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Correlation Between Levallois Core Preparation Techniques in China and Those Found in the Altai and Mongolian Regions

Zheyang Chen[1], **William Davies**[2]

1. Ph.D. Candidate Archaeology, Centre for the Archaeology of Human Origins, School of Humanities University of Southampton, Southampton, UK.
Email: zheyangchencz@sina.com
2. Professor, Centre for the Archaeology of Human Origins, School of Humanities University of Southampton, Southampton, UK. (Corresponding Author)
Email: S.W.G.Davies@soton.ac.uk

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Abstract

This study adopts a data-driven framework to investigate regional variation in Levallois core technology, aiming to assess the stability of flaking techniques and the diversity of technological exchange across Russia, Mongolia, and northern China. Guided by Boëda's comprehensive typology, cores are first classified into preferential, centripetal, bipolar, and unipolar types, then quantitatively analysed through two-dimensional lithic-image analysis. In Mongolia, preferential and centripetal Levallois sequences are mature and stable: scar-density indices at all sampled sites exceed 60%, and coefficients of variation remain low, demonstrating highly standardised reduction concepts. In contrast, Russian assemblages exhibit pronounced inter-site heterogeneity; centripetal cores from Anui-1 are remarkably consistent, whereas contemporaneous layers at Kara-Bom display wide metrical dispersion. At Shuidonggou in China, the overall technological level is slightly lower, yet Layers 7 and 6 clearly inherit technical traits from underlying Layer 8, implying in-situ continuity rather than abrupt replacement. At Tongtian Cave in western China, cores show markedly lower scar coverage and smaller detached-flake areas, indicating a lower degree of technical mastery than at the more centrally located Shuidonggou site. Russian bipolar Levallois shows limited affinity with Chinese counterparts, whereas centripetal cores from Kara-Tenesh cluster tightly with Shuidonggou Layer 7. Crucially, within single Chinese sites different stratigraphic layers alternately align with Mongolian or Russian traditions, evidencing repeated episodes of introduction, assimilation, and re-innovation. In sum, Levallois technology entered China not through a single corridor but via multiple temporally staggered pathways. Chinese Levallois origins are polygenic, and several dispersal routes likely operated across northern Eurasia. Rather than a unidirectional corridor, the region functioned as a reticulated, continuously interacting technological landscape.

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1. Introduction

Definition and Origin of the Levallois Technique

1.1. Evolution and Controversy of the Definition of Levallois Technology

The definition of Levallois technology has been a subject of debate among many researchers over the past decades. The term was first coined by the geologist Reboux in 1861, but it was not until the mid-20th century, with the development of archaeology and anthropology, that Levallois technology became a research hotspot (Schlanger, 2014; Chirikure, 2024). Bordes (Bordes, 1980) was the first to conduct a systematic study and propose a clear definition, arguing that Levallois technology is a unified and unchanging concept with a clear definition and consistent technical characteristics. He noted that the core features of Levallois technology were the careful preparation and retouching of cores, and the specific form of the flakes produced, which remained constant across various environments. Bordes's research laid the groundwork for subsequent archaeological studies. However, this view has been challenged in subsequent studies.

Copeland emphasized the diversity of Levallois technology, arguing that its manifestation varies significantly from site to site (Copeland, 1983). Geneste provided important references for archaeologists by replicating the characteristics of flakes from different knapping stages, which further advanced the study of Levallois technology (Geneste, 1986). Perpère focused on the morphological features of Levallois technology and its variability in Africa and Europe (Perpère, 1986). Chazan further emphasized the diversity of Levallois technology in different regions and time periods and proposed a reassessment of the definition of Levallois technology (Chazan, 1997). Dibble's research pointed out that the efficiency of Levallois technology lies in the ability to knap high-quality flakes multiple times from a single core through Levallois cores, significantly increasing the yield of flakes while reducing the rate of rejects (Dibble, 1989; Dibble and Bar-Yosef, 1995). This process not only requires careful design of the core's morphology but also strict requirements on the texture and structure of the stone. Boëda proposed a volumetric concept of Levallois technology, emphasizing the importance of the two-sided configuration of the core and the Levallois surface (Boëda, 1995). These different perspectives reflect the complexity and diversity of the definition of Levallois technology and demonstrate the deepening of its understanding within the archaeological community. However, the definition of Levallois technology remains controversial, particularly in terms of how to accurately identify and categorize Levallois technological artifacts, with different researchers proposing different criteria and approaches (Van Peer, 1995; White and Pettitt, 1995; Schlanger, 1996; Eren and Lycett, 2012; Boëda and Audouze, 2013; Wiśniewski, 2014; Shimelmitz and Kuhn, 2018a).

The core of Levallois technology is not only the technological core of Levallois technology but also reveals the standardization of its stone tool production. This is another significant feature of Levallois technology. Through econometric analysis, Dibble (Dibble, 1989; Dibble and Bar-Yosef, 1995) pointed out that the core of Levallois technology lies in producing many standardized flakes from a single core. This standardization is reflected in the shape and size of the flakes, enabling the flakes to better meet the diverse needs of ancient humans in their subsistence and production activities. Standardized flake production not only increased the utilization of flakes but also reduced the need for new cores, thereby lowering the costs of transporting raw materials and labor intensity (Lycett and Eren, 2018). Moreover, standardized flake production reflects a high level of mastery of stone tool-making techniques and a deep understanding of tool function by ancient humans. Through Levallois cores and standardized flake production, ancient humans were able to obtain tool blanks more efficiently to meet their needs in survival activities such as hunting, processing food, and making clothing (Brantingham, & Kuhn, 2001). This standardized production method not only demonstrates the functionality and practicality of Levallois technology but also shows its stability and adaptability across different regions and time periods. Despite the diversity of Levallois technology across regions and time periods, the standardization of flake production has always been one of its core features, enabling Levallois technology to play an important role in the lives of ancient humans.

In terms of tool making, Bordes argued that Levallois technology might not be as efficient as other technologies in making large or complex tools (Bordes, 1980). This is because Levallois technology primarily focuses on producing standardized flakes, which are usually used to make small tools such as scrapers and cutters. These small tools have a wide range of applications in daily activities such as hunting, processing food, and making clothing. However, the flakes produced by Levallois technology are typically thin and regular, making them suitable for fine cutting and scraping work. This standardized flake production not only improves tool utilization but also reduces the need for new cores, thereby lowering the costs of transporting raw materials and labor intensity (Eren & Lycett, 2012; Lycett & Eren, 2018).

However, when making large or complex tools, the limitations of Levallois technology become apparent. Large tools such as hand axes and choppers usually require larger flakes, and although Levallois cores can produce high-quality flakes, the flakes produced by this technology are typically smaller and difficult to meet the demands of large tools. Therefore, ancient humans might have preferred to use other technologies when making large tools (Foley & Lahr, 1997). Levallois technology is geographically widespread, and the timing and location of its emergence in different regions provide important clues to the study of its diffusion pathways. In Europe, Levallois technology mainly appeared during the Late Middle Pleistocene (MIS8-MIS6), especially in Western and Central Europe (Brantingham & Kuhn, 2001; Otte *et al.,* 2017). Wiśniewski's study suggests that Central Europe's Levallois technology emerged relatively late and may be closely related to the distribution of high-quality stone in the region (Wiśniewski, 2014). For example, Levallois technology artifacts have been widely found in several sites in France and Germany, mainly dating between about 250-100 ka BP (Kozłowski, 2014; Picin, 2018; Fat Cheung, 2020; Moncel *et al.,* 2021). In some sites in South Africa, such as the Canteen Kopje site, excavated Levallois-like core technology is considered to be representative of early Levallois core technology, dating to approximately 800,000 to 1 million years before present (Tian *et al.,* 2024). These early Levallois core technologies share similarities with Levallois technology in some features but also have significant differences, indicating that Levallois technology developed with some independence and diversity in Africa.

In Asia, the distribution of Levallois technology is more sporadic, but archaeological discoveries in recent years have gradually enriched the understanding of its spread in the region (Belousova *et al.,* 2018). Levallois technology is one of the core technologies of the Middle Paleolithic in the Altai region. This technology is characterized by Levallois cores and planned flake production, enabling the production of standardized flakes, stone blade s, and points. Levallois technology has been found in several sites in the Altai region, indicating its importance in the region (Lesage, 2019; Lesage *et al.,* 2020).

For example, at the Guanyin Cave site in Guizhou, Southwest China, Levallois technology artifacts have been found dating back to between 170,000 and 80,000 years before present (Boda, Li & Hou, 2009; Hu *et al.,* 2023). This discovery suggests that the spread of Levallois technology in East Asia may be earlier than previously thought. In addition, sporadic evidence of Levallois technology has been found in some Late Pleistocene sites in East Asia, such as the Tongtian Cave, Jinshi Tai, and Shuidonggou sites (Otte *et al.,* 2017; Li, 2018; Yu *et al.,* 2018; Hu *et al.,* 2023).

1.2. Controversy over the Dispersal Routes

The dispersal routes of Levallois technology have always been one of the focal points of controversy in the archaeological community. Different scholars have put forward different views, which are mainly based on archaeological findings, technical feature analysis, and research on the migration routes of ancient humans.

One view holds that the spread of Levallois technology is mainly related to the migration of ancient humans. Foley and Lahr (Foley and Lahr, 1997) proposed the "Mode 3" hypothesis, which argues that the origin of prepared core technology (including Levallois technology) is entirely African and was introduced to Europe around 250 ka BP. They believe that the spread of Levallois technology is closely related to the migration of ancient humans from Africa to Eurasia, and this technology spread to different regions with the migration of ancient humans. However, this view has also been questioned because there are differences in the appearance time of Levallois technology in different regions, and there may be the possibility of independent development in some regions. For example, Victoria West-like Core Technology is an important Levallois core technology in the Acheulean, first discovered in South Africa and considered one of the earliest Levallois core technologies (about 800,000 to 1.1 million years ago), (Tian *et al.,* 2024). This technology has many conceptual and technical similarities with later Levallois technology. The latest research reveals that the Fauresmith culture and Victoria West-like Core Technology at the Canteen Kopje site have promoted the development of Levallois core technology (Rybin and Khatsenovich, 2020; Olszewski *et al.,* 2023).

Another view emphasizes the independent development of Levallois technology. Scholars such as Chazan (Chazan, 1997) and Shimelmitz (Shimelmitz, 2013; Shimelmitz and Kuhn, 2018b) believe that the appearance of Levallois technology in different regions may be the result of independent development, rather than a single dissemination process. They pointed out that there are significant differences in the specific forms of Levallois technology in different regions, and these differences may originate from the environmental conditions, raw material properties, and local cultural traditions of different regions. For example, there are obvious morphological differences between Levallois technology in Africa and Europe, indicating that Levallois technology may have experienced different development paths in different regions. In addition, some scholars believe that the spread of Levallois technology is a complex process involving the combined effects of multiple factors. Wiśniewski pointed out that the spread of Levallois technology is not only related to the migration of ancient humans but also affected by geographical environment, raw material distribution, and cultural background and other factors (Wiśniewski, 2014). In Central Europe, the appearance of Levallois technology is relatively late and may be closely related to the distribution of high-quality stone materials in the region. This view holds that the spread of Levallois technology is a dynamic process, and its dissemination routes and times in different regions may be constrained by multiple factors. In East Asia, the discovery of Levallois technology is relatively rare and sporadic. Levallois technology in the Altai region is mainly concentrated in the Russian Altai and Xinjiang Altai regions of China (Belousova *et al.,* 2018; Lesage *et al.,* 2020). In Mongolia, the application of Levallois technology is mainly concentrated in the Final Middle Paleolithic (FMP) and Initial Upper Paleolithic (IUP), and its technical characteristics and application methods have significant regional characteristics, with the main prevalence time being 50-46 ka BP (Wu, 2022).

In summary, the geographical distribution and dispersal routes of Levallois technology are complex issues involving the combined effects of multiple factors. Although there is certain controversy in the archaeological community about its dissemination routes, with more archaeological discoveries and in-depth research, the understanding of its dissemination process will continue to deepen.

2. Method

The study adopts an interdisciplinary approach, including archaeology and mathematics. It summarizes the lithic technology of Levallois cores from multiple sites in the Altai region, Mongolia, and China based on published data, and explores the characteristics of Levallois technology in different regions in combination with geological background. Meanwhile, the study utilizes a two-dimensional lithic image analysis method to analyze sample data to reveal their similarities and differences.

This paper employs Boëda's (Boëda, 1994, 1995) Levallois classification method, combined with Scott's (Scott, 2006) Levallois core classification method (Fig.1) to study the cores from the Shuidonggou site and several published Levallois cores from the Altai and Mongolian regions.

Since the Levallois lithic artifacts from the Mongolian and Altai regions in this paper are mainly derived from published papers, the two-dimensional lithic image analysis method will be used to analyze the sample data. The two-dimensional lithic images utilize Suzuki's border following

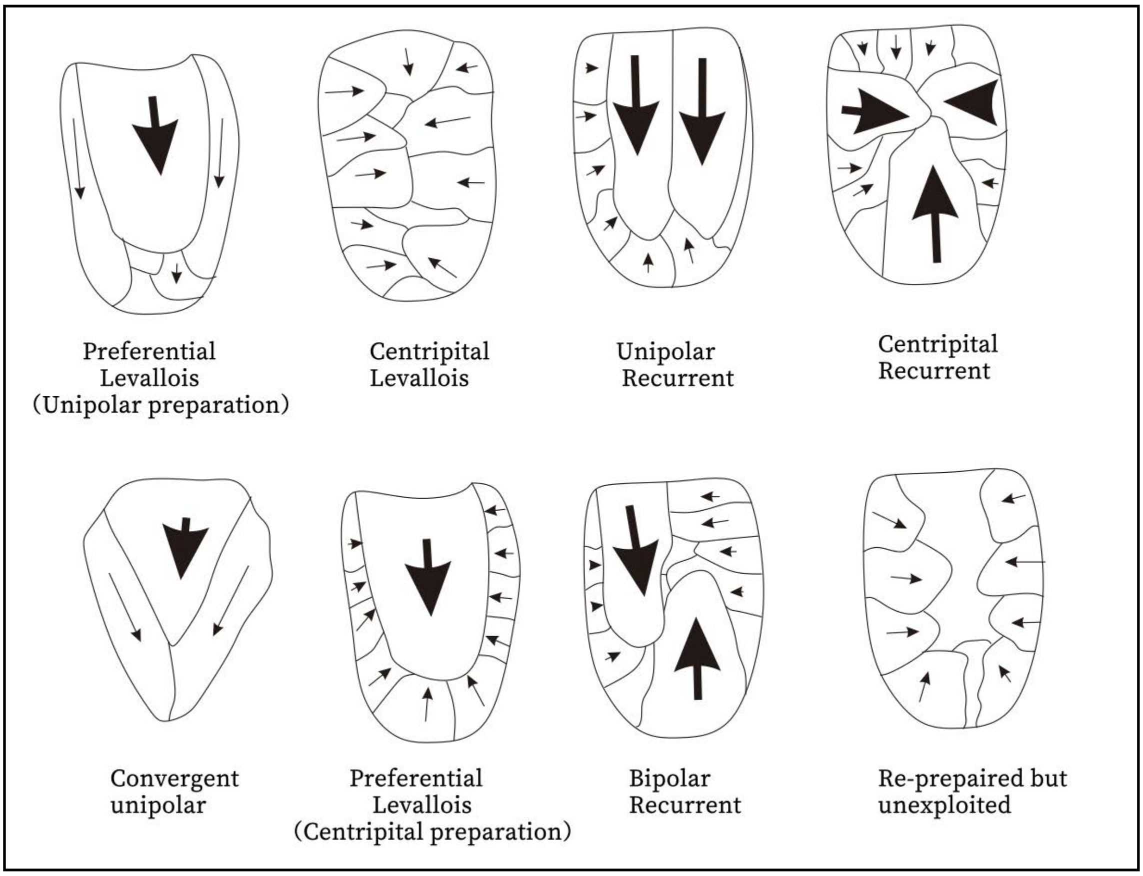

Fig. 1: Levallois surface preparation (After: Boëda, 1995; Scott, 2006).

algorithm (Suzuki and Be, 1985) to transform binary images into boundary representation forms, and extract the topological structure between boundaries, thereby obtaining the surroundness relations of the out border and hole border in the binary images, and assigning numbers to each enclosed area. Then, the pixels within the enclosed areas are calculated to obtain the area size of each corresponding numbered knapping scar in the lithic image. By summing the areas of different numbered knapping scars, the total area of the lithic artifact is obtained. Subsequently, the area of each numbered knapping scar is divided by the total area of the lithic artifact to obtain the proportion of the area of each numbered knapping scar to the total area (Chen *et al.,* 2024).

3. Results

Levallois Technology in the Altai Region, Mongolia, and China

Levallois technology is widely distributed in the Altai region, Mongolia, and China, showing certain similarities and diversities in these regions. This paper selects some sites from these three regions and, based on the research of previous archaeologists, uses the topological structure of two-dimensional lithic images combined with lithic technology analysis for data-based classification.

3.1. Mongolian Sites

Levallois technology in Mongolia is mainly distributed in several Paleolithic sites, such as

Tsagaan Agui Cave, Orkhon 1 and Orkhon 7 sites, and Kharganyn Gol 5 site. The morphology of Levallois cores in Mongolia is similar to that in the Altai region, but the Levallois process is relatively simple, showing certain technical diversity. The size of flakes is small, and their shapes are diverse, with a lower level of technical control compared to the Altai region (Derevianko *et al.,* 2007; Derevianko, Markin & Shunkov, 2013; Quan, 2015; Bolorbat *et al.,* 2020; Wu, 2022).

3.1.1. Tsagaan Agui Cave

Tsagaan Agui Cave is located in the Gobi Altai region of Mongolia, dating back to approximately 227,000–520,000 years ago, belonging to the Middle Paleolithic. Layers 6-11 of the cave have revealed early Levallois technology, mainly characterized by centripetal Levallois flaking and the use of a small amount of bipolar Levallois flaking. Cores and flakes show distinct Levallois features, such as polyhedral platforms and centripetal dorsal scar patterns. The emergence of these Levallois technologies is related to the use of local low-quality flint raw materials, indicating the adaptability of early humans to resources (Rybin & Khatsenovich, 2020; Wu, 2022; Khatsenovich *et al.*, 2023) .

3.1.2. Orkhon 1 and Orkhon 7 Sites

Orkhon 1 and Orkhon 7 sites are located in the Selenga River basin of Mongolia, dating back to approximately 45-40 ka BP, belonging to the Terminal Middle Paleolithic (TMP) (Khatsenovich *et al.,* 2019). Typical Levallois technology, including centripetal Levallois flaking method and bipolar Levallois flaking method, was found in the AH3 layer of Orkhon 1 and the AH5 layer of Orkhon 7 (Rybin and Khatsenovich, 2020). The Levallois technology of these sites is mainly focused on the production of Levallois flakes, showing a high level of technical complexity. The Levallois technology of Orkhon 1 is mainly centripetal, while Orkhon 7 uses more parallel methods, indicating technical diversity (Khatsenovich *et al.,* 2019; Wu, 2022).

3.1.3. Kharganyn Gol 5 Site

Kharganyn Gol 5 site is located in the Selenga River basin of Mongolia, dating back to approximately 50-47 ka BP, belonging to the TMP (Derevianko, 2016). Layers 7 and 6 of the site have revealed Levallois technology from the TMP period, including centripetal Levallois flaking and bipolar recurrent Levallois flaking. Cores and flakes show distinct Levallois features, such as polyhedral platforms and regular Y-shaped dorsal scar patterns. The Levallois technology of Kharganyn Gol 5 is directly superimposed on IUP technology, indicating the possible technical continuity between TMP and IUP (Rybin and Khatsenovich, 2020).

3.1.4. Moil'tyn-am Site

Moil'tyn-am site is located in the Orkhon Valley of Mongolia, dating back to approximately 45,000 years ago, belonging to the Transitional Middle Paleolithic (TMP). The AH5-4 layer of the site has revealed Levallois technology, including centripetal method and bidirectional convergent method (Rybin & Khatsenovich, 2020). Cores and flakes show distinct Levallois features, such as polyhedral platforms and regular Y-shaped dorsal scar patterns. The Levallois technology of Moil'tyn-am is similar to that of Orkhon 1 and Kharganyn Gol 5, indicating the possible existence of a common technical tradition in these regions (Derevianko & Petrin, 1995; Lesage, 2019).

3.1.5. Chikhen Agui Cave

Chikhen Agui Cave is located in the Gobi Altai region of Mongolia, dating back to approximately 39 ka BP, belonging to the Early Upper Paleolithic (EUP) (Li, 2018). Layer 3 of the cave has revealed Levallois technology from the IUP period, including bidirectional convergent method (Khatsenovich *et al.,* 2023). Cores and flakes show distinct Levallois features, such as polyhedral platforms and regular Y-shaped dorsal scar patterns. The Levallois technology of Chikhen Agui shows the typical features of IUP technology, indicating the possible rapid evolution of technology in this region (Derevianko *et al.,* 2008).

3.1.6. Tolbor 4 and Tolbor 21 Sites

Tolbor 4 and Tolbor 21 sites are located in the Selenga River basin of Mongolia, dating back to approximately 45-39 ka BP, belonging to the IUP (Derevianko, Markin and Shunkov, 2013). The AH6 layer of Tolbor 4 and the AH3 layer of Tolbor 21 have revealed Levallois technology from the IUP period, including double recurrent Levallois flaking (Lesage, 2019; Rybin and Khatsenovich, 2020). Cores and flakes show distinct Levallois features, such as polyhedral platforms and regular Y-shaped dorsal scar patterns. The Levallois technology of Tolbor 4 and Tolbor 21 shows the typical features of IUP technology, indicating the possible rapid evolution of technology in this region (Derevianko *et al.,* 2007; Derevianko, Markin and Shunkov, 2013; Tabarev *et al.,* 2013; Rigaud *et al.,* 2023).

3.1.7. Orog Nuur 1,2 Sites

The Orog Nuur 1,2 sites are located in the Altai Mountains region in northwestern Mongolia, near Orog Lake. However, according to Y. V. Kuzmin's article, these sites may belong to the Late Paleolithic period, dating back to approximately 33-27 ka BP (Kuzmin, 2019). This period corresponds to the Karginian interglacial period in Siberia (Oxygen Isotope Stage 3), with a climate cooler than today but still suitable for prehistoric human habitation (Kuhn and Zwyns, 2014).

The lithic types at the Orog Nuur 1,2 sites may be similar to those at other Late Paleolithic sites in Siberia, including flakes made using Levallois technology and microblades (Zwyns, 2021). The production techniques of these lithics reflect the high level of mastery of lithic production by humans at that time and their adaptability to the environment (Rybin & Khatsenovich, 2020).

3.2. Altai Region

The Altai region is one of the significant distribution areas of Levallois technology, with its

Levallois technology mainly concentrated in sites such as Denisova Cave. Studies have shown that the Levallois technology in the Altai region has a mature morphology of Levallois cores, including single-sided Levallois and double-sided Levallois. The Levallois process of the cores is complex, demonstrating a high level of technical proficiency. Meanwhile, the size of the flakes is relatively large, and their shapes are regular, showing a high degree of technical control ability (Shunkov *et al.,* 1994; Agadjanian & Shunkov, 2009; Kuhn & Zwyns, 2014; Belousova *et al.,* 2018; Derevyanko *et al.,* 2024).

3.2.1. Kara-Bom Site

The Kara-Bom site is located in the Altai region of Russia, with an age of 43 ka ± 1 ka - 34 ± 1 ka BP, belonging to the MP (Middle Paleolithic) (Krivoshapkin *et al.,* 2010). Typical Levallois technology, including the convergent unipolar method and Bipolar recurrent method, was found in the MP2 layer of this site (Li *et al.,* 2014). Cores and flakes show distinct Levallois features, such as polyhedral platforms and regular Y-shaped dorsal scar patterns. The Levallois technology of Kara-Bom demonstrates a high level of technical complexity, indicating the possible long-term inheritance of technology in this region (Belousova *et al.,* 2018; Rybin *et al.,* 2023).

3.2.2. Denisova Cave

Denisova Cave is one of the important discovery sites of Levallois technology in the Altai region, with an age of about 130-50 ka BP (Xia & Zhang, 2020; Koller *et al.,* 2022; Derevyanko, Kozlikin & Shunkov, 2024). The UP (Upper Paleolithic) dates back to approximately 12-4.8 ka BP. The best age estimate for Denisovans is about 73-13 ka BP (Brown *et al.,* 2021). The age of Neanderthals can be determined to be about 59-50 ka BP, and the age of modern humans is approximately 48-12 ka BP (Andreeva *et al.,* 2022; Kuzmin *et al.,* 2022). Levallois technology of the MP period, including the Covergent unipolar method and Bipolar recurrent method, was found in Layer 11 of this cave. Cores and flakes show distinct Levallois features, such as polyhedral platforms and regular Y-shaped dorsal scar patterns (Lesage, 2019; Derevyanko *et al.,* 2024). The Levallois technology of Denisova Cave is similar to that of Kara-Bom, indicating the possible existence of a common technical tradition in the Altai region (Andreeva *et al.,* 2022). Moreover, fossils of Denisovans were also found in Denisova Cave, and these ancient humans are closely related to the users of Levallois technology, reflecting the technical level and survival strategies of ancient humans in this region (Xia & Zhang, 2020; Derevyanko*et al.,* 2024).

3.2.3. Ust-Karakol 1 Site

The Ust-Karakol 1 site is located in the Altai region of Russia, with stratigraphic layers MP1 and MP2 (about 72.3-62.2 ka BP), IUP2 (about 43 ka BP), and UP1 (about 34 ka BP) (Belousova *et al.,* 2018; Li, 2018; Rybin *et al.,* 2023). Typical Levallois technology, including the Bipolar recurrent method, was found in the IUP layer of this site (Derevianko, 2011). Cores and flakes show distinct Levallois features, such as polyhedral platforms and regular Y-shaped dorsal scar patterns. The Levallois technology of Ust-Karakol 1 shows the typical features of IUP technology, indicating the possible rapid evolution of technology in this region (Rybin and Khatsenovich, 2020). This technological evolution may be closely related to the migration and cultural exchange of early modern humans, further revealing the technological development and cultural evolution in the Altai region during the Late Paleolithic (Derevianko*et al.,* 1996; Lesage, 2019; Lesage *et al.,* 2020).

3.2.4. Anui-1 Site

The Anui-1 site is located in the Gorny Altai region of the Altai Mountains in Siberia, Russia. This site is one of the important locations for studying the Paleolithic culture of Central and North Asia. The MP layer dates back to approximately 72.3-62 ka BP, the IUP layers to about 43 ka BP, and the EUP (Early Upper Paleolithic) to about 34-30 ka BP (Wu, 2022). It shows a high degree of prepared core features, including double-platform and single-platform cores (Li, 2018). The cores at the Anui-1 site usually have a flat knapping platform, and the morphology of the cores is prepared by planned removal of flakes, with a large number of flakes produced by Levallois technology found. These flakes can be used to make various tools, such as scrapers and blades (Rybin, 2014).

3.2.5. Ust'-Karakol Site

The Ust'-Karakol site is located in the Gorny Altai region of the Altai Mountains in Siberia, Russia. The dating data ranges from 43.7-33.6 ka BP (Belousova & Rybin, 2013; Rybin, 2014). Core types: In the early cultural layers of the Ust-Karakol 1 site, the types of cores are diverse, including Levallois cores (Belousova *et al.,* 2024). These cores usually have distinct prepared platforms and ridges, showing a high degree of technical complexity (Kuzmin, 2019).

3.3. Chinese Levallois Technology

Levallois technology in China is mainly distributed in a few sporadic Paleolithic sites in the north and west, such as the Shuidonggou site, Jinshi Tai site, and Tongtian cave site (Otte *et al.,* 2017; Li *et al.,* 2019; 2020). Meanwhile, sites discovered in the south of China are much earlier than those in the north, such as the Guanyin Cave site and Dadong site (Otte *et al.,* 2017). Levallois technology independently appeared in several sites in the south of China, and its lithic technology shows a high degree of localization, similar to Levallois technology in Europe and Africa, but not spread from outside (Otte *et al.,* 2017; Hu *et al.,* 2023; Gao, 2024).

3.3.1. Shuidonggou Site

The Shuidonggou site is located in Lingwu City, Ningxia Hui Autonomous Region, China, and is one of the important sites of the Late Paleolithic in northern China, dating back to about 40,000 years ago (Gao *et al.,* 2008; Kuhn & Li, 2019; Li *et al.,* 2020). The site has 12 different localities, among which Locality 1 and 9 have found Levallois cores(Gao *et al.,* 2009; Kuhn & Li, 2019;

Gao, 2023). Layers 8 and 7 of Locality 1 have found typical Levallois technology. Two types of cores were found in Locality 1, namely simple reduction cores and prepared cores. Among them, simple unipolar cores are the most common, especially in Layer 7 (Ningxia Institute of Cultural Relics & Archaeology, 2003; *Gao et al.,* 2008; Li *et al.,* 2020). Prepared cores are divided into Levallois cores, prismatic/subprismatic cores, edge-faceted cores, and burin cores (Gao *et al.,* 2008). The main technology of Levallois cores is unipolar and bipolar recurrent technology (Gao *et al.,* 2008; Boëda *et al.,* 2013; Kuhn & Li, 2019).

3.3.2. Tongtian Cave Site

In 2016, the development and excavation of the Tongtian cave site in Jimunai, Xinjiang, first discovered the exact Paleolithic site strata in the Xinjiang area. The site is located on the southern slope of the Altai Mountains, 20 kilometers south of Tuost Township, Jimunai County, Altai Region (Yu & He, 2017). Layers 6 and 7 of the Tongtian cave site are the thickest and have the densest distribution of abandoned materials. According to the radiocarbon dating results of animal bones in layers 6 and 7, the age is about 45,000 years ago (Yu, 2018; Yu *et al.,* 2018). In terms of lithic industry, the Tongtian cave site has found typical discoidal cores, Levallois cores, Levallois flakes, Mousterian culture edge scrapers, etc. (Chen *et al.,* 2021). The lithic artifacts have the typical characteristics of the Middle Paleolithic Levallois Mousterian industry, but a small number of Levallois flat-faced blade cores and long flakes were found, showing a transition to the Late Paleolithic, similar to the lithic industry of sites in the Altai region during the same period (Li, 2018).

4. Technical Comparative Analysis

4.1. Complexity of Levallois Core Technology

The core of Levallois technology lies in the Levallois core technology, which shows significant complexity in the Altai region, Mongolia, and China (Lesage, 2019). In the Altai region, such as the Kara-Bom site and Ust'-Kanskaya site, Levallois core technology demonstrates a high degree of complexity (Li, 2018; Wu, 2022). The Levallois technology at the Kara-Bom site includes the Unipolar convergent Levallois flaking method and Bipolar recurrent Levallois method, with cores and flakes showing polyhedral platforms and relatively regular Y-shaped dorsal scar patterns (Rybin and Khatsenovich, 2020). Similarly, the Levallois technology at the Ust'-Kanskaya site features the Unipolar convergent Levallois flaking method and bipolar Levallois knapping method (Lesage, 2019). These technical characteristics indicate that the ancient humans in the Altai region were able to perform multi-step operations in the Levallois core process, especially at the Kara-Bom site, which reflects a high degree of technical planning and foresight.

In Mongolia, although the morphology of Levallois cores is similar to that in the Altai region, the Levallois process is relatively simpler. For example, the Levallois technology at the Tsagaan Agui Cave is mainly characterized by the Centripetal Levallois method and a small amount of Bipolar Levallois method, with cores and flakes showing polyhedral platforms and centripetal dorsal scar patterns. The Levallois technology at the Orkhon 1 and Orkhon 7 sites is primarily focused on the production of Levallois flakes, demonstrating a higher degree of technical complexity, but with lower technical diversity compared to the Altai region. This indicates that the ancient humans in Mongolia, while able to perform certain technical operations during Levallois core preparation, had an overall complexity that was not as high as in the Altai region.

In China, at sites such as the Shuidonggou site and Tongtian cave site, the Levallois core technology also shows a high degree of complexity. The Levallois cores at the Shuidonggou site have diverse forms, including the Preferential Levallois flaking method, Bipolar Levallois flaking method, and Centripetal Levallois Flaking method. The flaking method of Shuidonggou site (Locality 1) shows the complexity of local techniques. The lithic technology at the Tongtian cave site is a relatively typical Mousterian lithic technique found in China, with the Preferential Levallois flaking method discovered (Yu, 2018). These technical characteristics are similar to those in the Altai region (Wu, 2022), (Figs. 2 & 3).

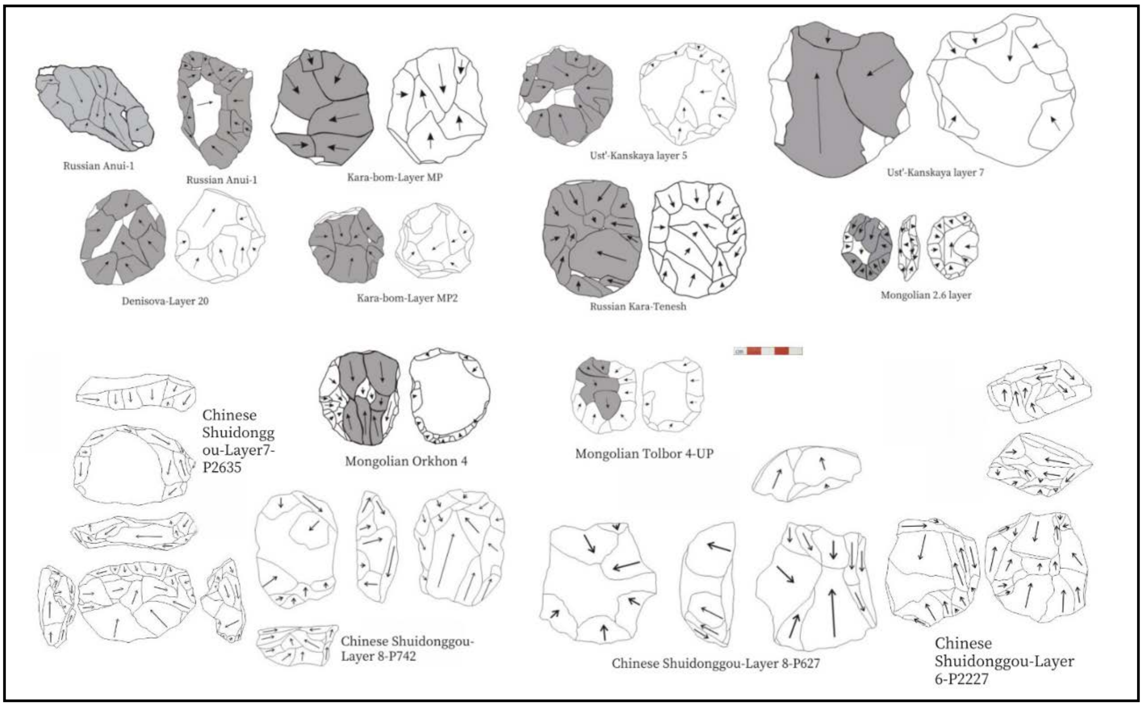

Fig. 2: Russian, Mongolian and Chinese centripetal Levallois cores (Ningxia Institute of Cultural Relics and Archaeology, 2003; Gao *et al.*, 2004; Belousova *et al.*, 2018; Li, 2018; Rybin & Khatsenovich, 2020; Wu, 2022).

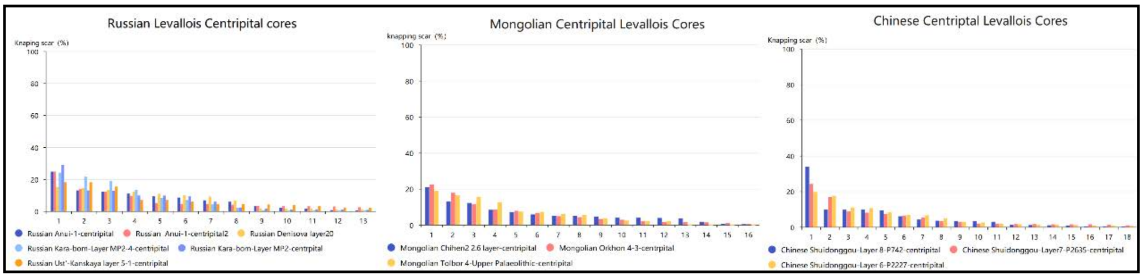

Fig. 3: This bar chart describes the percentage of knapping scars on the knapping surface of Levallois preferential cores from several sites in Russia, Mongolia, and China.

Overall, the Centripetal Levallois flaking method in the Mongolian region shows relatively more stable knapping flake sizes compared to the sites in Russia, indicating the stability of their technical mastery. At the Shuidonggou site in China, the Centripetal Levallois cores in Layer 7 and Layer 6 are more stable compared to the earlier Layer 8, showing an increase and stability in the proficiency of Levallois knapping method (Fig. 4).

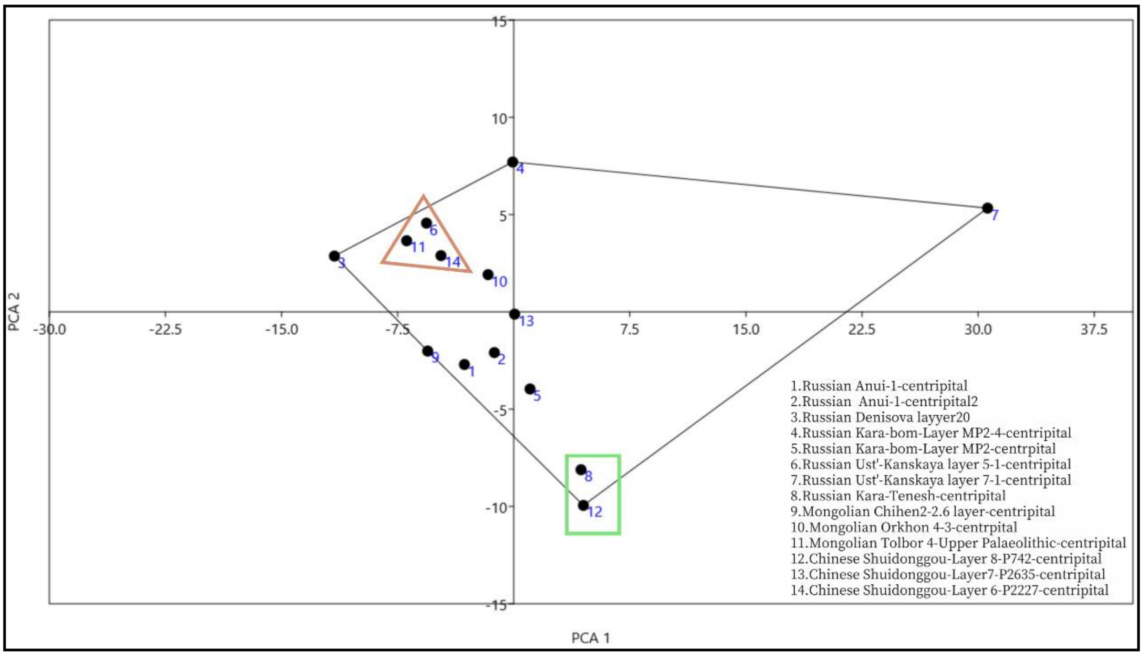

Fig. 4: PCA Analysis Based on Topological Structure Analysis (Levallois Centripetal Knapping Method in Russia, Mongolia, and China).

As shown in the figure, the Centripetal Levallois core at the Anui-1 site in Russia is relatively stable in terms of technology, while the Kara-Bom site is more variable in the Centripetal Levallois flaking method.

Based on the topological structure analysis, as shown in the figure, the P742 Levallois core from Shuidonggou Layer 8, represented by the orange triangle, is relatively close to the Levallois cores from the Upper Paleolithic (UP) period at Tolbor-4 in Mongolia and the Levallois cores from the Ust'-Kanskaya site in Russia in the PCA analysis, indicating the similarity of their techniques. The centripetal Levallois flaking technology from Locality 1 of the Shuidonggou site in China shows a stronger similarity to the technology from Kara-Tenesh in Russia. This suggests that the origins of the Levalllois centripetal Levallois technology at the Shuidonggou site may be diverse.

4.2. Regularity of Flakes

Another important characteristic of Levallois technology is the regularity of flakes. In the Altai region, when preparing cores in Levallois technology, craftsmen usually adopt a more complex centripetal preparation (Derevianko *et al.,* 2012). Craftsmen will preform a ridge on one side of a cobble, making the core overall, turtle-back shaped, and then preform a flaking platform at the end of the cobble through continuous knapping, using the preformed ridge as the guiding ridge, and knapping flakes through direct percussion (Xia & Zhang, 2020). The lithic types produced by Levallois technology in the Altai region are relatively rich, including edge scrapers, denticulate blades, burins, and notched scrapers. These lithic artifacts usually have more delicate processing marks, showing a high level of technical proficiency and emphasis on tool functionality (Li, 2018).

In Mongolia, although Levallois technology also uses complex methods such as centripetal when preparing cores, it is relatively simpler. Craftsmen may rely more on the shape and edges of natural cobbles when preforming cores, and directly knap flakes through simple preformed ridges and platforms (Khatsenovich *et al.,* 2010). The flakes from Tsagaan Agui Cave, although having Levallois characteristics, are small in size and not very regular in shape. The flakes from Orkhon 1 and Orkhon 7 sites are also diverse in shape, showing certain technical diversity, but their overall regularity is not as good as that in the Altai region (Lesage, 2019). This indicates that the ancient humans in Mongolia, although able to perform certain technical operations in the process of flake making, had a lower overall control ability (Khatsenovich *et al.,* 2019; Wu, 2022), (Figs. 5 & 6).

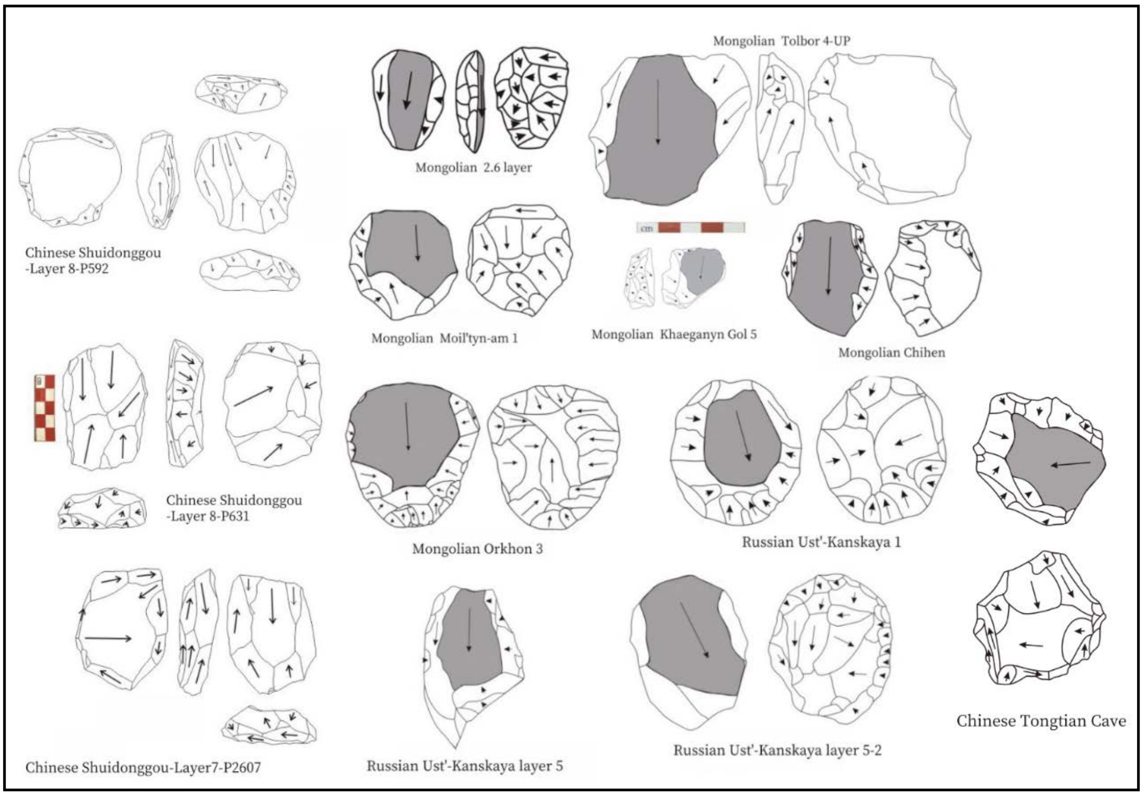

Fig. 5: Levallois preferential cores from Russia, Mongolia and China (Ningxia Institute of Cultural Relics and Archaeology, 2003; Gao *et al.,* 2004; Gao, Pei and Wang, 2004; Boëda *et al.,* 2013; Yu, 2018; Rybin and Khatsenovich, 2020).

Overall, the preferential Levallois knapping in the Mongolian region is more mature and stable. The ratio of preferential knapping scars to the total core knapping surface in all six Mongolian sites exceeds 60%, indicating a higher utilization rate of cores and a more stable technique compared to Russia, which may also suggest similar sources of technological dissemination. The

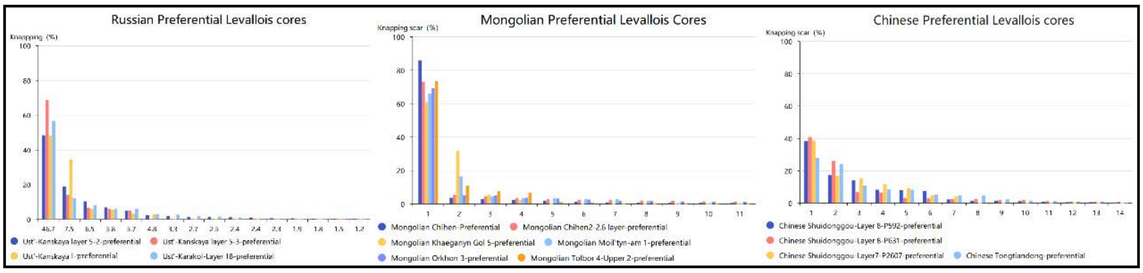

Fig. 6: The percentage of knapping scars on the knapping surface of Levallois preferential cores from several sites in Russia, Mongolia, and China.

cores from Russia mainly come from the Ust'-Kanskaya site and the Ust'-Karakol site, where the ratio of the largest flake knapping to the total core knapping surface by the preferential method all exceed 50%, showing a higher utilization rate of cores. The Levallois preferential knapping technology at Locality 1 of the Shuidonggou site in China is relatively less advanced than that in Russia and Mongolia, with stronger similarity in knapping technology between Layer 8 and Layer 7, demonstrating the inheritability of the technology. The Preferential knapping at the Tongtian cave, which is older than Locality 1 of the Shuidonggou site, has a relatively lower utilization rate of cores and a smaller total area of the largest knapping flake, indicating that the technology at Locality 1 of the Shuidonggou site is more mature than that at the Tongtian cave (Fig. 7).

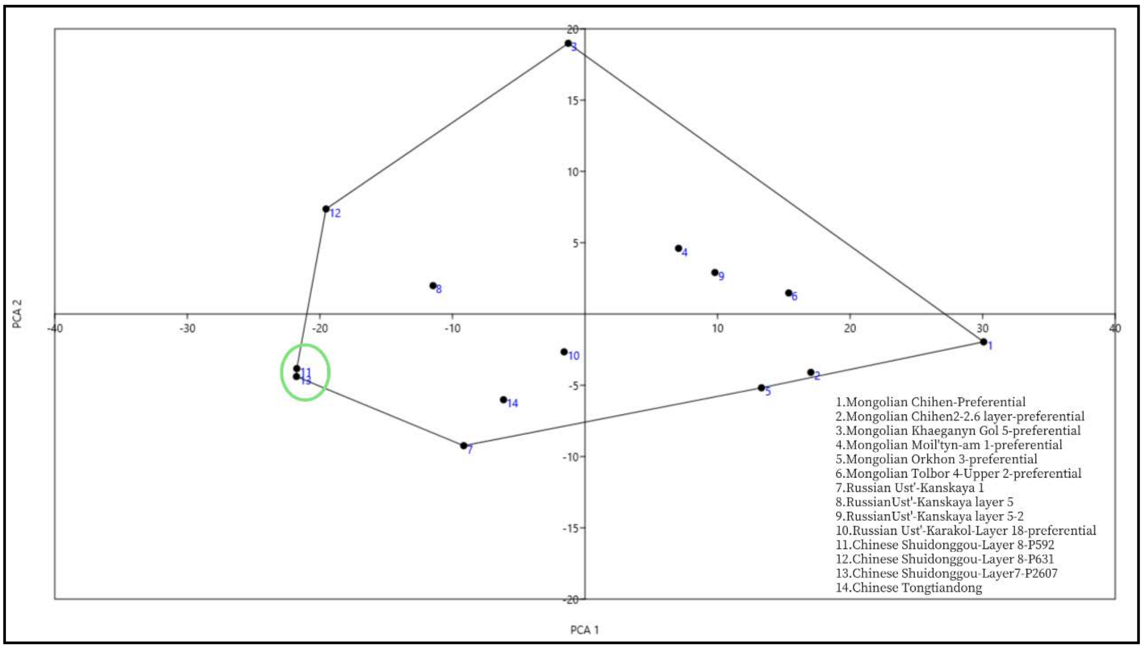

Fig. 7: PCA Analysis Based on Topological Structure Analysis (Levallois Preferential Knapping Method in Russia, Mongolia, and China).

As can be seen from the figure, there are certain differences in Levallois Preferential knapping among Russia, Mongolia, and China. Relatively speaking, the Preferential knapping in Russia is more correlated with that in China, while it is less correlated with that in Mongolia. Therefore, the Levallois Preferential knapping technology at the Shuidonggou site in China is likely to be more influenced by the Russian region. Regarding the Levallois preferential knapping technology at Locality 1 of the Shuidonggou site, there is a certain inheritance between the technology of Layer 8 and Layer 7.

4.3. Similarity in Cultural Background

Levallois technology in the Altai region, Mongolia, and China is closely related to the activities of early modern humans or related ancient humans, reflecting similar survival strategies and technological inheritance paths (Figs. 8 & 9).

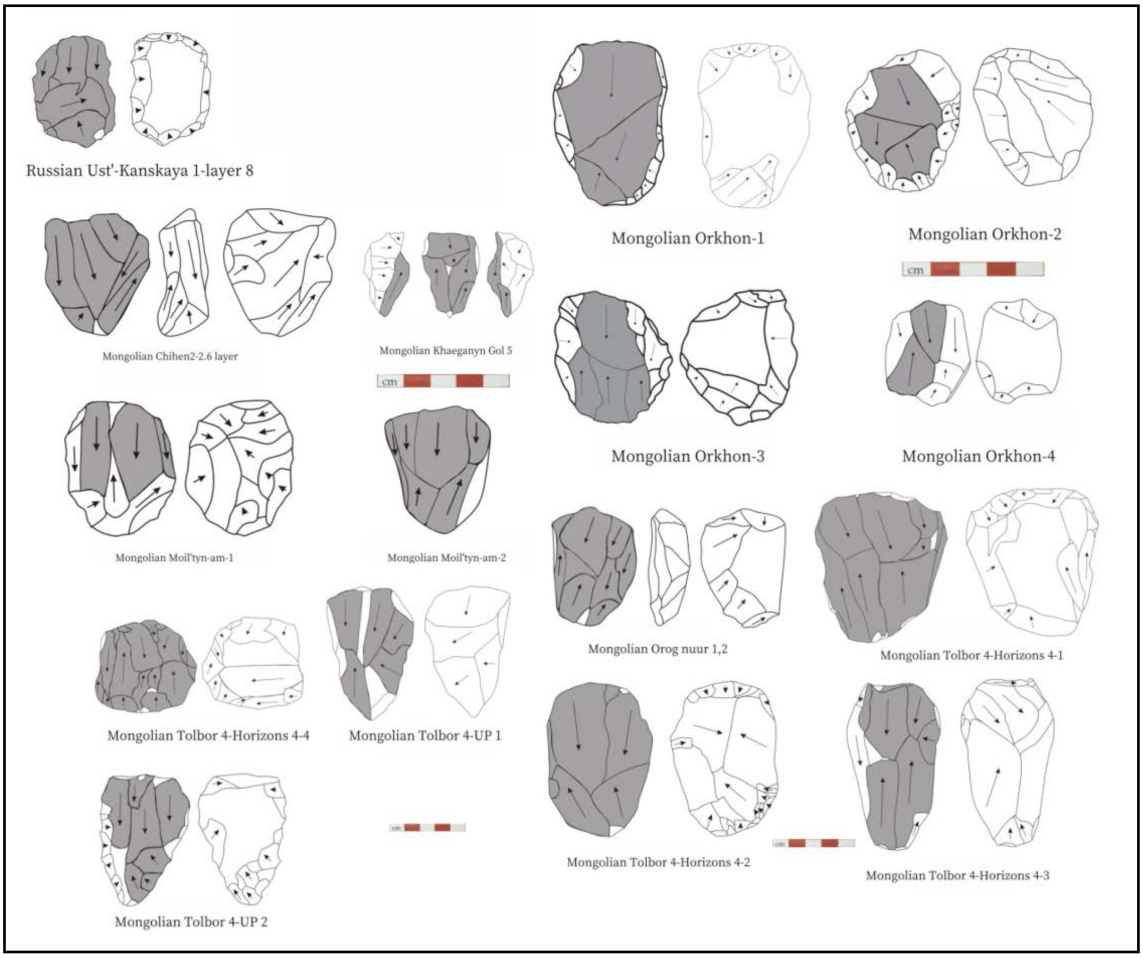

Fig. 8: Levallois bipolar cores from Russia,Mongolia and China (Belousova *et al.*, 2018; Lesage, 2019; Rybin & Khatsenovich, 2020; Wu, 2022).

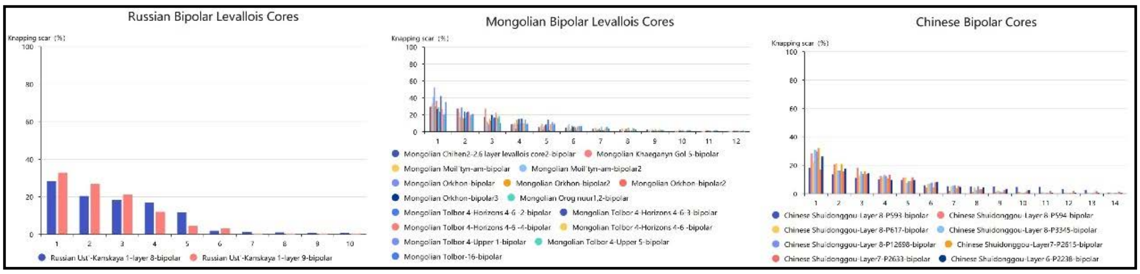

Fig. 9: This bar chart describes the percentage of knapping scars on the knapping surface of Levallois bipolar cores from several sites in Russia, Mongolia, and China.

Overall, bipolar Levallois knapping is a relatively popular method in the sites of the Mongolian region and Locality 1 of the Shuidonggou site in China, especially in the Mongolian region. In comparison, the Levallois bipolar cores found at the Shuidonggou site in China show relatively stable sizes and proportions of knapping flakes for each core (Fig. 10).

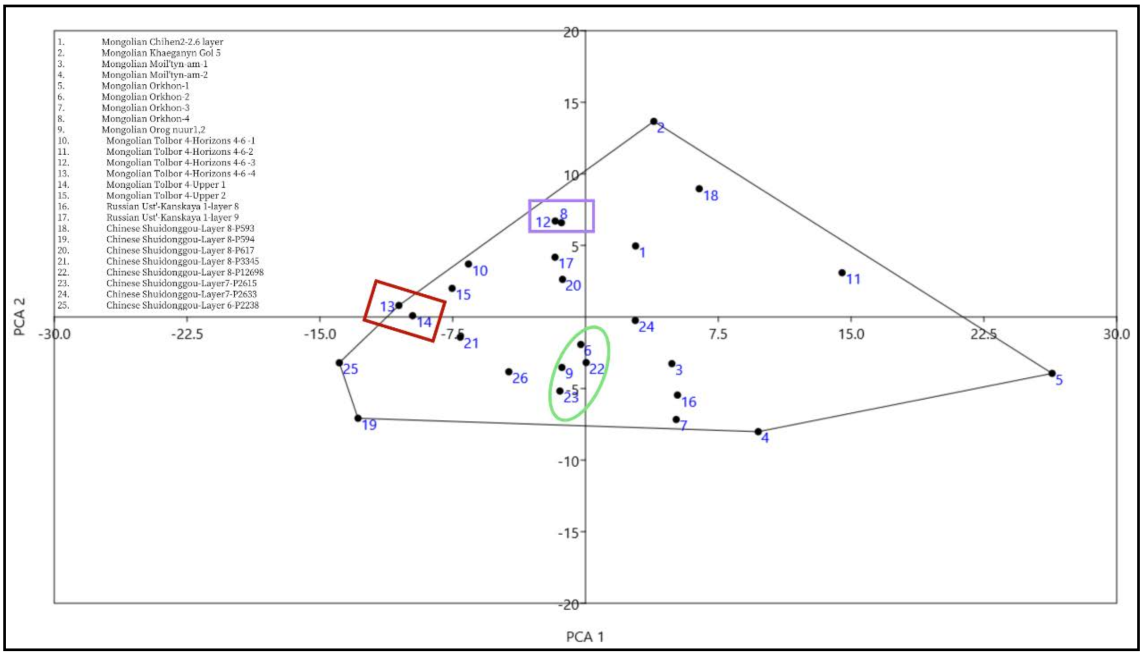

Fig. 10: PCA Analysis Based on Topological Structure Analysis (Levallois Bipolar Knapping Method in Russia, Mongolia, and China).

As can be seen from the figure, the Bipolar Levallois knapping method at the Orkhon site and Orog Nuur in the Mongolian region is highly similar to the method at the Chinese Shuidonggou site (green circle). There is a certain similarity in technology between the Orkhon site and Tolbor in the Mongolian region (purple square). Overall, the Bipolar Levallois knapping method in Russia is not highly correlated with the technology in China, while the technology in China is more similar to the Bipolar Levallois knapping method in the Mongolian region (Fig. 11).

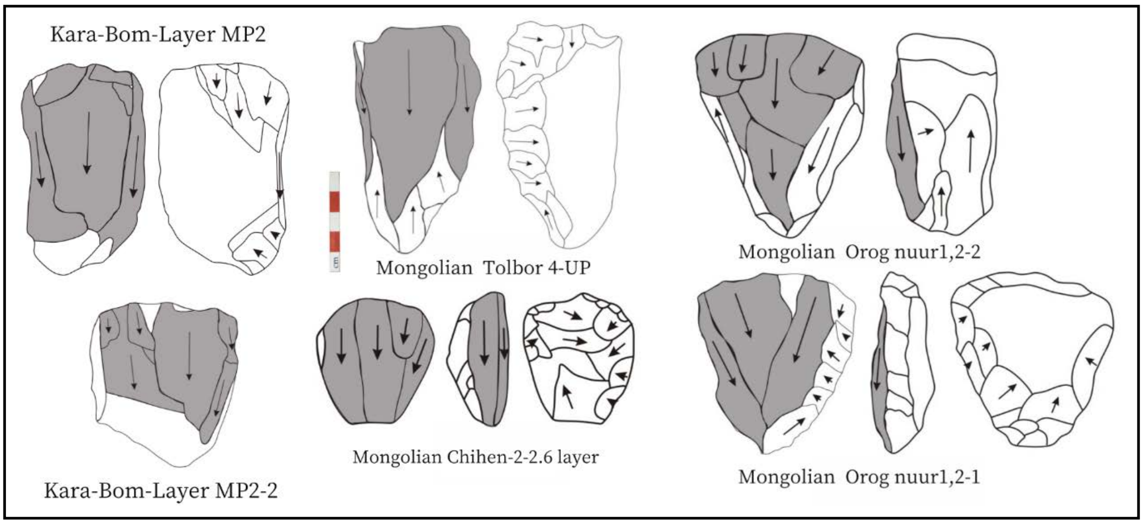

Fig. 11: Levallois Unipolar Cores from Russia, Mongolia, and China (Lesage, 2019; Rybin & Khatsenovich, 2020; Wu, 2022).

The Unipolar Levallois knapping method has been discovered at the Tolbor-4 site, Orog Nuur 1 and 2 sites, and Chiheng-2 site in Mongolia, as well as at the Kara-Bom site in Russia (Fig. 12).

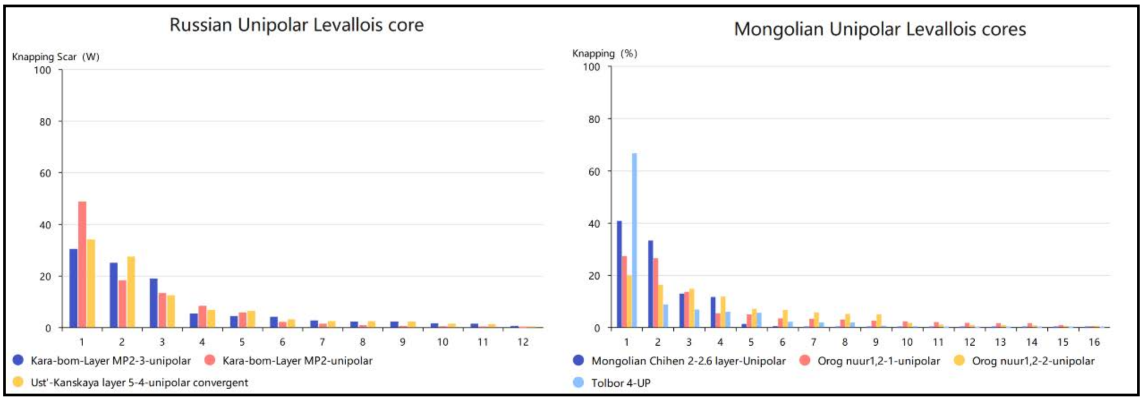

Fig. 12: This bar chart describes the percentage of knapping scars on the knapping surface of Levallois unipolar cores from several sites in Russia, Mongolia, and China.

Relatively speaking, the Orog Nuur 1,2 site in Mongolia is relatively stable, with not much difference in the relative proportion of the largest knapping scar and the knapping scar.

As can be seen from the figure, there are few discoveries of Unipolar Levallois Knapping in the China region for the time being. Many Unipolar Levallois cores have been found at the Kara-Bom site in the Russia region, and the prepared surface is mostly Y-shaped (Belousova *et al.,* 2018), (Fig. 13).

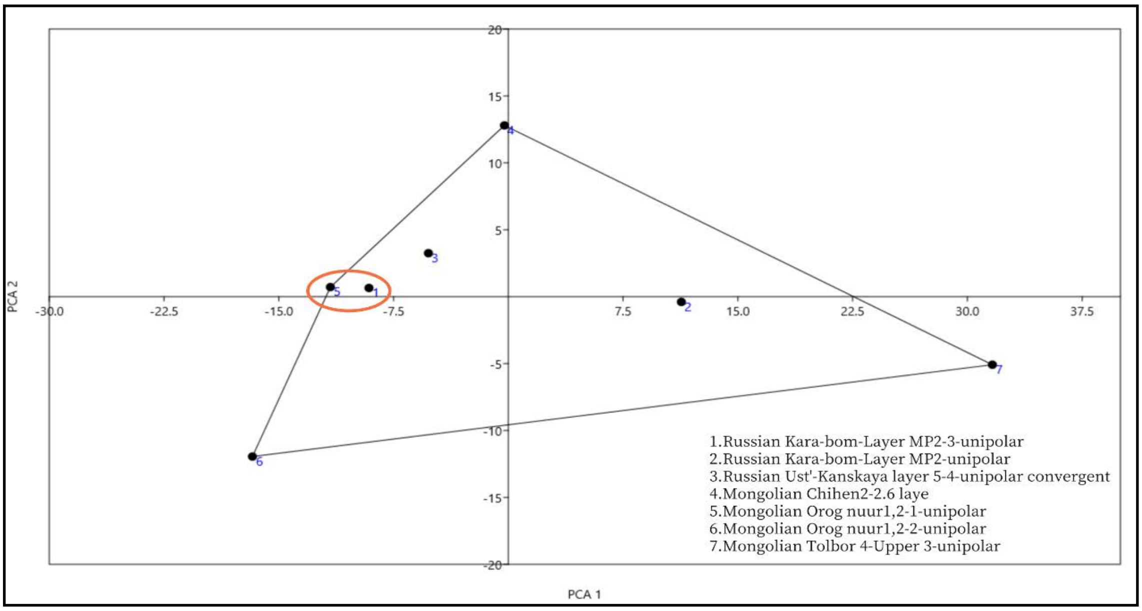

Fig. 13: PCA Analysis Based on Topological Structure Analysis (Levallois Unipolar Knapping Method in Russia, Mongolia, and China).

The Unipolar Levallois Knapping method of the Kara-Bom site in Russia is relatively close to that of the Orog Nuur 1,2 sites in Mongolia (red circle in Fig. 13). The Unipolar Levallois Core found in the UP layer of the Tolbor-4 site in Mongolia has a lower similarity with the Unipolar cores found in the Orog Nuur 1 and 2 sites and the Chihen-2 site.

5.1. The Distribution of Levallois Technology and Its Relationship with Paleo-environment and Paleo-ecology

The distribution and characteristics of Levallois technology are closely related to the paleo-environment and paleo-ecology. Paleo-environmental conditions have significantly influenced the dissemination and evolution of Levallois technology, and the users of Levallois technology could also adapt to and modify the environment through technological adaptation to enhance their survival capabilities.

During the MP and IUP periods, the Altai region had relatively cold climatic conditions, with an environment dominated by mountain forests and grasslands (Li, 2018). These environmental conditions required ancient humans to possess high technical and adaptive abilities to obtain sufficient resources and survival opportunities (Kuzmin *et al.,* 2022). The complexity and efficiency of Levallois technology made it an important tool for ancient humans to adapt to this environment. At the same time, the Altai region had relatively frequent cultural exchanges and dissemination with Western Europe and Western Asia during the Paleolithic period. This cultural exchange promoted the development and improvement of Levallois technology in the Altai region, making it more advanced and diverse in technology (Rybin and Khatsenovich, 2020).

During the MP and IUP periods, the Mongolian region had relatively dry climatic conditions, with an environment dominated by grasslands and deserts (Wu, 2022). The diversity and adaptability of Levallois technology made it an important tool for ancient humans to adapt to this environment. The Levallois technology in the Mongolian region was relatively sole, mainly unipolar, bipolar and preferential knapping methods (Lesage, 2019). The bipolar Levallois technique found at the Chihen-2 site, Orkhon 1 site and Tolbor sites in the Mongolian region is more than that in the Altai region, which can be regarded as a regional characteristic Levallois technique. Compared with the Altai region, the Mongolian region is relatively remote, all located in the inland, with less cultural exchange with the outside world. The development of Levallois technology in the Mongolian region is relatively independent, with less external influence, and therefore the technology is relatively conservative and sole (Ranov & Nesmeyanov, 1973; Derevianko, 1990).

During the MP and IUP periods, the climatic conditions in China were relatively complex, with an environment dominated by mountains, plains and forests (Gao *et al.,* 2008; Ding *et al.,* 2021). The complexity and regularity of Levallois technology made it an important tool for ancient humans to adapt to this environment. For example, the Levallois technology at the Shuidonggou site shows a relatively stable technical proficiency and regularity, with technical inheritance between different periods, indicating that ancient humans had a high level of technical proficiency in adapting to the environment. The Mousterian technological complex possessed by the Tongtian cave and the blade technological complex with mixed Mousterian elements found at the Shuidonggou site and the Jinsitai site in Inner Mongolia only spread in the northern and western marginal areas of North China (50-33 ka BP) (Peng *et al.,* 2014; Wang, 2021; Zhao, Wang & Walden, 2022). Zhao and Walden believe that these technological complexes have not penetrated into the inland of North China because they do not match the local geographical conditions (Zhao *et al.,* 2022). The dissemination of these technologies in China has certain limitations and has not replaced the local core-flake technology. Even after the rise of blade technology, it briefly returned to the core-flake mode, such as at the No. 2 site of Shuidonggou (Zhang *et al.,* 2022). One of the limiting factors may be that the IUP blade technique/Mousterian complex technology has not been popularized due to its high production cost (Ding *et al.,* 2021; Gao, 2024). Compared with the simple core-flake technology, these complex composite technologies do not have obvious advantages, which may be the reason why they have not flourished in North China (Zhao *et al.,* 2022).

In summary, the distribution and characteristics of Levallois technology are closely related to the paleo-environment and paleo-ecology. Paleo-environmental conditions have significantly influenced the dissemination and evolution of Levallois technology, and the users of Levallois technology have also enhanced their survival capabilities through technological adaptation and modification of the environment.

5.2. Inference of Technological Dissemination Routes

In the later Late Pleistocene, cultural exchanges between the East and the West increased slightly, and the emergence and development of blade technology, micro lithic technology, and bone and antler technology became more evident (Chen *et al.,* 2012; Li, 2023). The appearance of modern humans with improved intelligence and survival skills enabled them to bypass the Tibetan Plateau and Central Asian deserts, entering North China through the northern grassland areas (Li *et al.,* 2019). In the later Late Pleistocene or slightly earlier sites in South China, there were no obvious Western technological elements, and the cobble tools and flake industries constituted the main body of the development of Paleolithic culture in South China (Li, 2022). The Shuidonggou site in China is an important discovery site of blade technology in North China (Boëda *et al.,* 2013), and it is claimed that the Levallois technology and blade technology here show signs of East-West cultural exchanges (Gao, 2023; Yang, Petraglia & Deng, 2024).

The dissemination route of Levallois technology may have started from the Altai region, passed through the Mongolian region, and finally reached the Chinese region. This dissemination route not only reflects the migration patterns of ancient humans but also reveals the adaptability and evolution of technology in different regions.

The Altai region may have been the starting point of technological dissemination. The Levallois technology in the Altai region shows a high degree of complexity and maturity, and the technological characteristics of sites such as Kara-Bom and Ust'-Kanskaya indicate that the region may have been an important starting point for the dissemination of Levallois technology on the Eurasian continent (Li *et al.,* 2019). The Mongolian region may have been an intermediate link in technological dissemination. Although the morphology of Levallois cores in the Mongolian region is similar to that in the Altai region, the Levallois process is relatively simple, showing a certain degree of technical diversity (Khatsenovich *et al.,* 2019; Wu, 2022). At the same time, some new developments have emerged in technological inheritance, as shown in Figs. 6 and 7, the preferential Levallois knapping in the Mongolian region is more mature and stable, and there is more bipolar Levallois technique (Figs. 9 and 10). The Chinese region as the endpoint of technological dissemination: The Levallois technology in China shows a high degree of complexity and regularity, and the technological characteristics of sites such as Shuidonggou and Tongtiandong indicate that the region may have been one of the endpoints of Levallois technological dissemination (Liu, 2017; Zhao, Wang & Walden, 2022).

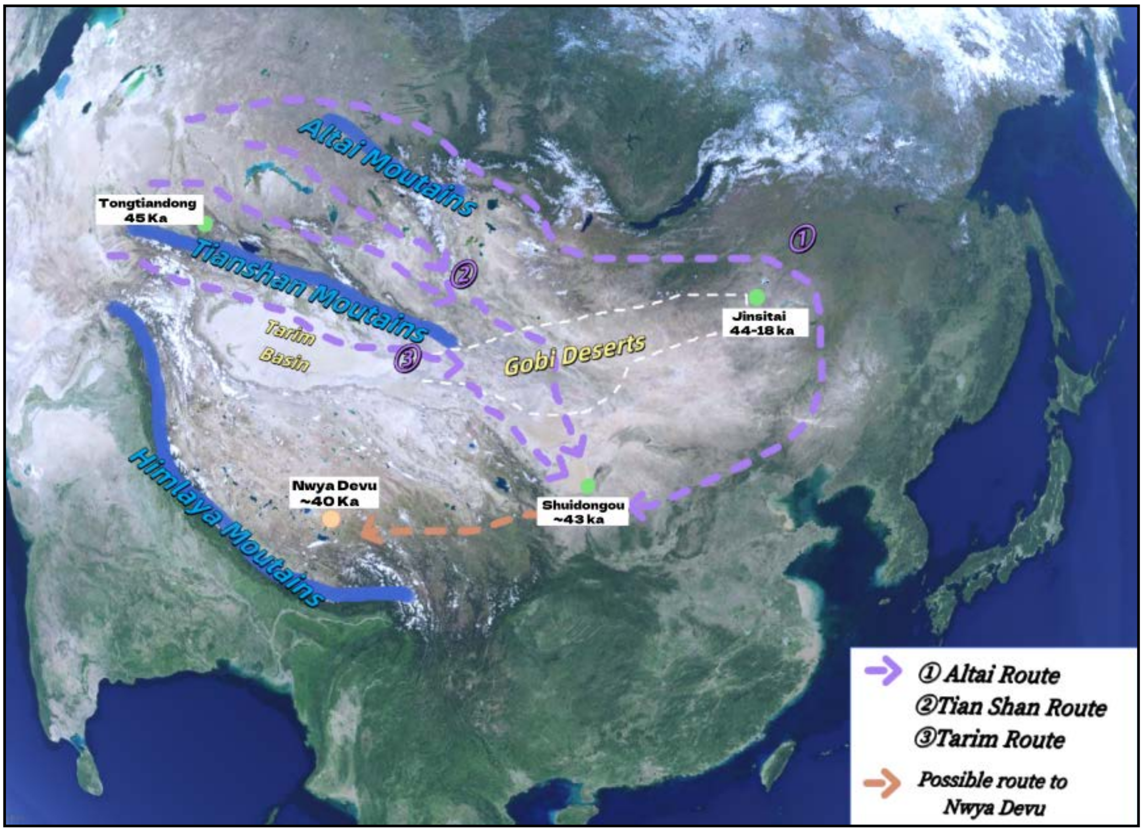

Fig. 14: Three 'wet paths' of expansion in northern China, the Mousterian-complex technological route and a possible spread to the Tibetan Plateau (modified from: Zhao *et al.*, 2016; Li *et al.*, 2019; Zhao, Wang and Walden, 2022).

Li et al. studied the northward diffusion routes in East Asia and ancient environments. They constructed a least cost path model to simulate potential human migration routes between Central Asia and East Asia under glacial and interglacial conditions. They integrated paleoclimatic, paleolimnological, and archaeological data to assess the potential of regions such as the Gobi Desert and the Altai Mountains as human migration routes (Li *et al.,* 2019). Using Geographic Information System (GIS) software and detailed paleoclimatic, paleoglacial, and paleolimnological data, they explored possible human migration routes between MIS 5 and MIS 3. The study found that during the relatively humid and warm interglacial periods, humans could migrate to the Gobi Desert, Taklamakan Desert, as well as the Altai and Tianshan Mountains (Belousova *et al.,* 2018; Li, 2018). They identified three potential "humid routes," namely the Altai route, Tianshan route, and Tarim route (Li *et al.,* 2019; Derevyanko, Kozlikin and Shunkov, 2024) (see: Fig. 14, purple routes ①②③). The three simulated routes under humid climatic conditions show that humans may have migrated through different routes between glacial and interglacial periods, influenced by the extent of paleolakes and glaciers (Li *et al.,* 2019).

Additionally, Zhao et al. pointed out that the IUP blade/Mousterian composite technology diffused from the MP to the UP, early from Siberia to Mongolia and then to North China, with Tongtian Cave and Jinsitai site being typical sites affected by it (Zhao *et al.,* 2022). The direction of this technology's spread is roughly the same as the least cost path model analysis by Li et al. (Li et al., 2019), both spreading from northwest to east (see Fig. 14, the spread route of the green sites is similar to the three purple route paths). Of course, this adaptation was not achieved overnight, as only on the north and south sides of the plateau and desert, east-west personnel and cultural exchanges were relatively easy (Wang, 2005), for example, in the Altai region and Mongolia, where similar IUP blade assemblages were found (Zhang *et al.,* 2022).

The dating data of the Nwya Devu site shows that ancient humans had reached the hinterland of the Tibetan Plateau at an altitude of about 4600 meters before 40 ka BP (Zhang *et al.,* 2022), and experienced multiple human activities in the past 45,000 years (Ge *et al.,* 2024). The Nwya Devu site discovered blade technology, indicating that the ancient residents of the site may have had contact and exchange with the ancient humans at the Shuidonggou site in terms of technology and l (Zhang *et al.,* 2022). Zhang et al. (2022) proposed two possible routes (see the orange routes in Fig. 14). The direct route can cross the Gobi Desert under relatively mild climatic conditions. The route bypassing the Gobi Desert is longer, but given the harsh environment of the Gobi Desert, hunter-gatherers may prefer to choose the route that avoids the desert. Moving along the edge of the desert, oases and water sources may be used as support for survival (Zhang *et al.,* 2022).

6. Conclusion

This study compares Levallois technology in Mongolia, Russia, and China using archaeological and topological analysis methods. In the comparison of centripetal Levallois technology, Mongolia's knapping technique is relatively stable with more consistent flake sizes. The Anui-1 site in Russia shows stable technology, while the Kara-Bom site exhibits more variability. At China's Shuidonggou site, Layer 7 and Layer 6 of Locality 1 demonstrate greater stability and technical proficiency compared to Layer 8. The Layer 8 Levallois core at Shuidonggou is similar to cores from Mongolia's Tolbor-4 and Russia's Ust'-Kanskaya site, indicating potential diverse origins. The centripetal Levallois flaking technique at Shuidonggou Locality 1 is more similar to Russia's Kara-Tenesh, suggesting varied technical sources.In the comparison of preferential Levallois technology, Mongolia's technique is more mature and stable, with knapping scars covering over 60% of the core surface in all six analyzed sites, indicating high core utilization and stable technique. The Ust'-Kanskaya and Ust'-Karakol sites in Russia have a flake knapping ratio exceeding 50%, showing efficient core use. Shuidonggou's Locality 1 in China shows less advanced technology compared to Russia and Mongolia, with stronger similarity between Layer 8 and Layer 7, indicating technical inheritance. Tongtian cave's preferential knapping has lower core utilization and flake area compared to Shuidonggou, showing more mature technology at the latter. The analysis of bipolar Levallois technology shows high similarity between Mongolia's Orkhon site and Orog Nuur and China's Shuidonggou site, with some similarity between Orkhon and Tolbor. Shuidonggou's Locality 1 has stable flake sizes and proportions. Russia's bipolar Levallois technique is less correlated with China's, which is more similar to Mongolia's.Unipolar Levallois technology is less common in China. The Kara-Bom site in Russia has many unipolar cores, similar to the Orog Nuur 1 and 2 sites in Mongolia, but less similar to the cores from Tolbor-4 and Chihen-2.The northern migration route map of the Altai-Mongolian region, drawn by archaeologists shows multiple routes from the Altai region to North China for Levallois technique transmission. In summary, combining the route analysis of archaeologists, the sources of China's Levallois technique are diverse, different Levallois core techniques may have diverse sources, and there may be multiple pathways for the spread of technology in the north.

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Authors' Contribution

Writing and Revision:Zheyang Chen; Revision: William Davies

All of the authors approved the content of the manuscript and agreed on all aspects of the work

Conflict of Interest

Authors declared no conflict of interest.

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تقارن بین تکنیک‌های آماده‌سازی سنگ مادر لووالوا در چین و تکنیک‌های موجود در مناطق آلتایی و مغولستان

ژیانگ چِن[1]، ویلیام دیویس[2]

۱. دانشجوی دکتری باستان‌شناسی، مرکز باستان‌شناسی خاستگاه‌های انسانی، دانشکدهٔ علوم انسانی، دانشگاه ساوت‌همپتون، ساوت‌همپتون، انگلستان.
رایانامه: zheyangchencz@sina.com

۲. استاد مرکز باستان‌شناسی خاستگاه‌های انسانی، دانشکدهٔ علوم انسانی، دانشگاه ساوت‌همپتون، ساوت‌همپتون، انگلستان (نویسندهٔ مسئول).
رایانامه: S.W.G.Davies@soton.ac.uk

چکیده

در این پژوهش از چارچوب مطالعاتی مبتنی‌بر داده‌ها برای بررسی تنوع منطقه‌ای فناوری سنگ مادرهای لوالوا با هدف فهم میزان ثبات روش‌های تراشه‌برداری و تنوع تبادلات فناورانه در روسیه، مغولستان، و شمال چین استفاده شده است. ابتدا براساس گونه‌شناسی اریک بوئدا، سنگ‌مادرها به انواع محیطی، هم‌مرکز، دوقطبی، و تک‌قطبی طبقه‌بندی شدند؛ سپس به‌لحاظ کمّی ازطریق تصاویر دوبُعدی تحلیل شدند. در مغولستان، توالی‌های لوالوای محیطی و هم‌مرکز در اوج پیچیدگی و ثبات هستند؛ نمایه‌های تراکم جای برداشته‌ها در همهٔ محوطه‌های نمونه‌برداری‌شده بیش از ۶۰٪ و هم‌بستگی میزان تنوع پایین است که نشانگر روش‌های تولید استانداردسازی‌شده است. در مقابل مجموعه‌های مربوط به روسیه تنوع بین‌محوطه‌ای را نشان می‌دهند؛ سنگ‌مادرهای هم‌مرکز از آنوی۱ به‌میزان چشمگیری یک‌دست هستند، درحالی‌که نمونه‌های هم‌زمان از کارابوم تنوع بالایی در اندازه را نشان می‌دهند. در شوییدونگو در چین سطح کلی فناوری کمّی پایین‌تر است؛ با این‌حال در لایه‌های ۶ و ۷ آن به‌وضوح روش‌های لایهٔ ۸ که پایین‌تر است، منتقل شده‌اند. این مسئله نشانگر تداوم فناورانه است. در غار تونگتیان غرب چین، سنگ‌مادرها به‌وضوح پوشش سطح کمتری دارند و نواحی برداشت تراشهٔ کوچک‌تر است. این موضوع نشانگر مهارت فنی کمتری نسبت به محوطهٔ شوییدونگو است. سنگ‌مادرهای دوقطبی روسی شباهت محدودی با نمونه‌های چینی دارند؛ درحالی‌که سنگ‌مادرهای هم‌مرکز از مجموعهٔ کارا-تنش بسیار شبیه لایهٔ ۷ شوییدونگو هستند. در محوطه‌های منفرد چینی لایه‌های مختلف به‌صورت متناوب با روش‌های چینی یا روسی شباهت دارند. این موضوع نشان می‌دهد به‌صورت موج‌های مکرر، معرفی و جذب و بازتولید تکنیک‌ها صورت گرفته است. در جمع‌بندی، فناوری لوالوا، فقط از طریق یک راه وارد چین نشده، بلکه از مسیرهای چندگانه و در زمان‌های مختلف به چین رسیده است. سرآغازهای لوالوای چین چندخاستگاهی هستند و احتمالاً راه‌های انتشار چندگانه در شمال اوراسیا وجود داشته است. به‌جای یک مسیر یک‌طرفه، این منطقه چشم‌اندازی درهم‌پیچیده بوده که در آن به‌صورت متداوم تعامل صورت می‌گرفته است.

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