Chapter

Island Migration, Resource Use, and Lithic Technology by Anatomically Modern Humans in Wallacea

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Abstract

Island migration and adaptation including both marine and terrestrial resource use and technological development by anatomically modern humans (AMH) are among the most significant issues for Pleistocene archaeology in Southeast Asia and Oceania, and directly related to the behavioral and technological advancements by AMH. This paper discusses such cases in the Wallacean islands, located between the past Sundaland and the Sahul continent during the Pleistocene. The Pleistocene open sea gaps between the Wallacean islands and both landmasses are very likely the major factor for the relative scarcity of animal species originating from Asia and Oceania and the high diversity of endemic species in Wallacea. They were also a barrier for hominin migration into the Wallacean islands and Sahul continent. We summarize three recent excavation results on the Talaud Islands, Sulawesi Island and Mindoro Island in Wallacea region and discuss the evidence and timeline for migrations of early modern humans into the Wallacean islands and their adaptation to island environments during the Pleistocene.

Keywords: early modern human migration, island adaptation, resource use, lithic technology, Wallacea

1. Introduction

Most archeological evidence of the earliest anatomically modern human (AMH or *Homo sapiens*) migration and maritime adaptation in the Asian region, including maritime Asia such as Wallacea and Japan, are dated to after 50 ka and mainly after 40 ka. The term "Wallacea" refers to Alfred Russel Wallace who proposed a zoo-geographic boundary line of the animal species of Asia and Oceania, which runs between Lombok and Bali, Borneo/Kalimantan and Sulawesi [1] and is now known as the Wallace Line. This zoogeographic line was soon after extended to the North and between Palawan Island and other Philippine islands by Thomas Henry Huxley and is known as Huxley's modification of the Wallace Line or simply Huxley's Line (**Figure 1**).

We recognize Wallacea as the archipelago between east of the Wallace-Huxley line and west of New Guinea and Australia that were part of the old continent of Sahul in Oceania. Geographically, Wallacea includes most of the Philippines except

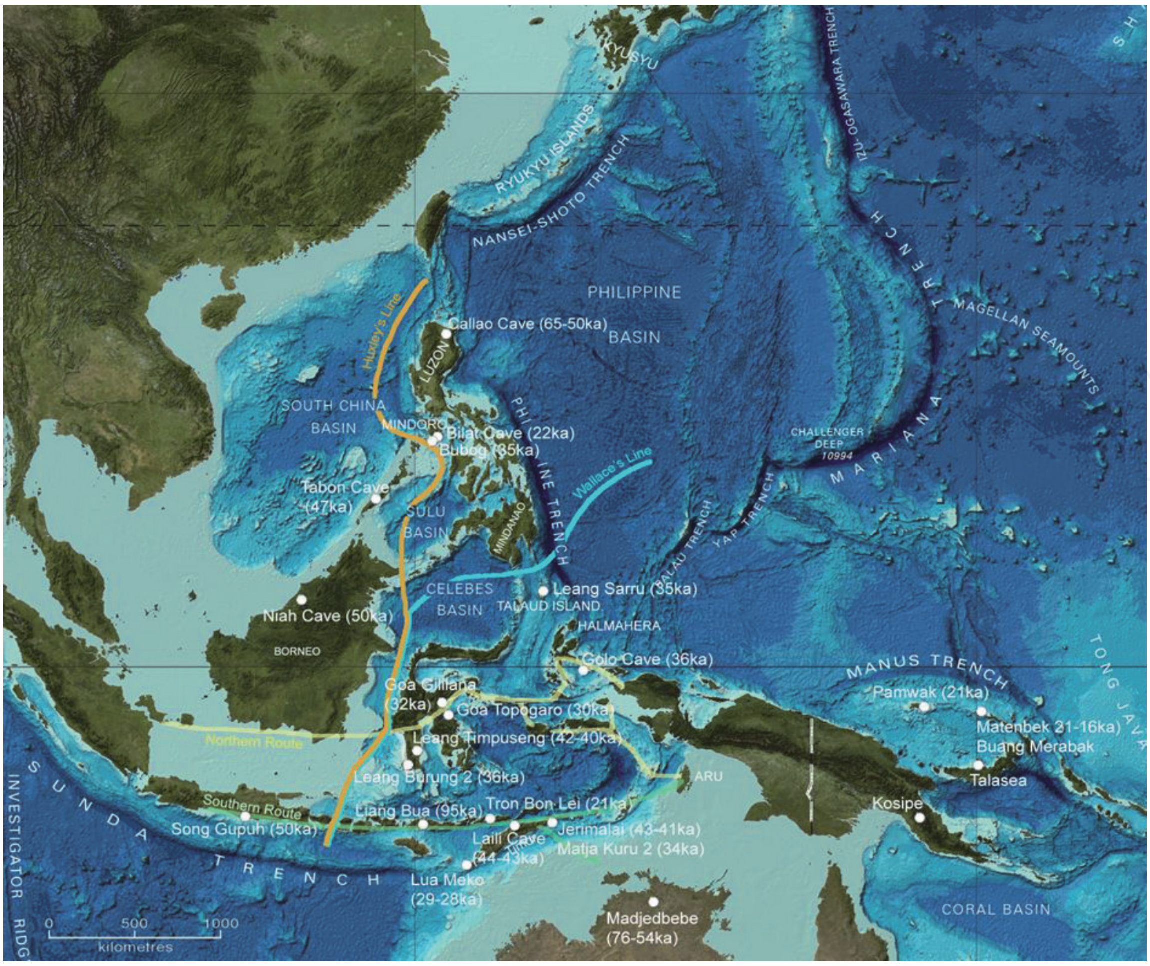

Figure 1.
Major Pleistocene sites in and around Wallacea Archipelago with Wallace Line. Image reproduced from the GEBCO world map 2014, www.gebco.net.

Palawan and East Indonesian islands including Timor Island - divided into Indonesian West Timor and independent East Timor (or Timor Leste). Currently, the oldest possible traces of AMH in Wallacea appear in several sites in Timor around 44 ka and 42 ka [2, 3], as well as rock art dated to as early as 44 ka on the basis of uranium-series dates of overlying speleothems in South Sulawesi [4].

In Flores Island, Liang Bua provides a long sequence of human presence over 90 ka, though the site was originally occupied and used by a small-bodied species known as *Homo floresiensis* [5, 6], who was possibly related to the *Homo erectus* group, and their early migration could have been before 840 ka by crossing at least 19 km distance of sea gap. Although the upper layers of Liang Bua provide evidence of modern human occupation, the exact date of boundary between modern humans and *Homo floresiensis* is yet unclear and estimated to be around 50 ka by the excavation team [7]. Similarly, in the Philippines the presence of fossils attributed to a small-bodied hominin dubbed "*Homo luzonensis*" was found in Callao Cave, Northern Luzon, and dated to c. 67-50 ka [8]. Currently, the earliest evidence for the appearance of modern humans in the Philippine islands east of the Wallace-Huxley line comes from several AMS 14C-dates ranging between 28 and 35 ka cal. BP that were retrieved from shell midden deposits at Bubog 1, a rockshelter on Ilin Island in Mindoro Occidental [9]. An earlier human presence is indicated by cultural and faunal remains in deposits underneath the radiocarbon-dated layers.

On the Sundaic part of the Philippines, Tabon Cave in Palawan Island has delivered ancient fossil remains of modern humans, and several U-series directly date them to an age as early as c. 47 ka [10]. However, the dates' high standard errors raise doubts on their reliability. Probably more accurate are recent AMS dates on charcoal from a hearth feature and associated with Fox's "Flake Assemblage III" [11], with dates between 39 and 33 ka [12]. Meanwhile, Niah Caves in Borneo Island, located southwest of Palawan and part of Pleistocene Sundaland, provided the earliest radiocarbon evidence of modern human presence with a number of AMS 14C dates ranging from 49 to 44 ka cal. BP [13]. Also, old sites associated with AMH were found in Australia and New Guinea, which formed Sahul land in the past. Madjedbebe site in Australia provides OSL dates of early modern human occupation over 60 ka [14, 15], while Kosipe Mission site in New Guinea Highland provides 14C dates of 49-44 ka [16]. All these current evidences taken together indicate the early appearance of AMH in Island Southeast Asia (ISEA) including Wallacea and Oceania could date back to around 50-47 ka, when they migrated by open sea crossing to the islands in Wallacea and to Sahul in Oceania.

In maritime Asia, another region where early modern humans were required to cross the sea to migrate, are the islands of central and southern Japan. While the large northern island, Hokkaido was partly connected with the continent, the deep Tsugaru Channel formed a sea gap between Hokkaido and Honsyu to the south. Honsyu and Kyusyu were partly connected with each other, although they were never connected to the Korean peninsula during glacial periods and a gap of at least 50 km remained. The chronology from over 100 sites in Honsyu Island now dates back to around 40 ka [17]. The southern part of Japan is mainly composed of the Ryukyu Islands. Most of the islands in Ryukyu were 100-200 km away from each other and the early traces of AMH are currently dated to around 30 ka. Such archeological data tentatively show that the early sea crossings of 50 km distance by *Homo sapiens* to the Japanese Islands could be as old as 40 ka, while the migration into the remote islands in Ryukyu Islands by sea crossing with 100-200 km distance commenced around 30 ka [18].

Although the early AMH migrations to Wallacea and Sahul could be slightly older than the migration to the Japanese Islands, both cases demonstrate new abilities and skills of AMH or *Homo sapiens* to colonize different island sizes and environments in maritime Asian regions. Based on such understanding, this paper firstly summarizes (1) possible early migration routes and dates as well as their lithic and resource use into Wallacea by AMH, then (2) reports some latest archeological cases by our archeological investigations in Wallacea and (3) discusses possible AMH island adaptations and migration strategies in Wallacea during the Pleistocene with comparative view of other island regions in the world.

2. Human migration and dispersal into Wallacea and Oceania

When following the current archeological traces, only modern humans had reached Sahul and Oceania by sea crossing via Wallacea. There are some evidences of earlier human species in Luzon, Sulawesi and Flores in Wallacea [5, 8, 19] but there are no traces of early humans before *Homo sapiens* in other islands so far. The possible traces of early human species, including *Homo floresiensis*, indicate that *Homo sapiens* was not the first species to reach Wallacea, though all other evidences tentatively indicate that it was only *Homo sapiens* who colonized most of Wallacea, including its remote and small-sized islands. From this understanding, one of the most significant topics for the early modern human migration into Wallacea and Sahul is to investigate the maritime technology and capacity to adapt to changing environments that enabled early *Homo sapiens* to colonize islands in Wallacea and Sahul.

For early human migration from Wallacea into Sahul, there are basically two major routes that have been suggested as "northern" routes from Sulawesi to

Maluku Islands into the region of New Guinea and "southern" routes leading into northern Australia [20]. Along the southern routes, the previous archeological studies have been conducted in the islands of Flores, Alor, and Timor (mainly in Timor-Leste), and have so far discovered some early sites occupied by modern humans dating back to 44 and 42 ka [2, 21, 22]. The appearance of *Homo sapiens* at Liang Bua site in Flores Island (see **Figure 1**) could be as old as 50-48 ka [7], though there is no clear evidence of modern humans by this age yet. Since the site was occupied by *Homo floresiensis*, we need more solid data to confirm when this early human species disappeared or was replaced by modern humans in Flores. On the other hand, Asitau Kuru, formerly named Jerimalai Cave, located along the eastern coast of East Timor (**Figure 1**) is one the oldest prehistoric sites left by modern humans and is dated to 42-38 ka [3]. There is no direct fossil evidence of modern humans in Asitau Kuru, though the site produced the oldest evidence of pelagic fish exploitation from 42 to 38 ka and the oldest shell-made fishhooks dated to 23-16 ka [21, 23], thus the site is believed to have been used by modern humans.

Along the northern routes, on the other hand, excavations have been conducted in Talaud Islands, Sulawesi, and Northern Maluku Islands. Among them the oldest evidence for presence of AMH comes from South Sulawesi, from rock paintings at some cave sites and direct U-series dates as old as 43 ka [4, 24], with the earliest 14C dates in South Sulawesi dated to 36 ka [25]. Other sites older than 30 ka along the northern routes are Golo Cave in Gebe Island (**Figure 1**) dated to c. 36 ka [26, 27], Leang Sarru in the Talaud Islands (**Figures 1** and **2**) dated to 35 ka [28–32], and Bubog 1 in Mindoro Island (**Figure 1**) dated to >35 ka [9, 33]. None of these sites produced early modern human fossil remains, however, if the U-series dates of the rock paintings are correct, they can be considered as evidence of early modern human appearance in Sulawesi, as rock paintings are now recognized as a marker for the arrival of *Homo sapiens*.

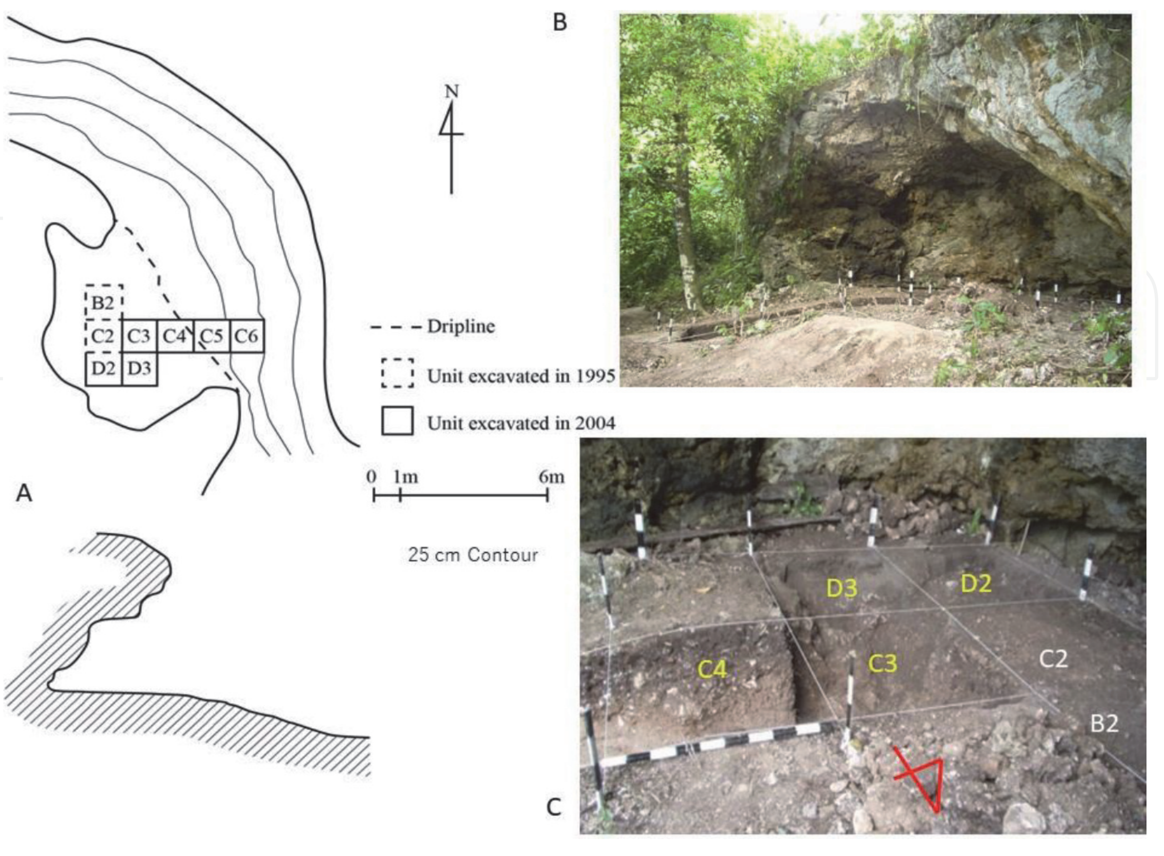

Figure 2.
Plan (A) and front view (B) of Leang Sarru with excavated units (C).

The dates of the Sulawesi rock paintings are also contemporary with some of the early modern human sites in Timor including Asitau Kuru, thus the appearance of modern humans could be as old as 44-42 ka in Wallacea, along both the northern and southern routes. Considering inter-visibility between islands, however, the northern route would have provided an easier path for early modern humans to reach Sahul [34]. On the other hand, by use of coastal-viewshed analysis and ocean drift modeling, Bird and colleagues propose that the probability of randomly reaching Sahul by any route is <5% until ≥40 adults are “washed off” an island at least once every 20 years [35]. Thus, they conclude that early migration by modern humans to Sahul could have been done by intentional voyage rather than by unintentional drifting [35]. If based on such understanding, the early modern humans who crossed into Wallacea might have developed their island and maritime adaptation before their first migration into Sahul, possibly by 50-45 ka, as well as after the initial migration, during the late Pleistocene from 45 to 12 ka. As described above, there are no archeological sites attributed to early modern humans older than 45 ka in Wallacea yet. We mainly report on some major Pleistocene modern human sites in Wallacea between 35 and 12 ka and compare these with other early dated sites to characterize the lithic technology and discuss the use and exploitation of available resources.

3. Resources use and lithic technology in Wallacea

3.1 Case 1: Archeological evidences from Leang Sarru Rockshelter, Talaud Islands

Leang Sarru is a limestone rock shelter located along the eastern coast of Salibabu, part of the Talaud Islands (**Figure 1**). The site is situated in an uplifted coral limestone block about 15 m above sea level and about 400 m inland from the current coast of Salibabu. The Talaud Islands have been located over 100 km away from their neighboring islands since the late Pleistocene, thus the modern humans undertook sea crossings of over 100 km to reach the Leang Sarru site. It is uncertain, however, if the early people reached the islands by intentional voyage or just as a result of drifting or other unintentional voyage.

The site was first excavated by Tanudirjo [30, 31] who in 1995 opened two 1 × 1 m^2 test-pits (B2 and C2) and excavated in 10 cm spits to a depth of about 80–90 cm below ground surface. He identified four sedimentary layers with thousands of chert lithics and shell remains. Later, Ono and *Balai Arkeologi Manado* (Institute for Archeological Research in Manado) re-excavated the site opening 6 m^2 of 1 × 1 m grids (D2, D3, C3, C4, C5, C6) in 2004 [28, 29, 32]. This excavation revealed three cultural layers (corresponding to Tanudirjo’s Layers 1 to 3) before reaching a hard, calcareous deposit (possibly corresponding to Tanudirjo’s Layer 4). Thousands of lithic and shell remains were retrieved during the excavation, but no mammal and fish bones were found, similar to the previous excavation by Tanudirjo [30, 31]. The lack of mammal bones possibly indicates that edible animals were scarce in the Talaud Islands. In fact, the Talaud Islands in modern times have no land mammals other than about 14 species of bat, 5 species of rat, 4 species of flying fox (*Pteropus* spp.), and 2 species of cuscus (*Ailurops ursinus* and *Strigocuscus celebensis*).

The 14C dates on marine shell indicate that Layers 3 and 4 (in Tanudirjo’s excavation) accumulated during the late Pleistocene between 35 and 32 ka and the lower part of Layer 2 accumulated during the final stage of the Last Glacial Maximum (LGM) around 21-18 ka. The upper part of Layer 2 and possibly the lower part of Layer 1 formed during the early Holocene, around 10-8 ka [28]. No 14C dates are available for the periods between 27 to 21 ka and 17 to 10 ka, thus it is possible that the shelter might not have been inhabited during these periods. All the evidence possibly shows that the shelter had been occupied during at least three different periods in the late Pleistocene and early Holocene, an interpretation consistent with the tentative conclusion reached by Tanudirjo [30, 31]. The 2004 excavation produced 9465 lithic artifacts that were categorized as flake tools, flakes, cores, chips and chunks mainly made of chert (**Figure 3A–D**), and igneous rock hammerstones, together with 3371 NISP (Number of Identified Specimen) of marine shell, land snail, crustacean, and sea urchin were excavated from all the layers. On the other hand, earthenware sherds (n = 580) were recovered only from the upper layer and modern surface. They are mainly Metal Age pottery, after 2000 BP.

In terms of resources used by early modern humans in the Talaud Islands, the excavated shellfish remains (n = 3281, 26 kg) were sorted into 53 taxa and 23 species, mainly belonging to marine shells and land snails. One species each of

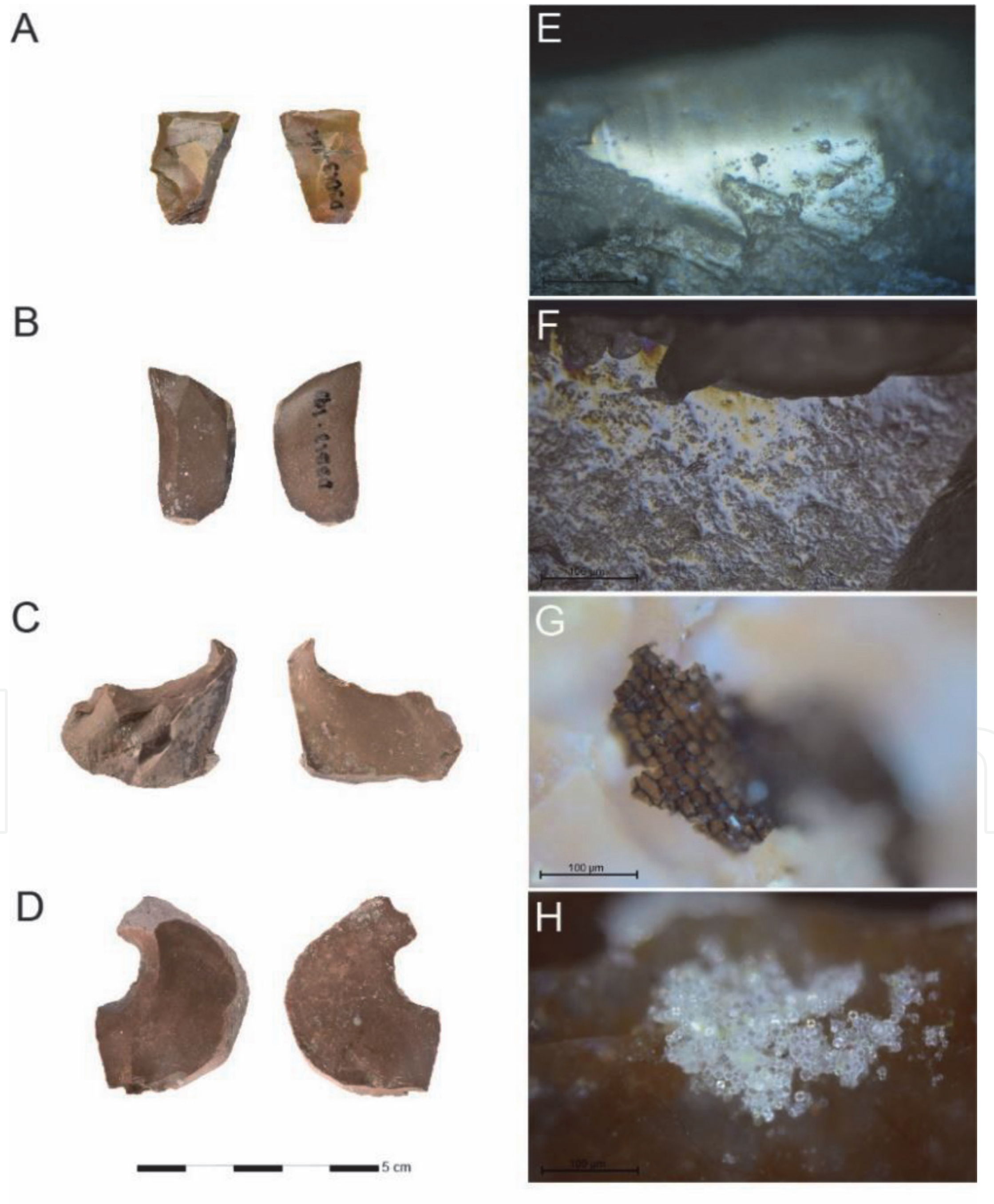

Figure 3.
Leang Sarru lithic tools (A-D) and corresponding plant micropolishes (E, F) and residues (G, H) along their edges.

crustacean (Brachyura) and sea urchin (*Heterocentrotus mammillatus*) were also identified as marine resources. The analysis of the shell remains confirmed that *Turbo* spp. (e.g. *Turbo marmoratus, Turbo setosus*), *Nerita* spp. (e.g. *Nerita balteata, Nerita undata*), and *Trochus* spp. (e.g., *Trochus maculatus, Trochus niloticus*) were the most important shell resources for the inhabitants of the site. Among them, the *Turbo* spp. and *Nerita* spp. were the most abundant in number, though in terms of size and actual meat value, the much larger *Turbo* spp. and *Trochus* spp. were more important in terms of food and protein sources [28].

For their temporal change, Layer 3 dated from 35 to 32 ka produced 33 species of shellfish taxa along with crustaceans and sea urchins. The dominant shellfish in the layer are intertidal to subtidal rocky shore species such as Neritidae (*Nerita balteata*), Patellidae, Muricidae, Haliotidae, and Chitonidae as well as *Turbo* spp., which are basically subtidal species. However, the total amount of marine shellfish is yet small in number (NISP = 859) during 35 to 32 ka. On the other hand, Layer 2B dated to 21 and 17 ka which corresponds to LGM produced a higher number and greater variety of species (n = 1456, 42 species). Among the marine shellfish species, the number of Neritidae, Turbinidae, and Trochidae families (particularly *Trochus maculatus*) increased dramatically, while the number of intertidal shell species such as *Haliotis varia* and land mollusks such as *Pythia* spp. slightly decreased. Such increase of shellfish remains in Layer 2B may indicate more active exploitation of marine shellfish resources during the LGM, despite the greater distance of the site from the coastline at the time. Alternatively, the site might have been more intensively used during this period.

The number of shellfish remains dramatically decreased in Layer 2A (N = 516) as well as in Layer 1 (N = 450), which together were dated to 10-8 ka. In Layer 2A, however, some subtidal and coral rubble–dwelling species belonging to Fasciolariidae (*Latirus nagasakiensis*) and Tridacnidae (*Tridacna maxima, Tridacna crocea*) increased in numbers. The increase of such coral rubble–dwelling species may indicate warming of sea and air temperatures and renewed growth of coastal corals after the Holocene. In contrast, the major subtidal and intertidal species such as *Turbo* sp., Trochus sp., *Nerita* sp., *Cellana* sp., and Chiton sp. considerably decreased after the Holocene in Leang Sarru [28].

For lithic analysis, Fuentes and colleagues (2019) selected 183 artifacts with 360 potentially used areas (PUA) or working edges to undergo multi-level microscopic use-wear analysis [32, 36, 37]. The samples have a median weight of 5.53 g and maximum dimensions of 30.8 mm (length) by 26.6 mm (width) by 9.3 mm (thickness). Microscopic analysis found intensive micropolishes on lithics formed by direct and prolonged contact with plants (**Figure 3E, F**). Such interpretation is also supported by the preservation of plant remains on unretouched and notched tools. The notched tools (**Figure 3C, D**), initially recorded by Tanudirjo [30, 31] were designed and employed for extraction of plant fibers. Although more evidence is needed, the plant fibers were possibly used as binding to support attachment of the lithic implements to a shaft.

Our microscopic analysis also detected plant residues deposited on the retouch scars and along the immediate working edge (**Figure 3G, H**). Among the analyzed material, plant remains such as tissues, starch, phytoliths, and fiber were preserved on 51 artifacts, 15 coming from the Pleistocene deposits and mainly dating to the LGM, and 36 from the Holocene layers [38]. The residues on the stone tools provided direct evidence of plant working. Additionally, we identified stone tools with impact scars, residues, scarring along the hafting boundary, sliced into scalar scars, and polishes that indicate production and use of hafted tools. The results of SEM-EDX analysis show that one residue sample which exhibits drying cracks, is highly organic in composition [32].

3.2 Case 2: Archeological evidence from Goa Topogaro in Central Sulawesi

Goa Topogaro or Topogaro Caves are located along the eastern coast of Central Sulawesi (**Figure 1**). They are c. 3.5 km distant from the current coast in Morowali District and about 75 m above current sea level. Goa Topogaro is composed of three large caves (Topogaro 1-3) and four rockshelters (Topogaro 4-7) which are located along the wall of the upper doline at 90 m above sea level. Since 2016, the Pusat Penelitian Arkeologi Nasional Indonesia (National Center of Archeological Research) and R. Ono have conducted excavation of two caves (Topogaro 1 and 2) and one rockshelter (Topogaro 7). Here, we report on the excavation results of Topogaro 1 and 2 (**Figure 4**), since both caves have traces of human occupation from the early Holocene and late Pleistocene [39], while Topogaro 7 is mainly an early Metal Age burial site [40].

Topogaro 1 is the largest cave in the Topogaro complex. It has a floor area of around 500m^2, and measures 24 m in width, 25 m in length and a maximum height of about 20 m, and faces northwest. Over 30 broken wooden coffins with human skeletal remains were found on the cave floor with fragments of prehistoric pottery, Chinese and European ceramics, chert flakes including finely retouched tools, and shell. The wooden coffins and the variety of Chinese and European ceramics show that the cave had been also used as a cemetery in more recent times, while the amount of chert flakes indicate the cave was used in later prehistoric times. Topogaro 2 is located south-west of Topogaro 1, and both caves are connected to each other by a narrow passage. Topogaro 2 is 15 m wide and 24 m deep width with a maximum height of about 12 m and faces north. The floor size of Topogaro 2 is about 360 m^2.

Two trenches in the northern (Trench A, 1 × 4 m trench area) and southern part (Trench B, 2 × 3 m trench area) were excavated in Topogaro 1 (10 m^2 in total). Both

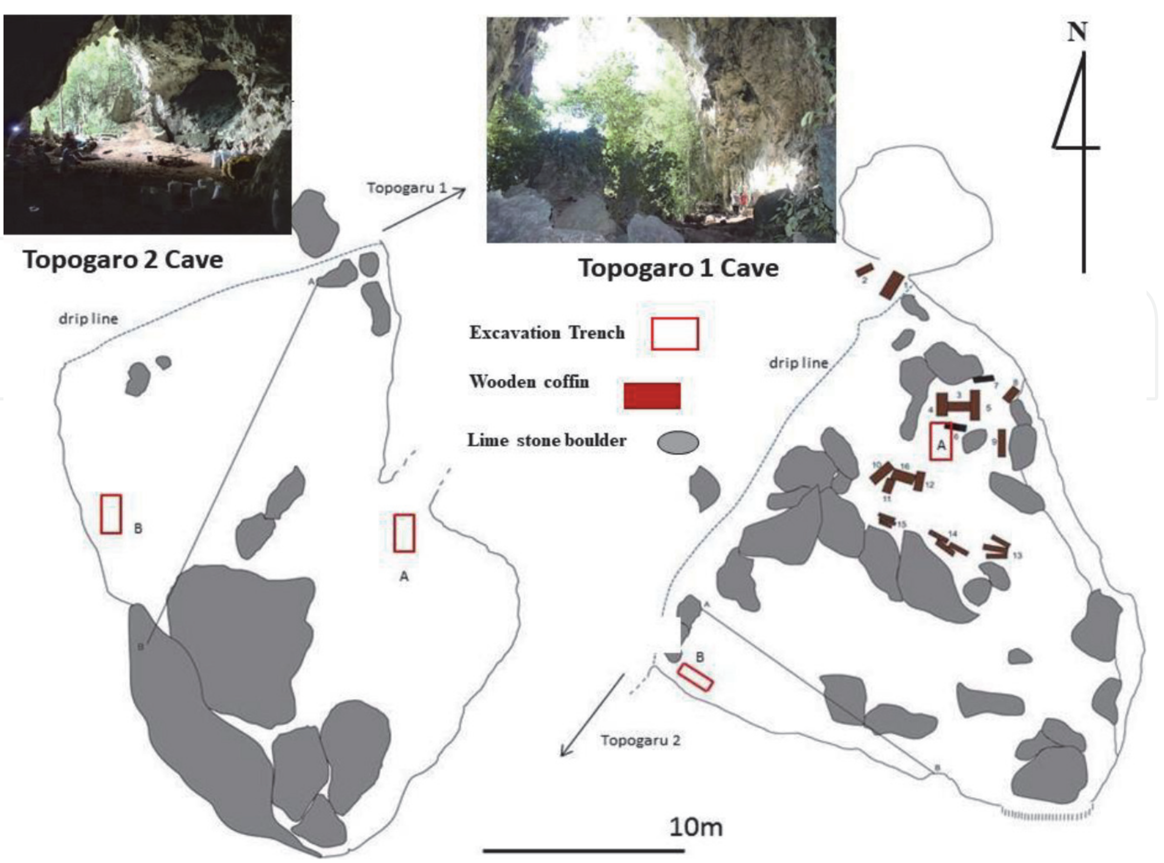

Figure 4.
Mouth views and plans of Topogaro 1 and 2 caves with excavation area.

excavations in Topogaro 1 exposed limestone rockfall at about 100 cm depth from the surface and have not yet reached the bed rock. Basically three layers are confirmed down to around 1 m depth and all the acquired 14C dates indicate occupation during the Holocene; Layers 3-2 as early Holocene during 10,000 to 8000 BP, and Layer 1 as late Holocene with burial human remains, pottery, glass beads, and metal materials after 600 BP. In Topogaro 2, Sector A along the eastern wall (2 × 3 m) and Sector B along the western wall (2 × 2 m) were excavated (10 m^2 in total) down to about 300 cm depth during 2016 and 2018 field seasons, although the bed rock was not reached. Eleven layers were identified in Sector A, containing shells, animal bones, and lithic flakes. Among the upper layers, Layer 2 produced a large number of shell remains. Layers 3, 5, 7, 8 and 10 produced significant amounts of lithic artifacts, mainly chert flakes while Layers 4, 6 and 9 contained very few or no artifacts, indicating a discontinuous occupation of the cave [40]. The results for Sector A indicate four occupation phases: (1) Late Pleistocene (c. 29-26 ka cal. BP/ Layer 9-11); (2) terminal Last Glacial Maximum (LGM) (c. 16 ka cal. BP/ Layer 6-8); (3) early Holocene (c. 10 ka cal. BP/ Layer 3-4); and (4) early Metal Age (c. 2.3 ka cal. BP/Layer 1-2).

Lithic artifacts, bone tools, shellfish and animal remains were mainly excavated in the Topogaro Caves. Bone tools and marine shells were only retrieved from the Holocene layers in Topogaro 1, albeit in large numbers. Topogaro 2 also produced a few bone tools and shells, mainly from the upper Holocene layers, while from its late Pleistocene layers mainly lithics and some animal remains were recovered. The majority of the mammal remains from the Pleistocene layers in Topogaro 2, belong to murid (rat) and chiropteran (bat) species. With few exceptions, they are mainly small in size and could be interpreted as natural cave deposits and not left behind by humans (e.g. [2, 22]). The bone elements for these small mammals include femur, humerus, tibia, ulna, radius, pelvis, mandible, premaxilla, teeth and canine. For chiropteran bones, at least one fruit bat species (Pteropodidae) and one insectivorous taxon were identified but the exact species is yet unknown [39].

In terms of larger sized mammals and other animals, wild pigs (Suidae) mainly Babirusa (*Babyrousa* sp.) and Anoa (*Bubalus* sp.), and as middle to large-sized mammals, marsupials (mainly Phalangeridae), reptiles like snakes (Serpentes) and lizards (Lacertila), as well as variety of mollusks were excavated from Topogaro 2. In general, the remains of wild pigs were commonly recovered both from the Holocene and Pleistocene layers in Topogaro caves, while Anoa were mainly excavated from the Pleistocene layers [39]. A phalanx of Anoa is associated with some chert flake tools and charcoals dated to 29 ka cal. BP in Topogaro 2. For shellfish remains, both bivalvia and gastropod species are excavated from the Pleistocene layers in Topogaro 2. The major gastropod families are Thiaridae while Cyerenidae are the dominant bivalve species. They both occupy fresh and brackish water habitats in river and mangrove environments. Limited numbers of Arcidae, Conidae, Neritidae, Potamididae shells also indicate shell fishing of marine and brackish water species to some extent [39]. The numbers and volume of mollusks are quite limited in the Pleistocene layers and significantly increase in the Holocene layers.

The Pleistocene layers in Topogaro 2 produced a variety of lithic tools mainly made of chert (**Figure 5A, B**). For example, the 1 × 1 m square excavated down to 3 m in depth produced a total of 252 lithic artifacts weighing 1920 g. Two complete chert flakes from Layer 11 (around 3 m depth) are associated with a phalange of Anoa and a few charcoal samples, one of which was dated to 29 ka cal. BP. Microscopic traces on these flaked tools indicate processing of hard materials, especially animal bones. Secondary edge scarring along their working edges reveals chopping motion associated with butchering (**Figure 5E, F**). The middle layers dated to around 16 ka cal. BP and the terminal LGM produced some blade-like flakes of

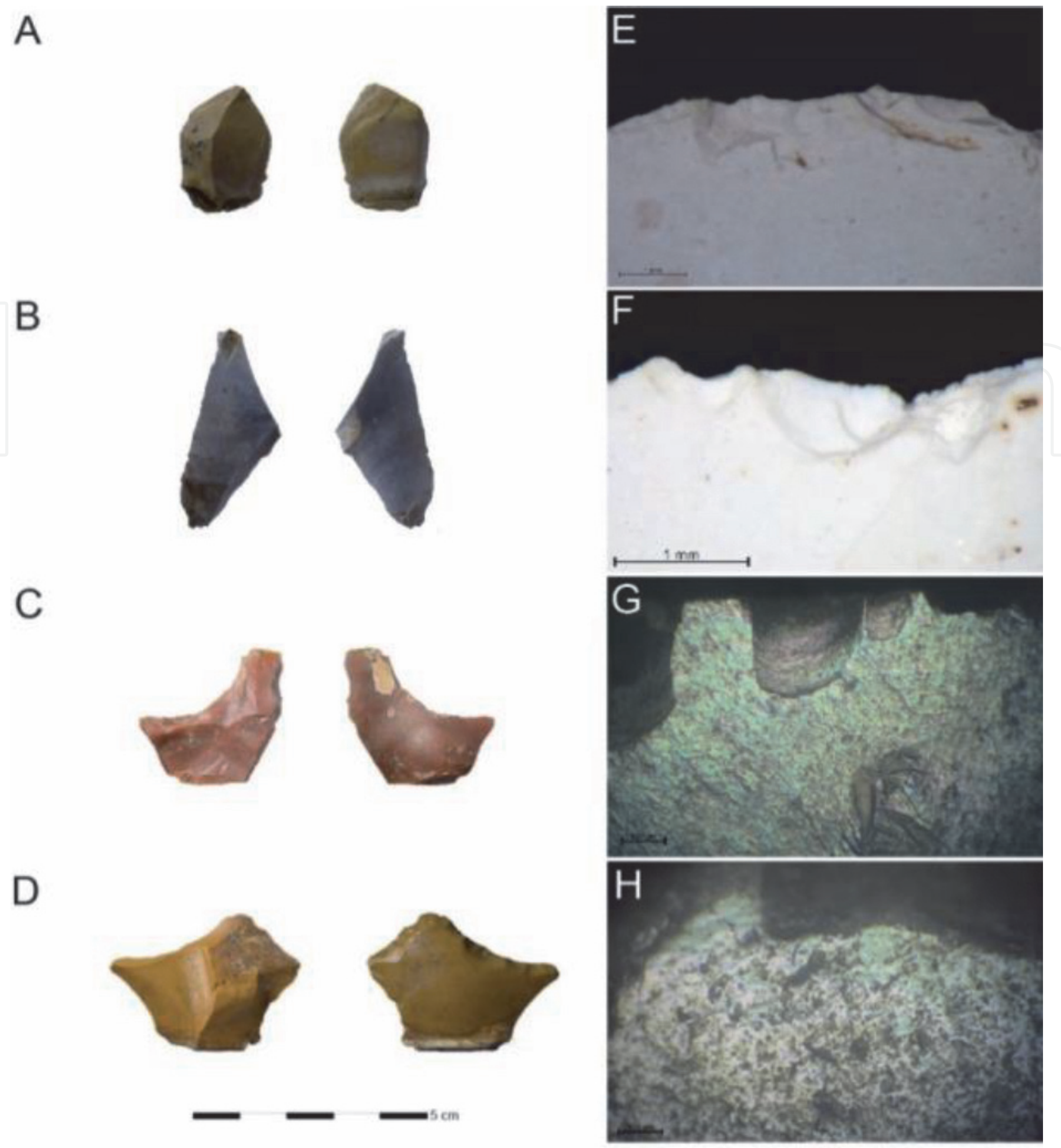

Figure 5.
Topogaro lithic tools (A-D) and use-wear traces of plant-working on their edges. E, F: edge scarring; G, H: micropolish.

white and yellowish chert, with ventral scars that were either caused by use or retouch. Some of these flakes display potlid fractures which might be heat-related. The flat polishes and diagonal and transversal striations on these tools indicate prolonged contact with phytolith-rich plants through scraping during the terminal LGM (**Figure 5G, H**). Retouched tools were recovered in Topogaro 1 during the Holocene period (**Figure 5C, D**).

3.3 Case 3: Archeological evidence from Bubog 1 rockshelter on Ilin Island, Mindoro

Ilin Island is a small elongated island just off the coast of Mindoro Occidental at its southern end and situated along the direct route from Sundaland (via Borneo and Palawan) to the Wallacean part of the Philippines. East of Huxley's Line, the island was close to the northern end of Pleistocene Palawan and possibly served as a steppingstone for the migration of early humans into the main Philippine archipelago. Ilin Island is part of the municipality of San Jose and separated from the mainland by the narrow, c. 900-1300 m wide Ilin Channel (**Figure 6**). It is mostly composed of bedded, coralline and fossiliferous limestone of the Pliocene Famnoan Formation with a small area of volcanic flows in its northeast. Most of the island is highly prone to karstic erosion and possesses numerous caves and rockshelters [33].

Among the over 40 caves and rockshelters discovered during initial surveys in 2010 and 2011, four sites have been excavated, Salamagi, Bubog 1 and 2, and Cansubong 2. Excavations focused mainly on Bubog 1 and 2, two rockshelters close to each other and located at the southeastern end of Ilin Island [9, 33, 41, 42]. Both sites face east and are situated at an altitude of *c.* 30 m amsl (Bubog 1) and 42 m amsl (Bubog 2). Bubog 1 is between 40 and 50 m long with a rock overhang in excess of 4 m wide. Its platform was disturbed by three more or less circular shaped pits that were dug by treasure hunters to a depth of over 1 m in the misconceived belief that they would find gold or other treasure. The pits cut through deposits of marine shells and exposed a well-stratified archeological shell midden. The edges of the treasure hunter pits were straightened in the course of the archeological excavation to provide vertical profiles for drawing and recording, and the pits were conjoined in the following seasons (**Figure 7**).

By 2016, the excavations in Bubog 1 had reached a depth of c. 4 m below the surface and exposed silty terrestrial deposits with a few artifacts, including a fully worked bone fishing gorge [9] (**Figure 8A**). While no more marine shells appear in those layers, the remains of pelagic fishes still provide evidence for open sea fishing [43]. The shell midden stratigraphy is connected to a radiocarbon chronology beginning at c. 4 ka cal. BP near the surface to 28-33 ka cal. BP at the lowest shell midden layer 9/9a (**Figure 7**). The absence of sufficient organic material prevented 14C dating for the layers below the shell midden, however at least an age of older than the 33 ka cal. BP retrieved from a *Geloina coaxans* shell from the lowest shell midden layer above can be assumed [9].

Associated with the shells from the midden deposits were several pebble and pebble fragments as well as fish remains and mammal bones. These animal bones were mainly from the endemic pig *Sus oliveri*, with few remains of deer (*Rusa marianna and Cervus alfredi*) and tamaraw (*Bubalus mindorensis*) as well as rodents, notably the cloud rat *Crateromys paulus*, known only from Ilin Island [44] and lizards [9, 33, 43]. While the use of the pebbles was obviously for breaking open the larger marine shells, flaked lithics were extremely rare in the shell midden [33]. Instead,

Figure 6.
Location and aerial view of Bubog 1 and 2 sites on Ilin Island.

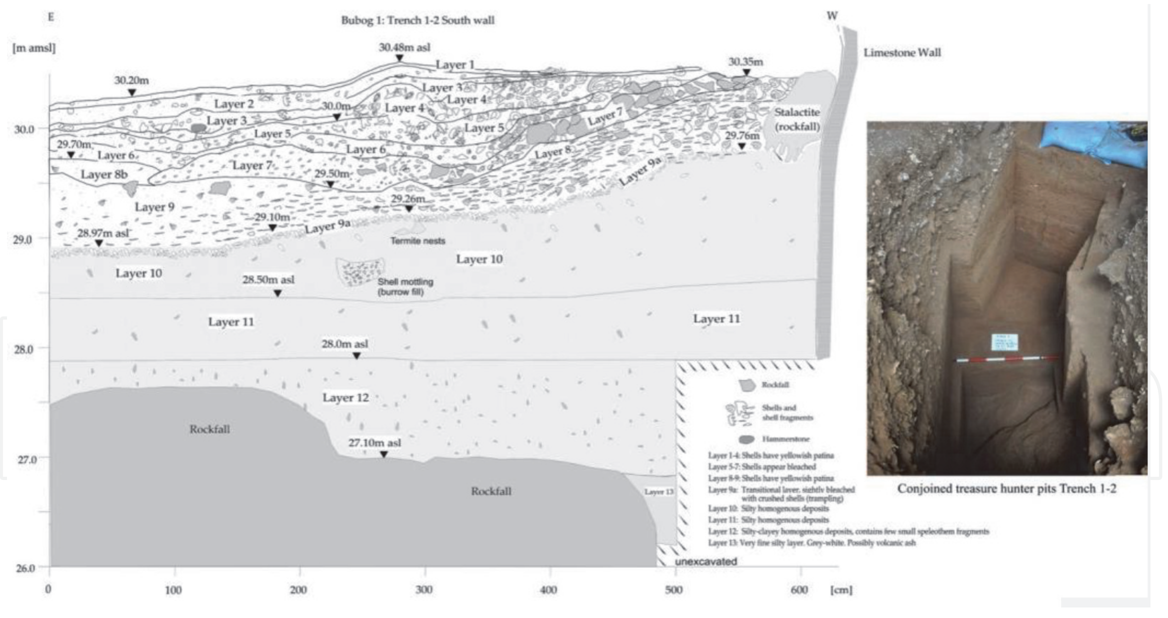

Figure 7.
Profile of Bubog 1 excavation trench (South wall).

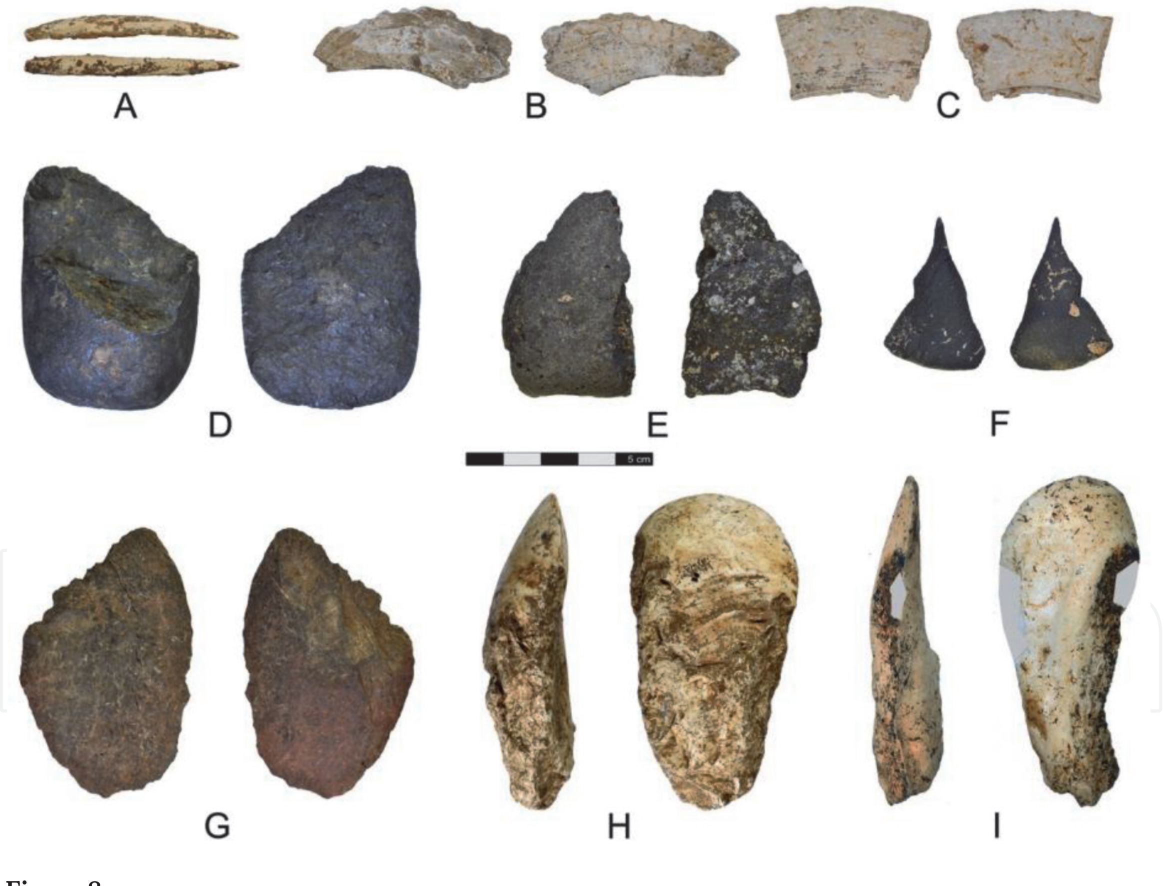

Figure 8.
Selected artifacts from Bubog and Bilat - shell adzes (H, I) and flaked tools (B, C), fishing gorge (A), pebble fragments (D–G).

pebble fragments broken during use, were picked up and re-used for a variety of activities (**Figure 8D–G**), functionally similar to flaked tools made of chert [45].

This finding is quite intriguing since chert flakes were observed in the layers below the shell midden. The finds of several flaked shell tools, including a symmetrical edge-ground shell adze made of giant clam (**Figure 8H**), throughout the midden might suggest that readily available raw material was preferred over chert which does not occur on the island but must be acquired on the mainland of

Mindoro [9, 42]. On the other hand, the finds of several small flakes made of obsidian, a material that does not appear naturally on Mindoro nor any of the neighboring islands, provides clear indication that the prehistoric settlers on Ilin Island had the means to access remote sources through open sea voyaging [46].

Beyond the main habitation area of Bubog 1, two 1 × 1m test pits on the eastern area of the rockshelter and outside the rockshelter were opened. While the outside trench was sterile down to a depth of 1 m, the remains of a burial were uncovered in the other. The remains of an adult interred in a tightly flexed arrangement, directly AMS-dated to c. 5 ka cal. BP., was recovered. However, no grave goods were identified. The use of flat limestone slabs to provide a base and a cover for the grave, however, indicated an organized burial [47]. The appearance of the flexed burial tradition across mainland and Island Southeast Asia is suggestive of Ilin Island being connected to a sphere of socio-cultural interaction that dealt with the immaterial world within emerging belief systems in the region [9, 48, 49].

Bubog 2 covers a leveled rectangular platform of c.18 m in length (in N-S direction) and about 6 m in width. The platform is surrounded by high ceilings and walls to the north, south and west, and two large rock falls to the east. No treasure hunter pits, or other disturbances were observed in Bubog 2. Beginning in 2011, four trenches were opened. While the trenches exposed shell deposits, although less dense than in Bubog 1, several hearth features (unlike in Bubog 1) appeared in the upper part of the stratigraphy.

Radiocarbon dating associates them to rather recent events and an occupation of the site until the 16th century AD. Below, a series of AMS 14C dates provide a chronological sequence of currently between c. 11-3.6 ka cal. BP. The retrieved marine and terrestrial fauna are similar to Bubog 1, although the deposited marine shells are significantly less numerous than in Bubog 1 [9, 33]. Also, the paucity of flaked lithic artifacts is similar to Bubog 1, as well as the appearance of pebble hammerstones and flaked tools made of Tridacna and Conus shells.

From the early Holocene deposits of Bubog 2 stems a large adze preform made of Tridacna shell that remained for some reason unfinished and was instead used as a heavy-duty chisel-like tool. Direct AMS 14C-dating of the shell preform delivered an age of c. 9 ka cal. BP which is the currently earliest indication for the utilization of shell adze technology [9]. The analysis of macrobotanical remains returned the use of *Canarium hirsutum* nuts as early as 10.7 ka cal. BP, obtained by a direct AMS 14C date on a charred nutshell fragment, and yams (*Dioscorea alata*) in the early-mid Holocene, which may suggest that these plants were already being managed on Ilin Island around the terminal Pleistocene/early Holocene [33]. For Bubog 2, a macrobotanical study of dry and mineralized plant fragments has identified several woody vines from Annonaceae, Dilleniaceae, and Mimosaceae families in early/mid Holocene contexts that were probably used for making ropes, cordage and wicker-work [50].

Another site simultaneously excavated by the Bubog team is Bilat Cave in Sta. Teresa on the mainland of Mindoro. The cave is located 7.5 km north of Bubog and is composed of three connecting chambers. The first chamber opens to the landside of Sta. Teresa, faces northeast and contains a fairly leveled platform of c.18 m in length (in N-S direction) and about 6 m in width. A dense shell midden covers the entire surface in the cave's eastern part. This chamber is connected to two other chambers that have both openings to the sea, facing Ilin strait in west and southwest direction. They are almost at sea level and the present cave floors show signs of occasional flooding. Nonetheless, test excavation revealed a stratigraphy of about 2 m until the water table. Several AMS 14C dates on charcoal and shell of c. 13.7 and 21.5 ka cal. BP indicate human presence in southern Mindoro during the LGM and terminal Pleistocene [9]. Also, a shell adze was found in Bilat (**Figure 8I**), and direct dating returned an age of 7.4-7.2 ka cal. BP, almost identical to the date of the shell adze from Bubog 1 [9, 42]. These dates complement the chrono-stratigraphic sequence of Bubog 1, where a hiatus between 11 and 27 ka was observed, suggesting a more or less continuous human presence in this area over the past 35 ka [9, 51].

4. Discussion

4.1 Island migration during the Pleistocene

The current archeological evidences show that AMH who arrived in ISEA already possessed the ability for sea crossings over 80 km distance. They reached Wallacea and Sahul (Australia and New Guinea) by at least 50 to 45 ka, and by 40 to 30 ka had arrived at the Japanese and Ryuku Islands in maritime Asia. There is no material evidence for reconstructing the early seafaring technology including their vessels, although the authors found evidence for the processing of grassy plants potentially for the manufacture of cords, bindings and woven materials, such as baskets, nets and ropes from the traceological analysis of lithic tools from Leang Sarru and Goa Topogaro [32, 38, 39]. However, as Bird and others show [52], the early migration into Sahul required intentional seafaring. The bamboo raft hypothesis is so far the most supported model [53, 54] for human migration in Wallacea and Sahul regions. The trial by Thorne and Raymond to build a 15 $\times$ 2 m bamboo raft with a 2 m^2 square sail of matting on a 2 m short mast revealed that such a raft could travel at 4-5 knots per hour speed in a light breeze [54].

After the initial migration(s) to Sahul, the nautical skills of those early migrants could be further developed during 35-20 ka in Wallacea, Oceania and also in the Ryuku Islands in East Asia. For instance, the excavations at Leang Sarru have shown that AMH already reached the Talaud Islands by crossing a distance of over 100 km at least by around 35 ka in Wallacea. Although the exact route of this migration to the islands is not known, it appears likely that many islands in Wallacea were already colonized by AMH at the time that the remote Talaud Islands were settled. Correspondingly, voyages to the Bismarck Archipelago and Solomon Islands from Sahul occurred between 40 to 30 ka [55–58]. While the initial settlement of New Guinea, New Britain, and New Ireland required voyages of up to 100 km, the colonization of Buka in the Solomon Islands by 28 ka or earlier required a minimum sea voyage of 140 km and possibly 175 km [59].

In East Asia, most of the Ryuku Islands were settled by c. 30 ka, even though some islands such as Miyako and Ishigaki were located over 150-200 km distance from other islands or the Asian continent during the late Pleistocene. The current experimental archeological study of the Pleistocene voyages from Taiwan (connected to the Asian continent during the late Pleistocene) to Yonaguni Island, which is one of the Ryuku Islands and nearest to Taiwan and currently located about 110 km west of Taiwan, indicates possible use of paddling to cross the fast running Black current (>2 knot speed in average from south to north direction) to reach the Ryuku Islands from Taiwan or Asian continent [18, 60]. In that study, the trial using a bamboo-made raft-boat in 2018 failed to cross the current [60], while the dug-out canoe with 6 people as paddlers in 2019 succeeded to reach Yonaguni Island in about 48 hours of voyage [60]. Although the earliest dug-out canoe found in Japan is dated to 7500 years BP, Kaifu pointed out that many Pleistocene sites in Japan produced edge-grounded adze/axe that were dated back to between 40 and 30 ka which have been considered as canoe making tools, and such evidences suggest the possible use of dug-out canoes by modern humans during the late

Pleistocene [60]. Since similar types of adzes/axes were also excavated from the earliest dated site in Australia [14], the use of dug-out canoes for sea crossings of 80-100 km distance by the first AMH reaching Sahul can be another possibility.

In Oceania, Pamwak site on Manus Island was initially settled around 21 ka. It required at least 230 km of open sea voyaging to reach Manus and Admiralty Islands from the north coast of New Guinea or the north-western tip of the New Ireland [61], thus it must be assumed that the seafaring skills of modern humans were very much developed by the LGM. Migration or movement to Manus required an uninterrupted voyage of 200–230 km, 60–90 km of which would have been completely out of sight of any land [59]. Furthermore, the archeological evidences at Matenbek and Buang Merabak on New Ireland also show the intentional transfer of obsidian as tool material and cuscus as a food resource at around 20-16 ka. Obsidian was mainly acquired from the New Britain source of Mopir or Talasea, c. 55 km from Mopir [62]. Two quite different source distributions might imply different connections between New Ireland sites and New Britain sources, with implications for canoe travel [63]. It is yet unknown whether the transfer of obsidian was done directly by crossing over 300 km sea or by hopping along the coasts of New Britain to New Ireland. In the latter case, the maximum distance to cross sea could be about 30 km, the same as for the estimated cuscus transfer.

It has often been argued that initial colonization of the many islands of Wallacea must have been facilitated by a maritime adaptation, and that lowland coastal regions would therefore have been the logical target of early settlement [64]. Current archeological evidences show that the modern human seafaring skill did indeed develop from the earliest periods of migration until the LGM in maritime Asia including Wallacea and Ryuku Islands, as well as in Oceania during the late Pleistocene. In the next section, we discuss the possible development of both marine and terrestrial resource use by early modern humans in Wallacea.

4.2 Resource use and island adaptation by early modern humans in Wallacea

Some early coastal sites in Wallacea, especially along the southern migration routes show the intensive use of marine resources by modern humans. The most famous case is Asitau Kuru on East Timor, which produced a large number of marine fish and shellfish species including the world oldest pelagic fish bones (e.g. Scombridae, including skipjack and yellowfin tuna species) dated to 42 ka cal. BP [3, 21]. The site also produced several fishhooks made of Trochus shell, and one of them was directly dated to c. 21-16 ka. Other sites in Timor and Alor Islands along the southern migration routes in Wallacea also provided numerous fish and shellfish remains for the late Pleistocene. For the late Pleistocene sites along the northern migration routes, on the other hand, all the sites reported here produced large number of shellfish remains, although the volume of excavated fish remains are rather limited or none. For example, Leang Sarru in Talaud and Topogaro Caves in Sulawesi have not provided any fish remains from the Pleistocene layers so far. Bubog 1 in Mindoro produced fish bones throughout its layers. Although its volume is far less than those from Asitau Kuru and other sites in Timor and Alor, a considerable variety of reef and pelagic fishes was recorded [43]. Also, no J-shaped fishhook is found yet from the prehistoric sites along the northern routes in Wallacea like the ones found in sites along the southern route [3]. Instead, Bubog 1 delivered a completely worked bone fishing gorge from deposits underneath the lowest shell midden layer which was dated to 33-28 ka cal. BP [9, 43].

The current absence of J-shaped fishhooks in Sulawesi and other islands along the northern routes might be just a matter of sampling the limited number of excavated sites but could also be caused by the availability of resources in each island. For example, there are no Pleistocene sites that have produced a large number of fish remains in Sulawesi, which is the largest Wallacean island with a high number and variety of terrestrial animals. The coasts with developed coral reefs are also limited along Sulawesi except for some remote islands, and the island coasts are mainly covered by mangrove forests. The larger volume of terrestrial animal bones and shellfish remains from the late Pleistocene sites in Sulawesi, including Topogaro caves, tentatively indicate this possibility. Leang Sarru in the remote Talaud Islands also produced only shellfish remains but no fish bones. The current island coast area with coral reefs is also limited in Talaud and could have been much less during the late Pleistocene, yet the exact reason(s) for absence of fish remains in Leang Sarru remains unclear. Also Golo Cave, located 60 m inland from the northwestern coast of Gebe Island in the Maluku Islands, produced shell tools and a variety (47 species) of marine shell remains [65], but a very limited number of fish bones as well.

In general, most of the late Pleistocene coastal sites in Wallacea produced larger numbers of shellfish remains, thus shellfish could have been the major marine resource of early modern humans. The most important shell species exploited at these sites during the late Pleistocene were *Turbo* spp., *Nerita* spp., *Trochus* spp., *Strombus* spp., *Geloina* spp., and Chiton. In terms of actual meat value, *Turbo* spp. might have been the most important, followed by *Trochus* spp., and *Strombus* spp. [28]. On the other hand, intensive use of fish was confirmed in some islands with limited worthwhile terrestrial animals such as Alor and Timor. There were no large and middle-sized mammals on these islands during the late Pleistocene. Similarly, no large and middle-sized mammals occurred in the Talaud and Maluku sites during the late Pleistocene, and the current archeological evidences show only intensive use of shellfish in these islands. The exact factor(s) of such differences are not clear yet, and further archeological and past environmental data will be required in future study.

In terms of temporal change of resource use in Wallacea during the late Pleistocene, the Topogaro case indicates the possible intensive hunting of larger mammal species such as Anoa by around 29 ka. Given the rock paintings of Anoa hunting on the cave dated to 44 ka [4] and other archeological evidences of Anoa bones from the late Pleistocene sites in the Maros district, South Sulawesi also supports such a possibility [25]. Evidence for the active use of Anoa, Babirusa and Celebes warty pigs (*Sus celebensis*) was also found at Leang Burung 2 [25, 66, 67] in South Sulawesi. In Topogaro, *Sus* species increase in the middle layers possibly around 16 ka, together with the appearance of retouched lithic tools.

Sulawesi is the only Wallacean island with large to middle sized mammals like Anoa and pig, as all of the other islands are much smaller. Stegodon species once existed in Flores, Timor and Sangihe Islands as well as in Sulawesi but they all went extinct, possibly before the migration by modern humans into Wallacea. Currently there are no sites with Stegodon fossils from deposits associated with modern humans, even though the deeper deposits of Liang Bua in Flores produced numbers of Stegodon remains associated with lithic tools, very likely used by *Homo floresiensis* until around 60 ka [68–70]. The lowest deposit of Leang Burung 2 in South Sulawesi also produced some Stegodon remains possibly dating back to around 70 ka and clearly before the appearance of modern humans [25].

Some Stegodon fossils were found in Timor, but no such remains were excavated from Asitau Kuru and Laili Cave, dated to 44 and 42 ka respectively [2, 23]. Thus, the terrestrial animals hunted and used by early modern humans were mainly small-sized mammals like rodents and fruit bats, as well as reptiles including monitor lizard species and snakes. Laili Cave in Timor has produced 16 different mammal taxa, mainly rodents (four extinct small rat species and four extinct giant rat species) and bats (including a fruit bat species) together with some reptile, amphibian, bird, fish and shellfish remains [2].

In Leang Sarru, the amount and variety of marine shellfish remains significantly increased in Layer 2 dated to around the LGM. With the drop of sea level down to around 150 m, the distance to the coast from each site basically increased during the LGM. Even so, Leang Sarru was located within 2.5 km of the nearest coast during LGM [30]. Similarly, a heavy reliance on marine shell and other marine resources continued at Asitau Kuru which continued to be located within 5 km of the coast during the LGM [23]. The Bubog sites on Ilin Island were at any time during their occupation in close proximity to the coast. Even during the LGM the walking distance to the steep dropping southern coast of Ilin did not significantly increase and was not more than 1 km [33]. While the habitat for shellfish decreased with lower sea levels and the closing of the Ilin Channel, and completely disappeared once Ilin was connected to the Mindoro mainland (at sea levels of −60 m and lower), open sea fishing remained as a food resource, indicated by the dominance of pelagic fishes in the early Holocene and late Pleistocene layers [9, 33, 43].

Also at Laili Cave, which was located around 4.3 km from the Pleistocene Timor coast, the volume of shellfish remains increased considerably [2]. However, other sites such as Matja Kuru 2 on Timor, which was over 10 km away from the past coast during LGM, had a reduced volume of shellfish and other marine species [71]. Such evidences indicate that the distance from coast (<5 km) may affect intensive use of marine resources at each site particularly in small sized islands during LGM. On the other hand, the amount of shellfish remains in Topogaro caves during the late Pleistocene and terminal LGM times is very limited. The site is currently located about 3.5 km inland from the current coastline; thus, the distance from the coast during LGM could be estimated to be around 5-6 km. The Topogaro case indicates that early modern humans had a much stronger dependence on terrestrial resources on larger sized islands such as Sulawesi, despite its coastal location.

What these sites seem to have in common is the presence of complex and specialized plant processing activities with dedicated stone tools. For instance, the association of notched tools with a variety of plant working has been identified within several late Pleistocene assemblages in ISEA like Tabon Cave [72], Leang Sarru and Topogaro [32, 38, 39]. The presence of tools with notched edges, both those caused by intentional retouching or by wear and tear, is a phenomenon also observed in other geographic regions and occurs in the prehistoric cultures in northern Africa and Europe, where they have been identified as being used for transversal activities (scraping, raking, splitting) of various plants, for example in the epipalaeolithic Capsian of the Maghreb region [73] and in the Mesolithic of western Europe [74, 75].

4.3 Development of lithic technology and lithic tool use in Island Southeast Asia

The technology and the manufacture of stone tools in ISEA are characterized by the production and use of simple unretouched flakes and lack of secondary modifications to create distinctive formal tool types [11, 25, 32, 76, 77]. Lithic technological analyses are often anchored on the premise that formal and typologically classifiable tools are absent in the region, implying “stagnated” stone tool traditions [76, 78, 79]. Technology in this region is often labeled as informal and even expedient, without any preparations as opposed to curated tools [80], and not exhibiting any visible development. From the stone tool assemblages of the late Pleistocene, the lack of diagnostic features carried on even until the late Holocene and historical periods [81–86]. In general, results from a techno-typological approach may therefore not reflect the actual level of technological development in the region and thus other approaches are deemed necessary. Thereby the functions of stone tools might be a better indicator of the level of technological capacity of prehistoric populations in ISEA. The results of a combined geometrics morphometrics study from Early Holocene lithics of Song Terus, Java indicate that form was not the major parameter in the selection of tools for use but rather their suitability for particular tasks [87].

To overcome the lack of formal tool types as an indicator of technological development, the "typology dilemma" of Southeast Asia's Paleolithic [85], several use-wear studies have recently provided more substantial insights into the functionality and technological capacity of informal flake tools. This analytical method, also known as traceology or the microscopic identification of traces of wear and tear [88] has the potential to fill the gaps on our understanding of lithic technology in the region. Use-wear analysis can provide actual information on the intended use and purpose of lithic tools, independent of their form and level of manufacture. While the absence of formal and standardized stone tools was previously often regarded as a result of the presence of a plant-based tool kit, sometimes referred to as a "bamboo industry" [81, 89], no material evidence of such "vegetal tools" has yet been found in the archeological record. On the other hand, the presence of a variety of useful plants and the identification of wear traces caused by plant working has led to extensive experimental research dedicated to the exploration of the various functions and uses of plants in prehistoric Southeast Asia [90, 91]. While direct evidence for an actual existence of bamboo tools is still lacking in the archeological record, experimental use-wear analysis has significantly contributed to our understanding of the importance and versatility of tropical plants throughout human history. Numerous artifacts have been found that carry traces of plant processing in form of intensive micropolishes, the so-called "sickle gloss," for instance in late Pleistocene sites in Central and North Sulawesi [32, 38, 39].

Although stone tool assemblages in ISEA are generally characterized by the production and use of unretouched flake tools, it does not necessarily mean that the prehistoric technology in the region was less complex. In several sites in ISEA, the existence of composite technologies have been identified that employed unretouched flakes by attaching them as insets to shafts with the aid of resinous adhesives, for hunting weapons and also for tools with handles such as knives [32, 86, 92]. This is another example when a microscopic approach is particularly suitable for addressing current issues in understanding the prehistoric lithic technology of ISEA [32, 38, 86, 93]. It has also rendered the stereotypical label of lithic technologies in Southeast Asia being backward obsolete.

Lithic technology during the course of human occupation in Wallacea indicates a reliance on secondary raw material sources, for instance nodules from rivers or streams [25, 32, 38, 77, 82]. Examples are the use of igneous beach pebbles as hammerstones and net sinkers, and their sharp-edged fragments as tools for cutting and scraping activities [9, 32]. Other examples are the use of marine shells that possess physical characteristics similar to rocks for non-formal and formal tools that were employed for a variety of activities [9, 42, 94–97]. While microscopic traces indicate intensive plant processing that was most likely associated with the production of other forms of technology and consumption during the late Pleistocene, this might also be a reflection of adaptation to environmental changes. The technological advancements in ISEA are often associated with the need for sea crossings and the processing and production of tools made from organic materials such as shells, animal bones and plants. Several aspects in the development and application of prehistoric technologies in island environments still need to be further explored, especially the role of plant working in the production of rafts, nets, traps, and binding materials. More experimental research on the identification and differentiation of traces from different types of materials, such as plants and animal bones, needs to be conducted. In terms of understanding prehistoric technology, a robust and encompassing experimental database is still lacking for ISEA, especially for its lithic tools during the late Pleistocene. Use-wear analysis could address this through comparison with studies from other regions that also deal with similar problems associated with "simple" lithic technology during the late Pleistocene.

5. Conclusion

The progress of maritime adaptation was far more developed than previously expected, when AMH or *Homo sapiens* reached various marine and coastal environments after migrating Out of Africa, particularly in ISEA including Wallacea and Oceania after 45-50 ka. Early traces of long-distance seafaring and intense maritime activities, including pelagic fishing, and the use of shell fishhooks and/or bone fishing gorges for bait fishing, as well as the increased processing of grassy plants for the extraction of fibrous materials for products that may also have been a part of the maritime technology of early modern humans, have been discovered in these maritime regions since the late Pleistocene. Such finds strongly indicate that the archipelagic environment of AMH, with many small and remote islands, could be the major background for their high maritime adaptation and mobility. After the Holocene, and with warmer temperatures, rapid rise of sea level, and the expansion of coastal areas including a possible development of coral reefs after around 6000 years ago, there were both, maritime adaptation and adaptation to new Holocene island environments, accompanied by the development of lithic production and functional tools for hunting and using plant and other materials by AMH in Wallacea.

Acknowledgements

This research is part of the Cultural History of PaleoAsia - Integrative research on the formative processes of modern human cultures in Asia project and is supported by a Japan Society for the Promotion of Science Research Grant (Grant Number: 16H06409). Alfred Pawlik was supported by the University Research Council of Ateneo de Manila University and an AdMU Loyola Schools Research and Creative Writing (RCW) Faculty Grant. The research of Riczar Fuentes was funded by a Lisa Maskell Fellowship of the Gerda Henkel Foundation, Düsseldorf, Germany. The excavations of Leang Sarru and Goa Topogaro reported here would not be possible without the support and the administrative personnel of Pusat Penelitian Arkeologi Nasional (ARKENAS) and Balai Arkeologi Sulawesi Utara in Indonesia.

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