fish exploitation. The large rotating hooks of the type found in the Alor sites are best suited for offshore fishing from watercraft (Reinman 1967; Allen 1996) and may signal an increased focus on pelagic species that occurred with improvements in seafaring technology. The size and shape of the hooks at both Tron Bon Lei and the largest of the hooks at Makpan (O'Connor et al. 2017b; Langley et al. 2021) indicate the capture of bigger fish than the specimens recovered from the sites (e.g. Samper Carro et al. 2016, 2018; Kealy et al. 2020). It is possible that these small-scale excavations are not representative of the full range of fish caught, or that large fish were consumed close to the point of capture.

The Kisar hooks are all of the jabbing variety and generally smaller than the Alor specimens, with the largest example being a little over 3 cm in shaft length. These hooks fit well with the size and type of fish remains recovered from Here Sorot Entapa; small individuals of carnivorous and herbivorous/omnivorous taxa which can be caught in-shore (O'Connor et al. 2019). As with Kisar, the majority of hooks thus far recovered from Timor have been jabbing, with the earliest record for the island from Asitau Kuru where a shell hook was bracketed by dates of 23,000 and 16,000 cal BP (O'Connor, Ono, and Clarkson 2011). Another fish hook, recovered from nearby Lene Hara, was directly dated to 10,706–10,252 cal. BP (O'Connor and Veth 2005). The single rotating fish hook thus far recovered from Timor is from the site of Bui Ceri Uato with bracketing dates of about 10,000 and 9,000 cal BP (Glover 1986).

These Alor and Timor-Leste sites witness major increases more generally in marine resource exploitation after the introduction of hooks including the intensified use of shellfish, crabs, and urchin, with the largest peaks coinciding with the rapid post glacial sea level rises of Meltwater Phase 1 (Kealy et al. 2020; Shipton, O'Connor, and Kealy 2021). To date fish hooks have not been found elsewhere in Wallacea in reliably pre-Neolithic contexts. To the east, possible hook blanks made of the same shell (*Rochia* sp.) have been recovered from Manus Island (dated to 9–5 ka) and New Ireland (dated to 24–20 ka) (Smith and Allen 1999; Spriggs 1997, 52), however the unformed nature of the specimens makes their identification as hooks ambiguous (Langley et al. 2021);

Shell adze technology in the Wallacean archipelago and beyond

Other changes in technology occurring at about this time also point to increased investment in maritime technologies. The earliest evidence for edge ground shell adze production in Wallacea comes from the Kelo 6 shelter on Obi Island in northern Maluku where it dates from *ca*.14,000 cal. BP (Figure 4) (Shipton et al. 2020a). Elsewhere in Wallacea, including Golo Cave and Buwawansi on nearby Gebe Island (Bellwood, Irwin, and Tanudirjo 2019), in Bubog on Ilin Island in the Philippines (Pawlik et al. 2014; Pawlik and Piper 2018), and Asitau Kuru in Timor (Shipton et al. 2020a), whole adzes and ground shell flakes detached from the edge of adzes have been recovered in early Holocene contexts. Early Holocene shell adzes are also known from Pamwak on Manus in the Admiralty islands north of New Guinea (Figure 4) (Spriggs 1997, 59–60). In the Talaud and Sula Islands complete shell adzes have been found in middle Holocene deposits (Tanudirjo 2001). All such adzes were made on the umbo or hinge section, as well as the folds, of *Tridacna* and *Hippopus* clams (e.g. Spriggs 1997, 59).

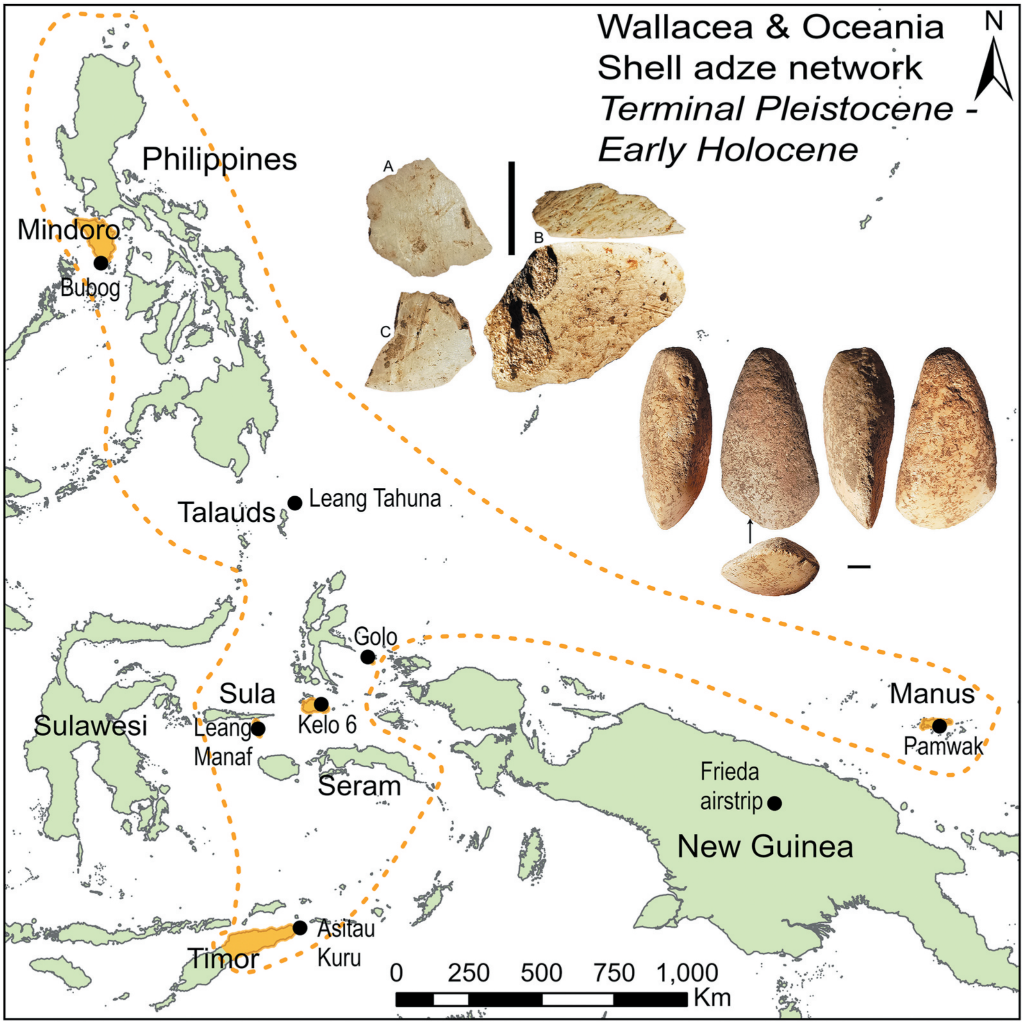

Figure 4. Shell adze network of Wallacea and Oceania from the terminal Pleistocene to early Holocene. Incorporating the islands of Ilin (Mindoro), Merampit (Talaud), Gebe, Obi, Sanana (Sula), Timor, and Manus. Dotted line shows possible extent of this network. Photo insets of ground shell flakes from Shipton et al. (2020b: fig. 12) and whole shell adze from Shipton et al. (2020a: fig. 9).

We think it is likely that shell adze technology was much more widespread than the current discontinuous distribution suggests (Figure 4) and has gone undetected in coastal sites. In many early excavations marine shell was not retained in its entirety but often only a column or bulk samples taken. Even when all shell is retained for analysis, small broken fragments are rarely analysed in detail, but merely weighed as unidentifiable shell. In these cases, flakes detached from the edges of adzes will have gone unrecognised. In addition, complete adzes are curated, long use-life artefacts so there will be relatively few to enter the archaeological record in the first place. On Timor eight caves and shelters were excavated prior to the first find of a pre-Neolithic shell adze, and then two complete adzes were found in close proximity in the same excavation square, suggesting either caching or perhaps adze maintenance activities in a discrete activity area within the shelter. Other multiple adze finds, such as those from Pamwak and the Golo adzes from Gebe are also suggestive of caches, further emphasising that these tools were valued and thus unlikely to be recovered in small excavations. Detached flakes from adzes will be the most reliable method of detecting such technology (Hiscock et al. 2016). Closer examination of the fragmentary shell from excavated assemblages is called for in order to address this.

The Kelo finds push the date of the earliest ground shell technology in this part of the world back into the terminal Pleistocene, and indicate that this technology may have a more continuous distribution across the archipelago than was hitherto appreciated. Whether this shell adze technology was shared throughout the Wallacean archipelago with a network extending north to the Philippines and east as far as Manus island (Figure 4), or was independently developed on the different islands in response to shared opportunities provided by their island environments and possibly sea level change, is unknown.

Shell appliqués and beads: a new style of personal ornamentation

Shell is also the material used for new and distinctive forms of personal decoration that appear in the terminal Pleistocene assemblages of Alor, Timor, and Kisar. Double-holed and single holed beads made on tabs of *Nautilus* shell have been recovered from sites on Alor (Makpan), Kisar (Here Sorot Entapa), Rote (Lua Meko), and Timor (Matja Kuru 2, Asitau Kuru, Bui Ceri Uato) dating to the terminal Pleistocene/early Holocene (Figure 5) (Glover 1986; Mahirta 2003; O'Connor 2010, 228; O'Connor et al. 2019; Langley et al. in press). One *Nautlilus* two-holed bead from Here Sorot Entapa in Kisar was recovered in a unit dated to 12,019–12,400 cal BP (ANU-47727) (O'Connor et al. 2018). Two directly dated double-holed beads from Makpan, Alor, overlap the age of the Kisar example

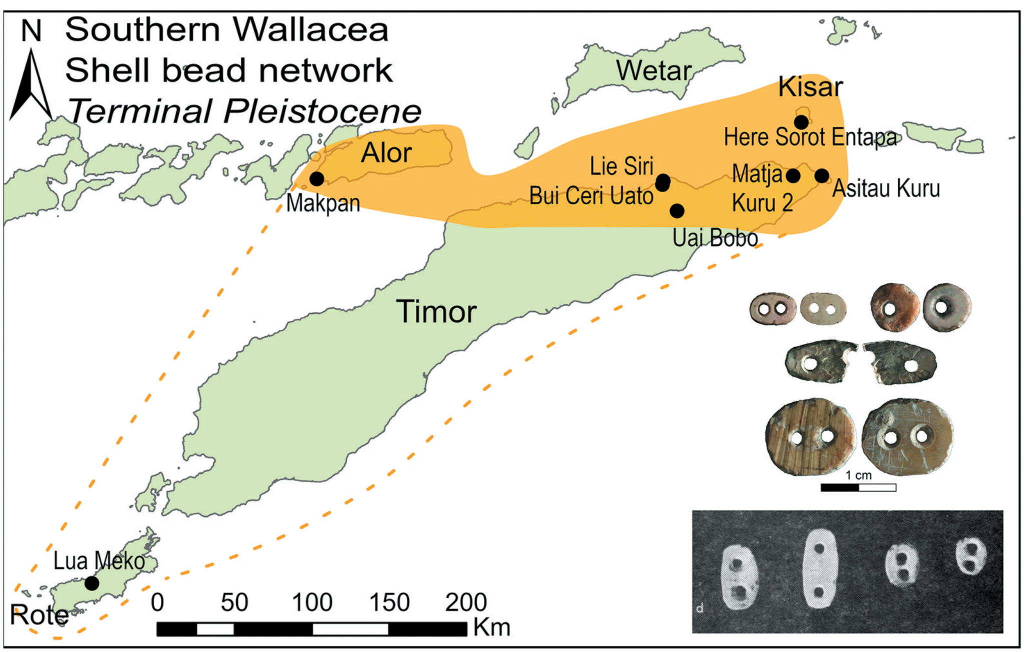

Figure 5. Double-holed appliqué bead network of southern Wallacea incorporating the islands of Alor, Timor, and Kisar. Dotted line shows possible extension of this network. Photo insets: colour from Kealy et al. (2020: fig. 12), black and white from Glover (1986: plate 32).

(Langley et al. in press). The drilled holes show evidence of wear from being sewn onto fabric. Double-holed *Nautlilus* beads have also been recovered from Bui Ceri Uato on Timor, from a context dated to *ca*.11,000–10,000 cal BP (Glover 1986).

Single-holed disc beads dating from about the same time are present on all three islands as well as Roti, with associated dates of *ca*.12,000–11,000 cal BP from the site of Lua Meko (Mahirta 2003, 54, 62). By about 7,000 BP, single-holed beads are also present in the Timor sites of Uai Bobo 2 and Lie Siri (Glover 1986). Disc beads were also recovered from pre-Neolithic excavations in Java, although the precise context and dating of these are uncertain (van Heekeren 1972, 98, 102). Van Heekeren (1972, 98) reports that Gua Lawa in Sampung, eastern Java, contained 'two miniature oval plates of mother-of-pearl pierced with two round holes.' These beads are likely manufactured from *Nautilus* shell rather than true 'mother-of-pearl' (abalone) (O'Connor 2010). Unfortunately, due to a lack of photographic or diagram evidence, it is not clear whether these disc beads are single or double-holed types. Figure 5 includes only the distribution of two-holed appliqué beads (with a possible continuation southwest to West Timor and Rote) as these almost certainly demonstrate shared notions of style in personal decoration that included beading sewn on to clothing or other fabric.

Mortuary and genetic evidence for maritime interaction in the Pleistocene

Evidence for exchange of ideas and customs can also be seen in mortuary treatments shared between mainland Southeast Asia and Wallacea during the Pleistocene/Holocene transition. Primary flexed burials are common in mainland Southeast Asia during the terminal Pleistocene being found in Vietnam, Thailand, the Malay Peninsula, and Java. Likewise, the oldest burial excavated at Tron Bon Lei (TLB-1), Alor dating to 11,100–12,600 cal BP, is a primary flexed burial of an adult female (Samper Carro et al. 2022).

Genetic research from the Wallacean islands is beginning to reveal the intricacies of early human ancestries throughout the archipelago, with distinct evidence for an increase in demographic movement across Wallacea in the terminal Pleistocene (Purnomo et al. 2021). In their study of mitochondrial sequences from modern Wallacean populations which expanded on the geographic extent of previous efforts, Purnomo et al.'s (2021) phylogeny revealed a significant westward movement of Papuan ancestry after the Last Glacial Maximum (LGM)(< 18,000 years ago). Similarly, a genomic study focused on the Philippines which incorporated over a thousand samples from modern indigenous Philippine peoples, also recovered evidence for the arrival of Papuan ancestry to Mindanao from about 15,000 years ago (Larena et al. 2021).

To-date the earliest successful recovery of human aDNA from Wallacea was from the 7,300 year old Leang Panninge burial in southwest Sulawesi (Carlhoff et al. 2021). Analysis of this mid-Holocene individual indicated ancestral divergence *ca*.37,000 years ago from a common ancestor shared with indigenous Australians and Papuans, likely reflecting the initial expansion of modern humans throughout Wallacea. However, what is interesting is that while some west-east movement may have occurred from Asia to Sulawesi after *ca*.37,000 years ago and before 7,300 years ago, the Leang Panninge sequence does not contain any evidence for the *ca*.15,000 BP east-west movement of Papuan ancestry detected in the two modern studies (Larena et al. 2021; Carlhoff et al. 2021; Purnomo et al. 2021). The presence of post-LGM arriving Papuan genes in the Indonesian islands to the east (e.g. Rote, Seram, etc; Purnomo et al. 2021), as well as the Philippines to the north (Carlhoff et al. 2021), indicates that this period of enhanced movement out of Papua, while wide ranging, was not universal in reach but rather sporadic in distribution, possibly the result of multiple rather than single waves of movement (Purnomo et al. 2021).

Discussion

One of the few ways to definitively identify prehistoric interaction networks is through the study of obsidian artefacts and their chemical sourcing. Research on obsidian resource use globally demonstrates that while transportation begins by 40,000 years ago, movement involving water crossings is rare prior to the end of the Pleistocene. In this respect it is useful to examine the evidence from Wallacea in the context of global data for the maritime capabilities of hunter-gatherers and the emergence of interaction networks.

Evidence of early maritime transport of obsidian is found in archaeological sites on mainland Japan, with obsidian artefacts sourced to Kozushima Island in the Izu Archipelago, dated from *ca*.38,000 BP (Ikeya 2015). Obsidian circulation on a larger scale has been identified from *ca*.19,000 years ago, covering the islands of Hokkaido and Sakhalin (Russian Far East), but transport could have been overland during the lowered sea levels of the LGM. Definite maritime transport is only demonstrated after *ca*.10,000 years ago when watercraft would have been needed to cross the newly formed La Pérouse Strait (Kuzmin 2017). Similarly, obsidian from the island of New Britain begins to be transported to adjacent New Ireland *ca*.20,000 years ago, but does not appear to move further until the Holocene (Summerhayes and Allen 1993). While slightly earlier in time than the southern Wallacean obsidian movement, it occurs between only two islands and thus is at a different scale. In the Philippines the earliest obsidian in Bubog 1 on Ilin Island dated at *ca*.28,000 years ago was suggested as an import from Near Oceania or Sulawesi (Reepmeyer et al. 2011; Pawlik 2021). However, this remains speculative as the source is unknown and movement is not demonstrated definitively until 12,000 years ago when the same obsidian is found in Ille cave/rockshelter, northern Palawan (Lewis et al. 2008; Neri 2015; Pawlik 2021). Thus, the southern Wallacean network currently stands as the earliest firm evidence of a maritime interaction network involving multiple islands found anywhere in the world.

Coincident with the appearance of the exotic Group 1 obsidian in Alor, Timor, and Kisar, is the appearance of shell adzes and fish hooks which would have facilitated maritime travel and resource use. We have previously argued that the creation of shell adzes in Wallacea is primarily related to the manufacture of dugout canoes (Shipton et al. 2020a, 2020b). This is supported by recent experimental evidence which suggests that reliable crossing of strong current flows, such as occur between Timor and Alor, would have needed the greater manoeuvrability, speed, and durability of dugout canoes rather than rafts (Normile 2019; Kaifu 2022). In many of the limestone islands where shell adzes occur suitable stone for adze manufacture is unavailable. In other islands such as Obi where hard igneous rock is available, ground shell adze production precedes stone adze production (Shipton et al. 2020b). Direct functional evidence for the use of shell adzes as hafted heavy-duty woodworking tools can be seen from the working edge scars and hafting residue on the Asitau Kuru adzes (Shipton et al. 2020a). In Micronesia, shell adzes were widely used for the construction of canoes before the introduction of steel (e.g. Loeb 1926; Ryan 1981; Bayman et al. 2012) and while rarer than stone, were widely used across the Pacific even where suitable stone for adze making was available (Intoh 2008; Radclyffe 2015).

Following the LGM, sea levels began rising *ca*.20,000 years ago, dividing some larger islands into multiple smaller islands and separating island communities (O'Connor et al. 2017a). Loss of landmass was not equally distributed, but dependant on the bathymetry of the coastal shelf. Western ISEA saw catastrophic inundation of coastlines, whereas the islands in eastern Wallacea did not see such dramatic changes in landmass due to their steep offshore profiles. However, several Wallacean islands were divided into multiple small islands (e.g. Alor and Pantar) and many gained longer and more productive coastlines. Indeed, research has shown that coastal populations in Wallacea showed substantial resilience during this period, even intensifying their use of marine resources (Pawlik et al. 2014; Samper Carro et al. 2016; Kealy et al. 2020; Shipton, O'Connor, and Kealy 2021). Parallel to the rising oceans, Wallacea experienced changes in vegetation cover. The more open savannah landscapes prevailing during the last glacial period were replaced during the early Holocene with closed rainforest (O'Connor et al. 2005a and b; Wurster and Bird 2014) potentially making access to inland environments for foraging more difficult and possibly prompting abandonment in some inland areas (O'Connor and Veth 2005; Shipton et al. 2020b). These environmental changes may have provided an additional incentive for island populations to focus more heavily on coastal resources.

Currently the evidence for Pleistocene and early Holocene fish hook manufacture and double-holed appliqué beads appears to map closely onto the 'Group 1' obsidian distribution, being restricted to the southern Wallacean islands of Alor, Timor, and Kisar. Adzes, however, have a far more extensive distribution encompassing parts of Near Oceania through to the Philippines. Whether the distribution of shell adzes reflects technological diffusion through an interaction network or, alternatively, whether adze technology was independently developed in different regions of its distribution, is currently unknown. It is interesting to note, however, that the similarities in our network distributions of both fishhooks and shell adzes, technologies which indicate a dedicated maritime subsistence focus, also appear to cover the regions which share a genetic history (Larena et al. 2021; Purnomo et al. 2021). The lack of evidence for the dedicated pursuit of maritime subsistence strategies on Sulawesi (e.g. Ono et al. 2020), alongside the lack of post-LGM connection to Papuan populations demonstrated by the genetic studies (Carlhoff et al. 2021), indicates that this was a maritime network which only incorporated those coastal island communities for whom maritime activity was the focus.

We have elsewhere hypothesised that the impact of sea-level rise was to accelerate maritime interaction in order to retain communication and guarantee sustainability for communities faced with changing resources and separation from kin by insulation (O'Connor et al. 2019; Shipton et al. 2020a). This is clearly evident in the movement of obsidian and shared personal decoration in southern Wallacea. From the time of Malinowski's (1922) seminal ethnography on *Kula* exchange in the Trobriand Islands there has been a great deal written about socially motivated trade, interaction networks and balanced reciprocity. Social networks provide resilience for populations on depauperate islands, and the reciprocity relationships cemented through inter-island exchange, marriage and information sharing, may have been as or more important than the resources moved across the network (e.g. O'Connor et al. 2019).

In southern Wallacea, shell beads and appliqué, and obsidian tools, were likely merely part of a much larger corpus of exchange items including perishable goods such as food stuffs and organic manufactured items which have not preserved in the archaeological record. In describing inter-island trade in the southern Massim, Macintyre and Allen (1990, 126–7) list shell beads, shell necklaces, fibre belts with shell appliqué, *Conus* shell armbands, stone artefacts in various stages of manufacture, and formerly obsidian, as categories of goods primarily used as medium of ceremonial exchange. But they also point out the futility of attempting to disentangle utilitarian/subsistence exchange from ceremonial exchange because all 'exchanges were performed with ceremony' and while 'rituals for the direct exchange of commodities such as food, pots and mats were less elaborate, many of these goods were transacted in marriage and mortuary ceremonies which were highly ceremonial', and included prestations of shell valuables (Macintyre and Allen 1990, 127). Even if the shell beads and appliqué in southern Wallacea were locally produced in each island of the network, they may still have been exchanged or worn emblematically during ceremonies to signal the exchange partnership relationship.

The terminal Pleistocene timing of the emergence of maritime interaction networks in the Philippines and southern Wallacea has parallels in other parts of the world. There appears to have been a global intensification of maritime interaction following the Last Glacial Maximum (LGM), when sea-levels rose episodically, and sometimes rapidly, until around 7000 years ago. Although the extent of the evidence for pre-LGM activity on islands in the Mediterranean is still much debated (e.g. Simmons 2014; Knapp 2020), the exploitation of island obsidian resources and its distribution to the continental mainland provides firm evidence for maritime activity during the transition from the terminal Pleistocene to the Early Holocene *ca*.12,000 years ago (Broodbank 2013). This evidence for increased voyaging and the onset of material transport in the Mediterranean has also been attributed to selective pressure on humans resulting from reductions in temperature and environmental changes accompanying the Younger Dryas (12,900–11,700 BP) as well as to sea level rises during this time (Ammerman 2010). Maritime exchange networks, would appear to be an innovation in response to rapid sea level rise and environmental change in the terminal Pleistocene, and a key factor in the intensification of island societies across the globe.

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