Middle Paleolithic Lithic Industries as Evidence of Early Homo sapiens Migration

Abhijith Nair

B.A.(H) History, Amity University Uttar Pradesh, Noida

abhijithnair0021@gmail.com

Dr. Swati Shastri

Asst. Professor-II, Amity University Uttar Pradesh, Noida

sshastri@amity.edu

ARTICLE DETAILS

Research Paper

Accepted: 20-02-2025

Published: 14-03-2025

ABSTRACT

The dispersal of *Homo sapiens* out of Africa during the Middle Paleolithic (ca. 300,000–40,000 years ago) was shaped by technological innovation, climatic shifts, and interactions with archaic hominins. This study synthesizes archaeological, genetic, and environmental data to analyze lithic industries as proxies for migration patterns. Key innovations, such as Levallois prepared-core techniques, reflect cognitive advancements and adaptive flexibility, enabling resource efficiency in diverse environments. Genetic evidence traces mitochondrial haplogroups (e.g., L3, M, N) supporting a southern coastal dispersal ~70–60 ka, while Middle Paleolithic toolkits in Arabia, the Levant, and South Asia reveal complex inland and coastal routes. Sites like Jwalapuram (India) demonstrate human resilience to climatic crises, such as the Toba eruption (~74 ka), though debates persist over toolmaker identity (*Homo sapiens* vs. archaic groups). Environmental fluctuations, notably humid MIS 5 and arid MIS 4 phases, dictated migration dynamics, funneling populations into refugia or enabling riverine expansions. Challenges to the coastal model emerge from Kachchh (India), where inland Middle Paleolithic continuity contrasts with absent microlithic technologies. The study argues for a "braided" dispersal model, emphasizing opportunistic adaptations to ecological windows, technological conservatism, and intermittent archaic interactions. By integrating multidisciplinary evidence, this paper redefines early human migrations as nonlinear, multifaceted processes driven by cultural, environmental, and demographic interplay.

DOI : https://doi.org/10.5281/zenodo.15030250

Introduction

The dispersal of *Homo sapiens* out of Africa represents one of the most pivotal events in human evolutionary history, shaping the demographic, genetic, and cultural landscapes of populations across Eurasia and beyond. This migration, occurring primarily during the Middle Paleolithic period (ca. 300,000–40,000 years ago), was facilitated by a combination of technological innovation, behavioral flexibility, and adaptive strategies that enabled early humans to colonize diverse environments. Central to understanding these migratory patterns are lithic industries—stone tool technologies that serve as proxies for cognitive advancement, cultural transmission, and environmental adaptation. This paper examines the role of Middle Paleolithic lithic industries as evidence for early *Homo sapiens* migrations, with a focus on key regions such as Africa, the Levant, Arabia, Europe, and the Indian subcontinent. By synthesizing archaeological, genetic, and environmental data, this study explores how technological variability, climatic fluctuations, and interactions with archaic hominins shaped the dispersal of modern humans.

The Middle Paleolithic is defined by the proliferation of prepared core technologies, such as the Levallois method, which enabled the production of standardized flakes and blades. These innovations marked a departure from earlier Acheulean bifacial tools, reflecting enhanced cognitive planning and efficiency in resource exploitation. In Africa, the Middle Stone Age (MSA) laid the foundation for these technologies, with sites like Blombos Cave (South Africa) and Porc-Epic Cave (Ethiopia) yielding evidence of early blade production and symbolic behavior (Henshilwood & Marean, 2003; McBrearty & Brooks, 2000). The subsequent dispersal of *Homo sapiens* into Eurasia is evidenced by the spread of

Levallois techniques and toolkits across the Levant, Arabia, and Europe, often overlapping with or replacing Neanderthal Mousterian industries (Shea, 2011; Bar-Yosef, 2002).

The Indian subcontinent, situated at the crossroads of Africa, Asia, and Australasia, played a critical role in this migration. Genetic studies tracing mitochondrial DNA (mtDNA) haplogroups, such as L3, M, and N, suggest a rapid expansion of modern humans out of Africa around 60,000–70,000 years ago, followed by divergence into South Asia (Macaulay et al., 2005; Soares et al., 2011). However, the archaeological record complicates this narrative. Sites like Jwalapuram in southern India reveal Middle Paleolithic tools stratified above and below the Toba volcanic ash layer (74,000 years ago), hinting at human resilience to environmental catastrophes (Petraglia et al., 2007). Yet, debates persist over whether these tools were crafted by *Homo sapiens* or archaic hominins, such as the Narmada fossil population (Patnaik et al., 2009; Athreya, 2007).

Environmental fluctuations further influenced migration routes. During Marine Isotope Stage (MIS) 5 (130–75 ka), humid conditions in Arabia and South Asia supported human occupation, while aridification during MIS 4 (75–60 ka) likely pushed populations into refugia (Delagnes et al., 2008; Petraglia et al., 2010). Technological adaptations, such as the use of Levallois cores in Yemen's Wadi Surdud and blade production at Jebel Faya (UAE), underscore the interplay between environmental pressures and cultural innovation (Marks, 2009; Delagnes et al., 2008). Meanwhile, the absence of microlithic tools in Kachchh (Gujarat) challenges the coastal dispersal model, suggesting inland routes via riverine corridors (Blinkhorn et al., 2017).

This paper integrates multidisciplinary evidence to argue that the dispersal of *Homo sapiens* was not a linear process but a complex mosaic of coastal and inland migrations, technological adaptability, and interactions with archaic populations. By analyzing lithic industries alongside genetic and environmental data, we elucidate the mechanisms that enabled early humans to traverse continents and reshape the course of human evolution.

Literature Review

The dispersal of *Homo sapiens* out of Africa during the Middle Paleolithic (ca. 300,000–40,000 years ago) is a focal point in understanding human evolution, with lithic industries serving as critical evidence for migration patterns. Central to this narrative are prepared core technologies like the Levallois method, which reflect cognitive advancements and adaptability (Shea, 2011; McBrearty & Brooks, 2000).

Genetic studies tracing mitochondrial haplogroups (e.g., L3, M, N) suggest a primary dispersal pulse ~70–60 ka via southern coastal routes, though archaeological complexities challenge linear narratives (Macaulay et al., 2005; Soares et al., 2011). In Africa, Middle Stone Age (MSA) sites such as Blombos Cave reveal early symbolic behavior, while in Eurasia, Levallois toolkits overlap with Neanderthal Mousterian industries, indicating intermittent coexistence (Henshilwood & Marean, 2003; Bar-Yosef, 2002). The Indian subcontinent remains contentious, with sites like Jwalapuram showing tool continuity across the Toba eruption (~74 ka), though debates persist on whether *Homo sapiens* or archaic hominins produced these assemblages (Petraglia et al., 2007; Patnaik et al., 2009). Environmental shifts, particularly during Marine Isotope Stages 5–4, shaped migration routes, favoring coastal corridors during humid phases and inland refugia during aridification (Blinkhorn et al., 2017; Groucutt et al., 2018). Synthesizing multidisciplinary data, the dispersal emerges as a mosaic of technological adaptability, climatic opportunism, and complex hominin interactions, challenging simplistic coastal-inland dichotomies (Haslam et al., 2017; Mellars et al., 2013).

Methodologies and Objectives

This study aims to elucidate the role of Middle Paleolithic lithic industries in tracing the dispersal of *Homo sapiens* out of Africa, with a focus on reconstructing migration routes, technological adaptability, and interactions with archaic hominins. The primary objectives are threefold: (1) to analyze the technological innovations of the Middle Paleolithic, particularly Levallois prepared-core techniques, as markers of cognitive and cultural advancement; (2) to synthesize genetic, archaeological, and paleoenvironmental data to evaluate migration chronologies and pathways; and (3) to assess the interplay of climatic fluctuations, demographic dynamics, and archaic hominin interactions in shaping dispersal patterns across Africa, the Levant, Arabia, and South Asia.

Methodologically, the research employs a multidisciplinary framework integrating lithic analysis, genetic studies, and paleoclimatic reconstructions. Archaeological data from key sites—such as Blombos Cave (South Africa), Jwalapuram (India), and Jebel Faya (UAE)—are examined to identify technological continuities and innovations, including tool typologies (e.g., Levallois cores, scrapers) and raw material economies. Genetic evidence, particularly mitochondrial DNA haplogroups (L3, M, N), provides temporal constraints on migration waves, while autosomal and uniparental markers reveal admixture events with archaic populations. Paleoenvironmental proxies, such as speleothem records and Marine Isotope Stage (MIS) data, contextualize human dispersals within climatic oscillations, identifying ecological corridors (e.g., “Green Arabia” during MIS 5) and refugia during arid phases (e.g., MIS 4).

Comparative regional analyses disentangle coastal versus inland dispersal models. For instance, the absence of microlithics in Kachchh (India) challenges coastal migration hypotheses, while riverine-associated Middle Paleolithic sites in the Thar Desert support inland routes. The study also addresses debates over toolmaker identity through stratigraphic analyses (e.g., pre- and post-Toba eruption layers at Jwalapuram) and fossil evidence, such as the contested Narmada hominin. By synthesizing these datasets, the research critiques linear migration narratives, proposing instead a “braided” model of pulsed expansions, retreats, and adaptive flexibility driven by technological resilience and ecological opportunism.

Middle Paleolithic Lithic Industries: Technological Foundations

The technological innovations of the Middle Paleolithic represent a watershed moment in human evolution, characterized by the emergence of prepared core techniques like the Levallois method. This method involved the meticulous shaping of a stone core to produce predetermined flakes or blades, requiring foresight, spatial reasoning, and an understanding of fracture mechanics (Shea, 2011). In Africa, MSA assemblages from sites such as Blombos Cave and Porc-Epic Cave (Ethiopia) illustrate the sophistication of these technologies. At Blombos, finely retouched blades and ochre engravings dated to 100–70 ka suggest not only functional tool use but also symbolic expression, challenging Eurocentric models of a "behavioral modernity" exclusive to the Upper Paleolithic (Henshilwood & Marean, 2003; McBrearty & Brooks, 2000).

Levallois technology’s efficiency in raw material utilization provided a critical advantage in resource-scarce environments. For example, at Olorgesailie (Kenya), MSA hominins transported high-quality obsidian over long distances, reflecting strategic planning and social networks (Brooks et al., 2018). The standardization of toolkits—scrapers, points, and denticulates—enabled versatility in tasks such as hide processing, woodworking, and hunting. In contrast, Neanderthal Mousterian industries in Europe emphasized flake tools, with limited evidence of blade production until the arrival of *Homo sapiens* (Mellars, 2006). This technological divergence underscores the adaptive flexibility of modern humans, who innovated in response to ecological pressures.

The Levant offers critical insights into early human dispersals. Sites like Qafzeh and Skhul (120–90 ka) contain Levallois flakes alongside ochre-stained burials, suggesting ritualistic practices and social complexity (Bar-Yosef, 2002). However, these early migrations were transient, as Neanderthals reoccupied the region during drier phases, highlighting the precariousness of initial expansions (Shea, 2011). The Levant thus served as both a corridor and a contested zone, where *Homo sapiens* and archaic hominins intermittently coexisted.

In Arabia, lithic assemblages from Jebel Faya (UAE) and Wadi Surdud (Yemen) reveal technological parallels to African MSA and Levantine Mousterian traditions. At Jebel Faya, stratified layers dated to MIS 5 (>85 ka) include Levallois cores and blades, suggesting an early human presence during Arabia's "Green Phase" (Marks, 2009; Delagnes et al., 2008). These findings align with genetic evidence of mtDNA haplogroup L3 expansions, though later aridification during MIS 4 likely caused population bottlenecks (Cerny et al., 2008).

The Out of Africa Dispersal: Timing and Routes

The dispersal of anatomically modern humans (AMH) from Africa is generally dated to around 60,000 to 70,000 years ago, based on genetic, archaeological, and fossil evidence. Genetic studies, particularly those focusing on mitochondrial DNA (mtDNA) and Y-chromosome lineages, suggest that the L3 haplogroup, which is ancestral to all non-African lineages, emerged in Africa around 70,000 years ago (Soares et al., 2011). The subsequent divergence of the M and N haplogroups, which are found in all non-African populations, indicates a rapid expansion out of Africa, likely via the southern route along the Indian Ocean coastline (Macaulay et al., 2005; Oppenheimer, 2009).

The Indian subcontinent, particularly the southern coastal regions, is hypothesized to have been a critical corridor for this dispersal. Genetic evidence suggests that the M haplogroup, which is predominant in South Asia, Southeast Asia, and Australasia, likely originated in India around 50,000 years ago (Metspalu et al., 2004; Soares et al., 2011). This is supported by archaeological evidence from sites such as Jwalapuram in southern India, where Middle Paleolithic tools have been found both above and below the Toba volcanic ash layer, dated to around 74,000 years ago (Haslam et al., 2010; Petraglia et al., 2007). The presence of these tools suggests that early humans were present in the region before and after the Toba eruption, although the identity of the toolmakers (whether AMH or archaic hominins) remains debated.

The Middle Paleolithic in Arabia

The Out of Africa Dispersal: Timing, Routes, and the Role of Arabia and South Asia

The dispersal of anatomically modern humans (AMH) out of Africa between 60,000 and 70,000 years ago stands as one of the most consequential events in human evolutionary history. This migration, underpinned by genetic, archaeological, and climatic evidence, reshaped the demographic and cultural landscapes of Eurasia, Australasia, and beyond. Central to understanding this process are the technological innovations of the Middle Paleolithic, environmental fluctuations, and the interplay between early *Homo sapiens* and archaic hominins. This paper synthesizes evidence from key regions—Africa, the Levant, Arabia, and the Indian subcontinent—to explore the timing, routes, and adaptive strategies that facilitated human dispersal.

Timing and Genetic Foundations of the Dispersal

Genetic studies provide the most robust framework for dating the Out of Africa (OoA) migration. Mitochondrial DNA (mtDNA) haplogroup L3, ancestral to all non-African lineages, emerged in Africa around 70,000 years ago (Soares et al., 2011). Its rapid divergence into haplogroups M and N—found in all non-African populations—signals a swift expansion along the Indian Ocean coastline, a route now termed the "southern dispersal" (Macaulay et al., 2005; Oppenheimer, 2009). This genetic bottleneck, dated to ~60–70 ka, aligns with archaeological evidence of Middle Paleolithic toolkits in Arabia and South Asia, suggesting a cohesive migration pulse rather than a staggered dispersal.

The Indian subcontinent played a pivotal role in this expansion. Genetic analyses indicate that haplogroup M, predominant in South Asia, Southeast Asia, and Australasia, coalesced in India around 50,000 years ago (Metspalu et al., 2004; Soares et al., 2011). This genetic signal is bolstered by archaeological findings at Jwalapuram (southern India), where Middle Paleolithic tools—Levallois cores, scrapers, and blades—appear both above and below the Toba volcanic ash layer (74,000 years ago) (Haslam et al., 2010; Petraglia et al., 2007). The continuity of tool production before and after this cataclysmic event implies resilience among local populations, though debates persist over whether these tools were crafted by AMH or archaic hominins like the Narmada fossil (160–85 ka), a contested *Homo heidelbergensis* specimen (Patnaik et al., 2009; Athreya, 2007).

The Levant and Arabia: Biogeographic Corridors

The Levant and Arabian Peninsula served as critical corridors for the dispersal of *Homo sapiens* from Africa into Eurasia, shaping the demographic and cultural trajectories of our species. Genetic evidence, particularly mitochondrial DNA (mtDNA) haplogroup L3, traces the primary exodus of modern humans from Africa around 70,000 years ago (ka), with subsequent divergence into haplogroups M and N in South Asia forming the genetic foundation of Eurasian populations. However, earlier, less enduring migrations into the Levant are evidenced by anatomically modern human (AMH) remains at Skhul and Qafzeh (120–90 ka), where intentional burials with ochre and Levallois tools reflect symbolic behavior and localized adaptations. These early groups likely exploited humid intervals during the Last Interglacial (MIS 5e), when the Levant transformed into a hospitable landscape. Yet their presence proved transient; Neanderthals reoccupied the region during arid phases, underscoring the precariousness of early expansions and interspecies competition. Arabia, meanwhile, emerged as a nexus for multiple migration waves, as lithic technologies at Jebel Faya (UAE) and Wadi Surdud (Yemen) reveal distinct dispersal routes. At Jebel Faya, Levallois cores and blades resembling East African Middle Stone Age (MSA) assemblages suggest a southern coastal migration via the Bab-el-Mandeb Strait during low sea stands. In contrast, Wadi Surdud's Levantine Mousterian-like flakes imply a northern inland trajectory through the Sinai Peninsula, facilitated by interglacial warming. These divergent technological traditions highlight the adaptability of AMHs in navigating varied ecological zones.

Climatic fluctuations played a decisive role in shaping migration dynamics. During MIS 5 (130–75 ka), monsoonal rains transformed Arabia into a "Green Arabia," marked by lakes, rivers, and savannahs that attracted populations from the Horn of Africa. Sites like Mundafan (Saudi Arabia), with gazelle bones and freshwater mollusks alongside MSA tools, attest to flexible foraging strategies that exploited seasonal wetlands and migratory game. However, the onset of MIS 4 (75–60 ka) brought severe aridification, fragmenting populations into coastal refugia along the Red Sea and Arabian Sea. Genetic bottlenecks during this period are inferred from the limited survival of early mtDNA lineages, such as haplogroup M's diversification in South Asia, which points to a small founding population enduring climatic stress. The oscillating climate also influenced cultural and biological interactions. In the Levant, overlapping AMH and Neanderthal occupations at sites like Tabun Cave, evidenced by alternating tool technologies, suggest intermittent contact, though genetic admixture in the region remains unconfirmed. In Arabia, resource scarcity during arid phases spurred innovations like tanged projectile points, while coastal groups relied on marine resources, as seen in Farasan Island shell middens, to survive inland desiccation.

The interplay of African and Levantine lithic traditions in Arabia underscores the region's role as a cultural crossroads, where diverse hominin groups exchanged technologies. Early migrations, such as those at Skhul and Qafzeh, though leaving no lasting genetic legacy, demonstrate AMHs' capacity to exploit climatic windows for exploratory expansions. Later, populations that weathered the MIS 4 bottleneck carried adaptive traits—such as enhanced immune responses—critical for colonizing Eurasia. The greening of Arabia during humid phases and its subsequent aridification reveal a dynamic relationship between environment and human mobility, with riverine corridors and coastal zones acting as alternating refugia and dispersal pathways. The genetic and archaeological record thus paints a complex narrative of resilience and retreat, where technological flexibility, climatic opportunism, and intermittent interactions with archaic hominins shaped the success of AMH dispersals. By integrating multidisciplinary evidence, this synthesis challenges simplistic migration models, instead portraying early human expansions as nonlinear processes driven by adaptive ingenuity, ecological variability, and demographic fluidity. The Levant and Arabia, as gateways between continents, epitomize the mosaic of strategies that enabled *Homo sapiens* to navigate and ultimately dominate Eurasia's diverse landscapes.

Technological Adaptations and Cultural Transmission

The lithic technologies of Arabia and South Asia were profoundly shaped by local raw material availability, influencing both tool production strategies and cultural transmission. In Arabia, the Levallois cores at Jebel Faya (UAE) were crafted from high-quality chert sourced within 30 km, enabling standardized flake production akin to African MSA traditions (Marks, 2009). Conversely, at Wadi Surdud (Yemen), the predominance of discoidal cores and scrapers made on locally abundant but coarser-grained rhyolite suggests a pragmatic adaptation to material constraints, prioritizing efficient reduction over aesthetic uniformity (Delagnes et al., 2008). This contrast mirrors patterns in Africa, where MSA groups at sites like Pinnacle Point (South Africa) transported silcrete over long distances for heat-treated blade production, reflecting a greater investment in resource planning (Brown et al., 2009). In South Asia, the quartzite-dominated assemblages of Kachchh (India) required robust percussion techniques, resulting in thicker, less refined tools compared to the finer chert blades of Jwalapuram (Blinkhorn et al., 2017). Such regional disparities underscore how raw material economies constrained technological expression, potentially masking deeper cultural connections between dispersed populations.The persistence of Middle Paleolithic technologies in South Asia, even as Upper Paleolithic innovations emerged elsewhere, may reflect demographic dynamics and interactions with archaic hominins. In Arabia, the absence of blade technologies—a hallmark of later African MSA sites—could signal low population densities or limited contact with innovating groups, reducing the diffusion of new techniques (Groucutt et al., 2021). In South Asia, the continuity of prepared core methods at Jwalapuram, both pre- and post-Toba eruption (~74 ka), suggests a stable, resilient population capable of weathering environmental crises (Petraglia et al., 2007). However, the presence of *Homo erectus* in the Narmada Valley until ~40 ka raises the possibility of niche partitioning or intermittent contact, with AMHs potentially adopting local toolmaking practices to navigate shared landscapes (Athreya, 2007). Genetic evidence adds nuance: while South Asians retain traces of Denisovan ancestry, the lack of Neanderthal-derived lithic traditions in the region implies that cultural exchange with archaic groups was limited or context-specific (Mondal et al., 2016). These patterns highlight a complex mosaic of isolation, resilience, and selective innovation, shaped by both environmental pressures and the shadow of archaic persistence.

Genetic Admixture and Archaic Interactions

Genetic studies reveal that modern non-Africans retain 1–4% Neanderthal DNA, a legacy of admixture during Eurasian migrations (Reich et al., 2011). In Arabia and South Asia, however, archaic introgression remains enigmatic. The Narmada hominin, though morphologically archaic, lacks associated genetic data, leaving its taxonomic status unresolved (Athreya, 2007). Meanwhile, Denisovan DNA in Australasian populations suggests admixture occurred in Sundaland or Wallacea, far from the South Asian mainland (Reich et al., 2011).

The survival of Middle Paleolithic toolkits in South Asia until ~40 ka hints at prolonged coexistence with archaic groups. At Jwalapuram, tool continuity across the Toba ash layer implies that local populations—whether AMH or archaic—adapted to volcanic winters (Haslam et al., 2010). Functional genetic studies propose that Neanderthal alleles enhanced immune responses to Eurasian pathogens, illustrating adaptive benefits of hybridization (Abi-Rached et al., 2011).

Environmental Pressures and Adaptive Flexibility

The climatic oscillations of the Late Pleistocene posed profound challenges for hominin populations, demanding behavioral flexibility to survive in shifting landscapes. In Arabia, the humid phase of Marine

Isotope Stage (MIS) 5 (130–75 ka) transformed the peninsula into a mosaic of freshwater lakes, river networks, and savannahs, as evidenced by speleothem records from Hoti Cave (Oman) and paleolake sediments in the Nefud Desert (Rosenberg et al., 2011). These conditions supported lakeside settlements, such as those at Jubbah (northern Saudi Arabia), where lithic assemblages and fossilized animal remains—including hippopotamus, cattle, and freshwater mollusks—reflect diverse subsistence strategies tied to wetland ecosystems (Petraglia et al., 2012). Monsoonal rains during MIS 5e (130–115 ka) likely facilitated migrations from the Horn of Africa, enabling hominins to exploit interconnected resource corridors. However, the abrupt onset of MIS 4 (75–60 ka) brought intense aridification, with dune incursions and desiccated basins fragmenting habitats. This climatic downturn forced populations into refugia, such as the Red Sea coastal shelf and the Dhofar Mountains (Oman), where groundwater-fed springs and coastal resources provided critical buffers (Breeze et al., 2015). Genetic studies suggest that these refugial zones sustained small, isolated groups, as seen in the low diversity of basal mtDNA haplogroups like N1a in modern Arabian populations (Fernandes et al., 2012).

At Mundafan (southwestern Saudi Arabia), adaptive responses to aridification are etched into the lithic record. During MIS 5, Levallois flake production dominated, optimized for procuring high-quality chert from distant sources and facilitating efficient butchery of migratory game (Groucutt et al., 2018). By MIS 4, however, toolkits shifted to simpler discoidal core technology, which prioritized the intensive reduction of locally available raw materials. This transition reflects a move toward expedient, resource-conserving strategies in response to constrained mobility and scarcer prey. Similarly, in the Thar Desert (India), quartzite quarries at sites like 16R Dune show evidence of “gearing up” with prepared cores during brief humid intervals, followed by reliance on smaller, recycled tools as aridity intensified (Blinkhorn et al., 2017).

In South Asia, the generalized Middle Paleolithic toolkit—characterized by Levallois cores, side scrapers, and bifacial points—proved remarkably adaptable to diverse biomes. In the Thar Desert, groups exploited seasonal playas, crafting scrapers for processing animal hides and points for hunting gazelle (James & Petraglia, 2005). Along the Gangetic plains, where forests and rivers intersected, tools were tailored for woodworking and aquatic resource extraction, as seen at the site of Mahagara, where bone harpoons and anvil stones suggest fishing activities (Clark & Williams, 1986). This technological versatility underscores a broader trend: as climate volatility destabilized ecosystems, humans increasingly relied on flexible niche construction—modifying tools and subsistence strategies to exploit locally variable resources.

These adaptive behaviors contrast with the rigid technological traditions of contemporaneous Neanderthals in Eurasia, highlighting a potential competitive advantage for Homo sapiens in unstable environments. While MIS 4's aridity likely extinguished some pioneer populations in Arabia, those who persisted laid the groundwork for later expansions. The interplay of climatic flux and innovation during this period illustrates a central theme of human evolution: survival hinged not merely on biological resilience but on the capacity to reimagine toolmaking, resource use, and social networks in the face of a changing world.

The Middle Paleolithic in the Indian Subcontinent

Genetic and Fossil Evidence

The Indian subcontinent is another critical region for understanding the dispersal of *Homo sapiens* out of Africa. Genetic studies indicate that South Asian populations belong to mtDNA haplogroups M and N, which are descended from the African L3 haplogroup (Kivisild et al. 1999; Macaulay et al. 2005). The coalescence dates for haplogroup M in South Asia (73–55 ka) suggest that early human populations reached the subcontinent during MIS 4, a period of climatic cooling and aridity (Endicott et al. 2003; Metspalu et al. 2004). However, the archaeological record suggests that *Homo sapiens* may have arrived in South Asia earlier, during MIS 5 (Petraglia et al. 2007).

Fossil evidence from the Indian subcontinent is scarce, but the Narmada hominin, dated to 160–85 ka, provides some insights into the presence of archaic humans in the region (Sonakia 1985; Patnaik et al. 2009). The taxonomic status of the Narmada fossil remains disputed, but it is generally classified as an archaic form of *Homo* (Athreya 2007). The presence of Late Acheulean industries in South Asia up to 100 ka suggests that archaic populations may have persisted in the region until the arrival of *Homo sapiens* (Sharma and Clark 1983; Petraglia et al. 2007).

Middle Paleolithic Lithic Industries

The Middle Paleolithic of the Indian subcontinent is characterized by a wide range of lithic technologies, including plain flake, discoidal, Levallois, and blade techniques (Jayaswal 1978; James and Petraglia 2005). The Jwalapuram site in southern India has yielded stratified Middle Paleolithic assemblages dating to 78–38 ka, which show technological similarities to African MSA industries (Petraglia et al. 2007). The presence of Levallois and discoidal cores, as well as retouched tools such as scrapers and notches, suggests a degree of technological continuity between the Middle and Late Paleolithic in South

Asia (James and Petraglia 2005; Clarkson et al. 2012).The absence of clear evidence for a rapid transition to Upper Paleolithic technologies in South Asia has led some researchers to argue that the Middle Paleolithic industries in the region were produced by *Homo sapiens* using locally developed technologies (Petraglia et al. 2007; Blinkhorn and Petraglia 2014). This view is supported by the presence of Middle Paleolithic sites in a variety of ecological settings, including river valleys, basins, and upland zones, which would have provided favorable conditions for human occupation during periods of climatic instability (Misra 1995a, b; Petraglia et al. 2009a).

Coastal vs. Inland Routes: The Role of Kachchh

The interplay between climatic variability and human adaptability further complicates the binary framing of coastal versus inland dispersal models. Paleoenvironmental reconstructions reveal that the Indian subcontinent experienced dramatic shifts during MIS 5–3, with humid phases (e.g., MIS 5e and 3) enabling the greening of now-arid regions like the Thar Desert and Kachchh, while arid intervals (e.g., MIS 4) contracted habitable zones to coastal and riverine refugia (Giosan et al., 2012). During humid periods, inland routes became viable, as evidenced by Kachchh's riverine-associated Middle Paleolithic sites, which align with African MSA technologies and suggest pulses of inland movement (Blinkhorn et al., 2017). Conversely, MIS 4's hyperaridity likely fragmented populations, pushing some groups toward the coast, where shell middens at sites like Patne (India) and Fa Hien Lena (Sri Lanka) indicate sustained marine resource use (Roberts et al., 2015). Genetic studies corroborate this pattern: the divergence of haplogroup M (~50 ka) coincides with post-aridity re-expansions from refugia, while ancient admixture signals with South Asian archaic populations suggest prolonged, intermittent interactions during these cycles (Mallick et al., 2016). Thus, dispersal routes were not static but contingent on ecological windows, with early humans opportunistically navigating both coastal and inland corridors as climate oscillated—a "braided" dispersal model that defies simplistic categorization.

The Coastal Dispersal Model: Predictions and Challenges

Proponents of the coastal dispersal model argue that early humans utilized the Indian Ocean coastline as a "highway" for rapid migration, facilitated by familiar coastal ecosystems and marine resources (Mellars et al., 2013; Oppenheimer, 2009). This hypothesis is supported by evidence of early marine resource use in southern Africa, such as shell middens and fish remains dated to ~160–60 ka, which suggest coastal adaptations (Jerardino & Marean, 2010). Additionally, the colonization of Australia by 50–60 ka implies a rapid coastal migration, as reaching Sahul required navigating open waters (Clarkson et al., 2015). Genetic studies further propose that mitochondrial haplogroups M and N, which underpin non-African populations, spread through a single southern exit from Africa ~65–55 ka (Macaulay et al., 2005).

However, the coastal model faces significant challenges in South Asia. Blinkhorn et al. (2017) conducted targeted surveys in Kachchh, a region adjacent to the Indus Delta and a proposed coastal dispersal corridor. Their findings revealed widespread Middle Palaeolithic occupation (e.g., Levallois cores, scrapers) in Late Pleistocene sediments but a striking absence of Late Palaeolithic microlithic tools—a technology often linked to AMH expansions—until the Holocene. This absence contradicts the expectation that microlithic industries, analogous to the African Howiesons Poort (~65–59 ka), would mark the arrival of AMH along the coast (Mellars et al., 2013). Instead, Kachchh's lithic record shows technological continuity with inland Middle Palaeolithic traditions, suggesting that coastal Gujarat was not a primary route for microlithic-bearing AMH (Blinkhorn et al., 2017). Furthermore, the submerged Pleistocene coastline and lack of marine resource exploitation evidence in Kachchh complicate efforts to validate the coastal model, as critical archaeological sites may now lie underwater (Erlandson & Braje, 2015).

Inland Routes and Middle Palaeolithic Continuity

In contrast to coastal models, inland dispersal hypotheses emphasize the role of riverine corridors and continental adaptations. Haslam et al. (2017) highlight the Jurreru Valley in southern India, where Middle Palaeolithic tools persist both before and after the Toba super-eruption (~74 ka). Crucially, microlithic technologies appear only after 38 ka, coinciding with the earliest AMH skeletal evidence in Sri Lanka (~40 ka) (Perera et al., 2011). This delayed adoption of microlithics suggests that archaic hominins, not AMH, produced the pre-Toba Middle Palaeolithic tools, with AMH arriving later and introducing new technologies (Haslam et al., 2017). Genetic data support this timeline: Indian-specific mitochondrial haplogroups (e.g., M30, U2) exhibit coalescent ages of ~49–53 ka, younger than counterparts in East Asia (~60 ka), implying a staggered dispersal into the subcontinent (Soares et al., 2009; Fernandes et al., 2012).

The persistence of Middle Palaeolithic technologies in India until ~35 ka further complicates the narrative of a rapid AMH takeover. At Jwalapuram, lithic continuity across the Toba ash layer indicates that local hominins—potentially archaic groups—survived the eruption and maintained technological traditions (Petraglia et al., 2007). This challenges the MPF model, which posits that AMH introduced

Middle Palaeolithic tools during Marine Isotope Stage 5 (MIS 5, ~130–80 ka). Instead, genetic evidence suggests AMH arrived later, during MIS 4 (~74–60 ka), and may have initially bypassed regions occupied by archaic populations (Haslam et al., 2017). The delayed dispersal into southern India mirrors patterns in Europe, where Neanderthals persisted until ~40 ka, possibly slowing AMH expansion (Higham et al., 2014).

Synthesizing Genetic, Archaeological, and Regional Data

The interplay of genetic and archaeological evidence underscores the complexity of South Asia's colonization. While mitochondrial DNA suggests a single out-of-Africa dispersal ~65–55 ka (Macaulay et al., 2005), regional genetic diversity points to multiple waves and admixture events. For instance, South Asian populations show traces of Neanderthal and Denisovan introgression, hinting at interactions with archaic hominins (Abi-Rached et al., 2011; Reich et al., 2011). These genetic "echoes" align with archaeological evidence of prolonged Middle Palaeolithic continuity, suggesting that AMH expansion was neither uniform nor swift.

The Kachchh findings reinforce this view. The absence of microlithics in Pleistocene contexts undermines the coastal model's prediction of a rapid, technology-driven dispersal. Instead, the prevalence of Middle Palaeolithic tools in both coastal and inland regions (e.g., Thar Desert, Jurreru Valley) suggests that early humans—whether AMH or archaic—utilized flexible foraging strategies adaptable to diverse environments (Blinkhorn et al., 2015; Haslam et al., 2017). This technological conservatism contrasts with Africa and Europe, where microlithic innovations often signal demographic shifts.

Technological and Cultural Adaptations

The Middle Paleolithic period (ca. 300,000–40,000 years ago) marks a transformative phase in human technological evolution, characterized by the development of prepared core techniques such as the Levallois method. This innovation required advanced cognitive skills, including foresight, spatial reasoning, and an understanding of fracture mechanics (Shea, 2011). The Levallois technique involved meticulously shaping a stone core to produce standardized flakes or blades, optimizing raw material efficiency. In Africa, Middle Stone Age (MSA) assemblages from sites like Blombos Cave (South Africa) and Porc-Epic Cave (Ethiopia) highlight the sophistication of these technologies. At Blombos, finely retouched blades and ochre engravings dated to ~100–70 ka suggest not only functional tool use but also symbolic behavior, challenging Eurocentric notions of a "behavioral modernity" exclusive to the Upper Paleolithic (Henshilwood & Marean, 2003; McBrearty & Brooks, 2000).

Levallois technology's efficiency in resource utilization provided a critical advantage in marginal environments. At Olorgesailie (Kenya), MSA hominins transported high-quality obsidian over distances exceeding 50 km, reflecting strategic planning and social networks (Brooks et al., 2018). Standardized toolkits—featuring scrapers, points, and denticulates—enabled versatility in tasks such as hide processing, woodworking, and hunting. In contrast, Neanderthal Mousterian industries in Europe emphasized flake tools, with limited evidence of blade production until the arrival of *Homo sapiens* (Mellars, 2006). This divergence underscores the adaptive flexibility of modern humans, who innovated in response to ecological pressures.

Genetic Evidence: Admixture and Regional Lineages

Genetic studies have revolutionized our understanding of early human dispersals, revealing complex interactions between modern and archaic populations. Non-African populations retain traces of Neanderthal (1–4%) and Denisovan (up to 6% in Melanesians) ancestry, indicating interbreeding during expansions into Eurasia (Reich et al., 2011). In South Asia, HLA loci inherited from Neanderthals and Denisovans suggest adaptive introgression, potentially enhancing immune responses to local pathogens (Abi-Rached et al., 2011). However, the extent of archaic admixture in the subcontinent remains debated, as uniparental markers (mtDNA and Y-chromosome) show limited archaic signals due to genetic drift (Soares et al., 2009).

Mitochondrial haplogroups M and N, which underpin non-African populations, diverged ~65–55 ka, supporting a single southern dispersal from Africa (Macaulay et al., 2005). However, regional genetic diversity complicates this narrative. Indian-specific subclades (e.g., M30, U2) exhibit coalescent ages of ~49–53 ka, younger than counterparts in East Asia (~60 ka), suggesting a staggered dispersal into the subcontinent (Fernandes et al., 2012). Autosomal data further reveal a basal divergence between South Asian and East Eurasian populations, consistent with an early split near the Persian Gulf (Metspalu et al., 2004). These findings align with archaeological evidence of prolonged Middle Paleolithic continuity in India, where archaic hominins may have delayed AMH colonization (Haslam et al., 2017).

Regional Case Studies: Africa, the Levant, and Arabia

Africa: Cradle of Innovation

The mosaic of MSA technologies across Africa underscores a deeper pattern of regional specialization and incremental innovation that likely primed populations for dispersal. In southern Africa, the Still Bay industry (~75–71 ka) at sites like Blombos Cave produced finely crafted bifacial points and ochre engravings, signaling advanced symbolic cognition and projectile technology that may have enhanced hunting efficiency and social cohesion (Henshilwood et al., 2001). Meanwhile, North Africa's Aterian industry (~145–30 ka) featured tanged tools suited for hafting, possibly as part of composite weapons or tools tailored to arid environments—an adaptation critical for traversing the Sahara during humid pulses (Scerri et al., 2021). These regional traditions, coupled with evidence of long-distance obsidian exchange networks in Ethiopia (~200 ka; Sahle et al., 2022), suggest that MSA populations developed not only technical versatility but also social and logistical frameworks for resource management. Such innovations—symbolic communication, adaptive toolkits, and extended trade networks—provided a behavioral "toolbox" that enabled AMHs to navigate unfamiliar ecologies during dispersals, whether along coastlines, riverine corridors, or desert margins. This intra-African diversity challenges monolithic narratives of a single "dispersal package," instead highlighting how fragmented yet interconnected populations accumulated the adaptive flexibility necessary to colonize Eurasia's mosaic habitats.

The Levant: A Contested Corridor

The Levant served as a critical crossroads for early human expansions. Sites like Qafzeh and Skhul (120–90 ka) contain Levallois flakes alongside ochre-stained burials, suggesting ritualistic practices among early *Homo sapiens* (Bar-Yosef, 2002). However, these populations were transient; Neanderthals reoccupied the region during drier phases (MIS 4), highlighting the precariousness of initial expansions (Shea, 2011). The Emiran industry (~47 ka), with its blade-rich assemblages, marks the transition to the Upper Paleolithic and the eventual displacement of Neanderthals (Belfer-Cohen & Goring-Morris, 2003). Additionally, the Levant witnessed the development of the Ahmarian industry (~42 ka), characterized by its elongated blade production and personal ornaments like shell beads. This industry is often associated with the early Upper Paleolithic modern humans and their advanced tool-making skills. These innovations hint at increased cognitive complexity and cultural expression, further differentiating Homo sapiens from Neanderthals in the region (Hublin, 2015). This period also marks the gradual establishment of more permanent settlements, indicating a shift from purely nomadic lifestyles to ones with defined territoriality and resource management.

Arabia: Gateway to Asia

The ecological volatility of Arabia during MIS 5 and 4 shaped both the opportunities and constraints faced by early human populations. Paleoenvironmental reconstructions reveal a mosaic of lakes, wetlands, and savannahs during humid intervals, such as those documented at Mundafan (Saudi Arabia), where repeated occupations coincide with phases of heightened monsoonal activity (Groucutt et al., 2018). These landscapes supported diverse megafauna, including oryx and gazelle, which early humans hunted using MSA toolkits adapted to mobile, open-terrain foraging. However, the onset of MIS 4 aridity after ~75 ka fragmented these habitats, desiccating lakes and triggering dune incursions across the Nefud and Rub' al-Khali deserts. Populations retreated to refugia such as the Dhofar Highlands (Oman) and the Red Sea coast, where groundwater-fed springs and marine resources—evidenced by shellfish remains at Al Wusta (Saudi Arabia)—provided critical subsistence buffers (Breeze et al., 2015; Stewart et al., 2020). The persistence of Nubian Complex Levallois technologies in Dhofar, despite regional aridification, suggests cultural continuity among isolated groups, while genetic bottlenecks in mtDNA haplogroup L3 hint at severe demographic contractions (Fernandes et al., 2012; Usik et al., 2013). These refugial zones likely served as staging grounds for later expansions, as evidenced by the re-emergence of populations during humid MIS 3 (~60–40 ka), who carried blended technological traditions into South Asia. Arabia's oscillating climate thus acted as a selective filter, winnowing out less adaptable groups while fostering innovations that enabled survival in Eurasia's unpredictable environments.

South Asia: Coastal vs. Inland Dispersal Debates

The Coastal Route Hypothesis

Proponents of the coastal dispersal model argue that early humans followed the Indian Ocean rim, exploiting marine resources and moving rapidly toward Southeast Asia and Australia (Mellars et al., 2013). Genetic coalescence dates (~65–55 ka) and the colonization of Sahul by ~50–60 ka support this model (Clarkson et al., 2017). However, archaeological evidence from Kachchh (Gujarat) challenges this narrative. Surveys by Blinkhorn et al. (2017) revealed Middle Paleolithic occupation (Levallois cores, scrapers) in Late Pleistocene sediments but no microlithic industries until the Holocene. This absence contradicts expectations of a coastal "microlithic trail" analogous to the African Howiesons Poort.

Inland Routes and Archaic Persistence

Inland dispersal models emphasize riverine corridors and continental adaptations. At Jwalapuram (India), Middle Paleolithic tools persist both before and after the Toba super-eruption (~74 ka), with microlithics appearing only after 38 ka (Haslam et al., 2010). This suggests archaic hominins produced pre-Toba assemblages, while AMH arrived later, introducing new technologies. Genetic data corroborate this timeline: Indian-specific haplogroups (e.g., M33, R30) coalesce ~45–64 ka, later than East Asian counterparts (Soares et al., 2009). The Thar Desert (Rajasthan) further illustrates AMH adaptability, with Middle Paleolithic sites showing affinities to African and Arabian MSA (Blinkhorn et al., 2015).

Technological Continuity and Adaptation

The persistence of Middle Paleolithic technologies in South Asia until ~35 ka reflects both environmental adaptability and potential interactions with archaic populations. At Attirampakkam (India), lithic continuity from the Acheulean to the Middle Paleolithic (~385–172 ka) challenges assumptions of abrupt technological shifts (Akhilesh et al., 2018). Similarly, the Jurreru Valley sequence demonstrates that prepared core techniques survived the Toba eruption, possibly indicating resilience among local hominins (Petraglia et al., 2007). These findings underscore the limitations of equating stone tools with specific hominin taxa, as convergent evolution and cultural transmission may blur technological boundaries (Clarkson et al., 2012).

Findings

The study reveals that the dispersal of *Homo sapiens* out of Africa during the Middle Paleolithic (ca. 300,000–40,000 years ago) was a multifaceted process shaped by technological innovation, climatic shifts, and interactions with archaic hominins. Lithic industries, particularly Levallois prepared-core techniques, served as critical markers of cognitive advancement and adaptability, enabling efficient resource exploitation in diverse environments. Genetic evidence from mitochondrial haplogroups (L3, M, N) supports a primary dispersal pulse ~70–60 ka via southern coastal routes, yet archaeological complexities challenge linear narratives. Sites like Jwalapuram (India) demonstrate human resilience to climatic crises, with Middle Paleolithic tools stratified above and below the Toba volcanic ash (~74 ka), though debates persist over whether these were crafted by *Homo sapiens* or archaic groups like the Narmada hominin.

Environmental fluctuations, notably humid MIS 5 (130–75 ka) and arid MIS 4 (75–60 ka), dictated migration dynamics. Arabia's "Green Phase" facilitated inland and coastal dispersals, evidenced by Levallois toolkits at Jebel Faya (UAE) and Wadi Surdud (Yemen), while later aridification fragmented populations into refugia. In South Asia, the absence of microlithic tools in Kachchh challenges coastal migration models, instead supporting inland riverine corridors during humid phases. Genetic bottlenecks and archaic admixture (e.g., Neanderthal DNA in non-Africans) highlight demographic fluidity and intermittent interactions. The synthesis of multidisciplinary data underscores a "braided" dispersal model, where early humans employed opportunistic, nonlinear strategies—alternating between coastal and inland routes—driven by technological adaptability, climatic opportunism, and dynamic hominin interactions. This redefines human migration as a complex mosaic of resilience, innovation, and ecological negotiation.

Conclusion

The discovery of Middle Paleolithic tools in the Kachchh region of northwestern India challenges traditional coastal migration models for early *Homo sapiens* in South Asia. During humid phases of MIS 5 and 3 (~130–40 ka), Kachchh—now arid—was interlaced with river systems connecting the Thar Desert to the Indus Valley and Gangetic plains. Sites like Dhaba and Pariyaj Lake beds yielded Levallois cores, scrapers, and bifacial points (~80–60 ka), technologically aligned with African and Arabian Middle Stone Age (MSA) traditions (Blinkhorn et al., 2021). These tools suggest early humans exploited inland riverine corridors during wet intervals, accessing freshwater and game. Crucially, the absence of Late Paleolithic microliths—a hallmark of coastal sites like Jwalapuram—implies Kachchh was later abandoned as populations shifted coastward during MIS 4 aridity (~75–60 ka) (Petraglia et al., 2009). Paleohydrological evidence, including fossilized monsoon-fed channels in the Thar Desert, further supports inland "green highways" that facilitated movement amid coastal ecological stress (Singhvi et al., 2010).

The inland toolkit reflects strategic adaptability to diverse ecosystems. At Kachchh, durable quartzite Levallois cores optimized processing of large herbivores like wild cattle (Groucutt et al., 2021), while Son Valley assemblages (central India) included notched scrapers for woodworking and denticulates for plant processing, showcasing versatile subsistence strategies (James & Petraglia, 2005). This generalized toolkit contrasts with coastal populations' specialized blade technologies tailored for marine resource reliance. The inland toolkit's flexibility likely enabled resilience during climatic downturns, allowing shifts between hunting, gathering, and scavenging. However, the lack of symbolic artifacts (e.g., ochre or beads) in inland contexts raises questions about cultural connections to coastal migrants or the development of isolated social practices.

The peopling of South Asia emerged as a dynamic, non-linear process shaped by climatic opportunism and technological innovation. Early humans employed a "leapfrog" strategy, dispersing inland during humid phases (e.g., MIS 5e) and retreating to refugia during aridification, as seen in cyclical Thar Desert occupations (Blinkhorn et al., 2017). Coastal and inland routes were complementary, with genetic and cultural legacies reflecting both isolation and interaction. For instance, coastal migrants may have introduced symbolic technologies, while inland groups contributed to genetic diversity through admixture and regional adaptations. This "braided" dispersal model underscores the interplay of ecological constraints, demographic fluidity, and technological resilience, rejecting simplistic coastal-inland dichotomies. The Levant and Arabia, as biogeographic crossroads, further illustrate how climatic shifts and archaic hominin interactions shaped *Homo sapiens*' successful colonization of Eurasia's varied landscapes.

In sum, the Kachchh findings redefine early human migrations as adaptive mosaics, driven by opportunistic responses to environmental variability and cultural ingenuity, rather than singular, linear routes.

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