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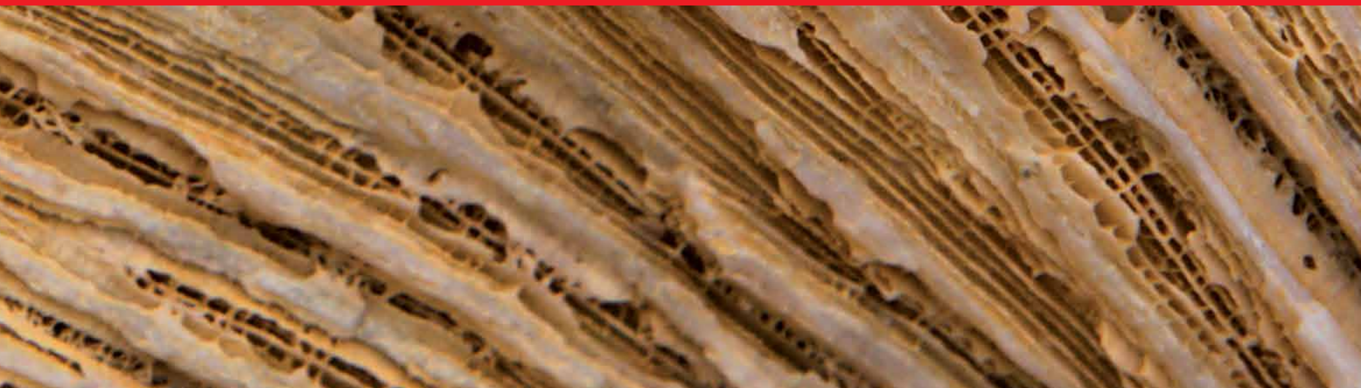
Pleistocene Archaeology

Migration, Technology, and Adaptation

Edited by Rintaro Ono and Alfred Pawlik



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Meet the editors

Dr. Rintaro Ono is an Associate Professor at the National Museum of Ethnology, Japan. His research is focused on Maritime Archaeology and Anthropology, and specifically: human maritime adaptation process, human migration into Island Southeast Asia and the Pacific Islands, human maritime exploitation history, and maritime trade history. He has been involved in many research projects in Japan (mainly Okinawa), Indonesia, the Philippines, Micronesia, and Melanesia. He has been a visiting researcher and research collaborator at several national and international laboratories and universities. He is the author of more than 50 academic papers, two books, and editor of several books including Prehistoric Marine Resource Use in the Indo-Pacific Regions. (ANU E Press, 2013).

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Contents

Preface

The aim of this book is to review the current research outcomes in the field of Pleistocene Archaeology around the world, particularly with regard to our own species, Homo sapiens. The collection of articles in this book focuses mainly on issues of migration, technology and adaptation of Homo sapiens as the only human species that have migrated all over the world and colonized every continent as well as the vast region of Oceania. It also provides information on the environment and life of earlier hominins like H. erectus, H. neanderthalensis and H. floresiensis in several regions of Europe and Asia.

This volume contains eight insightful chapters that constitute a diverse but generally coherent collection on human migration and expansion during the Pleistocene, the development and advancement of prehistoric technologies, and human adaptation to new and changing environments and climate conditions around the world. The geographical focus extends from Central Europe (Chapter 2) to South Asia (Chapter 3), Insular Southeast Asia including the Pleistocene Sunda region (Chapter 4) and the Wallacean islands (Chapter 5), Eastern Asia including South China (Chapter 6), and the Ryuku Islands in Japan (Chapter 7), and the American continent (Chapters 8 and 9).

For the preparation and envisioning of this book, we have received much support and inspiration from the on-going project "Cultural History of PaleoAsia" as the scientific research initiative of a MEXT Grant in Aid Project in Japan (headed by Prof. Yoshihiro Nishiaki from 2016-2020), in which both of us (Ono and Pawlik) have participated since 2016. This project aims to analyze an extensive set of relevant field and theoretical data from Asia in order to interpret the nature of distinct patterns in the formation and expansion of Homo sapiens across Asia and Oceania after the Out of Africa event. This project has already produced a number of relevant publications, including our own articles, on human history and evolution (anatomically, behaviorally, and culturally) in Southeast Asia.

Lastly, we would like to thank all the contributing authors for having made their research and their expertise available, and all the peer-reviewers who helped us in improving the quality of the papers and this book as well. Our special thanks go to IntechOpen and its Author Service Manager Mateo Pulko, for wholeheartedly supporting and promoting this book project.

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Section 1

Introduction

Chapter 1

Introductory Chapter: Pleistocene Archaeology - Migration, Technology, and Adaptation

Rintaro Ono and Alfred Pawlik

1. About this book

This book aims to review the current and latest research outcomes in the field of Pleistocene Archaeology around the world. From our understanding, the major purpose of Pleistocene Archaeology is to research the deep human history of hunter-gatherers before the development of agricultural or Neolithic societies and civilizations during the Holocene. The current geological timeline of the Pleistocene is regarded to be between about 2.58 million years ago and 11,700 years ago [1–3]. It is then followed by the Holocene as the present geological period. In terms of human history during the Pleistocene times, a variety of human species have been existed, and most important for us as modern-day *Homo sapiens* are the emergence, evolution, and dispersal of the genus Homo during this time range.

With such understanding, this book mainly focuses on archaeological studies of our species, from archaic hominins like *H. erectus*, H. *neanderthalensis*, H. *floresiensis*, to *Homo sapiens* as anatomically modern humans (AMH). The main topics of this book are: (1) human migrations in and out of Africa by Homo species, particularly by *Homo sapiens* who migrated into most regions of the world and various environments, (2) the development of human technology from early to archaic Homo species and *Homo sapiens* (e.g. stone and bone tool production and use, ornaments, rock art, hunting, fishing, gathering, resource exchange), and (3) human adaptation to new environments or environmental changes caused by past climate changes during the Pleistocene. With such perspectives in mind, this book contains a total of eight insightful and stimulating chapters related to these topics which review and discuss human history during the Pleistocene times.

It is true that the main human actors during the Pleistocene are Homo erectus and similar archaic hominins as Homo erectus appeared by 2 million years ago (2 Ma) in Africa and existed at least by around 110 ka in Java, Indonesia [4]. Homo erectus or their related species (e.g. H. rudolfensis, H. heidelbergensis, H. ergaster, and possibly H. habilis as well) most probably originated in Africa and are considered to be the first hominin group that succeeded to move "Out of Africa" and migrate into Asia and Europe possibly after [5–7]. Homo erectus and Homo heidelbergensis were also the likely ancestors to Neanderthals (H. neanderthalensis) and Denisovans in Europe and Siberia [8–10], as well as ancestral to small-bodied hominins like H. floresiensis, a recently found species in Flores Island in Indonesia [11] and H. luzonensis another newly discovered species in Luzon Island in the Philippines [12].

Although these facts clearly support Homo erectus and other archaic hominin species can be one of the main targets for Pleistocene Archaeology, this book mainly

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focuses on migration, technology and adaptation by Homo sapiens as anatomically modern humans. This is partly because of their wider migration area which covered almost the entire inhabitable world and the various and increasingly compex technologies they invented. Therefore, we consider Homo sapiens as the most important species and main actor in our discussion of Pleistocene Archaeology. In fact, Japan including the Ryukyu Islands, Oceania, Australia and New Guinea, and the American continent as the New World were initially reached and colonized by Homo sapiens, and no traces of other Homo species have been found, so far.

Another reason for us to focus on Homo sapiens is the on-going project "Cultural History of PaleoAsia" as the scientific research of a MEXT Grant in Aid Project in Japan (headed by Prof. Yoshihiro Nishiaki during 2016-2020) in which both editors of this book (Ono and Pawlik) have participated since the beginning. This project aims to analyze an extensive set of relevant field and theoretical data from Asia in order to interpret the nature of distinct patterns in the formation of modern human cultures across Asian region after the Out of Africa event, and has already produced a number of publications (e.g. [13–15]). The basic idea and major topics of this book were originally evoked by joining this interdisciplinary project and we are grateful for the opportunity to publish this book in the last year of this important project.

2. Introduction of the chapters

This volume is divided into four sections with a total of eight chapters which constitute a diverse but generally coherent collection on Pleistocene human migration, lithic tool use, and adaptation to changing environments and climate conditions in the world. The geographical focus extends from Eastern Asia including South China and Japan (Ryuku Islands), Insular Southeast Asia (both Sunda and Wallacea region), South Asia, Central Europe to the American continent (**Figure 1**). On the other hand, we have no chapter that reports about the Palaeolithic of the African continent as the most likely place for the origin of humans, thus this book focuses on the human migration and adaptation to new and changing environments after

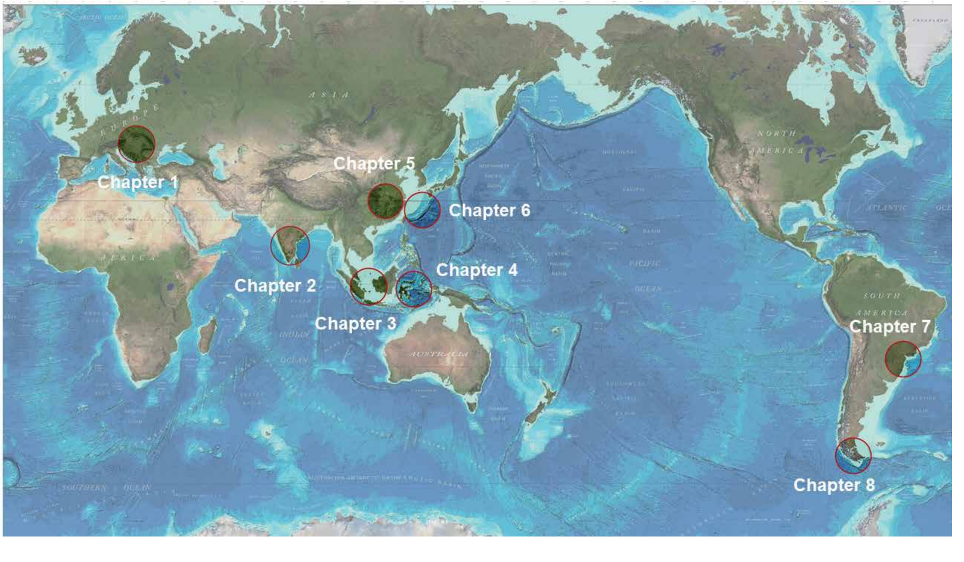

Figure 1.
Research location of each chapter of this book.

the "Out of Africa" events, especially by Homo sapiens during the Pleistocene. Since there is already a wealth of literature on the Palaeolithic archaeology of the African continent, it is not necessary to fill this gap here. Consequently, this book features reports on the prehistory of regions outside the classical Palaeolithic centres of Europe and Africa, and for this very reason these contributions convey new knowledge and introduce the reader to prehistoric regions unknown to many.

The first section "Pleistocene environment change and human evolution in Europe and South Asia" contains two important papers. Chapter 1 by Adriano Banak and Davor Pavelic entitled "Pleistocene Climate Change in Central Europe" investigates distinctive Loess-Paleosol-Successions in the Baranja region in northeastern Croatia and discusses the results of their stable oxygen isotope analysis (δ18O) and stable carbon isotope analysis (δ13C) of malacofauna during the Upper Pleistocene (130 ky - 20 ky) to quantify paleo-temperature changes in Central Europe and their effect to the environment and human populations [16]. Their analysis shows that stable carbon isotope values point to a dominance of C3 vegetation type during the Late Pleistocene in the southern part of Central Europe and that the overall climate was much cooler than present. The authors propose that climate change in the Late Pleistocene was very likely a significant but not the only factor that influenced the extinction of Neanderthal populations and paved the way for the prevalence of anatomically modern humans (AMH) in Central Europe.

Chapter 2 is entitled "Human evolution in the center of the Old World - An updated review of the South Asian Palaeolithic" by Parth Chauhan and presents us with an overview on the recent outcomes of Pleistocene archaeology in South Asia and its long chronology [17]. Chauhan discusses in his chapter the development of lithic technology from the Lower Palaeolithic to the Middle and Upper Palaeolithic with its early appearance of microlithic technology, and the timeline of the initial arrival of *Homo sapiens*. It also tackles the potential interactions between the archaic population and emerging modern humans, the marginal occurrence of symbolic behavior, the absolute dating of rock art and the potential role of hominins in specific animal extinctions and ecological marginalization.

The second section "Pleistocene Human Migration and Adaptation in Southeast Asia" contains two papers on the prehistory of the Sunda shelf region and the Wallacean islands. Chapter 3 by Halmi Insani and Masanaru Takaki is entitled "Mainland versus Island Adaptation: Palaeobiogeography of Sunda Shelf Primates Revisited" and focuses on dispersal events and phylogeographic analysis of human and non-human primates in the Sunda shelf region and mainly the Malay Peninsula and the islands of Sumatra, Java, and Borneo [18]. Southeast Asian primates, including humans are one of the most successful mammals in responding to the dynamic palaeoclimatic changes since at least 1 mya, and human and non-human primates reflect the complex history of a wide range of ecological and geographic variation. With this understanding, Insani and Takaki discuss body and cranial size of each primate, including Homo erectus, as well as their biodiversity changes and, eventually, their extinction, both in mainland and island environments to highlight the peculiarity of the effect of insularity

Chapter 4 is entitled "Island migration, resource use, and lithic technology by anatomically modern humans in Wallacea" by Rintaro Ono, Alfred Pawlik and Riczar Fuentes and discusses the evidence and timeline for island migrations into the Wallacean islands (mainly East Indonesian islands, East Timor, and the Philippines, except Palawan Island) by early modern humans, and their adaptation to these unique island environments during the Pleistocene [19]. The continuously existing 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. With this understanding, the authors summarize the results of three recent excavations on the islands of Talaud, Sulawesi and Mindoro in Wallacea, and discuss the evidence and timeline of migrations of early modern humans into the Wallacea region and their island adaptation during the Pleistocene, also under consideration of the development of lithic technology and tool use.

The third section "Pleistocene Human Migration and Technology in East Asia" also contains two papers on cases from South China and the Ryuku Islands in Japan. Chapter 5 is entitled "A Macroscopic Perspective on Lithic Technology and Human Behavior during the Pleistocene in Zhejiang Province, southeastern China" and written by Hong Chen, Jiying Liu, Xinmin Xu, and Huiru Lian, presents us with an overview of the Pleistocene sites in Zhejiang province and discusses the possible development of lithic technology in the South China region [20]. With the use of macroscopic analysis, the authors point out that the lithic industry in Zhejiang province basically belongs to the technological tradition of southern China as a transition from pebble-tool-industries in the Early and Middle Palaeolithic to flake-tool-based industries in the Upper Palaeolithic. This was accompanied by developing raw material selection and flaking techniques as flint was used as the main lithic raw material as well as the widespread use of the bipolar flaking method during the Upper Palaeolithic times

Chapter 6 entitled "The Migration, Culture, and Lifestyle of the Palaeolithic Ryukyu Islanders" and written by Masaki Fujita, Shinji Yamasaki and Ryohei Sawamura reports on the recent excavation of Palaeolithic deposits at Sakitari Cave, Okinawa Island [21]. The site provided a variety of shell artifacts including beads, scrapers, and fishhooks as well as the remains of aquatic animals, especially freshwater crabs. The initial appearance of humans on many of the remote islands in the Ryukyu Group can be traced back to at least 35,000 to 30,000 years ago, and their new findings at Sakitari Cave site clearly demonstrate that these early modern human are hunting-fishing-gathering people with considerably high seafaring and nautical skill to cross sea gaps of over 100-200 km to reach these islands. The currently oldest shell-made fishhooks in the world are dated to 23,000 years ago, thus supporting such interpretation. Together with the contribution in Chapter 4, it is now widely recognized that an intensive maritime and island adaptation of early modern humans (Homo sapiens) had developed in maritime Asia such as Wallacea and the Ryukyu Islands, as well as along the islands in Oceania during the Pleistocene

The final section of this volume focuses on the cases of the American continent as the New World. With the title of Pleistocene to Holocene Human Technology and Interaction in New World, this section contains two interesting papers. Chapter 7 entitled "The technological diversity of lithic industries in Eastern South America during the Late Pleistocene-Holocene transition" by João Carlos Moreno de Sousa provides us with an overview on the cultural traditions and lithic industries of this vast region and discusses the diversity and development of the prehistoric technologies of these Palaeoindian cultures [22]. Archaeological research began rather late and systematic archaeological investigations were conducted only from the late 1960s onwards. While there is only sparse evidence for human presence during the Late Pleistocene of this region, a significant increase in human settlements occurred during the Terminal Pleistocene and Early Holocene transitional phase. The chapter by Moreno de Sousa is a useful work of reference for this important period in the early human history of South America.

Chapter 8 is entitled "Socio-cultural interaction and symbolism in prehistoric South America: Quartz crystal manuports from Tierra del Fuego" by María Estela Mansur, Hernán Horacio De Angelis, Vanesa Esther Parmigiani, María Celina Alvarez Soncini, and Anna Franch Bach [23]. Their report introduces the archaeology of Tierra del Fuego, an archipelago located at the southern end of the continent. Various researches have produced a variety of archaeological, ethnohistorical, and palaeoecological data on this interesting region [23–25]. Mansur and colleagues discuss the use and meaning of distinctive minerals with special characteristics, particularly quartz crystals, not only as a raw material for the manufacture of lithic tools but especially their role in ornamental or ceremonial contexts. Quartz crystals appear at several sites of Tierra del Fuego in various forms and often with pyramidal and prismatic shapes. The authors inform about their techno-functional analysis of these artifacts, present evidence of their circulation over long distances and reflect on the interaction and symbolism of the hunter-gatherer populations in Tierra del Fuego on the basis of their appearance, and discuss their role in the ritualistic and ideological practices of the earliest inhabitants of the southernmost region ever settled by humans.

The editors of this book "Pleistocene Archaeology: Migration, Technology and Adaptation" wish to thank all authors for their invaluable and informative contributions to this volume. The topics, research and results presented in the chapters show how important it is to explore and investigate the earliest periods of our existence in order to understand and respond to the many challenges that our species faces in the present and future. Just as our early ancestors who migrated out of their homeland to discover and conquer new territories, reached new continents and colonized land- and seascapes around the world, and adapted to a variety of different environments along their voyage, so today's archaeologists are discovering the deep human history of these regions, revealing new sites, artifacts, fossils, material and immaterial culture. In this way we learn about the evolution of human behavior, cognition and technology as response to the constantly changing climatic conditions and ecosystems of the Pleistocene and early Holocene, and hopefully the data and information gained from Palaeolithic archaeology and palaeoecology can provide us with information and inspiration for our response to today's rapid changes in environment and climate.

Lastly, we like to thank IntechOpen for giving us the opportunity to publish this edited volume and in particular Mateo Pulka for his continuous help and support.

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Section 2

Pleistocene Environment Change and Human Evolution in Europe and South Asia

Chapter 2

Pleistocene Climate Change in Central Europe

Adriano Banak, Oleg Mandic, Davor Pavelić, Marijan Kovačić and Fabrizio Lirer

Abstract

Loess is terrestrial, clastic sediment formed by the accumulation of wind-blown dust. It is usually inter–bedded with paleosol horizons, forming loess-paleosol successions (LPS). Due to their characteristics LPS's represent valuable records of climate changes during Pleistocene. The thickest LPS sections in Croatia are in the Baranja region. Stable oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) isotope analysis were made on loess malacofauna in order to quantify paleo-temperature changes and describe paleo-vegetation in this part of Central Europe. $\delta^{18}O$ values show significant paleotemperature changes during the Upper Pleistocene (130 ky - 20 ky) in Baranja region. Average growing season (AGS) temperature varied 13.2 °C or 9.5 °C during that time period, depending on which formula is applied for calculations. Magnetic susceptibility (MS) measurements show strong peaks in the paleosol horizons pointing to more humid climate. The overall climate was much cooler then present. Stable carbon isotope values point to dominance of C3 vegetation type during the Late Pleistocene in southern part of Central Europe. Climate change in the Late Pleistocene is very likely a significant but not the only factor that influenced the extinction of Neanderthal population which paved the way for the dominance of anatomically modern humans (AMH) in Central Europe.

Keywords: Pleistocene, climate change, loess, stable isotopes, Central Europe, Neanderthals

1. Introduction

Definition of loess: It is s a terrestrial, clastic sediment, composed dominantly of silt-sized particles and formed by the accumulation of wind-blown dust. It covers up to 10% of the world's surface area and is usually inter-bedded with paleosol horizons forming loess-paleosol sequences, or LPS [1]. Such successions provide very detailed insight into Pleistocene climatic fluctuations [2–4]. Due to this characteristic, LPS's provide very good records of palaeoclimate and environmental changes in the Pannonian Basin for at least 1 Ma [5]. The region of Baranja situated in the north-eastern part of Croatia is located in the southern edge of Pannonian Basin which is a part of Central Europe (**Figure 1**). It was selected for this research because some of the thickest loess successions in Croatia are exposed along the Danube River in Baranja. The total thickness of these loess deposits (above and under the surface) probably exceeds 50 m [6]. The Zmajevac locality was selected because it is accessible, contains four paleosols in loess and has a total thickness of almost 20 m.

Grain-size distribution indicates that the loess from Zmajevac LPS in Baranja is typical loess, comparable with other loess profiles in the Pannonian Basin [3, 4].

The LPS of Baranja and northeastern Croatia have a long history of investigation [7, 8]. The molluscan fauna within LPS were investigated and provided an overview on warm periods in the Late Pleistocene of northeastern Croatia [9]. Other researchers focused on the molluscan fauna from LPS at the Vukovar and Đakovo loess plateaus, situated 20–30 km south of Baranja region [10–12].

Focus of this chapter is to describe the climate change during the Late Pleistocene based on the $\delta^{18}O$ and $\delta^{13}C$ values measured in land-snail (mollusk) shells from loess samples of the Zmajevac LPS. Overall, the results of this study will provide a better insight into the impact of climate change on the populations of Neanderthals and anatomically modern humans (AMH) in Central Europe, and the disappearance of the aforementioned. Emphasis is on $\delta^{18}O$ values which are used for determination of paleotemperature changes. This is especially important because it provides the temperature changes during the appearance of AMH in Central Europe and the disappearance of the Neanderthals from the same region. The values of stable isotopes of oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) can be used as a paleothermometer, as characteristic of mollusk assemblages [13, 14], or in a wider sense, as a tool to reconstruct the climatic conditions of the Late Pleistocene [15–17]. Previous research in the Pannonian Basin did not include stable isotope analysis of fossil mollusk shells for palaeoclimatic reconstructions in this specific time frame (130 ky - 20 ky). The only paper which included stable isotope analysis ($\delta^{18}O$ values) as a part of a comprehensive loess study in this region is limited to the Last glacial maximum (LGM), which is only a part of MIS2 [18] and does not cover the entire Upper Pleistocene. Most researchers used mollusk assemblages only as a malacothermometer tool, and to establish mean annual temperature (MAT) values and/or average summer month temperatures represented by mean July temperatures – MJT [4, 14, 19]. Most recently, X-ray fluorescence (XRF) and magnetic susceptibility (MS) based palaeoclimatic data have been established in the Pannonian Basin and they determined the paleotemperatures in the 6.7–8.9°C range [20]. However, other researchers in Southern [21] and Western Europe [16, 22, 23], in Eastern Mediterranean [17, 24] and also in North America [15, 25, 26] used stable isotope analysis widely in the last three decades.

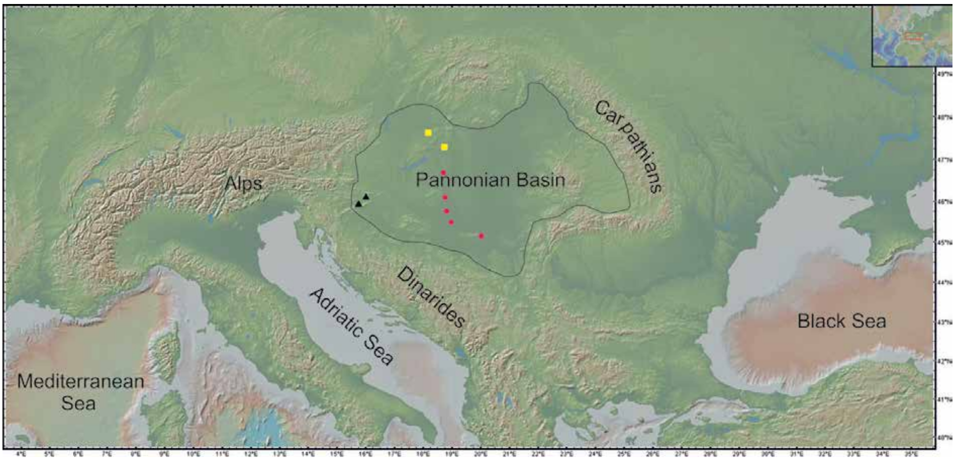

Figure 1.
Pannonian Basin with loess profiles from Croatia, Serbia and Hungary marked with red polygons. Neanderthal and early modern human sites marked with black triangles (Krapina and Vindija in Croatia) and yellow squares (Remete Felsö and Šal'a in Slovakia). This position map is made and adjusted by using a global multi-resolution topography map [78] (http://www.geomapapp.org).

Before using the stable isotope method in paleoenvironmental reconstruction it is necessary to understand the physical and chemical processes, or flux-balance model that takes place in mollusk shell <– > environment system. The most detailed explanation of that flux-balance model, and subsequent incorporation of isotope ratios in mollusk shells is given by Balakrishnan and Yapp [27]. The authors provide detailed insights into possible interpretational mistakes and constraints of this method and give all the necessary formulas which ensure better understanding of complex model used in palaeoclimatic research. That research lays the foundation for any future research which tends to use stable isotope data as a tool for paleoclimate or paleoenvironmental reconstruction.

2. Research methods

Field investigation and sampling in Baranja region is done during winter and early spring, because the lush vegetation in spring, summer and fall does not allow easy access to loess profiles (**Figure 2**). The aim of sampling is to identify the maximum thickness of chosen LPS. Bulk samples (8–10 kg) were collected from Zmajevac outcrop for malacological, sedimentological and stable isotope analysis.

Samples for grain size analysis were decalcified with 5% HCL acid and dried in a heater for 24 h. Grain size analyses combined wet sieving and the pipette method. Classification of the grain size distribution was done according to [28]. Each loess sample was sieved to obtain whole mollusk shells for stable isotope analysis. Shells were derived from samples by screen-washing in distilled, deionized water for the purpose of saving primary ratios of stable oxygen and carbon isotopes. The identification of mollusk species followed taxonomic concepts that were established in previous researches [13, 29]. Assemblage analysis is done according to Ložek [13]. Selected mollusk shells are then prepared for stable isotope analysis. This was done in IAMC - CNR laboratory in Naples (Italy). First the shells were crushed into powder which is then heated to 500°C for 30 min to remove the organic matter. Ratios were measured by automated continuous flow carbonate preparation GasBench II device and Thermo Electron Delta Plus XP mass spectrometer. Acidification of samples was performed

Figure 2.
Sampling at the Zmajevac LPS in Baranja region, Eastern Croatia. Beige colored sediment is loess and reddish – brown colored sediment is paleosol (Photo: Danijel Ivanišević).

at 50°C. Every sixth sample was compared with an internal standard (Carrara Marble with $\delta^{18}O$ = 2.43‰ versus VPDB; and $\delta^{13}C$ = 2.43‰ vs. VPDB) and for every 30th samples, the NBS19 international standard was additionally measured. Standard deviations of carbon and oxygen isotope results were estimated as 0.1% and 0.08%, respectively and based on 20 measured samples, three times each.

The magnetic mineral content recorded at Zmajevac LPS in a form of magnetic susceptibility (MS) signal was gathered from 44 samples collected into 200 ml plastic containers. Magnetic susceptibility measurements were performed in HGI-CGS laboratory, Zagreb (Croatia) using a Bartington MS2 device. Each sample was measured three times for better precision and statistical analysis.

3. Results

Grain-size analysis were also done in HGI-CGS laboratory, Zagreb (Croatia) following procedure by [30]. Results indicated silt as the dominant grain size fraction in all loess samples from the Zmajevac profile (**Table 1**). Average share of silt-size particles in samples is 88.11% and coarse-grained silt fraction is dominant with average percentage of 41.38%. The laminated horizon seen at the top of the middle part of the LPS, 1,5 m above the ladder (**Figure 2**) is composed of 81% sand, 11% silt and 8% clay. Silt dominance at the Zmajevac LPS confirms that this sediment was deposited during strong eolian activity in colder periods of Upper Pleistocene.

Magnetic susceptibility (MS) analysis provides the data about ferrimagnetic mineral content in sediment and/or soil. This is important because increased concentration of magnetic minerals indicates more humid and/or warmer climate conditions, while decreased concentration points to more arid and/or colder climate conditions. This method is also useful when data comparison from different localities is needed, in order to get the interpretation of palaeo-environmental evolution. MS values from Zmajevac LPS loess and loess like sediment range from 5 to 28.5×10^{-6} SI (**Figure 3**). MS values from L1 horizon from the upper part of the Zmajevac LPS range from 15 to 20×10^{-6} SI, which is typical for loess. The uppermost paleosol horizon (F2) shows the highest measured MS values within the LPS (82.5×10^{-6} SI). MS values in the loess unit L2 are again lower, with a mean of 14×10^{-6} SI and this is expected difference between loess and paleosol. However, one notable peak within this loess horizon was detected with MS value of 28.5×10^{-6} SI. The pedo-complex consisting of P3a and P3b paleosols is marked by significant peaks in MS values. They are however lower than MS values recorded in the F2 paleosol horizon. Upper paleosol F3a displays MS values of 67.7×10^{-6} SI, while underlying paleosol P3b displays MS values of 53.2×10^{-6} SI. Loess and loess like sediment under pedo-complex display MS values in range of 11 to 23.7×10^{-6} SI. The lowermost paleosol P4 shows again a somewhat higher MS value of 58.3×10^{-6} SI, and the lowermost loess horizon displays MS value of 25.1×10^{-6} SI.

The mollusk paleontology of the Zmajevac LPS was analyzed from 13 bulk loess samples [30]. A total of 1705 terrestrial gastropod shells were collected. 13 species-level taxa was determined. Specimen richness related to the number of mollusk shells within the loess samples varies significantly in Zmajevac LPS. Results show that the malacofaunal shell concentration is moderate in lower loess horizons L7 (85) and L6 (117). It is strongly decreased in L5 (5) and L4 (7) loess horizons, and then increased in L3 (90), L2 (213), and L1 (136) loess horizons. The identified mollusk species have been classified according to their palaeoenvironmental preferences following previous, well documented research in Pannonian Basin [14, 19]. The presence and abundance of each mollusk species in loess samples can be used to determine paleoclimate and/or type of palaeovegetation. These information are basis for paleoenvironmental reconstruction that shaped the Pannonian Basin area during the deposition of loess sediment.

Sample	>0,063 mm	0,032-0,063 mm	0,016-0,032 mm	0,004-0,016 mm	<0,004 mm
Kot 1/1	12	33	31	24	0
Kot 1/2	8	42	23	22	5
Kot 1/3	5,5	46,5	24	17	7
Kot 1/4	11	37	22	19	11
Kot 1/5	7,5	35,5	28	22	7
Kot 1/6	9,5	39,5	27	19	5
Kot 1/7	14,5	31,5	27	27	0
Kot 1/8	8	44	27	21	0
Kot 1/9	12,5	39	24,5	24	0
Zma 1/1	15	40	20	19	6
Zma 1/2	14,5	57,5	12	8	8
Zma 1/3	10	45	28	17	0
Zma 1/4	12,5	47,5	25	15	0
Average	10,8	41,4	24,5	19,5	3,8

Table 1.
Grain size distribution in Zmajevac LPS.

Therefore, each sample is characterized by a certain malacofaunal assemblage [13]. The obtained quantified data [30] allowed the definition of mollusk assemblages in the Zmajevac LPS for each loess horizon (from top L1 to lowermost L7). Species tolerating open and dry habitats are abundant in the Zmajevac LPS. Five specific assemblages which are all cold – resistant were determined in 13 loess samples.

Helicopsis striata assemblage is the most dominant among five assemblages detected in Zmajevac LPS. The *Helicopsis striata* assemblage indicates climate conditions preceding the last glacial/stadial maximum and it is characteristic assemblage of the 'warm' loess environment in Central Europe [13]. This 'warm' should not be considered warm in absolute terms, but relatively compared to the extremely cold periods during the Upper Pleistocene.

Chondrula tridens and *Arianta arbustorum* are generally abundant species in Zmajevac LPS, but their concentration in loess samples is never high enough for definition of a pure *Chondrula tridens* or *Arianta arbustorum assemblage*. This is not unusual, because it is not often that pure assemblages are found.

Arianta arbustorum species is cryogenic, hygrophilous species and related assemblage is typical for humid forests, hillsides and lowland areas.

Contrary to that, *Chondrula* tridens species is a warm steppe species and related assemblage is representative of interstadial, mild, dry steppe to forest steppe environment.

The *Pupilla loessica* and *Columella columella* assemblages are typical loess faunas and they represent glacial/stadial maximum. Arid and cold climate conditions are indicated by the *Pupilla loessica* assemblage, while more humid conditions are represented by the *Columella columella* assemblage.

The two most common mollusk species which appear in all of the samples from the Zmajevac LPS are *Helicopsis striata* (WAGNER) and *Arianta arbustorum* (LINNAEUS). Precisely because of their presence in all loess horizons they were used for stable isotopes ($\delta^{18}O$ and $\delta^{13}C$) analysis. They Stable oxygen isotope values for these two species range from −5.76‰ to −2.45‰ (**Table 2**). Stable carbon isotope values range from −8.83‰ to −6.84‰ (**Table 2**). Average value for $\delta^{18}O$ is −3.91‰ and average value for $\delta^{13}C$ is −7.95‰ (**Table 2**). It is obvious that $\delta^{13}C$ values vary to

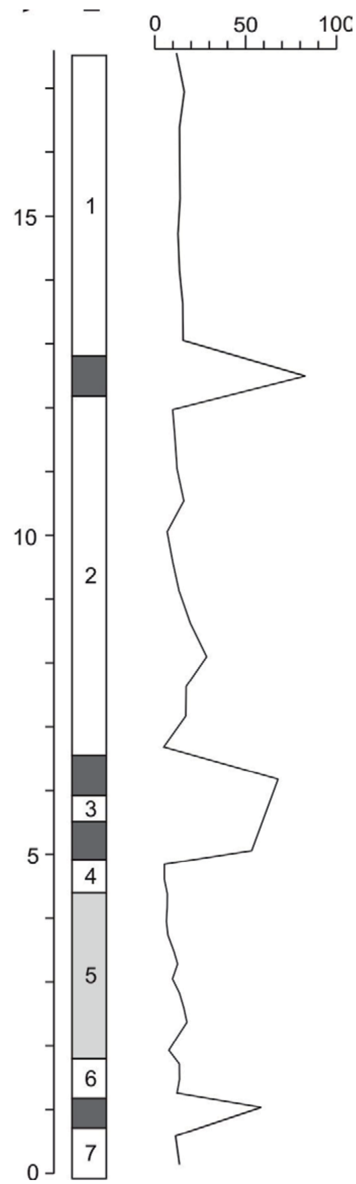

Figure 3.
MS values measured at Zmajevac LPS. Note: loess horizons in white and light gray color are numbered from 1 to 7. Four paleosols from top to bottom are: F2, F3a, F3b and F4; and they are represented with dark gray color.

a lesser extent than $\delta^{18}O$ values. The values in each sample vary depending on which mollusk species is analyzed, but that is to be expected. Regularity, which would indicate that one analyzed mollusk species shows constantly lower or higher $\delta^{18}O$ and $\delta^{13}C$ values in relation to the other analyzed species, was not registered. The values for stable oxygen isotope are in accordance with results from other loess profiles in the Pannonian Basin with emphasis on MIS 2 stage [18].

4. Comparison of mollusk assemblages with others in Central Europe (Pannonian Basin)

Data obtained from paleontological analysis from the Zmajevac LPS are valuable, but it is necessary to put them in a broader context and compare them with paleontological research from other sites in the Pannonian plain. Previous research of malacofauna conducted on loess profiles in Eastern Croatia [10, 12] show significant congruence with the results obtained by Banak et al. [30, 31] from the Zmajevac LPS.

In Erdut loess profile [10] which is situated 30 km to the southeast from Zmajevac LPS determined malacofauna was detected in four loess horizons. The base horizon is characterized by a *Columella columella* assemblage, while in the three remaining horizons *Helicopsis striata* assemblages is dominant. These results are comparable and almost identical to the results obtained from the Zmajevac LPS on Bansko Brdo hill (30). Still, there are some minor differences in faunal assemblages that probably reflect micro climate conditions during the Upper Pleistocene. The L4, L5 and L6 loess horizons of the studied Zmajevac LPS with dominant *Helicopsis striata* assemblage show strong influence of *Arianta arbustorum* and *Columella columella* assemblage. In Erdut loess profile dominance of *Helicopsis striata* assemblage with minor influence of a *Chondrula tridens* assemblage is detected [10]. The topmost L1 horizon from this study and the topmost horizon from the Erdut LPS [10] display similarity, with the dominant *Helicopsis striata* assemblage being accompanied by a *Chondrula tridens* assemblage. The lowermost horizons at Zmajevac LPS (L7 and L6) and from the Erdut LPS [10] display differences which are marked by dominant *Helicopsis striata* assemblage at the Erdut profile and *Columella columella* assemblage at Zmajevac LPS.

The mollusk species distribution of the Zmajevac LPS shows certain similarities also with the Irig loess profile on the southern slope of Fruška Gora Mt. in NW Serbia [2] which is less than 100 km away in east - southeast direction. *Chondrula tridens* and *Helicopsis striata* assemblages dominate in the Irig loess profile and are also present in the Zmajevac LPS, but *Chondrula tridens* is not so dominant in Zmajevac LPS. Further, in Irig loess profile *Vallonia costata* and *Clausilia dubia* species are present in the lowermost part of the LPS, but in contrast two lowermost loess horizons in the Zmajevac LPS bear cooler climate representative in form of *Columella columella* assemblage. This assemblage in Zmajevac LPS is reflecting the Middle Pleistocene Penultimate Glacial (MIS 6) conditions. Based on this compared data it is obvious that these two loess profiles are dominated by *Helicopsis striata* assemblage, but they differ significantly from each other, especially in lower horizons.

Sample	Stable oxygen ($\delta^{18}O$)	Stable carbon ($\delta^{13}C$)
Kot 1/1	−2,45	−7,45
Kot 1/2	−3,84	−6,96
Kot 1/3	−4,05	−6,84
Kot 1/4	−4,41	−7,75
Kot 1/5	−3,26	−8,83
Kot 1/6	−3,16	−7,47
Kot 1/7	−4,85	−8,04
Kot 1/8	−5,15	−8,82
Kot 1/9	−5,27	−8,31
Zma 1/1	−2,15	−9,21
Zma 1/2	−3,35	−8,62
Zma 1/3	−3,16	−7,84
Zma 1/4	−5,76	−7,23
Average	−3,91	−7,95

Table 2.
Stable isotope values from Zmajevac LPS malacofauna. Upper four samples represent MIS 2 stage.

The Upper Pleistocene malacofaunal assemblages from the Petrovaradin loess profile in NW Serbia show colder and more humid conditions than in either the Irig or Zmajevac LPS [3, 32]. This is probably an effect of the palaeogeographic position at the northern slope of Fruška Gora Mt. [3, 32], which is opposite to the positions of Zmajevac and Irig LPS's at the southern slopes.

The fauna from middle and upper loess horizons (L3, L2 and L1) of the Zmajevac LPS displays certain similarity also with Madaras loess section in South Hungary [33]. There are some differences present as well. Uppermost L1 loess horizon in the Zmajevac LPS differs from K L1 LL1 loess horizon in Madaras because *Helicopsis striata* and *Chondrula tridens* assemblages dominate here, while *Columella columella* and *Vallonia tenuilabris* species dominate in Madaras LPS. Also, oposite to Madaras LPS *Columella columella* species is scarce at Zmajevac LPS. L2 loess horizon from the Zmajevac LPS differs from K L1 LL2 loess horizon at Madaras section, because *Vallonia costata* and *Pupilla muscorum* species dominate in that LPS, while in the Zmajevac LPS *Pupilla muscorum* is present, but not dominant. Also, *Vallonia costata* species is not present at all. L3 loess horizon in the Zmajevac LPS and K L1 LL3 loess horizon from Madaras LPS both contain *Helicopsis striata* assemblage and show the greatest similarity.

Described mollusk assemblages from Zmajevac LPS show small but important differences to other Pannonian Basin LPS's. It is especially noticeable in loess horizons L7, L6 and L3 of Zmajevac LPS. Results of malacofaunal assemblages from nearby loess profiles in Serbia and Hungary suggest that climate conditions that dominated in this part of Central Europe were similar, with some differences which were a result of paleogeography and microclimate conditions driven by it.

Sedimentological and magnetic susceptibility (MS) data obtained from Zmajevac LPS show similarities with other LPS's in the Pannonian Basin that were described in last decade [2, 7, 8]. MS values are in the expected range, especially in loess horizons (**Figure 3**). MS values from four paleosols are comparable with those from Irig LPS in neighboring Vojvodina region [2]. The lowermost P4 paleosol from Zmajevac LPS displays significantly weaker signals, than the P2 paleosol, but it is stronger than signals from the overlying P3b paleosol horizon. The MS value of 58.3×10^{-6} SI in the P4 paleosol is lower than expected for a long, interglacial period in which favorable climatic conditions prevailed, thus enabling fully developed soil. Even though P4 is the oldest paleosol in Zmajevac LPS, a weaker signal than in the youngest F2 paleosol may indicate that the relatively low MS values are result of mineral leaching. Such a decrease in the MS signal in clayey horizons was also detected in LPS in Germany [34] and in Hungary [35], therefore, it is not a specificity of Zmajevac LPS. It is very likely that similar processes affected the P4 paleosol horizon in Zmajevac. In agreement with previous research of this area [7], the P4 horizon is correlated with the MIS 5e interglacial period. The pedo-complex forming paleosol horizons P3a and P3b is similar to a pedo-complex from the Vojvodina [2]. Reminiscent of synchronous horizon of Hungarian Sütto LPS [4], the signal from the P3 pedo-comlex is higher than the one measured in Vojvodina. Finally, the strongly increased MS value of 82.5×10^{-6} SI suggests that the uppermost paleosol P2 could represent an interglacial, rather than an interstadial phase.

5. Late Pleistocene climate reconstruction based on $\delta^{18}O$ and $\delta^{13}C$ values

Stable isotope ratios of $\delta^{18}O$ and $\delta^{13}C$ were measured from fossil shells of two species: *Helicopsis striata* and *Arianta arbustorum*. Modern European land snails are active in the +10 to +27°C temperature range and hibernate or become inactive at temperatures below +10°C [36, 37]. This implies that stable isotope ratios recorded in mollusk shells represent a warmer period when snails formed their shells. This period that spans from spring to fall can be 160–210 days long [38, 39] and it reflects an average growing season (AGS) temperature. The same principle can be applied on fossil snails. It is known that snails are active in building their shells during and immediately after the rain [40]. This information is crucial, because it provides a direct link from rainwater $\delta^{18}O$ values and $\delta^{18}O$ values that we measured in the mollusk shells. This complex relationship between the $\delta^{18}O$ value of meteoric water and the values measured in land-snail shells has been studied for more than 40 years [15–17, 24, 41]. Today it is reliable and well established method often used for paleoclimate and paleoenvironmental research. Variations in land snail shell $\delta^{18}O$ is a function of temperature, relative humidity, $\delta^{18}O$ of water vapor, and $\delta^{18}O$ of liquid water ingested by the snail [16, 27]. It is worth mentioning that intra-shell variation of values measured in snail shells from LGM ranges from 0‰ to −5.5‰ [18] in some studied areas.

To avoid errors and to obtain the average $\delta^{18}O$ and $\delta^{13}C$ values, whole snail shells were crushed and analyzed. The $\delta^{18}O$ value in mollusk shells is enriched on average by 5‰ relative to equilibrium with ingested rainwater [16]. This means that a $\delta^{18}O$ value of palaeo rainwater incorporated in a mollusk shell which displays a $\delta^{18}O$ value of approx. -3‰ was approx. -8‰.

In order to compare climate conditions in the Upper Pleistocene with recent climate and to obtain relative temperature changes, it is necessary to know the $\delta^{18}O$ values of recent meteoric water and recent AGS temperatures from the same or nearby region. The nearest measured $\delta^{18}O$ value of rainwater to Zmajevac LPS is recorded in city of Zagreb, Croatia, which is located 250 km to the west from Zmajevac LPS. This $\delta^{18}O$ value is −6.11‰ for summer months of June, July and August (JJA) and it is measured in the last two decades [18]. This values represent shorter periods than AGS, but it is the closest approximation as we can get. In the last two decades mean JJA temperature recorded in Zagreb was +19.7°C. If we compare $\delta^{18}O$ values from Zmajevac LPS mollusk shells, enlarged for 5‰, we can clearly see that $\delta^{18}O$ values of meteoric water in the Upper Pleistocene ranged from approx. -7.45‰ to approx. -10.76‰.

If we compare these approximate and indirect $\delta^{18}O$ values with $\delta^{18}O$ value of −6.11‰ from present JJA measurements in Zagreb, it is clear that $\delta^{18}O$ values were constantly lower/more negative. This means that AGS temperatures during the Upper Pleistocene in Baranj region were much lower than present temperature in city of Zagreb. The mean, annual $\delta^{18}O$ value of rainwater for Zagreb is −8.33‰ [18] and mean annual temperature (MAT) for Zagreb in last two decades is +12°C. As most of the samples from Zmajevac LPS display more negative $\delta^{18}O$ values than −8.33‰, we can say with some certainty that even the AGS temperatures (which represent the warmest period of the year) during the Upper Pleistocene were lower than the present MAT in Zagreb. It is hard to determine what was the absolute value of temperature in the Upper Pleistocene, but we can calculate relative values and compare them to present one.

Researchers [42] estimated the MAT for MIS 2 stage is in range from 6.2°C to 11.2°C. It was reconstructed from oxygen isotopes values measured in mammoth tooth enamel from sites in the Czech Republic and Slovakia [42]. This paleotemperature data represents climate conditions from part of the Central Europe that is quite north of Zmajevac LPS (more than 200 km). Still, it can serve as a marker if we assume that the decrease in temperature is indeed related with latitude increase. Other researchers [20] estimated temperatures of 6.7 C (based on MS values), 8.5 ± 0.6 C (based on XRF-1 values) and 8.9 ± 4.4 C (based on XRF-2 values) in Northern Hungary for the same period of the Upper Pleistocene (MIS 2 stage). Finally, researchers [43] calculated a MAT of 4.5 C in Central Europe using noble gas thermometry (NGT). This result displays significantly lower MAT than other results, which is probably due to this specific method.

Results from our research show that $\delta^{18}O$ values from Zmajevac LPS are in fair accordance with $\delta^{18}O$ values from North America and other LPS's in Central Europe, but they are partly different from $\delta^{18}O$ values from southern Europe (**Figure 4**).

$\delta^{18}O$ values measured in fossil shells indirectly reflect paleotemperature at a time when these fossil snails lived. This is useful if we want to reconstruct paleotemperature changes over longer period of time if we have enough data, that is, fossil findings. We know from previous research that if the $\delta^{18}O$ value in the shell changes by 0.5‰ it reflects a paleotemperature change of approximately 2°C [24]. The formula for calculating AGS paleotemperature changes in the Zmajevac LPS, adjusted according to [24], is as proposed:

$$\Omega\left(°C\right)=\left(\delta 18Omax.-\delta 18\,Omin./\,0{,}5‰\right)X\,2°C \tag{1}$$

where:

Ω is: relative paleotemperature change

δ18 Omax. is: maximal $\delta^{18}O$ value measured in a gastropod shell

δ18 Omin. is: minimal $\delta^{18}O$ value measured in a gastropod shell

We used the $\delta^{18}O$ values measured from Zmajevac LPS fossil shells and according to this formula AGS paleotemperature changes through entire Upper Pleistocene in Baranja region is: 13.2°C.

Other researchers propose different ratios and interdependence of $\delta^{18}O$ values and paleotemperature. According to [26] if the $\delta^{18}O$ value in shell changes by 0.35‰ it reflects a paleotemperature change of approximately 1°C. We can adjust the formula according to this research and then it is:

$$\Omega\left(°C\right)=\left(\delta 18Omax.-\delta 18Omin./\,0{,}35‰\right)X\,1°C \tag{2}$$

where:

Ω is: relative paleotemperature change

δ18 Omax. is: maximal $\delta^{18}O$ value measured in a gastropod shell

δ18 Omin. is: minimal $\delta^{18}O$ value measured in a gastropod shell

If we use the same $\delta^{18}O$ values from Zmajevac LPS fossil shells in this formula, AGS paleotemperature changes through the Upper Pleistocene in Baranaj region is: 9.5°C.

If we compare these results with MAT temperatures for other Pannonian Basin LPS, it is plausible to conclude that the second formula and the range of 9.5°C are more accurate. Both of these values suggest strong and constant changes of paleotemperature during the Upper Pleistocene in the Baranja region.

It is worth mentioning that he $\delta^{18}O$ values from Zmajevac LPS displays some deviation in regards to paleotemperatures or paleoclimate conditions determined by malacofaunal assemblages. These deviations are probably a result of complex flux-balance model between the rainwater used by the fossil snails and their shell, which does not respond with the same intensity to palaeo temperature changes [27].

Climate changes during the glacial and interglacial periods are the main cause for changes in vegetation which are reflected in $\delta^{13}C$ values of plants [44, 45]. Therefore, $\delta^{13}C$ values from fossil shells can be used to determine the diet of land snails, which can then help in palaeoenvironmental reconstruction. The $\delta^{13}C$ value of atmospheric CO does not affect the $\delta^{13}C$ value of snail shells, so these values are a relevant and reliable indicator of fossil snail diet [27]. If the $\delta^{13}C$ values are more negative, it is an indication that the mollusks consumed more C3 plants in their diet and that the climate was cooler and more humid [22, 25]. If the $\delta^{13}C$ values are more positive, it is an indication that the snails consumed more C4 plants in their diet, which indicates a more arid environment [22, 46].

Research from central parts of Pannonian Basin (Hungary) [47] shows that relatively stable woodland-grassland ecotone was the dominant vegetation type in the Pannonian Basin between 140 ky and 16 ky. This is a time span which largely coincides with Upper Pleistocene period. Described woodland-grassland ecotone

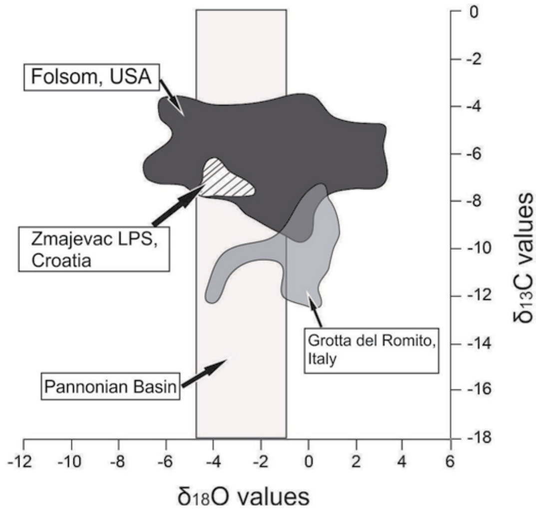

Figure 4.
Comparison of results for MIS2 from Zmajevac LPS with ones recorded in other European and north American LPS profiles from late Pleistocene.

was preserved even during the strongest cooling, when a treeless steppe dominated the landscape of Pannonian Basin [47]. In this mixture of temperate, arctic and alpine ecosystems C3 plants typically dominate [48]. Soils formed in Tokaj region (southern Hungary) at the southern edge of the Pannonian Basin, display $\delta^{13}C$ values in really narrow range from −24‰ to −25‰ [48]. This is typical for soils developed under plants using the C3 photosynthetic pathway [49].

The variation of $\delta^{13}C$ values measured in fossil shells from Zmajevac LPS loess samples ranges from −8.83‰ to −6.84‰. Therefore, C4 vegetation as a diet source for these fossil snails obtained from Zmajevac LPS can be excluded. C4 plants display very different $\delta^{13}C$ values, ranging from −8‰ to −16‰ [49] and this is contrary to our results from Baranja region. $\delta^{13}C$ values measured in any fossil mollusk shells are enriched by 8–19‰ compared to the values of the plants that they ingested [50]. This means that $\delta^{13}C$ values of plants that mollusk from Zmajevac LPS ingested, were approximately in the range from −14.84‰ to −16.83‰, if we use the minimal 8‰ enrichment approach. This is very close to the most negative margin for C4 plants. If we apply maximal 19‰ enrichment, these values are more negative and in range from −25.84‰ to −27.83‰. Results from nearby areas [2, 4, 47, 48] that were compared with the results from this study suggests that for the entire time span during which the Zmajevac LPS was accumulated, C3 plants have been the main vegetation type for analyzed fossil snails. This indicates that Upper Pleistocene climate in the Baranja region was similar to the paleoclimate in other regions in the Pannonian Basin. Certain differences in paleoclimate exist and they are probably an effect of local geomorphology and microclimate conditions.

6. Impact of paleoclimate changes on Neanderthals and anatomically modern humans (AMH) in Central Europe

The Balkan peninsula was likely the migration route of anatomically modern humans (AMH) into Europe [51], and the Danube valley which cuts the Pannonian Basin is one of the most important pathways of these population movements [52]. This region consists of vast lowlands associated with the middle Danube drainage basin and surrounded by the Carpathian Mountains, the Alps, Dinarides and the

Bohemian Massif. The Last Glacial loess provides widely extended sedimentary coverage of the area and provides valuable paleoclimate records [2–4]. Additional stratigraphic records are present in caves located in the highlands and peripheral mountain zones. The Zmajevac LPS, described above is located in this region. This geographical setting allows us to determine with considerable certainty the impact of climate change in the Late Pleistocene on Neanderthal and early modern human populations.

The Neanderthals clearly represent the autochthonous population of eastern Central Europe according to various research [53–55]. This is documented by a group of fossil finds, spread over space and time and in the various environments, ranging from the last interglacial to the temperate oscillations of the early Würmian glacial (OIS 5a–e). Some of the most important fossil finds of Neanderthals and AMH are located in the Pannonian Basin, especially in its central, western and southern parts (**Figure 1**). Here we briefly describe localities from Pannonian Basin: two in Croatia, one in Hungary and one in Slovakia.

Krapina (Croatia): Excavated layers 3–8 yielded more than 900 skeletal fragments of several Neanderthal individuals, especially cranial fragments, mandibles, teeth, and postcranial fragments. This makes Krapina one of the most important Neanderthal sites in Europe. ESR and U-series dating provided results between 178 and 120 ka, with average values pointing to 130 ka, i.e., to the last interglacial peak OIS 5e [56]. The Lithic industry is a variant of the Mousterian.

Vindija, G3 layer (Croatia): All layers in this cave are characterized by abundance of cave bear skeletal remains, especially in some of the layers. Within the sequence of the Mousterian industries, the Neanderthal fossils [54] appear in layer G3 in association with some endscrapers and possible leaf-point fragments [57, 58]. Age of neanderthal tibia fragment in G3 layer was dated and it is 38 ka B.P. [59].

Vindija G1 layer (Croatia): This layer yielded several human fragments of archaic morphology, which do not differ radically from the Neanderthals of the underlying layers and elsewhere in Central Europe [54]. However, the associated lithics, even if typical for the Initial Upper Paleolithic period in general, allow for somewhat contradictory interpretations. The leaf point suggests the Szeletian industry [59] and on the other hand the bone split-base point and the Mladeč type point suggest an Aurignacian [57, 60]. The Aurignacian industry that marked replacement of Neanderthals by anatomically modern humans (AMH) lasted from 43 to 26 ka years B.P. and it is characterized by worked bone or antler points with grooves cut in the bottom [61]. Their flint tools include fine blades struck from prepared cores rather than using crude flakes [61]. Mester [62] describes the problem of distinguishing these two cultural units and points to a possibility that Szeletian tools had been made by AMH. From this point of view Szeletian represents a sub variant of the Aurignacian. In this interpretation, Aurignacian bone points may have been the functional equivalents of Szeletian bifacial leaf points.

The associated bear bones were dated to 36–32 ka B.P., but dating of the human bones provided AMS radiocarbon dates of 29–28 ka B.P. [63]. Given the association of these objects in an 8–20 cm thick layer which is partially cryoturbated, we cannot exclude the possibility of some mixture of fossils and artifacts of various ages, as some researchers suggest [60]. However, since the two types of projectiles—the lithic leaf points and the polished bone-and-antler points – appear together in several other cave sites of the region (Dzeravá skala, Mamutowa Cave, Istá lloskö Cave, etc.) [64], it is rather unlikely that mechanical mixing was responsible in all cases. It seems that associations of these projectiles made from different materials and thus with different advantages and functions [65] with predefined cultures may not be as local as expected. The "Aurignacian" bone projectiles are actually being found more frequently in non-Aurignacian contexts, not only in the Central European caves, but also in other regions as far away as northeast Russia [57, 60]. This indicates that certain communication between separated Neanderthal groups could have existed.

Remete Felsö (Hungary): The stratigraphy of this cave includes two glacial horizons or layers marked as: 5 and 4. The upper one, which is a layer characterized by loess containes limestone debris. Three human teeth (right I1-I2 and C) belonging to the same individual were found and analyzed. They are rather large and worn, but nothing more can be said about their specific features. The fauna, including cave bears, hyenas, lions and musk ox, suggests a tendency to cooling between the lower and upper horizon. All this faunal remains point to Szeletian in sensu latu and age is determined as OIS 3 [65]. The associated industry is characterized by typical leaf points and retouched flakes (including a Levallois flake), and has been classified generally as Szeletian, or, as a specific Transdanubian form of the late Middle Paleolithic—the Jankovichian [66].

Šal'a (Slovakia): Two Neanderthal cranial fragments, Šal'a 1 and the subsequently discovered Šal'a 2, were found in two different locations in the Vah river gravel deposits, but in secondary position and without precise dating. According to the correlation of the phylogenetic stratigraphic ranges of the vertebrate finds, the primary position of the Neanderthal Šal'a 1 specimen could be–with high probability – set into the terrestrial layers of the last interglacial age, approx. 100–75 ka years B.P., which fits into OIS 5 stage [67].

Generally, eastern part of Central Europe provides solid evidence for the association of Neanderthals with the various Middle Paleolithic cultural entities of the interglacial and early glacial: the Taubachian, Mousterian, and Micoquian [68, 69]. Recent findings from the Neanderthal type locality Kleine Feldhofer Grotte site in the Neander Valley (Germany) also provide solid insights in various Middle and Upper Paleolithic cultural entities [70]. Preliminary analysis of the thousands of lithic artifacts recovered from this site has shown that two specific Paleolithic assemblages are represented: Micoquian artifacts typical of the late Middle Paleolithic and Upper Paleolithic artifacts from the Gravettian [70].

The question of the last Neanderthals and their relationship to the transitional or Initial Upper Paleolithic cultural entities of the region—the Szeletian and the Bohunician is far more susceptible to debate. Their "transitional" character is understood as a combination of archaic Middle Paleolithic patterns in technology, combined with the introduction of Upper Paleolithic tool-types [69].

The moment of AMH appearance in the Balkans and Central Europe has become better documented, since the new discovery at Pestera çu Oase 36–34 ka B.P. [71] and revisions of human fossil sites such as Mladeč which points to age of 35–34 ka B.P. In addition, the expansion of Aurignacian sites in Central Europe shows a specific time and space dynamic. While the early Aurignacian sites, dated as early as 42 ka B.P., are extremely rare and isolated (Willendorf II in Austria and Geissenklösterle in Germany) [72–74], the middle Aurignacian, dated between 34 and 29 ka years B.P., forms a kind of network of sites over large parts of the region. It also includes the emergence of Aurignacian figurative art. This findings point to interesting and probable conclusion. If the Aurignacian can be identified with AMH then the increased site density reflects their demographic growth. Also, if the art represents their higher social complexity and more advanced cognitive abilities, then the whole process may demonstrate the final "victory" of AMH over Neanderthals in Central Europe.

Various authors have listed several possible reasons for the extinction of Neanderthals. Some have discussed the possibility that their extinction was stimulated by violent conflict with *Homo sapiens* [75]. Violence in early hunter-gatherer societies usually occurred as a result of resource competition following major natural disasters. Another possibility, proposed recently is the spread of pathogens or parasites carried by *Homo sapiens* into the Neanderthal population [76]. The fact of coexistence also leaves open the possibility of interbreeding which resulted with a genetic heritage left by the Neanderthals in the anatomically modern human (AMH) population of the Upper Paleolithic Europe.

Neanderthals possessed the brain that enabled them greater visual acuity than *Homo sapiens* did, but the latter had better language-processing abilities [77]. It can be stated with certainty that Neanderthal brains were more adapted to vision and spatial memory and that resulted in less available area for cognition and social interactions [77]. This difference in brain structure could also lead to extinction of Neanderthals during short period of competition with *Homo sapiens*.

A separate set of factors that are not connected to the interaction of Neanderthals and AMH are climate change and natural disasters. It is well documented and described that the general characteristic of the paleoclimate in Central Europe (particularly in Pannonian Basin) is repeated succession of oscillations with varying intensity. This climate teeter started with an expansion of dense forests during the interglacial peak (OIS 5e). In OIS 5e the climate was very similar to today's climate. It continued throughout the long transitional stage of the early glacial (OIS 5a–d) with several oscillations that shaped a dry, steppe environment [2, 4, 5, 31]. This climate change has affected the whole region, but we must not forget that geomorphology has conditioned specific micro-climatic conditions within [2, 4, 20, 31]. As discussed in this book chapter, climate change was constant during the Upper Pleistocene in Central Europe. Average summer temperature changes were in range from 9.5°C and up to 13.2°C [24, 26, 31] compared to present day temperatures which are significant changes that have certainly affected the Neanderthal population.

Climate changes during the glacial and interglacial periods were also the main cause for changes in vegetation. C3 plants have been most probably the main vegetation type during the Late Pleistocene. These include trees and cold steppe grasses [31]. Changes in plant life were reflected in herbivore, mammal population and they would have led to a corresponding decline in big, plant-eating mammals hunted by the Neanderthals [78].

From the aforementioned sites and findings within, we can assume that the Neanderthal extinction in eastern Central Europe was not the result of just adverse climatic conditions during the Lower Pleniglacial maximum (OIS 4), but rather originated from several millennia of coexistence with the emerging early modern humans during the OIS 3 [79]. Data indicate that the disappearance of Neanderthals occurred at different times in different regions of Europe and Asia. Comparing the data with results obtained from the earliest dated AMH sites in Europe allowed the quantification of the temporal overlap between the two groups. The results reveal a significant overlap of 2600–5400 years (at 95.4% probability) [78]. It is clear that the coexistence with AMH population was long enough for the transmission of cultural and symbolic behavior, as well as possible genetic exchanges (interbreeding), between the two groups [78], but it is hard to conclude that it was the main cause of Neanderthal extinction. After the interbreeding episode(s), Neanderthals and their material culture disappeared and was replaced across Europe and Asia by AMH [79]. The precise timing of this transitional period has remained difficult to identify in the absence of a reliable chronological framework [79, 80].

In the end and as the most obvious conclusion, we can say that the extinction of Neanderthals and the rise of AMH population in Central Europe is due to a combination of all the factors mentioned in above, but it is difficult to reliably determine which one prevailed.

7. Conclusion

Data obtained from sedimentological and magnetic susceptibility analysis of Zmajevac LPS show a fairly good similarity with results from other LPS's in the

Pannonian Basin [2, 4, 8]. Stable oxygen values measured in fossil snail shells show significant paleotemperature changes during the Upper Pleistocene in the Baranja region. Average growing season (AGS) temperature changes during that period were 13.2°C [24] or 9.5°C [26], depending on which formula is applied. The second calculated value is more plausible and in accordance with other results from Pannonian Basin. The overall climate was much cooler then present day climate. Stable carbon isotope values show that the C3 plants have been the main vegetation type of fossil snails for the entire time span during which the Zmajevac LPS was accumulated. This indicates that they lived in environment dominated by trees and cold steppe grasses. Comparison of the results from Zmajevac LPS with other LPS's from Central Europe [2, 4, 81] suggests that Upper Pleistocene climate in the Baranja region was similar to the paleoclimate in other regions in the Pannonian Basin. Certain differences in paleoclimate existed and they are probably an effect of local geomorphology and microclimate conditions.

The described climate change in the Upper Pleistocene is very likely a significant but not the only factor that influenced the extinction of the Neanderthal population which paved the way for the dominance of anatomically modern humans (AMH) in Central Europe and everywhere else in the World.

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Chapter 3

Human Evolution in the Center of the Old World: An Updated Review of the South Asian Paleolithic

Parth R. Chauhan

Abstract

The Indian Subcontinent was an important geographic region for faunal and hominin evolution in Asia. While the Oldowan as the earliest technocomplex continues to be elusive, the oldest Acheulean is dated to ~1.5 Ma and the early Middle Paleolithic is ~385 ka (from the same site). New Late Pleistocene dates have been reported for the Middle Paleolithic which continues up to 38 Ka in southern India. The Upper Paleolithic remains ambiguous and requires critically multidisciplinary investigations. The microlithic evidence appears to spread rapidly across the subcontinent soon after its emergence at ~48 Ka (though its origin is debated) and continues into the Iron Age. The timeline of the initial arrival of *Homo sapiens* continues to be debated based on the archaeology (advanced Middle Paleolithic vs. microlithic) and genetic studies on indigenous groups. Other issues that need consideration are: interactions between archaics and arriving moderns, the marginal occurrence of symbolic behavior, the absolute dating of rock art and the potential role of hominins in specific animal extinctions and ecological marginalization. The region does not appear to have been a corridor for dispersals towards Southeast Asia (although gene flow may have occurred). Instead, once various prehistoric technologies appeared in the Subcontinent, they possibly followed complex trajectories within relative isolation.

Keywords: Asia, Indian subcontinent, Paleolithic, paleoanthropology, milestones

1. Introduction

Human evolutionary studies or paleoanthropological research are constantly yielding new information and thus revising previously assumed hypotheses as well as generating new ones. While Africa and Europe have dominated the bulk of our knowledge on human evolution over the last century, various parts of Asia are yielding new and unexpected paleoanthropological surprises. One of these vital Asian regions is South Asia or the Indian Subcontinent, its prehistory being known and regularly highlighted since the nineteenth century [1] and predominantly includes stone tool assemblages from various time periods ranging from the Lower Paleolithic to the Neolithic [2]. Prehistoric evidence is known from throughout the Subcontinent with specific geographic pockets as being exceptions due to various factors including research bias as well as other natural attributes. Lithic assemblages belonging to all prehistoric phases have been reported including Lower Paleolithic (Oldowan and Acheulean), Middle Paleolithic, Upper Paleolithic and microlithic/Mesolithic. Despite this large body of known evidence, very few sites have been properly dated using absolute dating techniques. The earlier results, though obtained through different dating methods [3, 4], should be viewed as provisional until verified by newly-available dating techniques. For example, some U-Th dates (between <390 Ka and < 131 Ka) processed a few decades ago at a multi-period site in Rajasthan have now been revised to younger estimates using the luminescence method e.g. [5], leading to a re-interpretation of that cultural sequence [6]. The persistent marginal profile of hominin fossils continues to afflict Indian prehistory and more systematic surveys are required to identify new areas with vertebrate fossil preservation. The only known pre-modern hominin fossils in the subcontinent, which may be contemporary with the Late or terminal Acheulean phase, come from Hathnora and nearby localities in the central Narmada Valley. They include a partial calvarium, possibly female, and possibly associated clavicles and a rib fragment, all

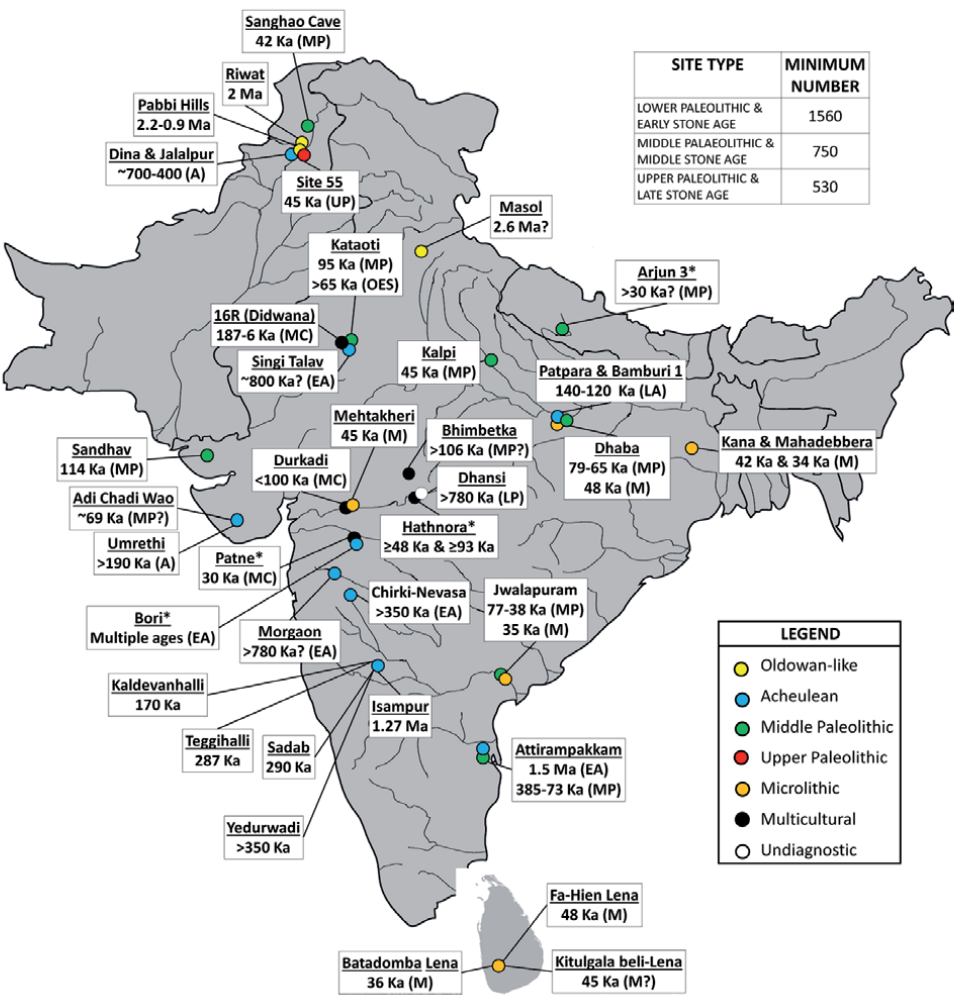

Figure 1.
*Map of dated Paleolithic technologies across the Indian subcontinent including Pakistan, India, Nepal and Sri Lanka (**LP**: Lower Paleolithic; **a**: Acheulean; **EA**: Early Acheulean; **LA**: Late Acheulean; **MP**: Middle Paleolithic; **UP**: Upper Paleolithic; **M**: Microlithic; **MC**: Multi-cultural; **OES**: Ostrich eggshell).*

Site	Age	Techno-chronology
Masol	2.6 Ma?	pre-Acheulean
Riwat (Pakistan)	~2 Ma	Pre-Acheulean
Pabbi Hills (Pakistan)	2.2–0.9 Ma	Pre-Acheulean
Attirampakkam	1.5 Ma & 385–73 Ka	Acheulean & Middle Paleolithic
Isampur	1.27 Ma?	Acheulean
Singi Talav	~800 Ka?	Acheulean
Dhansi	>780 Ka	Undiagnostic
Morgaon	>780 Ka & 41 Ka	Acheulean
Dina & Jalapur	~700–400 Ka	Acheulean
Chirki Nevasa	>350 Ka	Acheulean
Sadab	290 Ka	Acheulean
Teggihalli	287 Ka	Acheulean
Umrethi	>190 Ka	Acheulean
Kaldevanhalli	174 Ka	Acheulean
Patpara & Bamburi 1	140–120 Ka	Acheulean
Bori	1.38 Ma to 23 Ka	Acheulean
Adi Chadi Wao	190 to 69 Ka	Acheulean
16R (Didwana)	187 Ka - 6 Ka	Multi-period
Sandhav	114 Ka	Middle Paleolithic
Bhimbetka Rockshelter III-F23	>106 Ka & >41 Ka	Multi-period
Nakjhar Khurd	>100 Ka	Acheulean
Durkadi	<100 Ka	Multi-period
Kataoti	95 Ka	Middle Paleolithic
Dhaba	79–65 Ka & 48 Ka	Middle Paleolithic & microlithic
Jwalapuram	77–38 Ka & 35 Ka	Middle Paleolithic and microlithic
Mehtakheri	48 Ka	Microlithic
Fa-Hien Lena (Sri Lanka)	48 Ka	microlithic
Kalpi	45 Ka	Middle Paleolithic
Site 55 (Pakistan)	45 Ka	Upper Paleolithic
Kitulgala beli-Lena (Sri Lanka)	45 Ka	microlithic
Sanghao Cave (Pakistan)	42 Ka	Middle Paleolithic
Kana	42 Ka	Microlithic
Batadomba Lena (Sri Lanka)	36 Ka	microlithic
Mahadebbera	34 Ka	Microlithic
Arjun 3 (Nepal)	>30 Ka?	Middle Paleolithic
Patne	30 Ka	Multi-period

Table 1.
List of dated prehistoric sites in the Indian subcontinent.

recovered over a decade [7, 8]. The calvarium, originally identified as an "advanced" *Homo erectus*, was later reclassified as an archaic or early form of *H. sapiens* [9, 10]. Phylogenetic reevaluation of the calvarium reveals that it shares key morphological features with both *H. heidelbergensis and H. erectus* [11]; it has been most recently classified as *Homo* sp. indet. [12]. The oldest fossil evidence for *Homo sapiens* is dated to ~38 Ka and currently comes from Sri Lanka, while all younger evidence comes from multiple sites across India [13, 14].

What is also largely missing is direct evidence for butchery in the form of cut-marked fossil bones; some possible exceptions include Isampur [15] and Masol [16], both of which require further verification and substantiation through more evidence. Additionally, use-wear analyses and other scientific methods such as residue analysis are also required on well-preserved lithic assemblages. Other types of evidence that are poorly known is the age and nature of symbolic behavior (see [17]) as well as the nature of technological transitions. Indeed, there has been a recent global movement to decolonize earlier interpretations of hominin dispersals and population replacements across the Old World [18]. This also includes India, where earlier historical interpretations defined the Upper Paleolithic and modern human behavior based on the then-known European evidence [19]. Numerous reviews of the South Asian region's prehistoric records have been published elsewhere (e.g. [3, 4, 20–28]). Over three dozen Paleolithic and early microlithic sites have been dated in Pakistan [29–33], India [5, 14, 16, 34–58], Nepal [59] and Sri Lanka [60–63] since the 1980s onwards, using different relative and absolute dating methods including biochronology, palaeomagnetism, stratigraphic correlation, U-Th, U-series, K-Ar, Ar-Ar, luminescence, electron spin resonance, radiocarbon (calibrated and uncalibrated) and AMS. These various ages range from ~2.6 Ma to ~35 Ka, and include geographically random sites belonging to various prehistoric technologies including Oldowan-like, Acheulean, Middle Paleolithic, Upper Paleolithic and the earliest microlithic assemblages (**Figure 1** and **Table 1**). While broad summaries are provided here, the primary goal of this paper is to highlight the most salient attributes of this zone, provide specific updates to previously known data and discuss possible implications of new discoveries from surrounding regions outside the Subcontinent.

2. Lower Paleolithic

Despite numerous efforts by several researchers such as Armand in central India [64] and the British Archeological Mission to Pakistan [33], the Oldowan has continued to remain elusive in India. Instead of unequivocally deriving from well-dated excavated contexts, almost all reported occurrences (n = 12) come from surface contexts or there are other contextual and geochronological issues associated with these finds [65]. Oldowan evidence has been reported from the Siwalik Hills in Pakistan and northern India as well as from the Narmada Basin in central India. The latest evidence, from Masol near Chandigarh, was reported by an Indo-French team and includes stone tools from excavated contexts and a possible-cut-marked fossil bone from surface context [16]. The researchers have provided an age estimate of 2.6 Ma for this material, however the contexts are disparate and the cut-marks are not properly verified [66] as they could have been produced from other processes also, such as animal teeth or fluvial transport prior to fossilization (e.g. [67]). The Lower Paleolithic of South Asia is basically dominated by (Large Flake) Acheulean assemblages that currently range in age from 1.5 Ma to 120 Ka [40, 57]. Acheulean sites are known to occur almost throughout the Subcontinent with some exceptions - the Gangetic plains, northeastern India and surrounding areas, Kerala, the extreme southern tip of India and Sri Lanka [4]– owing to various factors such as topography, geology, ecology, climate, high sea-levels and the absence of suitable raw materials. Acheulean assemblages variably include handaxes, cleavers, miscellaneous bifaces, picks, giant and small cores, polyhedrons, large and small flake blanks, flake tools such as scrapers and debitage at some primary-context factory sites (for examples, see **Figures 2**–**7**). The site with the oldest-known Acheulean evidence (Attirampakkam) also happens to preserve the oldest-known early Middle Paleolithic at 385 Ka [58]. This indicates that the full transition from the Lower Paleolithic to the Middle Paleolithic in South Asia was lengthy, geographically and chronologically uneven and behaviorally complex. This is evident

Figure 2.
Diverse handaxes, picks and trihedral elements from the Narmada Basin, Central India.

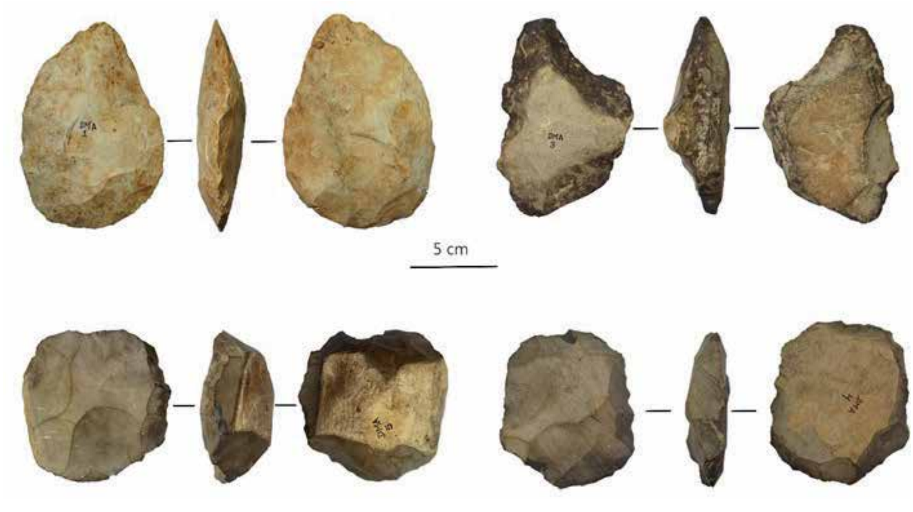

Figure 3.
Handaxe and miscellaneous bifacial elements from Son Valley, north-central India (pic courtesy: Shashi Mehra).

from the lengthy overlap between the earliest Middle Paleolithic at Attirampakkam and the Late Acheulean dated to 140–120 Ka in the Son Valley of north-central India [40]. In addition, such a lengthy transition is making it difficult for archeologists to often separate terminal Acheulean assemblages from early Middle Paleolithic ones. For example, the Son Valley evidence was respectively classified as Middle Paleolithic and Late Acheulean by two different groups of researchers over time (see supplemental data in [58]). It is also possible that the specific hominin groups during this transition made and used different technologies in differing contexts for diverse functional purposes: e.g. assemblages with Late Acheulean handaxes for heavy-duty tasks verses Levallois dominated flake assemblages for light duty tasks, a hypothesis that can only be resolved through chronologically-targeted landscape archaeology.

Key issues that are yet to be properly understood for the South Asian Acheulean include the nature of change within this techno-chronological phase as well as understanding factors to understand regional variations in assemblage compositions, artifact and site densities, timings of regional transitions, some geographic absences of occurrence and lack of absolute ages for most of the stratified assemblages. Broader aspects that remain to be properly understood include the number and directions of Acheulean dispersals into and out of the Subcontinent, the hominin species that were associated with that technology and the diverse subsistence strategies that took place across the region. In addition, specific regions have ambiguous features for which factors are currently unclear: for instance, the Gujarat zone (westernmost India) has not yet yielded Early Acheulean sites and while Maharashtra has numerous Early Acheulean sites on Deccan Trap basalt, no Late Acheulean sites have yet been reported. While future surveys may refine such observations, we need to explore additional explanations for such discrepancies. For example, lack of assemblage burial during specific fluvial and depositional cycles and associated sub-aerial weathering processes may have affected assemblages with smaller basalt specimens than in the Early Acheulean (see [68, 69]). However, this explanation may not be equally applicable to the entire zone of Maharashtra – perhaps basalt was not deemed suitable for Late Acheulean hominins or populations shifted to other regions to target different raw materials such as quartzite, and so forth. Based on preliminary counts from compiled data, a minimum of 1560 Acheulean/Early Stone Age sites and

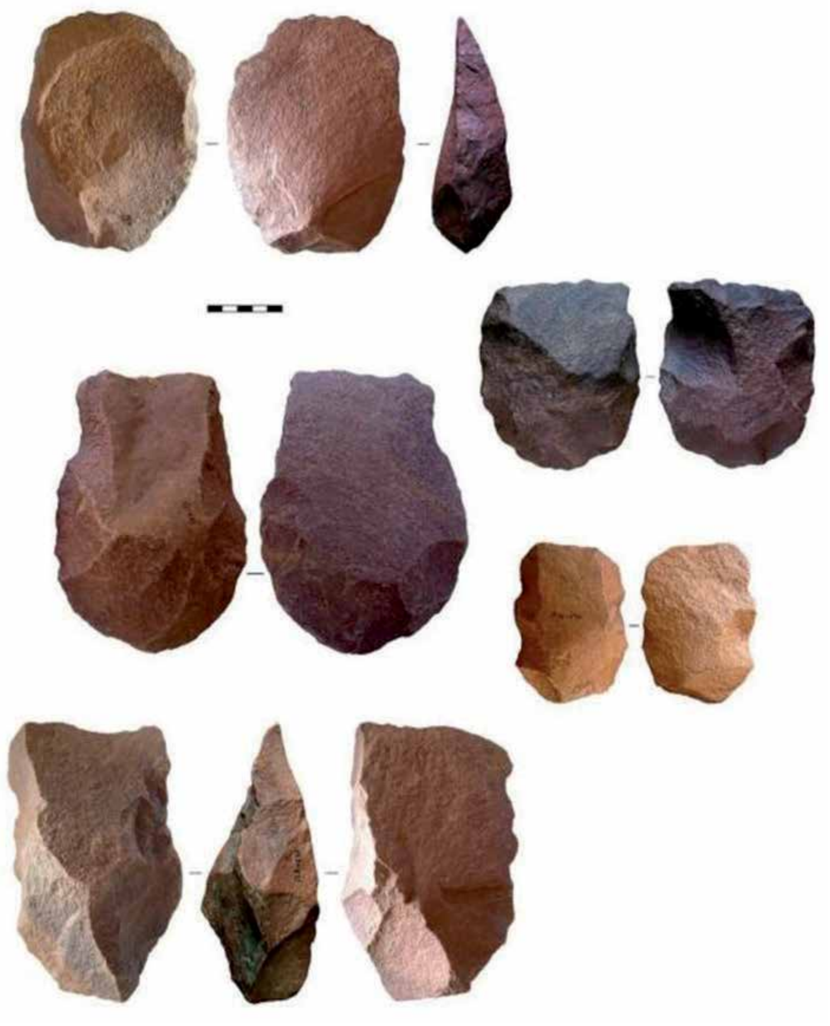

Figure 4.
Diverse cleavers from the site of Pilikarar in the central Narmada Basin.

site-complexes have been reported and there are major differences in the geographic patterns of occurrences.[1] While one factor may be research bias (i.e. lack of surveys in some zones), broad observations may still hold for most regions despite future survey efforts. For example, the northern zone, northeastern zone and the southern-most tip of India have the least number of Acheulean sites totaling to 51. The remaining zones have yielded significantly higher numbers of sites, especially central, eastern and peninsular India; for example, compiled data for central India alone yielded 305 published Lower Paleolithic sites out of which 17 have been excavated [70]. The virtual lack of Lower Paleolithic sites in southern Tamil Nadu and Kerala suggests that Lower Paleolithic hominins may have never reached the southernmost Indian coastal tip; this fact, along with a probable lack of a land bridge, may explain why no Acheulean evidence is known from Sri Lanka. This may further suggest that hominins first entered Sri Lanka after about 100 Ka when large bifaces ceased being made throughout India. In any case, more intensive surveys are required in Sri Lanka

[1] The minimum counts of different types of Paleolithic sites provided in this paper come from an ongoing compilation of published data (e.g. *Indian Archaeology- A Review; Man and Environment; Purattatva*).

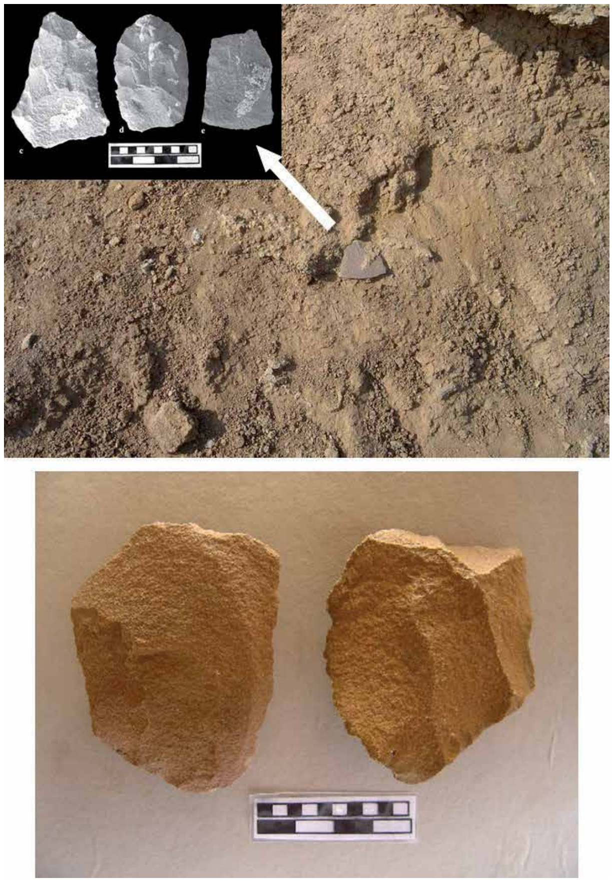

Figure 5.
Cleavers and cleaver-like flake blanks from the central Narmada Basin.

to confirm a true absence as well as recover, excavate and date potential Middle and Upper Paleolithic sites [71].

Other key anomalies for the Lower Paleolithic include 'missing contexts' and 'missing evidences'. For instance very few Early Pleistocene deposits, contexts and lithic assemblages have been identified south of the Siwalik Hills and the few known ones have been identified through limited but diverse methods such as palaeomagnetic dating, cosmogenic dating, electron spin resonance, associated stratigraphic correlation and microtremor readings [35, 50, 53, 57, 72–75]. This is probably due to a multitude of factors including the lack of focused surveys, lack of geochrononological applications and geological processes which may have both deeply buried such contexts as well as destroyed them (e.g. cut-and-fill regimes). These may explain why legitimate or unequivocal Oldowan assemblages have yet to be discovered, excavated and dated. In the same vein, Middle Pleistocene contexts and sites have also not been adequately identified, primarily owing to the earlier lack of suitable geochronological methods. Reliable Middle Pleistocene dates have started to be reported only recently as some of the sites have been studied and known for many decades to yielded important stratified lithic assemblages: the multicultural sequence at the 16R dune at Didwana in Rajasthan [5] now dated to between ~187–6 Ka [5][2], the Late Acheulean occurrences of Patpara

[2] The new luminescence dates for the 16R dune (<190 Ka) replace the previously-reported U-Th dates which had shown the bottom-most layer as being >350 Ka; the revised chronological framework has also led to the re-interpretation of the cultural sequence (see Blinkhorn 2013).

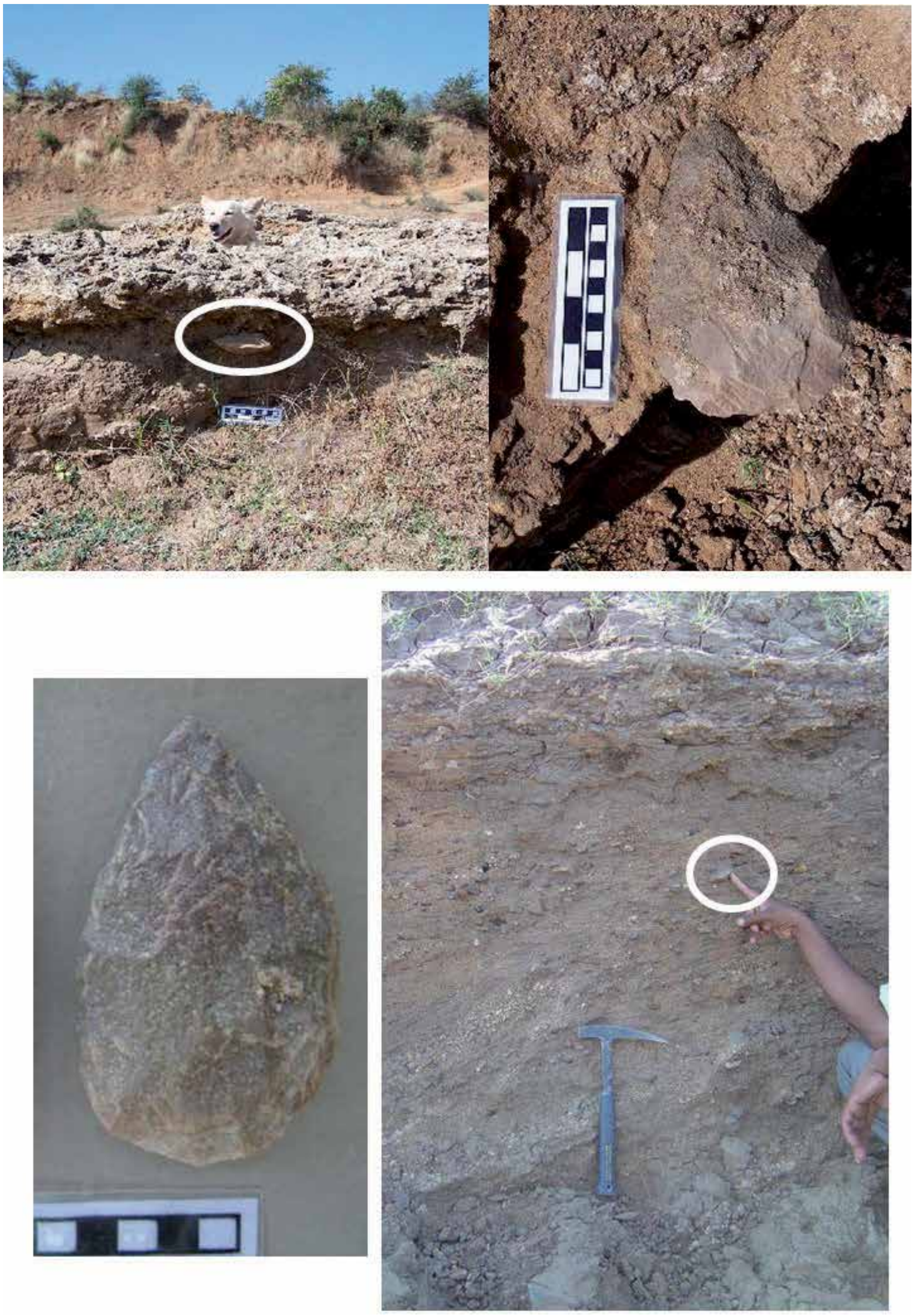

Figure 6.
In situ or stratified handaxes in quaternary fluvial sections of the central Narmada Basin.

and Bamburi in the Son Valley in Madhya Pradesh dated to between 140 and 120 Ka [40] and multiple early and later Middle Paleolithic assemblages from Attirampakkam in Tamil Nadu dated to between 385 and 73 Ka [58]. However, despite these investigations as well as stratigraphically and geochronologically identifying some Middle Pleistocene sites and contexts, they have not yet yielded any vertebrate fossil material. This temporal and contextual pattern of fossil preservation also applies to the known Early Pleistocene sites in central and peninsular India [50] which have yet to yield adequate vertebrate fossil evidence. Some rare

Figure 7.
Find-spots of cleavers in surface context with diverse sedimentary types from the central Narmada Basin (pic courtesy: Vivek Singh).

exceptions of vertebrate fossils found in contexts older than the Late Pleistocene in India include Isampur [15] and Attirampakkam in southern India ([76, 77]) and Dhansi in central India [44]. While the older contexts appear to be largely devoid of fossil preservation, it is highly probable that some or most of those older fossils have been redeposited in younger depositional contexts during landscape rejuvenation cycles. This probably also applies to some of the known fossil hominin material from the central Narmada Basin [7, 8] as associated mammalian teeth from Hathnora yielded variable absolute ages indicating chronologically-mixed fossils and probably artifacts as well [44]. Therefore, it is vital to date well-preserved vertebrate fossils directly using such methods as electron spin resonance and uranium-series, to obtain exact ages of the specimens rather than ages of their burial or minimum ages.

3. Middle Paleolithic

The early Middle Paleolithic appears to begin before 385 Ka [58] and is characterized by a gradual transition from large bifaces to small bifaces, before they disappear completely during the later Middle Paleolithic. In fact, the region allegedly preserves the youngest diminutive bifaces in the world (see [37, 78]), although this requires verification through more contextual and geochronological research across the Subcontinent as earlier U-Th dates need to be revised (e.g. [5]). The changing toolkit also includes the introduction of different reduction strategies and

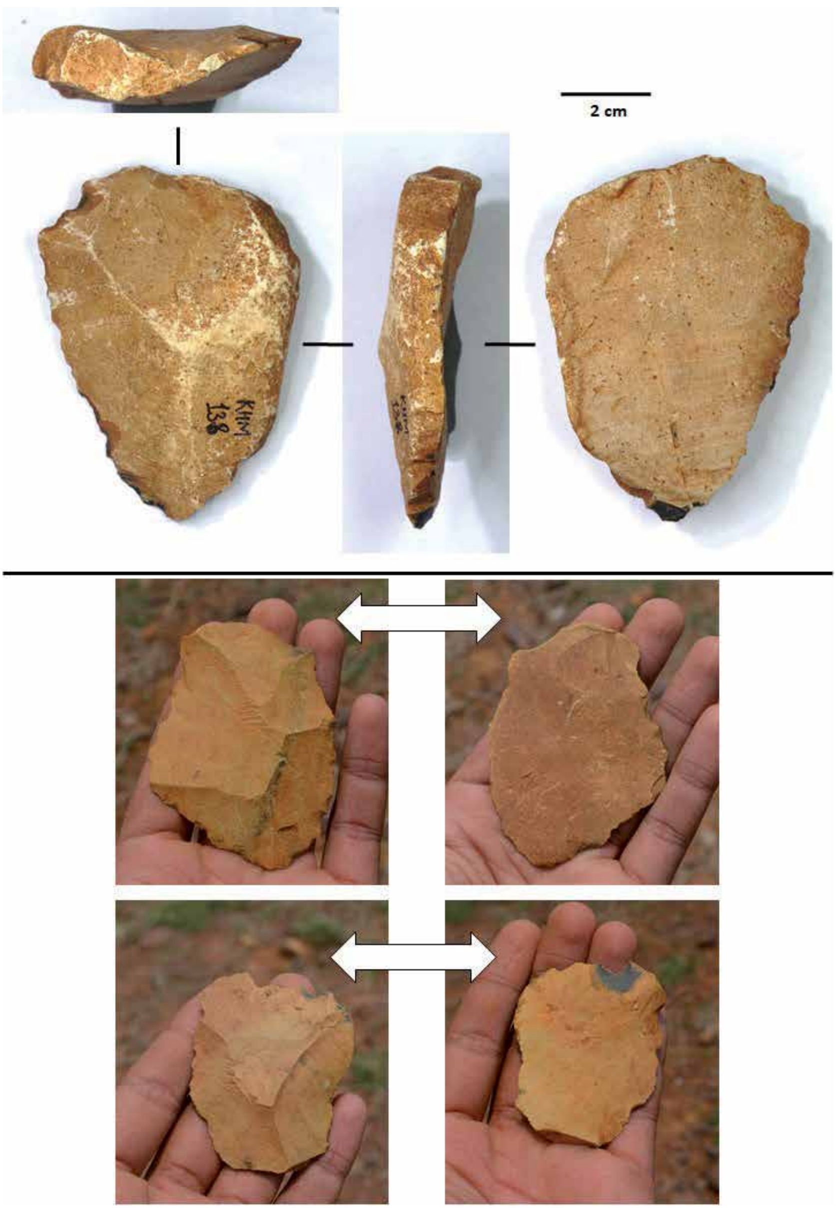

Figure 8.
Multiple perspectives of three Levallois flakes from the Son Valley, north-central India (pic courtesy: Shashi Mehra).

the emergence of prepared cores, points and blade elements (**Figures 8** and **9**). In fact, Middle Paleolithic points, which are first evident at 385 Ka at Attirampakkam, continue to occur in younger (Late Pleistocene) contexts as well [34, 36]. Late Pleistocene contexts and sites are more widespread but also remain inadequately dated. Recent examples of new and previously-known sites that were dated for the first time include Attirampakkam in Tamil Nadu where the later Middle Paleolithic ends at 73 Ka [58], Dhaba in Madhya Pradesh ([41, 79]), the Middle Paleolithic site of Sandhav in Gujarat [36] and Fa-Hien Lena in Sri Lanka [62]; the Sri Lankan evidence has been reported as the oldest known bow-and-arrow technology outside Africa at 48 Ka, making it contemporary with the microliths at Dhaba (also 48 Ka) and Mehtakheri which is 45 Ka [45]. The primary reason for the increase in such dates is the growing application of refined or new luminescence techniques as well as radiocarbon methods. The youngest Middle Paleolithic evidence has been

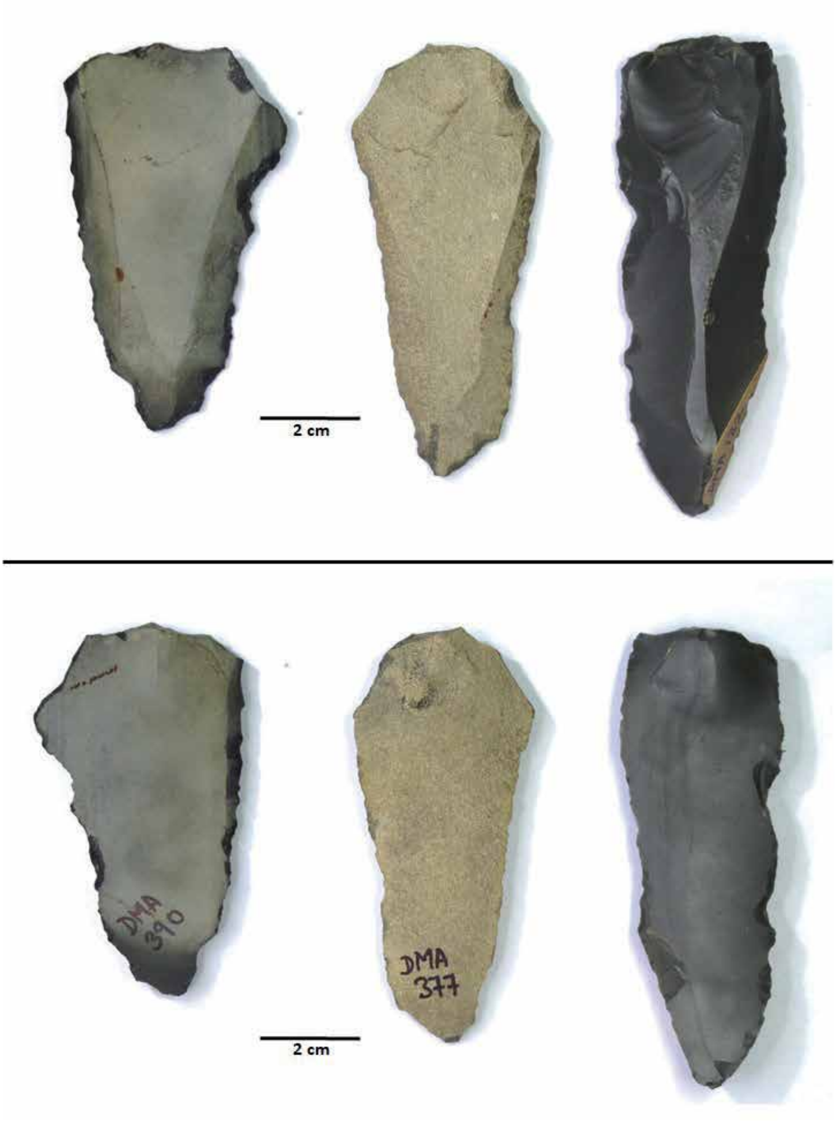

Figure 9.
Dorsal and ventral sides of three Levallois and Levallois-like points from the Son Valley, north-central India (pic courtesy: Shashi Mehra).

dated to 38 Ka in southern India [56] and as with the Acheulean, Middle Paleolithic assemblages have been reported from throughout the Subcontinent with (more or less) the same geographic exceptions.

Preliminary compilation of published data shows a minimum of 750 occurrences of Middle Paleolithic/Middle Stone Age sites and site-complex across India. While earlier researchers have identified Middle Paleolithic sites based on the absence of bifaces, dominance of flake-based assemblages and the presence of Levallois elements, some regions do not preserve a clear signature of this phase. For example, most of the enigmatic 'Soanian' evidence (**Figure 10**) in the Siwalik Hills region appears to variably comprise contemporaneous Mode 1 and Mode 3 technologies [4]. No absolute dates for that tradition/adaptation are yet available from excavated or stratified contexts and the only two earlier-dated occurrences in the Siwalik Hills of Pakistan [31] and Nepal [59] have *not* been classified as *Soanian*. Likewise in other regions, the Middle Paleolithic evidence may be equally undiagnostic or ambiguous and not necessarily absent. Based on current evidence, specific diagnostic attributes such as preferential Levallois elements and points do not appear to be as abundant or geographically widespread as expected. That being said, most of the earliest dispersals of *Homo sapiens* may not be typo-technologically diagnostic as seen with the younger technologies in the archeological record. In fact, the initial arrival of *Homo sapiens* continues to be debated based on archaeology (advanced Middle Paleolithic vs. microlithic) and genetic studies on indigenous groups [80]. Future surveys aimed at filling key geographic and stratigraphic contexts may gradually change this pattern. Over the last few decades, this technology has been increasingly thought to be associated with the initial arrival of *Homo sapiens* by various researchers, some of the most recent being the Jwalapuram evidence from southern India dated to ~77 [55], the Kataoti and Sandhav evidence from western India respectively

Figure 10.
Diverse artifact types from the Soanian site of Toka in Siwalik Hills of northern India.

dated to 95 Ka [34] and 114 Ka [36], and the Dhaba evidence in north-central India dated to between 79 Ka and 65 Ka [41].

4. Upper Paleolithic

This prehistoric phase is the most enigmatic in the Subcontinent as it lacks absolute dates, is geographically irregular and temporally overlaps with the terminal Middle Paleolithic and early microlithic in several regions. Due to the latter attribute, the South Asian Upper Paleolithic has been replaced with or incorporated within the 'Late Paleolithic' by some researchers (see [81]). Preliminary counts from published data has revealed a minimum of 530 reported Upper

Figure 11.
Laminar elements (blades) from the Son Valley, north-central India (pic courtesy: Shashi Mehra).

Paleolithic/Late Stone Age sites across India. It is interesting that classic and diagnostic Upper Paleolithic sites have not yet been reported (or classified as such) from Pakistan, Nepal and Sri Lanka. The dominating and defining features of this techno-chronological phase include a notable increase in the production of more specialized laminar tools such as blades and burins (**Figure 11**). Additional tool types during this techno-chronological period include flakes, knives, awls, borers, scrapers, cores including cylindrical types, choppers, and bone tools. Unfortunately, and surprisingly, there are still no absolute dates available for any exclusive (i.e. without a microlithic component) Upper Paleolithic assemblages in India, though numerous

Figure 12.
Diverse microlithic artifacts from the site of Bayan in the Central Narmada Basin (pic courtesy: Nupur Tiwari).

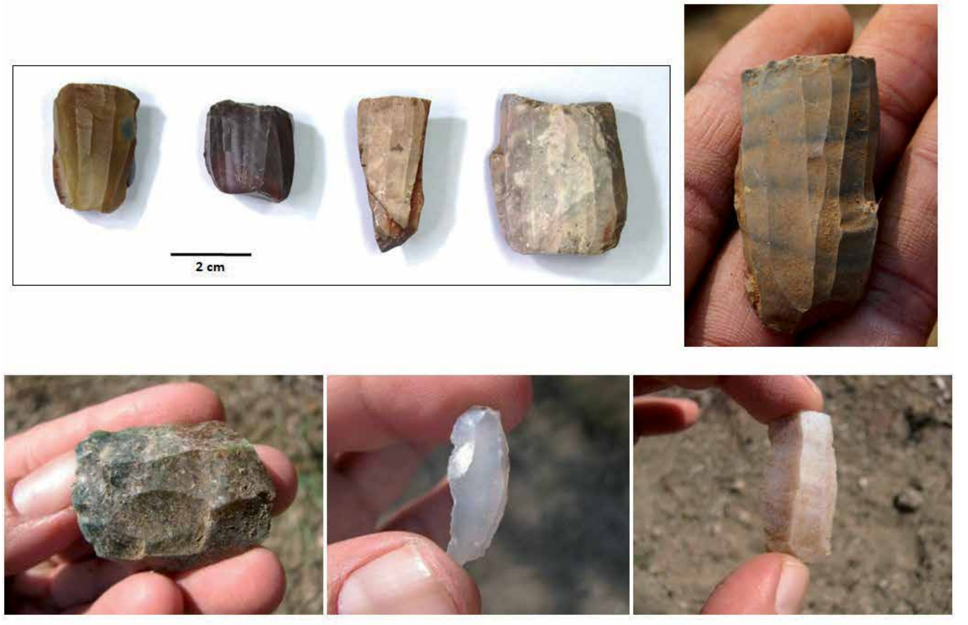

Figure 13.
Diverse microlithic cores and microblades/bladelets on different raw materials from the Son Valley (top row; pic courtesy: Shashi Mehra) and Patne (bottom row) in west-central India.

sites have been reported. The only date currently available for a blade-dominated assemblage in the entire Subcontinent is 45 Ka for Site 55 in Pakistan [31], making it contemporary with the young Middle Paleolithic assemblages in northern India [38] and old microlithic assemblages in central India and Sri Lanka [41, 62].

Besides chronology and ecological adaptations, a key issue that remains to be understood is the nature of the transitions between the Middle Paleolithic, Upper Paleolithic and early microlithic in South Asia (**Figures 12** and **13**). What is also lacking in association with these technologies is comparatively abundant symbolic behavior (see [82]), the main explanation for which may be the lack of adequate research and preservation. Given the geographic mosaic of ecological diversity across the Indian subcontinent, it is likely that only some regions do contain classic/typical Upper Paleolithic technologies as distinct techno-chronological entities. In the other geographic zones, their absence may be explained by the lack of suitable raw materials such as siliceous rocks (e.g. chert, fine-grained quartzite) and other factors such as a lack of geographic movements into some zones due to various climatic, ecological and adaptive constraints. Slightly younger evidence which was dated using the AMS method has also yielded new paleoanthropological insights including the youngest dated (~16 Ka) hippo fossils in India [83] and a new microlithic-faunal-pollen association (~18 Ka) from Odisha in eastern India [84], a poorly known but promising region for Indian palaeoanthropology. Such data demonstrate the broad temporal interface between fauna, environments and/or humans. Both studies span not only the end of the Last Glacial Maximum but also perhaps indirectly reflect major transformations within the microlithic phase including the beginning of geometric microliths, human burials and other symbolic behaviors, i.e. the beginning of the Mesolithic proper. Increased human-fauna interactions and rapid colonization of the Subcontinent may have led to the beginning of long-term eco-geographic marginalization of some species (e.g. lion, rhino) as well as their subsequent extinctions (e.g. hippo, ostrich). Only high-resolution multidisciplinary studies including robust chronological frameworks from across India can, however, verify or reject such broad multi-proxy relationships.

5. Discussion and conclusion

In addition to the observations and brief summaries provided above, additional key paleoanthropological discoveries in recent years include the first-ever recovery of *Sivapithecus* fossils outside the Siwalik Hills [85], extraction of DNA from ostrich eggshells and protohistoric human bones [86, 87] and the report of tool-use and object manipulation by the macaque populations of Andaman and Nicobar Islands [88, 89]. The *Sivapithecus* find comes from the western region of Gujarat and clearly demonstrates how little we know about past faunal distributions at the pan-Indian level. More systematic surveys of key sedimentary contexts in targeted locations across India may yield additional faunal surprises including the much-needed hominin fossils. The successful extraction of DNA from two diverse materials – human bone and ostrich eggshell - also demonstrates that there is now greater potential for further such studies despite earlier failed attempts which were attributed to tropical environmental conditions [90]. The observation of tool-use in monkeys further highlights the critical need for more primate studies in South Asia at various levels including primate archaeology, cognitive studies, ecological adaptations, social relationships, subsistence patterns, conservation strategies and so forth. One arguably important conclusion from the review of known data is that, with the exception of the Pabbi Hills in the Pakistan Siwaliks, no clear evidence currently exists for the presence of Oldowan evidence in the entire Indian subcontinent [65]. Based on the current lack of diagnostic Paleolithic (e.g. Acheulean, Levallois, Upper Paleolithic) and microlithic technologies in the northeastern part of the Indian Subcontinent (i.e. northeast India, Bhutan, Bangladesh, Myanmar), it does not appear to have been used as a biogeographic corridor during hominin dispersals to Southeast Asia. However, intensive surveys are required in the concerned areas as well as Southeast Asia to confirm whether the Subcontinent was a bio-cultural cul-de-sac. In that respect, Pakistan and surrounding border areas also require further surveys to increase the number of Paleolithic sites there, especially due to their significance as the geographic entry point into the Subcontinent. Numerous known sites require re-investigation through multidisciplinary methods including excavations, geological analyses, palaeoenvironmental reconstructions and absolute dating. This is especially critical as some previously-known sites are gradually getting destroyed through various geological and anthropogenic processes (e.g. Chirki-on-Pravara; Personal communication: Sheila Mishra).

Unfortunately, broad hypotheses/theories have been made for South Asian prehistory without adequate evidence, such as the innovation of microlithic technology following environmental deterioration soon after 40 Ka [46]. Not only is there no clear evidence for environmental degradation across the Subcontinent, but later discoveries have demonstrated that microlithic technology was well established in central India and Sri Lanka, respectively, between ~50 Ka and 45 ka. Though the source and nature of their origin remain ambiguous (innovated vs. introduced), it may be possible that specific evolutionary milestones converged at roughly the same time: arrival of *Homo sapiens* into South Asia with microlithic technology and the arrival of the ostrich into South Asia, possibly reflecting shared arid environments [66, 91]. On a related note, the nature of biological transition(s) between the archaic populations and incoming *Homo sapiens* has also not been theoretically explored. Was this replacement process gradual or rapid? Did the replacement of archaic populations include interbreeding, and what was its temporal rate and geographic pattern at the pan-Indian level? Did the technologies of both respective hominin groups mix and influence each other at any point in time and space? These and other questions require serious multidisciplinary attention at both empirical and theoretical levels.

Another example is the ongoing debate of the impact of 74 Ka Toba super-eruption on hominin behavior and lithic technology [55, 92–96]. While the Jwalapuram evidence in southern India yielded a problematic wide age range for the Toba-tephra-associated Middle Paleolithic evidence (77 Ka and 38 Ka), a similar investigation at the site of Dhaba in north-central India chronologically narrowed that gap to 79 Ka and 65 Ka [41]. Nonetheless, the lengthy time gap of 10,000 years between the eruption and the post-Toba archeological evidence makes it challenging to draw major conclusions regarding true occupational continuity and it is not clear if fluvial or other processes facilitated occupational/technological continuity by minimizing the ecological impact of the Toba tephra in the immediate region. In short, we have yet to identify a reliable site or area which preserves stratified and dateable lithic assemblages in *primary chrono-stratigraphic contexts immediately prior to and following* the Toba tephra [97], especially when considering that the impact of Toba was probably geographically variable across the Subcontinent [96]. Only when this is done in multiple ecological contexts *across* the Indian subcontinent, will we get a more comprehensive and objectively nuanced perspective on the degrees of impact.

Due to the unique geographic location and associated features of the Indian subcontinent, factors of hominin dispersals and adaptations observed in other Old World regions cannot readily apply here. For example, the link made between the dispersals of *Bos* and the Acheulean [98] may be applicable only to regions with Acheulean records considerably *younger* than India. Likewise, the discovery of a considerably older *Homo sapiens* presence in Europe at ~210 Ka [99] does not necessarily reflect a similar time of their arrival in Asia. However, new discoveries reported in the last few years within Asia may be more applicable and relevant to the Subcontinent. For example, the new decrease (to between 1.5 and 1.3 Ma) in the arrival date of *Homo erectus* in Southeast Asia [100] and the geographic extension of the Denisovans on the Tibetan Plateau in China [101] indirectly suggest the possibility of their presence in the Indian Subcontinent. Likewise, the chronological extension of *Homo sapiens*' arrival into Southeast Asia between 73 Ka and 63 Ka [102] and Australia to ~65 Ka [103] as well as the age of Sulawesi rock art [104] at par with Europe at ~44 Ka has major implications for the Indian zone. The oldest dated rock art from Europe is >64 Ka and has been attributed to Neanderthals [105]. Firstly, the complexity and skill reflected in these paintings suggest the global origin of figurative art is probably much older. Secondly, these discoveries indirectly hint of a possible biogeographic dispersal of *Homo sapiens* from west to east through tropical rainforest and coastal contexts across Southern Asia [106, 107]. While it is possible that the SE Asian and Australian hominin populations reached there via mainland China, the areas representing northeastern India, Bangladesh and Myanmar need to be intensively surveyed to confirm the routes of dispersal. It is also possible that both southern Asian and central Asian routes were used by various species over time to reach Southeast Asia and Australasia.

From a broader research level, the most important palaeoanthropological accomplishments in South Asia in the last few years include the chronological extension of the Middle Paleolithic to 385 Ka and of microlithic technology to ~48 Ka and the beginning of decolonization of past interpretations and conceptual frameworks regarding human dispersals and population replacements [66]. Nonetheless, much more palaeoanthropological research is required to make more holistic and meaningful comparisons with not only surrounding Asian regions but also with human evolutionary records in other parts of the Old World. The current lacunae suggest that more surveys are required to locate Oldowan sites and Early Acheulean sites to understand their pan-Indian distribution, possible demographic implications, and potential relationships (if any) with East and Southeast Asian lithic records. In light of the fact that the South Asian prehistoric record is poorly known when compared to other parts of Asia, Africa and Europe, and because much more empirical data is required (priorities being hominin fossils and absolute dates), it is premature and unnecessary to propose hypotheses or theories based on preliminary evidence. At this stage in our research in South Asian prehistory, we should perhaps focus on generating abundant empirical data and simply reporting it in a neutral manner without *any* specific hypothesis-building.

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Section 3

Pleistocene Human Migration and Adaptation in Southeast Asia

Chapter 4

Mainland versus Island Adaptation: Paleobiogeography of Sunda Shelf Primates Revisited

Halmi Insani and Masanaru Takai

Abstract

Southeast Asian primates appear to be one of the most successful mammals in the dynamic paleoclimatic changes since at least 1 mya. Human and non-human primates reflect the complex history of a wide range of ecological and geographic variation, which presents to be the source of different systematics and biogeographic models. The past combinative effects of geographic factors (latitude, bathymetric barrier, and duration of island isolation), periodic sea level changes, and the contribution of human and/or non-human primate interaction are crucial subjects in studying the north-to-south, which is from continental to archipelago of Sunda Shelf, dispersal events and phylogeographic analysis of human and non-human primates. Cranial size and shape difference between *Homo erectus* in mainland and island displays peculiarity on the effect of insularity. Data analyses on cranial landmarks of three non-human primate genera provide more clear resolution to reconstruct the complete scenario, whereby insular primates are dispersed and adapted to their present biogeographical distribution.

Keywords: primate, ecogeographical rule, body size, biodiversity, Sunda shelf

1. Introduction

Mainland and island are two unique bodies of landmasses that hold not only the obvious different area dimension but also a timeline that portrayed dynamic changes on their geographical and ecological features. Southeast Asia that comprises mainland and the patches of island is a home for the primate species diversity with high rate of endemism and provinciality [1]. Since the emergence of primates in the region during Quaternary to recent, 13 genera have been taxonomically recognized: *Homo*, *Pongo*, *Hylobates*, *Symphalangus*, *Nomascus*, *Hoolock*, *Macaca*, *Trachypithecus*, *Presbytis*, *Simias*, *Nasalis*, *Nycticebus*, and *Tarsius* [2]. With the high variability on body mass and body size, Southeast Asian primates, both the mainland and island populations, remain enigmatic when confronted toward ecogeographical "rules," resulting positive [3], contradictive [4, 5], and inconsistent results [6]. However, given their peculiarity in adaptive functional characters among other mammal taxa and their close evolutionary trajectory to human [7], primates share similarities showing their capability in grasping object [2] for faster food procurement and high occasional flexibility in locomotion (e.g., arboreal quadrupedalism, terrestrial quadrupedalism, and bipedalism) [2, 8]. These functional characters support their high adaptability in predator avoidance and alternate dietary shifts when resources are limited [9].

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Lying over a wide range of latitude and various sizes of islands, the Southeast Asian region is frequently subjected for the studies of primate insularity that involved spatial factors (e.g., island size, latitude, and island-mainland distance) [3–5, 10] and temporal factors (e.g., isolation duration and geological chronology) [5]. Insularity on primates is an interesting phenomenon that invites many reports, linking to their ecomorphological complex (body size and body shape) [6] and biodiversity changes [11].

In many ecological aspects, mainland environment differs from island environment. In addition, large-sized island provides different ecological scenarios from small-sized island. Certain duration of isolation on a relatively small island may lead to limited resources, fewer predators, and reduced interspecific competition [12]. Although it is not impacted universally, the combinative geographical effects on island size and island isolation can promote gigantism in smaller insular mammal species and dwarfism in larger mammal species. It is widely known as island rule (=Foster's rule) [6, 13–18]. With the wide span of latitudinal range, primates inhabiting the Sunda Shelf region are also assumed to follow Bergmann's rule, by testing the effect of latitudinal position to body size [3–5]. This study aims to elicit the validity of ecogeographical rules affected body size and biodiversity changes of primates around Sunda Shelf throughout the geological chronology, since their appearance in Quaternary until recent.

2. Mainland vs. island: impacts and consequences

2.1 Body size

Among mammal taxa, the record of body size shift has not been found spectacular in all primate species [19]. Before the Quaternary, the primate fossil records adapted to island rule are found in Madagascar and Caribbean islands. Strepsirrhine primates found in Madagascar (e.g., *Archaeoindris fontoynontii* and *Megaladapis edwardsi*) are known to have become gigantic [20], while an extinct dwarf lemur, *Cheirogaleus* spp., is known to occupy Nosy Hara Island, a small islet off the northwest coast of Madagascar [21]. The specific examples of island gigantism are also found in platyrrhine monkeys, such as *Paralouatta mariane* from Cuba [22] and *Xenothrix mcgregori* from Jamaica [23].

Hominine taxa represented by the *Homo floresiensis* [24] and *Homo luzonensis* (judging from the small-sized molar [25]) have become the object of comparison to their predicted common ancestor, *Homo erectus*, who inhabited a large-sized island (Java) and Asian continent (Zhoukoudian, China) [24–26]. Until recent, there is no evidence of gigantism found on Southeast Asian insular primates. Looking upon their localities, it shows that the island rule on primates likely occurs in a warmer area within the latitudinal span approaching equator. Throughout several reports [6] island rule on insular primates causing body size change is more evident in oceanic islands due to the deep bathymetric barrier from the mainland regardless of their short island-mainland distance (e.g., Madagascar Island and Mentawai Island) [12].

Gained with the fact that three primate genera (*Macaca*, *Presbytis*, and *Hylobates*) stand as the most widely distributed taxa over Sunda Shelf islands, an attempt is conducted to compare the body size profile between living populations in mainland and island, addressing that an island, regardless of their various sizes, bathymetric barrier, and distance to mainland, is assumed to generate body size changes or body shape variation. Three-dimensional measurements were employed on 20 landmark points on lateral crania (**Figure 1**, **Table 1**, **Table 2**) of five species that strictly inhabit mainland and island (*Hylobates lar*, *Hylobates agilis*, *Macaca fascicularis*,

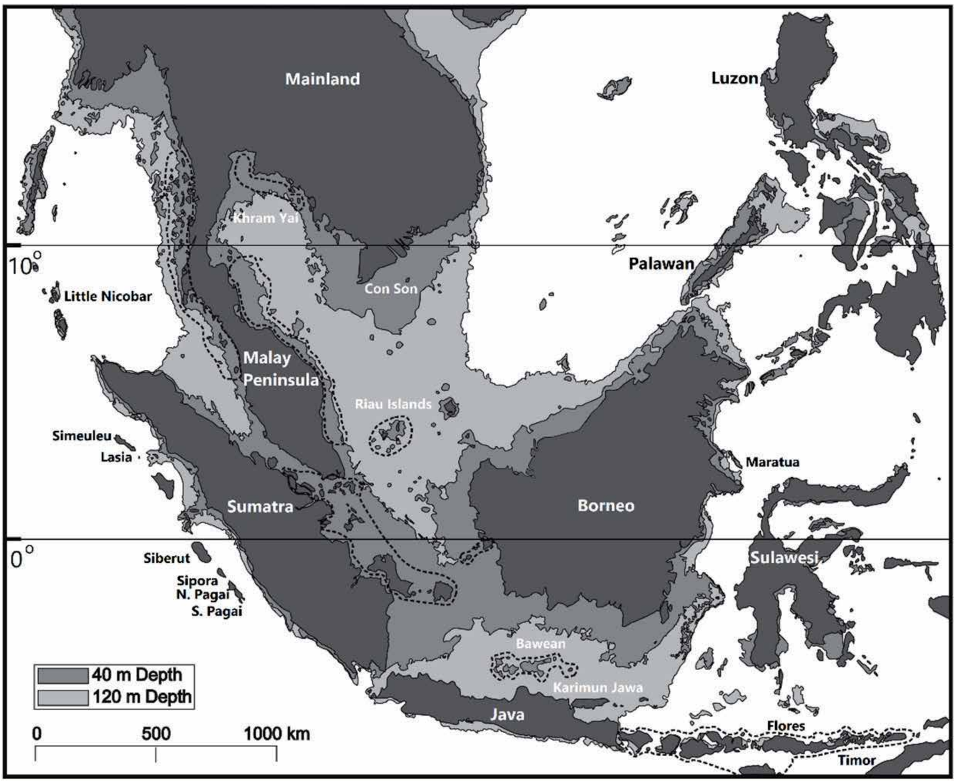

Figure 1.
Map showing two different generalized bathymetric levels from 40 and 120 m throughout Sunda shelf. Closed dash lines present the group of islands with relatively equal range of sea depth.

Sex group	*Hylobates*		*Macaca*		*Presbytis*
	H. lar	***H. agilis***	***M. fascicularis***	***M. nemestrina***	***P. femoralis***
M	31	9	60	20	38
F	22	12	39	8	43

All specimens are housed in Lee Kong Chian Natural History Museum and museum Zoologicum Bogoriense Indonesia.

Table 1.
Sample size measured in this study.

Macaca nemestrina, *Presbytis femoralis*). The landmark points were obtained using 3D digitizer (MicroScribe MX; Immersion Corp., San Jose, CA) and translated into centroid size that stands as alternative check to compensate spatial size over two-dimensional size (**Figure 2**).

The box and whisker plot diagrams (**Figure 3**) exhibit two distinction profiles between Hylobatidae and Cercopithecidae. Island populations of *H. lar* and *H. agilis* show smaller craniolateral size to the mainland population. Noting that most island Hylobatidae population inhabits large-sized islands (Sumatra, Borneo, and Java); their comparatively smaller craniolateral size is seemingly hard to be explained by island rule, knowing that they occupy large-sized islands with shallow bathymetric barrier to the mainland. The presence of much higher-canopy rain forest in mainland may contribute to large-sized body proportion of *Hylobates* in mainland. The reversed results profiled in Cercopithecidae (*M. fascicularis*, *M. nemestrina*, and *P. femoralis*) (**Figure 3**). Given that Southeast Asian islands

Abbreviation	Definition
PRS	Prosthion: anteroinferior point on projection of premaxilla between central incisors
PRS2	Prosthion2: anteroinferiormost point on premaxilla, equivalent to prosthion but between central and lateral incisors
PMS	The point where premaxillary suture crosses alveolar margin
MP3	Mesial P3: most mesial point on P3 alveolus, projected labially onto alveolar margin
MM1	Mesial M1: contact points between P4 and M1, projected labially onto alveolar margin
MM3	Mesial M3: contact point between M2 and M3, projected labially onto alveolar margin
DM3	Distal M3: posterior midpoint onto alveolar margin of M3
PMA	Most posterior point of maxillary alveolus on the maxilla palatine
NSP	Nasospinale: inferiormost midline point of piriform aperture
WPA	Point corresponding lo largest width of piriform aperture
NPM	Meeting point of nasal and premaxilla on margin of piriform aperture
RHI	Rhinion: most anterior midline point on nasals
PMN	Premaxillary maximum superior PMS where premaxillo-maxillary suture meets nasal bone or aperture
NAS	Nasion: midline point on fronto-nasal suture
GLA	Glabella: most forward projecting midline point of frontals at the level of the supraorbital ridges
BRG	Bregma: junction of coronal and sagittal sutures, on sagittal crest if necessary
INI	Inion: most posterior point of cranium, when viewed in the Frankfurt horizontal, be it on sagittal/nuchal crest or not
OPS	Opisthion: posterior most point of foramen magnum
LOC	Most anterior point on the occipital condyle along the margin of the foramen magnum
AOC	Occipital condyle along the margin of the foramen magnum between POC and AOC

Table 2.
Abbreviation and definition used in this study [27].

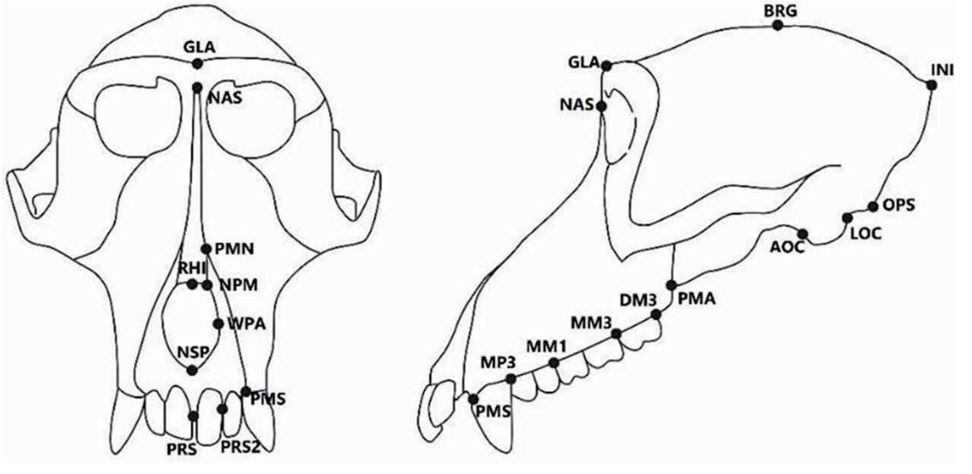

Figure 2.
Frontal (left) and lateral (right) views of the generalized M. fascicularis *skull, showing 20 landmark positions used in the analysis. Number and position of landmark points are applied with the same procedure in all species measured.*

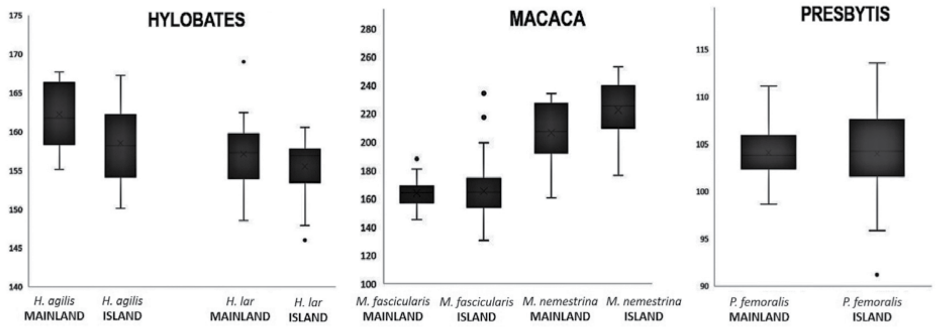

Figure 3.
Box and whisker diagram showing the variation of craniolateral centroid size (CS) among five non-human primate species in mainland and island group.

are geographically characterized with various sizes, latitudinal and longitudinal positions, maximum sea depth, and island-mainland distance, this condition arises to a consequence on more diverse insular adaptation that contributes to numerous variations in body size.

2.2 Biodiversity changes and extinction

For the last 30 years, benefited by the advanced methodology of molecular biology, the expansion of studies on primates of Southeast Asia have resulted in the increased number of taxonomic diversification [28–30], which was previously mostly explained by the superficial character (e.g., pelage color, tail length, and behavior) on the living taxa [2, 5]. Mainland and large islands have been claimed to correspond to the higher taxonomic diversity than islands [31]. With the wide span of area, mainland and large islands have a great advantage to develop more topographic diversity, formed as geographic barriers (e.g., peak, valley, river), linking to high possibility to allopatric speciation [32].

Principal component analyses (PCA) on the craniolateral shape of the five species share similarities in the wider shape variance of all three insular species (**Figure 4**). The mixed category between large-sized island and small-sized island in this study (**Table 3**) may strongly correspond to the higher craniolateral morphology, by considering (i) each isolated small island with unique geographical-ecological condition and different degrees of isolation may contribute to the shape modification, furthermore to endemism [12]; (ii) large islands may lead to various shape modifications, generated by various topographic-diversity-derived habitat variations [32]. Reflecting the wide variance morphology on three insular genera of this study, insularity does not gain merely on taxonomic diversity; furthermore strong individual differentiation within population or intraspecific variation could also possibly generated.

The isolation process on an island may lead to enforce the possibility of extinction in certain species [30]. For example, in Java Island, with area span 138,000 km^2, three primate species (*Homo erectus*, *Pongo pygmaeus*, and *M. nemestrina*) occurred during Middle-Late Pleistocene, but finally disappeared [33] (**Table 4**). Harsh ecological condition (e.g., low carnivore-herbivore ratio and habitat change) on island will contribute to the adaptability of particular species. *M. nemestrina*, which is more terrestrial species than the survived species, *M. fascicularis* [27] (**Table 4**), is assumed to be less adaptive to avoid terrestrial and predators. *Pongo*, which is recently absent in Java Island and

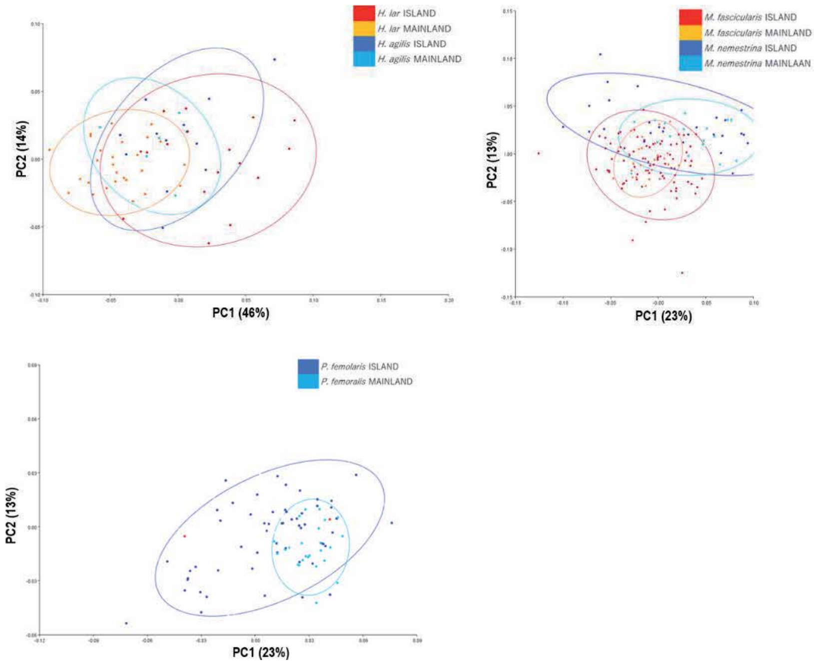

Figure 4.
Plots of principal component PC1–PC2 displaying the variance between mainland and island population among five species observed.

Genera	Species/subspecies	Island	Latitude	Island size (km²)	Island size category [33]	max. elevation (m)
CONTINENTAL ISLAND						
Ponginae	*Pongo pygmaeus* [2]	Borneo	8°N–2°S	743,330	Large	4095
	Pongo abelii [2]	Sumatra (north)	2°–4°N	473,481	Large	3805
	Pongo tapanuliensis [34]	Sumatra (north)	2°–4°N	473,481	Large	3805
Hylobatidae	*Hylobates moloch*	Java (west)	8°–10°N	128,300	Large	3676
	H. albibarbis [2]	Borneo (south)	8°N–2°S	743,330	Large	4095
	H. muelleri [2]	Borneo (north)	8°N–2°S	743,330	Large	4095
Cercopithecinae	*M. f. atriceps* [5]	Khram Yai	12.70°N	20,28	Small	219
	M. f. condorensis [5]	Con Son	8.71°N	51,52	Small	560.8
	M. f. mandibularis [5]	Riau Islands	2.50°–3.13°N	106	Small	959
	M. f. baweana [5]	Bawean	5.80°S	196,27	Small	655
	M. f. karimoendjawae [5]	Karimun Jawa	5.85°S	71,2	Small	506
Colobinae	*Presbytis natunae* [2]	Natuna Besar	4°N	1720	Small	187
	Presbytis thomasi [2]	Sumatra (north)	2°–4°N	473,481	Large	3805
	Presbytis frontata [2]	Borneo	8°N–2°S	743,330	Large	4095

Genera	Species/subspecies	Island	Latitude	Island size (km^2)	Island size category [33]	max. elevation (m)
	Presbytis chrysomelas [2]	Borneo (north)	8°N–2°S	743,330	Large	4095
	Presbytis hosei [2]	Borneo (northeast)	8°N–2°S	743,330	Large	4095
	Presbytis rubicunda [2]	Borneo (east)	8°N–2°S	743,330	Large	4095
	Trachypithecus auratus [2]	Java	8°–10°N	128,300	Large	3676
	Nasalis larvatus [2]	Borneo	8°N–2°S	743,330	Large	4095
OCEANIC ISLAND						
Hylobatidae	*Hylobates klossii* [2]	Mentawai Islands	1.2°–3°S	268–4030	Small	384
Cercopithecinae	*Macaca maura* [2]	Sulawesi (southwest)	0.3°N–5.3°S	174,600	Large	3478
	Macaca ochreata [2]	Sulawesi (southeast)	0.3°N–5.3°S	174,600	Large	3478
	Macaca tonkeana [2]	Sulawesi (central)	0.3°N–5.3°S	174,600	Large	3478
	Macaca hecki [2]	Sulawesi (northwest)	0.3°N–5.3°S	174,600	Large	3478
	Macaca nigrescens [2]	Sulawesi (north)	0.3°N–5.3°S	174,600	Large	3478
	Macaca nigra [2]	Sulawesi (northeast)	0.3°N–5.3°S	174,600	Large	3478
	Macaca siberu [2]	Mentawai Islands	1.2°–3°S	268–4030	Small	384
	Macaca pagensis [2]	Mentawai Islands	1.2–3S	268–4030	Small	384
	M. f. umbrosa [5]	Little Nicobar	7.32°N	140	Small	435
	M. f. tua [5]	Maratua	2.25°N	22,8	Small	94.18
	M. f. philippinensis [5]	Palawan	9.70°N	14,650	Large	2086
	M. f. philippinensis [5]	Luzon	16.9°N	110,000	Large	2922
	M. f. lasiae [5]	Lasia	2.17°N	15,12	Small	69
	M. f. fusca [5]	Simeulue	2.65°N	2310	Small	567
Colobinae	*Presbytis pagensis* [2]	Mentawai Islands	1.2–3°S	268–4030	Small	384
	Presbytis potenziani [2]	Mentawai Islands	1.2–3°S	268–4030	Small	384
	Simias concolor [2]	Mentawai Islands	1.2–3°S	268–4030	Small	384

The category of island refers to the indicator of small island category (<12,000 km^2) [34].

Table 3.
List of modern non-human primate species/subspecies native to islands with the latitudinal position.

mainland, became extinct probably due to the deterioration of the habitat from tropical forest to more open environment [33] during Late Pleistocene to Holocene.

3. Synthesis and discussion

3.1 Spatial cost: do primates follow ecogeographical rules in mainland and islands?

3.1.1 Bergmann's rule

Southeast Asia with wide span of latitude ranging from 6°N to 14°S is split by the equator line, demanding at least two comprehensive separations that require thermoregulation connection from the equator to southern and northern latitudes. Mammals of mainland Southeast Asia have been subjected to describe body size variation following thermoregulation effect, widely termed as Bergmann's rule [6]. Concluding that Bergmann's rule may occur within a species, it predicts that population in warmer climates (commonly referred to lower latitudes) have smaller mean body size than conspecifics in colder climates (generally marked with higher latitude) [6]. Published accounts applying this ecogeographical rule on non-human primates has been intensively investigated in the widely distributed species in Southeast Asia: *M. fascicularis* [4, 5, 10] and *M. nemestrina* [3]. The Bergmann's rule was positively performed on northern pig-tailed macaques (*M. leonina*) [3, 6] and crab-eating macaques (*M. fascicularis*) [4, 5, 10] in the mainland, demonstrated by the increasing body size toward higher latitude.

Interestingly, anti-Bergmann's rule appears north side of Kra Isthmus (the narrowest area differing Indochinese mainland and Malay Peninsula at 12.2°N) [4, 5]. Explanatory cause for this inversed Bergmann's rule has not been uncovered. In response to this matter, *M. fascicularis* population from the northeastern localities that is bound by the geographic barrier of north–south oriented high topographic range of Tenasserim Hills most likely underwent different and unique ecomorphological adaptations to the rest of the western low land area of Indochinese mainland population. Due to the limitation number on available samples, to date, there is no further study testing this ecogeographical rule in this species or in other non-human primate taxa.

Although serious attempts to test Bergmann's rule on insular non-human primates have increased, the result of the statistical analysis on the cranial size of southern pig-tailed macaque (*M. nemestrina)* surprisingly demonstrates anti-Bergmann's rule [3]. However, insular *M. fascicularis* tested in western Southeast Asian archipelago [4, 5, 10] and large-sized islands of Sunda Shelf still shows constant Bergmann's rule [27]. Taken together from observed results correlating non-human primate body size to thermoregulation mechanism in Southeast Asian archipelago, they frequently came as debatable subjects [6] because (i) most islands are situated in short range of latitudinal position referring to low temperature variation; (ii) the equator line that passes over or nearby most of the islands, both northward and southward, directs to similar typical tropical habitat; and (iii) each island is addressed to various unique insular geographical properties (e.g., island area, max. Depth separating to mainland, and island-island distance), which likely gives the stronger island effect than the latitude effect to the population. This aspect needs a more complicated operation when we apply Bergmann's rule in islands than in mainland.

3.1.2 Foster's rule

In the context of conservative classification on island area, primate insularity has been investigated into categorization of area size, e.g., small and large island, which was directly calculated by metric size of island [31]. This ecogeographical rule implemented exclusively on island, commonly known as Foster's rule, proposes that population of large-bodied mammals on island tend to have a smaller mean body size than mainland population (dwarfism), while small-bodied mammals become larger (gigantism) [6]. One suggested that, in the scope of insularity on Southeast Asian mammals, the small island criterion is defined by the island size <12.000 km^2 [34] (**Table 3**). Without providing the specific primate species group, one suggested that primates follow island rule [19]. However, a study tested in body length of *Macaca fascicularis* found that island area and body length shows no significant relationship [10].

The most spectacular evidences of dwarfism on extinct Homininae taxa are *Homo floresiensis* aged 60,000–100,000 years ago in oceanic island of Flores, Indonesia [11, 24], and *Homo luzonensis* (judging from the small molar) aged 66.700 ± 1000 years ago discovered in Callao Cave, Luzon Island, Philippines [25]. The consideration of island rule causing diminutive character on *Homo luzonensis* remains enigmatic, since Luzon Island is a large island (**Table 3**). However, the coexisted fossil macaque, *M. f. philippinensis*, which still occurs in modern western, eastern, and northern islands of the Philippines, suggests that it occupied the island since 160,000 years ago [5]. It permits the long duration of isolation that impacted not necessarily on body size reduction, but the possibility of endemism. Furthermore, insular dwarfisms that were reported on *M. fascicularis* in Bintan Island and Singapore are possibly caused by ecological effects, such as food limitation and high population density [6], not geographical effect such as island size.

Among gibbons, diminutive body size has been presented by *Hylobates klossii,* an endemic species of four Mentawai islands (Siberut, Sipora, North Pagai, and South Pagai). There are few gibbons occupying small-sized island in continental Sunda Shelf (only found in Paku Island, collection of Lee Kong Chian Natural History Museum), because the small island usually tends to do not support the development of dense rain forest habitat with high canopy cover where gibbon is dependable to live [34].

Researchers have long endeavored to uncover the Foster's rule in Southeast Asian archipelago [4, 5, 10], but most outcomes show no statistically significant results [11]. On exclusively *M. fascicularis* inhabiting shallow-water fringing islands over Sunda Shelf, small-sized island was found to contribute more to the variation of subspecies [4, 5] (**Table 3**). The implementation only using island size or the distance between island and mainland as a proxy is unlikely relevant to the test of Foster's rule in Southeast Asian archipelago, neither. Deep bathymetric barrier possessed by oceanic islands (**Table 3**) convincingly appears as the main factor of island rule, followed by the unique island ecological condition in the duration of island isolation.

3.1.3 Vicariance biogeography

Mainland Southeast Asia contains the high variation of non-human primate species. Recent molecular biological studies revealed critical systematics of non-human primates (i.e., *Macaca* [28, 29] and *Hylobates* [30]), showing the high intra- and interspecific variation. Topographic diversity in mainland Asia is likely correlated to the speciation process of animals [11, 35], and islands are not exception for this correlation. Historical change of paleobiogeography in large-sized islands (Sumatra, Java, and Borneo) over Sunda Shelf can be explained by Pleistocene volcanic activities caused by the geologic subduction between Sunda and Australian Plates.

In Java, a chain of 38 mountains forming east–west spine with various slopes, illustrated by jagged highlands by alternating peaks and valleys, leads to classes of topographic diversity [35]. This phenomenon led the geographically separated populations to undergo allopatric speciation. According to the modern Javanese mammal fauna, the low topographic diversity in East Java resulted in less

Genera	Specimen	Locality	Pleistocene			Holocene
			Early	Middle	Late	
MAINLAND						
Hominidae	*Homo erectus* all Zkd (but 5) [25]	Zhoukoudian Caves, China		0.6–0.4		
	Homo erectus Zkd 5 [36]	Zhoukoudian Caves, China		0.4–0.5		
	Homo erectus [37]	Had Pu Dai, Thailand		●		
	Homo erectus [37]	Tham Khuyen, Vietnam		●		
	Homo erectus [37]	Lang Trang, Vietnam		●		
	Homo sp. [37]	Ma U'Oi, Vietnam		●		
	Homo sp. [37]	Thum Wiman Nakin, Thailand		●		
Ponginae	*Gigantopithecus blacki* [37]	Gigantopithecus Cave, China	●			
	Gigantopithecus blacki [37]	Jianshi, China	●			
	Gigantopithecus sp. [38]	Baikong, China	2.2			
	Gigantopithecus sp. [21]	Juyuan, China	1.8			
	Gigantopithecus sp. [38]	Sanhe, China	1.2–1.6			
	Gigantopithecus sp. [38]	Queque, China	<0.7–1	≤0.7–0.8		
	Gigantopithecus sp. [38]	Yangliang, China	●			
	Gigantopithecus sp. [37]	Had Pu Dai, Thailand		●		
	Gigantopithecus blacki [37]	Daxin, China		●		
	Gigantopithecus blacki [37]	Wuming, China		●		
	Gigantopithecus blacki [37]	Bama, China		●		
	Gigantopithecus blacki [37]	Tham Khuyen, Vietnam		●		
	Gigantopithecus blacki [37]	Tham Hai, Vietnam		●		
	Gigantopithecus sp. [37]	Heijang, China		●		
	Gigantopithecus sp. [37]	Shuangtan, China			●	
	Pongo sp. [37]	Gigantopithecus Cave, China	●			
	Pongo sp. [38]	Baikong, China	>2.2			
	Pongo sp. [38]	Juyuan, China	>1.8			
	Pongo sp. [38]	Sanhe, China	1.2–1.6			

Genera	Specimen	Locality	Pleistocene			Holocene
			Early	Middle	Late	
	Pongo sp. [38]	Queque, China	<0.7–1	≤0.7–0.8		
	Pongo sp. [38]	Yangliang, China	●			
	Pongo sp. [37]	Had Pu Dai, Thailand		●		
	Pongo sp. [37]	Tham Khuyen, Vietnam		●		
	Pongo pygmaeus [37]	Thum Wiman Nakin, Thailand		●		
	Pongo sp. [37]	Daxin, China		●		
	Pongo pygmaeus [37]	Hoshantung, China		●		
	Pongo pygmaeus [37]	Koloshan, China		●		
	Pongo sp. [37]	Bama, China		●		
	Pongo pygmaeus [37]	Tam Hang, Laos		●		
	Pongo pygmaeus [37]	Tham Khuyen, Vietnam		●		
	Pongo pygmaeus [37]	Tham Hai, Vietnam		●		
	Pongo pygmaeus [37]	Phnom Loang, Cambodia		●		
	Pongo pygmaeus [37]	Thum Wiman Nakin, Thailand		●		
	Pongo sp.? [37]	Kao Pah Nam		●		
	Pongo cf. pygmaeus [37]	Thum Wiman Nakin, Thailand		●		
	Pongo sp. [38]	Hei, China		0.3–0.38		
	Pongo sp. [38]	Heijang, China		●		
	Pongo sp. [38]	Tongzi, China			●	
	Pongo pygmaeus	Keo Leng, Vietnam			●	
	Pongo pygmaeus	Hang Hum II, Vietnam			●	
	Pongo sp. [38]	Shuangtan, China			●	
	Pongo sp. [38]	Yixiantian, China			●	
	Pongo sp. [38]	Gonglishan, China			●	
	Pongo sp. [38]	Zhiren, China			●	
	Pongo sp. [38]	Nongbashankou, China			●	
	Pongo sp. [38]	Baxian, China			●	
	Pongo sp. [38]	Loushan, China			●	
Hylobatidae	*Hylobates* sp. [38]	Baikong, China	2.2			
	Hylobates sp. [38]	Juyuan, China	1.8			
	Hylobates sp. [38]	Sanhe, China	1.2–1.6			
	Hylobates sp. [38]	Queque, China	0.7–1	≤0.7–0.8		
	Hylobates sp. [38]	Hei, China		0.3–0.38		
	Hylobates sp. [38]	Heijang, China		0.4–0.32		
	Hylobates sp. [38]	Yenchinkou, China, China	●	●	●	
	Hylobates sp. [38]	Szechwan, China	●	●	●	

Genera	Specimen	Locality	Pleistocene			Holocene
			Early	Middle	Late	
	Hylobates sp. [38]	Niah Cave, Borneo, China			●	
	Hylobates sp. [38]	Shuangtan, China			●	
	Hylobates sp. [38]	Yixiantian, China			0.1	
	Hylobates sp. [38]	Gonglishan, China			●	
	Hylobates sp. [38]	Zhiren, China			0.11	
	Hylobates sp. [38]	Baxian, China			●	
	Hylobates sp. [38]	Loushan, China				●
Cercopithecinae	*Macaca* sp. [38]	Baikong, China	2.2			
	Macaca sp. [38]	Juyuan, China	1.8			
	Macaca sp. [38]	Sanhe, China	1.2–1.6			
	Macaca sp. [38]	Queque, China	<0.7–1	≤0.7–0.8		
	Macaca sp. [38]	Yangliang, China	●			
	Macaca sp. [38]	Hei, China		0.3–0.38		
	Macaca sp. [38]	Heijang, China		0.4–0.32		
	Macaca sp. [38]	Shuangtan, China			●	
	Macaca sp. [38]	Yixiantian, China			0.1	
	Macaca sp. [38]	Gonglishan, China			●	
	Macaca sp. [38]	Zhiren, China			0.11	
	Macaca sp. [38]	Nongbashankou, China			●	
	Macaca sp. [38]	Baxian, China			●	
	Macaca sp. [38]	Loushan, China				●
Colobinae	*Trachypithecus* sp. [38]	Baikong, China	2.2			
	Trachypithecus sp. [38]	Juyuan, China	1.8			
	Trachypithecus sp. [38]	Sanhe, China	1.2–1.6			
	Trachypithecus sp. [38]	Queque, China	<0.7–1	≤0.7–0.8		
	Trachypithecus sp. [38]	Hei, China		0.3–0.38		
	Trachypithecus sp. [38]	Heijang, China		0.4–0.32		
	Trachypithecus sp. [38]	Shuangtan, China			●	
	Trachypithecus sp. [38]	Yixiantian, China			0.1	
	Trachypithecus sp. [38]	Gonglishan, China			●	
	Trachypithecus sp. [38]	Zhiren, China			0.11	
	Trachypithecus sp. [38]	Nongbashankou, China			●	
	Trachypithecus sp. [38]	Baxian, China			●	
	Trachypithecus sp. [38]	Loushan, China				●
CONTINENTAL ISLAND						
Hominidae	*Homo erectus* S4 [25]	Sangiran, Java	0.99–1.5			
	Homo erectus S17 [25]	Sangiran, Java	0.78–1.3			
	Homo erectus S12 [25]	Sangiran, Java	1.2–0.98			

Genera	Specimen	Locality	Pleistocene			Holocene
			Early	**Middle**	**Late**	
	Homo erectus S2 [25]	Sangiran, Java	1.2–0.99			
	Homo erectus Smb [25]	Sambungmacan, Java	≤0.78			
	Homo erectus Ng [25]	Ngawi, Java		●	●	
	Homo erectus Nd [25]	Ngandong, Java		●	0.05–0.032 or 0.1	
	Homo sapiens [25]	Punung, Java			0.0118	●
Pongidae	*Gigantopithecus* sp. [39]	Semedo, Java	?	?		
	Pongo pygmaeus [33]	Punung, Java			0.125	
	Pongo sp. [40]	Lida Ayer, Sumatra				●
Hylobatidae	Hylobatidae [41]	Trinil, Java		●	●	
	Hylobates syndactylus [33]	Punung, Java			0.0118	●
	Hylobates sp. [40]	Lida Ayer, Sumatra				●
	Hylobates sp. [40]	Niah Cave, Borneo			0.04	
Cercopithecinae	*Macaca* sp. [38]	Sangiran, Java				
	Macaca sp. [38]	Punung, Java			0.0118	0.008
	Macaca nemestrina [38]	Sangiran, Java	1			
	Macaca fascicularis [38]	Sangiran, Java	1			
	Macaca fascicularis [38]	Callao Cave, Luzon			0.065	
	M. f. philippinensis [38]	Ille Cave, Palawan			●	●
Colobinae	*Presbytis comata*	Sangiran, Java		●		
	Presbytis sp.	Punung, Java				0.01
	Trachypithecus auratus	Sangiran, Java	1.9			
OCEANIC ISLAND						
Hominidae	*Homo cf. floresiensis* [42]	Mata Menge, Flores		0.7		
	Homo floresiensis [24]	Liang Bua, Flores		●	0.06–0.1	
	Homo luzonensis [25]	Callao Cave, Luzon			0.06	
Cercopithecidae	*M. f. philippinensis* [25]	Callao Cave, Luzon			0.065	
	M. f. philippinensis [43]	Ille Cave, Palawan			●	●
	Macaca fascicularis [28]	Timor Island				0.007

Table 4.
List of fossil/subfossils of primate species/subspecies discovered in archeological sites throughout Southeast Asia.

variation in endemic mammals than in the West and Central Java. This topographic profile is supported by the presence of two endemic non-human primate species/subspecies strictly occupying western Java forests; *Hylobates moloch* and *Trachypithecus auratus auratus.* This endemism also shows the high correlation with the number of natural parks in West and Central Java [32], which probably corresponds to the high soil fertility rates gained from the high-contained mineral of the eruption sediments.

Conversely, a higher endemic mammal species diversity was more visible in East Java during the Middle Pleistocene, in the stage of *Stegodon-Homo erectus* [32]. Two Hominoidae taxa, *Gigantopithecus* sp. [39] and *Homo erectus*, co-existed in the eastern part of the island during the Middle Pleistocene (**Table 4**). It is also followed by the known primate fossils, including *Trachypithecus auratus*, *Presbytis comata*, *M. nemestrina*, *M. fascicularis*, *Hylobates* sp., and later *Pongo pygmaeus* in the Late Pleistocene [33, 44]. All cercopithecid species are comparable to extant species inhabiting Java Island, while Hominoidae taxa are all extinct. *Gigantopithecus* sp., *Homo erectus*, *Pongo pygmaeus*, and *M. nemestrina*, which have disappeared in recent Java Island, are assumed to indicate the incapability to adapt toward paleoclimatic changes resulting in habitat loss or ecological replacement from rain forest to open woodland and possible human intervention such as hunting. Although this result is likely related to excavation bias where most of the archeological localities are located in East Java [32, 37], the possible intraspecific variation is reported in *Homo erectus*, which is commonly discovered in eastern Java localities, specifically as craniodental specimens [25].

With the numerous *Homo erectus* findings in Java Islands, it leads to the high morphological diversity [25] exclusively on cranial morphology. A comprehensive study on comparison of *Homo erectus* cranial morphology between island and mainland population has been investigated showing the peculiar distinction on mainland vs. island population. Zhoukoudian *Homo erectus* represents mainland population (**Table 4**), and the common ancestor of Javan *Homo erectus* demonstrates a less morphological variability to the Early Pleistocene Java *Homo erectus* (that mostly unearthed in Sangiran Dome), while Late-Middle Pleistocene Javan *Homo erectus* are reported to share similarities in cranial shape [25]. It is suggestive that the lower habitat vicariance in mainland during Middle Pleistocene and Java Island during Middle-Late Pleistocene indicates less genetic isolation. Taking this into account, geographic barriers such as volcanic mountains, added with the isolation of Java, might enforce high intraspecific variation during Early-Middle Pleistocene, supported by the extensive paleoclimatic change. Out of Sunda Shelf, the obvious record of this mechanism appears in Wallacea non-human primates inhabiting Sulawesi. High bathymetric boundaries to Sunda Shelf and the islands surrounding, and diversed topographic barrier of Sulawesi contributes to six endemic macaque species; *Macaca nigra, Macaca tonkeana, Macaca maura, Macaca nigrescens, Macaca ochreata*, and *Macaca hecki* that some of the species were found in the archeological cave Leang Burung 2 that occupied with the early human occupation on the island in Late Pleistocene.

3.2 Temporal cost: isolation and endemism from Pleistocene to modern

3.2.1 Duration

Time by duration and particular period falls to the temporal scope of inhabitation of certain population on island is pronounced to impact body size evolution [12]. Higher duration of island isolation increases the chance for ecological release to influence functional characters (e.g., diet, locomotion, and bauplan) among species. The report on paleoinsular mammals has claimed that body size shift on island mammal species occurred when residence time reached more than 10,000 years [12]. While the evidences are prominently strong on terrestrial herbivores, including terrestrial primates (e.g., *Homo floresiensis,* 60,000–100,000 years ago [26]), it also evidently impacts the arboreal non-human primate species or subspecies (e.g., *Macaca fascicularis* and endemic primate species on Simeulue, Lasia, Nicobar, Mentawai Islands).

Typically expressed by the estimated dispersal chronology in Southeast Asian Archipelago, duration of island isolation shows the function of maximum sea depth separating island from mainland or neighboring large island, mainly in small-sized island. Some oceanic islands in the region (Simeulue, Lasia, Siberut, Sipora, North Pagai, South Pagai) remarked with bathymetric barrier more than 120 m (**Figure 1**) display clear effect of isolation than the shallow-water fringing island over Sunda Shelf. The shallow depth of Sunda Shelf sea floor (0–40 m) allows the emergence of exposed dry land that permits colonization, reversed colonization, or recolonization of the island which most commonly occur during the sea level drop during the Last Glacial Maximum (LGM), which reduces the optimum genetic isolation.

On the level of subspecies, the long duration of island isolation appears to indicate the development of new intraspecific features in *Macaca fascicularis* inhabiting oceanic islands. Estimated from the last connection with the progenitor mainland species ca. 160 ka (gained from recent bathymetric barrier), some oceanic islands mostly located in western archipelago are interpreted to develop unique *M. fascicularis* subspecies, such as *M. f. umbrosa* in Nicobar Islands, *M. f. fusca* in Simeulue Island, *M. f. lasiae* in Lasia Island, *M. f. tua* in Maratua Island, and *M. f. philippinensis* in western, northern, and eastern islands of the Philippines. The subspecies variation also took place later in continental islands, with shorter island isolation duration started ca. <18 ka such as *M. f. karimoendjawae* in Karimun Jawa Island, *M. f. atriceps* in Khram Yai Island, and *M. f. condorensis* in Con Son Island, marking weak differentiation based on superficial characters [5].

3.2.2 Changes through time

According to the previous paleontological works on mammal evolution of Southeast Asia, there is no fossil evidence of primates before ca. 0.9 Ma in Java Island. The first colonization of primates to Java is estimated to occur at the end of Early Pleistocene, when Sunda Shelf fully emerged and then periodically entered Java via Siva-Malayan corridor route during Middle Pleistocene [33]. Along with the balanced mammal association, including *Homo erectus*, this period seemingly shows the suitable ecological condition for arboreal high-adapted non-human primates (*Macaca*, *Trachypithecus*, and *Presbytis*) to adapt to mainly open woodlands in relatively dry climate condition [33]. The long duration allowing the dry landmass that connected recent mainland and island during this period possibly permits the occupation access for a hominine species (elaborated as *Homo* cf. *floresiensis* [42]) to inhabit the oceanic island of Flores.

To date, there is no chronological and geographical comparative study demonstrating body size of non-human primates between fossils and recent on Java Island. It rather revealed the similarities on morphological characters in accordance with the attempt in determining species. So, it was difficult to answer whether Middle Pleistocene non-human primates of Java are the continuously highly adapted species until recent or the extinct species that disappeared in the Middle Pleistocene like other mammals (including *Homo erectus*).

Late Pleistocene displays the rise of tropical rain forest non-human primates (*Hylobates* and *Pongo*) to develop in Sunda Shelf where the Chinese origin fauna enter to exhibit similar association to recent fauna [33]. Primate species/subspecies that became native to some oceanic islands (e.g., *M. siberu*, *M. pagensis*, *H. klossii*, *P. potenziani*, *P. pagensis*, and *Simias concolor* in Mentawai islands, *M. f. condorensis* in Nicobar Islands, *M. f. fusca* in Simeulue Island, *M. f. lasiae* in Lasia Island, and *M. f. tua* in Maratua Island). Considering the limitation of swimming ability (max. Swimming distance limit 100 m in *M. fascicularis* [5]) and large island-mainland distance, dispersal route to the oceanic island is most likely through corridor route over dry landmass, furthermore by passive dispersal, such as natural rafting [5]. The dispersal scenario passing deep sea barrier to reach oceanic islands of Lesser Sunda presumably occurred by human transport during <4.5 ka [5], because swimming is not possible due to the strong sea current in Lombok Strait. This data is supported by the presence of *M. fascicularis* remains in archeological cave aged ca. 7 ka in Timor Island [5, 27].

3.3 Ecological cost: fauna association and vegetation

3.3.1 Fauna association

With limited connection to the diverse mainland fauna, isolated island promotes the poor taxonomic diversity and the imbalanced rate between herbivores and carnivores. Small island has been claimed to reduce the sympatric speciation than large island [31]. This condition drove a disharmonic inter- and intraspecific variation [12]. For instance, in severe ecological condition when food resources are limited in long duration, the large-bodied species tends to expand their territory where small-bodied species fails to compete and being enforced to undergo stronger dietary adaptation. This response to ecological condition led to a radiation into different size classes and morphotypes, which arrives to appear in the form such as anatomical modification (e.g., dental pattern, size, and shape of limb bone) causing genetic radiation [12].

In most case, this disharmonic taxonomic diversity condition dropped the survivability. The heavily impoverished condition leads to some species to extinction, for example, in all Late Pliocene-Early Pleistocene (*Sinomastodon-Megalochelys* stage) species in Java and large- to intermediate-bodied fauna in Flores Island in Late Pleistocene. It is followed by imbalanced condition where the normal ratio between carnivores and herbivores is high. Predator avoidance is suggested to cause the limb bone modification. A species that is not threatened by the carnivores might not often walk and run leading to the less development of limb bones.

3.3.2 Vegetation

The vegetation type of an area derives from mean temperature caused from latitudinal position, geographical topography, seasonality by monsoon, and geological sediments. During Quaternary, the fluctuating temperature prominently contributes to habitat changes. The ecological shift from tropical rainforest to more open environment in Early-Mid Holocene resulted in biodiversity loss in non-human primates; for example, it is shown by the disappearance of *Presbytis comata* (Javan langur) in eastern Java that was previously found in Braholo Cave, East Java (Late Pleistocene to Mid Holocene) [45], and the extinction of Pongo in Java that was formerly discovered in Punung rockshelter, East Java (Late Pleistocene) [46–48]. This open environment niches created the mosaic ecological niche in eastern Java [45, 49] that enforced the early *Homo sapiens* inhabiting Java to hunt the remaining arboreal fauna including non-human primates as food resources. Archeological evidence depicting *Homo sapiens* that consumed monkeys (*Macaca*, *Presbytis*, and *Trachypithecus*) are also discovered in Song Terus cave in the period from 9000 to 5000 years ago [50] and Niah Cave, Borneo [51]. Further ethnographic account resembling this phenomenon is found as butchery marks and burnt bone fragments on cercopithecids assemblage in Punan Vuhang, Sarawak, Borneo [52].

4. Conclusions

1. Prefigured by many geographic properties, bathymetric barrier presents to appear as the strongest casual effect in enforcing island isolation in Southeast

Asian Archipelago, expressed by the high degree of endemism in level of species in oceanic islands (i.e., *Homo floresiensis* in Flores Island and six non-human primates in Mentawai Islands). Vicariance geography in any form of barriers (e.g., mountain and river) could create allopatric speciation or endemism; however bathymetric barrier on island extraordinarily emerged in different process. The higher sea depth caused the higher chance for island population to disconnect more to the original continental population.

2. The duration of island isolation widens to promote the evolutionary results that yield the island ecological mechanism becoming intensified. The higher time cost on ecological factors such as selective pressures and predator avoidance could escalate the chance for anatomical feature to be modified. Although it is hard to know the absolute duration of island isolation, the relative isolation can be seen from the present bathymetry showing the predicted terminal time for body of water to cover the maximum depth that stop the connection from mainland to surrounding islands. Constituted by this concept, oceanic islands with high bathymetric barrier will definitely prolong the disconnection signal from mainland than continental islands.

3. When we control geographical and chronological isolation factors, the two main island ecosystem factors, faunal association and vegetation type, strongly contribute to the change of body size and shape, resulting in a higher island effect. Patterns impacted by this ecosystem factors are not the same in all islands. The imbalanced condition on fauna between the number of herbivores and carnivores and less interspecific faunal diversity could lead to the body size shift and anatomical modification. On primates, oceanic islands located near the equator covered with the densely tropical rain forest gave less likely island effect (e.g., Mentawai Island and Simeulue Island) than in oceanic island with drier and more open environment where resource is less abundantly available (e.g., Flores Island).

4. Latitudinal factor is clear to be seen in the mainland. While each island holds unique geographical properties directing to isolation (e.g., bathymetric barrier and island size), most Southeast Asian islands that are located around the equator with tropical weather resulting in major rain forest cover and short latitudinal range rather rise to contribute to more diverse body size and body shape longitudinally. Thus, Bergmann's rule is seemingly irrelevant to be evaluated in such condition.

5. The primates of Sunda Shelf occupying the great number of islands scattered in large scale area did not perform any pattern in regard to correlation between body size and island size. Potential causal relation to island size is more manifested in the increasing taxonomic diversity. Large-sized islands throughout Sunda Shelf hold higher diversity in anatomical variation than in small-sized island. It is supposedly due to the combination of possible isolation-derived process by geographic or ecological barrier and the resiliency of relict species along many stages of period. This circumstance is conceivably reassured from the Quaternary through recent, for example, the high diversity of calvarium morphology seen in *Homo erectus* of Java Island and the occurrence of four varied living *Presbytis* species in Borneo Island.

6. Endemism featured on non-human primates in continental islands of Sunda Shelf mostly direct to the resilience of relict groups occupying the island, not

necessarily in response to a long-term island isolation process. In the level of species, this premise is endorsed by the existence of a single taxon occupying large islands (e.g., *P. abelii* in Sumatra, *P. pygmaeus* in Borneo, *H. moloch* in Java). Smaller continental islands bordered by relatively higher bathymetric barrier could possibly produce the isolation-derived endemism process in the level of subspecies (e.g., *M. f. baweanus* in Bawean Island and *M. f. karimoendjawae* in Karimun Jawa Island).

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Conflict of interest

The authors declare no conflict of interest.

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Chapter 5

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

Rintaro Ono, Alfred Pawlik and Riczar Fuentes

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

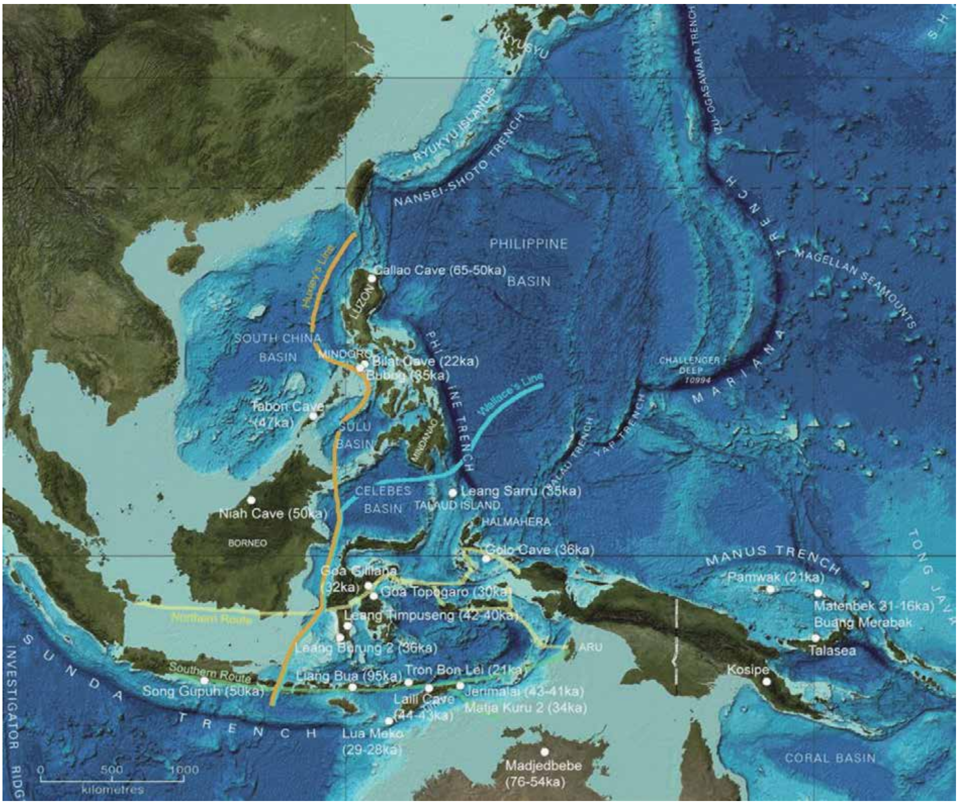

Figure 1.
Major Pleistocene sites in and around Wallacea Archipelago with Wallace Line. Image reproduced from the GEBCO world map 2014, www.gebco.net.

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*.

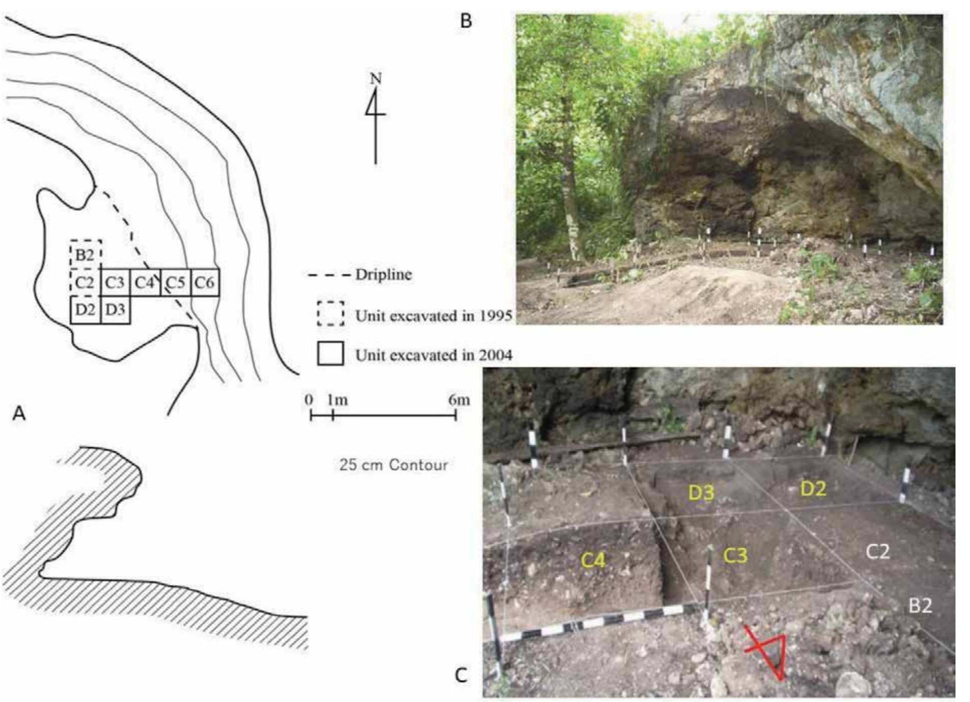

Figure 2.
Plan (A) and front view (B) of Leang Sarru with excavated units (C).

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

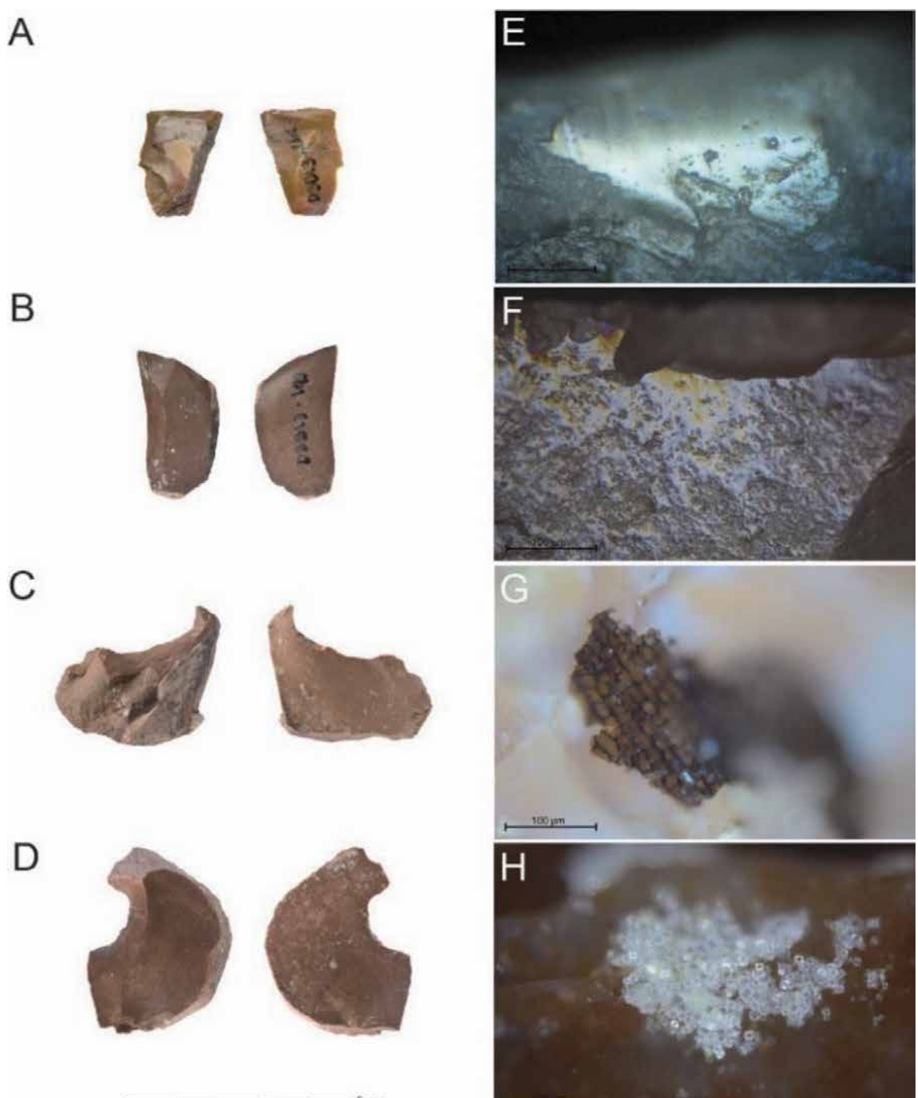

Figure 3.
Leang Sarru lithic tools (A-D) and corresponding plant micropolishes (E, F) and residues (G, H) along their edges.

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

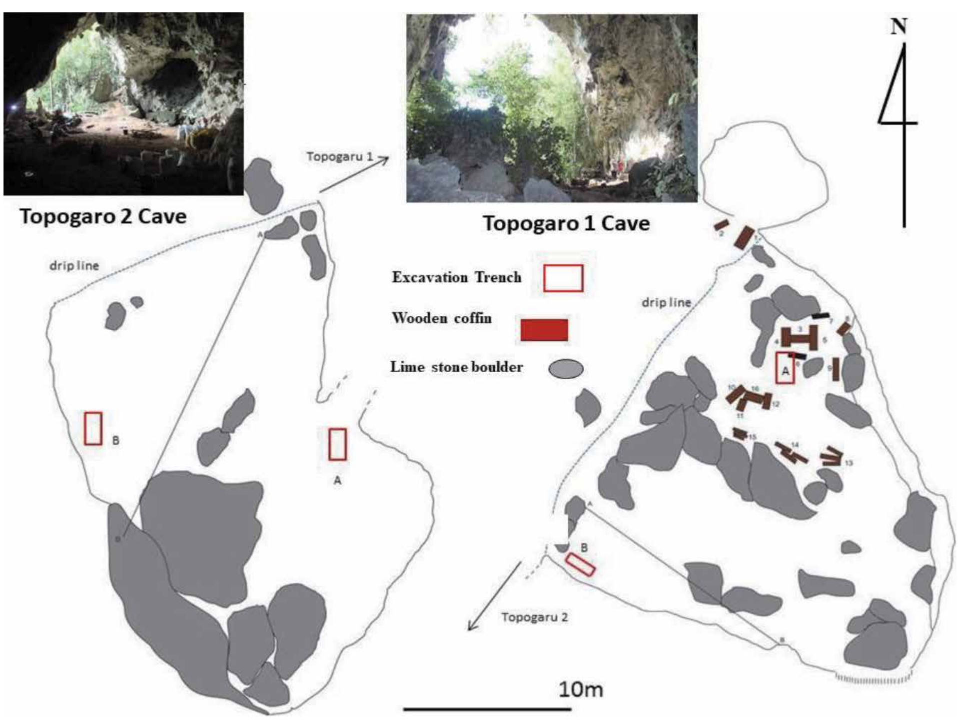

Figure 4.
Mouth views and plans of Topogaro 1 and 2 caves with excavation area.

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

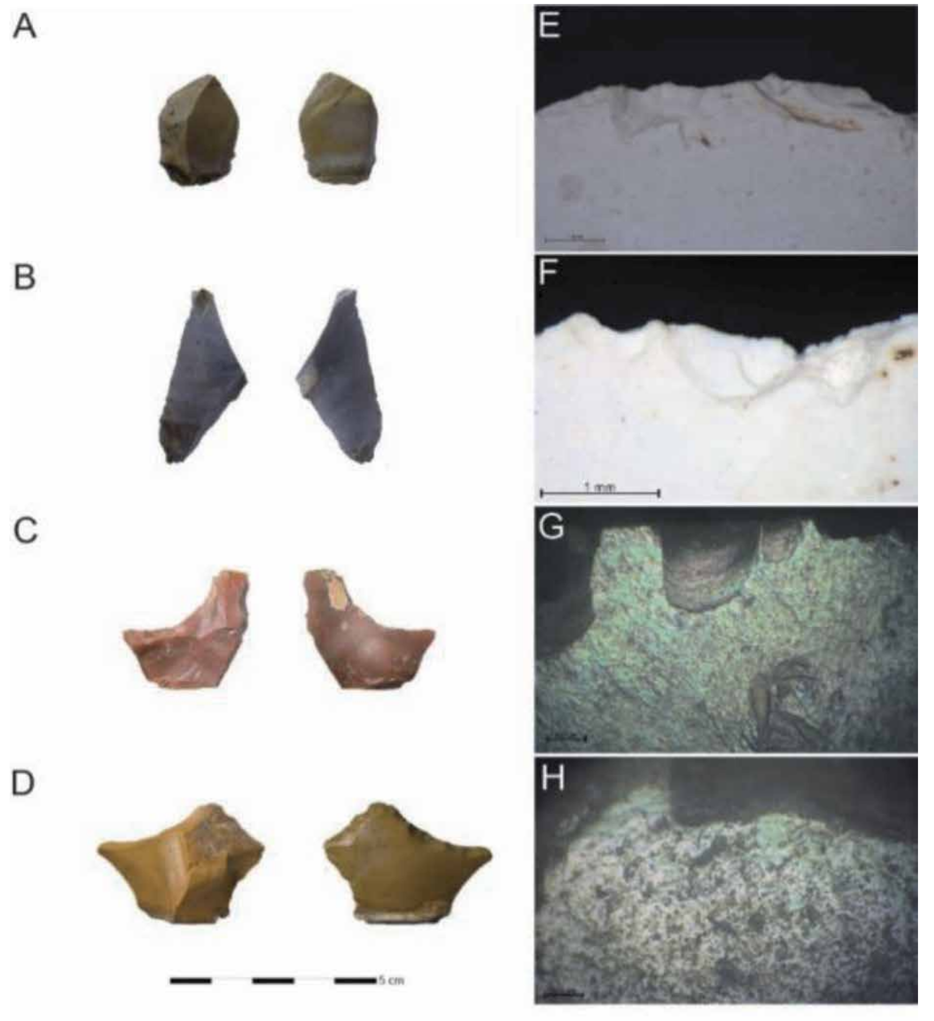

Figure 5.
Topogaro lithic tools (A-D) and use-wear traces of plant-working on their edges. E, F: edge scarring; G, H: micropolish.

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.

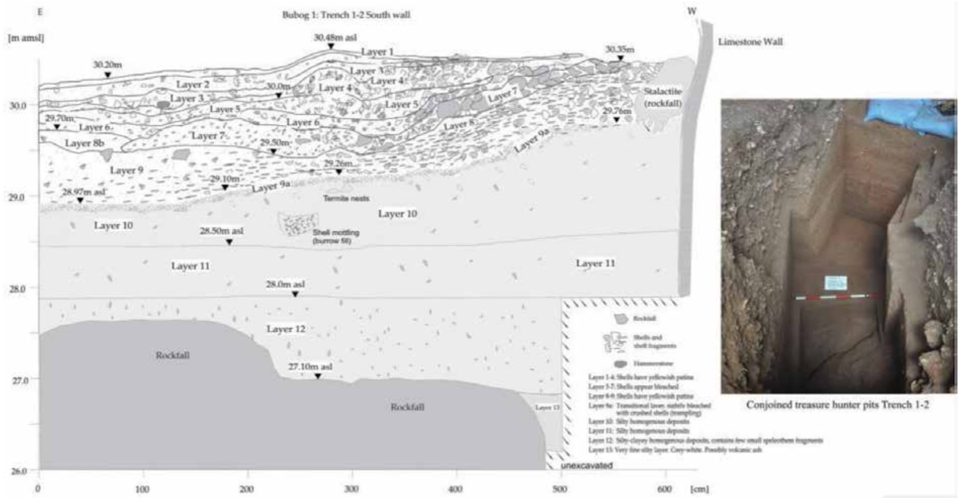

Figure 7.
Profile of Bubog 1 excavation trench (South wall).

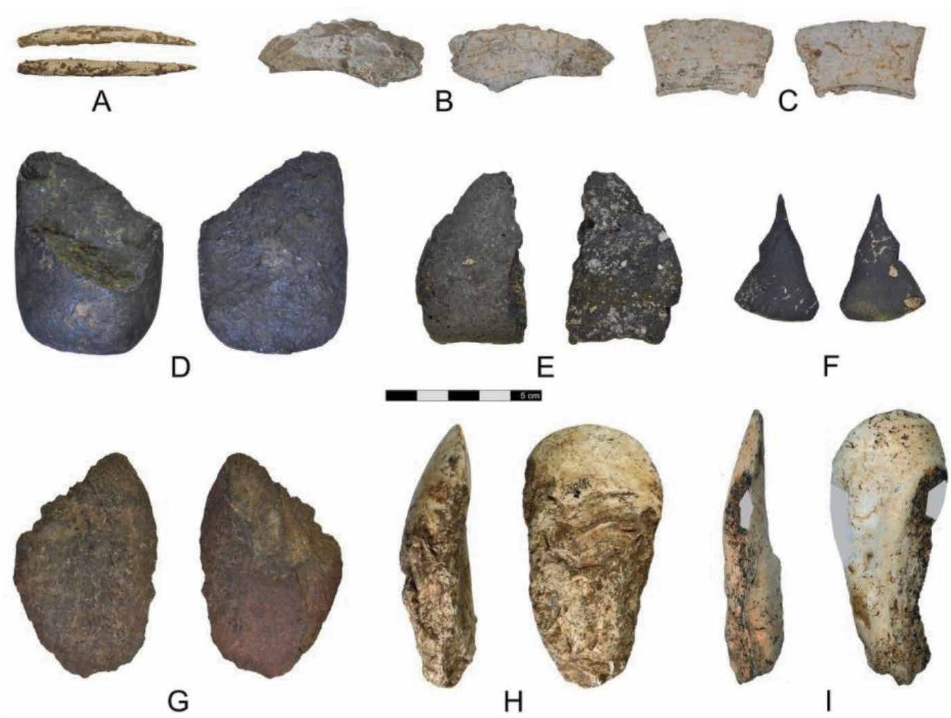

Figure 8.
Selected artifacts from Bubog and Bilat - shell adzes (H, I) and flaked tools (B, C), fishing gorge (A), pebble fragments (D–G).

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 15×2 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.

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Section 4

Pleistocene Human Migration and Technology in East Asia

Chapter 6

A Macroscopic Perspective on Lithic Technology and Human Behavior during Pleistocene in Zhejiang Province, Southeastern China

Hong Chen, Jiying Liu, Xinmin Xu and Huiru Lian

Abstract

Paleolithic archeological remains were not reported from Zhejiang until 2002. Up to now, over 70 Paleolithic sites and/or localities have been recovered through a series of surveys mainly in the north part of Zhejiang. An overview of the Paleolithic record and archeological sequence in this region during the Early to Late Pleistocene are present from a macroscopic perspective in this article, as well as the brief introduction of lithic technology and human adaptation in south China. In general, the lithic assemblages in Zhejiang represent the features of Pebble Industry in south China and show a trend of reduction on the size of stone artifacts since the Late Paleolithic. It is presumed that prehistoric humankind has shown the behavioral strategies as followed: a) exploited local raw material; b) the utilization of core and the degree of proficiency in knapping have been improved gradually; c) the retouching focused on the areas of edges; and d) preferred to use sharp edges of tools.

Keywords: Zhejiang, Pleistocene, lithic technology, human adaptation, pebble industry

1. Introduction

Zhejiang Province (118°01′ ~ 123°08′E, 27°01′ ~ 31°10’N) is a southeastern coastal region of China. Its name derives from the Zhi River, the former name of the Qiantang River which flows past Hangzhou and into the East China Sea (**Figure 1**). The landscape in Zhejiang consists mostly of hills, which reach altitudes of 700 to 1500 meters. Most rivers carve out valleys in the highlands, with plenty of rapids and other features associated with such topography. Its modern weather is dominated by humid subtropical climate, and average annual temperature is around 15–19°C (59–66°F). Pleistocene sediments are distributed widely on the second terraces of rivers with lots of valleys, plains and karst caves, which provided a good natural environment for hominid to live and multiply. However, most regional prehistoric

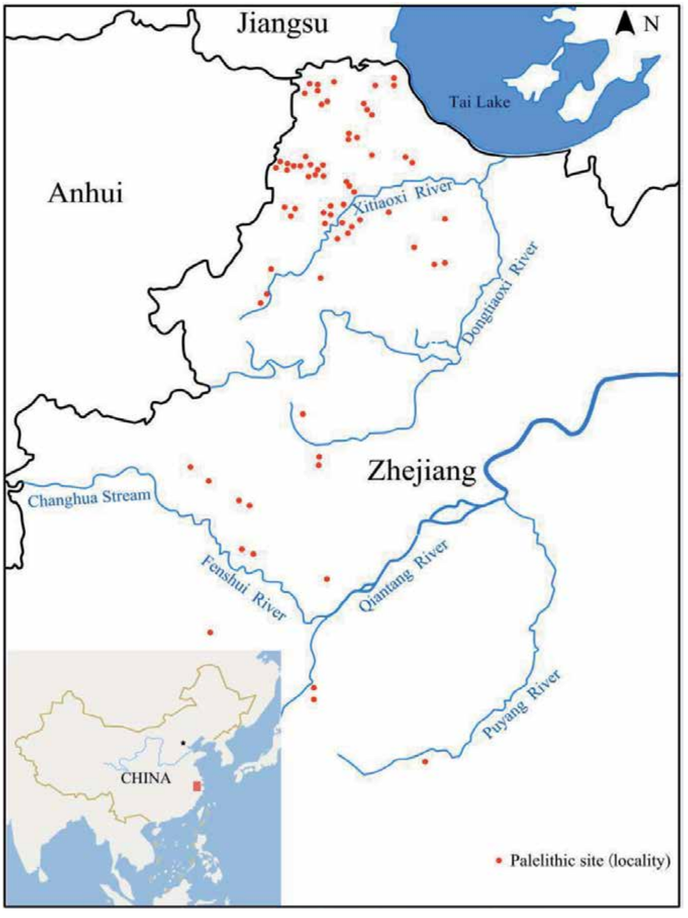

Figure 1.
The distribution of Paleolithic sites and localities in Zhejiang as mentioned.

studies have been about the Neolithic cultures, such as Hemudu and Liangzhu [1–3], one of the origins of rice agriculture in East Asia [4].

Research on the Paleolithic in Zhejiang can be traced back to the 1970s, when a fossil tooth of *Homo sapiens* named as Jiande Man was discovered [5]. However, the new archeological findings in this region were not reported until 2002. Up to now, over 70 Paleolithic sites and/or localities have been recovered through a series of surveys mainly in the north part of Zhejiang (**Figure 1**), mostly open-air sites but also some caves [6]. These archeological records provide new evidence and insights to the prehistory in Zhejiang. During this period, in several important sites test or formal excavations have been undertaken.

The Paleolithic archaeology of Zhejiang is characterized by its geological sediments and it is thus rather difficult to obtain dates. Open-air sites commonly are recovered in strata of reticulate red clay, sparse reticulate red clay and Xia-Shu loess. These stratigraphic layers usually can be used as the standard for dating by scholars. On the other hand, most cave sites were considered being occupied during the Lower Paleolithic period, while some caves might date back to the Upper Paleolithic according to the retrieved fossil fauna and lithic artifacts.

In this article, an overview of the Paleolithic records and archeological sequence in Zhejiang is presented from a macroscopic perspective, as well as the lithic technology and human behavior during Pleistocene as much as possible.

2. Early to middle Paleolithic archeological remains

2.1 Localities in Changxing County

Changxing County is located in the northwest part of Zhejiang, in the transitional zone between hilly areas and the Taihu plain. Regional surveys conducted between 2002 and 2006, in total 32 Paleolithic localities were found from tributaries of Xitiaoxi River [7]. Among them, the Qiliting site and Yindinggang site were selected for excavating (described in followed). Besides, 148 stone artifacts were collected from similar stratums at other localities, which are mainly made of sandstones (P = 56.08%), quartz sandstones (P = 27.03%), quartzites (P = 8.11%) as well as a small amount of silicolites and flints. This stone assemblage is dominated by the pebble industry of Southern China [8].

2.1.1 Qiliting site

Qiliting Site (No. CP029, N30°54′58.7″, E119°41′05.1″) is located 1.5 km south to a branch of Xitiaoxi River in Changxing County (see **Figure 1**), was discovered in 2004. An area over 600 ㎡ was excavated during 2005–2006. Its geological age is estimated to between the late Early Pleistocene to the late Middle Pleistocene, with an absolute age of c. 1.0–0.12 Ma BP dating by paleomagnetic method [9]. More than 700 stone artifacts were uncovered, with a majority of big-sized core tools and a few small-sized flake tools (**Figure 2**). The raw material of the assemblage is dominated by quartz sandstone, with a small amount of sandstone, flint and quartzite (**Figures 3** and **4**).

Three cultural layers with a sterile interval were identified from the top to the bottom of the stratigraphic sequence. 180 stone artifacts from upper layer include cores, flakes, chunks and a small number of stone tools, represented by scrapers, chopping-tools and spheroids [10]. Spheroids in this layer can be divided into preliminary processed type and intensive processed type. Preliminary processed spheroids are similar to the double-platform or multi-platform cores; however, their negatives and scars are mostly much smaller. Their length is nearly equal to the width, as is the width and thickness. Intensive processed spheroids have small natural platforms. These two types of spheroids might reflect the technological process of spheroid-making.

434 stone artifacts were recovered from the middle cultural layer, including cores, flakes, chunks, chopping-tools, scrapers, handpicks, points, stone anvils and so on. In this layer, the handpick is an important tool type. Its volume is large and takes up a high proportion of stone tools. Handpicks exhibit three stages of production. The first one is retouching along both sides of pebble or chunk, and converging into a pointed edge; the second one is taking advantage of the natural ridge of pebble and simply processing it into pointed edge; the third one is making use of the sharp edge after core knapping and modifying it into pointed edge. The pointed edge of a handpick has a higher technology requirement than chopping-tools. Processed directly from a pebble will require a greater workload, and its shape will not be regular. Thus, taking advantage of the sharp edge of core will be a better choice. Only one core was unearthed from the lower cultural layer, suggesting evidence of human activity, at least at the beginning of the Middle Pleistocene.

The technology of stone artifacts uncovered from Qiliting Site is overall consistent. Technological development can be seen on the stone artifacts from Middle and Upper layers, and provides clues of the transition from pebble-tool-industry to flake-tool-industry. The main method for of the manufacture of most stone

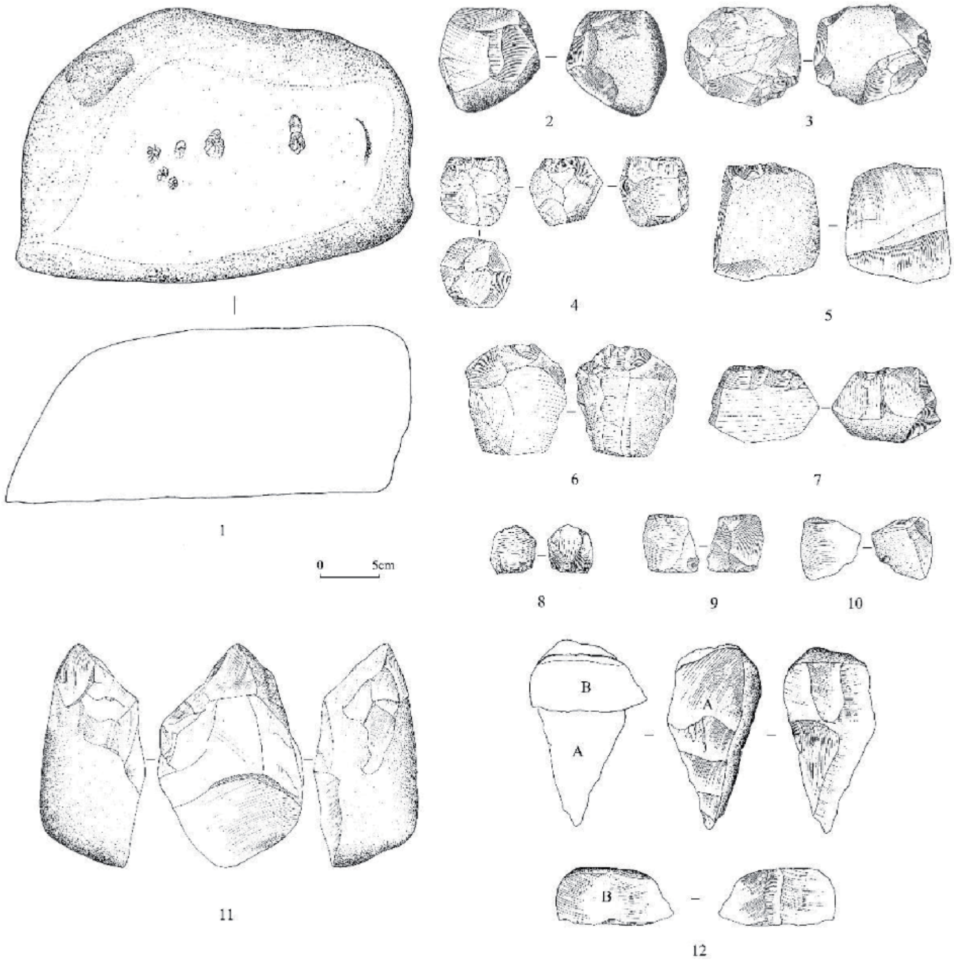

Figure 2.
Stone artifacts unearthed from Qiliting: 1. Stone anvil; 2–3. Core; 4. Spheroid; 5–6. chopping-tools; 7–8. scrapers; 9–10. flakes; 11. pick; 12. refitted flake and flake [10].

artifacts was direct hammer percussion; however, refitting shows a development of knapping skills in the different periods. In the middle cultural layer, four refitting groups belonging to the refitting relation of core to flake were recognized, and they are all in situ. The technique of these stone tools appears as unskillful and unidirectional flaking is in the majority.

The utilization rate of the cores is also low and the striking points are far from the reduction edge of the core. In one refitting group, only a single flake has been removed from its core by the flintknapper. In the eleventh layer, a workshop for lithic processing was possibly identified within the context a temporary camp site. The preparation of the core is crude with many pebble surfaces retained. On the other hand, five refitting groups unearthed from the upper cultural layer of Qiliting site all belong to the refitting relation of core to flake, and they are all single platform cores. Multidirectional flaking from the reverse side has been found on three flakes, which shows the existence of different knapping methods such as one-way, bipolar direction, overturn and multi-direction, which illustrates that the utilization rate of cores in refitting groups are relatively high. By observing the striking point of flakes, it is suggested that their prehistoric manufacturers were able to steadily control the position of the striking point.

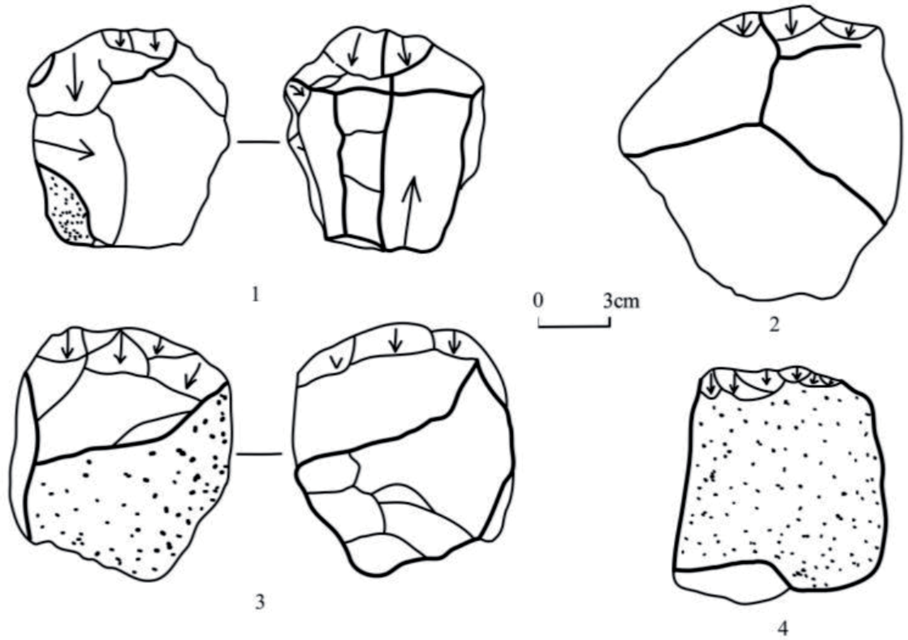

Figure 3.
The chopping-tools from Qiliting [10].

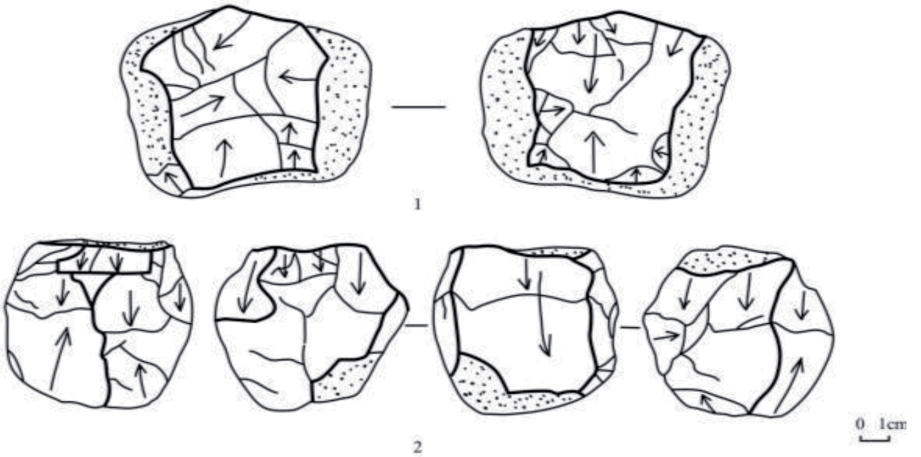

Figure 4.
The spheroids from Qiliting: 1. Preliminary processed type; 2. Intensive processed type [10].

Large tools are the representative types of the lithic assemblage in Qiliting Site, especially chopping tools. These tools are basically made from pebbles. Bifacial retouch is common, with relatively few retouch negatives. Basically, they used the sharp edge of pebbles or cores accompanied with simple processing to produce a useful tool for felling and chopping. Small-sized tools, dominated by scrapers, are made by flakes but also cores, although almost all scarpers from the upper layer are made by flakes. The manufacturing of scrapers is similar to chopping tools, by taking advantage of the sharp edge or the termination of blanks and with simple retouching to make it suitable for scraping. The difference is that most blanks of scrapers are flakes, only a few are made from flat chunks, and the production process is more complicated than for manufacturing chopping-tools. In the Paleolithic sites of southern China, due to the need of digging and chopping, chopping-tools and handpicks appear in large quantities; small-sized tools such as scrapers take only second place in the activity of production, and as a result, their manufacture is not so delicate.

It is suggested that the upper cultural layer of Qiliting might be a lithic manufacturing place *in situ*, since numerous cores and flakes were unearthed from an area about 30 square meters, and since five refitting groups were identified [10, 11]. According to use-wear analysis, 9 specimens from the upper layer retain positive traces of use (**Figure 5**), while 13 specimens from the middle layer were identified as used tools. Because of the lack of further functional analysis, the exact modes of utilization of these stone tools remains currently unclear, but to some extent, the result of use-wear shows that the knapping followed a purpose related to the function, for example, most of scrapers were retouched intentionally before use [12].

2.1.2 Yindinggang site

Yindinggang Site (No. CP029, 31°04′04.8"N, 119°46′32.8″E), which is not far from the Qiliting site was found in 2005 (**Figure 1**). The excavation with an area of near 560 ㎡ was carried out in 2007, and nearly 300 artifacts and over 200 pebbles were yielded. The deposit can be divided into two cultural layers, in which the lower cultural layer can date back to Late Pleistocene according to the geological sequence [12]. The main raw material consists not only of sandstone and quartzite but also includes flint, which is different from most localities in southern China. The lithic technology is dominated by hammer knapping in association with

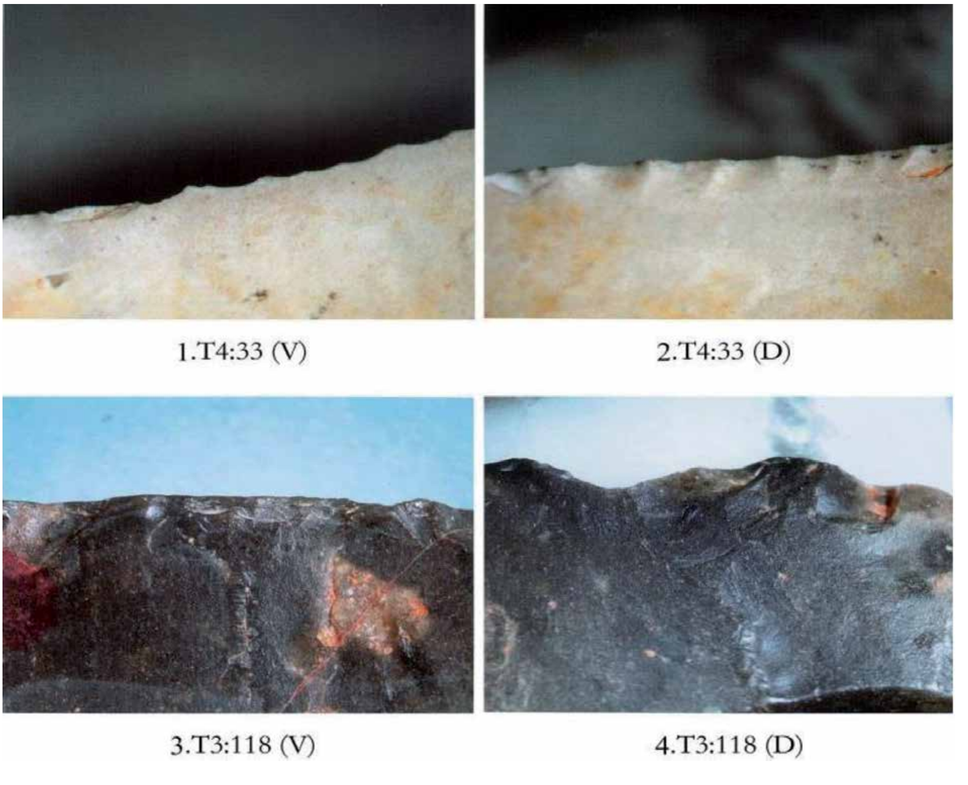

Figure 5.
Use-wear on specimens from Qiliting [12].

bipolar technique (with a ratio of 4:1). It is worth noting that bipolar technique was applied only on flint.

278 stone artifacts were excavated, including cores, flakes, debris, scrapers, chopping-tools and other forms. However, only 6 artifacts belong to the lower layer, the cores, flakes, chunks and points were made of the similar raw material as in the upper layer [13].

The upper cultural layer has discovered 13 refitting groups [12], eight of them have a refitting relation of core to flake, others are core to chunk, core to flake to half flake, core to flake to chunk, core to scraper, and chunks. The first 11 refitting relation (Type I) product were produced during the process of knapping tools from blanks. The twelfth refitting relation (Type II) is the product produced during the process of retouching tools from blanks. The last refitting relation (Type III) is composed of the stone artifacts that have broken off because of the fracture of joint place, the striking force or uneven stress during the process of knapping. Type I and Type II are refitting relations between stone artifacts, these are the result consciously made by prehistoric human, and these relations have reflected the technology of stone artifact processing and their purpose of behavior. Type III is the split joint relation between stone artifacts, an accidental result, which shows that the intended purpose of behavior did not match the result. In general, there are many ways of flake production, such as opposite direction, overturn, stagger, multi-direction, etc. Cores commonly have 2 to 3 scars, at most 9 scars, which means that the utilization of cores was relatively high. The shape of the flake is thick, its platform is wide, the position of striking points is scattered and far from the edge of the blank. It can be suggested that the technique of knapping is unskillful.

In the lower cultural layer of the Yindingang Site, one core to flake refitting group was discovered [10], which indicates that this might have been a place where prehistoric humans briefly stopped and produced some flakes. According to the characteristics of the stone artifacts and their raw materials, two different industries can be identified. One is dominated by artifacts made from raw materials like quartzitic sandstones and sandstones; the other is dominated by artifacts made by flint; these artifacts were much smaller. In general, the average size of the stone artifacts uncovered from this site is smaller than from the pebble industries.

2.2 Localities in Anji County

Anji County is located in the northern part of Zhejiang, south to Changxing County (**Figure 1**). During the field work, 186 stone artifacts from 13 Paleolithic localities were recovered. Moreover, the geological date can be estimated to be from Middle Pleistocene to Late Pleistocene. All of the raw materials are locally available, consisting mainly of sandstones and a few other kinds of rocks, such as trachyte, tuff, quartzite, blastopelitics, siliceous limestones, quartz and flint. A type of single-ended scraper is not common in the Pebble Industry in South China [8].

Shangmakan Site (No. AP003, 119°45′36.3″E, 30°45′19.5"N) is located on the second terrace west to the Xitiaoxi River in Anji County. The sediment can be divided into 5 layers from top to bottom: reticulate red clay, mottled clay, maroon-color boulder clay, taupe-color sandy clay and topsoil. Similar to the dating of Chenshan site in adjacent Anhui province, the age of Shangmakan is dated from ca. 0.455 Ma BP to the Late Pleistocene [14]. 107 stone artifacts were uncovered from the test excavation and investigation in 2002, including cores, flakes, scrapers, choppers, handpicks and spheroids. The majority of them are heavy and thick artifacts made from blocky blanks. The chopping-tools with blunt cutting edge (most over 70°) are a relatively frequent type in this assemblage.

In the excavation between 2004 and 2005, more than 430 stone artifacts were unearthed in three layers with various types: scraper, chopper, spheroid, awl, handpick, graver, point and so on. The lower layer is characterized by lots of pebbles, and the excavator considered it might date back over 0.78 Ma BP [7].

2.3 Localities in Pujiang County

Pujiang County (119°42′ ~ 120°07′E, 29°21′ ~ 29°41'N) is located at the middle part of Zhejiang. A total of 8 stone artifacts were collected without stratigraphic context from the No. PJ001 site of Daxu Village. The reticulate sediment marks on the surface of some stone artifacts are comparable to those uncovered in Anji and Changxing Counties, thus their age can be estimated to Early to Middle Paleolithic. The raw materials contain quartzites, flints, sandstones and siliceous mudstones. The types of artifacts include core, flake and tool. Flakes are produced by direct hammer percussion, and are commonly thick and heavy. The tool types consist of just chopping-tools and scrapers, which are made of blanks of either pebbles or large flakes. The cutting edges of the tools are often blunt with an edge angle of over 90° [14].

2.4 Localities in Lin'an City

Lin'an City (118°51′ ~ 119°52′E, 29°56′ ~ 30°23' N) is located at the northwest part of Zhejiang, north to Anji County and east to Hangzhou City. Several small rivers cross this region and form developed terraces and diluvia with a thickness of 7 ~ 20 m.

Fragmented fossils of ivory and the limbs of artiodactyl were found at Dadi Cave together with the fossil remains of horse, muntjac, deer, bear, tiger, cattle, monkey and boar were unearthed in Douchuan Cave. However, no archeological remains of hominid occurred.

Five Paleolithic localities have been found on the second terrace of rivers in this area [15]. Among the collection of 22 stone artifacts, only one piece has stratigraphic data. The main raw materials are sandstones and quartz sandstones, in association with a few quartzites. Most stone artifacts are heavy and thick, excepting those quartzite pieces in small size. Hammer percussion is used for flaking and retouching. Most features of this assemblage are similar to the sites in Xitiaoxi River area; however, the amount of thick-flake blanks is much higher.

2.5 Localities in Tonglu County

Tonglu County is located in the northwest part of Zhejiang, at the middle part of Qiantang River. 8 Paleolithic localities were investigated in the area of Fuchun River, including 3 open-air localities and 5 cave sites. Open-air localities are mainly found on the second river terraces, and cave sites in karst area of Fenshui River.

There are 12 stone artifacts gathered from the open-air localities. The reticulate marks on the surface of stone artifacts help us to date them into the Early to Middle Paleolithic. The main raw materials are quartz sandstones and sandstones, as well as several siliceous mudstones. The types of the stone artifacts are simple cores and tools. Direct hammer percussion is the main knapping method. The lithic artifacts are made from massive pebbles or cores as blanks. Only two kinds of tools were found, scrapers and points [16].

3. Upper Paleolithic archeological remains

3.1 Hexidong cave site

Hexidong Cave Site, located in 1 km distance from Yindinggang Site, was excavated from 2007 to 2010. Paleolithic remains were uncovered from five localities of this site [16]. According to the types of faunal remains and the stratigraphic sediment, the age of Hexidong Site can be placed into the Upper Paleolithic, though no C14 dates are reported yet and we do not know the exact date of the site.

Locality 1 is the main locality of Hexidong Site. Its 8-meter thick deposits can be divided into 6 cultural layers. A large amount of Quaternary faunal fossils, bone fragments, stone and bone artifacts were unearthed from the third to fifth layer. The great quantity of fragmentary bones might evidence food processing. In the fourth layer, a possible hearth feature was discovered. Moreover, lots of bone artifacts or bone pieces with cutting marks were discovered from Locality 2 and Locality 3.

A total of over 1000 stone artifacts were retrieved from the Hexidong Site. The raw materials include sandstone, quartz sandstone, quartzite and flint. The types consist of chunks (N = 30), cores (N ≈ 450), flakes (N ≈ 190), scrapers (N ≈ 300), chopping-tools (N ≈ 80), points (N = 30) and stone hammers. The technique applied for flaking and retouching is mainly direct hammer percussion, while several flakes exhibit features of anvilflaking. This is the first appearance of this technique in Zhejiang.

3.2 Cave sites in Tonglu County

As mentioned above, five cave sites were identified in Tonglu County. Some flint stone artifacts were collected from Longdong Cave, Hongshidong Cave and Longdongbeidong Cave. Huidong Cave and Heshangdong Cave discovered few Quaternary faunal remains, including the teeth of sika deer, the shinbone of a deer and the phalanx of roe deer. These artifacts are highly possibly as the Upper Paleolithic remains, though the exact C14 dates are not available yet.

10 stone artifacts were collected from the former three caves, with the types of cores, flakes and tools. They are made of siliceous mudstone mainly, and of a few quartzites and quartz sandstones. Hammer percussion is used to produce flakes and retouch tools. The tools are dominated by scrapers, and in association with a few chopping-tools. Most tools are retouched both sides on the massive blanks. The occurrence of small-sized stone artifacts is different from other localities in Zhejiang region [16].

4. Discussion: lithic technology and human behavior

Lithic technology, as defined by Odell (2001), incorporates the various processes that lead to the production of stone tools, including strategies of modification and reduction sequence, knapping equipment, as well as knowledge of raw materials and operative forces [17]. In this regard, lithic technology is an important method to understand the behavior of prehistoric humankind, their societies and history [18]. For the lithic technology during the Early to Middle Paleolithic sites here, we can assume they are products of early to archaic *Homo* species such as *Homo erectus*, while the lithic materials from Upper Paleolitihic sites (Hexidong Cave and some cave sites in Tonglu), they can be recognized as products by *Homo sapiens*.

However, with the limit of direct C14 dating of each site, it is yet hard to discuss the change and develop of lithic technology during the Pleistocene from the view of human evolution and behavior here. Thus we focus on lithic technology and human behavior in general by applying the concept of *Chaîne Opératoire*. This concept was developed to attempt describing and understanding the processes of culture transformation [19], so that it emphasis on the dynamics [20]. The analysis based on the concept of *Chaîne Opératoire* should consider the lithic artifacts as a life-cycle human being, and all of stages from raw material procurement to tool modification, utilization, maintenance, and finally discarding should be included [21].

4.1 Raw material procurement

The types and distributions of raw material at the Paleolithic localities in Zhejiang are recorded in **Table 1**.

A large number of pebbles were mostly found from open-air localities in Zhejiang, indicating that numerous pebbles were used as raw material for stone artifacts. Meanwhile, some sites also used sandstones and quartz sandstones or flint as raw material to stone tools. In general, raw materials are limited, and most of them can be found in the river or nearby outcrops. Thus, it is suggested that these raw materials come from the local river bed, bench land and stratum. Some excavations did not reach the bottom of the pebble deposits, but by comparing with the lithology and nearby stratum, the stratum with the same lithology as the stone artifacts and unearthed pebbles could be identified, which further proves the feature of local material use.

Considering the weight of stone artifacts, there is indication of artificial selection. For instance, the lithics unearthed from the upper cultural layer of the Qiliting

Locality	Major raw material (%)	Minor raw material (%)	Source
Qiliting Site (Changxing)	Quartz sandstone 92.91–98.1	Sandstone, flint, quartzite 7.09–1.9	Pebble from river
Pujiang	Quartz sandstone, sandstone, flint, siliceous mudstone		
Yindiangang Site (Changxing)	Flint 44.2, quartz sandstone41	Sandstone, quartzite	Pebble from bedrock; Flint from basin
Shangmakan Site (Anji)	Sandstone	Quartz sandstone, dolomite, granite, siliceous rock, quartz, igneous rock, quartzite	Pebble from river
Lin'an	Sandstone, quartz sandstone	Quartzite	Pebble layer
Open-air localities (Tonglu)	Quartz sandstone, sandstone	Siliceous mudstone	Pebble from bedrock (probably)
Caves (Tonglu)	Siliceous mudstone(flint)	Quartzite, quartz sandstone	
Hexidong Site (Changxing)	Quartz sandstone, sandstone, flint		Pebble from bedrock; Flint from basin (probably)

Table 1.
The types and distributions of raw material at the Paleolithic localities in Zhejiang.

Sitehave are basically similar in size and weight. Such tendency suggests that the craftsmen might have a strong selectivity of blanks for the lithic production. While the artifact weights in the middle cultural layer are scattered and show a strong randomness [10]. It is worth noting that stone artifacts unearthed from the localities such as Yindinggang, Hexidong and the cave sites in Tonglu County produce flints of good quality as their raw material, which might indicate that prehistoric human including both archaic Homo species and *Homo sapiens* might consciously choose better raw material.

4.2 Primary flake knapping

Cores and flakes are the production of flake knapping. Take the single platform Type I core [9] as example, after the first flake knapping, some cores were discarded as they lost the potential for further knapping. Flakes made by these simple cores have a natural platform and natural dorsal face, and generally they do not have much value in use. Some flakes that have a sharp edge can be directly used as tool. Thus, on some specimens, use-wear traces have been found. Some sites such as Qiliting Site have a high proportion of single platform Type I core, which is on one hand due to the choice of raw material, and on the other hand it is because the knapping technology of local craftsman was immature. In the upper cultural layer, the ratio of faceted platform has increased, numbers of wide and thick type flake have dropped, the ratio of long type flake as well as the overturn knapping has increased, which demonstrates the improvement in knapping technology and utilization rate of core.

Single platform Type II core [10], double platform core and multi-platform core can reflect certain procedures of flake knapping. When knapping single platform Type II core, craftsmen choose the flat plane as platform, and flaked along the edge in clockwise or counter-clockwise direction, then choose the platform that has a ridge on the lower part and continue knapping. They tried to take advantage of the longitudinal ridge to convey the hitting force, and thus some relatively long flakes are produced, and the level of core utilization is thus increased. Double platform cores have an increased area of platform as well as more suitable striking points, which raised the output of flakes, and thereby increased the knapping efficiency of the core.

The knapping of multi-platform cores basically follows the overturn knapping method, which means turning the blank 90° and then knap again. This knapping method is suitable to the condition that when the first knapping sequence becomes unsatisfactory the craftsmen do not need to discard the blank, but can still select other suitable striking points. The striking orientation from right to left of the reverse side of flake shows the knapping situation before, and the flake being peeled off successfully also took advantage of the longitudinal ridge form in previous knapping.

Refitting groups of flakes reveal the strategy of continuous knapping. The observed data of Qiliting Site show that the maximum number of scars on the core from the upper cultural layer core is more than nine, and the maximum number of scars on ridges of dorsal face is more than five [12]. Many double platform cores from the upper cultural layer are knapped from opposite directions, with one of the end platforms fully utilized, and the body of the core has some small scars. In terms of the size of scarring, the shape and structure of small flakes are cluttered and unsuitable for usage. If we keep on knapping the core, the shape of the blank will be like a sphere, and at last become a spheroid. Some multi-platform cores may have also transformed into spheroids.

Five refitting groups were identified from the upper cultural layer of Qiliting site that belong to the refitting relation of core to flake, and they are all single platform cores. Negatives in different directions from the reverse side have been found on three flakes, which shows the existence of different knapping methods such as one-way, opposite direction, overturn and multi-direction, which illustrates that the utilization rate of cores in refitting groups is relatively high. By observing the striking point of flakes, it is suggested that *Homo sapiens* were able to steadily control the position of striking point.

Four refitting groups were unearthed from the middle cultural layer of the Qiliting site, which are all in situ, and belong to the refitting relation of core to flake. The technique of these stone tools is unskillful and one-way knapping is in the majority. The utilization rate of the cores is also low and striking points are far from the cores' edges. In one refitting group, a single flake has been removed from its core. In the eleventh layer, a flintknapping workshop or lithic processing place can be preliminary inferred, which could be a temporary camp of prehistoric humans. The preparation of the cores is crude with many pebble surfaces retained.

From the upper cultural layer of Yindiangang Site, 13 refitting groups were discovered [12], and the eight of them are the refitting relation of core to flake, others are core to chunk, core to flake to half flake, core to flake to chunk, core to scraper and chunks. The first 11 refitting relation (Type I) products were produced during the process of knapping tools from blanks. The twelfth refitting relation (Type II) was produced during the process of retouching tools from blanks. The last refitting relation (Type III) is formed by the stone artifacts that have broken off because of the fracture of joint place, the striking force or uneven stress during the process of knapping. Type I and Type II is the refitting relation between stone artifacts, these are the result consciously made by prehistoric human, and these relations have reflected the technology of stone artifact processing and their purpose of behavior. Type III is the split joint relation between stone artifacts, an accidental result, which shows that the purpose of behavior did not match the result. In general, there are many ways of flake knapping, such as opposite direction, overturn, stagger, multi-direction etc. Cores commonly have 2 to 3 scars, at most 9 scars, which means that the utilization of core is relatively high. The shape of the flake is thick, its platform is wide, the position of striking points is scattered and far from the edge of the blank. It can be suggested that the technique of knapping is unskillful.

Lower cultural layer of Yindiangang Site has discovered one core to flake refitting group [10], which indicates that this might be a place prehistoric human produced flake or briefly stopped.

4.3 Retouching

Chopping-tools from Qiliting Site are all made from pebbles. Bifacial retouching is common, and the retouch scars are relatively few. Basically, they used the sharp edge of a pebble or core accompanied with simple processing to match the need of felling and chopping.

Spheroids in the upper cultural layer from Qiliting site can be divided into a preliminary processed type and an intensive processed type. Preliminary processed spheroids are closed to the double-platform or multi-platform cores; however, most scars are much smaller. Their length is nearly equaling to the width, and so as the rate of width and thickness. Intensive processed spheroids have small natural platforms, a big angle between dorsal and ventral without larger negatives. These two types of spheroids might reflect the technological process of spheroid-making.

In the middle cultural layer of Qiliting site, the handpick is an important type. Its volume is large and takes up a high proportion of stone tools. Handpicks show three stages of manufacture. The first one is retouching along both sides of pebble or chunk, and converging into a pointed edge; the second one is taking advantage of the natural ridge of pebble and simply processed it into pointed edge; the third one is making use of the sharp edge after core knapping and processed it into pointed edge. The pointed edge of a handpick has a higher technology requirement than chopping-tools. Processed directly from pebbles may cost great workload, and such production way is hard to make pointed edge regularly. Thus, taking advantage of the sharp edge of core can be a better choice.

The process of producing scraper is similar to that of chopping-tool, which takes advantage of the sharp edge or far terminal of blanks.. The difference is that most blanks of scrapers are flakes, only a few are trimmed by flat chunks, its procedure is more complicated than chopping-tools. In the Paleolithic sites of southern China, chopping-tools and handpicks appear in large quantities; and small-sized tools such as scrapers take second in the activity of production, as a result, their manufactures are not so delicate.

4.4 Utilization and maintenance

After preliminary examination, the 9 stone artifacts uncovered from the fifth layer and the 17 artifacts from eleventh layer of Qiliting were selected for use-wear analysis, which include flakes, scrapers, points and chopping tools. The analytic results suggest that all of the 9 specimens from the upper layer retain positive use-wear. The 13 specimens from the middle layer were identified as used pieces. The result of use-wear analysis shows that some flakes with sharp edge are used directly as tools without any retouching. It is suggested that most of scrapers were retouched intentionally before using, indicating that the knappers might have possessed some purpose related to the function during the tools manufacture. For points, use-wear was found on the tip and side edge [12].

5. Summary

Up to now, the archeological research of the Paleolithic sites of Zhejiang province focused on the counties along the borders of southern Anhui province, southern Jiangsu province and northern Zhejiang province. The second terrace of rivers and cave sites are the main target of surveys [22–23].

The types of raw materials and their physical limitations could have led the occupants to develop local technical solutions, and they reflect the level of lithic knapping technology. A large number of pebbles were found from open-air localities in Zhejiang, indicating plenty of pebbles were used as raw material of stone artifacts. Stone artifacts of this area were mostly unearthed from the reticulate red clay of the second to fourth terrace of the river. As most sites are in situ, we preliminary deduce that raw materials are from the river pebble or outcrop nearby. Meanwhile, some sites also used sandstones and quartz sandstones or flint as raw material to stone tools. It is worth noting that stone artifacts unearthed from the localities such as Yindingang, Hexidong and a cave site in Tonglu County produce flint that have a good quality as their raw material, which might indicate that prehistoric human including both archaic Homo species and modern human consciously choose better raw material. But the relation between raw material and lithic technology is complex, thus more study is needed to be done in the future.

From the view of lithic industry in Pleistocene south China, the raw materials of these stone artifacts are limited, hammer percussion is the main knapping technique and bipolar method appeared in Upper Paleolithic age and they were possibly produced by modern human or *Homo sapiens*.

Stone artifacts from Early and Middle Paleolithic were made of quartz sandstone and sandstone; direct hammer percussion was used during flake knapping and tool retouching; the utilization of the cores is low; most cores have a single natural platform; faceted platforms are rarely observed. The retouch is crude; one-way retouch and alternately retouch are common; and there are also reverse, stagger, both side and overturn retouching. Most stone tools are heavy and thick, with a length more than 100 mm. Tools smaller than 40 mm are rare, and most blanks are massive. Heavy-sized tools appear in larger numbers than small-sized tools. Chopping-tools are the main tool type, and handpicks and spheroids are also commonly seen. Stone tools in this period basically belong to the industry of southern China [24, 25]. The use of flint increased in the Upper Paleolithic; bipolar method gradually appeared; and the proportion of scrapers also increased; flakes became the main blank form. The trend towards tool miniaturization increased and the characteristic of stone tools gradually approached the flake-tool-industry that is commonly seen in northern China.

In conclusion, the Pleistocene lithic industry in Zhejiang province basically belongs to the industry of southern China [11, 16]. Accompanied by the transition from pebble-tool-industry to flake-tool-industry possibly started by early and archaic Homo species, raw material procurement, the knapping methods and lithic assemblages also changed gradually. The basic characteristic of the lithic industry in Zhejiang is similar to the southern Anhui province and southern Jiangsu province. But some regional differences are also seen. For example, in Early and Middle Paleolithic sites, small-sized and heavy-sized stone artifacts are similar in numbers, and the proportion of spheroid is lower than surrounding areas. Short handpick is also a unique tool type of this region. In Upper Paleolithic sites, on the other hand, flint was used as the main raw material, and with hammer percussion, bipolar method was also widely used. Such new lithic production technology could be introduced and practiced by modern human, though the details are yet unclear.

In terms of human adaptation, most raw materials were gathered locally; the utilization of cores and the degree of proficiency during primary flake knapping improved gradually. Retouching is mostly found on the sharp edge or distal end. The sharp edges of blades are frequently used. Flake refitting and use-wear analysis provided useful information about the manufacture and utilization of tools. As current investigation and material are not comprehensive enough, the archeological investigation of the Paleolithic sites and prehistoric human behavior of Zhejiang province in regard with human evolution and migration during the Pleistocene is an ongoing research.

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Chapter 7

The Migration, Culture, and Lifestyle of the Paleolithic Ryukyu Islanders

Masaki Fujita, Shinji Yamasaki and Ryohei Sawaura

Abstract

Roughly 35,000 years ago, hunting-fishing-gathering people occupied the Ryukyu Islands of Japan, a chain of small-sized islands in the western Pacific. There are Paleolithic sites scattered over most of the relatively large islands, thereby suggesting an extensive human dispersal over the sea at least 30,000 years ago. Recent morphological and genetic studies of the human fossils found in this area revealed that Paleolithic occupants might have an affinity with the modern and prehistoric populations of Southeast Asia. Recent excavation of Paleolithic sediments at Sakitari Cave, Okinawa Island, provided a variety of shell artifacts, including beads, scrapers, and fishhooks, and evidence of seasonal consumption of aquatic animals, especially freshwater crabs. The Paleolithic Ryukyu Islanders' culture and lifestyle, which made use of unique resources, demonstrate behavioral adaptations to living on relatively small islands.

Keywords: Paleolithic, Ryukyu Islands, maritime adaptation, human remains, material culture, shell artifacts, aquatic animals, seasonality

1. Introduction

Intensive immigration to the island is a tremendous environmental adaptation achieved by *Homo sapiens* [1]. Recently, pre-sapiens hominin has been reported to enter the islands [2–4]. But *H. sapiens* has been much more aggressive in immigrating to the islands, especially relatively small and remote islands [5], and utilization of marine resources even at the late Pleistocene [6–10]. Intensive colonization to the island demands complex planning and technological innovation such as seagoing craft, navigation on the ocean, adaptation to unfamiliar fauna, flora, and landscapes [1, 5].

The Ryukyu Islands are one of the oldest oceanic islands to which Pleistocene people immigrated, comparable with the islands of Southeast Asia [1, 11]. Early modern humans inhabited this area no later than 30,000 years ago and probably earlier than 36,500 years ago [1, 11, 12]. The Paleolithic sites cover most of the relatively large islands of this area (**Figure 1**, **Table 1**). The human remains found in this area consist of male and female adults, and children [13–16]. These facts suggest the intentional voyages of early modern humans with their families to the islands.

In Australia, researchers found evidence of the oldest voyage in the world from the islands of Southeast Asia; that voyage occurred earlier than 50,000 years ago [17, 18]. The maritime technology for open sea fishing seems to have been developed prior to the journey, as reported in the case of Timor [19]. Although the use of aquatic resources by early modern human developed before Out-of-Africa,

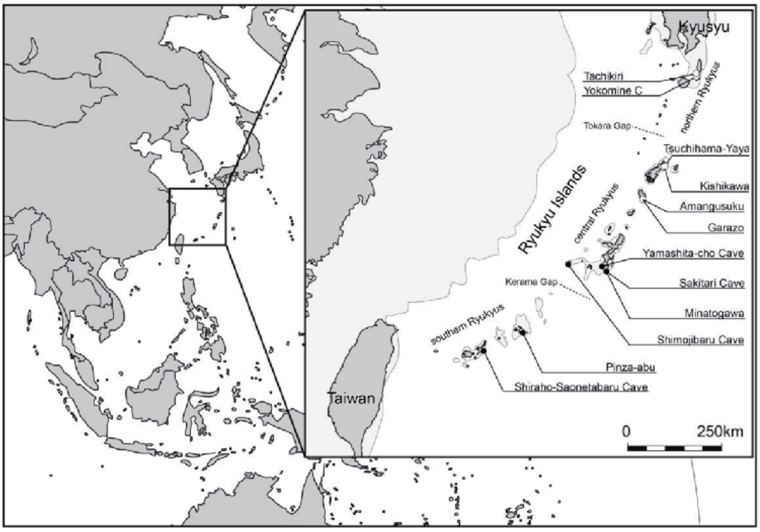

Figure 1.
Paleolithic sites of the Ryukyu archipelago. The white circle represents the sites with stone tools, and the black circle represents the sites with human remains. The dark gray area represents the current land, and the light gray area represents the contour at 120 m depth.

Region	Site	Island	Area of the island	Age of the oldest layer	Artifacts	Human remains
Northern Ryukyus	Tachikiri	Tanega-shima	444 km^2	35k	Cobble tools, grinding stones, polished adze blades, flakes	
	Yokomine C	Tanega-shima	444 km^2	35k	Cobble tools, grinding stones, flakes, anvil stones	
Central Ryukyus	Tsuchihama-Yaya	Amami-O-shima	712 km^2	>30k?	Shale flakes	
	Kishikawa	Amami-O-shima	712 km^2	30k?	Chert flakes	
	Amangusuku	Tokuno-shima	248 km^2	>30k?	Chert flakes	
	Garazo	Tokuno-shima	248 km^2	>30k?	Granite and sandstone cobbles	
	Yamashita-cho Cave 1	Okinawa	1,207 km^2	36k	Sandstone cobbles	Partial infant
	Sakitari Cave	Okinawa	1,207 km^2	35k	Shell artifacts and sandstone (whetstone) (23k~20k) Quartz flakes (16k~14k)	Partial adults and infants (14k~16k, 23k, 30k)
	Minatogawa	Okinawa	1,207 km^2	20k~23k		Four adults
	Shimojibaru	Kume-jima	56 km^2	18k		Infant

Region	Site	Island	Area of the island	Age of the oldest layer	Artifacts	Human remains
Southern Ryukyus	Pinza-abu	Miyako	158 km^2	29k~32k		Partial adult(s)
	Shiraho-Saonetabaru Cave	Ishigaki	223 km^2	27k		Four adults and more (18k~27k)

Table 1.
Paleolithic sites of the Ryukyu Islands.

much earlier than 100,000 years ago [20–22], the populations who came to Islands Southeast Asia (ISEA), in the course of the worldwide dispersal of early modern humans, may have developed much more extensive uses of marine resources [19, 23–26].

Developed maritime technology and flexible resource usage would have enabled Paleolithic people to advance into the island environment beyond the tropical zone. The Ryukyu Islands consist of relatively small islands that are distributed on the margins of the tropical to temperate zone, and which are isolated from each other and mainland Japan. Natural resources such as stone materials and terrestrial animals differ among the islands. Between 30,000 and 36,500 years ago, Paleolithic people immigrated to these variable islands, which spread over 1200 km. Their entry into these diverse environments for a relatively short period provides evidence of the malleable behavior of the early modern humans who adapted to these islands. The purpose of this paper is to review the Paleolithic archeological sites of the Ryukyu Archipelago and to clarify how people adapted to sub-tropical remote islands with limited resources, especially in contrast with the ISEA, thus providing the basis for the global distribution of Paleolithic people.

2. Geographic setting and paleofauna of the Ryukyu Islands

The chain of Ryukyu Islands stretches roughly 1200 km between Kyusyu Island of Japan and Taiwan in the west Pacific. More than 150 relatively small islands (<1207 km^2) are dispersed from the northeast to the southwest at roughly 27° north in latitude (**Figure 1**). A dry and sandy climate generally exists at this latitude around the world, but the Ryukyus are covered with subtropical forests nourished by the hot and humid atmosphere created by the Kuroshio ocean current.

Previously, the Ryukyu Islands were at the eastern end of the Eurasian continent. The tectonic plate movements of the Eurasian and Philippine plates formed the deep ocean basin named the “Okinawa trough” to the west of the Ryukyus and divided the islands from the continent. This geological event probably occurred no later than the early Pleistocene [27]. Today the islands are divided into three parts by the sea, which is over 1000 meters deep: the northern, central, and southern Ryukyus. Some of the northern Ryukyu Islands were connected to the Kyushu Island of Japan during the Last Glacial Maximum (LGM) around 20,000 years ago. The fauna and prehistoric culture of these islands were closely related to those of Kyusyu. By contrast, the central and the southern Ryukyus were isolated throughout the Pleistocene.

The islands now are located at the margin of two biogeographic areas: the Oriental and Sino-Japanese regions [28]. The fauna and flora of the Ryukyus

Figure 2.
Overviewed stratigraphy of the Minatogawa site. The uppermost part of the fissure deposit contained Holocene Jomon. The lower level (layers III and IV) contained late Pleistocene animal and human fossils. Although only medium-sized animals are drawn in the figure, many small animal fossils were found in the lower deposit.

gradually shifted from Sino-Japanese species to Oriental species from the north to the south. The basis of the terrestrial fauna was formed before the isolation from the Eurasian Continent in the early Pleistocene [29–31].

Nearly two million years of isolation have fostered many of the islands' endemic animals. Today, the fauna of the Ryukyus consists of many endemic small animals but lacks large and middle-sized animals except for the wild boar. The late Pleistocene fauna throughout the islands has not been studied thoroughly; it has only been cursorily reviewed by several authors [31–33]. The consensus is that the Pleistocene fauna was similar to the existing fauna of each island. There were several middle-sized animals that are now extinct: one or two species of middle-sized deer and a species of middle-sized tortoise. They became extinct almost simultaneously at the end of the Pleistocene, but the precise timing of extinction is not known yet.

The flora of the Pleistocene Ryukyus was shrouded in mystery. Kuroda and Ozawa (1998) studied pollen samples obtained from a boring core specimen extracted from Izena Island, which is northwest of Okinawa Island [34]. They suggested that the evergreen broad-leaved forest reduced in size and the pine tree became dominant during the LGM. However, the composition of the terminal-Pleistocene fossil-amphibian species of the southern area was similar to the modern fauna of the northern broad-leaved evergreen forest area of Okinawa Island [35]. A dominance of forest species is also reported among avifauna [36, 37], reptiles, and mice [38–40] at the Minatogawa site, a terminal-Pleistocene site of Okinawa Island (**Figures 1** and **2**, **Table 1**). Based on the composition of these fossil species, we can assume that a large area of Okinawa Island was covered with a broad-leaved evergreen forest during the late Pleistocene and even the LGM period.

3. A possible migration route estimated from the Phylogenetic studies of Paleolithic Ryukyu Islanders

Limestone is widely dispersed throughout the Ryukyu Islands, especially in the southwestern half of them. Karstic caves are well suited for preserving bone remains, and there are many Pleistocene fossil sites. Paleolithic research in the Ryukyu Islands began with the discovery of human bone fragments that were mixed with extinct animal fossils in several karstic caves [13]. After the discovery of these partial human fossils, researchers began an exhaustive survey for Paleolithic human remains. In 1970, four well-preserved adult human fossils were discovered at the Minatogawa site, Okinawa Island. The Minatogawa human fossils were about 20,000 years old based on the Carbon-14 dating of the charcoal obtained in their vicinity (**Figure 2**) [14, 41, 42]. Their morphological features and phylogenetic positions were investigated primarily through morphological studies. The Minatogawa human had many morphological traits such as relatively short stature, short clavicles, and a slender upper body with relatively robust lower limb bones. They differ from those of Jomon people, the Holocene hunting-gathering-fishing people who lived in the Japanese Archipelago including the Ryukyu Islands, from 3000 to 15,000 years ago [43–45]. Despite these differences, the Minatogawa people were previously considered ancestors of Jomon and modern Japanese people, based mainly on the morphological characteristics of the skull [14, 44, 45].

In the 2000s, researchers conducted a more detailed comparison of the Minatogawa human fossils and a relatively larger sample of Jomon and modern Japanese people using newly developed methods such as three-dimensional scanning and computed tomography. These studies indicated that there are many differences between the Minatogawa humans and the Jomon/Modern Japanese people even in the skull morphology, including the length and thickness of tooth roots [46], the three-dimensional morphology of the glabellar region [47], the shape of the braincase [48], and the mandible shapes [49]. If there are so many differences, we may need to reconsider the traditional hypothesis that the Minatogawa people were a direct ancestor of Jomon and modern Japanese people.

Genetic analysis of modern Okinawan people also suggests the weakness of the relationship between the Pleistocene and Holocene populations of the Ryukyu Islands. Sato et al. indicated that modern Okinawan people diverged from the continental group (Han Chinese) more recently than 15,000 years ago, based on a comparison of the modern Okinawan genome [50]. If so, the Paleolithic people who had lived in the Ryukyus before this divergence would have little or no genetic contribution to the present population of Okinawa.

Then, is there an affinity between the Minatogawa people and the surrounding populations? Kaifu et al. suggested that their slender mandible morphology may be similar to that of the modern Australo-Melanesian who are found throughout parts of Southeast Asia and Oceania today [49]. A morphological study of the recently unearthed 27,000-year-old human skull from Shiraho-Saonetabaru Cave in Ishigaki Island suggests a possible relationship between Paleolithic Ryukyu Islanders and prehistoric Southeast Asians. Kono et al. pointed out that the Paleolithic skull of the Shiraho-Saonetabaru showed a morphological similarity to that of the Mesolithic Vietnamese [51]. This result coincides with the results of ancient mtDNA analyses of two other Paleolithic human bone fragments obtained from the same site. The haplotypes B4 and R were obtained in the mtDNA analyses [52]. The current center of the distribution of haplotype B4 is in Southeast Asia, and that of haplotype R is an ancestral haplotype of the haplogroup that includes European, Southeast Asian, and Australian Aboriginal people [52].

In summary, these results indicate that Paleolithic people traveled to the Ryukyu Islands through Southeast Asia after leaving Africa. They appear to have little or no similarity with the Holocene populations of the Japanese Archipelago in terms of morphological and genetic traits. However, morphological and genetic research of Paleolithic people from this area is still underway. The recent excavation at Sakitari

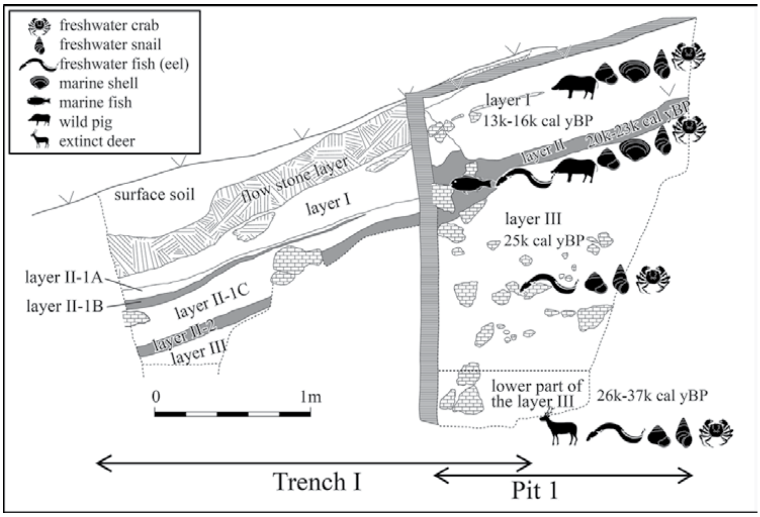

Figure 3.
Section of trench I and pit 1 of Sakitari cave. Partial human remains and animal remains consumed by humans were obtained from layers I to III. Artifacts were unearthed from layers I and II (see also ***Figure 4****).*

Cave indicates that Paleolithic people occupied Okinawa Island almost continuously from 30,000 to 13,000 years ago (**Figure 3**). Studies of the other Paleolithic individuals excavated from Shiraho-Saonetabaru Cave and the human bones recently discovered in Sakitari Cave near the Minatogawa site will provide insight into this problem in the near future.

4. Material culture of Paleolithic Ryukyu Islands

In contrast to the relatively good preservation of human bone, few artifacts have been found from the Paleolithic sites of the Ryukyu Islands. Small amorphous flakes made of chert, quartz, and shales and sandstone cobble tools were found at several sites. Notably, several types of flake tools, which are often discovered at Paleolithic sites in mainland Japan, are restricted to islands north of Tokunoshima (**Table 1**). No chipped stone tools of Paleolithic age have been found from Okinawa or other southern islands.

All the stone materials were available at surrounding area of each site, and no obvious oversea transportation of stone material is known in the Paleolithic Ryukyu Islands. It seems a strange phenomenon since Paleolithic people came across the sea to the Ryukyu Islands and probably were familiar with maritime technologies, including oversea voyage [1, 11]. In mainland Japan, Paleolithic people translocated obsidians beyond the sea [53]. Although the possible oversea transportation of wild pigs more than 20,000 years ago is suggested in the southern and the central Ryukyus [31, 54], it is controversial as discussed later.

The small amorphous flakes and cobble tools are not suitable for typological study or analysis of usage. The Paleolithic and Neolithic cultures of the northern Ryukyus were closely related to those of Kyusyu Island, Japan, as mentioned above. However, the cultures of the central and southern Ryukyus have little in common with them. In the Holocene, the Jomon and subsequent mainland Japanese cultures influenced the prehistoric cultures of the central Ryukyus. In the southern Ryukyus, endemic prehistoric culture continued until 1000 years ago. After the tenth century, the inhabitants eventually constructed a cultural network throughout the Ryukyus. Cultural exchange across islands was difficult in prehistoric times. In summary, the Paleolithic people and culture of the central and the southern Ryukyus seem different from those of mainland Japan, probably because of the difficulty in oversea voyage between the islands.

The material culture of the Paleolithic Ryukyu Islands was a mystery until the authors and colleagues found a variety of shell artifacts and stone tools in the Paleolithic sediments of Sakitari Cave, Okinawa Island (**Figure 4**) [16, 55, 56]. The shell artifacts uncovered from the 20,000 to 23,000-year-old sediments (layer II) of Sakitari Cave consist of fishhooks, two types of scrapers, and two types of beads. The fishhooks were made of *Trochus* shells, similarly to the hooks found in the Paleolithic site of Timor [19]. Therefore, the fishhook technology distributed around the western Pacific might be related to each other, though the locations of the sites differ; Sakitari Cave is a riverside cave and a seasonal campsite for seeking freshwater animal resources such as crabs and snails [16], while the Asitau kuru (Jerimalai Shelter), Timor, is a coastal site for marine resources such as fish and shellfish [5, 19, 57].

The Sakitari assemblage is unique in its lack of stone tools. There were three 13,000-year-old amorphous quartz flakes [55] and a 23,000-year-old tiny fragment of sandstone, which probably was used to grind fishhooks [16]. The Paleolithic stone artifacts of Sakitari Cave consist of only these four items, while many more shell artifacts were unearthed from the same sediments (**Figure 4**). Paleolithic shell flakes were reported in *Homo sapiens* sites of Philippines [58] and Indonesia [59] dating back to 30,000 years ago. It is known that pre-sapiens hominin also uses shellfish tools [60], so it may be difficult to talk about the relevance of culture with shellfish tools alone. But the Paleolithic culture of ISEA and Okinawa seems similar in terms of shell flakes and fishhooks.

However, Sakitari assemblage is quite unique in the dominance of shell artifacts. It probably is linked to the distribution of stone and shell materials on the island. There is no good stone material for making tools except the low-quality chert and small-sized quartz, which are available only in the northern half of Okinawa Island. In contrast to this stone distribution, shells are abundantly available on the island, especially in the coastal area. Sakitari Cave is located at the southern end of

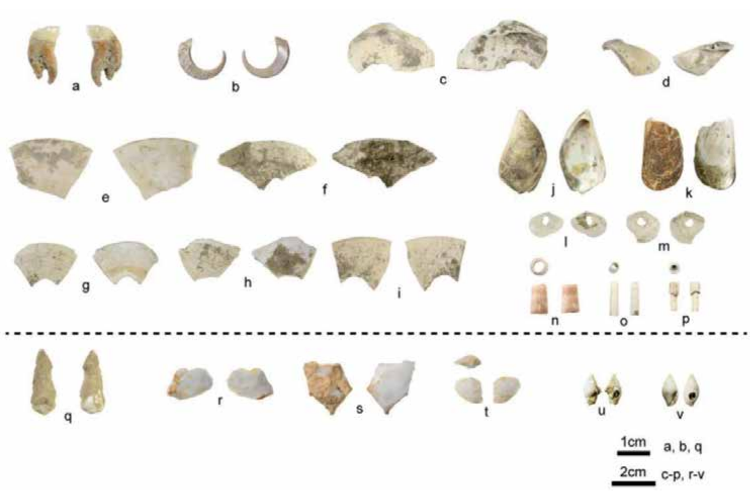

Figure 4.
*Isolated human teeth and artifacts obtained from layer II (20,000–23,000 years ago; a–p) and layer I (13,000–16,000 years ago; q–v) of Sakitari cave. (a) Human tooth (right lower third molar), (b) shell fishhook, (c–i) bivalve shell scraper (*Callista chinensis*), (j, k) bivalve shell scraper (*Septifer bilocularis*), (l, m) bivalve shell bead (*Sunetta kirai*), (n–p) Scaphopoda bead, (q) human tooth (right upper deciduous canine), (r–t) quartz flake, (u, v) snail shell bead (*Pyrene testudinaria*).*

Okinawa Island, a stone-poor region. At present, it is about 2 km inland from the nearest coast, and it was 5–6 km away from the coast around 20,000–23,000 years ago. Therefore, the Paleolithic people of Sakitari Cave were able to access the coast easily and collect shells and other marine products such as fish. The unique material culture of Sakitari Cave was suitable for the island environment, and it represents the behavioral plasticity of the Paleolithic people and their capacity to adapt to the stone-poor, shell-rich island environment of Okinawa.

5. Plastic behavior in the utilization of animal resources

The behavioral plasticity of Paleolithic people is observable in their material culture and hunting-gathering actions. The Paleolithic people in Sakitari Cave mostly consumed freshwater crabs (Japanese mitten crab) and freshwater snails. They also ate small vertebrates such as mice, birds, lizards, snakes, frogs, and fish (freshwater and marine). The food waste in Sakitari indicates that small, nocturnal animals living in or near the river were dominant. As in the general example of island fauna, the fauna of Okinawa Island lacks large terrestrial mammals (**Figure 5**). At the first stage of human arrival, there were two species of middle- or small-sized deer and one species of a middle-sized tortoise [33], but they went extinct probably earlier than 30,000 years ago [42, 54]. Based on the limitedness of the terrestrial fauna, some researchers theorize that Paleolithic people were unable to maintain their population on the small island [61, 62]. However, research of the Sakitari remains revealed that the Paleolithic people maintained their population for nearly 20,000 years by consuming small, aquatic animals, which generally are highly reproductive and densely inhabited the area compared to large and middle-sized mammals. This unique, effective use of animal resources enabled the Paleolithic hunter-gatherers to live on relatively small islands for a long time.

The extensive consumption of marine resources was reported in ISEA [19, 23–26]. Paleolithic immigrants who came to this area developed diverse fishing and shellfishing

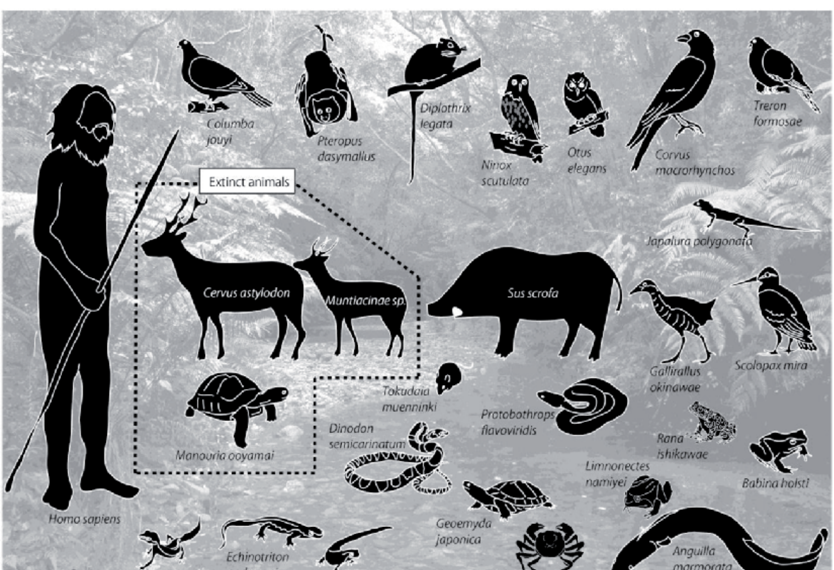

Figure 5.
Terrestrial and freshwater animals of Okinawa Island.

activity. The exploitation of variety of marine resources may be one of the factors that enabled Paleolithic migration to the variety of islands. As indicated by the studies on human remains and shell artifacts, relation between Okinawa and ISEA is suggested again in the viewpoint of aquatic resource usage. However, dominance of the freshwater animals is the unique point of Paleolithic Okinawa. One reason may be the limited terrestrial animals, and another reason may be seasonality. The oxygen isotope study on freshwater snails indicated that these freshwater animals were consumed mainly in autumn [16]. Paleolithic people of Okinawa may have used more marine resources in other seasons, though we do not have any evidence at present.

Another notable behavior of Paleolithic Ryukyu Islanders is the possible translocation of wild pigs earlier than 20,000 years ago. Researchers have reported that the Pleistocene translocation of animals occurred in Cyprus around 11,000 years ago [63] and Manus Island around 13,000 years ago [64]. In the case of the Ryukyu Islands, after the extinction of the endemic deer between 30,000 and 35,000 years ago, wild pigs appeared and increased in number around 20,000 to 27,000 years ago [31, 39, 54, 65]. Because Okinawa Island was isolated from the Eurasia continent, mainland Japan, and the remaining Ryukyu Islands during the Pleistocene [27], the increase in the wild pig population might have resulted from people translocating pigs onto the islands from elsewhere [31, 54, 66]. However, one difficulty in this scenario is the recent analysis of the mtDNA of extant wild pigs which showed that the current Ryukyu wild pig population (*Sus scrofa ryukyuanus*) is a unique, endemic species of the Ryukyu Islands. It was separated from the Eurasian wild pig populations much earlier than the human arrival, probably during the middle Pleistocene [67]. Another difficulty is an ancient DNA study of wild pigs from Holocene archeological sites which suggests the possible translocation of pigs by Holocene prehistoric people [68]. We do not know the genetic relation between the Paleolithic and modern wild pig population of the Ryukyus, and how the Holocene prehistoric translocation of pigs affected the genetic traits of the Ryukyu wild pigs. Therefore, the details of when and how the endemic Ryukyu wild pigs were distributed throughout the Ryukyu Islands remain controversial.

6. Conclusion

Paleolithic people immigrated to the Ryukyu Islands more than 36,000 years ago. Morphological and genetic studies of Paleolithic human fossils from this area have indicated that they probably came through Southeast Asia in the course of the worldwide dispersal of early modern humans. The common use of shell tools including fishhooks and the remarkable consumption of aquatic resources as foods by Paleolithic Ryukyu Islanders suggest the relation to the ISEA.

However, Paleolithic Okinawan culture was unique in dominance of marine shell artifacts and biased consumption of freshwater animals. This unique lifestyle adapted to the stone-poor and shell-rich environment of the island, where there were limited terrestrial animals. The adaptive lifestyle on Okinawa, which is a relatively small oceanic island, suggests the plasticity of Paleolithic people's behavior. Their behavioral plasticity may be one of the driving forces that enabled *Homo sapiens* to migrate to various environments all over the world.

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Section 5

Pleistocene to Holocene Human Technology and Interaction in New World

Chapter 8

The Technological Diversity of Lithic Industries in Eastern South America during the Late Pleistocene-Holocene Transition

João Carlos Moreno De Sousa

Abstract

Brazilian archaeological literature has insisted for decades upon associating hunter-gatherer sites dated to the Pleistocene–Holocene transition either to the Itaparica tradition, if located in central or northeastern Brazil, or to the Umbu tradition and Humaitá tradition, if located in southern Brazil, Uruguay, or any other adjacent part of Paraguay and Argentina. These associations have been based almost entirely on the presence or absence of *lesmas* and "projectile points," regardless of their morphological and technological features. In the Uruguayan archaeological literature, three other cultures are recognised: Fell industry, Catalanense industry, and Tigre tradition, all in the Uruguayan region. However, the last 10 years of systematic studies on the lithic assemblages from these sites have shown that Paleoindian societies from Eastern South America are more culturally diverse than expected and that previously defined archaeological cultures present several issues in their definition, suggesting that many of these "traditions" are not valid and should no longer be used. Instead, new lithic industries and archaeological cultures should be defined only when cultural patterns are observable through systematic analyses.

Keywords: Paleoindian, hunter-gatherers, lithic technology, eastern South America, cultural diversity

1. Introduction

When we think about the archaeology of the Pleistocene in the Americas, we can only point to a few sites that are not dated from the very end of that period. This is because the American continent only started to be densely occupied after 13,000 BP, when the Pleistocene was ending. In South America, there are only four places known to this day that present strong evidence that some people settled the continent before 13,000 BP: the Serra da Capivara region, in Northwestern Brazil, which has sites containing simple tools of quartzite pebbles made by direct percussion (choppers), the oldest one being Boqueirão da Pedra Furada, dating around 50,000 BP [1–11]; Monte Verde site, in central Chile, where choppers and flakes are presenting dates older than 33,000 BP [12]; Santa Elina site, in Midwestern Brazil, where retouched limestone flakes and polished pendants made of *Megatherium sp.* (giant sloth) osteoderms were found and dated to around 23,000 BP [13, 14]; and

Taima Taima site in Venezuela, where the El Jobo lithic industry was found dating back to 13,000 BP (or 15,000 cal BP) [15]. It seems that this first phase of human settlement of the Americas is mainly defined by small populations that entered the continent and did not necessarily meet each other. These are just suppositions, since data is still insufficient for a better understanding and discussion of the first phase.

It was only around 13,000 cal BP, during the Pleistocene/Holocene transition, that the continent started to be densely occupied—and this is what we may call the "second phase" of America's "human settlement." The first studies of Paleoindians in the Eastern part of South America, which is the focus of this article, emerged in the 1960s with the second generation of academic archaeologists in Brazil. Before them, the only systematic archaeological research in the country was carried out by the *Programa Nacional de Pesquisas Arqueológicas* (a.k.a. PRONAPA), between the 1950s and 1960s [16]. PRONAPA researchers applied the concepts of "phase" and "tradition" which were heavily inspired by the historical-cultural American school. Even after the end of PRONAPA, its theorical-methodological approach influenced many researchers to classify material culture assemblages into traditions or phases, especially pottery vessels, lithic artefacts, and even rock art, mainly by their size, shape, and decoration, as well as morphological-typological classifications of artefacts and archaeological sites settings. A new "archaeological tradition" would be created for each identified type, and the new assemblages presenting the same types were associated to these "traditions." Similar types presenting slight regional or chronological differences were associated to subcategories known as "archaeological phases." This was the first attempt to classify archaeological materials into archaeological cultures. Unfortunately, when Paleoindian research started to be carried out between the 1960s and 1970s, it was not always clear which types could be included in a tradition or phase, due the lack of solid criteria for these definitions. These definition problems affected the classification of Paleoindian cultures in a way that, until the end of the 2010s, archaeological literature defined only five Paleoindian cultures in Eastern South America: the Itaparica tradition, the Umbu or Tigre tradition, the Humaitá tradition, the Catalanense industry, and the Fell industry. But most of these "traditions" have been questioned on the validity of their concepts.

During the 1970s, Brazilian archaeologist Pedro Ignácio Schmitz [17–19] discovered several Paleoindian sites in the Serranópolis region, Midwestern Brazil, dating around 10,700 BP and presenting hundreds of unifacial plan-convex tools. Schmitz gave a name to these tools: *lesmas*. He also defined a new archaeological tradition as a result—the Itaparica tradition—and associated all known sites with *lesmas* to it. In the decades to come, several researchers would associate the presence of *lesmas* to the Itaparica tradition in Northeastern and Midwestern Brazil, even though there was a lot of doubt about the supposed technological homogeneity of these tools [20–27]. Systematical research on comparing *lesmas* from different sites, regions and periods are still scarce to this day, but most authors agree that in most regions where *lesmas* appear, there is a lack of stemmed points or bifacial technology in general. The oldest site known to present *lesmas* is the Lapa do Boquete site [21], in mid-eastern Brazil, dating to 12,070 ± 317 BP (15,098–13,289 cal BP).

In Brazil, the term *lesma* was initially used as a synonym for *limace*. The term *limace* was first defined by León Henri-Martin [28] but later redefined by François Bordes [29] to refer to unifacial tools that are symmetric, three times wider than they are thick, presenting one pointed extremity (tip), biconvex edges, and uninterrupted retouches all around the artefact. In popular language, *limace* means "slug" in French, while *lesma* also means "slug" in Portuguese, being just a literal translation. However, most recent studies on Paleoindian *lesmas* have made clear that these tools are not that similar to the ones originally defined from the European Mousterian. Instead, *lesmas* present some other patterns, such as the use of a big flake as a blank, unifacial reduction/*façonnage* (not only retouch), the presence of several active edges, and at least one in one extremity (proximal or distal), plan-convex cross-section, a longer than wider shape, width being bigger or equal to the thickness, and a length that is usually greater than 7 cm. It does not seem to have a more specific standard on general morphology and technology, but this is probably due the lack of research in order to define regional or chronological patterns, especially because the presence of *lesmas* was the only attribute considered to this cultural association. The presence of *lesmas* is only observed in hunter-gatherer groups of Eastern South America, but more studies are necessary in order to better understand cultural patterns before making any cultural affiliations.

The Umbu tradition was supposed to be the opposite of the Itaparica tradition, since there were no *lesmas* associated to it. Instead, many types of "projectile points" were found. Itaparica is located in the Midwestern to Northeastern Brazil, while the Umbu tradition coverage area is only associated to the Southeastern and Southern states of Brazil, Uruguay, and some adjacent areas of Paraguay and Argentina. The concept of the Umbu tradition was created during the 1980s after a series of failed attempts to define "traditions" of stemmed points in Southern Brazil [30]. Those traditions and phase definitions were not clear, and sometimes even contradictory, making it difficult to understand to which tradition or phase new findings should be associated. At the end of the 1980s, all sites presenting stemmed points were aggregated into the Umbu tradition regardless of their morphology and technology. The oldest known site associated to it was supposed to be the Laranjito site [31, 32], in the middle of the Uruguay River, dating to 10,985 ± 100 BP (13,035–12,715 cal BP).

In the same area that the Umbu tradition was found, there was a second, contemporary tradition defined based on the presence of large, thick bifaces, some of them boomerang-shaped. This culture was first referred as the Altoparanaense Tradition [33, 34] and later renamed as the Humaitá tradition [35, 36]. However, this tradition was discarded from Brazilian archaeological literature at the end of the 2010s [37], since new findings revealed that typical Umbu and Humaitá tools were now being found in the same contexts. This meant there was only one tradition to associate new Paleoindian findings with stemmed points in southern Brazil and nearby regions.

Many critiques were made of the concept of the Umbu tradition just after a large quantity of assemblages had been aggregated into it [38–43], especially about the fact that the presence of stemmed points was the only attribute used to define it. In fact, until the end of the 2010s, no study was ever made to confirm this supposed cultural homogeneity in assemblages associated to the Umbu tradition. Added to this question, no researcher outside Brazil ever associated stemmed points to the Umbu tradition—even though Uruguay, Paraguay, and Argentina were supposedly part of it. One of the critiques also highlighted that Uruguayan archaeologists were defining the same points that Brazilian archaeologists were calling Umbu tradition to the Tigre tradition [43]. Tigre points were not the only ones found in levels related to the Pleistocene–Holocene transition. In fact, a good chronology for at least three types of stemmed points defined three different lithic industries [44]: Fell industry, Tigre industry, and Pay Paso industry (**Figure 1**).

Since the beginning of the current decade, Brazilian archaeologists also started to verify the validity of this supposed cultural homogeneity in Umbu tradition sites. Studies on geometric morphometry [45–47] and technology [48, 49] on Umbu-associated stemmed points revealed that these artefacts are indeed traditional, since they persist for millennia. However, these studies also revealed that they are heterogeneous in space, since regional cultural patterns revealed the existence of at least three lithic industries in the supposed Umbu tradition coverage area: Rioclarense industry, Tunas industry, and Garivaldinense industry (**Figure 1**).

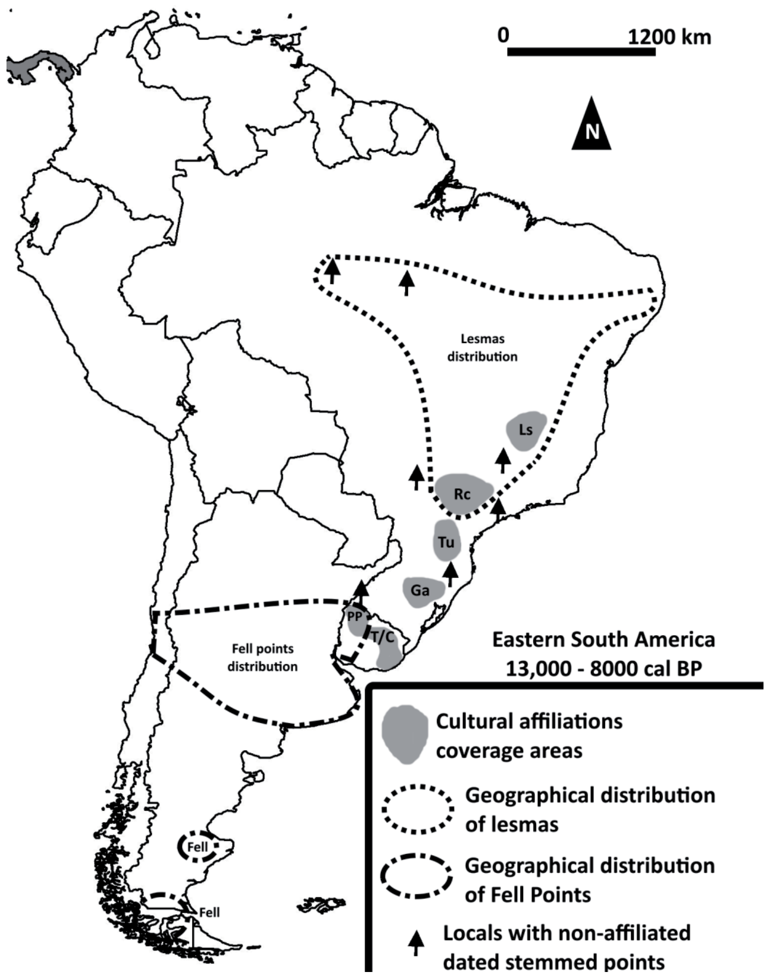

Figure 1.
The distribution of Paleoindian cultures in eastern South America between 13,000 and 8000 cal BP. Ls, Lagoassantense culture. Rc, Rioclarense lithic industry. Tu, tunas lithic industry. Ga, Garivaldinense lithic industry. T/C, Tigre tradition and Catalanense lithic industry coverage areas. PP, pay Paso lithic industry. Sites outside this chronological range were not considered.

The Umbu tradition was declared to be no longer a valid concept [41, 48, 49], and none of these identified industries are related to the previously associated Humaitá tradition. In fact, no studies have ever been made in order to verify if there is any cultural pattern of point types associated to boomerang-shaped bifaces.

2. The fell industry

The Fell industry is named after the first site to present what are now called Fell points (a.k.a. Fishtail points): the Fell Cave site, in southern Patagonia (Chile) [50–53]. Since then, many sites found in the Southern Cone, which extends from the extreme south of Chile and Argentina to the Northern parts of Uruguay, presented Fell points dating back to 11,000 BP (13,000 cal BP) [54–90]. In Eastern South America, specifically Uruguay, the Fell industry disappeared around 10,000 BP (12,000 cal BP) [82], but it is not clear if this is the case for all regions. Blade technology is also observable in some of these sites, even though the cores are not found.

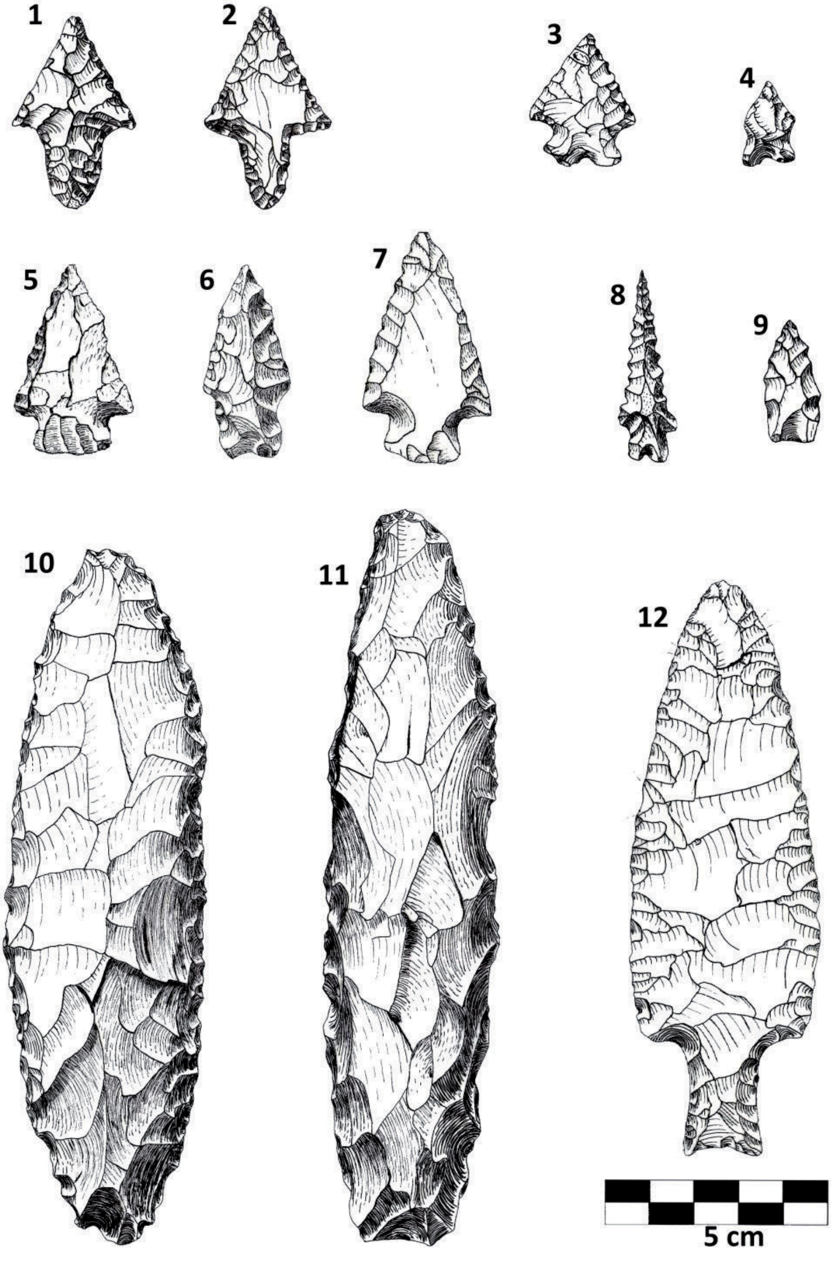

Figure 2.
Examples of formal artefacts affiliated to Paleoindian industries in eastern South America during the Pleistocene–Holocene transition, previously associated to Itaparica or Umbu traditions. (1 and 2) Rioclarense points on flint (Alice Boer site). (3 and 4) Star points on flint (Tunas site). (5–7) Garivaldinense points on silicified sandstone (Garivaldino site). (8) Montenegro point on silicified sandstone (Garivaldino site). (9) Brochier point on agate (Garivaldino site). (10 and 11) Rioclarense lesmas on silicified sandstone (Caetetuba site). (12) un-fluted fell point on flint (unclear context from Mauá municipality, eastern São Paulo state, Brazil). Scale bar is the same for all artefacts in the figure. All drawings by the author.

The Fell point was initially defined only by its shape, but recent studies have been defining it based on more accurate technological aspects [81–86]. The Fell points are defined by the bifacial thinning reduction method by percussion technique followed by the fluting technique—the removal of a long flake from the base—and finished by retouch in order to form convex edges in the body and the typical "fish tail" shape of the stem that is usually ca. 20 mm wide. Miniature versions of Fell points can also be found in Eastern Argentina (Pampas region) which are basically thin flakes with retouch that imitates the general shape of the traditional Fell point. These miniatures present no bifacial thinning or fluting. The smaller Fell points may also be the result of body reshaping. Whatever the reason is for the smaller versions, they tend not to have well-delineated wings.

Fell points have also been found in other distant parts of South America, like meridional Brazil [87, 88], the equatorial Andes [55], and even the Caribbean sea of Venezuela [71], but they do not have a clear context since they usually constitute surface finds by local habitants. Brazilian Fell points usually differ from those found in other parts of South America because they lack the fluting technique (**Figure 2**: 12).

3. Early lithic industries in Uruguay: Tigre, Catalanense and Pay Paso

The Tigre tradition, the Catalanense industry, and the Pay Paso industry are all found in Uruguay. It is not yet clear yet when these industries appeared and disappeared, since there are some definition problems in the Uruguayan literature.

The Tigre tradition got its name due the Tigre River, where the first sites associated to it were found, including the Tigre site, where the oldest date for this tradition was obtained: 10,420 ± 90 BP (12,553–11,841 cal BP) [42, 43]. Tigre points have never been well-defined and are usually described in the literature as presenting bifacial reduction, a triangular body, and a convex stem [44, 82], regardless of the presence of bifurcated stems in points associated to this same tradition [43]. Some of these features are the same as those found in the Garivaldinense points of Southern Brazil, but the lack of published data on Uruguayan point technology makes it hard to compare and verify if both Garivaldinense and Tigre points are actually the same.

The Catalanense industry is named after the Catalán Chico River, where the first sites associated to it were found, although it extends across other regions of Uruguay [91–97]. Its chronological range would fit between 9000 and 7000 BP (11,000 and 8500 cal BP), being defined by the presence of large retouched flakes in the initial period and an increase of discoidal cores and retouched blades in the latest period [43].

The Pay Paso industry comes from the Pay Paso site, the first one to be associated to it, and the oldest date for this industry is 9585 ± 25 BP (11,081–10,711 cal BP) [82]. The main artefact related to this industry is the Pay Paso point type, defined as having a triangle body with convex edges, bifurcated stem, and bifacial technology. Bladelets are also found in this industry. Pay Paso industry studies are quite recent, and more research needs to be done in order to better understand its chronological and geographical range.

In sum, more technological studies are still necessary in Uruguayan archaeology in order to better understand these first lithic industries and the possible relationships between them and the other ones found in Brazilian territory.

4. The Rioclarense industry

The Rioclarense industry is named after the region of Rio Claro, in central São Paulo State, where it was first identified by Tom Miller Jr. in the 1960s [98, 99]. Since stemmed points were part of the Rio Claro tradition, it was also aggregated into the Umbu tradition in the early 1990s [35], regardless of the fact that not all its phases presented stemmed points and that *lesmas* were also present in those assemblages.

As mentioned before, recent studies revealed morphological and technological differences between the previously Umbu tradition-associated assemblages. The Rio Claro tradition has now been redefined as the Rioclarense lithic industry due the presence of both *lesmas* and stemmed points of the Rioclarense type in several sites in central São Paulo State dating between the Pleistocene–Holocene transition and mid-Holocene [48, 49], with the Caetetuba site presenting the oldest date—9590 ± 30 BP (11,086–10,712 cal BP)—but previous studies also identified Rioclarense artifacts on the southern Brazilian coast, in the Paranaguá region, after 5000 BP, around the same time when the sambaqui culture started to expand in the region [100].

The Rioclarense point type is defined by a triangle-shaped body with straight edges and wings, an ovalate stem, and two technological types of reduction: (a) bifacial reduction by selective and trespassed flakes removed by percussion (**Figure 2**: 2) and (b) bifacial reduction by parallel flaking by pressure and no retouch, followed by retouch of the active edges (**Figure 2**: 1). By selective we refer to the lack of a systematical diachrony of the flake negatives, and by trespassed we refer to negatives that trespass the middle of the piece in order to make it thinner (in proportion to the width).

The presence of *lesmas* (**Figure 2**: 10, 11) in the Rioclarense industry brings back the discussion on the necessity of studies that compare *lesmas* from sites with good chronologies in order to verify possible technological and morphological patterns in space and time—without just associating them to the supposed Itaparica tradition.

5. The tunas industry

The Tunas industry has never been identified by another name, except by the Umbu tradition [101]—since all stemmed points were directly associated to it since the late 1980s. The name of the industry is related to the Tunas Rock Shelter site, where it was defined [48, 49]. It is found in the Eastern part of Paraná state, Brazil, and presents blade cores, lesminas, and star-type points. The oldest site associated to the industry is in fact the Tunas Rock Shelter itself, dating back to 9630 ± 40 BP (11,134–10,744 cal BP). It is still not clear when this industry disappeared, but in the Tunas Rock Shelter site, this industry is only present until 7170 ± 60 BP (8152–7795 cal BP). After that, a totally different lithic technology replaces it [48].

The star point type is defined by the triangle-shaped body with straight or concave active edges, a bifurcated stem, and bifacial reduction by convergent trespassed pressure flaking (**Figure 2**: 3, 4). Blade cores are rare in Brazilian archaeology, but they are present in the Tunas industry, and one of the main types of tools produced by those cores are the lesminas—unifacially retouched blades or blade fragments presenting less than 7 cm length with edges that are appropriate as scrapers. This same technology seems to be present in other sites from Eastern Paraná state.

6. The Garivaldinense industry

The Garivaldinense industry was also one of those industries that were masked by the concept of the Umbu tradition. Its name comes from the site where it was first defined: the Garivaldino site, in mid-eastern Rio Grande do Sul State, Brazil. The oldest dates for the industry also come from this site: 9430 ± 360 BP (11,772–9625 cal BP) [48]. It is not clear when this industry disappeared, since the most recent layers of the Garivaldino site itself presents the same material and the same point types since its oldest layers [48, 102]. The most recent layers have not been dated yet, but they are in the same context as some Taquara Tradition pottery fragments [103], indicating that its occupation lasted at least until the Late Holocene. In technological terms, three point types were identified in this industry: Garivaldinense, Montenegro, and Brochier types. Sites presenting these same types of points can be found in mid-eastern Rio Grande do Sul State.

The Garivaldinense point type is defined by its triangle-shaped body with irregular or straight active edges and straight wings, straight or bifurcated stems, and three distinct technological methods of production: (a) bifacial reduction by selective and trespassed percussion or pressure flaking, followed by bifacial retouch by pressure flaking (**Figure 2**: 5); (b) bifacial reduction by convergent non-trespassed percussion or pressure flaking, followed by bifacial retouch by pressure flaking (**Figure 2**: 6); and (c) thin flakes bifacially retouched by pressure (**Figure 2**: 7). Some of these points are clearly recycled and turned into scrapers, with unifacial retouch of the body forming a convex edge.

The Montenegro point type is defined by its triangle blade-shaped bodies with serrated edges, small bifurcate stems, and systematic bifacial parallel reduction forming a vertical central rib in the artefact body. Pressure flaking always starts from the extremities and finishes in the middle of the point (**Figure 2**: 8). This seems to be a logical strategy to avoid leaving the middle of the point thinner than the rest and breaking the point during pressure flaking. The ones with a triangle-shaped, shorter body seem to be broken and reworked, due the diachrony of the body negatives.

The Brochier point type is defined by having no stem and wings, being small, and presenting a tapered or lanceolate shape formed by bifacial or unifacial retouch by pressure flaking. They rarely present reduction, since thin agate flakes are used as blanks most of the time (**Figure 2**: 9).

7. The Lagoassantense culture

The Lagoassantense Paleoindian culture gets its name from the name of the region where it was first defined. The region of Lagoa Santa, in Southeastern Brazil, was a target of archaeological and paleontological studies ever since Danish researcher Peter W. Lund visited the region in the nineteenth century [104]. However, it was only in the 1970s that the region started to be systematically studied by a French-Brazilian program led by Annette Laming-Emperaire [105]. Unfortunately, these studies were suddenly interrupted by the unfortunate case of her death, but they were responsible for the discovery of Lagoa Santa and Luzia—the oldest human skeleton known in the Americas until then. It was only in the 2010s that new systematic research in the area was carried out, led by Walter Neves [106], including interdisciplinary analyses of the material culture, such as fauna [107, 108], human skeletons, and burials [109–111], lithic industry [112–117], micro residues [20, 118, 119], and bone industry [120, 121]. Thanks to this research, specific cultural patterns were identified for the region that persisted from the Pleistocene–Holocene transition until some centuries before the Portuguese conquest. The Lapa do Santo site, for example, that presents the best chronology dates to between 10,490 ± 50 BP (12,552–12,057 cal BP) and 790 ± 40 BP (739–571 cal BP).

The Lagoassantense lithic industry was clearly not taken into account by the previously proposed Itaparica-Umbu traditions model, since it does not present *lesmas* or stemmed points in its assemblage. Even though two stemmed points have been found at the Lagoa Santa site [116, 117], they are exceptions within an assemblage dominated by thousands of microliths—lithic tools that are no bigger than 30 mm [99]. These two points have no parallels to any point type defined in

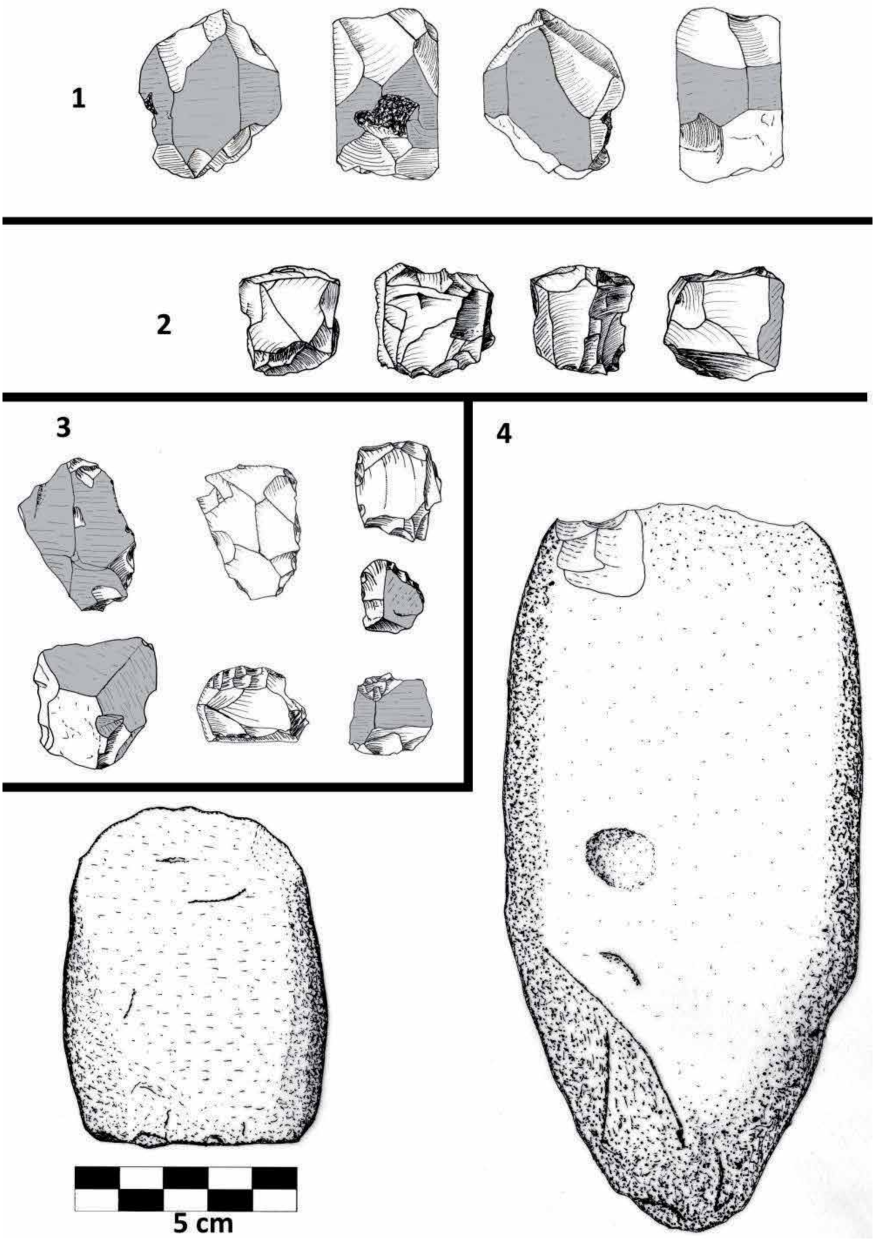

Figure 3.
Typical artefacts of the Lagoassantense industry from the Pleistocene–Holocene transition. All examples are from Lapa do Santo site, except the bigger ground axe blade which is from the Lapa das Boleiras site. (1) Diagonal slicing core on crystal quartz. (2) Opposite-platforms core on crystal quartz. (3) Retouched microliths on crystal quartz. (4) Ground axe blades on igneous rocks. Scale is the same for all artefacts in the figure. All drawings by the author.

South America. They are not bifacially reduced, and they are basically flakes with some retouches that shape the stemmed point. Some other formal artefacts, such as a lesma and a bifacial tool fragment [just the tip], were found in Lagoa Santa region sites but in layers that are not directly related to the Lagoassantense culture occupation [116, 117]. The bifacial artefact could be a preform of any point type, while the lesma was found in the same context as some other non-Lagoassantense flakes and might be related to both Itaparica and Rioclarense industries.

The Lagoassantense lithic industry is defined by the debitage of small crystal quartz flakes (**Figure 3**: 3) using the diagonal slicing core (**Figure 3**: 1) and the opposite platform core methods (**Figure 3**: 2) and by the low production of ground axes [94]. These are the oldest records for ground axe blades in the Americas (**Figure 3**: 4). The lithic industry is also defined by the persistence of making those microliths in the exact same way for at least 8000 years [122], considering that crystal quartz is not a common raw material in the Lagoa Santa region, and other tools (bigger and more complex) could be produced using other types of raw material, like high-quality quartzite, that could be easily found in the area. In this sense, the cultural norm for using small crystals defined the technological limitations of the industry.

8. Paleoindians without cultural association

Even though some lithic industries are finally being defined in technological terms in Eastern South America, many Paleoindian sites are known which have never been the target of systematic technological studies.

We can mention the Paleoindian sites in the Amazon region. The Pedra Pintada cave, for example, presents *lesmas* and bifacial stemmed points in layers dating back to 10,655 ± 285 BP (13,090–11,415 cal BP) [123]. The Dona Stella site also presents *lesmas* and bifacial stemmed points, dating back to 9460 ± 50 BP (11,057–10,501 cal BP) [124]. There are at least 12 Paleoindian sites in the Amazon region [124–129] that had never been completely studied in order to verify if there is any technological pattern between them or any other of the mentioned lithic industries. Unfortunately, archaeologists in the Amazon basin are more concerned with pottery industries and early agriculture than the initial occupation of the region.

In the Serra da Canastra region, located between the Rioclarense and Lagoassantense coverage areas, some sites are known that present *lesmas* and stemmed points dating back to 10,290 ± 35 BP (12,067–11,775 cal BP) [130]. The Carcará site, in eastern São Paulo state, is another example of a site with stemmed points, dating back to 8870 ± 50 BP (10,158–9692 cal BP) [131] that have never been studied in technological terms.

The same must be said about the Paleoindian sites located in the middle Uruguay River, close to the Tigre/Catalanense/Pay Paso coverage areas. Even though some technological studies have been carried out in the Laranjito site [32], the technological analysis of the stemmed points in that region has never been done.

The Lagoassantense and the Catalanense industries are proof that not all Paleoindian industries present *lesmas* or stemmed points. Other sites like Bastos, in central São Paulo state and in the Linha Policial 07 site in the upper Uruguay River, do not present these types of formal artefacts. Bastos site dates back to 10,590 ± 40 BP (12,645–12,427 cal BP), and its assemblage is mainly defined by the presence of large retouched flakes [132], while the Linha Policial 07 site dates back to 8370 ± 60 BP (9475–9135 cal BP) and is known by the presence of blade debitage [133], specifically the flat-back blade core type, usually found in Clovis sites in North America [134]. In the northeastern region of Brazil, there is the Justino site, for example, that dates back to 8950 ± 70 BP (10,222–9747 cal BP) and presents simple unifacial retouched scrapers [135]. Many sites in Eastern South America are probably being left undated due to the lack of formal artefacts in their assemblages, especially from sites excavated in private archaeology projects. But these sites are just some of the most known examples of Paleoindian industries that could never be included in the Itaparica-Umbu model proposed by Brazilian archaeologists during the second half of the twentieth century.

9. Conclusion

Paleoindian cultures in Eastern South America are finally starting to be studied more in detail due to the systematic research that has been carried out since the beginning of the twenty-first century. It is not yet possible to define archaeological cultures for the earlier Paleoindian period (before 13,000 cal BP) since those sites are rare in the whole American continent. But due the high presence of sites in the late Paleoindian period (after 13,000 cal BP), it is now possible to describe these cultures through systematic research of their lithic technologies. However, it is important to notice that much more research still needs to be carried out in order to have a more complete understanding.

Archaeological evidence in South America does not corroborate the "Clovis First" hypothesis—which assumes that the oldest evidence in Americas are the Clovis Culture artefacts—since many of these cultures arise simultaneously, or even previous to, the Clovis lithic industry [136], considering that the oldest associate Clovis sites date around 11,000 BP (13,000 cal BP) [137]. Few of the Eastern South American Paleoindian assemblages present technological features that are similar to Clovis, except maybe the Fell industry, which presents both blade technology and points made by the bifacial thinning method with fluting. In simple terms, Fell points are Clovis points with a retouched stem, and they are probably related, but it does not necessarily mean that Fell points are derived from Clovis [138]. No other artefact type in Eastern South America presents any similarities to Fell or Clovis points that could indicate any trace of cultural ancestry. In fact, it seems that several cultures emerged independently in South America, with particular, well-defined, attributes. The empirical data in South America is not feasible under the "Clovis First" hypothesis. Not surprisingly, new models are now being discussed, considering multiple migrations, the earliest ones before the Last Glacial Maximum [136].

More research still needs to be done to better delimitate these industries in chronological and geographical terms and to enable verification of cultural ancestry relationships. Regarding the Itaparica tradition, even though recent studies cannot contradict the hypothesis that all sites are culturally homogeneous, few studies have actually been carried out, and the available data are not sufficient to verify if sites with *lesmas* are actually more cultural diverse. The Rioclarense industry is a good example of a lithic industry that presents specific cultural attributes, within which *lesmas* are included. This might be true for other lithic industries in the supposed Itaparica tradition coverage area that are still being obscured under the Itaparica tradition concept, like the new findings (yet to published) found relatively close to Serranópolis region, presenting small *lesmas* and stemmed points with a distinct cultural pattern.

Lithic studies are important for the understanding of ancient societies, since lithics are the best-preserved class of material culture and many methods can be applied in their analysis. Lithics are the class of vestiges that most achieved results on understanding cultural diversity of the first human settlers in the Americas to this day. Other types of vestiges have not presented such potential either due to their preservation issues (the case of organic materials), lack of studies and data (e.g., bone artefacts), or even lack of potential to achieve cultural aspects (e.g., ancient DNA)—even though DNA brings us important data on the understanding of people's biological dispersal, it does not tell us about cultural history of societies, like cultural origins and diversity, since genes and culture do not necessarily flow together. Studies of other archaeological materials related to the Eastern South American Paleoindian cultures are still necessary in order to understand them in a more complete and accurate way. Many of these sites present rock art, faunal remains, and micro residues that have never been studied until now. The bone industry is perhaps the category of material culture that most warrants detailed analysis in Eastern South America, since they also enable a technological analysis and are preserved in many Paleoindian sites in Eastern South America [121]. The more archaeologists become concerned with these issues, the more we can understand cultural diversity and the dispersal of the first human societies to colonise the South American continent during the Late Pleistocene. To understand this cultural diversity throughout time and space is the best way to understand the real history of native people, the ancestors of many of us.

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Note

All dates were calibrated using the most appropriate curve for its location (IntCal 13 or SHCal13 calibration curves) [139], with 95.4% probability range.

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Chapter 9

Sociocultural Interaction and Symbolism in Prehistoric South America: Quartz Crystal Manuports from Tierra del Fuego

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Abstract

The use of mineral elements with special characteristics, such as quartz crystals, in ornamental or ceremonial contexts, is not uncommon in archaeology. Their appearance in different archaeological sites is the basis to discuss their significance for past societies. However, while these objects are loaded with symbolic value, it is difficult to identify them in hunter-gatherer sites. In this chapter, we discuss this subject from the case of a series of crystals discovered in the central area of the Big Island of Tierra del Fuego, and we outline their interpretation based on techno-functional analysis confronted with the ethnographic information for the region. Tierra del Fuego is located at the southern tip of South America. It was inhabited by hunter-gatherer societies since the end of last glaciation until the beginning of the twentieth century. In historical times, the central-northern sector of the Big Island was occupied by the Selknam society, in which there is an extensive ethnographic and ethnohistorical bibliography. Archaeological research in the central area of Tierra del Fuego has revealed a continuous occupation of hunter-gatherer societies. The analysis of provenience of raw materials lets us to propose hypothesis about mobility and interaction networks that can be confronted with the ethnographic information.

Keywords: interaction networks, ornaments, ceremonial, technofunctional analysis, raw materials

1. Introduction

Tierra del Fuego is located at the extreme south of South America. The archipelago is formed by a large island, the Big Island of Tierra del Fuego, and a series of smaller ones extending to the south up to Cape Horn. From there, the Nassau Strait separates the southern tip of the American continent from the top of Antarctic Peninsula. Politically, the archipelago is divided between two countries, Chile and Argentina (i.e., in [1–10]).

The Big Island is separated from the continent, to the north and west, by the Magellan Strait. However, by the end of last glaciation, low sea levels converted the island in a peninsula of Southern Patagonia and gave one of the windows of opportunity for the peopling of Tierra del Fuego. During that short time, pedestrian hunter-gatherer populations arrived from Northern Patagonia via this existing land connection (i.e., in [11–14]). Their older remains have been dated from 11.000 BP. Shortly later, canoe hunter-gatherers from Southern Chile colonized the islands, sailing along the Pacific southern coast. Their older remains in the Big Island Beagle Channel coasts date from 9.000 BP (i.e., in [15, 16]) (**Figure 1**).

Thereafter, hunter-gatherer societies spread all over the Big Island and the archipelagos, keeping these two different ways of life. One of them extended in almost all the Island; it was oriented to exploitation of inland resources, especially hunting of the biggest mammal in Tierra del Fuego, the *guanaco (Lama glama guanicoe),* as well as rodents, that was complemented by collection of a wide variety of plant products, eggs, and occasional fishing and shellfish collection near the coast. The other one developed on the southern coast of the Big Island as well as in the archipelagos extending to the south. It was adapted to sea mammal hunting, especially sea otters (*Otaria flavescens* and *Arctocephalus australis*), as well as to exploitation of coastal resources including all types of shellfish, maritime birds, and plant resources from the forest. These two different ways of life of hunter-gatherer populations persisted in Tierra del Fuego until the early twentieth century.

A long tradition of ethnographic and archeological studies produced a detailed corpus of information about the occupation dynamics of large portions of the island by these societies, their ways of life, and the characteristics of biotic and abiotic resource management strategies (i.e., in [1–6, 11, 13, 15, 17–22]).

Our research concerns specifically the central mountains region of the Big Island, within the frame of an ethnoarchaeological project called "Proyecto Arqueológico Corazón de la Isla" (PACI) that started in the late 80s and early 90s. This region, according to the reports written by the travelers arrived to Tierra del Fuego during the nineteenth century, was inhabited by the Selknam, a nomad hunter-gatherer society who exploited a wide range of biotic and abiotic resources

Figure 1.
Geographic location of the study area and archeological sites.

that were used for subsistence goods (food, medicine), as well as sociocultural (shelter, clothing, technology, ornament, ceremonies, etc.).

Anthropologist A. Chapman registered different modes of interaction that allowed the maintenance of the hunter-gatherer way of life, until the arrival of the Europeans. The most important were different aggregation events, in which the ceremonies stand out. As an example, we can mention the initiation ritual of adolescent males, the Hain ceremony. While this ritual has as an essential objective the consolidation and maintenance of social order, it is also true that it is an opportunity to meet relatives or friends, coming from different territories, who gather and camp together for months. These events were ideal occasions for carrying out exchanges and transactions (i.e., in [4]).

Within the scope of our archeological project, evaluations and systematic surveys were carried out in several sectors that allowed evaluating the intensity of human occupation and locating archeological sites in different environments and microenvironments within the mountain landscape. The results of these investigations show evidence of different types of archeological sites. On one hand, there are small archeological sites with diffuse combustion structures, poor conservation of bone remains, and reduced lithic registry, attributed to short occupations of small and mobile family groups. On the other, there are large extensive sites with abundant archeological material and evidence of different activities considered as multiple task base camps, as Kami and Ewan (i.e., in Refs. [6, 7, 9, 18, 23, 24]).

The archeological site Kami is formed by horizontal palimpsests caused by successive reoccupations, at least over the last 1000 years approximately (i.e., in [7, 19, 24–28]). It is located on the southern coast of Fagnano Lake, the largest lake in the Big Island, cutting the relief in two parts, north and south of Fagnano (**Figure 1**). On the other hand, Ewan is a very special site, with only one occupation. It is formed by two sectors. In one of them, there is still visible part of the structure of a log hut, thus indicating its recent chronology (Ewan 1). The other sector (Ewan 2), apart around 200 mts from the first one, has no aerial structure conserved. It was identified by systematic survey, where we could locate four more structures, smaller than that of Ewan I. Excavations and analysis in both sectors let us confirm that Ewan I was a ceremonial hut. The whole site's settlement pattern as well as the characteristics of materials and distributions recorded correspond to those described for the Hain ceremony (i.e., in Refs. [3–5]). This ceremony was held, as dated by dendrochronology and other chronological indicators, in the spring–summer of 1905 (i.e., in [26, 29, 30]).

In recent years, PACI investigations have extended to the eastern and western extremes of this central strip of the Big Island that is to the Atlantic coast to the east and to the west where the international border Argentina-Chile is located. In general, the results obtained allowed the identification of sites near to the Atlantic coast (Cabo San Pablo and Lainez and Irigoyen rivers) and at the western end of the Fagnano Lake (National Park and Torito Bay). The spatial distribution of archeological sites and remains indicates a general occupation of all environments within the subantarctic forest. However, for the different environments, it has been possible to document differences in density and intensity of occupation, as well as differences in raw materials used, as revealed by technofunctional analysis. These variations are related to the mobility of hunter-gatherer groups, due to the accessibility, availability, and/or seasonal abundance of resources (i.e., in Refs. [7, 24, 27, 28, 31–33]).

We believe that these differences are good indicators to study mobility of hunter-gatherer groups around the whole territory. Currently we are investigating social interaction networks from the archeological point of view, from the determination of nodes and internodal spaces (i.e., in [34, 35]), taking as a basis the circulation of raw materials and ornaments (i.e., in [10, 36]). However, there are elements that we cannot explain from the point of view of circulation of raw materials, because they are really exceptional in archeological contexts and also because they have not been manufactured or used.

If we consider these elements as manuports, we can analyze the possibility of circulation as ornamental pieces loaded with symbolic value within social interaction networks. From this point of view, we present and discuss the case of a series of nine prismatic quartz crystals that were discovered in one of the sites. This is something really unusual for the archeological record of Tierra del Fuego. The technofunctional analysis revealed that they have neither been manufactured nor used. Their provenience source is far from the site, and the primary sources of this raw material have not yet been identified.

Different scenarios can be proposed to explain their presence here; however, the most probable interpretation is that they have arrived as a "gift" between relatives in one of the social interaction networks. Because of their attractiveness, color, rarity, and difficulty to be found, they are likely to be included in exchange activities, reinforcing connections, like the Hain ceremony. Since the works of Marcel Mauss, especially the publication of the essay *The Gift* (i.e., in [37]), the concepts of "gift" and "counter-gift" start to be used to understand the economic logics in primitive societies. For Mauss, "gift" and "counter-gift" constitute the basis of reciprocity. They are not a simple exchange; they give prestige and importance to the donor. Then, Lévi-Strauss gives a clear dimension to reciprocity in relation to kinship relations and alliances. He considers that in primitive societies, the reason for gifts is to create alliances. In the type of exchange where there is a gift and a counter-gift, there is much more in the exchange than the exchanged objects themselves (i.e., in [38]). In this case, we understand as a gift the exchange of particular objects (with ornamental or symbolic value) that have as purpose to strengthen the relations between groups during and after aggregation events, as the Hain ceremony.

We believe that the models extracted from ethnographic and ethnohistoric information, which we utilize to explain this perspective on strategies implemented by Fuegian hunter-gatherer societies, are an excellent starting point to approach the interpretation of different aspects of Paleolithic hunter-gatherer strategies. Consequently, it would be interesting to explore them in relation with different findings of quartz crystals in archeological contexts in other parts of the world.

2. Quartz as raw material

Quartz is a common raw material on earth that occurs in different states, such as milky quartz or as hyaline quartz (rock crystal). Due to this availability, it was a raw material highly used in prehistory, mainly milky quartz. This archeological abundance does not occur in the same way for hyaline quartz crystals; however, they have been used as raw materials for lithic assemblages in certain regions as central Brazil, South Africa, Russia, Greece, and Portugal (i.e., in Refs. [39–44]). On the other hand, this material has been interpreted with functions associated with the symbolic, votive aspect, as part of funeral garments, in megalithic constructions, or used by the shamans for their possible magical powers (i.e., e.g., [45–49]). There are ethnographic works that account for the use of quartz by shamans and their magical-symbolic function (i.e., [50–52]). However, as mentioned by Fenandez-Machena and Ollé (i.e., [53]), these attributions are difficult to prove with materials from archaeological contexts.

In the case of quartz crystal prisms, with little or no modification, something similar occurs; they are not represented in a large number of archeological sites. Some examples are the quartz prisms found within the megalithic complex of Palace III, in the Almadén de la Plata, Seville. The complex consists three different funeral structures in type and temporality. It is a Dolmen in Gallery, a monument of the Tholos type of the Copper Age, and finally a cremation burial mound of the Iron Age. There, quartz elements of different aspects such as pebbles and sheets were recovered, but the most striking were the quartz prisms. In addition, other quartz prisms associated with other dolmen have been found in Spain such as Navalcán (Toledo) (i.e., in [54]) or the single crystal of Alberite (Cádiz) which is 20 cm long (i.e., in [55]). Another case with the presence of prisms of quartz crystals is the Dembeni site, on Mayotte Island in East Africa, dated between the ninth and twelfth centuries. These crystals are not native to the island but possibly come from Madagascar. The authors suggest that it would be a material transported as part of regional trade at short and long distance; this data is in turn supported by ethnohistoric information (i.e., in [56]). Finally, in Paleolithic sites associated with hunter-gatherer societies, some quartz crystal prisms without modification have been identified, in Europe, India, the Near East, and China (i.e., in [57]).

Specifically, in the Great Island of Tierra del Fuego, quartz is a raw material that is widely distributed. Its ubiquity, accessibility, and effectiveness to make usable edges can explain its presence in several archeological sites on the island.

Generally, it is milky quartz that appears in the landscape like a boulder of various sizes (from 3 to 15 cm) or in veins within the Yaghan Formation (of the lower Cretaceous) (i.e., in [58]). For lithic production activity, it can be exploited using various knapping techniques. However, in the region a type of exploitation has been identified that appears on a recurring basis. This is the selection of quartz pebbles that are opened using bipolar percussion technique, which produces elongated flakes or hemi-pebbles. These have been systematically used to make only one type of tool, scrapers (i.e., in [59]). These are small artifacts, whose maximum lengths range between 1.5 and 2.5 cm. With respect to their use, in most of the cases analyzed, they have been used to scrape skins and to a lesser extent for wood and bone, with a kinematics of work transverse to the edge (i.e., e.g., [27, 59, 60]).

As we have written on other occasions, the particularity of the quartz edges is that they have no tendency to round by losing grains—as occurs with other raw materials such as sandstones, rhyolites, or basalts when they are used—but to shear; as a result, they allow longer use and continuous sharp edge, with no need for constant reactivation (i.e., in [61]).

Undoubtedly, this material was specially selected by hunter-gatherers of Tierra del Fuego, as indicated by the recurrence of this raw material in lithic samples of different archeological sites of the island, in particular those of the IV component of Tunel I (i.e., in [59]), Shamakush 1 (i.e., in [60]), Kami 1 (i.e., in [19]), and La Vueltas and La Herradura—although in smaller proportions (i.e., in [62]).

Unlikewise, with respect to the quartz crystals, it is surprising to note that their presence in archeological sites is very low: they have only been registered in Laguna town northwest of Filaret (NOF), in San Sebastián Bay (one fragment), and in Rancho Donata site (two fragments) (Borrazzo, personal communication, 2013) and the cases of our research that we present in this work.

3. Quartz crystals in Tierra del Fuego

During its geological evolution, Tierra del Fuego experienced the necessary conditions for the development of quartz crystals: hydrothermal solutions loaded on silica and cavities in the rock, where these solutions decompress and deposit dissolved silica. Both during the Jurassic volcanism generated by the Fm Lemaire (which occupies the northern flank of the Sorondo mountain range, the Vinciguerra mountain range, the Valdivieso-Alvear mountain range, Montes Negros, etc. to States Island and to the west in Chile) and then during the regional metamorphism, these conditions could occur together with a moderate temperature of more than 200°C. The first case is more favorable than the second, because there was a higher temperature and wide availability of silica since it is an acid volcanism. Given the extent reached by the geological formations affected by these characteristics (i.e., in [58]), there may be outcrops of this raw material distributed in various parts of the island.

However, as mentioned above, its presence in archeological sites is very low. Therefore, it is interesting to mention the case of those we discovered the investigations in the central strip of Tierra del Fuego.

4. Quartz crystals at the sites of *Corazón de la Isla*

In the central strip of Tierra del Fuego, hyaline quartz materials were recovered at two archeological sites, Kami 7 site and Lainez 1 site.

Kami 7 is an extensive site located on an elevation of till, surrounded by a small pebble beach on the south coast of Lake Fagnano. This area has a thin soil eroded in many sectors, characterized by a mixed evergreen forest of *Nothofagus pumilio* and *Nothofagus betuloides*, and the presence of an extensive *Sphagnum* bog to the east (i.e., in Refs. [19, 28]).

The archeological researches in Kami 7 were made from two methodological strategies: excavation and surface collection. Two excavations were carried out: a large one (K7a) in which a total area of 12.75 m^2 and another 1 × 1 m (K7b) were excavated to protect material that was at the edge of the road. Finally, the whole area was squared and the surface material recovered following the grid.

In the wide excavation, two combustion areas could be determined, located 1 m away from each other. These areas have important differences between them, as well as in the archeological materials associated with each one. The combustion area no. 1 has an approximate diameter of 60 cm, and its thickness does not exceed 3 cm. The associated archeological materials include coals, bone remains, remains of lithic technology, etc. Within the raw materials represented, there are various types of rhyolites and green industrial glass (flake and microflakes). The presence of glass microflakes in this combustion area implies that this occupation took place after contact with the Europeans (**Table 1**).

The combustion area no. 2 has an approximate diameter of 50 cm, and its thickness did not exceed 2 cm. Coals of various sizes and with a wider dispersion than in combustion area no. 1 were recovered. It was obtained by analysis of AMS, on a sample of charcoal, a date of 769–974 cal AD (OxCal V 4.3.2, SHtCal 13, 95.4%) which implies that the site was occupied—so less—also in this antiquity. The lithic sample inside this combustion area is formed by 1757 elements. The majority correspond to remains smaller than 2 cm, followed by numerous flakes and fragments of various sizes, while the finished instruments are very scarce, as well as cores (**Table 2** and **Figure 2**). The raw materials represented are mainly fine- and medium-grain rhyolites, followed by cinerites.

During the excavation, the presence of prismatic crystals of hyaline quartz was recorded. They were scattered over a radius of approximately 4 m. The sample consists of eight crystals with varying degrees of fragmentation, although large, pyramidal, and bipyramidal between 1.5 and 4 cm (**Figure 3**). To date, no sources of supply of this raw material have been detected near the site.

	Tipe	Chalcedony	Chert	Cinerite	Quartz	Indet.	Lutite	Slate	Riolite	Flint	Glass	Total
Not retouched	Fragment	4		41	2	13	4	4	90	1		159
	Flake	6		58		5	2		74	2	1	148
	Core	2		3					30			35
	Percutor					3			1			4
	Bipolar Fragm.		1							1		2
	Bipolar core					1				1		2
	small flake	1	2	39	2	2			14			60
	Debris	1	2	58	2	3			22			88
	Total	14	5	199	6	27	6	4	231	5	1	498

Table 1.
Not retouched artifacts from the Kami 7 site.

Sites	Size	Technological types	Raw materials										
			Basalt	Slate	Lutite	Quartz	Flint	Chert	Chalcedony	Cinerite	Rhyolite	Undet.	Total
Kami 7	> 2 cm	Bifacial tool								1			1
		Instrument fragment			1				1	2	3		7
		Composite instrument								1			1
		Notch		1									1
		Projectil point preform									1		1
		Bifacial tool fragment								2			2
		Endscraper	1				2	2	1	1	10		17
		Sidescraper	1							3	4		8
		Total retouched	2	1	1	0	2	2	2	10	18		38
	<2cm	Micro endscraper				1				1	1	1	4
		Total retouched				1				1	1	1	4
		Total	2	1	1	1	2	2	2	11	19	1	42

Table 2.
Retouched artifacts from the Kami 7 site.

Figure 2.
Kami 7 archeological site excavation plant.

To carry out the techno-morphological study, we treated the crystals surfaces with ammonium chloride powder in order to avoid translucency that impeded examination (**Figure 4**). The crystals generally have a faceted structure that even

Figure 3.
Quartz crystal from the Kami 7 site, natural surface.

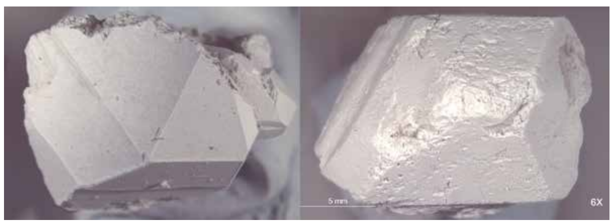

Figure 4.
Quartz crystals from with bleaching process for techno-morphological analysis.

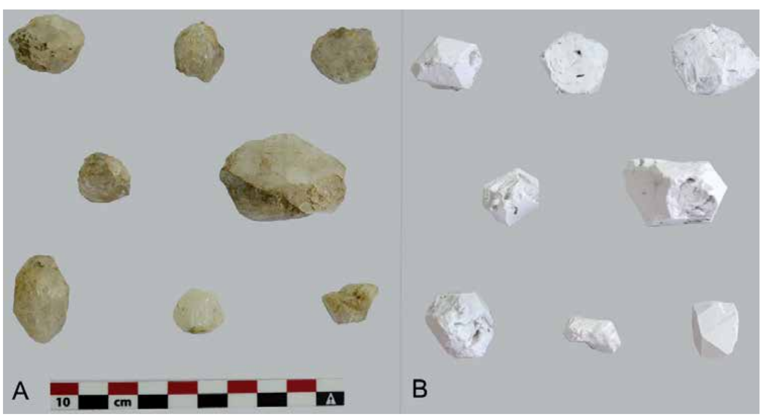

Figure 5.
Totality of quartz crystals from the Kami 7 site. A. Crystals with natural surfaces. B. Crystals with bleaching process.

some of them extend on the pyramidal end (**Figure 5**). Although they are not 100% complete, we could determine that they do not present technological modifications that can be attributed to manufacture (débitage, knapping, etc.), nor do they present extractions of flakes by bipolar technique, so they can be considered as manuports. Only one of them, the largest, has a possible flake scar.

The microscopic-based functional analysis developed on the natural edges present in the prisms (n = 4) did not reveal traces of use. It is worth mentioning that three of the edges belong to the same piece. However, the analysis allowed us to recognize postdepositional alterations such as patinas and surfaces with abrasion and stretch marks (**Table 3**).

Site	Colour	Surface	Thickness	Width	length	Section	N° facets	Knapping
Kami 7	Translucent	patina	17	27	41	R/B/A	5	Flakescar
	Translucent	patina	15	21	28	R/B/A	6	NO
	Translucent	patina	13	18	25	B/A	4	UNDET.
	Translucent	well	15	21	25	UNDET.	UNDET.	Flakescar
	Translucent	very well	11	18	20	B/A	3	UNDET.
	Translucent	patina	14	16	19	B/A	6	NO
	Translucent	patina	12	17	19	B/A	5	UNDET.
	Translucent	Rolled/patina	8	14	17	A	6	Flakescar

Table 3.
Techno-morphological characteristics of quartz crystals from the Kami 7 site.

Figure 6.
Excavation of the Lainez site.

Figure 7.
Elements of quartz crystal and bipolar obsidian fragment from the Lainez 1 site.

Lainez 1 site is located in the middle course of the homonymous valley. The area has a pasture vegetation near the banks of the river, frequently interrupted by extensive bogs. The open forest develops toward the slopes of the mountains (**Figure 6**). Near the site there are river meanders with pebbles of different sizes (i.e., in [22, 25]). On the site, an excavation and four surveys were carried out. Radiocarbon analysis indicates a date of 767–971 cal AD (OxCal V 4.3.2, SHtCal 13, 95.4%) (i.e., in [26]).

Among the lithic materials recovered in the excavations, two subsamples stand out. One is composed of two obsidian artifacts and the other by eight microflakes and a fragment of a quartz crystal instrument. The latter were discovered in the same survey of 1 m^2. The technofunctional studies showed no use in the instrument fragment, which due to its morphology could have been considered as micro-scraper, since its maximum length does not exceed 2 cm (**Figure 7**).

5. Discussion

The archeology of the central strip of Tierra del Fuego is key to understand the ways of human circulation along the territory of the Big Island. Technofunctional analysis including determination of raw materials provenience has demonstrated that there were long-distance movements of materials. Hypothesis derived from the ethnographic and historical records discusses these movements as exchanges included in social interaction networks between different groups along Tierra del Fuego (i.e., in [10]). In this research, we concentrated in a series of exceptional materials, i.e., quartz prisms. The objective of the analysis was to determine whether they had been either manufactured or used and to discuss their appearance in some sites within the mountain environment.

5.1 Meaning of quartz as manuports

The presence of these materials in Kami 7 and Lainez sites, in the central part of the Big Island, is extremely interesting in several aspects.

In the first place, it is not the case of materials that were taken to the site as raw materials for tool making, nor for uses of any kind, as it was revealed to be the technofunctional analysis, since they do not present any kind of modification.

Secondly, it is unlikely that their presence is natural in the sites, since they are not located close or within outcrops. Although the characteristics of the geology of Tierra del Fuego could allow the formation of quartz crystals, these are associated with the Le Maire formations, and so far no outcrops of large crystals have been identified. Some very small crystals were found in the Emerald lagoon area, in the Paso Francés valley that flows into the Domo Blanco hill. And others of larger sizes have been identified in the elevations near the springs of the Malengüena River (**Figure 8**).

It is also unlikely that the crystals correspond to secondary deposits formed by glacial or river drag. The microscopic analysis does not reveal the characteristic surface alteration traces produced by glacial or river erosion. Moreover, the crystals were in direct association and stratigraphy with the archeological materials of Kami 7 site, and the same happened at Lainez 1 site.

Consequently, we started to consider the possible scenarios for their arrival to the site, in routine migrations circuits or in more complex social interaction networks.

Circulation of materials along long distances is not a new phenomenon in Tierra del Fuego (i.e., in Refs. [25, 63]). It has been recorded in different contexts, such as the case of the Miraflores silicified tuff in the Kami 1 site, the quartz crystals in the Kami 7 site, the black obsidian and microflake of quartz crystal in Lainez 1, the silicified wood of Cabo San Pablo, and even the presence of a marine shell of *Fasciolariidae* family discovered in Punta Amarilla, an area inside the forest on the south coast of lake Fagnano (i.e., in [64]).

The Miraflores silicified tuff has its primary outcrop about 200 km in a straight line from Kami 1. The inhabitants of the Kami 1 site could have obtained this raw material directly from the outcrop, although it is a little improbable, due to both

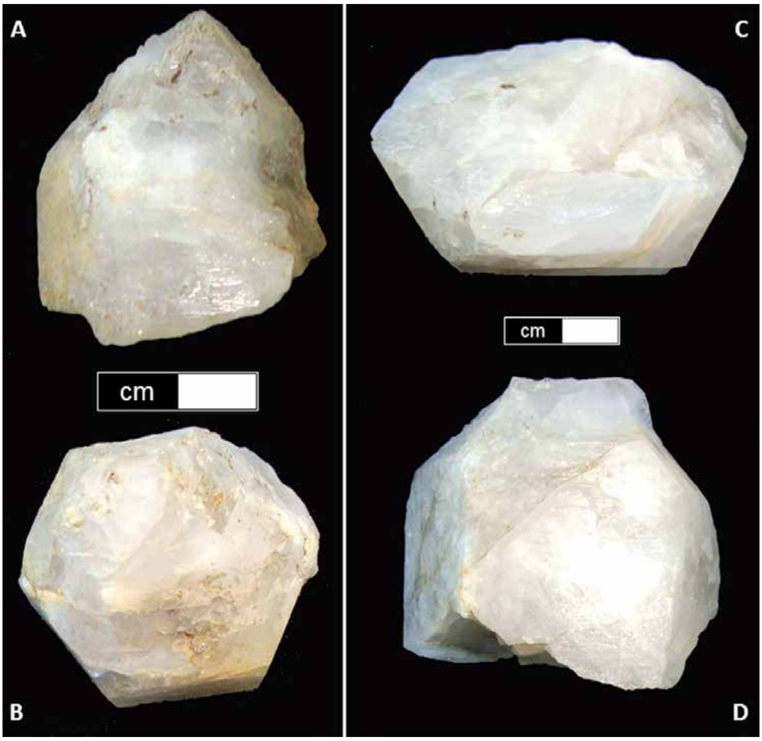

Figure 8.
Quartz prisms from the Malengüena River. (A–D) Different quartz prisms from the Malengüena River area. They show natural impact traces and erosion marks.

distance, different landscape units, and the technological characteristics of the tools and fragments from Kami 1 (i.e., in [63]). In order to get to source and assure provision of material, it would be necessary that the source be included in the mobility circuits for seasonal migration, or resource exploitation, of the group. Alternatively, the raw material could have been obtained through exchange with people from the northern or western territories of the island, where this silicified tuff has been identified, in low quantities, in several sites (i.e., in [63]).

In the case of Lainez 1 site, there are two fragments of black obsidian, a raw material that up to now has not been discovered in Tierra del Fuego. If it corresponds to a source located in the continent, on the other side of Magellan Strait, it would indicate long-distance interaction networks that interlink territories with different landscapes, peoples, and probably even languages. As here it is the case of just two non-used fragments, we believe that the most likely scenario corresponds to prestige goods exchanged in social interaction networks (i.e., in [63]). As for the elements of quartz crystal, outcrops or primary sources of this raw material have not yet been identified.

As for the silicified wood, a core was discovered in a site on the Atlantic coast. This raw material is very abundant across the Magellan Strait (in continental Patagonia), but in Tierra del Fuego, until now only one area was identified in the northeast, near Cullen River (i.e., in [65]).

We believe that the most relevant indicators for interaction recovered up to now are those that come from the analysis of raw materials use in the sites in the center of the island; they show evidence of nonlocal raw materials, which reveal then some mode of circulation. However, these observations suggest that their acquisition and conservation can be connected with symbolic or ornamental aspects related to social interaction (i.e., in [28]).

5.2 Interaction and symbolism in the hunter-gatherer populations of the area

There is an important number of publications where the role of quartz is evidenced as a raw material for the manufacture of artifacts that intervene in different production and use processes. But in addition, quartz, especially pyramidal or bipyramidal prisms or monocrystals, were used for symbolic and votive purposes, and they could even be part of the shamans' toolkits as suggested by Márquez Pecchio and Eielson (i.e., in Ref. [66]) in their work Pre-Columbian Sculpture of Quartz, where they comment that for some pre-Hispanic societies of Venezuela, the crystals were used as amulets by the shamans. It is also mentioned that because of their attractiveness, color, rarity, and difficulty in being found, they were objects that were included in exchange activities.

The central region of Tierra del Fuego was inhabited by a hunter-gatherer society until the beginnings of the twentieth century. There are many reports written by travelers who arrived during the eighteenth and nineteenth century and by missionaries and colonialists in the early twentieth century (i.e., in Ref. [1, 2]). However, the best information about these people comes from the work and publications of two ethnographers, Martin Gusinde, who made different stays in the island during the years 1920, and Anne Chapman, who worked in Tierra del Fuego since 1966 until her death in 2011 (i.e., in Refs. [3–5]).

According to the ethnographic data, each Selknam family had a territory that was considered as their "own," called "haruwen." However, the borders of these territories were relatively permeable. They could be opened, especially at certain times, such as for passage for aggregation events, or at critical times for the exploitation of animal resources (i.e., in [4]).

Aggregation events and particularly ceremonies played an essential role in maintenance of biological and social reproduction. The most relevant for the Selknam people was the initiation ritual of adolescent males, the Hain ceremony. While this ritual has as an essential objective the consolidation and maintenance of social order, it is also true that it is an opportunity to meet relatives or friends coming from different territories, who gather and camp together for months. These events were ideal occasions for carrying out exchanges and transactions (i.e., in [4]). They could take the form of gifts, understood in the sense of Levi Strauss (i.e., in [38]), reinforce social links among relatives, or constitute formal exchanges. In any case, mobility circuits, fortuitous meetings, or events as ceremonies, many of which were made up of families or distant groups that shared long periods of time, were propitious moments to exchange material goods, sumptuaries, ideas, etc. (i.e., in Refs. [3–5]).

As for circulation of other goods within the different groups and territories, the literature mentions an important circulation of materials, among which perishable resources are abundant: woods from the forest area that are exchanged with the neighbors of the northern steppe (in the form of bows, sticks, etc.) or sea lion skins from the coastal areas (i.e., in [3]). We believe that circulation could also include other resources that we consider critical, such as the case of the lithic raw materials. However, although there are all these mentions to movements and exchanges in mechanisms of reciprocity and redistribution, there are no detailed accounts of the type of prestige goods with symbolic value that could enter in this exchange.

6. Conclusions

In most of the cases of findings of distant origin materials that we have analyzed, these are materials that have entered the productive circuit, since they were modified into instruments and used. However, their small number, their distant origin, and the fact that the complete operational chains are not present suggest the hypothesis that these materials could have arrived as "gifts" between relatives, in some of the interaction circuits that reinforce connections between distant groups.

Materials that by their exotism, or by their physical characteristics, their place of origin, etc. that were used by societies at various times and places, can be traced from the Middle Paleolithic with the incorporation, by Neanderthal societies, of such elements as marine fossils found at the Chez-Pourrez and the Grotte de l'Hyene (i.e., in [67, 68]).

The justification for these hypotheses can be found in the diversity of evidence of the use of quartz crystals in various archeological sites around the world. The use of this raw material can be divided into two fields of social activities of human groups: on the one hand, within the production and use process, included in the subsistence context, and on the other, within the activities of symbolic and/or magical character, granting powers by the shamans.

However, in the case of the quartz crystals that we present, there is an important difference, and that is that they were not manufactured or used. For this reason, they are considered as manuports. As we said, so far there have never been discovered so many crystals and of such large dimensions in sites of Tierra del Fuego. Then these crystals could have been collected somewhere for their peculiarity, their size, their translucent character, their rarity, etc.; they could have been considered as amulets or ornaments that could be used for exchange or have been obtained by exchange. From this point of view, we can consider them as elements that have an important ornamental or symbolic value and therefore circulated in reciprocity circuits that reinforced social structure.

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This book presents an overview of recent research in the field of Pleistocene Archaeology around the world. The main topics of this book are: (1) human migrations, particularly by Homo sapiens who have migrated into most regions of the world and settled in different environments, (2) the development of human technology from early to archaic hominins and Homo sapiens, and (3) human adaptation to new environments and responses to environmental changes caused by climate changes during the Pleistocene. With such perspectives in mind, this book contains a total of nine insightful and stimulating chapters on these topics, in which human history during the time of the Pleistocene is reviewed and discussed.

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