Applying cultural evolutionary theory to the technological transition during the Late Pleistocene in Korea

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A dissertation

Submitted in partial fulfillment of the

Requirements for the degree of

Doctors of Philosophy

University of Washington

2023

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Program Authorized to Offer Degree:

Anthropology

University of Washington

Abstract

Applying cultural evolutionary theory to the technological transition during the Late Pleistocene in Korea

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The cultural-technological transition in stone artifacts from the Middle to Upper Paleolithic during the Late Pleistocene is considered as one of the major revolutions in the prehistory of humankind, along with the appearance of modern humans. The new technologies include introduction of blade and bladelets, a high degree of morphological standardization in tool types, exploitation of bone, antler, and ivory as raw materials for tools, systematic use of grinding and pounding stone tools, and extensive use of bows and arrows. One of the explanations for this transition is to connect the technological change to hunter-gatherers' subsistence strategies using a theoretical framework derived from cultural evolution theory. The evolutionary approach enables us to understand human behaviors by linking material evidence and socio-environmental dynamics.

In this research, I explore the technological transition from the Early to Late Paleolithic in Korea represented by the appearance of stemmed points through evolutionary concepts including human behavioral ecology (HBE) and cultural transmission (CT). I also examined different

likely uses of stemmed points by measuring tip cross-sectional area (TCSA). The previous studies have primarily discussed the origin and route of stemmed points and blades while my research focuses more on related human behaviors and decision-making processes. I raised three questions to address cultural and environmental roles in the technological transition: what changes in foragers' landscape use and mobility were associated with the introduction of new tools? What were stemmed points used for? And what was the dominant mode of cultural transmission during the time of technological innovation in the Korean Late Paleolithic? My approach to answer these questions is combined with traditional theoretical frameworks and novel methods for testing hypotheses.

As an answer to the first question, I hypothesized that stemmed points enabled foragers to survive in more marginal and extreme environments based on HBE. I applied quantitative analyses of artifact volumetric density, retouch frequency, composition of toolkits, and artifact raw materials. I explore environmental and demographic contexts by applying paleoclimate simulations and summed probability distribution models. My results show that forager groups using stemmed points may have been associated with occupation of marginal or extreme environments, represented by higher altitude and decreased temperature. I raised the second question to understand the possible role of stemmed points played related during the technological transition. Using the metric called tip cross-sectional area (TCSA), I was able to discriminate between different likely use classes of projectile points such as stabbing spears or poisoned arrow tips. I also explored the temporal and spatial patterns of TCSA values of stemmed points. My results show the multiple likely uses of stemmed points in a site, which indicate people might use them as multi-functional tools, with many likely designed for javelin and stabbing spear tips. I applied the CT framework to examine the process and social context of the technological transition and address the third question. I built two models that describe the transition process based on guided variation and indirect bias and tested them through computing coefficients of variation (CV), and correlation coefficients. The results show high variation and low correlation between morphological attributes on stemmed points, indicating the guided variation as the dominant mode of cultural transmission.

Combining all results, my dissertation research concludes that stemmed points were introduced to maximize the landscape use during the Late Pleistocene and the shape and usage of the tools were adjusted depending on the local environment. In addition to achieving research goals, this dissertation demonstrates how to apply theoretical frameworks and test hypotheses by applying noble quantitative methodologies. My research pursues an open science approach by enabling maximum access to research data, analysis processes, and final results to promote research transparency to promote reproducibility. I expect to see that my approaches will be adopted in future research about technological transition and cultural evolution.

Acknowledgements

The completion of this dissertation could not have been possible without the unconditional support and encouragement of my mentors, friends, and family.

The biggest thank you goes to Dr. Ben Marwick, who not only served as my academic advisor and mentor, but also acted as my guardian in this foreign country. Whenever I ran into some trouble, I knew who I could talk to. Without his patience and understanding, I could not have reached where I am today. The passion he has for archaeology and open science becomes a great influence on my academic career. In addition Dr. Ben (Chair), I also have to thank my dissertation committee for their support and help throughout my PhD, including Dr. Ben Fitzhugh, Dr. Peter Lape, and Dr. Clark Sorensen (GSR). My gratitude goes out to Dr. Donald Grayson and Dr. Marcos Lobera for always opening their doors to me whenever I needed them. In University of Washington, I had the opportunity to learn about archaeology from amazing professors including Sara Gonzalez, Sven Haakanson, Jim Feathers, and Alison Wylie. I would also like to thank the staff of the University of Washington Department of Anthropology: Catherine Zeigler, John Cady, and Mike Caputi for their service and support.

I met Lauryl Zenobi and Steven Lautzenheiser who came to pick me up as I arrived at the Tacoma airport and helped me settle down. I have made lifelong friends at UW: Erin Bowen, Anna Cohen, David Carlson, Jake Deppen, Mikhail Echavarri, Alex Hammerberg, Dave Hunt, Alec Iacobucci, Ian Kretzler, Seungki Kwak, Sam Lagos, Jiun-Yu Liu, Hope Loiselle, Hollis

Miller, Yoli Ngandali, Rodrigo Solinis-Casparius, Li-Ying Wang, Elizabeth Wessells, and Joss Whittaker.

Especially, having Joss, Alex, and Li-Ying who have gone through the same process at the same time as me would have made the process much easier. I also met my best friends during my time at UW: Melody Young, Camila Jenkin, and Sommer McWinter. They were my roommates at Mercer Court (graduate student housing at UW) and became my family.

My journey for archaeology started 15 years ago in Pusan National University. I have benefited from faculties and colleagues from PNU: Dr. Sangtaek Lim, Dr. Kyungchul Shin, Dr. Duchul Kim, Dr. Eunkyeong Yang, Dr. Jinsung Bae, Dr. Yongjoon Chang, and Dr. Sangkyu Lee. I would like to specifically thank Dr. Chuntaek Seong, whose warm and thoughtful mentorship was greatly valued. I look forward to joining him as a fellow alumnus of the UW Archaeology program

I would also like to thank Seonsook Park, Jaeyoung Kim, Soonmi Lee, Taeyoung Kim, and the staff in Korean national museums, and Sangmin Cha, Sooa Kim, Gigil Lee, Myeongjin Choi, and Chanho Park in local archaeological institutions and University museums in Korea for their assistance and support in accessing to the data used in this dissertation research and accommodating my trip to their collections. This research was supported by a research grant from the Quaternary Research Center and travel grants from the Department of Anthropology and Center for Statistics and the Social Sciences at University of Washington.

Finally, I would like to thank my family, my amazing husband Aaron, my mom, dad and brother for their sacrifices and support. Without them, it would have been impossible for me to accomplish my PhD.

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Chapter 1

Introduction

1.1 Technological Transition from the Middle to Upper Paleolithic

A well-known example in early human history of profound technological change is the transition in stone artifacts from the Middle to Upper Paleolithic during the Late Pleistocene. This cultural-technological transition is considered as one of the major transitions in the prehistory of humankind, along with the appearance of cally modern humans as we see "transitional industries" with the replacement of local Neanderthal populations by modern humans at several key sites —El Castillo, Labeko Koba, La Viña, Esquilleu and Morín—in northern Spain at ~48-40 ka (Bar-Yosef, 2007, 2002; Marín-Arroyo et al., 2018; Morales et al., 2019; Rios-Garaizar et al., 2022; Vidal-Cordasco et al., 2022). The transition to the Upper Paleolithic technology includes blade and bladelets combined with the elements of the Levallois method (e.g. faceted platforms, flat-faced cores), morphologically standardized tool types, exploitation of bone, antler, and ivory as raw materials for tools, systematic use of grinding and pounding stone tools, and extensive use of bows and arrows (Bar-Yosef, 2002; Derevianko, 2009; Kuhn and Zwyns, 2014; Lbova, 2021; Mellars, 1989). This change has been intensively studied in Europe and Africa, but many details of the technological transition during the Late Pleistocene in northeast Asia remain open questions. This is because most of the studies have focused on describing typology and examining the origins of new tools rather than understanding the technology of the artifacts, transition process, and human behaviors associated with them (Kato, 2021; Lee et al., 2017; Li et al., 2019, 2014; Sano, 2016; Shen et al., 2016).

Taking northeast Asia as a case study, this research will examine the social-ecological impacts on the transitions, the process of the technological dispersal, and the role of new technologies for subsistence strategies for the appearance of the Korean Late Paleolithic. There have been a few attempts to explain this technological transition and origins of the new artifacts, but they mainly focus on the composition of lithic assemblages and the morphological changes in stemmed points without considering the related human behaviors (Bae et al., 2013; Bae and Bae, 2012; Bae, 2010; Chang, 2013; Lee, 2016, 2013; Lee et al., 2017; Seong, 2009, 2008). To close this gap, I will examine stone artifact assemblages from Korea by drawing on cultural evolutionary theory to explain the appearance of new technologies. My research addresses three main questions: what changes in foragers' landscape use and mobility were associated with the introduction of new tools? What were stemmed points, the representative artifacts of the Korean Late Paleolithic, used for? Lastly, what was the dominant mode of cultural transmission during the time of technological innovation in the Korean Late Paleolithic?

In this chapter, I provide an overview of the Korean Paleolithic period and previous research. Specifically, I focus on the transition to the Late Paleolithic and discuss two main models that have been proposed: the indigenous and gradual development model versus the migration model, in addition to the complex model that argues for more sophisticated and non-directional development. I then introduce two sub-theories of cultural evolution, human behavioral ecology

(HBE) and cultural transmission, which I apply to my dissertation. I provide examples that are relevant to my topic to clarify key concepts. Finally, I summarize the overall structure of my dissertation and provide brief summaries of the following chapters.

1.2. Technological Transition during the Late Pleistocene in Korea

1.2.1. Korea as a Case Study for Application of Cultural Evolution to Understanding Technological Transitions

There are three reasons that make it important to study the technological transition to the Korean Late Paleolithic. First, previous research shows that Levallois elements as the main technology for the Middle Paleolithic, and modern human remains are absent in Korea (Bae and Bae, 2012; Lee, 2013; Seong, 2009). This limits the applicability of the European and African frameworks that acknowledge the origins of new technologies in earlier Levallois forms (e.g. the concepts of the Middle and Upper Paleolithic in Europe, and the Middle and Upper Stone Age in Africa) to Korea. Therefore, a novel framework is required to understand technological change in the Korean peninsula during the Late Pleistocene.

Second, there are unique characteristics of lithic assemblages in Korea, which make it distinct from elsewhere in northeast Asia, such as China and Japan. One of these characteristics is the early emergence of a type of projectile point, stemmed points, preceding that of blade technology. Northeast Asian archaeologists have debated the origins of stemmed points since they appeared among coarse flake-tools (Park, 2013).

Third, the Korean Peninsula has a unique geography, which may have been relevant in the emergence of new technologies in the area. With both continental and coastal characteristics, isolated by the Qinling mountains and rivers in the north and by seas on three sides, might impact on environmental and social contexts that derived the emergence of new technology during the Late Pleistocene. During times when the sea level was low enough, Korea may have been influenced by technology from adjacent regions such as China and Japan. Overall geographic isolation, however, facilitates the possibility of indigenous technology development in response to local conditions.

1.2.2. A Brief Overview of the Korean Paleolithic Period

After the first Paleolithic sites in the Korean peninsula were identified in the 1930s, more than 150 open-air and cave sites have been discovered. Due to restrictions resulting from the economic and political situation in North Korea, my research only focuses on sites in South Korea. The early evidence of human activity in Korea consist of stone artifacts in deposits dating to 350 ka at several sites, such as Chongeokri, Geumpari, Chuwolli, Kawolli, and Jangnamgyo, located in the Imjin-Hantan River Basin. The stone artifacts at these sites have been described as 'Oldowan-like' and 'Acheulean-like' tools made of coarse-grained materials such as pebbles from nearby rivers. The toolkits include handaxes, choppers, cleavers, polyhedrons, cores and flakes. The technological transition, occurring around 40-35 ka, is represented by the appearance of blades, stemmed points, end scrapers, burins, denticulates, etc. Another notable change is the selective use of raw materials along with the emergence of new tools. Previously quartzite and vein quartz were the most commonly used for core and flake tools but finer grained materials such as silicified tuff (shale), chert, hornfels, and obsidian became more important to the lithic technology during the Late Paleolithic. While people still used coarse materials with existing tools, they selectively chose finer materials for newly introduced tools (Bae, 2017, 2010; Bae et al., 2017; Lee, 2016; Lee et al., 2017; Nakazawa and Bae, 2018; Seong, 2009).

Bae (2010) claims two sub-stages for the duration of these new technologies, or the Late Paleolithic period, based on the presence of AT tephra (presumably earlier than 25 ka). His earlier stage started from Goreyri site dated to 27 ka. This stage consists of long, thick blades and prismatic cores with stemmed points. Bae's later stage has a microlithic industry, such as that found at Sinbuk in southwestern Korea, dated to 25 ka. An alternative view comes from Seong (2009) and Park (2013) who propose three sub-stages by distinguishing an early stage when stemmed points appeared before blades. The difference between the two stages of division and the three stages hinges on the recognition of stemmed points as a technology, which is distinctive from blades. Bae considers a stemmed point as one of blade-tools, while Seong and Park recognize the artifact as a new technology that changed the previous subsistence strategies, having a stem part that connects to other material. Different perspectives on the stemmed point have led to a heated debate about the nature and cause of the transition from the Early to the Late Paleolithic.

1.2.3. Stemmed Points, Leading Technology of the Late Paleolithic

To understand the technological transition to the late Paleolithic, it is crucial to examine stemmed points because its technology and human behaviors imply cultural and ecological contexts for the transition. A stemmed point is an elongated flake or blade with an acute tip on the distal end and a stem on the proximal end that connects to a shaft. In Western hemisphere, this type of artifact is typically called a tanged point (Ivanovaitė et al., 2020; Serwatka and Riede, 2016), but I purposely choose to use the term ‘stemmed point’ here to distinguish from Bronze Age stone projectile points that have long been called ‘tanged points’ in Korea. It is likely that stemmed points served as projectile weapon tips since the stem of these tools represents a hafting projection used to join the stone artifact to the wooden shaft. However, most open sites in Korea do not preserve organic remains due to acidic soil, so shafts have not been found. There are very few limestone cave sites containing human fossils or faunal remains (e.g. Durubong and Jeommal Cave), which are located in restricted areas in North Korea, or have been rarely analyzed (Bae et al., 2013).

Regardless of the different perspectives in chronology, stemmed points are considered to be the earliest evidence of new technology and Late Paleolithic periods. Due to the fact that they are the first composite projectile tool indicating more specialized hunting practices, it is assumed that their early appearance could be closely associated with behavioral characteristics of modern humans including mobility, and site formation and occupation (Chang, 2013; Seong, 2008). Since there is little other evidence for human behavior during this time period, stemmed points are the best window to examine subsistence and hunting techniques. However, most researchers discuss stemmed points relating to their origin, chronology of the Korean Late Paleolithic and their relationship with Japan rather than related human behaviors (Chang, 2013; Chong, 2021; Lee and Sano, 2019; Park, 2013).

1.2.4. Debates about the Origin of Stemmed Points and New Technologies

Discrepancies between Bae and Seong/Park in chronology and the leading role of stemmed points in the technological transition become part of a bigger debate about the nature and cause of the Late Paleolithic transition. There are several questions addressed in this debate, such as the origin of the new tools, the process of technological transition, existence and nature of Middle Paleolithic technology, and reconstructions of modern human dispersals in eastern Asia. The debate about origins can be summarized into two main models competing to explain the appearance of the new Late Pleistocene technologies: *in situ* evolution (Seong, 2006) and 'heterogenic' migration (Bae, 2010). In addition to the main models, Lee proposed another model that claims a more complex and non-directional transition (Lee, 2016; Lee et al., 2017). I will explain about those three models in the following chapters.

My research engages with this debate by testing two main models built on theoretical frameworks and testing with novel methods.

Seong and Bae's models for the Late Paleolithic transition in Korea bear similarities to Western archaeologists' competing explanations of the Upper Paleolithic revolution. For instance, Kuhn and Stiner (2006) categorized the different explanations into two models: sudden large-scale population replacement and continuous *in situ* evolution across a broad front. However, Seong and Bae's models lack the complexity of human behaviors related to the technological transition process. The main limitation of the debate is the paucity of archaeological evidence they use to support their arguments. They mainly rely on summary ratios of stone tool artifacts, such as blades to flakes, and raw material proportions in lithic assemblages. They do not directly address the technology or human behavior characteristics, such as the movement or interaction of hunter-gatherers, which provide contexts for technological change. I am motivated by the idea that evolutionary principles can help us better understand the technological change during the Late Pleistocene in Korea and similar cases in northeast Asia by providing explanatory frameworks (Kuhn, 2004, 2020). To this end, I will use evolutionary concepts to analyze data, stone artifacts and infer behavioral variation in modern humans in Korea during the Late Paleolithic period. Specifically, I will evaluate the role of ecological and social contexts in technological innovation for hunter-gatherers. For ecological contexts, I draw HBE and explore the paleoclimate change to examine the possible impact of ecological change on technological innovation and human behaviors such as site occupation and mobility patterns. I use the concepts of different transmission biases from cultural transmission to investigate the learning process of stemmed point manufacturing technology, which can infer the social environments between forager groups.

1.3. Theoretical Models

1.3.1. Cultural Evolution Theory in Archaeology

To examine the process of technological transmission in the late Pleistocene of Korea, and to gain insight into the ecological and social contexts that led to these changes and their impact on human behavior, I adopt cultural evolution theory and apply concepts of its sub-theories into analysis of stemmed points. Evolutionary concepts provide the best tools to learn out those long-term process (Kuhn, 2004)

Cultural evolution is a theory that explains innovations of material cultures and human behaviors as Darwinian evolutionists examine biological changes in humans and other species. Within this theoretical framework, archaeologists borrow the same concepts, tools and methods from biologists to to explain the diversity and complexity of cultural phenomena, just as biologists aim to explain the diversity and complexity of living organisms (Boyd and Richerson, 2009, 1988; Dunnell, 1980; Manem, 2020; Mesoudi, 2011; Richerson and Christiansen, 2013; Walsh et al., 2019).

However, some critics contend that complexity of cultural phenomena precludes the applicability of simplest models driven from cultural evolution (Fracchia and Lewontin, 1999). For example, is it nearly impossible to archaeologically distinguish, much less track, descent with modification between individuals. Cultural processes such as selection, adaptation, drift, and mutation - although acting on individuals - only become observable as patterns at the population level when viewed retrospectively. To some extent, ethnographic, ethnohistoric, and detailed material culture studies can bridge the inferential gaps between these various scales of observation. Nevertheless, most archaeologists lack such records, and thus, judicious ethnographic analogues need to be combined with theoretical and possibly mathematical models and a meticulous examination of the archaeological record to enhance inferences about general transmission modes (Tehrani and Riede, 2008; Walsh et al., 2019).

Despite its limitations, the cultural evolution methodology has gained notable popularity in archaeological investigations over the last three decades owing to its practicality and efficacy. Mathematical models have been a crucial part of this field, along with laboratory experiments, field studies, phylogenetic studies (Cardillo and Charlin, 2016; Manem, 2020; O'Brien et al., 2014; Society, 2005), the research of historical dynamics, and the comparative study of non-human culture (Mesoudi, 2016; Mesoudi et al., 2006). There exists a vast array of subjects that fall within the extensive framework of evolution. While certain perspectives may not be in accord with one another, three fundamental approaches - namely, behavioral ecology (HBE), cultural transmission, and phylogenetic approach - are widely accepted (Boyd and Richerson, 1992; Eerkens and Lipo, 2007; Goodale and Andrefsky Jr., 2015; O'Brien et al., 2014). I selected the human HBE and cultural transmission approaches for my study on technological innovation in the Korean Late Paleolithic. These frameworks allow for a comprehensive understanding of the ecological and social contexts that influenced the production of stone artifacts during the Korean Late Paleolithic, and are both statistically testable. Furthermore, both HBE and cultural transmission have been previously utilized to study similar cases, making them well-established tools for archaeological investigations.

1.3.2. Human Behavioral Ecology (HBE)

I am using HBE to address my question about behavioral change in landscape use and mobility, possible impact of environment and population on the transition, likely use of stemmed points and their temporal and regional change. HBE aims to comprehend patterns of human behavior by assessing how selective pressures in the environment influence decisions about food procurement, mobility, division of labor, task-group membership, social affiliation, prestige, and social subordination (Bird and O'Connell, 2006; Fitzhugh, 2001; Fitzhugh et al., 2018; Smith, 2000; Smith and Winterhalder, 1992). HBE models typically investigate environmental factors (e.g., resource density, competitor frequency) and behaviors reflecting choices about time and energy allocation (Bird and O'Connell, 2006; Fitzhugh et al., 2018; Kelly, 2007; Smith, 2000). HBE provides concepts for understanding how foragers adjust their technologies, resource management strategies, schedule movements, foraging, food processing (including storage and consumption), and investment in technologies to optimize time and energy (Kelly, 2007). The fitness optimizing behaviors as a foundation of HBE, archaeologists propose mathematically testable models. As one of the pioneering evolutionary archaeologists, Winterhalder proposed a framework that weighs the value of subsistence efficiency against other competing objectives in respect of fitness-enhancing behaviors. His approach considers opportunity costs, which arise when resources such as time, energy, and money are limited and spending resources on one commodity reduces the resources available for others (Winterhalder, 1983). Patch choice, for example, posits that hunter-gatherers prefer to stay longer at high ranked patches, which will produce the best return per unit of foraging time and to move sooner from low ranked patches (Bird and O'Connell, 2006; Kaplan and Hill, 1992; Winterhalder, 1986, n.d.). This optimality based model enables us to build testable predictions by estimating how long the hunter-gatherers would stay in patch based on archaeological evidence using the concept of the marginal value theorem (Bettinger and Grote, 2016; Charnov, 1976; James et al., 2022). However, due to the aspect of optimality, archaeologists tend to focus on directly observable and measurable properties whose function can be assumed (e.g. projectile point, hearth, house, irrigation ditch, etc.), which can limit the understanding of hunter-gatherers. In addition, this optimality approach views behavioral variation as the product of natural selection impacting directly on behavioral innovations, which could be the results of random and undirected behaviors (Bettinger et al., 2015).

HBE models usually incorporate radiocarbon data, climate data, fauna, and stone artifacts to estimate population sizes or explore direct connections between ecological shifts and human behavior (Burke et al., 2017, 2014; Fitzhugh, 2002, 2001; Stiner and Munro, 2002). For instance, Burke et al. investigate the relationship between human population in the Iberian Peninsula and climate variability, such as interannual variability in precipitation level measured by the standard precipitation index (Burke et al., 2014). Similarly, I will use HBE with radiocarbon data and paleoclimate simulation data to examine their potential impact on appearance of stemmed points during the late Pleistocene in Korea. Under application of HBE, stone artifacts have been often used to understand hunter-gatherers' mobility and site occupation patterns (Clarkson, 2013; Goodale and Andrefsky Jr., 2015; Marwick, 2013). For example Clark and Barton investigate changes in mobility and land-use using artifact density and the frequency of retouched pieces as proxies of human site occupation patterns (Clark and Barton, 2017). Inspired by their study, I will explore the difference of site occupation and mobility between forager groups with stemmed points and groups without the new tools. Combined with the population and climate information, I will examine the significance of the development of stemmed points and their likely uses as a strategy of adaptation.

1.3.3. Cultural Transmission

I adapt cultural transmission to examine the learning process of stemmed point technology and assess the two main models describing the origin of the Korean late paleolithic : *in situ* evolution (Seong, 2006) and 'heterogenic' migration (Bae, 2010). Cultural transmission is the process of transferring information among individuals via social learning methods such as imitation, teaching or language (Mesoudi, 2011; Mesoudi and Lycett, 2009; Mesoudi and Whiten, 2008). This mode of information acquisition differs from genetic inheritance, which is passed on directly from biological parents, and from individual learning, which does not involve influence from conspecifics. During the transmission of cultural information, biases can arise and these biases can become important loci where changes occur in material culture (Creanza et al., 2017; Lycett, 2015). Boyd and Richerson and Henrich and McElreath have defined many of these biases, including 'guided variation' (where individuals learn new behaviors and then modify them through trial and error), 'content-based bias' (where some aspect of the transmitted instructions, such as cultural preferences, makes them more likely to be adopted), 'frequency-based bias' (where an individual is biased to choose particular instructions based on their perceived frequency in the population, such as extremely popular or rare instructions), and 'model-based bias' (where a variant is transmitted because of its association with other attributes, such as the prestige or skill of other individuals) (Boyd and Richerson, 1988; Henrich and McElreath, 2003).

After the work of Bettinger and Eerkens, who demonstrated how biases in cultural transmission could be detected in stone artifacts (1997, 1999; Eerkens and Bettinger, 2008), archaeologists have continued to use this approach in the study of stone artifacts, combining it with simulation analysis (Garvey, 2018) and experimental research to test the underlying assumptions (Mesoudi and O'Brien, 2008). I use this conceptual framework to analyze the social context of transmission (i.e. the connection between forager groups) during the late Paleolithic in Korea by testing learning biases through the shape of stemmed points.

1.4. Dissertation Structure and Chapter Summaries

In the following three chapters I present my research to answer the research questions. Each chapter focuses on answering one research question by addressing the specific questions, theoretical models and predictions, analysis and results, and discussion about human behaviors related to the appearance and transmission process of stemmed points. Here I provide brief summaries of the main goals for each chapter.

Chapter two tackles the question of How did the introduction of stemmed points affect mobility and site occupation during the late Pleistocene in Korea? The primary aim of the second chapter is to study the behavioral changes that occurred alongside the emergence of new hunting technologies represented by stemmed points, and to investigate the possible motivations behind their adoption. To achieve this goal, two research questions were formulated: What changes in foragers' use of the environment were associated with the introduction of the new tools, and what changes in people's mobility and use of habitation sites were associated with the new technology? To address these questions, I employed the standard patch choice model from HBE, which predicts that forager mobility and inter-patch travel times increase when resource patch productivity decreases. I used quantitative analyses of artifact volumetric density, retouch frequency, toolkits composition, and raw material to estimate the changes in duration of site occupation and mobility, comparing results between groups with and without stemmed points. I hypothesize that the adoption of new hunting technologies was a response to either ecological or demographic changes. To explore the ecological impact, I employed paleoclimate data, and for demographic impact, I computed summed probability distribution models. This research analyzed 35 assemblages from 23 sites dated from 49-24 ka. The results suggest that the forager groups with stemmed points were able to settle in higher elevation with cooler temperatures compared to those without stemmed points, indicating residential and less mobile behaviors. I also found that the appearance of stemmed points appears to have been less impacted by population dynamics.

This chapter was published as a peer reviewed article in *Quaternary Science Reviews* (Park and Marwick, 2022) in February 2022. An open access pre-print is also available online at https://osf.io/ws2tj/. This research compendium containing data and R code for reproducing the published results is at https://doi.org/10.17605/OSF.IO/JXWY5. Through this platform, I share raw data, R code, and manuscript to facilitate reproducibility of this research.

The third chapter, Variation in use of East Asian Late Paleolithic weapons: A study of tip cross-sectional area of stemmed points from Korea, explores the potential role of stemmed points in the technological transition. To guide my investigation, I formulated three research questions: What were the best-fit ballistic probabilities for the stemmed points if they were hafted as weapon tips? How diverse were their likely uses? And what are the temporal and spatial patterns of stemmed point use? To answer these questions, I used tip cross-sectional area (TCSA) measurements, in combination with information on raw materials and weight, to identify likely use categories for different types of projectile points. Drawing on the HBE framework, I postulated that weapon-tip selection would reflect the environmental conditions faced by foragers. For instance, narrow TCSA ranges would suggest specialized tool use, whereas wider TCSA ranges would indicate more versatile tools and the TCSA ranges could be changed depending on ecological contexts. To test these hypotheses, I examined temporal and spatial distribution of TCSA ranges, considering the potential impact of climate change and local environments. A total of 173 stemmed points from 36 assemblages excavated from 29 sites dated to 44-10 ka were analyzed in this research. The findings show that stemmed points were likely used as javelin tips and stabbing spear tips.

Additionally, the TCSA ranges of stemmed points varied across different sites, indicating that they were used in different ways depending on the local environment. It was also found that stemmed points were primarily used before the Last Glacial Maximum (LGM) and were concentrated in specific ecoregions in Korea.

This chapter was submitted for publication to the *Journal of Paleolithic Archaeology* in May 2023 and is under peer review at the time of writing (June 2023). An open access pre-print is also available online at https://osf.io/urw95/. This research compendium containing data and R code for reproducing the published results is at https://doi.org/10.17605/osf.io/dqna8.

Chapter four, Cultural Transmission and the Social Contexts of Technological Transitions during the Late Paleolithic of Korea, examines the cultural and social factors that contributed to the emergence of stemmed points during the Korean Late Paleolithic. To investigate these factors, I adopt a cultural transmission framework and formulate three research questions: what is the dominant mode of cultural transmission for technological innovation in the Korean Late Paleolithic? Do the modes of cultural transmission vary over time? And do the modes of cultural transmission vary over space? Following the previous study that analyzed projectile points with transmission biases (Bettinger and Eerkens, 1999), I proposed two scenarios for the development of stemmed points: guided variation, whereby socially isolated groups experimentally developed these points through trial and error, and indirect bias, whereby socially connected groups learned about stemmed points by copying from others with whom they regularly interacted. To assess the plausibility of these scenarios, I computed correlation coefficients and coefficients of variation (CV) of morphological attributes on stemmed points. For the temporal and spatial pattern, I applied existing Korean Late Paleolithic chronology and compared the results between assemblages. I analyzed 152 stemmed points from 23 assemblages at 20 sites spanning 40-17 ka. My results suggest that the transmission of the new technology was likely facilitated by guided variation with a smaller contribution from indirect bias. I observed a slight shift towards indirect bias in later chronological phases. I assumed that individuals or groups experimented with existing blade technologies to develop better stemmed points, copying essential components of successful models to optimize tool usage. This process led to greater standardization of the shape of stemmed points among their social groups.

This chapter was submitted for publication to the *Archaeological Research in Asia* in May 2023 and is under peer review at the time of writing (June 2023). An open access pre-print is also available online at https://osf.io/x4q8a/. This research compendium containing data and R code for reproducing the published results is at https://doi.org/10.17605/osf.io/eb8mx.

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Chapter 2

How did the Introduction of Stemmed Points affect Mobility and Site Occupation during the Late Pleistocene in Korea?

Note: This chapter was published as a peer reviewed article in *Quaternary Science Reviews* in February 2022 (Park and Marwick 2022). An open access pre-print is also available online at https://osf.io/ws2tj/. This research compendium containing data and R code for reproducing the published results is at https://doi.org/10.17605/OSF.IO/JXWY5.

Abstract

We use models from human behavioral ecology to examine stone artifacts from 23 sites in Korea to investigate mobility and site occupation patterns during the Late Pleistocene. This is an important period because new tools, such as stemmed points and blades, appeared in the archaeological record. We focus on two questions: what changes in foragers' landscape use were associated with the introduction of new tools? And what changes in the way people use habitation sites and mobility were associated with the new technology? To answer these questions we present quantitative analyses of artifact volumetric density, retouch frequency, composition of toolkits, and artifact raw materials. We explore environmental and demographic

contexts by applying paleoclimate simulations and summed probability distribution models. We find that quartz and side scrapers, in addition to cores and choppers, remain dominant in assemblages before and after the introduction of stemmed points throughout the Late Pleistocene. Our results show that forager groups using stemmed points may have been associated with occupation of marginal or extreme environments. Groups with stemmed points were associated with expedient technologies, indicating residential and less mobile behaviors. The environmental context of this technological innovation was a gradual decrease in temperature into the LGM. Population increased before the appearance of stemmed points.

2.1. Introduction

The appearance of stemmed points (Figure 2.1) in the Late Pleistocene (ca. 42-35 ka) in Korea is often assumed to have transformed forager lifeways because it was thought to have indicated more specialized hunting practices (Chang, 2013; Seong, 2008). Stemmed points are projectile points made from an elongated flake or blade with slight retouch on the distal end to shape an acute tip and on the proximal end to make a stem, which connects to a shaft. These types of artifacts are often called tanged points in the western hemisphere (Ivanovaitė et al., 2020; Serwatka and Riede, 2016), but we use ‘stemmed point’ here to distinguish from Bronze Age stone projectile points that have long been called ‘tanged points’ in Korea. Stemmed points are likely to have been projectile weapon tips because the stem of these tools is considered to represent a hafting projection used for joining the lithic to a wooden shaft. If these artifacts were projectile weapon tips, then stemmed points represent the first appearance of hafting technology in Korea. However, most open sites in Korea do not preserve organic remains due to acidic soil, so shafts have not been found. There are very few limestone cave sites containing human fossils or faunal remains (e.g. Durubong and Jeommal Cave), which located in constrained area to access in North Korea or have been rarely analyzed to directly apply to other archaeological research (Bae, 2013). Therefore stone artifacts such as stemmed points are our only window to examine hunting and subsistence strategies. Here we apply a behavioral ecological framework to explore questions about the implications of the appearance of this new technology. We use data from 23 sites in South Korea to explore changes in the way people occupied the landscape, the way people used sites, and the social and ecological contexts associated with the appearance stemmed points, and the blade industry that followed.

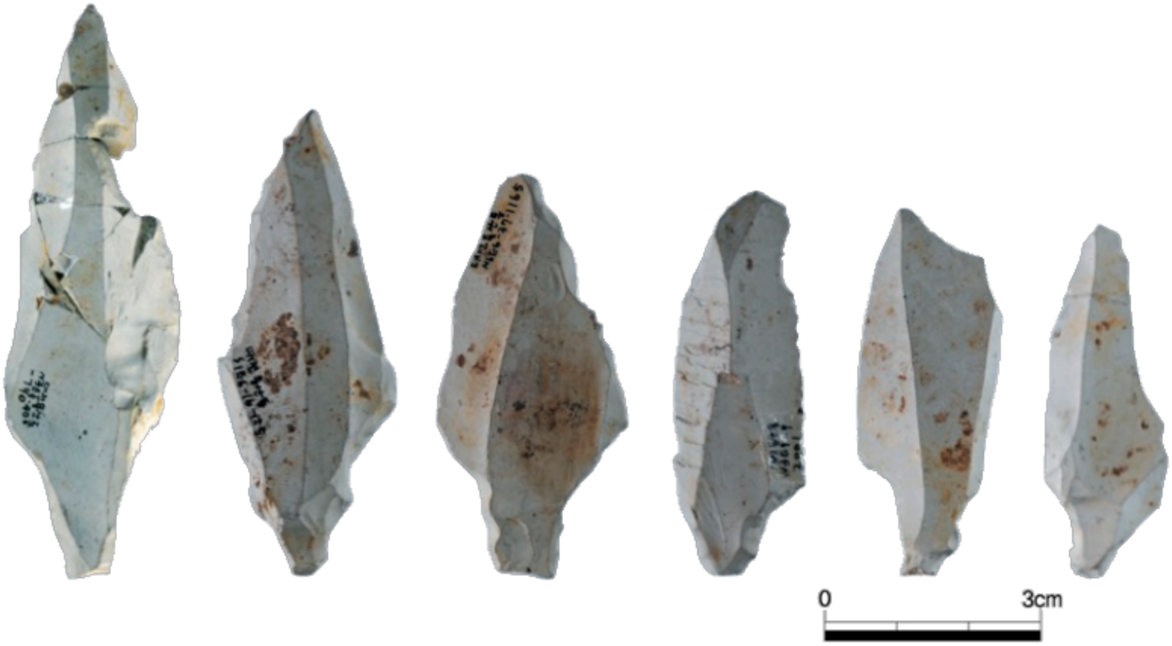

Figure 2.1: Stemmed points from Yongsandong site

Previous work on this technological change in Korea has focused on issues of the transition from the Early to the Late Paleolithic and modern human dispersals (Bae, 2017; Bae, 2010; Norton and Jin, 2009; Seong and Bae, 2016). To our knowledge, the implications of the appearance of stemmed points for forager mobility and site use have not been explored in detail. Here, we attempt to identify patterns of mobility and site occupation through analysis of the stone artifact assemblages using Human Behavioral Ecology (HBE) models. Drawing on established relationships between lithic technology and forager mobility (Capriles et al., 2018; Hiscock, 1994; Kuhn et al., 2016; Kuhn, 2004, 1994; Kuhn and Miller, 2015; Seong, 2015, 2008; Shott, 1986), we hypothesize that the appearance of the new hunting tool might reflect a preference for more portable and efficient technologies, that were part of a broader strategy of moving frequently and further, possibly as an adaptation to environmental or population changes.

2.2. Late Pleistocene Lithic Technologies in East Asia

In the Eastern hemisphere, some of the most striking technological innovations during the Late Pleistocene are found in Northeast Asia, such as northern China, Japan and Korea. These innovations include blade technology, high frequencies of retouched blade tools, several novel tools such as projectile points, stemmed points, end scrapers, burins, denticulates, ground stone tools etc, and frequent use of high-quality raw materials (Bae et al., 2017; Bae, 2017; Bar-Yosef, 2002; Bar-Yosef and Kuhn, 1999; Brantingham et al., 2001; Lee et al., 2017; Nakazawa and Bae, 2018). Previous work has argued that the appearance of new stone artifact technologies in this region may be linked to modern human dispersals (Bae et al., 2017; Bae and Bae, 2012; Bae, 2010; Seong, 2008). For example, the new dating results from Zhoukoudian Upper Cave from northern China (35.1–33.5 ka) and material evidence such as ornaments and hominin fossil show close relation to one of multiple dispersal events out of Africa into Eurasia (Li et al., 2018).

The Shuidonggou site in northern China is an important example of the transition from cobble to blade tool industries in the Late Pleistocene of Northeast Asia (Brantingham and Perreault, 2010; Gao et al., 2010; Pei et al., 2012). Shuidonggou Locality SDG 2, which dates to around ca. 32 ka, contains faunal specimens, ostrich eggshell beads, and stone artifacts including blades, retouched flakes, cores, and debris along with well-preserved hearths. In Locality 9 dated to ca. 29 ka, there is a small scatter of stone artifacts consisting of blades, Levallois flakes, cores and other retouched flakes. Excavations at Locality 12 shows that its archaeological context, dated to 13,078–13,296 cal BP, includes ground stone and more than 30,000 microlithics made out of a variety of raw materials such as fine-grained and siliceous rocks. In addition, more than 10,000 animal fossils and bone tools including a tool for fishing nets, an awl, and two needles were excavated (Gao et al., 2014; Pei et al., 2012; Zhang et al., 2016). Shuidonggou shows that although stemmed points are not present at all, a blade technology came from Siberia and/or Mongolia at 41 ka (SDG Locality1 and 9). Advanced core and flake tools were likely to have been locally developed at 33 ka (SDG Locality 2 and 8), and at 10.8 ka microblade technology appears, but the origin is uncertain (SDG Locality 12) (Li et al., 2019; Yi et al., 2014). The microblade technology is argued to have appeared related to changes in mobility associated with colder climates towards the Last Glacial Maximum (LGM) (Yi et al., 2014).

In Japan, Early Upper Paleolithic (EUP) technologies appeared in different regions of the archipelago around 38 ka, accompanied by remains of Homo sapiens found in Okinawa Island (ca. 36 ka) (Izuho and Kaifu, 2014; Yamaoka, 2012). These technologies include trap pits, cobble concentrations, hearths, charcoal concentrations, and toolkits including trapezoids, pointed-shaped backed blades, backed points, burins, end scrapers, side scrapers, wedges, beak-shaped tools, axes, edge-ground axes, hammerstones, cobble tools, and anvils (Bae et al., 2017; Izuho and Kaifu, 2014). These innovations have been interpreted as evidence of new foraging methods such as watercraft (marine transport of obsidian from the Kozu Island) and bow-and-arrow technology, driven by increased population and ecological changes and led to the megafaunal extinctions (Bae et al., 2017; Bae, 2017; Kaifu et al., 2019; Morisaki et al., 2019; Nakazawa, 2017; Nakazawa and Bae, 2018; Norton et al., 2010; Yamaoka, 2012). Hafted trapezoids were likely multifunctional tools adapted to the specific environmental settings of the different Japanese Islands (Ono et al., 2002; Yamaoka, 2012). An important example is Ishinomoto 8-ku, which is one of the earliest sites, dated to 39,690–34,790 cal BP, located in Takuma upland of Kumamoto Prefecture. A total of 500 stone artifacts, mostly chert and andesite, were discovered including trapezoids, side scrapers, flakes, flake cores, edge-ground axes, and cobble tools (Izuho and Kaifu, 2014). Stemmed points appear in Japan much later than in Korea, dated to between about 15,500 and 13,800 cal BP (Ono et al., 2002; Tsutsumi, 2007).

What makes the Korean Late Pleistocene technological transition distinctive from what we see at Shuidonggou and in Japan? The key difference is that the earliest signs of new technologies in Korean assemblages are stemmed points, followed by blade technologies. This contrasts with China and Japan where stemmed points appear after their first appearance in the Korean Peninsula. Stemmed points from the Bonggok site are currently accepted as the oldest stemmed points, dated to ca. 41.5 ka, and made on elongated flakes (Bae et al., 2017; Seong, 2015, 2009).

After blades became widespread in Korea at ca. 27 ka, they were used to make the stemmed points, and the shape of points became more standardized with one or two ridges on the dorsal side and a triangular cross section. Replacing flakes with blades as blanks of the stemmed points led to an increase in quantity of the points over time. In addition to the stemmed points, flake tools became more complex, with a greater diversity in both type and size along with continuously used core tools during the Late Pleistocene (Bae, 2010; Lee, 2016, 2013). A notable exception to this pattern is the recently excavated Hajinri site which is an outlier with both stemmed points and blades appearing together at 42 ka (Lee et al., 2018).

There have been several attempts to explain this technological transition and they can be summarized into two competing models: 'heterogenic' migration (Bae, 2010) or *in situ* evolution (Seong, 2009). The migration model argues that the new blade industry including stemmed points, and the earlier coarse flake tradition including large cores, polyhedrons, choppers, and even handaxes, came from different origins as the result of continuing influx of modern human migration from two routes. Bae (2010) explains that blade and stemmed points arrived in the Korean peninsula from Siberia, Mongolia, or other regions of northeast China following the Liaohe and Sunghe rivers around 35 ka with the earliest evidence of blades in those regions. He assumes that core and flake industries come from southern China based on the existence of similar assemblages in both Korea and southern China. In addition, the genetic studies of two "Asian-specific" Y-chromosome haplogroups (O3-M122, D-M174), mtDNA and autosomal SNPs, and other analyses verify that modern humans initially arrive in southern China and the population migrated to northward (Bae et al., 2013; Lee, 2013).

The alternative model, which we call the '*in situ*' model, claims that stemmed points and other Late Paleolithic technologies, including blade industries, autonomously emerged in the south of the Korean peninsula, with no apparent external influence (Seong, 2008). This claim is supported by Korea having the earliest appearance of stemmed points in Northeast Asia, at sites such as Bonggok, Hwadaeri, Hopyeongdong, and Yonghodong dated to approximately 42-35 ka BP (Seong, 2009). Seong (2009) presents the increased blade-to-flake ratios of lithic assemblages after the appearance of stemmed points as support of the *in situ* model, based on the premise that the blade industry represents a new exogenous technology while flakes indicate a continuing local one.

2.3. Behavioral Ecology and Forager Land Use Behaviors

Our brief review of Late Pleistocene technological innovations in Northeast Asia shows that previous work has largely focused on the timing, location, origins and description of these new tools (Bae, 2010; Lee, 2016, 2013; Seong, 2009, 2008). Modeling the land-use behaviors associated with these assemblages has rarely been undertaken. We focus on the appearance of stemmed points in Korea because these are a new technology that likely represented new hunting behaviors. This is because the hafting implies throwing techniques that can reach long-distance targets (Keeley, 1982; Kuhn and Miller, 2015). We draw on behavioral ecological theory to model the effects of this technological change. Behavioral ecology theory is well established in international archaeology and offers structured models and testable hypotheses based on optimality assumptions derived from principles of economic rationality and environmental adaptation (Prentiss, 2019; Winterhalder and Smith, 1992). Specifically, we use the standard patch choice model, which is built around the widely-used marginal value theorem, to predict that forager mobility between patches and inter-patch travel times will increase when resource patch productivity decreases (Bettinger and Eerkens, 1997; Llano, 2015; Smith, 1991; Smith et al., 1983; Wolverton et al., 2015). We model individual artifact types as a kind of resource patch. Foragers may find a more costly and complicated technology (such as stemmed points, relative to flakes) optimal if they have a long cumulative time in use, if they are maintainable and reusable in a landscape where lithic raw material supply is uncertain (Bleed, 1986; Torrence, 1983). That is, foragers may move to a patch where they can stay longer (i.e. prefer to make and use an artifact type that has a long and extendible use-life) when they are not certain of the productivity and travel times of other patches (i.e. the productivity and use-life of other artifact types) (Kuhn and Miller, 2015).

We ask two questions to investigate the period around the introduction of stemmed points in Korea. First, what changes in foragers' landscape use were associated with the introduction of the new tools? Specifically, was the use of stemmed points associated with occupation of marginal or extreme environments? Our assumption here is that this new technology, and the ability to reach long-distance targets, might have allowed foragers to explore and sojourn in less productive landscapes by increasing their mobility. For example, in Australia during the mid-Holocene, Hiscock et al. argue that the first appearance of microlithics in many locations represent a portable and multi-functional toolkit that minimize travel expenses and increase tool readiness to adapt to patchy and unpredictable resources associated with environmental change (Hiscock et al., 2011; Hiscock, 1994). Similarly, in Japan, Morisaki et al. (2015) argue that the transition from trapezoid to blades and projectile points around 25 ka in north Paleo-Honshu Island enabled the foragers to extend their occupation into cold grassland landscapes.

Second, we ask what changes in the way people used habitation sites and mobility were associated with the new technology? After the appearance of these new tools, did people tend to be more or less mobile? The stone artifact assemblage from a site can inform us how long individuals or groups stayed and give insights into their activities (Binford, 1979; Holdaway and Davies, 2019; Kelly, 1995; Kuhn et al., 2016). For example, stone artifact density and the frequency of retouched pieces (scaled to the volume of excavated sediment) can be used as proxies to represent occupation patterns (Barton et al., 2011; Clark and Barton, 2017). Assemblages with low density but a high proportion of retouched and backed pieces may indicate the remains of ‘short-term camp’, which is a site for small and ephemeral overnight camp or limited activity station. On the other hand, the combination of high density and low retouched pieces might be expected at logistically organized ‘base camp’, which is a site with greater residential stability, long site occupation and occupied by larger groups (Clark et al., 2019; Clark and Barton, 2017).

2.4. Methods

2.4.1. Archaeological Sites

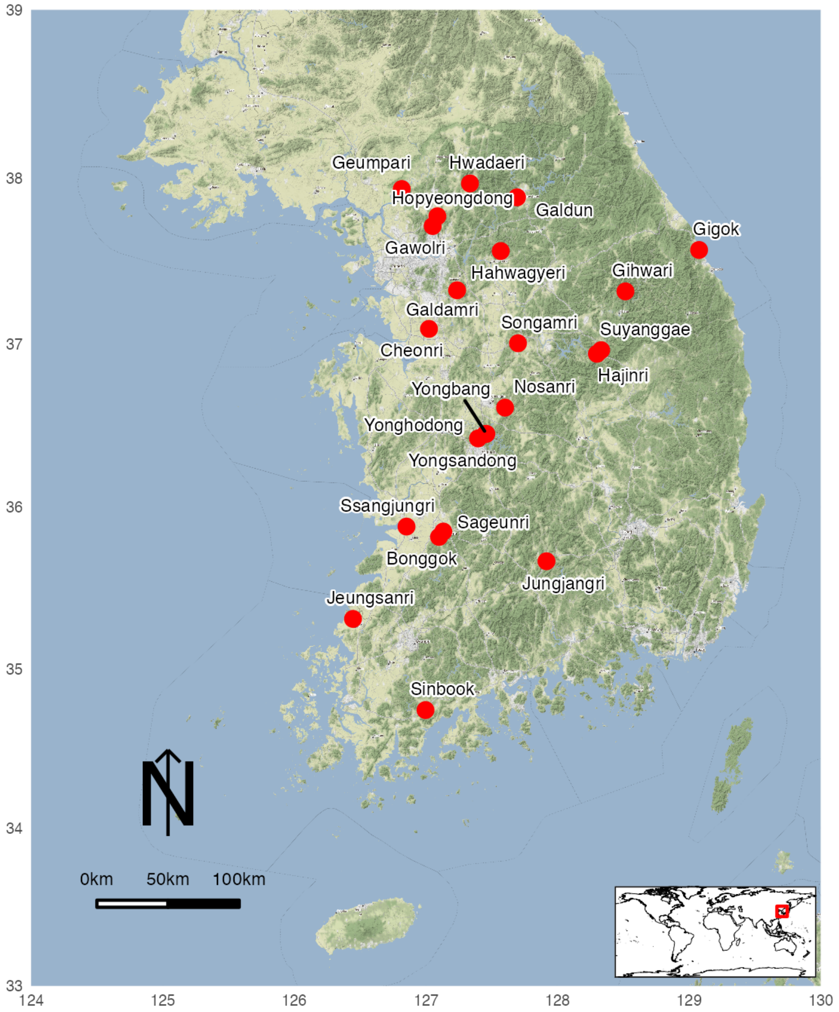

Figure 2.2: Korean Paleolithic sites mentioned in the text.

After the first Paleolithic sites such as Dongkwanjin and Yondaebong were discovered during the mid-1930s, more than 200 Paleolithic sites have been discovered in South Korea (Lee and Sano, 2019; Lee et al., 2017; Norton, 2000). We selected sites dated to before and after the transition period (42-35 ka) to analyze the process of technological change. It is important to note that the quality of excavation and reporting of Paleolithic sites in Korea varies greatly. Furthermore the stratigraphic integrity of the deposits is also variable, as the sites are open-air localities formed as loose accumulation of artifacts in fluviatile condition or within a colluvium developed at the edge of low-angled slope. To ensure our analysis employs reliable data, we applied a chronometric hygiene protocol (described below) to exclude sites with problematic chronologies and stratigraphy. After applying our protocol to the 200+ sites currently known, we produced a sample of 35 assemblages from 23 sites spanning 49-24 ka (Figure 2.2). We identified multiple assemblages in a site where culturally sterile deposits separated artifact-bearing deposits, or where stratigraphic units could be identified by major differences in the texture and composition of the sedimentary deposit containing the stone artifacts. For example, the Hwadaeri site has three cultural layers. The lowest horizon at the bottom, dated to 39,000±1400 BP by OSL, contains coarse flake tools made of vein quartz and quartzite. The middle cultural horizon has stemmed points made of porphyry, with quartz and quartzite dominating the assemblage. This layer was dated to 31,200±900 BP by radiocarbon dating and 30,000±1,700 BP by OSL. The uppermost layer, dated to 22,000±100 BP by OSL, contains blades, scrapers, awls, and denticulates (Seong, 2009). We obtained the data from published excavation reports held by provincial museums.

2.4.2. Stone Artifact Assemblages

The 35 assemblages consist of (non-blade) cores, blade cores, blades, flakes, debris, hammers, choppers, planes, polyhedrals, side scrapers, end scrapers, notches, cleavers, stemmed points, awls, denticulates, burins, handaxes, blanks, knives, handadzes, peaks, flatters, flakers etc. We excluded some artifacts from our sample because of uncertainty about their typology. The stone artifacts from all of these sites are stored in museums located throughout South Korea, and have been briefly described in Korean language excavation reports. We have visited most of these collections to obtain permission to study the materials directly.

2.4.3. Methods for Analyzing Stone Artifact Assemblages

To answer our two research questions, we compiled information about artifact density, retouch frequency, toolkit composition, raw materials, site elevation, and radiocarbon ages for the sites in our sample.

Artifact volumetric density is defined as the total number of artifacts per cubic meter of excavated sediment, and serves as a proxy for the accumulation ratio of artifacts (Clark et al., 2019; Clark and Barton, 2017). We used these density values to evaluate mobility and land-use practices of hunter-gatherers during the Late Pleistocene. Retouch frequency is the number of retouched tools divided by the total number of artifacts in an assemblage. This value represents mobility and duration of site occupation based on the assumption that tool reduction is a tactic to extend the use-life of a tool by generating sharp, usable edges while minimizing the cost of transporting tools or bulky raw materials by reducing the total load weight (Buvit et al., 2014; Clark et al., 2019; Kuhn, 1990). In other words, producing and carrying highly retouched tools increased tool portability and efficiency by decreasing the size of both individual tools and the assemblages so that hunter-gatherers could move often or further, or both (Andrefsky, 1994;

Davies et al., 2018; Kuhn, 2004, 1994, 1991). Combining these two proxies, the artifact volumetric density and the retouch frequency, we infer whether or not the hunter-gatherers were residentially mobile or logistically organized. If the assemblage in a site has a high artifact density and small proportion of retouch, we interpret it as a more expedient assemblage that represents “base camps” or “residences”, while lower artifact densities with higher proportions of retouched pieces shows a more curated assemblage and indicates either residential mobility or certain task groups away from residential sites (Clark and Barton, 2017; Riel-Salvatore and Barton, 2004).

We calculated toolkit composition by analyzing tool and debitage frequencies to identify changes in the assemblages during the study period. Toolkit composition helps us answer the question of how site occupation patterns changed before and after the appearance of new technology. The type and proportion of retouched tools and knapping products, including debris and hammerstones, provide information about settlement patterns based on a premise that more activities are conducted with a wider range of tool types for longer occupation (Buvit et al., 2014; Centi et al., 2019; García-Medrano et al., 2017). For example, we interpret small sized assemblages with a low diversity of tools as representing a short duration of site occupation (Buvit et al., 2014; Shott, 2010).

Our study of raw material consumption patterns assumes that stone tool was transported and utilized to optimize mobility and minimize risks of not having artifacts when they were needed (Andrefsky, 1994; Brantingham, 2003; Brantingham et al., 2000; Yue et al., 2020). It follows that the representation of raw materials in an assemblage can be an indicator of site occupation patterns. For example, a large variability of raw materials in a site can suggest long-term settlement, while a small assemblage of exotic raw materials can indicate higher mobility (Valde-Nowak and Cieśla, 2020). Here we quantify the specific raw materials that relate to the appearance of a new technology, and investigate site occupation patterns by examining changes in the proportions of raw material types in the assemblages.

2.4.4. Methods for Analyzing Environmental Context

In addition to these data on human behavior from the stone artifact assemblages, our HBE models require environmental proxies to build hypotheses of behavioral change influenced by the surrounding environment. However, there are few paleoenvironmental proxies in Korea relevant to our study period. For example, geoarchaeological observations simply suggest that environment of the period was overall cooler and drier during MIS 3 (Bak and Lee, 2017; Chang, 2013; Choi, 2011; Han, 2008; Im and Choo, 2015; Seong, 2008). To supplement the limited availability of high-resolution local proxies, we used climate information from a simulated data set of paleoclimate including global monthly temperature, covering the last 120,000 years (Beyer et al., 2020). We extracted annual temperature values from the data generated by Beyer et al. (2020) for all site locations in our sample. In addition, we extracted site elevation values from a raster, as a proxy to represent environmental variation at local scales, to assist in identifying how these impact mobility and site occupation, and their relationship with the stemmed points.

2.4.5. Methods for Analyzing Demographic Context

We used radiocarbon dates as a proxy for human population to infer the demographic context of technological change. Summed probability distributions (SPD) of radiocarbon dates are widely used by archaeologists to infer temporal trends in past human populations (Bamforth and Grund, 2012; Contreras and Meadows, 2014; Rick, 1987; Riris and Arroyo-Kalin, 2019; Shennan et al., 2013; Timpson et al., 2014). Despite concerns about limitations of the validity of SPD (Bamforth and Grund, 2012; Carleton, 2021; Williams, 2012), several studies have shown good agreement between SPDs and other archaeological indicators (e.g. site counts, settlement size) so this method may allow a first approximation of population fluctuations (French and Collins, 2015; Palmisano et al., 2017). Although this is often used with samples of thousands of ages, this method can also be useful for small sample sizes. For instance, Timpson et al. (2014) apply SPD to 93 ages from Eastern Middle Sweden and demonstrate that the result is equivalent to a larger sample size (n = 243). In addition to the 93 radiocarbon ages from our targeted sites, we included all available dating results (540 ages) from other Korean Paleolithic sites that have younger and older assemblages. We compiled a total of 633 dates from 113 sites and applied a chronometric hygiene protocol to assess the reliability of radiocarbon determinations in relation to target events. Following the criteria from Napolitano et al. (2019) and Fitzpatrick (2006), we kept ages from dating short-lived terrestrial material (i.e., plant remains) and charcoal, and having laboratory name and number. We excluded OSL dates and sites with only one date. This resulted in a sample of 400 radiocarbon ages from 23 sites which we use to examine connections between population trends during the Late Pleistocene in Korea and technological innovation.

There is a debate about whether past population growth has played a role in technological change (Hosfield, 2005; Kline and Boyd, 2010; Shennan, 2001). Shennan (2009) observed a correlation between population decrease and technological simplification in his study of lithic arrowheads from the southern Scandinavian Mesolithic. He found that the lithics became less complex, and point shape changed as the population level dropped. By proposing the generalized null demographic model built on cultural transmission theory, Lycett and Norton (2010) also claimed that relatively lower effective population sizes in East Asia could be strongly associated with a lower frequency of handaxe sites, a lower percentage of bifaces, and morphological difference between East Asian handaxes and classic Acheulean artifacts. They also suggested that a lack of Levallois technologies in East Asia might be similar to the previous example of handaxe. On the other hand, Collard et al. (2013) argue that regional archaeological data do not support the population-driven models. For example, Buchanan et al. (2016) concluded that changes in point types from >13,000 years ago to 400 years ago in Texas were related to environmental risk, and not dependent on population size.

We used SPD to test for correlations between population, environmental proxies and technological change. We used the R package 'rcarbon' (Crema and Bevan, 2021) to perform statistical analyzes and conduct model testing using Monte Carlo methods (Crema et al., 2016; Palmisano et al., 2020; Timpson et al., 2014). We generated exponential, uniform, linear, and logistic models and evaluated the model goodness-of-fit by applying Akaike's Information Criterion (AIC) as a ranking criterion (Bevan et al., 2017; Riris and Arroyo-Kalin, 2019; Sakamoto et al., 1986).

2.4.6. Reproducibility and Open Source Materials

The entire R code (Team, 2019) used for all the analysis and visualizations contained in this paper is openly available at https://doi.org/10.17605/OSF.IO/JXWY5 to enable re-use of materials and improve reproducibility and transparency (Marwick, 2017). Also in this version-controlled compendium (Marwick et al., 2018) are the raw data for all the visualizations and tests reported here. All of the figures, tables, and statistical test results presented here can be independently reproduced with the code and data in this repository. The code is released under the MIT license, the data as CC-0, and figures as CC-BY, to enable maximum re-use.

2.5. Results

2.5.1. Artifact Volumetric Density and Retouch Frequency

Figure 2.3 shows that there is no strong directional temporal pattern of changes in artifact density. The upper bound of artifact density increases in more recent periods. For example, the density of some assemblages are two or three times higher than others, especially after 30 ka. The inset figure shows that assemblages with stemmed points have higher artifact densities than the assemblages without. With the newer tools, hunter-gatherers may have stayed in the same location for longer duration. We may be seeing site occupation patterns in this sample that represent the long term trend of the use of both base camps or residences, represented by the higher artifact densities, and more briefly occupied camps with lower densities. The most striking result here is that the maximum size of base camps increases in more recent periods.

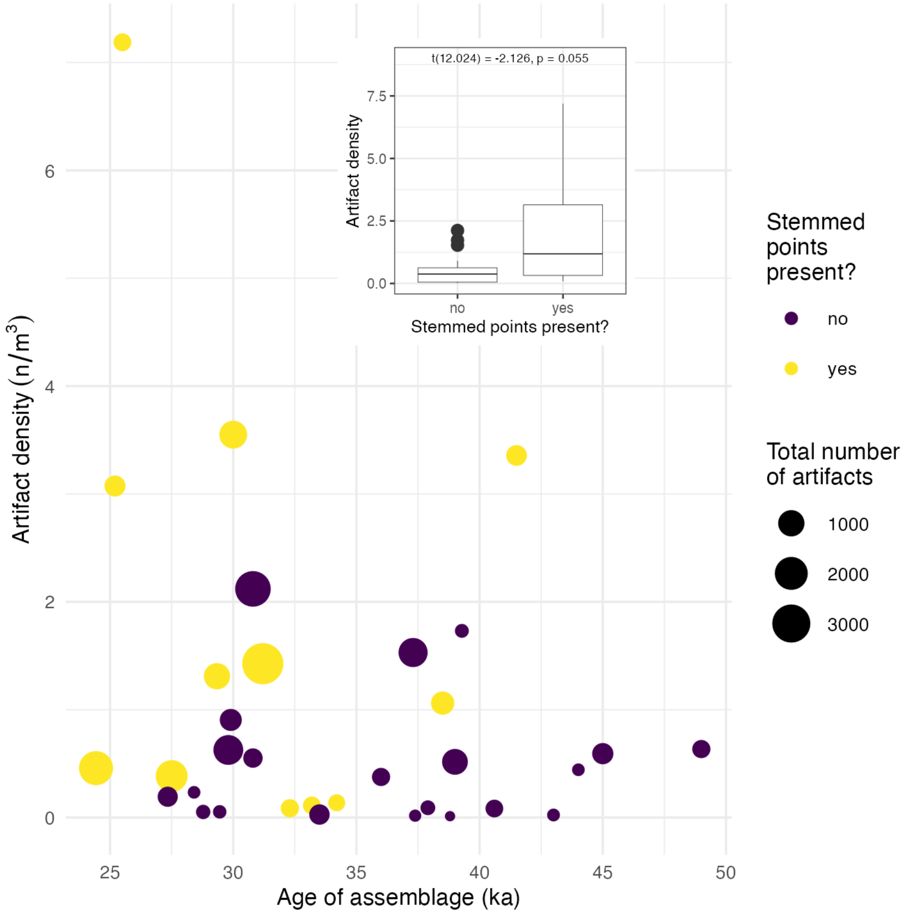

Figure 2.3: Artifact volumetric density over time. The size of data points represents the total number of artifacts from each assemblage and the color indicates the presence of stemmed points. The inset plot shows direct comparison of artifact densities for assemblages with and without stemmed points.

Figure 2.4 shows a strong pattern of artifacts from less dense assemblages having higher retouch frequencies while more dense assemblages have lower retouch frequencies (t(31) = -2.162, p = 0.038), further showing a spectrum of site functions in this sample. As we saw for artifact density, there are no clear directional chronological trends in retouch frequencies. Assemblages containing stemmed points tend to have substantially fewer retouched pieces compared to assemblages without stemmed points (t(27.009) = 2.752, p = 0.01).

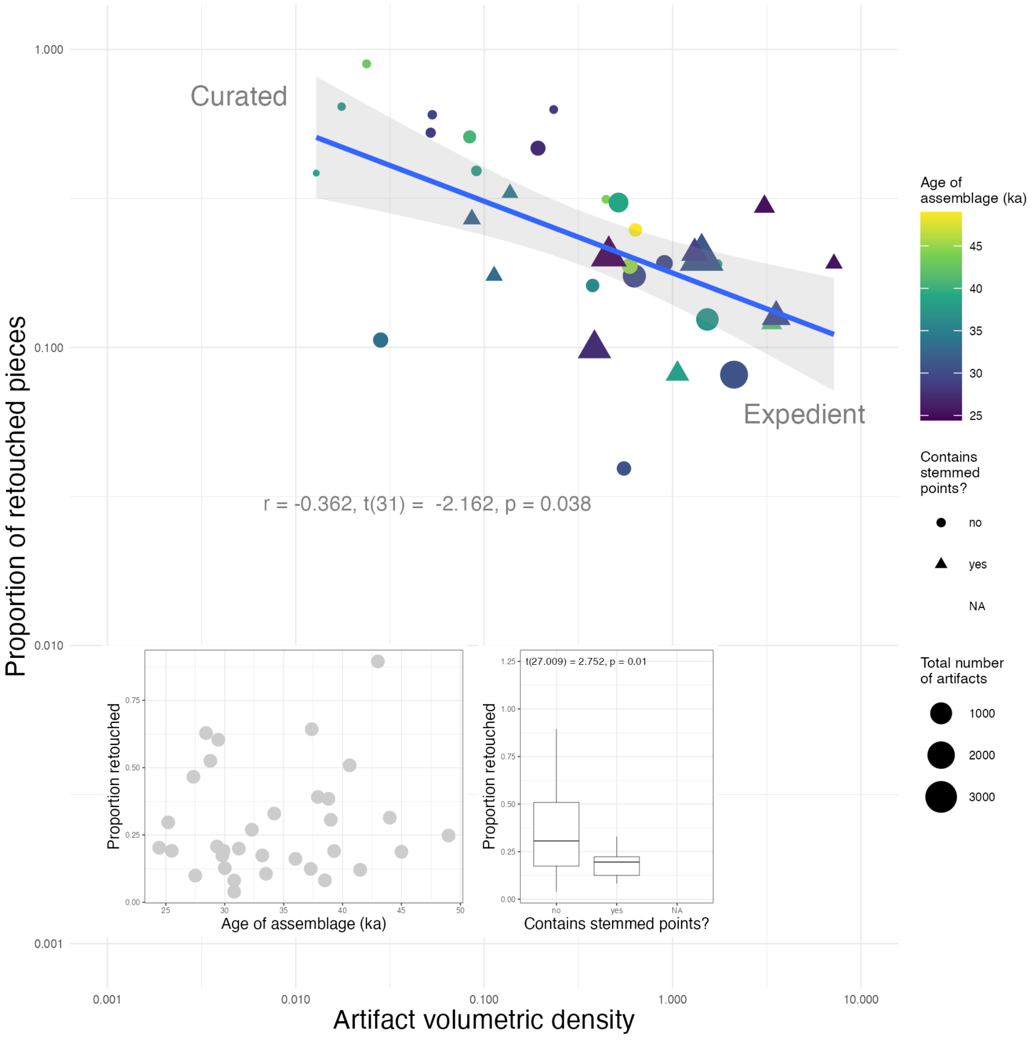

Figure 2.4: Relationship between artifact density and retouch frequency. The color of the data points indicate the age of the assemblage, point size indicates assemblage size, and shape indicates presence or absence of stemmed points. Assemblages with higher proportions of retouched pieces and lower densities indicate curated technologies, and assemblages at the other end of the spectrum indicate expedient technologies (Riel-Salvatore and Barton, 2004). The inset plot on the bottom left shows the proportion of retouched pieces in the assemblages over time. The inset plot on the bottom right shows the proportion of retouched pieces in the assemblages with or without stemmed points.

2.5.2. Toolkit Composition

In Figure 2.5 we see that side scrapers are the major part of most assemblages and are present in all assemblages. For example, more than 70 percent of the two assemblages from Hwaderi are side scrapers. The proportion of side scrapers shows a striking trend over time, rising to a peak at 38-39 ka, and declining thereafter. In addition to side scrapers, cores also exist in all assemblages, often as a high proportion. The proportion of choppers is lower in more recent assemblages. Stemmed points first appeared in Hajinri around 42 ka and were typically found in assemblages that contain blades, except for Songamri. The earliest blades and blade cores are also recorded from Hajinri but the date of this site is an unusual outlier because the stemmed points and blades are highly standardized and refined, which are only found at other sites much later in time. Bonggok site, which is the second-earliest site for stemmed points in our sample, also includes blades but it has not been demonstrated that those artifacts, as well as other earlier blades, are actual blades or elongate flakes without accompanying blade core. Aside from the outlier site Hajinri, blade cores first appeared in Suyanggae-C at 34.3 ka. Other artifacts, including burins, denticulates, end scrapers, handaxes, knives, notches, planes, and polyhedrals made up a small proportion of the assemblages and show no directional chronological change.

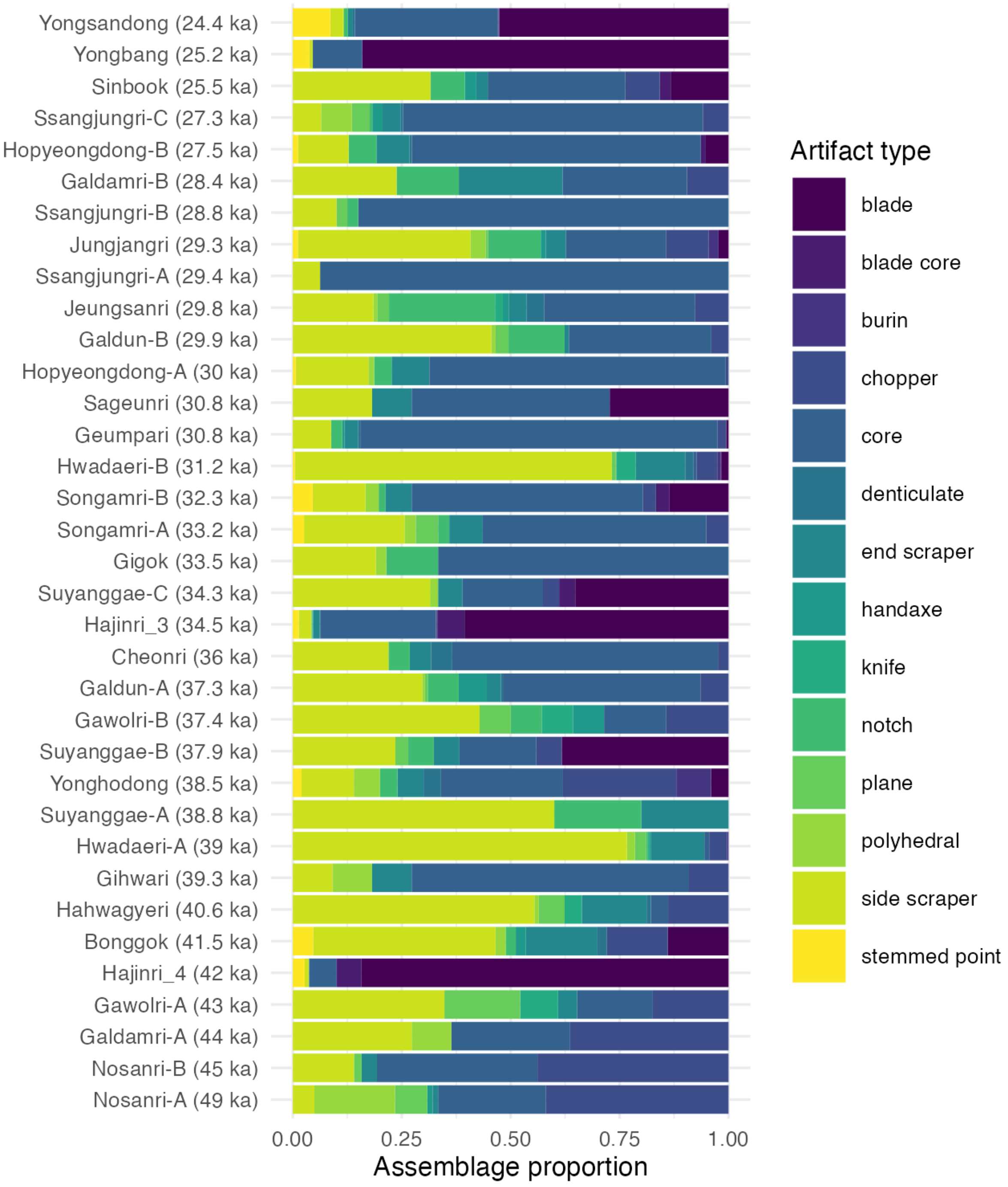

Figure 2.5: The composition of each assemblage. We excluded artifacts related to manufacturing processes such as pebbles, hammers, flakes and debris, and artifacts that appeared only in a few assemblages including points, beak shaped pieces, awls, and anvils, and unknown pieces. The color represents different types of tools and the assemblages are placed in chronological order.

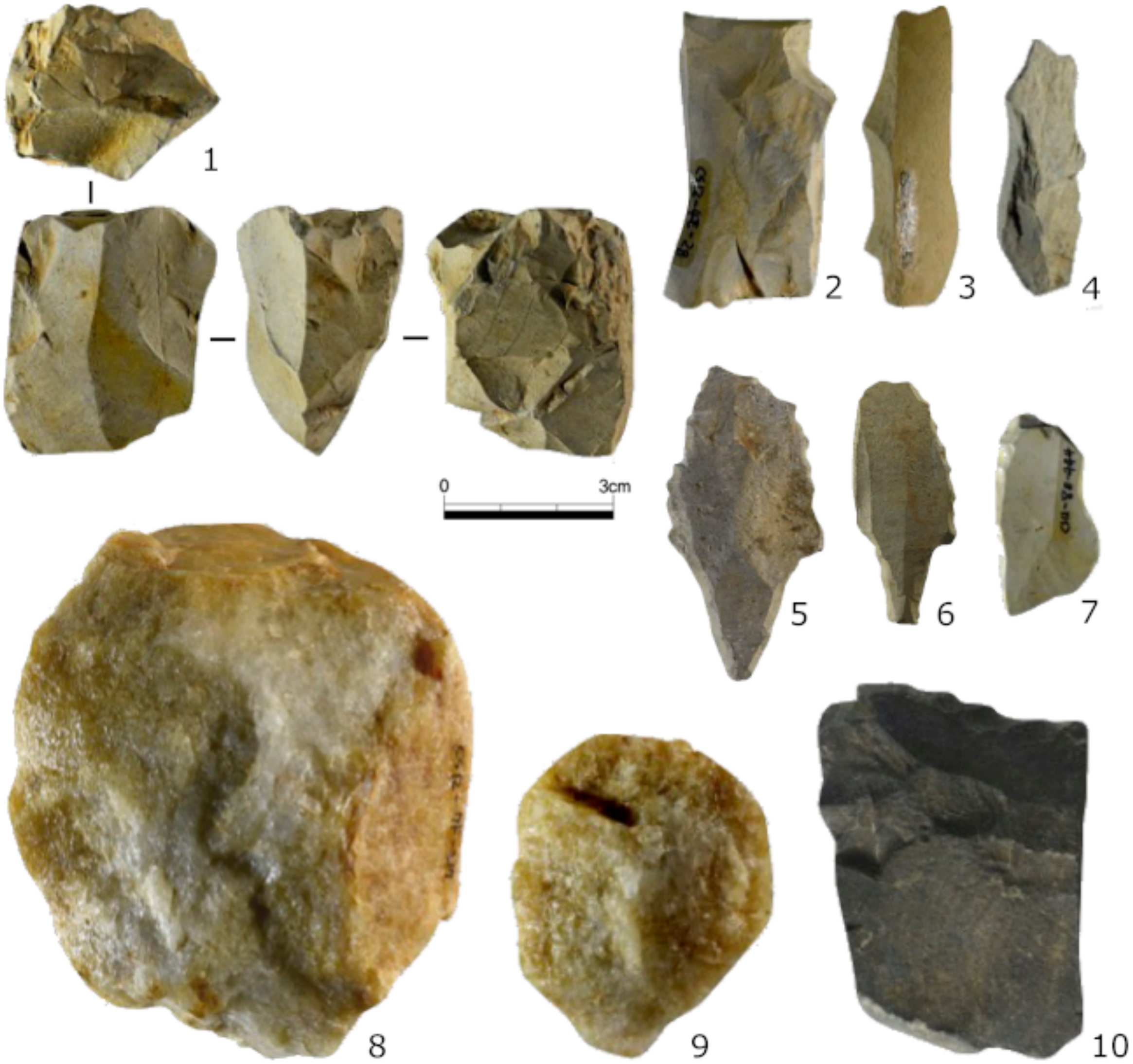

Figure 2.6: Stone artifacts from Songamri site. 1. Blade core, 2~4. Blades, 5~6. Stemmed points, 7. Side scraper, 8. Chopper, 9~10. Side scrapers.

2.5.3. Raw Materials

Quartz, quartz vein and quartzites were the most frequently found raw materials, and they were constantly used throughout the Late Pleistocene (Figure 2.7). For example, both Galdamri-A, dated to 44 ka with a small assemblage, and Hopyeongdong-B, dated to 27.5 ka with a larger assemblage, consist of only the quartz related materials. The use of chert, hornfels, rhyolite, and shale increased after 42 ka, but these raw materials remained a small proportion of assemblages until 25 ka. They are very suitable to make elongate blades and stemmed points because of the predictability of flaking afforded by their fine-grained texture. For example, Hajinri has the largest number of stemmed points (n=86) among the assemblages studied here, and most stemmed points from Hajinri are made from shale. Other raw materials, such as porphyry and sandstone, were found in just a few assemblages in small proportions.

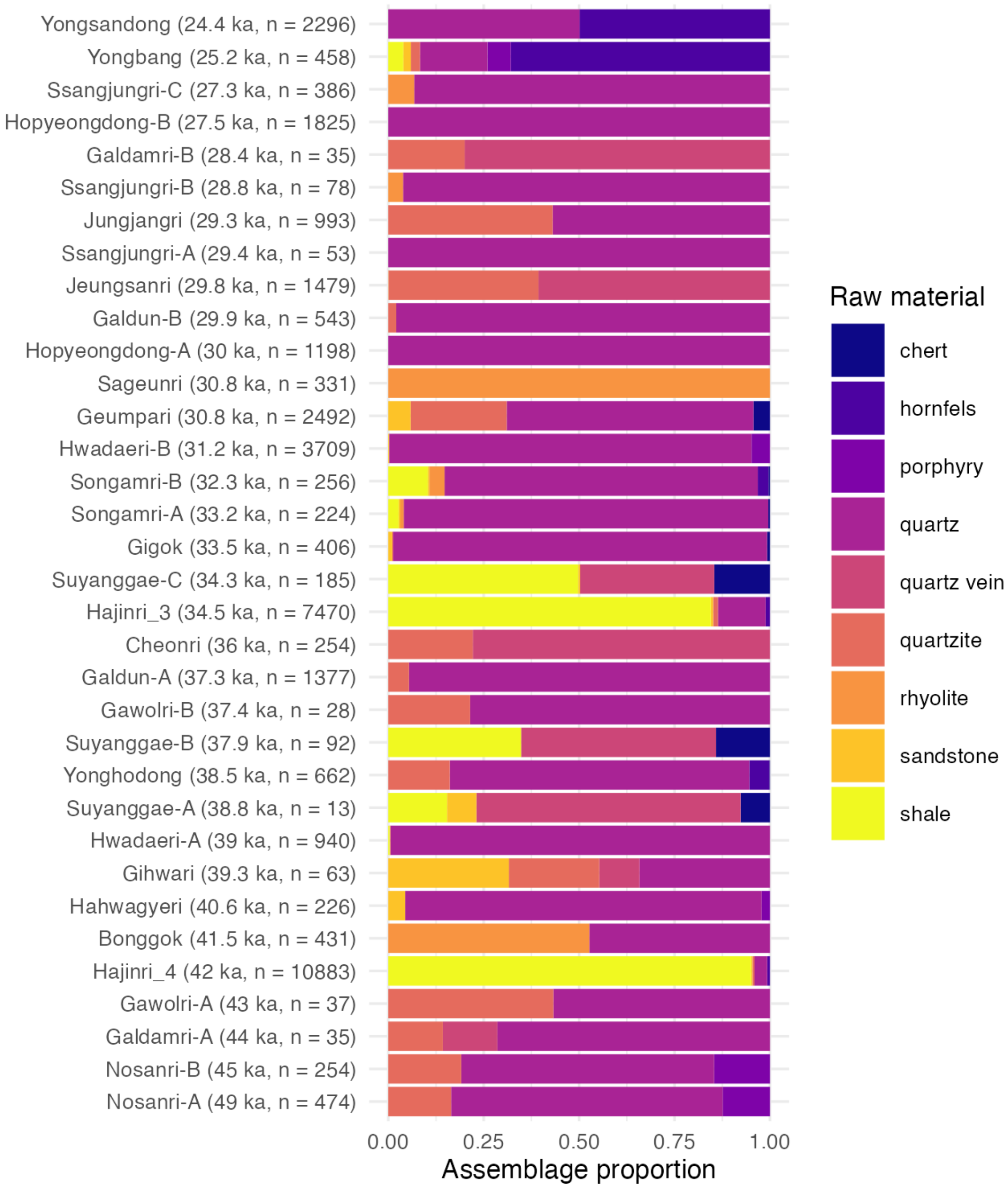

Figure 2.7: The composition of raw material type in each assemblage. We excluded raw materials that are included in less than 5 assemblages including crystal, basalt, ironore, slate, limestone, granite, gneiss, tuff, amphibolite, andesite, grit, metamorphic-rock, quartzitic-gneiss, siliceous-schist, and unidentified ones. Hornfels are shown in four assemblages but since it occupies more than half of the Yongsandong and Yongband assemblages, we included it in the plot. The color represents different types of raw materials, and the assemblages are placed in chronological order.

2.5.4. Environmental Context

Figure 2.8 shows that people occupied sites located at a wide variety of elevations from around 0 to 200 meters above sea level. Elevation correlates with the ecological diversity of plants and animals in Korea (Park and Kim, 2020; Sohn et al., 2019) and thus elevation is a suitable proxy for the environmental context of human behavior. As we saw for artifact density, there is an increase in the upper bound of site elevation in more recent times. The most striking pattern in the elevation data is the substantial difference in elevation between sites with stemmed points and sites without. The distribution of elevations of sites without stemmed points is generally lower than the elevations of sites with stemmed points. Although not a statistically significant difference in elevations ($t(25.702) = -1.695$, $p = 0.102$), this may indicate that forager groups who used stemmed points were generally more able to occupy higher altitudes, while the groups without stemmed points tended to prefer lower altitudes. According to our locally weighted regression, sites without stemmed points reach a maximum elevation of about 150 m at around 39 ka. Sites containing stemmed points reach a maximum elevation of 175 m at 28 ka. While the elevation difference is well within the total range of elevation throughout the Korean Peninsula (which exceeds 500 m in the more mountainous eastern regions), the slightly higher elevation sites occupied by stemmed point users probably provided better views of the valleys in search of large game.

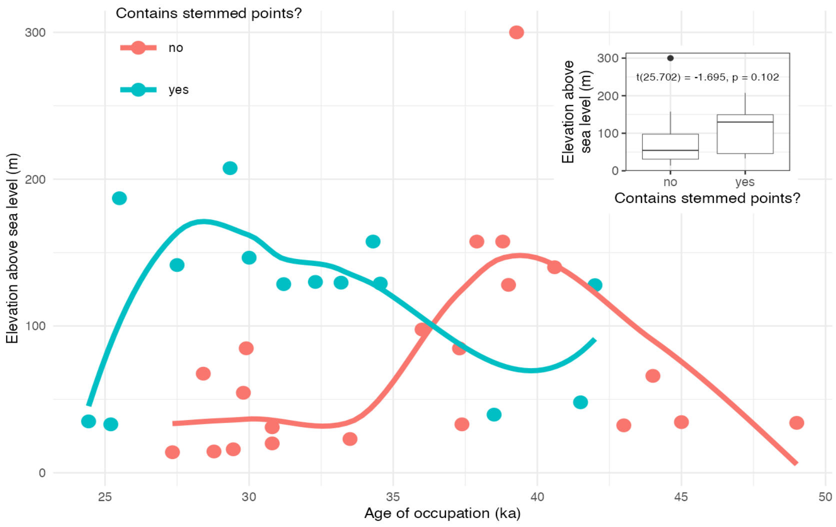

Figure 2.8: Site elevation by the age of the deposit. Color indicates presence/absence of stemmed points. The lines display a locally weighted regression. The inset plot shows a direct relationship between the site elevation and stemmed points.

Among the sites in our sample there is a variation of about 5 degrees in the mean annual temperature (MAT), mostly controlled by elevation (Figure 2.9). Through MIS 3, the temperature gradually decreased until the Last Glacial Maximum (LGM, 26.5-20 ka) (Clark et al., 2009). The MAT of MIS 2, including LGM, was relatively stable. The temperature increased again from late MIS 2 towards MIS 1. Compared to the east side of the Korean Peninsula, the west side tends to be relatively warmer. The range of MAT at the sites over our study period is 2-10°C. Gihwari and Gigok sites have the lowest (3°C) and Jeungsan-ri site has the highest MAT (8°C). The mean MAT for all sites fluctuated within 4°C between 50 ka and 10 ka. The first appearance of stemmed points occurred in the middle of the decreasing MAT trend in MIS 3, at 40-35 ka. Figure 2.9D shows a negative relationship between temperature and elevation. For example, Gihwari Cave site, with one of the lowest MAT distributions, is located in the highest elevation around 300m above sea level. Jeungsanri is located at a lower elevation and has one of the highest MAT distributions.

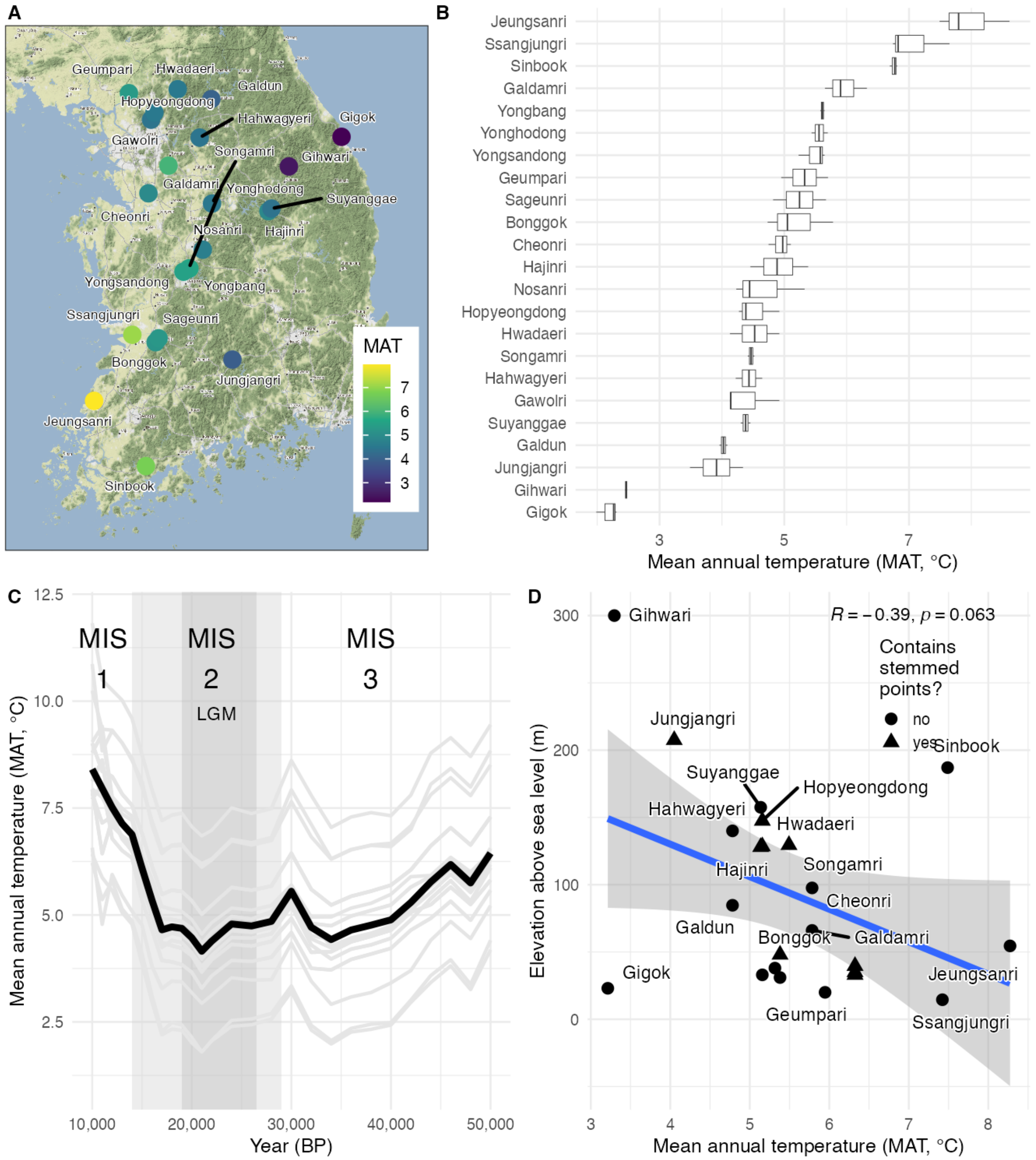

Figure 2.9: Mean Annual Temperature (MAT) of the Korean Paleolithic assemblages mentioned in the text. A: Site locations and their MAT. B: MAT distributions for each site during the period they were occupied. C: MAT from 50 ka to 10 ka. The gray lines indicate the MAT for each site and the black line is the mean temperature of all sites. The light gray area in the middle of the plot indicates the duration of MIS 2, and the dark gray area represents the duration of the LGM. D: The relationship between MAT and site elevation. The blue line is a linear regression on elevation and MAT with the gray area showing the 95% confidence interval.

2.5.5. Demographic Context

Figure 2.10 shows the summed probability distribution (SPD) of the radiocarbon ages from the sites in our sample overlaid with distributions (indicated by the gray envelopes) generated from four models of demographic change for the period 50 ka to 10 ka (linear, exponential, logistic, and uniform). The fit of models to our observed SPD was computed using 1000 simulations, and the resulting global p-values indicate significant deviations in the observed SPD from the modeled distributions. Overall, the linear model is the best fit with the observed SPD, having the lowest AIC value of the three models where we could compute this. We can say that the population did not grow or decline strongly logistically, exponentially or linearly during the Late Pleistocene, but instead followed a noisy distribution. The most striking results here are the SPD showing a steady growth rising to a peak at about 43 ka, indicated by the positive deviations from the three null models (shaded in red), except for the logistic model. During the transition period, SPD hits another peak at about 35ka. Then the SPD goes down with minor deviations to a lower level at 31.5 ka. From 27 ka the SPD constantly fluctuates with temporary positive deviation until 20ka.

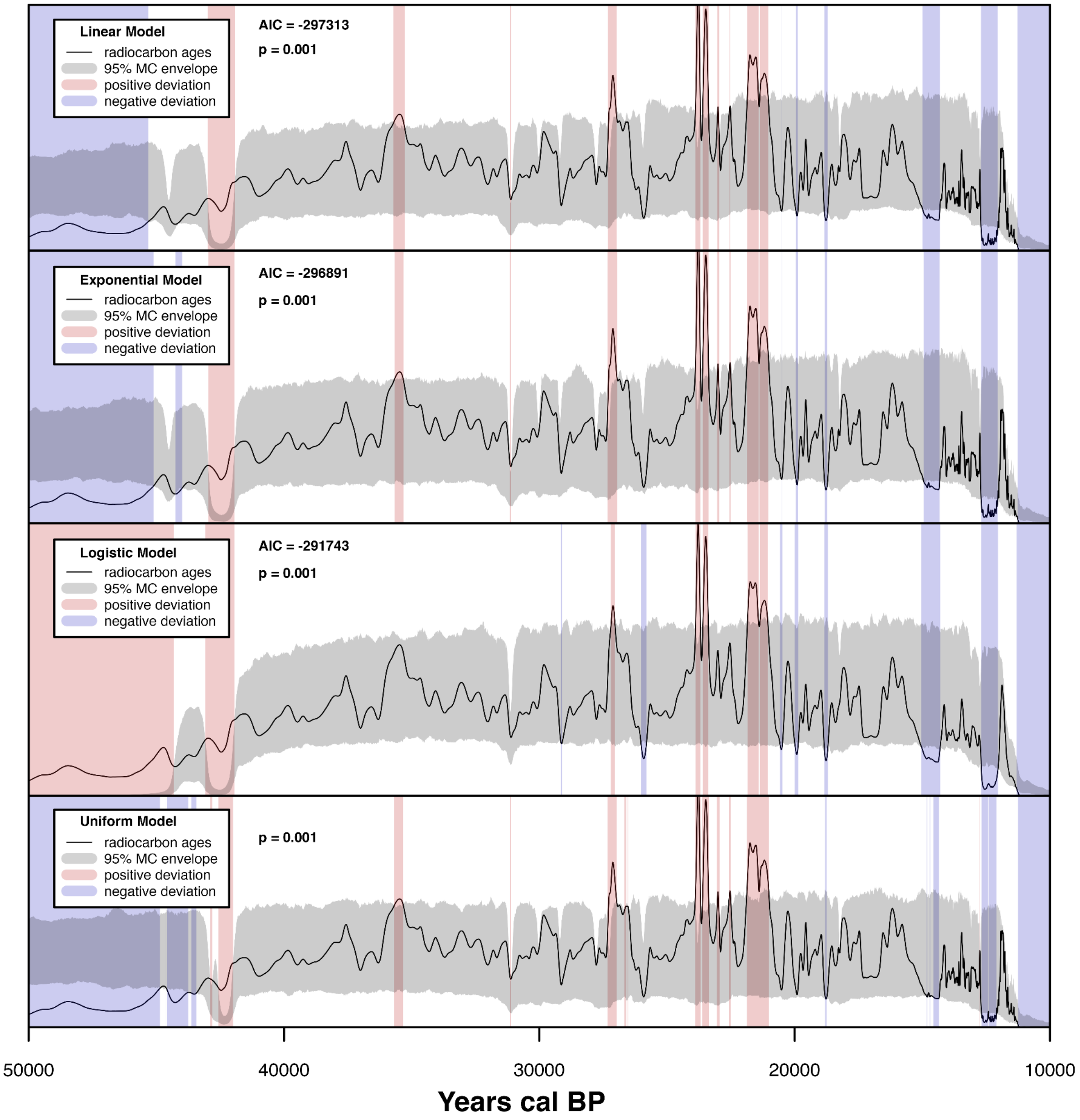

Figure 2.10: Summed probability distribution of 400 radiocarbon dates. The black solid line represents actual radiocarbon ages. The gray shaded region shows the Monte Carlo envelope that encompasses the 95% confidence interval for the null models. The red and blue vertical bands highlight the portions of the SPD where positive and negative deviations are detected. We applied linear, exponential and logistic to AIC along with the logistical growth model (fit) to evaluate each model (Riris and Arroyo-Kalin, 2019). We excluded the uniform model because it has no fitted curve or surface to evaluate. The best fit model has the lowest AIC score. In this case, the linear model is the best fit for the observed data.

2.6. Discussion

Our study focused on two questions: (1) what changes in foragers' landscape use were associated with the introduction of the new tools?; and (2) what changes in people's mobility and use of habitation sites were associated with the new technology? Overall, our results show that assemblages with stemmed points tend to have higher artifact densities and lower proportions of retouched pieces. Quartz and side scrapers, in addition to cores and choppers, remain dominant in assemblages throughout the late Pleistocene. The environmental context of this technological innovation was a gradual decrease in temperature into the LGM. Analysis of radiocarbon ages suggest a population increase before the appearance of stemmed points.

2.6.1. Artifact Volumetric Density and Retouch Frequency

We examined the artifact volumetric density and retouch frequency to understand the difference in mobility strategies and site occupation patterns associated with the introduction of stemmed points. The analyses are based on the premise, established on global ethnographic data, that highly mobile groups carried lightweight toolkits with more retouched and easily replaceable composite tools, and left smaller amounts of artifacts at sites as a result of short-term occupations. These curated technologies reflect an investment of time and effort in stone artifact manufacturing and maintenance to minimize travel costs of carrying the tools for high mobility or special purpose foray groups. On the other hand, less mobile groups produced fewer retouched tools and left higher densities of artifacts generated from long-term occupations. These expedient technologies are more typical for groups with greater residential stability who can make, use, abandon, and remake their tools frequently in the same location (Binford, 1979; Clark et al., 2019; Kuhn, 2014, 1994; Meignen et al., 2006; Torrence et al., 1989; Vaquero and Romagnoli, 2018). As mentioned above, the sites we addressed here are all open-air localities with limited material remains to infer the clear view of subsistence strategies, nevertheless, our data are highly consistent with these concepts of curated and expedient technologies, showing a strong pattern of artifacts from less dense assemblages having higher retouch frequencies, and more dense assemblages having lower retouch frequencies. In general, the new technology of stemmed points was more associated with expedient technological strategies. Our results show that foragers with stemmed points tended to stay in the same site for longer periods with higher artifact densities and fewer retouched pieces, compared to assemblages without stemmed points.

If stemmed points were primarily a hunting tool, as prior work has assumed, we might expect foragers to have been using stemmed points in highly mobile groups and stemmed points mostly found in small assemblages at task-specific sites (Chang, 2013; Lee and Sano, 2019). However, our results show the opposite, namely that this new technology was more often associated with expedient technological strategies, implying that the tools may have been multipurpose. Furthermore, our results show that different sites represent different occupation patterns during the time of technological transition, making it difficult to characterize this period with a single land use strategy. Seong claims that transitions from the expedient to curated technology in the Late Pleistocene were neither a straightforward nor unilineal processes and diverse site types can be more related to different occupation purposes including hunting camps, limited activity stations, caches, and so forth (Seong, 2015). Our findings support Seong, with some sites such as Bonggok and Yonghodong containing only two stemmed points, while Yongsandong has 38 points including broken tips and a base. Yongsandong stemmed points are made from blades, dominating the tool kit with 233 blades and other byproducts related to lithic manufacturing including cores and debris made of the same raw materials (i.e. hornfels) (Bae and Bae, 2012; Kim, 2004). In the specific case of Yongsandong it seems likely that stemmed points were manufactured for hunting purposes, which dominated the function of the site. On the other hand, at Bonggok and Yonghodong stemmed points were only a minor part of activities there.

2.6.2. Toolkit Composition and Raw Materials

Previous work on toolkit composition during the Late Pleistocene of Korea attempted to divide it up into multiple chronological sub-periods. Seong divides five successive assemblage types for the Late Paleolithic in Korea: (1) quartzite and quartz vein artifacts; (2) mostly small quartzite and quartz vein artifacts with some large artifacts such as cores and choppers; (3) stemmed points dominant; (4) typical blade assemblages including stemmed points; and (5) microblade after 30 ka (Seong, 2015). Lee focuses on the Honam region in southwestern Korea and divides the same time frame into two phases; ‘core tool industry with large flake knapping’ during early MIS 3 (59−40 ka), and ‘blade industry with tanged point chiefly’ during late MIS (40−24 ka) (Lee, 2012). Both Seong and Lee mention that core tools made of quartz or quartz vein never disappeared and they point out the appearance of stemmed points and blade technology as an addition, rather than replacement. Our results, covering 49-24 ka and corresponding to the first three types of Seong’s divisions, show that the divisions are subtle, with the continuation of core tools abundantly throughout the Late Pleistocene. In addition, our data show that side scrapers remained as major tools while other tools occupied only a small portion of the assemblages. As stemmed points and blades increased in the toolkits, both choppers and side scrapers went through minor decreases but still remained abundant.

Changes in raw material composition were closely associated with the appearance of stemmed points. Previous studies claim that the existing tools, including choppers, polyhedrals, handaxes and cores were usually made of locally acquired quartzite, while the new tools including stemmed points and other blade assemblages were made of more fine-grained materials such as siliceous shale, hornfels, and obsidian which might be brought from distant sources (Chang, 2013; Seong, 2015). Our data also show that quartz, quartz vein and quartzite were consistently dominant and the use of fine-grained materials including chert, hornfels, rhyolite, and shale, increased after 42 ka, around the time that stemmed points appear. Projectile points, such as stemmed points, benefit from high quality materials which enable high flaking quality, durability and effectiveness of an edge, as well as the creation of well-defined outline forms (Bamforth, 2009). The increased use of finer-grained raw materials likely changed forager mobility patterns to ensure their movements over the landscape supplied them with the materials needed to make stemmed points.

2.6.3. Environmental and Demographic Contexts

We hypothesized that the introduction of stemmed points might reflect a preference for more portable and efficient hunting tools, as an adaptation to environmental or demographic changes. As the first composite tool appearing on the Korean Peninsula, stemmed points represent a major change in stone artifact technology. An important quality of composite tools is that the user can easily replace damaged parts, contributing to an increased maintainability of the tool (Cardillo, 2010; Kuhn and Miller, 2015). Combining the stone projectile with a wooden shaft further materials enhances functionality of the tool by improving penetration by increasing weight and sharpness (Browne, 1940). We predicted that the functional advantage of the new composite tool would have allowed foragers to be more effective in less productive or more marginal landscapes. To explore the environmental and demographic contexts related to the technological transition, we examined the distribution of site elevations, and simulated MAT during the Late Pleistocene. The results show that groups with stemmed points generally reached higher elevations, where the MAT was generally lower. This supports our hypothesis that stemmed points were associated with the occupation of more challenging habitats. Furthermore, through MIS 3 the temperature gradually decreased until the LGM, suggesting that stemmed points may have been part of a suite of adaptations to cooler temperatures at any elevation. We see a similar pattern of new technologies enabling expansion into marginal areas at a later time in north Paleo-Honshu Island, Japan, where the appearance of blade and projectile points at about 25 ka were associated with foragers moving into cold grassland areas (Morisaki et al., 2015).

We investigated forager population dynamics to assess if demographic change might be a relevant mechanism to explain the appearance of stemmed points. The output of our SPD models indicate population increasing before the appearance of stemmed points and remaining at the peak with minor deviations until 35ka and then declining after 35 ka. If population dynamics were a key driver, then we expect the population to see more frequent and constant positive deviations during the transition period. We conclude that population dynamics were not a major mechanism in the appearance of this new technology. Bae claims that stemmed points are the result of the continuous influx of modern humans from a Siberian migration (Bae, 2010). Our results are partly consistent with this scenario, showing a gradual increase in population before the appearance of stemmed points, however with the evidence currently available we cannot discern if this is endogenous population growth or external migration.

2.7. Conclusion

To understand the change in mobility and site occupation related to the appearance of new technologies during the late Pleistocene in Korea, we examined stone artifacts from 23 sites dated to 49-24 ka. The results show that the forager groups with stemmed points tended to be located at higher elevations. The temperature gradually decreased during the technological transition and after the appearance of stemmed points. Overall, the result indicates that the use of stemmed points was associated with occupation of marginal environments. In addition, the groups with stemmed points had expedient technologies which reflect residential and less mobile land use patterns.

Our findings are limited by the relatively small number of sites and radiocarbon ages currently available. The absence of detailed stratigraphic data limit the chronological resolution for the assemblages in our sample. Furthermore, we currently lack functional data on individual artifact assemblages to support our conclusions about site use to evaluate whether stemmed points were primarily hunting projectiles, or multipurpose, as we have proposed here. With future work we may be better able to distinguish a high density of stone artifacts resulting from a long-term/small group occupation versus a short-term/large group occupation. We acknowledge that our coarse resolution of environmental data is not fully satisfying to patternize the subsistence strategies of forager groups. Therefore we aim to increase the spatial resolution of the data from the sites in our future work. Further research should also aim to identify the mechanisms behind the population increase that we have reported here, was it local population growth, or a result of new groups arriving from outside of Korea?

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Chapter 3

Variation in Use of East Asian Late Paleolithic Weapons: A Study of Tip Cross-Sectional Area of Stemmed Points from Korea

An open access pre-print is also available online at https://osf.io/urw95/. This research compendium containing data and R code for reproducing the published results is at https://doi.org/10.17605/osf.io/dqna8.

Abstract

The transition from the Early to Late Paleolithic in Korea is characterized by the introduction of blade technology, stemmed points, end scrapers, burins, denticulates, and higher proportions of finer grained materials. Stemmed points have been considered a representative tool that led this set of changes. In this study, we examine the possible role that stemmed points played during this technological transition, as well as throughout the Late Paleolithic period. Our main questions are: What were the best-fit ballistic probabilities for the stemmed points if they were hafted as weapon tips? How diverse were their likely uses? What are the temporal and spatial patterns of stemmed point use? We measured tip cross-sectional area (TCSA) to distinguish different likely use classes of projectile points, for example, as poisoned arrow tips or as stabbing spears. We analyzed TCSA with other variables, including raw materials, weight, radiocarbon dates and locations. Our results show that the stemmed points likely served as javelin tips and stabbing spear tips, with smaller numbers as dart tips and un-poisoned arrow tips. TCSA values were controlled mostly by size rather than raw material types. We found different TCSA ranges of stemmed points at different sites, which could indicate people used stemmed points in different ways depending on the local environment. Some sites show a wide range of TCSA values that represent multi-purpose usage of stemmed points. The temporal pattern of TCSA values is one of little change throughout the Late Paleolithic period, but points were predominantly produced before the Last Glacial Maximum (LGM). We observed that stemmed points were mostly located in certain ecoregions in Korea, but no clear spatial pattern was apparent. We conclude that stemmed points were multi-functional tools, with many likely designed for use as javelin and stabbing spear tips.

3.1. Introduction

The introduction of new stone artifact technologies marked a major transition in the Korean Paleolithic, from the Early (approx.350~40 ka) to the Late Paleolithic periods (approx.40~12 ka). The transition includes blade technology, stemmed points, end scrapers, burins, denticulates, etc. (Bae et al., 2017; Bae, 2017; Lee et al., 2017; Nakazawa and Bae, 2018; Seong and Bae, 2016). Stemmed points are considered to be the first evidence of a suite of new technologies defining the Late Paleolithic period in this region (Seong, 2008; Seong and Bae, 2016). This is related to the fact that stemmed points appear to originate from Korea and spread throughout Northeast Asia, and they have a close association with mobility, site formation, and occupation diversity

(Chong, 2021; O'Driscoll and Thompson, 2018; Park and Marwick, 2022). Despite the importance of stemmed points, only a few studies to date have examined their likely uses. Previous work mostly discussed their origin, the chronology of the Korean Late Paleolithic, and their relationship with the Japanese archipelago (Chang, 2013; Chong, 2021; Lee and Sano, 2019; Park, 2013).

The purpose of this study is to examine the possible uses of stemmed points to understand what role they may have played in the technological transition from the Early to the Late Paleolithic in Korea. We use the tip cross-sectional area (TCSA) metric to infer weapon-use strategies based on comparison with other archaeological and ethnographic assemblages, assuming that different ranges of TCSA values correspond to different weapon types (Lombard, 2021). We then explore the relationship between the TCSA range and raw materials, artifact size and discard location, and how these changed over time in Korea. Our main questions are: What were the best-fit ballistic probabilities for the stemmed points if they were hafted as weapon tips? How diverse were their likely uses? What are the temporal and spatial patterns of stemmed point uses? We examine possible links between the roles of stemmed points and environmental change, especially the Last Glacial Maximum, or population dynamics during the Late Paleolithic period. To understand how a certain weapon-tip type was chosen, we apply an evolutionary perspective with the assumption that people chose their weapon tip types as part of their adaptation to their socio-environmental circumstances.

3.2. Stemmed Points in Korea and East Asia

Stemmed points (Sumbejjirugae in Korean) are projectile points made on an elongated blade-like flake or blade with two parallel facets and a single or two ridges that converge to form an inverted "Y" (Pratt et al., 2020) (Figure 3.1). Slight retouch is typically performed on the distal end to shape an acute tip and on the proximal end to make a stem, which connects to a wooden shaft. Elsewhere in the world these types of artifacts are often called "tanged points", but we prefer "stemmed points" to distinguish them from Bronze Age stone projectile points known as "tanged points" in Korea (Park and Marwick, 2022). Understanding the appearance of stemmed points is relevant to general questions about the direction of projectile technology, the technological transition into the Late Paleolithic, and relationships between Korea and adjacent regions in East Asia, such as Japan.

Stemmed points are the first composite tools in the Korean Paleolithic. They require two different parts to be form one complete tool: a stone point and a shaft, presumably made out of wood (Seong, 2008). Using blades as the blank for the point enables mass production of this composite tool and its shape can become more standardized (Lee, 2015; Park and Marwick, 2022). Therefore, as O'Driscoll and Thompson (2018) claimed, understanding the emergence of projectile technology provides insights into greater cultural, evolutionary, and behavioral cognitive flexibility.

Since the first appearance of stemmed points defines the beginning of the Korean Late Paleolithic, investigating their origins is critical to understanding the technological transition from the Early Paleolithic, modern human dispersals into the region, and claims for the existence of the 'Middle' Paleolithic in Korea (Bae, 2017; Bae, 2010; Norton and Jin, 2009; Seong and Bae, 2016). The debate around the origin of stemmed points can be summarized into two competing models (Bae et al., 2013; Lee, 2016) : (1) a 'heterogenic' migration (Bae, 2010), and (2) an *in situ* evolution model (Seong, 2006). The migration model claims that the new blade industry - including stemmed points - and the earlier coarse flake tradition - including large cores, polyhedrons, choppers, and even handaxes - came from different origins. These are (1) a Northern route: Siberia, Mongolia, or other regions of northeast China, and (2) a Southern route: southern China) as the result of a continuing influx of modern human migration from two routes.

The *in situ* model argues that stemmed points and other Late Paleolithic technologies, such as blade industries, autonomously emerged in the south of the Korean peninsula, with no apparent external influence. The difference between the two models comes from how they explain a few early sites and stemmed points made out of flakes. The *in situ* model argues that stemmed points appeared before blades, and identifies early sites such as Bonggok, Songamri, Yonghodong, and Hwadaeri as evidence that the Korean Late Paleolithic began with the emergence of stemmed points. In contrast, the migration model contends that the Late Paleolithic began with the introduction and widespread use of blade technology similar to the traditional definition of the Late or Upper Paleolithic in Europe and the Later Stone Age in Africa, without counting the stemmed points made out of non-blade materials. (Seong and Bae, 2016). Besides these two main models, there are a combination of migration and trade interaction models (Bae and Bae, 2012) and complex and non-directional models (Lee, 2016).

Stemmed points are important proxies to understand human behaviors during the Late Paleolithic. Park and Marwick (2022) examined mobility and site occupation patterns by applying concepts of human behavioral ecology to lithic assemblages. The study found that forager groups using stemmed points may have been associated with the occupation of marginal or extreme environments, in contrast to groups with no stemmed points. Also, stemmed points were more frequently associated with expedient technologies, indicating residential and less mobile behaviors. Chong (2021) claims that the morphological variation of the stemmed points along with tool types in lithic assemblages, assemblage size, use of raw materials, and types of blanks could represent specific characteristics of occupation, such as a “limited activity station” and a “residential base camp.” For example, stemmed points with high morphological variations in tool size, shape of edge, degrees of damage, and types of edge retouching from the Yongsandong site may indicate that the site was used for specific or limited activities, such as hunting (Chong, 2021; Kim, 2004; Seong, 2015).

The connection between stemmed points in both Korea and Japan has been studied since the late 1980s as a part of evidence for long-distance/maritime cultural interchanges or social networks (Chang, 2013; Lee, 2015). Stemmed points from the Bonggok site in Korea are currently accepted as the oldest ones within Northeast Asia, dating to ca. 41.5 ka, and are made from elongated flakes (Bae et al., 2017; Seong, 2015, 2009). After their first appearance in Korea, stemmed points (Hakuhensenntouki in Japanese) appeared in Kyushu, Japan during the late Marine Isotope Stage (MIS) 3. In addition to the stemmed points, there are similar artifacts found in both regions, such as microblade cores, Moppule-seokgi (Kakusuijyosekki in Japanese), backed knives, bilateral points, bifacial points, and transport of obsidian (Chang, 2013; Kim and Chang, 2021; Lee, 2015, 2012).

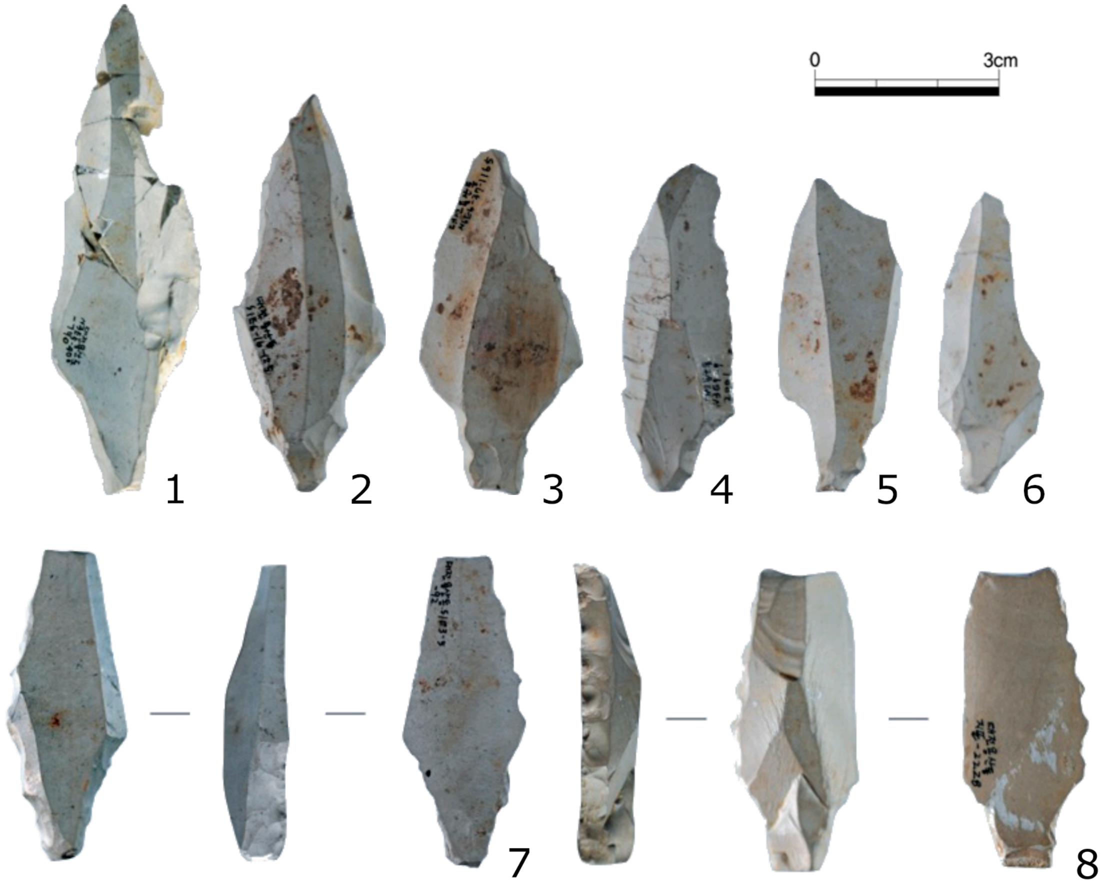

Figure 3.1: Korean stemmed points. Excavated from Yongsandong site. 1-6: plain stemmed points, 7-8: one-sided denticulate stemmed points.

3.3. Previous Studies about the Function of Stemmed Points

Though stemmed points have generally been assumed to have been hunting armatures (Chang, 2013; Lee and Sano, 2019; Lee and Jang, 2011a; Lee and Kong, 2002a; Seong, 2008), it is difficult to determine their likely uses without knowing their complete shape when attached to other components. Preserved wooden components of prehistoric projectile tools are too few and rare to standardize their overall scale and variability (Shea, 2006). Lee and Kong (2002b) claim stemmed points should be considered more generally as 'stemmed tools' because of the uncertainty of their complete shape. Other researchers propose that non-symmetrical stemmed points - with retouch on one side or denticulate blades on one side - should not be referred to as stemmed points but rather as stemmed knives, stemmed side-scrapers, stemmed end-scrapers, or stemmed burins (Figure 3.1: 7-8) (Kim, n.d.; Lee and Jang, 2011b; Seong, 2008).

Stemmed points are typically symmetrical from tip to tang, with the central axis serving as a line of symmetry (Lee and Jang, 2011b). There is a high percentage of broken tips and stems, and the reused tools were repaired in accordance with symmetry (Kim, 2017; Park, 2013). Studies of stemmed point manufacturing processes and the patterns of broken pieces show that stemmed points may have been used mainly as spear tips (Chang, 2002; Lee, 1985). For example, at Yongsandong site, only 10% of the tools are complete, while 33% of the tips are missing. In the case of Jingeuneul, the percentages are 16% and 50%, respectively (Park, 2013). In addition to the morphological aspect of stemmed points, investigations of a whole site and the tool composition of an assemblage suggest that stemmed points or stemmed tools could be strongly associated with hunting activities including peeling the animal skin after slaughtering or separating the bones from the flesh (Chong, 2021; Seong, 2008).

3.4. Tip Cross-Sectional Area

The tip cross-sectional area (TCSA) of stone artifacts has been used as a ballistically relevant standard to probabilistically discriminate between likely weapon-tip types, such as spear-thrower (a.k.a. atlatl) dart tips, un-poisoned arrow tips and large stabbing/thrusting spears (Lombard, 2022, 2021, 2020; Lombard et al., 2022; Lombard and Moncel, 2023; Lombard and Shea, 2021; Metz et al., 2023; O'Driscoll and Thompson, 2018; Sisk and Shea, 2011). It is critical to note that the TCSA metric alone cannot unambiguously determine artifact function; it only suggests a best-fit ballistic probability for the points if they were hafted as weapon tips. The TCSA metric represents the part of the tool that cuts the target's hide and is related to weapon flight and penetration dynamics (Hughes, 1998; Lombard, 2021; Sitton et al., 2020). This method was first proposed by Hughes (1998) and validated by Shea (2006) through the comparison of archaeological examples with ethnographically collected samples of known use. Lombard et al. demonstrated the efficacy of TCSA by analyzing Middle Stone Age points from Sibudu Cave in KwaZulu-Natal, South Africa, which are dated to approximately 35-50 ka. They compared the results obtained from experimental and use-trace studies such as organic residue analysis, macrofracture analysis and use-wear analysis with TCSA values [Lombard (2021); Lombard (2004); Lombard (2005)). Shea (2009) also applied the approach to compare projectile points from Africa, the Levant, and Europe, claiming that projectile weapons first appeared in Africa.

One of the key advantages of the TCSA metric is its convenience of application: regardless of the point type, only the maximum width and thickness measurements are required to calculate the TCSA value (0.5 x maximum width x maximum thickness) (Lombard, 2020; Sisk and Shea, 2011). Later, Sisk and Shea (2011) proposed an alternate metric, tip cross-sectional perimeter (TCSP), for a more precise measure of the force required to penetrate a target to a lethal depth, whereas the TCSA metric is more associated with cutting. However, TCSP has a few disadvantages that limit its applicability to our case study of Korean stemmed points. The force and penetration depth are not only affected by the stone tip, but also by the mass of the shaft, which cannot be known for most archaeological stone-tipped weapons because they have not been preserved in the archaeological record (Lombard, 2020). Sisk and Shea (2011) also mentioned that TCSP cannot be applied to backed pieces that were hafted as projectile armatures.

Lee and Sano (2019) first applied TCSA to stemmed points from Korea along with use-wear analysis. They analyzed stemmed points from Jingeuneul, located in the southwest of Korea, which has the largest number of stemmed points (n = 99) found at a single site to date. For the TCSA, they were only able to use ten stemmed points since they selected stemmed points that retained the widest and thickest parts of the specimens and showed diagnostic impact fractures for the use-wear analysis. Their purpose in using TCSA was to compare the values to North American dart tips and arrowheads. Their results show that the range of TCSA values for Jingeuneul stemmed points is relatively wide, overlapping with both North American dart tips and arrowheads. According to their use-wear analysis, a significant number of the stemmed points have diagnostic impact fractures (DIFs) on the surface, likely caused by longitudinal forces from the shaft. Based on the results, they conclude that stemmed points may have been used as spear-throwers or bows. Inspired by Lee and Sano (2019) and TCSA research from lithic assemblages in other parts of the world, we aim to investigate TCSA values for a much larger sample of stemmed points from all over South Korea to better understand their likely uses during the Late Paleolithic.

3.5. Methods

3.5.1. Archaeological Sites

After the first discovery at the Seokjangri site in the 1960s, more than 450 stemmed points have been found at over 30 sites throughout South Korea (Chong, 2021; Lee and Sano, 2019; Sohn, 1967). Most sites contain only a few stemmed points and only a few sites have many more, such as Jingeuneul, Suyanggae (n = 55), and Yongsandong (n = 38) (Kim, 2017). Among these stemmed points, we selected those that retained their widest and thickest parts. We included stemmed points discovered during field surveys as well as those found at sites that were never dated but were associated with other Late Paleolithic artifacts. Applying these sampling criteria resulted in a sample of 173 stemmed points from 36 assemblages unearthed from 29 sites spanning the period 44-10 ka (Figure 3.2). The dimensions of the 173 stemmed points were obtained from published excavation reports and by direct measurements during our visits to the collections of local museums and archaeological institutions in Korea.

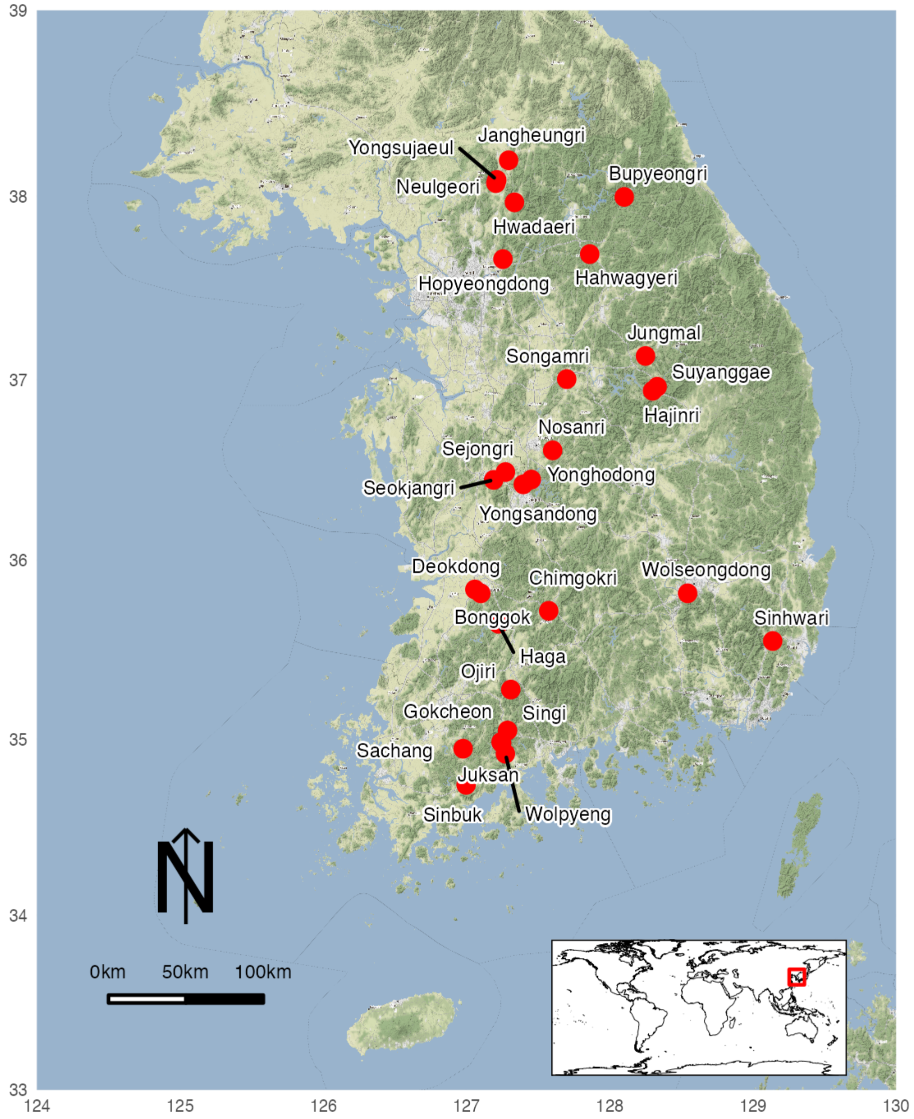

Figure 3.2: Korean Paleolithic sites mentioned in this study

We distinguished between multiple assemblages at a single site where numerous excavations have taken place in different locations at the site, and by different institutions under the same site name. For example, Suyanggae site, a registered Korean National Heritage site, has been excavated more than ten times since 1980 by the local university museum, and later, by archaeological research institutions. There are six different excavation locations that range from a few meters apart to a few kilometers. Similarly, we identified multiple assemblages in a single excavation or even a trench where archaeological deposits were separated by culturally sterile deposits, or where distinct artifact-bearing stratigraphic units could be identified by major differences in the texture, color, and composition of the sedimentary deposits. As a result, in this research we used four assemblages from Suyanggae. We separated one assemblage from the four by using a different site name, Hajinri, following the convention established by the excavators at that location. Hajinri is the sixth excavation location at Suyanggae, which is 3.5 kilometers apart from the other areas and dated much earlier (around 42-30 ka) than the other assemblages (around 31-15 ka). According to the excavation reports for Hajinri, stemmed points first appeared there around 42 ka with the earliest blades and blade cores (Lee et al., 2018). While we include data from Hajinri here, we consider this assemblage as an unusual outlier because the stemmed points and blades from Hajinri are highly standardized and refined, which are only found at other sites much later in time. We have more confidence in finds from Bonggok, which has the second-earliest dates (around 41.5 ka) in our collection as the first appearance of stemmed points. Bonggok includes blades or elongate flakes, but without any accompanying blade cores (Park and Marwick, 2022).

3.5.2. Investigating Patterns in TCSA Values

To answer our research questions about the likely uses for stemmed points, we calculated TCSA values for the stemmed points in our sample. We also explored the interaction of TCSA values with raw materials and artifact size, using weight as a proxy. Because the shape of stone artifacts is highly influenced by the raw materials (McPherron et al., 2014), we assumed that raw materials may be highly correlated with tool size. We investigated radiocarbon ages associated with the points in order to determine temporal patterns in TCSA values. We separated the research time period into three phases, based on the major climate event during the Late Pleistocene, the Last Glacial Maximum (LGM). Previous research on the LGM climate in Korea, using age-controlled pollen records (Yi and Kim, 2010) and computational simulation models (Kim et al., 2015; Park and Marwick, 2022), indicates that the climate was colder and drier than the preceding period. Surface temperature cooling ranged from 5 to 6°C, and there was a precipitation decrease of approximately 14%. Using this chronology, we examined the distribution of TCSA values before, during, and after the LGM. We then explored the relationship between TCSA values and the location of assemblages by comparing the distribution of TCSA values across ecological and vegetation zones.

Table 3.1: TCSA ranges from Lombard et al. (2022)

Weapon type	N of tools	Mean TCSA	SD	TCSA Range
Poisoned arrow tips	565	11	7	4-18
Un-poisoned arrow tips	338	32	15	17-47
Dart tips	40	58	18	40-76
Javelin tips	270	66	24	42-90
Stabbing spear tips	141	140	60	80-200

To aid in interpreting our results, we referenced the TCSA ranges for different weapon-delivery systems that Lombard et al. (2022) and Lombard (2021) created by summarizing the analysis by Wadley and Mohapi (2008) of backed microliths (Table 3.1). We excluded 12 artifacts from our dataset with TCSA greater than 250, which were outside of the range of our comparative data. For this comparison with weapon-delivery systems, we included TCSA values from a total of 161 stemmed points from 33 assemblages unearthed from 25 sites.

3.5.3. Raw Materials

Selective use of raw materials is a key characteristic of the technological transition of the Korean Late Paleolithic. Prior to the Late Paleolithic, people mostly used quartzite and vein quartz for stone artifacts. Then, finer grained materials were added to assemblages for producing the newly introduced tools (Seong, 2004). We analyzed TCSA values of 160 artifacts with raw material information to examine the interaction of raw material types and TCSA values. We categorized rare raw materials, which have less than 10 artifacts, as "Other."

3.5.4. Weight

Different sizes of stone artifacts can constrain or enable different functions. Overall size of stone points has been used as a potential proxy for identifying different types of armatures (Sahle and Brooks, 2019; Thomas, 1978). We chose weight as a proxy for the overall size of the stemmed points. As a reliable discriminator between tools of different sizes as well as a descriptive attribute, weight can be measured rapidly and objectively (Fenenga, 1953; Shea, 2006). We then explored the relationship between weight and raw materials on TCSA values. Excluding points that we were not able to directly measure or obtain records of their weight, we explored the relationship between TCSA and weight for 152 artifacts.

3.5.5. Temporal Patterns

We used radiocarbon ages to investigate the temporal patterns of the likely uses of stemmed points. After excluding assemblages that have no radiocarbon dates, we used 26 assemblages dated from 45ka to 14.8ka to explore variation in TCSA over time. We divided the artifacts from dated assemblages into three groups based on the LGM: before, during and after, to examine the impact of this major climate event on TCSA values.

3.5.6. Spatial Patterns

We summarized the distribution of TCSA values for each assemblage to analyze spatial patterns in TCSA values. Among the 25 sites, we combined those that contained fewer than five stemmed points and named them “Other.” We explored the possible effect of environmental variation on TCSA values by grouping stemmed points by the eco-regional zones that they were found in, and comparing the distributions of TCSA values across the different zones. We compared the distributions across four vegetation zones and 16 zones that differed in terms of their geographical characteristics.

The vegetation zones are based on Yi and Kim’s (2010) classification of South Korea into three zones: Central Temperate Zone (CT), South Temperate Zone (ST), and Subtropical-warm Temperate Zone (SWT). These divisions are based on Yim and Kira’s (1975) forest vegetation map, defined by recent temperature and precipitation values.

We also explored spatial patterns using 16 geographical zones based on geographical characteristics including inland, coastal areas, major rivers, islands, and major mountain ranges in addition to ecological information including temperature and precipitation (Lee et al., 2008). The sites in our sample occur in 14 of these zones: Imjin river basin (IRB), Metropolitan (MP), Central inland (CI), Kangwon coastal (KC), Choongnam coastal (CC), Southwestern inland (SWI), Upper Nagdong river basin (UNRB), WoolYoung coastal (WYC), Western Cholla (WC), Southern mountain (SM), Southeastern inland (SEI), Hyungsan Taewha coastal (HTC), Western south coastal (WSC), and Eastern south coastal (ESC). Then, we used longitude and latitude to locate individual assemblages and examined TCSA values for each zone. We note that modern eco-regional maps may not fully resemble the Pleistocene landscape in which the points were made and used. Unfortunately, reconstructions of Pleistocene landscapes are not available for our study area. We assume the underlying environmental factors such as altitude, slope, drainage, hydrology, and bedrock are relatively stable over time, and are suitable as an analogy for initial hypothesizing about relationships between Pleistocene geographical variation and stone artifact technology.

3.5.7. Modelling Weapon-Tip Type Selection

The process of introducing novel technologies can vary based on the social and environmental context in which the transmission of manufacturing techniques for the new tools takes place. Furthermore, the new tools themselves can alter the typical contexts of tool use. In America, for example, the advent of bows and arrows provided non-elite hunters with the opportunity to produce their own subsistence or pursue individual wealth without the necessity of hunting in teams (Angelbeck and Cameron, 2014; Bettinger, 2013; Rorabaugh and Fulkerson, 2015). Taking an evolutionary approach, we assume that, given an opportunity to explore alternative technologies, human groups selected a specific stone tool technology based on its advantages over other alternatives, according to their performance in a variety of domains, such as physical and social functions (Lombard et al., 2022). Thus, the selection of weapon-tip types is likely to reflect the socio-environmental circumstances that people encountered and managed. In one example, Eren et al. (2022) compared the morphological variance of Clovis and Folsom points and claimed that Clovis points were more variable in shape than Folsom points because Clovis foragers were exposed to largely unfamiliar landscapes. Clovis points were used as multifunctional tools that performed a wider range of tasks, including cutting and sawing. On the other hand, Folsom points show a narrower range of variation, indicating they were more likely used for a small set of specific tasks.

Inspired by Eren et al. (2022)'s approach, we hypothesized simple scenarios that might explain the temporal and spatial patterns of TCSA range in Korea. If stemmed points have a narrow range of TCSA values, then people likely produced tools that performed a small set of specific tasks. This may be related to low levels of uncertainty in the forager's social and physical environments. On the other hand, a wide range of TCSA values may indicate that stemmed points were multifunctional tools, suggesting that people were responding to unfamiliar situations, such as moving into an unfamiliar landscape or unpredictable variation in patch productivity and travel times (Bettinger and Grote, 2016; Bird and O'Connell, 2006; Kelly, 2007).

We predict a temporal pattern of more variable TCSA values at the first appearance of stemmed points, suggesting that the tools were being used as part of an adaptation to moving into unfamiliar landscapes, with unpredictable variations in patch productivity and travel times. The variability of TCSA values, as measured by coefficients of variation (CV), in the LGM is predicted to increase as lower temperatures alter the distribution of resources and reduce the predictability of resource encounters. After the LGM we anticipate a reduction in the range of TCSA values, with higher temperatures and increased bioproductivity.

In response to heterogeneously distributed food resources, TCSA values are predicted to vary across vegetation types and geographical zones. In harsh environments with lower patch productivity, similar to the case of the LGM duration, we expect to observe a further increase in the variability of TCSA values. On the other hand, we predict a reduction in the range of TCSA values in affluent patches with predictable types of prey. In their study of hunter-gatherer mobility strategies, Hamilton et al. (2016) show that resources are abundant and predictable along coasts or lake shores, which is highly dependent on temperature and precipitation and thus hunter-gatherers often become effectively sedentary. Therefore, our prediction is that the range of TCSA values will be narrower in coastal areas such as vegetation zones ST and SW and geographical zone ESC, compared to inland areas such as vegetation zone CT and geographical zone CI.

3.5.8. Reproducibility and Open Source Materials

The entire R code (R Core Team, 2021) and data files used for all the analyses and visualizations contained in this paper are openly available at https://doi.org/10.17605/osf.io/dqna8 to enable re-use of materials and improve reproducibility and transparency (Marwick, 2017). All of the figures, tables, statistical test results presented here can be independently reproduced with the code and data in this repository. The code is released under the MIT license, the data as CC-0, and the figures as CC-BY, to enable maximum re-use.

3.6. Results

3.6.1. TCSA Range of Korean Stemmed Points

Figure 3.3 shows TCSA values for all stemmed points in our sample, with shaded rectangles to assist in the interpretation of their likely uses. Overall we see a wide variation in TCSA values. The sample mean of TCSA is 95.5, and the standard deviation of TCSA is 44.1. According to the TCSA ranges presented in Table 3.1, Korean stemmed points are mostly found in the categories of javelin tips and stabbing spear tips, with smaller numbers as dart tips and un-poisoned arrow tips. Among the weapon-tip types, only poison arrow tips appear to be absent from these Korean assemblages.

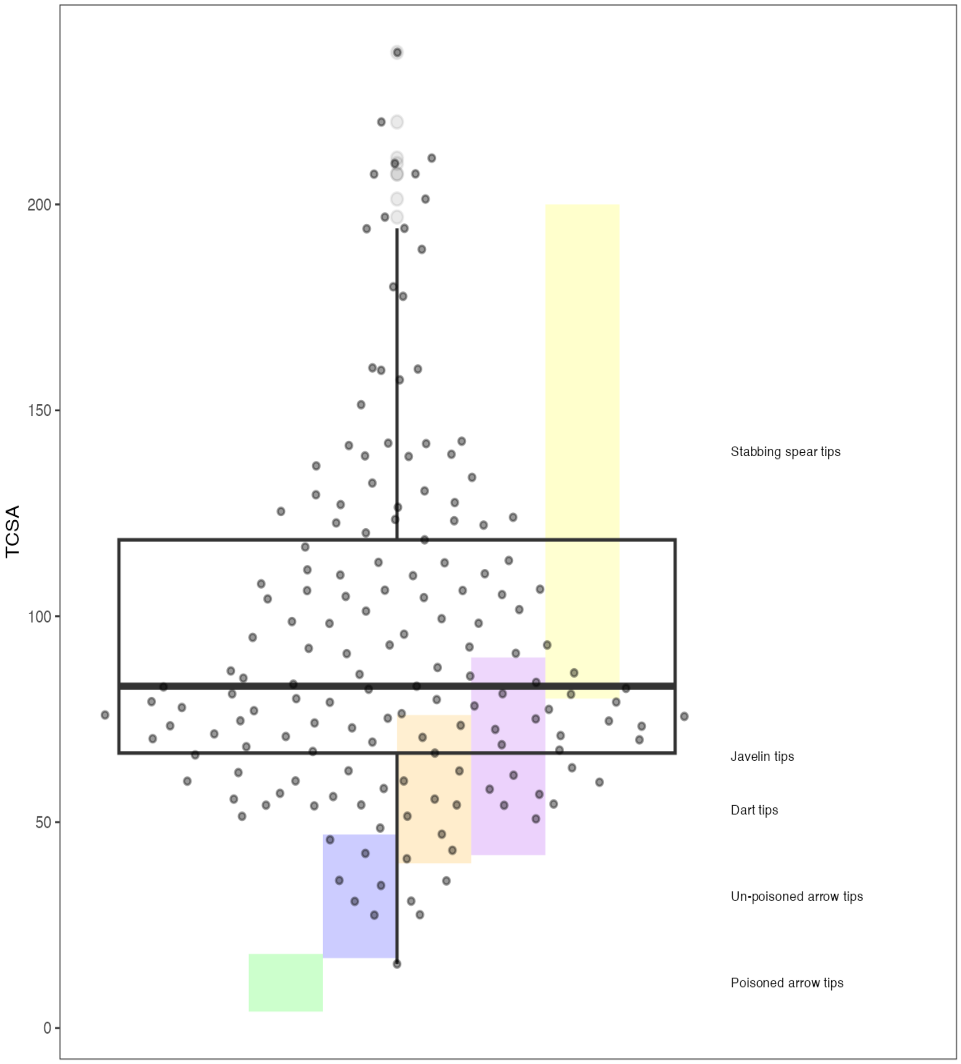

Figure 3.3: Distribution of TCSA values for all Korean stemmed points in the current dataset. The shaded boxes in color indicate TCSA ranges for different weapon types based on Table 3.1.

3.6.2. Variation in TCSA Values by Artifact Size

Using weight as a size proxy, we examined the relationship between size and likely use of the stemmed points inferred from TCSA values. We conducted a univariate cluster analysis (Song and Zhong, 2020; Wang and Song, 2011) of stemmed points by weight, revealing three clusters of artifact sizes (A of Figure 3.4, mean = 10.1, SD = 7.3). Cluster 1, the smallest (lightest) artifacts, has a lower range of TCSA values compared to Cluster 2 (B of Figure 3.4, mean = 94.5, SD = 42.8). TCSA values for Cluster 3 are the highest, except for one artifact, which is lower than 50.

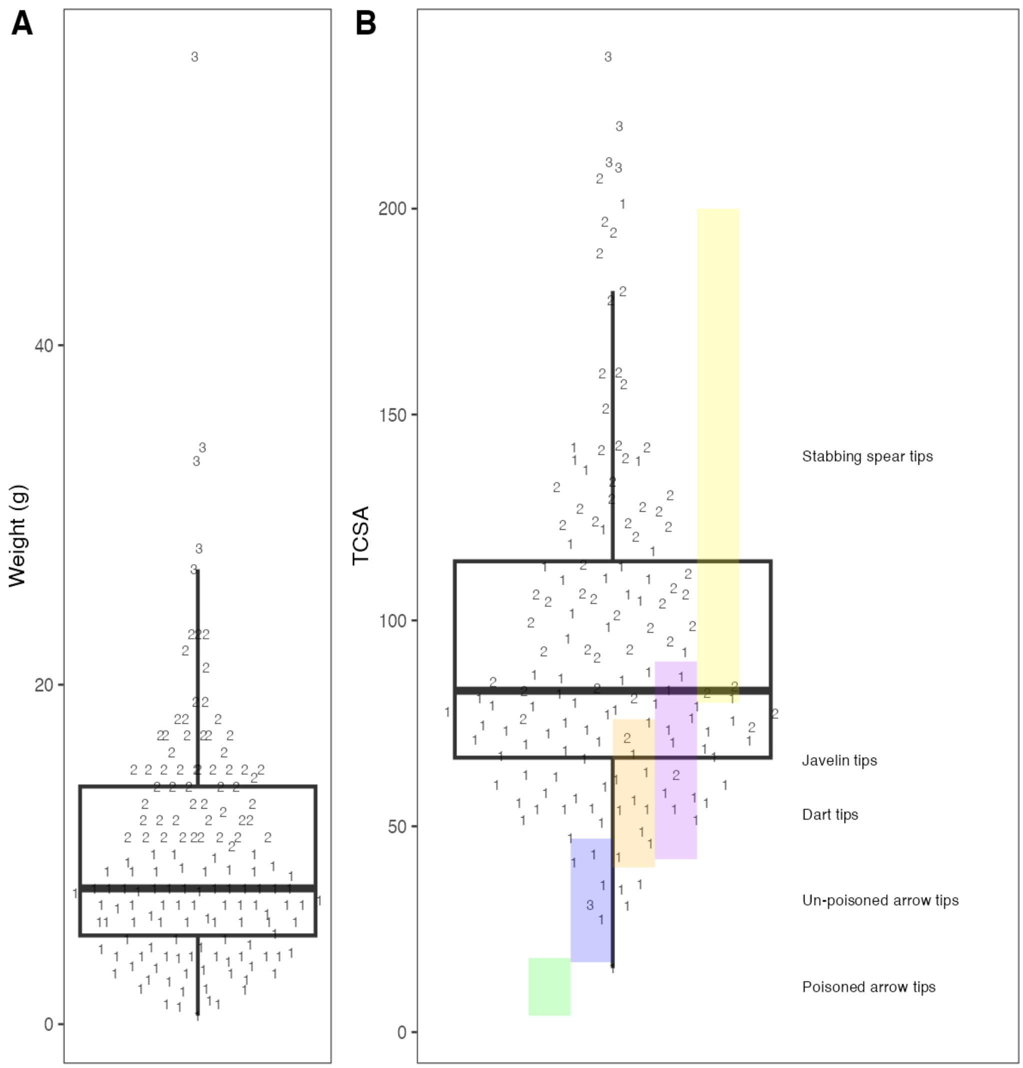

Figure 3.4: Variation in TCSA value by size. A. Distribution of artifact weight showing three clusters. B. TCSA values for all artifacts. Artifact size classes indicated by the digits representing data point values. The shaded boxes in color indicate TCSA ranges for different weapon types based on Table 3.1.

3.6.3.Variation in TCSA Values by Raw Material

Figure 3.5 shows that about half of the stemmed points were made from shale and its TCSA range is widely distributed. The TCSA values of acidic volcanic rocks are commonly skewed lower. Other raw materials, including hornfels, rhyolite, and tuff, show a wide distribution, similar to shale. The category of "Other" raw materials includes porphyry, trachyte, felsite, chert, quartz, quartzite, granite, mudstone, and unidentified rocks. Overall, there is no clear pattern of TCSA values among different raw materials (F(5, 154) = 2.72, p = .022).

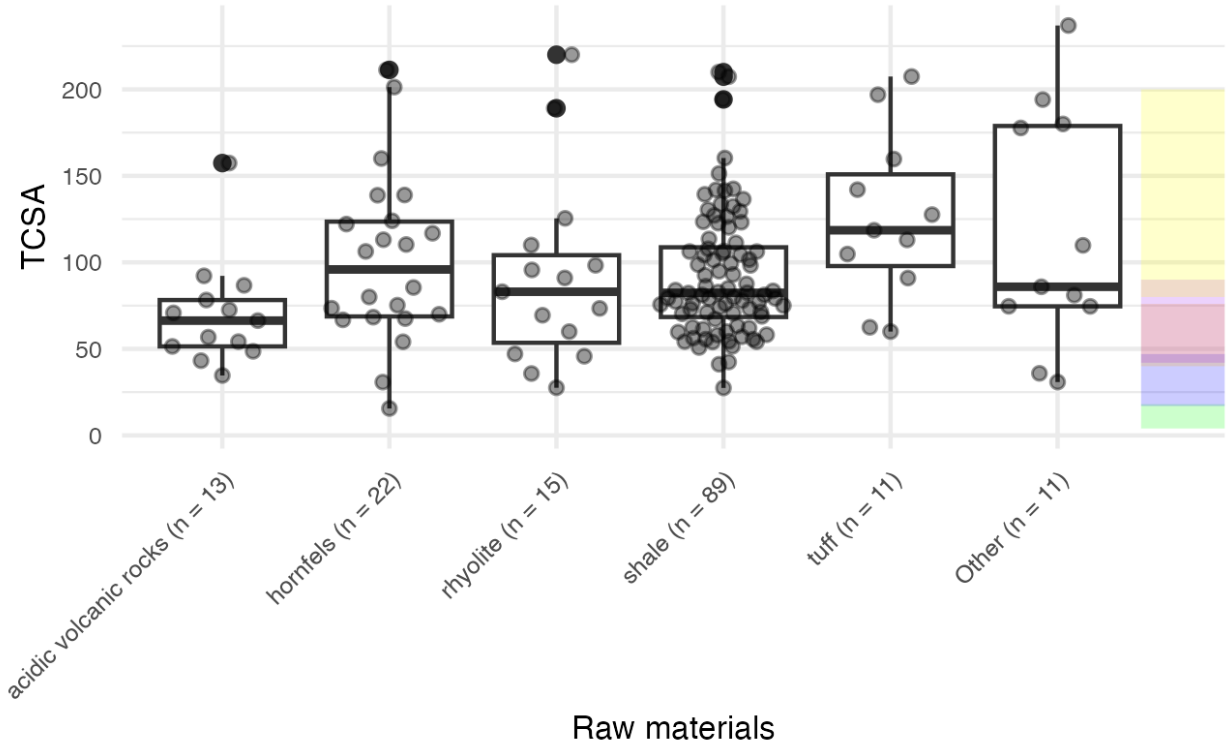

Figure 3.5: TCSA values by lithic raw material. The shaded boxes in color indicate TCSA ranges for different weapon types based on Table 3.1.

Figure 3.6 shows positive relationships between TCSA for raw material and artifact weight. There is a stronger correlation between TCSA and artifact weight for acidic volcanic points (i.e. points are closer to the regression line), whereas the correlation for shale stemmed points is weaker. The other raw materials show various distribution patterns around the regression line, confirming that raw material appears not to have strongly influenced TCSA (see also Figure 3.5).

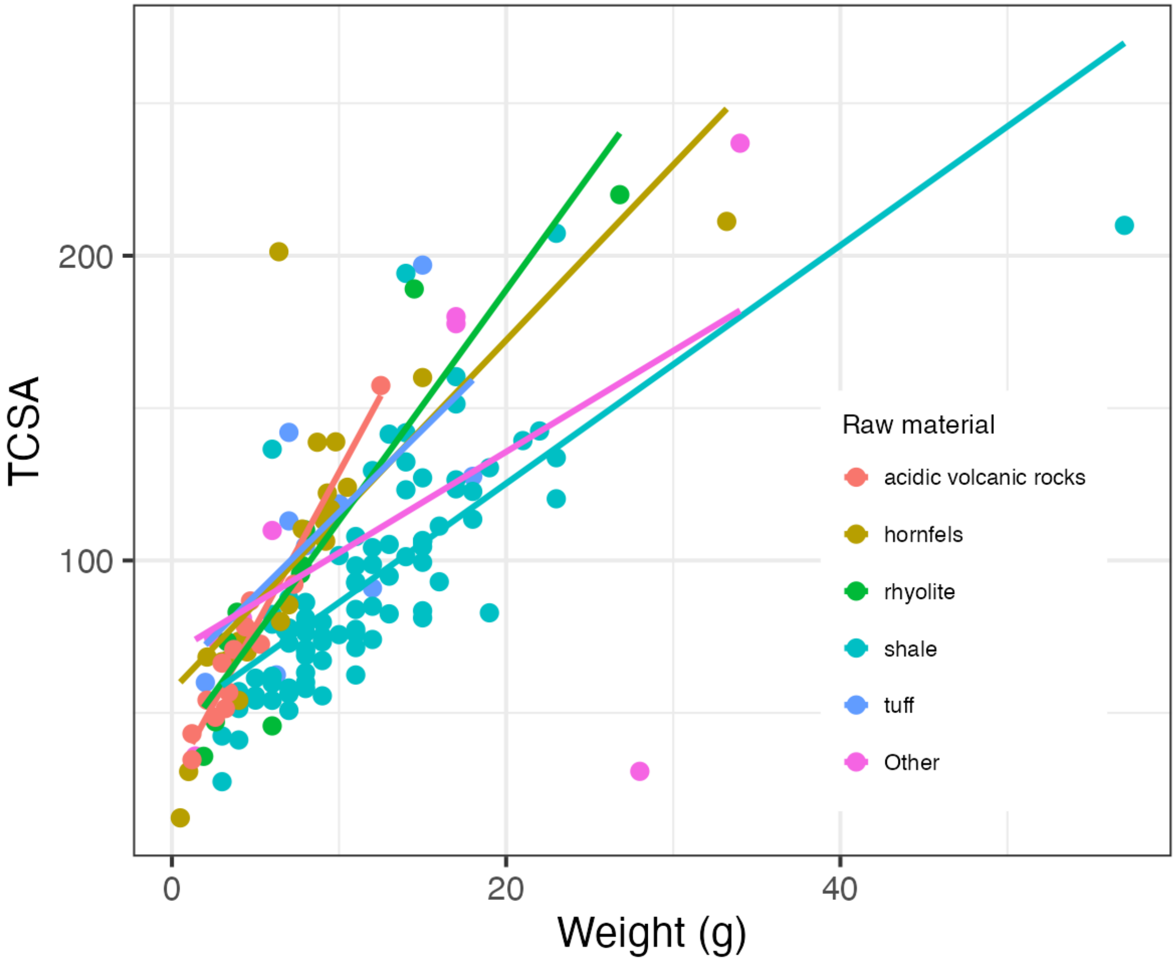

Figure 3.6: Artifact size and TCSA values by lithic raw material.

3.6.4. Temporal Patterns of TCSA Values

Figure 3.7 shows 26 assemblages with stemmed points in chronological order (panel A). These assemblages have a wide range of TCSA values, indicating multiple likely uses for stemmed points. Overall, there is no clear pattern in these assemblages over time. The TCSA range varies depending on the assemblage.

To explore the impact of climate change on the likely uses of the artifacts, panel B of Figure 3.7 shows the distribution of TCSA values from assemblages aggregated into three periods: before, during, and after the LGM. Our results show that stemmed points were made predominantly before LGM and only a few after LGM. Each category shows wide variation in LGM, which indicates diverse uses of stemmed points. While the median TCSA value for assemblages discarded during the LGM is higher than assemblages from earlier and later, there is no statistically significant difference in TCSA values across the three periods (F(2, 139) = 0.92, p = .400).

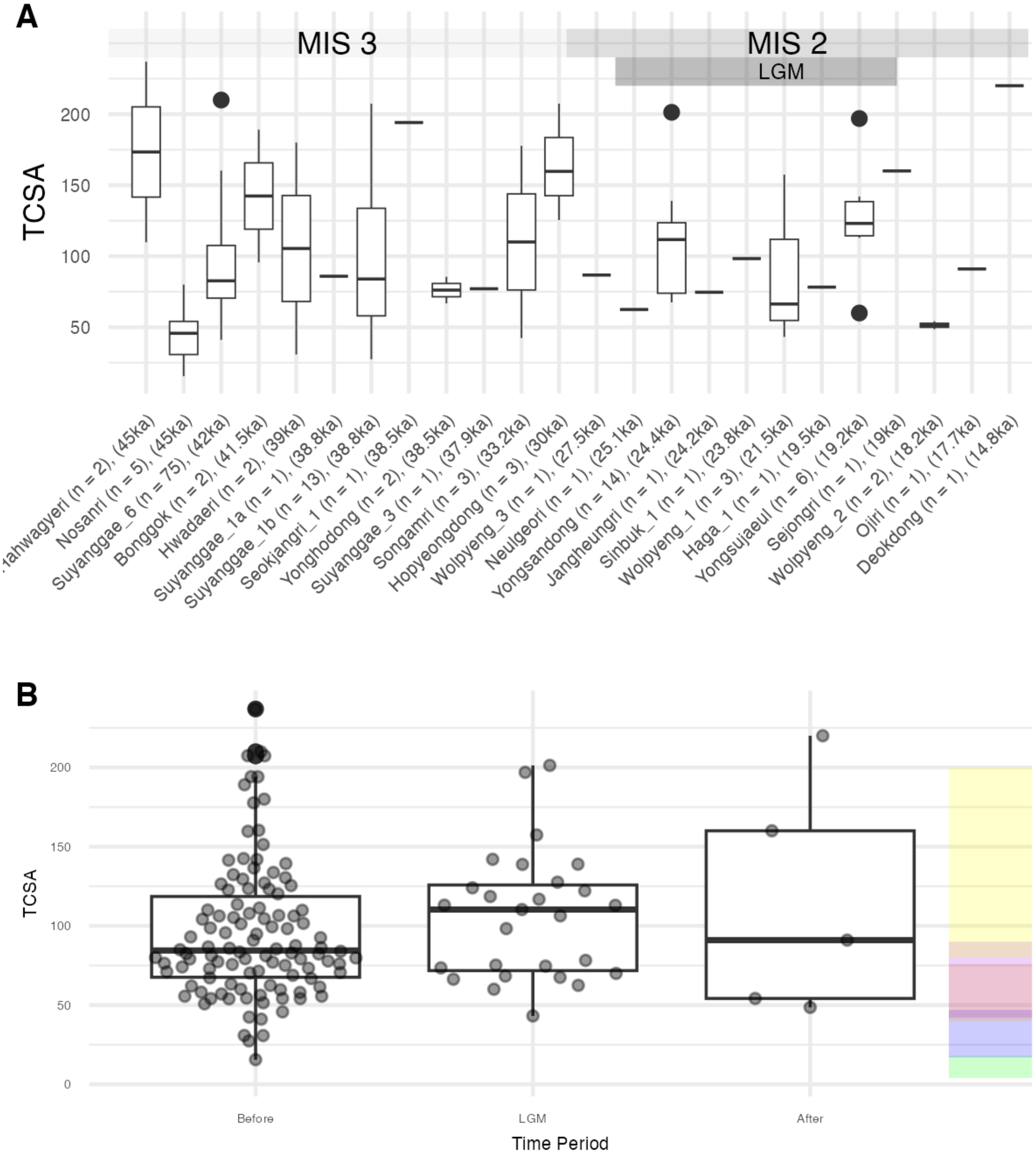

Figure 3.7: Temporal patterns of TCSA values. A: Distribution of TCSA values over time. The light gray shade indicates Marine Isotope Stages (MIS) 3; the gray shade indicates MIS 2; and the darkest shade indicates the duration of LGM. B: Distribution of TCSA values grouped by LGM event. The shaded boxes in color indicate TCSA ranges for different weapon types based on Table 3.1.

3.6.5. Spatial Patterns of TCSA Values

We computed artifact TCSA values for 25 sites that contain more than five stemmed points to observe variation between sites (F(6, 154) = 3.29, p = .004) (Figure 3.8). Sites with fewer than five stemmed points were grouped under the category of "Other." Among the sites in our sample, Suyanggae has the most stemmed points and the widest range of TCSA values. This suggests that people made stemmed points for accomplishing a variety of tasks at the Suyanggae site. Nosanri, Sibuk, and Wolpyeng have a narrower range of lower values, which indicates less diverse likely uses for stemmed points. Yongsujaeul shows a narrower range but higher TCSA values. Yongsandong has the second highest number of stemmed points and shows two clusters of TCSA values.

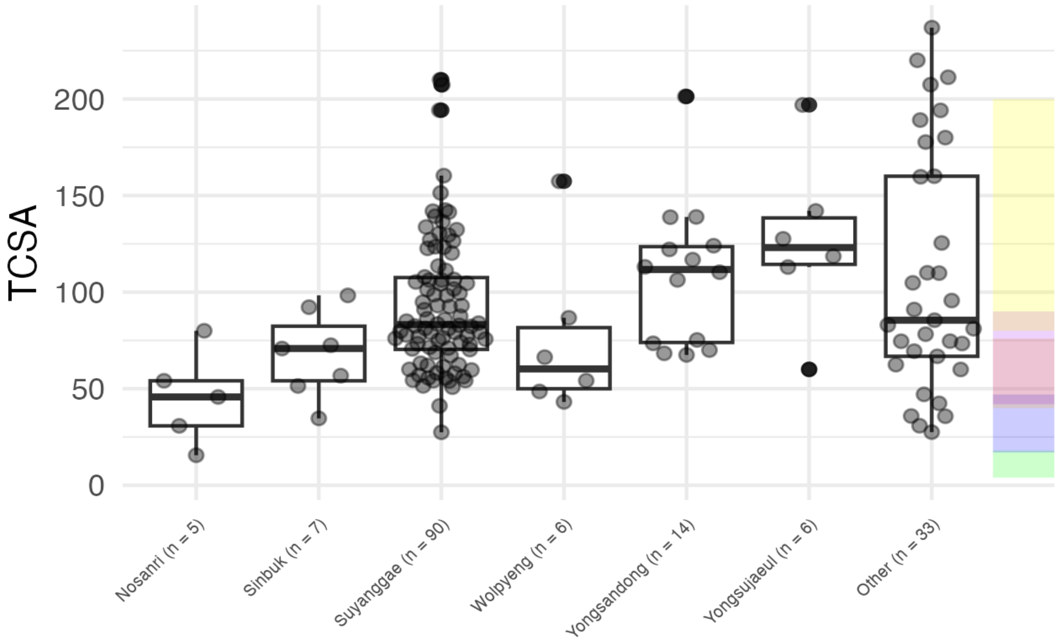

Figure 3.8: TCSA values by archaeological site. The shaded boxes in color indicate TCSA ranges for different weapon types based on Table 3.1.

To explore spatial patterns and the relationship between the role of stemmed points and the environment, we located individual assemblages on maps that depict eco-regional zones. Our results show that stemmed points are only located in certain zones, Central Temperature Zone (CT) of the vegetation map and Central inland (CI) (Figure 3.9 panel A & D) of the eco-region map. We observed some statistically significant differences in the distribution of TCSA values between some zones (Vegetation zones: $F(2, 140) = 4.27$, $p = .016$, Ecoregion zones: $F(6, 136) = 2.58$, $p = .021$). The Tukey's HSD results show that TCSA values from the South Temperature Zone (ST) are significantly different from the other two vegetation zones (Figure 3.9 panel C). Looking into this further, we see that there are only six artifacts from the ST zone, with only three of these having TCSA values above 175. The other three have TCSA values lower than 100, similar to the other zones (Figure 3.9 panel B). Given the small number of artifacts with extreme TCSA values in the ST zone, we hesitate to conclude that this is an archaeologically significant pattern of different TCSA values. The Tukey HSD pairwise differences show no pairs of eco-regions with significant differences in TCSA values; this was likely due to the small number of points in several zones (Figure 3.9 panel F). Overall, our results indicate no clear patterns in the distribution of TCSA values across vegetation and eco-regional zones.

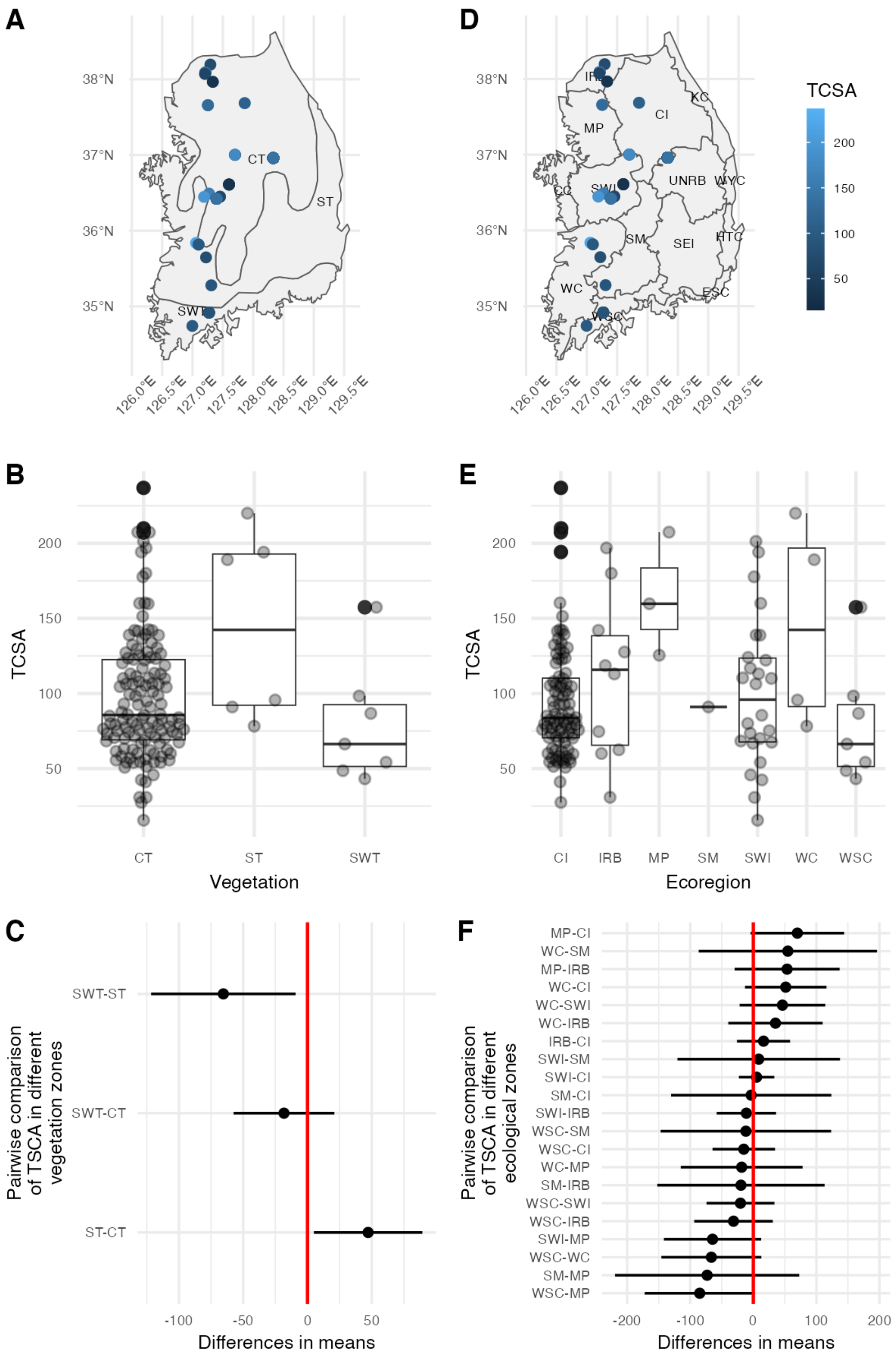

Figure 3.9: TCSA values by assemblages and ecoregions. A: Modern vegetation map defined by temperature and precipitation. The individual points indicate assemblages. B: TCSA distribution for vegetation zones. The individual points indicate artifacts. C: Tukey test result for vegetation zones. D: Eco-region map based on geographical boundaries and ecological conditions (modified from Lee et al. (2008)). E: TCSA distribution for ecoregion zones, excluding zones with no artifacts. F: Tukey test result for eco-region zones.

3.7. Discussion

By comparing the results with the TCSA ranges from other archaeological and ethnographic cases (Table 3.1), we were able to examine what role stemmed points played in the technological transition during the Korean Late Paleolithic. Our main questions were: What were the best-fit ballistic probabilities for stemmed points if they were hafted as weapon tips? How diverse were their likely uses? What are the temporal and spatial patterns of stemmed point uses?

Our results indicate that javelin tips and stabbing spear tips are the most probable ballistic uses for stemmed points. There are a few stemmed points in our sample that fall within the ranges of dart tips and un-poisoned arrow tips. None have TCSA values in the range of poison arrow tips (Figure 3.3). In their study, Lee and Sano (2019) calculated TCSA values for ten stemmed points from Jingeuneul site, which were not included in this research due to the unavailability of their data. They claimed that these values are within the range of North American dart tips and arrowheads. We found a wider range of TCSA in our sample covering the range of dart tips and un-poisoned arrow tips, which are assumed to be equivalent to arrowheads. In general, the wide range of TCSA suggest that stemmed points might play diverse roles in foraging toolkits.

TCSA can be impacted by other factors such as raw materials and portability. Eren et al. (2022) explain that lower TCSA values could be the result of pursuing production economy and transport efficiency. We explored the relationship between TCSA for weight and raw material types in order to examine these factors. We found that different clusters of weight are matched with different types of weapon tips (Figure 3.4). There was no clear pattern for raw materials (Figure 3.5). However, combined with weight, we observed a positive relationship between raw material type and TCSA values (Figure 3.6). We speculate that this might be due to the higher availability of raw materials, such as shale and hornfels within the landscape. Therefore, we find that raw materials, via nodule size, were influential on TCSA values.

Our results show that TCSA values vary between assemblages with few discernible temporal patterns in function (Figure 3.7 panel A). Contrary to our prediction, the earliest stemmed points do not have more variable TSCA values than subsequent ones. The most striking temporal pattern is simply that stemmed points were produced and discarded most frequently before the LGM (Figure 3.7 panel B). While we predicted the greatest variation in TCSA values during the LGM, our results show the opposite: variability decreased during the LGM (CV = 38.08), in comparison to the previous period (CV = 44.87). This could be explained by the overall decline in stemmed point usage, perhaps due to a retreat into refugia during the LGM, rather than increased mobility into unfamiliar areas.

We found that stemmed points are primarily located in a small number of eco-regional zones such as the Central Temperature (CT) Zone with few clear patterns in TCSA function evident across the zones (Figure 3.9). As predicted, TCSA values in inland areas, such as the CT Zone, show higher variability. These results suggest that stemmed points performed a wider range of tasks in low-productivity patches. Prates et al. (2022) claimed that fishtail projectile points in South America were used to hunt megafauna and contributed to their extinction by demonstrating a strong correlation between the spatial and temporal distribution of megafauna and the projectile points. We similarly found that stemmed points are more densely distributed in certain environments in South Korea. Future work should investigate more specifically patterns in the distribution of stemmed points and ranges of faunal taxa.

Overall, our results show a wide range of TCSA values throughout the Late Paleolithic period and between eco-regional zones. The widest TCSA range was found at a single site, Suyanggae (Figure 3.8). Our findings are therefore consistent with our second scenario, in which stemmed points are best described as multifunctional tools, suggesting that in most cases people created stemmed points as a response to unexpected or varying circumstances in their specific habitats, similar to how Eren et al. (2022) explained Clovis points. The LGM period may be the exception here, with a reduction in variability during this time.

3.8. Conclusion

Considering the importance of stemmed points for the technological transition during the Late Paleolithic in Korea, our research examines the likely uses for stemmed points by asking three research questions: What were the best-fit ballistic probabilities for the stemmed points if they were hafted as weapon tips? How diverse were their likely uses? What were the temporal and spatial patterns of stemmed point use? We applied the tip cross-sectional area (TCSA) metric because it has been used as a ballistically relevant standard to discriminate different likely use classes of projectile points and it requires only a few measurements on a stone artifact (i.e., maximum width and thickness) to compute the metric. We calculated TCSA for a total of 161 stemmed points from 33 assemblages excavated from 25 sites. Then we examined the TCSA values with other variables, including raw materials, weight, radiocarbon dates, and site locations. Drawing on evolutionary theory, we premised that the uses of stemmed points likely reflects the socio-environmental circumstances that people encountered. We examined the possible impact of LGM on stemmed points and their distribution across eco-regional zones.

According to the different weapon-delivery systems that can be inferred from TCSA values, the majority of stemmed points from the Korean Paleolithic were probably used as javelin tips and stabbing spear tips. In general, though, we noted a wide range and also differing distributions of TCSA values in each assemblage. Therefore, we conclude that stemmed points served diverse and not highly patterned roles during the Late Paleolithic. Prior to the LGM, people may have encountered unfamiliar situations and use stemmed points as a multifunctional tool to carry out multiple tasks. During the LGM and following we find production and discard of stemmed points declined, but their ballistic properties remained largely unchanged. Considering that many of our predictions about TCSA were not supported by the data, we speculate that composite projectile points made with microblades were introduced (Chang, 2013) in response to global climate dynamics, and stemmed points were optimal for the wide range of conditions encountered by people during the Late Paleolithic in Korea.

We are aware that discriminating the likely use of small numbers of projectile points could be arbitrary (Erlandson et al., 2014). Since TCSA covers the critical elements of projectiles, flight and penetration dynamics (i.e. increase or decrease by shape of tip and cross section), we nevertheless consider it a useful metric for hypothesizing about different weapon-delivery systems (Hughes, 1998; Lombard, 2021; Sitton et al., 2020). Use-wear analyses and experiments should be part of future research into the function of stemmed points to investigate the validity of our current results.

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Chapter 4

Cultural Transmission and the Social Contexts of Technological Transitions during the Late Paleolithic of Korea

An open access pre-print is also available online at https://osf.io/x4q8a/. This research compendium containing data and R code for reproducing the published results is at https://doi.org/10.17605/osf.io/eb8mx.

Abstract

The onset of the Late Paleolithic period in Korea, represented by the appearance of stemmed points and blades, was a key event in the dispersal of modern humans in Northeast Asia. Previous studies have mainly focused on possible origin locations of these new technologies. The specific cultural processes of the appearance of stemmed points and blades have rarely been considered. We explore these cultural processes by applying a cultural transmission framework to investigate the social contexts of the emergence of these new technologies. Our main question is: what was the dominant mode of cultural transmission during this time of technological innovation in the Korean Late Paleolithic? Following Bettinger and Eerkens (1999), we evaluated models of guided variation and indirect bias using data from Korean assemblages

containing stemmed points. To evaluate these models and understand the transmission processes, we computed correlation coefficients and coefficients of variation (CV). We found that information about the new technology was likely transmitted via guided variation with small contribution from indirect bias. Some attributes, including length and width, were transmitted with less variation while other attributes have more variation. Our results suggest that the dominant mode of cultural transmission for the earliest stemmed points was guided variation. A slight shift in the social context of transmission towards indirect bias was observed in the later chronological phase. We assume that individuals or groups developed stemmed points by experimenting with existing blade technologies and then copied crucial parts of a successful model to ensure the quality to optimize tool usage. As a result, the shape of stemmed points became more standardized among their social groups.

4.1. Introduction

The application of evolutionary theory to archaeological research has been fruitful for the study of technological transitions and related human behaviors in the remote past (Bettinger et al., 1997; Bettinger and Eerkens, 1999; Dunnell, 1980; Lipo et al., 1997; Mesoudi and O'Brien, 2008; Prentiss et al., 2020; Walsh et al., 2019; Zwyns, 2021). Archaeologists have used evolutionary theories and methods to get insights into human behavioral ecology, cultural transmission, and artifact phylogenetics in the past (Garvey, 2018; Gjesfjeld and Jordan, 2019; O'Brien and Bentley, 2017; Riede, 2010; Straffon, 2019). In this paper, we use cultural transmission theory to investigate technological transitions during the Korean Late Paleolithic (40-35 ka). The primary technological innovation of this period was the introduction of stemmed points and blades. These new lithic technologies may represent the first arrival of modern humans in this region, and thus, they may also mark an important event in human dispersal through East Asia (Seong, 2009). Previous studies on Korean stemmed points have mostly focused on where these new technologies may have originated, connecting Korea with global patterns of modern human dispersal (Bae et al., 2017; Bae, 2010; Seong, 2008). There are, however, largely unanswered questions about the specific cultural processes and social contexts of this technological change in Korea. Our study explores the social contexts in which new technologies emerged in the Korean Late Paleolithic, using evolutionary theory to make inferences about cultural transmission from artifact measurements. Our main question is: What was the dominant mode of cultural transmission for technological innovation in the Korean Late Paleolithic? We also ask: Did the mode of cultural transmission vary over time and space? We consider three possible modes of cultural transmission: guided variation (trial and error), indirect bias (copying others), or a combination of the two. The results of this study have implications for determining whether these novel technologies originated outside of the Korean Peninsula or if they were locally and independently developed.

4.2. The Late Paleolithic of the Korean Peninsula

The emergence of stemmed points marks the beginning of the Late Paleolithic period in Korea around 40-35 ka BP. A stemmed point is a projectile point made out of an elongated flake or blade with a slight retouch on the distal end to the shape of an acute tip, and on the proximal end to make a stem, which connects to a shaft. Stemmed points were the first composite tool types to appear on the Korean Peninsula, and were a symbol of new hunting strategies there and in adjacent regions (Lee and Sano, 2019; Seong, 2008). A number of technological innovations are evident on stemmed points, including blade technology, multiple manufacturing stages, and evidence of resharpening and reusing, which were rarely seen earlier (Bamforth, 2009; Chang, 2013; Seong, 2015). Currently, the oldest stemmed points in Northeast Asia are from the Yonghodong site in Korea, dating back to 38.5 ka BP (Bae and Bae, 2012; Seong, 2015, 2008). Following their appearance in Korea, stemmed points spread to the Japanese archipelago (Chang, 2013).

Previous studies of the Late Paleolithic technological transitions in Korea have mainly focused on the possible origin locations of stemmed points as part of the discussion of the timing and routes of modern human dispersal in eastern Asia. The debate about the origin of stemmed points can be summarized into two competing models: in situ evolution (Seong, 2009) and heterogenic migration (Bae, 2010). The in situ model claims that stemmed points and other Late Paleolithic assemblages, including blade industries, autonomously emerged in the Korean peninsula as a form of convergent evolution (Seong, 2009, 2008; Seong, 2006). To support his claim, Seong (2009) examined the blade-to-flake ratios of stone artifact assemblages in South Korea. In his view, the blade industry represents a new technology, while flakes indicate a continuously-used existing one. He argues that the increased ratio of blades in stone artifact assemblages during the Late Paleolithic shows an expansion of the new technology after its local invention. In addition, Seong claims that increased numbers of stemmed points over time, and standardization of their shape, supports the prominance of gradual, local, evolutionary processes in the emergence of new technologies.

By contrast, the migration model contends that the new blade industry includes stemmed points, and the earlier flake tool tradition, including large cores, polyhedrals, choppers, and handaxes, originated outside of Korea (Bae et al., 2013; Bae and Bae, 2012; Bae, 2010). While the in situ model claims that the heterogenic character is the result of indigenous development, the migration model proposes that the heterogeneity is the result of the continuous influx of modern human populations from both north and south. Specifically, the blade technology is claimed to have been introduced from Siberia, Mongolia, or other regions of northeast China following the Liaohe and Sunghe rivers around 35 ka BP, while the simple flake-tool tradition came from southern China (Bae et al., 2013). Bae uses Shi et al. (2005)'s genetic studies of the Y chromosome to support the southern route, showing that the O3-M122 M122 haplotype originated from southern East Asia and moved to northeastern Asia, including Korea, at 30-25 ka BP. Bae and Bae (2012) assume this southern migration could be related to paleoenvironmental fluctuations during the MIS 3 to 2 transition, which made the Yellow Sea/West Sea region open.

Lee (2013) argues that the transition to the Korean Late Paleolithic might be more complicated than either models of migration or in situ development. He partly agrees with the in situ model that simple flake tools had continuously been used in Korea as the result of ancestor-descendant relationships under conditions of low effective population size. With regard to the blade industry, he claims that the low degrees of uniformity and small quantities of blade-associated toolkits indicate an origin outside of Korea, perhaps resulting from trade or migration. We explore these three options, in situ, migration, and a mixture of the two, by measuring transmission biases in assemblages of stemmed points.

4.3. Cultural Transmission and Transmission Biases

To measure transmission biases in tool-making, we draw on Darwinian evolutionary theory. This body of theory has aided archaeologists in understanding a variety of technological innovations and related human behaviors (Bettinger and Eerkens, 1999; Bettinger and Eerkens, 1997; Crema et al., 2023; Dunnell, 1980; Eerkens and Bettinger, 2008; Lipo et al., 1997; Mesoudi and O'Brien, 2008; Prentiss, 2019; Richerson and Boyd, 1992). Cultural evolutionary approaches have been effective at explaining cultural changes using mechanisms of inheritance, variation-generating processes, and selection. These mechanisms are similar to biological evolution, but in cultural systems they have unique and distinctive properties (Acerbi and Mesoudi, 2015; Claidière et al., 2014; Creanza et al., 2017a; Mesoudi et al., 2004). Social transmission strongly affects these key evolutionary processes (Whiten, 2017) and can occur through various learning processes, such as stimulus enhancement, emulation, imitation, and teaching (O'brien and Lyman, 2000; Schillinger et al., 2014). We focus here on how different social contexts can result in different modes of social transmission of tool-making skills among hunter-gatherer populations.

Cultural transmission theory holds that information about social and technological behaviors is acquired through interaction with other individuals and the environment (Boyd and Richerson, 1988; Richerson and Boyd, 1992). Individuals learn by themselves (e.g. trial and error) or from each other by sharing information. Information can be modified (also known as 'biased') depending on an individual's transmission context and cultural repertoire (Richerson and Boyd, 2008). Modification of information can occur by recombination, loss, or partial alteration

(Eerkens and Lipo, 2005; O'Brien and Bentley, 2017). These transmission biases can be important loci of changes in material culture, and can be influenced by the social contexts of cultural transmission (Creanza et al., 2017b; Eerkens and Lipo, 2007; Heyes, 1994; Kendal et al., 2018; Lycett, 2015). These biases include guided variation (where individuals learn new behaviors through trial and error), content-based bias (where some aspect of the transmitted instructions, such as cultural preferences, makes them more likely to be adopted), frequency-based bias (where an individual is biased to choose particular behaviors based on their perceived frequency in the population, such as extremely popular or rare behaviors), and indirect bias (where a behavior is transmitted because of its association with other attributes, such as the prestige or skill of other individuals) (Boyd and Richerson, 1988; O'Brien and Bentley, 2017; Richerson and Boyd, 2008, 1992).

Bettinger and Eerkens (1999; 1997; 2008) have shown how two of these biases can be identified in stone artifact assemblages. Their research focused on the metric variables of stone points during the introduction of bow and arrow technology in the Great Basin around AD 300-600. They equated guided transmission (where individuals learn about new behaviors through trial and error) with high metric variation and low correlation between metric attributes. Conversely, they inferred indirect bias (where a behavior is transmitted because of its association with other attributes, such as the prestige or skill of other individuals) from less variation and more correlated variables. They found that artifacts in the new bow and arrow technology in eastern California have low correlations of basal width and mass, which they interpreted as a result of guided transmission dominating the introduction and spread of these tools. Based on these results, they inferred that eastern California had a social context of distant and unfamiliar neighbors with little direct contact between groups. In this context of limited contact, they argue that the new technologies developed largely by trial and error. On the other hand, in central Nevada they found that metric variables were highly correlated, and concluded that the bow and arrow was introduced and spread by indirect bias.

Following Bettinger and Eerkens' framework, Garvey (2018) used simulation to explore the degree of standardization represented by coefficient of variation (CV) values of projectile points from the US Southwest and westernmost southern High Plains. Garvey measured CV values for weight, thickness, width and length on two types of projectile points, Washita and Fresno points, from the Henderson site in southeastern New Mexico, USA. She then computed simulated CV values according to three scenarios of different levels of transmission fidelity (i.e. CV = 10%, 5%, and 3%). The observed metrics of archaeological projectile points are closest to simulated metrics with 3% CV, which represents "extremely high-fidelity copying." A CV of 3% is close to the Weber fraction for manually made human artifacts, that is, the threshold of human visual perception, with variation below this value being too subtle for people to notice (Eerkens, 2000). Garvey's work demonstrates how the cultural transmission of tool-making behaviors can be measured, simulated, and interpreted from the archaeological record.

Garvey and Bettinger and Eerkens inferred transmission processes from material culture because they were unable to observe them directly. Direct observations have been reported by Mesoudi and O'Brien (2008), who conducted experimental research using groups of undergraduate students to test the underlying assumptions of Bettinger and Eerkens' study. They simulated model-based bias in projectile point-making by providing the design of a model and information about the model’s prior success to their research participants. They also simulated guided variation by allowing their participants to explore their own designs. They observed that the majority of participants who were able to choose from the previous design ultimately copied the most-successful model. Metric attributes of projectile points made when copied from successful models were more highly correlated than attributes of points made by trial and error. Mesoudi and O’Brien’s experimental results are important because they confirm the robustness of previous assumptions about cultural transmission biases, and validate the connection between material culture variation and cultural transmission biases.

4.4. Modeling the Social Context of the Appearance of Stemmed Points in the Late Paleolithic of Korea

Inspired by Bettinger and Eerkens’ approach, we use two contrasting transmission modes, guided variation and indirect bias, to investigate the spread of stemmed point technology during the Korean Late Paleolithic period. We propose a spectrum on which we can locate foraging groups and how they started to make stemmed points, depending on their degree of social isolation or social connectedness. On one end of the spectrum we have socially isolated groups who made stemmed points through guided variation; and on the other end of the spectrum, we have socially connected groups whose knowledge of stemmed points derived from transmission processes dominated by indirect bias.

To contextualize this further, on one end of the spectrum we have socially isolated groups who stayed in physically remote places apart from other groups, or had unfamiliar neighbors with limited contact between groups. Our assumption for this social context is that individuals or groups acquired the technology of stemmed points by modifying existing flake tool forms through trial-and-error processes to solve problems relating to resource procurement (cf. Seong's in situ model). If this social context was prevalent, we predict that this trial and error behavior could have left a distinctive signature on the metric variables of the stemmed points. If trial and error was the dominant bias in the transmission of knowledge about how to make stemmed points, we expect that the morphological attributes on a stemmed point will be poorly correlated and show high variation within assemblages and between sites.

On the other end of the spectrum, we have socially connected groups that occupied places close to other groups or had regular contact with them. Relatively high degrees of social connectivity provide frequent opportunities for observing others and acquiring information. Individuals or groups learned the technology of stemmed points by copying a model from another individual or group. In this scenario, it is likely that the model, or ideal, stemmed point has been highly successful and frequently chosen, and learners copy all information about the point design as a package. This implies a small number of locations, or a single point (perhaps from a source external to the Korean peninsula, cf. Bae's migration model), where stemmed points first appeared and then spread from. In this social context, indirect bias is the dominant influence on the transmission of lithic technology. If indirect bias was prominent in the Korean Paleolithic, we expect that stemmed points would be more standardized, attributes on the stemmed points would be more correlated, and assemblages from multiple sites would exhibit less variance between and within them.

4.5. Methods

4.5.1. Materials and Stemmed Points Chronology

After the first discovery of stemmed points at the Seokjangri site in the 1960s, more than 450 have been found in nearly 30 sites across Korea (Figure 4.1) (Chong, 2021; Lee and Sano, 2019; Sohn, 1967). While most sites contain only a few points, a few sites have many more, such as Suyanggae (n = 55), Jingeuneul (n = 99), and Yongsandong (n = 38) (Kim, 2017). Among these stemmed points, we selected those that were unbroken from the tip to the stem. We excluded artifacts that were recorded as stemmed points but lacked a stem. This resulted in a sample of 152 stemmed points from 23 assemblages unearthed from 20 sites spanning the period 40-17 ka (Table 4.1). The images of the stemmed points were obtained through published excavation reports and direct photography during our research in local museums. We defined multiple assemblages from a site where artifact-bearing deposits were separated by culturally sterile deposits, or where distinct artifact-bearing stratigraphic units could be identified by major differences in the texture, color, and composition of the sedimentary deposits.

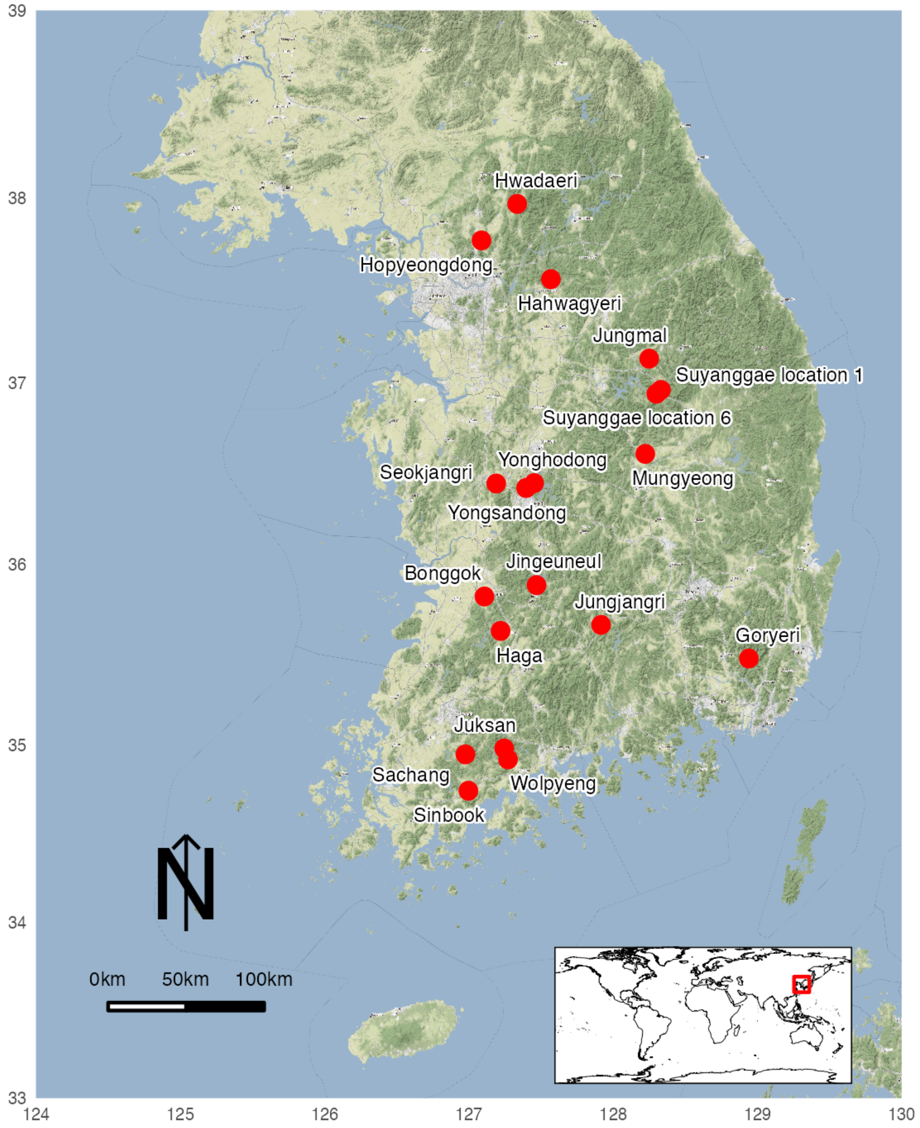

Figure 4.1: Korean Paleolithic sites used in this study.

Table 4.1: Total number of stemmed points found in sites and the number of stemmed points we used in the research. We excluded broken and unclear artifacts.

Site name	# of SP used in this study	Total # of SP
Bonggok	1	2
Goryeri	1	15
Hwadaeri	2	4
Haga	2	41
Hahwagyeri	1	2
Hopyeongdong	3	5
Jingeuneul	4	99
Jungjangri	1	1
Jungmal	1	1
Juksan	1	1
Mungyeong	1	1
Songamri	3	3
Sinbook	1	12
Sachang	2	2
Seokjangri	1	2
Suyanggae location 1	42	67
Suyanggae location 6 (Hajinri)	67	86
Wolpyeng	5	6
Yonghodong	2	2
Yongsandong	11	38
Total	152	390

To analyze morphological change over time, we used previously developed chronologies that identify three phases in the Korean Late Paleolithic (Park, 2013; Seong, 2015). These chronologies were constructed based on radiocarbon ages; assemblages without radiocarbon ages were classified by blades, stemmed point blanks, and toolkit composition. Following these previous chronological schemes, we divided the Korean Late Paleolithic assemblages into three chronological phases: 1) assemblages with stemmed points made out of flakes and no blades, 2) assemblages with stemmed points made out of blades or flakes and the existence of blades, and 3) assemblages with stemmed points made out of blades and the existence of micro-blades (Table 4.2). Applying this division is necessary because some sites such as Yonghodong, Goryeri, Jungmal, and Mungyeong have no radiocarbon ages. Inferring approximate ages for these sites by analogy to the technological sequences at sites with dates is necessary for making maximal use of the available archaeological data to increase our sample size. We arranged our 23 assemblages containing stemmed points into these three phases to facilitate observations of change over time.

Table 4.2: Korean Late Paleolithic Chronology edited based on Seong (2015) and Park (2013). SP = stemmed point

Phase	SP	Blades	Micro-blade	SP blank	Newly added raw materials	New changes	Radiocarbon ages
1	Present	Absent	Absent	Flake	Higher-quality quartzite, Vein quartz	Increasing number of small flake tools, appearance of SP	~35ka
2	Present	Present	Absent	Blade	Porphyry, Siliceous shale, Hornfels, Rhyolite	Appearance of blades, increasing number of SP	34-25ka
3	Present until 16ka	Present	Present	Blade, Micro-blade	Obsidian	Appearance of Micro-blade, microliths	25-12ka

Panel A of Figure 4.2 summarizes the amount of stemmed points in each chronological phase, and the distribution of raw materials across the phases. We exclude Phase 1 from our analyses below because we consider the sample size too small to compute reliable correlations and CVs. Shale is the dominant raw material in both Phase 2 and 3. In Phase 3 there is an increase in the proportion of porphyry, driven largely by findings from Yongsangdong, and other raw materials. Panel B of Figure 4.2 shows the count of stemmed points by raw material type in assemblages with more than five stemmed points. Much of the raw material diversity comes from isolated finds, with those assemblages containing more than five points, showing high homogeneity in raw materials.

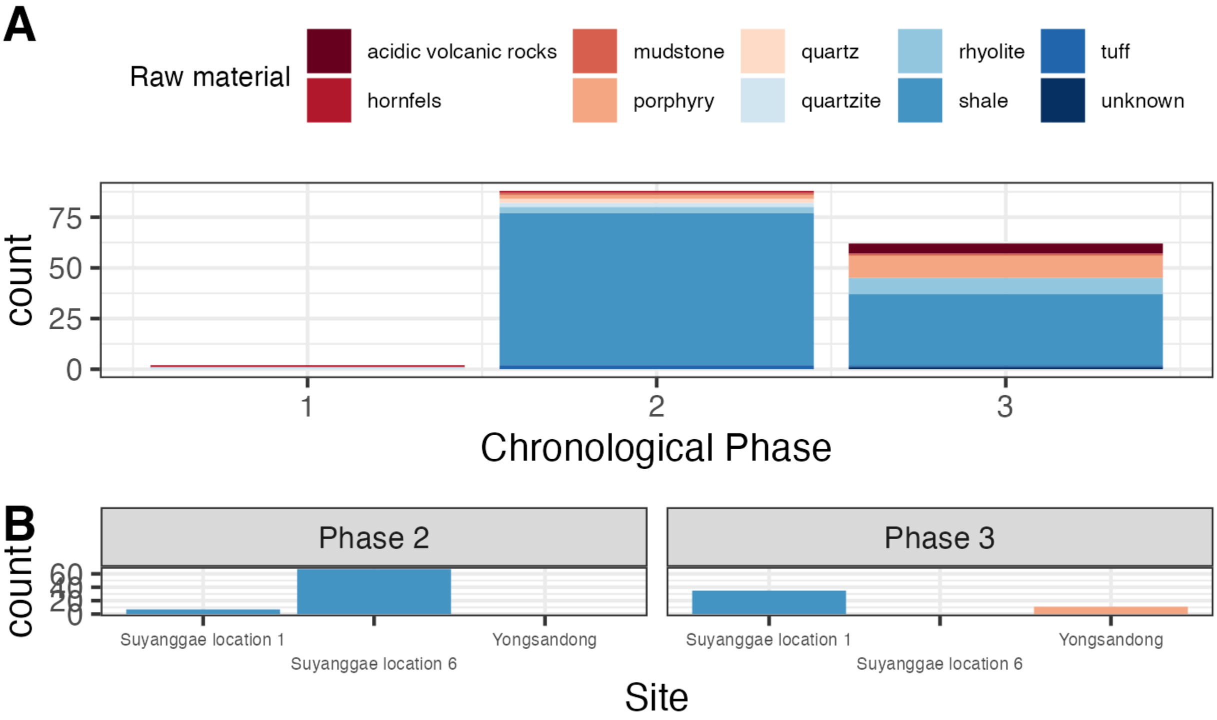

Figure 4.2:Distribution of stemmed points during the late Paleolithic sub-periods. A: Three chronological phases of the Korean Late Paleolithic, and frequencies of stemmed points and distribution of raw materials in each phase. B: Frequencies of stemmed points by assemblage and raw material, for assemblages with five or more stemmed points.

4.5.2. Morphometric Analysis

Following the metric attributes used in previous studies of cultural transmission and projectile points, i.e. maximum length and width (Bettinger and Eerkens, 1999; Bettinger and Eerkens, 1997; Eerkens and Bettinger, 2008; Garvey, 2018), we examined variations in shape and the relationship between each attribute using morphological attributes on stemmed points (Figure 4.3). We obtained our morphological attribute data from landmark analysis of digitized images of stemmed points. Compared to traditional caliper measurements, morphometric data yield easily interpretable numerical and visual outcomes (Buchanan and Collard, 2010; Cardillo et al., 2016; MacLeod, 2018; Okumura and Araujo, 2019; Petřík et al., 2018; Suárez and Cardillo, 2019; Thulman, 2012). We did not include weight and thickness because these measurements were not available to us. For the landmark analysis, we placed 11 landmarks on the outline of each stemmed point and calculated distances between landmark coordinate pairs to derive attributes for statistical analysis. The landmarks we recorded are described in Table 4.3 and shown in Figure 4.3. Using the point tool in ImageJ (Schneider et al., 2012), we captured the landmarks from images of the artifacts, and exported them as XY coordinate data for further analysis. We consider that the stone artifacts were generally modified very little during their use life by reuse and resharpening. While retouching can alter artefact shapes independent of transmission biases (i.e. the Frison Effect) (Dibble, 1995; Frison, 1968; Jelinek, 1976), retouch is very rare on the margins and tip of stemmed points, so we consider that the majority of stemmed points used in our sample have retained their original shape.

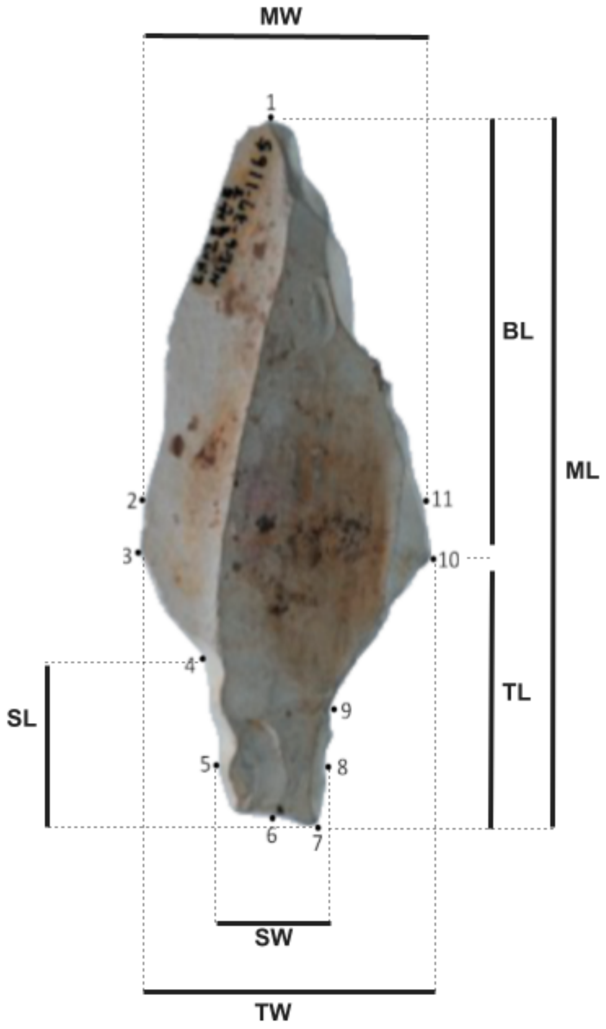

Figure 4.3: Stemmed point from Yongsandong site with landmarks showing the attributes considered in this study and further research

Table 4.3: Description of artifact landmarks used in this study

Abbreviation	Description	Line segment on the image
ML	Maximum length, tip to bottom, perpendicular to the length axis	1-7
BL	Body length, tip to the closest wing, perpendicular to the length axis	1-3 or 1-10 depending on the artifact
TL	Tang length, the closest wing from the tip to bottom, perpendicular to the length axis	3-7 or 10-7 depending on the artifact
SL	Maximum stem length, perpendicular to the length axis. Closer tang curve's middle point from the tip to the most distant point of the basal end	9-7 or 4-7 depending on the artifact
MW	Mid width, dimension from margin to margin at the mid-point of the length	2-11 axis, perpendicular to the width axis
TW	tang width, dimension between each wing, perpendicular to the width axis	3-10
SW	Stem width, width of the basal end of the point, 5mm above the end	5-8

Following Bettinger and Eerkens (1999) we computed Pearson's correlation coefficient for all attributes on the stemmed points. High correlations between artifact attributes were proposed by Bettinger and Eerkens (1999) as a key indicator of indirect bias during cultural transmission. It is based on the assumption that artifact-making was transmitted in packages of traits inherited from socially successful individuals who were role models. In their work, Bettinger and Eerkens (1999) interpreted correlation coefficient values around 0.5 and higher as evidence of indirect bias, and lower values as evidence of guided variation. In this research, we examine the correlation between attributes and explore other variables, such as different phases, raw materials and assemblages.

To complement the correlation measurements, we chose Coefficient of Variation (CV) to measure the variation among the measurements of the stemmed points. The CV is determined by the ratio of the standard deviation to the mean and is usually expressed as a percentage. The method has been used in various disciplines to calculate standardization, precision, equality, homogeneity, etc. (Ng, 2006; Panichkitkosolkul, 2013, 2009; Wang and Marwick, 2020). In archaeological studies, CV has been applied to measure the variation between artifacts and to test hypotheses about cultural evolutionary processes, including distinguishing between the types of learning biases affecting cultural transmission (Eerkens and Bettinger, 2001; Eerkens and Lipo, 2005; Garvey, 2018; Schillinger et al., 2014). As a guide to interpreting CV values, Eerkens and Bettinger (2001) claim that CV values over 57.7% are the result of random production. CV values below 1.7% are the byproduct of using a scale or template. Among all the various artifacts for which Eerkens and Bettinger (2001) summarized CV values, the most comparable case to the stemmed points examined here was Great Basin projectile points, whose CV values range from 6-55%, with an average of 22%. Similarly, projectile points from the US Southwest have CV values ranging from 11% to 33% (Garvey, 2018).

Sample size can impact the accuracy of CV estimates (Kelley, 2007; Toebe et al., 2018; VanPool and Leonard, 2011). In previous archaeological studies, sample sizes for CV values have varied from five to more than a thousand artifacts (Bettinger and Eerkens, 1999; Costin and Hagstrum, 1995; Garvey, 2018; Kvamme et al., 1996; Rivals et al., 2009; Wierer, 2013). A variety of methods are available for improving the reliability of CV measurements when using small samples. VanPool and Leonard (2011), for instance, proposed a “corrected CV” for smaller samples (i.e. n<25). Statistical research has resulted in several methods for computing confidence intervals on CVs to show uncertainties related to sample size (Banik and Kibria, 2011; Curto and Pinto, 2009; Gulhar et al., 2012; Koopmans et al., 1964; Mahmoudvand and Hassani, 2009; McKay, 1932; Miller, 1991; Panichkitkosolkul, 2013; Sharma and Krishna, 1994; Vangel, 1996). Although we have a total of 152 artifacts, most of our analyses involve comparisons of smaller subsets. For example, we compared samples of less than 25 pieces in order to explore temporal and regional patterns. Given these relatively small sample sizes in our study, we used the corrected CV formula of VanPool and Leonard (2011), which we have implemented here in a function in the R programming language for others to use. We also computed confidence intervals using the method proposed by Sharma and Krishna (1994) to be transparent about the precision of our results (Albatineh et al., 2014; Kelley, 2007).

One limitation of previous work is the absence of a clear threshold value for interpreting CV values in terms of different transmission biases. Bettinger and Eerkens (1999) did not identify a threshold for CV values to distinguish guided variation from indirect bias. However, one can be inferred from their data. We used data from Bettinger and Eerkens (1999) to calculate CV values of Rosegate points from Monitor Valley, California, which were claimed by Bettinger and Eerkens to result from indirect bias. With the exception of weight, the CVs for metric attributes on Rosegate points ranged from 17% to 24%. Based on these values, we propose 25% as an approximate threshold to distinguish between guided variation from indirect bias. We have three reasons to believe the higher side of the CV range of Rosegate points is appropriate as a threshold value. First, variation is generated by small errors that are transmitted between individuals and the errors get bigger through generations (Eerkens and Lipo, 2005). The duration of the transmission process for stemmed points is much longer (in the order of thousands of years) than in the case of Rosegate (in the order of hundreds of years in the Fremont region) (Bischoff and Allison, 2021). Second, the errors are likely to vary by raw materials. Some raw materials, such as clay for pots, are easier to control variation in while less controllable materials such as stone for flaked stone artefacts are likely to have higher CV values because of the relatively unpredictable nature of flaking (Eerkens and Bettinger, 2001). We assume that Rosegate projectile points were made from more finer-grained raw materials such as flint, compared to the raw materials for Korean stemmed points, which include shale, rhyolite, porphyry, etc. (Figure 4.2). Third, the corrected CV calculation for small sample sizes that we are using tends to result in slightly higher values compared to standard CV values (VanPool and Leonard, 2011). Given the tentative identification of this threshold value, we assume that CV values that are higher than 25% likely represent guided variation (trial and error) while CV values less than 25% likely reflect indirect bias (copying from a prestigious or skilled individual).

4.5.3. Reproducibility and Open Source Materials

All data preparation, analyses and visualization were computed in the R environment (R Core Team, 2022). Our R code and data, including the original artifact images, are fully and openly available in our compendium (Marwick et al., 2018) online at https://doi.org/10.17605/osf.io/eb8mx to enable transparency, reproducibility, and reuse (Marwick, 2017).

4.6. Results

4.6.1. Correlation Coefficients

Our results show positive correlations between attributes throughout the Late Paleolithic (Panel A of Figure 4.4). Some relationships such as body length (BL) and maximum length (ML) have stronger correlations (i.e. darker-blue points) than others (i.e. lighter-blue or almost invisible points). To understand temporal patterns in the modes of cultural transmission, we grouped our assemblages into the three Korean Late Paleolithic chronological phases summarized in Table 4.2. Among the three chronological phases, we excluded Phase 1 from our analysis because there are only two complete stemmed points from Yonghodong and Sachang that belong to this phase.

Panel D of Figure 4.4 shows that the correlations between attributes became stronger over time. The median correlation value for Phase 2 is much lower than 0.5, which Bettinger and Eerkens (1999) interpreted as a threshold to distinguish between transmission biases, while the Phase 3 median is close to this threshold value. We interpret Phase 2 as evidence of guided variation and Phase 3 a mixture of guided variation and of indirect bias.

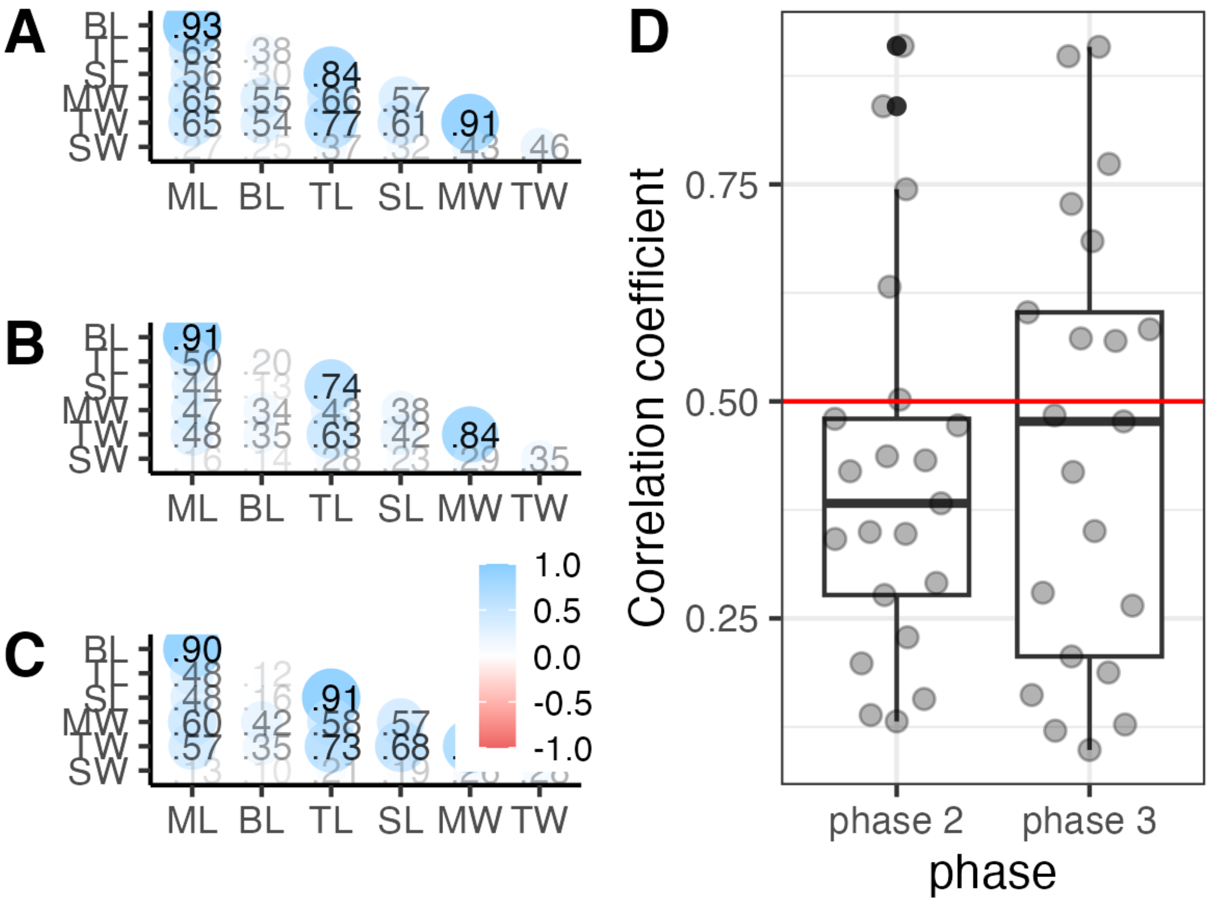

Figure 4.4: Correlation analysis by chronological phases in the Korean Late Paleolithic period. A. Correlation coefficient between attributes for all periods. B. Correlation coefficient between attributes for Phase 1. C. Correlation coefficient between attributes for Phase 2. The individual point represents correlation between two attributes. Some points are invisible due to their weak relationship. D. Correlation coefficient for the second and third chronological phases. The gray points represent correlation between two attributes.

One limitation of this aggregation of stemmed points into chronological phases is that the sample consists of a relatively large number of assemblages with only 1-2 stemmed points. These isolated finds are ambiguous with respect to local traditions of artifact making, so to further investigate temporal change, we focus only on the four assemblages that have more than five stemmed points (Figure 4.5). We assume these four assemblages are more likely to represent a consistent, recurring way of making stemmed points than isolated finds, and thus more relevant for comparing modes of cultural transmission of artifact making. The four assemblages include three from Suyanggae (SYG) and one from Yongsandong (YS).

Figure 4.5 shows that at this finer scale of resolution the picture is complex. Phase 2 shows both highly correlated attributes, from SYG1_2, and relatively uncorrelated attributes, from SYG6_2. The two assemblages from Phase 3 show similarly highly correlated attributes, with the median right around our threshold value of 0.5; however, the spread of correlations is high, suggesting some influence of indirect bias.

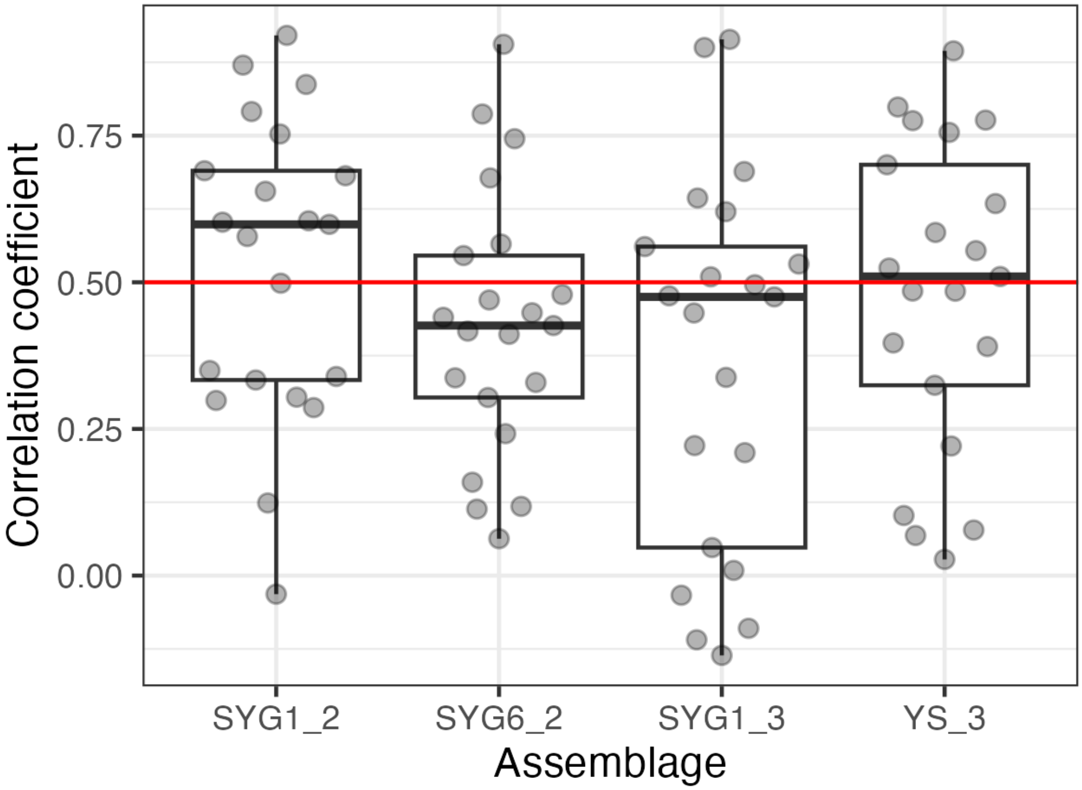

Figure 4.5: Correlation for assemblages with more than five stemmed points. Among the four assemblages, SYG1_2 and SYG6_2 are from Phase 2 of the Korean Late Paleolithic chronology and SYG1_3 and YS_3 are from Phase 3. The gray points represent correlation between two attributes.

4.6.2. Correlations and Raw Materials

To examine the impact of raw materials on the shape of stemmed points, we computed the correlations of attributes among raw material groups. We excluded raw materials that were used for less than three points. Figure 4.6 shows that the most abundant raw materials have relatively high correlation coefficients. The stemmed points made from quartzite and porphyry have the highest correlation coefficients with relatively narrow distributions. Acidic volcanic rocks are one of the more highly correlated materials, with an outlier group with much lower correlations. Similarly, the correlation of shale stemmed points is also divided into two groups. Rhyolite stemmed points have a wide distribution of correlations, and some of the attributes are even negatively correlated. Tuff stemmed points have a wide distribution with a high median value.

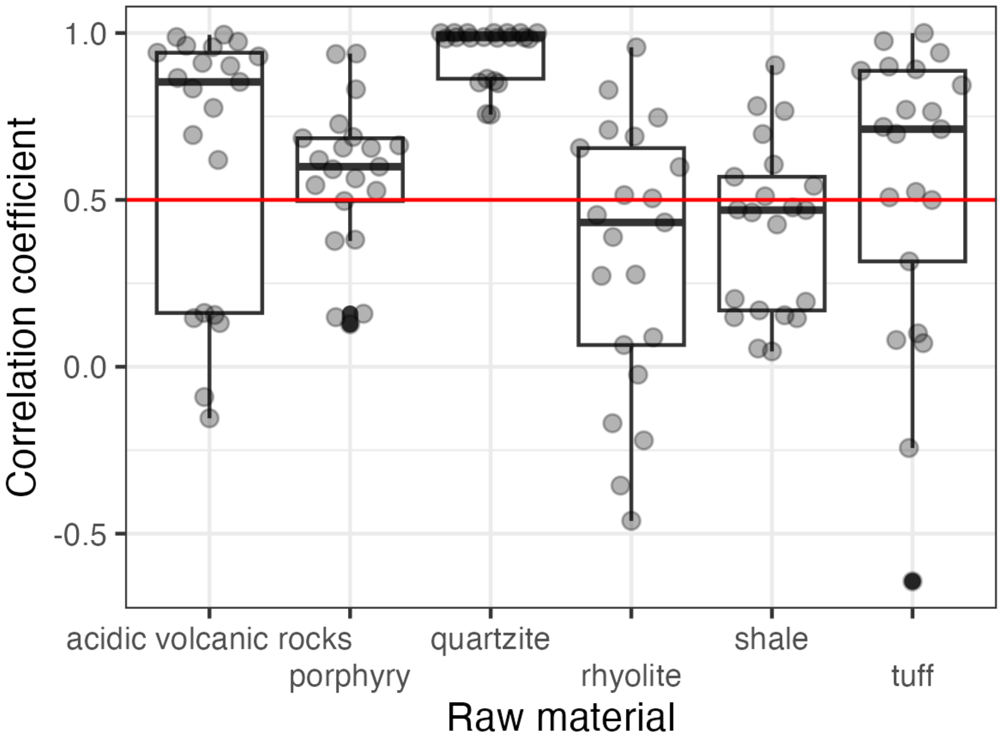

Figure 4.6: Correlation for raw materials that were used for making more than three stemmed points. The gray points represent correlation between two attributes.

4.6.3. Coefficients of Variation

In addition to correlation coefficients of point attributes, we measured coefficients of variation (CVs) to quantify variability in individual attributes. Figure 4.7 shows that CV values for all attributes are distributed from 23.9% to 36.4%. Compared to the CVs of Great Basin projectile points (Eerkens and Bettinger, 2001), the average CV for Korean artifacts is higher. The CVs for body length (BL) and maximum length (ML) have the lowest values. The low CV and narrow confidence intervals for maximum length indicate that this dimension is highly standardized relative to the others. Tang and stem related attributes (e.g. SL, SW, TL, TW) are less standardized with higher CV values and wider confidence intervals than other attributes. Overall, with all but one attribute having CV values above our threshold value at this level of aggregation of assemblages, our results suggest that the transmission of stemmed points was mostly influenced by guided variation.

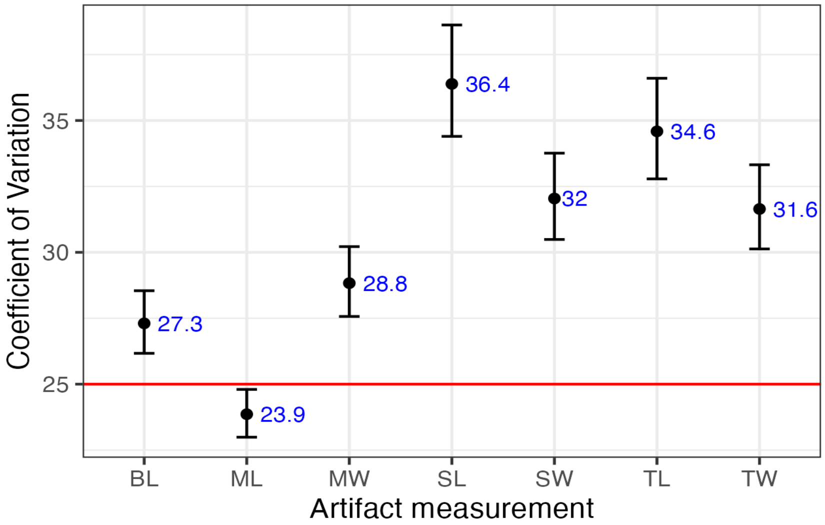

Figure 4.7: CV values for each attribute measured on the stemmed points. The vertical lines indicate the 95% confidence intervals for the CV values, which were computed using Sharma and Krishna's method. The red line at CV = 25 indicates our approximate threshold to distinguish between guided variation (>25) from indirect bias (<25).

In Figure 4.8, CV values for stemmed points are grouped into three chronological phases to analyze temporal patterns in cultural transmission. We excluded stemmed points from Phase 1 due to the limited number of artifacts dating to this time. Figure 4.8 shows that the temporal trend in CV values of artifact attributes is complicated. Half of the attributes are below our threshold value of 25, and half are above for both phases. Only body length (BL) crosses the threshold value, changing from <25 to >25 over time, suggesting a shift from indirect bias to guided variation. For those attributes where the CV is <25, the trend is decreasing CV values from Phase 2 to Phase 3 for maximum width (MW) and tang width (TW), indicating increasing influence of indirect bias for these attributes. For stem length (SL), stem width (SW) and tang length (TL), CV values remain above 25, and show a slight trend to increase over time, suggesting increased influence of guided variation for these stem and tang attributes.

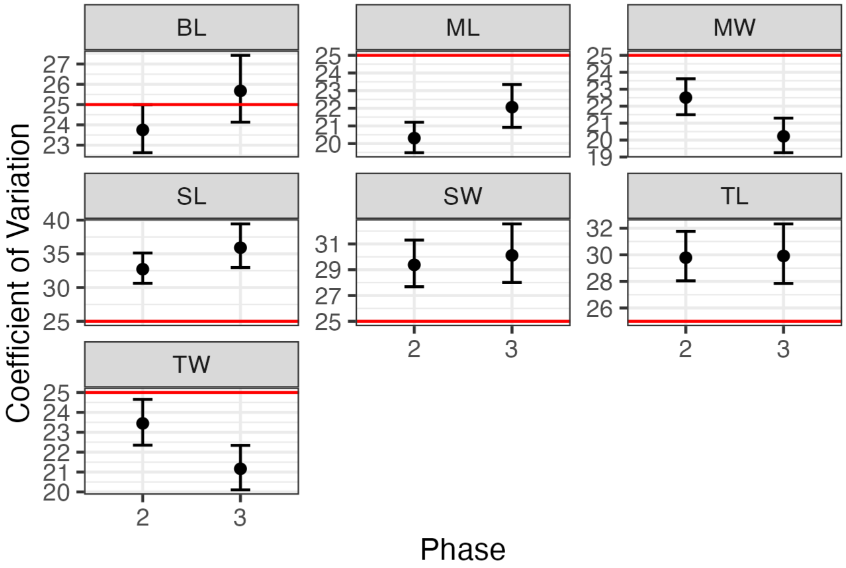

Figure 4.8: CV values for the second and third chronological phases in the Korean Late Paleolithic period. The points represent CV values for each attribute. The vertical lines indicate the 95% confidence intervals for the CV values, which were computed using Sharma and Krishna's method. The red line at CV = 25 indicates our approximate threshold to distinguish between guided variation (>25) from indirect bias (<25).

We further analyzed temporal change by looking at specific assemblages in each chronological phase. Following previous studies (Bettinger and Eerkens, 1999; Bettinger and Eerkens, 1997; Eerkens and Bettinger, 2008; Garvey, 2018; Mesoudi and O'Brien, 2008), we focused on CV values for body length (BL), maximum length (ML), mid width (MW), and tang width (TW) for assemblages that have five or more stemmed points. Figure 4.9 shows that CV values for the four assemblages are mostly slightly below 25, with no temporal trend apparent between Phase 2 and Phase 3. Overall we see only subtle changes in CV values from Phase 2 to Phase 3 in Figure 4.9. Among the assemblages, SYG1_2 has higher CV values as well as the widest ranges of confidence intervals. This is unexpected because SYG1_2 has a strong correlation between attributes (Figure 4.5). Perhaps it could be related to its small sample size, relative to the other assemblages compared here. The larger assemblages in Figure 4.9 indicate guided variation, while the smaller assemblages that dominate Figure 4.8 suggest indirect bias. Perhaps smaller assemblages represented a social context of higher fidelity copying because the cost of failure was greater due to low social insurance because of low population network sizes and densities (Fitzhugh et al., 2011). Another interpretation is that these results suggest that the complex temporal trends in Figure 4.8 might be best interpreted as noise in an overall signal of guided variation, rather than substantial changes in the type of bias dominating cultural transmission.

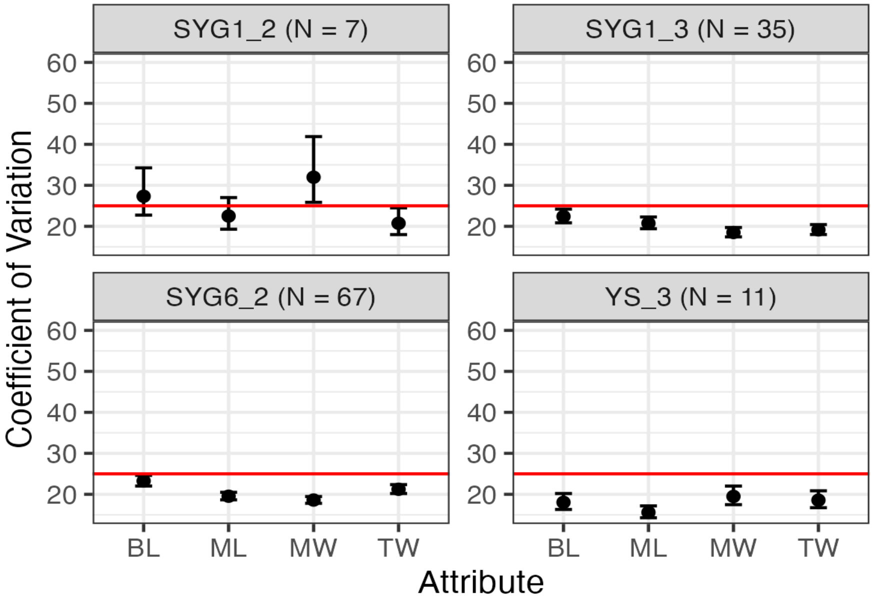

Figure 4.9: CV values of four attributes from assemblages with more than five stemmed points. Among the four assemblages, SYG1_2 and SYG6_2 are from Phase 2 of the Korean Late Paleolithic chronology and SYG1_3 and YS_3 are from Phase 3. The points represent CV values for each attribute. The vertical lines indicate the confidence intervals. The red line at CV = 25 indicates our approximate threshold to distinguish between guided variation (>25) from indirect bias (<25).

4.6.4. Variation Between Raw Materials

We examined the relationship between CV values and raw materials to test the hypothesis that the shape variability of stemmed points was dependent on raw materials. We excluded raw materials that were used for less than three points. Figure 4.10 shows that quartzite, the raw material for stemmed points at Sachang, has the highest CV values, and also has wide confidence intervals. Other raw materials are generally low, right around our threshold value, and stable in variation across the attributes.

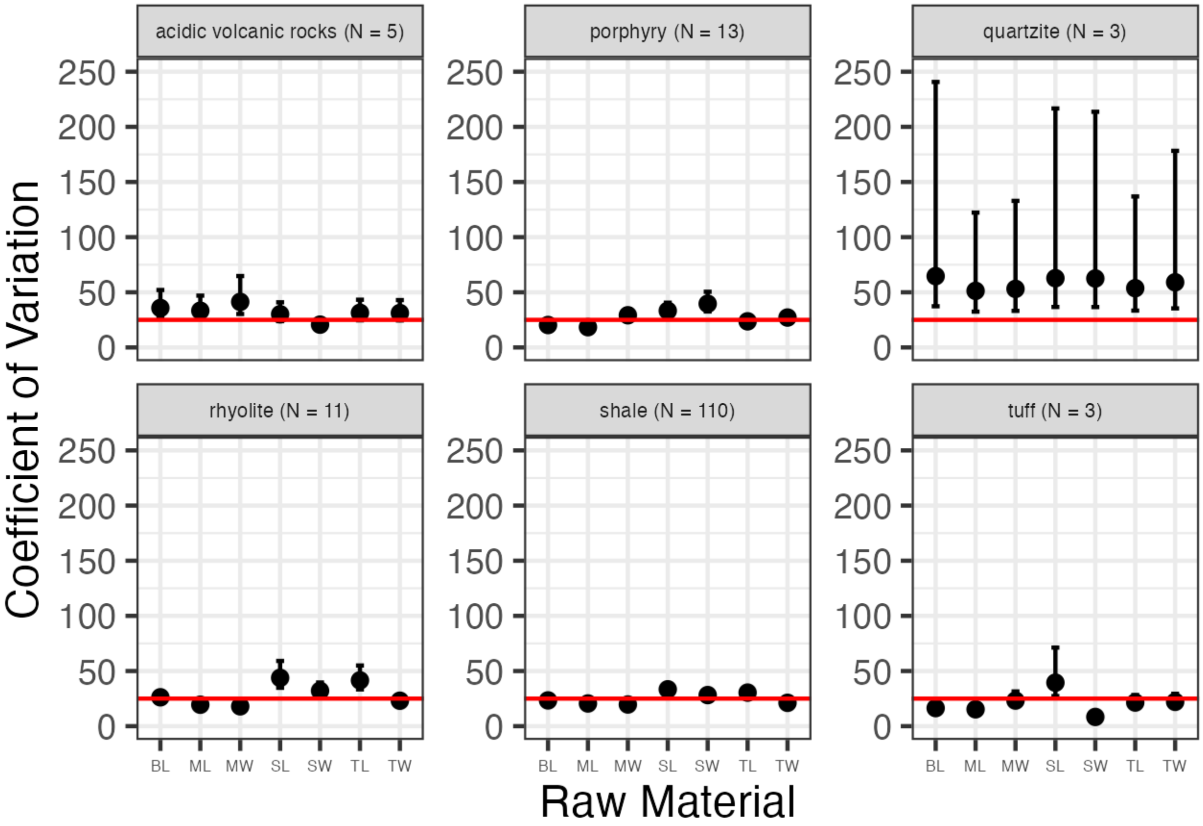

Figure 4.10: CV values for raw materials that were used for making more than three stemmed points. The points represent CV values for each attribute. The vertical lines indicate the confidence intervals. The red line at CV = 25 indicates our approximate threshold to distinguish between guided variation (>25) from indirect bias (<25).

4.7. Discussion

To investigate the social contexts of technological transitions represented by the emergence of stemmed points during the Korean Late Paleolithic, we drew on concepts of cultural transmission from the broader framework of cultural evolutionary theory. We asked three questions to examine the cultural transmission process over time: what was the dominant mode of cultural transmission for technological innovation in the Korean Late Paleolithic? Do the modes of cultural transmission vary over time? And do the modes of cultural transmission vary over space? We focused on two transmission biases: guided variation (socially isolated groups making stemmed points through trial and error) and indirect bias (socially connected groups whose knowledge of stemmed points derived from copying others). Following Bettinger and Eerkens (1999), we used 0.5 as an approximate threshold value for interpreting correlation coefficients to evaluate which of the two transmission biases was dominant. Correlation coefficients below 0.5 are indicative of guided variation and higher values indicate indirect bias. Since there are no previously established criteria for CV, we derived 25% from previous work to use as our threshold of the CV value to decide between these two types of transmission biases, based on prior work on Great Basin Projectiles (Eerkens and Bettinger, 2001). If the CV value is lower than 25, we interpret this as indicating indirect bias while values higher than 25 are interpreted as guided variation.

Our correlation analyses found that the correlation coefficients of stemmed points are mostly positive and mostly at or under 0.5, showing the possibility of guided variation as their main transmission bias. Some correlations such as body length and maximum length have strong relationships while other correlations such as tang length and body length are much weaker. Given these results, transmission of the artifact shape as a package seems unlikely. The correlation coefficients increase from chronological Phases 2 to 3 (Panel D of Figure 4.4), but when we look at individual assemblages, the pattern is not consistent and the values vary depending on the assemblage (Figure 4.5). When all artifacts are considered together, CV values for all stemmed point attributes are mostly over 25, except for maximum length, which is just below. However, further analysis by site and raw material shows more ambiguous patterns, with CV values close to or below the threshold value. Change in CV values over time in the Korean

Late Paleolithic period is complex, with no clear directional changes (Figure 4.8). Comparing chronological Phase 2 and 3, we found that there are only minor differences between the two phases. Applying the Modified Signed-Likelihood Ratio Test (MSLR) to test for the equality of CVs (Krishnamoorthy and Lee, 2014; Smallwood et al., 2022), we found no statistically significant changes in the CV values of any attributes (Table 4.4) between the two phases. In exploring individual assemblages that contain multiple stemmed points, we observed minimal changes in CV values over time (Figure 4.9).

Table 4.4: Summary of significance tests for CV values between the two chronological phases

Variable	MSLR statistic	p value
TL	0.014	0.905
SW	0.023	0.880
BL	0.369	0.543
ML	0.406	0.524
SL	0.484	0.487
TW	0.715	0.398
MW	0.781	0.377

In exploring variation between sites, as a proxy for spatial variation, we found no readily interpretable pattern of variation in both correlation coefficients (Figure 4.5) and CV values (Figure 4.9) between assemblages with more than five stemmed points. We found that correlation coefficients and CV values are distributed differently in each assemblage. While SYG1_2 and SYG1_3 are from the same site, they belong to different chronological periods, and their correlation decreases over time. It is likely that the correlation or overall shape may be more dependent on individual knappers. We also found that some attributes such as maximum width (MW) and maximum length (ML) have stronger correlation, while the others including stem length (SL) and body length (BL) have lower or even negative correlation. Based on these findings, we propose that certain attributes were more carefully transmitted than others. Artifact shape does not appear to have been transmitted as a package, but as a flexible set of attributes that can vary with respect to each other. We observed that CV values of body length (BL), maximum length (ML), mid width (MW), and tang width (TW) are generally lower than tang length (TL), stem length (SL), and stem width (SW) (cf. Figure 4.7).

According to our model, attributes with lower CV values were transmitted in a social context dominated by indirect bias, whereas attributes with high CV values were likely influenced more by specific local manufacturing and maintenance situations. We assume that the lower CV values imply that those attributes, BL, ML, MW and TW, were closely associated with the generic projectile function of the tool, Keeping variability low for those attributes would have standardized the shape to ensure predictable performance. For example, body length is related to penetration, durability, hardness, and rejuvenation of a projectile point and tang width is connected to wound damage, penetration, durability and hardness (Bebber et al., 2017; Cheshier and Kelly, 2006; Odell and Cowan, 1986; Shea et al., 2001; Wood and Fitzhugh, 2018; Yaroshevich et al., 2016). This can be contrasted with tang length, stem length, and stem width, which are away from the point of impact at the end of the artifact. Our results show these were allowed to vary more freely between specimens, perhaps to be able to accommodate shafts of different types of wood with varying properties of strength, flexibility, and weight.

The most striking differences in both correlation coefficients and CV values are in comparisons of points grouped by raw materials (Figure 4.6, Figure 4.10). Raw materials likely had a substantial impact on stemmed points' shape variance. We expected that stemmed points with higher correlation coefficients would also have lower CV values, but the results do not exactly match our expectations because of how influential raw materials are on CV values. For example, artifacts made from acidic quartzite have the highest correlations, but their CV values are also much higher with wider confidence intervals than all other raw materials. These complex results might be related to the relatively unpredictable knapping quality of quartzite. Large grains within quartzite can redirect knapping forces in unexpected directions, resulting in unintended flake removals. This makes it harder for the knapper to repeatedly produce the same size and shape end product. Variation in raw material nodule size may also contribute to this pattern, for example quartzite nodules may have been found in a much wider range of sizes than nodules of other raw materials. The small sample size of quartzite artefacts in our study limits how far we can generalize this pattern, but this hints at the possibility that the physical properties of the stone artifact raw materials were a key mechanism in determining shape and size variability. Further analysis of raw material properties and availability is needed to make robust conclusions about their influence here.

4.8. Conclusion

In this research we investigated the social contexts of technological innovation in the Korean Late Paleolithic. Following previous studies that applied cultural transmission to the introduction of new technologies (Bettinger and Eerkens, 1999; Bettinger and Eerkens, 1997; Eerkens and

Bettinger, 2008; Garvey, 2018), we examined two transmission biases, guided variation (trial and error) and indirect bias (copying a model). We proposed two scenarios for explaining the introduction of new technology: socially isolated groups that developed stemmed points through trial and error (guided variation) or socially connected groups whose knowledge of stemmed points derived from copying others that they regularly came into contact with (indirect bias). We asked three questions: what is the dominant mode of cultural transmission for technological innovation in the Korean Late Paleolithic? Do the modes of cultural transmission vary over time? And do the modes of cultural transmission vary over space?

We conclude that the dominant mode of cultural transmission for the earliest stemmed points was mostly likely guided variation (trial and error). This is indicated by mostly low correlation coefficients of less than 0.5 and relatively high CV values of around and above 25. A social context that favored trial and error for artifact making is most consistent with Seong's in situ model for the appearance of stemmed points in Korea. This model proposes that people developed stemmed points by experimenting with existing elongated flakes and blades. Our results support experimentation and trial and error as important processes in the cultural transmission of this artifact technology.

The correlation coefficients suggest a change in the dominant bias of cultural transmission over time, with values around 0.5 in chronological Phase 3, after 25 ka. This is in the same range as the correlation coefficients that Bettinger and Eerkens interpreted as indirect bias. We also found a slight decrease in CV values. Those results may indicate a shift away from trial and error, towards a greater reliance on copying a model in the social context of tool-making skill transmission. Raw material choice appears to be important in driving this trend, with acid volcanic rocks and porphyry becoming more abundant in Phase 3, and dominating assemblages at Yonsangdong that date to this period.

One possibility is that these more easily manageable raw materials were part of an adaptive shift during the Last Glacial Maximum, where perhaps the cooler climate favored an expanded range for searching for raw materials, leading to a higher diversity. Similarly, changes in occupation and mobility patterns may have resulted in more frequent contacts and connections with members of social networks (Park and Marwick, 2022). Drawing on evolutionary ecological theory, we might speculate that the cooler conditions of the Last Glacial Maximum promoted greater integration of social networks to buffer risks of resource failure (cf. Fitzhugh, 2001). Another possibility is that the cooler climate might have resulted in better overall fitness due to an increase in available food resources, or an increase in the patchiness of food and water resources, which would have concentrated them in fewer predictable locations. In our previous research, we observed that forager groups with stemmed points were able to occupy higher elevation, where the temperature was generally lower (Park and Marwick, 2022). The changes in occupation and mobility patterns may have resulted in more frequent contacts and connections with members of increased social networks. This may have provided more opportunities to learn point-making directly from socially successful individuals, and increased the contribution of indirect bias during cultural transmission during Phase 3.

A key difference between our work and that of Bettinger and Eerkens and Garvey, which motivated our approach, is the time span that we are attempting to infer cultural transmission for.

For Bettinger and Eerkens and Garvey the time span is in the order of 100s of years or dozens of human generations, while our study spans 1000s of years and 100s of human generations. In her simulation study, Garvey was able to derive the population at a particular site based on the number room block (house) and assumed four learning generation for about 100 years of site occupation (Garvey, 2018). Our findings rely on the untested assumption that similar regularities about cultural transmission are relevant over much longer time periods. Are transmission biases scale invariant with respect to time? Or is there a time span that when exceeded, patterns in cultural transmission become so overwhelmed with noise such that they are no longer discernible? We recognize that the answer to this question is important for determining the validity of our results. Premo and Kuhn (2010) used an agent-based model to investigate Paleolithic cultural change and found that the visibility of cultural change is strongly affected by local extinction rates, in some cases mimicking the results of conformist cultural transmission. Longer time periods may increase the probability of extinction events altering the archaeological record in this way. Hopefully our claims will stimulate future work on this question to assess the reliability of our assumptions. A good entry point to this next phase of work could be adapting Garvey's social learning models to cover a 20,000 year span, such as reported in our study. This would require drawing on archaeological and ethnographic information for approximate estimates for the population and generation turnover values required to transmit knowledge of new technology. Approximate Bayesian Computation is likely to be a productive computational method for refining these estimates, give how effective it has been in inferring models of cultural transmission from the archaeological record (Crema et al., 2014).

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Chapter 5

Conclusion

5.1. Introduction

In this final chapter, I provide a brief summary of the results and highlight the novel approach employed in this study. I also discuss the limitations of my study, which stem from the lack of empirical evidence and quantitative-focused methods that may overlook the unique characteristics of individual artifacts or assemblages. Moreover, I review the broader implications and contributions of this research. Beyond archaeology, I briefly introduce the practice of open science and research reproducibility, which I have applied in my research practice to enhance accessibility and applicability to fellow researchers. Lastly, I provide directions for future research related but not limited to Korean late Paleolithic assemblages.

Cultural evolution has been applied to archaeological research by providing quantitatively testable models and detailed explanations of human behaviors (Mesoudi, 2016; Prentiss et al., 2020; Shennan, 2008; Spencer, 1997; Walsh et al., 2019; Zwyns, 2021). In this dissertation, I employed the two principles of cultural evolution theory, Human Behavioral Ecology (HBE), and cultural transmission to investigate the technological shift from the Early to Late Paleolithic in Korea during the late Pleistocene. This cultural innovation is characterized by the appearance of stemmed points and blade technology and due to the limited material evidence, stone artifacts were the primary tool for understanding both technological and behavioral changes. The three research questions were addressed in this dissertation: what changes in foragers' landscape use and mobility were associated with the introduction of new tools? What were stemmed points, the representative artifacts of the Korean Late Paleolithic, used for? Lastly, what was the dominant mode of cultural transmission during the time of technological innovation in the Korean Late Paleolithic? To address the research questions, I analyzed the stone artifact assemblages and developed hypotheses based on cultural evolution in each of the previous three chapters. These chapters consist of one main research question, more detailed and directional questions, models or predictions based on cultural evolution theory, archaeological materials and quantitative methods, results, discussion and conclusion remarks. Here I summarize key findings from each chapter.

5.2. Research Summary

Chapter 2 explores the impact of stemmed points on mobility and site occupation during the late Pleistocene in Korea. To examine this topic, I utilized the patch choice model from human behavioral ecology (HBE) and formulated two research questions: what changes in foragers' landscape use were associated with the introduction of the new tools? And what changes in people's mobility and use of habitation sites were associated with the new technology? I predicted that the new projectile tool could have enabled foragers to explore more marginal and less productive patches, increase their mobility, and reach long-distance targets. To understand site occupation patterns, I computed stone artifact density and frequency of retouched pieces, which were scaled to the volume of excavated sediment. For instance, assemblages with low density but a high proportion of retouched and backed pieces could represent the remains of a "short-term camp," which is a site for small and ephemeral overnight camps or limited activity stations. On the other hand, a combination of high density and low retouched pieces may indicate a logistically organized "base camp," a site with greater residential stability, longer duration of occupation, and occupied by larger groups. I analyzed 35 assemblages from 23 sites spanning 49-24 ka. To infer the ecological impact of technological change, I utilized information on annual temperature per site location from a simulated data set of paleoclimate by Beyer et al. (2020). To understand the temporal trends of the demographic context, I used radiocarbon dates and computed summed probability distributions (SPD).

The results demonstrate that forager groups with stemmed points were able to occupy higher elevations with cooler temperatures compared to those without. These groups might be more associated with expedient technologies, suggesting more residential and less mobile behaviors. The technological innovation of stemmed points occurred within a gradual decrease in temperature leading up to the Last Glacial Maximum (LGM). Impact of population would be minor showing that population increased prior to the appearance of stemmed points.

Building upon the results of Chapter 2, which indicated that stemmed points could have facilitated human survival in harsh environments, Chapter 3 investigates the likely uses of stemmed points by examining the tip cross-sectional area (TCSA) metric and inferring their potential weapon-use strategies based on comparisons with other archaeological and ethnographic cases. To guide this research, I formulated three key questions: What were the best-fit ballistic probabilities for the stemmed points if they were hafted as weapon tips? How diverse were their likely uses? And what were the temporal and spatial patterns of stemmed point use? Based on the hint of HBE, I predicted the difference in TCSA range depending on location and time. For instance, I expected an increase in TCSA range (i.e. used as multifunctional tools) in harsh environments such as lower quality of patches or colder climate. After excluding all broken and damaged points, I collected a sample of 173 stemmed points from 36 assemblages spanning 44-10 ka. Utilizing a range of variables, including raw materials, weight, radiocarbon dates, and locations, I analyzed TCSA values in conjunction with eco-regional information of South Korea to explore the influence of vegetation and geographical features on the stemmed points. The results indicate that while the stemmed points were used for multiple purposes, they were primarily used as javelin tips and stabbing spear tips. TCSA values were primarily determined by size (i.e. weight), rather than raw material types. The observed un patternized variation in TCSA ranges across different sites suggests that people used stemmed points in response to local environmental conditions. Additionally, the distribution of stemmed points was found to be predominantly in certain ecoregions, inland areas, with no clear temporal patterns of TCSA values. Stemmed points were mainly produced before the LGM. In conclusion, this chapter confirms that stemmed points were multi-functional tools utilized in a variety of ways, with their specific use dependent on the local environment in which they were utilized.

Unlike the previous two chapters, which explored ecological contexts, chapter 4 focused on the social context by examining the transmission process of stemmed points and two learning biases using the concepts of cultural transmission. The main research question was to determine the dominant mode of cultural transmission during this technological innovation. Building upon the approach used in previous studies on Great Basin projectile points (Bettinger and Eerkens, 1999), I developed and tested two models based on guided variation and indirect bias. Guided variation model assumes socially isolated groups made stemmed points, leading to a relatively diverse range of shapes that are not correlated with each other. In contrast, socially connected groups learned to make stemmed points through indirect bias, leading to less variation and more correlation among the shapes. To evaluate these models, I computed correlation coefficients and coefficients of variation (CV) of morphological attributes for 152 stemmed points from 23 assemblages spanning 40-17 ka. The results indicate that information about the new technology was more likely transmitted via guided variation. However, I observed a slight shift in the social context of transmission towards indirect bias in the later chronological phase. It is likely that individuals or groups developed stemmed points by experimenting with existing blade technologies and then copied successful models to optimize tool usage. My results are more closely associated with the 'in situ' development model.

5.3. Open Science in Archaeological Science

In addition to my archaeological research on the technological transition during the late Pleistocene in Korea, I have placed a strong emphasis on open science and research reproducibility. Open science involves three key components: open access, open data, and open methods (Marwick et al., 2017). In my three chapters, which have been derived from individual papers, I have adhered to these three principles by sharing my raw data, codes for conducting statistical analysis and visualization, manuscripts, and pre-prints on openly accessible platforms and repositories such as GitHub and Open Science Framework.

Reproducibility in research refers to the ability to reanalyze data from the original study with the same methods to produce comparable results (Karoune and Plomp 2022). By providing a transparent record of my research I expect to see other researchers benefit from my work and apply it to their own projects. Pursuing open science practices has been beneficial for my own research as well, such as when I used paleoclimate information by exploring openly available codes from Beyer et al. (2020), applying the codes to my research using coordinates of the sites. In addition, I employed the "rcarbon" R code package developed by Crema and Bevan (2021) in Chapter 2 to explore SPD models for population dynamics. Convenience is another reason for me to advocate this practice. Storing my work on online repositories has allowed me to access my research from any computer and location. This has enabled me to easily download and use my data and code in various labs at UW.

Promoting open science is essential for archaeologists, who draw on theories and methodologies from various disciplines. For example, the cultural evolution theory that I have adapted for this dissertation research emerged from Darwinian biology (Mesoudi, 2016). However, researchers from other fields may not benefit from archaeological research if they lack access to it. Pursuing openness in archaeological research enhances sustainability and reusability of data, while also increasing access to research outputs for both researchers and the public (Karoune and Plomp, 2022). Open access provides a means for researchers who lack journal subscriptions by being outside of academic institutions to access the most up-to-date research. Moreover, local communities can also benefit from open access to archaeological data that has been collected from their areas. Research transparency is another benefit of openness, as sharing raw data and the research process enhances the credibility of archaeological research (Marwick et al., 2017).

The conventional research process in archaeology involves collecting data directly from fieldwork, museum collections, or published papers, analyzing, visualizing, writing, and publishing results. Throughout this process, archaeologists may modify or exclude raw data or analysis due to damaged material evidence or statistical outliers. By sharing the research process and raw data openly, readers can follow the analytical choices and gain a better understanding of the findings as well as all stages of the scientific research. In addition, researchers can utilize unfiltered data with updated methods to retest the original study.

I chose the R as my primary tool to conduct my entire research, from analyzing data to writing manuscripts. R is a free open source programming language, which is designed for statistical analysis and data visualization (Marwick, 2017). The biggest advantage of using R is that it provides access to more packages that contain code, data, and documentation for statistical analysis than other commercial softwares including Excel and SPSS (Karoune and Plomp, 2022; Trancón y Widemann et al., 2012). These packages have been continuously updated and newly created by researchers. Currently there are around 20,000 packages according to the Comprehensive R Archive Network (CRAN) package repository, and these are all freely available. R is a powerful tool that I use not only for statistical analysis, but also for organizing my data, code, text, and references. To this end, I have created three research compendiums for my three papers using the R package 'rrtools' (Marwick, 2022). This package offers a reproducible template for writing journal articles or reports, making it easy for myself and other researchers to navigate the research (Marwick et al., 2018). I wrote my papers including codes for statistical analysis and visualization as well as text with citation in R markdown and quarto. These document formats combine the codes with text and generate output in a single document, such as a Word Document with figures and references. By using these formats, I have ensured a fully reproducible workflow.

Besides R, I use GitHub, an online platform for storing, tracking and collaborating on projects. As mentioned earlier, GitHub as an online repository allows me to work remotely and collaborate with other researchers. Especially, through the version control function of GitHub, my collaborators and I could view changes easily and update research simultaneously (Braga et al., 2023; Dabbish et al., 2012; Gilroy and Kaplan, 2019; Mergel, 2015; Perez-Riverol et al., 2016). Open Science Framework (OSF) is another free and open platform that I have posted my papers on. Once the paper is ready, I have posted pre-prints of each paper on SocArxiv, making the full text of my papers freely accessible to anyone. I described my use of R and R markdown/quarto, GitHub as my open access repositories, and pre-prints at the end of the method section in each paper to guide readers to explore my research easily as well as promote open science. Through this practice, other researchers can fully explore my research including the research process without expensive journal subscriptions.

The practice of open science has gained momentum, particularly since the onset of the COVID-19 pandemic. Publishers have made COVID-19 articles freely available, contributing to this trend. Additionally, the rise of virtual conferences and online collaboration has facilitated global partnerships among researchers (Besançon et al., 2021; Karoune and Plomp, 2022; Maher and Van Noorden, 2021). I believe that archaeologists could benefit greatly from the practice of open science, especially during the COVID-19 pandemic when travel restrictions have made fieldwork and data collection difficult. While I was fortunate enough to have collected the majority of my data before the pandemic, I witnessed many of my fellow archaeologists struggle as their planned fieldwork was canceled or postponed. If raw data were made openly available, some researchers would still be able to conduct their research during lockdowns and other disruptions. This could not only provide a workaround for travel restrictions but also encourage more collaborative research within the archaeological community.

I acknowledge that becoming familiar with software and acquiring the necessary skills for coding and conducting research using code is a process that takes time. I propose that researchers take small steps towards implementing a reproducible workflow. Making your work openly available by storing it in online repositories, providing pre-prints, publishing in open access journals, or choosing “gold” (publishing in an open access journal or in a journal which supports open access) or “green” (archiving a version of the manuscript in an open access repository) open access options for publication, depending on the financial support from your institution, can be the first step.

5.4. Broader Implications and Impacts of this Research

5.4.1. Modern Human Dispersal during the Late Paleolithic in Korea

My research explores the modern human dispersal in Korea during the Late Paleolithic. Given the absence of reliable human remains, understanding this process in Korea has been challenging. Previous research on the topic has mainly focused on the possible origin or routes of their migration (e.g. *in situ* and migration models). My research directly examined behaviors of modern humans using HBE and cultural transmission theory. The analytical results suggest that modern human groups in Korea might be socially isolated and developed survival tactics to adapt to changing environments, including the creation of new tools, the application of different hunting methods, and changes in diet. My approach, the frameworks and specific methods, is applicable to other regions to further our understanding of modern humans and the transition to the Late Paleolithic.

5.4.2. Examination of Ecological and Social Contexts for the Technological Innovation

The primary goal of my dissertation was to investigate the potential factors that led to the development of new technologies. I adopted cultural evolution as a theoretical foundation to explore the ecological and social contexts that influenced tool usage and morphological variations during the late Pleistocene in Korea. Through this approach, I found that the emergence of stemmed points was strongly linked to the cooler climate and adaptation to specific local environments, such as inland areas and higher elevations. The foragers would be rather isolated and tended to stay in the base-camp type of sites for a long time. These factors might have been the driving force behind this new development. I anticipate that my methodology provides a framework for future research to identify the drivers of technological change in diverse regions or time periods such as the appearance and spread of pottery in Jomon period, Japan (e.g. Morisaki, 2022; Robson et al., 2020).

5.4.3. Application of Novel Empirical Methods to Prehistoric and Northeast Archaeology

Until now studies of the Korean Paleolithic have not used many quantitative methods. My work has introduced many quantitative methods that have been very productive in other regions of the world. Here are some of them that feature in my work. This is a novel contribution to the archaeology of the region. To explore the ecological and social contexts, I utilized innovative empirical methods and conducted extensive statistical analyses. Leveraging my proficiency in R programming, I was able to explore and apply the methods from the outside of archaeology into my research. For instance, to compensate for the lack of material evidence for paleoclimate, I employed a simulation from Beyer et al. (2020) that generates paleoclimate data, including temperature, precipitation, cloud cover, etc., for the last 120,000 years, which enabled me to get temperature estimates for each site. I also used GIS software (QGIS) to trace ecoregional maps and then R enabled to locate the sites in each ecoregional zone. To investigate population dynamics, I computed SPD models (Crema and Bevan, 2021) and identified the linear model as the best fit for my observed data based on Akaike's Information Criterion (AIC). For examining social contexts through cultural transmission biases, I used geometric morphometric analysis of stone artifacts using landmarks. This approach was advantageous because I could reuse the landmarks and create new morphometric attributes for further analysis or research, rather than needing to revisit the collections and measure the attributes every time I required new data. My work demonstrates how to incorporate novel methods from diverse fields, not just archaeology, and apply them to a specific case. I hope that my approach can serve as a guide or instruction for other researchers.

5.4.4. Reproducibility and Transparency

My research is openly available for other researchers to check and reuse. Through this practice, I could guarantee the reproducibility and transparency in my research, which is why I have provided detailed descriptions for each line or chunk of code that I used in my study, as well as information about any outliers that were excluded from my dataset. As a result of this transparency, a colleague, Sangkyu Lee, who is studying the change of fishing tools in the Korean Neolithic period was able to use my code to explore the relationship between climate change and the evolution of fishing tools (He and I presented this research at the 30th Annual Meeting of Korean Neolithic Research Society in 2020). This is the first time any research on the Korean Paleolithic has been presented in this way, with R code and data fully available to anyone without barriers. I expect to see more of this research inspired by my work as well as the benefits of open science.

5.5. Limitations

I have chosen to heavily rely on statistical analysis with testable predictions as a means to understand the technological transition and related human behaviors. This approach has been motivated by two key factors. Firstly, there is a lack of empirical evidence beyond stone artifacts, which are often heavily damaged, to examine this research period. For instance, there are no reliable human remains that can be utilized to study modern human dispersal, and few proxies are available to reconstruct paleoenvironments. This is largely due to both environmental conditions (e.g. acidic soil) and political conditions in Korea (e.g. archaeological evidence was destroyed by rapid industrialization especially in 1970~1990s, no access to the archaeological data in North Korea). Secondly, previous studies have focused primarily on chronology and typology, which are not directly connected to human behaviors. There are a few studies that have conducted scientific analysis such as usewear analysis (e.g. Lee and Sano 2019), they have only analyzed stemmed points from a single assemblage, making it difficult to discern their roles for the technological transition. In my research, I have examined the stemmed points from all available sites by statistical analysis with testable predictions, which can be used as one of multiple lines of evidence for future research on this topic. However, it is important to note that this statistical-centered analysis may have several limitations for this study such as simplification of the predictions, ignorance of other possibilities for stone artifact morphology, in addition to the issue of raw data itself.

To build testable hypotheses, I focused on only two specific routes of social learning - guided variation and indirect bias - which explain the social network between the group with stemmed points. However, this approach may have limited the exploration of other possibilities for manufacturing stemmed points. For example, some shapes could have arisen from random creation (Bentley et al., 2004; Fogarty et al., 2015; Lehmann et al., 2011; Strimling et al., 2009). In addition, I was not able to directly evaluate the possibility of the shape of stone artifacts being modified through reuse and resharpening, which can result in a different shape from the original inherited technology (Dibble, 1995; Frison, 1968). I also acknowledge that stone artifacts are not the best materials for studying transmission processes because they are produced via an irreversible "reductive" process, generating higher shape copying error rates, compared to “additive” materials such as pottery and basketry, such errors can be reversed (Schillinger et al., 2014a, 2014b). However testing these possibilities was beyond the scope of my current study with currently available data.

Another limitation comes from the quality of data, which may impact the robustness of my findings. In examining the morphological attributes of stemmed points, I had to exclude damaged pieces and those that are not openly available (i.e., formal excavation reports are unpublished yet). As a result, I only analyzed 173 or fewer stemmed points out of the approximately 400 stemmed points discovered in Korea, which might impact my analytical results.

Similarly, the available data is not enough to examine the long duration of the late Paleolithic period. For example, some archaeologists have considered population density or size as an influential factor for the transmission of successful technological innovations. Specifically, skills become more complex in societies with a high population size as a result of the growth of technological knowledge accumulated over generations (Henrich, 2004; Powell et al., 2009; Shennan, 2001). On the other hand, others have shown that population size itself has no effect on skill level (Grove, 2016), and the degree of group "connectedness" can be more influential (Andersson and Törnberg, 2016; Premo, 2016). I was inspired by Garvey's work (2018), where she used population size for simulating the change of CV values and then compared it with archaeological data, this approach is not a perfect analogy for the Paleolithic". While she estimated the population size for 100 years of occupancy (1250~1350 AD, approximately four generations) using "room blocks" remaining in the site as a proxy, my research covers a time span longer than 20,000 years and lacks remaining dwelling structures on the sites, which would require much more proxies to apply this approach to my research. Therefore, I decided not to consider adding population size, though I included population dynamics through computing SPD models.

Another limitation of this study is to apply modern eco-regional maps to examine the spatial distribution of TCSA values along with simulational paleoclimate data. I am fully aware that modern eco-regional maps do not resemble the Pleistocene landscape but those maps are only available options that I could apply to my research.

5.6. Future Research

The application of cultural evolution to the study of the development of new stone artifacts holds significant potential, as it offers insights not only into the transmission processes and related human behaviors but also into the hierarchical relationships among groups of foragers. Incorporating another concept of cultural evolution could provide an intriguing approach to further enhance our understanding. For example, the utilization of the phylogenetic approach to analyze stone artifacts could examine their interconnections and evolutionary trajectories. Cladistics generates phylogenetic trees that reflect relatedness hypotheses and show change within lineages. This enables the identification of ancestral traits and their transformation into derived traits (Houkes, 2012; Manem, 2020; Straffon, 2019). Application of the phylogenetic approach in archaeology is based on a premise that types of tools have shared derived traits, which constitute the units of evolutionary transformation. Unlike typology, which only organizes artifacts into discrete groups, phylogenetic methods offer additional information on the hierarchical relationships between the groups. By identifying divergence events, researchers can ultimately reconstruct the patterns of cultural evolution (Mace and Holden, 2005; O’Brien et al., 2003; Rivero, 2016; Straffon, 2019). After its initial use in Paleoindian stone artifacts (O’Brien et al., 2002; O’Brien et al., 2001), this approach has been successfully applied in various artifacts, time periods, and regions (Marwick, 2012; Riede, 2008; Rivero and O’Brien, 2014; Tripp, 2016).

Drawing inspiration from Matzig et al.’s research (2021), which utilized the phylogenetic approach to distinguish unique tool shapes and validated the effectiveness of this method by cross-referencing it with previously observed typo-chronological patterns, which could be employed in the study of stemmed points. They used geometric morphometrics (GMM) outline data for analyzing projectile points from European Upper Paleolithic. One exciting potential future direction is to expand the dataset by incorporating stemmed points from Japan (called ‘Hakuhen-Sentoki projectile point'). By doing so, it is possible to investigate the connections between the Korean and Japanese groups, as well as the relationship between the foragers in Japan.

My work points to productive future research by using cultural evolutionary concepts. Cultural transmission and phylogenetic approach could provide insight into the issue of peopling of the Americas. Davis et al. (2019, 2022) attempted to connect bifacial stemmed points from Japan, dated to 20-19 ka, to those found at the Cooper's Ferry site in Idaho, suggesting that people carrying stemmed projectile points from Japan migrated to the Americas via the northern Pacific Rim during the late Pleistocene (i.e., pre-Jomon Late Upper Paleolithic). However, biological evidence including cranial, dental, and genetic comparison suggest a stronger biological affinity between people living in the South Pacific and early Native Americans (Scott et al., 2021). Testing transmission biases and applying phylogenetic methods to the bifacial stemmed points from both regions could help address this issue. I observed that similar projectile points have also been discovered in southern Korea, such as the Haga site dated to 21 ka. By including more similar artifacts from Northeast Asia, this approach could be an intriguing way to test hypotheses about the peopling of the Americas.

5.7. Concluding Remarks on the Technological Transition during the Late Pleistocene in Korea

The main goal of this dissertation was to investigate the possible ecological and social contexts that led to the technological transition during the late Pleistocene in Korea. To address this research question, I applied concepts of HBE and cultural transmission from cultural evolution theory to explore the relevant human behaviors with statistically testable hypotheses. For the ecological context, I utilized paleoclimate simulation data and employed eco-regional maps to account for variations in vegetation and geography. Given that the LGM occurred during the research period, I used it as a proxy for cooler and drier climate. Site elevation was another ecological proxy used in the study. To investigate the social context, I computed SPD with radiocarbon dates to examine population dynamics. Testing hypotheses built upon transmission biases allowed for speculation regarding the connection between groups of foragers. The results suggest that the technological transition was influenced by ecological contexts, including decreasing temperature, assemblages located in specific ecoregional zones, and groups with stemmed points being able to occupy higher elevations. Notably, local environments had a greater impact on the use of stemmed points than overall temperature drops in Korea. TCSA analysis per assemblage indicates that people used stemmed points differently depending on their location. Population size did not appear to change conspicuously during the technological transition, and stemmed points were made by socially isolated groups.

In Chapter 1, I introduced two competing models that explain the origin of stemmed points and other new technologies, which also tackle the issue of modern human dispersal. My results are more closely aligned with the *in situ* model (Seong, 2006) rather than the 'heterogenic' migration model (Bae, 2010), based on the lithic evidence. I examined the impact of guided variation and indirect bias on learning how to make stemmed points. My findings suggest that stemmed points were likely produced through guided variation through trial and error. This explains why the morphological attributes of stemmed points show less correlation and more variation across assemblages. My results also show a strong correlation between raw materials and the shape of stemmed points, and their likely use. Thus, the availability of raw materials might play an important role in determining the shape of stemmed points, regardless of the skill level for making them. Local environments can also affect the probable use of stemmed points.

By applying cultural evolutionary theory to the technological transition during the late Pleistocene in Korea, I was able to investigate the related human behaviors and their changing patterns over time and location. During the transition period, relatively isolated groups possessing stemmed points were able to adapt better to harsher environments or less productive patches than groups without stemmed points. These groups relied more on inland resources rather than coastal regions and were less mobile, preferring to stay longer at base camp sites. Local development seemed to have been dominant, with only a small contribution from copying existing tools. They adjusted the shape of the tools depending on the surrounding environment and available raw materials. Stemmed points had been multi-functional with the wide morphological variation, and then their roles may have been partially replaced by other composite projectile points made with micro-blades after LGM. In future research, we are likely to gain many insights from the use of phylogenetic approaches to investigate the connection between the forager groups based on the hierarchical relationships of stemmed points, and to determine at what point indirect bias became more influential than guided variation. Through this analysis, we will gain a deeper understanding of the dispersion process of stemmed points in Korea.

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