UNIVERSITAT ROVIRA I VIRGILI

LOWER AND MIDDLE PALAEOLITHIC LITHIC ASSEMBLAGES FROM SOUTHERN PENINSULAR INDIA: A GEOMETRIC MORPHOMETRIC AND CLASSICAL APPROACH TO LARGE CUTTING TOOLS

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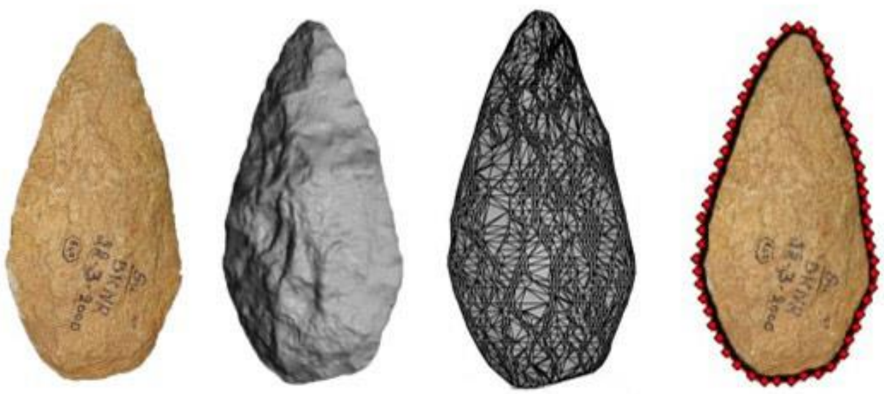

DOCTORAL THESIS
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Cover page: Handaxe from Middle Palaeolithic Benkaneri site, Malaprabha Valley, Karnataka, India (photograph, 3D scan image, 3D mesh and with 2D semi-landmarks (author: M. Kunneriath)

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Lower to Middle Palaeolithic lithic assemblages from southern Peninsular India: A geometric morphometric and classical approach to Large Cutting Tools

Doctoral thesis

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WE STATE that the present study, entitled "Lower and Middle Palaeolithic lithic assemblages from southern Peninsular India: a geometric morphometric and classical analysis to Large Cutting Tools", presented by Madhavi KUNNERIATH for the award of the degree of Doctor, has been carried out under our supervision at the Department of History and Art History, of this university.

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M. Gema Chacón | Claire Gaillard | Ravi Korisettar

"A people without the knowledge of their past history, origin and culture is like a tree without roots."

Marcus Garvey

Dedicated to my family, my roots.

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Madhavi KUNNERIATH

ABSTRACT

The Indian sub-continent, midway between Africa and South-east Asia, offers great potential to contribute to the ongoing debates of hominin dispersals and techno-cultural transitions. The Malaprabha Valley sites, in south-western Peninsular India, provides a regional perspective on the transitional processes between Lower and Middle Palaeolithic.

Three assemblages, from local Late Acheulean to Middle Palaeolithic were chosen as the key collections and then compared to two of their south-eastern counterparts. These assemblages, excavated or collected from surface, are housed in various museums in India, France and UK.

The aim of this PhD was to trace the technological and typological changes of the Large cutting tools (LCTs: handaxes and cleavers) at the transition from Lower to Middle Palaeolithic. A second objective was to discern raw material blank effects on the shape variabilities of the LCTs. Combining the classical techno-typological analysis and Geometric Morphometric approach (2D and 3D) allow us to get accurate, reversible holistic results.

LCTs in Malaprabha Valley always include more handaxes than cleavers. They are constantly made from local quartzite on various types of blanks with gradual increasing use of the flakes. Their shape variability is mostly located on their periphery and is not influenced by the blank types. Whatever variability occurred it seemed to result from varying relative width and thickness.

This study highlights that the technological and morphological traits of the LCTs reflect a regional continuity with gradual changes from the Lower to the Middle Palaeolithic, rather than an abrupt external introduction of new technical behaviors. Irrespective of the diverse blank types, the hominin tool makers in this part of Peninsular India were able to achieve similar tool forms, through adaptive shaping strategies, reflecting a mental template that continued through generations apart from the technical progress identifiable in other products.

RESUMEN

El subcontinente indio, a medio camino entre África y el Sudeste Asiático, ofrece un gran potencial para contribuir a los debates en curso sobre la dispersión de los homínidos y de las transiciones tecnoculturales. Los yacimientos del Valle de Malaprabha, en el suroeste de la India peninsular, proporcionan una perspectiva regional sobre los procesos de transición entre el Paleolítico Inferior y Medio.

Se eligieron tres conjuntos, del Achelense tardío hasta el Paleolítico medio local, como colecciones clave y luego se compararon con dos de sus homólogos del sureste. Estos conjuntos, excavados o procedentes de recogidas de superficie, se encuentran en varios museos de India, Francia y Reino Unido.

El objetivo de esta tesis doctoral era trazar los cambios tecnológicos y tipológicos de los Large Cutting Tools (LCTs: bifaces y hendedores) en la transición del Paleolítico Inferior al Medio. Un segundo objetivo ha sido discernir la influencia de las materias primas y los tipos de soporte en las variabilidades de forma de los LCTs. La combinación del análisis tecno-tipológico clásico y el enfoque de la morfometría geométrica (2D y 3D) nos permite obtener resultados holísticos precisos y reversibles.

Los LCTs del Valle de Malaprabha siempre incluyen más bifaces que hendedores. Se fabrican casi exclusivamente a partir de cuarcita local en varios tipos de soportes con un uso progresivo de las lascas. Su variabilidad de forma se encuentra principalmente en la periferia y no está influenciada por los tipos de soportes. Cualquiera que sea la variabilidad que se haya producido, parece ser el resultado de variar el ancho y el grosor relativo de los soportes.

Este estudio destaca que los rasgos tecnológicos y morfológicos de los LCT reflejan una continuidad regional con cambios graduales desde el Paleolítico Inferior al Medio, más que una abrupta introducción externa de nuevos comportamientos tecnológicos. Independientemente de los diversos tipos de soporte utilizados, los grupos de homínidos de esta parte de la India peninsular consiguieron útiles de formas similares, a través de estrategias de conformación adaptativas, lo que refleja un esquema mental que continuó a través de generaciones aparte del progreso técnico identificable en otros productos.

RESUM

El subcontinent indi, a mig camí entre l'Àfrica i el sud-est asiàtic, ofereix un gran potencial per contribuir als debats en curs sobre dispersions d'hominins i transicions tecnoculturals. Els jaciments de la vall de Malaprabha, al sud de l'Índia peninsular, proporcionen una perspectiva regional sobre els processos de transició entre el Paleolític inferior i el Paleolític mitjà.

Es van triar tres conjunts, des del final de l'Aixelià fins al Paleolític mitjà, com a col·leccions clau i després es van comparar amb dos dels seus homòlegs del sud-est. Aquests conjunts, excavats o recollits en superfície, es troben en diversos Museus de l'Índia, França i el Regne Unit.

L'objectiu d'aquesta tesi doctoral és rastrejar els canvis tecnològics i tipològics dels *Large Cutting Tools* (LCT: Grans Eines Tallants, bifaços i fenedors) en la transició del Paleolític inferior al Paleolític mitjà. Un segon objectiu era discernir els efectes de les matèries primeres sobre la variabilitat de formes dels LCT. La combinació de l'anàlisi tecno-tipològica clàssica i l'anàlisi Geomètrica-Morfomètrica (2D i 3D) ens permet obtenir resultats holístics precisos i reversibles.

Els LCT a la vall de Malaprabha sempre inclouen més bifaços que fenedors. Es fabriquen constantment a partir de quarsita local en diversos tipus de suports amb un ús creixent de les ascles com a suport. La seva variabilitat morfològica s'observa principalment en la perifèria de l'objecte i no està influenciada pels tipus de suports. Qualsevol variabilitat ocorreguda sembla resultar de variar l'amplada i el gruix relatius.

Aquest estudi posa de manifest que els trets tecnològics i morfològics dels LCT reflecteixen una continuïtat regional amb canvis graduals del Paleolític inferior al mitjà, en lloc d'una introducció brusca externa de nous comportaments tecnològics. Independentment dels diversos tipus de suports, els hominins fabricants d'eines d'aquesta part de l'Índia peninsular van ser capaços d'aconseguir formes similars, mitjançant estratègies adaptatives de configuració, que reflecteixen uns esquemes mentals que van continuar durant generacions a banda del progrés tècnic identificable en altres productes.

RÉSUMÉ

Le sous-continent indien, entre l'Afrique et l'Asie du sud-est, est susceptible de contribuer efficacement au débat sur la dispersion des populations humaines et les transitions techno-culturelles. La vallée de la Malaprabha, dans le sud-ouest de la Péninsule indienne, offre une perspective régionale sur la compréhension des processus de transition entre le Paléolithique inférieur et moyen.

Trois assemblages, de l'Acheuléen tardif au Paléolithique moyen, ont été choisis pour étude et comparés à deux autres du sud-est de la Péninsule. Ces assemblages issus de collections de surface ou de fouille sont conservés dans différents musées d'Inde, de France ou du Royaume-Uni.

Le but de ce travail de doctorat était d'identifier les changements technologiques et typologiques des bifaces et hachereaux (« *LCTs* ») à la transition entre Paléolithique inférieur et moyen. Un second objectif était de discerner l'influence des supports sur la variabilité des formes. L'association d'une analyse techno-typologique classique avec une approche de morphométrie géométrique (2D et 3D) permet d'obtenir des résultats précis, reproductibles et intégrés.

Dans la vallée de la Malaprabha, les bifaces sont toujours plus fréquents que les hachereaux. Ces outils en quartzite local, façonnés sur différents supports parmi lesquels la proportion d'éclats, augmentent progressivement. La variabilité des formes concerne principalement la périphérie des outils et n'est pas influencée par le type de support. L'éventuelle variabilité résulte des mesures relatives au volume.

Cette étude souligne que les caractères technologiques et morphologiques des *LCTs* reflètent une continuité régionale, avec des changements graduels entre Paléolithique inférieur et moyen, plutôt que l'introduction abrupte de nouveaux comportements techniques. Les artisans paléolithiques dans cette partie de l'Inde péninsulaire étaient capables de réaliser des formes d'outils similaires, indépendamment des types de support, grâce à l'adaptation de leurs stratégies de façonnage, qui traduisaient un modèle mental transmis entre générations, en dehors des progrès techniques régissant les autres productions.

ASTRATTO

Il subcontinente indiano, a metà strada tra l'Africa e il sud-est asiatico, offre un gran potenziale per contribuire al dibattito in corso sulle dispersioni di ominidi e al dibattito sulle transizioni tecno-culturali. I siti della valle del Malaprabha, nel sud della penisola indiana, offrono una prospettiva regionale sui processi di transizione tra il Paleolitico inferiore e quello medio.

Tre raccolte archeologiche, dal tardo Acheuleano al Paleolitico medio, furono scelte come collezione chiave e poi confrontate con due delle loro controparti sud-orientali. Queste, scavate o raccolte in superficie, sono ospitate in vari musei in India, Francia e Regno Unito.

L'obiettivo primario del dottorato è stato quello di rintracciare i cambiamenti tecnologici e tipologici dei grandi bifacciali (LCTs: bifacciali e *hachereau*) transizionali dell'antico e del medio Paleolitico. Il secondo obiettivo è analizzare gli effetti delle materie prime sulle variabilità di forma di differenti strumenti LCT. La combinazione dell'analisi tecno-tipologica classica e dell'approccio geometrico morfometrico (2D e 3D) ci consente di ottenere risultati olistici, accurati e reversibili.

I LCT nella Malaprabha Valley includono sempre più bifaccili che *hachereau*. Sono costantemente realizzati con quarzite locale su vari tipi di supporti con un utilizzo crescente dei schegge. La loro variabilità di forma si trova principalmente alla loro periferia e non è influenzata dai tipi di supporto. Qualunque variabilità si sia verificata, sembra derivare dalla variazione della larghezza e dello spessore relativi.

Questo studio evidenzia che i tratti tecnologici e morfologici dei LCT riflettono una graduale continuità regionale dal Paleolitico inferiore a quello medio, piuttosto che una brusca introduzione esterna di nuovi comportamenti tecnologici. Indipendentemente dai diversi tipi di supporti, gli ominidi in questa parte dell'India peninsulare sono stati in grado di ottenere forme di strumenti simili, attraverso strategie di modellazione adattive, riflettendo un modello mentale che è continuato per generazioni a prescindere dal progresso tecnico identificabile in altri prodotti.

CONTENTS

ORGANISATION AND STRUCTURE OF THESIS

This thesis contains seven chapters. The first chapter is “State of the Art and Objectives” that introduces the study area of southern Peninsular India within the Indian sub-continent. In the opening part of this chapter, the broad geographical and geological features of the Indian sub-continent, the cultural and chronological features identified within the Lower and Middle Palaeolithic, previous research, and the recent research trends are introduced. The second part of this chapter deals with issues of classification terminologies and summarises the theoretical and conceptual frameworks regarding the question of dispersals, transitions, and handaxe variability. Based on this, the scope of the current study is identified, and the aims and objectives stated.

The second chapter “Regional Settings” focusses on the study region and the sites. The previous works are summarised and detailed description of the sites are given.

The third chapter “Study Materials” describes the composition and nature of the assemblages studied, besides contextualizing the location of these assemblages in the various museums.

The fourth chapter deals with the “Methodology”, where the sampling techniques, the attributes, and the methodologies are detailed. The methodology of both classical and Geometric Morphometric 2D and 3D approaches has been covered by Article 1 and 2, given as appendices.

The fifth chapter outlines the “Results” of the study. Handaxes and Cleavers are dealt with separately, with both classical and 2D and 3D Geometric Morphometric results.

The sixth chapter “Discussion” aims to give a summary and interpretation of the results. This is an examination of what the findings indicate in terms of the research questions put forward in the first chapter. Finally, they are placed in regional and global contexts to identify broad trends, using published and unpublished data from other parts of the continent and elsewhere.

The seventh chapter “Conclusion” brings us to the final part of the thesis, where the applications of the different methodologies to the study material are compared and assessed and broad general conclusions are drawn. Future perspectives identify and states the aspects of the research which need to be developed.

1. CHAPTER I – STATE OF THE ART AND OBJECTIVES

Lithic tools have played an important role in reconstructing our prehistorical past. Their nature, durable and abundant, along with their distribution across vast temporal and geographical spaces underline their potentiality to decode our ancestor's lifeways. Lithic evidence not only provide insights into hominin behaviour, and changes through time and space—reflected through techno-typological aspects of the tools—but also cognitive differences, and evolutions. Stone tools, thus, are reflections of adaptive strategies to their landscape and environment through their choice and exploitation of raw materials (Nowell et al., 2003).

1.1 Study Context

Indian sub-continent is one such region where these aspects of the lithic evidence are of essential importance in reconstructing the Palaeolithic lifeways, in lieu of poor preservation of datable materials, past environmental and climatic indicators and paucity of fossil remains of the makers of these tools (Mishra, 2007). They remain the most abundant and too often the only archaeological evidence that has been preserved and that we can study in Peninsular India.

Despite the meagre evidence of hominin remains, it is clear from the rich archaeological remains that the strategic location of the Indian sub-continent has played an important role as "a possible migration corridor" in the context of hominin dispersals from Africa (Patnaik and Chauhan, 2009:729), as Peninsular India possesses "one of the densest concentrations of Lower Palaeolithic sites anywhere in the world" (Mishra, 2007:54). Located between East Africa, Western Asia, and Southeast Asia, increasing genetic, archaeological as well as fossil evidence suggests its significant contribution to the hominin evolution, their dispersals as well as to the bio-cultural diversity in the Old World, in the Late Pleistocene (Schug and Walimbe, 2016).

1.1.1 Geographical and Geological Settings

1.1.1.1 The Indian Sub-Continent

Often referred to as South Asia (political demarcation), the Indian sub-continent (geographical unit), one of the largest areas of tropical grassland, comprises the countries of India, Sri Lanka, Nepal, Bhutan, Myanmar, Bangladesh, and Pakistan.

India is the major physiographic zone of the sub-continent. Some of its numerous geographical figures include the greater and lesser Himalayas, the Siwalik region, the Indo-Gangetic Alluvial Plains, and the Indian Peninsular Region (Figure 1.1).

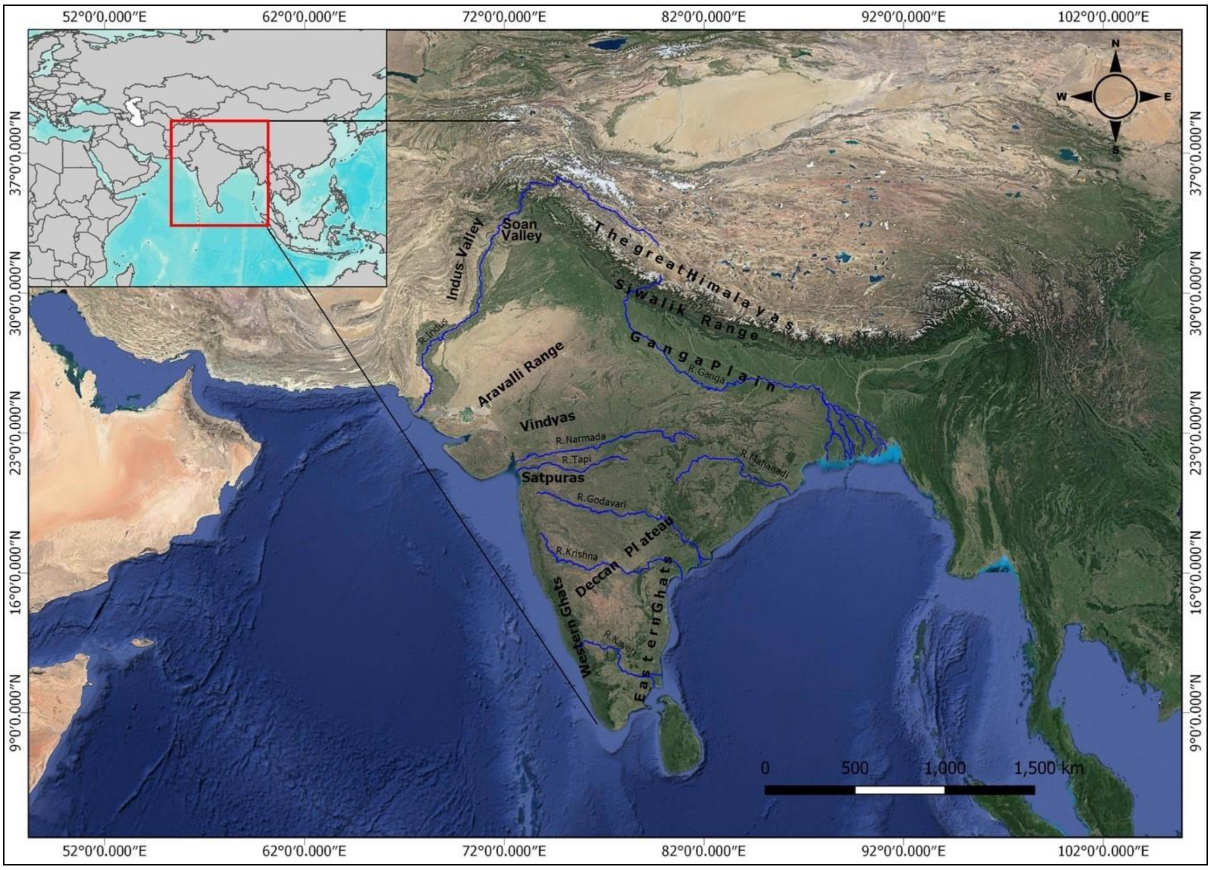


Figure 1. 1 Geographical features of the Indian sub-continent (base map: https//www.google.com/intl/es/earth).

Scattered throughout these territories is rich prehistoric evidence stretching from the Lower Palaeolithic cultural phase to the more recent ones, including an abundance of Mesolithic and Neolithic sites. Dispersed all over the region, these sites—open air, caves, shelters, excavated and/or surveyed—are found in varied climatic and vegetational contexts, from the desertic Rajasthan in the west to heavily forested east India, from the northern alluvial plains to the plateaus in the Deccan region and coastal regions of the south-west and east. Although the Himalayas form a prominent geographical feature in the north, most parts of India form a part of the Peninsula.

1.1.1.2 Peninsular and Southern Peninsular Region

Politically, the Peninsular India comprises of the States of Kerala, Tamil Nadu, Karnataka, Goa, Andhra Pradesh, Orissa, Chhattisgarh, Telangana, and Maharashtra (Figure 1.2). The southern most parts of the Peninsular region are formed by Kerala, Andhra Pradesh, Telangana, Karnataka, and Tamil Nadu, the last two are the focus of this study.

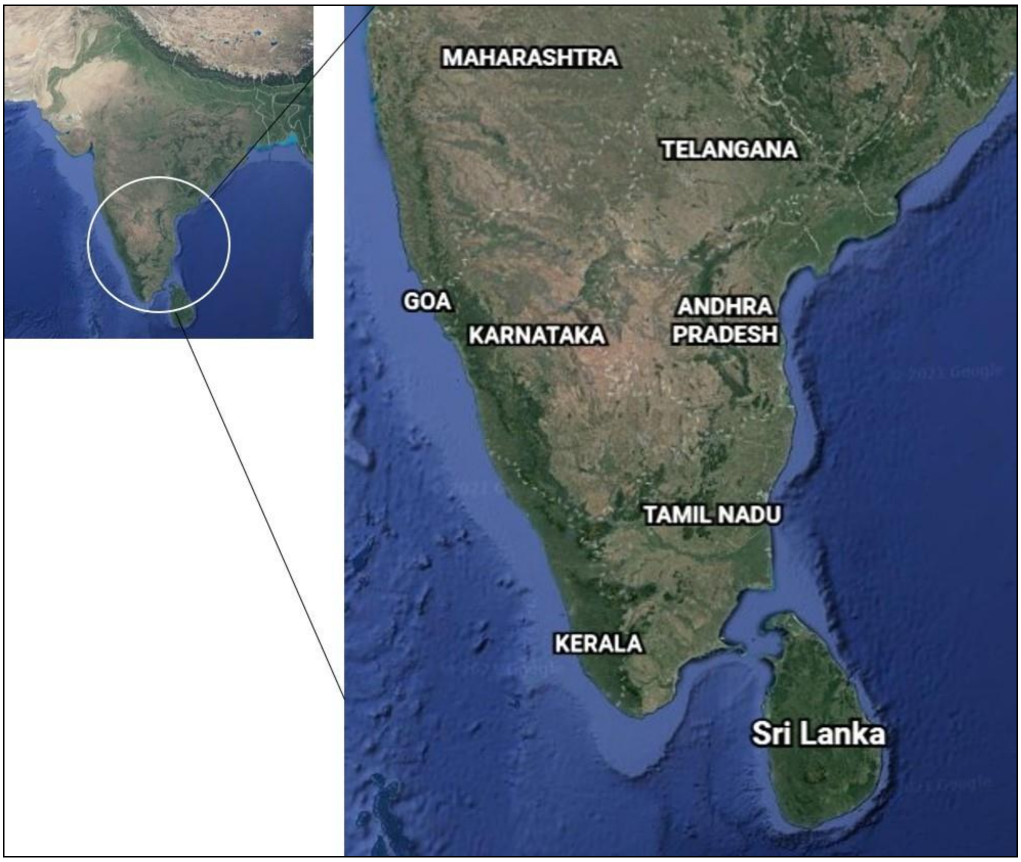


Figure 1. 2 Map of southern Peninsular India showing the states of Karnataka, Tamil Nadu, Kerala, Andhra Pradesh and Telangana (base map: https://www.google.com/intl/es/earth/).

Centrally positioned between the Arabian and South-east Asian peninsulas, Peninsular India has always played a "pivotal and not a peripheral position" in the story of humanity (Paddayya, 2015:7). This will be demonstrated through the subsequent sessions which will highlight the long and continuous nature of the archaeological record, especially in the contexts of the Lower and Middle Palaeolithic cultural phase, the research focus of this PhD.

1.1.1.3 Physiography

Peninsular India, surrounded on the west by Arabian Sea and on the east by Bay of Bengal Sea, is endowed with "… a geographical personality of its own" (Paddayya, 2015:3). Representing the oldest and stable block of the earth's crust (Chakrabarty, 2000; Paddayya 2015:7), Peninsular India includes the Vindhyas and the Satpura mountain ranges on the north, the Western and Eastern Ghat hill ranges with narrow sea-boards attached on the south, while the inland areas are covered by plateaus with alluvial areas in between (Figure 1.1) (Petraglia, 1998; Paddayya and Deo, 2017). Although the Himalayan region has been shaped due to tectonics, structurally stable Peninsular India does not show evidence of major folding and faulting (Mishra, 1994). However, some amount of landscape deformations arising out of sporadic tectonic disturbances might have played a role in the aggradation and erosion of the Peninsular rivers (Rajaguru, 1969).

1.1.1.4 Geology

Dominated by the Deccan Plateau inland, Peninsular Indian geology consists of an upper layer of Deccan Trap basalt, overlying the Archaean and Proterozoic sedimentary rocks (Figure 1.3). The Archaen granite gneiss underlying these upper layers forms the base craton.

The bed rocks exposed throughout the Quaternary cover a large area of the Peninsular India, with only a part covered by sedimentation (Mishra, 2007). However, the notion of the lack of depositional records in the Peninsular India due to its erosional landscape has been questioned with findings of a large number of Palaeolithic sites (Korisettar, 1994; Petraglia, 1998).

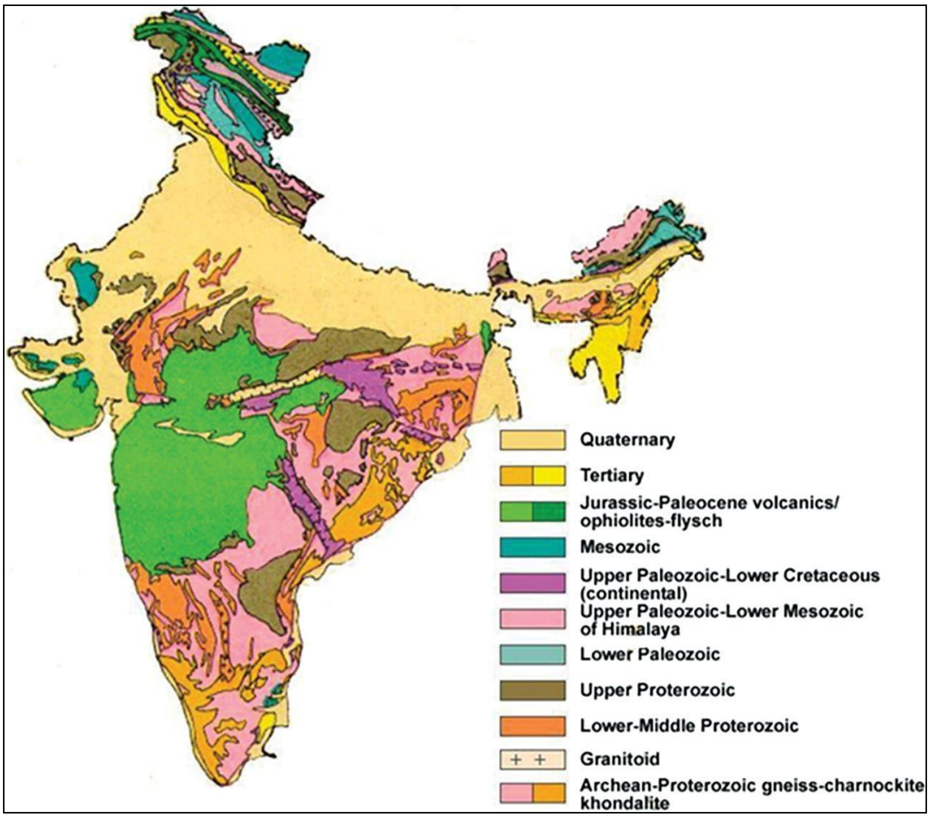


Figure 1. 3 Geology of the Indian sub-continent (https://mines.gov.in/writereaddata).

Often the Palaeolithic sites are found correlated with the type of the bed rock. The low density of Palaeolithic sites at some areas have been attributed to the weathering of the basalt tools, exposed on the surface (Mishra, 1982).

The sedimentation in Peninsular India has been minimal, owing to the Deccan Trap eruption around 60 Myr, and the Quaternary sedimentation is limited to narrow belts close to the present perennial rivers (Mishra, 2007). Laterite forms a component of the lithounits in many places and a larger amount of Tertiary regolith was present in the Lower Palaeolithic times (Mishra, 2007).

1.1.1.5 Vegetation and Climate

The environmental conditions in India are largely shaped by the weather system of the monsoon rainfall. It plays a huge role in the extreme seasonality of the climate in the Indian sub-continent, resulting in the differential aridity in regions and contributing to the river discharge variability. The diverse vegetation encountered, as a result, is reflected in the Sahyadris with the semi-evergreen forests, Vidarbha and Chhattisgarh with dry or wet deciduous vegetation, and the inland plateaus with scrub jungle (Paddayya, 2015).

Notwithstanding the changes in the Quaternary climate, hominin presence seems to have been of a continuous nature, as evidenced by the long sequence of Palaeolithic occupation (Mishra, 2007). Forming one of the largest areas of tropical grasslands in the world, the Indian sub-continent would have been a favourable location for human settlements.

The absence of Palaeolithic evidence in certain pockets of India has been attributed to the presence of dense forests, hilly terrain, heavy rainfall, and harsh climatic conditions (Misra, 2001). However, increasing evidence from the North-east India (Hazarika, 2012), has highlighted the possibilities of survey bias, and the use of perishable raw materials—as attested by evidence of fossil wood Palaeolithic artefacts from the North-east of India—as possible reasons for this lacuna. This is often attributed to lack of suitable raw material also (like in Kerala).

Quaternary studies integrating geological, climatological and Palaeolithic studies finds its roots to the first discoveries of the stone tools by Robert Bruce Foote, who made a graphical description of their geological contexts and inferred the possible age and climatic conditions (Korisettar and Rajaguru, 1998). Several phases of research over the years saw interchanging interpretations, mainly based on the correlation with European Alpine glacial, inter-glacial and East-African pluvial, inter-pluvial contexts (Korisettar and Rajaguru, 1998).

Renewed regional investigations coupled with new dating methods have resulted in a better understanding of the Quaternary environments, largely influenced by the varying intensity of the monsoons, especially the South-west monsoon in the Peninsular region.

Multidisciplinary research has indicated the presence of tropical evergreen and savanna ecosystems with riverine gallery forests during the Palaeolithic period (Korisettar and Rajguru, 1998).

Overall similarity of geomorphic processes in all regions has been attested through various regional studies although the influence of the fluctuating monsoon has resulted in regional specificities which cannot be correlated at a global level.

1.1.1.6 Water Resources

Monsoons, the major contributor of rainfalls, has had a significant say in the hominin occupation of these areas; either being a detrimental or beneficial factor in landscape formations. The main south-west and north-east monsoons, often unpredictable and erratic has had a huge impact in the inland areas, often resulting in drought. This similarity in climatic and ecological (grassland) nature can be compared to East Africa (Petraglia, 1998), with huge implications for understanding the hominin occupation in this part of the world. Besides the monsoons, major sources of water in the area are the number of rivers and their tributaries. Originating from both fluvio-lacustrine formations, these are mainly west-flowing (Narmada and Tapi) and east-flowing (Mahanadi, Godavari, Krishna, and Kaveri) in nature (Paddayya, 2015).

It was earlier believed that most Palaeolithic sites could be located along the palaeo channels only. However, renewed regional studies have proven that even the inland basin areas like Malaprabha Basin in the Kaladgi Basin, sustained a continuous presence of hominins, who were able to take advantage of the several natural springs and lakes that sustained the water tables perennially (Petraglia et al., 2003b).

Despite the huge diversity of the landscapes in the Indian sub-continent, from low and middle hill ranges to the plateaux and the river plains, the highly dispersed presence of Palaeolithic evidence attests to human-land adaptability. Physical barriers notwithstanding, hominins were highly mobile across the landscape, probably influenced by the movement of game and availability of water and raw materials. While the plains offered food resources in plenty, the plateaux would have given them an easily navigable visual landscape. The physical boundaries that could slow down or prevent a movement of hominins, are absent.

1.1.2 A brief review of Palaeolithic research in the Indian sub-continent with special reference to Peninsular India

1.1.2.1 Robert Bruce Foote – The Father of Indian Prehistory

The roots of Palaeolithic research in the Indian sub-continent were laid down by the Antiquarian interests of the British colonisers in the 16th century. Several discoveries that established the antiquity of mankind in Europe found its influence in India, where the first discovery of a Palaeolithic tool was made in Peninsular India (Figure 1.4). This momentous discovery was made by Robert Bruce Foote, a geologist in Geological Survey of India, who discovered a handaxe from the lateritic gravel bed, from Pallavaram near Madras (now Chennai) in 1863 (Paddayya and Deo, 2017).

Figure 1. 4 The first Palaeolithic findings from Tamil Nadu reported by R.B. Foote (source: R. Ravindran, www.thehindu.com/2013/CHENNAI).

He followed up his discovery with many extensive surveys across Peninsular India resulting in the discovery of numerous sites (around 459) ranging from Palaeolithic (42 sites) to Iron Age cultural phases (Foote, 1916). It was to his credit that he tried to find a stratigraphic, chronological, and climatic context for all the sites right from his first discovery. His very detailed and complete publication (1916) inspired other scholars to follow up with more vigorous surveys, ultimately leading to discovery of many new sites and systematic excavations of some of them. Mapping of the rocks and minerals used as raw materials by the early humans has also been carried out by the end of the nineteenth century (Chakrabarti, 2000).

1.1.2.2 Pre-Independence era (pre-1947)

In the 1930's there was a new phase, wherein, environmental and geochronological factors of the sites began to be seriously considered to attempt a holistic understanding of the past. Some of the notable contributions in this regard include that of L.A. Cammaide and M.C. Burkitt in South East India (1930), de Terra and T.T. Paterson in 1939 in North India, and Todd (1939) in Bombay (now Mumbai). The Archaeological Survey of India (ASI) established in 1861 and the Geological Survey of India (GSI), besides the many University departments, were the main contributors to the many surveys and discoveries during this phase (Dennell, 2000-2001).

1.1.2.3 Post-independence era (post-1947)

Post-independence, prehistoric research in the Indian sub-continent saw a renewed focus on regional surveys and excavations which led to discovery of a large number of Palaeolithic and Mesolithic sites in diverse ecological settings (Misra, 2001; Korisettar, 2002; Paddayya, 2002-2003). In the search of early Hominin remains, the finding of Hathnora fossil from Narmada Basin marked a landmark discovery (Kennedy and Chiment, 1991). Chronometric dating began to be increasingly applied during this phase. Palaeolithic research moved beyond searching for and documenting tools, to their analysis and interpretation in terms of climate and landscape adaptations by early hominins. Settlement pattern studies was introduced through their applications in the Hunsgi-Baichbal Valley in Peninsular India (Paddayya, 1982a).

1.1.2.4 Recent Trends

Regional studies continue to be a focus with multidisciplinary contributions. From an initial focus on descriptive typology of Palaeolithic tools, an increased focus on a multi-disciplinary integrated approach (Kashyap, 2005) is observed. Aspects of reduction processes in the tool making, from quarry to discard, site formation processes, experimental tool making, petrofabric analysis (of the Isampur limestone beds) from sites like Isampur, Attirampakkam, Lakhmapur, are a few examples (Paddayya et al., 2001, 2006; Petraglia et al., 1999, 2003a, 2005; Shipton et al., 2009). Use-wear analysis has been initiated (Chaturvedi, 1992; Pal, 2002) but largely limited for the Mesolithic period.

Along with new lithic approaches of Indian material, many new trends in the Indian Palaeolithic research must be highlighted, as they offer a more precise understanding of those epochs, despite, as we will see, the scarcity of data. Site formation processes, raw material acquisition, landscape archaeology, Ethno-archaeology, all form an integral part of the recent trends (Jhaldiyal, 1997; Koshy, 2009). At Attirampakkam, site formation processes, Ethno-archaeology, lithic techno-typology, geomorphology, and palaeo-environments (clay minerology, isotope studies, rock magnetics), Palaeontology, Palaeobotany, Micropalaeontology, Palaeomagnetic dating, Cosmogenic Nuclide dating, Luminescence dating, and Electron Spin Resonance dating are applied. Remote sensing has also been utilised (Pappu et al., 2011a).

The search for Palaeolithic has shifted, with scholars focusing mainly on inland areas, unlike the earlier spotlight on alluvial deposits. It has already resulted in identification of several Palaeolithic site complexes (Figure 1.5).

Newer chronometric dating methods as the Cosmogenic Nuclide dating for Attirampakkam are, more than rewriting, putting chapters of Indian prehistory long known into order, into chronology. The presence of dates is, as we will see in our study, extremely precious to recontextualize undated material.

Indian scholars are, for several years now, revising many earlier concepts and theories like the presence of Mode 1 or the Soanian tradition. This work—building solid conceptual basis—is essential to build a correct framework on which new and old research can find its place. As we are going to see, such a work is needed as the use of European or African concepts applied to Indian findings has several problems as well as limiting our understanding of the regional specificities.

Application of adaptation of terminology for tool categories like Large Cutting Tools, Large Flake Acheulean, increased multidisciplinary approaches to have a holistic understanding, newer methodologies in the field and laboratory etc. (e.g., of experimental and use wear), use of GIS and focus on hominin dispersals, Palaeolithic transitions etc. are new.

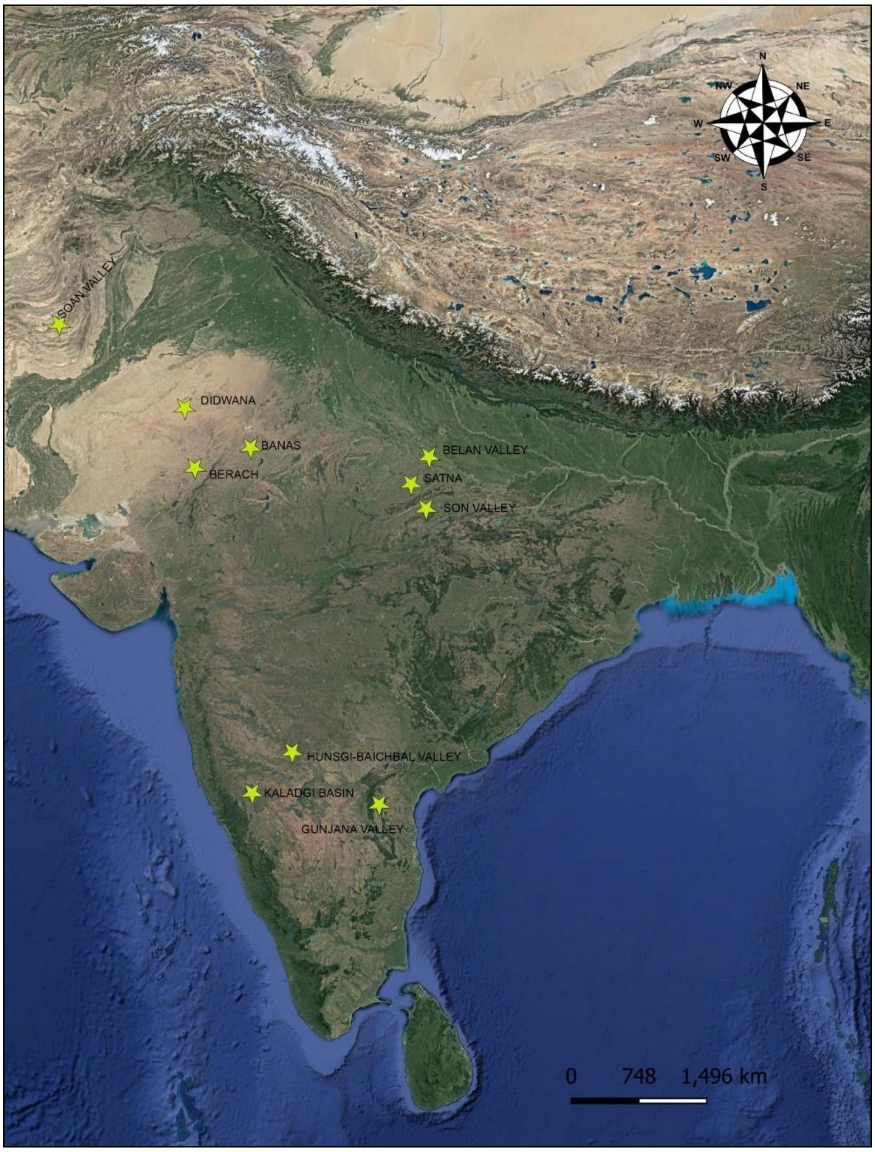


Figure 1. 5 Map showing the location of different Palaeolithic complexes in the Indian sub-continent (base map: https//www.google.com/intl/es/earth).

Still, some important researches need to be carried, especially in the reconstruction of paleo-environments. However, each new discovery helps place the Indian sub-continent on the map of World Prehistory and increases the scope of understanding its position in key concepts of hominin dispersals, adaptation, and cognition.

1.2 Terminology issues in Palaeolithic research

1.2.1 Prehistoric divisions

Following the European and African systems of classifications, the Palaeolithic research in Indian sub-continent followed different terminologies at different times.

At first, following their use by R. B. Foote, the Three Age classification system of Palaeolithic, Neolithic and Iron Age cultural phases was followed for the cultural findings in India. The systematic division of Palaeolithic sites in India initially followed that of European system of terminologies of L.A. Cammaide and M.C. Burkitt, (1930) where Lower Palaeolithic was termed Series I, Middle Palaeolithic was termed Series II, and Upper Palaeolithic was Series III (Allchin, 1963; Misra and Mate, 1964). Mesolithic cultural phase was called Series IV.

Later, based on the affinities to southern African findings, where Goodwin and Lowe adopted the terms of Early, Middle and Late Stone Age, under the proposition of Subbarao in 1956, the International Congress of Asian Archaeology in New Delhi reviewed and adopted this terminology (Korisettar, 2004). However, the European terminologies of Lower, Middle and Upper Palaeolithic continued to be in use by some scholars (Sankalia, 1974).

Nomenclatures for the Palaeolithic cultural phases kept being modified and refined for a long time according to changes in the inferred affinities in tool typologies with that of Europe and Africa. Currently the European nomenclature is adopted (Mishra, 1962; 2008).

Lately, many earlier terminologies and concepts have been revised with new investigations. For example, the Soanian tradition previously considered to be pre-Acheulean in nature is now considered as part of the Middle Palaeolithic cultural phase (Chauhan, 2010; Gaillard and Mishra, 2001; Lycett, 2007b).

Another example is to be found with the term Upper Palaeolithic, used in most of literature, that has been replaced with Late Palaeolithic for the Indian sub-continent (James and Petraglia, 2005).

At present, the terms Lower Palaeolithic, Acheulean, Middle Palaeolithic and Late Palaeolithic are in use.

As seen from the above summary, the different terminologies adapted through time were largely based on the tool type affinities with the European and African Palaeolithic record. Such approaches have highlighted the issues of extrapolating European and African terms which often result in overlooking the local regional specificities. However, within the Indian sub-continent too, the use of terms like Soanian, Nevasian, Madrasian, Mahadevian etc. to denote separate traditions have also proved problematic.

In this study, terms of Lower Palaeolithic, Middle Palaeolithic, Acheulean are used.

1.3 Lower and Middle Palaeolithic phases in the Indian sub-continent with special reference to southern Peninsular India

1.3.1 Lower Palaeolithic – Traditions of "Soanian" and Handaxe/Acheulean lithic production

1.3.1.1 Soanian

Lower Palaeolithic cultural phase was initially classified into two traditions – 'Soanian' tradition of the north-west India and adjoining Pakistan and the 'Madrasian' Handaxe tradition (Paddayya and Deo, 2017) of the Peninsular region. This was established with the findings of de Terra and Patterson's Yale-Cambridge expedition at Soan Valley in the Potwar region in 1930's (1939). The Soanian tradition was classified as an essentially core tool tradition with a preponderance of unifacial chopper tools made from pebble/cobble and a few simple bifaces along with flake tools. Based on the refinement, patination and associated terraces, the Soanian was divided into pre, early, late and evolved phases (de Terra and Paterson, 1939; Petraglia, 1998) and was found to be devoid of classical Acheulean type of tools like the handaxe or cleavers at many sites (Gaillard, 1996).

Although Soanian evidence was considered as Mode 1 and typo-technologically identified with the Oldowan cultures, a renewed study later found that it was not on secure stratigraphic context (Dennell and Rendell, 1991).

However, evidence corresponding to the occurrence of Soanian industries or Oldowan-like industries come from well-dated contexts of Pabbi Hills, Riwat and Masol (Rendell and Dennell, 1985; Dennell, 2004) (Figure 1.6). Although some sites were later identified to be of the same nature as that of the "Soanian" like the "Mahadevian" of the Durkadi site (Khatri, 1962), it is no longer accepted as a separate tradition of the Lower Palaeolithic and instead is believed to have more of Middle Palaeolithic affinities (Chauhan, 2010; Mishra, 2008) at least for the Late Soan, while the so-called Early Soan, may correspond to the Hoabinhian of South-east Asia (Gaillard et al., 2011). Again, only with accurate dating and stratigraphy can the questions of its cultural affinities be addressed.

Proper dating is needed to properly place this tradition / cultural phase, as its antiquity can only be assessed relatively to other traditions.

1.3.1.2 Acheulean

The Acheulean phase, earlier named the "Madrasian Handaxe tradition" (after its type site in Madras), is the better-known phase of Lower Palaeolithic in India. Except for the southern Tamil Nadu region and Kerala, which are yet to reveal credible evidence, all other parts of the Peninsula, especially the southern parts—Karnataka, Andhra Pradesh, Telangana and Tamil Nadu—have rich evidence. The main tool types are handaxes, cleavers, picks, flake tools, choppers, polyhedrons and spheroids. Hard hammer and soft hammer techniques, with Discoidal, Kombewa and (possible) Levallois methods, are the main characteristics attested in the Acheulean assemblages. The use of various raw materials like quartzite, basalt, siliceous limestone (among others) is attested.

1.3.1.2.1 Early Acheulean

Based on tool preservation and techno-typological features, tool type frequencies, and knapping techniques, temporal trends classifying the Acheulean into Early and Late phases of Acheulean have been suggested (Misra, 1979, 1987; Paddayya, 1985; Joshi and Marathe, 1985; Gaillard et al., 1986; Mishra, 2007; Paddayya, 2007; Shipton et al., 2009; Shipton, 2013).

Early Acheulean handaxes are defined as large and thick tools, often asymmetrical, made on cores, with massive butts and irregular thick cross sections having large, bold and irregular flake scars, indicative of hard hammer use (Joshi and Marathe, 1985; Misra, 1987; Petraglia, 1998; Chauhan, 2009). A higher proportion of handaxes to cleavers and a marked absence of Levallois method were other features (Misra, 1987; Petraglia, 2006). The presence of Levallois method in Indian context, reported from later periods, remains moot. Early Acheulean sites are generally found to be in fluvial deposit contexts "with the best sites sealed within silty or clayey sediments" (Mishra, 2008).

1.3.1.2.2 Late Acheulean

Late Acheulean handaxes, predominantly made on flakes, are characterised as more refined, smaller, thinner, more symmetrical, with secondary retouch and having higher flake scar densities (Shipton, 2013). Levallois and Discoid core techniques and a higher proportion of cleavers are some of the identified characteristics of the assemblages from this phase (Misra, 1987; Chauhan, 2009; Petraglia, 1998, 2006; Shipton et al., 2014). “The Late Acheulian is found typically in the areas of quartzite bedrock in colluvial rubble deposits away from the streams […] and although the density of tools is lesser there are more sites” (Mishra, 2008:21).

Some of the important Early Acheulean sites are Attirampakkam, Isampur, Morgaon, Chirki-Nevasa, Bori, Lalitpur, Singi Talav, Anagwadi, Hunsgi, and Yediyapur while that of Late Acheulean include Teggihalli II, Mudnur X, Bhimbetka III F-23 and Patpara.

Although these stages have been identified on techno-typological grounds, stratigraphic profiles reflecting the same are yet to be identified.

1.3.2 Middle Palaeolithic Phase

The Middle Palaeolithic cultural and especially technical phase in India is defined by the increasing shift to flake tools (scrapers, points etc.) on crypto-crystalline raw materials (like chert, jasper, chalcedony) and application of Discoidal and Levallois prepared core techniques. The presence of diminutive handaxes and cleavers have also been attested in many sites (Petraglia et al., 2003a; Petraglia, 2006, Haslam et al., 2011, 2012b) perhaps indicative of “…overlapping with and perhaps developing out of the South Asian Late Acheulean industry” (Mishra, 1995). This feature of diminutive handaxes and cleavers survived until a late phase of the Middle Palaeolithic, around 60 kya in some parts of India (Chauhan, 2016). Important sites from Peninsular India are Attirampakkam, Dhom dam, Mula dam and Jwalapuram (Clarkson et al., 2009; Haslam et al., 2012a; Paddayya and Deo, 2017; Akhilesh et al., 2018).

1.4 Palaeo-environmental settings

1.4.1 Floral evidence

As Premathilake et al. have noted (2017:479), "the palaeoecological context of hominin occupation in South Asia during the early and middle Pleistocene is virtually unknown".

Evidence of fossil flora appear in the form of carbonised log pieces of *Terminalia arjuna*, recovered from the river sediments at Deccan and indirectly from the presence of pitted pegmatite specimens, probably used for plant food processing (Paddayya and Deo, 2017).

Floral data being scarce, other information allowing an idea on palaeoecological contexts do exist, even if, they too, often, lack proper dating.

1.4.2 Faunal evidence

Palaeolithic fossil fauna associated with lithic assemblages are dated from the Lower Pleistocene to the Late Pleistocene in the Indian subcontinent. As early as 1930's, de Terra and Paterson (1939) had discovered fossil fauna along with *in situ* lithics in Central India (Singh, 2018). Although the Lower Pleistocene faunal evidence has come from the Siwalik formations of Punjab and Himachal Pradesh and the Karewa beds of Kashmir (Paddayya and Deo, 2017), most of the faunal evidence are associated with the Middle and Late Pleistocene (Badam, 2002).

Central Narmada Valley has been particularly rich in the findings of Middle Pleistocene mammalian fossils like *Elephas, Equus, Sus, Hexaprotodon, Stegadon, Bos,* Hippopotamus and *Bubalus* species (Sankhyan, 1997; Chauhan, 2008; Patnaik et al., 2009). The fossil fauna here, associated with hominin fossils and Acheulean artefacts, indicate wooded grasslands and shallow and permanent lakes and pools, indicated by the Ostracods analysis (Patnaik, 2000). One of the bovid pieces found near the hominin cranium has indicated an age of 236 Ka (Cameron et al., 2004; Dennell, 2009).

A late Pleistocene fossil assemblage consisting of bovids, Rhinoceros, *Equus* and *Canis* species along with *Zootecus insularis* shells, terrestrial tortoise (*Geochelone sp.*), and a soft-shelled aquatic turtle (*Nilssonia sp.*) have been recovered from an undisturbed open-air site near Gopnath in western India representing an important evidence of glacial stage coastal oasis (Costa, 2017). This has been correlated with the Late Acheulean lithics from a coastal cliff locality (<8 km) at Madhuban.

The only direct evidence of hominin-faunal relations has come from the Middle Palaeolithic site of Kalpi (dated to 45 ka) in the Ganga Plains. Here, bone tools along with evidence of cut-marks on bones have been reported in association with lithic tools (Tewari et al, 2002).

From the Peninsular India, the Lower Palaeolithic sites (Chirki, Hunsgi and Baichbal Valleys, Kortallayar Valley) have provided dental and cranial remains of *Bos*, *Equus*, *Elephas* and other species (Paddayya, 1989; Paddayya and Petraglia,1995; Paddayya and Deo, 2017). A rich faunal presence has been attested in the semi-arid tracts of Peninsular until the Late Pleistocene from studies of molluscan and mammalian remains from Deccan and Kurnool caves (Paddayya and Deo, 2017). Exploitation of small game like turtle and snails (both land and freshwater) have been indicated by their direct presence at sites of Isampur and Jwalapuram and ethnographic studies (Paddayya and Deo, 2017).

Although of valuable nature in reconstructing palaeo-landscapes and environment, the absence of direct evidence for subsistence strategies (e.g., cut-marks), absolute dating, their secondary contexts as well as the ambiguous phylogenetic relationships between extinct and extant species presents a limiting factor (Chauhan, 2008).

Palaeo-monsoonal and semi-arid landscape with a model of dry season aggregation and wet season dispersal has been hypothesised (Paddayya, 1982b).

1.5 Associated cultural evidence

Structural remains from the Palaeolithic period are rarely encountered except at sites like Lazaret and Kostenki 11 (de Lumley, 1969; Pryor et al., 2020). In India too, they remain largely absent except for some indirect evidences. Some exceptions are possible stone alignments at Paisra (Pant and Jayaswal, 1991), stone alignments at Bhimbetka (Misra, 1987) and at Hunsgi (Paddayya, 2007). Early Acheulean level (Layer 4) at Singi Talav has yielded six complete, unmodified manuports of quartz crystals (d’Errico et al., 1989; Gaillard et al., 1983). Similarly, from the Acheulean layer at Hunsgi, 20 exotic haematite pebbles, including one with striations have been identified. From this site, a cache of tools has also been recovered (Paddayya, 1987). From the Middle Palaeolithic Attirampakkam, manuports of a tool on silicified wood and an unmodified quartz crystal have been reported (Akhilesh et al., 2018).

Unfortunately, no traces of fire have been found. Burnt tools are yet to be found (which could help to also date those sites) which indicate a possible absence of use of fire in improving the knapping qualities of stones. Organic tools from the Palaeolithic are found in Kalpi.

1.6 Chronology

Dating of most of the Lower and Middle Palaeolithic sites has relied on relative chronology based on stratigraphy or in cases of surface finds, based on index tool types (Petraglia, 1998). Absence of index fossil fauna for Pleistocene classification, inaccurate and limited correlation of absolute dates with Fluorine/Phosphate ratios on bone and fossils, lack of secure chronological controls on alluvial deposits with associated artefacts are some of the problems that have been related to the limitations of the relative chronology used in India (Petraglia, 1998). Wherever, absolute dating has been possible, the methods of Thermoluminescence and Uranium Thorium (Th/U) have been utilised, then also optically stimulated luminescence (OSL); electron spin resonance (ESR), cosmogenic Al/Be, post-infrared infrared-stimulated luminescence (pIR-IRSL). They indicate a Middle to Late Pleistocene age for the Acheulean in India, similar to the African Acheulean sites (Paddayya et al., 2002; Mishra, 2008; Pappu et al., 2011b; Akhilesh et al., 2018) (Figure 1.6).

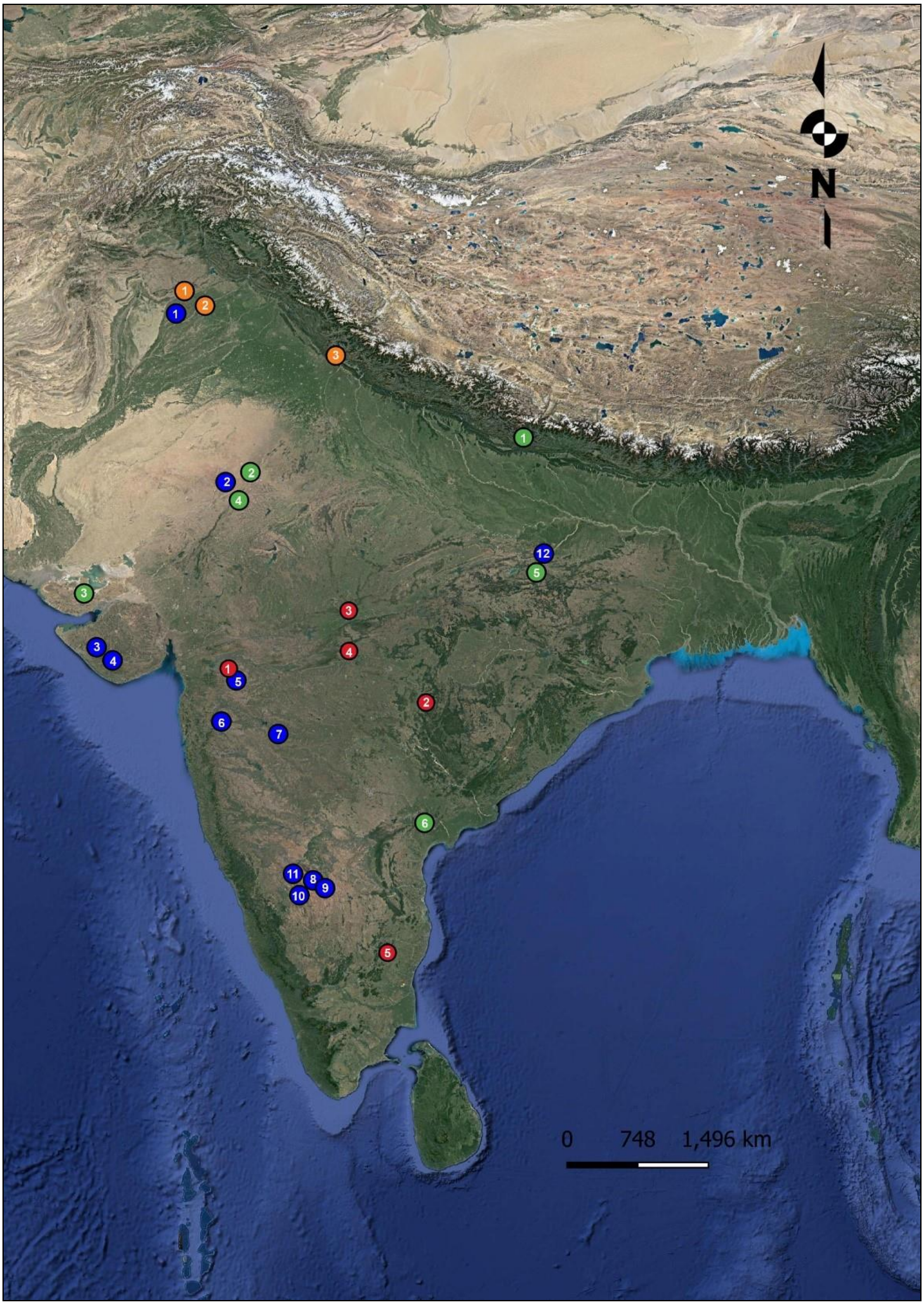


Figure 1. 6 Map of dated sites with Lower Palaeolithic – Oldowan-like (orange dots), Acheulean (blue dots), Middle Palaeolithic (green dots), and multi-cultural (red dots) industries from the Indian sub-continent (Pakistan, India, Nepal and Sri Lanka). Modified after Chauhan, 2020. (base map: https://www.google.com/intl/es/earth/). Details of site names and chronology given in Tables 1.1-1.4.

Sites with pre-Acheulean (Oldowan like) industry	Absolute Date
Pabbi Hills[1]	2.2-0.9 Ma
Riwat[2]	2 Ma
Masol[3]	2.6 Ma?

Table 1. 1 Dated pre-Acheulean Oldowan-like industry sites in the Indian sub-continent; Ma (Million years ago). Modified after Paddayya and Deo, 2017 and Chauhan, 2020. Numbers 1-3 indicate their location (orange dots) in Figure 1. 6.

Lower Palaeolithic sites	Absolute Date
Dina and Jalalpur[1]	~700-400 ka
Singhi Talav[2]	~800 ka?
Adi Chadi Wao[3]	~69 ka (MP?)
Umrethi[4]	>190 ka
Bori[5]	Multiple Ages - 670 ka, 538 ka
Morgaon[6]	>780 ka?
Chirki-Nevasa[7]	>350 ka

Table 1. 2 Dated Lower Palaeolithic (Acheulean) sites in the Indian sub-continent; MP (Middle Palaeolithic), ka (Kilo years ago). Modified after Paddayya and Deo, 2017 and Chauhan, 2020. Numbers 1-7 indicate their location (blue dots) in Figure 1. 6.

Middle Palaeolithic sites	Absolute Date
Arjun 3[1]	>30 ka?
Kataoti[2]	95 ka
Sandhav[3]	114 ka
Kalpi[4]	45 ka
Dhaba[5]	79-65 ka

Table 1. 3 Dated Middle Palaeolithic sites in the Indian sub-continent. Modified after Paddayya and Deo, 2017 and Chauhan, 2020. Numbers 1-5 indicate their location (green dots) in Figure 1.6.

Multicultural sites	Absolute Date
Patne[1]	30 ka
Durkadi[2]	<100 ka
Bhimbetka[3]	>106 ka (MP?)
Hathnora[4]	>48 ka and >93 ka
Attirampakkam[5]	1.5 Ma (EA), 385-73 ka (MP)

Table 1. 4 Dated multi-cultural Palaeolithic sites in the Indian sub-continent; EA (Early Acheulean), ka (Kilo years ago), MP (Middle Palaeolithic) and Ma (Million years ago). Modified after Paddayya and Deo, 2017 and Chauhan, 2020. Numbers 1-5 indicate their location (red dots) in Figure 1.6.

1.6.1 Lower Palaeolithic

Lower Palaeolithic sites (Figure 1.6) have thus been dated to Middle to Late Pleistocene. Many of the previously dated Lower Palaeolithic sites have relied on U/Th dating methods. which remain single determinations and perhaps indicate minimum ages that undermine the actual dates (Dennell, 2009). However, increasing application of new radiometric dating techniques in recent years have brought more precision and clarity to the age of the sites pushing the potential age of the Lower Palaeolithic further back in the Pleistocene. At Isampur, a preliminary Electron Spin Resonance (ESR) date on two fossilised bovid teeth enamel indicates an age of > 1.2 Ma (Table 1.5) (Paddayya et al., 2002) on the south-west coast of Peninsular India. The oldest yet known chronometric date for Acheulean come from the south-east coast site of Attirampakkam, where for the first time in India, Cosmogenic Nuclide dating gave a mean age of 1.51 Ma (Table 1.5) (Pappu et al., 2011b). These dates thus show that Acheulean survived the longest in terms of chronology, approximately 1.5 million years (Shipton, 2013). Some younger dates come from the extra peninsular India, from the sites in Son Valley, with 140-131 kyr Optically Stimulated Luminescence (OSL) dates (Haslam et al., 2011).

No.	Site and Location	Sample dated	Method employed	Age
1.	Yedurwadi, Karnataka	Calcrete (associated with Acheulean assemblage)	Thorium-Uranium	>350 ka
2.	Kaldevanhalli	Travertine (associated with overlying Acheulean assemblage)	Thorium-Uranium	170 ka
3.	Sadab, Baichbal Valley, Karnataka	*Elephas* molar (associated with Acheulean assemblage)	Thorium-Uranium	290 ka
4.	Teggihallo, Baichbal Valley, Karnataka	*Bos* molar, *Elephas* molar (associated with Acheulean assemblage)	Thorium-Uranium Thorium-Uranium	287 ka >350 ka
5.	Isampur, Hunsgi Valley, Karnataka	Tooth enamel of *Bos sp.*	Electron Spin Resonance	1.27 Ma
6.	Attirampakkam, Kortallayar Valley	Buried stones	Palaeomagnetism and the Cosmo-Nuclide (^{26} A1 and ^{10}Be) direct method	1.51 Ma

Table 1. 5 Lower Palaeolithic sites with absolute chronology, sample, method and date, southern Peninsular India; Ma (Million years ago), ka (Kilo years ago). Modified after Paddayya and Deo, 2017 and Chauhan, 2020.

1.6.2 Middle Palaeolithic

Middle Palaeolithic sites (Figure 1.6) in India has been dated to >74 ka at Jwalapuram Locality 3, in Andhra Pradesh with volcanic Toba Ash correlated with YTT (Table 1.6) (Petraglia et al., 2012). Other sites from Peninsular India with Radio-Carbon dates on wood are Dhom dam and Mula dam from Maharashtra, with dates of 37 ka and 31 ka respectively (Paddayya and Deo, 2017). At the site of Attirampakkam, Luminescence dating has placed the emergence of the Middle Palaeolithic at 385 ± 64 ka (Akhilesh et al., 2018).

No.	Site and Location	Sample dated	Method employed	Age
1.	Locality 3 at Jwalapuram, Kurnool, Andhra Pradesh	Volcanic ash	Correlated with YTT	77-38 ka
2.	Attirampakkam, Kortallayar Valley	Sedimentary deposits (associated with Middle Palaeolithic assemblages)	OSL	385-73 ka

Table 1. 6 Middle Palaeolithic sites with absolute chronology, sample, method and date, southern Peninsular India; YTT (Youngest Toba Tuff), ka (Kilo years ago), OSL (Optimally Stimulated Luminescence). Modified after Paddayya and Deo, 2017 and Chauhan, 2020).

1.7 Hominin Tool makers

Although there are many Palaeolithic sites with rich lithic assemblages, the evidence for their makers remains meagre and fragmentary. The finding of a hominin fossil from Hathnora, Central Narmada Valley, by Arun Sonakia (1984) of the Geological Survey of India in 1982, was the first discovery of a pre-*Homo sapiens* specimen from India. The fossil was that of a partial cranial vault, found embedded in a 3 m thick gravel conglomerate and was found associated with vertebrate fossils consisting of proboscideans and bovids and a few late Acheulean tool (Patnaik and Chauhan, 2009; Paddayya and Deo, 2017; Korisettar, 2017b). Although initially thought to belong to a male *Homo* erectus, later re-examination (Badam et al., 1986) indicate it to be a female archaic *Homo* sapiens specimen.

Another specimen was discovered during 1983-92 from a nearby location. This consisted of rib fragments and clavicle (Korisettar, 2017; Paddayya and Deo, 2017).

Another hominin fossil discovered in 2001 from Peninsular India is that of the Middle Pleistocene “Laterite baby” (Rajendran et al., 2006). Discovered from Odai, Villupuram District in Tamil Nadu, the specimen is that of a baby skull within a ferricrete matrix underlying aeolian and intermittent fluvial gravel and sand deposits (Rajendran et al., 2003). Subjected to Magnetic Resonance Imaging (MRI), CT scanning, 2D and 3D imaging, this specimen was assigned the date of the enclosing ferricrete matrix (TL date of 166 ka) (Rajendran et al., 2006).

Jwalapuram (Locality 9), a Middle Palaeolithic Toba ash site, located in Kurnool area, dated to 74 Ka, has yielded human remains associated to modern humans in the form of isolated tooth (Clarkson et al., 2009).

1.8 Theoretical and Conceptual Framework

1.8.1 Question of Hominin dispersals – Fossil and Genetic record

The topic of hominin dispersals has remained a long-contentious one, especially on questions of their precise time frame, their nature, the triggers/catalysts, and their routes. Established and dated fossil records and archaeological finds have pointed to multiple waves of more than one hominin taxa from Africa during the Pleistocene (Bae et al., 2017a).

1.8.1.1 Out of Africa? – Early Pleistocene dispersals

Prat (2017), in a recent critical review of the tempo and mode of the first human expansions of Africa, contends that the very early dates for cutmarks from Masol in the Siwalik Range (north western India) around 2.6 Ma (Coppens, 2016; Dambricourt-Malassé et al., 2016) and technical activity at Longgupo (central south China) around 2.48 Ma (Han et al., 2016) in comparison with the 3.3 Ma Lomekwi record (Kenya) (Harmand et al., 2015), push the dispersal event more than 2 Ma earlier than previously thought. On the one hand, the results of this appraisal highlighted the exogenous and endogenous hypotheses for these dispersals along with the adaptive capacities of these dispersing early hominins. On the other hand, fossil and archaeological records show that factors of climatic change and increase in body and brain size, have proven to be non-relevant indicators in terms of hominin expansions. Redefining the nature of these dispersals, which were multidirectional and with ‘episodes of turning back’, the author proposes the terms “first settlements”, “Out of Africa” or “first dispersal”, in lieu of “Out of Africa 1” (Prat, 2017). This review also highlighted the role of Asia in the colonization of Europe during the Early and Middle Pleistocene (through the genetic studies of Martinón-Torres et al., 2007) and along with the evidence of initial anthropoid primate expansion from Eurasia to Africa presented by Chaimanee et al., (2012) leading to the proposition of an “Out of Asia” or “Into Africa” scenario (Prat, 2017).

1.8.1.2 Anatomically modern human (AMH) dispersals

The discovery of fossil remains, recently enriched with genetic studies and archaeological proxies, have contributed to our understanding of the various models and theories on hominin dispersals. Genetic studies, more especially, has refined theories and offered unexpected results.

Detailed reviews of the different dispersal models of the AMHs are given by Goder-Goldberger (2014) and Lopez et al. (2015) and the references therein. A summary of the various existing models and concepts on the AMH dispersals are given below (Table 1.7).

No.	Model	Summary
1.	Candelabra model	Originally proposed by Coon in 1962: modern humans evolved autonomously at multiple times in different regions. Proposes independent parallel evolution of AMH features. Discarded theory now.
2.	Assimilation Model	Genetic exchange between the anatomically modern humans (AMH) from Africa and indigenous Neanderthal populations in Europe and Levant played a key role in the modern human origins.
3.	Multiregional or the Continuity model	Proposed by Weidenreich in 1946: modern humans evolved from multiple hominin groups in multiple regions. Advocated significant gene flow in Pleistocene among subpopulations of *Homo erectus* in these regions.
4.	Replacement model or Recent African Origin	Proposed the recent evolution of AMH (55-200 ka) in Africa followed by their subsequent migrations and replacement of other extant hominin populations.
5.	Single dispersal model	AMH migrated out of Africa to the rest of Eurasia as a single wave exiting via a single route, whether North or South. The serial founder effect model is one possibility of this model.
6.	Multiple Dispersal Model or Biogeographic Model	First proposed by Lahr and Foley (1994): multiple waves of dispersals from East Africa through ecological dispersal corridors created by geographic and climatic constraints during the Middle Stone Age. While the initial dispersals occurred via the Southern route between 50-100 ka, the second migration happened via the Northern route between 40-50 ka.

Table 1. 7 Summary of the various existing models and important concepts (after Goder-Goldberger, 2014 and Lopez et al., 2015 and references therein).

An earlier and a later phase have been proposed for the Eurasian dispersals of anatomically modern humans from Africa. While the former would have happened around 100–130 ka, prior to the mega-eruption of Mount Toba (Northern Sumatra) dated to 74 ka, the latter took place around 50–60 ka, reaching Australia by 45–50 ka (Macaulay et al., 2005).

Presence of early modern humans in Japan, Korea, Vietnam, and China (Bae et al., 2018 and the references therein) lend support to the latter.

Recent migrations, pointing to a "back to Africa" scenario, have also been established through new research (López et al., 2015). Using a new approach—Progressive Phylogenetic Analysis (PPA)—Árnason and Hallström (2020) showed that Eurasia was not the receiver but the donor in the evolution of modern humans in Africa.

1.8.1.3 Catalysts for the dispersals

Environmental and climatic factors including geographical corridors have been recognised as major catalysts for hominin dispersals (Dennell, 2009, 2017; Boivin et al., 2013; Bae et al., 2017b). At the same time, regional extinctions arising because of major geological events have been implied. One of the examples includes the probable regional and global die offs or bottle necks of various faunas including hominins post-Toba super eruption (Ambrose, 1998). However, recent researches (Petraglia et al., 2007, 2012; Roberts et al., 2015) have shown that this may not be the case every time, citing examples of the continuous presence of hominins from pre-Toba to post-Toba deposits at the site of Jwalapuram, in southern Peninsular India.

Other scenarios suggest that local extinctions as well as reoccupation of the same sites by earlier or new populations occurred regularly, as the evidence from the complex site of Denisova reveals. Here, traces of both *Homo erectus* and Neanderthals remains along with symbolic modern human behaviour have been found (Bae et al., 2017a, 2017b) highlighting multiple possibilities.

1.8.1.4 Dispersal Routes

Two main routes have been proposed for the exodus from Africa. One is the "Northern route", through Egypt and Sinai Peninsula, along with the Strait of Gibraltar from Northern Africa, into Europe (Derricourt, 2005) and the second one is a "Southern coastal route", a shorter one, following the southern coasts (Horn of Africa to Bab-el-Mandeb Strait to Arabia and along the Indian Ocean coast) at around 60 ka (López et al., 2015).

The Northern route finds support in the early archaeological evidence (Dmanisi in Georgia dated to 1.77 Ma) along with climatic record and genetic studies, for Early Pleistocene dispersals, while the mtDNA (Ingman et al., 2000; Thomson et al., 2000) results has favoured the AMH dispersals.

1.8.1.5 Genetic and Fossil evidence from Asia

As mentioned above, the recent ESR/U-series dating of mammalian fossil teeth and the sedimentary layers with hominins and stone tools, to around 2.48 Ma from the site of Longgupo (China) attests the antiquity of hominins in Eastern Asia (Han et al., 2016). This evidence along with the Masol findings (2.6 Ma – Dambricourt-Malassé, 2016), although indirectly, have thrown new light on the earlier hominin dispersals from Africa towards Asia (Prat, 2017).

In Eastern Asia, Early Pleistocene *Homo erectus* sites are found to be mostly from Southern (e.g., Yuanmou) and Central China (e.g., Lantian-Gongwangling) while the Middle Pleistocene *Homo erectus* sites are generally from Northern China (e.g., Zhoukoudian Locality 1) (Zhu et al, 2008; Shen et al., 2009; Bae et al., 2018). The archaic modern hominin record (late Middle Pleistocene) is found to be more widespread and evidenced from sites like Zhoukoudian Locality 4 and the Southern Maba Shizishan Cave (Bae et al., 2018 and references therein).

A unique specimen that does not conform to the other finds, is from the site of Hexian (0.4 Ma) in Southern China, which raises the question of the presence of a previously unknown regional population of *Homo erectus* (Kaifu, 2017).

South-east Asia has revealed rich fossil records of *Homo erectus* from Java. Evidence from Early Pleistocene contexts of Sangiran, Mojokerto, and probably Trinil, represent the early phase of *Homo erectus* evolution in Java from ≥1.2 to 0.8 Ma while Late Middle and Late Pleistocene archaic AMHs of Java are represented by the fossils from Ngandong, Sambungmacan and Ngawi within the time range of 70–30 ka (Kaifu, 2017; Zeitoun et al., 2010).

In Taiwan an archaic Homo mandible was discovered in Penghu 1 (Chang et al., 2015). Considered as probably younger than 190 ka, this specimen, with its similarities to the Hexian specimen from China, has added to the implications of existence and persistence of unknown regional species of archaic Homo in this region (Chang et al., 2015; Kaifu, 2017).

A hominin fossil remains from the Denisova Cave, a reference site for the Middle and Upper Palaeolithic period, when subjected to genetic analysis, brought to light a previously unknown species, the Denisovans (Meyer et al., 2012). This population is considered to have diverged before the Neanderthals and the AMHs shared genes. The presence of Denisovan genes in different populations from the East, like the modern Melanesian, Chinese, etc., highlighted the vast area this species had occupied. It also established the presence of two forms of archaic hominins during the Late Pleistocene in the Eastern part of Eurasia, the Neanderthals and the Denisovans, who shared a common ancestry (Reich et al., 2010).

An earlier presence of Denisovans has been now posited in Eastern Asia through the findings of a late Middle Pleistocene Denisovan mandible from the Tibetan Plateau and the Denisovan-like molar teeth from Xujiayao (Chen et al., 2019; Ao et al., 2017). This is interesting for the understanding of the role of geographical entities like the Himalayan Mountains for the dispersals into Asia.

1.8.1.6 Ghost species

The DNA revolution has resulted in unravelling the presence of many more unknown species in the saga of hominin evolution and dispersals. Modern genome studies point to the presence of an extinct ghost population among the Western African and Central African hunter-gatherers (Gibbons, 2020). Another evidence comes from the genomic analysis of Andamanese population (Mondal et al., 2016, 2018) which identified the presence of a ghost DNA in this group of South Asian islanders, deriving from a single African origin. This ghost DNA is absent from Europeans and East Asians.

1.8.1.7 Specific island species

Echoing the ghost species of Andaman Islands, recent findings of *Homo floresiensis*, dated to ~60 ka, 0.7Ma (Brown et al., 2004; Van den Bergh et al., 2016) and *Homo luzonensis* (Détroit et al., 2019; Mijares et al., 2010) from Flores (Indonesia) and Luzon (Philippines) Islands respectively, have been significant in understanding the hominin evolution tree. Being among the most comparable with *Homo erectus* (Baab et al., 2013), these two evidences suggest the persistence of *Homo erectus* to a much recent time in these regions.

1.8.1.8 "…The trees are familiar, but the forest is not." (William Howells, 1976:477)

The above evidence suggests a complex scenario of the hominin dispersals during different waves of dispersals, with the possibilities of several of previously unknown species besides the ghost species. As to the origins of modern humans, although Africa has been long considered as the key candidate, recent studies also highlight the possibilities of Eurasia having played a major role. Today three key phases have been identified within the time frame of hominin dispersals: the first phase from 1 Ma to 300 ka with the separation of modern human ancestors from an archaic human group, the second phase from 300 ka to 60 ka with modern human diversity related to African origins and the third phase of 60 ka to 40 ka with the modern human expansion and last known contacts with archaic species of Neanderthals and Denisovans (Bergstrom et al., 2021). Considering all the current palaeo-anthropological and genomic records, this latest study also highlights that with the behavioural patterns attributed to *Homo sapiens* falling within broader evolutionary histories, no cultural specificities can be attributed to this modern humanity nor can we differentiate a specific time "at which modern human ancestry was confined to a limited birthplace" (Bergstrom et al., 2021: 229).

The above summarised current knowledge from fossil and genetic evidence is pertinent to contextualise India in this background.

1.8.1.9 Locating Indian sub-continent in the hominin dispersals debate – Very few hominin fossils

Located halfway between Africa in the west and Australia in the east, the Indian subcontinent occupies a strategic position, and helps link the Asian evidence with that of the West, to Levant, Europe, and Africa. This significance is only all the more highlighted in the background of well dated sites emerging from recent research (Pappu et al., 2011b; Paddayya et al., 2002).

However, unlike the other parts of the world where hominin fossils have laid strength to the different theories, the scenario in India is blurred. In the background of hundreds of sites with abundant lithic tools, their makers are largely absent. Only a few hominin fossils discoveries have been made (Sonakia, 1984; Rajendran et al., 2006) but they are riddled with their fragmented nature and lack of well-established confirmed affinities with any one species (as discussed in the previous section). The only clues to their earliest presence in India are their proxies: the lithic industries.

The presence of well dated pre-Acheulean tools from secondary deposits at Riwat (Denell et al., 1988), and the occurrence of cut marks on animal bones in Masol (both sites in the Siwalik Range) attests to the presence of early hominins (Dambricourt-Malassé et al. 2016), at least 2 Ma ago, in the north of South Asia. But, at the same time, their absence from secure stratigraphic Lower Palaeolithic sequences from the Indian Palaeolithic sites, raises the question of their movement southwards, towards Peninsular India.

In southern Peninsular India, the earliest tools appear at 1.51 Ma from Acheulean contexts at Attirampakkam near Chennai in Tamil Nadu (Pappu et al., 2011b). Although there are abundant sites throughout India and some of them are securely dated, their distribution pattern shows glaring gaps in parts of southern India (southern Tamil Nadu region and Kerala) and north-east India (Petraglia, 1998). This brings up the question whether Peninsular India was a corridor for dispersing hominins towards the east or a *cul-de-sac* like the Iberian Peninsula has been for Neanderthals (O'Regan, 2008). Adding to the debate is the continuous sequence of occupation at several sites from Palaeolithic to Historic times, attesting to the continuous presence of hominins in the centre and the south of the Peninsula (sites like Attirampakkam in Tamil Nadu, and Bhimbetka in Madhya Pradesh). South India has also been mentioned as a route of hominin dispersals in the beginning of Late Pleistocene (Field et al., 2007; Reyes-Centeno et al., 2014).

1.8.1.10 Genetic evidence

Genetic studies in South Asia although largely limited to modern DNA, show an admixture of non-African and Neanderthal in the modern populations, from the main Out of Africa event at 50 Ka (see review by Metspalu et al., 2018). As mentioned earlier, genomic analysis of Andamanese population suggests a single African origin of all Asian and Pacific populations and the presence of a ghost DNA, absent from Europeans and East Asians (Mondal et al., 2016, 2018). However, this was contested by Skoglund et al. (2018) whose analyses found the contrary. The genetic makeup of South Asians today comprises an admixture of ancestral northern populations (closer to the West Eurasian genetic variation) and the ancestral southern Indians, arising from the deep autochthonous genetic legacy, later joined by recent waves mostly from the West (Iranian agriculturalists, Steppe pastoralists (Metspalu et al., 2018).

1.8.1.11 Where does the Narmada fossil record fit?

The Narmada fossil (Sonakia, 1984), consisting of the partial cranium is the 'single unquestionable' archaic hominin fossil from southern Asia (Kaifu, 2017). Although assigned to different taxa (advanced *Homo erectus* and to a post-*erectus*) by different scholars (de

Lumley and Sonakia, 1985; Kennedy et al., 1991), generally it is agreed that it shows morphological similarities to other Middle Pleistocene Homo evidence from Africa, Europe and Asia. Although it has been hypothesized that late archaic Maba cranium and Narmada cranium have strong morphological similarities, this remains untested (Kaifu, 2017) and if proven true, their origins remain a question.

1.8.1.12 First peopling of hominins in South Asia

In the absence of comparable fossil record, the question of the first waves of hominins into the Indian sub-continent is largely dependent on the archaeological record. The earliest evidence, as mentioned above, comes from Riwat and Masol in the Siwalik Range, which points to the presence of early hominins between 2.6 and 2 Ma, but raises questions on their identity as well as continuation towards south. The earliest well-established dates for some sites in Peninsular India confirm their existence one million years later but whether they were a regional species of archaic *Homo* remains to be answered. Growing evidence from China and Taiwan (Chang et al., 2015; Kaifu, 2017), discovery of previously unknown species of Denisovans (Meyer et al., 2012), their early presence in China (Ao et al., 2017; Chen et al., 2019) and presence of a similar haplotype in high altitude Tibet (Huerta-Sánchez et al., 2014) besides the findings of ghost DNA in W. Africans (Gibbons, 2020) suggest that this scenario cannot be ruled out.

If we consider that *Homo erectus* was the key candidate, their origins, in the light of their presence further east: China (Bae et al., 2018), Indonesia (Kaifu et al., 2008), and their persistence till later times as evidenced further east by the findings of *Homo floresiensis* and *Homo luzonensis* (Van den Bergh et al., 2016; Détroit et al., 2019) should be addressed. Did they evolve locally into *Homo sapiens* or were they replaced by an outside arrival? If so, the timing and route of their arrival, besides the possibility of local extinctions and possible integrations need to be looked into. In short, the archaeological record points to the pre-modern hominin occupation of the Indian sub-continent, by archaic hominins (Neanderthals and/or Denisovans, late *Homo erectus* or related taxa) (Athreya, 2010).

1.8.1.13 Arrival of anatomically modern humans (AMH) in South Asia

In the Indian context, stone tool vestiges and genetic evidence from South Asian populations remain the major proxies for assessing the arrival of *Homo sapiens*. The dispersals of this new species were essentially a regionally diverse process. Modern humans were believed to have arrived after the Toba super eruption of 74 ka (beginning in the Marine Isotope Stage 4) but their initial dispersals from Africa cannot be temporally linked with their presence in India (Haslam et al., 2017). However, recent dating of Middle Palaeolithic sites in India and Arabia going back to more than 78 ka, have suggested the presence of modern humans in the Indian sub-continent in MI5, much earlier than thought (Korisettar, 2017). Mitochondrial DNA of South Asian tribes possess signatures as far back as 60-70ka with reflecting ongoing connections with South-east Asia (Athreya, 2017:168). Genetic reconstruction has further thrown light on a major occupation of *Homo sapiens* in India between 45 and 20 ka (Atkinson et al., 2008).

Three models, largely based on lithic traditions, are proposed for the arrival of modern humans into India; Middle Palaeolithic first model (Mellars, 2006; Mellars et al., 2013) Microlithic first Model (Macaulay, et al., 2005) and Indian Staged Dispersal model (Atkinson et al., 2008). While the first two are based on the appearance or the introduction of new traditions, Middle Palaeolithic and microlithic industries respectively, the third one proposes a later movement of AMHs into the Indian Peninsula (Haslam et al., 2017). Recent investigations have given dated evidence from Arabia and Indian sub-continent, favouring a long chronology and Northern routes for both the major hominin expansions (Korisettar, 2017). The Southern Dispersal model which had considered Arabia and India as gateways into Asia, had postulated the role of India as a *cul-de-sac*. However, the new approaches of 'Green Sahara' models, integrating palaeo-environmental and palaeo-hydrological evidence and findings of earlier occupations in Arabia (Groucutt et al., 2018) do not lend support to this.

The role of refugia or core habitats in the Indian sub-continent facilitating inland dispersals of hominins thus highlighting its role as a corridor, has been highlighted in the Basin Model theory (Korisettar 2007). This will be addressed further in relation to the study region.

1.8.1.14 India: Corridor to the East or a dead-end towards Sri Lanka?

As summarised above, the presence of early hominins in the Indian sub-continent is now unrefuted on archaeological basis but their anthropological origins remain unknown. In the southernmost area, in Sri Lanka, the earliest well established cultural and palaeontological evidence occurs much later than in mainland Indian Peninsula (Deraniyagala, 1984; Pereira et al., 2011). Centrally located in the inferred "southern route", this island and the Indian sub-continent were periodically linked by a land bridge which also facilitated faunal exchanges (Kulatilake, 2016 and references therein). Hominin occupation is attested in the Middle Palaeolithic by the flake industry suggesting the presence of either archaic humans (e.g., *Homo heidelbergensis*) or anatomically modern humans (*Homo sapiens*) in Sri Lanka c. 100,000 years ago (Kulatilake, 2016). The earliest well-established cultural occupations of the Mesolithic period are supported by the dating of modern human fossils from three key sites, Fa Hien-lena, Batadomba-lena and Belilena Kitulgala. These occupations occurred between 37 ka and 7 ka. Multiple waves of migrations from mainland South Asia are indicated by the linguistic, genetic, archaeological, and cultural evidence from Sri Lanka.

This raises the question of whether Indian Peninsula remained a dead-end at the time of the earlier hominins who persisted in this geographical entity. This question is pertinent in the background of presence of hominin fossils from the islands of Flores and Luzon, having closest similarity to *Homo erectus*. If Indian Peninsula was indeed a common route towards (and from) East Asia, when did it first occur? If it occurred only later, as evidenced by the later dates of cultural remains and Hominin fossils in Sri Lanka, what was the reason for this delayed dispersal?

Forming an important component of Palaeolithic archaeology, hominin dispersals are often perceived through the tool kits and cultural remains. Artefact assemblage variability is expected to answer questions on the transition-continuity or discontinuity of the technologies and typologies, the former indicating a local evolution of production by existing indigenous populations while the latter suggests an external introduction by incoming populations. This will be addressed in the coming sections.

1.8.2 Questions of Transitions – Can we characterise a Lower to Middle Palaeolithic phase in Peninsular India? What criteria can be used for such a characterisation?

1.8.2.1 New people, new technology?

Initially transitions implied linear progression, the change, gradual or sudden from simple to complex technologies. However, aspects of hominin adaptations to their varied environment including the raw material constraints (Brantingham and Kuhn, 2001), their skills and expertise, their subsistence strategies all need to be taken into account to understand the nature of these transitions, which, currently is largely limited to lithic technologies. Lithic technology is only a part of the economic, social and cultural systems and unless we understand them and the various interacting factors within, the real nature of the transitional processes cannot be addressed (Ménendez-Granda, 2009). Absence of chronometric dates, and primary well stratified evidences correlated with faunal and hominin remains, all restrict our understanding of the same. Use of a home base, change in the subsistence strategy from very large game to medium game, use of fire are some components that have been attributed as major catalysts for this transition (Chazan, 2009) but there is a paucity of such evidence in the archaeological data and using biological markers for identifying cultural innovations should be taken with caution.

Reliance on *fossile-directeurs* as markers of techno-complexes, problems of extrapolating terminologies that derived from general classification systems, leads to the risk of overlooking regional tendencies (Ménendez-Granda, 2009). The notion of transitions arose out of the classical compartmentalisation of cultural periods. This system has to be reassessed to see if its implementation has "… outlived its usefulness" (Straus, 2009:3). And it must be remembered that "…the evidence of a 'behavioural' evolution in technological terms does not enable us to draw conclusions about the social and adaptive changes that accompanied the cultural transition from the Lower to the Middle Palaeolithic (Muttillo et al., 2014:148).

Appearance and/or dispersals of new species of hominins is closely linked to the question of transitions in prehistoric contexts. In the beginning of research, the strict compartmentalization of Palaeolithic periods into Lower, Middle and Upper Palaeolithic based on *fossile-directeurs*, and their succession of epochs remained the focus of Palaeolithic research (Brooks, 2009:vi). However, with the discovery of lithic assemblages with new technological and typological characteristics in cultural contexts, and their wide geographical dispersal/distribution, it has led to a renewed interest in the intervening periods between them. Questions on these transitions, their nature and origin, besides their catalysts, now became significant.

The major transitions considered important in Palaeolithic studies began with that of Oldowan industries to Acheulean industries, then the Lower to Middle Palaeolithic followed by the Middle to Upper Palaeolithic. Of these, the Lower to Middle Palaeolithic transition received less attention when compared to others for a long time. However, the discovery of early *Homo sapiens* and the search for some specific technical behaviour, renewed the interest in this transitional period. The appearance of prepared core technologies associated with the Middle Palaeolithic or Middle Stone Age led the research to focus on this phase and its origin(s) (White and Ashton, 2003; Chazan, 2009; Meignen and Bar-Yosef, 2020). The emergence of Levallois prepared core method, considered as a game-changer in the Middle Palaeolithic/Middle Stone Age period, is perceived as an important reflection of cognitive and behavioural evolution in the hominin history (Peretto et al., 2016). Its appearance in distinct regions gave rise to the proposal of scenarios wherein modern hominins with their new advanced technologies and typologies replaced or "erased" the indigenous groups with their Mode 2 toolkits (Malinsky-Buller, 2016a). Discontinuity of preceding tool traditions and appearance of new elements involving 'modern' behaviour signalling evolutionary adaptations, were thus considered as a major leap of change or transition (Adler et al., 2014).

The origins of Levallois prepared core methodology initially thought to be of African origin (Foley and Lahr, 1997), was later increasingly found to have independent regional origins (White and Ashton 2003; Moncel et al., 2005, 2011b, 2012; Monnier, 2006; Adler et al., 2014; Santonja et al., 2014; Malinsky-Buller, 2016b). Many characteristics previously thought to be originated in Middle Palaeolithic period are now being increasingly recognized as having been present in the preceding Lower Palaeolithic period (Tryon et al., 2005; Sharon and Beaumont, 2006; Villa, 2009; Goren-Inbar, 2011; Barkai and Gopher, 2013). The possibility of a local or regional evolution from the simple core technologies or 'proto-Levallois' (Copeland, 1998; White and Ashton, 2003) is now well attested in many sites.

In the Indian sub-continent, the presence of true Levallois is still debated as it has often been identified on typological and lesser on technological basis as proposed by Boëda (1995), Bar-Yosef and Van Peer (2009), or Shimelmitz et al. (2016). However, Levallois cores and flakes have been reported from the sites of Bhimbetka (Misra, 1979), from the Orsang Valley (Ajithprasad, 2005) and Attirampakkam (Akhilesh et al., 2018), to name a few. Their scarcity, varied densities and their *sensu lato* nature however, leaves the question of Levallois presence open and hampers its use as a valid marker of transitions in the Indian sub-continent. Extrapolating classification systems developed in the European continent to Africa, Middle East or Asia (McBrearty and Tryon, 2006), often prove to be futile in explaining regional innovations and remain invalid in such a scenario (Ménendez-Granda, 2009).

Simple core preparation—or 'proto-Levallois' (Copeland, 1998; White and Ashton, 2003)—is attested to be widespread as early as the end of MIS9 in Western Europe (Peretto et al., 2016). Several sites with Lower to Middle Palaeolithic transitional evidence (some with synchronous presence of Acheulean and Levallois technology) are reported from Western Europe, Eurasia and the Indian-subcontinent (Figure 1.7) (Tuffreau, 1995; James and Petraglia, 2009; Chauhan, 2009; Moncel et al., 2011; Adler et al., 2014; Wisniewski, 2014; Peretto et al., 2016; Shimelmitz et al., 2016). In Africa, late Early Stone Age sites have revealed the presence of Levallois cores and flakes (Rolland, 1995; Tryon, 2006; McBrearty and Tryon, 2006). A recent study has claimed the presence of Levallois from south-west China, appearing as early as the Late Middle Pleistocene levels (Hu et al., 2019).

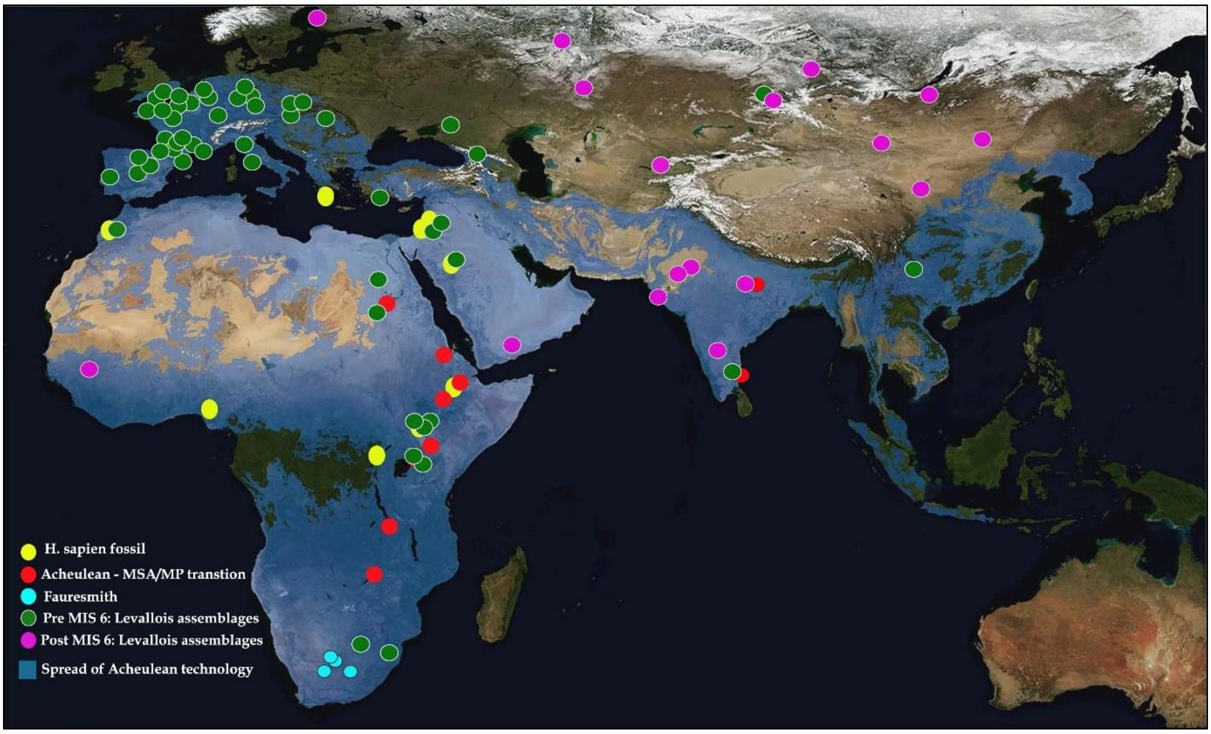


Figure 1. 7 Map showing the distribution of archaeological and fossil finds related to questions of transitions from the Lower to Middle Palaeolithic. Modified after Herries, 2011, Hu et al., 2019 and Key et al., 2021.

Regional adaptations of European terminologies and classifications with sub-terminologies within can be problematic, especially when using them to synchronise regional differences (biological and cultural) (Ménendez-Granda, 2009). The case of Soanian tradition in the Siwaliks (typologically similar to Mode 1), initially believed to be Lower Palaeolithic in nature, based on the application of European terminology, is an example on how the Palaeolithic terminologies have influenced, through European and African practices, the Indian Palaeolithic research. Hence, defining transition or correlating lithic assemblages with chrono-cultural phases through typological studies adapted from elsewhere has to be approached with caution. This underlines the necessity to study the Indian material within its regional specificities, even if the data are scarce.

As mentioned in the previous sections, the scarce data, largely in the form of lithic assemblages are the main source which we can use to throw light on these problems.

1.8.2.2 Nature of evidence in the Indian sub-continent

The absence of well dated, well stratified findings with no hiatus between the strata, and correlated hominin and faunal evidence are all problems that have to be addressed with regard to the prehistory of the Indian sub-continent (Chauhan, 2009). Innovations arising out of different subsistence strategies and raw material constraints as well as the possibilities of co-existence and exchange of ideas or tool kits cannot be ruled out (Chauhan, 2009) as reasons for the changes in the Palaeolithic record, mainly lithic assemblages.

However, Indian Peninsular region, with its continuous Palaeolithic record from Acheulean to Late/Upper Palaeolithic remains a potential area which can throw light on transitions. By and large, the transition from Lower to Middle Palaeolithic here is characterised by a continuation of Acheulean handaxes and cleavers, in a diminutive form and in lower proportions, an increasing flake tool component, along with prepared core technologies like Victoria West, Discoidal and Levallois (Cammiade and Burkitt, 1930; Corvinus, 1983).

The continued use of quartzite as a preferred raw material for these tools is also attested in many sites and this reinforces the features of a very gradual transition. Some of the regions where these transitions have been reported include the Orsang Valley in Gujarat (Ajithprasad, 2005), Luni Valley in Rajasthan (Misra, 1967), Tapi Valley in Maharashtra (Joshi and Sali, 1969), Adamgarh hills in Madhya Pradesh (Joshi, 1978), Son Valley in Central India (Clark and Williams, 1986), Singbhum in Bihar (Ghosh, 1970). In southern Peninsular India, the Kaladgi and Hunsgi Basins in Karnataka (Paddayya, 1982a; Petraglia et al., 2003a), Kortallayar Basin (Pappu, 2001a), Gunjana Valley (Raju, 1988) and Renigunta site in Andhra Pradesh (Murty, 1966) have reported evidences of the Lower to Middle Palaeolithic transitions. Another area from the sub-continent, where transitional phase is reported is from Dang-Deokhuri Valleys in Nepal (Corvinus, 2002).

If we consider prepared core technologies as an indication of incoming Middle Palaeolithic/Middle Stone Age culture resulting from hominin dispersals, we also have to consider here another hall-mark of this period, the tanged point, which is an integral part of the North African Aterian cultural techno-complex. Its presence in Peninsular India has been reported from the Middle Palaeolithic industries of Deccan, Karnataka, and Central India (Sankalia and Banerjee, 1958; Haslam et al., 2012a). From Rajasthan, it has been reported from the site of Katoati in the Thar Desert (Blinkorn et al., 2017). The presence of these tanged points along with handaxes, cleavers and Levallois cores has been attested from the 385±64 ka Early Middle Palaeolithic deposits from Attirampakkam (Akhilesh et al., 2018). Another recent discovery comes from the site of Torajunga in Odisha, where two tanged points, morphologically similar to Aterian points have been recently discovered from stratified and surface contexts (Behera and Thakur, 2019). The comparison to Aterian points suggests directly or indirectly a North African relationship. This is a problem when terminologies are used to compare assemblages with a large spatial distance and when regional cultural terms are taken to imply chronological similarity.

An interesting regional characteristic that has been reported from Peninsular India are the use of bifacial tools, especially handaxes, as cores in the Middle Palaeolithic. Considering this along with the Levallois (*senso lato*) presence in the Middle Palaeolithic, with other ascribed features of transitions, in the absence of their hominin makers, it remains difficult to assess the true nature of these transitions (Chauhan, 2009).

The pitfalls of categorising cultural phases and thereby transitions on the basis of techno-typological markers alone notwithstanding, the regional lithic evidence from the Malaprabha Valley, forms the key focus of research here. Although the data is scarce, this study will attempt to throw light on the various aspects of the hominin adaptation through time using the methodologies explained in the succeeding chapters.

1.8.3 Question of Handaxe shape variability

Handaxe which first appeared in the Acheulean is the longest persistent tool type, being the most curated (Zaidner et al., 2006) since its first noted appearance as early as 1.76 Ma (Beyene et al., 2013). Considered a sophisticated and standardised technology when compared to the Oldowan Mode 1 (McPherron, 2000), these tools belonging to Mode 2, show considerable similarity of form over large spatial and temporal distribution and yet, display variability within its shapes. The question of form and symmetry has been one of the key aspects of the widespread debate on this enigmatic tool type (Machin et al., 2007).

Much of the studies on the handaxes have focused on the question of the variability and standardisation among its shapes and sizes.

This question has been approached at two levels. One is at a global level with large scale inter-continental comparisons excluding the local ecological drivers (Roe, 1968; Wynn and Tierson, 1990; Vaughan, 2001; Lycett and Gowlett, 2008; Petraglia and Shipton, 2008; Shipton and Petraglia, 2011). This approach sees the variations as resulting from hominin technological intent.

An example of one of the studies at a global level, undertaken on the shape variability of the late Acheulean handaxes, is that of the comparative studies on Indian, African, European and Near East Handaxes, using a system of polar coordinates to measure the plan shape of the handaxes (Wynn and Tierson, 1990). This study emphasized the geographical differences in modal shapes produced in these different regions.

Another study by Shipton and Petraglia (2011) considered Euclidean distance measurements of biface length, width, and thickness (elongation vs. refinement) to assess bifaces from eastern Asia, Arabian Peninsula and eastern Africa, and Indian sub-continent. They concluded that bifaces from Imjin and Hantan River basins in Korea and Bose Basin in China are not part of Acheulean tradition, suggesting independent development of bifacial forms. However, bifaces from Luonan Basin in China were found to resemble those of Acheulean, indicating intermittent dispersals of populations manufacturing Acheulean bifaces into eastern Asia (Shipton and Petraglia, 2011).

The second approach considers the handaxe variation at the tool level, where each tool is placed within a dynamic continuum of its life history (Presnyakova et al., 2018). The proponents of this approach (Davidson and Noble, 1993; Ashton and McNabb, 1994; Jones, 1994; McPherron, 1994, 2000; White, 1995, 1998; Archer and Braun, 2010; Archer et al., 2015, 2016; Iovita et al., 2017) identify the complex nature of trying to distinguish the influence of different variables on the forms.

One of the underlying concepts that has been used as a base to support these approaches is to consider the handaxe as a taxonomic unit, wherein the "mental template" or the "mental construct" of knappers with similar cultures in the same chronological frame, result in the similar forms (Wynn and Tierson, 1990; Ashton and White, 2003). This "mental template" would have included the necessity of bifacial flaking, sharp, durable cutting edge, broad symmetry and good prehensile qualities in a tool. Gowlett (2006:205) prefers the term "instruction set" or a set of parameters instead of "mental template" for this.

The contrasting view, focusing on the regional scale, states that raw material and different local traditions played an important role in the independent emergence of convergent technologies (Wynn, 2004).

Thus, the properties and shapes of the raw material available in each area would largely determine the handaxe form variability (Isaac, 1977; Jones, 1979; Clark, 1980; Wynn and Tierson, 1990; Bar-Yosef and Goren-Inbar, 1993; Ashton and McNabb, 1994; Roe, 1994; White, 1995; Noll and Petraglia, 2003; Ashton and White, 2003; Sharon, 2008; Jennings et al., 2010; Archer and Braun, 2010; Costa, 2010; Wang et al., 2012: Eren et al., 2014). The form (shape and size) of the raw material is considered to have had an influence on the production of tools (Roe, 2003) while the properties of the nodule and texture (Schick and Clark, 2003), besides the thickness and composition is believed to lead to restricted forms and sizes (Nowell et al., 2003). The distribution and distance of raw material from the sites, also is believed to have important consequences on the tool types produced (Presnyakova et al., 2018). Types of blank and raw material effects were also highlighted as contributing factors by Gamble and Marshall (2001).

Hominid technology is conditioned by local availability and accessibility of raw materials, which changes across regions on a micro-scale level (Ashton and White, 2003).

Using this premise, the British handaxe variability was accessed to reflect patterns of shape differences (White, 1995, 1998). Pointed handaxes were found to be more on smaller, poorer quality raw material obtained from river deposits while rounded forms were on larger, higher-quality primary raw material (White, 1995, 1998).

Another model which arose from considering the variability at the tool level, was the reduction intensity model, proposed by McPherron (1994, 1999, 2000). In this model, the tool is seen as representing the shape when it entered the assemblage and different tool shapes is considered to represent different phases in the reduction strategies. This has been shown in several studies (Nowell et al., 2003; Presnyakova et al., 2018), as one of the underpinning factors in shape variation.

Raw material differences were not found to have a necessary impact on the handaxe shapes as shown by the study of Lycett et al. (2016).

It was reiterated in other studies that whenever knapping properties and shape of the raw materials posed a challenge, the hominins came up with innovative and sophisticated core methods to ensure the production of planned flakes (Sharon, 2008).

Much earlier, Mellars (1989) had proposed that substantial human modification, more than the shape of the blank, results in the shape variation.

Variability has been attested to functional constraints (Gowlett and Crompton, 1994; Nowell et al., 2003; Roe, 2003) besides mechanical/technological constraints, imposed by the raw material size (Jones, 1979, 1994; Gowlett and Crompton, 1994) which impact the reduction strategy (Jones, 1979, 1994; White, 1995, 1998; Noll and Petraglia, 2003). Moreover, the form of the handaxe has been explained in terms of functional efficiency as a butchery tool (Mitchell, 1996).

Symmetry and form are considered other key aspects of this variability. Early Acheulean handaxes, less refined, considered less symmetrical bifacially and bilaterally, represents a simple *chaine operatoire* (Inizan et al., 1999; Stout, 2011). The succeeding phase of Late Acheulean with larger instance of standardized symmetry and refinement is believed to involve the “imposition of form” (Nowell et al., 2003). Refinement is also related to measures of size (McPherron, 1994, 1995, 1999), in turn, influenced by raw material variability (Noll and Petraglia, 2003). Elongation, refinement, and tip shapes have been considered as the most important contributing factors in shape variation (McPherron, 2006).

Handaxe symmetry and form have also been attributed to sexual display (Kohn and Mithen, 1999), a cultural marker within the landscape (Gamble, 1999), besides reflecting an aesthetic sense (Pelegrin,1993; Mithen, 2008; Edwards, 2001; Hodgson, 2011). Symmetry has been regarded as the beginnings of an artistic or symbolic sense (Le Tensorer, 2006; Hodgson, 2011). A number of studies contributing to the understanding of symmetry and form exist (Saragusti and Sharon, 1998; Sharon and Goren-Inbar, 1999; Saragusti et al., 2005; Goren-Inbar and Sharon, 2006; Machin et al., 2007; Grosman et al., 2011; to name a few).

Allometric studies exploring the relation between size and shape resulted in the observation of systematic shape shifts in bifaces according to size (Crompton and Gowlett, 1993).

Learned behaviour, reflected in conservative trends in shapes (Roe, 1964, 1968; Gowlett and Crompton, 1994) and the copying errors that arise within, during the course of social learning (Eerkens and Lipo, 2005; Hamilton and Buchanan, 2009; Schillinger et al., 2016) have also been considered as major contributors to this variation. A higher standardisation of the handaxe form is believed to reflect the influence of social learning on the formation of the tools (McNabb et al., 2004; Monnier, 2006).

The study of handaxe variation initiated through typological classifications (Bordes, 1961), further emphasized through metrical analysis (Roe, 1964, 1968) has remained one of the key aspects of handaxe tool variability.

Many key models and approaches have been initiated to explain this variability in shape and size. However, one of the key issues that it has raised include the emphasis of the final form being taken into consideration without the inclusion of the reduction process (Davidson, 1991; Davidson and Noble, 1993). At the same time, in the context of the difficulties that arise to reconstruct the entire process of bifacial reduction, the necessity to understand better the discard behaviours, which ultimately structures the range of shape has been proposed (McPherron, 2006).

Moreover, factors of the role of resharpening (Nowell, 2003), recycling, knapping, traditional differences, and idiosyncrasies of the individual knappers (Ashton and White, 2003), the behavioural activities according to age and sex, opportunities or necessities and group composition of the tool-makers (Schick and Clark, 2003), the social act of making them by negotiating social relationships (Gamble, 1999) all need to be taken into account if we are to look for a comprehensive answer. Although cultural and cognitive differences can be discerned to some extent from the analysis of tools, the degree of this variability will inherently be dependent on the sample size. Aspects of site preservation and varying degrees of discard, mobility patterns in relation to the site etc. will have an undoubted effect on the assemblage and thereby the tool shapes encountered.

1.9 Statement of Research Problems and Objectives

Indian Palaeolithic sites are mostly open-air sites (sometimes with mixed assemblages) and only a few of them have been recently dated through “absolute”, mostly radiometric methods. Palaeo-faunal and palaeo-botanical remains are almost absent in most sites and except for the Narmada hominin fossil, there are no other remains of the makers of the abundant tools found in these sites. This is one of the principal reasons why lithic tools, especially the “*fossile directeurs*”, have been used mainly to techno-typologically assign a cultural phase for most sites.

Museum collections (resulting from numerous surveys from the past and present as well as individual donations of stray finds and surface collections from findspots/sites) have been chosen for this study due to the difficulties of accessibility to excavated assemblages.

These collections do not always have information on their provenance and mostly represent the index type tools, in this case, handaxes and cleavers. Classification based on their reduction and refinement has assigned them to Lower and Middle Palaeolithic in Indian prehistory. The data at hand from open-air sites come with a number of limitations like lack of stratigraphical information, absence of absolute chronology, mixed multicultural assemblages, presence of both excavated and collected tools (from sites and findspots).

By studying collections from sites that have already been securely attributed to a—quite long perhaps, but certain—chrono-cultural phase, it is expected to determine “anomalies” or trends that traditional methods of studies may not perceive.

The combination of both Geometric Morphometrics contour analysis (2D and 3D) and classical approach, may lead to a more accurate cultural definition of the tools and allow incorporating the stray finds from findspots/museums (resulting in a recontextualization of open-air sites) as well as excavated collections in order to create a database. From this interregional and diachronic comparisons, more precise information on the Palaeolithic period in their local and regional settings can be extracted.

To do so, two hypotheses are advanced to test our results. The first hypothesis relies on the fundamental question of techno-cultural continuity or discontinuity. It can be expressed like this: The technological and morphological traits of the LCTs reflect a gradual regional continuity from the Lower to the Middle Palaeolithic rather than an abrupt external introduction of new elements.

The collections of the Malaprabha Valley, stretching from Lower to Middle Palaeolithic, will be used to try to understand the characteristics of change (largely cultural, technological, and related to raw material) from Lower to Middle Palaeolithic and also scrutinise their implications on hominin dispersals and transitions.

The second hypothesis concerns the shape variability of the LCTs and the causative factors that explain them (technological choices? raw material?) The hypothesis can be expressed like this: There is an influence of the raw material and blank types on the shape variability. Convergence and divergence of shapes across the two regions and influence of the factors responsible for it will also be examined.

1.10 Scope and limitations of the study

The scope of this study lies in its methodological considerations. It is the first instance of a direct application of a new method—Geometric Morphometric (GM) analysis—to southern Peninsular Indian lithic assemblages from the Malaprabha Valley, especially the large cutting tools of Lower and Middle Palaeolithic. Besides, the three approaches—2D, 3D GM analyses, and traditional typo-technological studies—are applied to both excavated and surface collections.

Such type of analysis will help:

1. to answer questions of variation or homogeneity within and between the assemblages of each site and region in terms of tool shape and techno-typological characteristics,
2. to answer questions of nature of this variation or homogeneity,
3. to answer questions of influence of blank types on the shape of the tools,
4. to lead to a re-evaluation of ancient collections from the studied sites, such as those housed in the British Museum, London, and Musée de l'Homme, Paris.

The resulting better classification of the LCTs and their precise characteristics will contribute to better assessments regarding hominid decision making and factors that influenced their choices.

Since this research considers both Lower and Middle Palaeolithic LCTs, it will look into temporal changes in tool shapes and despite the lack of precise chronology try to see if there was a standardisation. This will shed further light on the question of continuity or discontinuity between Lower and Middle Palaeolithic, at least in the studied area, and the question of modern behaviours versus modern humans (Petraglia et al., 2007).

Focussing on one region, the Malaprabha Valley, this study will try to place the lithic assemblages from both excavated and surface collected contexts in the broader context of transitional behaviours from Lower to Middle Palaeolithic.

Traditional analysis evaluating the handaxe shape variability have relied on often inept and subjective measurements that are not capable of capturing the intricacies of the attribute of shape on its own. Geometric Morphometrics will help to separate size from shape, thus enabling understanding of the hominin choices and preferences when it comes to standardised and non-standardised shapes. The precise and accurate nature of the methodology will help extract replicable data that can be used to build an easily shareable database.

One of the drawbacks of this study has been that all the sites are open-air sites in both Karnataka and Tamil Nadu. Although, surface finds are equally important as excavated finds, especially in the context of fast disappearing sites due to human activities, the possibility of some sort of disturbance resulting in a mixed context, cannot be ruled out. Only Benkaneri (stratigraphical) and the Lakhmapur (spit) excavations have given precise contexts. Although the Attirampakkam tools available for this study are also a result of excavations, not much is known about their provenance details apart from a sporadic mention. The other minor sites from Tamil Nadu, considered in Article 1 (Appendice) do not have much information in terms of field notes or documentation, including their journey to the museums where they are housed.

The site of Singadivakkam, which has yielded tools from surface quadrant collection, also lack point provenance details of the tools but the assemblages occur within a delimited area. All these sites have been assigned to their cultural phases on the basis of relative dating as no chronometric dates are as yet available. Typo-technological characteristics of the tools, especially the index type tools, have been the major deciding factor to assign them to Lower and Middle Palaeolithic cultural phases. This can lead to many interpretative errors as the current classificatory system may not be sufficient for a proper understanding of the Lower and Middle Palaeolithic contexts.

2. CHAPTER II – REGIONAL SETTINGS

2.1 Malaprabha Valley

The Malaprabha region is rich in Lower and Middle Palaeolithic sites as illustrated in the extensive Pleistocene studies of Joshi (1955) and R.S. Pappu and Deo (Pappu, 1984; Pappu and Deo, 1994). These sites were identified as belonging to different palaeo-geomorphological settings. As a result of the extensive surveys aimed at reconstructing Quaternary alluvial stratigraphy, landforms, and palaeoclimates, besides mapping the site distributions, the study by Pappu and Deo (1994) inferred that the site distribution was intricately related to the Malaprabha River palaeo-courses (Petraglia, 1998). Later surveys and renewed investigations into the landscape by Korisettar and Petraglia (Korisettar and Petraglia, 1993) identified Quaternary stratigraphy (extensive lateritic surface overlain by calcrete and fluvial formations) (Petraglia, 1998; Korisettar and Rajaguru, 1998). These investigations led to a revision of the contexts of the Lower Palaeolithic sites, which now was found not to correspond to the alluvial occurrences but situated on an ancient series of coalescent fans, cross-cut at several places by Terminal Pleistocene stream-action (Petraglia, 1998). Sedimentary and archaeological observations have strengthened this view.

The Acheulean exposed in the conglomerates from the Malaprabha riverbed, could be traced away from the channels up into the piedmont region, post-dating the deposition from the former alluvial fan systems originating from the Kaladgi ridges (Petraglia, 1998).

The quartzites of the Kaladgi series which is of Precambrian origin are found in a long and narrow ridge like hill chain which trends in a West-North-east to East-South-east direction (Figure 2.1).

Figure 2. 1 General view of the Kaladgi hill chains at Malaprabha Valley, north Karnataka, south India (photo: M. Kunneriath).

Quartzarenites or quartzite (in varying shades of red, pink, grey and white) is the predominant lithology of the area (Figure 2.2). Due to the poor rainfall and vegetation cover, these are not subjected to chemical weathering (Koshy, 2009).

Figure 2. 2 Quartzite outcrop section observed at Malaprabha Valley (photo: M. Kunneriath).

The Basin Model (Korisettar, 2007) related to hominin dispersals proposes that the Palaeolithic site distribution is linked to the Purana and Gondwana basins. These basins are located in the north-west, Peninsular, and along the eastern half of the India, and near the coast. Characterised by similar features of perennial water in the form of springs and ponds which would have supported a high biomass, availability of lithic raw materials, and cave and rock shelter, geomorphic settings would all have attracted the hominins. These areas would have acted as a refugia in times of aridity. The rich distribution of sites in many of these basins probably reflect the same. Further, this model supports inland terrestrial routes of dispersals rather than dispersals along the coast. Kaladgi Basin, of which Malaprabha Valley is a part of, is one of the Purana basins, and the sites with diverse Palaeolithic evidence from this valley makes it an ideal focus area to test the hypotheses of transitions. Possible coastal sites submerged, like in Arabia landscapes (Petraglia, 2003). The three sites selected for the study are described below.

2.1.1 Khyad (Kaira) (15° 51ˈN; 75°42ˈE)

2.1.1.1 Site settings

This site is located on the left bank of one of the major meanders of the Malaprabha River (Figure 2.3). Situated to the south-east of the Badami town, this site was first reported by Robert Bruce Foote, who described it as a very rich Palaeolithic site (Joshi, 1955). Subsequently, Zeuner and Joshi examined the site in early 1950's. An extensive research on the Pleistocene period of the Malaprabha Valley by R.V. Joshi, included the typological descriptions of the Acheulean tools from this site. It was identified as a factory site and the black soil was interpreted as representing possible wood vegetation in humid climate (Joshi, 1955:37). On account of the high proportion of the cleavers to handaxes at this site, it was postulated that this was related to this environmental setting.

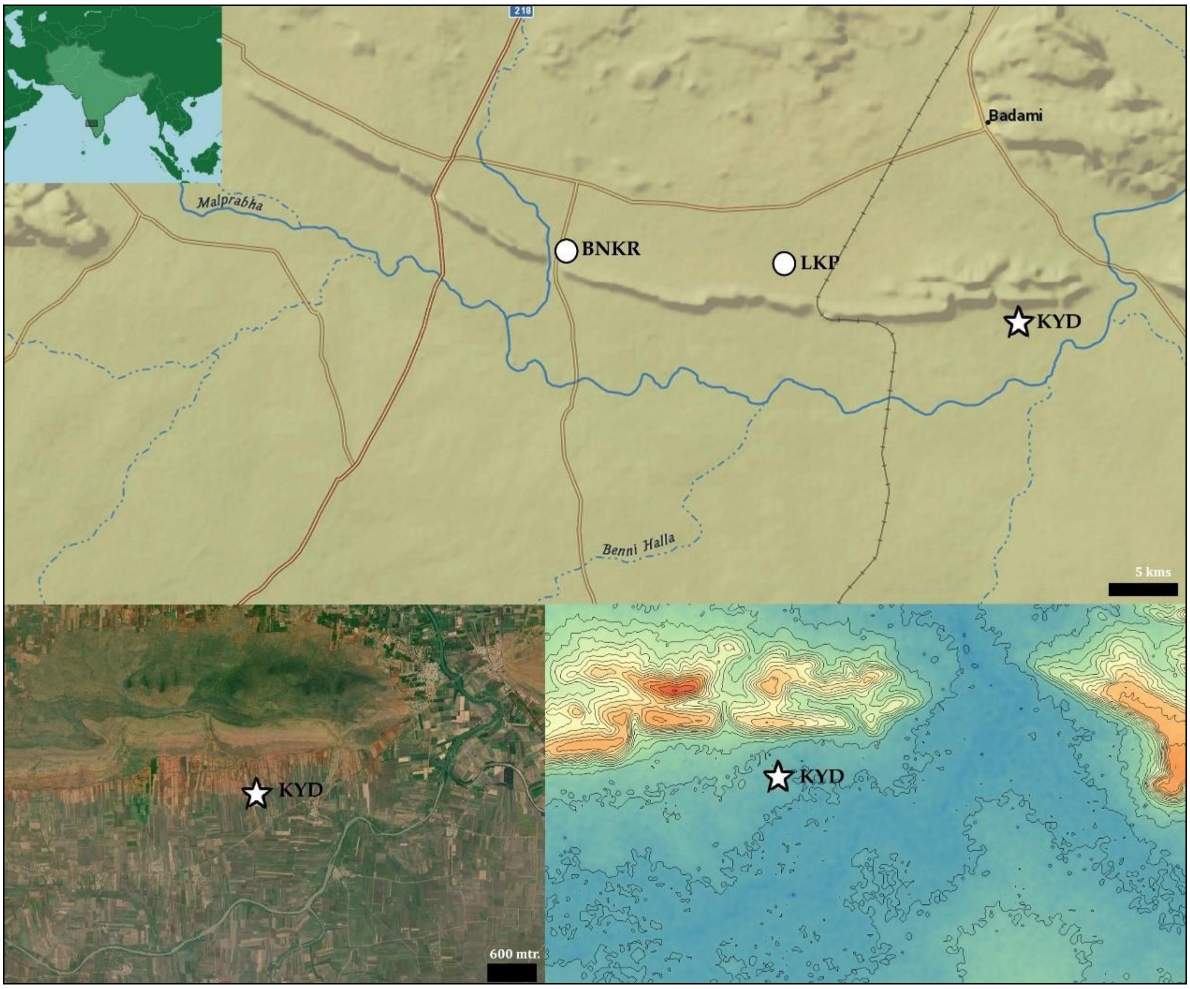


Figure 2. 3 Map showing the location of Khyad (topography, LANDSAT and DEM) in relation into Lakhmapur West and Benkaneri in the Malaprabha Valley (base map: https://www.natgeomaps.com/).

Following this, preliminary surveys in the area was conducted in 1993 (Korisettar and Petraglia, 1993) during which Quaternary soil deposits with Acheulean artefacts (from the calcrete horizon) were also noticed, at a location away from the river. A doctoral thesis by Jinu Koshy in 2009 included the site for understanding the raw material behaviour and lithic technology. The present author paid a visit to the site in 2018 and noticed the preponderance of *in-situ* cleavers on the surface (Figure 2.4).

Figure 2. 4 General view of the Khyad site (Malaprabha Valley) and *in situ* cleavers within the old gravel (photo: M. Kunneriath).

The bed rock is granite-gneiss. The Acheulean artefacts occurred in the old gravel conglomerate contexts that lay over the bed rock (Figure 2.4). Stratigraphically, the exposed banks show yellow-mottled clay-silt at the bottom, followed by brown sand, which is covered by black soil (Koshy, 2009).

2.1.2 Lakhmapur (15°52ˈN; 75°37ˈE)

Two localities have been identified at Lakhmapur, which is located in the northern quartzitic ridge slopes of the southern margin of the Kaladgi escarpment; Lakhmapur West and Lakhmapur East. The site is located in a piedmont coalescent fan complex, at a break in the Kaladgi quartzitic ridge and is substantially removed from the flood belt of the Malaprabha River (Petraglia et al., 2003a). The Lower Palaeolithic occupation, associated with dried up ponds and shallow water sources, was found on the lateritic surface, which was later sealed by low-energy processes (Petraglia, 1998; Petraglia et al., 2003).

The site was first explored by Korisettar and Petraglia who undertook test excavations in both the localities in 1997 (Figure 2.5).

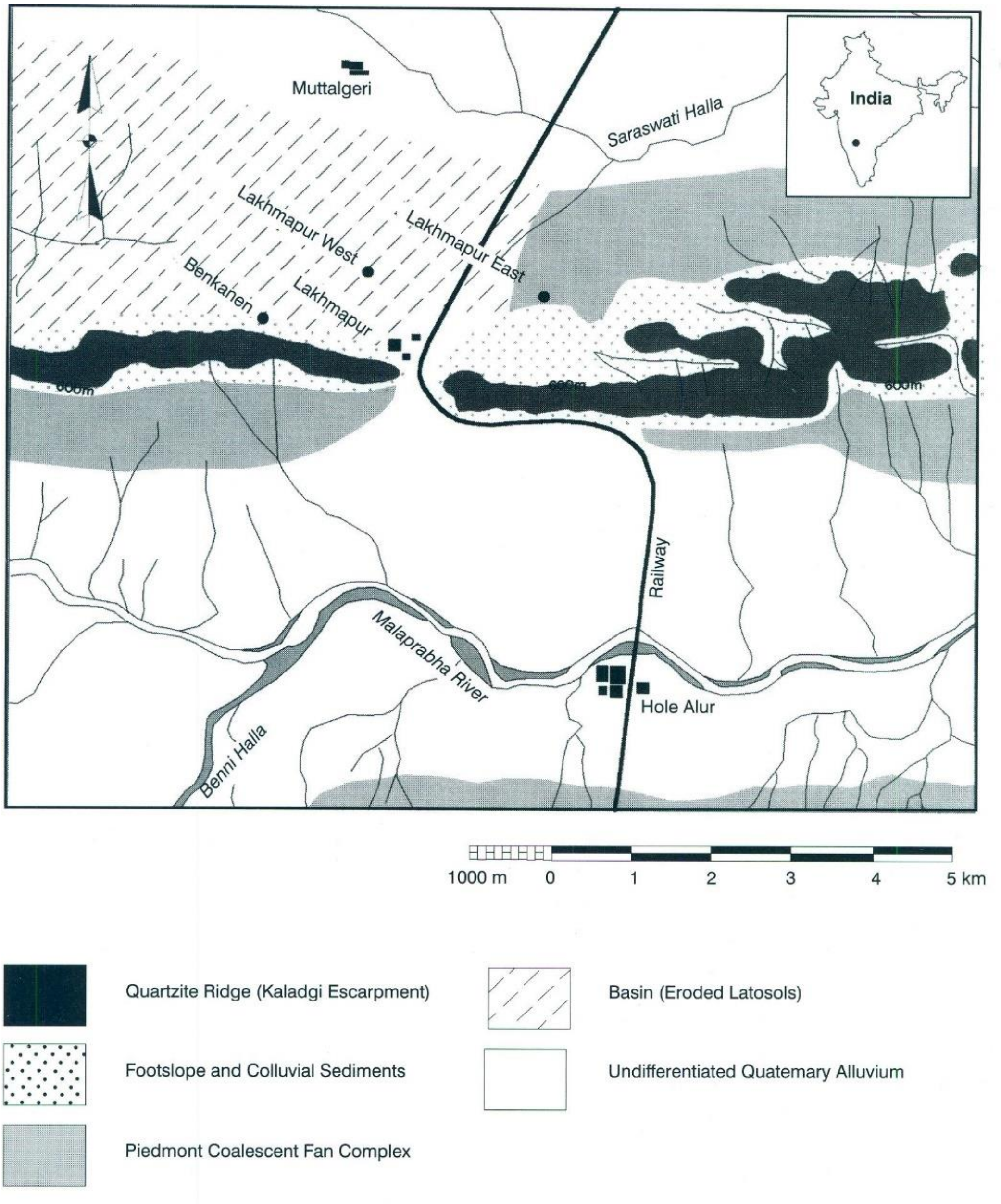


Figure 2. 5 Map showing the surface geology of Benkaneri and Lakhmapur sites (excavated areas noted in circles). After Petraglia et al., 2003.

2.1.2.1 Lakhmapur West

This site is located 1 km north-west of the Lakhmapur village (Figure 2.6). The author of the current study visited the site in 2018 (Figure 2.8) and noticed that most of the previously excavated areas were overgrown with shrubs and a large portion of the area has been converted to agricultural land.

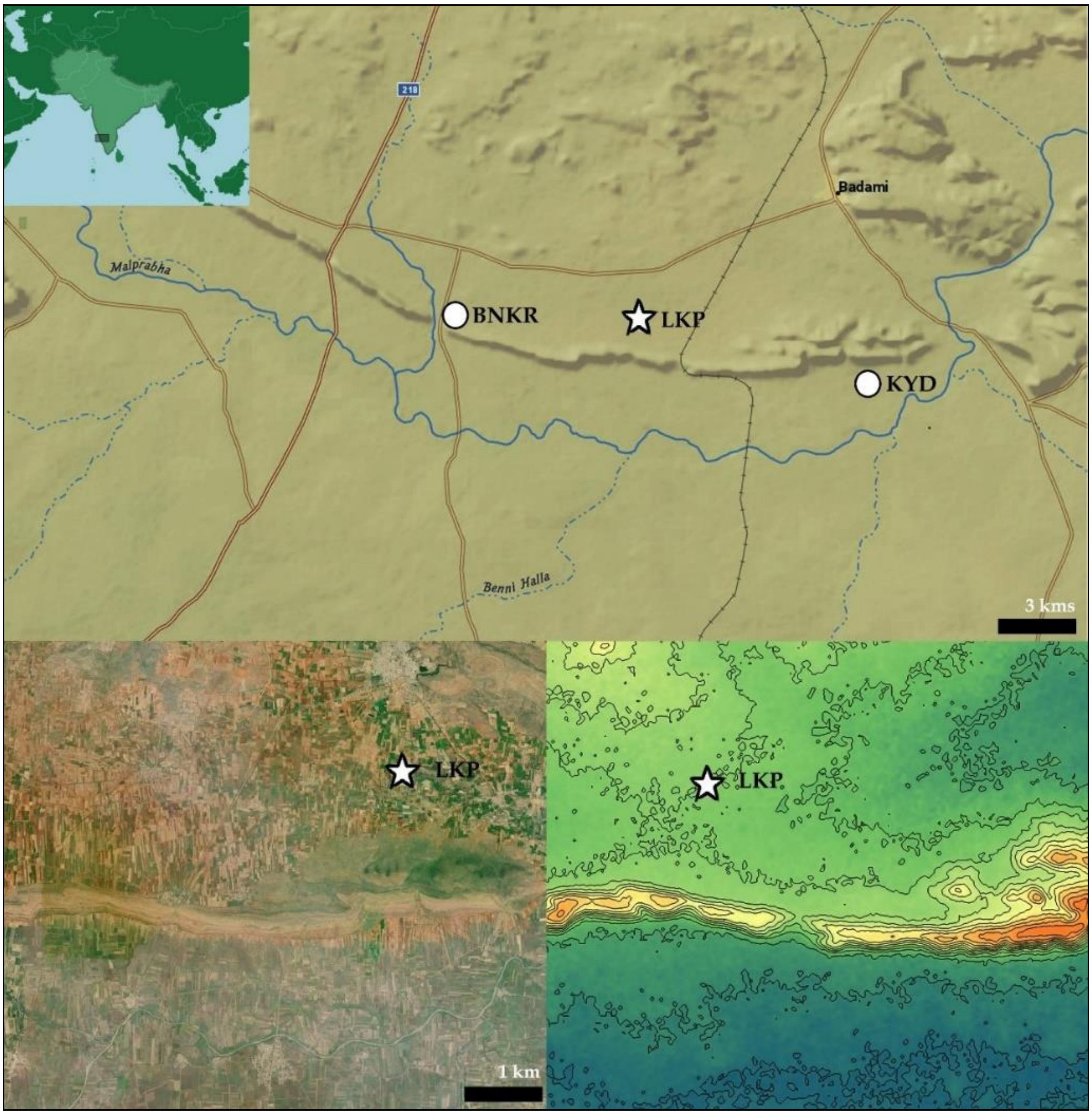


Figure 2. 6 Map showing the location of the site of Lakhmapur West (topography, LANDSAT and DEM) in the Malaprabha Valley (base map: https://www.natgeomaps.com/).

Stratigraphic profile at Lakhmapur West showed presence of successive Acheulean and Middle Palaeolithic assemblages (Figure 2.7). From this locality, a total of 151 artefacts were recovered, including handaxes and cleavers, cores of regular, prepared, and pyramidal types, flakes, tabular pieces and scrapers along with a hammerstone (Petraglia et al., 2003).

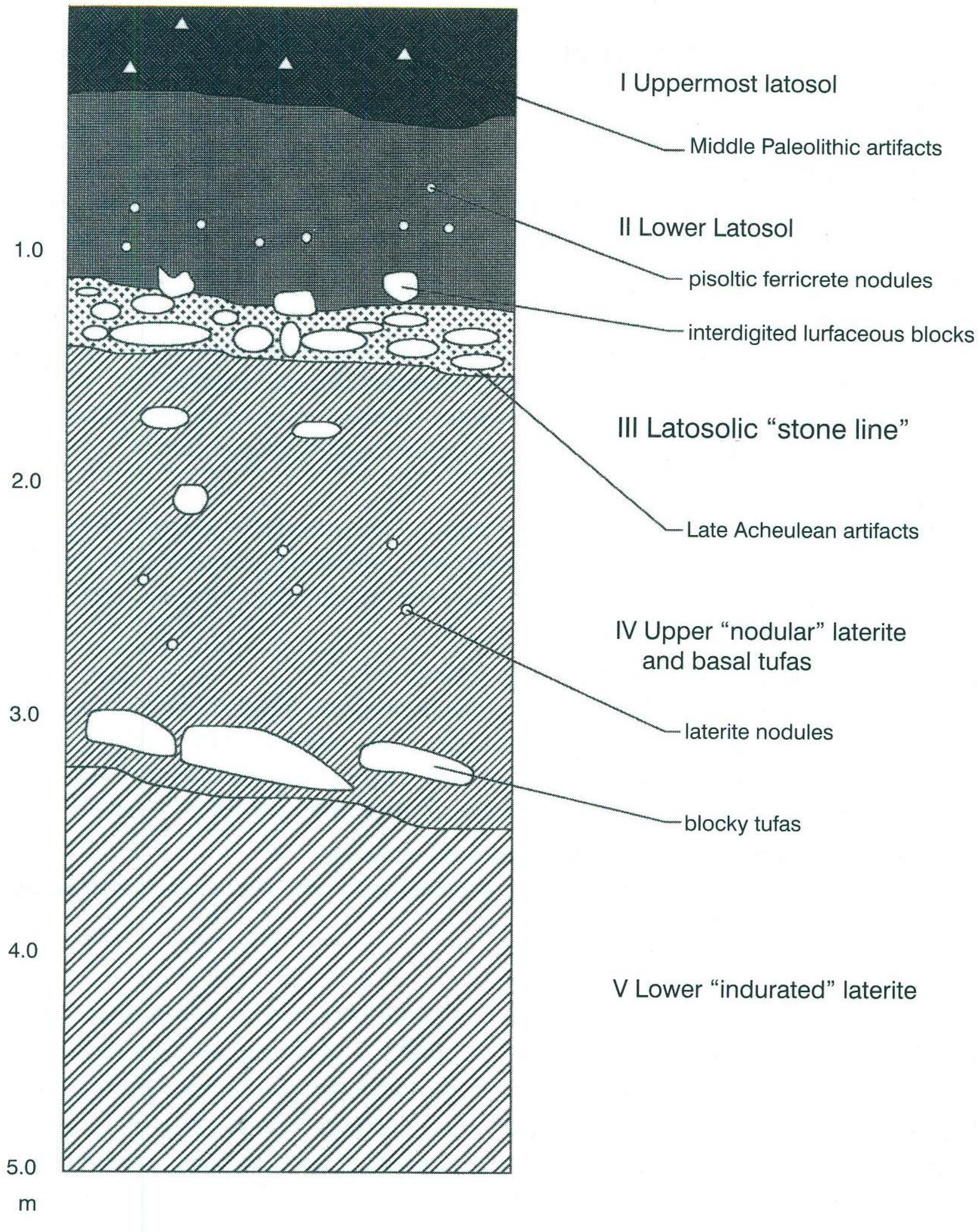


Fig. 2. Stratigraphic profile, Lakhmapur West

Figure 2. 7 Stratigraphic profile, Lakhmapur West (after Petraglia et al., 2003).

Acheulean artefacts, typo-technologically assigned to the Late Acheulean occurred on a semi-continuous 'stone line' (Unit III), lying ca.1.2 to 1.5 m below surface (Petraglia et al., 2003).

Figure 2. 8 General view of the Lakhmapur (West) site and an exposed section showing in situ artefacts. (photo: M. Kunneriath).

Acheulean artefacts were also found exposed in modern burrow pits dug by local villagers. Four separate blocks (I-IV), composed of a total of thirteen one-meter square units, were placed in the area (Petraglia et al., 2003). Tools and debitage recovered were typologically and technologically consistent with the Acheulean.

2.1.2.2 Lakhmapur East

This locality is situated 2 km north-east of the modern Lakhmapur Village. Middle Palaeolithic assemblages were initially identified as a buried surface along a road cut at Lakhmapur East. Excavation was conducted in two separate areas (Blocks 1 and 2) along the distal (piedmont margin) of the lower peneplain. Six 1×1 m^2 units were excavated in Blocks 1 and 2 (3 units each).

From this locality, a total of 1701 artefacts, including diminutive handaxes and cleavers, choppers, scrapers, borers, points, (prepared, regular, and pyramidal) cores, flakes and hammer stones were recovered.

Unit	Description
I	"Plowzone" in upper black clays (0.0-0.15 m) 7.5 YR4/3 heterogenous matrix of gritty sands and clays; structures are weak, subangular blocky; cobbles and stones abundant; roots are common and fibrous; occasional sedimentary nodules (reworked from upslope soils); secondary carbonates ('kankars') at base; clear and smooth lower boundary.
II	Blacky clay ('Paleovertisol") (0.15-0.85 m) 7.5 YR4/2 to 2.5YR4/6 columnar to coarse prismatic, firmly structured black clays with thick (1-2 mm) sandy veins; a few stones and roots; diffuse sedimentary inclusions (disaggregated ferricrete nodules); abundant organic films/clay skins (organans); carbonate filled root casts at base; shrink-swell structures account for diffuse artefacts; sharp and smooth lower boundary.
III	Nodular laterite (0.85->1.20 m at base of exposure 2.5 YR4/4 medium-coarse friable to moderately cemented sands and consolidated clays with dense ferricrete filaments and pisoliths (ca. 35 percent by volume; 3-6mm size range); extensive oxidation-reduction streaking (5 YR5/6) at ped interfaces. Laterite contains quartzite boulders.
IV	Weathered Kaladgi Quartzite Bedrock

Table 2. 1 Stratigraphy of Lakhmapur East, Block 1 (after Petraglia et al., 2003).

From Block 1 (Table 2.1), located at the interface of the footslope and coalescent fan, 1 km north of the ridge, Middle Palaeolithic artefacts were recovered from Unit II to the top of Unit III (Petraglia et al., 2003). From Block 2 (Table 2.2), Middle Palaeolithic artefacts were exposed from the Lower Latosol, which formed the Unit II.

Unit	Description
I	Upper latosol sediments (0.0-0.1 m) 2.5 YR3/4 friable to weak, sub-angular blocky gritty fine and medium sands; abundant, well-rounded pebbles (2-5 mm); roots and root casts with organic inclusions; sharp and smooth lower boundary.
II	Lower latosol (0.1-0.35 m) 2.5 YR3/3 weak sub-angular blocky to friable clay-sand with ferricrete and manganese filaments, largely disaggregated (2-7 mm size range, 25% by volume); clear, smooth lower boundary. High density of Middle Palaeolithic artefacts; sharp artifact edges.
III	Nodular laterite (0.35-0.5 m) 2.5 YR3/4 weak to moderately subangular blocky clay sands, sub horizontally bedded; loose to indurated matrix with ferricrete and manganese nodules, densely packed; clear, wavy, lower boundary.
IV	Chert breccia and indurated laterite (>0.5 m) Cemented and consolidated calcareous cement with spongy fabric.

Table 2. 2 Stratigraphy of Lakhmapur East, Block 2 (after Petraglia et al., 2003).

2.1.3 Benkaneri (15° 52' N; 75°32'E)

Located to the north of the Kaladgi escarpment, 5 km to the east of Lakhmapur (Figure 2.9), the site has been identified as a Middle Palaeolithic quarry site (Petraglia et al., 2003).

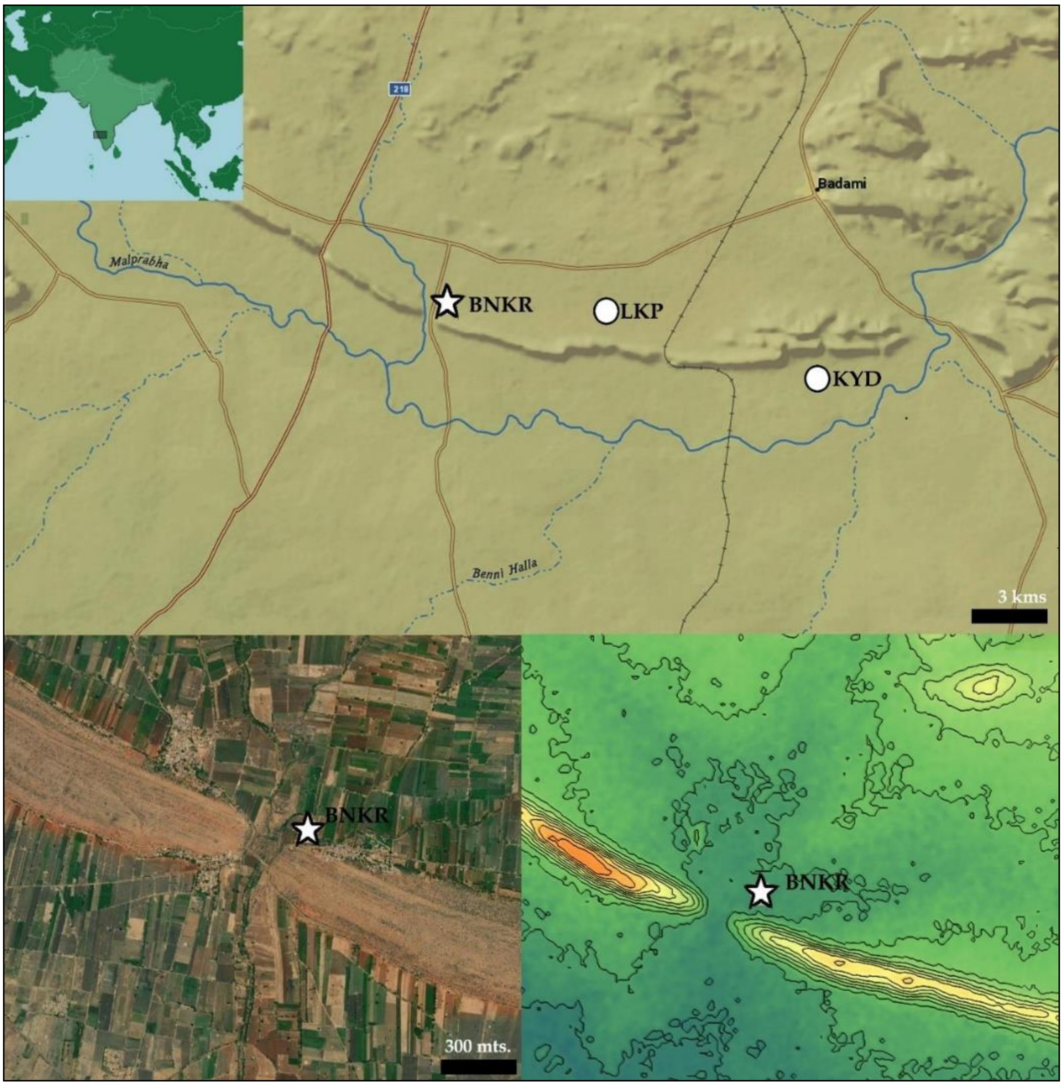


Figure 2. 9 Map showing the location of Benkaneri (topography, LANDSAT and DEM) in relation to Lakhmapur West and Khyad in the Malaprabha Valley (base map: https://www.natgeomaps.com/).

This site was first discovered in 1990's as a result of systematic explorations carried out by Korisettar and Petraglia in the Malaprabha Valley (Korisettar and Petraglia, 1993). A test excavation was conducted in 2000 which revealed a complete *chaîne opératoire* of a Middle Palaeolithic industry from the latosol colluvium (Petraglia et al., 2003b), at the foot hill of the quartzitic ridge (Figure 2.10). The assemblages from here were also subject to a raw material analysis in the doctoral thesis of Jinu Koshy (2009).

Figure 2. 10 General view of the Benkaneri site, showing the quartzitic hills and the hill slopes littered with finished and unfinished artefacts and raw material (photo: M. Kunneriath).

2.1.3.1 A brief summary of the non-LCTs from this site

From L1, 14 cores were recovered. Bifacial discoid, partial bifacial discoid, residual bifacial core, centripetal bifacial core, and casual unifacial core besides multiplatform, semi-rotating, and an exhausted multiplatform core were the main types. A non-rotating blade core also occurred among the assemblage. From L2 also, 14 cores were recovered; bifacial discoid, partial bifacial discoid, bifacial core, centripetal non-discoidal bifacial core, unidirectional bifacial core (broken), casual bifacial core, multi-platform core, casual multiplatform core, and a core fragment.

Among the flakes, several broken pieces, siret flakes, Kombewa flakes and "débordant" flake were noticed. Examples of a composite flake and a chopper on a flake were also noticed. Blades include only 2 pieces, one of which was broken. Among the retouched pieces, there were denticulates, a large number of scrapers, transverse and end types, along with scrapers with notch.

2.2 Tamil Nadu

Although the main focus of this study is the Malaprabha Valley, in order to have a better understanding of its context with what is evidenced at the eastern part of this region, assemblages from two sites in Tamil Nadu, located in the south-east of the Peninsular region, were selected, based on their availability and access.

2.2.1 Singadivakkam (12° 96ˈ 78ˈˈ N; 79° 94ˈ 37ˈˈ E)

The site of Singadivakkam is located 65 km south of Chennai, in the district of Kanchipuram, Tamil Nadu (Figure 2.11). Kanchipuram is drained by the Palar River and the lithology of the region consists of Gondwana basin quartzite.

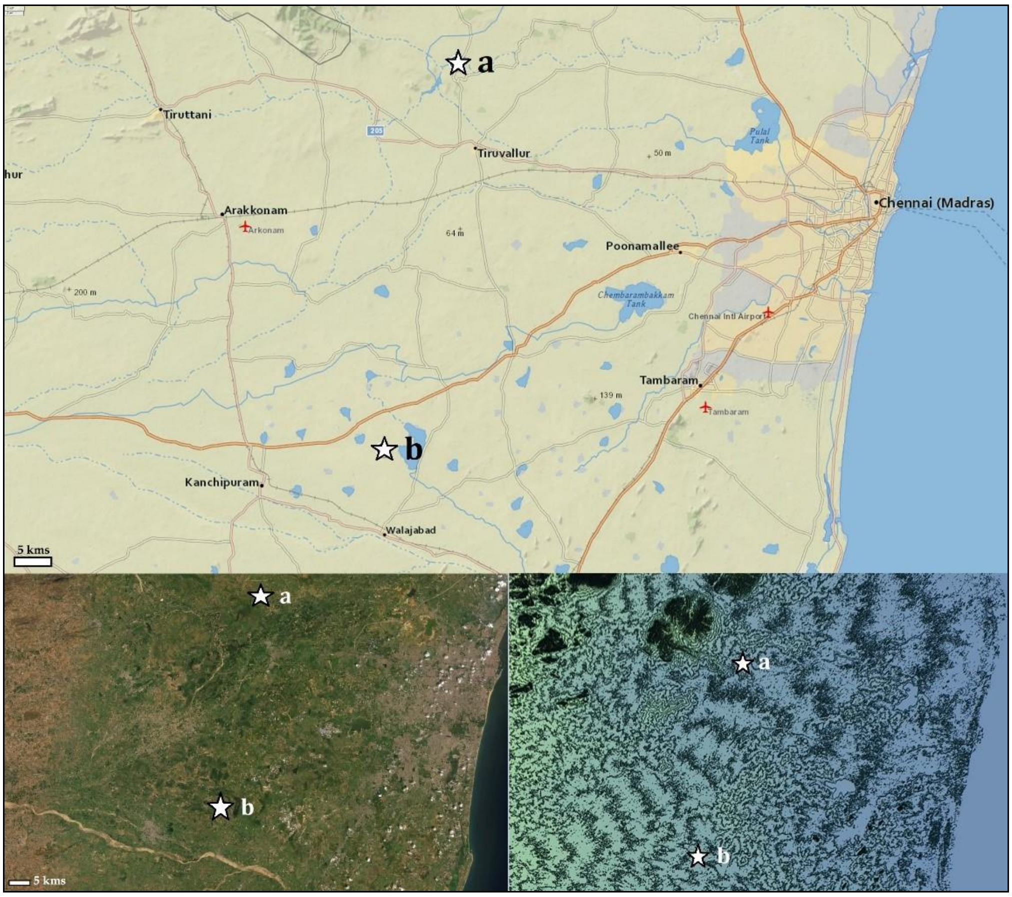


Figure 2. 11 Map showing the location of the site (topography, LANDSAT and DEM) of Singadivakkam (b) in relation with the site of Attirampakkam (a)

The site was initially discovered by S. Rama Krishna Pisipaty and his student S. Shanmugavelu, of the Department of Sanskrit and Culture at Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya (SCSVM) as part of their surveys in 2010 and subsequently examined by Pappu (2011a).

The site is an open waste land where gravels are exposed eroding out over an area of around 1 km^2. The area is geomorphologically an upland dissected by a few rain rills, with scrub vegetation.

Artefacts occur on the surface of the fine sandy gravel, with a density of around 10 per m^2 if not more in some clusters (Figure 2.12).

Figure 2. 12 General view of the Singadivakkam site, Tamil Nadu. Inset: an *in situ* chopping tool and a flaked cobble tool (photo: M. Kunneriath).

Two localities were identified, one located on an open area, a dry lake bed, which is rapidly being converted into a modern industrial plant and another, behind a nearby temple (Rama Krishna Pisipaty: personal communication).

More than 200 lithic artefacts were systematically collected from a one metre by one metre quadrant from a one-hectare area, located on a dry lake bed. The assemblage includes handaxes, atypical cleavers, scrapers, flakes and retouched flake tools, borers, many choppers, besides hammer stones and other debitage. The lithic assemblage has been typo-technologically dated to Lower and Middle Palaeolithic.

2.2.2 Attirampakkam (13°13ˈ50ˈˈN; 79°53ˈ20ˈˈE)

One of the best-known Palaeolithic sites with absolute dates for both Acheulean and Middle Palaeolithic from the Indian sub-continent, this site, located in Tamil Nadu has been well-published (Pappu, 2001a and b; Pappu and Akhilesh, 2007).

As the museum collections undertaken for studies do not have an accurate context and only one publication exists with a brief mention of the artefacts being Acheulean, only a brief note of the cultural evidence and chronology of the site is given below, from the published literature.

The site of Attirampakkam is located on the banks of a tributary of the Kortallayar River (Pappu, 2001a and b). The site is rich in both Early Acheulean and Middle Palaeolithic assemblages. While the Early Acheulean tools has been dated to 1.7 ka (Pappu et al., 2011b), the succeeding Middle Palaeolithic sediments (which occur after a hiatus) have been dated to 385 ka (Akhilesh et al., 2018). The transitional elements of bifaces being more sporadic and diminutive in nature, towards the Middle Palaeolithic, with increased flake tools and prepared cores are also attested at this site (Akhilesh et al., 2018).

3. CHAPTER III – STUDY MATERIALS

3.1 Origin of the assemblages

The study material consists of the LCTs of handaxes, cleavers, including the unifaces and picks from five different sites, located in the southern Peninsular India.

The LCTs of the Malaprabha Valley are from different contexts; random surface collections and excavated materials. Khyad (Acheulean) tools are found distributed among Musée de l'Homme (Paris, France), the British Museum (London, UK) and the Robert Bruce Foote Sanganakallu Archaeological Museum located at Ballary (Karnataka, India). The collections at Musée de l'Homme are a result of possible exchanges with the Deccan College Post Graduate Research Institute (DCPRI) Museum, as the labelling indicates, although there are no acquisition details available. The Khyad tools at the British Museum, originate from the collections of the Institute of Archaeology, London and form part of individual collections spanning many years, as understood from the data in the acquisition record.

Benkaneri (Middle Palaeolithic site) and Lakhmapur (Acheulean and Middle Palaeolithic site) collections are housed in the museum at Ballary and constitute both excavated materials as well as surface collections (Petraglia et al., 2003a and b; Koshy, 2009). This museum also stores many surface-collected tools from Khyad.

The Attirampakkam LCTs under study (Acheulean), are currently distributed among the British Museum and Musée de l'Homme and consist of both excavated (Table 11) and surface finds (Roberts, 1999; Cook and Martingell, 1994). Apart from a sporadic mention of the excavated finds, no detailed publications exist (IAR, 1964-65). Some of the surface collections housed at the State Department of Archaeology, Government of Tamil Nadu, Chennai, were also included in this study. These surface finds have also been ascribed to the Acheulean on the basis of typo-technological features by the collectors.

The tools from Singadivakkam (Middle Palaeolithic site) are housed at the departmental museum of the Department of Sanskrit and Culture at Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya (SCSVM), Kanchipuram, Tamil Nadu, India.

The choice of these assemblages was largely influenced by the focus of the study as well as their availability and accessibility.

3.2 Nature of the assemblages

As mentioned above, the assemblages are widely distributed and uneven in terms of quantity and are from mixed contexts. The handaxes and cleavers form the majority of the LCTs from all the sites, with a negligible number of picks from all the sites of the Malaprabha Valley sites and Singadivakkam. No preforms were noticed.

Although Benkaneri and Lakhmapur has excavated assemblages including cores, flakes etc., these were not considered for the study as the focus was on the LCTs. Khyad surface collections, did not have any flakes and neither were they observed on the site, during the visit in 2018. Cores were however, present but not included for the study.

Singadivakkam collections included chopper tools, flake tools, cores and hammer stones. However, they could not be included in the current study as they form a different aspect and were kept aside for future study.

3.3 Previous studies

The excavated finds from Benkaneri and Lakhmapur have been published, the former very briefly (Petraglia et al., 2003a and b) and they also form part of the study materials of the doctoral thesis of Jinu Koshy (2009) on raw materials and lithic technology.

Some of the lithic tools from Khyad has been previously examined by R.V. Joshi (1955) although mainly typologically based, and also by Jinu Koshy (2009).

Singadivakkam assemblage has not been published with exemption of a few general reports of the findings in the press.

3.4 Assemblage composition

As indicated above, the nature of the study materials is very diverse in terms of quantity, context, and cultural period. The distribution of tools according to the sites are given in Table 3.1.

Site	Handaxes	Cleavers	Picks	Total
Khyad	116	80	4	200
Lakhmapur	50	14	1	65
Benkaneri	25	15	5	45
Attirampakkam	45	20	–	65
Singadivakkam	33	4	4	41
Total	269	133	14	416

Table 3. 1 Distribution of the LCT tool types according to the sites.

The tool types according to the Layers at Lakhmapur and Benkaneri (identified on the basis of previous labelling) are given in Table 3.2 and Table 3.3. The LCT distribution from Attirampakkam according to localities are given in Table 3.4 (from the British Museum acquisition information).

	Handaxe	Cleavers	Picks	Total
L1	8	1	–	9
L2	9	1	–	10
L3	11	4	1	16
Surface and Indeterminate	22	8	–	30
Total	50	14	1	65

Table 3. 2 LCT tool distribution according to the Layers – Lakhmapur.

	Handaxe	Cleavers	Picks	Total
L1	9	4	–	13
L2	3	3	–	6
L3	1	1	1	3
Surface and Indeterminate	12	7	4	23
Total	25	15	5	45

Table 3. 3 LCT tool distribution according to the Layers – Benkaneri.

	Handaxes	Cleavers	Total
Locality I	5	–	5
Locality II	7	1	8
Locality III	8	5	13
Locality V	4	3	7
Surface and indeterminate	21	11	32
Total	45	20	65

Table 3. 4 All museum collection finds for Attirampakkam LCT tool types according to the locality.

3.5 Classification of the tool types

3.5.1 Handaxes

"While the term biface is probably the most widely used in recent literature to encompass all typical Acheulean forms (i.e., picks, knives, cleavers, and bifacial handaxes), it is here advocated that 'handaxe' would be more accurate as a generic term, for in many Acheulean assemblages (particularly in the early African sites), LCTs are often unifacial (rather than bifacial) tools' (de la Torre and Mora; 2005:2).

Handaxe is "characterized by a cutting edge around the entire circumference of the tool, or more rarely around the entire circumference with the exception of the butt. The emphasis in manufacture, if distinguishable, seems to have been upon the point and both edges. Usually bilaterally symmetrical, and more-or-less biconvex in major and minor sections (i.e., along the major and minor axes). Points range from exceedingly acuate to linguate. There is a large variation in size, degree and quality of workmanship, and plan-view, primarily according to the curvature of the edges, the length to width ratio, and the placement of the greatest width relative to the length of the tool" Kleindienst (1962: 85).

3.5.2 Cleavers

Cleavers have a wide distribution spread throughout Africa (with the exception of Nile Valley), the Near East, South Asia, and south-western Europe.

Although initially considered as a "… part of the overall variation within handaxes/bifaces that occasionally emerges from a common technological practice" White (2006:365), it is now increasingly being recognised that cleavers form a distinct morpho-techno-typological group (Herzlinger et al., 2017). Several approaches to the definition of cleavers, its typology and manufacture techniques exist (Tixier, 1958; Biberson, 1961; Bordes, 1961; Kleindienst, 1962; Wymer, 1968; Isaac, 1977; Gilead, 1973; Roe, 2001; Corvinus, 1983; Cranshaw, 1983; Ranov, 2001; Mourre, 2003; White, 2006; Sharon, 2007).

One of the main schools of definition comes from Tixier (1958) which defines cleavers as (predominantly) flake tools with a transverse cutting edge resulting from the intersection of the ventral and dorsal surfaces of a flake. The definition by Gilead (1973) focusses on the working edge properties resulting from the flake blank morphology or from the bifacial retouch on a cobble. Based on the metrical attributes, Roe's (1964, 1968) definition of cleavers is based on the ratio of the width near the working edge to the maximal width of the item (i.e., cleaver edge should measure more than half the implement's breadth). Another definition by Mourre (2003) considered the angle of cleaver edge as an essential functional characteristic and excluded the predetermination of the edge as an intrinsic characteristic.

Cleaver flakes were defined by Kleindienst (1962:100) as "Flakes in the large size range which have a cleaver-bit edge, but which have not been secondarily trimmed. Of the type on which cleavers or other large implements could have been made. Presumably, the shape is due to the type of core used." Accordingly, a large number of cleaver flakes have been identified from India (Corvinus, 1983), and from North Africa (Sharon, 2007).

This study uses the term handaxes and cleavers (which includes tools with predominant unifacial removals on one face and marginal shaping on another). The terms *sensu stricto* and *sensu lato* has been used to describe some handaxes and cleavers. While *sensu stricto* includes the typical classical forms of tool categories with volumetric bifacial reduction, *sensu lato* includes the forms which morphologically show similarity or dissimilarity but do not conform to classical form or strict technological definition and hence are considered 'atypical' in nature. Whenever a handaxe was noticed with shaping occurring only on one face, it was categorized as a uniface.

3.5.3 Picks

It is a tool in which the focus is on the distal 'point'. The cross section is triangular or sometimes quadrangular created by flake removals from two or three working edges (or platforms) in the case of trihedral. The base of the tools is relatively thick. It can be bifacial or unifacial or even largely cortical, with minimal working apart from the tip. Many picks therefore show less overall shaping and symmetry than handaxes.

3.6 Terminology used in this study

Most of the terminologies used in this study are modified adaptations of terminology from Inizan et al., (1999) and Andrefsky (2005).

<u>Blank</u> – The rock type on which a tool can be knapped or shaped directly. Differently struck flakes, cobbles, split cobbles, pebbles, tabular blocks of different angular, sub-angular, rounded, sub-rounded morphologies fall in this category.

<u>Clast</u> – Any piece of rock that could be modified into a tool either directly or on flakes removed from them. They can be of different sizes and shapes and include cobbles, pebbles, blocks, nodules, boulders.

Cobble – Can be round, sub-round, angular and sub-angular, besides flat forms. The Wentworth scale categorized cobbles as bigger (64-256 mm) than pebbles (4-64 mm), the latter often rounded by the action of water.

End-struck flake – Flakes that are struck at the proximal part of the tool, at a perpendicular angle to the length. The length, when measured perpendicular to the striking platform, exceeds or equals the breadth. (Clark and Kleindienst, 1974).

Entame – Opening flake of a cobble with cortical remnants on one surface.

Kombewa flake – Flake with two lower or ventral faces, obtained through Kombewa method of flaking. A Kombewa blank is a complete flake with two ventral faces.

Large Cutting Tool (LCT) – It includes all unifacially and bifacially knapped Acheulean tools, including handaxes, cleavers, knives, picks, core axes, trihedrals, etc. This term emphasizes the cutting edge of the tools.

Morphology – Generally indicating the form including size and shape of the tool. In the context of Geometric Morphometrics, only the shape is considered, exempting the size of the tool.

Notch – A sharp dent, concave with small curvature radius, created by various retouch techniques.

Quartzite – Generalized term for a sandstone that has been recrystallized or cemented.

Retouch - Patterned flaking, with the deliberate intention of altering its form (Clark and Kleindienst, 1974).

Scar removal pattern – In this study, it refers to the directional pattern of shaping the tool, removing flakes in the process of thinning the tool.

Side-struck flake – Flakes that are struck at the lateral edges (in this study, including the ones struck at angles) which result in a morphology with longer width in comparison to the maximum length (Clark and Kleindienst, 1974).

Split cobble – The blanks which display the surface morphology of a cobble on one face and a flat surface on another, achieved when the cobble is split open. This could be intentional or a result of heat spall.

Striking platform – The surface area of the rock piece receiving the force to detach the flake piece. The detached flake will exhibit this point of applied force, generally located at the proximal part of a flake tool.

Tabular blocks – Blocks that are tabular in nature, generally occurring with flat surfaces on either side. In most publications, the terms slabs, tabular slabs etc. have been used intermittently. It was noted that with the use of slabs, blanks could be detached which served as handaxes and cleavers without much secondary flaking and so this blank detachment strategy may have been preferred.

Tranchet blow – A blow struck at an oblique angle, used to resharpen the cleavers and handaxes. Lateral tranchet blow has been used to produce a lateral cutting edge at Acheulean handaxes from Western Europe.

4. CHAPTER IV – METHODOLOGY

To realise the objectives of this study outlined in Chapter I, specific methodologies have been adopted. Before outlining the methodology used, a brief review of the different traditions existing in lithic analysis is given. This will justify and explain their appropriateness of choice in this study. Following this, the protocols for sampling, documentation and subsequent analytical methods and tools are described.

4.1 Lithic Analyses – A brief review with special reference to LCT studies

From its inception, the branch of lithic analysis in Palaeolithic studies have relied on a set of methods to retrieve different aspects of information on the ancient life ways. These methods have changed over time with changing theoretical, methodological and research focus. Different research traditions (English, Spanish, French) have developed different typological and technological approaches over the years. However, data collection by different scholars from different regions remained largely incomparable, arising from differential research focus and ways of documentation.

Typology has been at the forefront of these analyses, identification of *fossile directeurs* often being the basis to culturally and temporally differentiate the assemblages. F. Bordes's typology (1961) of the Lower and Middle Palaeolithic, typology of Olduvai tools by R. Leakey (1971) and that of M. Brezillon (1977), are the initial typological systems. Experimental knapping was also in practise although not on a scientific basis (Johnson, 1978). Typological studies also underwent many modifications with technological and experimental inputs by F. Bordes (Rodríguez, 2004) and application of statistical methods (Tixier, 1991) and use of analytical and structural classifications (Laplace, 1972, 1974). Metrical measurements have been further developed by different scholars (Roe,1994).

A significant development was the *Chaine opératoire* concept introduced by André Leroi-Gourhan (1964) which emphasized the production processes in place of descriptive morphologies to classify the tools. This method was further developed to encompass the tool history from procurement of the raw materials to its final discard. The development of Logical Analytical System (LAS) was another landmark in lithic analysis, in which morphotechnical, morphopotential and morphofunctional components of a tool are believed to influence the final morphology (Carbonell et al.,1983). Boëda's techno-economical and techno-psychological perspectives (Boëda et al., 1990; Boëda, 2013) form the focus of many tool analyses which is integrally based on the former technological and typological analysis.

Recent years with computational advancements have seen increased use of multivariate statistical analysis and morphometric (traditional and geometrical) methods to bring more precision and accuracy to the studies. Methods like photogrammetry, the use of 3D scanners and the geometric morphometric (Herzlinger and Grosman, 2018; Garcia-Medrano et al., 2019, Okumura and Araujo, 2014, among others) has increased the potentiality of data sharing for cross-regional comparisons, increasing the accessibility to data bases. Also, it has significant implications for preservation of museum collections and for educative purposes.

In the presence of different methods, the choice of one over other often limits the scope of understanding the lithic tools and a combined approach is desirable. One such recent example to bring in uniformity in handaxe variability studies is that of the WEAP project developed in the West European context (García-Medrano et.al., 2020a).

Handaxe and cleaver studies have been approached from a multitude of angles. Although shape variability remains at the forefront of many studies (e.g., Ashton and McNabb 1994; McPherron, 1995, 2000; White, 1998), experimental studies and use-wear analysis (e.g., Bello et al., 2009; de Juana et al., 2010) are increasingly being applied. Aspects of cognition and mental template is another area which has caught the attention of many researchers (e.g., Schillinger et al., 2016, García-Medrano et al., 2019), while raw material studies (e.g., Gamble and Marshall, 2001) are also being undertaken.

A literary review was first undertaken to understand the context of the region and sites and the state of art applications. This served as the base on which methodologies and approaches were selected.

In this PhD, both classical techno-typological as well as Geometric Morphometric (GM) approaches have been used to analyse the LCTs from the sites selected as case study (see Chapter II). The choice of these methods was guided by the focus of this research, the availability, accessibility and location of materials, and their nature, but mainly to apply new methodological approaches to the study of LCTs to provide more quantitative data to reconstruct the technological behaviours. While the former approach was guided by previous models of Bordes (1961), Roe (1994), Sharon (2007), Debénath and Dibble (1994), Inizan et al. (1999), the GM approach followed the methodology by Okumaura and Araujo, 2014, and Herzlinger and Grosman (2018).

The methodology followed in this study included 3 main steps: sample selection and preparation, its documentation, and finally application of the different methodological approaches.

4.2 General Sampling protocol – selection and preparation

All the assemblages were sampled in a uniform manner, although they were of different contexts (accumulated by different individual explorations and excavations by institutions over the years) and varying in their quantity (ranged from 50 to 160 tools). As the focus of this study was LCTs, mainly handaxes, cleavers, and picks were selected for analysis. Since assemblages that came from excavated sites (like the Malaprabha Valley sites of Benkaneri and Lakhmapur) and systematic explorations (Singadivakkam), contained besides these heavy-duty tools, cores, flakes and flake tools, preliminary observations on them were noted. LCTs from Singadivakkam and Khyad, being surface collections and due to their limited numbers from the excavated sites, irrespective of their contexts and numbers were added to the initial selection.

All the LCTs were washed, dried, and numbered (except for the British Museum and Musée de l'Homme assemblages). Already catalogued into typologies by these respective museums, they were recorded accordingly and were subjected to a re-examination later. All the available published data and associated discoverers/excavators were consulted for additional information, especially in ascribing tools to their stratigraphic layers (Chapter III) and spits (as in the case of Lakhmapur site), in the case of loss of previous labels.

Following this, all the LCTs were sorted into different classes based on the preliminary typological and technological assessment (Table 12).

4.3 Classical approach – Typological and Technological analysis

As the first step, all the LCTs were systematically oriented typologically with the Dorsal and Ventral faces identified using the classical definitions (in the cases of flake blanks). Consistent attributes (common as well as specific for handaxes and cleavers) were chosen to facilitate meaningful comparisons between different assemblages (Table 3, Article 2, Appendix II). Qualitative and quantitative attributes based on the tool's morphological and technological aspects, along with typological observations, were recorded into a common database. Attributes that could shed information on tool production techniques, morphological preferences, functional aspects, and taphonomic processes were selected.

Attribute analysis for the broken tools, (which were more than half) was not processed. For the specimens in which it was difficult to accurately identify specific traits, the entry was recorded as indeterminate.

All the results are given in total tool number and percentages. The percentages are all rounded to the nearest 0.5. The elongation and refinement are expressed in ratios, while the standard deviation is expressed in numerical terms, and coefficient of variation (Standard variation / mean) is expressed in percentage.

Attributes recorded for classical approach and forms the part of the methodology are summarized in Table 3 of Article 1. (Appendix I).

The classificatory criteria of the attribute are as follows:

Abrasion and Patination – The tools were classified as very fresh or little abraded if the scar ridges appeared clearly, moderately abraded, if there was some rolling detected. In case of heavy weathering or heavily rolled specimens, they were termed as highly abraded. Patination is an important criterion which can shed light on the life history of the tool, including resharpening and/or recycling. Wherever, it was noticed, the location: Dorsal or Ventral, were noted.

Bilateral symmetry – On the basis of visual observation, the presence or absence of symmetry was noted. Wherever the tool showed a roughly symmetrical profile, the term median symmetry was used to denote it.

Blank – Tool blank has a potential influence in the final form, besides playing an important role in the choices made by the knappers at different stages of manufacture. Classified into flakes and non-flakes, the former was identified as end-struck and side-struck on the basis of location of the striking platform, the bulb of percussion (wherever recognisable) and the convexity of the original flake surface. Although special side-struck and angle-struck have been used to describe those flakes struck at an angle by others (Herzlinger and Goren-Inbar, 2020), in this study the information is included within the broad flake categories. Kombewa blanks were also identified and the extent of the Kombewa (ventral face of the larger flake that served as a core) portion noted. Entames or opening cobble flake is recognised by the cortical surface of the cobble and the inner face of the flake. The convexity and cortical nature of both faces were keys to identifying a cobble while split cobble was identified on the basis of absence of a bulb and with very flat ventral surface. Tabular blocks rather than the general term slabs, were used to term the blanks with flat cortical portions on either one or two faces.

Cortex – The presence of cortex on a tool can indicate not only the stage of reduction sequence but also factors like intentional retention for prehensile purposes. If the flakes retain lots of cortex on their dorsal face, they may indicate an earlier stage of reduction while absence of residual cortex can be indicative of later stage (Andrefsky, 2005). Cortex also played an important role in identifying the type of blanks, especially cobbles and tabular blocks. The tools were observed to find out if cortex was present or absent and if present, their location (dorsal/ventral) was noted. This attribute was noted as an ordinal scale; 1 (0 to 1/4), 2 (1/4 to 1/2), 3 (1/2 to 3/4), 4 (3/4 to total).

Cross-section – It is categorised and established as biconvex, biplanar, plano-convex (Figure 17, Appendix III) and others on visual observation. It is an important criterion used for deducing shape attributes.

Dimensions – Following the morphological documentation and evaluation, linear (recorded to the nearest 0.1 mm) and angular measurements were taken. Artefact dimensions/size from the linear measurements can often be related to form and knapping techniques. In this study, only the maximum length (distance from the proximal to the distal end), the maximum width (distance between lateral left and right, perpendicular to the length) and maximum thickness (distance between ventral and dorsal surface) were recorded and mid distance measurements were ignored. The primary linear measurements were then used to derive the elongation (Length/Width) and refinement (Width/Thickness) ratios (Roe 1964, 1968; Debénath and Dibble, 1999). Elongated tools were categorised as all tools with a ratio of 1.5 and above and refined tools were all tools with a ratio of 2.35 and above. Angular measurements were taken at both lateral, and proximal and distal edges. For the lateral sides, to maximize the objectivity, measurements were taken at the mid-point. Angular data can indicate functional aspects of the tool with steep angled edges thought to be suited for handling the tool for scraping action while acute angled edges are associated with cutting actions (Andrefsky 2005).

Dorsal previous flake scar – Significantly, previous scars can give clues to how the flakes were detached from their parent core and thus indicate different core or flake production strategies. Also, their presence and the proportion can throw light on the subsequent shaping intensity and the stage of tool manufacture. Although almost always unrecognisable in cases of invasively shaped tools, wherever it was retained and identified, this was recorded.

Picks – were classified into dihedral or trihedral.

Preservation – All the tools were examined to see if they were complete morphologically, or were broken. In the latter case, the location of the break was noted. Similarly, traces of damage and their intensity on both faces were noted down. This gave important clues on the post-depositional history of the tool.

Raw material – The raw materials were classified based on visual and macroscopical examination and were categorised with the additional help of the published geological studies of the sites and immediate vicinity. As grain size is important to understand mechanical fractures of the raw materials, this attribute was also defined as fine, medium and coarse grained on the basis of surface observation and in cases of breaks, the inner texture was taken as an indicator for the classification.

Striking platform – This attribute gives information on the reduction processes, particularly the preparation strategies for the flake blanks. While the plain and dihedral category was determined from single and double scar facets, facetted represented those with more than 2 scar facets. The presence of cortex helped classify the cortical ones. As the shaping and thinning often results in removal of the striking platform, the removed ones were categorised as indeterminate along with the missing ones.

Shaping and retouches – Apart from general observations on whether the tool was shaped all along the periphery or concentrated on a particular sector, the morphology and type (shallow or deep) of the removals were recorded. The proportion of shaped surface was also ordinally scored: 1 (0 to 1/4), 2 (1/4 to 1/2), 3 (1/2 to 3/4), 4 (3/4 to total). The longest shaping removal was measured (along its flaking axis) and the number of recognisable removals (> 5 mm) counted. The scars and their series of removals were counted for both dorsal and ventral faces. The directional pattern was also noted to identify shaping strategies (Figure 16,

Appendix III). Besides giving information on the knapping sequences, techniques and the type of hammers used, intensity of shaping allows us to estimate the time investment and workmanship skills and quality (Sharon, 2006). Flake scar sequences can be used for technological reconstruction and reduction strategy as shown in the study by Jöris (2006).

The presence of retouches and/or use-wear macro traces and their location was another description included. This attribute was observed for both dorsal and ventral faces.

Tool Morphology – A highly subjective characterization used in classical method, this study has adopted the usage of descriptive terms like ovates, almond-shaped, pear-shaped, triangular and sub-triangular for the handaxes while the cleavers were described having diagonal, straight or convex distal ends and the butt as either square, U- or V-shaped. For the handaxes, the distal edges were also noted as pointed, rounded or transversal.

Wherever difficulties were faced while categorizing tools with both handaxe and cleaver morphology, they were grouped separately as handaxes-cum-cleavers. If the tool presented any specificity regarding its morphological appearance, this was also noted. Besides the attributes recorded, personal observations were noted.

4.4 Geometric Morphometrics

Coined by Robert E. Blackith in 1957, the roots of morphometrics (Greek word *morph*, meaning form, shape and *metrics* meaning measurement) can be traced back to the Pythagorus school as early as 5th c. BC, where lines and junctions of drawings of living organisms formed the basic principles of morphometrics, the form. This is also evident in the later Egyptians pictographs where they used standardised square patterns to form a framework for their carvings of figures. "Mosimann's (1970) paper on allometry, and the 'identification' of the size vector can be said to mark the starting point for a more geometrical approach to morphometrics and one which lies near to the heart of the new geometric morphometrics …" (Elewa, 2010:12).

Geometric morphometrics was a 'revolution', an outcome of the inadequacies of traditional morphometrics to capture morphology from three dimensional objects. It is a set of statistical methods to study relative shape and size (geometry) of the collections of objects in an explicit mathematical framework. The adaptation of GM from Evolutionary Biology, into the field of Archaeology (Okumura and Araujo, 2014) was faced with problems of homology on stone tools, which were unique creations unlike biological specimens where readily identifiable points could be located (Lycett and Chauhan, 2010).

The application of the GM methods to shape analysis of stone tools, although relatively recent, is increasingly becoming an important tool to produce objective, precise, reproducible datasets, and results in the field of lithic analysis.

4.4.1 Geometric Morphometrics – 2D

For the 2D GM outline analysis (detailed in Article 1. Appendix I) only those tools that were unbroken and complete were considered (Table 12). The detailed analytical process has been outlined in Article 1. In summary, the outlines of each tool were photographed and processed in Adobe Photoshop version 2021. The data (semi-landmarks captured from the contours) were then extracted using the Thin Plate Spline (TpS) software (outlined in Article 1, Appendix I) and subsequently subjected to statistical analysis. The analysis was undertaken on both handaxes and cleavers only, as the number of picks available for study was negligible and statistically irrelevant to make comparisons. At first, all the sites were analysed individually, followed by inter-site comparison among and between different cultural sites in each region. Finally, an inter-regional comparison was carried out. Illustrations consisted of the scatterplots displaying the shape distribution in morpho-space along with TpS deformations, which allow visualising hypothetical range of shape variation at different points along the X and Y axis, depicting Principal Component 1 and 2 respectively. The deformed images in TpS format allows us to see the variations from the mean shape, depicted as the lollipop spikes and the bending of the grid allows us to visualise the location of the maximal variation.

4.4.2 Geometric Morphometrics – 3D

For the 3D GM analysis, the 3D scans were first obtained and processed using Geomagic and AGMT-3D software (outlined in Article 2. Appendix II) for detailed description). Although an attempt was made to scan the maximum number of tools, many tools ended up with poor resolution in the 3D models, partly due to the raw material surface, especially the coarse-grained quartzite. Technical problems encountered with the working of the Next Engine scanner also reduced the possibility to extract more scans. Along with the time constraints, this resulted in a random sampling from each assemblage, mainly based on quality (Table 12). After the analysis on the 3D scans with the AGMT-3D software, inherent statistical tests were carried out and relevant graphical, numerical, and textual information produced were extracted and interpreted. Illustrations include the warped images, with colour codes to help visualise the hypothetical changes in shape and location of the variation on the tool. Mean shapes of both handaxe and cleaver tools on different blank types and with different distal edge morphologies were extracted for all type groups with more than 2 specimens. Similarly, only groups with more than 2 specimens were included for statistical analysis of Wilcoxon Rank sum test on inter-point distance between mean shapes. All the individual sites with handaxes and cleavers were treated separately first, followed by an inter-site comparison and finally an inter-regional comparison. All the numbers of tools, chosen for classical and Geometric Morphometric analysis, according to typology and site is given in Table 4.1.

Sites	**Classical Analysis**			**2D Geometric Morphometric Analysis**		**3D Geometric Morphometric Analysis**	
	Handaxes	Cleavers	Picks	Handaxes	Cleavers	Handaxes	Cleavers
Khyad	116	80	4	113	90	63	45
Lakhmapur	50	14	1	48	14	18	10
Benkaneri	25	15	5	22	15	22	11
Attirampakkam	45	20	–	40	19	14	10
Singadivakkam	33	4	4	33	4	33	4
Total	269	133	14	256	142	150	80

Table 4. 1 Number of LCTs considered for each type of analysis – Classical and Geometric Morphometrics (2D and 3D).

4.5 Documentation and Analytical tools

4.5.1 Equipments

Linear measurements were taken using a digital calliper while the angular measurements were taken with a goniometer. Nikon Digital Camera D5600 was used to take photographs of all the tools, with a metrical scale placed next to them. A portable Next Engine 3D Studio HD was used to acquire the 3D scans.

4.5.2 Data entry, processing, and software used

Different software assisted in the data collection, processing, and analytical treatment. The database was stored in Microsoft Excel sheet (version 2000) and for processing this, both Microsoft software and PAST (version 2.3) (Hammer and Harper, 2006) were used. The digital images were all processed in Adobe Photoshop version 2021.

For the 2D GM method, TpS software were used. TpS Util and TpS Dig were used to process the data and collect the 2D coordinates.

The 3D images were initially processed in the Next Engine software, followed by the Geomagic Studio version 2013 (shorturl.at/yAER3) to reduce the background noise.

After this, the software Artifact-3D (Grosman et al., 2008) was used to extract the automatic scar delineation. Artifact Geomorph Toolbox 3D (AGMT-3D) version 3.01 (shorturl.at/kmHO3) was used to process the data further to obtain the statistical and graphical outputs.

4.6 Statistical analysis

Statistical analysis brings accuracy and precision in quantifying and comparing assemblages. From the linear measurements, mean, standard deviation (gives the average amount of variability within the assemblage in numbers), and coefficient of variation percentage (standard deviation/mean×100) were all extracted using PAST. A correlation test in Microsoft Excel version 2000, was carried out to assess the correlation between elongation and refinement. Summary statistics of the linear measurements of handaxes and cleavers were extracted using PAST (version 2.3) (Hammer and Harper, 2006).

Multivariate statistical procedures and analysis were carried out for both 2D and 3D GM method. The principal methods include the Procrustes Analysis and Principal Component Analysis (PCA).

Procrustes analysis serves as a superimposition procedure. It helps rotate, rescale, and reorient the tools on the basis of their centroid (mean value) exempting the size factor.

The PCA is used to reduce the data dimensionality and detect the main axis of variability within a sample. It produces a number of components (i.e., non-correlated perpendicular axes in shape space) equal to the number of items in the sample minus one (Herzlinger and Grosman, 2018). It is sorted in descending order according to the proportion of variability that they explain. Each principal component (PC) reflects a specific shape trend, a mutual change in the values of a number of homologous landmarks. Each item receives a value for each PC, which is based on the values of its relevant landmark coordinates in relation to the shape trend described by that particular PC. The AGMT-3D software's inbuilt statistical tools (especially the Wilcoxon Rank-Sum Significance Test, a non-parametric alternative to two sample t-test) were also used.

4.7 Graphical and tabular representation

Photographs, drawings (diacretic), and statistical results in the form of scatterplots, distribution charts, box plots, were used in depicting the tools and the data extracted and analysed. A schematic diagram was used to illustrate the reduction sequences. All the photographs were processed using Adobe Photoshop version 2021 while the statistical results and illustrations were extracted using Microsoft Excel, PAST and the inbuilt programs within the AGMT-3D software.

For the 2D and 3D, the illustrations include the deformed and warped images along the PC axis, besides the mean shape comparison and scatterplot depicting the distribution of shapes in morpho-space.

While the classical approach has been largely followed in Indian Palaeolithic research, only a handful of studies have attempted to adopt newer methodologies like the GM shape analysis; Soanian cores (Lycett, 2007), bifaces from Patpara (Shipton et al., 2013) and Hunsgi-Baichbal Valley (Shipton, 2013). A combination of both 2D and 3D along with classical techno-typological methods is applied for the first time, through this study on tools from southern Peninsular India on both excavated and surface collections from sites of Karnataka and Tamil Nadu.

5. CHAPTER V – RESULTS

5.1 Classical Analysis - Handaxes and Cleavers – Malaprabha Valley

5.1.1 Assemblage

A total number of 191 handaxes and 109 cleavers were studied from the sites of Khyad, Lakhmapur and Benkaneri. While the first site tools were all surface collected, the others are a mix of surface and excavated contexts. The distribution of the large cutting tools (LCTs), mainly handaxes and cleavers, across the three sites of Khyad, Lakhmapur and Benkaneri in the Malaprabha Valley shows a higher density at Khyad and lesser numbers in Lakhmapur and Benkaneri (Table 5.1). There were 5 unifaces from Khyad and 3 unifaces from Lakhmapur. Predominantly unifacial handaxes also existed (n=12) at this site, as also at Lakhmapur (n=3) and Benkaneri (n=3).

Site	Handaxes	Cleavers
Khyad	n=116	n=80
Lakhmapur	n=50	n=14
Benkaneri	n=25	n=15
Total	n=191	n=109

Table 5. 1 Distribution of handaxes and cleavers by site, Malaprabha Valley.

This trend of the decrease in LCTs in Middle Palaeolithic sites is in conformity with the general characteristics of the Indian Middle Palaeolithic noticed elsewhere (Paddayya, 2007; Shipton et al., 2014).

5.1.2 Preservation

Majority of the cleavers and handaxes seem to be complete in Khyad and Lakhmapur but in Benkaneri more than one fourth of the handaxes were broken (Table 5.2). Khyad seemed to have the least broken number of LCTs indicating its undisturbed nature. As assessed by Korisettar (personal communication), the river Malaprabha came into existence only towards the end of the Pleistocene and the current channel running along the site, with its low gradient nature, resulted in little movement of the tools. The abrasion observed on the tools occurred *in situ*, caused by the running water.

	Khyad (n = 196)		**Lakhmapur (n = 64)**		**Benkaneri (n = 40)**	
Preservation	Handaxes (n=116)	Cleavers (n=80)	Handaxes (n=50)	Cleavers (n=14)	Handaxes (n=25)	Cleavers (n=15)
Complete/Broken						
Complete	96% (n=111)	96% (n=77)	94% (n=47)	86% (n=12)	72% (n=18)	100% (n=15)
Broken	4% (n=5)	4% (n=3)	6% (n=3)	14% (n=2)	28% (n=7)	–
Abrasion						
Low	23% (n=27)	39% (n=31)	74% (n=37)	64% (n=9)	80% (n=20)	67% (n=10)
Medium	52% (n=60)	35% (n=28)	20% (n=10)	14% (n=2)	20% (n=5)	27% (n=4)
High	25% (n=29)	26% (n=21)	6% (n=3)	21% (n=3)	–	7% (n=1)
Patination						
Patinated	45% (n=52)	45% (n=36)	22% (n=11)	57% (n=8)	8% (n=2)	27% (n=4)
Unpatinated	55% (n=64)	55% (n=44)	78% (n=39)	43% (n=6)	92% (n=23)	73% (n=11)

Table 5. 2 Nature of preservation, morphology (complete/broken), abrasion (low, medium and high), patination (patinated, unpatinated) – handaxes and cleavers, Malaprabha Valley sites.

5.1.3 Raw material, Clasts and Blank Type

A preference for quartzite of the fine-grained variety was observed for all the handaxes and cleavers (Table 5.3). These rocks were locally exploited from the Lokapur Subgroup of Kaladgi Supergroup escarpments (Koshy, 2009:100).

	Khyad (n = 196)		**Lakhmapur (n = 64)**		**Benkaneri (n = 40)**	
Raw material texture	Handaxes (n=116)	Cleavers (n=80)	Handaxes (n=50)	Cleavers (n=14)	Handaxes (n=25)	Cleavers (n=15)
Fine-grained	58% (n=67)	70% (n=56)	74% (n=37)	93% (n=13)	92% (n=23)	75% (n=11)
Medium grained	22% (n=26)	25% (n=20)	20% (n=10)	7% (n=1)	8% (n=2)	25% (n=4)
Coarse-grained	20% (n=23)	5% (n=4)	6% (n=3)	–	–	–

Table 5. 3 Raw material texture (fine-grained, medium grained, coarse-grained) – handaxes and cleavers, Malaprabha Valley sites.

The cores were available in the form of tabular blocks (occurring as a result of weathering of the quartzite beddings), and as cobbles in the colluvium deposits (Figure 5.1).

Figure 5. 1 Different types of cores for LCTs – Cobbles and Tabular blocks at Benkaneri (A and B) and Cobbles at Khyad (C).

Present in varying shapes and sizes, from angular and sub-angular to tabular forms, these cores were selected for making both cleavers and handaxes. They were directly shaped into the finished tools or flakes removed from them were shaped into tools. Only 2 handaxes on quartz were noted at Khyad (Figure 5.2).

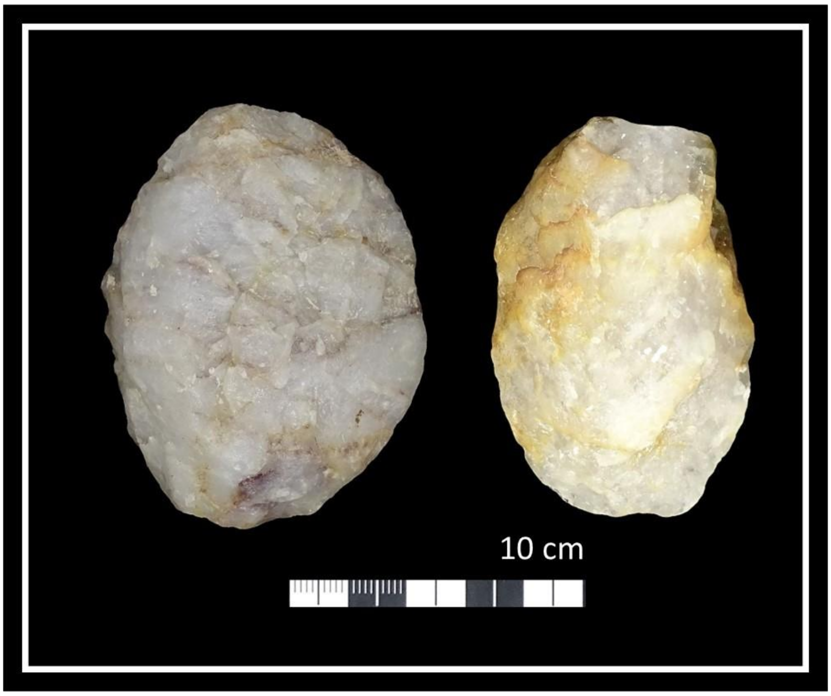


Figure 5. 2 Two handaxes on quartz raw material, Khyad.

The increased use of flakes, especially end-struck flakes, as blanks for handaxes in comparison with cobbles, split cobbles, pebbles, and tabular blocks is attested at the sites of Lakhmapur and Benkaneri (Table 5.4).

	Khyad (n = 196)		**Lakhmapur (n = 64)**		**Benkaneri (n = 40)**	
Type of blank	Handaxes (n=116)	Cleavers (n=80)	Handaxes (n=50)	Cleavers (n=14)	Handaxes (n=25)	Cleavers (n=15)
Cobble	12% (n=14)	5% (n=4)	6% (n=3)	7% (n=1)	12% (n=3)	–
Split cobble	7% (n=8)	–	6% (n=3)	–	–	–
Entame	3% (n=3)	5% (n=4)	–	–	–	–
Pebble	3% (n=3)	–	–	–	–	–
End-struck flake	14% (n=16)	38% (n=30)	32% (n=16)	29% (n=4)	44% (n=11)	40% (n=6)
Side-struck flake	19% (n=22)	35% (n=28)	6% (n=3)	7% (n=1)	12% (n=3)	13% (n=2)
Kombewa flake	–	–	–	7% (n=1)	–	13% (n=2)
Tabular block	11% (n=13)	4% (n=3)	18% (n=9)	14% (n=2)	32% (n=8)	27% (n=4)
Indeterminate	32% (n=37)	14% (n=11)	32% (n=16)	36% (n=5)	–	7% (n=1)

Table 5. 4 Type of blanks – handaxes and cleavers, Malaprabha Valley sites.

For the cleavers, a larger number were shaped on flakes, both end-struck and side-struck, at the Acheulean site of Khyad when compared to the handaxes. One cleaver and one handaxe with a steep (backed) edge, probably a result of shaping is observed from Lakhmapur (Figure 5.3).

Figure 5. 3 Example of a handaxe (A) and a cleaver (B) with backed edge from Lakhmapur

Benkaneri and Lakhmapur, a large number of LCTs were on tabular blocks. Compared to Khyad, these sites also had lesser variance with regard to the type of blanks for LCTs. The presence of Kombewa method is only observed in the Lakhmapur and Benkaneri assemblages, with the latter having the greatest number of cleavers on Kombewa flakes. This is in contrast to other sites in India, where cleavers on Kombewa flakes are regularly present at Acheulean sites (Agarwal, 2012). For the tabular blocks, slab-slicing method (Figure 5.4), attested at sites of Isampur (Shipton et al., 2015) could have been used to extract both end-struck and side-struck flakes for *façonnage* of flake tools, and smaller sized tabular blocks could have been used to make tools by debitage. Simple alternate bifacial knapping and SSDA ("*Système par surface de débitage alternée*" (Forestier, 1993) method seems to have been the methods used at these sites.

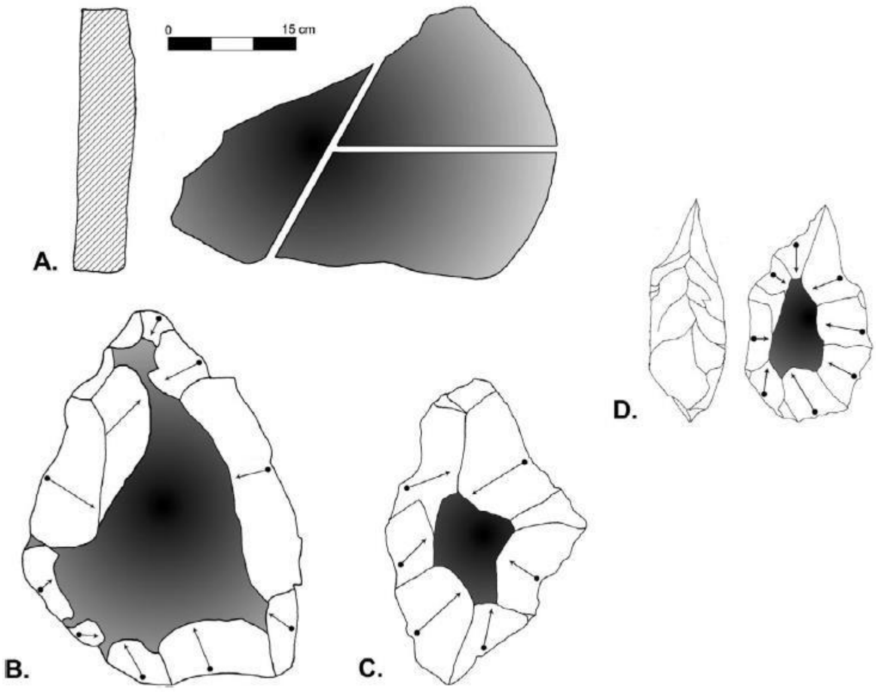


Figure 5. 4 A model of handaxe reduction at Isampur Quarry: A) selection of block 4-8 cm in thickness, which is then split into manageable pieces; B) bifacial reduction of one of the block fragments; C) reduction to biface preform; D) finished handaxe (after Shipton et al., 2015).

For a large number of LCTs on flake blanks, the nature of the striking platform could not be determined due to the invasive shaping thinning the butt, often including its intentional removal. Wherever it could be noted, the striking platform seems to be plain with a single surface for the majority of the tools. However, dihedral platforms were also observed for handaxes at all sites and for cleavers at Khyad and Benkaneri. Facetted striking platforms were represented only on handaxes from Khyad and Lakhmapur (Table 5.5).

	Khyad (n = 166)		**Lakhmapur (n = 58)**		**Benkaneri (n = 37)**	
Nature of striking platform	Handaxes (n=90)	Cleavers (n=76)	Handaxes (n=44)	Cleavers (n=13)	Handaxes (n=22)	Cleavers (n=15)
Cortical	10% (n=9)	8% (n=6)	11% (n=5)	–	5% (n=1)	–
Plain	29% (n=26)	50% (n=38)	18% (n=8)	15% (n=2)	14% (n=3)	40% (n=6)
Dihedral	2% (n=2)	1% (n=1)	2% (n=1)	–	5% (n=1)	7% (n=1)
Facetted	2% (n=2)	–	2% (n=1)	–	–	–
Indeterminate	49% (n=44)	32% (n=24)	66% (n=29)	46% (n=6)	77% (n=17)	53% (n=8)
Absent	8% (n=7)	9% (n=7)	–	38% (n=5)	–	–

Table 5. 5 Nature of striking platform for all flake blanks (end-struck, side-struck, entame, Kombewa flakes and tabular blocks) – handaxes and cleavers, Malaprabha Valley sites.

The reduction sequence finds similarities in all the sites. Cobbles, tabular blocks, and flakes were directly transformed into complete tools or were used to remove flakes, which could then be shaped into the tools.

5.1.4 Shaping

At all the three sites, both bifacial and unifacial strategies are attested among the handaxes and cleavers.

Radial (convergent) shaping as well as three-directional shaping (Figures 5.5 A and B and Figures 5.6 A, B and C) seems to have been preferred for both handaxes and cleavers respectively (Tables 5.6 and 5.7).

	Khyad (n = 196)		**Lakhmapur (n = 64)**		**Benkaneri (n = 40)**	
Dorsal removal pattern	Handaxes (n=116)	Cleavers (n=80)	Handaxes (n=50)	Cleavers (n=14)	Handaxes (n=25)	Cleavers (n=15)
Convergent	49% (n=57)	29% (n=23)	66% (n=33)	7% (n=1)	52% (n=13)	13% (n=2)
Three-directional	35% (n=41)	44% (n=35)	30% (n=15)	64% (n=9)	44% (n=11)	47% (n=7)
Orthogonal	4% (n=5)	10% (n=8)	2% (n=1)	7% (n=1)	4% (n=1)	7% (n=1)
Bidirectional	9% (n=10)	13% (n=10)	2% (n=1)	7% (n=1)	–	20% (n=3)
Unidirectional	1% (n=1)	3% (n=2)	–	7% (n=1)	–	7% (n=1)
Unipolar, longitudinal	1% (n=1)	3% (n=2)	–	–	–	–
Multidirectional	–	–	–	7% (n=1)	–	–
Indeterminate	1% (n=1)	–	–	–	–	7% (n=1)

Table 5. 6 Shaping removal patterns on the dorsal face – handaxes and cleavers, Malaprabha Valley sites.

	Khyad (n = 196)		**Lakhmapur (n = 64)**		**Benkaneri (n = 40)**	
Ventral removal pattern	Handaxes (n=116)	Cleavers (n=80)	Handaxes (n=50)	Cleavers (n=14)	Handaxes (n=25)	Cleavers (n=15)
Convergent	54% (n=63)	8% (n=6)	30% (n=15)	21% (n=3)	32% (n=8)	13% (n=2)
Three-directional	34% (n=39)	38% (n=30)	34% (n=17)	37% (n=5)	44% (n=11)	33% (n=5)
Orthogonal	4% (n=5)	15% (n=12)	4% (n=2)	7% (n=1)	12% (n=3)	20% (n=3)
Bidirectional	7% (n=8)	14% (n=11)	14% (n=7)	14% (n=2)	4% (n=1)	20% (n=3)
Unidirectional	–	11% (n=9)	6% (n=3)	14% (n=2)	–	7% (n=1)
Multidirectional	–	–	6% (n=3)	–	4% (n=1)	–
Indeterminate	1% (n=1)	1% (n=1)	2% (n=1)	–	–	7% (n=1)
No removals	–	14% (n=11)	4% (n=2)	7% (n=1)	4% (n=1)	–

Table 5. 7 Shaping removal patterns on the ventral face – handaxes and cleavers from Malaprabha Valley sites.

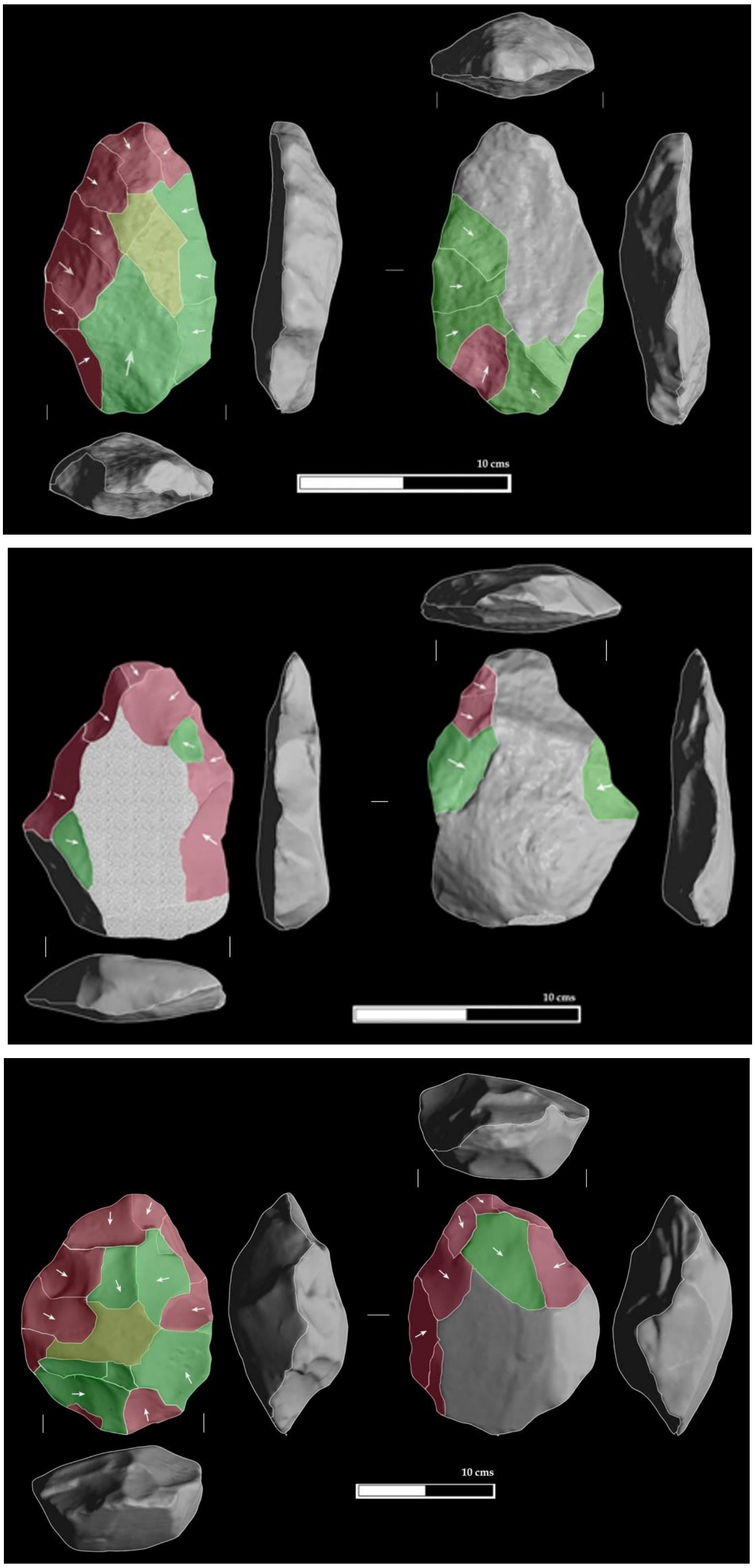


Figure 5. 5 A. Handaxes from Khyad showing the shaping patterns and the series of shaping removals. Last series of removal, Second series of removal, First series of removal, Cortical surface, Unflaked surface.

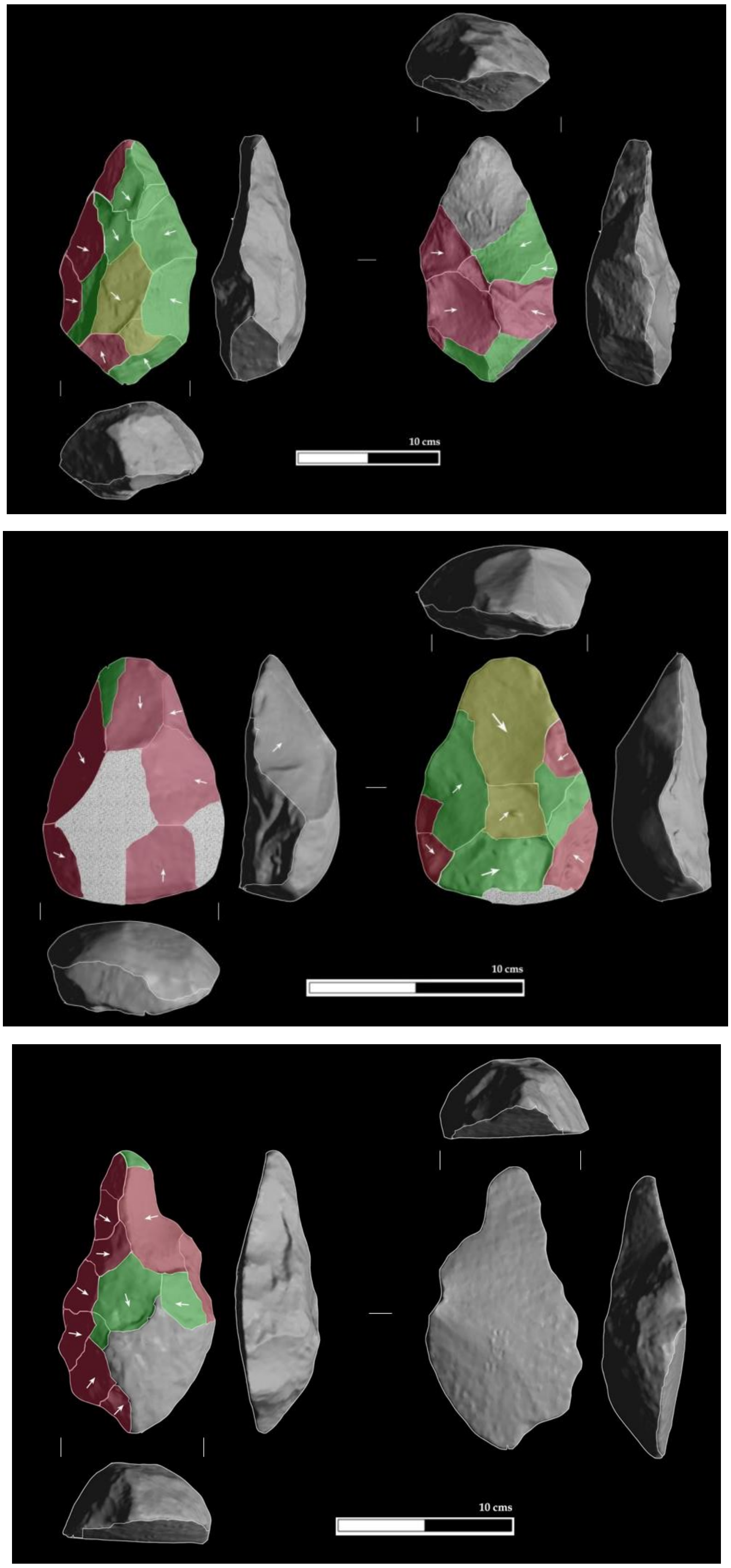


Figure 5.5 B. Handaxes from Lakhmapur showing the shaping patterns and the series of shaping removals. Last series of removal, Second series of removal, First series of removal, Cortical surface, Unflaked surface.

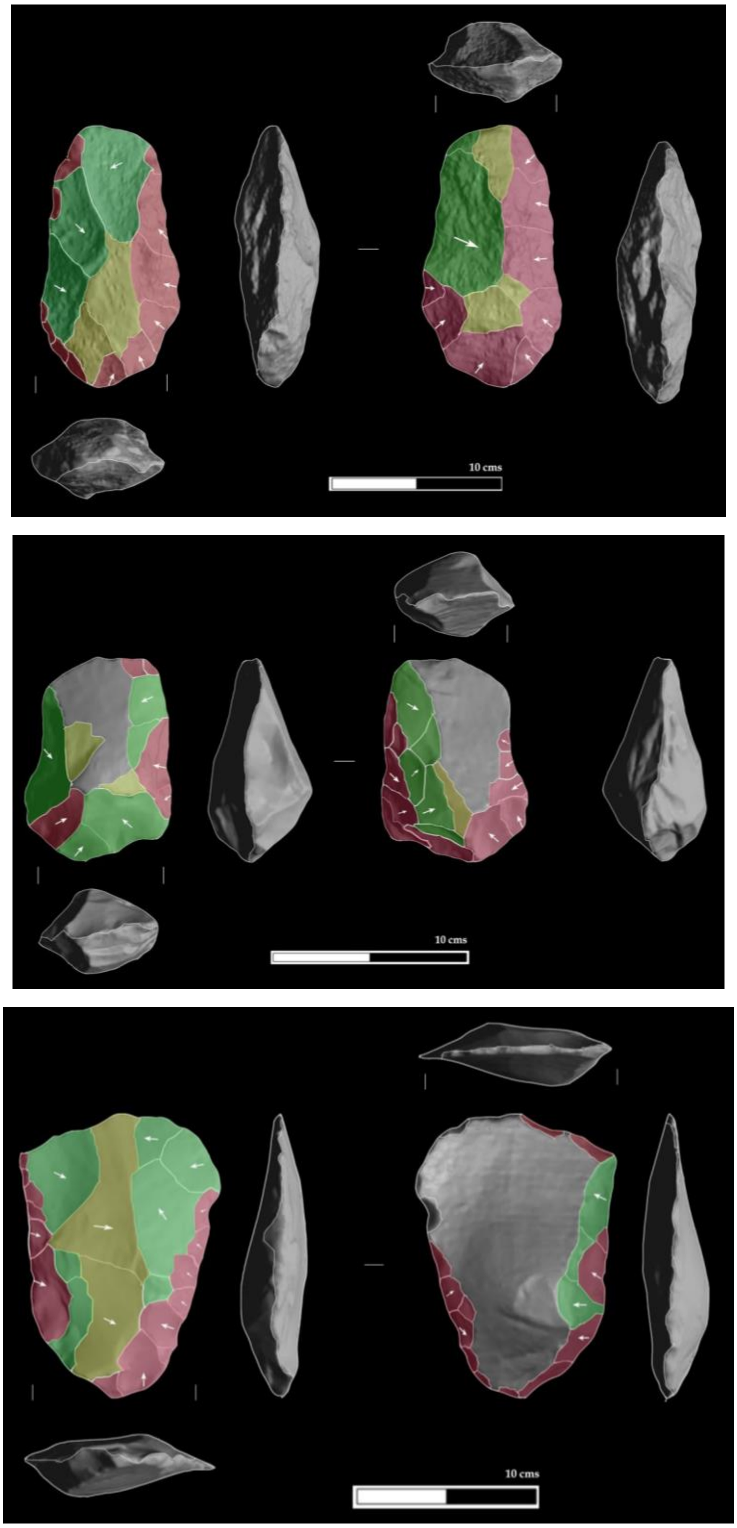


Figure 5. 6 A. Cleavers from Khyad showing the shaping patterns and the series of shaping removals. Last series of removal, Second series of removal, First series of removal, Unflaked surface.

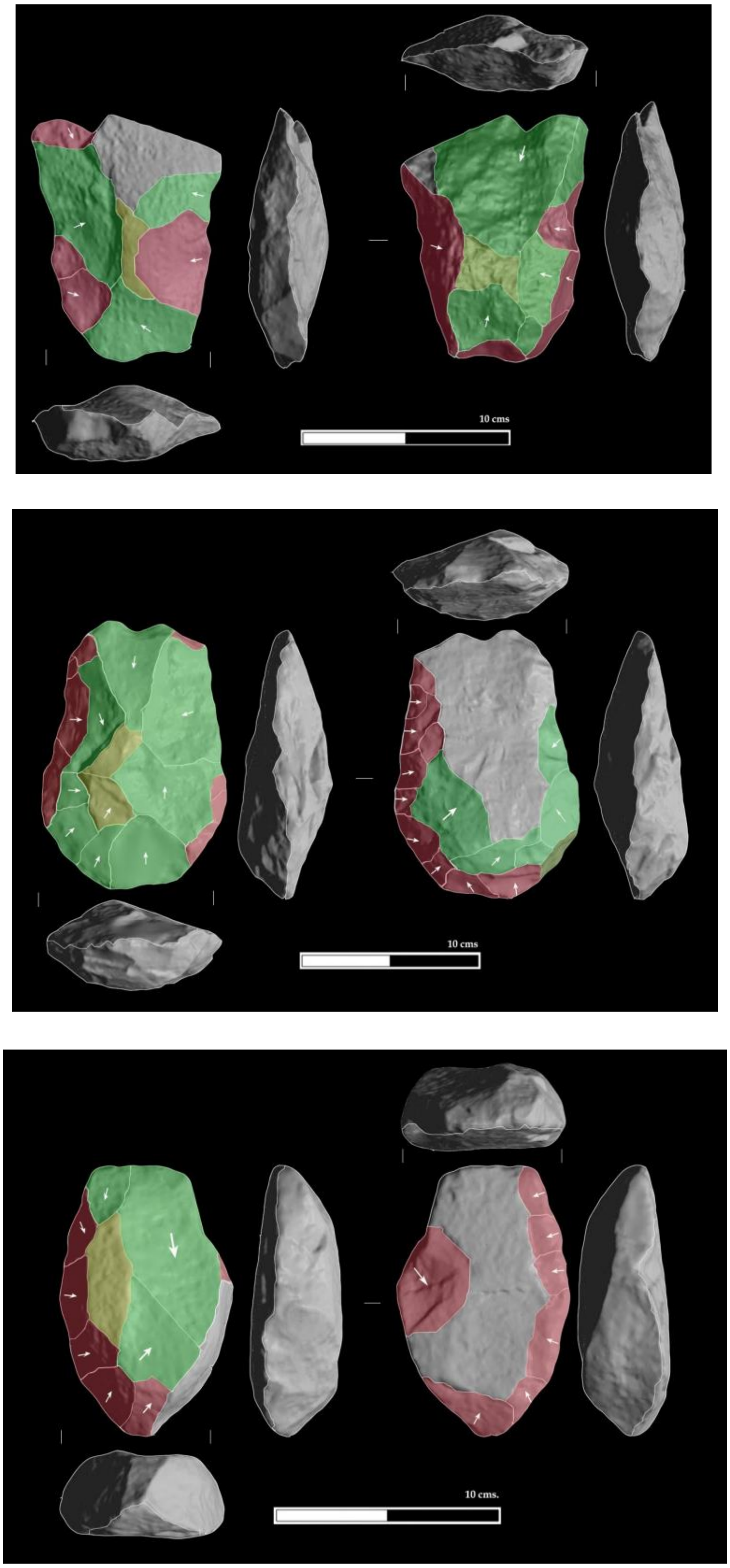


Figure 5.6 B. Cleavers from Lakhmapur showing the shaping patterns and the series of shaping removals. Last series of removal , Second series of removal , First series of removal , Unflaked surface .

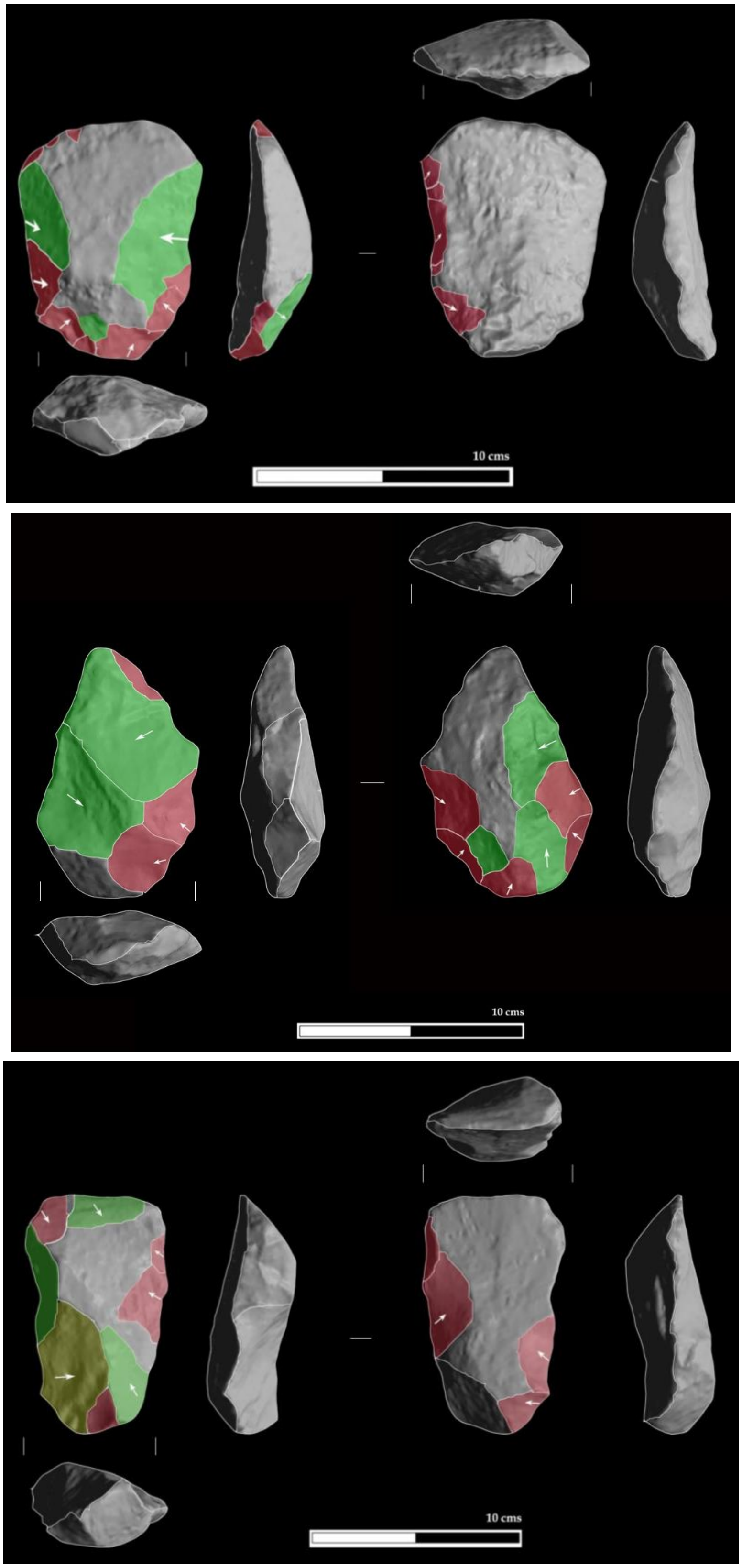


Figure 5.6 C. Cleavers from Benkaneri showing the shaping patterns and the series of shaping removals. Last series of removal, Second series of removal, First series of removal, Cortical surface , Unflaked surface.

Removals were both shallow and deep in nature, attesting to the use of hard and soft hammers. At Khyad, for the handaxes, on an average 35 removals could be observed while for the cleavers this ranged from 2 to 13 removals (between 26-65 mm long for the cleavers and 20-57 mm for the handaxes). At Lakhmapur, invasive removals ranging from 3 to 9 were observed on cleavers covering up to more than 3 quarters of the tool. For the handaxes, the shaping invasiveness was the same (up to 4/5 on an ordinal scale), with 6 removals on an average (between 2 to 8 mm long). Benkaneri cleavers had 2 to 10 removals ranging from 17-73 mm on the cleavers while for the handaxes, the removals ranging from 5 mm to 68 mm long, covered most of the tool surface with an average of 4-5 removals.

On an average the removals were mostly limited to one series. A large majority of the LCTs were shaped either marginally or invasively, all along the periphery, especially the handaxes. A large number of handaxes were retouched including tranchet removals (Figure 5.7 and 5.8).

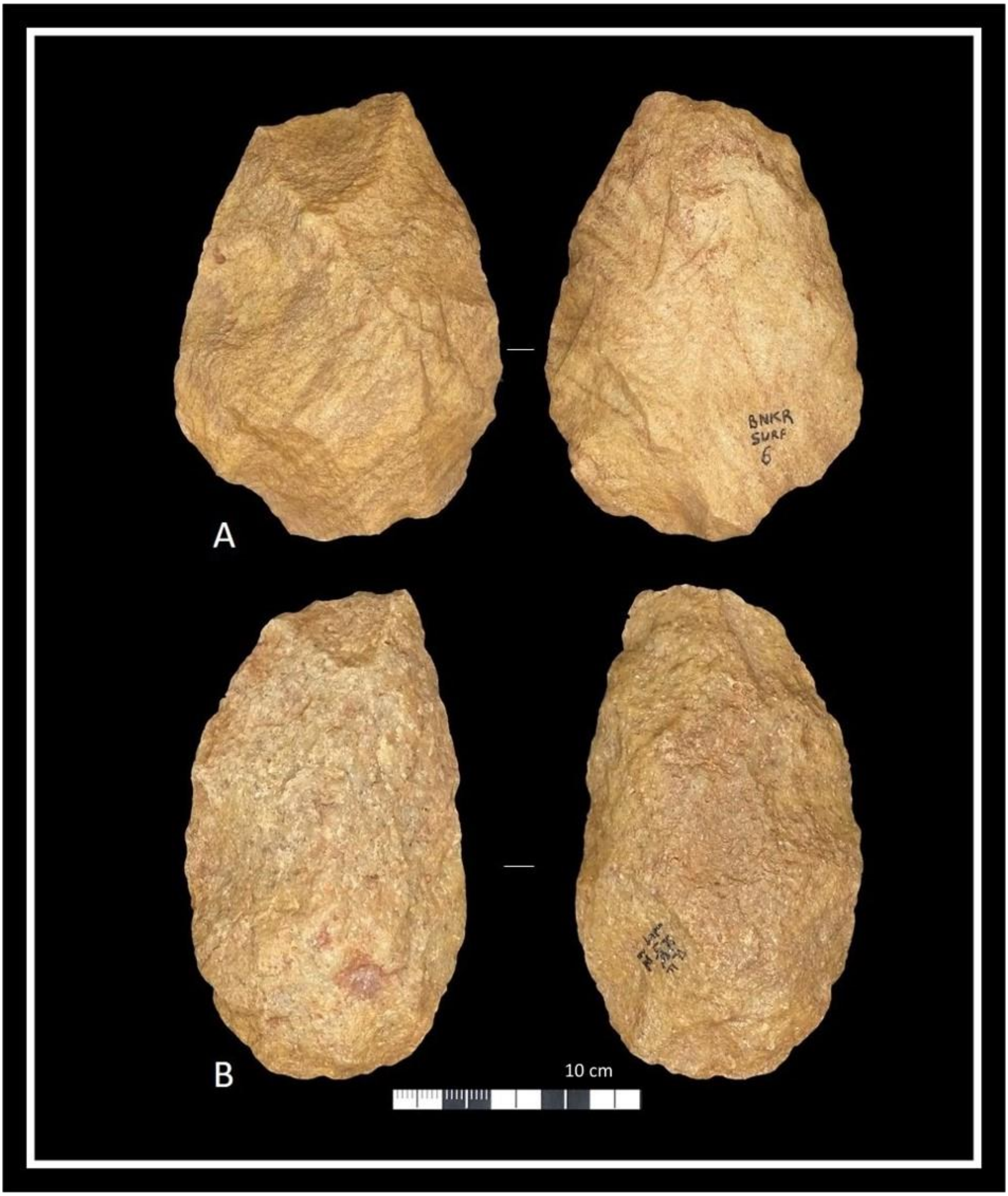


Figure 5. 7 Handaxe from Lakhmapur (A) and Benkaneri (B) showing tranchet removals.

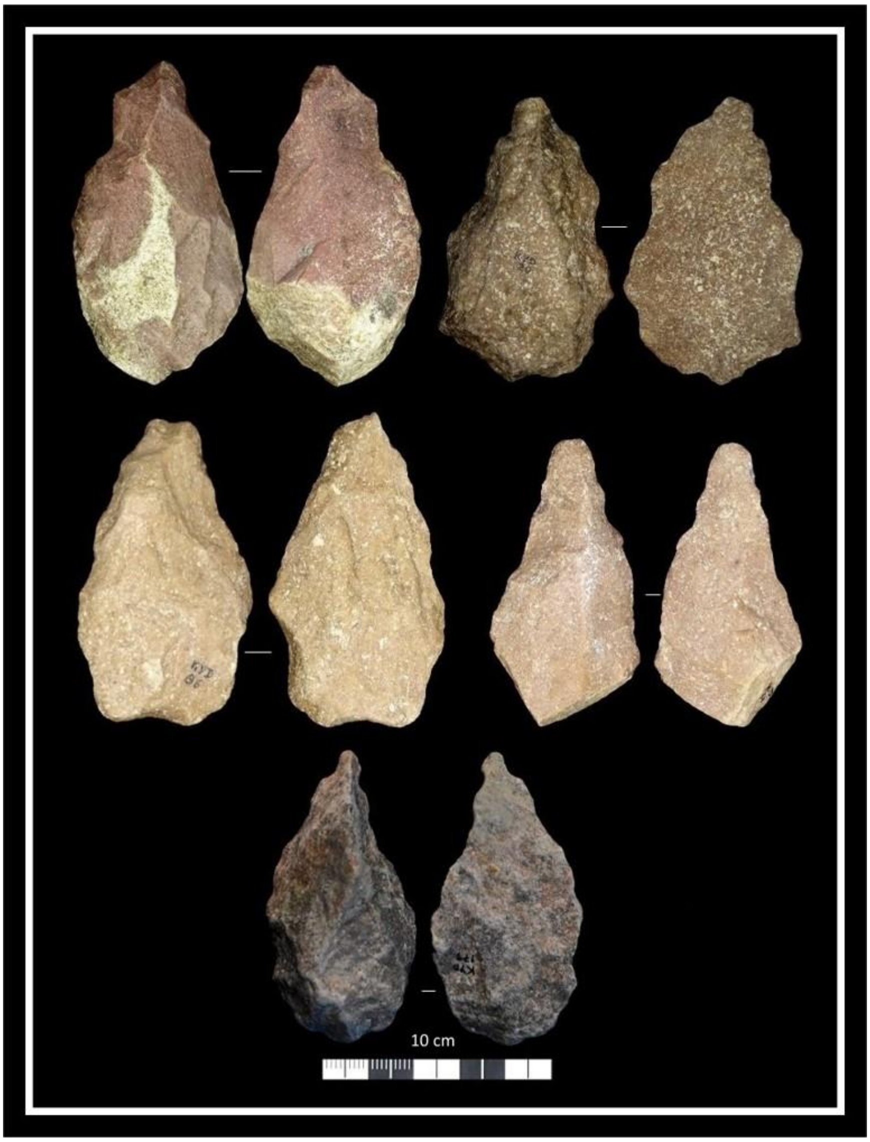


Figure 5. 8 Retouched handaxes from Khyad.

Cleaver distal edge was formed in different ways, with different combinations:

1. Using the dorsal previous scar and laterally retouched ventral face to form the cutting edge.
2. Using the dorsal previous scar and ventral unretouched face to form the cutting edge (Figure 5.19 C).
3. Using a distal longitudinal removal on the dorsal face and unretouched ventral face (Figure 5.19 B).

The presence of cortical surface on LCTs was mainly attested in Khyad where a large number of blanks included cobbles and entames (Table 5.8). Cortical striking platform was noticed for most of these tools. At Lakhmapur and Benkaneri, the cortex was present on the tabular blocks selected as blanks, with most of it located at the proximal end as striking platform and also on the dorsal and ventral surfaces.

	Khyad (n = 196)		Lakhmapur (n = 64)		Benkaneri (n = 40)	
Presence and Absence of Cortex	Handaxes (n=116)	Cleavers (n=80)	Handaxes (n=50)	Cleavers (n=14)	Handaxes (n=25)	Cleavers (n=15)
Cortex	34% (n=39)	11% (n=9)	28% (n=14)	7% (n=1)	24% (n=6)	7% (n=1)
No cortex	66% (n=77)	89% (n=71)	72% (n=36)	93% (n=13)	76% (n=19)	93% (n=14)

Table 5. 8 Presence and absence of cortex - handaxes and cleavers, Malaprabha Valley sites.

5.1.5 Morphology of the edges

Both the lateral and proximal edges of handaxes and cleavers showed a preponderance of obliquity at all the sites. Distal edges showed most tools having cutting edges (Table 5.11). However, interestingly, a number of handaxes and cleavers from all sites have a cutting edge in both lateral and proximal positions (Tables 5.9, 5.10 and 5.12). The presence of composite cleavers at Khyad with more than one cutting edge indicates that these tools were utilized in multifunctional ways.

This type of shaping might have been performed right from the first time of tool making or at a later stage by transformation through retouching, possibly at different moments. Aspects of recycling is also observed through an example of a highly rolled cleaver transformed into a handaxe, at Khyad.

	Khyad (n = 196)		Lakhmapur (n = 64)		Benkaneri (n = 40)	
Lateral left-side angle	Handaxes (n=116)	Cleavers (n=80)	Handaxes (n=50)	Cleavers (n=14)	Handaxes (n=25)	Cleavers (n=15)
< 60°	9% (n=10)	13% (n=10)	8% (n=4)	–	4% (n=1)	–
60°-80°	68% (n=79)	61% (n=49)	68% (n=34)	79% (n=11)	52% (n=13)	73% (n=11)
80°-110°	23% (n=27)	26% (n=21)	24% (n=12)	21% (n=3)	44% (n=11)	27% (n=4)

Table 5. 9 Lateral left-side angle – handaxes and cleavers, Malaprabha Valley sites.

	Khyad (n = 196)		**Lakhmapur (n = 64)**		**Benkaneri (n = 40)**	
Lateral right-side angle	Handaxes (n=116)	Cleavers (n=80)	Handaxes (n=50)	Cleavers (n=14)	Handaxes (n=25)	Cleavers (n=15)
< 60°	8% (n=9)	11% (n=9)	16% (n=8)	14% (n=2)	–	27% (n=4)
60°-80°	73% (n=85)	60% (n=48)	68% (n=34)	71% (n=10)	48% (n=12)	47% (n=7)
80°-110°	19% (n=22)	29% (n=23)	16% (n=8)	14% (n=2)	52% (n=13)	27% (n=4)

Table 5. 10 Lateral right-side angle – handaxes and cleavers, Malaprabha Valley sites.

	Khyad (n = 196)		**Lakhmapur (n = 64)**		**Benkaneri (n = 40)**	
Distal end angle	Handaxes (n=116)	Cleavers (n=80)	Handaxes (n=50)	Cleavers (n=14)	Handaxes (n=25)	Cleavers (n=15)
< 60°	78% (n=90)	90% (n=72)	60% (n=30)	93% (n=13)	64% (n=16)	60% (n=9)
60°-80°	16% (n=19)	8% (n=6)	36% (n=18)	7% (n=1)	20% (n=5)	20% (n=3)
80°-110°	6% (n=7)	2% (n=2)	4% (n=2)	–	16% (n=4)	20% (n=3)

Table 5. 11 Distal edge angle – handaxes and cleavers, Malaprabha Valley sites.

	Khyad (n = 196)		**Lakhmapur (n = 64)**		**Benkaneri (n = 40)**	
Proximal end angle	Handaxes (n=116)	Cleavers (n=80)	Handaxes (n=50)	Cleavers (n=14)	Handaxes (n=25)	Cleavers (n=15)
< 60°	17% (n=20)	21% (n=17)	20% (n=10)	7% (n=1)	4% (n=1)	13% (n=2)
60°-80°	63% (n=73)	60% (n=48)	50% (n=25)	71% (n=10)	44% (n=11)	20% (n=3)
80°-110°	20% (n=23)	19% (n=15)	28% (n=14)	21% (n=3)	52% (n=13)	67% (n=10)
> 110°	–	–	2% (n=1)	–	–	–

Table 5. 12 Proximal edge angle – handaxes and cleavers, Malaprabha Valley sites.

5.1.6 Outline and Symmetry

At Benkaneri most of the LCTs display a biconvex cross-section while at Khyad and Lakhmapur, majority of them show a plano-convex cross-section (Table 5.13). Both the sites of Khyad and Lakhmapur yielded more symmetrical handaxes and cleavers in plan-view when compared to Benkaneri (Table 5.14). Ovates, elongated ovates, triangular, sub-triangular, cordiform, almond shaped, pear shaped handaxes all can be identified from these sites. Cleavers varied with U/V/angled butts and with convex, convergent, diagonal and straight distal edges.

	Khyad (n = 196)		**Lakhmapur (n = 64)**		**Benkaneri (n = 40)**	
Cross-section profile	Handaxes (n=116)	Cleavers (n=80)	Handaxes (n=50)	Cleavers (n=14)	Handaxes (n=25)	Cleavers (n=15)
Biconvex	28% (n=32)	36% (n=29)	42% (n=21)	29% (n=4)	52% (n=13)	47% (n=7)
Biplanar	16% (n=19)	10% (n=8)	16% (n=8)	7% (n=1)	–	20% (n=3)
Plano-convex	55% (n=64)	54% (n=43)	38% (n=19)	64% (n=9)	40% (n=10)	33% (n=5)
Lenticular	1% (n=1)	–	4% (n=2)	–	–	–
Others	–	–	–	–	8% (n=2)	–

Table 5. 13 Morphology of the cross-section – handaxes and cleavers, Malaprabha Valley sites.

	Khyad (n = 196)		**Lakhmapur (n = 64)**		**Benkaneri (n = 40)**	
Bilateral profile	Handaxes (n=116)	Cleavers (n=80)	Handaxes (n=50)	Cleavers (n=14)	Handaxes (n=25)	Cleavers (n=15)
Symmetrical	36% (n=42)	50% (n=40)	52% (n=26)	29% (n=4)	28% (n=7)	7% (n=1)
Roughly symmetrical/median symmetry	22% (n=26)	18% (n=14)	30% (n=15)	29% (n=4)	16% (n=4)	26% (n=4)
Asymmetrical	41% (n=48)	33% (n=26)	18% (n=9)	42% (n=6)	56% (n=14)	67% (n=10)

Table 5. 14 Bilateral profile – handaxes and cleavers, Malaprabha Valley sites.

5.1.7 Metrical dimensions

The handaxes and cleavers show striking similarities when it came to linear measurements (Table 5.15-5.17). Use of >10 cm blanks for handaxes and cleavers is uniform for all the sites. Khyad tools were longer and wider when compared to Lakhmapur and Benkaneri tools. However, Lakhmapur had thicker cleavers than the other two sites. A reduction in the size is observed among the LCTs of Lakhmapur and Benkaneri, another aspect reflective of the general Middle Palaeolithic tendencies in the Indian sub-continent.

	Khyad		**Lakhmapur**		**Benkaneri**	
	Handaxes (n=116)	Cleavers (n=80)	Handaxes (n=50)	Cleavers (n=14)	Handaxes (n=25)	Cleavers (n=15)
Min (mm)	62	89	33	96	36	33
Max (mm)	211	188	186	157	204	156
Mean (mm)	132	136	111	123	113	110
SD (number)	25	21	25	18	32	28
CV (%)	19	15	23	15	28	26

Table 5. 15 Summary statistics with minimum (Min), maximum (Max), mean, standard deviation (SD), coefficient of variation (CV) of Length – handaxes and cleavers, Malaprabha Valley sites.

	Khyad		**Lakhmapur**		**Benkaneri**	
	Handaxes (n=116)	Cleavers (n=80)	Handaxes (n=50)	Cleavers (n=14)	Handaxes (n=25)	Cleavers (n=15)
Min (mm)	36	50	46	67	24	11
Max (mm)	118	138	118	114	108	100
Mean (mm)	82	89	76	88	71	74
SD (number)	14	16	16	13	20	22
CV (%)	17	17	21	15	29	29

Table 5. 16 Summary statistics with minimum (Min), maximum (Max), mean, standard deviation (SD), coefficient of variation (CV) of Width – handaxes and cleavers, Malaprabha Valley sites.

	Khyad		**Lakhmapur**		**Benkaneri**	
	Handaxes (n=116)	Cleavers (n=80)	Handaxes (n=50)	Cleavers (n=14)	Handaxes (n=25)	Cleavers (n=15)
Min (mm)	23	29	24	31	18	26
Max (mm)	70	73	62	68	70	51
Mean (mm)	42	42	40	42	40	37
SD (number)	9	8	9	9	13	7
CV (%)	22	19	23	22	33	19

Table 5. 17 Summary statistics with minimum (Min), maximum (Max), mean, standard deviation (SD), coefficient of variation (CV) of Thickness of handaxes and cleavers, Malaprabha Valley sites.

5.1.8 Elongation and Refinement

Handaxes were more elongated and refined at Khyad while this trend was observed for cleavers at Benkaneri. Lakhmapur had the least number of LCTs with refinement (Table 5.18). The thickness of the blanks seems to have had considerable impact on the shaping of the LCTs here. The raw material at Lakhmapur seems to be of poorer quality than at Khyad and Benkaneri and this is noticed in the number of step fractures occurring on some tools.

	Khyad (n = 196)		**Lakhmapur (n = 64)**		**Benkaneri (n = 40)**	
	Handaxes	Cleavers	Handaxes	Cleavers	Handaxes	Cleavers
Elongated (>1.5)	1.61 (n=78)	1.54 (n=44)	1.48 (n=60)	1.97 (n=40)	1.62 (n=60)	1.58 (n=60)
Refined (>2.3)	1.98 (n=17)	2.18 (n=25)	1.97 (n=9)	–	1.95 (n=16)	2.02 (n=27)

Table 5. 18 Mean values (ratio) and the distribution (=n) of Elongated (Maximum Length/Maximum Width) and Refined (Maximum Width/Maximum Thickness) handaxes and cleavers from Malaprabha Valley sites.

5.2 Handaxes and Cleavers – Attirampakkam and Singadivakkam

5.2.1 Assemblage

The lithic series of LCTs from Attirampakkam (ATM) is a mix of museum collections kept in the British Museum, London, the Musée de l'Homme, Paris, and the State Department of Archaeology, Government of Tamil Nadu, Chennai. It originates from different contexts – individual surface collections spanning many years as well as parts of excavated material (IAR, 1964-65). This study includes 65 items (Table 5.19).

Singadivakkam (SGV) assemblage is a quadrant surface collection made by Department of Sanskrit and Culture at Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya (SCSVM), Kanchipuram, Tamil Nadu. This site has been identified as a Middle Palaeolithic (Archaeological Survey of India report) site on the basis of techno-typological characteristics. In this work, 37 LCTs are analysed (Table 5.19).

Site	**Handaxes**	**Cleavers**
Attirampakkam	n=45	n=20
Singadivakkam	n=33	n=4
Total	n=78	n=24

Table 5. 19 Distribution of handaxes and cleavers by site, Tamil Nadu.

5.2.2 Preservation

The Attirampakkam collections (Figure 5.9 and 5.10) being of mixed nature, they are in various states of preservation. Five of the handaxes were observed to have been subjected to some kind of rock analysis and hence do not provide complete outline profile. Patination and abrasion are also of differential states among both handaxes and cleavers. The tools from Singadivakkam are from surface collections and appear fresh with no abrasion or patination (Table 5.20).

Preservation	**Attirampakkam (n = 65)**		**Singadivakkam (n = 37)**	
Complete/Broken	Handaxes (n=45)	Cleavers (n=20)	Handaxes (n=33)	Cleavers (n=4)
Complete	89% (n=40)	95% (n=19)	100% (n=33)	100% (n=4)
Broken	11% (n=5)	5% (n=1)	–	–
Abrasion				
Low	73% (n=33)	60% (n=12)	100% (n=33)	100% (n=4)
Medium	11% (n=5)	30% (n=6)	–	–
High	16% (n=7)	10% (n=2)	–	–
Patination				
Patinated	11% (n=5)	20% (n=4)	–	–
Unpatinated	89% (n=40)	80% (n=16)	100% (n=33)	100% (n=4)

Table 5. 20 Nature of preservation; morphology (Complete/Broken), abrasion (Low, Medium, and High), patination (Patinated, Unpatinated) – handaxes and cleavers, Tamil Nadu sites.

Figure 5. 9 Handaxes from Attirampakkam.

Figure 5. 10 Cleavers from Attirampakkam.

5.2.3 Raw material, Clasts and Blank types

The raw materials of the LCTs at Attirampakkam were quartzite, obtained from quartzitic conglomerates in the nearby Allikulli and Satyavedu Hills (Pappu et al., 2011). All of them appeared to have a predominant fine-grained texture (Table 5.21).

	Attirampakkam (n = 65)		Singadivakkam (n = 37)	
Raw material Texture	Handaxes (n=45)	Cleavers (n=20)	Handaxes (n=33)	Cleavers (n=4)
Fine-grained	98% (n=44)	100% (n=20)	100% (n=33)	100% (n=4)
Medium grained	2% (n=1)	–	–	–

Table 5. 21 Raw material texture (Fine-grained, Medium grained) – handaxes and cleavers, Tamil Nadu sites.

Different blanks were utilized for the handaxe and cleaver manufacture at both sites (Table 5.22). While Attirampakkam displays the dominant use of flakes as blanks for both the types of LCTs, cobbles as well as flakes were utilized equally for the LCTs at Singadivakkam. Of the flake blanks, the end-struck ones were more frequent. The use of pebble as a blank for handaxes is noticed only at the latter site.

	Attirampakkam (n = 65)		**Singadivakkam (n = 37)**	
Type of blanks	Handaxes (n=45)	Cleavers (n=20)	Handaxes (n=33)	Cleavers (n=4)
Cobble	13% (n=6)	15% (n=3)	27% (n=9)	25% (n=1)
Split cobble	13% (n=6)	5% (n=1)	15% (n=5)	–
Pebble	–	–	12% (n=4)	–
Entame	9% (n=4)	5% (n=1)	21% (n=7)	50% (n=2)
Side-struck flake	20% (n=9)	25% (n=5)	3% (n=1)	–
End-struck flake	42% (n=19)	50% (n=10)	21% (n=7)	25% (n=1)
Tabular block	2% (n=1)	–	–	–

Table 5. 22 Type of blanks - handaxes and cleavers, Tamil Nadu sites.

Striking platform for many of the LCTs from both the sites remained indeterminate due to the thinning of the butt. However, both cortical and plain ones were identified, mainly for the handaxes. Cleavers from both the sites display a low proportion of cortical striking platform in comparison. Striking platforms of the plain, dihedral, facetted and even punctiform are identified on the handaxes from Attirampakkam (Table 5.23).

	Attirampakkam (n = 49)		**Singadivakkam (n =19)**	
Nature of striking platform	Handaxes (n=33)	Cleavers (n=16)	Handaxes (n=16)	Cleavers (n=2)
Cortical	9% (n=3)	6% (n=1)	50% (n=8)	–
Plain	15% (n=5)	25% (n=4)	19% (n=3)	50% (n=1)
Dihedral	9% (n=3)	13% (n=2)	–	–
Facetted	6% (n=2)	–	–	–
Punctiform	9% (n=3)	6% (n=1)	–	–
Indeterminate	52% (n=17)	50% (n=8)	31% (n=5)	50% (n=1)

Table 5. 23 Nature of striking platform for all flake blanks (End-struck, Side-struck, Entame) – handaxes and cleavers, Tamil Nadu sites.

The reduction sequence at Singadivakkam is that of the cobble, from which entames were utilized or they were split or used directly. Simple bifacial and at times, unifacial shaping are observed at this site and most cleavers show bifacial flaking from Attirampakkam.

5.2.4 Shaping

Radial (convergent) shaping as well as three-directional shaping (Figure 5.11 A and B and Figure 5.12 A and B) seem to have been preferred for both handaxes and cleavers respectively. Other directions of shaping include orthogonal, transversal bidirectional and unidirectional for both LCTs from both sites (Table 5.24 and 5.25).

Large, deep, and invasive removals as well as shallow, marginal removals are noted for both sites. Use of hard hammer and soft hammer can be inferred from this pattern.

	Attirampakkam (n = 65)		**Singadivakkam (n = 37)**	
Dorsal removal pattern	Handaxes (n=45)	Cleavers (n=20)	Handaxes (n=33)	Cleavers (n=4)
Convergent	47% (n=21)	25% (n=5)	33% (n=11)	50% (n=2)
Three-directional	40% (n=18)	40% (n=8)	36% (n=12)	–
Orthogonal	4% (n=2)	–	9% (n=3)	–
Bidirectional	4% (n=2)	10% (n=2)	12% (n=4)	50% (n=2)
Unidirectional	4% (n=2)	5% (n=1)	6% (n=2)	–
No removal	–	20% (n=4)	3% (n=1)	–

Table 5. 24 Shaping removal pattern on dorsal face – handaxes and cleavers, Tamil Nadu sites.

Handaxes from Attirampakkam are shaped by 3 to 16 removals on the dorsal face, 5 mm to 67 mm long while the ventral face is shaped more intensively, with 5 to 15 removals, 19-60 mm long.

	Attirampakkam (n = 65)		**Singadivakkam (n = 37)**	
Ventral removal pattern	Handaxes (n=45)	Cleavers (n=20)	Handaxes (n=33)	Cleavers (n=4)
Convergent	42% (n=19)	25% (n=5)	39% (n=13)	–
Three-directional	40% (n=18)	55% (n=11)	30% (n=10)	50% (n=2)
Orthogonal	7% (n=3)	5% (n=1)	6% (n=2)	–
Bidirectional	9% (n=4)	10% (n=2)	21% (n=7)	25% (n=1)
Unidirectional	–	–	3% (n=1)	25% (n=1)
No removal	2% (n=1)	5% (n=1)	–	–

Table 5. 25 Shaping removal pattern on ventral face – handaxes and cleavers, Tamil Nadu sites.

Singadivakkam handaxes displayed the same nature of removals with ventral face being more shaped than the dorsal face. The length of the removals on dorsal face of the handaxes here measured 17 to 87 mm long and those on the ventral, 23 to 104 mm.

Cleavers from Attirampakkam had 8 to 49 mm long removals on the dorsal face and 18 to 61 mm long removals on the ventral face. Generally, 2 series of removals were observed for the cleavers (Figure 5.12 A). On average, the dorsal face shows up to 8 removals while the ventral numbered up to 10 removals.

For the Singadivakkam cleavers, on an average, 4 removals were visible on both faces (Figure 5.12 B) with the dorsal removals varying from 36 to 60 mm long and the ventral ones extending up to 64 mm long.

A large number of handaxes and cleavers were retouched.

Cleaver distal edge was formed in different ways, with different combinations (Figure 5.19):

- Using the dorsal previous scar and laterally retouched ventral face to form the cutting edge.
- Using the dorsal previous scar and ventral unretouched face to form the cutting edge.
- Using a distal longitudinal removal on the dorsal and unretouched ventral face.
- Or in a rare instance, using the unmodified cortical surface of an entame and ventral unretouched surface as at Attirampakkam (Figure 5.19 D).

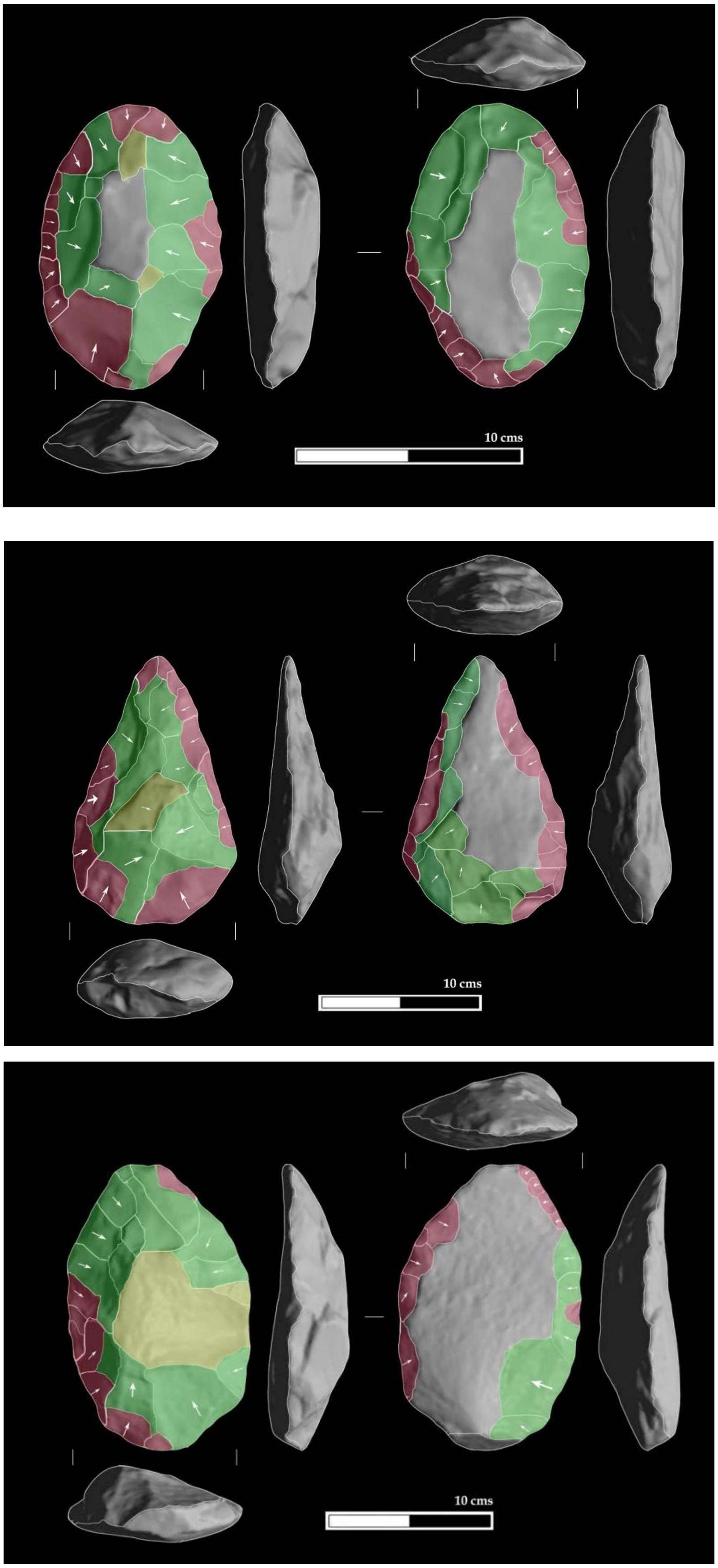


Figure 5. 11 A. Handaxes from Attirampakkam showing the shaping patterns and the series of shaping removals. Last series of removal, Second series of removal, First series of removal, Unflaked surface.

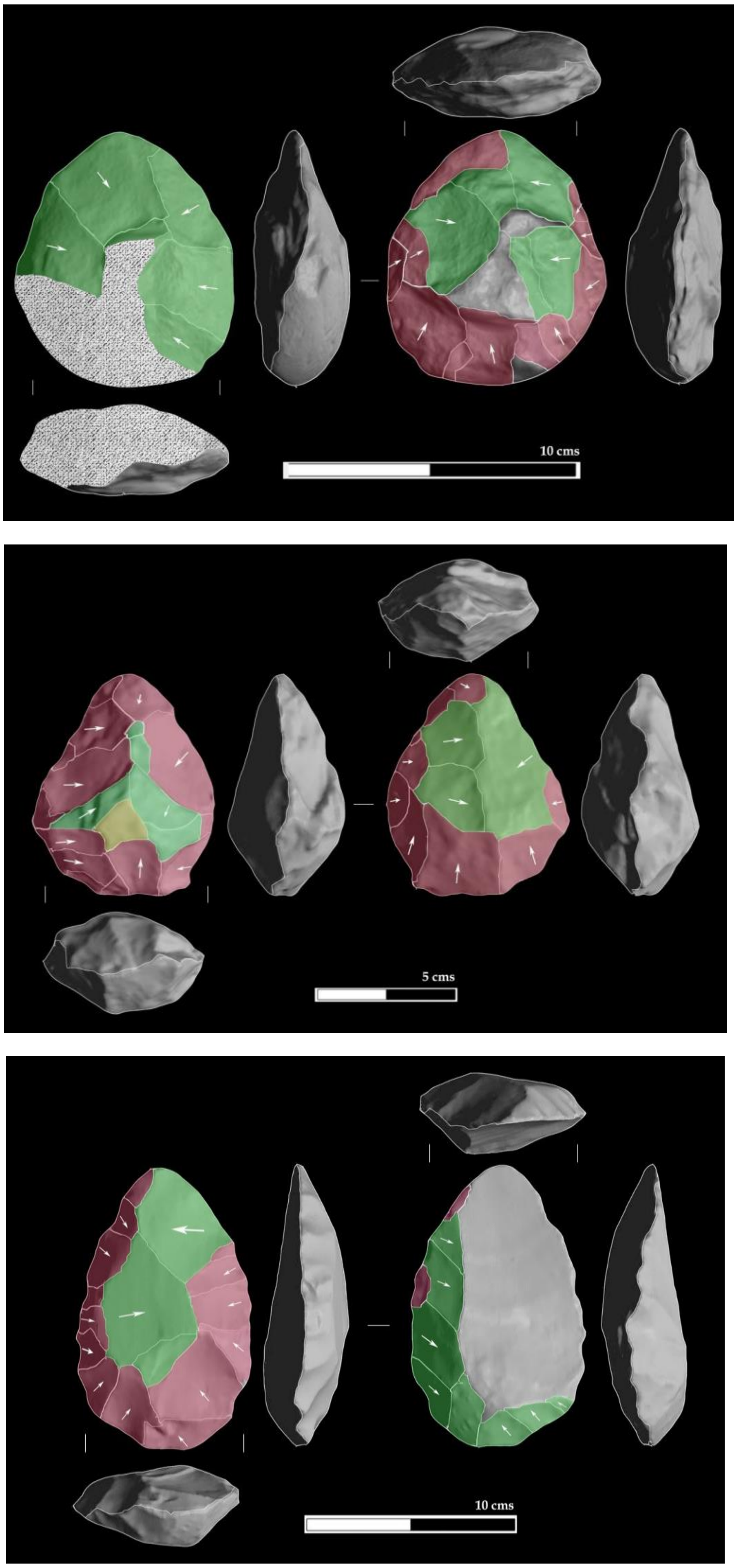


Figure 5.11 B. Handaxes from Singadivakkam showing the shaping patterns and the series of shaping removals. Last series of removal, Second series of removal, First series of removal, Cortical surface, Unflaked surface.

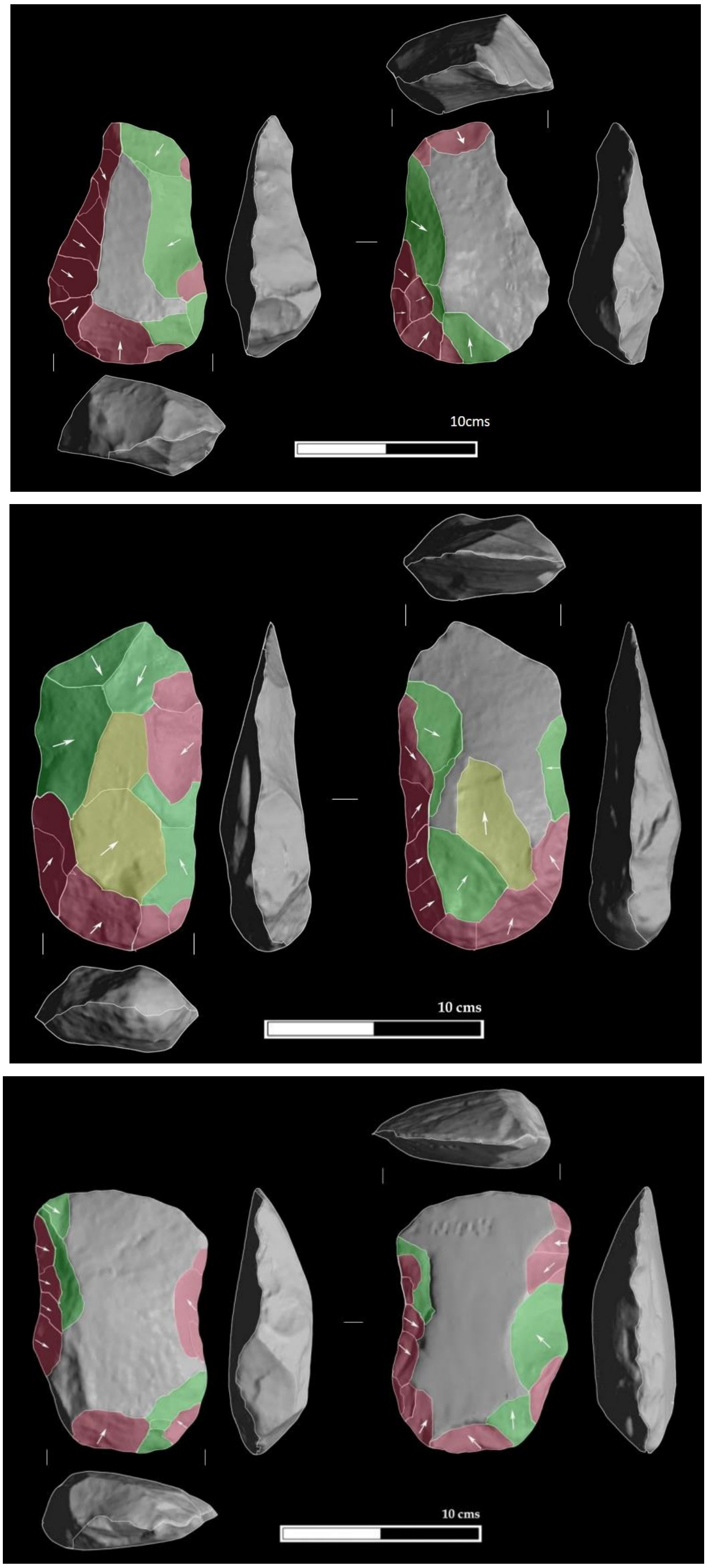


Figure 5. 12 A. Cleavers from Attirampakkam showing the shaping patterns and the series of shaping removals. Last series of removal, Second series of removal, First series of removal, Unflaked surface.

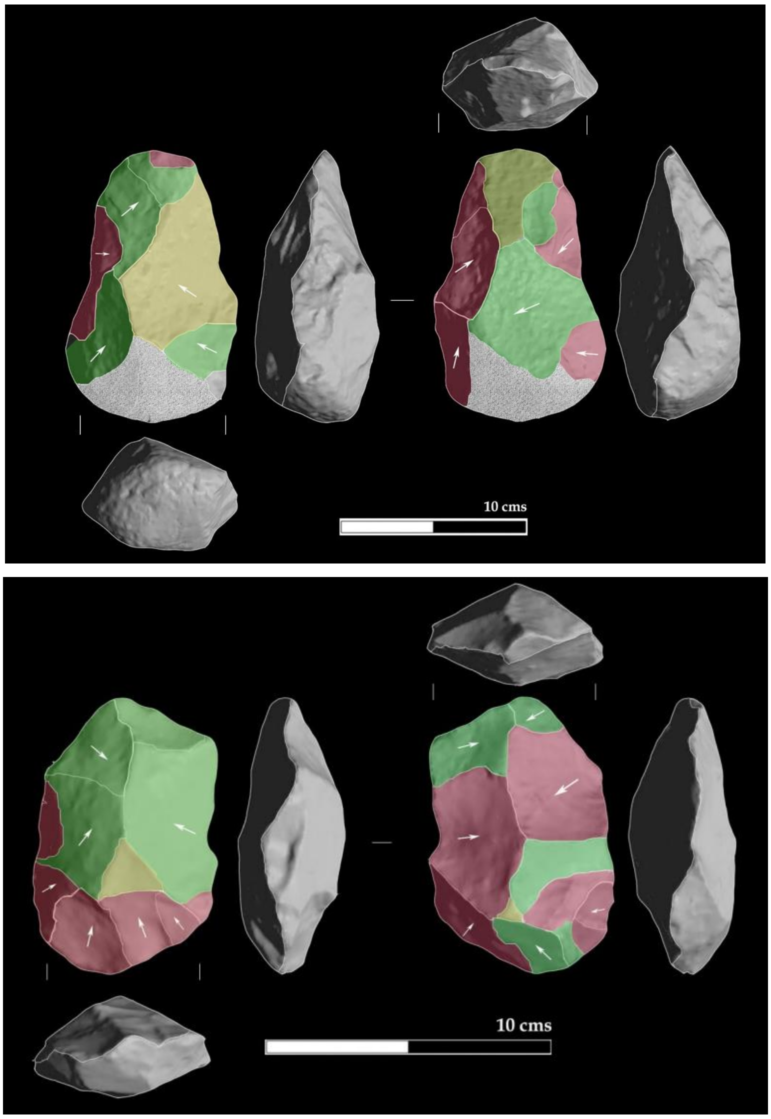


Figure 5.12 B. Cleavers from Singadivakkam showing the shaping patterns and the series of shaping removals. Last series of removal, Second series of removal, First series of removal, Cortical surface, Unflaked surface.

The presence of cortex on the surface (Table 5.26) is more noted on LCTs from Singadivakkam where the majority of the LCTs were shaped on cobbles and retained the cortex in the dorsal and ventral faces, especially at the proximal end.

	Attirampakkam (n = 65)		**Singadivakkam (n = 37)**	
Presence/Absence of Cortex	Handaxes (n=45)	Cleavers (n=20)	Handaxes (n=33)	Cleavers (n=4)
Cortex	29% (n=13)	15% (n=3)	85% (n=28)	100% (n=4)
No cortex	71% (n=32)	85% (n=17)	15% (n=5)	–

Table 5. 26 Presence and absence of cortex – handaxes and cleavers, Tamil Nadu sites.

5.2.5 Morphology of the edges

Lateral and proximal sides of the handaxes from both the sites have oblique angles (medium angles). They can be considered (and used) as cutting edges. Some tools have steep sides. Only at Attirampakkam do we notice sharp edges on the lateral sides. Cleavers from Singadivakkam had only oblique and steep angles in lateral and proximal positions while at Attirampakkam all the angle types were observed (Table 5.27, 5.28 and 5.30).

	Attirampakkam (n = 65)		**Singadivakkam (n = 37)**	
Lateral left-side angle	Handaxes (n=45)	Cleavers (n=20)	Handaxes (n=33)	Cleavers (n=4)
< 60°	9% (n=4)	15% (n=3)	–	–
60°-80°	47% (n=21)	35% (n=7)	76% (n=25)	100% (n=4)
80°-110°	44% (n=20)	50% (n=10)	24% (n=8)	–

Table 5. 27 Lateral left-side edge angles – handaxes and cleavers, Tamil Nadu sites.

	Attirampakkam (n = 65)		**Singadivakkam (n = 37)**	
Lateral right-side angle	Handaxes (n=45)	Cleavers (n=20)	Handaxes (n=33)	Cleavers (n=4)
< 60°	7% (n=3)	10% (n=2)	–	–
60°-80°	40% (n=18)	50% (n=10)	76% (n=25)	100% (n=4)
80°-110°	53% (n=24)	40% (n=8)	24% (n=8)	–

Table 5. 28 Lateral right-side edge angles – handaxes and cleavers, Tamil Nadu sites.

At Attirampakkam, generally 2 series of removals are observed, with some tools having up to 3 series. This would have resulted in the thinning of the edges leading to cutting angles. On the other hand, tools from Singadivakkam, made on thicker and rounder blanks, often cobbles, are usually shaped by 1 series of removals. At the distal end, most of the LCT's have a cutting edge as expected (Table 5.29).

	Attirampakkam (n = 65)		**Singadivakkam (n = 37)**	
Distal end angle	Handaxes	Cleavers	Handaxes	Cleavers
< 60°	49% (n=22)	40% (n=8)	6% (n=2)	75% (n=3)
60°-80°	27% (n=12)	35% (n=7)	42% (n=14)	25% (n=1)
80°-110°	24% (n=11)	25% (n=5)	52% (n=17)	–

Table 5. 29 Distal edge angles – handaxes and cleavers from Tamil Nadu sites.

The proximal ends of handaxes from Singadivakkam mostly show steep angles, followed by oblique angles. The keeping of cortical surfaces and the use of pebbles and cobbles as blanks would have reinforced this trait. Attirampakkam LCTs also display a trend of both oblique and steep angles for the proximal ends. However, the presence of some tools with cutting edges at this part of the tool is also noticed (Table 44).

	Attirampakkam (n = 65)		**Singadivakkam (n = 37)**	
Proximal end angle	Handaxes (n=45)	Cleavers (n=20)	Handaxes (n=33)	Cleavers (n=4)
< 60°	7% (n=3)	5% (n=1)	6% (n=2)	–
60°-80°	29% (n=13)	30% (n=6)	42% (n=14)	100% (n=4)
80°-110°	64% (n=29)	65% (n=13)	52% (n=17)	–

Table 5. 30 Proximal edge angles – handaxes and cleavers, Tamil Nadu sites.

5.2.6 Outline and Symmetry

In Attirampakkam, handaxes and cleavers displayed both plano-convex and biplanar cross-sections while in Singadivakkam biconvex followed by plano-convex cross-sections are dominant for the handaxes, with only 3 handaxes having a biplanar profile. Both symmetrical and asymmetrical handaxes in shapes of ovates, elongated ovates, triangular, sub-triangular, pear shaped, almond shaped, cordiform etc. can be identified from both the sites. Cleavers were with V, U and angled proximal edge and with straight, convex or diagonal distal edges. All the cleavers from this Singadivakkam displayed a biconvex cross-section (Table 5.31) and were asymmetrical in plain view. The use of cobbles and pebbles for fashioning the handaxes would have heavily influenced this feature.

	Attirampakkam (n = 65)		**Singadivakkam (n = 37)**	
Cross-section profile	Handaxes (n=45)	Cleavers (n=20)	Handaxes (n=33)	Cleavers (n=4)
Biconvex	22% (n=10)	35% (n=7)	55% (n=18)	100% (n=4)
Biplanar	42% (n=19)	35% (n=7)	9% (n=3)	–
Plano-convex	35% (n=16)	305% (n=6)	36% (n=12)	–

Table 5. 31 Morphology of cross-section - handaxes and cleavers, Tamil Nadu sites.

5.2.7 Metrical dimensions

In Attirampakkam cleavers were short (40 mm) to long (170 mm) and from very narrow (24 mm) to wide (126 mm) with thickness varying from 14 mm to 47 mm (Table 5.32-5.34).

On the other hand, the length of the cleavers from Singadivakkam ranged from 90 to 148 mm (Table 5.32). The width varied between 55 and 92 mm while the thickness was from 31 to 61 mm (Table 5.33 and 5.34).

	Attirampakkam		**Singadivakkam**	
	Handaxes (n=45)	Cleavers (n=20)	Handaxes (n=33)	Cleavers (n=4)
Min (mm)	68	40	53	24
Max (mm)	179	170	174	126
Mean (mm)	117	120	104	77
SD (number)	26	34	29	9
CV (%)	22	28	28	28

Table 5. 32 Summary statistics with minimum (Min), maximum (Max), mean, standard deviation (SD), coefficient of variation (CV) of Length - handaxes and cleavers, Tamil Nadu sites.

	Attirampakkam		**Singadivakkam**	
	Handaxes (n=45)	Cleavers (n=20)	Handaxes (n=33)	Cleavers (n=4)
Min (mm)	43	24	38	55
Max (mm)	114	126	112	92
Mean (mm)	75	77	72	71
SD (number)	17	24	19	16
CV (%)	22	31	26	22

Table 5. 33 Summary statistics with minimum (Min), maximum (Max), mean, standard deviation (SD), coefficient of variation (CV) of Width - handaxes and cleavers, Tamil Nadu sites.

	Attirampakkam		**Singadivakkam**	
	Handaxes (n=45)	Cleavers (n=20)	Handaxes (n=33)	Cleavers (n=4)
Min (mm)	20	14	23	31
Max (mm)	59	47	60	61
Mean (mm)	37	32	38	41
SD (number)	9	9	11	14
CV (%)	24	28	29	35

Table 5. 34 Summary statistics with minimum (Min), maximum (Max), mean, standard deviation (SD), coefficient of variation (CV) of Thickness - handaxes and cleavers, Tamil Nadu sites.

5.2.8 Elongation and Refinement

Of the 45 Attirampakkam handaxes studied, 31 were elongated and 11 showed some refinement (Table 5.35). A correlation test of the elongation and refinement index ratios showed that the longer handaxes were more refined. However, this correlation was not present in the case of cleavers.

Singadivakkam did not show any correlation between the elongation and refinement of handaxes.

	Attirampakkam (n = 65)		**Singadivakkam (n = 37)**	
	Handaxes	Cleavers	Handaxes	Cleavers
Elongated (>1.5)	1.57 (n=31)	1.59 (n=12)	1.45 (n=15)	–
Refined (>2.3)	2.07 (n=11)	2.40 (n=7)	1.96 (n=8)	–

Table 5. 35 Mean values (ratio) and distribution (=n) of Elongated (Maximum Length/Maximum Width) and Refined (Maximum Width/Maximum Thickness) – handaxes and cleavers, Tamil Nadu sites.

5.3 Picks – Malaprabha Valley and Tamil Nadu

Compared to the handaxes and cleavers, the number of picks were very few. Singadivakkam had the highest number (n=11), followed by Benkaneri (n=5), Khyad (n=4) and one single specimen from Lakhmapur (Figure 5.13).

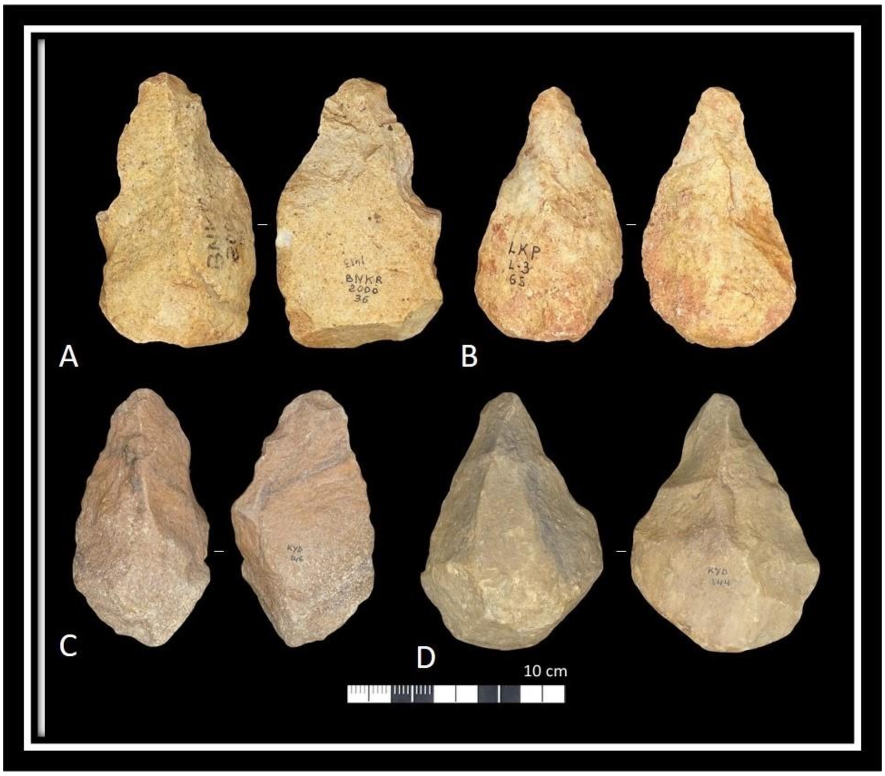


Figure 5. 13 Picks from Malaprabha Valley sites – Benkaneri (A) and Lakhmapur (B) and Khyad (C and D).

Picks from Khyad measured 126 mm to 161 mm in length, were 68 mm to 94 mm wide and 46 mm to 59 mm thick. Three of them were dihedral picks while one was a trihedral. Shaping observed on both the faces were three-directional, unidirectional and bidirectional in pattern. The striking platform of one pick on side struck flake was plain and located on the proximal angle. Three picks were made on cobbles. At Benkaneri, one pick was broken, 2 were trihedral and 2 were dihedral, all made on quartzite raw material. The single specimen from Lakhmapur was trihedral in shape.

All the picks from Singadivakkam are on cobbles and four were trihedral with the rest dihedral. The length of the picks varied from 90 to 134 mm, while in width, they varied from 60 to 87 mm. The thickness was the most variable part with the thinnest pick measuring 38 mm and the thickest measuring 78 mm.

5.4 Key features of handaxes and cleavers from Malaprabha Valley and Tamil Nadu

Khyad had 5 unifaces and 12 handaxes that showed predominant shaping only on one face. Handaxes mostly modified on one surface and marginally modified on another was also present at Lakhmapur, besides the 3 complete unifaces. Several composite cleavers, with double and triple cutting edges (Figure 5.14) as well as cleavers with scraper edges were noticed.

Figure 5. 14 A cleaver from Khyad with multiple cutting edges and notch.

From the site of Benkaneri we have a handaxe very different from the rest in both elongation and refinement (Figure 5.15).

The discovery of this huge handaxe at this site indicates a probably non-utilitarian character, which further gives insights into the cognitive state of the inhabitants at this site.

From Khyad, we have evidences of individual idiosyncrasies where aspects of recycling and possible knapping mistakes being corrected (Figure 5.16) are found.

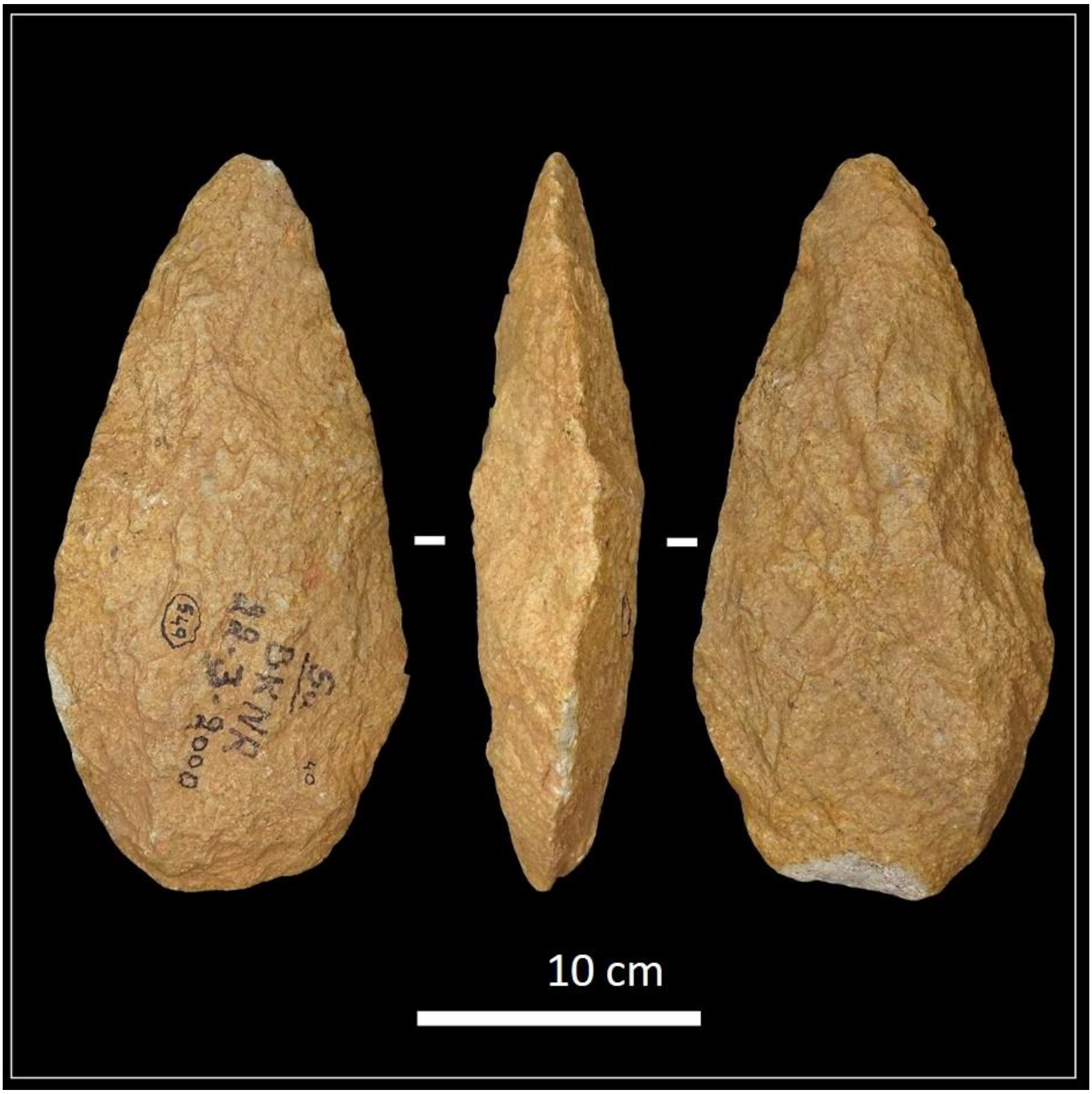


Figure 5. 15 An elongated and refined handaxe from Benkaneri.

Figure 5. 16 A handaxe from Khyad displaying a possible knapping error being corrected by creating a notch on the other side to create a balance.

From the site of Singadivakkam we have two handaxes that are extremely similar in shape and dimensions, probably indicating the same knapper (Figure 5.17).

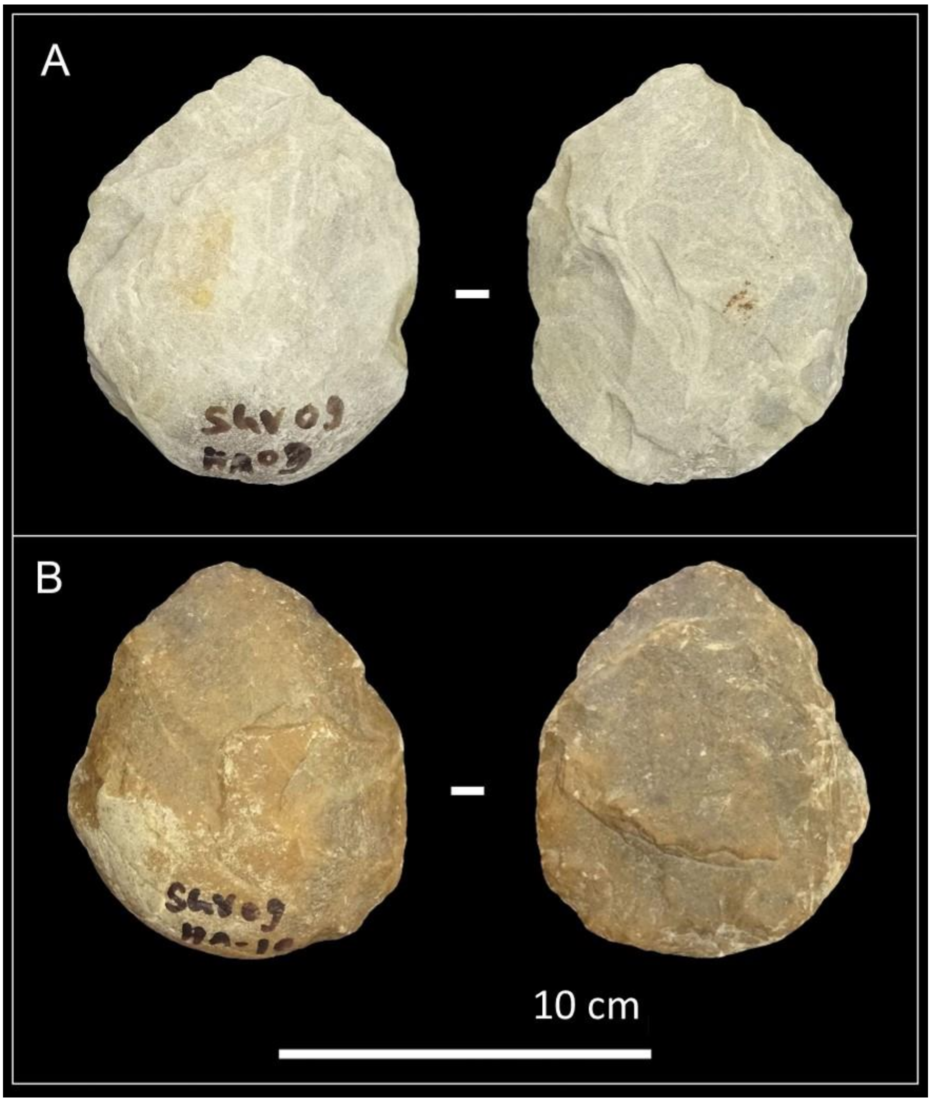


Figure 5. 17 Handaxes from Singadivakkam displaying very close similarities.

At all the sites, predominant use of quartzite is noticed for the LCTs. While at the Malaprabha Valley sites, these are from the Kaladgi outcrops, the Tamil Nadu quartzite is from the Satyavedu geological formations. Khyad is the only site which has evidence of handaxes on quartz raw material. Quartz is rarely used to shape handaxes and only a few examples exist in the Indian sub-continent (e.g., at the site from Jonk river, Padhan, 2013). The raw material was of fine-grained, medium grained and coarse-grained varieties (Figure 5.18), of which the fine-grained was the preferred rock types at both the regions.

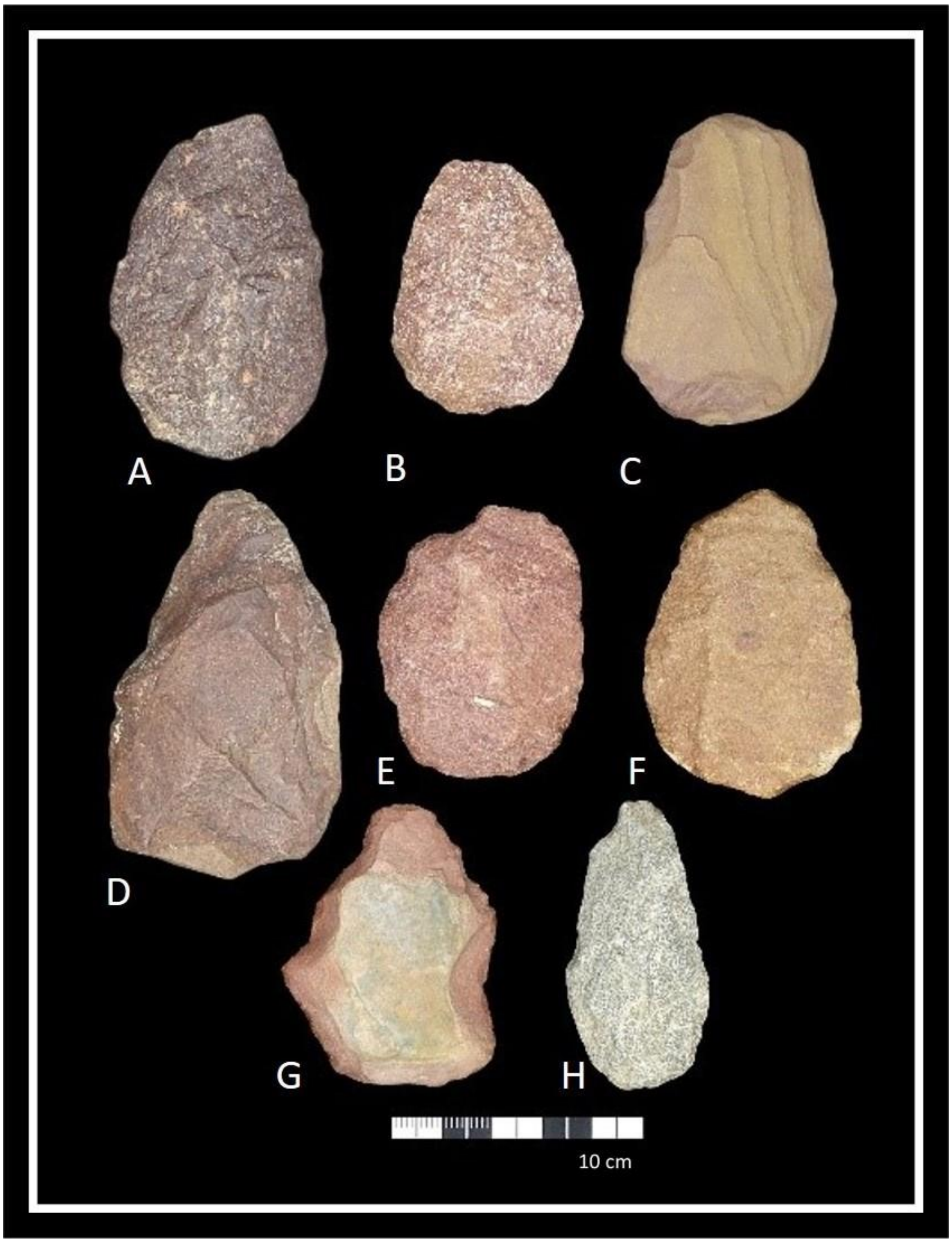


Figure 5. 18 Tool Raw material textures showing fine-grained (C, D, F and G), medium grained (A and E) and coarse-grained (B and H) quartzite from Malaprabha Valley.

The raw material was available in different clast forms like the tabular blocks at Benkaneri, angular and sub-angular cobbles and pebbles at Khyad and rounded-sub-rounded cobbles and pebbles of Singadivakkam.

They were obtained from the nearby vicinities in the form of different clasts at both the regions. While at Lakhmapur West, Benkaneri and Singadivakkam, all the stages of the reduction process could be identified through the presence of cores, flakes, and debitage of all stages, indicating the tools were produced at the site, Lakhmapur East and Khyad did not have similar evidence. Attirampakkam tools were also brought into the site as finished forms (Pappu et al, 2011).

The reduction sequence is similar at all the sites consisting of reduction of different blank forms into tools directly or on the flakes detached from them.

Both bifacial and unifacial strategies were followed in the production of handaxes and cleavers. The handaxes were shaped in a radial or centripetal (convergent removals) way, with marginal and invasive deep and shallow removals indicating the use of hard and soft hammers. Some of the handaxes display regular retouch all along the periphery or limited to the upper distal edges. Tranchet removal was also noticed.

Cleavers, made on both cobbles and flakes had the distal ends shaped through different ways (Figure 5.19).

1. Using the dorsal previous scar and laterally retouched ventral face to form the cutting edge.
2. Using the dorsal previous scar and ventral unretouched face to form the cutting edge.
3. Using a distal longitudinal removal on the dorsal and unretouched ventral face.

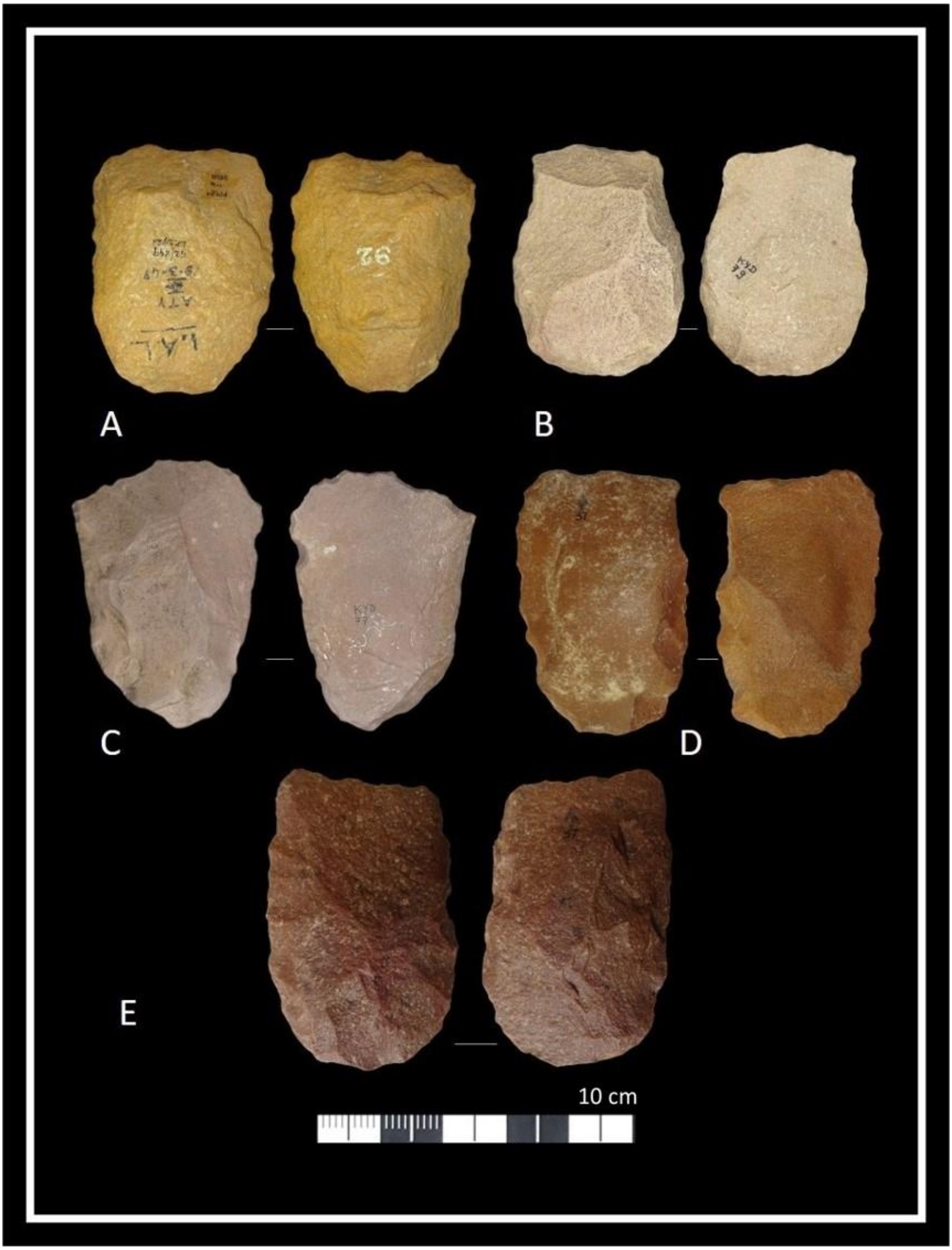


Figure 5. 19 Cleavers with distal tips shaped using different methods and combinations of methods - Attirampakkam(A, D, E) and Khyad (B and C).

5.5 2D Geometric Morphometric Analysis – Handaxes

The method of 2D Geometric morphometrics has been detailed in Article 1 (Appendix I). In summary, it consists of four steps: creating a TpS (thin-plate spline) file of each specimen's outline using the TpS utility program, placing the equidistant semi-landmarks using TpS Dig, processing the TpS data file created with PAST (Palaeontological Statistics) including the Procrustes analysis, and finally using PCA (principal component analysis) plotting the variations on the scatter plot. For the individual sites, TpS deformation images are used to illustrate the hypothetical shape changes along the various points at both the axis. It gives information on the differences from the mean shape (through the lollipop points) and the location where these differences are the most important (through the bending of the grid).

Only the specimens that had unbroken, complete contours in plan-view were chosen for this study.

5.5.1 Khyad

A total of 113 handaxes were considered for the 2D GM analysis. They generated 112 PCs of which the first 10 accounted for 94% of the variation. The first 3 PCs explained 71% of the variation. The distribution of the PC shapes in the morpho-space (Figure 5.20) shows a close cluster of handaxes skewed positively (within the 95% ellipse) on the PC1. Along with this, some dispersed shapes and another cluster with outliers are noticed skewed towards the negative values of the axis. The shape trend on this PC1 shows a change from long pointed handaxes with one lateral steep edge to round tipped broader handaxes. PC2 shows a change trend from asymmetrical and symmetrical handaxes with rounded distal ends to symmetrical pointed handaxes with shaped distal ends.

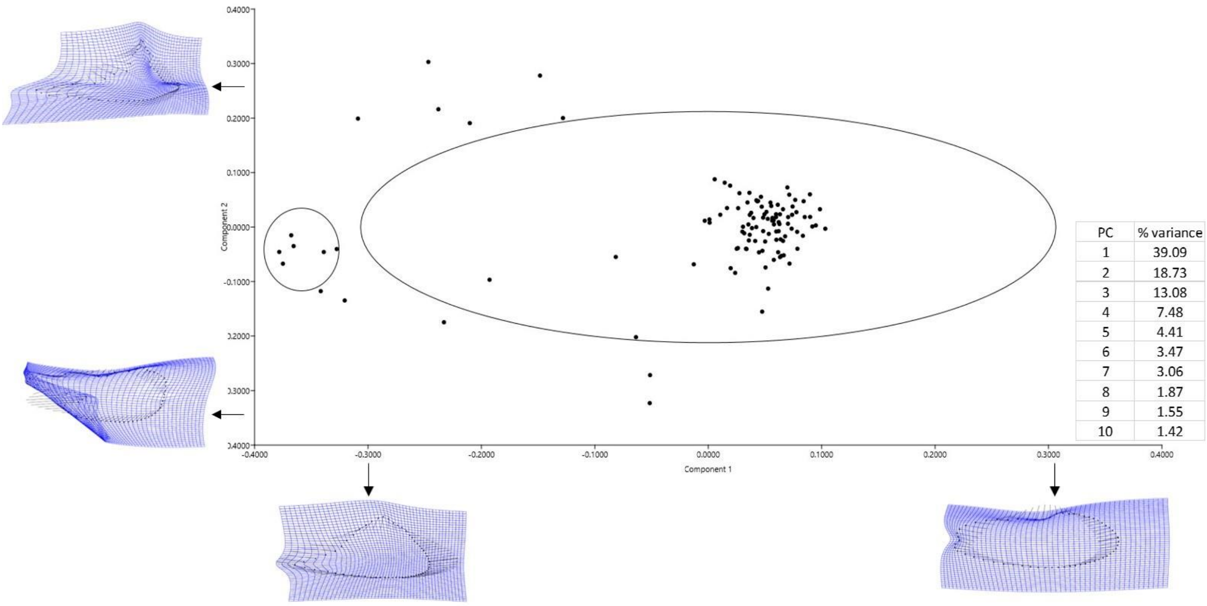


Figure 5. 20 Scatterplot showing the shape distribution along PC1 and 2 with TpS deformations of the handaxes from Khyad.

5.5.2 Lakhmapur

Handaxes from this site subjected to this analysis included a total of 48 tools. Out of the resulting 47 PCs created, the first 10 explain 95% of the total variability. The first 3 PCs account for 73% of the variation. PC1 covers longer to shorter handaxes while PC2 covers the aspects of symmetry. There were 4 outliers. (Figure 5.21).

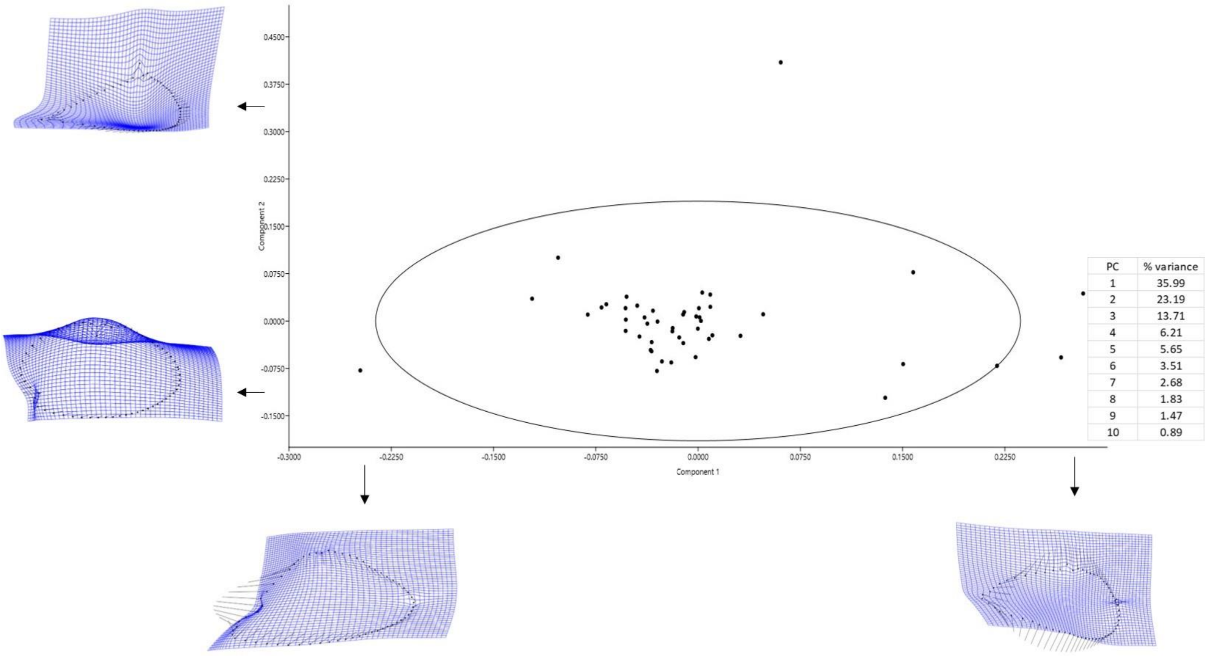


Figure 5. 21 Scatterplot showing the shape distribution along PC1 and 2 with TpS deformations of the handaxes from Lakhmapur.

5.5.3 Benkaneri

From Benkaneri 22 handaxes were analysed. A total number of 21 principal components were generated. The first three PCs explain 68% of the total variability. The PC1 covers shape differences from elongated pointed handaxes towards shorter handaxes with rounded distal ends (Figure 5.22). PC2 covering 19% of variance reflects a gradient form narrow asymmetrical handaxes with transverse distal edge towards handaxes with rounded distal ends and pointed butts, with median symmetry. Only one outlier was observed, a handaxe, completely different from the rest. It is very elongated, finely shaped, and symmetrical with pointed distal edges.

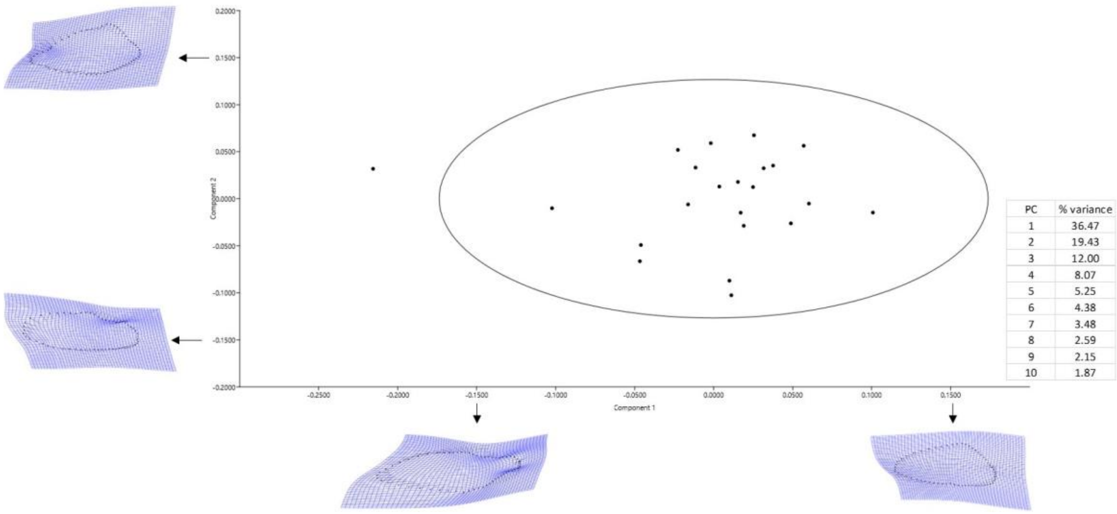


Figure 5. 22 Scatterplot showing the shape distribution along PC 1 and 2 with TpS deformations of the handaxes from Benkaneri.

5.5.4 Khyad, Lakhmapur and Benkaneri

A total number of 120 PCs were generated for the 121 handaxes from these three sites. The first 10 accounted for 92% of the variability (Table 5.36).

PC	% variance
1	35.28
2	16.95
3	13.81
4	8.98
5	4.45
6	3.65
7	2.89
8	2.65
9	1.88
10	1.76

Table 5. 36 The first 10 PCs explaining 92% of the handaxe variability – Malaprabha Valley sites.

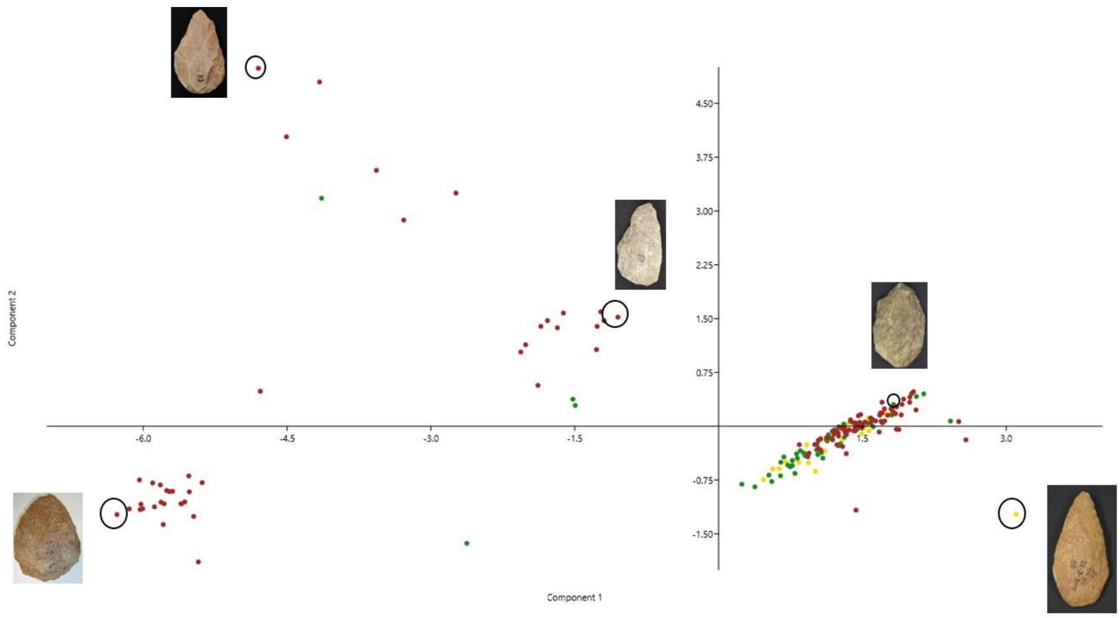


Figure 5. 23 Scatterplot showing the shape distribution along PC 1 and 2 of the handaxes from Khyad (red dot), Lakhmapur (green dot), Benkaneri (yellow dot).

The morpho-space depicting the PC shape distribution (Figure 5.23), shows that the majority of the handaxes from all the three sites fall into the positive values along the axis of PC1. This axis expresses a change from a group of Khyad handaxes which are broad butted with rounded distal edges to narrower, longer, asymmetrical pointed handaxes. PC2 with most of the handaxes skewed towards the negative values represents symmetrical handaxes with broader proximal half passing to handaxes either narrow asymmetrical or slightly wider and bilaterally symmetrical. These handaxes were found to be shaped on flake blanks.

Overall, there is a shape overlap between the handaxes from Khyad, Lakhmapur and Benkaneri suggesting an adherence to similar shapes. Khyad handaxes show more variability in terms of symmetry and elongation. The use of a wide range of blank types at this site is attested through classical analysis.

The handaxe from Benkaneri, located on the extreme end of the PC1 with bilateral symmetry and marked elongation is an outlier as other handaxes, shorter, fall within the handaxe shapes of Khyad and Lakhmapur. Lakhmapur and Benkaneri handaxes shapes are seen overlapping in the lower right quadrant. The increased use of tabular blocks and side struck flakes at these sites have been attested through the classical analysis and indicates the influence of similar blank types and technique.

5.5.5 Attirampakkam

A total of 40 handaxes from Attirampakkam were chosen for this analysis. Out of the 39 PCs generated, the first 10 covered 98% of the variation. The first three accounted for 86% of the changes with PC1 explaining more than half the variability (58%). The plotting of the shapes in morpho-space (Figure 5.24) displays a wider distribution with one outlier. The outlier is a handaxe of ovate form, with rounded butt and transverse distal edge, made on end-struck flake and with continuous retouch throughout the periphery. Most of the handaxes were skewed negatively on PC1 while an equal distribution can be observed on the negative and positive Y axis for PC2. PC1 shows a trend from wide handaxes with rounded distal tip to rounded and elongated handaxes with pointed tip. PC2 shows a trend from narrower to broader handaxes, more rounded at the distal tip.

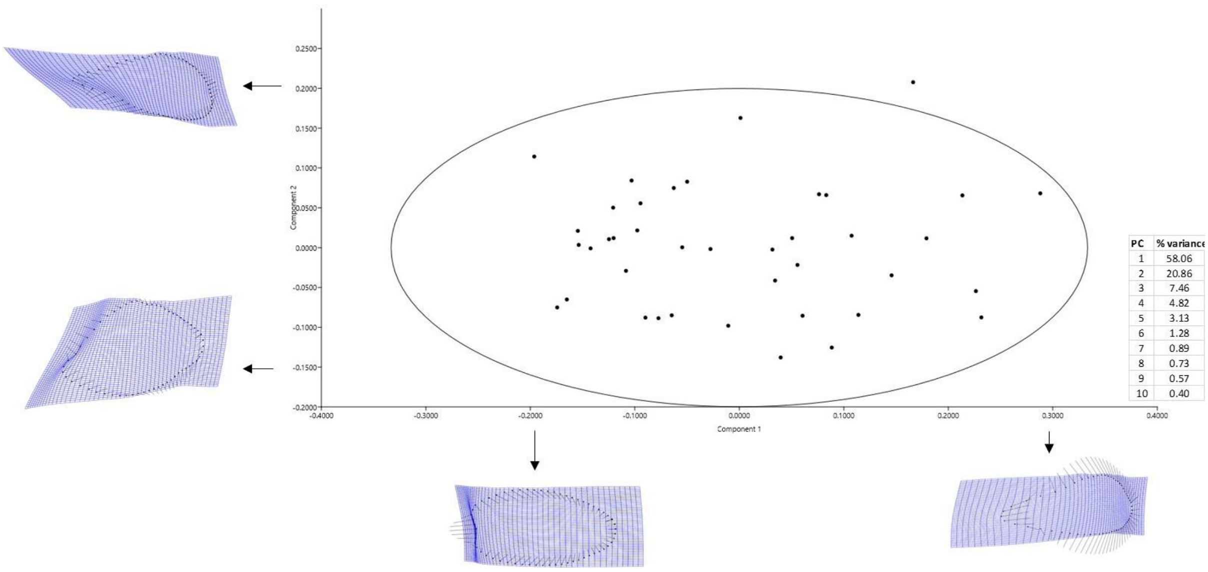


Figure 5. 24 Scatterplot showing the shape distribution along PC 1 and 2 with TpS deformations of the handaxes from Attirampakkam.

5.5.6 Singadivakkam

A total number of 33 handaxes were analysed which generated 32 PCs. From the first 10 PCs explaining 98% of the total variance, the first 3 accounted for 83% of it.

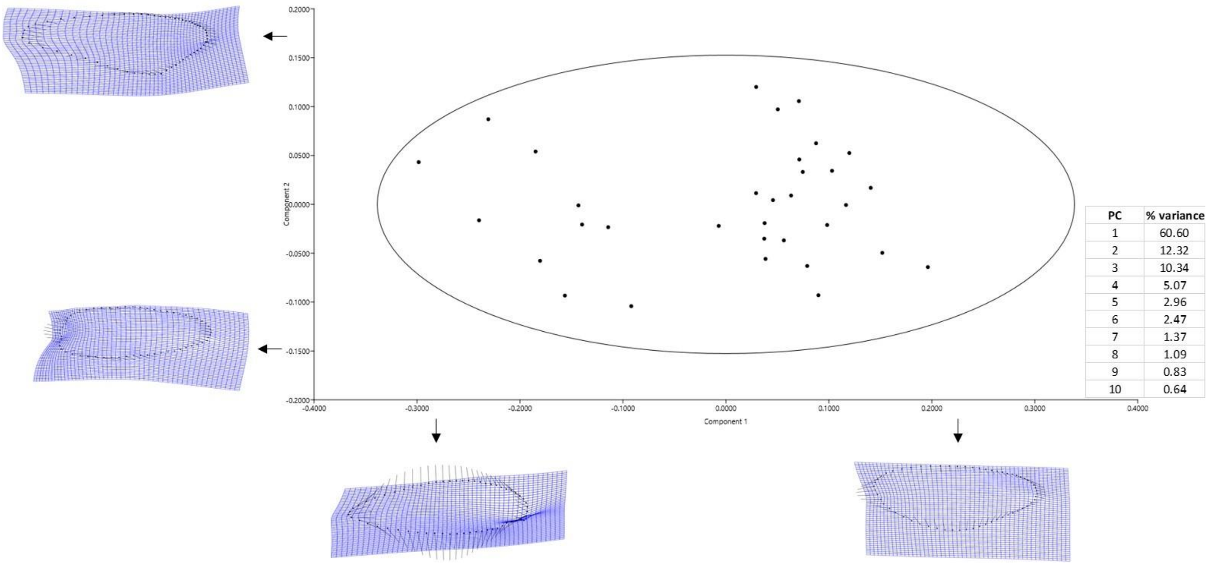


Figure 5. 25 Scatterplot showing the shape distribution along PC 1 and 2 with TpS deformations of the handaxes from Singadivakkam.

From the distribution of the handaxe shapes (Figure 5.25), we see that the large majority of the handaxes from this site were skewed positively on the PC1 axis. The TpS deformation points to the trend of intense variability at the lateral edges to variability located at the distal and proximal ends. PC2 on the other hand, shows a different picture of more handaxes skewed negatively. Here, the variations, as expressed by the TpS deformation change from the distal ends to proximal ends. Along the PC1, variability ranges from asymmetrical handaxes which are shorter and wider at the proximal end to pointed handaxes with a narrower width and a good symmetry. The shorter and wider handaxes are made on pebbles while the longer ones are on cobbles and split cobbles. The latter were invasively shaped unlike the shorter ones, which had minimal shaping.

PC2 shows a shape trend of short handaxes with rounded edges changing to elongated handaxes with transverse or pointed distal tips.

5.5.7 Attirampakkam and Singadivakkam

As more specimens were included in the 2D GM analysis, unlike the 3D GM analysis, despite the mixed nature of the Attirampakkam handaxes, these were compared with the Singadivakkam handaxes. A total of 72 PCs were generated for 73 handaxes from both the sites. The first 10 accounted for 98% of the variance (Table 5.37) and the first 3 explained 89% of the variability within this. PC1 covered a higher percentage of this variance (nearly 62%).

PC	% variance
1	61.83
2	15.47
3	10.57
4	2.94
5	1.91
6	1.56
7	1.40
8	0.99
9	0.55
10	0.50

Table 5. 37 The first 10 PCs explaining 98% of the hand axe variability – Tamil Nadu sites.

PC1 (Figure 5.26) shows that most of the Singadivakkam tools are skewed negatively, with some overlapping with the Attirampakkam, which is skewed mostly towards the positive values on the X axis. The handaxes from Singadivakkam were mostly made on cobbles and split cobbles while the majority of handaxes Attirampakkam were usually made on flakes. It shows a shape trend of ovate shaped handaxes with rounded distal ends to elongated handaxes with pointed distal ends.

PC2 marks the change from wider handaxes to narrower handaxes with transverse distal end.

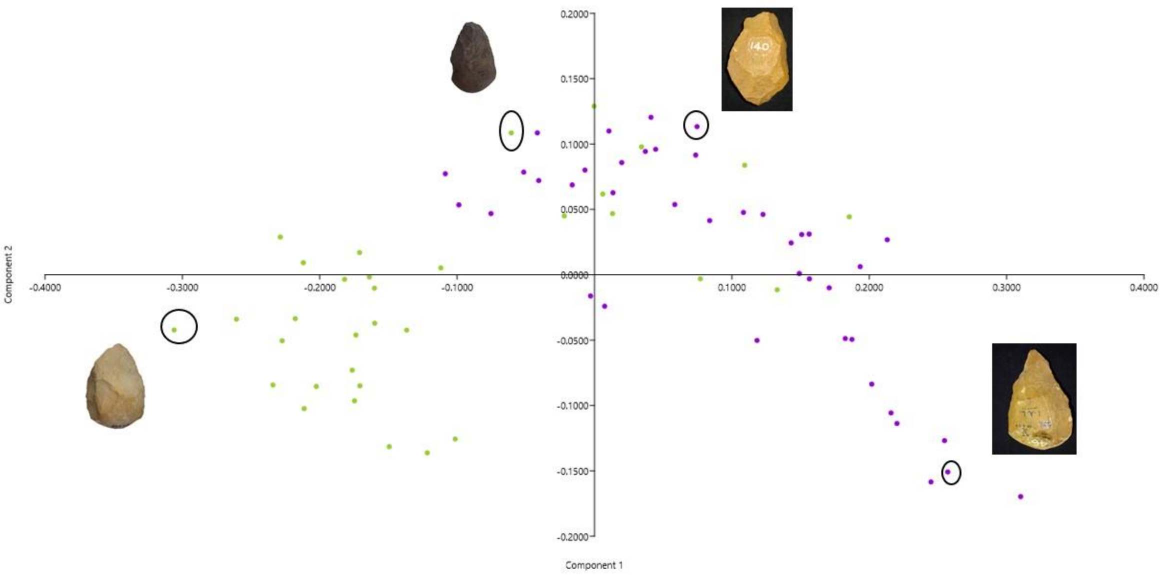


Figure 5. 26 Scatterplot showing the shape distribution along PC 1 and 2 of handaxes from Attirampakkam (purple dot) and Singadivakkam (light green dot)

5.6 Inter-regional comparison

The comparison of handaxe shapes from the two regions, Malaprabha Valley in Karnataka, and Tamil Nadu, show interesting results. Of the PCs generated, the first 10 accounted for 95% of the total variation (Table 5.38). The first two explain 67% of the variability.

PC	% variance
1	50.88
2	15.91
3	9.96
4	6.52
5	3.24
6	2.77
7	1.98
8	1.46
9	1.35
10	1.08

Table 5. 38 The first 10 PCs explaining 95% of the handaxe variability -Malaprabha Valley and Tamil Nadu sites.

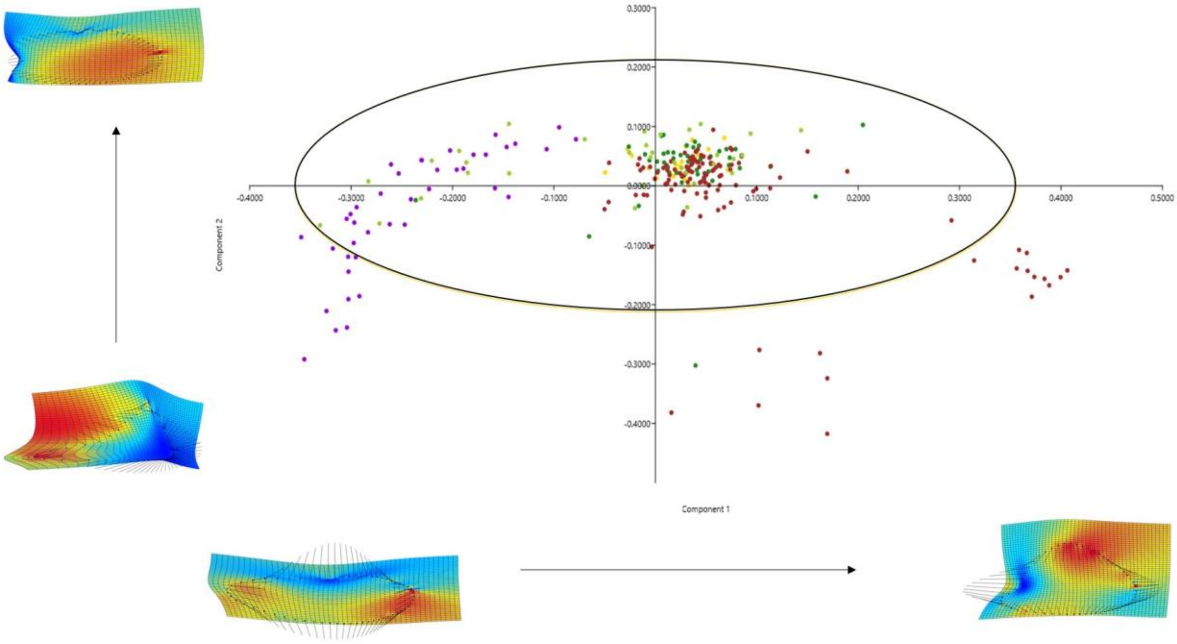


Figure 5. 27 Scatterplot showing the shape distribution along PC 1 and 2 (with warped shapes) of handaxes from Khyad (red dot), Lakhmapur (green dot), Benkaneri (yellow dot), Attirampakkam (purple dot) and Singadivakkam (light green dot).

The distribution of the handaxe shapes in morpho-space, (Figure 5.27) shows all the Attirampakkam handaxes skewed towards the negative values of the PC1 axis. These handaxes had more variability on their lateral edges and proximal end. They were round handaxes with pointed distal edge. Towards the positive values of the same PC1 axis, it appears a change towards more variability at the proximal and distal ends along with the lateral right edge. The handaxes become more elongated with rounded distal tips.

PC2 axis shows only a few handaxes from Attirampakkam and Singadivakkam along with a few handaxes from Khyad in projection to its negative values. These are elongated handaxes fashioned on flakes with pointed distal ends. Towards the positive values of this axis, these shapes change to broader handaxes with wider distal ends and with rounded butts. A large majority of the handaxes on different blanks like cobbles, tabular blocks, and flakes from the sites of Malaprabha Valley are seen clustered and overlapping with some handaxes from Singadivakkam on the right upper quadrant of the graph. The handaxe shape seems to have been systematically retained throughout the Lower and Middle Palaeolithic period in the Malaprabha Valley, despite the different nature of the blanks.

5.7 2D Geometric Morphometric Analysis – Cleavers

5.7.1 Khyad

Geometric morphometric analysis (2D) was applied on 90 complete cleavers from this site. A total number of 89 principal components were generated from this. The first 10 PCs explain the 94% of the variability within the tools.

Of these, 70% of the variability is covered by the first three components. From the shape distribution (Figure 5.28) we see two different clusters of cleavers.

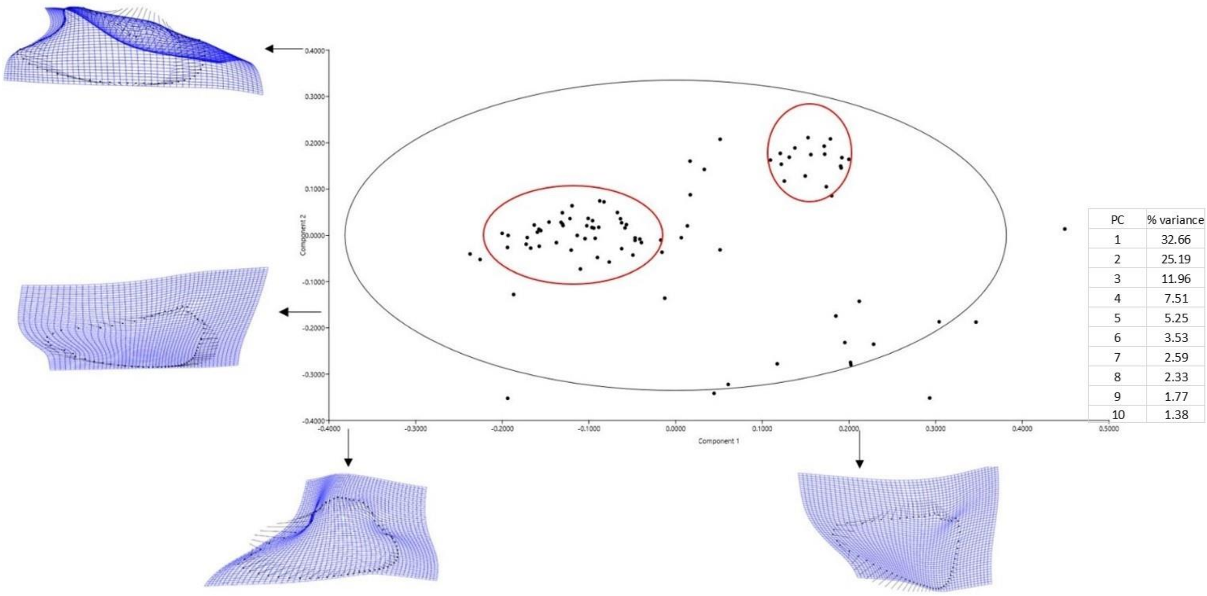


Figure 5. 28 Scatterplot showing the shape distribution of cleavers along PC 1 and 2 with TpS deformations from Khyad.

The first cluster concentrated on the left part of the scatterplot (Figure 5.28) with some cleavers skewed towards the negative (X) axis and lesser number skewed towards the positive on the Y axis.

While the PC1 axis covers cleavers with median symmetry and angled butts to symmetrical and struck on side flakes predominantly, PC2 ranged from the composite tools to cleavers with U, V and angled proximal ends and straight and convex distal ends. These cleavers had median symmetry mostly on their lateral edges.

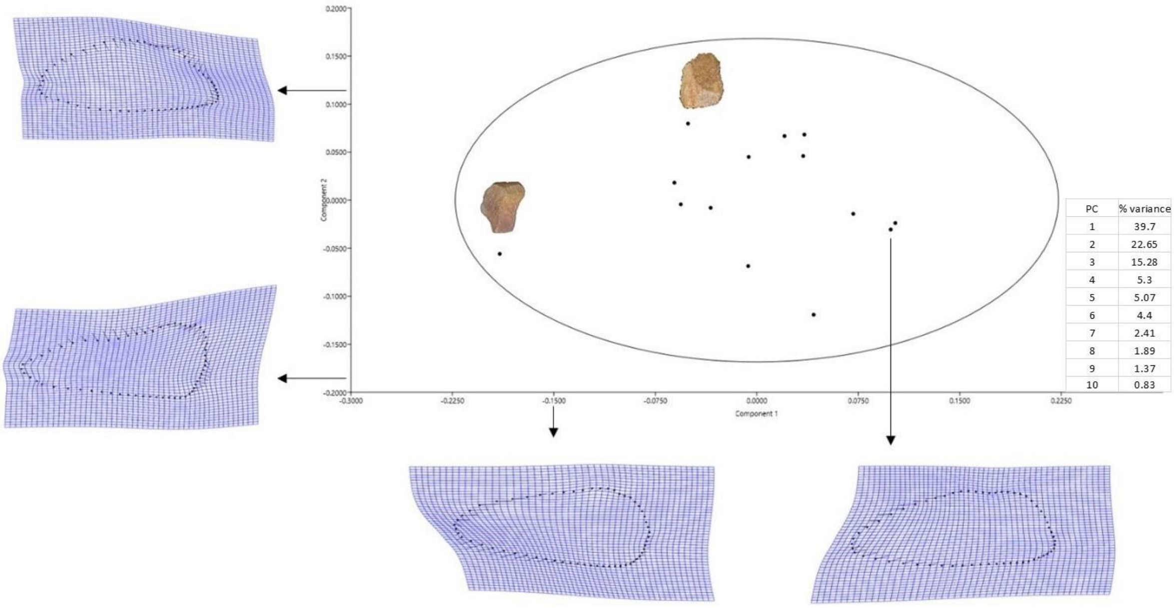
Figure 5. 29 Cleavers from cluster 1 (A) and 2 (B) (*not to scale*).

The first cluster included asymmetrical, elongated cleavers with rounded and angled butts, and convergent, straight, and diagonal distal tips on flakes and entames (Figure 5.29 A). The second cluster is located on the upper right of the scatter plot skewed towards the positive axis on X and Y (Figure 5.29 B). It had cleavers with symmetrical lateral and proximal and distal edges and were side-struck on flakes and entame. There were 5 outliers which included two composite cleavers along with an elongated specimen and a cleaver with ultra-pointed distal tip. One specimen was asymmetrical. The TpS deformation on both the PCs show modification on the lateral and proximal parts.

5.7.2 Lakhmapur

Fourteen specimens from this site were subjected to this analysis. It included twelve complete cleavers along with 2 specimens identified as cleaver blanks. The first 10 PC explain 99% of the variability. Of them, the first 3 accounted for more than 78% variation. Most of the cleavers were skewed positively for the PC1. The cleavers here were roughly symmetrical (except for the distal and proximal ends) with rounded butts.

PC1 showed a tendency from convex towards straight and diagonal distal edged cleavers. The latter were mostly struck on side-struck flakes. PC2 showed a trend of asymmetrical to roughly symmetrical cleavers with broader distal and proximal ends. Interestingly, the two cleaver blanks showed high variation, the asymmetrical unifacial one, located on the bottom left of the scatter plot and the roughly symmetrical convex edged one located on the upper left of the scatter plot (Figure 5.30). The differences of these cleaver blanks probably indicate the different stages of production. The TpS deformations show modifications to the lateral left and proximal ends.



PC	% variance
1	39.7
2	22.65
3	15.28
4	5.3
5	5.07
6	4.4
7	2.41
8	1.89
9	1.37
10	0.83

Figure 5. 30 Scatterplot showing the shape distribution along PC 1 and 2 with TpS deformations and the two cleaver blanks from Lakhmapur

5.7.3 Benkaneri

Fifteen cleavers were chosen on the basis of their complete unbroken profile. The PCs generated were 14, with the first 10 amounting to 98% of the total variance. The first three covered 70% of the variability. The shape visualisation (Figure 5.31) through TpS deformation shows variation from broader cleavers with angled butts to U shaped diagonal edged cleavers for PC1. The cleavers along this trend show the use of Kombewa flakes and tabular blocks. TpS deformations on this axis show the majority of the cleavers skewed negatively, with shaping on the distal lateral sides (Figure 5.31). PC2 show a trend of cleavers which were shaped on the proximal lateral edges resulting in an angled morphology towards a regular, more symmetrical U and V shaped cleavers. These cleavers were shaped on tabular blocks and flakes.

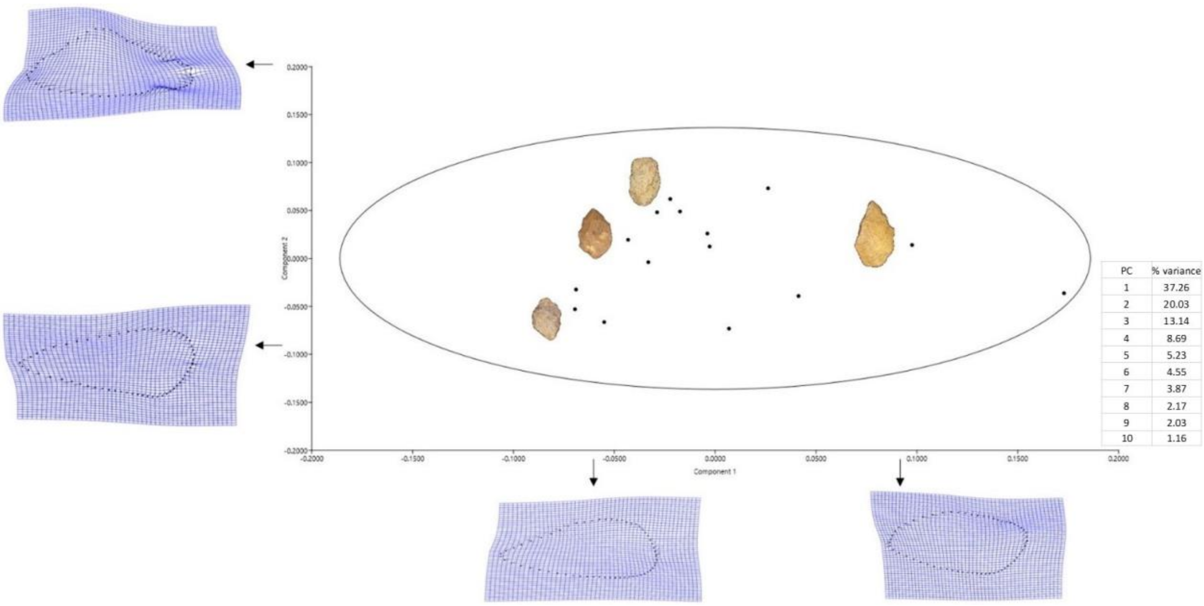


Figure 5. 31 Scatterplot displaying shape variations along PC 1 and 2 with TpS deformations of all the cleavers from Benkaneri.

5.7.4 Khyad, Lakhmapur and Benkaneri

All the cleavers from the three sites were compared to see if there was a tendency to retain similar shapes and, if so, the distribution of that trend. The total number of PCs generated were 118 with the first 10 explaining 94% of the total variation. The first two PCs explain 58% of the variation (Table 5.39).

PC	% of variance
1	34.45
2	23.26
3	11.37
4	7.54
5	5.14
6	3.46
7	2.69
8	2.46
9	1.82
10	1.51

Table 5. 39 The first 10 PCs explaining 94% of the cleaver variability – Malaprabha Valley sites.

The morpho-space depicting the PC shape distribution (Figure 43), shows that the majority of the cleavers were skewed positively on PC1 with an overlap of cleavers shapes from all the three sites (Figure 5.32).

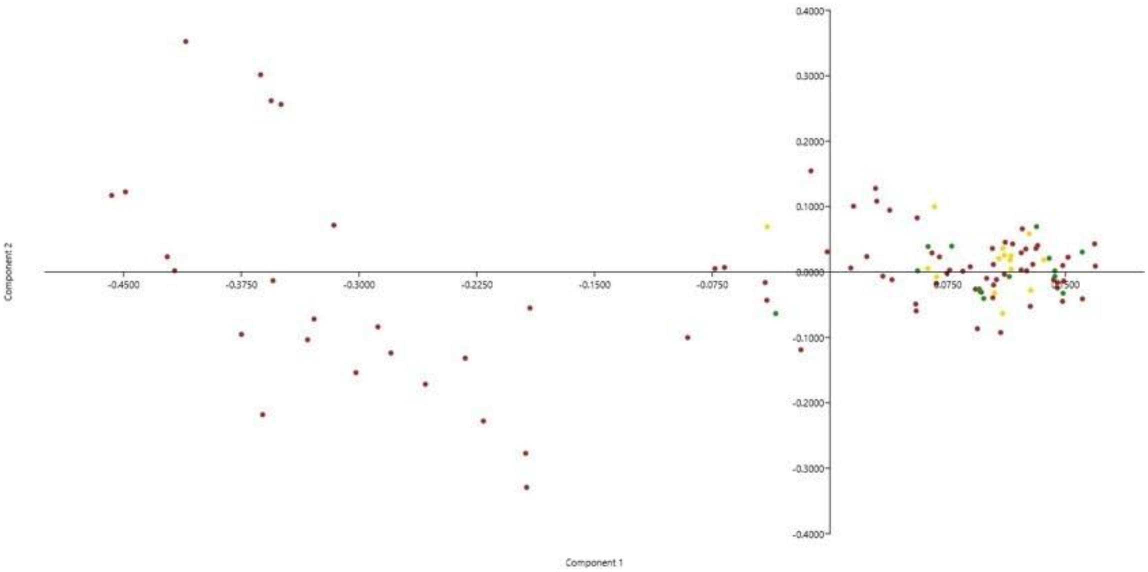


Figure 5. 32 Scatterplot displaying shape variations along PC 1 and 2 of all the cleavers from Khyad (red dot), Lakhmapur (green dot) and Benkaneri (yellow dot).

PC2 explains the variability from cleavers with minimal modification on the right lateral sides and distal ends to increased shaping on the left and distal ends.

Two different clusters are visible with one cluster of Khyad Acheulean cleavers and another with both Khyad Acheulean, and Acheulean and Middle Palaeolithic cleavers from Lakhmapur and Benkaneri. This suggests a continuity of some shape of cleavers from the Acheulean to the Middle Palaeolithic. Use of similar type of blanks for making the cleavers and the predominance of quartzite, especially of the fine-grained variety and similarities in shaping of the proximal edges all would have played a significant role in the use of some particular cleaver shapes. Similar reduction strategies employed at the three sites like the unifacial and bifacial cobble and tabular block reduction methods using both hard and soft hammer would also have been an influencing factor. Although the differential unbalanced sampling from the three sites would no doubt create a bias, it does give us information on the retention of similar shapes at all the three sites.

5.7.5 Attirampakkam

The cleavers analysed for 2D Geometric Morphometrics are a mix of collections from different museums at Paris, London, and India. A total of 19 cleavers were analysed which gave 18 PC's. Of these, the first 10 accounted for 99% of the variation and among them, the first three explained 89% of the variation.

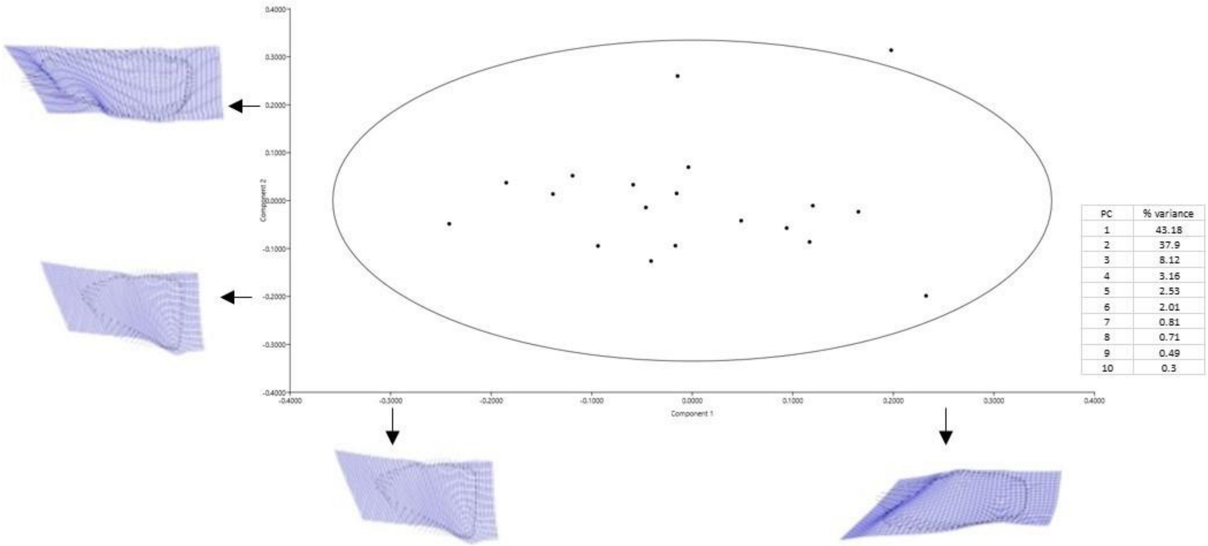


Figure 5. 33 Scatterplot displaying shape variations along PC 1 and 2 with TpS deformations of all the cleavers from Attirampakkam.

The shape distribution of the cleavers on the scatter plot (Figure 5.33) shows a widely dispersed pattern with one outlier. PC1 explained the change of cleavers with V shaped butts and broad straight distal tip to cleavers with U and angled butts and convex distal tips. Most of the cleavers were skewed negatively on this axis. PC2 traced the differences of cleavers with straight distal tips to oblique and round butted cleavers. Here also, similar to PC1, the majority of the cleavers were skewed negatively. The TpS deformations allow us to visualize the hypothetical shape change and the location of it along both the axis.

5.7.6 Singadivakkam

Only 4 cleavers were identified within the Singadivakkam tool assemblage. All the 4 were analysed which resulted in 3 PC's. The first PC explained 58% of the variation (Figure 5.34). The TpS deformed hypothetical shapes on PC1 indicate a change from narrower proximal butt and wider distal to cleavers with broader proximal butt and narrower distal tips. PC2 TpS deformations show the trend from cleavers with rounded butts and broader cleaving edge to narrow cleaving edge with shaping on lateral edges. No outliers were observed within this small sample. Two cleaver shapes appear morphologically similar (with shorter cutting edge) while 2 others were widely distributed.

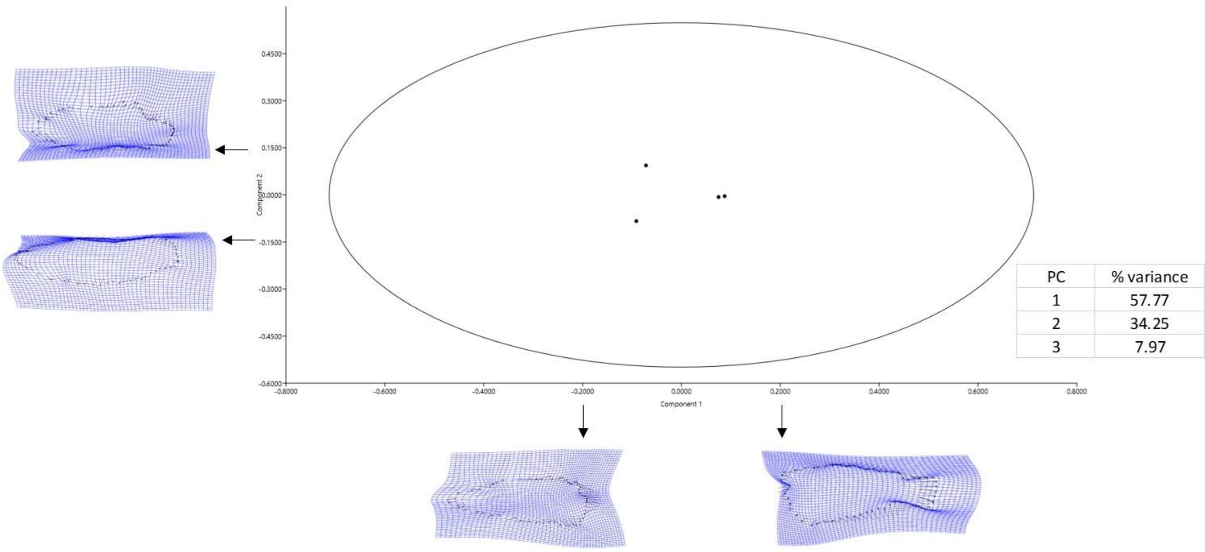


Figure 5. 34 Scatterplot displaying shape variations along PC 1 and 2 with TpS deformations of all the cleavers from Singadivakkam.

5.7.7 Attirampakkam and Singadivakkam

Cleavers from Attirampakkam were compared along with the very few cleavers (n=4) from Singadivakkam. The first 3 PCs explain 85% of the variability (Table 5.40).

PC	% of variance
1	50.53
2	29.46
3	7.71
4	3.17
5	2.41
6	1.91
7	1.71
8	0.67
9	0.59
10	0.50

Table 5. 40 The first 10 PCs explaining the variability within the cleavers from Attirampakkam and Singadivakkam.

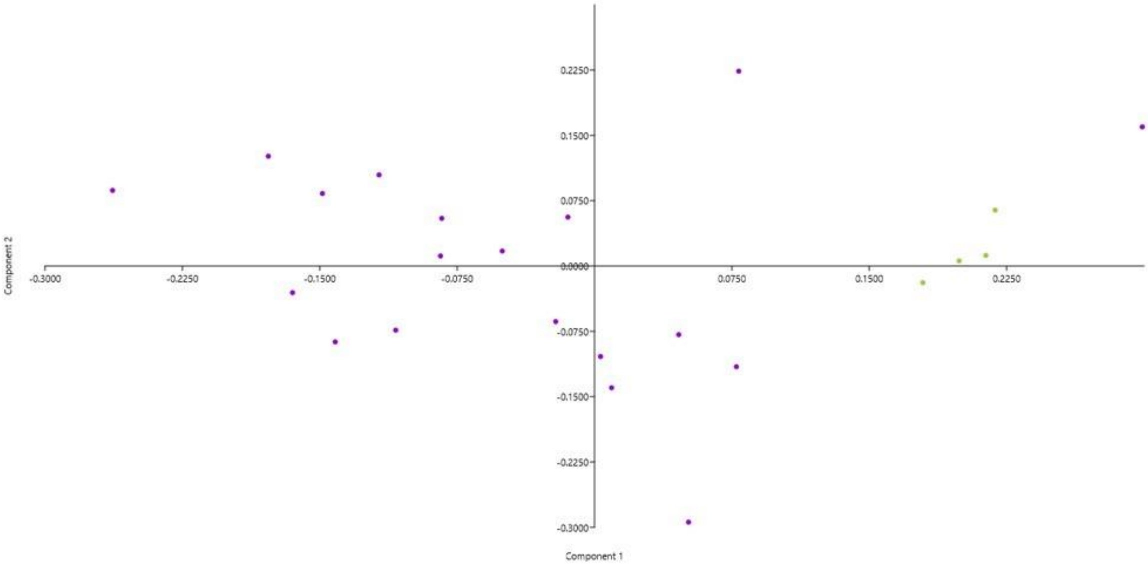


Figure 5. 35 Scatterplot displaying shape variations along PC 1 and 2 of all the cleavers from Attirampakkam (purple dot) and Singadivakkam (light green dot).

The distribution of the cleaver shapes in the morpho-space show that the Attirampakkam cleavers are largely negatively skewed on the PC1 while the Singadivakkam cleavers are positively skewed (Figure 5.35).

5.8 Inter-regional comparison

A total of 121 cleavers from the three sites in Karnataka and Tamil Nadu were compared within a single morpho-space to discern similarities and dissimilarities.

Of the 120 PC's generated, the first 10 explained 94% of the variability of the cleavers (Table 5.41). Of these, the first 3 accounted for 72% of the variation in the cleavers.

PC	% of variance
1	39.60
2	21.71
3	10.87
4	7.15
5	4.50
6	2.90
7	2.40
8	2.20
9	1.59
10	1.42

Table 5. 41 The first 10 PCs explaining the cleaver variability within the cleavers from all the sites.

Examining the distribution of the cleavers in the morpho-space (Figure 5.36) we notice that only a few cleavers from Attirampakkam showed similarities in shape with that of Khyad cleavers. Benkaneri and Lakhmapur shapes along with the very few cleavers from Singadivakkam formed a distinct cluster along with a large number of Khyad cleavers. Among the outliers, mostly restricted to Khyad, one single specimen from Attirampakkam was noted. Most of the cleavers were negatively skewed on PC1 and showed a trend to U shaped diagonal and straight edged cleavers, with almost parallel lateral edges for many. Complete symmetry to median symmetry is observed in the cleavers towards the positive axis. PC2 as opposed to PC1, showed a predominance of cleavers positively skewed on its axis.

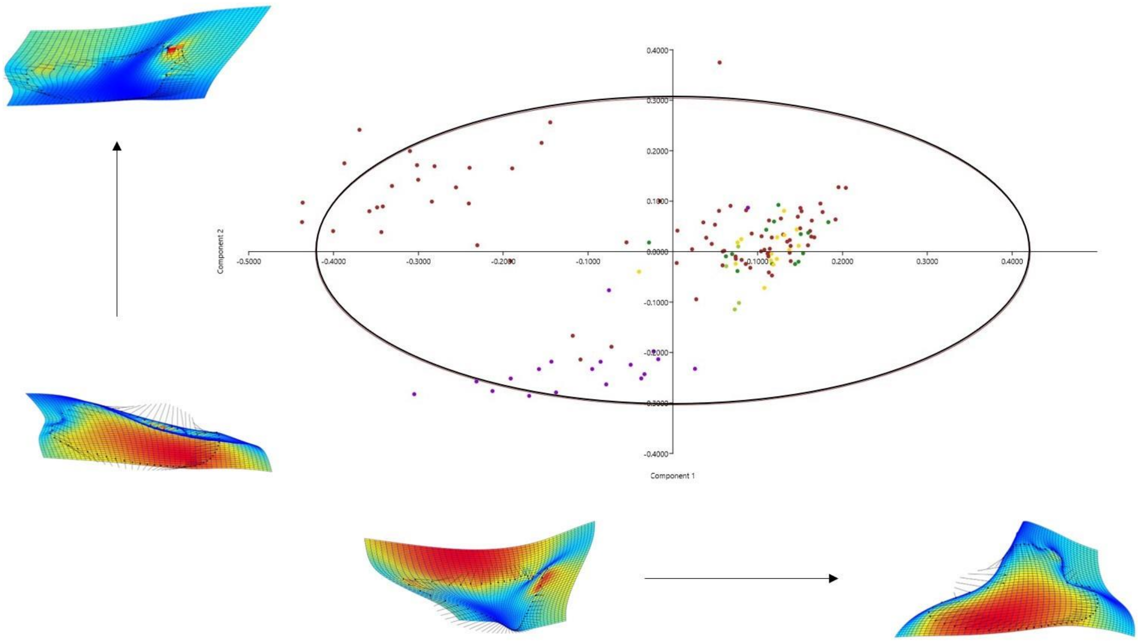


Figure 5. 36 Scatterplot displaying shape variations along PC 1 and PC 2 (with warped shapes) of all the cleavers from Karnataka and Tamil Nadu - Khyad (red dot), Lakhmapur (green dot), Benkaneri (yellow dot), Attirampakkam (purple dot) and Singadivakkam (light green dot).

5.9 3D Geometric Morphometric Analysis – Handaxes

All the handaxes from individual sites were analysed separately to understand the variability in different blanks type and their distal tip morphologies. This was followed by an experimental analysis retaining one group of attributes and grouping all other attributes into another. This was done in order to include the single specimens, which otherwise, could not be included in the previous test as the specimens did not conform to the minimum requirement for statistically significant results. Including these previously unincluded specimens, helped understand the distribution of variability among all the specimens irrespective of their quantity. Then, comparison between the three sites were made to understand the inter-site variability. Finally, an inter-regional analysis was done, with all the handaxes from both Malaprabha Valley and Tamil Nadu sites. A detailed description of the methodology followed is given in Article 2 (Appendix II).

5.9.1 Khyad

A total of 63 handaxes were used for this analysis. The tools came from different locational contexts, from Musée de l'Homme, Paris, British Museum, London, and the Robert Bruce Foote Archaeological Museum of Sanganakallu, located in Ballary, India.

The number of PC's generated was 62, of which the first 10 explained 73% of the variability. The first 3 accounted for 41% variability. From the distribution of the blank shapes, we see that similar shapes existed for handaxes on all type of blanks except for the side struck and tabular blocks as well as the indeterminate ones. The TpS warped images show an elongation of the handaxes towards the positive axis of PC1 and handaxes with rounded right oriented tips on the positive axis of PC2 (Figure 5.37).

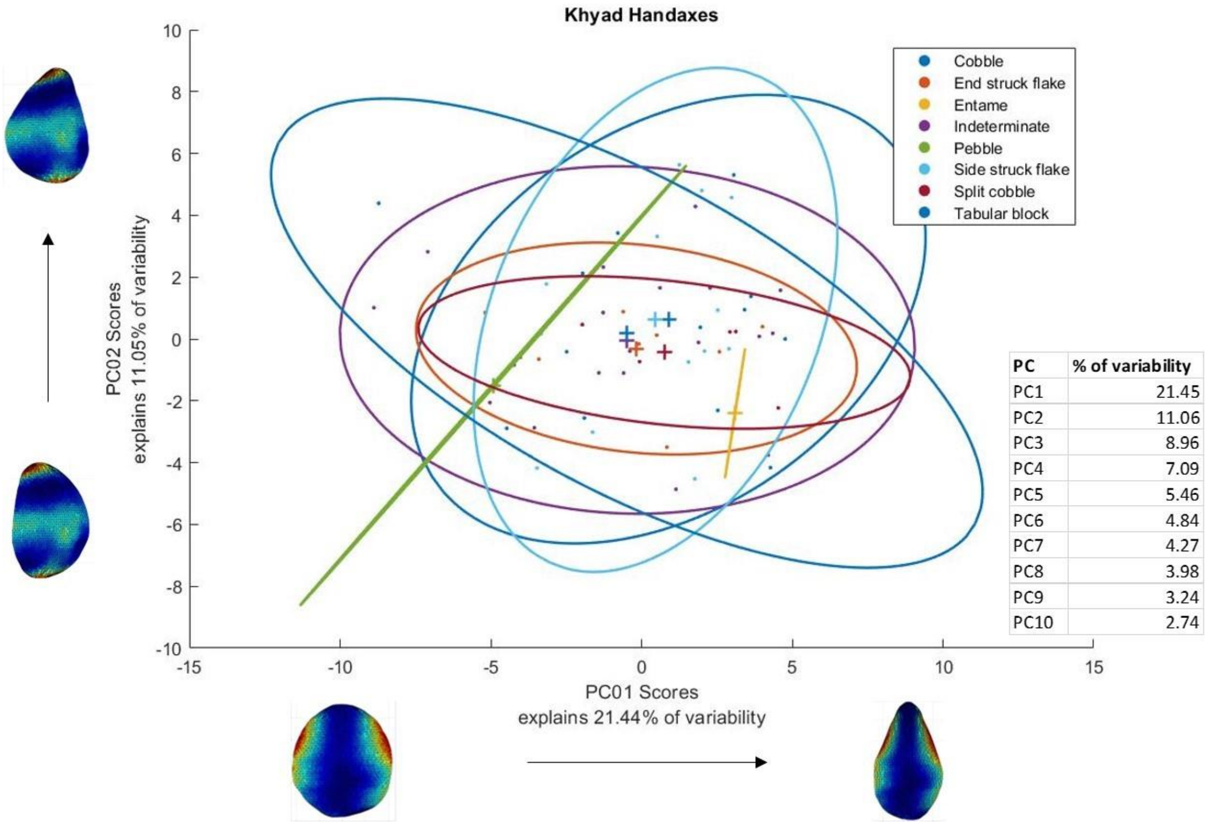


Figure 5. 37 Scatterplot of the first two principal components. Warped images represent hypothetical shape change of the tool along the axis. + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses. Khyad handaxes blank type.

A Wilcoxon Rank-Sum Test on the Inter-point Distances between the group means of all blank types was conducted which resulted in significant differences between some blank types (Table 5.42).

Blank Type 1 and no. of handaxes	Blank Type 2 and no. of handaxes	Rank-Sum	pValue
Cobble (n=7)	Indeterminate (n=19)	550	0.01
Split Cobble (n=6)	Indeterminate (n=19)	534	0.04
Cobble (n=7)	Side-struck flake (n=13)	279	<0.01
Split Cobble (n=6)	End-struck flake (n=8)	152	0.02
Cobble (n=7)	End struck flake (n=8)	150	<0.01
Cobble (n=7)	Split Cobble (n=6)	109	<0.01
Cobble (n=7)	Tabular block(n=6)	136	0.04

Table 5. 42 Result of a Wilcoxon Rank-Sum Test on the Inter-point Distances between the group means of all blank types - Khyad Handaxes.

An examination of the mean shapes (Figure 5.38) shows similarities and dissimilarities in the location and intensity of the variability of the handaxes. While the cobble, pebble, and entame handaxes remained less intensively variable, the split cobble had the most variability on the lateral edges. Tabular blocks showed the same trend along with invasive variability on the surface. This indicates the bifacial volumetric thinning as tabular blocks were available in different shapes and sizes. The indeterminate handaxes displayed variability all along the periphery while the flake tools had lateral and proximal modification. All the blank types had variability present at the proximal end, attesting to removal of striking platform to get the handaxes morphology and their symmetry.

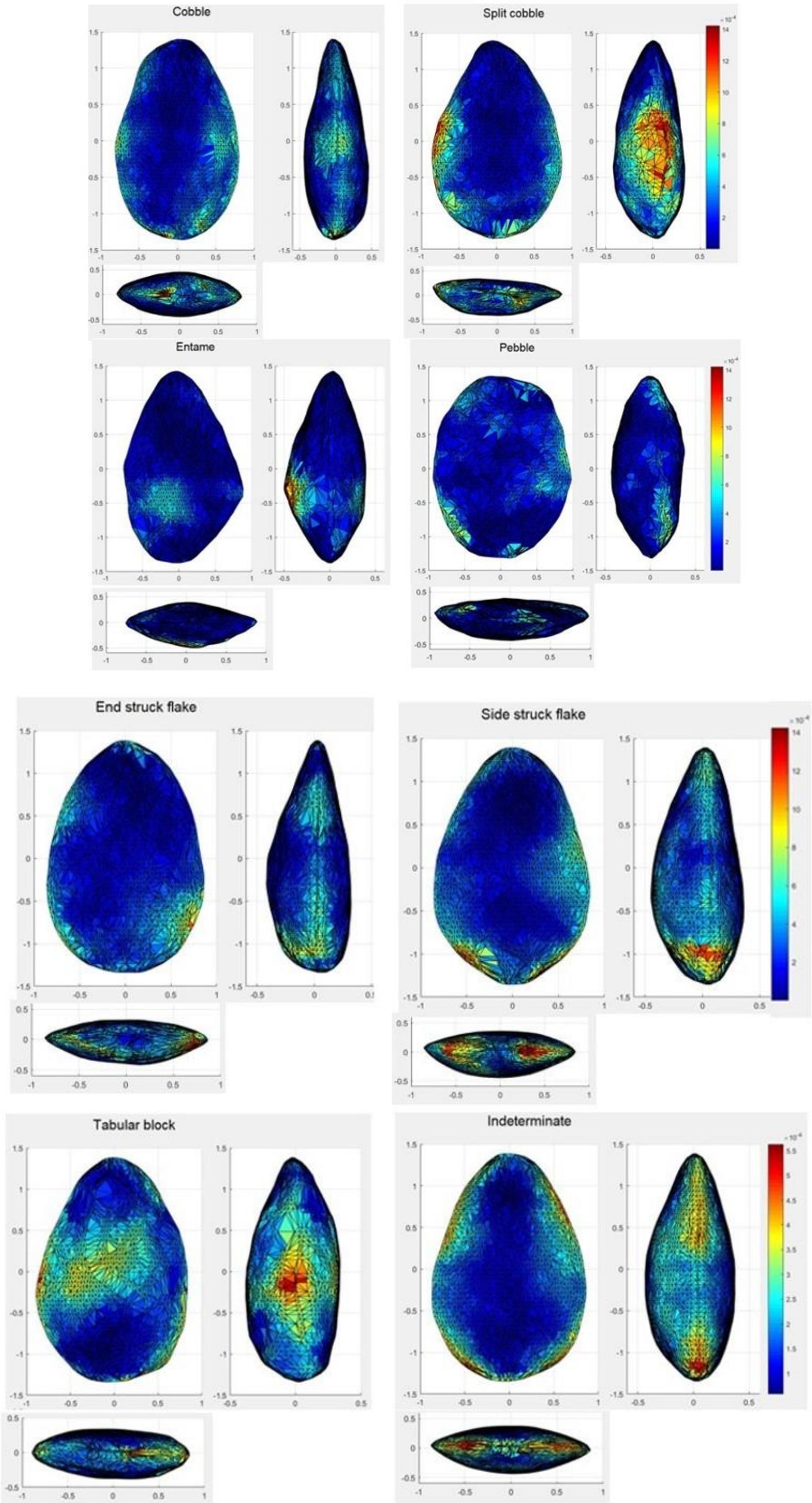


Figure 5. 38 Comparison of the mean shapes of all handaxes on different blanks from Khyad. Colour coding represents degree and the location of variability.

Table 5.43 summarises the variability intensity and the causative factors. In all the cases, X (relative width) and Z (relative thickness) dimensions play an important part in causing the shape variability while Y (relative length) dimension had little effect. Entame shape variability was largely influenced by the Z factor. The handaxes on entame from this site were largely shaped only on one face.

Blank Type	**No. of Items**	**Shape Variability within the group**	**% caused by X (relative width)**	**% caused by Y (relative length**	**% caused by Z (relative thickness)**
Cobble	7	6.92	46.86	2.99	50.14
Split cobble	6	6.16	47.46	4.21	48.33
Entame	2	4.79	21.23	5.20	73.57
Pebble	2	5.09	43.91	3.99	52.10
End-struck flake	8	6.21	52.16	3.91	43.93
Side-struck flake	13	7.05	45.30	2.74	51.96
Tabular block	6	7.44	40.06	3.10	56.84
Indeterminate	19	7.35	52.02	3.69	44.29

Table 5. 43 The distribution of variability among the blank type groups and the causative factor - Khyad handaxes.

The second attribute chosen for this analysis is the distal tip morphology. The shape distribution of the distal edges shows that handaxe shapes in all the categories were similar and overlap (Figure 5.39).

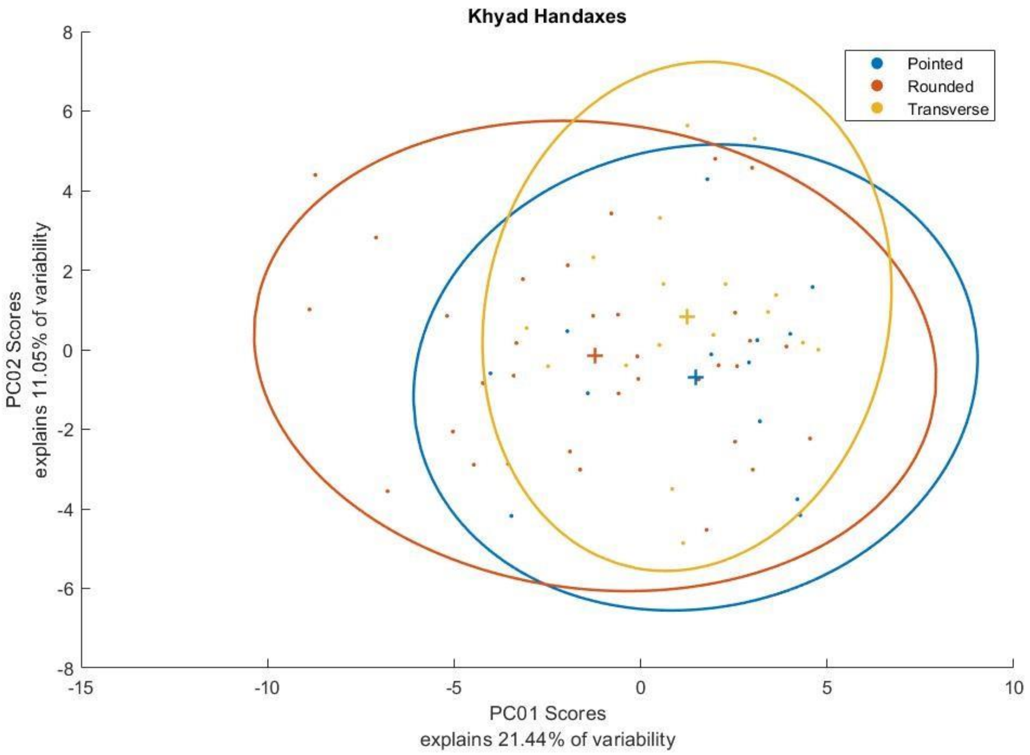


Figure 5. 39 Scatterplot of the first two principal components + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses. Khyad handaxe distal tip.

An examination of the distribution of the distal morphologies of rounded, pointed, and transverse edged handaxes (Figure 5.40) show that the handaxes with rounded and transverse edged distal tips had similar pattern of variability, all around the periphery. The intensity of the variability is located on the proximal butt along with the lateral edges.

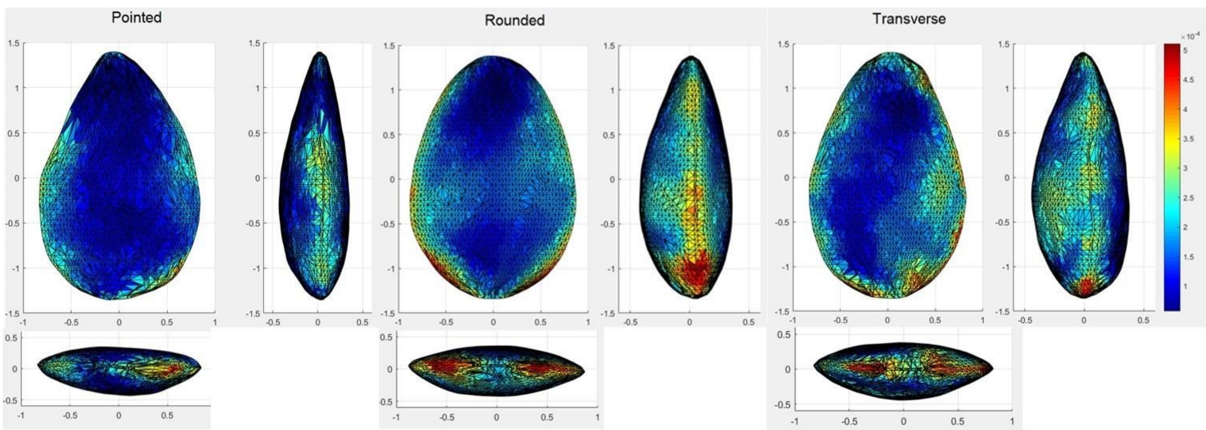


Figure 5. 40 Comparison of the mean shapes of all handaxes with different distal tip morphologies from Khyad. Colour coding represents the degree and location of variability

While the relative thickness was the main contributor to this variability within the rounded and transverse edged handaxes, it was the relative width that resulted in the variation within the pointed handaxes (Table 5.44).

Distal morphology	No. of Items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Pointed	13	6.89	50.76	2.69	46.55
Rounded	33	7.35	46.03	3.84	50.13
Transverse	17	6.67	41.86	2.35	55.79

Table 5. 44 Result of a Wilcoxon Rank-Sum Test on the Inter-point Distances between the group means of all distal types - Khyad handaxes.

A Wilcoxon Rank-Sum Test on the Inter-point Distances between the group means of pointed and rounded handaxes showed a significant difference at pValue <0.01 (rank-sum=1202, n1=10, n2=29). The same test between transverse and round also produced variability significant at p Value=0.03 (rank-sum=1699, n1=29, n2=15). However, there was no significant difference between transverse and pointed ones.

To include all the blank types, a further test was conducted by grouping together all the blank types, leaving out the tabular block handaxes. This allowed us to extract the mean shape differences between them (Figure 5.41). Irrespective of the blank morphology, there seems to be some standardisation, with the major variability located at the proximal, lateral, and lower half of the handaxes. This pattern is consistent with the three-directional pattern observed during the classical analysis.

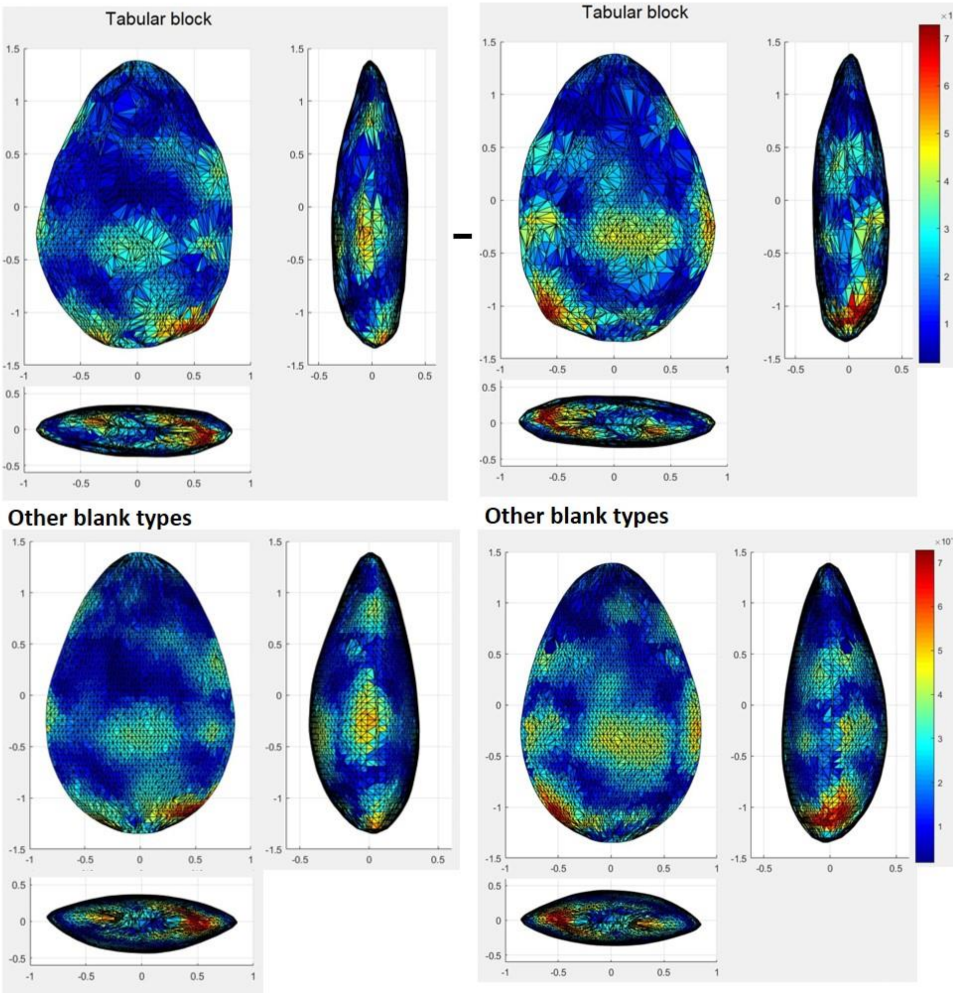


Figure 5. 41 Comparison of the mean shapes of all handaxes (Dorsal and Ventral) on tabular block and handaxes on other blanks (Dorsal and Ventral) from Khyad. Colour coding represents the degree and location of variability.

A similar test was conducted on the attribute of the distal morphology. The results show a similarity of variability which indicate some amount of standardisation (Figure 5.42).

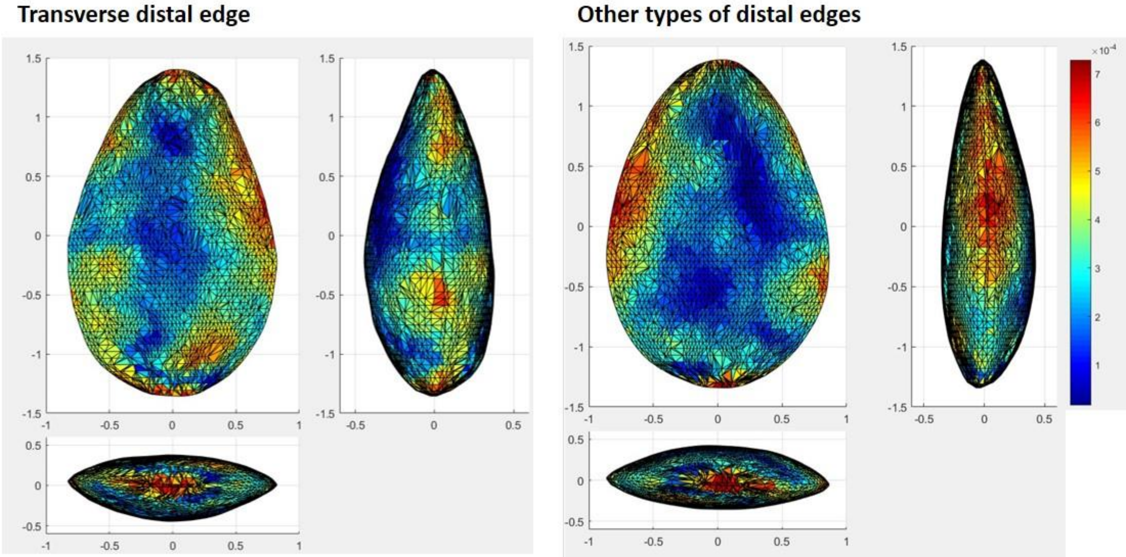


Figure 5. 42 Comparison of the mean shapes of all handaxes with transverse distal type and handaxes with other distal edge types from Khyad. Colour coding represents the degree and location of variability.

5.9.2 Lakhmapur

From this site, 18 handaxes were analysed. The number of PC's generated was 17, of which the first 10 explained most of the variability (91%). The first three accounted for 60% of the variance within. The shape distribution of different blanks (Figure 5.43) shows that except for two specimens, one on split cobble and another on end-struck flake, the shapes of handaxes on other blanks remain similar. The warped images show a trend of rounded handaxes warping towards elongated pointed handaxes on the PC1 while on the PC2 axis, broad butted pointed handaxes (cordiform) give way to elongated ovate handaxes.

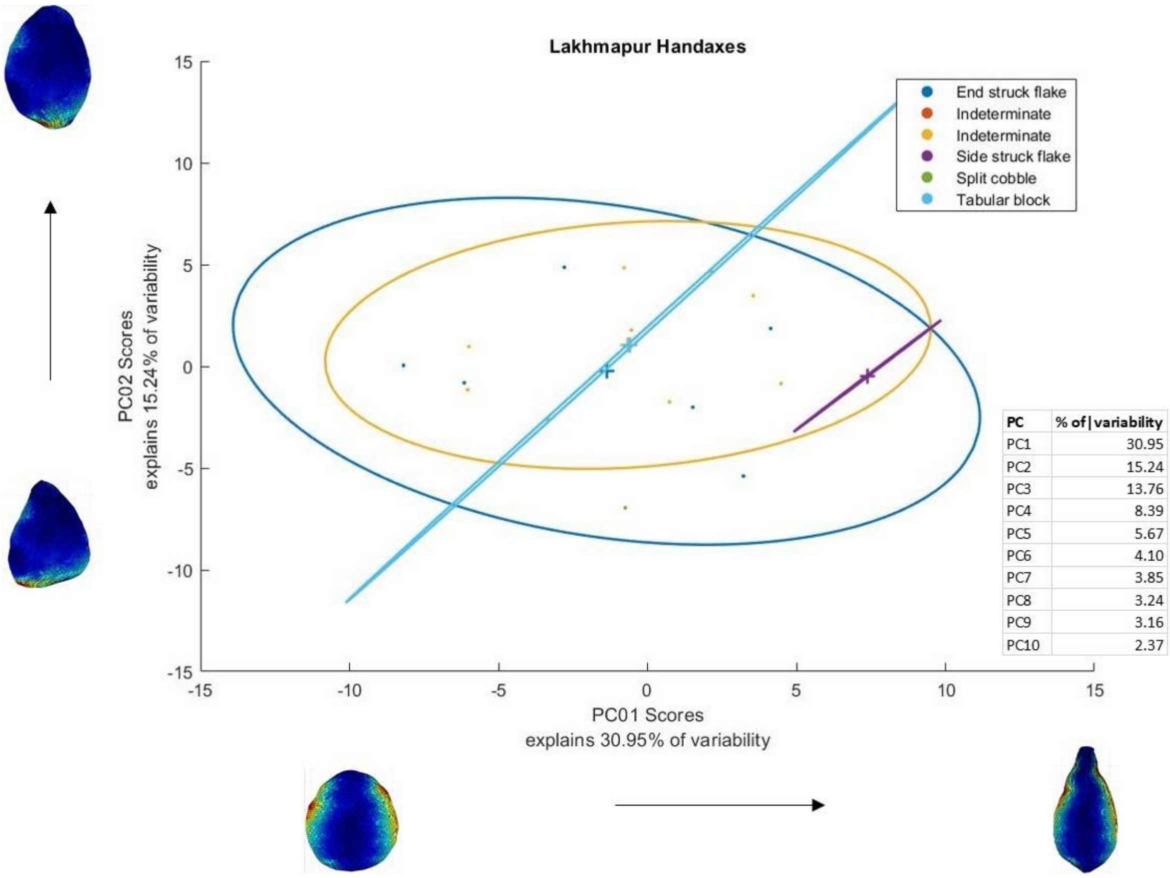


Figure 5. 43 Scatterplot of the first two principal components. Warped images represent hypothetical shape change of the tool along the axis. + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses - Lakhmapur handaxe blank type.

A Wilcoxon Rank-Sum Test on the Inter-point Distances on shape variabilities between that of end struck flake and indeterminate group showed no significance (rank-sum=48, p=0.44). As the samples of side-struck handaxes, split cobbles and tabular blanks were insufficient, they could not be tested for the same.

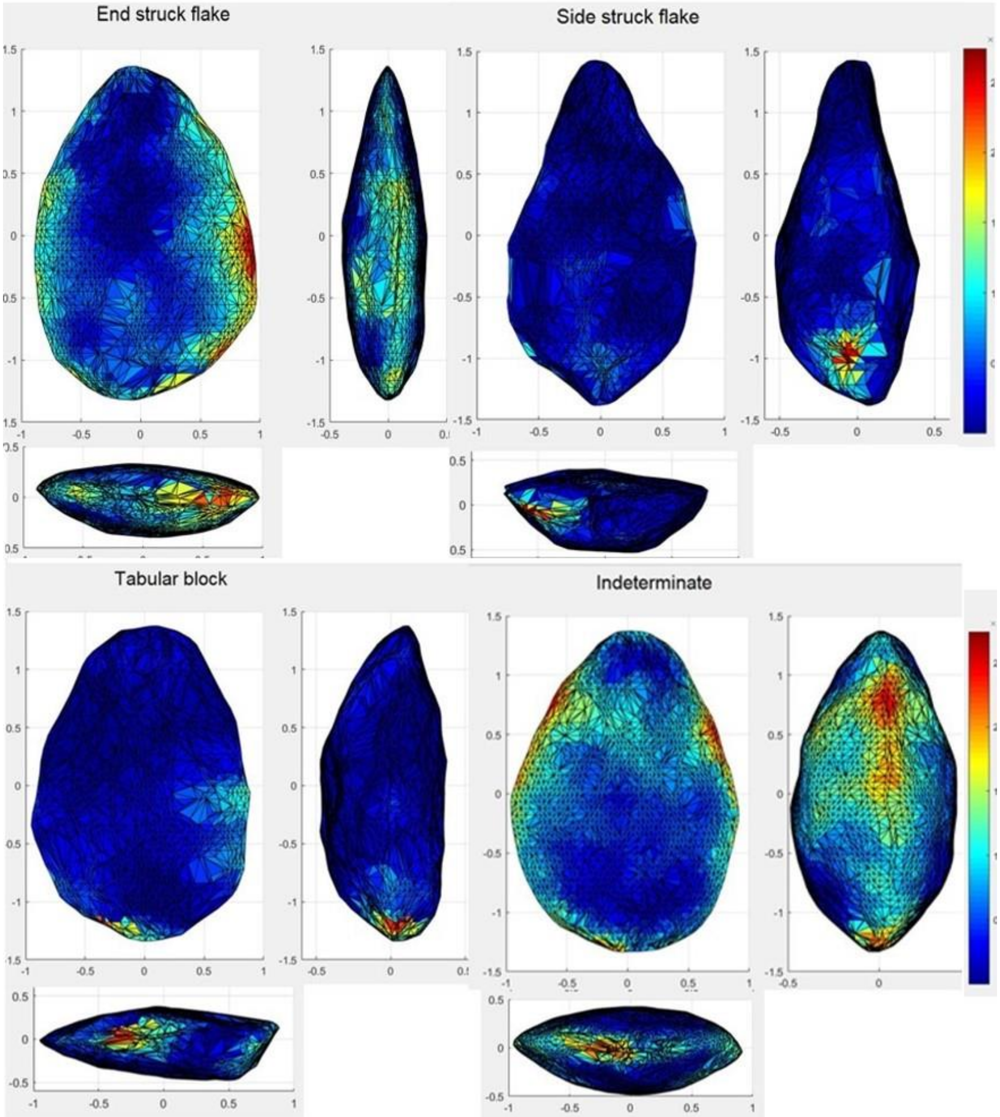


Figure 5. 44 Comparison of the mean shapes of handaxes on different blanks. Lakhmapur handaxe. Colour coding represents degree and the location of variability.

The mean shape comparison of the blanks shows similarities within the group of end-struck flakes and indeterminate on one hand and the group of tabular blocks and side-struck flakes on other hand (Figure 5.44). The former has variabilities on the proximal and lateral edges while the latter group display the main variation at the proximal ends. The variability at the proximal ends indicates the thinning of the butt while the lateral variability indicates attempts at bringing symmetry as well as making the tool pointed.

We find that the major contributor to the variation came from X dimension for the end-struck flakes, indeterminate blanks, and tabular blocks (Table 5.45) while for the side-struck flakes it was caused by the Z dimension. In all the cases Y dimension caused the least variation.

Blank Type	**No. of Items**	**Shape Variability within the groups**	**% caused by X (relative width)**	**% caused by Y (relative length)**	**% caused by Z (relative thickness)**
End-struck flake	6	7.60	49.97	6.98	43.05
Side-struck flake	2	4.58	25.65	0.55	73.80
Tabular block	2	5.50	65.24	2.97	31.79
Indeterminate	7	6.93	47.37	6.36	46.26

Table 5. 45 Result of a Wilcoxon Rank-Sum Test on the Inter-point Distances between the group means of all blank types - Lakhmapur handaxes.

The second attribute examined, that of the distal morphology, showed a wide distribution of the distal morphologies (Figure 5.45).

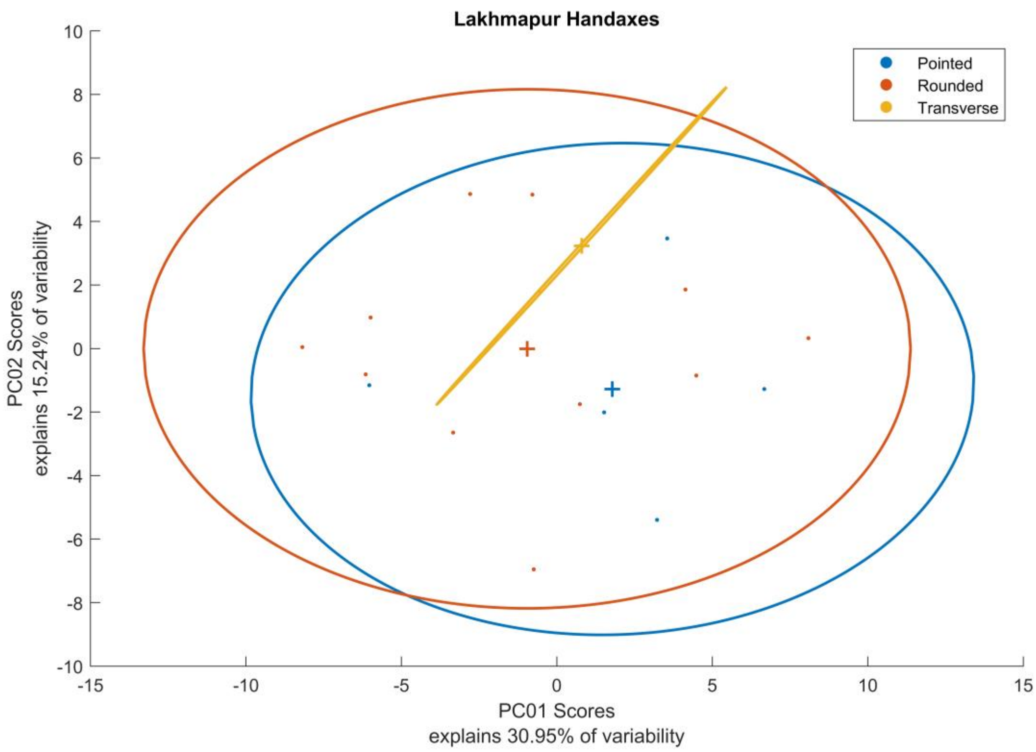


Figure 5. 45 Scatterplot of the first two principal components + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses - Lakhmapur handaxe distal tip.

The shape variabilities of pointed and rounded distal ended handaxes were tested for the Wilcoxon Rank-Sum Test on the Inter-point Distances and the result was negative at p=0.66 (rank-sum=38).

The mean shapes of the distal morphologies when compared (Figure 5.46) show more variability at the distal ends for the rounded and pointed handaxes. This is corroborated by the convergent shaping, and shaping of the lateral edges to make it more pointed. The proximal modifications indicate platform removal through shaping. Both rounded and pointed handaxes with lateral variability also probably indicate a shaping tendency to achieve symmetry.

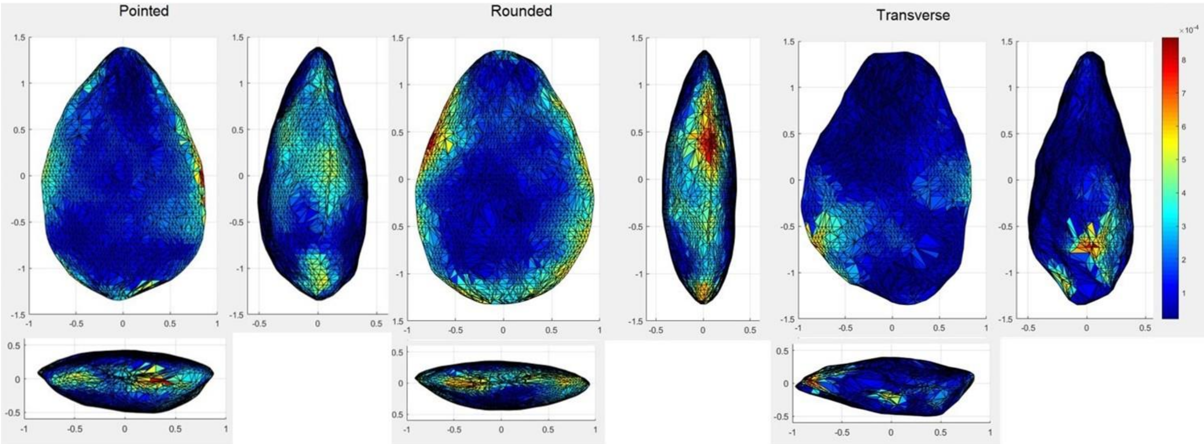


Figure 5. 46 Comparison of the mean shapes of all handaxes with different distal tip morphologies from Lakhmapur. Colour coding represents the degree and location of variability

The distal tip morphology for both the pointed and rounded handaxes were influenced by the X dimension, followed by the Z dimension. In contrast, the transverse edged handaxes show the morphological difference caused mainly by Z, followed by X dimension. In all the cases, the Y dimension played little role, except for the rounded handaxes where 7% of the variation was a result of this dimension (Table 5.46).

Distal morphology	No. of Items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	%caused by Z (relative thickness)
Pointed	5	7.59	48.96	2.82	48.22
Rounded	11	8.06	49.52	6.54	43.94
Transverse	2	4.52	36.28	1.80	61.92

Table 5. 46 Result of a Wilcoxon Rank-Sum Test on the Inter-point Distances between the group means of all distal types - Lakhmapur handaxes.

In order to examine the variability among all specimens, including the single ones, a comparative analysis was carried out between two groups (blank types) created artificially by grouping 3 end struck handaxes and another group combining all the rest of the blanks together. The results (Figure 5.47) show an interesting trend of similar variability pattern, with the main variability located on the proximal ends and lateral right and distal tip. The surface variability also seems to be consistently the same with moderate to little intensity.

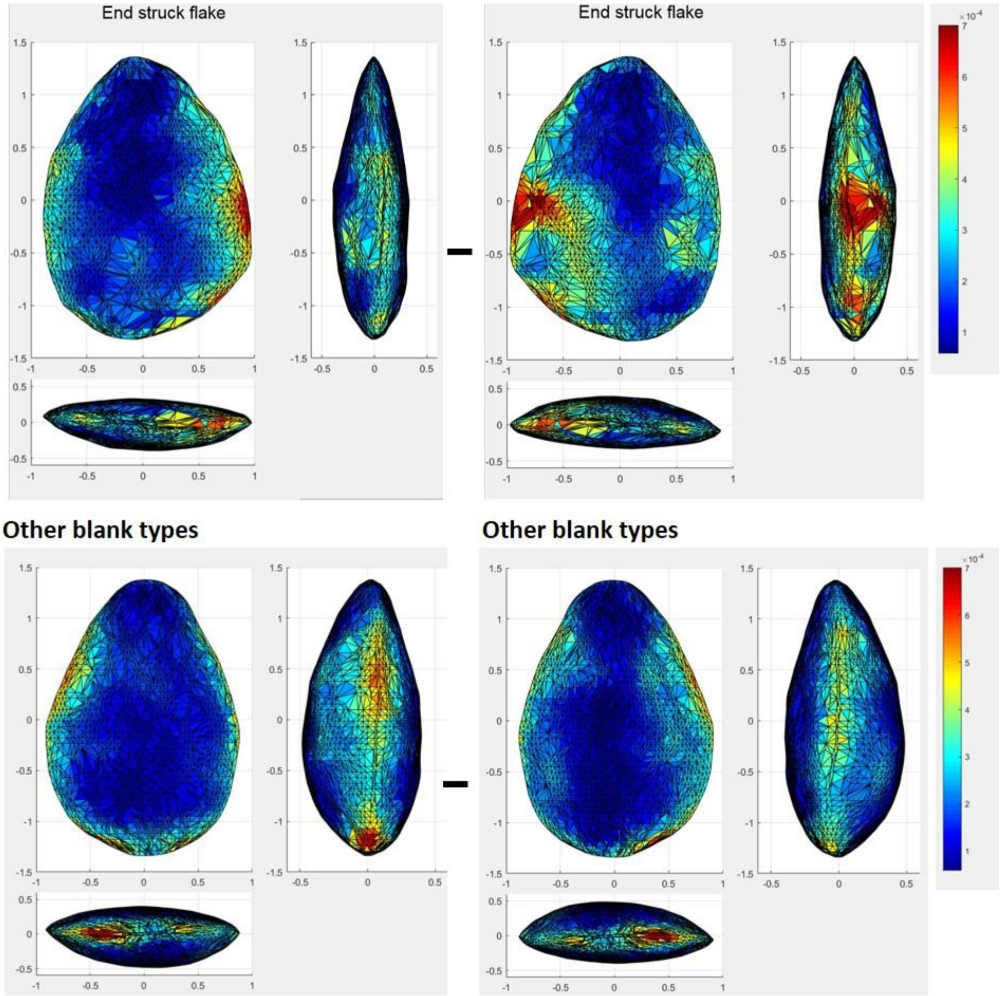


Figure 5. 47 Comparison of the mean shapes of all handaxes (Dorsal and Ventral) on end-struck flakes and handaxes on other blanks (Dorsal and Ventral) from Lakhmapur. Colour coding represents the degree and location of variability

The same test was carried out for the distal morphologies with the pointed handaxes isolated as one group with the rest (rounded and transverse) forming another group.

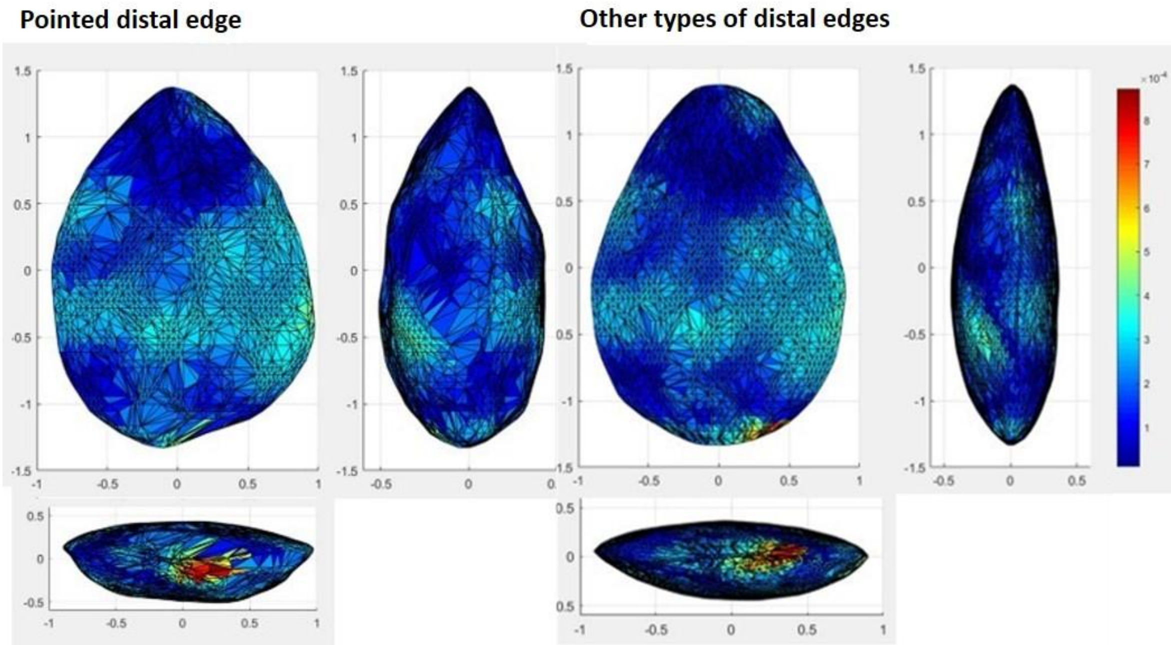


Figure 5. 48 Comparison of the mean shapes of all handaxes with pointed distal type and handaxes with other distal edge types from Lakhmapur. Colour coding represents the degree and location of variability

The results reflect the trend observed in the case of the blanks. Similar variability pattern with proximal having the most intense variability and little to moderate variability on the lateral and distal edges and the surface area is observed (Figure 5.48). Bifacial symmetry was one result as can be observed from the majority of the handaxes.

Overall, a shaping standardisation can be inferred from the mean shapes observed.

5.9.3 Benkaneri

From this site, 22 tools were analysed. Only a summary of the results is given below as a detailed description is provided in Article 2 (Appendix II).

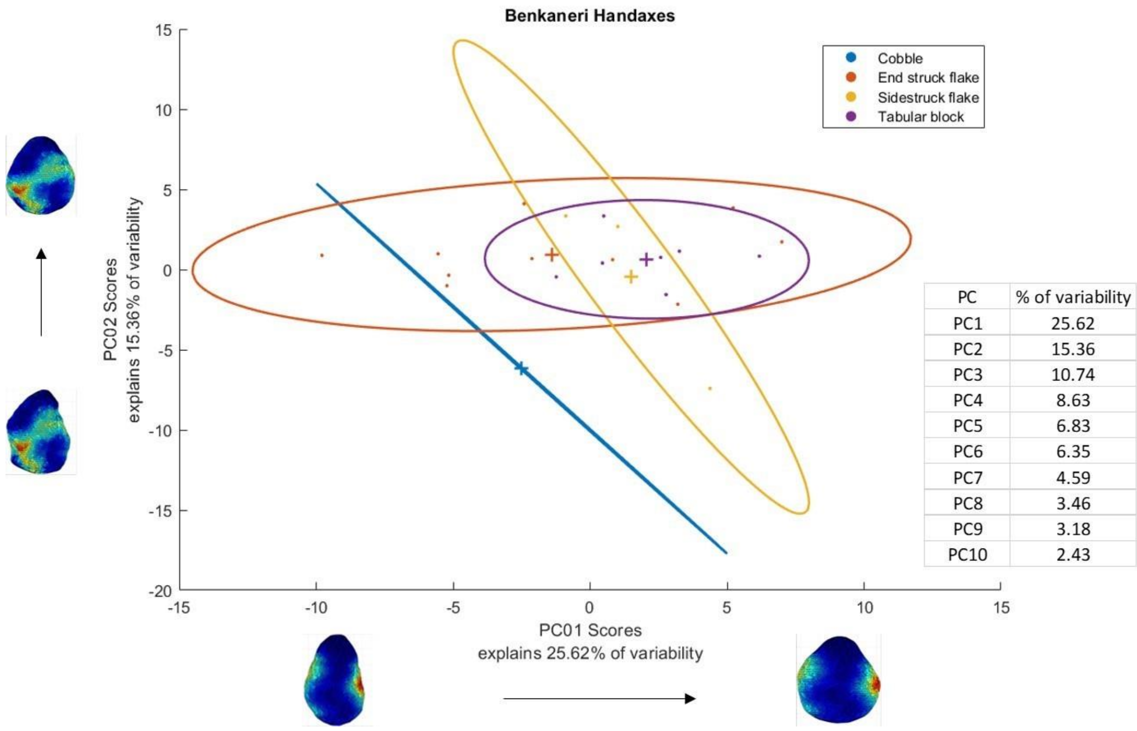


Figure 5. 49 Scatterplot of the first two principal components. Warped images represent hypothetical shape change of the tool along the axis. + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses. Benkaneri handaxes blank type.

Tabular block and end-struck handaxes show similarities, represented by the overlap in the morpho-space (Figure 5.49). One cobble specimen and another on side-struck flake stand out from the rest.

Wilcoxon Rank-Sum statistical test showed significance of variability within end-struck and side-struck (p Value=0.02). The test conducted on shape variabilities between the blanks, however, do not show any significance. The factor contributing to the variability present is similar in all the types of blanks – that of the relative width and relative thickness.

The second attribute of the distal morphology shows majority of the handaxes (n=9) skewed towards the positive axes of the PC, being more or less pointed.

Wilcoxon Rank-Sum Test on Inter-point Distances between Group Means, resulted in significant (.05 level) differences between the mean shapes of rounded, pointed and transverse (pValue $< .01$ for rounded and pointed, and pValue $= 0.03$ for pointed and transverse).

To understand the intensity and nature of variability on all the specimens, irrespective of the blank types, a comparative test was done on the blank types and distal morphologies. All the blanks were grouped together with the 3 tabular blocks considered as another group.

The results show similar pattern and intensity of variability on both the dorsal and ventral surfaces as can be seen from Figure 5.50.

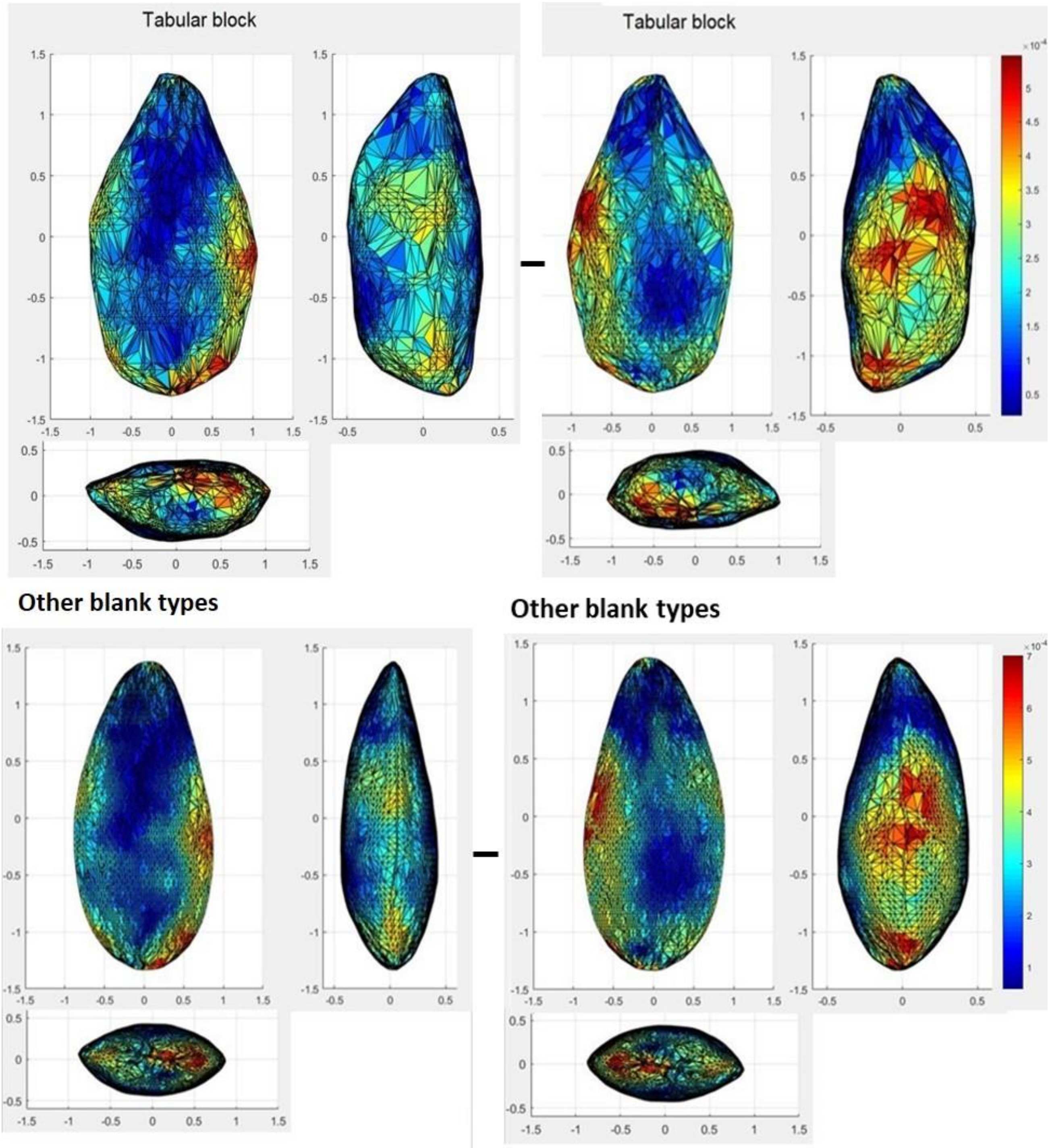


Figure 5. 50 Comparison of the mean shapes of all handaxes (Dorsal and Ventral) on tabular blocks and handaxes on other blanks (Dorsal and Ventral) from Benkaneri. Colour coding represents the degree and location of variability.

The second attribute used for this test was the distal tip morphology, with the 3-transverse edged handaxes grouped as one, and the rest grouped into another. The results are similar to the test results conducted on the blank types. Similar intensity and location of the variability are indicated by the Figure 5.51.

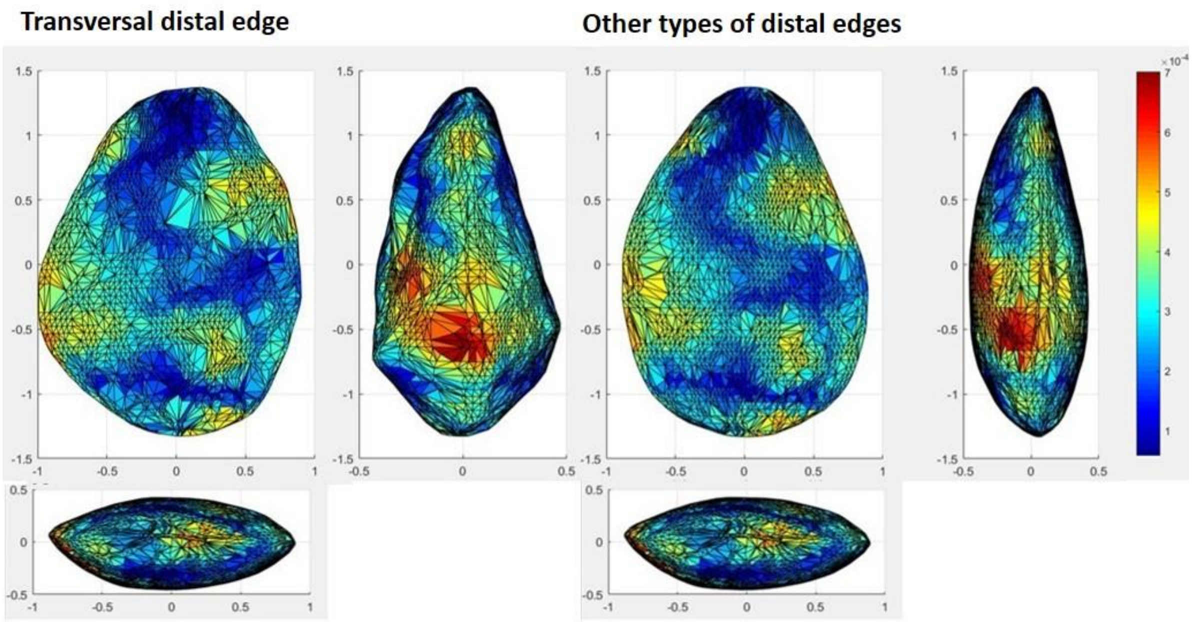


Figure 5. 51 Comparison of the mean shapes of all handaxes with transverse distal type and handaxes with other distal edge types from Benkaneri. Colour coding represents the degree and location of variability

5.9.4 Khyad, Lakhmapur and Benkaneri

All the handaxes from the three sites were compared together in a single morpho-space to understand if the sites display similar variabilities or not.

A total of 104 handaxes from the three sites were analysed which produced 103 PC's, of which the first 10 explained 71% of the total assemblage variability. The first 3 accounted for 43% of the variability among the shapes.

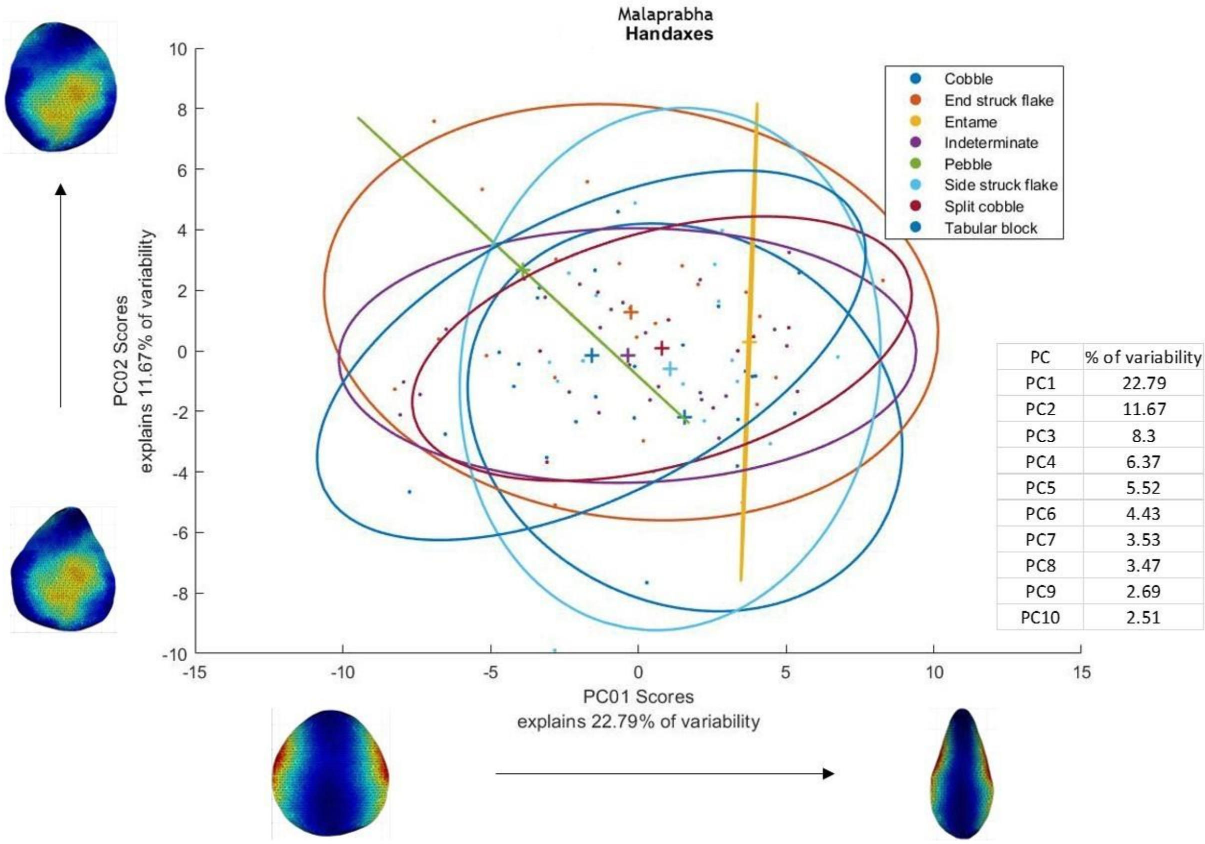


Figure 5. 52 Scatterplot of the first two principal components. Warped images represent hypothetical shape change of the tool along the axis. + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses. Malaprabha Valley handaxes blank type.

The distribution of the blank shapes across the morpho-shape (Figure 5.52) shows overlap of many shapes, with the majority of tools falling within the shape space of end-struck handaxes. The mean shapes of the handaxes on pebbles and entames were located separately, from the rest of the handaxes on flakes, cobbles, and tabular block blanks.

There was one outlier, a handaxe from Lakhmapur, which was on an end-struck blank. The shape of this handaxe was discoid with a notch at the distal tip. The warped images show a shape trend of handaxes from rounded shapes to elongated ones in PC1 while on PC2, a change from handaxes with wide proximal ends and pointed edges to rounded proximal and distal ends can be noticed.

Wilcoxon Rank-Sum Test on Inter-point Distances between Group Means showed significant differences between blanks of cobble, end-struck, and side-struck flakes, split cobbles, and tabular blanks (Table 5.47).

Blank Type 1 and no. of handaxes	Blank Type 2 and no. of handaxes	Rank-Sum	pValue
Cobble (n9)	Indeterminate (n=26)	1012	<0.01
Split Cobble (n=7)	Indeterminate (n=26)	940	0.03
Side-struck flake (n=18)	Tabular block(n=15)	910	0.01
Cobble (n=9)	End-struck flake (n=24)	884	<0.01
Cobble (n=9)	Side-struck flake (n=18)	579	<0.01
Cobble (n=9)	Tabular block(n=15)	451	<0.01
Split Cobble (n=7)	Tabular block(n=15)	394	0.01
Cobble (n=9)	Split Cobble (n=7)	189	<0.01

Table 5. 47 Result of a Wilcoxon Rank-Sum Test on the Inter-point Distances between the group means of all blank types - Malaprabha Valley handaxes.

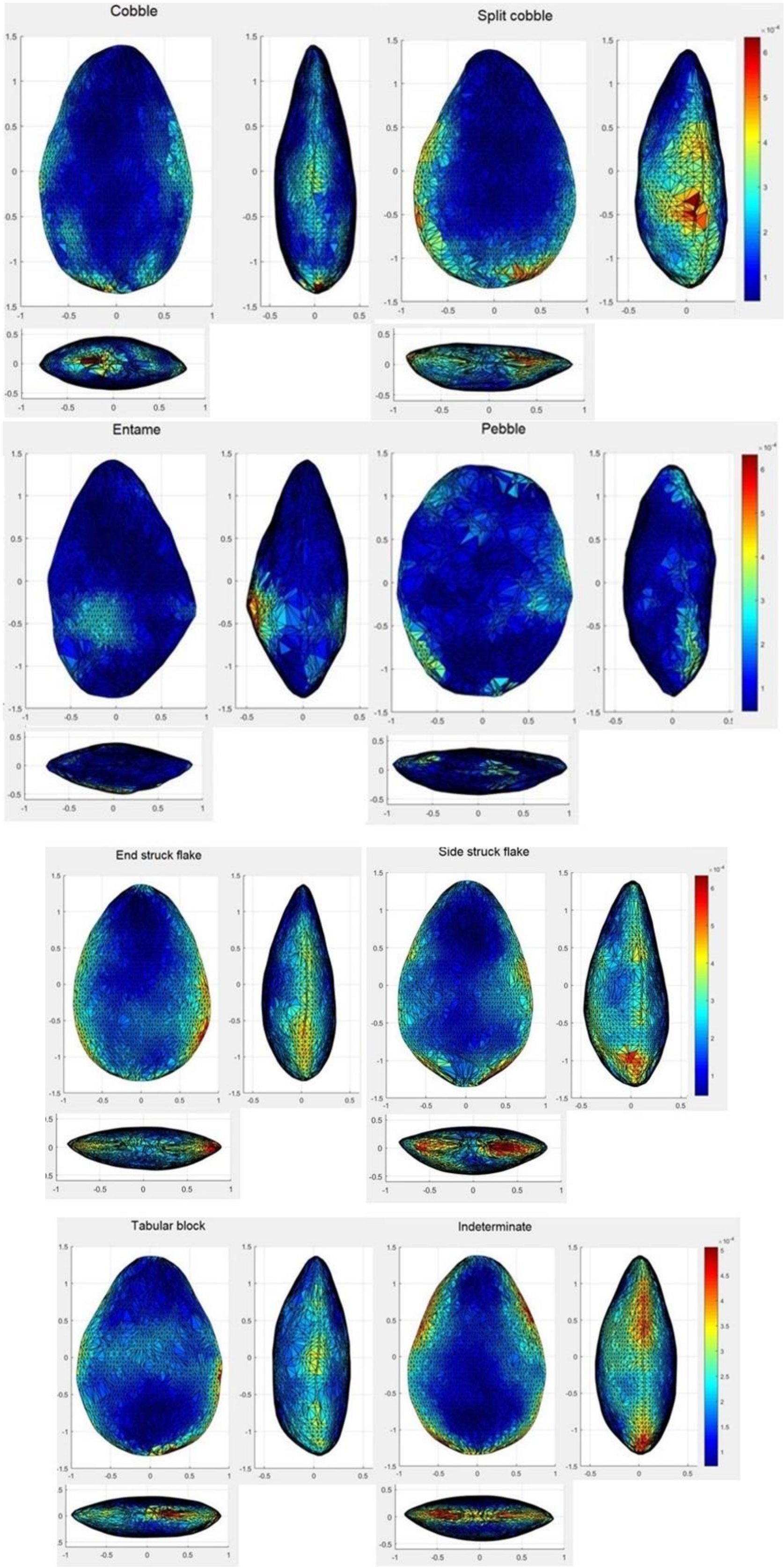


Figure 5. 53 Comparison of the mean shapes of all handaxes on different blanks - Malaprabha Valley sites. Colour coding represents the degree and location of variability.

From Figure 5.53, it can be noted that the handaxes that were on indeterminate blanks along with flake blanks and split cobbles show similarities on the location and intensity of variability, proximal and lateral edges. Cobbles and pebbles received the least variability with entames having variability only at the lower half of the tool (Table 5.48). This could indicate the thinning of the butt.

Blank Type	**No. of Items**	**Shape Variability within the groups**	**% caused by X (relative width)**	**% caused by Y (relative length)**	**% caused by Z (relative thickness)**
Cobble	9	7.27	38.20	2.58	59.22
Split Cobble	7	6.74	42.40	4.60	53.00
Entame	2	4.79	21.23	5.20	73.57
Pebble	2	5.09	43.91	3.99	52.10
End-struck flake	24	7.67	51.58	4.89	43.52
Side-struck flake	18	7.59	42.33	2.69	54.98
Tabular block	15	7.54	43.54	3.06	53.40
Indeterminate	26	7.44	51.02	4.22	44.75

Table 5. 48 The distribution of the variability within the handaxe blank types and the causative factor -Malaprabha Valley sites.

The distal tip morphologies of the handaxes were analysed next.

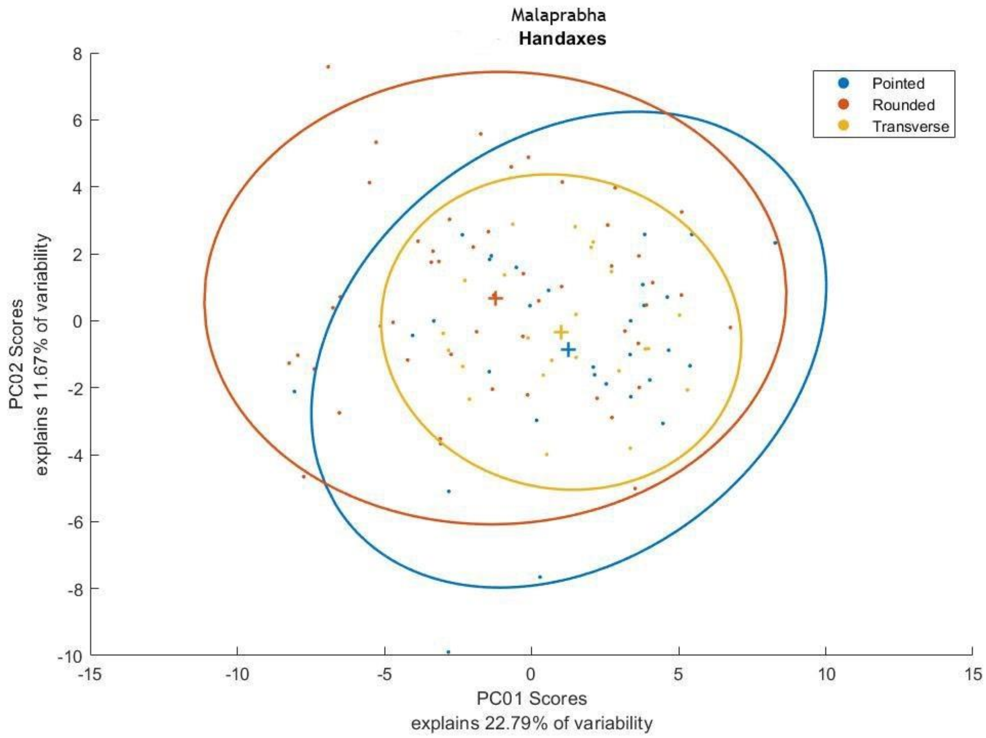


Figure 5. 54 Scatterplot of the first two principal components - Mean shapes of all handaxes with different distal tips - Malaprabha Valley sites. + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses.

From the shape distribution displayed in the scatterplot above (Figure 5.54), it can be clearly noted that there is considerable overlap between handaxes with pointed, rounded, and transverse edges. The round tipped handaxes show a larger variation within, and the two outliers represent handaxes from Lakhmapur and Khyad respectively. While the former was a flake handaxe, very thin and discoid in shape, with a notch at the distal tip, the latter was a very thick, rounded handaxe.

A Wilcoxon Rank-Sum Test on Inter-point distances between the group means of pointed and rounded handaxes showed a significant difference at pValue <0.01 (rank-sum=5655, n1=30, n2=50).

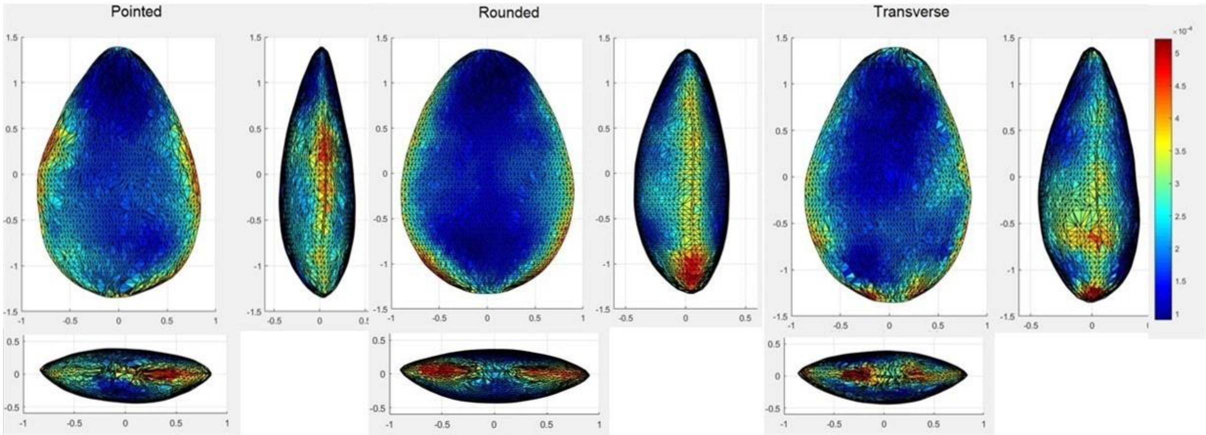


Figure 5. 55 Comparison of the mean shapes of all handaxes with different distal tip morphologies from Malaprabha Valley sites. Colour coding represents the degree and location of variability.

An examination of the mean shapes of the handaxes with different distal morphologies (Figure 5.55), show that both the transverse and pointed handaxes were intensively variable along the lateral edges, especially towards the upper half of the tool. The rounded handaxes on the other hand show a well distributed variability all along the lateral edges. All the three had proximal variability, probably resulting from the thinning of the butt. Relative thickness was the main factor for the variability among these groups, followed by relative width (Table 5.49).

Distal morphology	No. of Items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Pointed	30	7.77	44.81	2.62	52.57
Rounded	50	7.72	46.51	4.70	48.79
Transverse	23	6.83	44.33	2.41	53.26

Table 5. 49 The distribution of the variability within the handaxe distal tip morphologies and the causative factor - Malaprabha Valley sites.

5.9.5 Attirampakkam

A total number of 14 handaxes were analysed. They came from different museum collections located at Paris (Musée de l'Homme) and London (The British Museum), and surface collected located in the State Department of Archaeology, Government of Tamil Nadu, Chennai. As they included surface and excavated tools, but there are no published details or information to separate them, they were all considered together.

The number of PC's generated were 13. The first 10 explain 98% of the variance of the assemblage. Among them, the first 3 account for 63% of the variance.

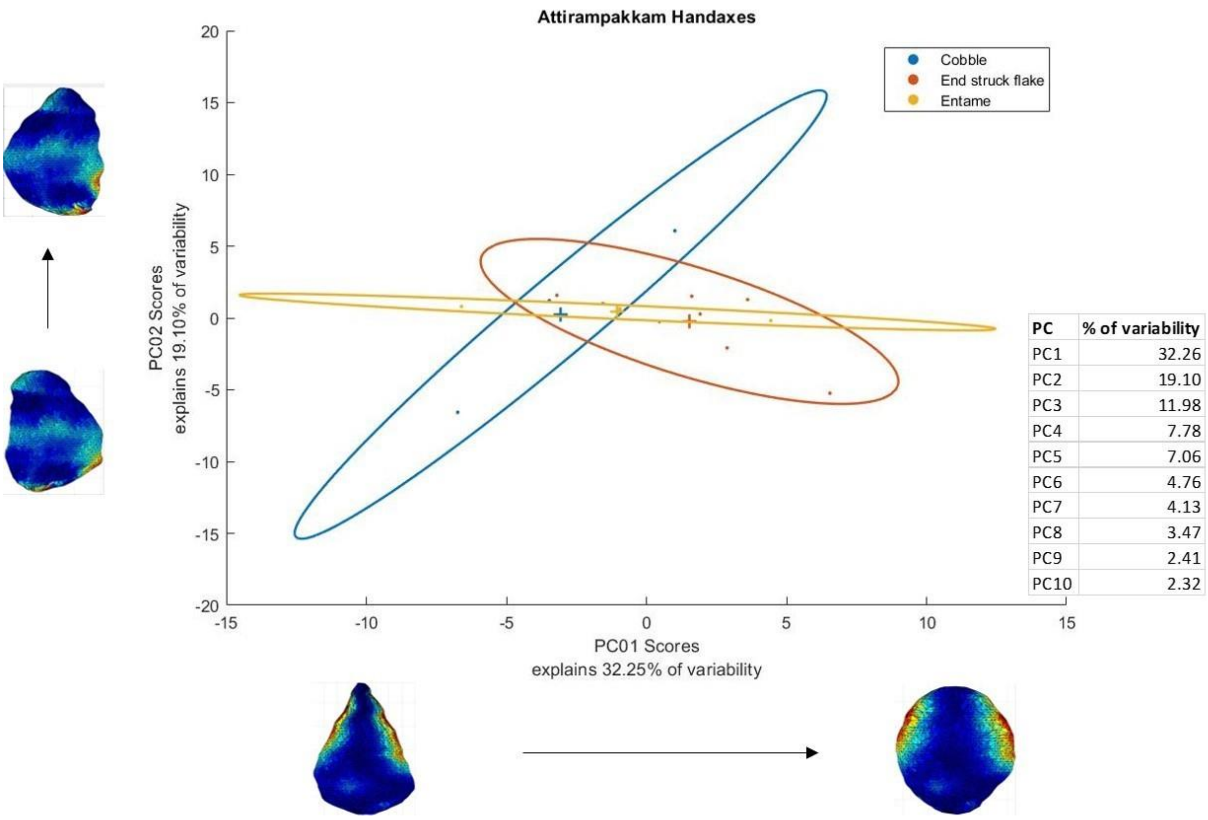


Figure 5. 56 Scatterplot of the first two principal components. Warped images represent hypothetical shape change of the tool along the axis. + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses. Attirampakkam handaxes blank type.

From the distribution pattern of the different blank morphologies on Figure 5.56, it can be inferred that the end struck and entame handaxes overlapped in their shapes while the handaxes on cobbles were dispersed further away from both and from each other.

The warped images help visualise a progression of rounding of the edges from pointed ones on PC1 and the change of orientation of the tool from left to right and from symmetrical to asymmetrical specimens in the PC2.

Wilcoxon Rank-Sum Test on Inter-point Distances between Group Means of cobbles and end-struck handaxes and between entame and end-struck handaxes showed a significant difference at pValue=0.01 (rank-sum=89, rank-sum=88).

A comparison of the mean shapes (Figure 5.57) shows differential patterns of variability on the three blanks. While for the cobbles it tended to be located on the central part of the lateral edge, for the end struck handaxes, it was more on the upper half of the lateral edge. The invasiveness also was more. For the handaxes on entames, lateral edges seem to have more variability, especially towards the distal end.

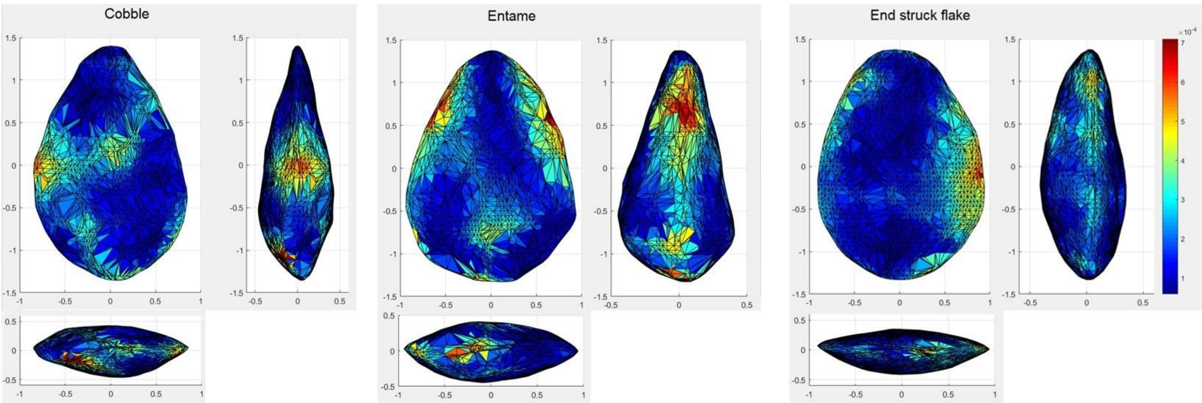


Figure 5. 57 Comparison of the mean shapes of all handaxes on different blanks - Attirampakkam. Colour coding represents the degree and location of variability.

The distribution of the variability within each group and the contributing factor is given in Table 5.50. All the blank types show a greater influence of the relative width, followed by relative thickness. The relative length seems to have played little role in the modification.

Blank Type	No. of Items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Cobble	3	6.92	55.57	4.14	40.29
Entame	3	6.14	61.37	3.91	34.72
End-struck flake	8	5.61	51.35	4.60	44.05

Table 5. 50 The distribution of the variability within the handaxe blank types and the causative factor. Attirampakkam handaxes.

The distribution of the distal morphologies of the handaxes in morpho-space, as depicted in Figure 5.58 shows that the rounded and transverse tipped handaxes were more similar in shape. The pointed handaxes were completely different and located further away from them and from each other.

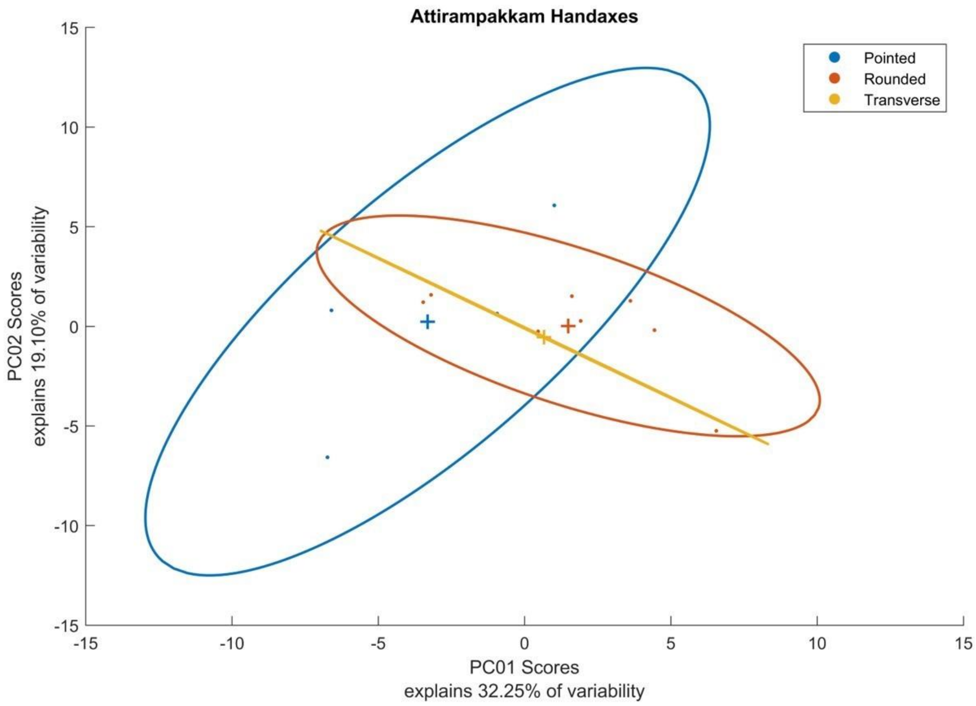


Figure 5. 58 Scatterplot of the first two principal components + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses. Attirampakkam handaxe distal tip.

Figure 5.59 makes this clear with the mean shapes of pointed tools showing intensity of variability largely confined to the lateral left edges and proximal, and being invasive, while the rounded ones have variability limited to the right lateral. The transverse tipped handaxes show the variability concentrated on the distal tip.

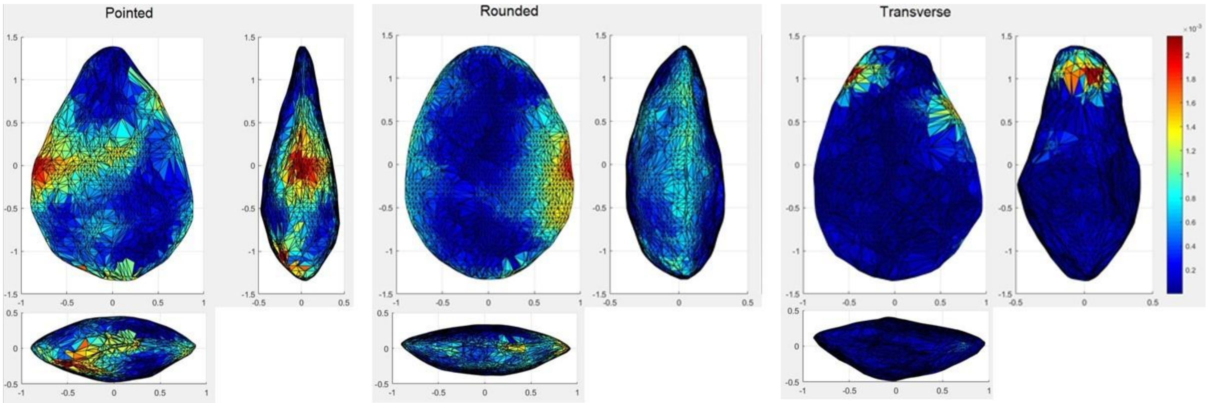


Figure 5. 59 Comparison of the mean shapes of all handaxes with different distal tip morphologies from Attirampakkam. Colour coding represents the degree and location of variability.

This difference in the morphology is largely caused by the X dimension, especially in the case of transverse tipped handaxes (Table 5.51).

Distal morphology	No. of Items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Pointed	4	6.83	57.91	3.96	38.13
Rounded	8	5.75	52.27	6.25	41.48
Transverse	2	4.21	73.62	2.83	23.55

Table 5. 51 The distribution of the variability within the handaxe distal tip morphologies and the causative factor - Attirampakkam handaxes.

To understand the intensity and distribution pattern of variability among the entire assemblage, blank types of cobbles were separated into one group with the rest forming another.

A comparison between the mean shapes shows similar variability pattern, occurring along the periphery, with intensified variability on proximal edges (Figure 5.60). Variability also was invasive on the surface in both cases.

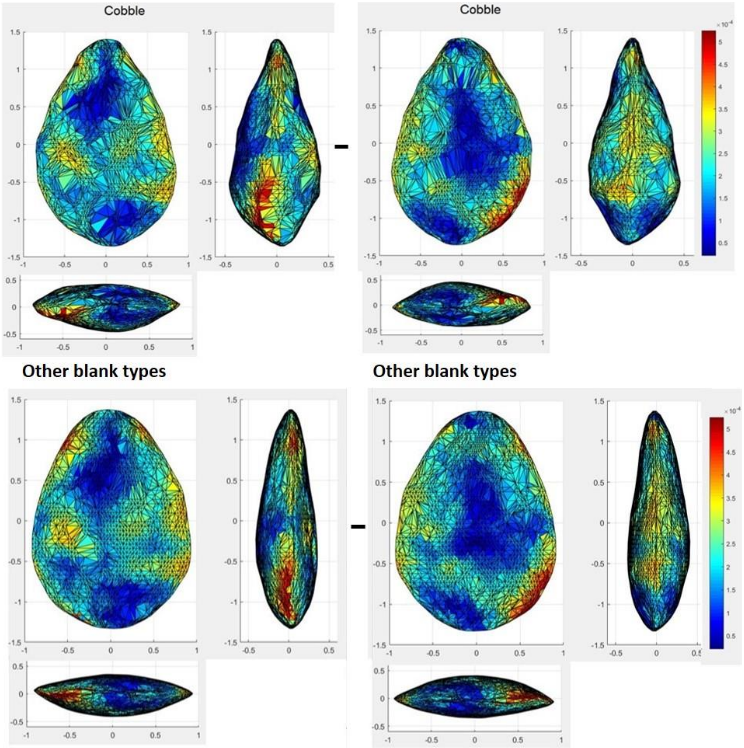


Figure 5. 60 Comparison of the mean shapes of all handaxes (Dorsal and Ventral) on cobbles, and handaxes on other blanks (Dorsal and Ventral) from Attirampakkam. Colour coding represents the degree and location of variability

A similar test conducted on the distal morphologies with pointed ones forming one group and the rest another, showed a similar pattern of intensity and location of the variability (Figure 5.61).

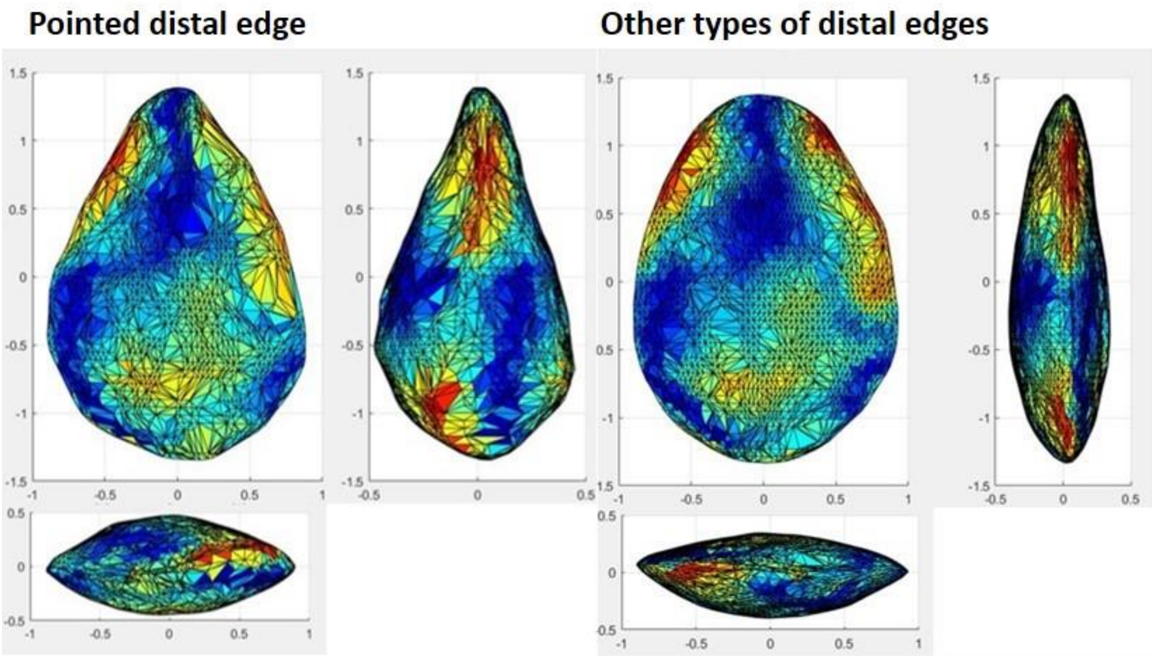


Figure 5. 61 Comparison of the mean shapes of the mean shapes of all handaxes with pointed distal type and handaxes with other distal edge types from Attirampakkam. Colour coding represents the degree and location of variability.

5.9.6 Singadivakkam

From this site, 33 handaxes were subject to this analysis. 32 PCs were generated of which the 10 explained 81% of the total variability. Among these, the first 3 accounted for 48% of the variability.

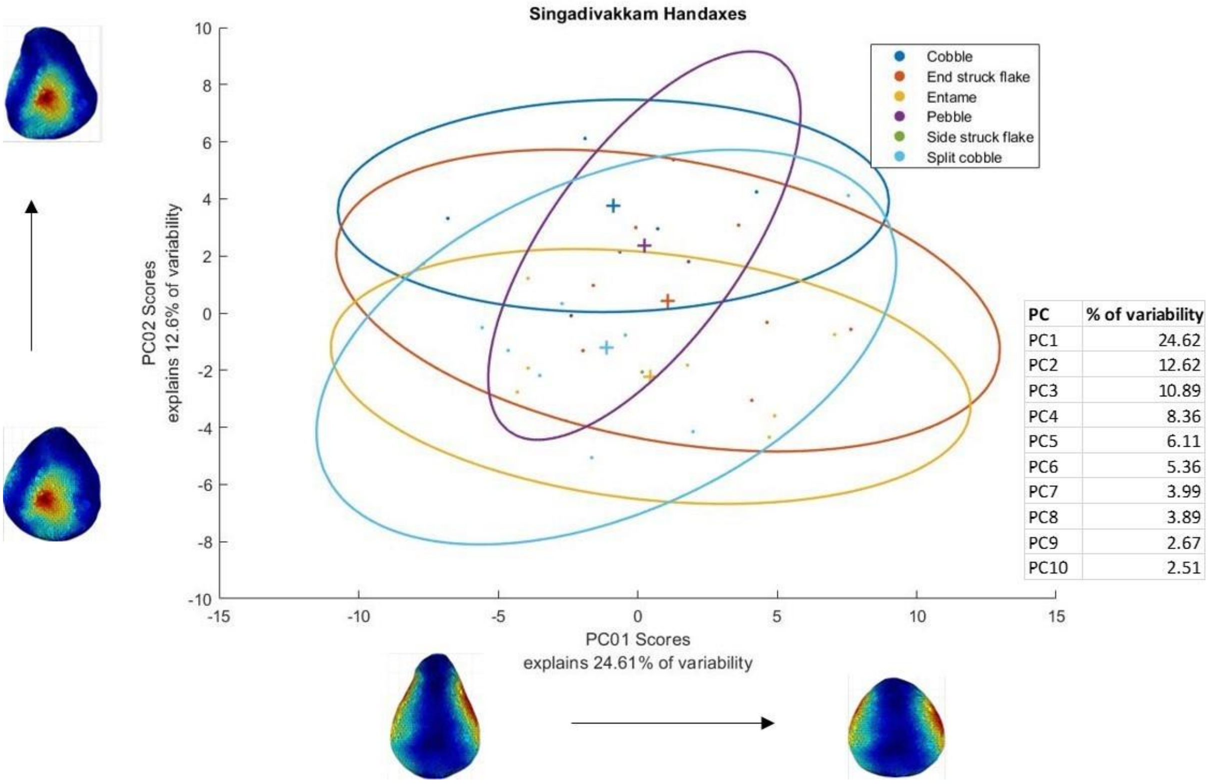


Figure 5. 62 Scatterplot of the first two principal components. Warped images represent hypothetical shape change of the tool along the axis. + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses - Singadivakkam handaxes.

The shape distribution of the different blank types shows that a large majority of the handaxes on different blanks had similar shapes (Figure 5.62). Except for 2 handaxes on split cobbles, the rest were all subsumed under the shapes of the handaxes on end struck flakes. The results of a Wilcoxon Rank-Sum Test on the Inter-point Distances between the group means of all blank types, showed significant differences between blank types (Table 5.52).

Blank Type 1 and no. of handaxes	Blank Type 2 and no. of handaxes	Rank-Sum	pValue
Split Cobble (n=8)	End-struck flake (n=8)	202	0.02
End-struck flake (n=8)	Entame (n=8)	179	<0.01
Cobble (n=5)	End-struck flake (n=8)	120	<0.01
Cobble (n=5)	Split Cobble (n=8)	116	<0.01
Cobble (n=5)	Entame (n=8)	95	<0.01
Pebble (n=3)	Split Cobble (n=8)	87	0.01
End-struck flake (n=8)	Pebble (n=3)	76	<0.01
Entame (n=8)	Pebble (n=3)	73	<0.01
Cobble (n=5)	Pebble (n=3)	41	<0.01

Table 5. 52 Result of a Wilcoxon Rank-Sum Test on the Inter-point Distances between the group means of all blank types - Singadivakkam handaxes.

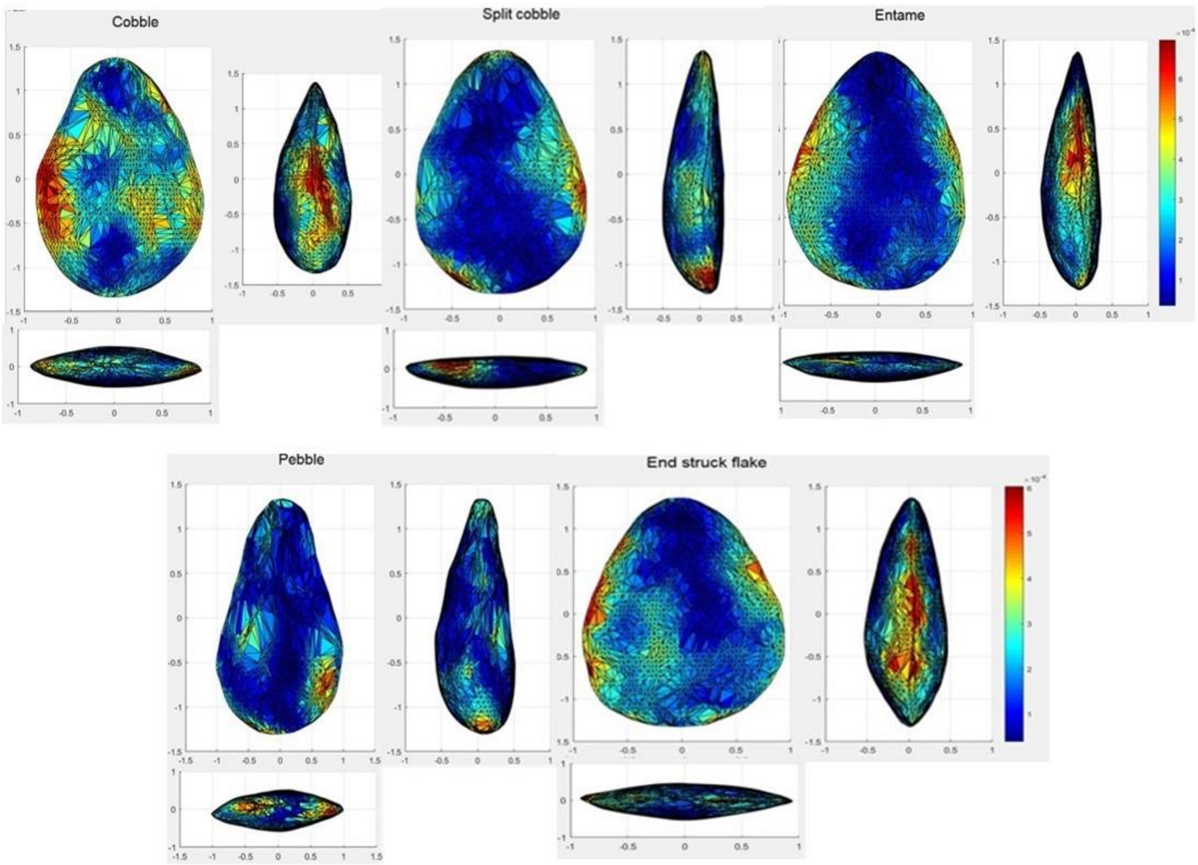


Figure 5. 63 Comparison of the mean shapes of all handaxes on different blank types from Singadivakkam. Colour coding represents the degree and location of variability.

A visual examination of the mean shapes of the handaxes (Figure 5.63) on different blanks show that cobble handaxes were the most intensively variable and this variability was dispersed all across the tool with maximum located at the lateral edges. Handaxes on entames, split cobbles and end-struck flakes showed similarities in their location and intensity of variability. The least variable blank type was the pebble, with its variability limited to the proximal ends and lateral sides.

Blank Type	No. of Items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Cobble	5	7.43	40.42	3.22	56.36
Split cobble	8	7.69	50.55	5.88	43.58
Entame	8	7.14	50.37	5.44	44.19
Pebble	3	6.64	42.46	7.24	50.30
End-struck flake	8	7.48	48.98	4.69	46.33

Table 5. 53 The distribution of the variability within the blank types and the causative factor - Singadivakkam handaxes.

From Table 5.53, we can see that one of the factors that contributed to the variability among the blank types was the relative X (width) dimension, especially for the end struck, entame and split cobble handaxes, while for the cobble and pebble tools, the variability was accounted for by their Z (thickness) dimension.

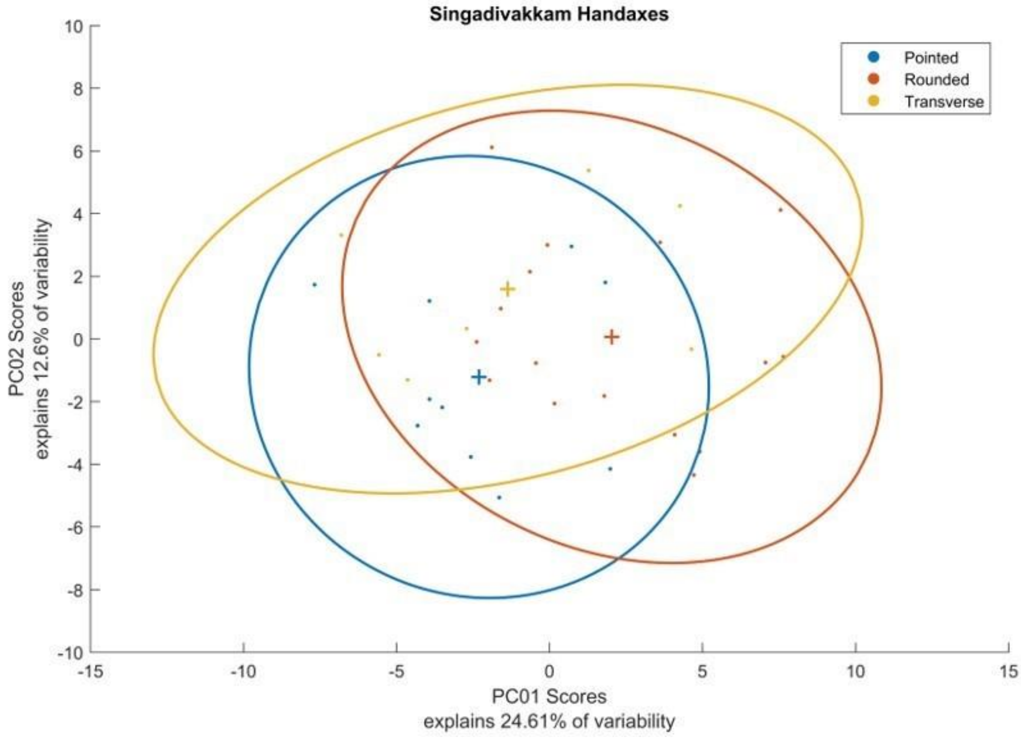


Figure 5. 64 Scatterplot of the first two principal components + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses - Singadivakkam handaxe distal tip.

When we take into account the second attribute of the distal morphologies, the pointed, rounded, and transverse edged handaxes were all found to be widely dispersed as inferred from Figure 5.64. The handaxes with rounded distal edges showed more variability along the surface and periphery, while the pointed and transverse tipped handaxes show variability intensified on their lateral edges and the distal part too (Figure 5.65).

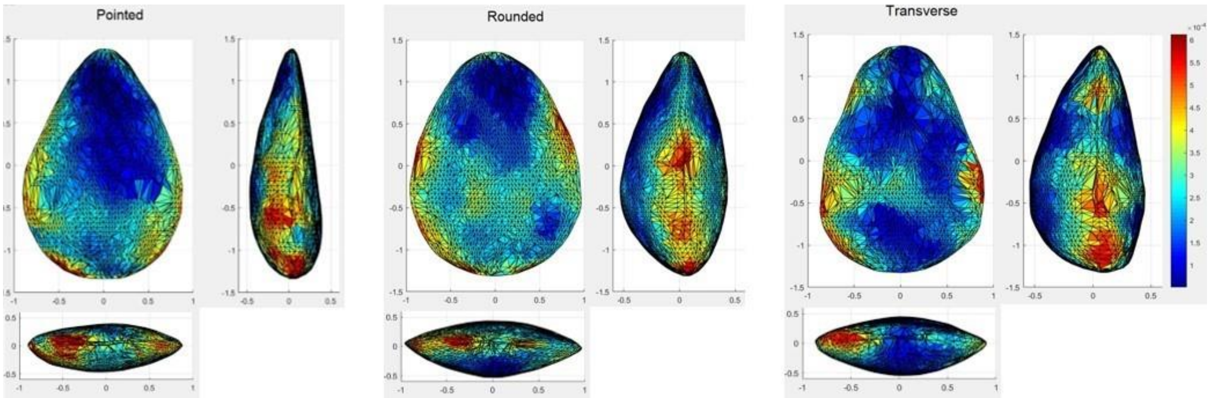


Figure 5. 65 Comparison of the mean shapes of all handaxes with different distal morphologies - Singadivakkam. Colour coding represents the degree and location of variability.

Table 5.54 shows the distribution of variability within each group and the contributing dimensions. The relative thickness contributed majorly to the variability of the distal tip, followed by the relative width dimension. Relative length had little influence.

Distal morphology	No. of Items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Pointed	10	7.29	45.92	4.28	49.80
Rounded	16	7.57	41.99	5.87	52.14
Transverse	7	8.12	40.27	3.51	56.23

Table 5. 54 The distribution of the variability within the distal tips and the causative factor - Singadivakkam handaxes.

To understand the intensity and nature of variability including all the specimens in this assemblage, a comparative test was done on the blank types and distal morphologies. All the handaxes on blanks were grouped together, with the handaxes on split cobbles considered as another group. The results show similar pattern and intensity of variability on both the dorsal and ventral surfaces as can be seen from Figure 5.66.

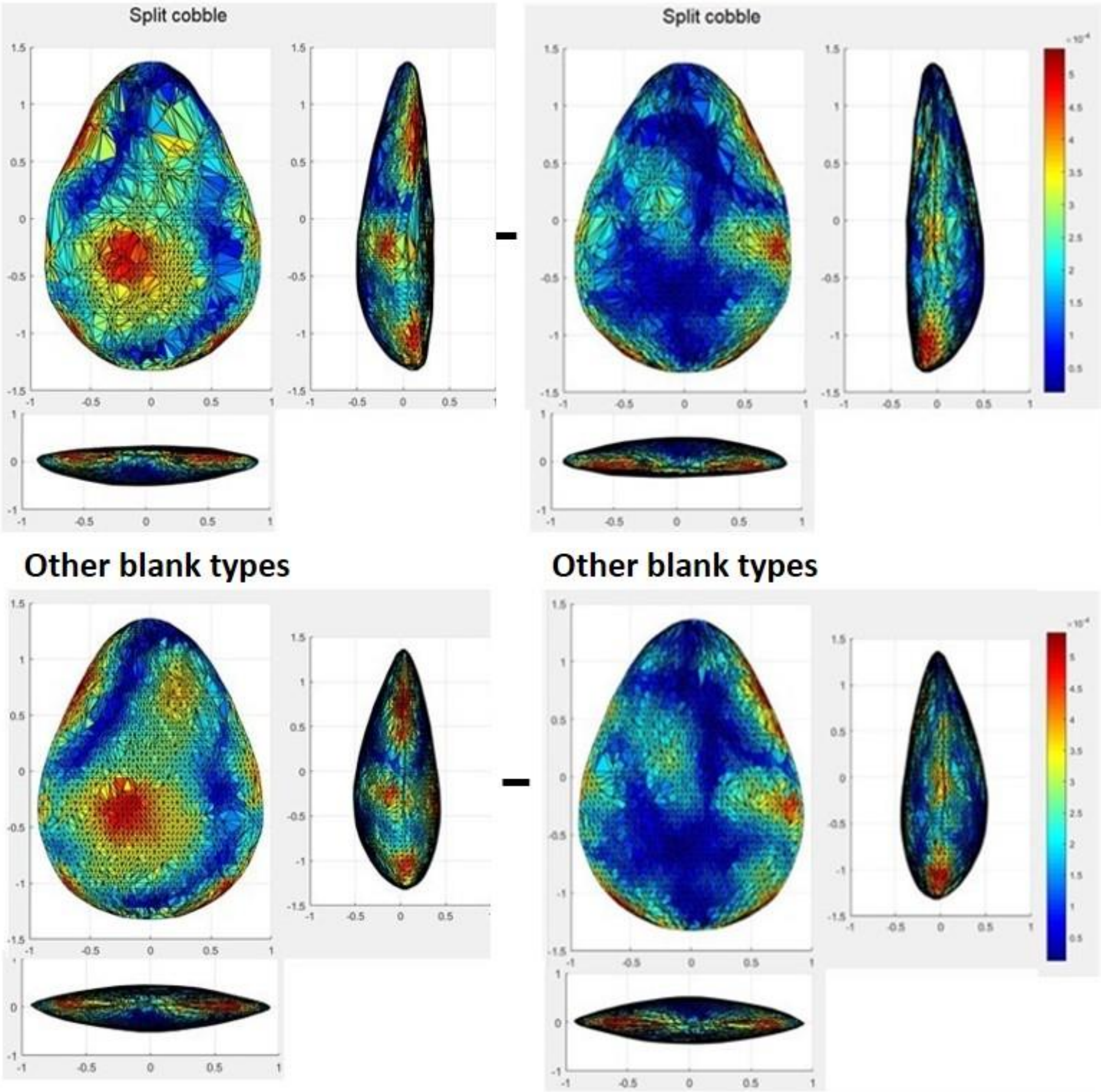


Figure 5. 66 Comparison of the mean shapes of all handaxes (Dorsal and Ventral) on split cobbles and handaxes on other blanks (Dorsal and Ventral) from Singadivakkam. Colour coding represents the degree and location of variability.

The second attribute used for this test was the distal end morphology, with the transverse edged handaxes grouped as one, and the rest grouped as another. The results are similar to the test results conducted on the blank types. Similar intensity and location of the variability are indicated by the Figure 5.67.

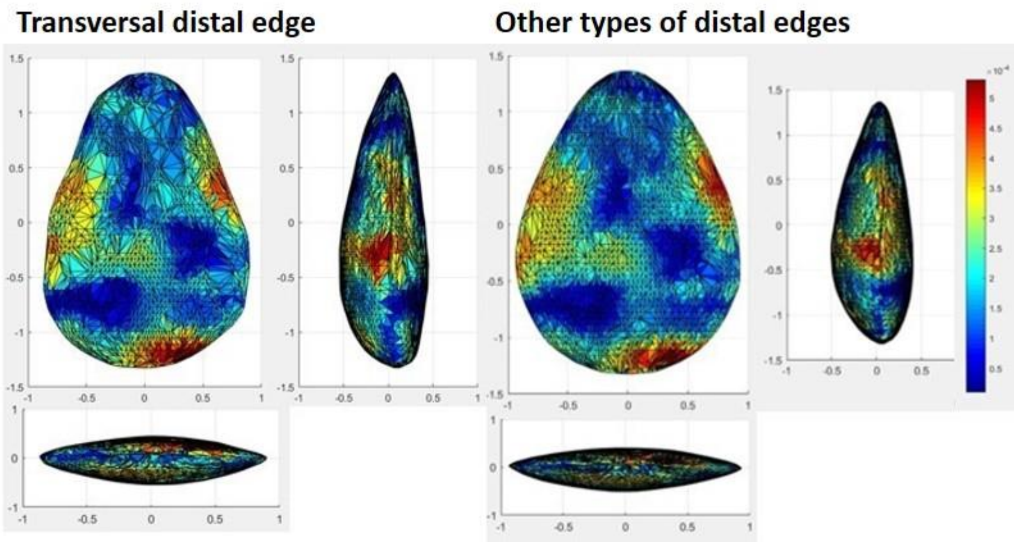


Figure 5. 67 Comparison of the mean shapes of all handaxes with transverse distal type and handaxes with other distal edge types from Singadivakkam. Colour coding represents the degree and location of variability.

As the handaxe specimens from Attirampakkam were lesser compared to those subjected to the 2D GM analysis, and were of mixed and indeterminate contexts, a meaningful comparison with those of Singadivakkam was not feasible and therefore not undertaken.

5.10 3D Geometric Morphometric Analysis – Cleavers

Following the methodology outlined in Article 2 (Appendix II), cleavers from individual sites were analysed first to understand the variability between different blank types and distal end morphologies. Second, a comparison of all cleavers from the sites of Malaprabha Valley was carried out in a single morpho-space. However, the number of cleavers were insufficient in Singadivakkam to make a meaningful comparison with those from Attirampakkam and so this step was skipped. Finally, comparison between Acheulean and Middle Palaeolithic cleavers from all the sites was done to understand whether any significant variation is visible. As in the case of handaxes, an experimental analysis including all specimens (irrespective of their quantities), enabled an understanding of the distribution of variability among all specimens.

5.10.1 Khyad

A total of 45 cleavers were analysed in order to translate into statistics their shape variations and test how these variations change according to particular attributes. For this, two attributes were selected, blank type and distal end morphology. The total assemblage variability was 8.2. The principal components (PCs) generated were 44 of which the first ten explained 81% of the total variability. The first two PCs amounted to 38% of the variation. The results show an overlap of the shapes between the different blank types that are flakes, cobbles, entame and Kombewa flakes while the shapes of indeterminate blanks fall within the flake shape ellipse (Figure 5.69). Among the flakes only one cleaver stood out from the rest (Figure 5.69). This was an end-struck flake cleaver with a dihedral platform, parallel lateral edges and straight distal end (Figure 5.68). It was minimally shaped only on the dorsal face.

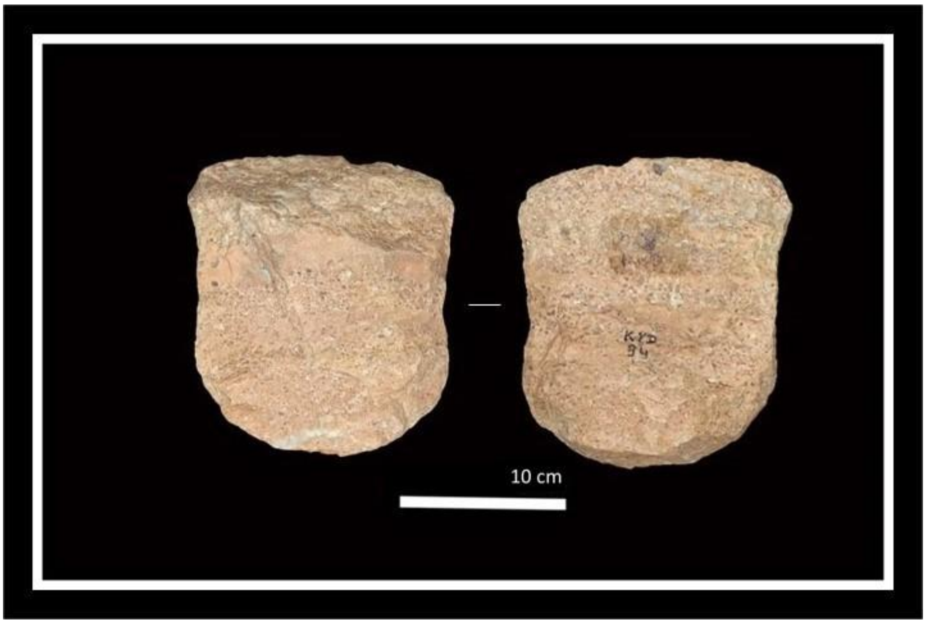


Figure 5. 68 Khyad cleaver on an end-struck flake (with dihedral platform) that represented an outlier.

PC1 shows a trend of cleavers from shapes with rounded butt and with left diagonal distal edges to shapes with right diagonal distal edges. PC2 shows a trend from broad cutting-edged cleavers with square and U shapes to cleavers with convex distal edges and narrower butt.

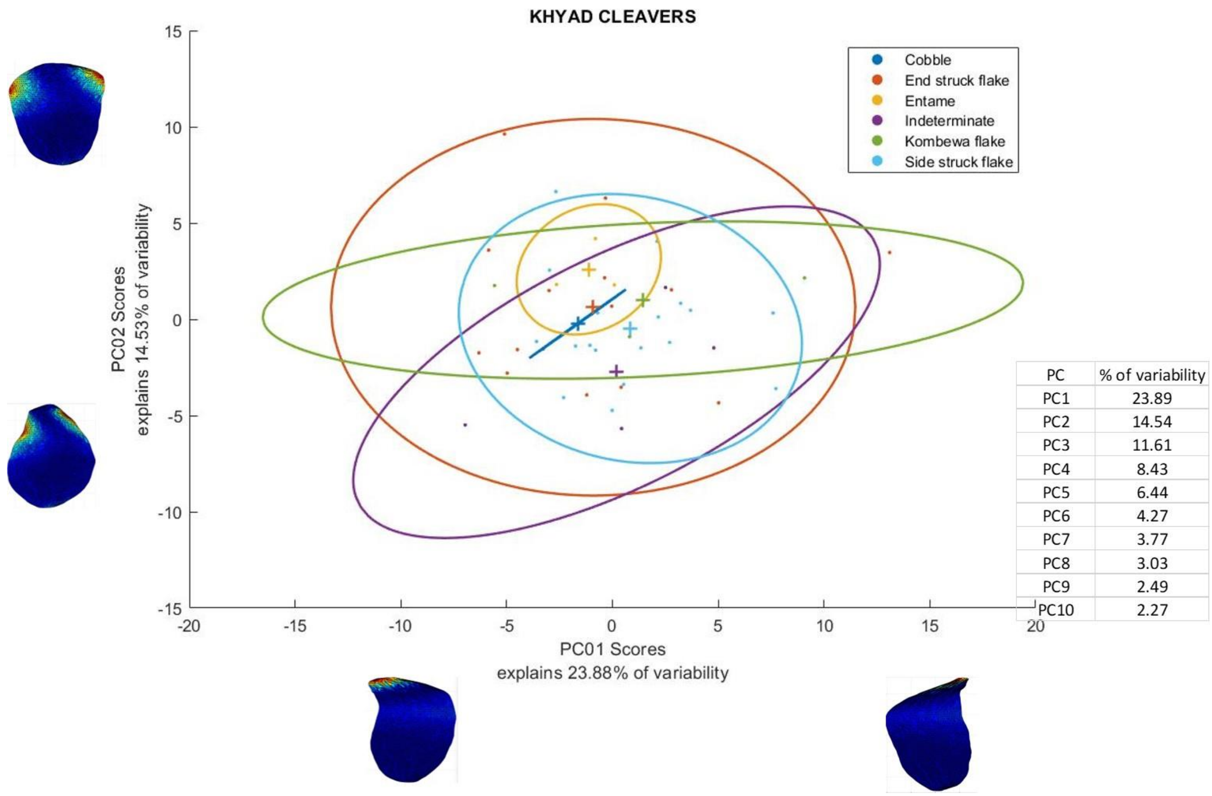


Figure 5. 69 Scatterplot of the first two principal components. Warped images represent hypothetical shape change of the tool along the axis. + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses - Khyad cleavers blank types.

A Wilcoxon Rank-Sum Test on the group means of indeterminate blanks and entame blanks showed that there were significant differences between flake blanks, entames and indeterminate blanks (Table 5.55).

Blank Type 1 and no. of handaxes	Blank Type 2 and no. of handaxes	Rank-Sum	pValue
Side-struck flakes (n=18)	Entames (n=3)	324	<0.01
End-struck flakes (n=15)	Indeterminate blanks (n=4)	298	0.03
End-struck flakes (n=15)	Kombewa flakes (3)	250	<0.01
Entames (n=3)	Indeterminate blanks (n=4)	34	0.01
Kombewa flakes (n=3)	Indeterminate blanks (n=4)	32	<0.01
Kombewa flakes (n=3)	Entames (n=3)	23	<0.01

Table 5. 55 Result of a Wilcoxon Rank-Sum Test on the Inter-point Distances between the group means of all blank types – Khyad cleavers.

The shape variability of all the blanks was largely influenced by the width (X) and thickness (Z) (Table 5.56).

Blank Type	No. of items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Cobbles	2	4.99	37.65	0.09	62.27
Entames	3	6.92	48.63	2.22	49.16
End-struck flakes	15	8.44	63.99	4.87	31.15
Side-struck flakes	18	7.52	56.92	2.59	40.49
Kombewa flakes	3	8.51	68.25	4.17	27.57
Indeterminate blanks	4	7.88	64.60	2.71	32.69

Table 5. 56 The distribution of the variability within the blank tips and the causative factor - Khyad cleavers.

A comparison of the mean shapes of all the blanks shows modification on the distal part for all the blank types, with little modification on the cobble blank which had straight edges (Figure 5.70). The proximal ends displayed larger variability for flakes, indeterminate blanks, entames and cobbles. Cleavers on flakes, on entames and on indeterminate blanks display biconvex and plano-convex cross-sections.

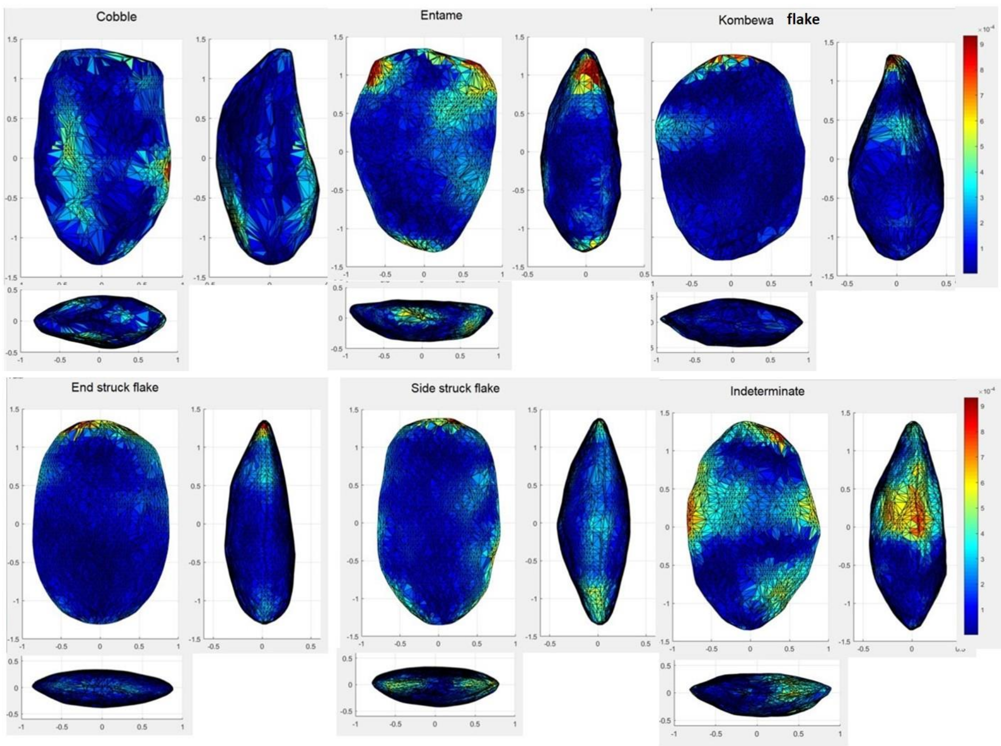


Figure 5. 70 Comparison of the mean shapes of cleavers on different blank types – Khyad. Colour coding represents the degree and location of variability.

As far as the distal edge is concerned, the cleavers show similarities whether they are convergent, convex, diagonal or straight (Figure 5.71). Only five cleavers made on flakes showed different shapes from the rest of the tools.

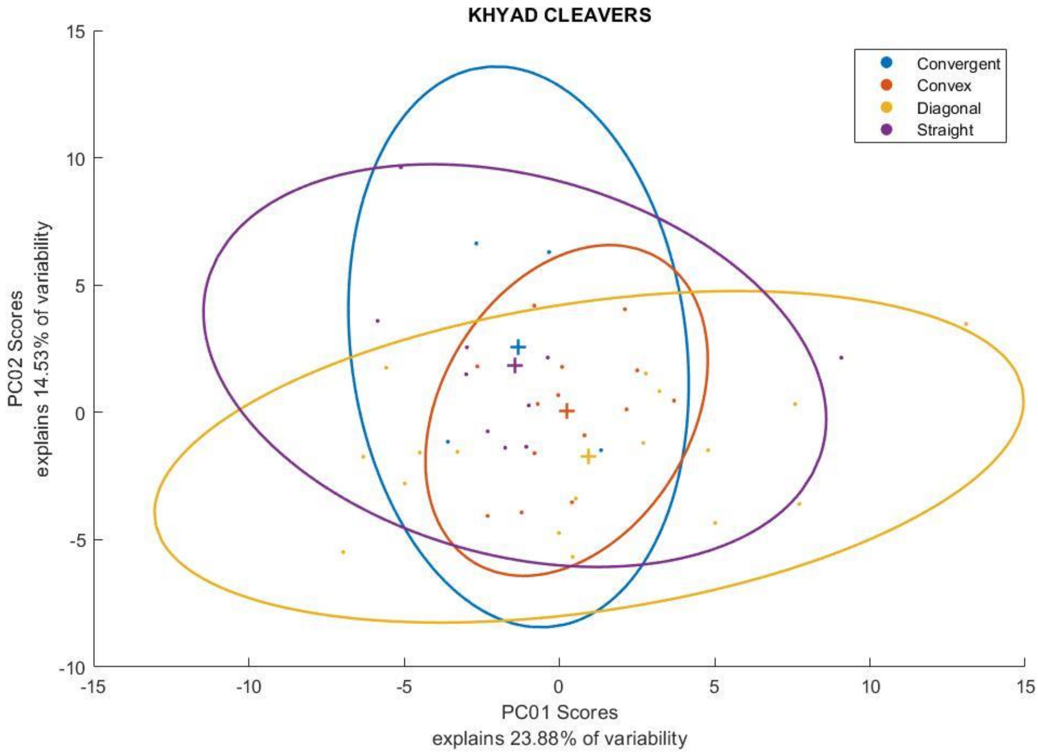


Figure 5. 71 Scatterplot of the first two principal components. + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses - Khyad Cleaver distal tips.

The distribution of the variability among the distal morphologies shows a higher influence of relative width for straight, diagonal, and convergent types, while it was the relative thickness that contributed to the convex morphologies (Table 5.57).

Distal morphology	No: of items	Shape Variability within the groups	% Caused by X (relative width)	% Caused by Y (relative length)	% Caused by Z (relative thickness)
Convergent	4	7.62	55.81	2.60	41.59
Convex	14	7.01	46.48	3.24	50.28
Straight	10	7.59	61.97	5.43	32.60
Diagonal	17	8.77	65.33	3.01	31.66

Table 5. 57 The distribution of the variability within the distal tips and the causative factor - Khyad cleavers.

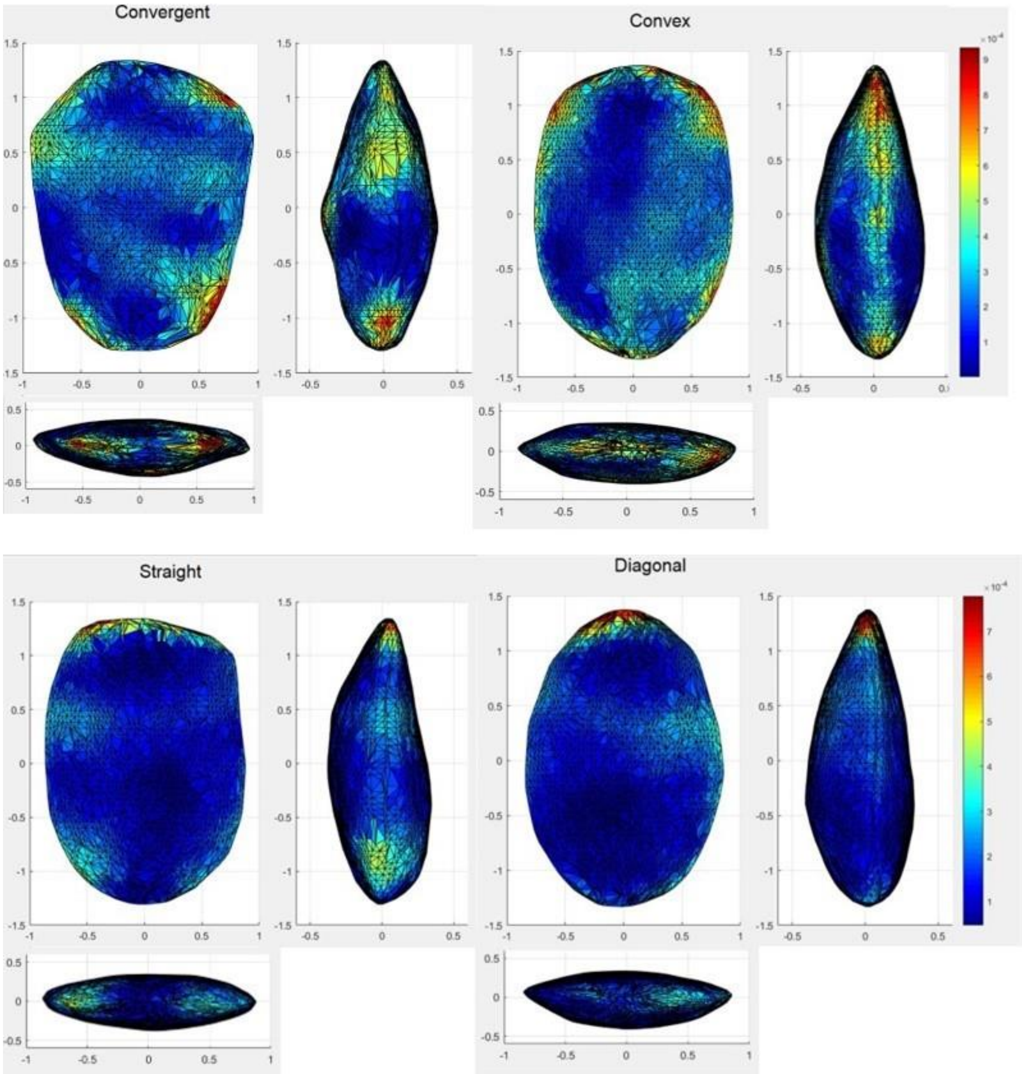


Figure 5. 72 Comparison of the mean shapes of all cleavers with different distal tip morphologies from Khyad. Colour coding represents the degree and location of variability.

All the cleavers showed variability on the distal ends with the convex ended cleavers being more variable on both lateral right and left corners (Figure 5.72).

To understand if shape standardisation existed according to the blank of the tool, all the cleavers made on different blanks were grouped with the exception of the 3 cleavers on Kombewa flakes. This exception was made in order to analyse the variability among all the specimens and their mean shape using the software and to get accurate results.

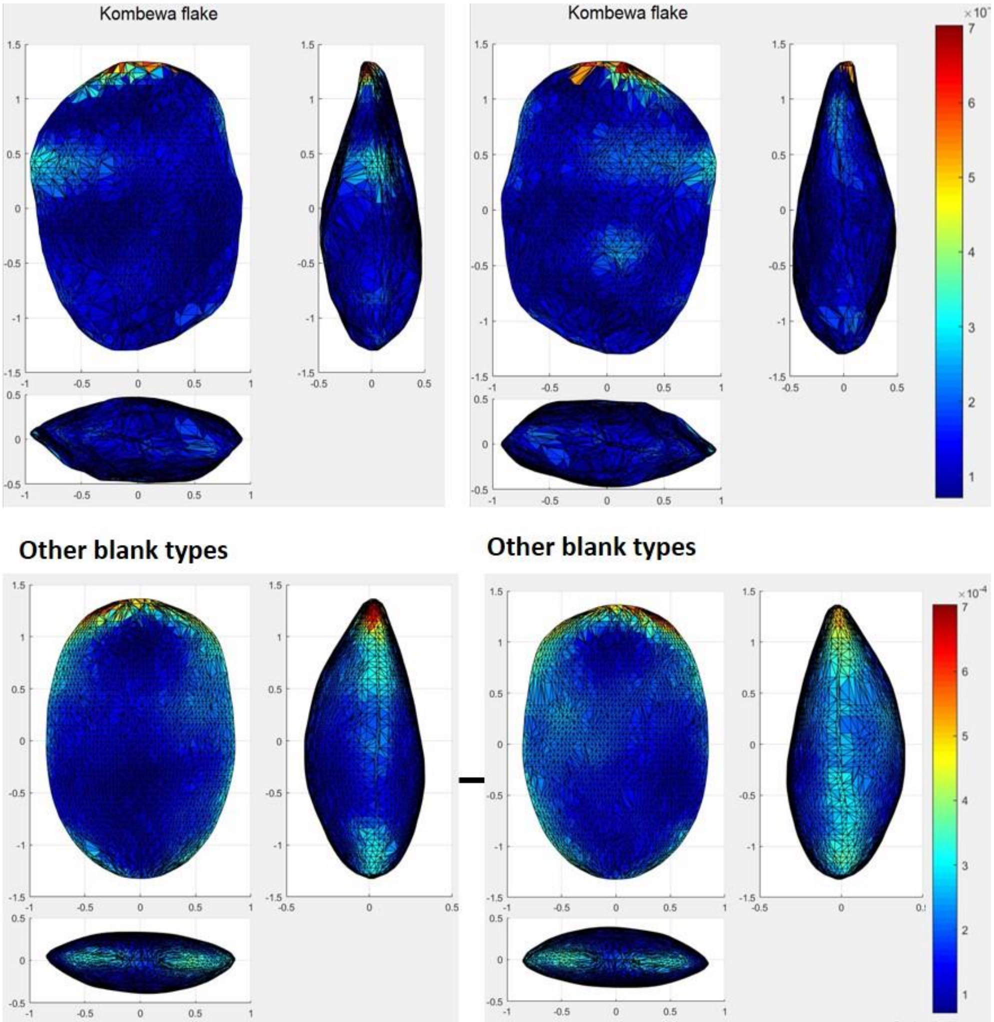


Figure 5. 73 Comparison of the mean shapes of cleavers on Kombewa flakes and all other blanks - Khyad cleavers. Colour coding represents the degree and location of variability

Interestingly, both the cleavers on Kombewa flakes and all the rest of the cleavers on various flakes, cobbles and entames blanks showed similarity in variability at the distal end (Figure 5.73).

In the same way as done with the blanks, in order to answer the question of whether the distal edge variability was standardised, all the different distal typologies were categorised as one group, with the 3 cleavers with convergent distal ends categorised separately. The results (Figure 5.74) show a similar pattern to that of the blanks where irrespectively of the different morphologies of the distal edges, all the cleavers from Khyad followed a standardised variability pattern. Major variations are noticed at three locations on the cleavers, the proximal end, distal left and distal right sides. Although different blanks were used to make cleavers and though at first glance they appear with different distal morphologies, the process/way of shaping seems to be standardised.

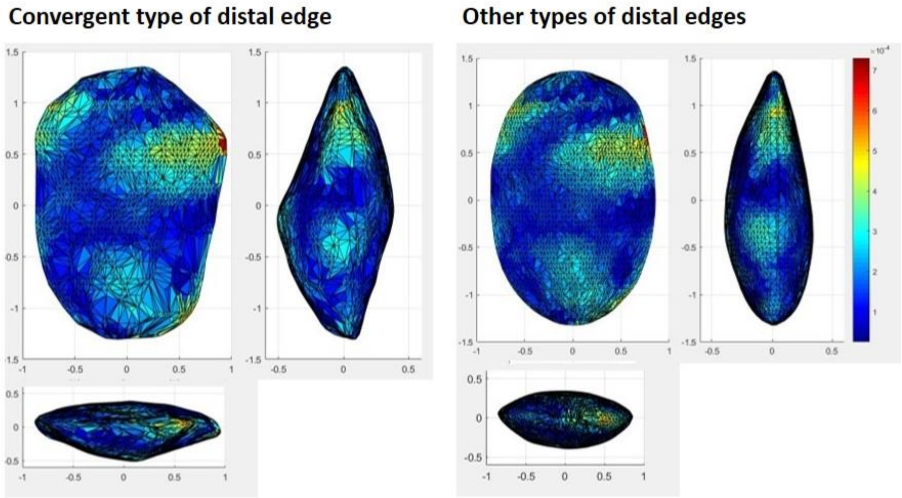


Figure 5. 74 Comparison of the mean shapes of cleavers with convergent distal tip with other types of distal edges – Khyad cleavers. Colour coding represents the degree and location of variability

We have seen that comparing all the tools under one blank type show an extremely strong standardisation. It is interesting to note that even with the high level of standardisation in the number of tools studied, even if we cannot know for sure, it seems obvious that all the tools have not been knapped at the same moment or by the same person. Yet throughout those events since we see a high standardisation, we can assume a technological 'mental template' irrespective of blank types and different reduction sequences at Khyad.

5.10.2 Lakhmapur

Ten cleavers were analysed from Lakhmapur. They were on different blanks with different distal ends. A total of 9 PCs were generated of which the first three PCs explain 65% of the total variability. The shape distribution (Figure 5.75) shows that among the cleavers, those whose blanks are cobble and flakes had similar shapes while those on tabular blocks were different. The TpS warped images help in visualising the shape differences (Figure 5.75) on PC1 axis from cleavers with broad butt and convex distal edge to U or square shaped specimens with broad cutting edge and a pointed corner. On PC2, there is little change at the distal edge which remains convex, but the butt end changes from square to angled.

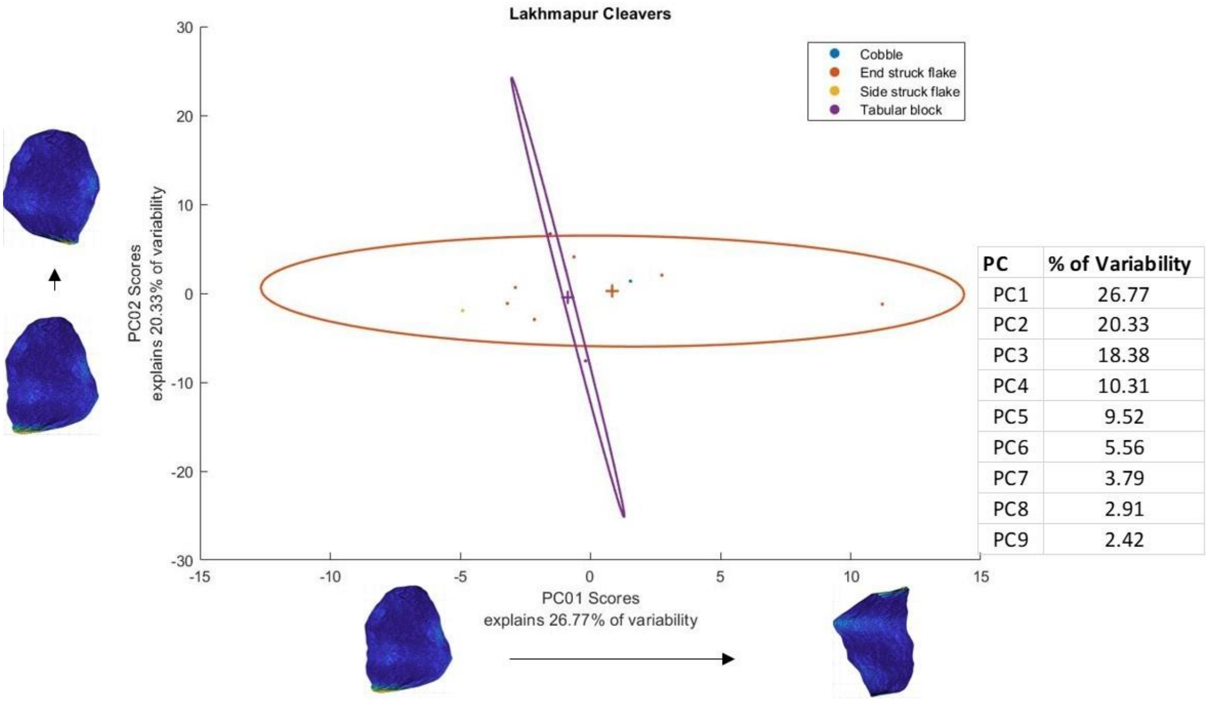


Figure 5. 75 Scatterplot of the first two principal components. Warped images represent hypothetical shape change of the tool along the axis. + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses - Lakhmapur cleavers blank types.

As there were only single samples of cleavers made on cobble and on side-struck flake, a comparative analysis could not be carried out.

Blank Type	No. of items	Shape variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
End-struck flake	6	7.79	59.35	1.62	39.03
Tabular block	2	7.66	63.88	3.07	33.05

Table 5. 58 The distribution of the variability within the blank types and the causative factor- Lakhmapur cleavers. Please note that the single cleavers on cobble and side-struck flake were not included due to statistical requirements of more than one sample.

From Table 5.58, it becomes clear that relative width was a major factor causing the variability among the blank types of end-struck flakes and tabular blocks.

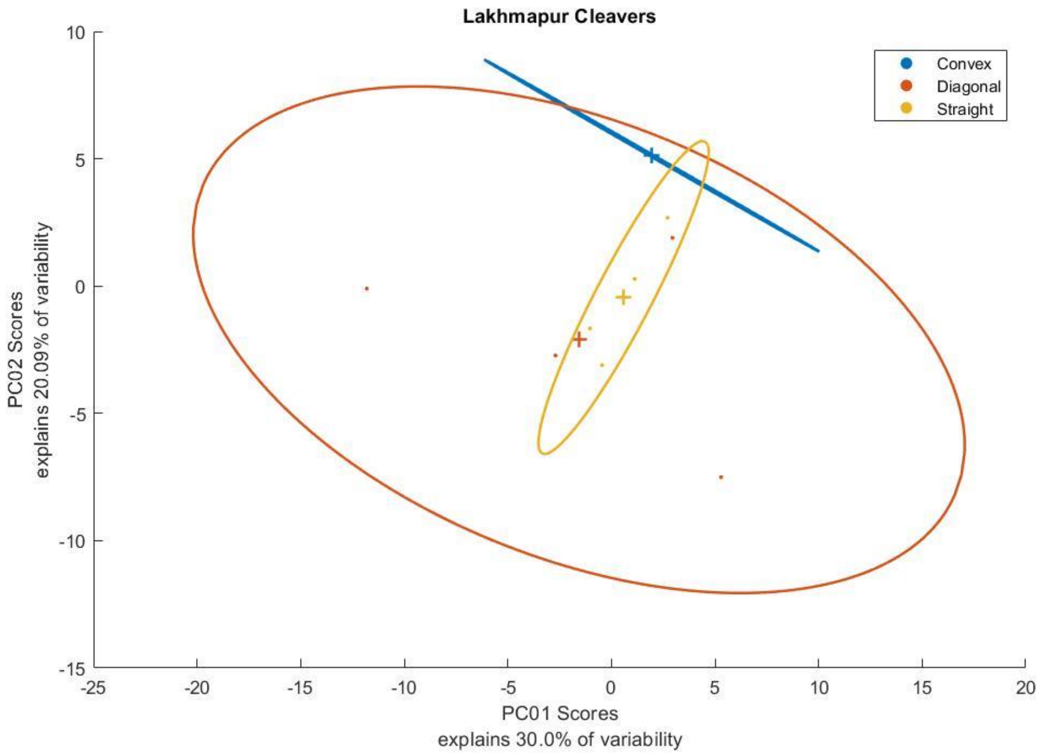


Figure 5. 76 Scatterplot of the first two principal components + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses - Lakhmapur cleaver distal tips

The shape distribution of different morphologies of the Lakhmapur cleavers show a difference in the mean shapes of convex from those of diagonal and straight ones (Figure 5.76). Taking the second attribute of distal morphology into account, we notice that the straight-edged cleavers are all made on end-struck flakes. Here again, due to limited sampling, tests for significance of variability could not be carried out. However, for the diagonal and straight-edged cleavers, a Wilcoxon Rank-Sum Test was done. The results did not show any significant variation in their mean shapes (rank-sum=52, n1=4, pValue = 0.10).

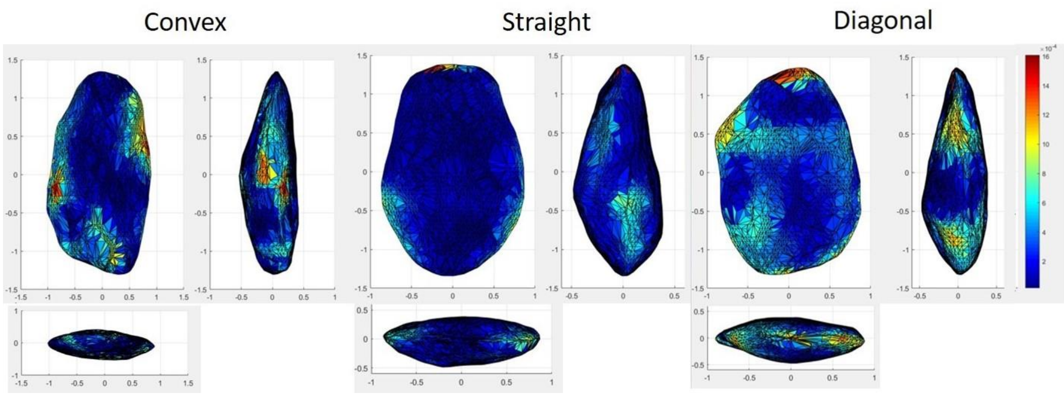


Figure 5. 77 Comparison of the mean shapes of all cleavers with different distal tip morphologies from Lakhmapur. Colour coding represents the degree and location of variability

The comparison of the mean shapes of the cleavers with diagonal, convex and straight distal edges (Figure 5.77) show variability with intensity on the distal ends for the diagonal edged cleavers, while for the convex tools, strong variability was located on the lateral edges (Figure 5.77). For the straight edged ones, there was minimal variability in the middle of the distal edge.

The shape variability within straight edged and convex edged cleavers was similar while the diagonal edged ones have more variability. The causative factor for the variation was similar for the former with volumetric influence followed by the X dimension (Table 5.59). In the case of diagonal edged cleavers, it was the X dimension that gave rise to variation within the group. In all cases, Y dimension seems to have played little to no role.

Distal morphology	No. of Items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Convex	2	5.32	48.13	1.95	49.92
Straight	4	6.22	43.06	1.39	55.55
Diagonal	4	8.51	55.83	5.80	38.37

Table 5. 59 The distribution of the variability within the distal tips and the causative factor - Lakhmapur cleavers.

Finally, to understand the distribution of variability among all specimens, the group of end-struck flake cleavers were separated from the other group containing all other blank types. The results show that the variability distribution remained the same on all blank types (Figure 5.78).

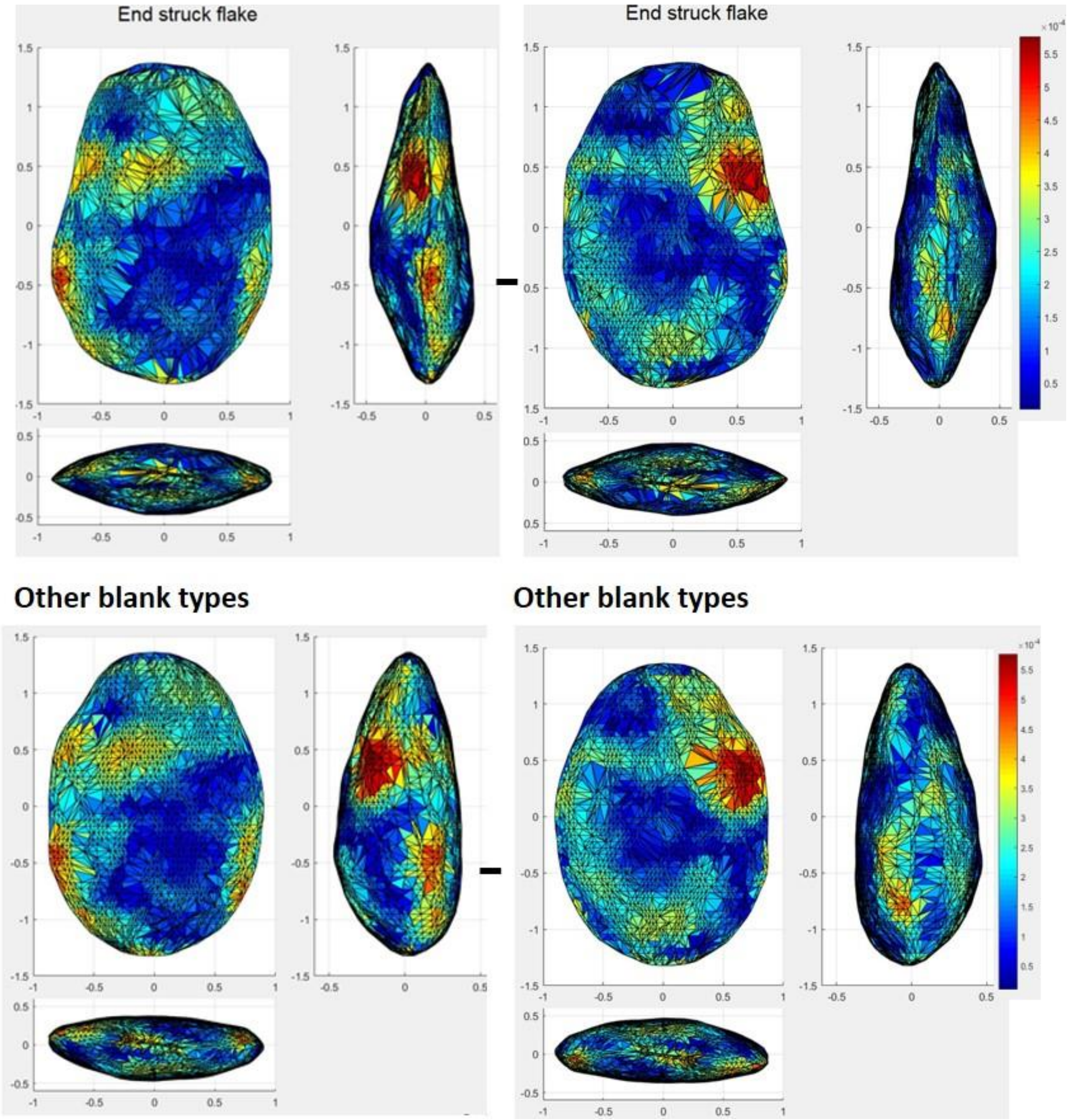


Figure 5. 78 Comparison of the mean shapes of cleavers on end-struck flakes (Dorsal and Ventral) and all other blanks (Dorsal and Ventral) - Lakhmapur cleavers. Colour coding represents the degree and location of variability

The second attribute, the distal end morphology was also subjected to this test which showed similar distribution of variability among all the cleavers with different distal edges (Figure 5.79).

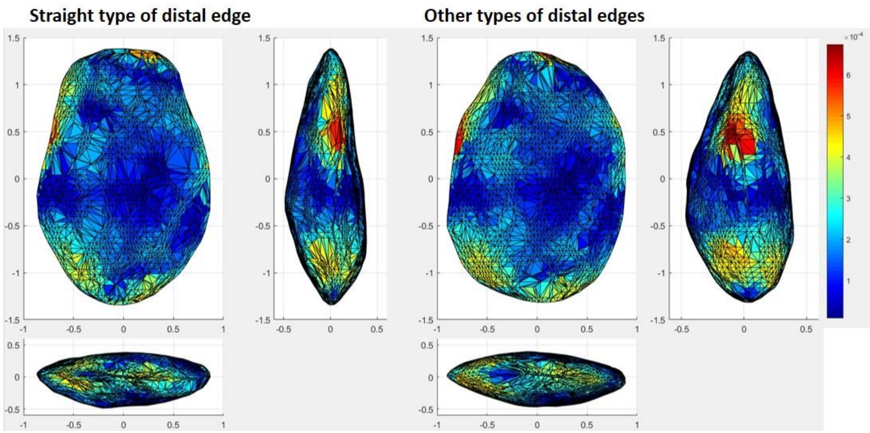


Figure 5. 79 Comparison of the mean shapes of cleavers with straight distal tip with other types of distal edges – Lakhmapur cleavers. Colour coding represents the degree and location of variability

5.10.3 Benkaneri

From Benkaneri, 13 cleavers were analysed. The blank types were chosen as the first attribute to see their influence on shapes. The total variability for this attribute within the assemblage was 7. Of the four types of blanks, Kombewa flakes and tabular blocks were only represented by 2 specimens each and so could not be used for comparison with flake blanks.

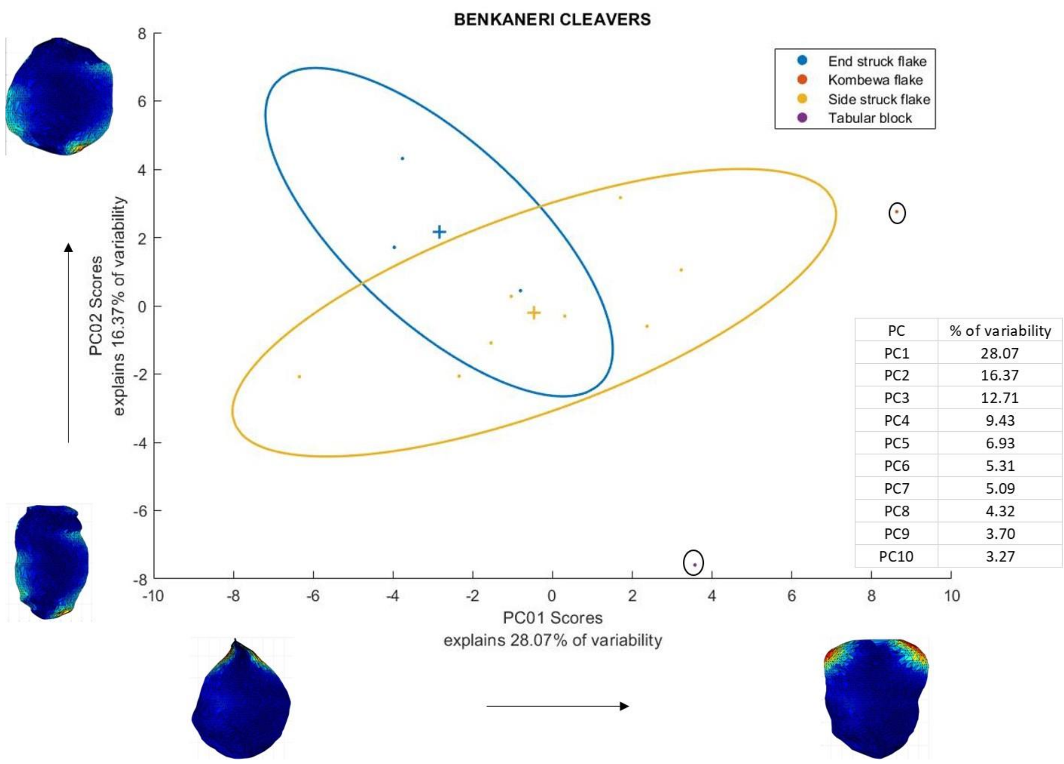


Figure 5. 80 Scatterplot of the first two principal components. Warped images represent hypothetical shape change of the tool along the axis. + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses - Benkaneri cleavers blank types.

Of the 12 PCs generated, the first 10 explained 97% of the variability. PC1 and PC2 explain 44% of the variability within. The shape distribution (Figure 5.80) indicates that only one cleaver on end-struck flake has a shape similar to those on side-struck flakes. The hypothetical warped shapes show a change from cleavers with rounded butts and diagonal distal tips to cleavers with broader and straight cutting edges and angled butts on the PC1, as represented by the tool on tabular block and Kombewa flake and some cleavers on flake. The knappers adapted to the natural morphology of the tabular blocks and the side-struck flakes to minimise the shaping and were able to make these tools.

On the other hand, PC2 shows a trend of cleavers on side-struck flakes with U shaped proximal ends and straight distal edges, to diagonal butted cleavers with angled or convex distal edge. As the sample size was below 3 for both the specimens on Kombewa flake and tabular block, only the end-struck and side-struck flakes could be tested for significance of shape variability. A Wilcoxon Rank-Sum Test conducted on their group means showed that there was a significant shape variation between the two types of blanks (p value=<.01; rank-sum=77, n1=1, n2=8). This is confirmed with the mean shape differences between both the flake blanks (Figure 5.81).

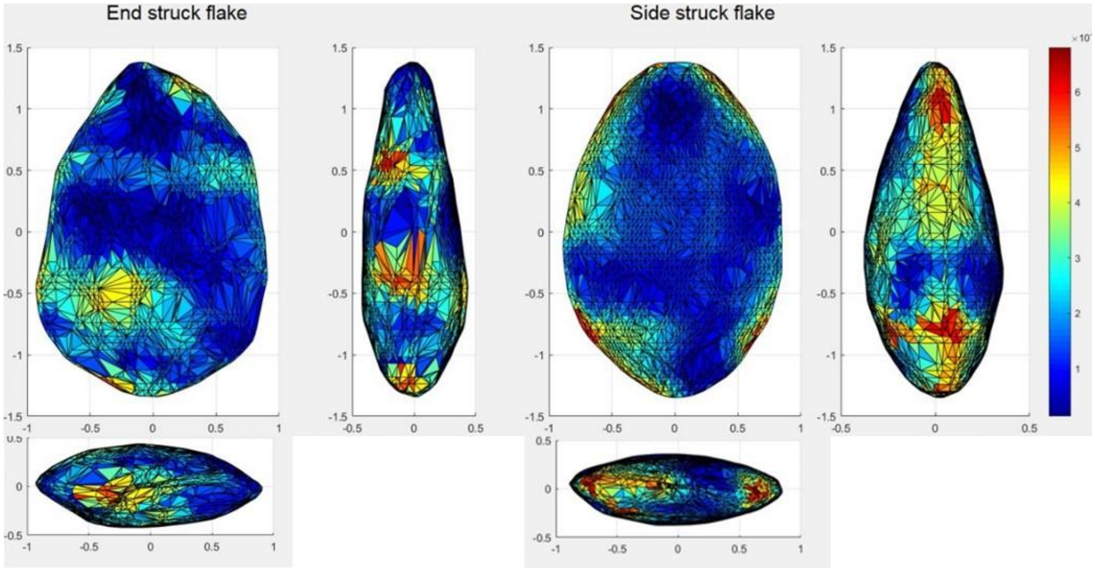


Figure 5. 81 Comparison of the mean shapes of cleavers on end-struck and side-struck flake – Benkaneri cleavers. Colour coding represents the degree and location of variability

An examination of the differences between the mean shapes (Figure 5.81) shows that the cleavers on side-struck flakes were more diversified on all the edges while the cleavers on end-struck flakes have their maximal variability on the dorsal surface with minor variations on the distal and proximal ends. The variability is mostly caused by the X dimension followed by Z for both the blanks with the least variation caused by the Y (Table 5.60).

Blank Type	No. of items	Shape variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
End-struck flake	3	5.11	46.90	1.14	51.96
Side-struck flake	8	6.12	48.99	3.31	47.70

Table 5. 60 The distribution of the variability within the blank types and the causative factor - Lakhmapur cleavers.

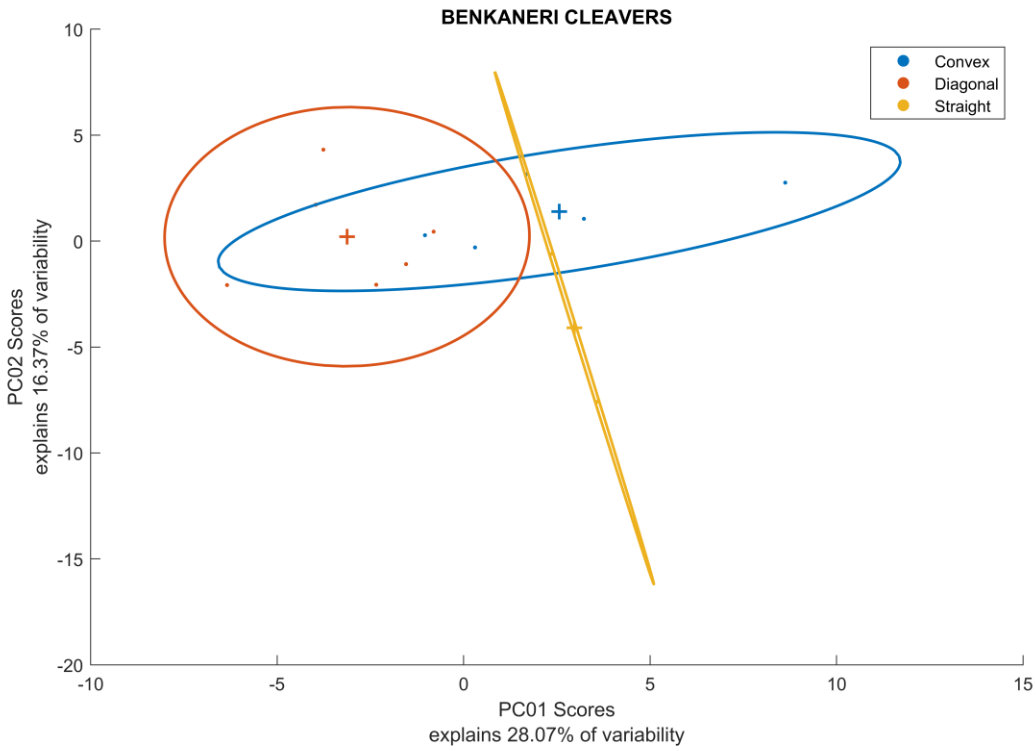


Figure 5. 82 Scatterplot of the first two principal components. + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses – Benkaneri cleaver distal tip.

Considering the second attribute, the distal cutting edge, a comparison of the different morphologies shows that the cleaver's mean shapes between the convex and diagonal distal edges are significantly different (Figure 5.82) at pValue=0.03 (Wilcoxon Rank- Sum Test – rank-sum=94, n1=5, n2=6). This is also displayed in Figure 5.83.

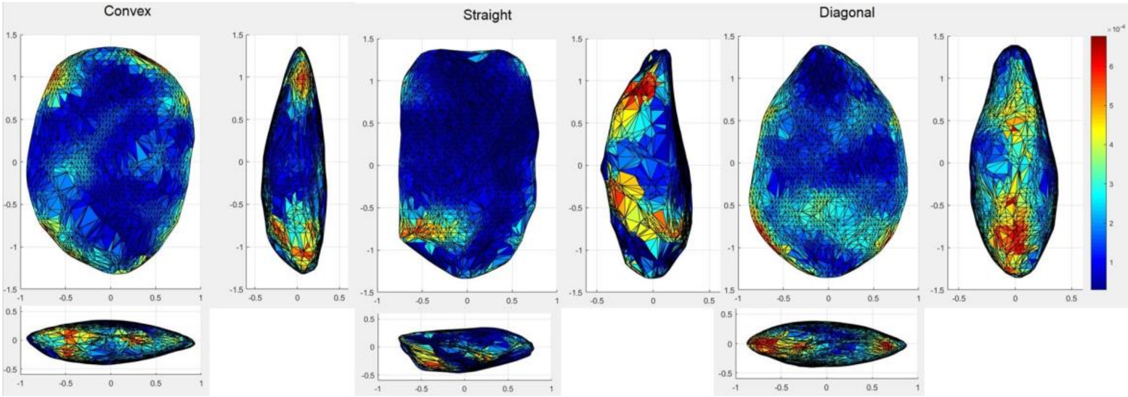


Figure 5. 83 Comparison of the mean shapes of all cleavers with different distal tip morphologies from Benkaneri. Colour coding represents the degree and location of variability.

Like the attribute of blank types, the distal edges also showed variation mainly resulting from X and Z dimensions (Table 5.61). The variability is mainly concentrated on the lateral edges, especially at the proximal ends, which is consistent with the striking platform removal for the cleavers on side-struck flakes and thinning of the butt.

Distal morphology	No. of Items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Convex	5	6.75	50.28	5.53	44.18
Straight	2	5.45	39.62	0.79	59.59
Diagonal	6	6.64	51.84	2.37	45.79

Table 5. 61 The distribution of the variability within the distal tips and the causative factor - Benkaneri cleavers.

The examination of mean shapes of cleavers on side-struck flakes, Kombewa flakes and tabular blocks grouped together on the one hand and end-struck cleavers on the other hand shows similar patterns of variability on the lateral edges as well as on the lateral and lower half of the tool surface (Figure 5.84).

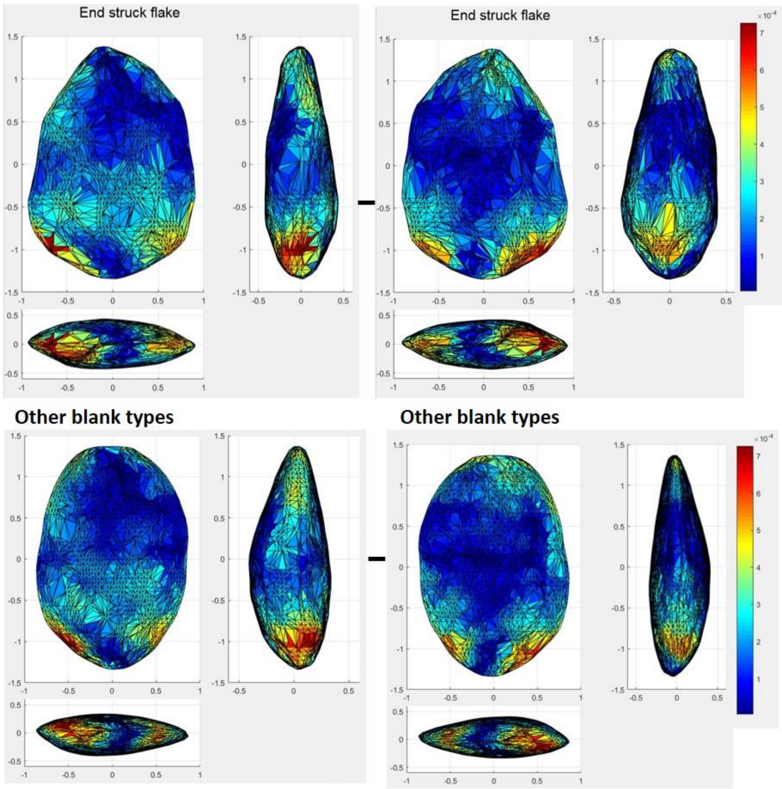


Figure 5. 84 Comparison of the mean shapes of cleavers on end-struck flakes and other blank types – Benkaneri cleavers.

A similar pattern of volumetric features is also evidenced between the groups of convex and diagonal edged cleavers on one hand and the straight edged cleavers on the other (Figure 5.85). The variability is located on the proximal ends and lateral edges, especially on the proximal half of the cleavers. Variability on the distal edges also remains similar and not as important as in the proximal half of the tools.

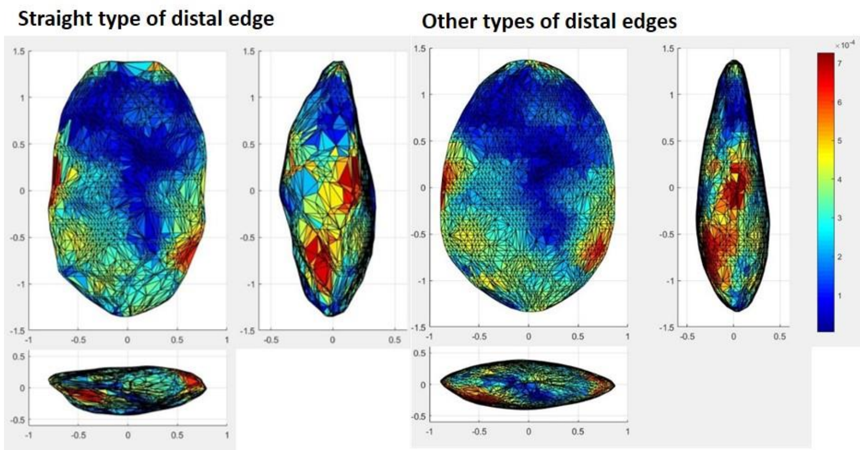
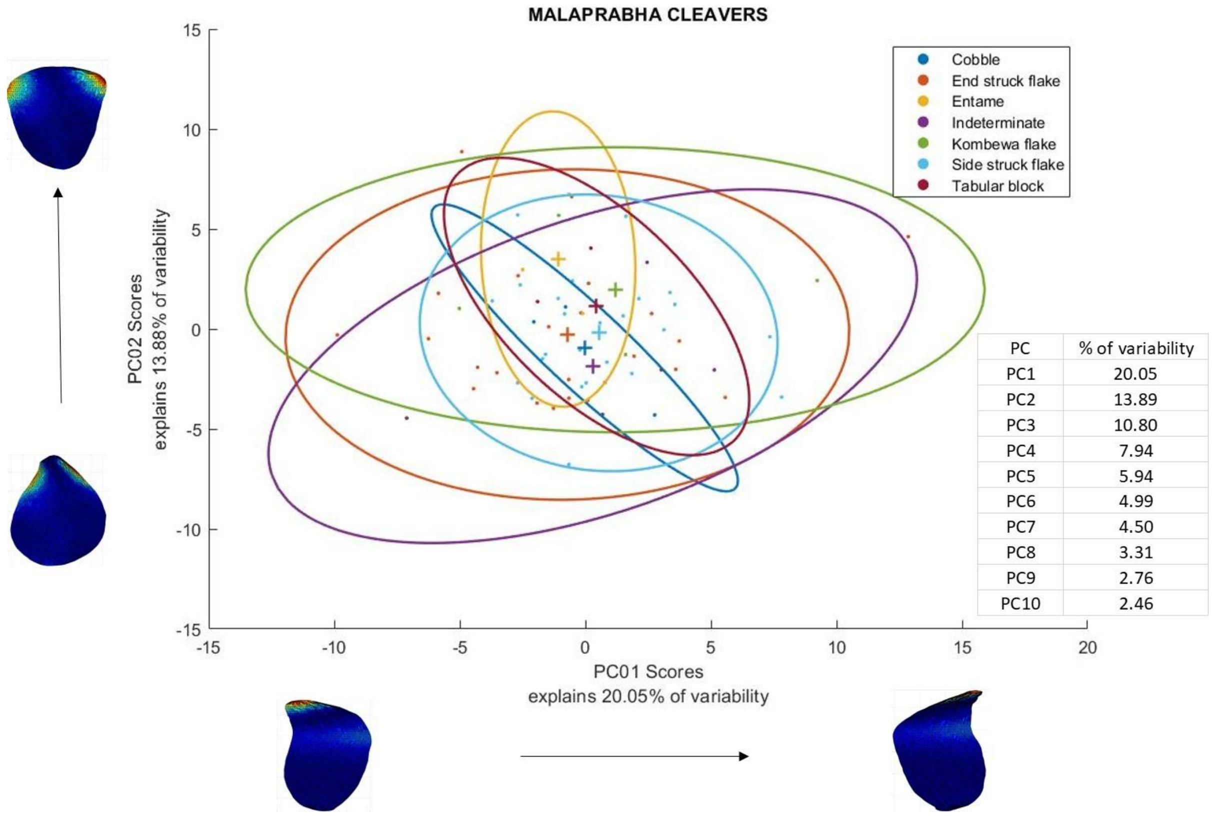


Figure 5. 85 Comparison of the mean shapes of cleavers on end-struck flakes and other blank types – Benkaneri cleavers. Colour coding represents the degree and location of variability.

5.10.4 Khyad, Lakhmapur and Benkaneri

All the cleavers on different blank types were compared together first. A total of 65 PCs were generated. The first 10 explained 77% of the total variation with the first three accounting for 45%. It is clear that there are many overlapping shapes among the different blanks (Figure 5.86). Except for one straight edged short symmetrical cleaver with dihedral platform from Khyad, which formed an outlier from all the rest and a diagonal edged ultra-pointed cleaver with V butt from Lakhmapur, which was an outlier from that site, all the other specimens are found to be overlapping (Figure 5.86). Cleavers on entames, cobbles, indeterminate blanks, Kombewa flakes, and tabular blocks are all subsumed within the shapes found on the flakes. The TpS warp hypothetical shape changes within the morpho-space show a trend of round butted cleavers with bilateral symmetry to U shaped diagonal edged asymmetrical cleavers on the PC1 axis and PC2 having U shaped elongated cleavers with narrower distal edges changing to V shaped and angled asymmetrical convex and straight edged cleavers (Figure 5.86).



PC	% of variability
PC1	20.05
PC2	13.89
PC3	10.80
PC4	7.94
PC5	5.94
PC6	4.99
PC7	4.50
PC8	3.31
PC9	2.76
PC10	2.46

Figure 5. 86 Scatterplot of the first two principal components. Warped images represent hypothetical shape change of the tool along the axis. + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses - Malaprabha Valley cleavers blank type.

A Wilcoxon Rank- Sum Test was carried out among the mean shape differences between the blanks to see if they were significant or not (Table 5.62).

Blank Type 1 and no. of cleavers	**Blank Type 2 and no. of cleavers**	**Rank-sum**	**pValue**
Side-struck flake (n=25)	Indeterminate (n=4)	728	0.04
End-struck flake (n=24)	Indeterminate (n=4)	663	0.02
Side-struck flake (n=25)	Cobble (n=3)	637	<0.01
End-struck flake (n=24)	Kombewa flake (n=4)	633	<0.01
End-struck flake (n=24)	Cobble (n=3)	617	0.03
Side-struck flake (n=25)	Kombewa flake (n=4)	605	0.05
Side-struck flake (n=25)	Entame (n=3)	580	<0.01
End-struck flake (n=24)	Entame (n=3)	563	<0.01
End-struck flake (n=24)	Tabular block (n=3)	550	<0.01
Side-struck flake (n=25)	Tabular block (n=3)	537	<0.01
Kombewa flake (n=4)	Indeterminate (n=4)	42	<0.01
Kombewa flake (n=4)	Entame (n=3)	35	0.02
Kombewa flake (n=4)	Cobble (n=3)	35	0.02
Kombewa flake (n=4)	Tabular block (n=3)	32	<0.01
Tabular block (n=3)	Indeterminate (n=4)	28	<0.01
Cobble (n=3)	Tabular block (n=3)	23	<0.01
Entame (n=3)	Cobble (n=3)	22	<0.01
Entame (n=3)	Tabular block (n=3)	21	<0.01

Table 5. 62 Result of a Wilcoxon Rank-Sum Test on the Inter-point Distances between the group means of all blank types – Malaprabha Valley cleavers.

The mean shapes of all the blank types from all the three sites were extracted and compared (Figure 5.87). The main variations for all the cleaver blanks were located on the lateral distal and proximal sides (Figure 5.87.). While for the cleavers on flake blanks, this variability was limited to the peripheral areas of the tool, cleavers on cobble, entame, indeterminate and tabular blocks, had more variations on their surface. This is consistent with the volume reduction of these blank types. Cleavers on flake showed more symmetrical outlines and less variability when compared to other blanks. This was also noticed for the cleavers on tabular blocks and Kombewa flakes.

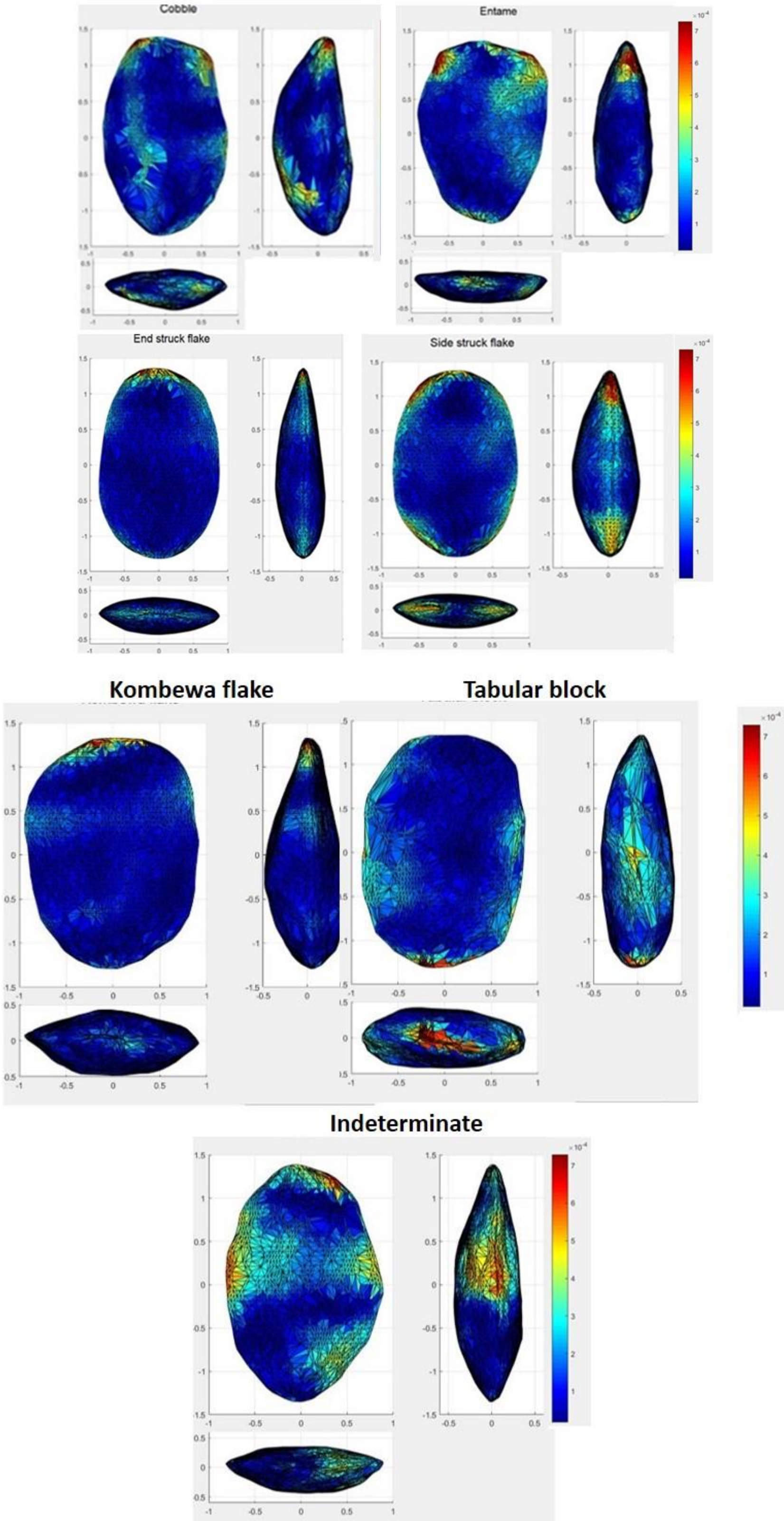


Figure 5. 87 Comparison of the mean shapes of cleavers on different blank types from Malaprabha Valley sites. Colour coding represents the degree and location of variability.

The second attribute, that of cleaver distal edges, was also compared between all the sites to assess variations within (Figure 5.88).

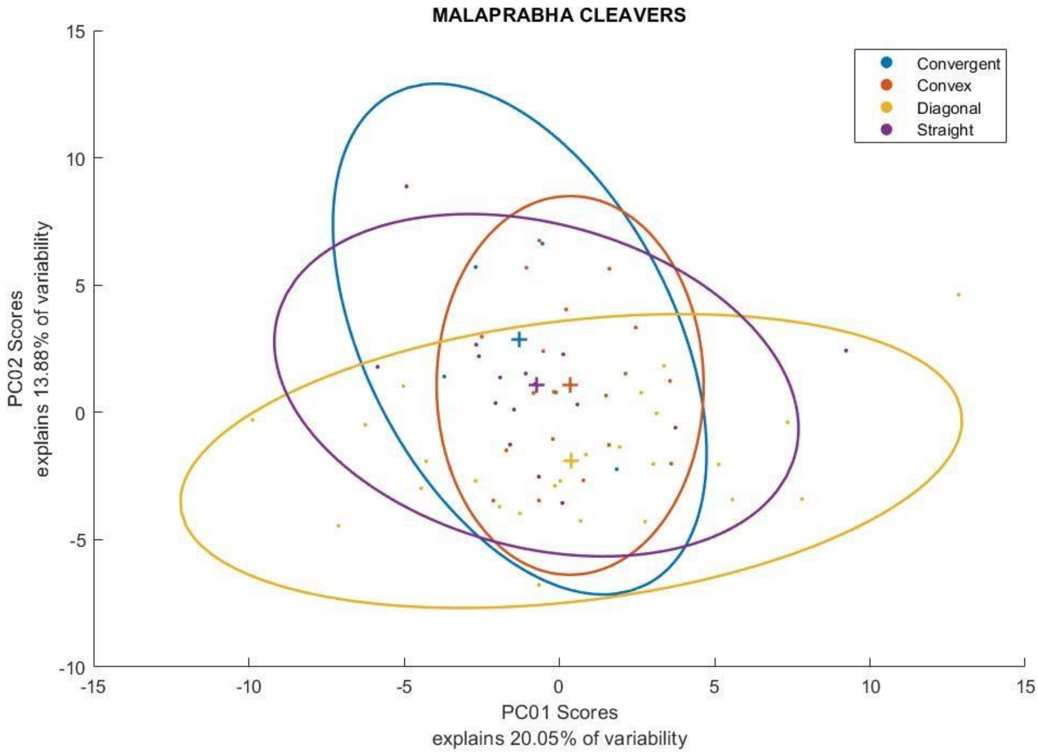


Figure 5. 88 Scatterplot of the first two principal components. Warped images represent hypothetical shape change of the tool along the axis. + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses - Malaprabha Valley cleavers distal tip.

The distribution of the shapes of cleavers with different distal tip morphologies (Figure 5.88), shows that most of the shapes overlapped with those within the cleavers with convex distal edges. Only a few straight and diagonal edged cleavers are widely dispersed outside this ellipse. Only one outlier from all the sites is noticed, a specimen from Khyad with pointed diagonal cutting edge. Khyad had another outlier among its specimens, that of a square, symmetrical, thick cleaver with dihedral striking platform.

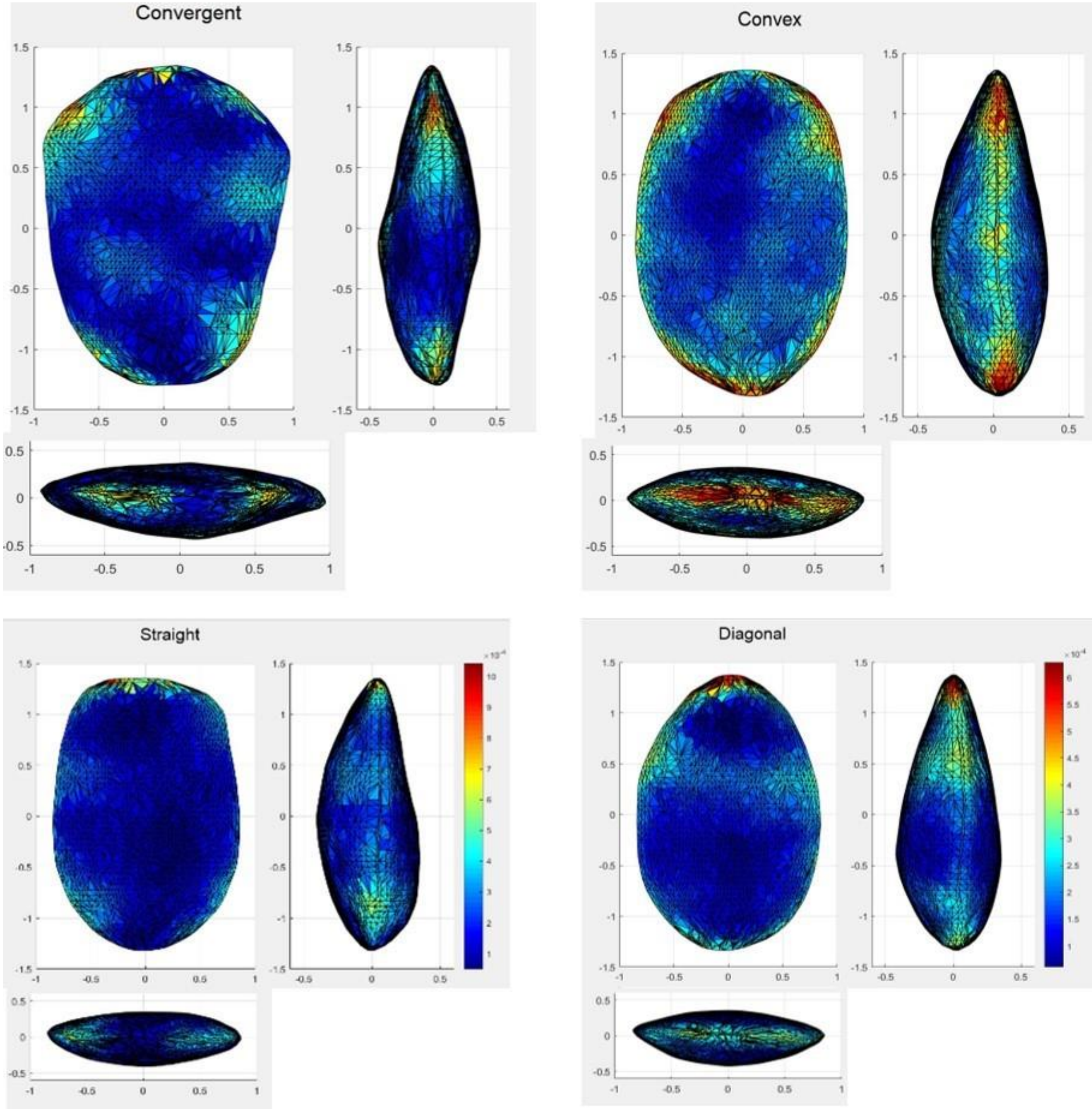


Figure 5. 89 Comparison of the mean shapes of cleavers with different distal tip morphologies from Malaprabha Valley sites. Colour coding represents the degree and location of variability.

All the cleavers, irrespective of their distal edge type, show a similar pattern of variability located at the lateral edges (Figure 5.89). Among these, the convex, convergent, and the diagonal ended cleavers showed a more intense variability. The convex ended cleavers had more variability on the surface, which would have been the result of the volume reduction. The proximal variability on all the tools, may be an indication of the platform preparation or the shaping of the butt, through removals and volumetric reduction.

5.10.5 Attirampakkam

A total number of 10 cleavers were analysed which produced 9 PCs of which the first 3 explained 68% of the variation.

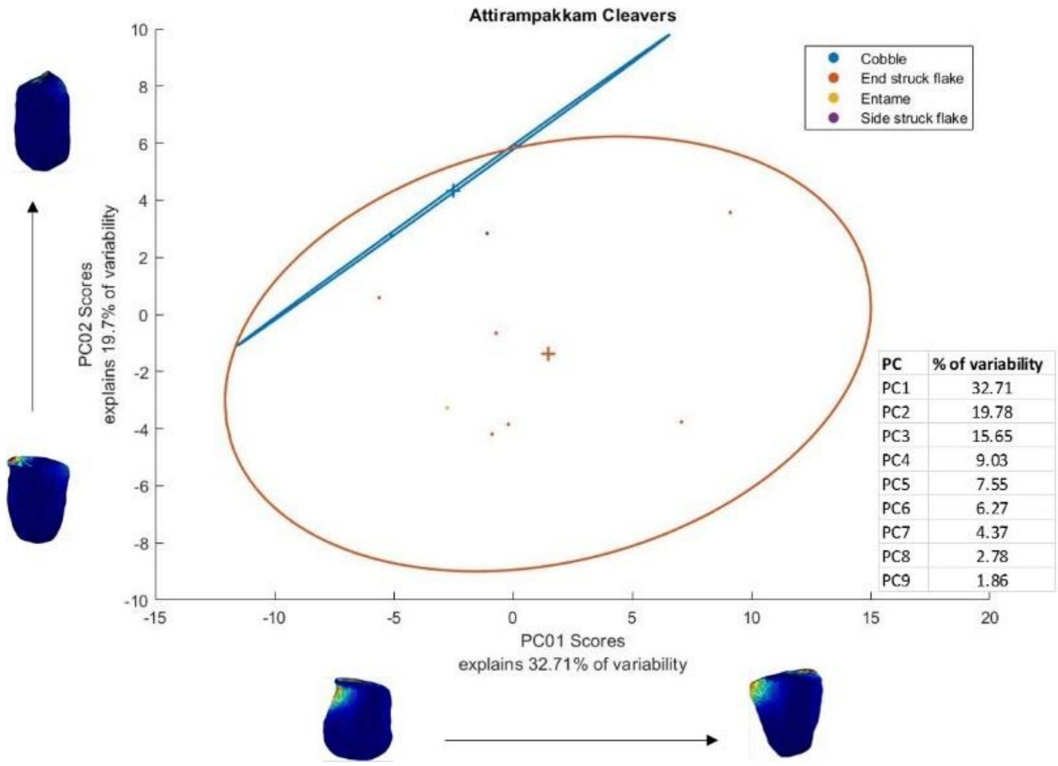


Figure 5. 90 Scatterplot of the first two principal components. Warped images represent hypothetical shape change of the tool along the axis. + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses - Attirampakkam cleavers blank types.

From the distribution pattern of the blank shapes in Figure 5.90, we can see that all the cleavers irrespective of the blank differences, fall within the shape range of cleavers on end-struck flakes. TpS warped images show a shape trend of cleavers with almost parallel edges and U-shaped butt and straight edges to V shaped cleavers with wider cutting edge on PC1. PC2 shows the shape change from U shaped convex and straight edged cleavers to U shaped diagonal edged cleavers. From Figure 5.91, we see that the mean shape as well as the distribution and intensity of variability is different for cobble and end-struck flake cleavers. The variability among both these blanks resulted from relative width, followed by relative thickness (Table 5.63).

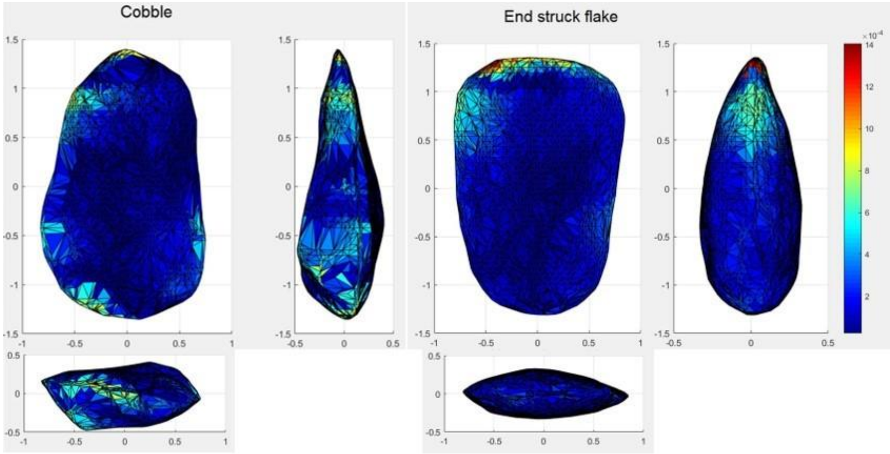


Figure 5. 91 Comparison of the mean shapes of cleavers on cobble and end-struck flake from Attirampakkam. Side-struck and entame specimens are not included due to insufficient numbers. Colour coding represents the degree and location of variability.

Blank Type	No. of Items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Cobble	2	5.18	58.25	1.00	40.76
End-struck flake	6	7.67	67.98	5.09	26.93

Table 5. 63 The distribution of the variability within the blank types and the causative factor - Attirampakkam cleavers.

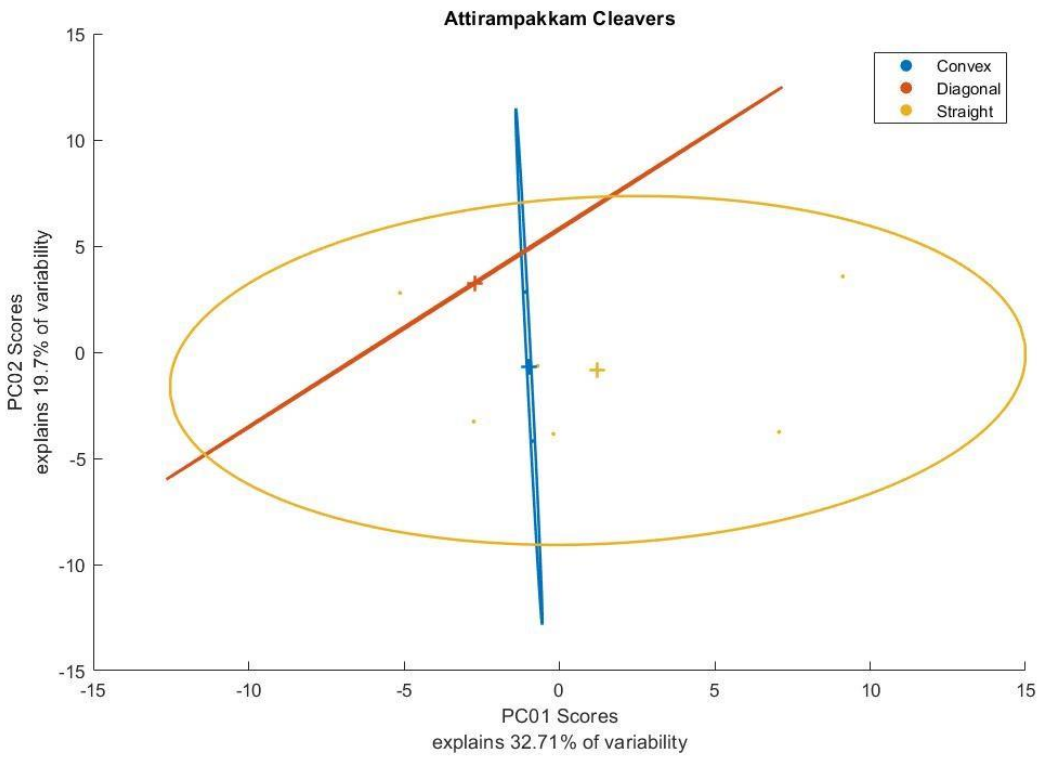


Figure 5. 92 Scatterplot of the first two principal components. + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses. Attirampakkam cleavers distal tip.

The distribution of the distal tip shapes in the morpho-space show a wide distribution. However, all the cleaver shapes are subsumed by the shapes of cleavers with straight distal ends (Figure 5.92).

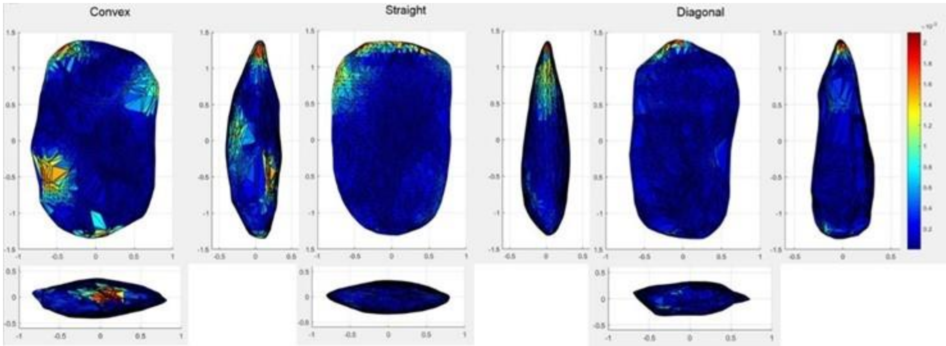


Figure 5. 93 Comparison of the mean shapes of all cleavers with different distal tip morphologies from Attirampakkam. Colour coding represents the degree and location of variability

From the mean shapes of cleavers (Figure 5.94) with different distal morphologies, it is evident that the variability for all the cleavers lay in distal edge. In addition, the convex ended cleavers showed an intense variability located on the lateral edges on the lower half of the tool as well as in the proximal ends.

Distal morphology	No. of Items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Convex	2	5.46	60.43	6.28	33.29
Straight	6	7.96	66.62	4.44	28.94
Diagonal	2	4.82	71.95	0.32	27.74

Table 5. 64 The distribution of the variability within the distal tips and the causative factor - Attirampakkam cleavers.

From the Table 5.64 we see that the relative width was a significant contributor to this variability followed by the relative thickness.

To understand the variability within the cleavers, all the cleavers on blanks other than end struck flakes were put in a group and tested against the group of end-struck cleavers. The results show similarities in the location of the variability (distal tips) in both groups (Figure 5.94). However, in the end struck cleavers, the intensity is more pronounced at the distal, lateral as well as at the proximal edges.

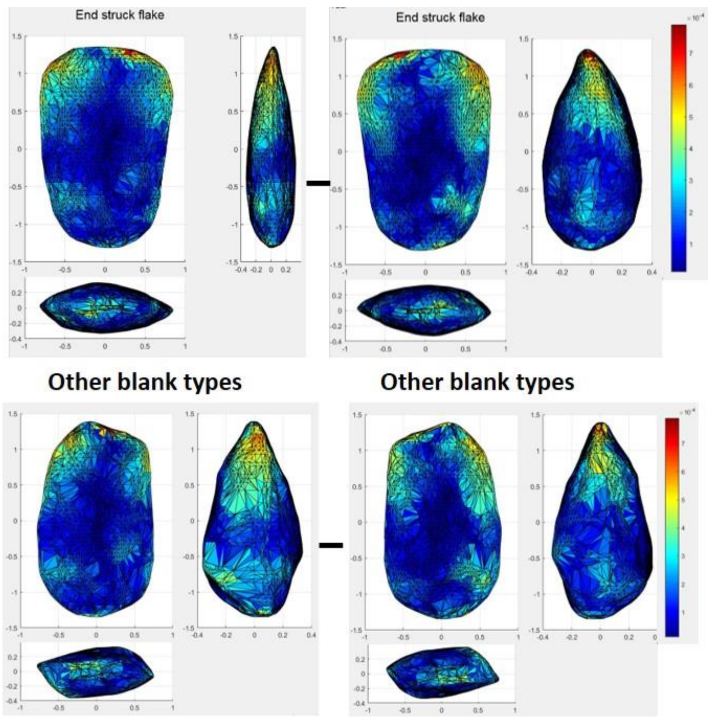


Figure 5. 94 Comparison of the mean shapes of cleavers on end-struck blanks and other blank types from Attirampakkam. Colour coding represents the degree and location of variability.

A similar test was conducted with the cleavers with straight edges put in one group and all the diagonal and convex edges in another group. The results show similar patterns of intensity as well as distribution of the variability across the surface of the tool (Figure 5.95).

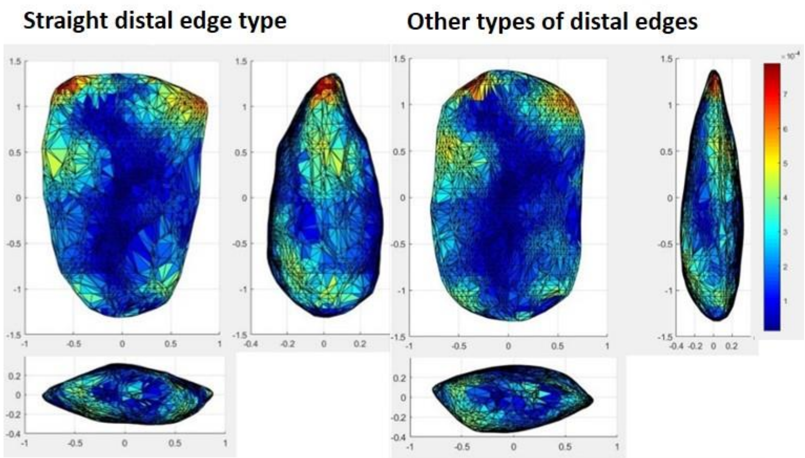


Figure 5. 95 Comparison of the mean shapes of all straight distal tip and other types of distal edge tips – Attirampakkam cleavers. Colour coding represents the degree and location of variability

5.10.6 Singadivakkam

Only 4 cleavers were present in this assemblage. All the three occupied different locations as seen from their distribution in the morpho-space (Figure 5.96). As the specimens for each group of blank types and distal end morphologies are the same, they are represented in one Figure (Figure 5.96).

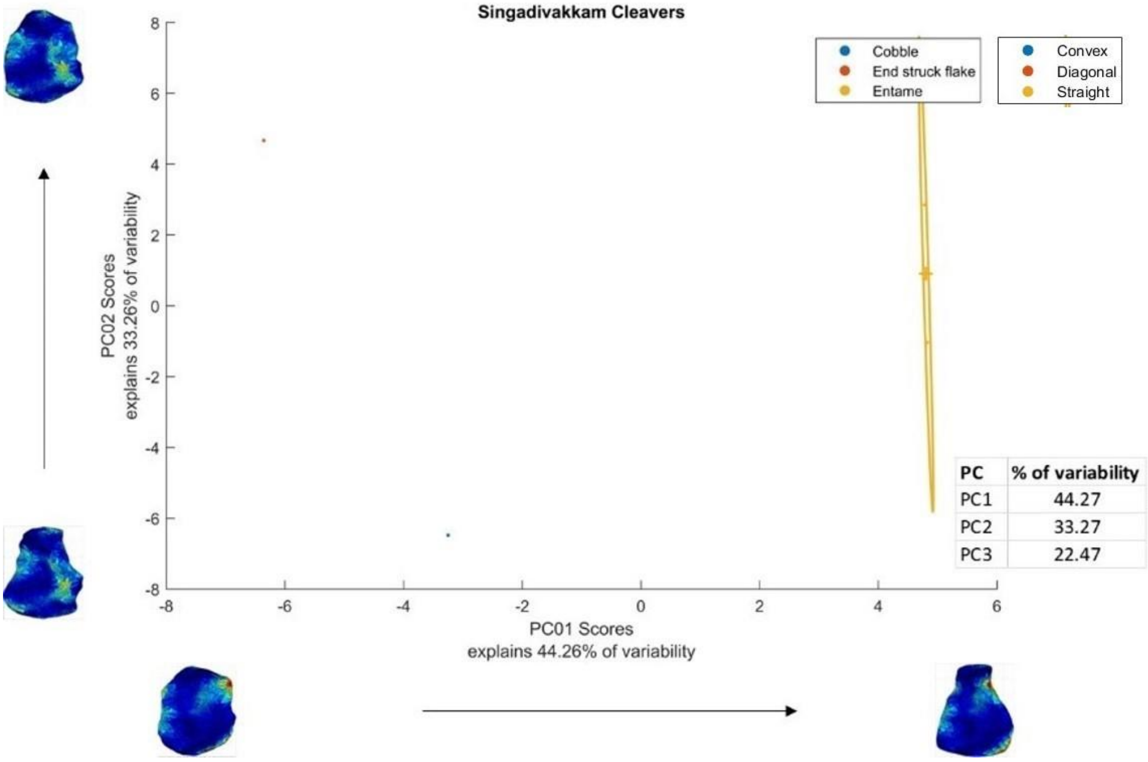


Figure 5. 96 Scatterplot of the first two principal components. Warped images represent hypothetical shape change of the tool along the axis. + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses - Singadivakkam cleavers blank types and distal tip.

As the cleavers from Attirampakkam were from unclear and mixed contexts and due to the Singadivakkam specimens not reaching the statistical requirements for a meaningful comparison, a comparative study between the 2 sites were not carried out.

5.11 Inter-regional comparison – Handaxes

5.11.1 General features

All the handaxes from Malaprabha and Tamil Nadu sites were compared together in a single morpho-space to identify if there are patterns in the shape distribution. The total number of PCs generated were 150, of which the first 10 explained 71% of the variability (Table 5.65).

PC	% of variability
PC1	22.85
PC2	11.68
PC3	8.63
PC4	6.86
PC5	5.04
PC6	4.29
PC7	3.23
PC8	2.96
PC9	2.77
PC10	2.31

Table 5. 65 The first 10 PCs explaining 71% of the handaxe variability – all handaxes.

From their distribution displayed in the scatterplot (Figure 5.97) it is clearly noticed that the mean shapes of handaxes from the Acheulean sites of Attirampakkam and Khyad, and the transitional Lakhmapur are located separately. Lakhmapur is also found to be different from both Middle Palaeolithic sites of Benkaneri and Singadivakkam.

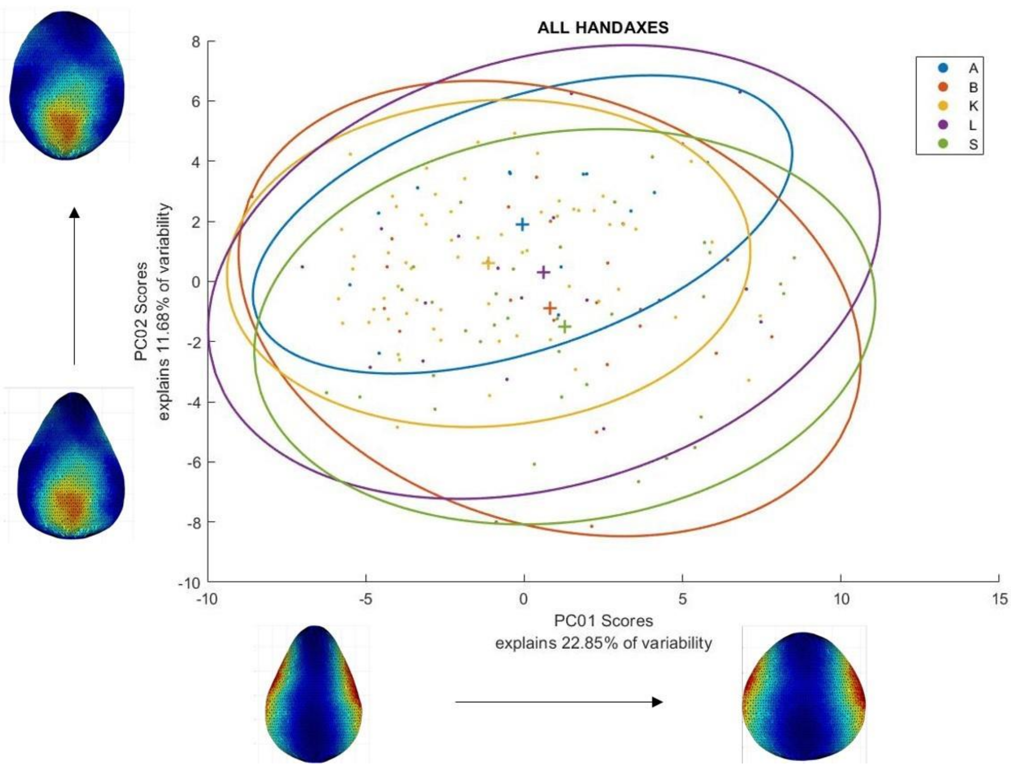


Figure 5. 97 Scatterplot of the first two principal components. Warped images represent hypothetical shape change of the tool along the axis. + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses - all handaxes.

From the mean shape differences noticed below (Figure 5.98) Singadivakkam handaxes seems to display the maximum variability, which is located across the surface of the tool as well as the lateral edges. The Malaprabha sites all show a similarity in the variability distribution, which is peripheral and mostly on the upper edge of the lateral side and the proximal ends. Attirampakkam handaxes show more invasive variability on the lateral edges on the upper half of the tool but unlike the Singadivakkam tools, do not extend beyond the mid width.

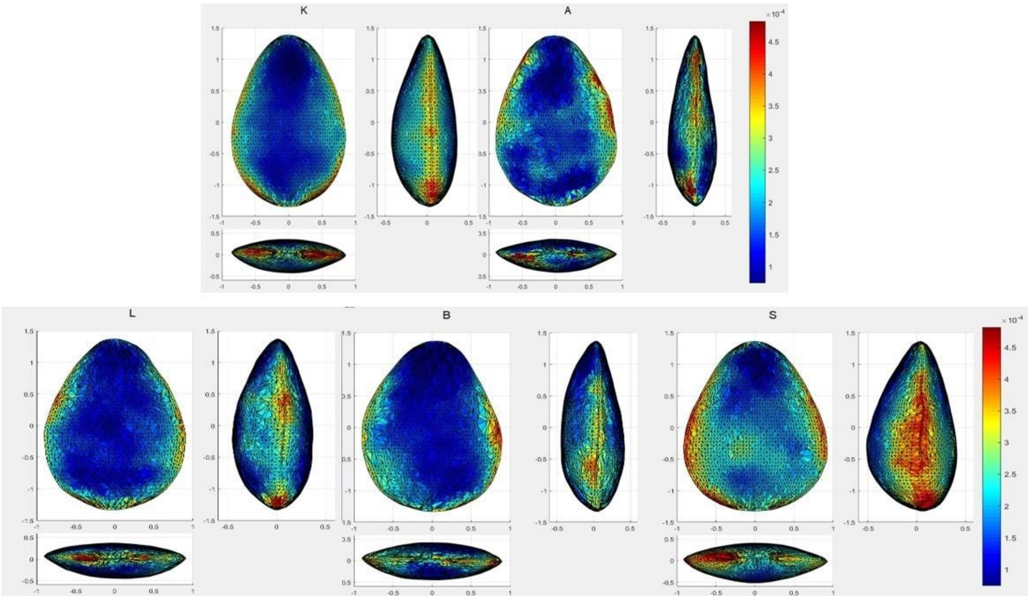


Figure 5. 98 Comparison of the mean shapes of handaxes from Khyad (K), Attirampakkam (A), Lakhmapur (L), Benkaneri (B) and Singadivakkam (S). Colour coding represents the degree and location of variability.

The relative thickness seems to have played an important role in the resulting variability within handaxes at Khyad, Benkaneri and Singadivakkam while at Attirampakkam and Lakhmapur, it was the relative width that has contributed significantly to the variability (Table 5.66).

Site name	No. of Items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Khyad	63	7.31	47.59	3.34	49.07
Attirampakkam	14	6.57	54.00	4.43	41.57
Lakhmapur	18	8.09	49.60	5.01	45.39
Benkaneri	22	8.12	43.18	3.44	53.38
Singadivakkam	33	8.04	43.58	4.67	51.76

Table 5. 66 The distribution of the variability within the handaxes from all sites and the causative factor.

A Wilcoxon Rank-Sum Test on Inter-point Distances between Group Means was conducted which showed significant differences between the handaxes of Khyad and Attirampakkam on the one hand, and Khyad and Benkaneri on the other (Table 5.67).

Site 1 and number of tools	Site 2 and number of tools	Rank-Sum	pValue
Khyad (n=63)	Attirampakkam (n=14)	5390	0.03
Khyad (n=63)	Benkaneri (n=22)	6269	<0.01

Table 5. 67 Result of a Wilcoxon Rank-Sum Test on the Inter-point Distances between the group means of all handaxes.

When the bifacial and bilateral symmetries are taken into consideration, we find Khyad was the most asymmetrically shaped. Bilateral and bifacial symmetry was more or less maintained at Benkaneri and Singadivakkam while Lakhmapur exhibits more bilateral asymmetry than bifacial asymmetry (Table 5.68).

Site name	No. of handaxes	Variability (%)	Deviation from bilateral symmetry (%)	Deviation from bifacial symmetry (%)
Khyad	63	7.30	6.68	6.22
Attirampakkam	14	6.57	6.37	5.27
Lakhmapur	18	8.08	6.29	5.44
Benkaneri	22	8.12	5.30	5.61
Singadivakkam	33	8.04	5.22	5.57

Table 5. 68 Distribution of bilateral and bifacial symmetry of all handaxes.

5.11.2 Blank types

5.11.2.1 Cobbles

Singadivakkam cobble blanks seems to be the most variable among the cobble blanks from Khyad, Attirampakkam and Benkaneri. The variability on the handaxes on cobbles from this site (Figure 5.99), display an intensity of variability on the lateral edges as well as a well dispersed variability throughout the surface of the tool. The handaxes from the other sites have lesser variability, with different intensities.

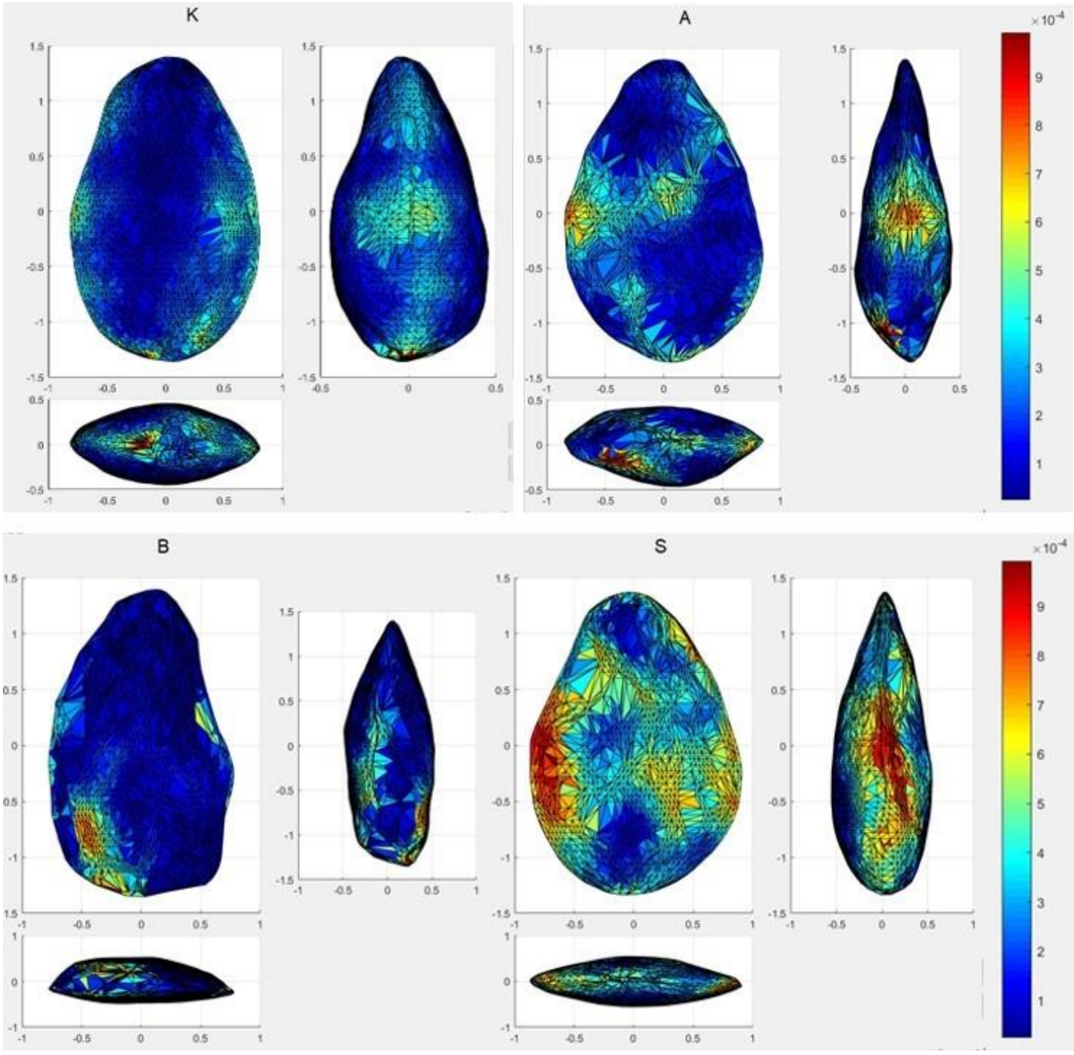


Figure 5. 99 Comparison of mean shapes of handaxes on cobbles from Khyad (K), Attirampakkam (A), Benkaneri (B) and Singadivakkam (S). Colour coding represents the degree and location of variability.

Singadivakkam cobble blanks seems to be the most variable compared to the cobble blanks from Khyad, Attirampakkam and Benkaneri. The variability in the handaxes on cobbles from this site display an intensity of variability on the lateral edges as well as a well dispersed variability throughout the surface of the tool. The handaxes from the other sites have lesser variability, with different intensities. The causative factors and distribution of variability are summarised in Table 81.

A Wilcoxon Rank-Sum Test on Inter-Point Distances between Group Means showed significant differences between the cobble blanks of Khyad and Attirampakkam at pValue=0.02 (rank-sum=75, n1=7, n2=3).

The causative factor for the shape variability was the relative thickness in the case of handaxes on cobbles from the sites of Khyad, Benkaneri and Singadivakkam (Table 5.69).

Site name	No. of Items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Khyad	7	6.92	46.86	2.99	50.14
Attirampakkam	3	6.92	55.57	4.14	40.29
Benkaneri	2	5.75	10.51	3.55	85.93
Singadivakkam	5	7.43	40.42	3.22	56.36

Table 5. 69 The distribution of the variability within the handaxes on cobble from all sites and the causative factor.

5.11.2.2 Entames

Handaxes shaped on entames were encountered in only one site from the Malaprabha Basin, while both the Tamil Nadu sites had some examples. The variability observed on the mean shapes (Figure 5.100) shows that unlike Khyad, where there is minimal variability located at the lower half of the tool, at Attirampakkam and Singadivakkam this is located at the lateral edges, with more intensity on the surface of the tool.

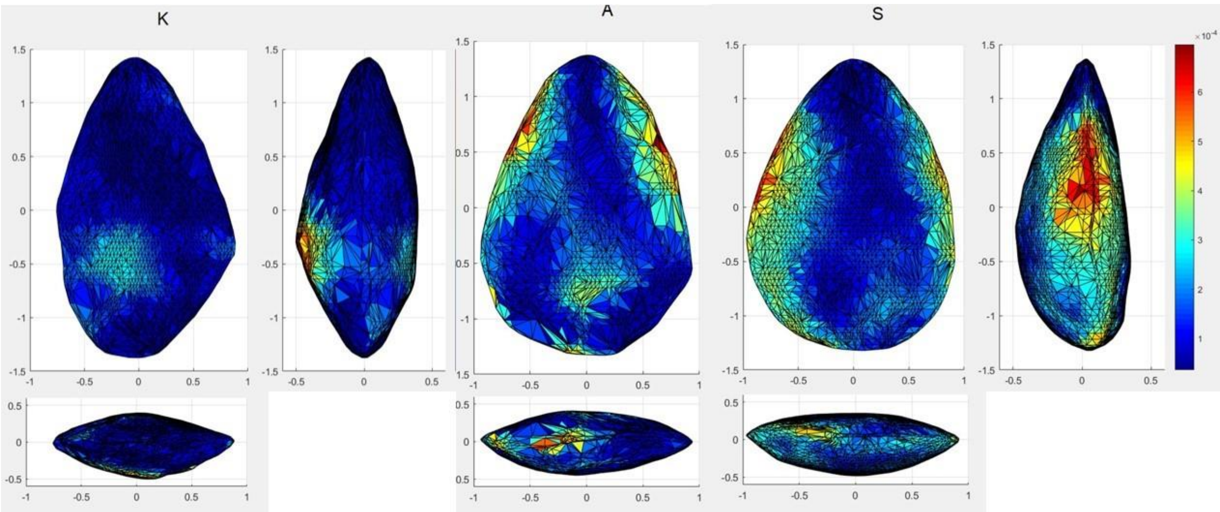


Figure 5. 100 Comparison of mean shapes of handaxes on entame from Khyad (K), Attirampakkam (A) and Singadivakkam (S). Colour coding represents the degree and location of variability.

This variability seems to stem from relative thickness in the case of Khyad handaxes while relative width was the main influence on the handaxe shape at the Tamil Nadu sites (Table 5.70).

Site name	No. of Items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Khyad	2	4.79	21.23	5.20	73.57
Attirampakkam	3	6.14	61.37	3.91	34.72
Singadivakkam	8	7.14	50.37	5.44	44.19

Table 5. 70 The distribution of the variability within the handaxes on entame from all sites and the causative factor.

5.11.2.3 End-struck flakes

Handaxes on end-struck blanks were encountered in all the assemblages. When the Acheulean sites of Khyad and Attirampakkam are compared, we see a relatively similar intensity of the variability, located at the right lateral edge. While for the Khyad specimens this is distributed all along the lateral edge, at Attirampakkam, we see the central and upper part of the lateral edge displaying more variability (Figure 5.101).

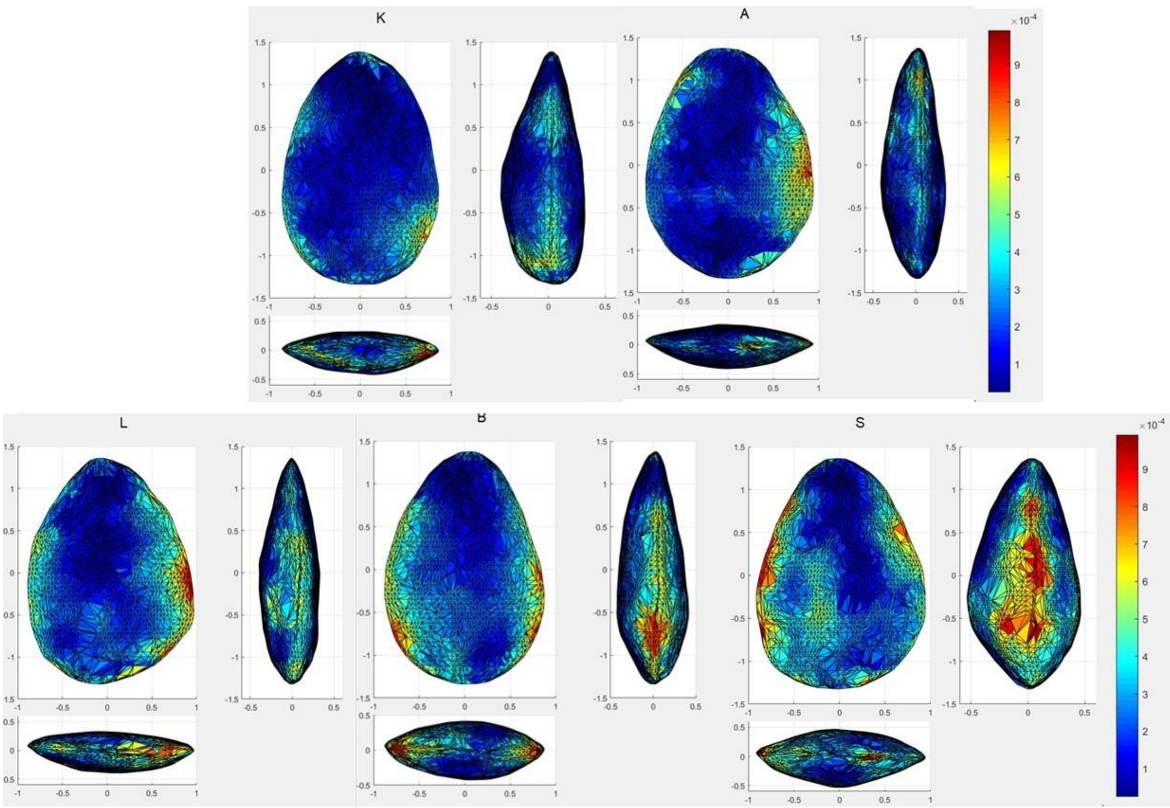


Figure 5. 101 Comparison of the mean shapes of handaxes on end struck flakes from Khyad (K), Attirampakkam (A), Lakhmapur (L), Benkaneri (B) and Singadivakkam (S). Colour coding represents the degree and location of variability.

This variability is caused by the relative width followed by the relative thickness at all sites. Only at Lakhmapur, the relative length seems to have played an important role in the variability (Table 5.71).

Site name	No. of Items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Khyad	8	6.21	52.16	3.91	43.93
Attirampakkam	8	5.61	51.35	4.60	44.05
Lakhmapur	6	7.60	49.97	6.98	43.05
Benkaneri	10	7.98	52.30	4.69	43.01
Singadivakkam	8	7.48	48.98	4.69	46.33

Table 5. 71 The distribution of the variability within the end-struck handaxes from all sites and the causative factor.

A Wilcoxon Rank-Sum Test on Inter-point Distances between Group Means was conducted on the handaxes on end-struck flake blanks and the results are given in Table 5.72.

Site 1 and no. of handaxes	Site 2 and no. of handaxes	Rank-Sum	pValue
Khyad (n=8)	Singadivakkam (n=8)	183	<0.01
Lakhmapur (n=6)	Benkaneri (n=10)	201	0.01
Attirampakkam (n=8)	Singadivakkam (n=8)	190	<0.01

Table 5. 72 Wilcoxon Rank-Sum Test results on Inter-point Distances between Group Means of end-struck flake handaxes from sites of Khyad, Lakhmapur, Singavadivakkam and Attirampakkam.

5.11.2.4 Side-struck flakes

Handaxes on side-struck blanks were present only at Malaprabha sites. From the mean shape (Figure 5.102) we see that the variability was the least in the Lakhmapur handaxes. While for Benkaneri and Khyad, this variability was located on the lateral edges as well as proximal ends, for Lakhmapur, this was located only at the lower lateral edge.

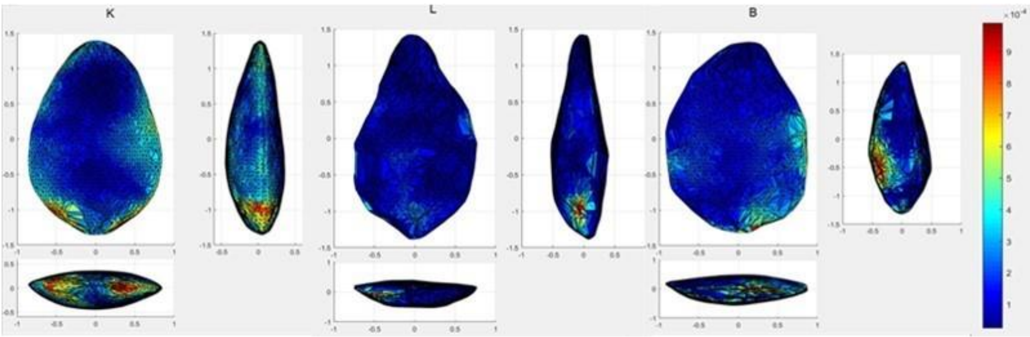


Figure 5. 102 Comparison of mean shapes of handaxes on side-struck flakes from Khyad (K), Lakhmapur (L) and Benkaneri (B). Colour coding represents the degree and location of variability.

In all the handaxes from all the sites, the variability seems to be caused by the relative thickness, followed by relative width. Relative length played little to no role in this variability (Table 5.73).

Site name	No. of Items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Khyad	13	7.05	45.30	2.74	51.96
Lakhmapur	2	4.58	25.65	0.55	73.80
Benkaneri	3	7.73	31.10	2.04	66.86

Table 5. 73 The distribution of the variability within the handaxes on side-struck flakes from all sites and the causative factor.

5.11.2.5 Tabular blocks

Noticed only in the assemblage of sites from the Malaprabha Basin, the variability was more pronounced among the handaxes of Khyad and Benkaneri. On the handaxes from the former site, this variability was dispersed across the mid region of the tool, with intensified variability at the lateral edges. At Lakhmapur and Benkaneri, similar trends of peripheral location of the variability can be inferred (Figure 5.103).

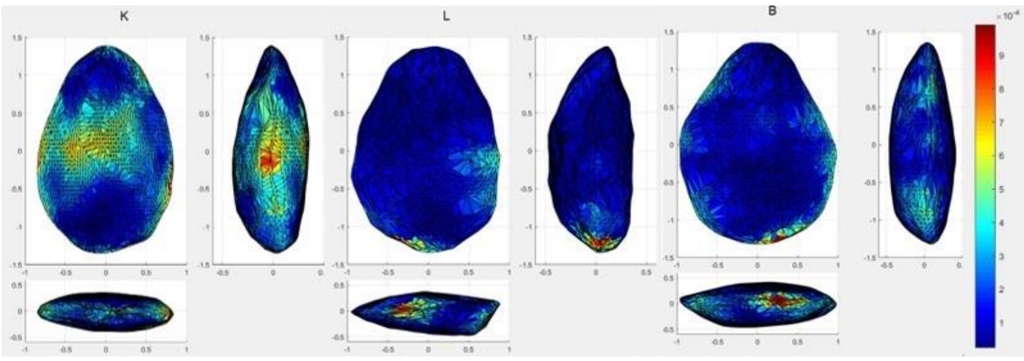


Figure 5. 103 Comparison of mean shapes of handaxes from tabular block from Khyad (K), Lakhmapur (L) and Benkaneri (B). Colour coding represents the degree and location of variability

At both Khyad and Benkaneri, while relative thickness seemed to be a major cause for this variability, Lakhmapur variability was greatly influenced by its relative width (Table 5.74).

Site name	No. of Items	Shape Variability with the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Khyad	5	7.45	36.81	3.09	60.11
Lakhmapur	2	5.50	65.24	2.97	31.79
Benkaneri	7	6.74	45.39	3.13	51.48

Table 5. 74 The distribution of the variability within the handaxes on tabular block from all sites and their causative factors.

5.11.3 Distal Morphology

5.11.3.1Pointed distal tip

Handaxes, pointed at the distal tip, was found in all the sites. An examination of the mean shapes of handaxes with this distal morphology shows that Khyad and Lakhmapur display the least variability, located on the lateral edges, with Singadivakkam and Benkaneri handaxes having invasive peripheral variability at the lower half of the tool. At Attirampakkam, which also displays intense variability on the lateral edges, this was mainly concentrated at the mid part of the tool, with invasive nature of the variability (Figure 5.104).

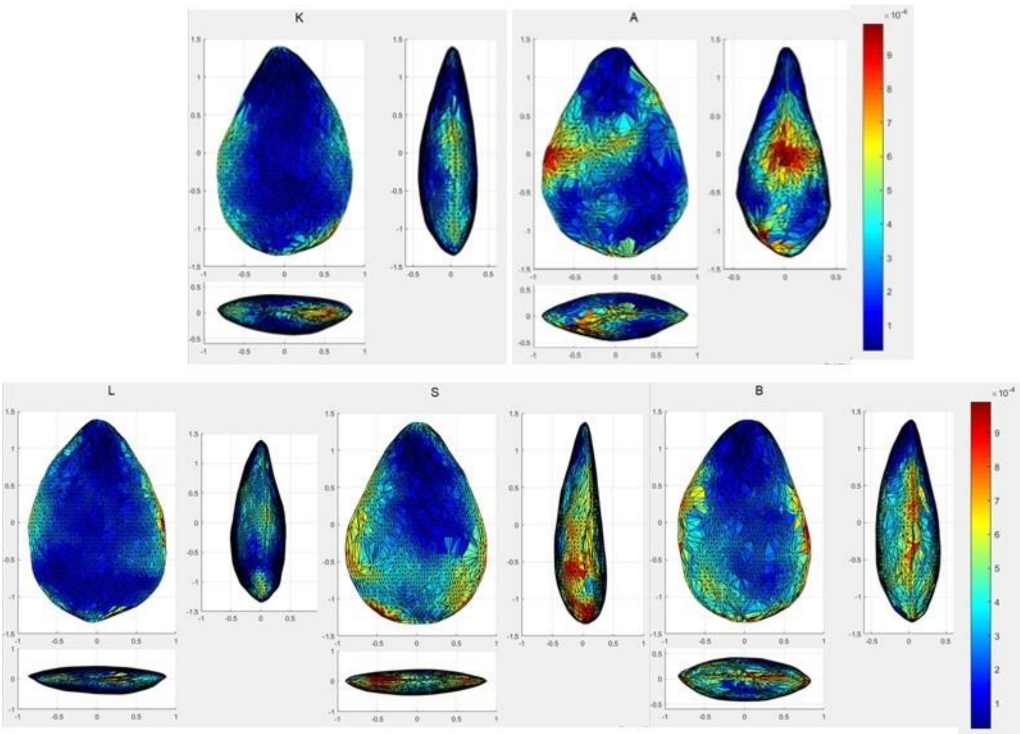


Figure 5. 104 Comparison of handaxes with pointed distal tips from Khyad (K), Attirampakkam (A), Lakhmapur (L), Singadivakkam (S) and Benkaneri (B). Colour coding represents the degree and location of variability

A Wilcoxon Rank-Sum Test on Inter-point Distances between Group Means was conducted on the pointed handaxes between all the sites. Significant differences were found between Khyad and Attirampakkam on one hand and between Lakhmapur and Singadivakkam (Table 5.75) on the other.

Site 1 and no. of handaxes	Site 2 and no. of handaxes	Rank-Sum	pValue
Khyad (n=13)	Attirampakkam (n=4)	220	<0.01
Lakhmapur (n=5)	Singadivakkam (n=10)	170	0.01

Table 5. 75 Wilcoxon Rank-Sum Test results on Inter-point Distances between Group Means of pointed handaxes from sites of Khyad and Lakhmapur.

While at Khyad, Attirampakkam, and Lakhmapur the variability within these distal morphologies were largely influenced by the relative width, at the rest of the sites, it was the relative thickness that had an effect on the distal morphology (Table 5.76).

Site name	No. of Items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Khyad	13	6.89	50.76	2.69	46.55
Attirampakkam	4	6.83	57.91	3.96	38.13
Lakhmapur	5	7.59	48.96	2.82	48.22
Benkaneri	12	8.07	37.99	2.58	59.42
Singadivakkam	10	7.29	45.92	4.28	49.80

Table 5. 76 The distribution of the variability within the handaxes on its pointed distal morphologies and their causative factors.

5.11.3.2 Rounded distal tip

Handaxes from all the sites had specimens with rounded distal ends. While Khyad showed variability distributed all along the margins, with greater intensity at the proximal ends, Attirampakkam handaxes displayed this variability on the lateral right of the tool. The handaxes from this site also showed this variability extending towards the centre of the tool. Among the handaxes from Middle Palaeolithic sites, Singadivakkam showed a higher variability, which was dispersed along the lateral edges and the lower half of the surface of the tool. At Benkaneri and Lakhmapur, the variability was much less intense, located mainly at the lateral edges (Figure 5.105).

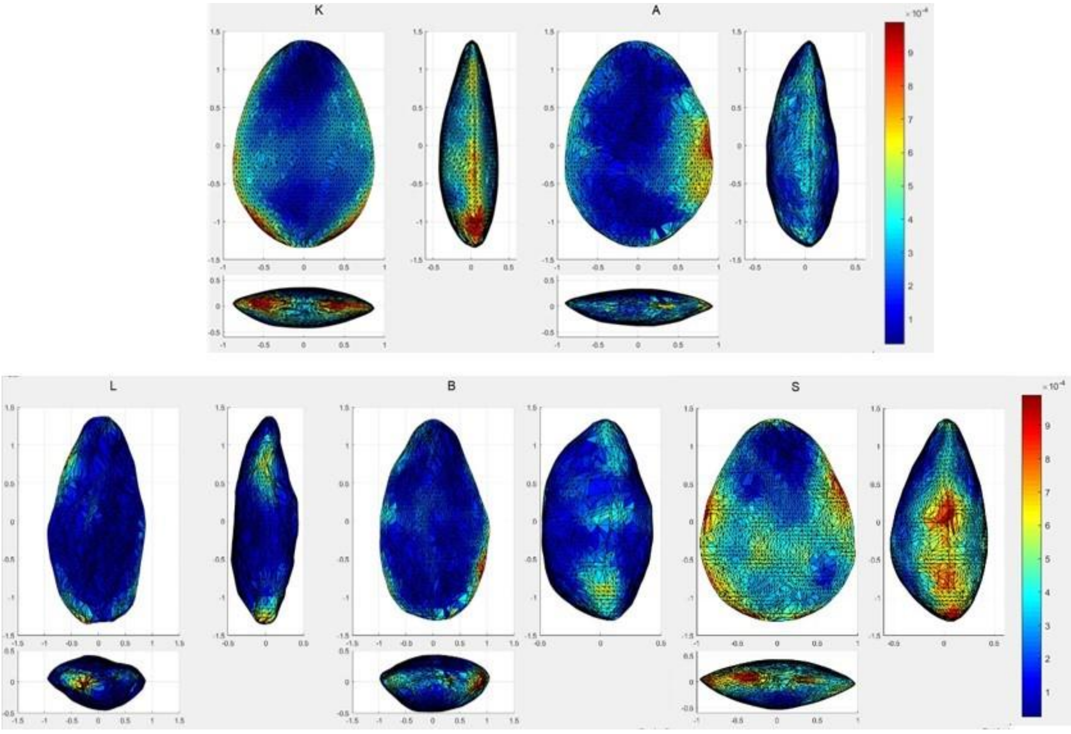


Figure 5. 105 Comparison of handaxes with rounded distal tip from Khyad (K), Attirampakkam (A), Lakhmapur (L), Benkaneri (B), Singadivakkam (S). Colour coding represents the degree and location of variability.

When the group mean shapes of round tipped handaxes from all the sites were subject to a Wilcoxon Rank- Sum Test, it found a significant difference only between Benkaneri and Singadivakkam handaxes (rank-sum=396, n1=6, n2=16, pValue=0.02).

Site name	No. of Items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Khyad	33	7.35	46.03	3.84	50.13
Attirampakkam	8	5.75	52.27	6.25	41.48
Lakhmapur	2	5.28	47.03	12.46	40.51
Benkaneri	6	6.44	33.70	3.57	62.73
Singadivakkam	16	7.57	41.99	5.87	52.14

Table 5. 77 The distribution of the variability within the handaxes with rounded tips and their causative factors.

From the Table 5.77, it can be seen that at Attirampakkam and Lakhmapur, the variability was caused by the relative width, while at other sites, relative thickness contributed significantly to the variability. At Lakhmapur, Attirampakkam, and Singadivakkam, the relative length also seems to have played a role in causing this variability.

5.11.3.3 Transverse distal tip

Handaxes with a transverse tip were noticed in the assemblages from all sites.

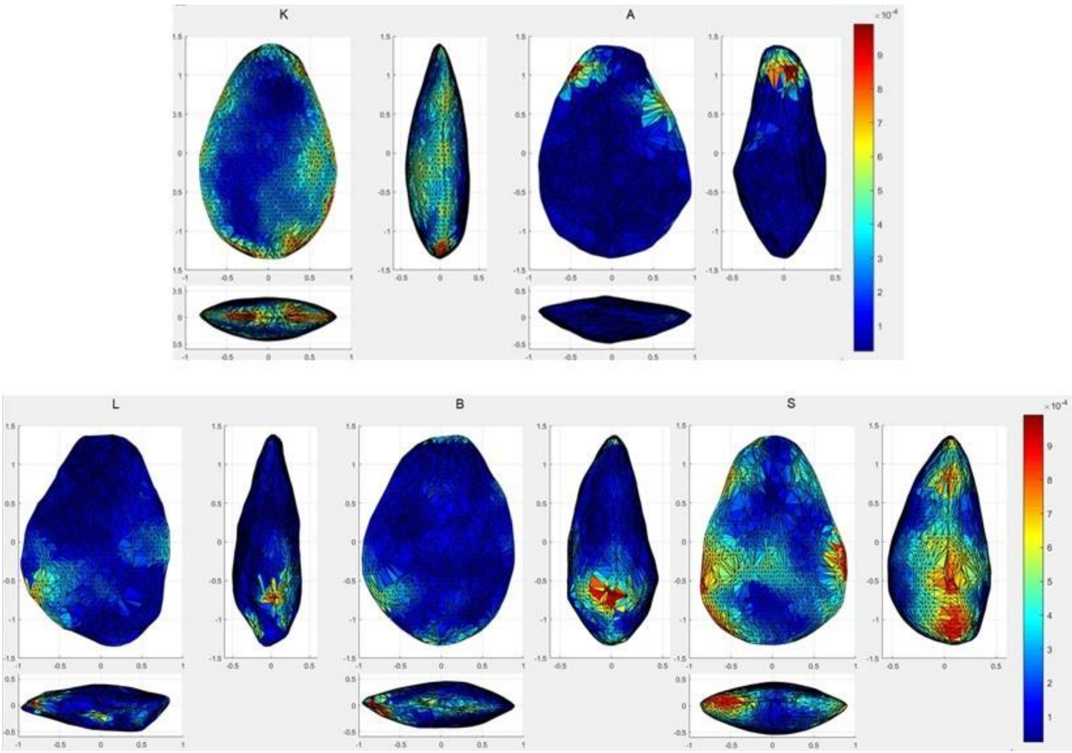


Figure 5. 106 Comparison of the mean shapes of handaxes with transverse distal tip from Khyad (K), Attirampakkam (A), Lakhmapur (L), Benkaneri (B), and Singadivakkam (S). Colour coding represents the degree and location of variability.

From the mean shapes (Figure 5.106) we see that Khyad and Attirampakkam handaxes with the transverse edge varied in the intensity and location of the variability. The handaxes from Khyad had the variability dispersed along the periphery of the tool while at Attirampakkam, the variability was limited to the upper part of the handaxes, at the lateral edges. Among the sites of Lakhmapur, Benkaneri, and Singadivakkam, we seem a similar trend of variability for the first two sites (limited to the lateral edges at the proximal part of the handaxe) while the third site displayed a more dispersed intense variability across the tool.

A Wilcoxon Rank-Sum Test on Inter-point Distances between the group means of handaxes with transverse edges showed significant difference at p Value<0.01 between Benkaneri (n=4) and Singadivakkam (n=7) (rank-sum=83).

Site name	No. of Items	Shape Variability within the group	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Khyad	17	6.67	41.86	2.35	55.79
Attirampakkam	2	4.21	73.62	2.83	23.55
Lakhmapur	2	4.52	36.28	1.80	61.92
Benkaneri	4	6.11	39.55	0.92	59.53
Singadivakkam	7	8.12	40.27	3.51	56.23

Table 5. 78 The distribution of variability within transverse edged handaxes and their causative factors.

From Table 5.78, we see that for the transverse-edged handaxes from Attirampakkam, relative width played an important role in this variability while for all the other sites, relative thickness seems to have been a major causative factor.

5.12 Inter-regional comparison – Cleavers

5.12.1 General features

All the cleavers from both regions were visualized in the same morpho-space to determine their similarities and dissimilarities.

A total number of 79 PCs were generated for the 80 cleavers from all the sites. The first 10 explained 76% of the variance (Table 5.79).

PC	% of variability
PC1	18.18
PC2	15.26
PC3	10.89
PC4	7.09
PC5	5.53
PC6	4.79
PC7	4.70
PC8	3.85
PC9	2.71
PC10	2.52

Table 5. 79 The first 10 PCs explaining the cleaver variability in all the sites.

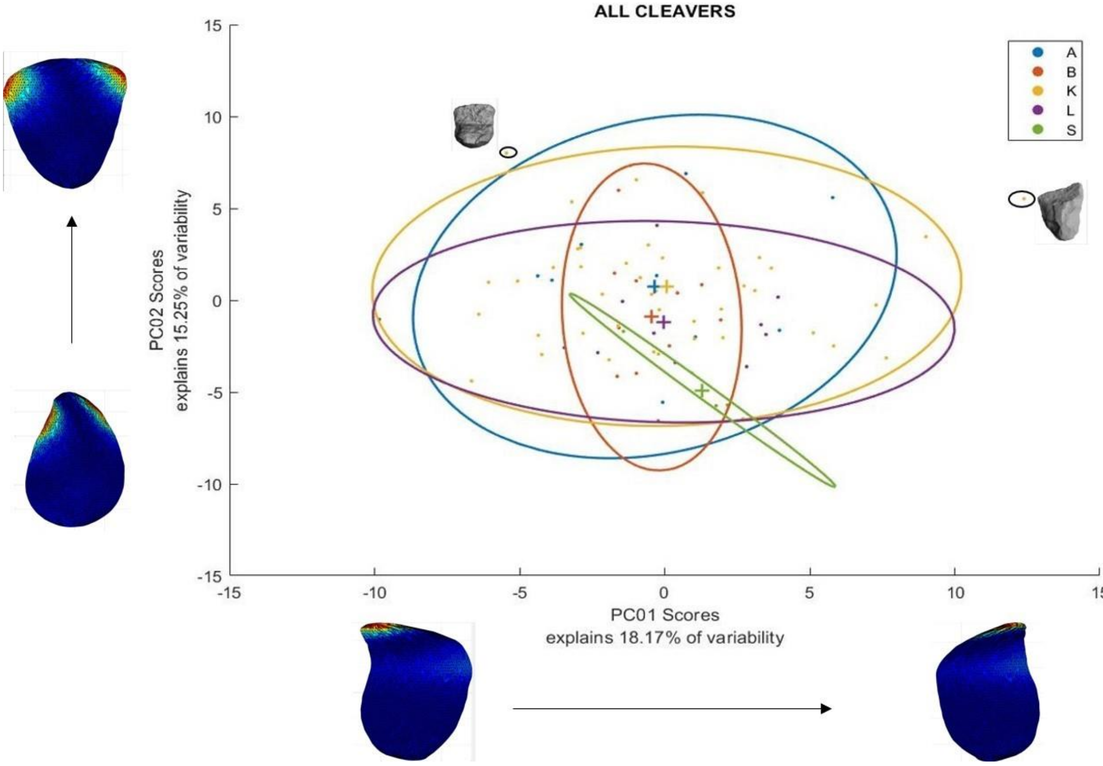


Figure 5. 107 Scatterplot of the first two principal components of all cleavers. + signs represent the mean shapes (centroids of each group). Ellipses represent 95% of confidence ellipses. All cleavers.

From the scatterplot with cleaver distribution, it is clear that all the sites had similar shaped cleavers and only Khyad had two outliers (Figure 5.107). The centroid size (mean shape) of all the sites except Singadivakkam finds closer similarities. Interestingly, both the Acheulean sites of Attirampakkam and Khyad show extreme close similarities with each other while Middle Palaeolithic Lakhmapur and Benkaneri are located closer.

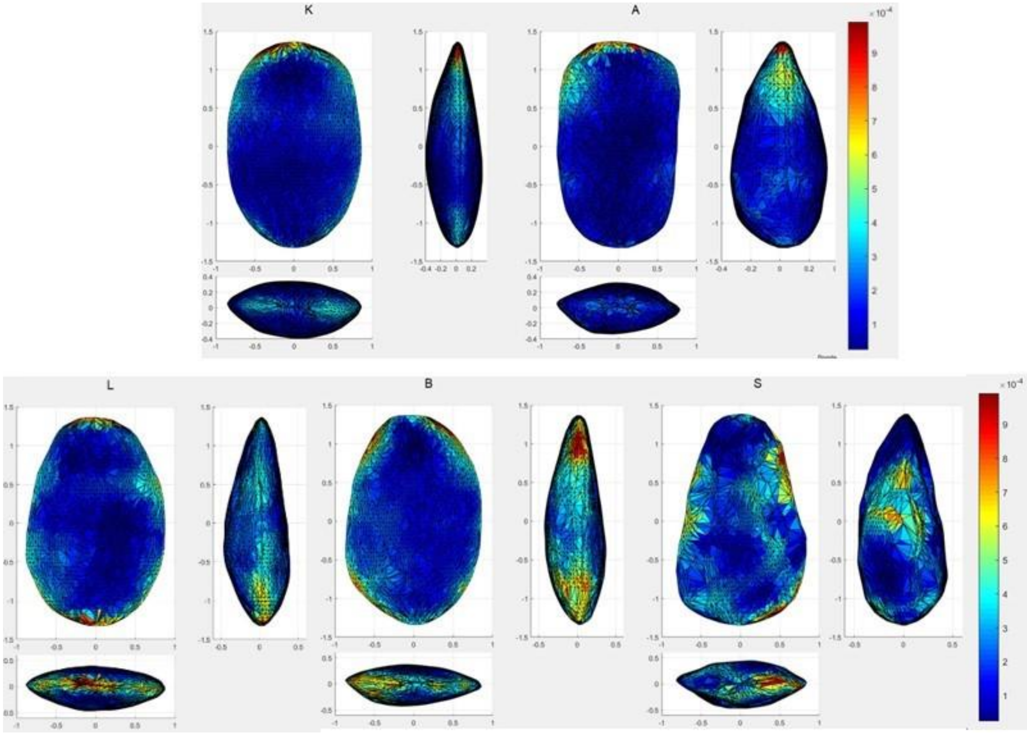


Figure 5. 108 Comparison of the mean shapes of cleavers from Khyad (K), Attirampakkam (A), Lakhmapur (L), Benkaneri (B), Singadivakkam (S). Colour coding represents the degree and location of variability.

The cleavers from Khyad and Attirampakkam exhibit little variability, with most of it located at the distal ends (Figure 5.108). Lakhmapur and Benkaneri cleavers exhibit less intense variability at the peripheral edges of the cleavers while at Singadivakkam, this is dispersed on both the edges and extends across the surface of the cleavers.

If we examine the variability within the limited number of specimens in each site, we see that all the sites expressed the same amount of variability within their cleavers irrespective of their quantity. Except for Singadivakkam, all the sites had the relative width contributing to this variability (Table 5.80).

Site name	No. of Items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Khyad	45	8.27	59.87	3.80	36.33
Attirampakkam	10	7.73	64.72	4.46	30.82
Lakhmapur	10	8.15	56.64	3.57	39.79
Benkaneri	11	7.00	50.70	3.00	46.30
Singadivakkam	4	7.39	34.53	2.24	63.23

Table 5. 80 The distribution of variability within all cleavers and their causative factors.

The Wilcoxon Rank-Sum Test on Inter-Point Distances between group means of all cleavers showed significant differences between the Khyad (n=45) and Attirampakkam (n=10) at pValue 0.04 (rank-sum=2710) and between Benkaneri (n=11) and Singadivakkam (n=4) at pValue <0.01 (rank-sum=151).

5.12.2 Blank types

As the sample size was insufficient, comparative analysis on the different groups of blanks between the sites could not be carried out for all. Only the blank types of end-struck flakes present at all sites, except for Singadivakkam, were analysed. An examination of the variability within these 5 sites shows that irrespective of the number of tools, the variability was higher in the sites of Khyad, Attirampakkam and Lakhmapur in comparison with Benkaneri (Table 5.81).

Site name	No. of Items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Khyad	15	8.44	63.99	4.87	31.15
Attirampakkam	6	7.67	67.98	5.09	26.93
Lakhmapur	6	7.82	58.92	1.57	39.51
Benkaneri	3	5.11	46.90	1.14	51.96

Table 5. 81 The distribution of variability within end-struck cleavers and their causative factors.

The Lakhmapur and the Benkaneri cleavers differ in their relative width, which seems to have a greater influence on the shape at Lakhmapur, while at Benkaneri, the relative thickness seems to be the influencing factor on shape. The use of tabular blocks is more attested in Benkaneri for the making of the cleavers and the differences in the thickness of these blocks would have impacted the shaping (which in the case of Benkaneri is orthogonal).

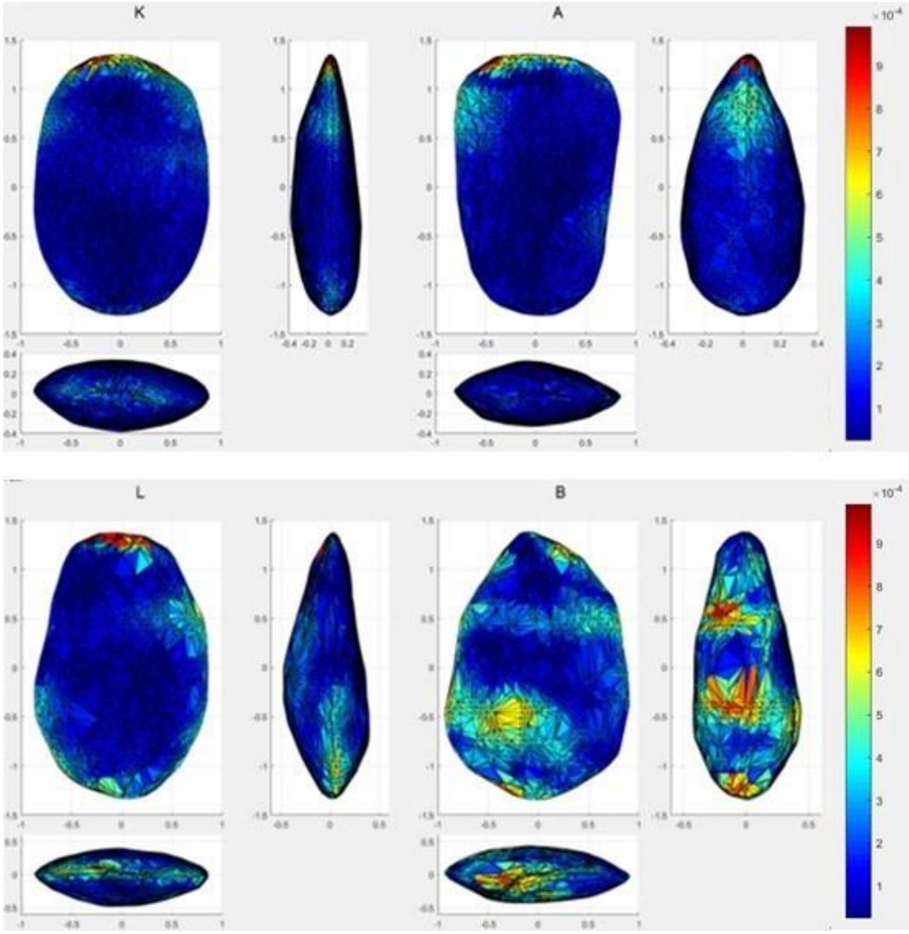


Figure 5. 109 Comparison of the mean shapes of cleavers on end-struck blanks from Khyad (K), Attirampakkam (A), Lakhmapur (L), and Benkaneri (B). Colour coding represents the degree and location of variability.

From Figure 5.109 displaying the mean shapes of the cleavers on end-struck blanks, it can be inferred that while Benkaneri cleavers had more variability distributed across the tool surface and the lateral edges, the variability among the cleavers from Lakhmapur show this limited to the distal edge and marginal areas of the lateral and proximal edges. The least variability is observed on the cleavers from Attirampakkam and Khyad, the former showing more straight-edged cleavers on an average. The cleavers from Khyad, on the other hand show similar location of the variability to that of the Attirampakkam. The cleavers from both these sites seem to differ on their X dimension. While Lakhmapur, Benkaneri and Khyad might indicate an expedient technology, Attirampakkam hominins seems to have taken care to extract the flakes of suitable dimensions. The cleavers from this site are longer and narrower than the Khyad cleavers, which are thick, wide, and shorter.

5.12.3 Distal Morphology

5.12.3.1 Convex distal tip

Khyad and Benkaneri had more variability among the convex distal edged cleavers than the rest (Table 94 and Figure 5.110).

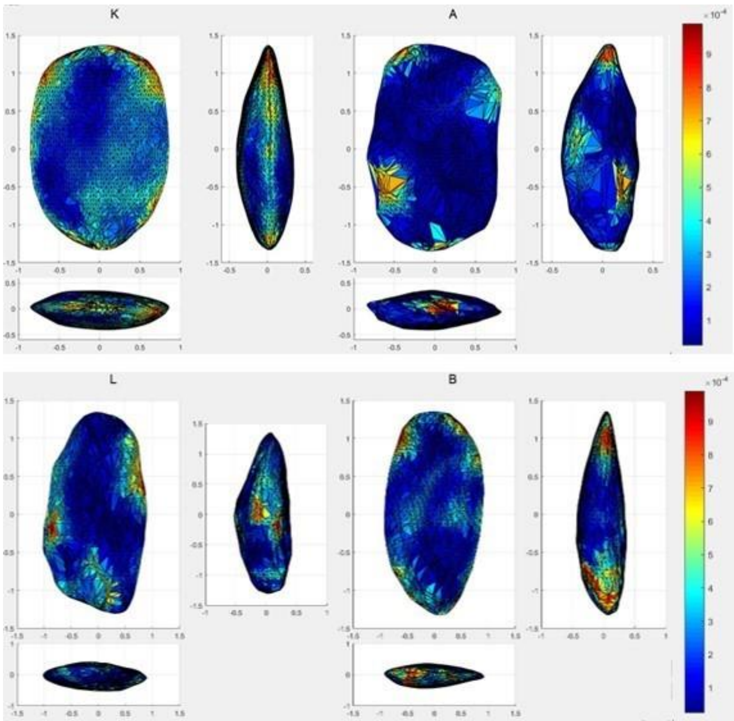


Figure 5. 110 Comparison of mean shape differences of cleavers with convex distal edges-Khyad (K), Attirampakkam (A), Lakhmapur (L), and Benkaneri (B). Colour coding represents the degree and location of variability

The Khyad cleavers with convex distal ends were more influenced by the relative thickness, while for the Attirampakkam cleavers, it was the relative width that resulted in this variability (Table 5.82). At this site, the relative length also seems to have a marginal effect on the distal morphology.

Site name	No. of Items	Shape Variability within the groups	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Khyad	14	7.01	46.48	3.24	50.28
Attirampakkam	2	5.46	60.43	6.28	33.29
Lakhmapur	2	5.32	48.13	1.95	49.92
Benkaneri	4	6.11	43.70	6.19	50.11

Table 5. 82 The distribution of variability within convex distal edged cleavers and their causative factors.

For the convex edged cleavers at both Lakhmapur and Benkaneri, relative thickness played a more significant factor than relative width. At Benkaneri, an effect of relative length on the convex shape of the distal ends can also be noticed.

5.12.3.2 Straight distal tip

Cleavers with straight distal edge was found at all the sites. However, the Wilcoxon Rank-Sum Test on Inter-Point Distances between group means of the cleavers from all the sites showed no significant difference.

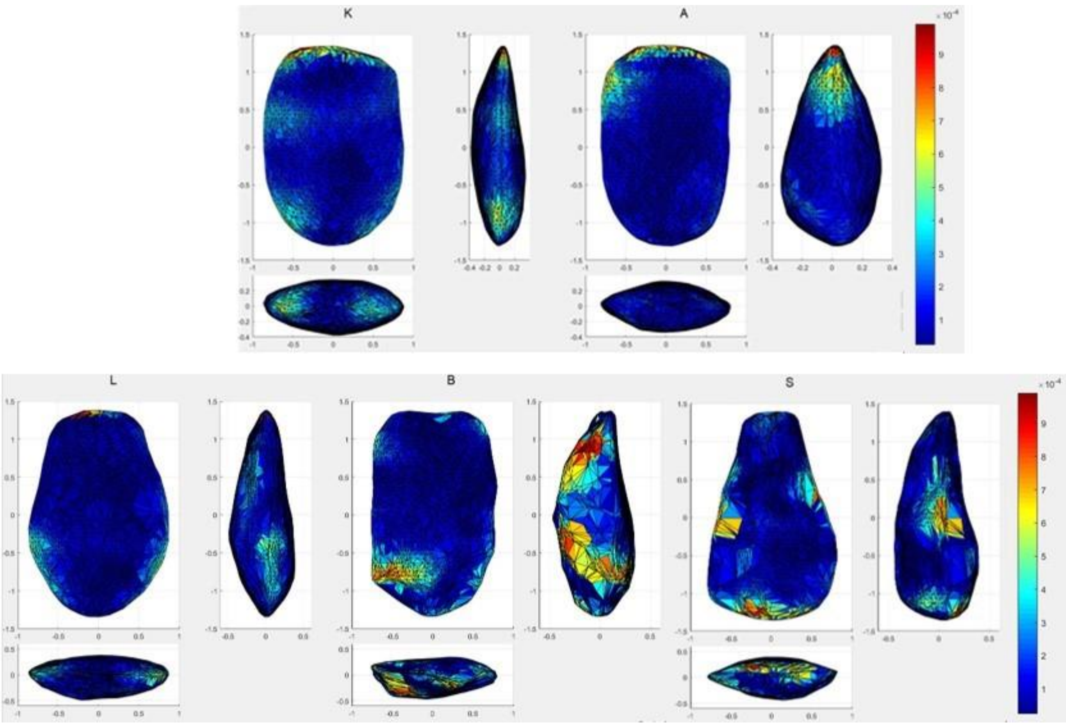


Figure 5. 111 Comparison of the mean shapes of cleavers with straight distal edges from Khyad (K), Attirampakkam (A), Lakhmapur (L), Benkaneri (B), and Singadivakkam (S). Colour coding represents the degree and location of variability.

From the mean shapes (Figure 5.111) we notice that the Khyad and Attirampakkam cleavers with straight distal edges show similar variability, located at the distal ends with Khyad also showing variability on the proximal part of the tool.

Site name	No. of Items	Shape Variability within the group	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Khyad	10	7.59	61.97	5.43	32.60
Attirampakkam	6	7.96	66.62	4.44	28.94
Lakhmapur	4	6.22	43.06	1.39	55.55
Benkaneri	2	5.45	39.62	0.79	59.59

Table 5. 83 Distribution of shape variability within the cleavers of Khyad, Attirampakkam, Lakhmapur, and Benkaneri and their causative factors.

The variability observed at Khyad and Attirampakkam seems to have stemmed from the differences arising from their relative width, whereas for the Lakhmapur and Benkaneri cleavers, relative thickness seems to have played a more important role (Table 5.83).

5.12.3.3 Diagonal distal tip

Cleavers with diagonal distal ends were noticed at all the five sites. Benkaneri showed the most variability among its group of cleavers with intense variability located at its lateral edges. Khyad along with Attirampakkam showed less variability, which was limited to the distal ends. Lakhmapur cleavers showed variability at both lateral edges and distal and proximal ends (Figure 5.112).

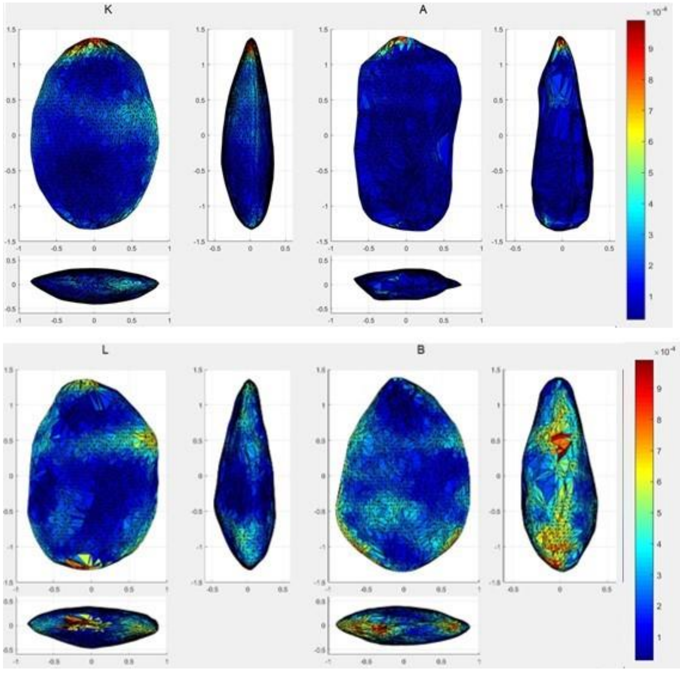


Figure 5. 112 Comparison of the mean shapes of cleavers with diagonal distal ends from Khyad (K), Attirampakkam (A), Lakhmapur (L), and Benkaneri (B). Colour coding represents the degree and location of variability.

While for the Khyad and Attirampakkam cleavers with diagonal distal ends the influencing factor remained the relative width followed by the relative thickness, for Benkaneri and Lakhmapur we see different trends (Table 5.84). For Lakhmapur cleavers, the diagonal edge was affected by the relative width in comparison with the Benkaneri cleavers, where the diagonal edge morphology was highly influenced by the relative thickness.

Site name	No. of Items	Shape Variability within the group	% caused by X (relative width)	% caused by Y (relative length)	% caused by Z (relative thickness)
Khyad	14	7.01	46.48	3.24	50.28
Attirampakkam	2	5.46	60.43	6.28	33.29
Lakhmapur	2	5.32	48.13	1.95	49.92
Benkaneri	4	6.11	43.70	6.19	50.11

Table 5. 84 The distribution of variability among cleavers with diagonal distal ends and their causative factors.

6. CHAPTER VI – DISCUSSION

6.1 Synthesis and interpretation of the results obtained from classical and GM analysis

6.1.1 Handaxes

Handaxes are more frequent than cleavers in the three sites in the Malaprabha Valley (Table 5.1, Chapter V). They represent about 60% of the LCTs in Khyad (116/196) and Benkaneri (25/40) and reach more than 75% in Lakhmapur (50/64). In the two sites of Tamil Nadu also, handaxes dominate (Table 5.19, Chapter V). The collection from Attirampakkam provides an intermediate result of 70% (45/65) while that from Singadivakkam is largely dominated by handaxes (90%, 33/37).

Benkaneri site yielded more broken specimens (Table 5.2, Chapter V), probably as a result of it being a quarry site and with presence of poorer raw material, but their freshness and low patination, like in Lakhmapur, indicated their nearly primary situation. The semi-primary nature of the Khyad assemblage, occurring along the Malaprabha River, was attested on the basis of low to medium abrasion of the tools as well as a lower frequency of patination.

Benkaneri exhibited the least variability among blank types, with Khyad having the most diverse blank types (Table 5.4, Chapter V). Increased use of flakes as blanks was attested at Lakhmapur and Benkaneri, the majority of which were end-struck. More tabular blocks were used at these sites for shaping the handaxes (similar usage of tabular blocks have been attested at the sites of Hunsgi Valley, Shipton, 2013; Patpara, Shipton et al., 2014). Slab-slicing method (Figure 5.4, Chapter V) attested at Hunsgi-Baichbal Valley could have been used for extracting the tabular blocks and the smaller sized ones, directly shaped into tool, or through debitage.

Blanks were obtained through alternate bifacial flaking and SSDA method. Use of hard hammer and soft hammer was attested through the nature of the removals, which was invasive in Benkaneri, removing almost all cortical surfaces. Khyad, like the quarry of Benkaneri, had plentiful raw material resources, but show more retention of cortex as striking platform, probably resulting from higher use of cobbles as blanks (Table 5.5, Chapter V). Unifaces occur at all the sites in the Malaprabha Valley. Almost all the handaxes had evidence of sharp cutting edges largely limited to proximal and distal ends, unlike Benkaneri, where some handaxes had a cutting edge throughout the lateral edges also (Tables 5.9 and 5.10, Chapter V). At Lakhmapur and Benkaneri, higher use of tabular blocks may have necessitated further thinning of the tool, substantiated by 1 or 2 shaping removal series on an average, unlike Khyad, where only 1 series of mostly radial/convergent removals were noticed.

Biconvex cross-sections were the norm in Benkaneri handaxes while Khyad and Lakhmapur yielded more biconvex, plano-convex specimens (Table 5.13, Chapter V). Khyad provided longer handaxes than Lakhmapur and Benkaneri, the latter two, showing a similar range of shorter length (Table 5.15). The average width is seen to be gradually decreasing from Khyad to Benkaneri and the thickness is comparable in the three sites. More elongated handaxes appeared from Khyad and more refined ones occurred in both Khyad and Benkaneri (Table 5.18, Chapter V and Article 2, Appendix II). Many step fractures at Lakhmapur, probably indicate poor quality of the raw material, similar to Benkaneri (Petraglia et al., 2003a) or the differential skills of the hominins at managing the volume of the tools. However, the mean values remained similar at all the sites for refinement (1.95-1.98), and Khyad and Benkaneri had similar mean values for elongation 1.61/1.62 (Table 5.18, Chapter V). Only at Benkaneri, a positive correlation between the elongation and refinement is noted.

The handaxes from Attirampakkam, being of mixed and uncertain contexts, do not allow a precise comparison with other sites. However, general observations point to flakes being the predominant blank in this assemblage when compared to Singadivakkam where cobbles and pebbles are quite frequent (Figure 5.22, Chapter V). Diverse types of striking platforms were recognized among the handaxes on flake at Attirampakkam, while they were predominantly cortical at Singadivakkam (Figure 5.23, Chapter V).

Convergent and three-directional shaping was the norm for both the sites with ventral face more shaped than the dorsal face. Handaxes at Attirampakkam had sharp cutting edges (< 60°) along their lateral sides, with an average of 2 series of shaping removals (Figure 5.11 A, Chapter V). This is the only site from the entire study region, to exhibit this feature, other sites rather yielding handaxes with medium angles in lateral position. The number of handaxes from Attirampakkam having biplanar cross-section indicate the knapping skills of the hominins. All the handaxes from both sites exhibited similar range of length, width, and thickness. Both the sites provided elongated handaxes but Attirampakkam assemblage included a larger number of refined handaxes and showed a positive correlation with elongation. However, these inferences are preliminary and must be approached with caution, due to the unbalanced sample sizes.

Individual idiosyncrasies, evidence of recycling at Khyad and Benkaneri and non-utilitarian "symbolic" behaviour at Benkaneri (one highly worked, symmetrical, refined, and elongated large handaxe), all point to the cognitive abilities of the hominins here (see section 5.4, Chapter V). Well aware of the raw material constraints (e.g., Benkaneri), they adapted using flexible technologies to result in similar shaped handaxes across sites. Using the tabular blocks to shape handaxes directly they minimized their efforts at producing cutting edges, taking advantage of the morphology of these blanks. Variability among the handaxe assemblage reduces considerably and most of the shapes continue throughout the Lower and Middle Palaeolithic, indicating a rigid mental template or absence of stimuli for technological changes. Also noticed is the progressive reduction in the size and quantity in later periods.

In Tamil Nadu, Attirampakkam handaxes are more standardized when compared to those from the sites of Malaprabha Valley. In comparison to others, Attirampakkam had a refinement index of 2.07 which showed a positive correlation with elongation (Table 5.35, Chapter V). Singadivakkam handaxes show a unique preference of pebbles and cobbles as main blanks besides flakes.

The techno-typological analysis of the handaxes from the Malaprabha Valley show continuity of similar shapes (ovates, elongated ovates, cordiform, subtriangular, almond shaped etc.), use of similar raw material, reduction sequences and shaping patterns.

In order to understand the shape variability of the handaxes in a precise, accurate, reproducible manner, an outline shape analysis through 2D-Geometric Morphometric method was undertaken. The results (see section 5.5, Chapter V) show that the first two PCs captured more than half the variability in the case of Khyad, Benkaneri and Attirampakkam, explained by the relative length (PC1) and symmetry (PC2). Khyad had 17 outliers while Lakhmapur had 4 (Figure 5.23, Chapter V) and Attirampakkam had 1 (Figure 5.24, Chapter V). Among all the sites from the Malaprabha Valley, Khyad (more specimens and diverse blanks) clearly stood out. Clear distinctive groups, formed by ovate forms on one hand, and irregular and regular forms (cordiform, triangular, sub-triangular and elongated ovate) on the other characterised the tools from this site.

"Assemblages are characterised by a modal shape around which there is typically substantial variability and a gradual or continuous transition from one form to another (McPherron, 2003:56)".

The existence of these two groups, probably reflect the different modal shapes (probably exhibiting cultural/functional choices, differential skills, differential occupation of the site) present at the site. The distribution of the 2D shapes in the morpho-space, indicate that shape differences could have resulted from the size of the blanks and not the shapes of the blanks as morphological overlaps are observed through all blank types at all sites from this valley (Figure 5.23, Chapter V). While Khyad handaxe forms appear to continue into Lakhmapur, the handaxes from the latter site are noticed overlapping with almost all the Benkaneri handaxes. The use of tabular blocks as blanks has been attested in all the three sites, with more from Benkaneri and Lakhmapur. Irrespective of the blank type morphology, the hominins in Malaprabha Valley were able to obtain similar shapes of handaxes through differential shaping patterns and intensity. The size and weight of the blanks could have played an important role in the resulting lesser variability as shorter blanks appear to be more rounded and *vice versa*. However, this aspect is beyond the scope of this study.

When compared with the handaxes from Tamil Nadu, a clear distinction between handaxes from Attirampakkam and the rest is visible (Figure 5.27, Chapter V). As the context of these collections are mixed and uncertain (Chapter III), no substantial conclusions can be made.

Singadivakkam handaxes, mainly shaped on cobbles and pebbles and flakes struck from them, also overlapping with some shapes from Attirampakkam, are mostly found differently clustered when compared to the Malaprabha Valley handaxes. Here, the shaping was more rudimentary in most cases and probably reflect an opportunistic behaviour.

When the results of the 3D GM are considered, only Benkaneri and Attirampakkam show more than half the variability covered by the first two PCs. The shape variability within the samples considered was lesser among the Attirampakkam and Khyad assemblages (Table 5.66, Chapter V). Among the blank types, the mean shape differences were found to be significantly different between cobbles, pebbles and entames in relation to other blank types like tabular blocks and flakes. This is reflected in Khyad, Attirampakkam and Singadivakkam (see section 5.9, Chapter V). The cobble shapes from both these sites vary–-Khyad showed a preference for sub-angular and angular cobbles (Koshy, 2009)–-while Attirampakkam cobbles were elongated (Pappu and Akhilesh, 2011). This is corroborated by the intensive and invasive shaping for the handaxes from Attirampakkam, whereas, at Khyad, minimal shaping was followed to achieve the desired cutting edge. Cobbles at Singadivakkam were long, and invasively shaped while pebbles were minimally shaped and were shorter and wider. Handaxes on entames from Khyad were unifacially shaped and relative thickness seems to have played an important role in the variability on these types of blanks. For Lakhmapur handaxes on side-struck flakes and cobble handaxes from Singadivakkam also, relative thickness was an important factor. For Lakhmapur, this could be due to their removal from thick tabular blocks and the poor quality of the raw material (Petraglia et al., 2003a) obstructing further thinning and shaping the tool. Singadivakkam included split forms of cobbles of varying thickness utilized for shaping handaxes. For the rest of the blanks from all sites, relative width was the main causative factor of variability.

When the distal tip morphologies are compared, the shape differences between all the types are significant from Khyad, Benkaneri and Attirampakkam with relative width being the main cause of variability (see section 5.9, Chapter V). The transverse-edged handaxes from Lakhmapur, and the rounded handaxes from Singadivakkam, seemed to have been influenced by the relative thickness of the blanks (indicated by use of tabular blocks in the former and cobbles and split cobbles in the latter). When both regions are considered together, rounded handaxes showed more variability than pointed or transverse edges and this variability seems to be highly influenced by relative thickness of the tool (Table 5.76, Chapter V). Round tipped handaxe variability was also linked to the relative length, unlike the other types.

Overall, the distribution and intensity of the handaxe shape variability among all the sites, as shown by the coloured graphic representations, seem to reflect similar patterns. Proximal and lateral edges were mainly variable, indicating the influence of shaping strategies involving removal of striking platform and thinning of the butt for the proximal ends and shaping into elongated and symmetrical outlines for the lateral edges. The retouching of the lateral edges as seen in the series of removals and the cutting-edge angles for many tools also could have resulted in this distribution of the variability. The surface of the handaxes remained less variable, and this is attested also by the less invasive, deep, shallow removals.

6.1.2 Cleavers

The proportion of cleavers to handaxes reduces at the site of Lakhmapur (22%) compared to Khyad (41%) and Benkaneri (38%). The higher proportion of cleavers at Khyad has been earlier attributed to functional needs (Joshi, 1955) and the availability of abundant raw material resources would have led to lesser curation. However, interestingly, many composite cleavers appear from here, with more than one cutting edge and with evidence of resharpening (Figure 10, Appendix III). Also, a specimen of a cleaver recycled into handaxe is to be noted at Khyad.

Highly patinated specimens only occur at Lakhmapur (probably as a result of the matrix of iron rich sediments). In both Lakhmapur and Benkaneri, the cleavers are more patinated than the handaxes, which seems difficult to explain. A mixed pattern of patinated and unpatinated cleavers emerges from Khyad, reflecting its surface collection bias.

While the raw materials remained the same, i.e., local quartzite, texturally the fine-grained varieties were preferred, followed by a lesser amount of medium grained rocks at Khyad and Benkaneri (Table 5.3, Chapter V). At Lakhmapur, only the fine-grained varieties have been noted. This could be because the tools were brought into the site in semi-prepared stage, unlike the other two factory sites (Petraglia et al., 2003).

Flakes are the preferred blanks for cleavers, mainly end-struck flakes and secondarily side-struck except at Khyad where both are nearly equal (struck at an angle, n=8 out of 28 side-struck cleavers). Like the handaxes, cleavers at Khyad were also made on a wide range of blank types, from cobbles, entames, tabular blocks as well as end-struck and side-struck flakes. Entames were used as cleaver blanks only at this site, probably due to the abundance of colluvial cobbles. Due to the heavy patination, some difficulties were encountered in differentiating between entames and patinated flakes. However, unusual Kombewa flakes only appear at Benkaneri and Lakhmapur as cleaver blanks. As Kombewa method is considered to represent the highest degree of predetermination in Acheulean context (Texier and Roche, 1995), it matches the increase in prepared core methods at these latter sites, and probably reflects the technical and cognitive skills of the tool makers. Tabular blocks were among the main blanks in Benkaneri, even for cleavers (explained by the readily available weathered clasts and the quarry nature of the site), while they are less common at Lakhmapur and even rarer at Khyad.

While shaping on tabular blocks seem to be more plausible for handaxes, debitage could have been preferred for the cleavers, as evidenced from Hunsgi-Baichbal Valley sites (Shipton, 2013). As mentioned above, Kombewa flaking is only observed at Benkaneri and Lakhmapur.

Plain striking platforms have been observed for most of the cleavers from all the sites, while cortical ones only appear from Khyad, resulting from use of cobble blanks. A large number of specimens remained indeterminate in this regard from both Lakhmapur and Benkaneri, arising from removal of the platform due to thinning the butt and invasive shaping removals. Dihedral platforms were only noticed for single specimens at Khyad and

Lakhmapur. The reduction sequence remained the same for Lakhmapur and Benkaneri, from flakes on sub-angular, tabular, or angular blocks, while at Khyad, reduction from cobbles was also noted (Figure 18, Appendix III).

Three-directional removal pattern was the norm for the cleavers which would result in the cutting edge on the distal ends, already present on the blank, before subsequent shaping. Orthogonal, bidirectional, and unidirectional removals were also present in some cleavers from all the sites. Only Khyad cleavers exhibited unipolar longitudinal removals. The lateral and proximal parts seem to be shaped invasively sometimes and in one case, even a pointed tip was made (Figure 11 D, Appendix III), maybe to facilitate hafting or for better prehension. Use of both hard and soft hammers can be deduced from deep and bold or shallow scars. On an average these removals were up to one series only.

Compared to handaxes, the presence of cortex on cleavers was minimal, reflecting the intensity and invasiveness of the shaping patterns and use of flakes rather than other blanks. This feature also could represent the volumetric (weight) management, however, with the presence of cutting edges and composite nature of specimens from Khyad, this seems more unlikely. Composite cleavers from Khyad with more than one cutting edge, indicate their multifunctional use as well as resharpening as an opportunistic behaviour. This type of shaping might have been performed right from the first time of tool making or at a later stage by transformation through retouching, possibly at different moments. Aspects of recycling is also observed through an example of a highly rolled cleaver transformed into a handaxe, at Khyad.

The multiple cutting edges are also attested by the presence of cutting angles (<60°) at both proximal and lateral right edges for cleavers at all sites and at lateral left edges also for Khyad (Tables 5.9, 5.10 and 5.12, Chapter V). Steep angles (80°-110°) for the distal edges were noticed at Benkaneri, probably reflecting the use of tabular block flakes as blanks with varying thickness or to lesser thinning due to the poor raw material properties (Petraglia et al., 2003).

Plano-convex cross-sections were observed for majority of the cleavers followed by biconvex and a few biplanar, at all sites.

Symmetrical or roughly symmetrical cleavers were mostly noted from Khyad and Lakhmapur while the Benkaneri cleavers were mostly asymmetrical.

Regarding the linear dimensions, all the sites displayed both short and long (>10cm), wide (>4cm) and between 20 mm-70 mm thickness of the tools (Tables 5.15-5.17, Chapter V).

In the studied assemblages from Tamil Nadu, the preservation of the tools was better than in Malaprabha Valley. Only one cleaver was broken in the collection from Attirampakkam despite it being from surface while all the cleavers from Singadivakkam, also surface collected, remain complete. Patinated and highly abraded specimens only occur in the Attirampakkam assemblage, while all the cleavers from Singadivakkam appear to be fresh and unpatinated.

Fine-grained quartzite was the preferred raw material, obtained from the quartzitic conglomerates in the nearby Allikulli and Satyavedu Hills at Attirampakkam (Pappu et al., 2011) and the quartzite cobbles and pebbles from the local gravel deposits at Singadivakkam. (Chapter II). While the Attirampakkam assemblage displays use of flake blanks (end-struck being predominant), cobbles, split cobbles and entames, only single specimens of end-struck and entame cleavers besides 2 cobble cleavers appear in the Singadivakkam assemblage. Plain and dihedral striking platforms were identified from Attirampakkam, with a large number remaining indeterminate due to thinning of butt and invasive removals (Table 5.23, Chapter V). Only single examples of cortical platform exist from both sites. Simple bifacial flaking can be deduced at both sites.

Three-directional shaping pattern is the predominant one, followed by convergent and bidirectional at Attirampakkam while at Singadivakkam a mixed usage of convergent, three-directional, bidirectional, and unidirectional flaking is discerned (Tables 5.24 and 5.25, Chapter V). On an average Attirampakkam shows more removals (8 on dorsal and 10 on ventral) while for Singadivakkam, there were 4 removals on an average for both faces. At both sites invasive removals were observed more on the ventral than the dorsal face. The presence of cortex remained the same for both sites.

Cleavers from Singadivakkam had only medium and steep angles in lateral and proximal positions while at Attirampakkam all the angle types were observed (Tables 5.27, 5.28 and 5.30, Chapter V). Singadivakkam had only cutting and oblique angles for the distal edge while the cleavers from Attirampakkam had cutting, oblique as well as steep angles for this part of the tool. The use of different sized blanks or specific shaping strategies (use of entames with unmodified cortical surface) could explain this feature at Attirampakkam. Biconvex, biplanar and plano-convex cross-sections are observed for the cleavers at Attirampakkam while only biconvex is observed at Singadivakkam.

Attirampakkam cleavers displayed a lower range of length variations in relation to width and thickness while Singadivakkam showed a higher range of length variations in comparison to the other metrical measurements. Elongated and refined cleavers were only represented among the Attirampakkam specimens (Table 5.35, Chapter V).

The 2D outline GM analysis of the cleavers from Malaprabha Valley showed that like the handaxes, the PC variability was higher in all the sites when compared to the 3D GM results. Khyad cleaver distribution across morpho-space displayed two identifiable clusters along with many dispersed shapes as well as 5 outliers. The outliers included composite and ultra-pointed tips. Benkaneri cleavers displayed a similar wider distribution with one symmetrical specimen on an elongated flake standing apart, However, no outliers were observed.

The 2D outline GM shape analysis of all the cleavers from Malaprabha Valley and Tamil Nadu showed interesting distribution patterns. The Acheulean sites of Attirampakkam and Khyad did not show much similarities and the only outliers come from these two sites (Figure 5.36, Chapter V). The majority of the outliers were in Khyad cleaver assemblage similar to the handaxe distribution. Composite cleavers are only noted from this site. A continuity of shapes is displayed by the overlapping forms in the single morpho-space.

Two separate groups of cleavers are represented from this site in the morpho-space. One dispersed group skewed negatively and another clustered group with other Malaprabha Valley and Singadivakkam sites, skewed positively (Figure 5.36, Chapter V). The negatively skewed group included flake cleavers that were side-struck (some at an angle), shorter and symmetrical square butted straight-edged tools along with convex to diagonal pointed distal-ended cleavers with V shaped proximal end. The positively skewed cleavers from the site of Singadivakkam showed similarities to those from other Malaprabha Valley sites – having diagonal, convex and straight edged cleavers with U and V and angled butts. This group had cleavers made on flakes as well as on entames and cobbles. These two separate groups of cleavers from Khyad probably are a reflection of two different modal shapes (for different functions?) or two different groups of hominins or differential skill levels of the tool makers.

Attirampakkam cleavers are mostly skewed on the negative axis of both PC1 and PC2, except for one positively skewed (PC1) specimen with short and straight cleaver edge. The cleavers from this site were mostly elongated and refined with bilateral symmetry.

Both Lakhmapur and Benkaneri cleavers showed a more dispersed distribution, when taken individually, with the cleavers from Lakhmapur showing a clear distinction from the two cleaver blanks (Figure 5.30, Chapter V). This difference probably reflects their unfinished shaping at different stages of production. At Benkaneri, only one specimen was widely separated from the others, on the far right on the PC1 axis. This was an elongated and symmetrical flake cleaver.

It is interesting to note that cleavers from Lakhmapur (Late Acheulean and Middle Palaeolithic) and Benkaneri (Middle Palaeolithic) formed a cluster with those from Singadivakkam (Middle Palaeolithic) overlapping the ones from Khyad (Late Acheulean). They were made on diverse blanks but predominantly on flake blanks. This suggests that many shapes continued through time and space, probably reflecting cultural traditions ("mental templates") or technological and functional (e.g., hafting requirements resulting in similarities at the proximal end) constrains.

Considering the volumetric aspect of the cleavers, in the 3D GM analysis, we can observe many trends. Shapes that are displayed on blanks of flakes are also represented on other blank types of cobbles and tabular blocks (see section 5.10.4, Chapter V). This reflects a more rigid shape form for this type of tools than the handaxes, probably because the distal end, being the *raison d'être*, does not change as it cannot be retouched at a later stage. Cleavers on Kombewa flakes appear to be distinct from the rest of the flake shapes. Entame also is widely dispersed. Cleavers on tabular blocks, indeterminate blanks, and cobbles seem to have more similarities in their mean shape than entame and Kombewa flake cleavers. The only one outlier from all the sites comes from Khyad (Figure 5.71 and 5.86, Chapter V) and is a thick-butted, minimally shaped (only on dorsal), symmetrical, short, and square cleaver. Lakhmapur had one outlier but it was subsumed within the Kombewa flake cleaver shape ellipse.

Lesser variability among the flake cleavers, including Kombewa flaked ones, probably represent the application of a strict form template, also arising out from the preplanned flake extraction strategies than other blanks like cobbles.

Significant differences between the mean shapes of cleavers on cobbles, Kombewa flakes, other flakes, tabular blocks, and the indeterminate blanks were noticed (Figure 5.109, Chapter V). While the cobble and entame variability distribution showed similar trends, the end-struck and the Kombewa cleavers showed the least variability among the blank types. For the cleavers on end-struck flakes, this could be because the dimensions of the end-struck flakes could have been controlled in its extraction which necessitated in lesser thinning and shaping with an already sharp edge, easily convertible into a cutting edge. For the Kombewa cleavers, the particular strategies for extracting this type of flakes would have resulted in minimal post investment related to shaping. All this point to the capacity of these hominins to plan and apply expedient strategies. The tabular blocks were another blank type which was probably preferred due to the wide surface, and the breakage patterns which would give sharp edges with minimal effort. These cleavers showed maximum variability in their proximal end, resulting from thinning the bulb. Indeterminate blanks showed a higher intensity and distribution (almost covering the upper surface of the cleavers) which could indicate clasts of varying thickness.

Cobbles and entames on the other hand, require massive thinning through *façonnage* and the side-struck flakes would have to be shaped at the distal ends to achieve wider cutting edges.

When the distal tip morphologies are taken into account, we find that the straight-edged and convex-edged cleaver mean shapes are nearer than the straight-edged or convergent types. Only Khyad has outliers, one from its own assemblage (Figure 5.71, Chapter V), and another from all the rest of the sites. As is expected, the distribution of the variability among the mean shapes displays the concentration of variability at the distal ends. Besides, only the convex-edged and convergent types had variability extending to the surface, although in the majority of types, the surface remains standardized.

The Tamil Nadu group of cleavers having lesser number of cleavers (n=10) from Attirampakkam and only 4 from Singadivakkam were analysed separately first. The inter-site comparison was not done (unlike for the 2D GM) due to the mixed and unknown contexts as well as insufficient number of 3D specimens. However, individual site results are summarised below.

Attirampakkam cleaver distribution in morpho-space showed the mean shapes of cleavers on end-struck flakes and cobbles widely separated from each other (Figure 5.90, Chapter V). The comparison of these two mean shapes, displays intensity of variability at the distal end for the end-struck cleavers and for the cleavers widely dispersed along the periphery and proximal angle. Some end-struck cleavers were seen with retouched distal edges, with longitudinal removals to create the cutting edge. However, all shapes were broadly within the end-struck cleaver shape ellipses. Entame and side-struck cleavers were poorly represented by this site (Table 5.22, Chapter V).

When the distal edges of all the cleavers from this site was considered, all the cleaver shapes were found to be within the straight edged cleaver shape ellipses. However, the mean shapes differed, as can be inferred from their widely separated locations in the morpho-space (Figure 5.92, Chapter V). While the convex-edged cleavers showed variability located at distal lateral ends and proximal part, the straight-edged cleavers showed variability limited to the distal edges, with the rest of the surface of the tool remaining standardised. This is expected, as to achieve a straight edge, modifications have to be made at this part. Diagonal-edged cleavers exhibit similar tendencies at only the tip. The convex-edged cleavers show that length played a minor factor in the resultant variability (Table 5.64, Chapter V).

Singadivakkam cleavers were on end-struck flakes, cobbles and entames and with convex, straight, and diagonal edges. The straight-edged cleavers had a shorter cutting edge when compared to regular cleavers. All the specimens were widely distributed in the morpho-space, resulting from the blank type and distal edge morphologies. However, this cannot be considered conclusive on the basis of only 4 cleavers.

Experimental tests undertaken with the aim to examine the variability on all the specimens (insufficient number of tools prevented inclusion of all types for statistical analysis), showed a very standardized location and intensity of variability among all the different blank types and distal edge morphologies for all the sites. This suggests that despite the differences, the variability in the shape of the tools could result more from reduction strategies and size of the blanks. The latter seems a more feasible explanation as similar reduction and shaping strategies are observed from all the sites. However, this aspect was not explored in this study and would require future inclusions of cores, flakes, and clast studies.

All the cleavers when compared in a single morpho-space show 33% variability covered by PC1 and 2 (Figure 5.79, Chapter V). All the cleaver types are represented within the Khyad ellipse, probably because of the presence of a wide range of blank types and the higher number of tools. The two outliers also come from this site. Mean shapes (represented by centroids) distribution show that almost all the sites are located near to each other, except for Singadivakkam which is located far from them. This could be explained by the extensive use of cobble blanks for the cleavers here and the atypical shapes and shorter cutting edges. This site, assigned to a Middle Palaeolithic period, yielded a large number of cobble tools (associated with Middle Palaeolithic period, in the sub-continent, Chapter I). The presence of many unifacial and bifacial choppers at this site could have served the functions of a cleaver and the decrease in LCTs in Middle Palaeolithic assemblages is attested elsewhere. Also, different subsistence strategies could possibly result in the lesser number of cleavers when compared to the handaxes from here. Poor differential skills could also have been an important factor.

PC1 reflects differences in the direction of the distal skewness of the tools and PC2 describes a shape trend ranging from pointed to broad distal ends as can be observed from the warped images along these two axes.

Unlike the 2D GM outline shape analysis, it is interesting to note that culturally similar (largely attributed on techno-typological factors) sites of Khyad and Attirampakkam being Acheulean show more similarities (Figure 5.107, Chapter V). It is also noted that Lakhmapur and Benkaneri with Middle Palaeolithic assemblages are located closer to each other. However, significant differences between the Acheulean sites and between Benkaneri and Singadivakkam were observed through the Wilcoxon Rank- Sum Test results. While Khyad and Attirampakkam had variability located at the distal ends, the other sites show a peripheral distribution of variability. One aspect, the size of the blanks could probably result in this variation. However, it remains out of the scope of this work.

While relative width was an important factor that contributed to the resulting variability at all the sites, only Singadivakkam displayed an opposite trend (Table 5.80, Chapter V). At this site, the variability (although only 4 tools are studied), is largely caused by the relative thickness.

An analysis was carried on the similar blank types and distal morphologies from all the sites to discern if they resulted in similar shapes.

For the cleavers on end-struck flakes on all sites except for Singadivakkam, similar variability with relative width being the most influential factor was noticed. Only at Benkaneri, relative thickness seems to have played a role. This aspect is corroborated by the fact that this quarry site had readily available weathered tabular blocks of quartzite with varying thickness. Shaping strategies (orthogonal removals) also is attested. Attirampakkam cleavers clearly stand out with longer and narrower specimens, indicating a prepared strategy rather than the expedient technology evidenced at other sites.

When the distal edge morphologies are compared, among the convex-edged cleavers from Khyad, Attirampakkam, Lakhmapur and Benkaneri, the variability remained more or less similar at Khyad and Benkaneri on the one hand and Attirampakkam and Lakhmapur on the other (Table 5.82, Chapter V). Interestingly, only Attirampakkam and Benkaneri cleavers show an influence of relative length. Relative thickness played an important role in the resulting cleavers with convex edges at Khyad, Lakhmapur and Benkaneri. The use of tabular blocks and cobbles would have necessitated the thinning of the distal edge. Diagonal-edged cleavers are noticed from all the Malaprabha Valley sites and Attirampakkam, with most variability among the Khyad specimens, probably owing to the larger number of specimens from this site. Except for Attirampakkam, all the other assemblages show an influence of relative thickness. At this site and Benkaneri, the relative length of the tools also seems to have played a role in shaping the diagonal-edged cleavers (Table 5.82, Chapter V). Straight-edged cleavers occur in all the assemblages, with the variability within them occurring as a result of relative width at the sites of Khyad and Attirampakkam. For Lakhmapur and Benkaneri, relative thickness played an important role in the variability, as attested by use of tabular blocks.

6.1.3 Picks

All the sites from Malaprabha Valley and Singadivakkam had examples of picks. Dihedral and Trihedral varieties were represented at all sites. Both the regions had picks with similar width but larger picks were only observed at Malaprabha sites. Singadivakkam had the thickest picks.

6.2 Implications on the research hypothesis

The first of the two main hypotheses set forward in the objectives was:

> *The technological and morphological traits of the LCTs reflect a gradual regional continuity from the Lower to the Middle Palaeolithic rather than an abrupt external introduction of new elements.*

An assessment of the results from the Malaprabha Valley sites shows that there is substantial evidence to suggest that the first hypothesis stands true.

The arguments for this, as indicated by the results are summarized and discussed below:

1. The hominins in Malaprabha Valley show a continuous preference for fine grained quartzite (Kaladgi outcrops) for making the LCTs, which they exploited from their vicinity. The clasts were available in the exposed bed rock and colluvial deposits. Present in tabular, angular, sub-angular, rounded blocks, and cobbles, they were shaped into tools directly or on flakes detached from them. Although the raw material at Benkaneri and Lakhmapur were not good for flaking (Petraglia et al., 2003b) as attested by a number of step fractures on some tools), the hominins were flexible to adapt to their situation and were able to master the production of their tools. Middle Palaeolithic in the Indian sub-continent is largely characterized by a shift to siliceous fine-grained and even microcrystalline raw materials like chert, jasper, chalcedony, etc. (Haslam, et al., 2011). The continuity of the use of quartzite as the preferred raw material throughout the Lower and Middle Palaeolithic is a

significant feature here. Even at Khyad, only two handaxes were on quartz (Figure 5.2, Chapter V). Although one LCT on dolerite has been reported (Koshy, 2009), the present study did not come across this specimen.

2. Similar reduction sequences (Figure 18, Appendix III) can be observed throughout the Palaeolithic period, mainly from the cobbles and tabular blocks, indicating a cultural and technological continuity. Simple alternate bifacial and unifacial knapping and SSDA methods of flaking, with hard hammer and soft hammer, are observed from both Acheulean and Middle Palaeolithic contexts. However, tools are more intensively and invasively shaped in the Middle Palaeolithic sites, as shown by the almost non-cortical tools from Benkaneri and Lakhmapur. The number of indeterminate blanks also increase at these sites, due to the obliteration of the original blank morphology through shaping.

3. A large number of diminutive handaxes and cleavers is observed at Lakhmapur and Benkaneri (Figure 6.1). The size of the handaxes especially seems to decrease from Lakhmapur to Benkaneri. This is especially of significance as Lakhmapur has been identified as a transitional industry with presence of Acheulean (Lakhmapur West), along with a few prepared cores (Petraglia et al., 2003) and Middle Palaeolithic (at two different localities, Lakhmapur West and East). Benkaneri, on the other hand, represents a complete Middle Palaeolithic industry with evidence of quarrying at the site (Petraglia et al., 2003). Tools which are intensively reduced will have smaller sizes resulting in a shorter life history, unlike Khyad, where raw material was better and available in diverse clasts. The tools at Lakhmapur and Benkaneri, being of poor quality, could have been curated for long.

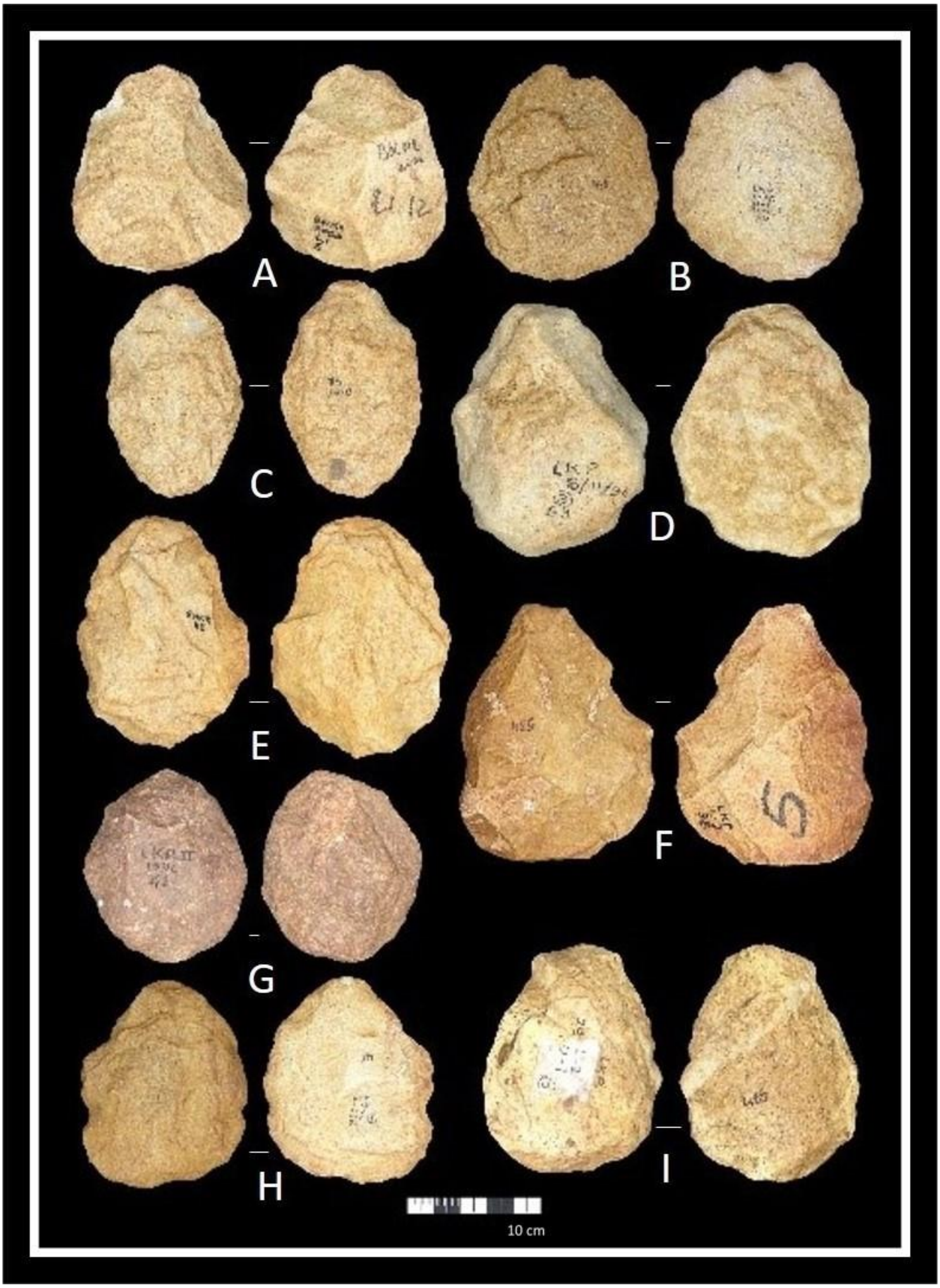


Figure 6. 1 Diminutive handaxes from Lakhmapur and Benkaneri

4. Persistence of tool types like handaxes and cleavers from the Acheulean to the Middle Palaeolithic is observed at all the sites from Malaprabha Valley similar to other transitional sites in South Asia (Mishra, 1985,1989; Akhilesh et al., 2018).

5. Another characteristic observed in the Middle Palaeolithic assemblages across the sub-continent is the relative decrease in the handaxe and cleaver numbers in relation to an increase in retouched flake tools like scrapers, points etc. The site of Khyad, although it is known from surface collections favouring dominance of larger specimens, yields an overwhelming frequency of LCTs and represents good evidence of the importance of these large tools in the Acheulean when compared to the excavated sites of Lakhmapur and Benkaneri. This trait could relate to changing functional requirements. This trend of the decrease in LCTs in Middle Palaeolithic sites is in conformity with the general characteristics of the Indian Middle Palaeolithic noticed elsewhere (Paddayya, 2007; Shipton et al., 2014).

6. Khyad presents a higher proportion (40%) of cleavers to handaxes, a trend, that has been associated with late Acheulean characteristics outside Malaprabha Valley. Joshi (1955) has attributed the presence of a larger number of cleavers here to probable functional requirements related to environmental settings and especially the forested landscape. As inferred from climatic and fossil faunal studies (see Chapter I), the existence of deciduous wooded forests as well as savanna landscapes has been postulated to be in existence in Peninsular India during the Quaternary period (especially in the Purana Basin landscapes; Korisettar, 2007). The LCT's on flakes from this site are concurrent with the Large Flake Acheulean (LFA; Sharon 2007) >10 cm, characteristic of the Acheulean in India (Gaillard et al., 2010; Mishra et al., 2010).

7. Another key feature observed is the possible reuse of handaxes as cores. Both Lakhmapur and Singadivakkam (Middle Palaeolithic site from Tamil Nadu) have produced evidence for this (Figure 6.2). Morphological continuities between Acheulean handaxes and Levallois cores have also been noted (Lycett, 2009). Although no true Levallois cores have been identified from Lakhmapur or Benkaneri, appearance of prepared cores both along with Late Acheulean at

Lakhmapur West as well as Middle Palaeolithic occupations have been attested (Petraglia et al, 2003).

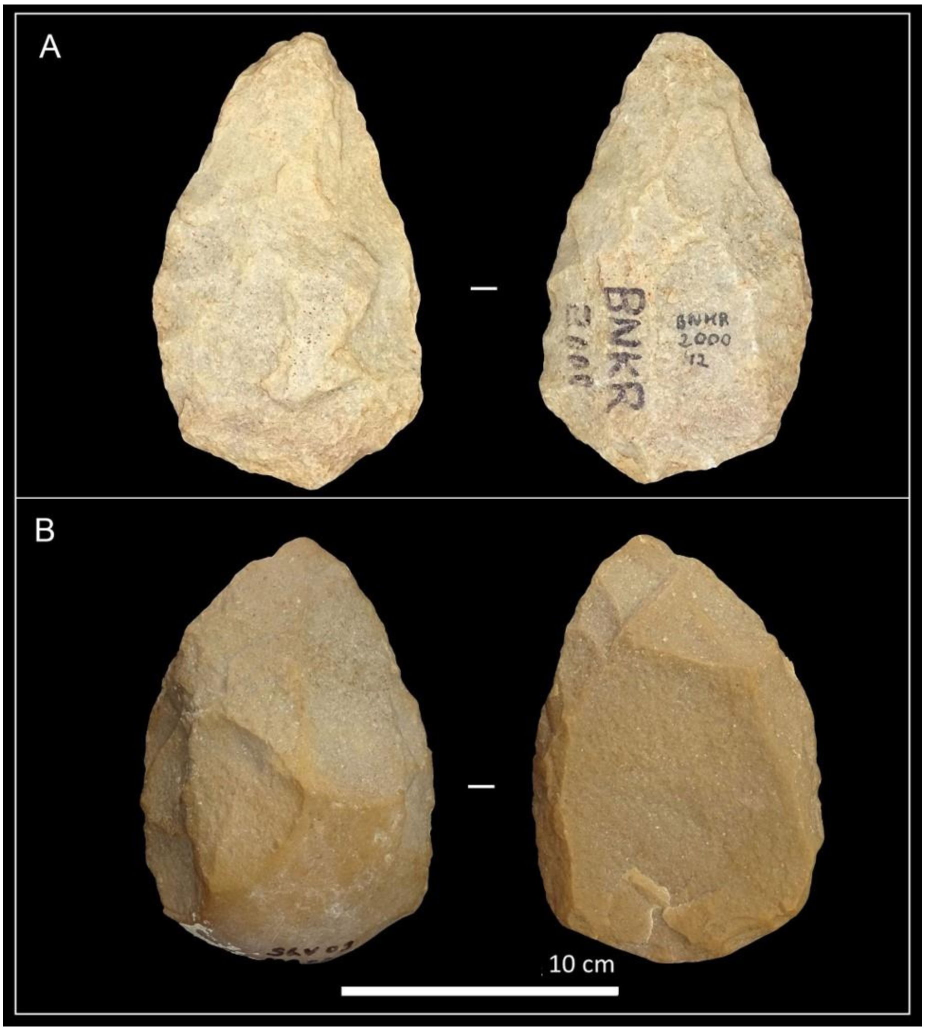


Figure 6. 2 Handaxes from Lakhmapur (top) and Singadivakkam (bottom) showing evidence of preferential scar removal on ventral face, possibly indicating reuse as core.

8. An interesting question related to the point listed above, is whether this correlation between handaxes and smaller cores is related to raw material properties. For example, at both Lakhmapur and Benkaneri, the quartzite raw material does not appear to have good knapping properties as reflected in the number of step fractures on a number of LCTs. In such a scenario, could heavily exhausted cores in the Middle Palaeolithic (as assessed in the Benkaneri core assemblage on preliminary examination) be previous handaxes? And could some of the Middle Palaeolithic tool cores be further recycled into the diminutive handaxes? The existence of these two strategies, in the background of poor raw material quality, cannot be ruled out. However, further studies incorporating the

flakes and cores, examining the flake scars and weight will be needed to corroborate these hypotheses.

9. The presence of refined handaxes and cleavers in the Late Acheulean is considered as significant indication of the transitional phase. This is reflected in Khyad and Lakhmapur. However, an interesting trait is observed for the handaxes from Malaprabha Valley, where despite the differential specimen numbers, the average refinement remains the same between all the sites; Khyad (17/116, 1.98), Lakhmapur (9/50, 1.97), Benkaneri (16/25, 1.95). A correlation between elongation and refinement among the handaxes has further been attested at the site of Benkaneri (Kunneriath et al., 2021; Appendix II).

10. Increased use of flakes as blanks is evidenced from all the sites in the Malaprabha Valley, although the use of tabular blocks and cobbles are also attested. Khyad represents more variability among blank types with use of entames, cobbles, pebbles, tabular blocks, etc., although large flakes are preferred in this Late Acheulean site also.

To sum up, all the Lower to Middle Palaeolithic transitional elements (size reduction of the handaxes, increased refinement and decrease in the number of the handaxes and cleavers within the assemblages) attested in the Indian sub-continent are well represented in the studied assemblages of Khyad, Lakhmapur and Benkaneri ranging from Acheulean to Middle Palaeolithic. The excavated site of Lakhmapur West is especially significant in this regard as it yields in the same stratigraphic sequence evidence of successive Acheulean and Middle Palaeolithic assemblages (Petraglia et al., 2003). The results from the Malaprabha Valley are fully supportive of the hypothesis of a regional continuity.

They also fit well with similar findings on the Lower to Middle Palaeolithic transitions from other parts of the Indian sub-continent (Shipton et al., 2013). This change was a gradual one and does not support the hominin replacement theory, except if this replacement is a soft process of population movements that may not imply any visible change in the technical behaviour. This is hypothesised in many parts of the Old World, especially in Asia (see for instance Boivin et al., 2013).

Assessing the second hypothesis:

Are the LCT shapes influenced by raw material and blank types?

The results of the 2D GM analysis display a greater diversity of forms among the handaxes from Khyad compared to Lakhmapur and Benkaneri where, it is to be noted, the number of items is much lower. Handaxe shapes in Lakhmapur and Benkaneri are almost all grouped with the main cluster for Khyad representing rather elongated and pointed handaxes. The large diversity of forms in Khyad might be arising from differential shaping intensity and reduction strategies on a greater variety of blanks. The handaxe forms displayed on the graphs are overlapping, which indicates continuation of forms from the Lower to the Middle Palaeolithic in the Malaprabha Valley. In Tamil Nadu, round pointed handaxes constitute the majority among the Attirampakkam handaxes, which are clearly separated from the Malaprabha Valley handaxes and show a high correlation between refinement and elongation, as indicated by the classical analyses results. Singadivakkam handaxe forms are found overlapping with some of those from Attirampakkam and Malaprabha Valley.

The results of the 3D GM analysis show a general overlap of shapes of handaxes between all the sites although subtle differences are also exhibited.

The handaxe shapes were analysed separately according to the blank type in the different sites. The shape variability for handaxes on cobbles and entames from Khyad and Attirampakkam show morphological differences caused by relative thickness at Khyad and relative width at Attirampakkam. The classical analysis points to a larger number of these tools unifacially reduced at Khyad, usually made on entames. This feature would have contributed to the variability within the assemblage.

For the handaxes on end-struck flakes at Lakhmapur, the relative length had slightly more importance in the variability of shapes (more than in the other sites), besides the usual major contributors of relative width, followed by relative thickness. Flakes from tabular blocks form a major type of blank at this site and the morphology of the blank would have facilitated a better control of flake removals with a predetermined length. The peripheral location of the variability on the tabular block blanks, indicates that minimal shaping was required to convert the blank into the desired form. This is also indicated by the techno-typological observations where the number of flake scars, removal pattern and nature of removals correspond to little technical investment.

For the handaxes on side-struck flakes, the shape variability at all sites was highly influenced by the relative thickness, followed by the relative width. Despite the differences in the intensity of shaping at different sites, all the tools show an overall symmetry and similar morphology. At Singadivakkam, deep, invasive shaping removals in single series are the norm as noticed from the classical analysis. Most of the handaxes are atypical in this site, being exclusively shaped on one face and marginally or not shaped on the other. Although morphologically similar to handaxes, technologically there is no true volumetric reduction. Most of these, on cobbles, are tools with large invasive and deep removals, reminiscent of biface-core tool. Some exhibit preferential flake removal on the ventral face as discussed in the above section (Figure 6.2).

The presence of a large number of flake tools along with debitage and cores from this Middle Palaeolithic site makes it comparable to the Middle Palaeolithic evidence from the Malaprabha Valley. What really makes the site stand apart is the presence of a large number of unifacial and bifacial choppers.

When the shapes and their contributing factors are compared with those of Malaprabha Valley, Singadivakkam shows closer affinities to Benkaneri and Khyad with the major contributor to the shape variability being relative thickness. At all these sites, similar blanks such as cobbles, split cobbles, pebbles and entames are used. These occur in rounded and sub-rounded forms at Singadivakkam while in the Malaprabha Valley assemblages, they are mostly angular, sub-angular, tabular, and round to sub-round in morphology. They occur in varying thickness.

Attirampakkam and Lakhmapur, on the other hand, show that the handaxe shape variability was largely a result of the relative width of the blanks. At both these sites, majority of the blanks were flakes. The 3D GM on cleavers showed a similar overlap of shapes among all sites, except for two specimens from Khyad. A clear difference among the mean shapes of Acheulean and Middle Palaeolithic cleavers has been observed. Except for Singadivakkam cleavers, with narrow distal tips, on cobble blanks, all the other specimens display a similar variability with relative width playing a major role in the variability. Benkaneri cleavers on tabular blocks showed that the thickness of the blanks was important in the resulting variability. The cleavers from Attirampakkam showed a more standardized form, followed by cleavers from Khyad. At both Lakhmapur and Benkaneri, cleavers are less in number; they have narrower cutting edge and often exhibit steep (backed) edges as shown by the classical analysis. Although the blank types differ, resulting shapes did not differ much and whatever variability is observed, is due to the relative width of the blank.

Combined with the results of 2D and the classical analysis, it can be concluded that the overall variability of the handaxes at all these sites seems to stem from the size differences of the blanks rather than the shape of the blanks. The differences in the shape of the blanks were overcome with shaping strategies to achieve similar forms. While elongation has played a role in shape variation as indicated by the 2D results, the overall shape of the handaxes remains more or less the same throughout the Lower and Middle Palaeolithic in these sites of southern Peninsular India. Raw material shape, and even reduction sequence models (see section 1.8.3, Chapter I, for a discussion on handaxe variability) can thus not be substantiated through this study.

The shape of the cleavers shows more variations among and between the sites as a result of the influence of the blank types, the reduction strategies, and the shaping methods although an overall modal shape seems to be maintained.

These results, however, based on a small representative and unbalanced sample, is to be taken as preliminary in nature and an increased sample size only can give statistically significant results.

In conclusion, the hypothesis that the blank types play an important role in the shape variation, does not hold true for the handaxes studied, while for the cleavers some amount of influence of blank morphology can be observed.

The differences observed among the LCTs of Lower and Middle Palaeolithic of southern Peninsular India cannot in any way be taken conclusively to reflect the arrival of new populations with new technologies applied to the manufacture of large cutting tools. Population movements probably occurred both eastwards and westwards between Africa and South east Asia since long. From about 50 ka ago these movements involved *Homo sapiens* but it seems that people belonging to this new species did not import the evolved technology they might have practiced elsewhere (Blinkhorn, 2013; Boivin et al., 2013; Dennel, 2017).

6.3 Insights into regional and global patterns

Although the data used for this study is limited in quantity and are of mixed contexts (surface and excavated), which renders significant comparisons problematic, a few interesting observations can be put forward. Lack of sufficient published data and the differential scale of studies allow only broad comparisons regarding the questions of LCTs in transitional industries

Several transitional elements like the recycling of handaxes as cores has been attested in the Levant (Tabun and Revadim Quarry; DeBono and Goren-Inbar, 2001, Marder et al., 2006) and North-west Africa (Tuffreau, 2004) as well as Western Europe (Olle et al., 2013).

Besides the use of handaxes as cores, morphological continuities between Acheulean handaxes and Levallois cores have also been noted (Lycett, 2009). The adoption of prepared cores at Lakhmapur, Late Acheulean and Middle Palaeolithic, are reminiscent of the continuous technological trends elsewhere in African, Near-eastern and West European Palaeolithic records (Rolland, 1995, Debono and Goren-Inbar, 2001; White and Ashton, 2003).

The reduction of size of LCTs has been noticed in Africa in the Lower Stone Age to Middle Stone Age transitional phase. This is probably a reflection of differential subsistence strategies and changing functional needs. Increased use of flake tools and decrease in LCTs (especially cleavers) are noticed almost in all the transitional sites. However, the marked presence of tanged tools in Middle Palaeolithic with reducing number of cleavers and handaxes, is nearly absent in the Indian sub-continent with only rare occurrences, especially at Attirampakkam (Akhilesh et al. 2018).

The transitional elements (reduction in the number of LCTs, decreasing size, use of handaxes as cores, continuity in raw material preference for LCT, associated prepared core technologies etc.) from Malaprabha Valley are comparable with similar findings from other parts of the sub-continent Middle Son Valley (Shipton et al., 2013), Orsang Valley (Ajithprasad, 2006), Hunsgi-Baichbal Valley (Paddayya, 1982), Gunjana Valley (Raju,1988) Renigunta (Murty, 1996) and Dang-Deokhuri Valleys in Nepal (Corvinus, 2002). and Upper Paleru River Basin in the neighbouring state of Andhra Pradesh (Anil et al., 2018).

However, cultural hiatus or lack of continuous stratigraphy at most sites limit their use in transitional studies (Chauhan, 2009). In this regard, the site integrity of Lakhmapur representing a transitional industry is significant (Petraglia et al., 2003).

Regarding the elongation of handaxes, the data of the studies assemblages compares well with other Acheulean sites in the Indian sub-continent and Africa (Table 6.1 and 6.2). However, it is to be noted that elongation is usually correlated positively with length in the Lower Palaeolithic (McPherron, 1995, Iovita and McPherron, 2011). When it came to refinement, a tendency for higher refinement mean values are observed from all the sites, which only finds a parallel in the Acheulean site of Shangarakatta in Andhra Pradesh (Koshy, 2009).

Site and No. of tools	Elongation ratio - Mean values (Length/Width)	Refinement ratio - Mean values (Width/Thickness)
Khyad (n=116) (Karnataka)	1.61	1.98
Lakhmapur (n=50) (Karnataka)	1.48	1.97
Benkaneri (n=25) (Karnataka)	1.62	1.95
Attirampakkam (n=45) (Tamil Nadu)	1.57	2.07
Singadivakkam (n=33) (Tamil Nadu)	1.45	1.96
Hunsgi V (n=151) (Karnataka)	1.63	0.53
Hunsgi II (n=34) (Karnataka)	1.68	0.52
Gulbal II (n=17) (Karnataka)	1.58	0.49
Mudnur VIII (n=9) (Karnataka)	2.15	0.58
Yediyapur I (n=21) (Karnataka)	1.54	0.43
Yediyapur IV (n=20) (Karnataka)	1.66	0.54
Yediyapur VI (n=66) (Karnataka)	1.53	0.49
Fatehpur V (n=31) (Karnataka)	1.49	0.44
Anagwadi (n=25) (Karnataka)	1.70	0.57
Godavari (n=10) (Karnataka)	1.31	0.52
Teggihalli II (n=31) (Karnataka)	1.52	0.47
Shankaragatta (Andhra Pradesh) (*data not available*)	1.60	1.83
Jalindri (Rajasthan) (*data not available*)	1.78	0.48

Table 6. 1 Elongation of handaxes in different Acheulean sites of Indian sub-continent (Data from Shipton and Petraglia, 2008, 2009; Koshy, 2009; Vyas, 2020, and the present study).

Region and number of handaxes	Mean elongation
East Africa (n=232)	1.72
Arabia (n=84)	1.64
India (n=302)	1.60

Table 6. 2 Elongation of handaxes from East Africa, Arabia and India. Modified after Shipton and Petraglia, 2009: Table 2.

Handaxes, which were shaped only on one face, have been found at all sites from Malaprabha Valley. Such unifacially shaped LCTs occur in the Acheulean contexts of Middle Awash, Ethiopia (Shick and Clark, 2003), at the Acheulean site of Koobi Fora, Kenya (Presnyakova et al., 2018), Middle Palaeolithic site of Misiliya Cave, Israel, and Bezez Cave, Lebanon (Copeland, 1983; Zaidner et al., 2006) to name a few. Whether they represented functional differences, or were a result of opportunistic knapping, or corresponded to unfinished stages of bifaces, or curated tools, can only be proved with further studies.

Further, if we take the individual idiosyncrasies evident in the correctional flaking of a handaxe from Khyad, it finds similarity to the specimen from Lower Palaeolithic Elveden, UK (Ashton and White, 2003:118) and the large refined unique specimen from Benkaneri finds parallel in size to handaxes from the Late Acheulean site of Jalindri in Rajasthan (Vyas, 2020). However, the specimen from Benkaneri is very refined with intensive multiple removals on both surfaces and with a pointed tip, probably reflecting symbolic behaviour.

Presence of notched LCTs is attested from Benkaneri and Lakhmapur. Notched handaxes and cleavers are also reported from the transitional site of Patpara (Shipton et al., 2013) and in a global context, from the Acheulean sites between Rhone and Loire Valley (Moncel et al., 2011) and at Lynford in UK (Emery, 2010).

By and large, the cleavers were mostly on flakes, with a few on other blanks like tabular blocks, cobbles and entames (as evidenced at the Malaprabha Valley sites). The use of cobbles for making cleavers has been attested at other sites. For example, at Acheulean sites of Gran Dolina TD10, Atapuerca, Spain (García-Medrano et al, 2017), and Tabun Cave in Israel (Sharon, 2006). The use of tabular blocks for cleavers were absent at the Tamil Nadu sites, where the available raw materials of cobbles were utilised in addition to the preferred flake blanks. To give an example, tabular blocks used as blanks for cleavers have been reported from Acheulean sites of Hunsgi Valley (Paddayya et al., 2002, 2006) and also at Jalindri (Vyas, 2020) in the Indian sub-continent, while it has also been reported from Cuxton, England (Sharon, 2006).

Although Kombewa flakes have been attested at many sites in the sub-continent for the making of cleavers e.g., Chirki (Corvinus 1983), Morgaon (Mishra et al. 2009), Jonk river valley sites (Padhan, 2014); Attirampakkam, (Pappu and Akhilesh, 2019), they were largely absent at Khyad, where larger and diverse morphologies of the cleavers were noticed.

Entame cleavers (resembling Tixier's type 0), alternately termed as "proto-hachereaux", has been reported from Acheulean assemblages from North Africa and Iberian Peninsula (Santoja and Villa, 1990; Mourre, 2003). Khyad has given the highest representation of cleavers on entames, followed by two cleavers from Singadivakkam and a single one from Attirampakkam. Entame cleavers has also been noted at Hunsgi (Sharon, 2006). The presence of a larger quantity of cleavers from this site, finds similarities with sites of Tikoda (Ota and Deo, 2014), Siwaliks (Gaillard and Singh, 2014), and Bhimbetka (Misra, 2014) in the Indian sub-continent and these often-cortical edged cleavers have been reported from Isimila Gesher Benot Ya'aqov in the Levant to name a few (Sharon, 2006).

Based on Chatterjee's (2016) identification of 11 main types of cleavers from the Indian sub-continent, using both edge and butt morphologies, the cleavers from the study region include the dominant types of straight edge with rounded-pointed-angular butt (corresponding to the straight-edged U-V-angled butt) and convex edge with rounded-pointed-angular butt (corresponding to the convex-edged U-V-angled butt). Cleavers with a convergent distal edge corresponds to the cleavers with pointed tip from Tachenghit (Sharon, 2006) or the "double cleavers", reported by Roe (2001:501) from Kalambo Falls. While the convex-edged cleavers show similarities with those from Tachenghit (Sharon, 2006), the diagonal-edged ones are similar to the "ultra-convergent", angle-edged cleavers (Roe, 1994) also described as "guillotine-type", chisels or bevels (Clark and Kleindienst, 2001:49).

All these examples cited above show a tendency of shape conservatism, which has been one of the main traits of Acheulean period. However, as mentioned in Chapter I, when it comes to regional level, the similarities apparent in global overlook are often masked by local variants.

While broad typological and cultural tendencies in the Acheulean and Middle Palaeolithic appear across the continents, as discussed above, aspects of local ecological drivers in resulting variabilities at a local site level appears too, as demonstrated by the absence of tanged points, differential quantity of cleavers, predominant absence of true Levallois technology (see section 1.82, Chapter I). Further issues of site integrity, collectional bias, absence of absolute chronology and attribution of a culture based on the *fossile directeurs* alone, complicate the scenario, where precise comparison remains elusive (see Chapters I, II and III for discussions on these various aspects).

In the background of absence of comparable hominin fossils in India, nothing conclusive can be said about the makers of these tool traditions, their variability and similarity which could be arising out of different groups producing the same types, arising out of transfer of ideas, or mixing of populations, differential functional and raw material constraints, or as cultural preferences or skill or technological differences, as well as cultural traditions, based on a common mental template.

7. CHAPTER VII – CONCLUSIONS AND FUTURE PERSPECTIVES

The present study was undertaken with the objective of understanding the cultural processes of change, over time and space within a regional perspective. The Malaprabha Valley, part of the Kaladgi Basin, was chosen as the key focus area due to the presence of Lower and Middle Palaeolithic sites within a small region. On the premise that this area reflects the concepts of the "Basin Model theory" (Korisettar, 2007), significant hypotheses regarding the transitions between the Lower and Middle Palaeolithic cultural periods were put forward.

In addition to the classical methods, new methodological approaches of 2D and 3D Geometric Morphometrics were applied to the LCTs from this area for the first time, to infer the technological and typological variations occurring through time.

The applications of these methods have highlighted the advantages of 2D outline shape methods being an inexpensive, accurate, objective, and reversible and replicable method of shape analysis, making it an ideal method for larger data (with an additional advantage of using all kinds of illustrations from old and new publications, without the need for size (or scale) adjustment). At the same time, tools, being three-dimensional, when studied with their volumetric inclusion, as done through 3D Geometric Morphometric analysis, display the importance of thickness playing an important role in shape variability. The role played by thickness of the blanks and the reduction and shaping strategies in the final product is highlighted in this study (see section 5.9 and 5.10, Chapter V). However, one of the major drawbacks of this method remains the requirement of expensive scanners and the need for larger data storage besides the time-consuming nature of data collection and processing.

In the end, as we are dealing with hominin made unique artefacts, the need to go beyond just categorization and explain the variability in terms of hominin choices and cognition remains relevant. The use of Geometric Morphometric methods surely helps us in obtaining objective results, which, however, needs to be explained further. Also, the exclusion of incomplete, broken specimens in these studies may limit our understanding of hominin behaviour. This is where the relevance of classical technological observations is very important. Many aspects that cannot be captured by digital data can be observed through personal handling of these tools. A combination of all the three methods thus proves to be complementary, as illustrated by this study.

Well defined stratigraphic contexts of sites with high integrity and with minimal post depositional effects in the Malaprabha Valley are significant in the background of the questions of transitions and hominin dispersals, all the more as they display the continuation of raw materials and tool types, as well as reduction and shaping strategies.

Through this study, it has been demonstrated that the transitional processes were gradual and local and not a result of rapid external stimulus. Although the current study is based on a limited sample size with no absolute dates, it contributes significantly to a better understanding of the often blurry and complicated scenario of the Middle Palaeolithic in the Indian sub-continent from a regional perspective.

The comparative analysis with the south-eastern counterpart sites of Attirampakkam and Singadivakkam from Tamil Nadu, aimed at understanding the effects of raw material blank type on final morphology of the handaxes and cleavers. This comparative analysis, however, was done with limited integrity of data arising from differential and limited contextual information, smaller sample size, and lack of absolute chronology. The results show that although blank types differ, an overall sense of shape prevailed and were achieved through flexible shaping strategies, reflecting the existence and adherence to a “mental template”.

The current study has effectively demonstrated that old museum collections, often considered unimportant due to contextual problems, can play, and do play a significant role if we apply new perspectives and methodologies in their study. Aiding in not only preservation and conservation of data and enabling cross-regional comparisons through digital databases, incorporating them into the current research scenarios can help revise earlier assumptions on a better footing. In the growing scenario of rapid loss of sites, in our case, Singadivakkam and Lakhmapur, where industrialisation and agricultural activities wipe out and modify the past remains, such studies find pertinence. Also, this study has highlighted the potential of open-air assemblages despite their possible mixed context to give important results, highlighted in other studies (e.g., Arzarello et al., 2013).

This study has produced some very interesting and promising results. However, it also leaves space for many more future avenues to be explored. As the raw material remained the same, quartzite, the variability of raw material type also could not be exploited in this work, which is another avenue to explore in future. Another point highlighted through this study is the need for comparison between well-dated, contemporaneous sites with larger samples to make coherent statistical conclusions. The sample size, which has been a limitation in this study, needs to be strengthened further. Our samples can be enriched with not only more LCT, core, and flake assemblages, the relations of which remain critical, especially to understand the question of handaxe being converted into cores for flake tools. This will be initiated in the next stage of the research. Further inclusion of the find spots that are spread over the Malaprabha Valley can help understand the landscape use and mobility patterns of the hominins. For this, 2D and 3D Geometric Morphometrics that shows promising results in separating some aspects of chrono-cultural difference more accurately can be applied. A database of 2D and 3D data consisting of the assemblages from this region will not only enrich the existing data but also facilitate cross-regional studies on a more accurate footing. One other aspect to be explored in future can be comparative studies across the sites located between the south-western and south-eastern Peninsular India. This would enable characterising the changing technological and cultural behaviours across space and can possibly throw further light on the dispersal patterns and place it on accurate footing. An exploration of the assemblages that exist in Malaprabha Valley and Tamil Nadu will help understand the spatial and temporal evolution and change between these regions. Further it will throw light on the key issues of hominin dispersal routes.

By studying assemblage and artefact variability, pertinent questions on cultural and technological transitions, and in turn, hominin dispersals, can be answered, as shown in this study. The initial results between Khyad and Attirampakkam tends to show typological affinities, to which if we apply the Basin model, we see distinct local traditions within a broader general technological background. Further, the Lower to Middle Palaeolithic transitional elements observed at the Malaprabha Valley reflect a gradual, regional characteristic indicating that there have been no abrupt technological changes. However, as we still lack the knowledge of which species of hominins were responsible for these assemblages, we cannot eliminate the presence of multiple hominins producing the same assemblages. Recent studies (Blinkorn et al., 2021) have demonstrated the perils of associating a particular lithic technology as an exclusive marker of a specific hominin species. In this background of emerging evidence, technological continuity cannot be considered as necessarily implying the presence of the same hominins either. Technological continuity can also be inferred as cultural sharing or convergence among different species. What we can, however, highlight is the prevalence and persistence of a particular technology and typology within a time frame. This continuity of forms, irrespective of diverse blank types, also may reflect cultural traditions or preferences or mental template, shared among the groups.

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Software

AGMT-3D	https://sourceforge.net/projects/artifact-geomorph-toolbox-3d/files/ https://www.3dsystems.com/press-releases/geomagic/announces-studio-2013
Artifact-3D (Grosman et al., 2008)	
Geomagic Studio version 2013	https://www.3dsystems.com/
PAST Version (4.03 June 2020)	https://folk.uio.no/ohammer/past/
TpS Util and TpS Dig	https://life2.bio.sunysb.edu/ee/rohlf/software.html

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APPENDIX I – ARTICLE 1

A TALE OF BIFACES FROM SOUTHERN PENINSULAR INDIA (BRITISH MUSEUM AND MUSÉE DE L'HOMME COLLECTIONS): A GEOMETRIC MORPHOMETRIC AND CLASSICAL APPROACH

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ABSTRACT

Bifacial tools (especially handaxes and cleavers) have played an important role in the Lower Palaeolithic studies trying to decode Acheulean lifeways through them. The methodological approach based on classical metrical analysis, could be insufficient and often subjective, especially in instances of asymmetrical tools, and incorrect orientation for capturing the morphological data. Recent years have seen the application of geometric morphometric methods on lithic tools (2D contours and 3D volumetric forms)–as an accurate, efficient and objective method of data collection. This alternative approach has the additional advantage of being both interactive and reversible analytic process, reducing the time and effort in collection of data.

Traditionally the museum collections of Palaeolithic artefacts of old surveys and fieldworks, are seldom subject to study due to their incomplete and often doubtful or mixed context. In the current study, both geometric morphometric on 2D contour analysis as well as classical techno-typological analytical methods has been applied to bifaces from Southern Peninsular Indian Palaeolithic kept in the British Museum (London, UK) and Musée de l'Homme (Paris, France). The aim of this study is to highlight the complementary nature of both analytical methods in deciphering and throwing light on the patterns of bifaces (handaxes and cleavers), their technological variability and stability and to identify if there are regional technological trends.

The results obtained from both classical analysis and geometric morphometric analysis allow to show that handaxes were highly variable in both the regions while the cleavers show high irecteurs tion. While the former approach throw light on the knapping techniques and preferences, the latter complement the results with the shape preferences and variations across regions.

KEY WORDS:
LITHIC TECHNOLOGY
HANDAXES
CLEAVERS
DIGITAL DATA
GEOMETRIC MORPHOMETRICS
2D CONTOUR ANALYSIS
MUSEUM COLLECTIONS
PENINSULAR INDIA

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INTRODUCTION

Historical background of the study material

Museum lithic assemblages collected in the past and having very little documentation associated to them are rarely studied as they are considered biased and incomplete, thus resulting in being non-representative of the sites. Indian Palaeolithic assemblages that are dispersed in various museums in the world are not an exception. The present study bears on the type series (small representative groups of material from important sites) and stray finds of bifaces from South Indian Palaeolithic kept in the British Museum, London and Musée de l'Homme, Paris. These collections were formed as parts of personal and institutional collections (Accessions Register: British Museum and Musée de l'Homme), donations and exchanges, namely from A.C. Carleylle, R.B. Joyner, H. Wellcome, H.W. Seton Karr, G. de G. Sieveking, and W.G. Smith, and institutes of University of London – Institute of Archaeology and Geological Museum (former Museum of Practical Geology), London, University Museum of Archaeology and Ethnology, Cambridge, Archaeological Survey of India, Delhi and Deccan College of Post graduate and Research Institute, Pune (Roberts, 1999; Cook and Martingell, 1994).

Although the exact provenance of most of these artefacts is not known, with only a few publications and reports on them, they offer an opportunity to integrate them into current studies from the same sites and regions. In the background of increasing loss of sites, scattered museum collections assume importance in preserving sometimes the only previous evidence of those sites. They give us a glimpse into the past landscapes and circumstances when they were collected and the methodologies and the criteria which the collectors or excavators applied.

"There is no doubt that variability in material culture—in artefacts—is the *sine qua non* of archaeology. This variability has both a spatial and a temporal dimension and includes variability in the form of artefacts and their associations with one another" (Ugan *et al.,* 2003). One such category in lithic tools which displays an immense variability in its form is the biface, long considered the index fossil of Acheulean culture. It spreads over a vast geographic area and spans a long time from its first appearance in East Africa around 1.7 Ma (Lepre *et al*., 2011; Beyene *et al*., 2013). Bifaces are tools that are flaked on both sides and both faces and in the Acheulean context they include handaxes, cleavers, picks and knives.

Prehistoric lithic studies have followed various approaches, mainly typological, and technological but also functional, taphonomical (experimental and traceology), related to *chaine opératoire* or to raw material (quantity, availability, size and shape of the nodules and texture of the stone itself) etc. (Koshy, 2009). The first two approaches have been extensively used to understand form (size and shape). Both qualitative descriptions and morphometrical analysis have been the major methods used for this.

Following the Geometric Morphometric (hereafter GM) "revolution" (Rohlf and Marcus, 1993), a set of statistical methods for studying the relative shape and size (geometry) of collections of objects, based on their cartesian coordinates (Webster and Sheets, 2010), its application in the field of archaeological materials has seen a sharp increase in the last decade (Okumura and Araujo, 2019).

This method has rarely been applied on the museum collections and will be applied for the first time on Southern Peninsular Indian lithic assemblages. This paper will focus on the integrated use of both methodologies to throw light on the technological and morphological variations of bifaces in a more comprehensive manner and to discern the possible regional trends.

REGIONAL SETTINGS

Southern Peninsular India (Fig.1) has played a crucial role in establishing the prehistoric studies in India with the first ever discovery of a Palaeolithic tool by Robert Bruce Foote from Pallavaram, in Madras District, Tamil Nadu (TN) in 1863 (Foote, 1866). This formed the primary basis for all subsequent discoveries and established the prehistoric past of India. However, the systematic documentation of prehistoric remains really started in the 1960's; techno-typological analyses of tools became more common (Mishra, 1994) and these followed mainly the Bordes (1961) and Roe's (1964, 1968) systems of measurement.

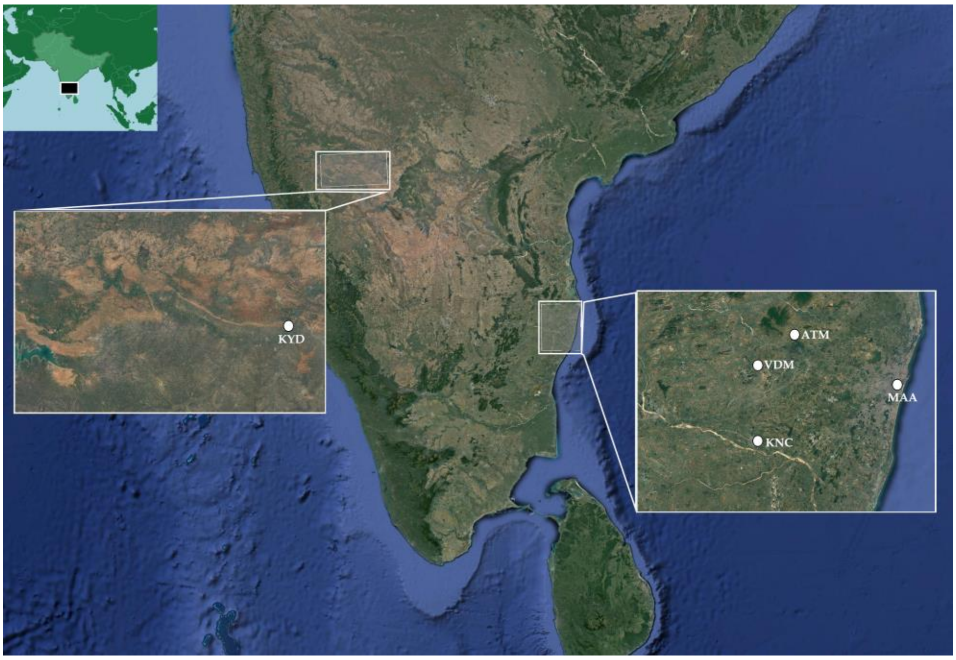


Fig. 1: Map of study area showing location of the main sites; Attirampakkam (ATM), Vadamambakkam (VDM), Madras (MAA), Kancheepuram (KNC) and Khyad (KYD).

Tamil Nadu

Tamil Nadu State (TN) is one of the richest geographic areas in the South east Peninsular India for prehistoric sites. The site of Attirampakkam (Fig.1), type-site of the "Madras Handaxe Tradition" (Pappu, 2001) discovered by Foote in 1863 (Pappu, 2001) located in the Kortallayar basin, continued to attract the attention of several scholars who investigated this site sporadically over the years (IAR, 1969). Absence of detailed analysis of the findings and of systematic publications hampered the understanding of this region in detail till a renewed research in later years. A reinvestigation of the stratified open-air site of Attirampakkam, "the reference point for the early out of Africa Acheulean" (Moncel *et al*., 2018) on a large scale, with international collaborations using a multidisciplinary approach began in the 1980's (Pappu, 1996). An important result of this research program was the absolute palaeomagnetic and cosmogenic nuclide date of 1.5 Ma for the stratified Acheulean layer (Pappu *et al.,* 2011). This has pushed the antiquity of man in India further back. The site has been identified as Type 1 site of high integrity with Acheulean and Middle Palaeolithic tools occurring in the low-energy ferrecritized and gravel contexts (Pappu, 1999). Most of the museum collections from this region are from this site and result from the excavations conducted by the prehistory branch of the Archaeological Survey of India in the 1960's (IAR, 1969) apart from some individual surface collections.

Karnataka

Another important area in the Peninsular India that has gained importance due to its Palaeolithic study potential is the state of Karnataka. Following the discovery of Palaeolithic evidences in 1916 from this region by Robert Bruce Foote, many subsequent Palaeolithic sites were found. All this "has resulted in the establishment of a firm stratigraphy, and at some sites, of a chronology, as also new information on hominin behaviour" (Srinivas, 2017). The discovery of an Acheulean quarry site at Isampur (Fig.1) in the Hunsgi-Baichbal Valley, with an absolute ESR mean date of 1.27 ± 0.17 Ma for the Early Acheulean levels (Paddayya *et al.,* 2002) has been one of its kind for the application of multidisciplinary studies including site formation approach.

The Malaprabha Valley (Fig.1), the origins of some of the collections considered in this study, is another rich potential area with numerous Pleistocene sites. This region has been extensively explored along with geological, sedimentary, and climatological studies (Korisettar and Petraglia, 1993). The site of Khyad (Kaira) (Fig.1) is located on the main meander of the Malaprabha River, in the Kaladgi Basin, Bagalkot District, Badami Taluk, Karnataka. It was first explored by Foote (and later by F.E. Zeuner, R.V. Joshi, Ravi Korisettar, Michael Petraglia and Jinu Koshy), who noticed "the large number of fine, well-shaped and mostly large-sized chipped quartzite implements, some of which were firmly cemented into the mass" on the Kankar-cemented shingle bed (Joshi, 1955). "Undoubtedly a Palaeolithic factory site" (Joshi, 1955), Khyad yielded tools of different sizes and types, mostly Acheulean. The site, which was subsequently revisited by R. Korisettar and M. Petraglia (Korisettar and Petraglia, 1993) and in 2018 by the first and last authors of the present paper, confirms the view of Joshi (1955) that regarding the tools, it "still has an almost inexhaustible reserve in its gravel".

MATERIALS AND METHODS

Data collection and sampling

Only the bifaces were chosen for this study and although biface is a term often used as a synonym of handaxe, in this study both handaxes and cleavers are collectively grouped. Handaxes, the "first tools made by form-shaping" are made on cores or flakes, with modified lateral edges, the cutting edge of which are formed by the intersection of two large flake-scars, one on either face" (Wynn, 1995; Iovita and McPherron, 2011). The Early Acheulean handaxes are often "asymmetrical, large with thick butts or mid-sections, and possess large, bold, and irregular flake scars, indicative of hard -hammer percussion" (Chauhan, 2009). The Late Acheulian handaxes are generally "smaller, thinner, and morphologically more refined, with a significant increase in the degree of retouching and controlled bifacial thinning/flaking" (Chauhan, 2009). Cleaver with a transverse working edge, is essentially "a tool made on either a rectangular, rarely triangular or convex side flake or end flake, the cutting edge of which is the transverse edge" (Sankalia, 1964; Bhattacharya, 1979).

The total number of bifaces used in this study is 155 (Table 1.) from the sites of Vadamambakkam, Satyavedu, Cuddalore, Sholavaram, Attirampakkam (I, II, III and V), Madras (now known as Chennai) and Kancheepuram Districts in TN and from Khyad and Malaprabha region in Karnataka (Fig. 1). They are a result of several individual and institutional explorations and excavations and include single as well as multiple number of tools from sites. For the purposes of this study, all the different site collections from both the museums (British Museum and Musée de l'Homme) were grouped into two major regional groups, namely that of TN State from the east part of Southern Peninsular India and Karnataka State from the west part. The majority of tools from TN come from Attirampakkam while those of Karnataka are from Khyad. All the tools were considered for the traditional techno-typological analysis while only those tools that were not damaged or fractured (either technological or post-depositional) were selected for the GM analysis so as not to render extraction of complete outlines a problem. A total number of 30 handaxes and 18 cleavers from each region (from Madras and Attirampakkam for TN and Malaprabha and Khyad for Karnataka) were chosen, for the GM analysis to maintain the statistical balance between the two as the distribution of tools by site in these collections was unbalanced. Multivariate statistics was then applied to both traditional and geometric morphometric analyses.

REGION	Tool type	Rawmaterial	TT sampling		GM sampling	
			BM	MdH	BM	MdH
Tamilnadu	**Handaxes**	Quartzite	64	14	30	
(sites of	**Cleavers**	Quartzite	17	9	12	6
Satyavedu,						
Cuddalore,						
Sholavaram,						
Madras,						
Vadamambakkam,						
Attirampakkam,						
Kancheepuram)						
Total count	103					
Karnataka	**Handaxes**	Quartzite	24	9	26	4
(sites of	**Cleavers**	Quartzite	15	4	14	4
Malaprabha Basin,						
Khyad,						
Menasgi)						
Total count	52					

Tab. 1: Distribution of study material from British Museum (BM) and Musée de l'Homme (MdH) and techno-typological (TT) and Geometric Morphometric (GM) sampling.

Techno-Typological analysis

For the techno-typological analysis, all the tools were typologically oriented with their dorsal face up. Whenever it was difficult to differentiate the two faces, the flatter face was considered to be ventral. Classical morphological descriptions were recorded besides the metrical details collected using a digital calliper for linear measurements and goniometer for angular measurements.

The various attributes recorded for the bifaces include their tool type (cleaver, handaxe) and blank (side-struck, end-struck flake, tabular block/slab and cobble), preservation status (complete/incomplete, abrasion level, breaks and traces of damage), raw material (texture/eye granology and colour), classical descriptive outline (ovate, almond shaped, pear shaped) eye symmetry (presence/absence) and cross section (biconvex, plano-convex, biplanar, irregular), cortex (presence/absence, location), striking platform (type ; plain, dihedral, facetted, location) and shaping patterns (convergent/centripetal, three directional, bidirectional and unidirectional). Shaping was characterised by the number, pattern, and invasiveness of removals (scale of 0 to 5). The proportion of shaping on each face, length of the longest removal and retouches if any were also noted. Edge angles (sharp = >60°, medium = 60°-80°, steep = 80°-110°) and the metrical measurements (in mm) of maximum length, width, and thickness were noted. The weight (g) of the tools was recorded. After the primary variables of linear measurements (length, width, and thickness) were taken, the secondary variables were extracted from it, like the mean, standard deviation and coefficient of variation which helped derive further results. The principal measurement systems of Bordes (1961) and Roe (1964, 1968), "primarily intended to be converted into ratios to describe three aspects of shape: elongation, refinement (relative thickness) and edge shape" (McPherron, 2006) with some modifications (Fig. 2) were adopted in this study. Following this, Roe's (1964) refinement indices Width/Thickness and shape indices were derived from the ratios of Width/Length. All the data were recorded and processed in Microsoft Excel 2010 and Palaeontological Statistics (PAST) version 3.22 (Hammer, 2001) for analysis. Diacritic illustrations for selected samples were also undertaken. All the tools were photographed digitally (with a metric scale) using a digital camera, Nikon D60, attached to a fixed stand and kept at a right angle.

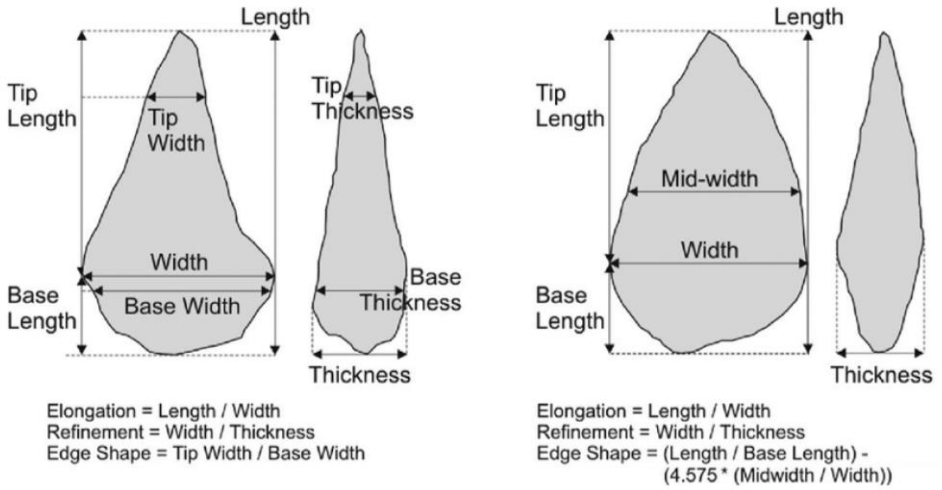


Fig. 2: Measurements used for the analysis following Roe (1964, 1968) and Bordes (1961) with some modifications.

Geometric Morphometric (2D) contour analysis of lithic tools

GM method was used for the first time on these collections for the many advantages it offers like its accuracy, visual power of illustration and the possibility to replicate the results in an objective manner (Webster and Sheets, 2010; Klingenberg, 2013). Also, the digital non-destructive data repositories resulting from such analysis can be made easily accessible for studies and cross reference and can prove advantageous especially in comparative studies. An important advantage of shape analysis is that the total appearance of a tool is considered rather than highlighting any particular feature or dimension as a defining characterisation of standardisation. Also, it allows asymmetry to be quantified and analysed for variance.

This study adopts 2D GM contour (outline) analysis for the many advantages it offers- the data (photographs and illustrations) are easy and less time consuming to obtain, inexpensive and "can be applied in a wider context, realistic, requires minimal preparation of specimens where availability of expensive scanners and tools become an issue" (Zelditch *et al.,*2004). Outline data in GM are shapes of open or closed curves or parameters (Webster and Sheets, 2010) which can be analysed using Elliptical Fourier analysis (EFA), Eigenshape and semi-landmarks.

Recent years have seen a huge increase in the use of 2D GM for analysing stone tools in their spatial and temporal variation. Most of these studies have focussed on standardised tools, especially on Paleoindian projectile point types. Pioneering works include that of Tompkins (1993) and Thulman (2006) who studied Clovis points. Castineira *et al.* (2007, 2011, 2012) analysed the outline form of Fluted Fishtail points from Uruguay and Argentina. Cardillo (2009) applied GM to understand the temporal trends in the morphometric variation of the projectile points during the Middle Holocene of Southern Andes (Puna region) while Buchanan (2006) analysed Folsom projectile point resharpening using quantitative comparisons of form and allometry. Application of 2D GM was also made by Buchanan and Hamilton (2009) to define a set of dimensions that links landmark points at the tip, base corners and other locations of Paleoindian projectile point types from western North America while Buchanan and Collard (2010) used blade shape analysis to differentiate Clovis points from both Folsom points and Plainview points and to show how their similarities and differences are independent of allometry, raw material quality, and resharpening. Later in 2014, Buchanan *et al*., explored the variations in Clovis point shape to support that they were a result of the regional environmental adaptation rather than the continent-wide adaptation. Thulman (2012) used landmark GM to show how the base shape can be used to define three Palaeoindian point types from Florida. Okumura and Araujo (2013, 2014, 2016) applied GM to test the morphological differences of stemmed bifacial points from Brazil and their cultural implications. De Azevedo *et al.* (2014) studied a sample of Southern Patagonia lithic stemmed points, including arrows and spears to show how the original design attributes explained most of the total tool shape variation than changes resulting from maintenance activities. Sholts *et al.* (2012) used 2D to analyse flake scar contours on early North American projectile points to show how asymmetric patterning reflected temporal variation probably signifying beginnings of regionalisation among early New World colonists.

In Europe, Picin *et al.,* (2014) emphasised that there were similar techno-morphological features shared by the Discoid and Levallois recurrent centripetal methods based on his study from Abric Romani. In another study, Serwatka and Riede (2016) used 2D GM to show how large tanged points do not function as culturally diagnostic marker artefacts in the Final Palaeolithic technocomplexes in Europe. One example of application on informal non-European lithic assemblage is that of Borel *et al*., (2017) who applied EFA to informal flake assemblages from Song Terus, Indonesia, to show that specific form of stone flake is not related to a particular function and *vice versa*.

As the first step in this analysis, all the selected specimen images for 2D analysis were enhanced using Adobe Photoshop version CS6. Using the free Thin Plate Spine (TpS) software available on http://life.bio.sunysb.edu/ee/rohlf/software.html, 2D data was extracted. The TpS program series by James Rohlf (Rohlf, 2015) not only offers possibilities for digitising landmarks, but also Procrustes superimposition including semi-landmarks, deformation grids, image warping and shape regression (Mitteroecker and Gunz, 2009). A tps file was created in the TpsUtil version 1.76 program (http://life.bio.sunysb.edu/ee/rohlf/software.html) which allowed the storage of all images in one TpS format file. Following this, TpsDig 2.31 version (http://life.bio.sunysb.edu/ee/rohlf/software.html) was used to open the images. After placing a digital scale for each image, the contours of each tool were captured using the automatic outline tool (Fig. 3).

Using the options in the software, the equidistant semi-landmark points were resampled to 60 (Fig. 3) as this was considered sufficient to capture the entire periphery of the tool. PAST software version 3.22 (Hammer *et al.,* 2001) was used to treat the data. Using PAST, the variables of X and Y, the 2-dimensional cartesian coordinates were log transformed in the first step and then subjected to a " irecteurs paradigm" (Adams *et al*., 2013) (Fig. 4). Ordination method of Principal Component Analysis (PCA) was then applied, which gave a hierarchical organisation of the shape variation components. Thus, the first principal component (PC) identifies the major axis of shape variation or the first principal aspects of variation.

After the data acquisition and analysis, the results were presented graphically to facilitate identification and description of shape differences. In this study, the mean landmark configuration was warped to particular positions in the shape space (depending on the questions asked; here, outline variation in particular) and tps were also used.

Fig. 3: Geometric Morphometric semi-landmark outline capture with 60 equidistant points a. handaxe b. cleaver.

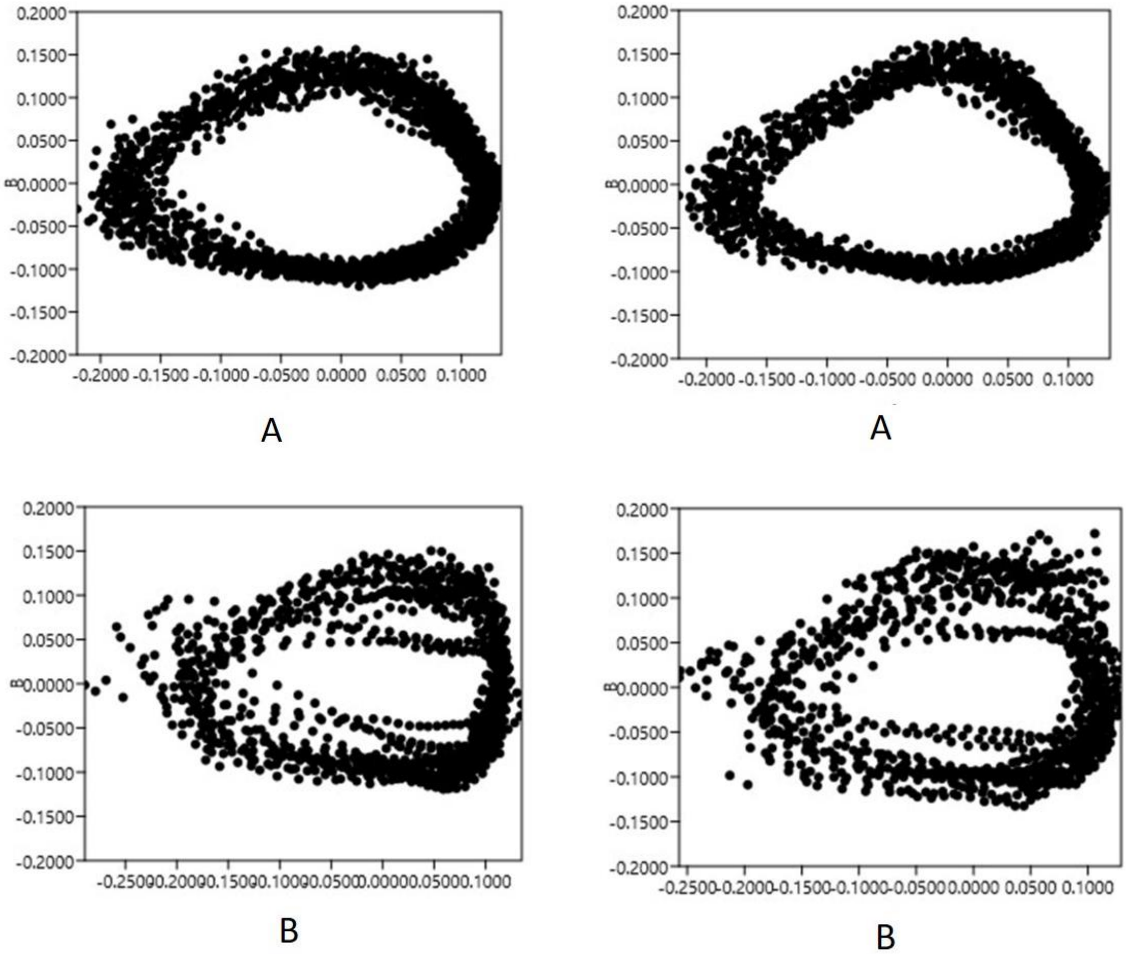


Fig. 4: Visualisation of the handaxes and cleavers after Procrustes transformation a. Tamil Nadu b. Karnataka

Although, here we use only semi-landmarks, shape variation can be studied by applying multiple combined landmark sets to verify results on larger samples and on 2D and 3D images. Some of the applications of 2D contour analysis on bifaces include that of Costa (2010), who used GM to assess the plan shape in bone and stone Acheulean bifaces from the Middle Pleistocene site of Castel di Guido, Latium, Italy. Iovita and McPherron., (2011) used EFA approach to examine and explain the shape and size variability in the Mousterian of Acheulean Tradition handaxes in comparison with Lower Palaeolithic Acheulean. Other examples include the semi-landmark approach used to compare handaxes from Bose Basin (China) and the western Acheulean, the results of which demonstrated an overlap of ranges of shape variation indicating cognitive similarities (Wang *et al*., 2012) and EFA approach to understand biface shape and symmetry in British–Acheulean handaxes by Hoggard *et al*., (2019). A recent application of shape morphometric analysis on the contours of handaxes using EFA, have demonstrated its utility to reappraise old collections from Congo Basin (Mesfin *et al*., 2020).

RESULTS

Typo-technological results – TN group

Handaxe (Fig. 5) was the predominant (75%) type of bifaces in this group of 103 tools. Handaxe dimensions ranged from 55 to 250 mm in length, 40 to 110 mm in width and 17 to 60 mm in thickness. Means, Standard Deviations and Coefficients of variation of linear measurements and weights are presented in Table 2, 3 and 4. While the heaviest handaxe weighed 1692 g, the lightest one weighed 38 g. Characterised by ovate, discoidal, and amygdaloid and triangular shapes, the majority of the handaxes were made on >10cm flakes. The handaxe butt was mostly dihedral (44%), plain or facetted with a few of the trihedral type.

Region	Number of tools	Length			Width			Thickness		
		Mean	S.D	C.V	Mean	S.D	C.V	Mean	S.D	C.V
TN	78	110	34	31	70	17	25	35	11	32
Karnataka	33	131	34	26	79	16	20	38	8	22

Tab. 2: Means, Standard Deviations and Coefficients of variation of linear measurements (mm) of handaxes by region.

Region	Number of tools	Length			Width			Thickness		
		Mean	S.D	C.V	Mean	S.D	C.V	Mean	S.D	C.V
TN	25	122	35	29	78	24	30	33	12	37
Karnataka	19	138	30	22	89	22	25	47	32	68

Tab. 3: Means, Standard Deviations and Coefficients of variation of linear measurements (mm) of cleavers by region.

Region	Number of tools	Weight		
		Mean	S.D	C.V
TN	78	271	261	96
Karnataka	33	422	342	81

Tab. 4a: Means, Standard Deviations and Coefficients of variation of weight (g) of handaxes by region.

Region	Number of tools	Weight		
		Mean	S.D	C.V
TN	25	438	317	72
Karnataka	19	472	365	77

Tab. 4b: Means, Standard Deviations and Coefficients of variation of weight (g) of cleavers by region

Fig 5. Tamil Nadu group a. Handaxe types b. Cleaver types

Fine grained quartzite was the preferred raw material of the tools, which were mostly in fresh condition with little abrasion. Iron encrusting has contributed to the weathering in the few abraded tools. The raw material from Attirampakkam is consistent with the other studies from the site (Pappu, 1999; Pappu *et al*., 2011) which reports cobbles and boulders of quartzite and quartzitic sandstone from the Satyavedu Formation as being the main raw materials used. Patination was largely absent with only a few tools having low amounts of red, yellow and black patination. Unpatinated tools are reported to be of earlier age with patination (due to presence of calcrete nodules) appearing more on quartzitic sandstones

(Pappu, 1996). Artefacts from surface sites are in general unpatinated (Pappu, 1999). As the museum collection seems to have resulted as an admixture of both surface and excavations, and by individuals and institutions at different times the non-patinated tools probably reflect those from the surface.

The attribute of cortex is an important indicator for the raw material, core reduction/technology and transport (Dibble *et al.,* 2005). Factors that influence the cortex retention in the tools assemblages has been discussed like the size of nodules, surface volume based on shape, emphasis on production of large flakes from the beginning of reduction process as would use of split cobbles as blanks (Dibble *et al*., 2005). In the studied sample, cortex was present only on 29% of the tools and it was mostly confined to the proximal end. These tools could represent an earlier stage of reduction or an intentional preference for ease of handling. The high percentage of handaxes without cortex suggest a high intensity of reduction. This is consistent with the refinement ratio (Length/Width) of 48% of the tools showing >1.5 values. Only 21 tools were flat handaxes following the flatness ratio of Bordes and Roe while most handaxes remained thick. Majority (55%) of the handaxes displayed bilateral symmetry in which 6 tools had symmetry except for the distal and proximal ends. In cross section of the handaxes, mainly biconvex and trapeze shapes were observed.

Most of the tools were made on both end-struck (37%) and side-struck flakes (18%). Although with a warning of not being definitive, Madsen and Goren-Inbar (2004) associate side-struck flakes with Levallois and bifacial cores and end-struck flakes with a long axis or "slicing" cores. Cobbles and split cobbles were also utilised as blanks for many tools (25%) which has also resulted in the cortex retention as mentioned above. Only one possible Kombewa flake was noted. "Flake blanks usually require less reduction to arrive at the handaxe form than cobbles" (Shipton and Clarkson, 2015). In this study, for most of the tools, the original blank-morphology has been completely modified by retouch. Thickness of the tool is the only indicator of the original blank size.

Intensive shaping has removed almost all traces of striking platform and only on a few specimens the type of striking platform could be determined. Striking platform, an important indicator of core preparation procedure (Herzlinger and Goren-Inbar, 2019) was plain for the majority (15%) of the recognisable ones and only 5% of the tools exhibited dihedral striking platform. A preference for lateral left angle and proximal centre could be discerned wherever the striking platform was noted.

Previous scar pattern is another attribute that throws light on the technology of reduction process. Convergent scar pattern is often associated with discoidal or centripetal cores (Koshy, 2009). Increase in the dorsal shaping scar count can reflect a later stage of reduction while the decrease in the dorsal scar count tells us that it has been removed in the early stage of reduction (Koshy, 2009). On the dorsal surface, the shaping scar pattern (2 to 10 scars) mostly followed convergent directions with three-directional preferred next (Fig.6) Unidirectional and Unipolar longitudinal scar patterned tools remained negligible with only 1% each. However, the invasiveness of the scars on the dorsal face varied between 5 and 83 mm in maximum length, whereas for the ventral face it was 15-46 mm. Comparisons between the ventral and dorsal flake scar density and pattern show similar trimming actions on both faces.

The edge angles for the lateral left and right sides were medium (60°-80°). While for the former, there were 3 generations of removals on the upper face and 1 on the lower face, the latter had 4 generations of removals and 1 minimum on the lower face. The proximal and distal edges had an average of 1 generation of removals. The proximal and distal part with sharp (60°) and steep angles (80°-110°) had an average of 1 generation of removals.

Only 3 handaxes were found broken at the distal end, which could be the result of usage or post-depositional damage.

PCA results on the elongation vs. thickness of the handaxes showed that most of the handaxes from TN were thin and were neither too long nor short (Fig. 7). Four tools fall outside the cluster of tools within the ellipses as can be seen in the figure.

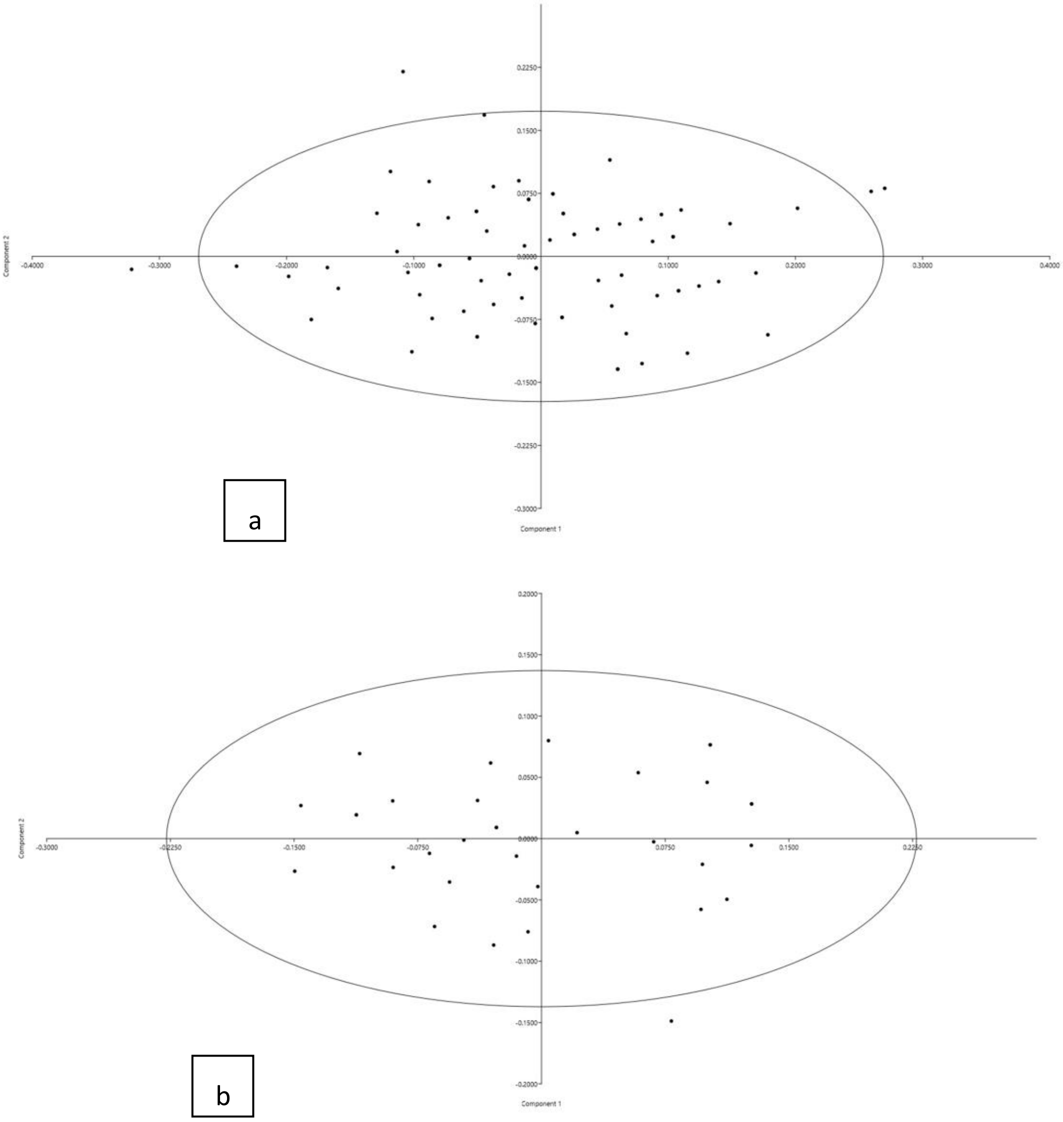


Fig. 7: Principal Component Analysis on shape indices elongation (length/width) and thickness in relation with flatness ratio (width/thickness) on a. Tamil Nadu handaxes and b. Karnataka handaxes.

The cleavers (25 tools) (Fig. 5) in this group from TN were mainly on medium grained quartzite, with 17 tools showing bilateral symmetry. The tool measurements ranged between 40-175 mm in length and 24-126 mm in width and in 14-74 mm thickness. Since the cleavers are less intensively shaped than handaxes, the thickness of these tools reflects the thickness of the original blank in most cases (Sharon, 2007). The heaviest cleaver was 1036 g and the lightest cleaver was 37 g. Although all the blank forms could not be identified, mainly end (38%) and side-struck (30%) blanks seem to have been used wherever it could be discerned. With medium abrasion and mostly on dihedrally shaped butt, these tools retained cortex only on two specimens. In cross section, they were plano-convex, and biconvex for most tools. Previous flake scar pattern was mainly three-directional with 42% of the tools having orthogonal and bidirectional scars. As in the case of handaxes, the striking platform could not be identified for the majority of cleavers and where it could be identified, it was mostly plain. Only one

specimen each had a cortical and dihedral platform. Angle right was the common location for the striking point, followed by left and centre.
Lateral left and right edges measured 60° to 80° while the distal ends were both sharp and steep angled. The proximal edge remained largely steep angled. Secondary shaping/retouch was up to 2 generations in the ventral faces except for the distal edge while on the dorsal it was up to 4 on lateral sides.

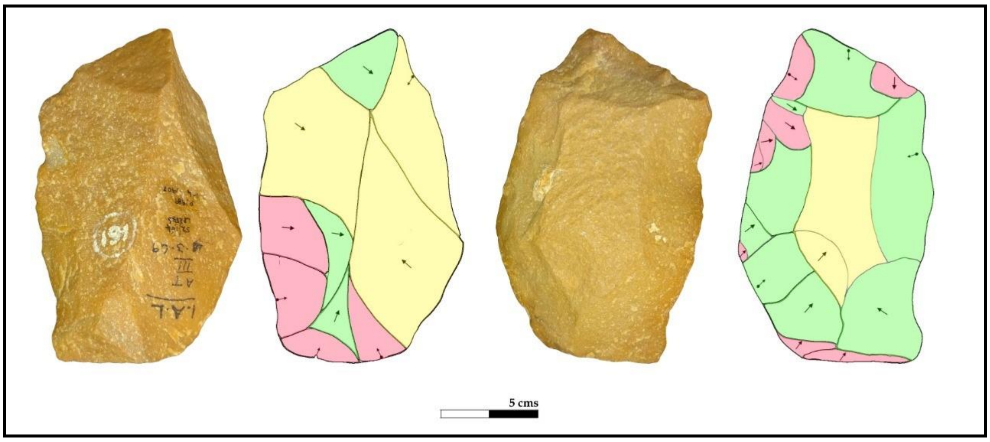


Fig 6. Shaping removal patterns and of series of removals on cleaver from Attirampakkam - Last series of removal, Second series of removal, First series of removal.

Typo-technological results –Karnataka group

Handaxes (33 tools) varied in shapes (Fig. 8) of triangular, sub-triangular, ovate etc. Raw material was quartzite, mostly fine grained, and on varying shades of brown with some tools having red or yellow patination. The Malaprabha raw material, has its origins from the Kaladgi series (Joshi, 1955; Koshy, 2009). While the shortest handaxe measured 72 mm, the longest measured 202 mm. The width of the handaxes ranged from 50 to 117 mm while the thickness was between 23 and 55 mm. The heaviest handaxe was 1322 g and the lightest was 100 g. Abrasion was medium to high for 78% of the tools. The handaxe butts were mainly plain, followed by dihedral 27% and cortical types. Facetted and trihedral forms were limited to less than 5 specimens. One specimen had a shouldered butt resembling a hafting shaft and probably could be the "correction" made by the knapper during a knapping error, to make it symmetrical (either for functional; better grasping, or aesthetic purpose).

Cortex pattern shows 24% of the handaxes with cortex, mainly confined to the proximal left. Only one handaxe had cortex extending to the ventral face. Bilateral symmetry was present for almost all the tools (85%), among which 2 tools had asymmetry observed on the proximal end. Plano-convex was the main cross section observed with some tools also having biconvex and biplanar shapes. Although a few blanks could not be identified due to intensive shaping, flake blanks include a majority of both side and end-struck products (51%) apart from 7 cobble blanks and 3 tabular blocks/slabs.

Fig. 8: Karnataka group a. Handaxe types b. Cleaver types.

Unfortunately, the striking platforms remained indeterminate for a large number of specimens and wherever it could be identified, it was plain with just 2 specimens showing facetted and dihedral types each. They were located mostly on the centre of the proximal end and angle right. Shaping scars (from 3 to 12 scars) showed mostly convergent directions with a few tools displaying three-directional and bidirectional pattern. Flake scars on both dorsal and ventral faces showed a uniformity with most of the tools intensively flaked to the point of entire removal of original surface. Flake scars were both deep and shallow, which attests to the use of hard hammer and soft hammer. Edge angles for the lateral left, right and proximal ends were medium (60°-80°) while for the distal end it was a sharp edge (<60°). There were 1 to 2 generations of shaping in average observed on both faces but the proximal end seems to be more retouched with 3 generations at least. This could be related to the thinning of the butt for better grasp and reflects the knapper's skill. Generally, the handaxes were refined (70%) and thick in size. Only one tool was broken at the distal end.

PCs generated for the shape indices of elongation in relation to thickness (Fig. 6) show that most of the Karnataka handaxes were thinner but when it came to elongation, there were both short and long ones. The one specimen, which stood out of the ellipses, was very round and thicker than the rest and is from the site of Khyad.

The cleavers (19 tools) (Fig. 8) were produced on medium grained quartzite in shades of brown and cream with no patination observed on any tool. Abrasion was medium to high. While the length varied from 89 mm to 180 mm, the width ranged from 50 mm to 138 mm and the thickness from 26 mm to 175 mm (Fig. 6). The tools weighed between 165 to 1024 g. They were mostly produced on side-struck flakes (37%) followed by end-struck flakes (26%) as can be observed from the recognisable blank types. Although shaping has removed information on majority of the tools, plain striking platforms located at angle right seems to be the norm for the majority of tools. Cortex was present on only two tools on angle right. Bilateral symmetry was observed on majority of the tools (95%), except for two tools, which were asymmetrical towards the distal and proximal extremities. Cross section of the tools showed plano-convex and trapeze types. Shaping scar patterns show three-directional followed by orthogonal and bidirectional patterns (Fig. 9).

Lateral left, right and proximal edge angles were oblique while the distal edge had a cutting edge of <60°. Only one generation of retouch was observed on all edges on both faces for many, except for the lateral right and distal part of the cleavers.

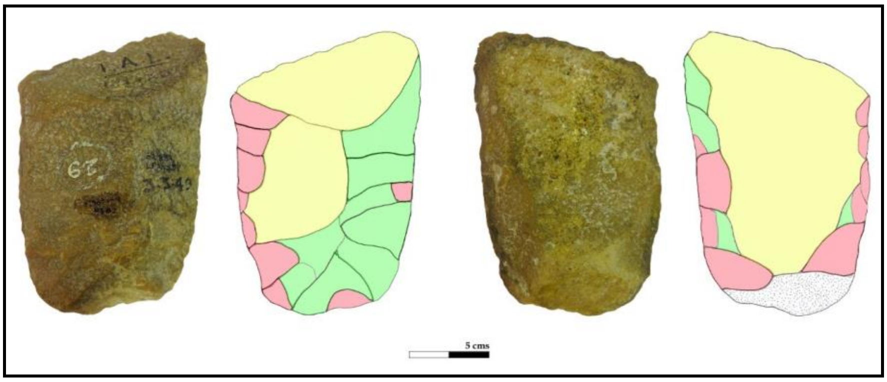
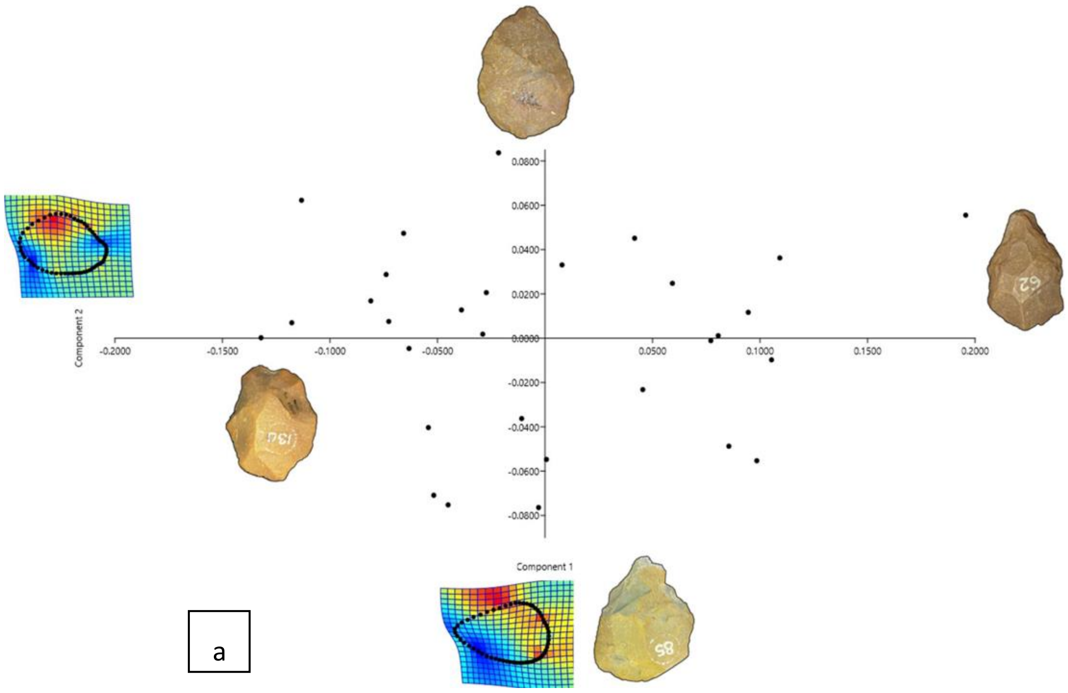


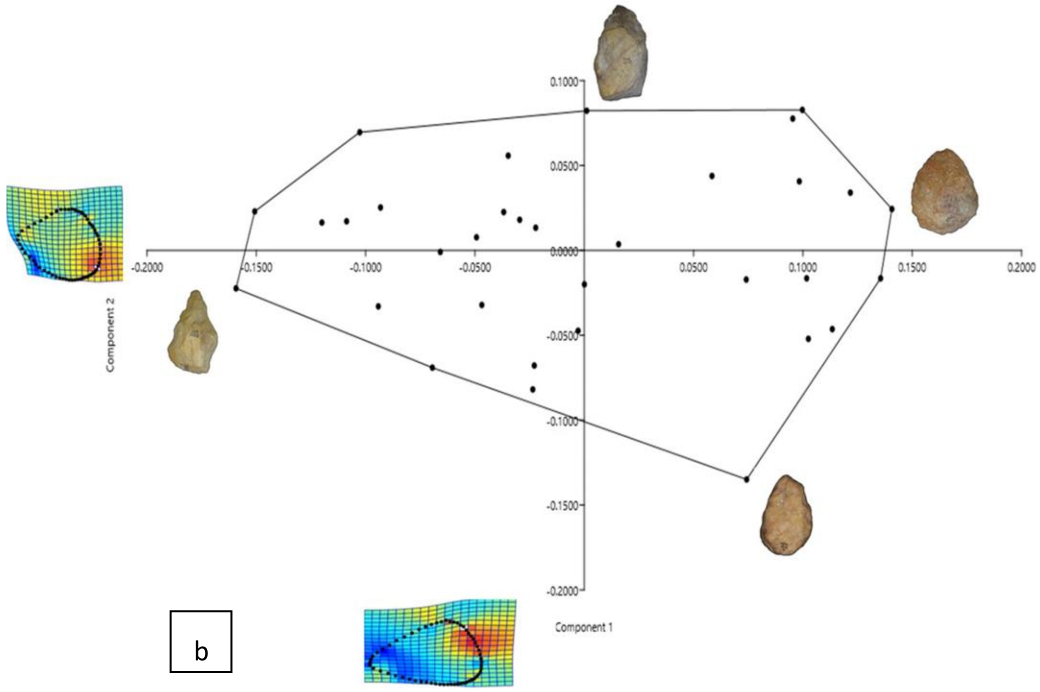
Fig 9. Shaping removal patterns and series of removals on cleaver from Khyad – Last series of removal , Second series of removal , First series of removal , Cortical surface .

Geometric Morphometric results – TN group

The results of the Principal components analysis for the handaxes demonstrate that the first three PCs account for 48.7 %, 13.4 %, and 9.7% of the variation in the handaxes respectively (Table 5). Cumulatively, PCs 1 to 10 account for over 95% of the total variation in shape differences between the handaxes.

While PC1 covers the range of handaxes from rounded to pointed or elongated ones, PC2 covers the handaxes from non-symmetrical to symmetrical shapes. The clustering of the majority of the handaxes in the upper left quadrant indicates that most of them were shorter and symmetrical ones while the lower right quadrant shows that a few of the handaxes were non-symmetrical but elongated (Fig.10).





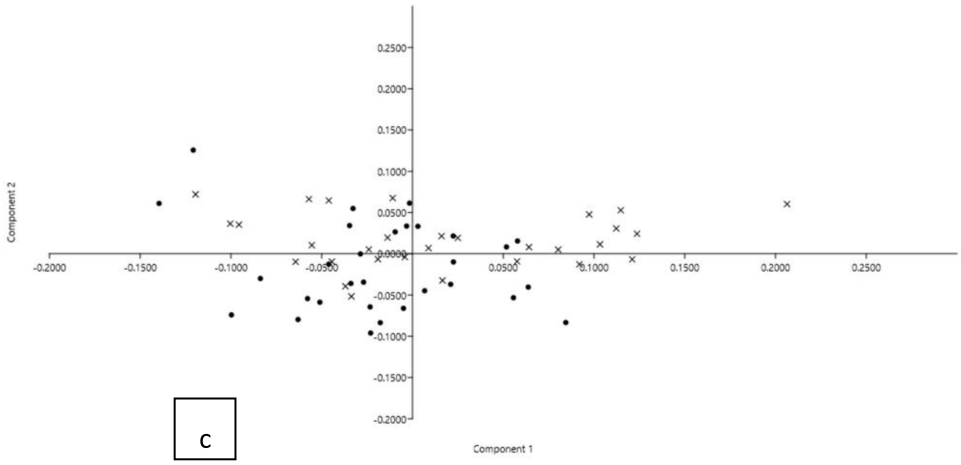
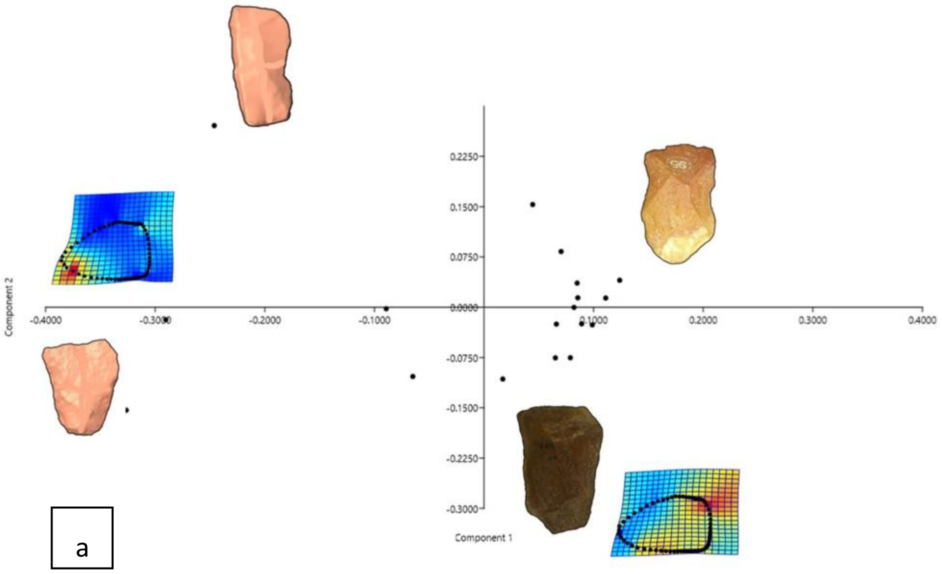
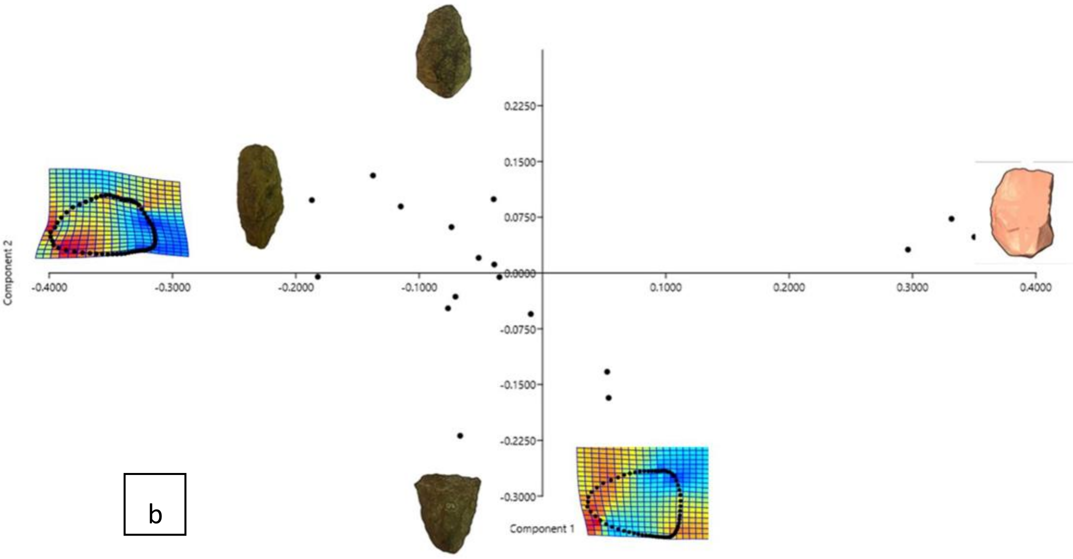


Fig. 10: Principal Component Analysis of Geometric Morphometric analysis of Handaxes 2D contours: scatter plot of PC1 versus PC2, and visualization of the shape differences and TpS deformation a) Tamil Nadu b) Karnataka c) combined, (×) representing Tamil Nadu and (.) representing Karnataka.

Of the 17 PC's generated for cleavers, the first three capture 87% (Table 7) variation. While up to the sixth PC captures a total of 96% variance, all remaining PCs each account for less than 4% of overall variation. As reflected in the figure 11, the shape variation in cleavers with broader cutting edge and butt to almost bilaterally symmetrical cleavers with shorter cutting edge are covered by PC1 while PC2 shows cleavers from broader to narrower ones.


Component 2
Component 1
a


Component 2
Component 1
b

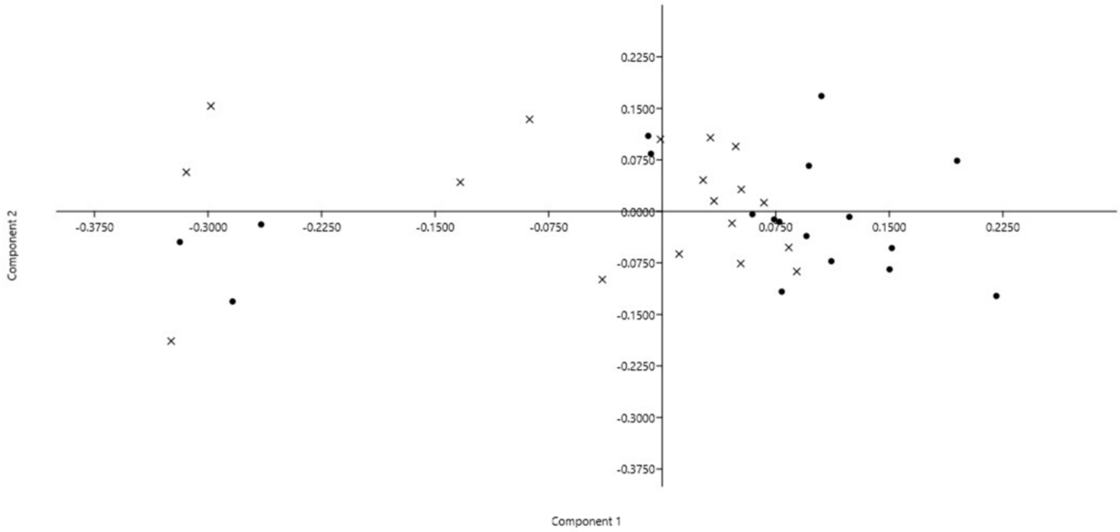


Fig. 11: Principal Component Analysis of Geometric Morphometric analysis of Cleavers 2D contours: scatter plot of PC1 versus PC2 and visualization of the shape differences and tps deformation a. Tamil Nadu b. Karnataka c. combined (×) representing Tamil Nadu and (.) representing Karnataka.

PC	Eigenvalue	% variance
1	0.0207211	52.51
2	0.00979438	24.82
3	0.00380893	9.6523
4	0.00150888	3.8237
5	0.00112964	2.8626
6	0.000823858	2.0878
7	0.000385053	0.97577
8	0.00036195	0.91723
9	0.000259035	0.65643
10	0.000192022	0.48661

Tab. 6a: Principal Component scores (first 10) of cleavers from TN.

PC	Eigenvalue	% variance
1	0.0267146	56.815
2	0.00928344	19.743
3	0.00363356	7.7276
4	0.002545	5.4126
5	0.00143562	3.0532
6	0.00110434	2.3487
7	0.000638451	1.3578
8	0.000419794	0.89279
9	0.000317479	0.67519
10	0.000305858	0.65048

Tab. 5b: Principal Component scores (first 10) of cleavers from Karnataka

The PCs generated for the cleavers are 17 and the first seven (Table 6) contribute to 96% of the variation. Together the first three PCs explain 84% of the total variance. While the cleavers from fan-like shape, with broad cutting edge and narrow butt, to triangular shape, looking like handaxe, are covered by the first PC, narrow to broader cleavers are covered by PC2 (Fig.11). The clustering of most cleavers in the upper left quadrant indicates preponderance of narrow cleavers with shorter cutting edges.

DISCUSSION AND CONCLUSION

Sample size, if small, especially in comparisons between various assemblages, can be an issue. However, in the studies of Weiss *et al*. (2017), it has been shown that a reduced sample can still capture the characteristics of the site. Undertaking studies on even small samples "when successful, can produce incredibly detailed results that bring to life the actions of an individual sometime in the past." (McPherron, 2006). The current study on a small representative sample from two regions give interesting insights on the techno-typological knapping behaviour of the site occupants.

The results show some inter-regional convergences and divergences. While the handaxe remained the most variable tool in both regions, corroborated with the GM analysis (Fig.10), cleavers from both the regions showed an adherence to specific types (Fig.11).

The handaxes predominated in the TN sample, cleavers accounted for 56% in the Karnataka sample. Both groups showed similarities in use of quartzite as raw material (fine-grained for handaxes and medium grained for cleavers), low patination and presence of cortex on handaxes (predominantly on proximal end). Although the use of other raw materials for bifaces like sandstone, clay-schist, granite pegmatite etc., has been reported by Joshi (1955) from the Malaprabha region, these raw materials were not encountered in these museum collections. Joshi (1955) reports that most of the tools were made on flakes with a low proportion of core and pebble tools. This is reflected in this collection. While the TN handaxes were in fresh condition, those from Karnataka appeared in medium abraded condition. Bilateral symmetry was higher for handaxes in the latter. Use of both hard hammer and soft hammer can be suspected from the morphology of the shaping scars, as deep and marginal scars result from the use of the former. A few tools displayed asymmetry at the distal and proximal ends in both sites. Biconvex (majority in TN), plano-convex (majority in Karnataka) and trapeze were the main cross sections observed in both sites. The variable with the most variations in both regions, were the weight and in linear measurements, the length for the handaxes. In the PCA of elongation versus thickness rules, the extreme variability shown by the 4 outliers in the TN group can be explained as except for one tool from Attirampakkam, all other 3 tools are from different sites of Satyavedu, Kanchipuram and Madras. Karnataka handaxes show the same range of variability with only one outlier, a specimen of a handaxe possibly recycled as a core.

Cleavers from both regions were longer, broader, and thicker (except for TN) than the handaxes (Table 2 and 3). The use of side-struck and end-struck flakes as blanks may explain this. Cleavers were also heavier in both regions. Broadly, the morphology of the handaxes and cleavers overlap in both the regions despite a few differences. While in TN the majority of cleavers were with straight cutting edge and U-shaped butt, in Karnataka, cleavers with short, diagonal cutting edge and V-shaped butts were the preference. While the variation in handaxes could be due to the different flake blanks (cobbles, end-struck flakes, and tabular blocks/slabs), raw material clast differences in shape and size and the cleaver's similar shapes could be the result of a higher standardisation apart from use of similar flake blanks. A high percentage of bifacial artefacts (68.66%) with no cortex suggest a high intensity of reduction, of which the initial stages were carried out elsewhere. This is consistent with studies on Attirampakkam site (Pappu, 1996) where finished tools outnumber the unfinished ones.

Indian Acheulean is generally considered as "Large Flake Acheulian" with affinities with the African Acheulean (Sharon, 2010). The handaxes from both the regions reflect this with their lengths being more than 10 cm. The bifaces from both groups of tools exhibit Late Acheulean characteristics, as reflected by the majority of surface site collections of Acheulean bifaces in India (Mishra, 2008). 'Madras Industry is thus extra-ordinarily similar to the Karnatak industry, particularly so in its groups II and III" (Joshi, 1955), II and III groups being Middle and Late Acheulean, based on patination being less in the latter. This is true of the museum collections studied here although the handaxe variation is more in this study collection, probably owing to differential collection from different times and uneven distribution among museums.

"**F**or collection and archiving of digital models from the massive collections of stone tools in museums and private hands, just on practical grounds there will always be a role for 2D methods" (Shott, 2014). In this preliminary study, we have shown how 2D GM contour analysis can give accurate and precise information on morphological divergences and convergences on small representative museal collections and even bring out regional variations on smaller samples. In future, more tools from the study region will be analysed to increase the accuracy and integrity of these museum collections to give a comprehensive picture. In addition to 2D GM contour analysis, 3D GM landmark approach will also be implemented using the latest software like AGMT 3-D.

In this paper, we have shown how traditional methods (descriptive and metrical) need not be set aside completely while embracing new methodologies like geometric morphometrics (2D contour analysis in this study) and how we can use both in complementary ways. This will enhance our understanding of the biface analysis by including as many perspectives as we can because if we restrict our tool analysis to just typology or just technology it "…may not help elucidate the rationale of tool production in the first place" (Andrefsky, 2009).

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APPENDIX II – ARTICLE 2

Geometric Morphometrics and Handaxe shape at Benkaneri, Malaprabha Valley, India

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1. Introduction

Tools made on stone, by virtue of their abundance, long survivorship, and widespread spatial and temporal distribution, have been the main focus of Palaeolithic studies. Lithic analysis "can address issues from the evolution of modern human cognition to pragmatic action in the past to labour organisation to symbolic manipulation" (Moloney and Shott 2003). The morphology of tools has been an important aspect of this analysis. Typological classification is often used to determine industrial and cultural affinities and used to make comparative studies across regions.

One of the tool types which has been an important focus in this regard is that of the handaxe, long considered as the "fossile directeur" of the Acheulean culture. Found in both Lower and Middle Palaeolithic cultural contexts, research on handaxe variability has spanned nearly two centuries (Key 2019). This research has encompassed many approaches, including a cultural historical approach, which examined the evolution and refinement in forms, a processual method, which studied reduction processes in detail, and a post processual perspective, which zeroed in on "social technology" (Milliken and Cooke 2001).

Variation in handaxes has been attributed to various technological influences, including the shape, size and properties of raw materials and blank shapes and types (Ashton and McNabb 1994; Jones 1994; White 1998; McPherron 1995, 2000; Gamble and Marshall 2001), artefact maintenance behaviours, curation and recycling (Dibble 1987, 1988, 1991) and tool resharpening and bifacial reduction (McPherron 1994, 1995, 2000; Shipton and Clarkson 2015). Some researchers (Davidson and Noble 1993; Ashton and McNabb 1994; White 1998; Wenban-Smith et al. 2000; Milliken and Cooke 2001) attribute handaxe shape differences to a wide range of biological and cultural factors, such as the mental templates of knappers, copying errors (Schillinger et al. 2016), tool traditions (Roe 1964, 1968) and skill acquisition (Pargeter et al. 2019), learning and know-how (Wynn and Tierson 1990; Pargeter et al. 2020). Allometric, or size-related variations have been considered to be a key factor by Crompton and Gowlett (Crompton and Gowlett 1993; Gowlett and Crompton 1994). Utilitarian and non-utilitarian functions have also been proposed for conditioning handaxe variability (O'Brien 1981; Mitchell 1996; Gowlett 1998; Kohn, and Mithen 1999; Vaughan 2001; Bello et al. 2009; de Juana et al. 2010; Spikins 2012; Brenet et al. 2017; Pedergnana et al. 2020;).

In the present study, classical and geometric morphometric approaches have been undertaken to quantify and analyse handaxe variability from the Middle Palaeolithic site of Benkaneri in the Malaprabha Basin (Karnataka). It is the first time a geometric morphometric approach is used on lithic assemblages from this region. Handaxes are predominantly bifacial, but sometimes include unifacial forms (Debenath and Dibble 1994) with cutting edges mostly on lateral and distal sides and having pointed or oval shapes.

The aim of this study is three-fold: (1) to explore handaxe variability from Benkaneri; (2) to examine the main attributes responsible for handaxe variability, and to determine where this variability is located on the tools; (3) to make inferences about the planning abilities of the Benkaneri hominins, specifically addressing their choices, preferences, and skills. Application of state-of-the-art research methods to quantify handaxe shape variability is combined here with technological and typological characteristics of these lithic tools.

1.1 Geometric Morphometrics - A “Revolution”

Both qualitative descriptions and Morphometrics (Greek morph = form, shape and metrics = measurement), or quantitative analysis of form, remain an essential approach to any lithic analysis. Handaxe techno-typological analyses have been heavily influenced by the methods described by Bordes (1961) and Roe (1964,1968). Subjectivity owing to differential levels of expertise, manual errors arising from incorrect orientation of tools, and inefficiency of orthogonal analysis to capture the absolute form and volume of asymmetrical, irregular shaped tools, and poor differentiation of tool size and shape were problems which necessitated a new approach (Grosman et al. 2008; Ioviţă 2010; Tyldesley et al. 1985) in the field of lithic metrical analysis.

From the 1970's onwards, attempts were made to provide a precise description of artefact shape (Gero and Mazzullo 1984; Montet-White 1973; Wynn and Tierson 1990). These were based on coordinate methods borrowed from the biological sciences.

Geometric morphometrics (GM) is an approach that was initiated in the 1980's in the field of Evolutionary Biology (Okumura, and Araujo 2019). This "revolution" (Rohlf and Marcus 1993) was an alternative answer to the shortcomings of traditional morphometrics. GM are a class of multivariate statistical methods that measures and analyses the shape variations of an object based on its cartesian coordinates (X, Y, Z) of variables expressed as landmarks (Bookstein 1991; Okumura, and Araujo 2019; Rohlf and Marcus 1993).

Main concepts of GM (Table 1) include homology, morphological integration, landmark types, modularity and allometry (Okumura, and Araujo 2019; Webster and Sheets 2010). In GM analysis, shape is defined as all the geometric information that remains on an object when factors of size/scale, location/position, and rotational effects/orientation are taken out (Bookstein 1998; Klingenberg 2013), whereas size is often equivalent to centroid size, the "measure of size that quantifies the spread of landmarks around their centroid, or centre of gravity" (Klingenberg 2013; Okumura, and Araujo 2014). Form integrates information from both shape and size (Mitteroecker and Gunz 2009; Adams et al. 2013). In Kendall's shape space, a key component of GM, "each possible shape (for a given number of landmarks and dimensionality) corresponds to a single point in the shape space and every point in shape space corresponds to a particular shape" (Klingenberg, 2013).

The major types of data in GM are the homologous landmarks, outlines, and surfaces. Unlike biological specimens, lithic tools are often neither symmetrical nor complete and lack homologous points. Although landmarks can be placed manually at tool plan view extremities (the distal and proximal areas/sectors of the tool), differences in their number and location often causes problems in comparative studies, besides being inept at capturing the whole shape details. In an attempt to solve this problem, Lycett et al. (2006) used an instrument called a Crossbeam Co-ordinate Caliper (CCC) to locate geometric homologous landmarks (named as “semi-landmarks”) on the lithic nuclei they studied, which helped in their morphometric analysis (Lycett 2007; Lycett et al. 2006). Outline data are shapes of open or closed curves (Rohlf and Slice 1990) which can be analysed using Elliptical Fourier Analysis (EFA), Eigenshape and semi-landmarks or otherwise known as sliding landmarks (Mitteroecker and Gunz 2009; Okumura and Araujo 1993). Surface data that can be used in GM analysis can be collected by superimposing a grid with equidistant landmarks, to capture the surface of the tool evenly.

GM data is in the form of 2 or 3 (X, Y and Z) dimensional Cartesian coordinates (Rohlf and Marcus 1993) which are unique point locations in a plane, defined by a set of numerical coordinates (X, Y, Z) measured in the same units. While the former is captured from images, such as photos or drawings, the latter is captured directly using a coordinate digitizer or measured on surface or volumetric scans (Mitteroecker and Gunz 2009).

Generalised Procrustes Analysis (GPA) (Bookstein 1990) and Principal Component Analysis (PCA) are the principal multivariate statistical procedures to extract and to exploit the GM data.

	Terms	Definition	References
1	Landmarks	Corresponding homologous finite points appearing in consistent location in each specimen/ "samples of discrete points which correspond among all the forms of a data set" (Bookstein, 1990:58).	Bookstein, 1990 Okumara and Araujo, 2019
2	Semi-landmarks, sliding landmarks	"landmarks on smooth curves/surfaces with positions along the curvature that cannot be identified and that are thus estimated" (Mitteroecker and Gunz, 2009:236). Semi-landmarks make it possible to quantify two or three-dimensional homologous curves and surfaces. Sliding landmarks are semi-landmarks that are made to slide to minimize shape differences between each specimen and the average shape in the sample.	Rohlf and Marcus, 1993 Mitteroecker and Gunz, 2009
3	Homology	Biological (based on phylogenetic, developmental functional aspects) and Geometrical (based on consistent geometric positioning of tools) consistent pattern of location of points. In lithic tools, "correspondence of point(s) (or measurement) across the range of lithic forms in a given analysis." (Lycett, 2009:81)	Mitteroecker and Gunz, 2013 Lycett, 2009
4	Morphological integration	"The covariation of morphological structures in an organism or of parts in a structure, which may reflect developmental or functional interactions among traits" (Klingenberg, 2010: 623). Closely related to the concept of modularity, it is the "particular pattern of variation and covariation among parts that modularity brought about..." (Okumara and Araujo, 2019:153, Mitteroecker and Bookstein, 2007).	Mitteroecker and Bookstein, 2007 Klingenberg, 2010 Okumara and Araujo, 2019
5	Modularity	Modularity can be "characterized as a property of processes/modules." "Modules were defined in terms of internal relations/dependent elements (like size and shape characteristics of the stem or blade), as well as external relations/independent elements (the blade in relation to the rest of the point) in the case of a projectile point" (Okumara and Araujo, 2019:153, Mitteroecker and Bookstein, 2007).	Mitteroecker and Bookstein, 2007 Okumura and Araujo, 2019
6	Allometry	Size–shape relation in a morphological integration.	Okumura and Araujo, 2019
7	Kendell's shape space	"(the non-linear) space induced by a set of shape coordinates". (Mitteroecker and Gunz, 2009:236).	Mitteroecker and Gunz, 2009
8	Centroid	"…the centre of form" (Okumura and Araujo, 2014:62)/central point of all regular and irregular shaped objects.	Okumura and Araujo, 2014
9	Centroid size	"square root of the sum of the squared distances from all the landmarks to the centre of the form (centroid)" (Okumura and Araujo, 2014:62).	Okumura and Araujo, 2019

Table 1. Terms and concepts used in Geometric Morphometric Methods.

1.2 Application of 3D GM shape analysis to handaxes

The introduction of 3D scanners and photogrammetry facilitated the creation of 3D models of Lower Palaeolithic handaxes (Grosman et al. 2008; Sumner and Riddle 2008) which helped to eliminate measurement errors due to incorrect orientation. Various aspects of handaxe studies have been addressed such as the morphological similarity of Victoria West and Lower Palaeolithic handaxe forms (Lycett and Chauhan 2010), the efficiency of both 2D and 3D GM analysis of handaxes from Elandsfontein in comparison with experimentally produced handaxes to determine the influence of specific reduction strategies (Archer and Braun 2010), the characterisation, quantification and description of post depositional damage on Acheulian bifaces (Grosman et al. 2011), the relation of reduction intensity to handaxe symmetry (Li et al. 2015), the quantification of knappers skill and resulting shape differences (Herzlinger et al. 2017), the similarity in form and the relationship between Keilmesser, handaxes, simple scrapers, and unifacially shaped scrapers with a Keilmesser-like morphology (Weiss et al. 2018), the relationship between initial nodule or blank morphology and final handaxe (García-Medrano et al. 2019), and the functional potentiality of bifaces (Viallet 2019). Using handaxes from ten different assemblages and incorporating replicas, a comparative 2D and 3D GM analysis was carried out, which showed that 3D forms displayed stronger form limitations. Aredo et al. (2019) applied the 3D homologous GM method to handaxes and cleavers from stratified localities at Melka Wakena and came up with the result that the technological characteristics and tool morphology did not have any clear association. An Elliptic Fourier Analysis was used to quantify the shape and symmetry of British Acheulean bifaces and explore their changing relationship in corresponding individual interglacial period (Hoggard et al. 2019). Handaxes from Gahagan site from the southern Caddo area and central Texas were subjected to geometric morphometric analysis to discern the intraspecific morphological variations (Selden et al. 2020).

Using the newly developed AGMT3-D software, the landmark-based shape analysis was also carried out on experimentally produced handaxes and compared with the Acheulean bifaces from Gesher Benot Ya'aqov (GBY), Israel, to reconstruct the *chaîne opératoire* (Herzlinger and Grosman 2018). Acheulean handaxes and cleavers were subject to a 3D morphometric analysis to discern the influences of technological procedures, reduction intensity and raw material characteristics on final tool shape, from the site of Melka Wakena (Gossa Aredo et al. 2018). Similar to the earlier study (Herzlinger and Grosman 2018), the Acheulean handaxes and cleavers from GBY were subject to a AGMT3-D GM analysis to understand their morphological and technological traits (Herzlinger and Goren-Inbar 2019). Morphologically different handaxes from two Middle Pleistocene sites, Boxgrove and Swanscombe, were subjected to 2D and 3D shape analysis using AGMT3-D Software (García-Medrano et al. 2020), while handaxes and cleaver-like tools from La Noira were subject to the AGMT3-D Geometric Morphometric analysis (García-Medrano et al. 2021).

Although Lycett (2007) used GM techniques to compare some of the Soanian cores (earlier believed to be of Lower Palaeolithic origin), the first site to be directly subjected to this approach in India, was that of Patpara in the Son Valley (Shipton et al. 2013) and large cutting tools from the Hunsgi-Baichbal Valley (Shipton, 2013). At the site of Patpara, through applying 3D shape analysis, the similarity of Acheulian cores to Levallois cores and the essential technical nature of transition from Lower to Middle Palaeolithic was brought to focus (Shipton et al. 2013).

1.3 Advantages of Geometric Morphometric Methods

A classical morphological approach, while being able to take into account many attributes for detailed technological analysis, has had a problem of "…replicability – the likelihood that two researchers measuring the same variable (or one researcher measuring a variable at two different points in time) can consistently achieve the same result" (Odell 2004). In addition, traditional lithic analyses are limited in capturing the multivariate nature of morphology through one-dimensional measurements and angles (Crompton 2007).

A GM approach brings precision and reproducibility of the tool measurements besides providing immediate visual results. It also helps in pinpointing the exact location of the morphometric changes on tools, while making the 3D models easily accessible to international scholars for comparative studies. GM results take into account the entire tool volumetric configuration (combining the plan-shape, profile-shape and topography of the tool and thus providing the three cartesian coordinate dimensions of X, Y and Z), moving beyond morphological descriptions while identifying the causative variables in tool variability (Shipton et al. 2013). Moreover, this approach can be used as a verification of existing tool classifications which were based on temporal, spatial and cultural affinities (Herzlinger et al. 2017). This is important in the context of the classification of Indian lithic tools mainly dependent on typology, as assemblages often originate from open-air sites, in the absence of absolute dates for many.

However, traditional methods should not be simply replaced by digital methods and, indeed, to evaluate the meaning of objects, one must go beyond statistical results, incorporating both sets of methods (Grosman 2016). To realise this end, this study incorporates both GM and classical analysis to study the handaxes from Benkaneri site (India).

2. Study Material

2.1 Site description and excavation history

Benkaneri (Fig.1) is located in the Malaprabha Basin, Karnataka, southern peninsular India. This region is rich in Lower and Middle Palaeolithic sites as illustrated in the extensive Pleistocene studies of Joshi (1955) and R.S. Pappu and Deo (Pappu 1984, Pappu and Deo 1994). Located on foot slopes north of the Kaladgi escarpment, the site of Benkaneri was first discovered in 1990's as a result of systematic explorations carried out by Korisettar and Petraglia in the Malaprabha Basin (Korisettar and Petraglia 1993). Along with the excavations at the nearby Lakhmapur site, located 5 km to the west, Benkaneri was subject to test excavations in 2000 (Petraglia et al. 2003a). Two trenches (2×1 m and 2×2 m) were laid out in a colluvium at the base of the quartzitic ridge and hill slope. As in the case of Lakhmapur-East, the archaeological material was found in a latosol horizon (Petraglia et al. 2003b). During the site excavations, lithic material was subdivided into three layers (or spits) of ~10 cm thick. Later, a North-South geological transect (240 m, 24 squares of 10×5 m) was laid out from the escarpment to the nearby cultivated fields in order to study raw material and artefact variations by Jinu Koshy for his doctoral thesis (Koshy 2009). Use of prepared core methods, radially prepared flake tools, the presence of diminutive bifaces, and the presence of the complete chaine operatoire at Benkaneri led to the site to be classified as the first Middle Palaeolithic quarry site to be excavated in India (Petraglia et al. 2003b).

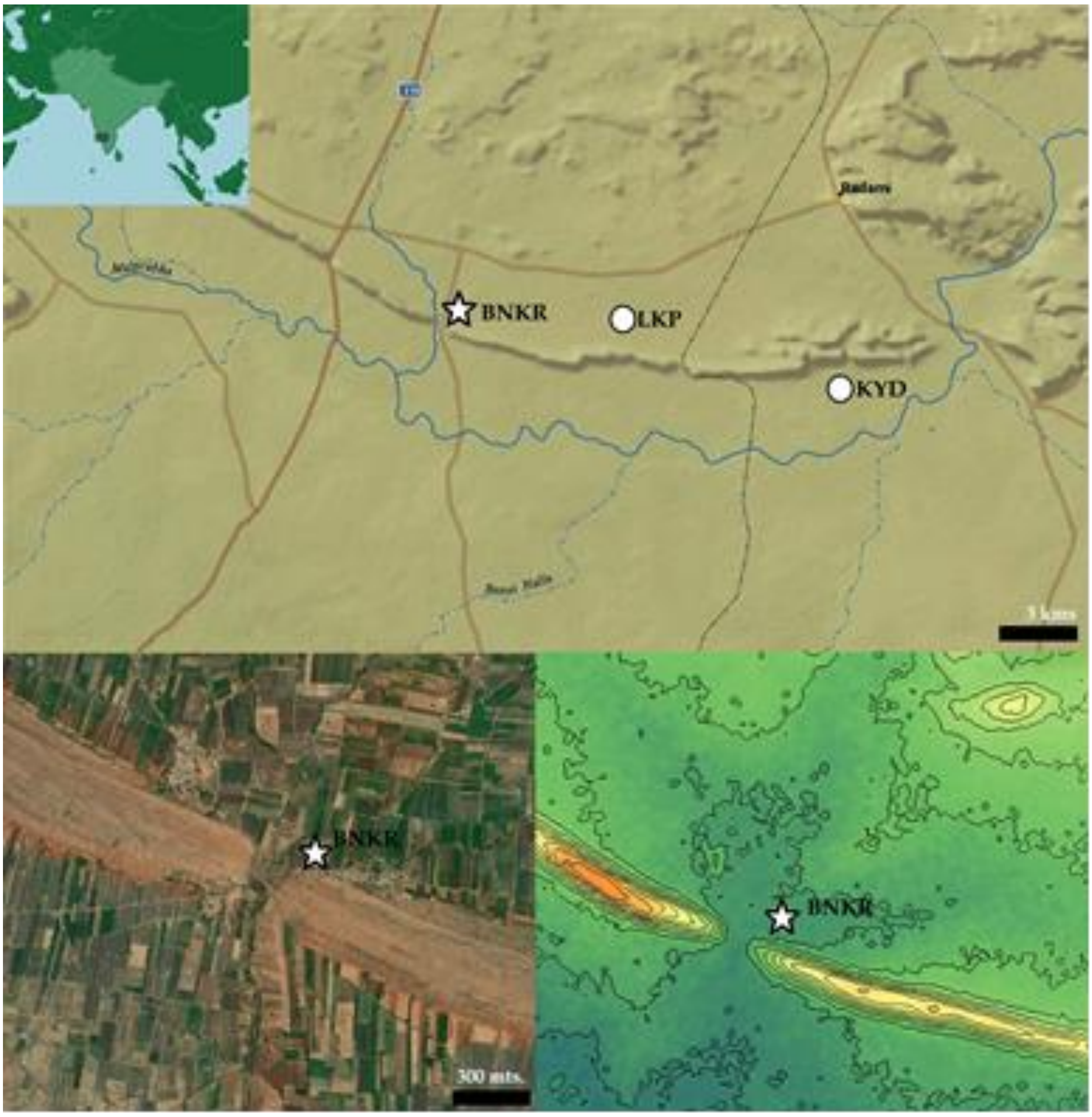


Fig. 1. (A) Location of Benkaneri in the Malaprabha Valley, Karnataka, in relation with other sites of Khyad and Lakhmapur - general topography (B) LANDSAT and (C) DEM (source: modified NatGeo map).

Fig. 2. (A) General view of the site showing the type of raw material clasts in surface, (B) quartzarenite beddings of Lokapur Subgroup formation and weathered clasts.

All of the Benkaneri artefacts (Table 2), including the large cutting tools as well as flakes, cores and debitage, were recovered from the escarpment slopes and the colluvial deposits (Fig 2). The lithic assemblage includes the surface finds as well as excavated material. The cores included bifacial discoidal cores with alternate flaking observed in a continuous manner and prepared radial cores (Koshy 2009). The presence of prepared technology is attested in the removal of pre-determined large flakes, as shown by negative scars on the cores. The flake tools include retouched pieces, classifiable as scrapers, and non-retouched flakes showing signs of use.

In this study, we only consider handaxe forms (Fig. 3) from excavated and surface contexts. They were chosen for both the techno-typological and 3D GM analyses as they represented the majority among the bifacially shaped tools (see Table 2). The study material is currently housed in the Robert Bruce Foote Sanganakallu Archaeological Museum, in Ballary, Karnataka.

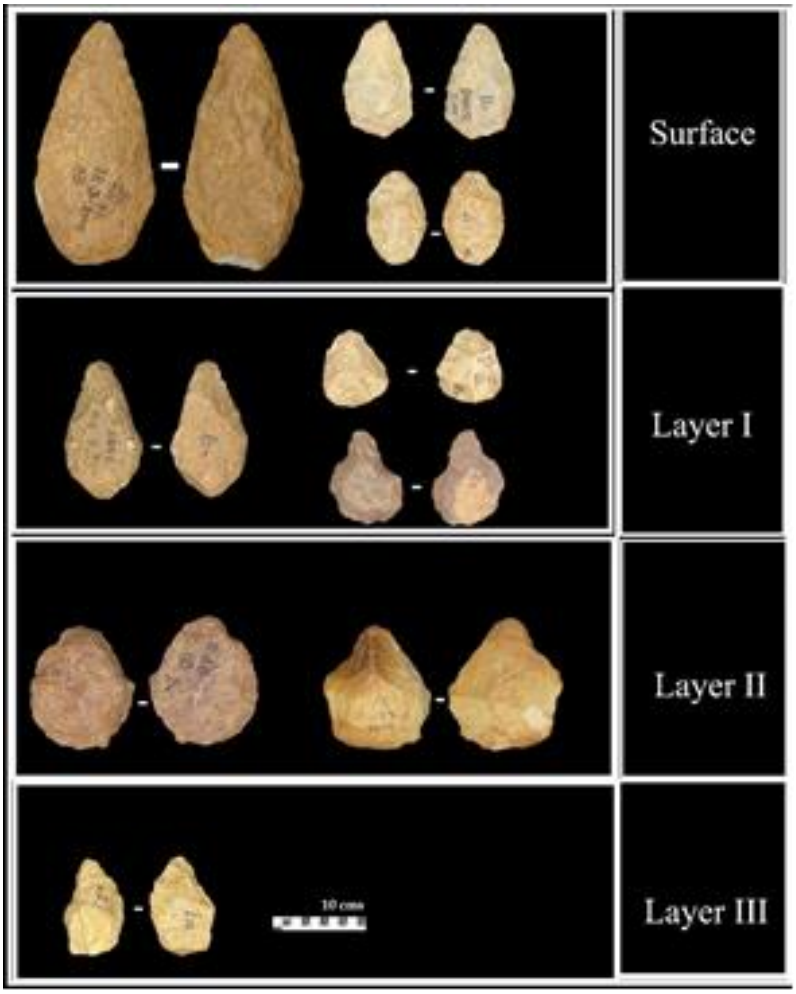


Fig. 3. Some examples of handaxes from Benkaneri, Karnataka. Note the diversity of dimensions and shapes.

Tool types	Layer 1	Layer 2	Layer 3	Indeterminate and Surface	Total
Handaxes	8	3	1	13	25
Cleavers	5	2	-	6	13
Handaxe cum Cleaver	-	1	-	1	2
Picks	1	-	1	4	6
Flakes (including retouched pieces)	35	160	-	-	195
Cores	14	14	-	1	29
TOTAL	63	180	2	25	270

Table 2. Artefact types and distribution by provenience, from excavations and the surface at Benkaneri, Karnataka.

3. Methodology

Techno-typological analysis was followed by GM shape analysis on 3D models. Primarily based on the classical methods of Bordes (1961) and Roe (1964, 1968), this study followed the work of Sharon (2007), Gaillard et al. (2008) and Pappu and Akhilesh (2007) in the techno-typological analysis. For the GM shape analysis, the methodology from Herzlinger and Grosman (2018) was used.

3.1. Classical approach

The handaxes from Benkaneri (n=25) were first examined using techno-typological methods (Table 3). The handaxes were oriented typologically, with the dorsal face up. In some cases, where the tools were shaped intensively, the flatter face was considered as the ventral surface. A digital camera (Nikon D60) fixed to a stand at a right angle was used to capture the photographs of each tool (placed with a metric scale). Using the Artifact3-D software, developed by Grosman et al. (2008), the lines representing scars and ridges on the tool's 3D surface were automatically extracted. The direction of flake removals and the order of the different series of removals were then indicated on the photos captured from the resulting 3D images using the Adobe Photoshop version 2021 (Fig. 4).

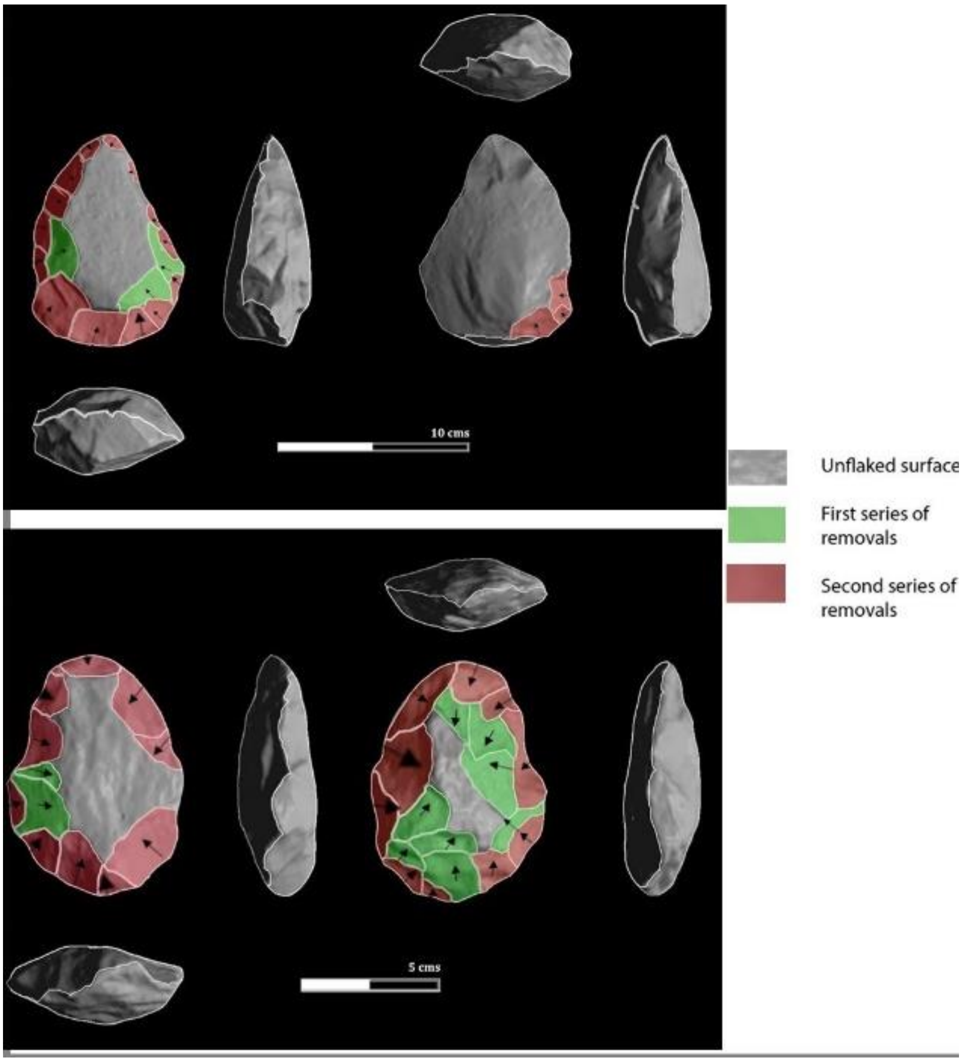


Fig. 4. Examples of unifacial and bifacial handaxes from Benkaneri (Karnataka) showing two series of removals in convergent/centripetal direction.

Linear measurements (mm) were taken with a digital calliper: maximum length, breadth and thickness as well as the longest shaping removal on both faces. Each tool was weighed (g) on a scale. Goniometer measurements of lateral, distal and proximal edge angles were recorded and categorised: sharp = <60°; medium = 60°-80°; steep = 80°-110°. Using the linear measurements, Roe's (1964) refinement index (Width/Thickness) and shape index (Width/Length) were obtained. All the data recording and analysis were done with Microsoft Excel 2010 and PAST (Palaeontological Statistics) (Hammer et al. 2001) version 4.03 (shorturl.at/emLTX).

The techno-typological attributes used for this study are the following (Table 3):

	Attribute	**Classification/Description**
1.	Preservation	complete / incomplete, breaks and traces of damage
2.	Abrasion	low / medium / high
3.	Raw material	geological nomenclature, texture / eye granology and colour
4.	Blank	end- / side-struck flake / cobble / split cobble, tabular block
5.	Eye symmetry	present / absent
6.	Cross section	biconvex / plano-convex / biplanar / others
7.	Cortex	present / absent and location
8.	Striking platform	type and location
9.	Shaping / retouch: amplitude, depth and direction	invasive / medium / marginal; deep / medium / shallow; direct / down / inverse
10.	Previous flake scar pattern on the dorsal face of the flakes	unidirectional / bidirectional / orthogonal / three-directional / convergent or centripetal / multidirectional
11.	Invasiveness of removals, proportion of shaping on each face	scale of 0 to 5, retouches

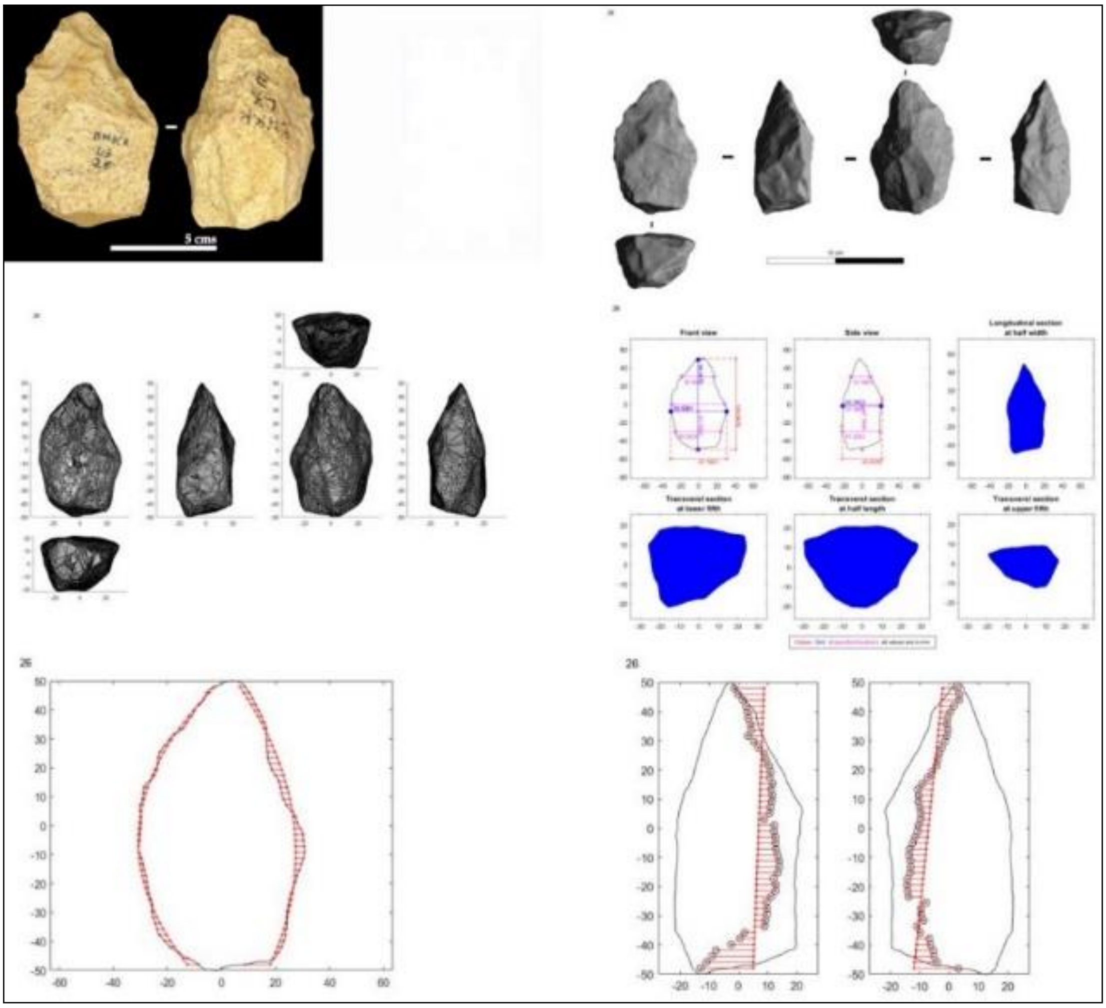
Table 3. Attributes considered for the techno-typological analysis of the handaxes from Benkaneri (Karnataka).

3.2 GM approach

For the GM analysis, 22 out of 25 specimens were selected, including those with minor distal breaks (a result of usage or post-depositional processes). Three tools were excluded as they were broken.

The GM approach followed 3 steps: acquisition of 3D models, processing, and analysis. For the acquisition of 3D models of the handaxes, a portable Next Engine 3D Scan Studio HD was used. The images of the tools placed on a turn table, rotating at 360° (resulting in 12 views) were captured with the help of the Scan Studio HD software. All the vertically placed tools were scanned in colour in the macro mode (HD setting) with 400 points per inch. The basal and distal parts of the tools were captured in two different single scans (each having 3 views). The 20 digitized images of each specimen were merged and aligned, and minor holes were fixed in Geomagic Studio version 2013 (shorturl.at/yAER3). After solving all the problems of software compatibility, the total time for the entire process took an hour per tool. The final mesh prepared was then exported in VRML (*wrl) format for further processing and analysis.

All the models in *wrl format were then loaded into an open access software written using the Matlab programming language: Artifact Geomorph Toolbox 3D (AGMT-3D) version 3.01 (shorturl.at/kmHO3). This analytical software was used for further processing and analysis. AGMT-3D offers many advantages over other softwares - namely, their built-in data-acquisition procedure for automatically positioning 3D models in space and fitting them with grids of 3D semi-landmarks. Their built-in analytical statistical tools like GPA, PCA, Wilcoxon Rank Sum Significance test apart from automatic calculations of linear measurements and symmetry variations make it an ideal choice for those with no prior knowledge of programming or proficiency in statistics (Herzlinger and Grosman 2018). Moreover, this software provides immediate graphical and raw results (Fig. 5 a & b) providing the cross-sections, profile views and mean shape comparisons.



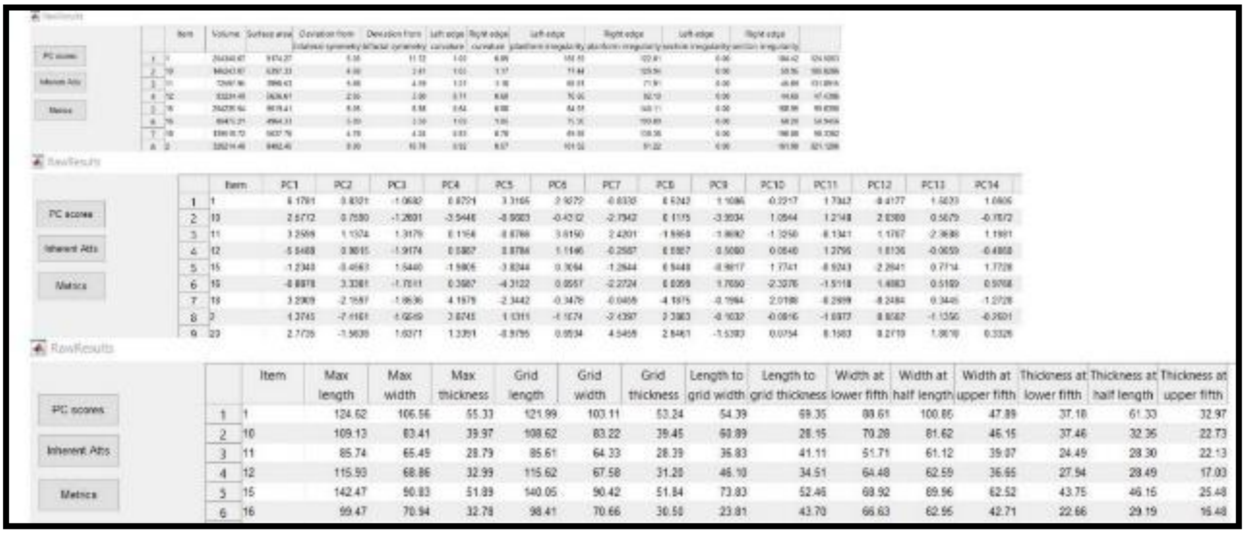


Fig. 5. (A) Example of graphical and (B) raw results provided by AGMT-3D software for Geometric Morphometric analysis for each piece (https://sourceforge.net/projects/artifact-geomorph-toolbox-3d/).

As a first step, all the 3D models were uploaded into the software in the *wrl format which automatically positioned them (based on their centroid), following which manual confirmation of their plan view and lateral views was required. Then, the number of latitudes and landmarks per latitude are chosen and fed into the software which places the resulting grid (Fig. 6). In this study, 50 latitudes and 50 landmarks per latitude were considered enough to express the specimen's volumetric configuration. A new file with a *.3dl extension is automatically created. This file containing both landmark lists and the specimen models are then used for the subsequent automatic in-built statistical analysis of GPA and PCA. While GPA reduces the variability to only those related to shape while removing other differences owing to orientation and other factors, PCA results in isolation of shape trends causing the variability within groups and subgroups while also calculating the mean shapes (Herzlinger and Grosman 2018). Wilcoxon Rank Sum statistical test also in-built in this software is used to test the significance level of the results.

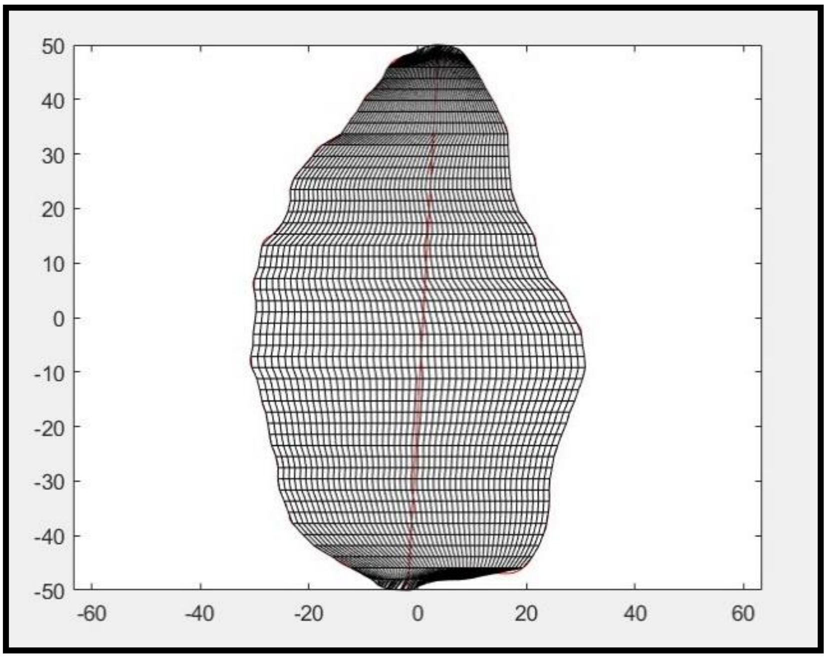


Fig. 6. Landmark placement (covering the surface topography, plan, and profile shape) using the AGMT-3D software for Geometric Morphometric analysis (https://sourceforge.net/projects/artifact-geomorph-toolbox-3d/).

Only the technological attributes can be processed in this software. Accordingly, two attributes selected to understand their influence on shape variation, were fed into the software for it to do further statistical treatments. Since the effect of tool blank form and the apex shape differences/tips of the handaxes are believed to result in variation in the tool shapes, these two attributes were used in this analysis (Gamble and Marshall 2001; García-Medrano et al. 2019).

4. Results

4.1. Techno-typological analysis

Of the total 25 handaxes techno-typologically analysed, 3 were unifacial forms. Two of the unifaces were on end-struck flakes and one was on side struck flake. Handaxes (senso stricto, i.e., bifacial) with typical shapes (ovate = 4, almond = 6, pear shaped =3, sub-triangular = 3) occurred along with atypical ones (n=9).

The handaxes were made on angular/subangular, sub-rounded and tabular quartzarenite (quartzite) raw material with a grain size of 1/16 to 2 mm (Koshy 2009). Although the primary raw material utilised was quartzarenite, both fine-grained (92%) and medium-grained (8%) varieties were observed. They ranged in shades from cream to brown and red. Patination observed is negligible with only two specimens displaying the same. Most of these tools were fresh (80%) with the remaining specimens showing medium abrasion indicating the undisturbed nature of the site, which lies away from the flood plains of the Malaprabha River (Petraglia et al. 2003b). Seven handaxes (28%) had broken distal tips, either a result of use or post-depositional processes.

The majority of the handaxes were fashioned on flake blanks with 44% on end-struck and 12% on side struck types. Tabular blocks formed another major category of blank types (32%), including one tool shaped directly on it and tools shaped on the flakes removed from them. Three handaxes were fashioned on cobbles. Four specimens had cortex, mostly located on the dorsal and central position of the handaxe, while one was at the proximal end (made on a tabular block blank). In planar cross section, the majority of the handaxes (52%) showed biconvex profiles (both symmetrical and nearly symmetrical) while 40% were plano-convex. One handaxe was plano-trapeze, another was irregular in cross-section.

Bilateral (36%), three-directional (24%) and convergent (20%) patterns of shaping scars were observed on the dorsal face of the tools made on flake blanks. There were up to 3 – 4 removals recognisable on an average. The striking platform remained indeterminate for the majority (76%) of the artefacts due to the extent of shaping and thinning of the butt. Of the recognisable ones, four were plain, one was dihedral and another one was cortical on a tabular block blank. The platform location remained difficult to ascertain for the majority (n=19) though five could be tentatively identified as located on the proximal right corner and one on the proximal left corner.

	Length (mm)	**Width (mm)**	**Thickness (mm)**	**Weight (g)**
Maximum	204	108	70	1457
Minimum	36	24	18	200
Mean	113	71	40	435
S.D.	32	20	13	289
C.V.	28	29	33	67

Table 4. Dimensional measurements of the handaxes (n=25) from Benkaneri (Karnataka).

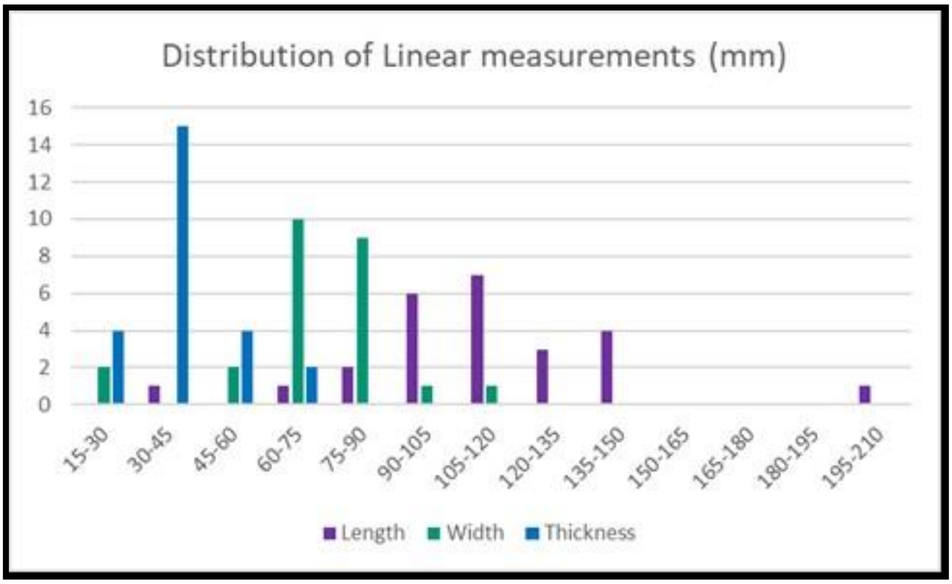


Fig. 7. Linear measurements (mm) distribution of the Benkaneri handaxes (n=25).

The dimensions of the handaxes from Benkaneri varied within a large range of values. The longest handaxe measured more than 20 cm and the smallest less than 5 cm (Table 4). While the widest handaxe measured 10.8 cm, the narrowest one was 2.4 cm. The thickness ranged from 1.8 cm to 7 cm (Table 4). However, these dimensions showed normal distributions (Gaussian distributions) with values clustering around the mean. This indicates that all the specimens belong to the same population and represent a homogenous sample, as far as their dimensions are concerned. The length of most tools was in the range of 90-120 mm, width between 60 and 75 mm and thickness between 30 and 45 mm (Fig. 7). The linear measurements seem to be more standardized than the weight (Table 4).

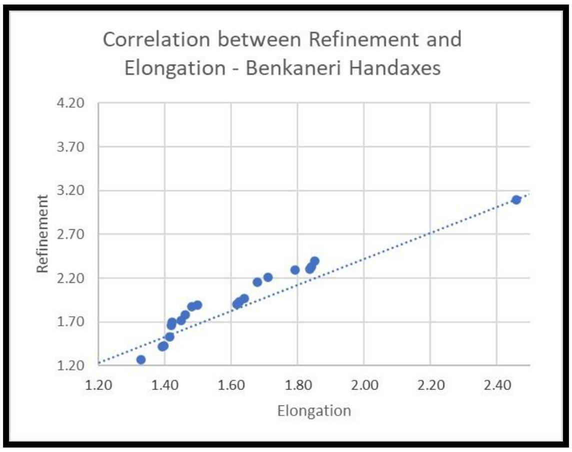


Fig. 8 Elongation versus Refinement correlation for the handaxes (n=25) from Benkaneri (Karnataka).

Only 16% of the handaxes were flat according to Bordes's Flatness ratio (1961) while the majority were thick (with an average of 40 mm in thickness). The thickness of the blanks was usually retained on the tools with minimal shaping, limited to the cutting edges and butt area. The majority of the handaxes (56%) can be considered elongated (more than 1.5 ratio of length to width) in the shape indices. As seen in Figure 8, elongation and refinement show a positive correlation with longer handaxes showing more refinement.

The shapes of the distal ends were either rounded, pointed or in one case, transverse. In the case of the pointed ones, none of them display the ultra-pointed tip characteristics (Sharon 2007).

Edge angles of the handaxes give information on functional parts of the tools and indirectly on the choices of the knappers. Both lateral edges of the studied tools showed similar angles, varying from 55° to 100° on the left side and from 60° to 100° on the right side. On the distal end, most angles were between 40° and 70° (40°-115°) indicating the number of tools with a sharp distal tip (convex edge or point) (Fig. 9). The three high values (>80°) correspond to the three handaxes with broken tips. Proximal edge angles were mostly oblique and steep and ranged from 60° to 105°.

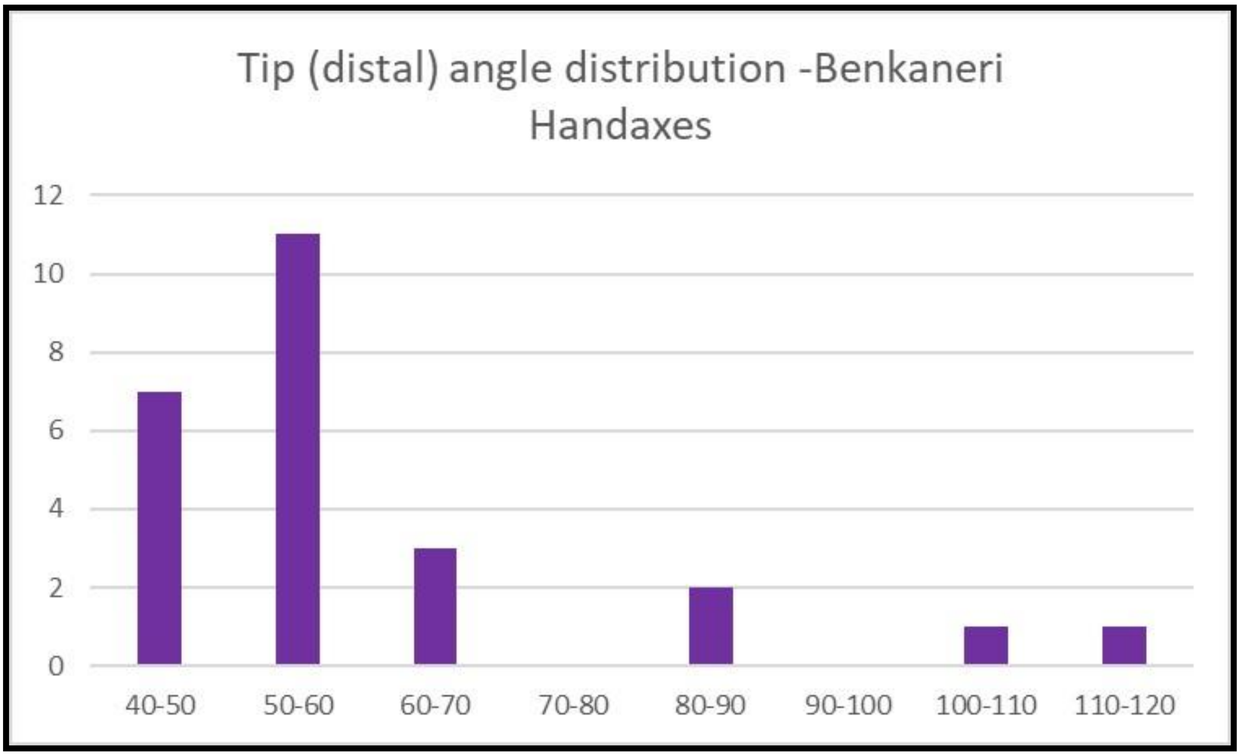


Fig. 9. Frequency distribution of distal angle measurements of the Benkaneri handaxes (n=25).

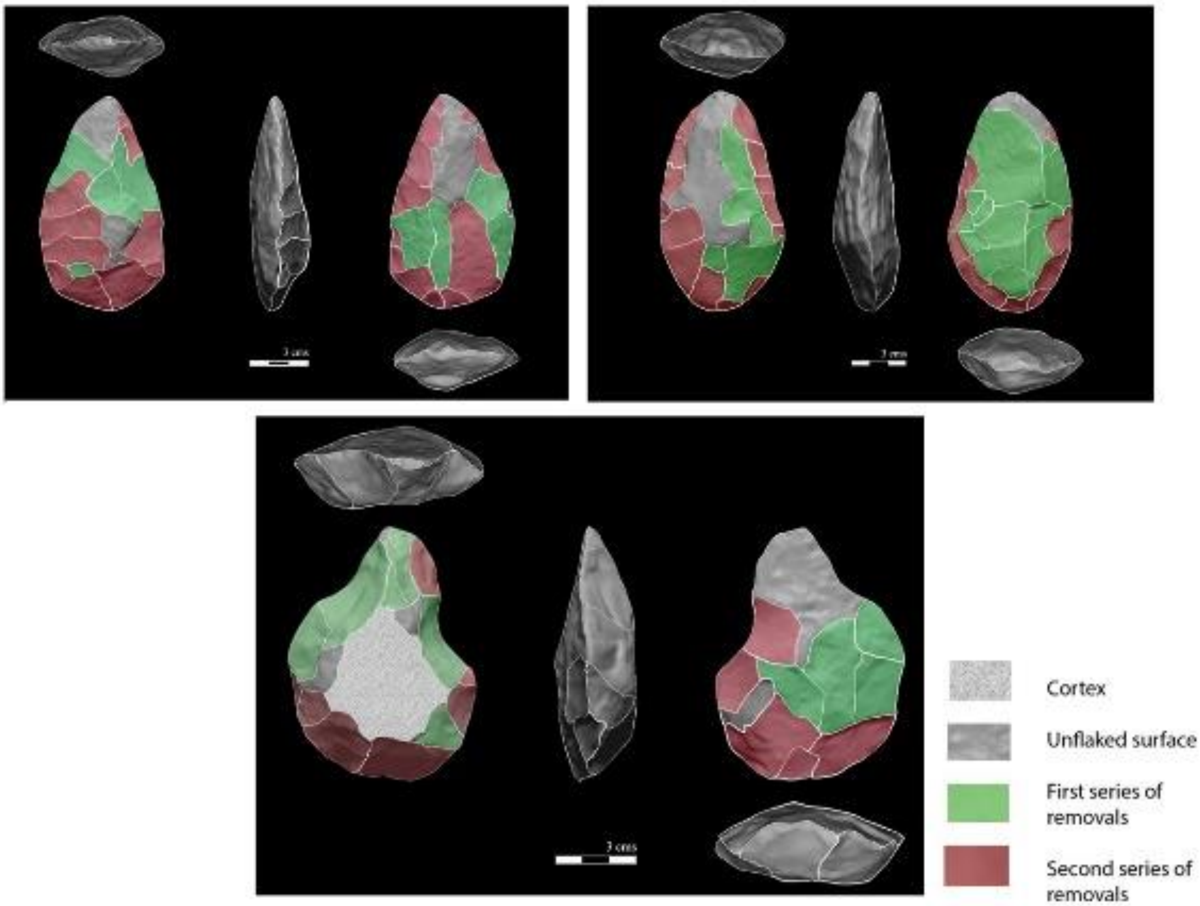


Fig. 10. Examples of 3 Benkaneri handaxes showing 2 series of removals.

Two series of removals were observed on a majority of tools (Fig. 10). The butt was worked in most cases, in order to reduce the thickness.

Regarding the shaping of the handaxes, the longest removal on the dorsal side ranged from 60 to 15 mm with an average of 37 mm while that on ventral face was 35 mm in average (68 to 5 mm). The handaxes were almost completely shaped (60%) on both dorsal and ventral faces with invasive and deep as well as secondary shallow/thinning shaping removals. The minimum number of shaping scars was 4 while the maximum exceeded 15. Only one specimen has a tranchet removal and this tool was shaped in a unilateral direction. A notable feature on the left lateral distal point was the presence of a single notch (Fig. 14).

4.2 GM analysis

Blank types and apex shapes of the handaxes were used for the GM shape analysis to understand the variability within the assemblage and between the blank types. Results from the 3D GM analysis show a higher variability (8% both) among the group means of end- struck and side-struck handaxes (Table 5). While in the end-struck specimens, this is mainly caused by the length, it is the thickness that causes the most variation in the side struck handaxes. Handaxes made on tabular blocks display 7% variation, mostly in their thickness followed by length, while cobble tools (n=2) had only 6% variability (caused by thickness followed by length). Most of the handaxe variability (87%) in the assemblage is explained by the first 10 principal components (Table 6). The first three principal components (PC) explain 51.74% of the total variability in this.

Blank Type	**No. of items**	**Shape variability within the groups**	**% caused by X (relative width)**	**% caused by Y (relative length)**	**% caused by Z (relative thickness)**
End-struck flake	10	8	52	5	43
Side-struck flake	3	8	31	2	67
Tabular block	7	7	45	3	51
Cobble	2	6	11	4	86
Total no:	22				

Table 5. Group mean comparison of variation between blank types and the causative relative width, length, and thickness (X, Y and Z).

PC	**% of variability**
PC1	25.62
PC2	15.37
PC3	10.75
PC4	8.64
PC5	6.83
PC6	6.36
PC7	4.60
PC8	3.47
PC9	3.18
PC10	2.44

Table 6. PC variability of the Benkaneri handaxes (n=22) displaying the first 10 components accounting for 87% variation.

The shape space illustrated in the scatter plot (Fig. 11) shows that there is an overlap between the ellipses representing handaxes made on end-struck flakes and those made on tabular blocks. Shapes in these two categories remain broadly similar. Nearly all the handaxes, except the ones on cobble and one specimen on side struck flake, are subsumed within the end-struck handaxe ellipse.

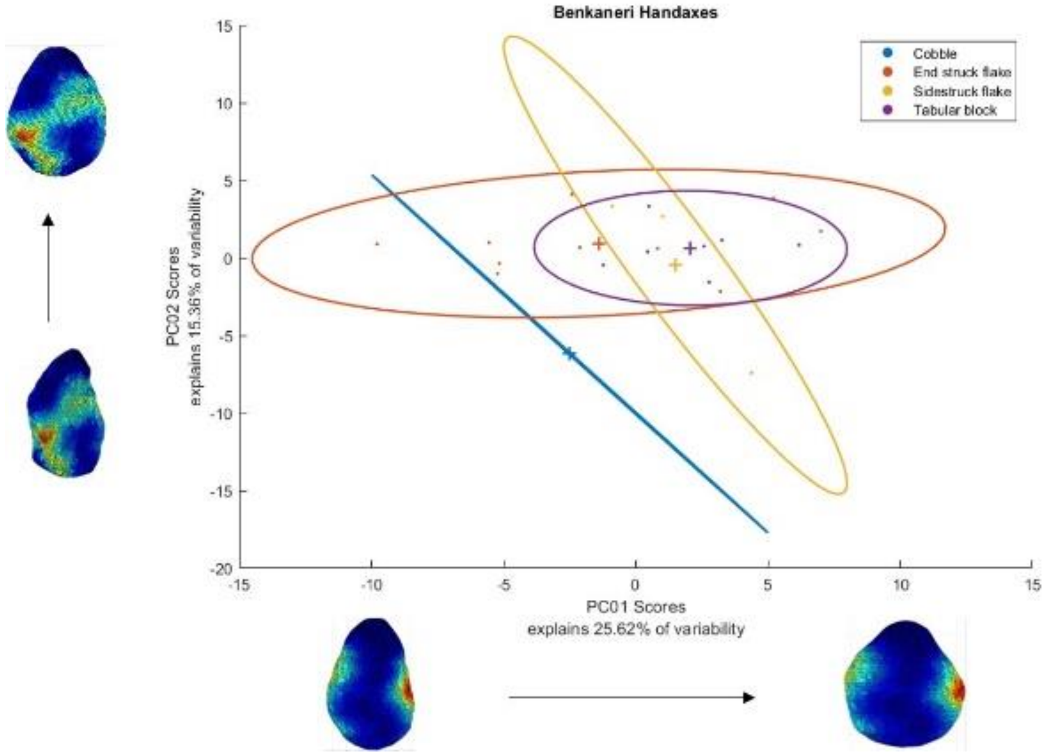


Fig. 11. PCA scatterplot (95% ellipses) showing the distribution of blank types among the handaxes (n=22) from Benkaneri (Karnataka) along with the warped shapes of the handaxes on PC1 and PC2.

When it comes to handaxes made on side struck flakes and on cobbles, their shapes (except for two specimens within each category) also fall within the broad shape variations of end -struck flake tools (Fig. 11).

Wilcoxon Rank Sum statistical test shows that shape variability within groups of end-struck and side-struck handaxes is significantly different at 0.05 level (Rank Sum=131, n1=10, n2=3, p Value=0.02). This is also reflected in the visual comparison of the mean shapes of end-struck and side-struck handaxes (Fig. 12).

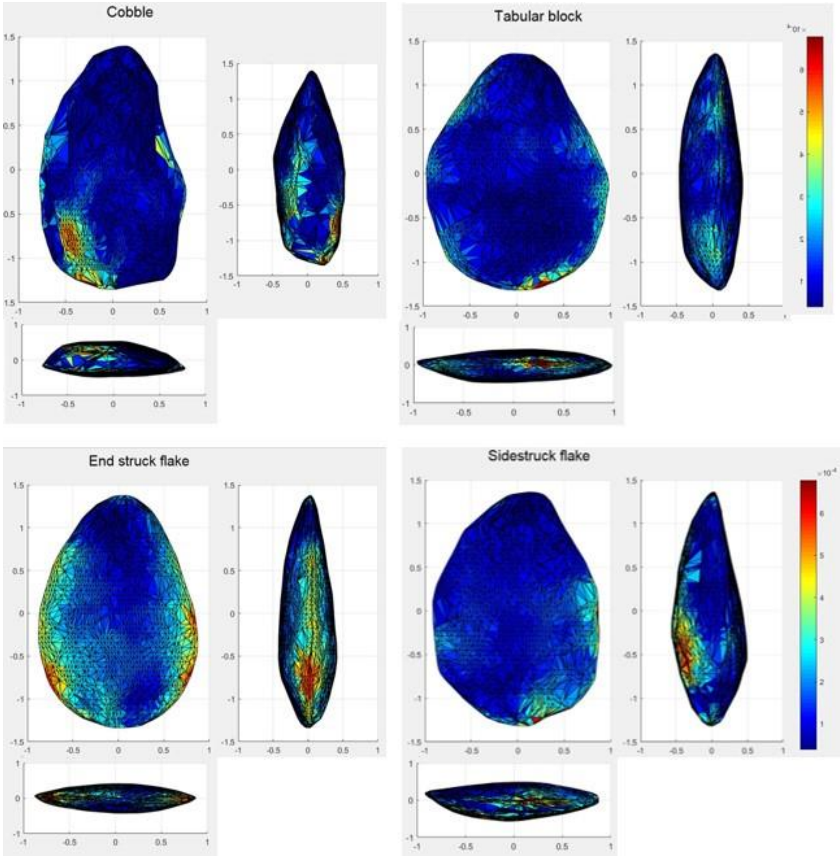


Fig. 12. Mean shapes of the handaxes from Benkaneri (Karnataka) made on side-struck flakes, end-struck flakes, tabular blocks, and cobbles respectively. The yellow colour indicates the location of more variability/modification while green shows medium variability/modification and blue, the least.

The shape variabilities between the groups of different blank types are not significantly different; end-struck flake and side-struck flake - Rank Sum = 71, p = 0.93, end-struck flake and Tabular block - Rank Sum = 105, p = 0.16, side-struck flake and Tabular block - Rank Sum = 21, p = 0.38. In all the types of blanks, the maximum variability is caused by the length and thickness (Table 5).

However, when it comes to within each groups of blank types, we notice that the mean shapes of handaxes within the groups of both, end-struck flakes and tabular blocks differ significantly at .05 level (Rank sum=232, n1=10, n2=7, p Value=0.02). Similarly, handaxes within the group of side struck flakes and tabular blocks differ in their mean shapes significantly at .05 level (Rank Sum=63, n1=3, n2=7, p Value <.01).

In comparison to the least modification of the lateral proximal ends of the end-struck flake handaxes, those shaped on tabular blocks show modification on the proximal central part (Fig. 12). This was probably due to the reduction strategy wherein the thickness of the block had to be reduced to achieve the cutting edges.

The two specimens of handaxes on cobbles also show the maximum variability on the central part of the lateral sides. The handaxes on side struck flakes showed the least variability when compared to the other blank types, and this variability was restricted to a minor area on the proximal end. The least amount of modification on the flake blank types could be due to the prepared core techniques to extract a desired shape of the flake. This would result in a flake which needed to be minimally shaped into a handaxe. This is also reflected in the cross section of the tools, which are more regular and more or less symmetrical, whereas in the case of tabular block and cobble blank types, the cross-section is more irregular and thicker.

On observing the variability of the distal ends or the apex shapes of the handaxes, we notice three categories of pointed, rounded and those with transverse edge. From Fig. 13, it appears that the majority of the handaxes (n=9) are skewed towards the positive axes of the PC, being more or less pointed. Except for two specimens which are more rounded than others, all other tools fall within the broader shape categories of the edged ones. In other words, although there are different clusters of each group, there are overlaps among them. An interesting feature was the appearance of a notch, especially on the lateral left distal end. There were 4 handaxes that were rounded (Fig 14.), with this feature, while for the pointed specimens, it appeared in 2 of the handaxes.

When we examine the mean shapes of the tools along different edges, we find that there is no noticeable variability within them (as also attested by Fig 13.). However, between the mean shapes of groups of handaxes with pointed, transverse and rounded edges, there are significant differences. The software, auto calculated Wilcoxon Rank-Sum Test on Inter-point Distances between Group Means, resulted in significant (.05 level) differences between the mean shapes of rounded, pointed and transverse (pValue $< .01$ for rounded and pointed, and pValue $= 0.03$ for pointed and transverse). The main locations of modification in terms of shaping among all these categories of apex type handaxes remained the lateral edges and the butt. The most homogenous part with minimum variability for all the blank types remained the apex area except for the rounded apex ones. Among the rounded apex tools, a higher level of modification can be seen on the left lateral distal area, corresponding to the notches (see Fig. 14 and 15), indicating an intentional modification.

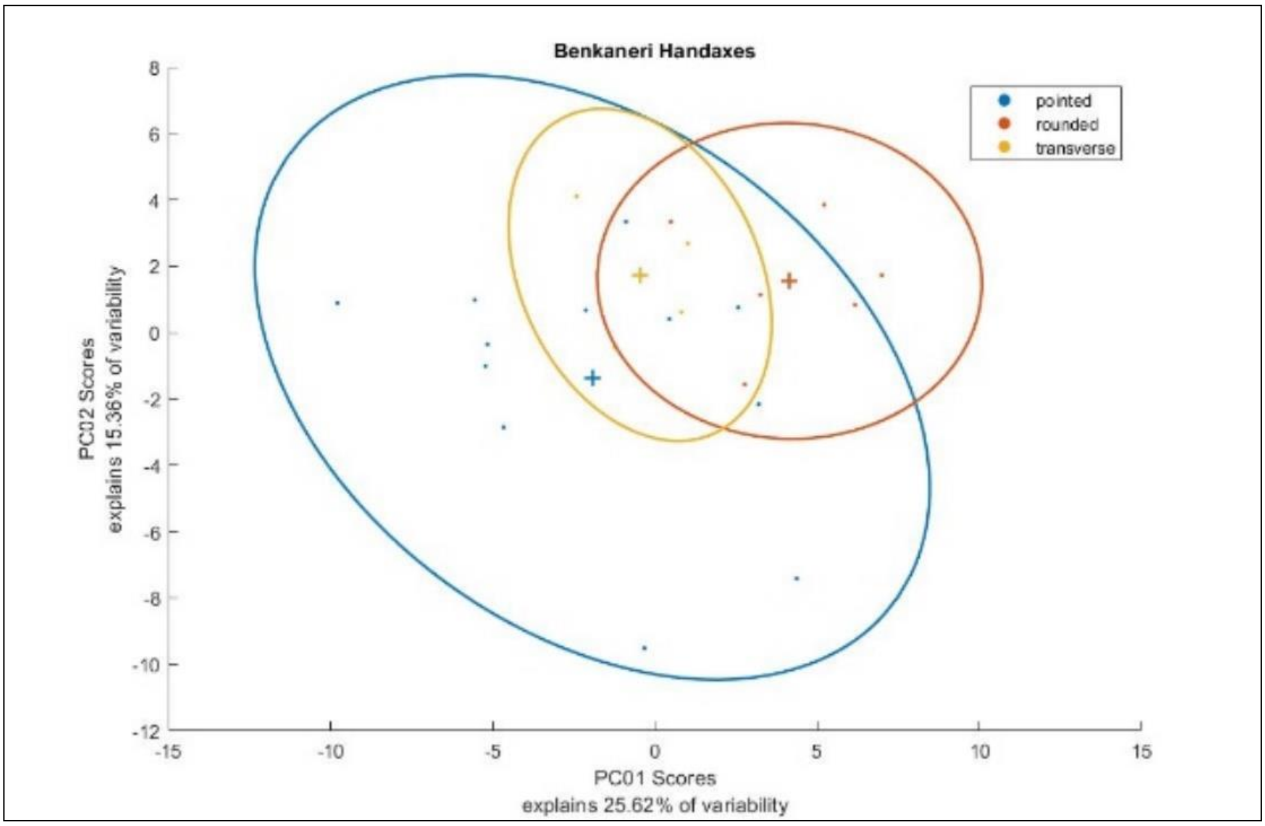


Fig 13. PCA scatter plot (95% ellipses) showing the distribution of apex types among the handaxes (n=22) from Benkaneri (Karnataka): pointed edge (n=12), rounded edge (n=6) and transverge edge (n=4).

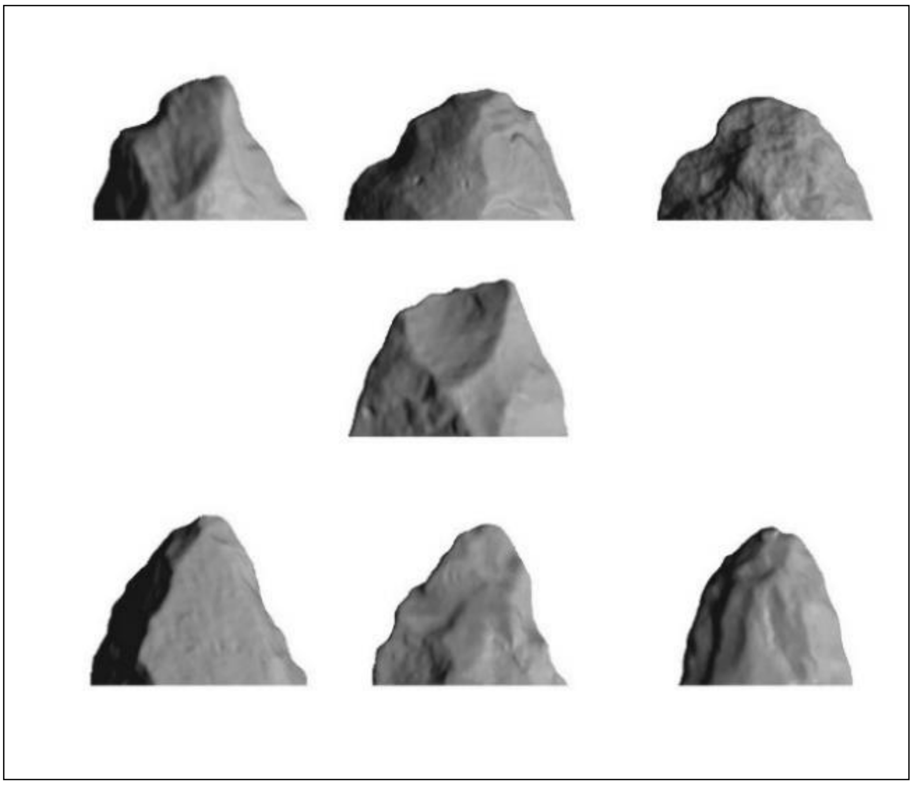


Fig. 14 Representative examples of apex shapes (not to scale): From top to bottom – rounded (note the notched left lateral), transverse and pointed.

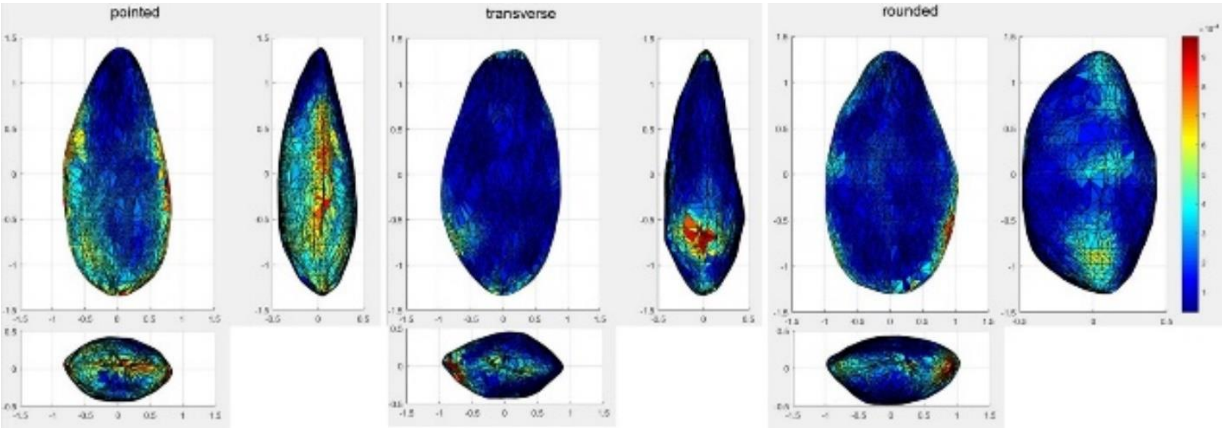


Fig. 15. Comparison of mean shapes of apex shape types - pointed (n=12), transverse (n=4), rounded (n=6) of handaxes from Benkaneri.

To sum up the shape variability results, we see that the length and thickness of the blanks played an important role in shape variability which is corroborated by the classical analysis that shows the use of different blanks of varying lengths and thicknesses. Although the blank types did not display a significant variation between themselves, the single tools shaped on different blanks showed a higher variability, most probably a result of the individual varying nature of the blanks. Blanks, such as tabular blocks and cobbles, appear to be more shaped on their lateral and proximal edges, probably in order to obtain an elongated shape.

5. Discussion and Conclusions

The meaning of handaxe variability, a subject of intensive debate in archaeology for decades, has mainly relied on traditional methods to support various theories behind their manufacture. Recent years have shown an increase in new approaches (García-Medrano et al. 2020; Herzlinger and Grosman 2018; Hoggard et al. 2019; Lycett et al. 2016). This study, applying the precise replicable approach of GM, combined with complementary technological analysis, has thrown light into the shape variability in the Benkaneri handaxe assemblage. Although handaxe representation is relatively low in the assemblage, valuable new insights have nevertheless been obtained.

The Benkaneri hominins showed a preference for the finer variety of quartzarenite (quartzite) for handaxe manufacture, which was readily available in the site vicinity, in the form of angular and tabular clasts alongside cobbles. An experimental knapping session at the site indicated difficulties in knapping with these raw materials owing to their hardness (Petraglia et al. 2003b). However, this difficulty may have been partially overcome as the emphasis was mainly on flake production to manufacture handaxes. Although the percentage of refined handaxes was low, elongation was an attribute adhered to. Only a few handaxes achieved bifacial symmetry while bilateral symmetry was more or less present in almost all of the specimens. The shape of the blanks and their thickness would have been one reason underlying this observation. Despite constraints of the raw materials and clast shapes, the presence of typical handaxe shapes and symmetry in a large majority of the samples indicate the high dexterity and skill of these early knappers, who clearly were able to manage the bifacial volume.

Hard hammer use was applied primarily for flake removals through bifacial centripetal flaking. The handaxes from Benkaneri were shaped all along the periphery, with a secondary series of flaking indicated by the deep and invasive scar pattern on the tools as well as on discoidal cores recovered from the excavation. As tabular blocks were used as blanks for some handaxes, the use of the slab-slicing method cannot be ruled out. This method has also been attested at the Isampur Acheulean quarry site, located 150 km away (Sharon 2007).

The GM shape analysis shows that there were no significant shape differences among the tools on different blank types, but within the groups of each blank type, there were variations, which can be explained by the size and shape of the blanks. Different clast shapes and sizes occur at Benkaneri, which were exploited for making flakes to be shaped into handaxes. Almost all the handaxe shapes occur within the broader range of shapes of end-struck flake handaxes. Although tools were mainly pointed, a few rounded tools also occurred with marginal modification in the form of notches, the purpose of which is currently unknown.

The combined results from the techno-typological and GM analyses show that regardless of the reduction strategy and different blank types present, the Benkaneri hominins were able to achieve similar shapes, the majority of which were pointed. These results display the fluidity and flexibility of the knappers in making the most of the raw materials available with all possible reduction strategies to reach the target shape template. Blank type variability and apex shapes did not seem to limit the shaping of these tools.

In conclusion, the presence of handaxes, alongside other Acheulean types (e.g., cleavers) in the quarry site of Benkaneri attests to the continuing nature of the industries in this region, as reflected in many other Indian sites like Lakhmapur East and West, Attirampakkam etc, (Pappu 2001). This continuity is reflected not only in the tool types but also in the raw material preferences (quartzites) for these tool forms (Pappu and Deo 1994; Raju 1985; Pappu 2001). The increasing shift to flake blanks for tools (also evidenced for handaxes on >10 cm flakes), along with the presence of flake based prepared core technologies, is a characteristic feature of the Lower to Middle Palaeolithic transition, evidenced at Benkaneri and elsewhere across India. This transition represents a gradual local/regional process rather than an abrupt, or external introduction (James and M.D. Petraglia 1990). In the absence of hominin fossils to identify the makers of these tools, we can only surmise that the techno-typological transition is not a consequence of biological changes per se, but they reflect cultural choices, as the Benkaneri evidence illustrates (James and M.D. Petraglia 1990). The Malaprabha region would have been a strategic area for early hominins as elevated areas had good vistas of the surroundings and there would have been an abundance of game, readily available raw material outcrops, and a perennial water supply (indicated by the presence of extinct springs and lakes). Benkaneri is thus a significant site to understand the Lower to Middle Palaeolithic transition in India and to understand the underlying reasons for its origins.

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APPENDIX III – FIGURES

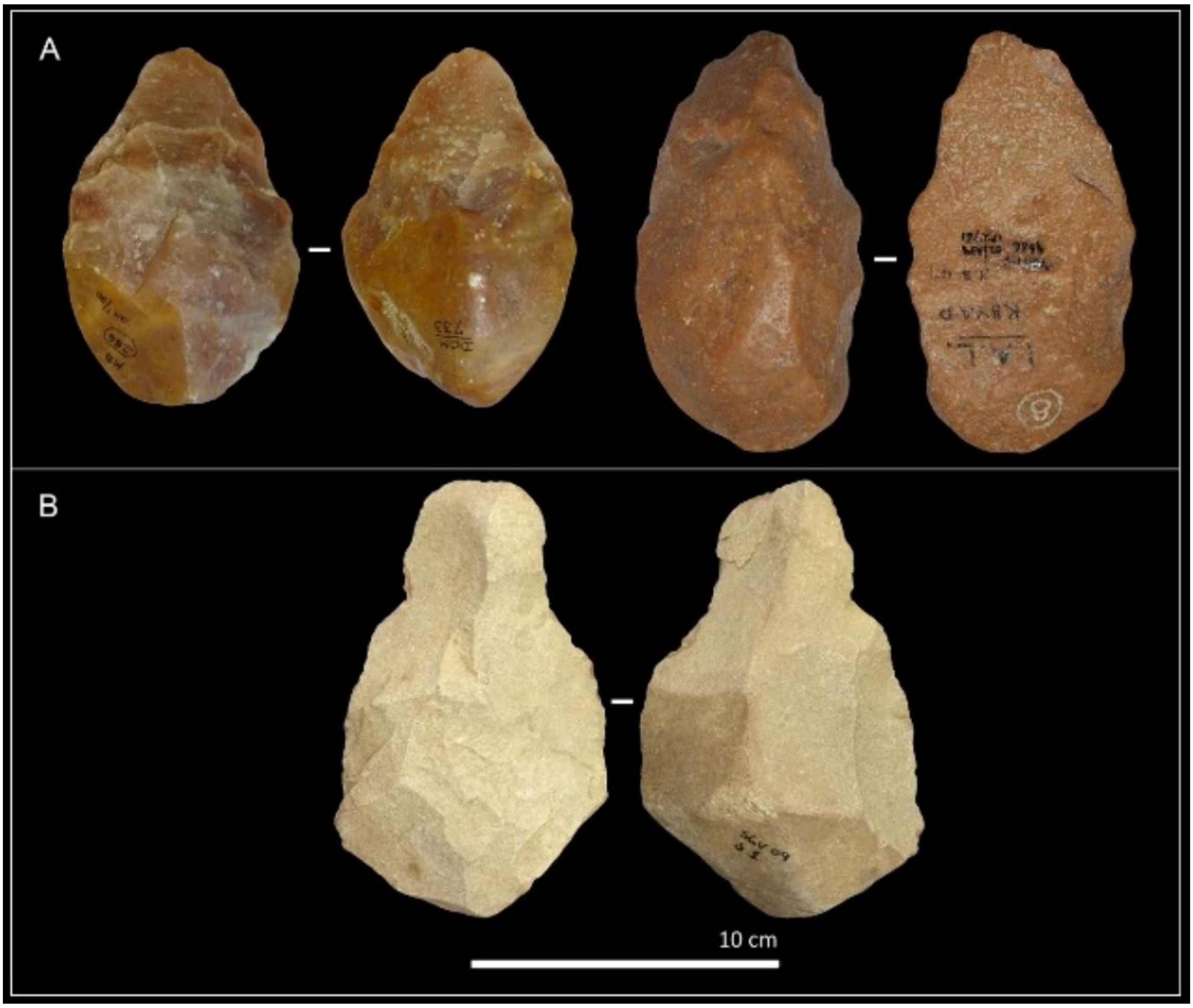

Figure 1. Handaxes on cobble blanks from Khyad.

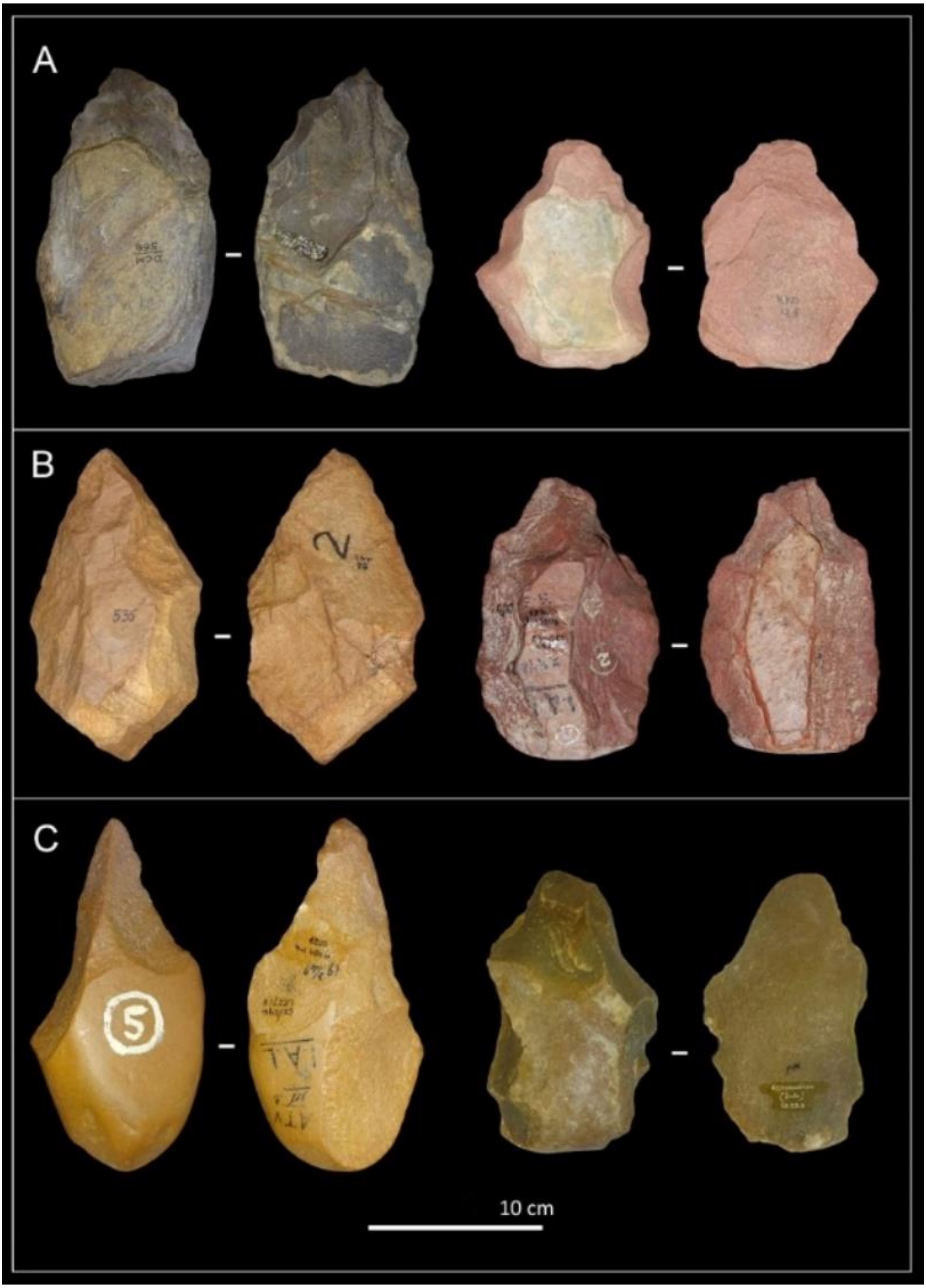

Figure 2. Handaxes on end-struck tabular blocks, side-struck flakes, cobbles and entames – Khyad (A), Lakhmapur and Khyad (B), Attirampakkam (C).

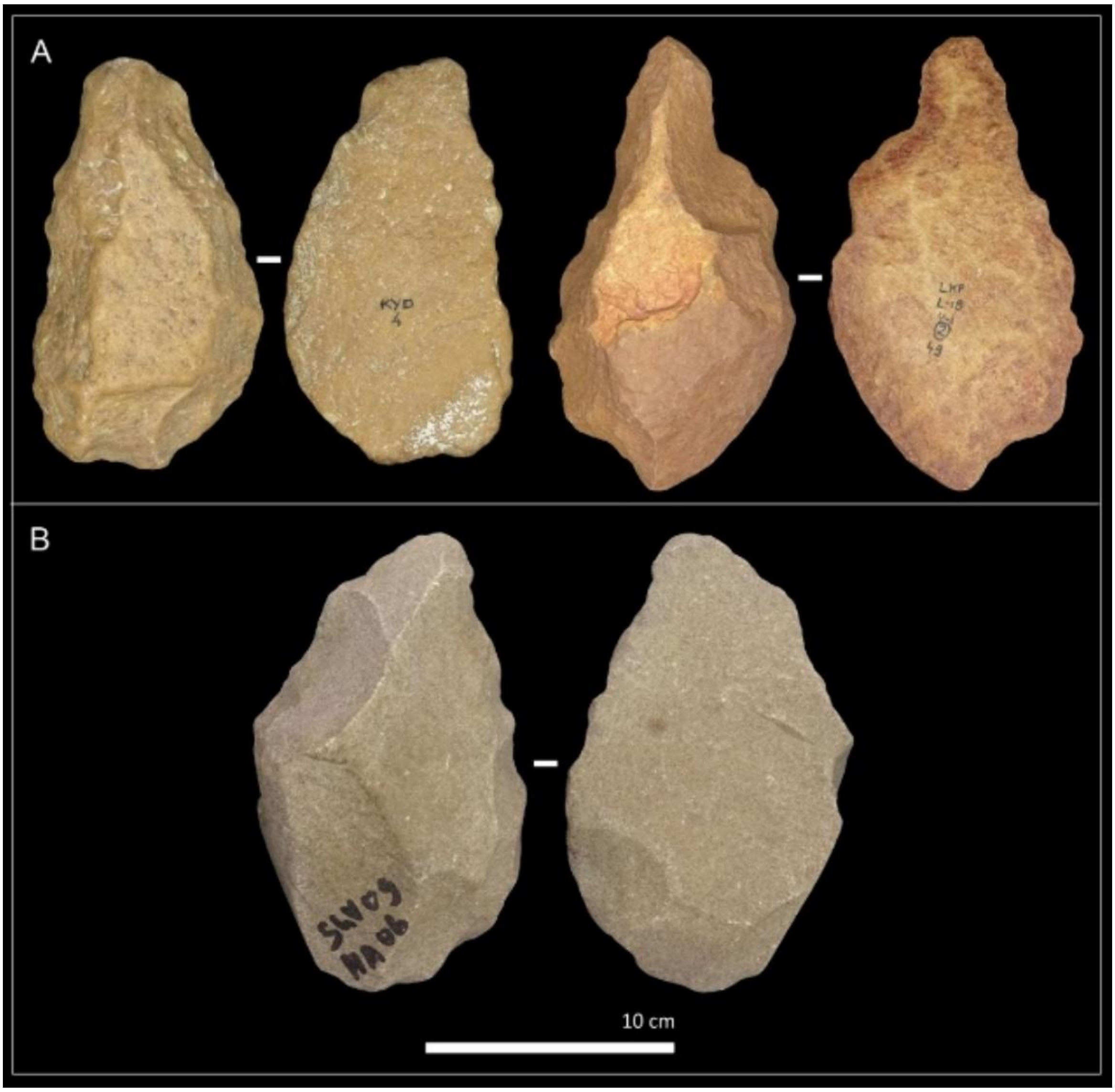

Figure 3. Unifacially modified handaxes from Khyad and Lakhmapur (A) and Singadivakkam (B).

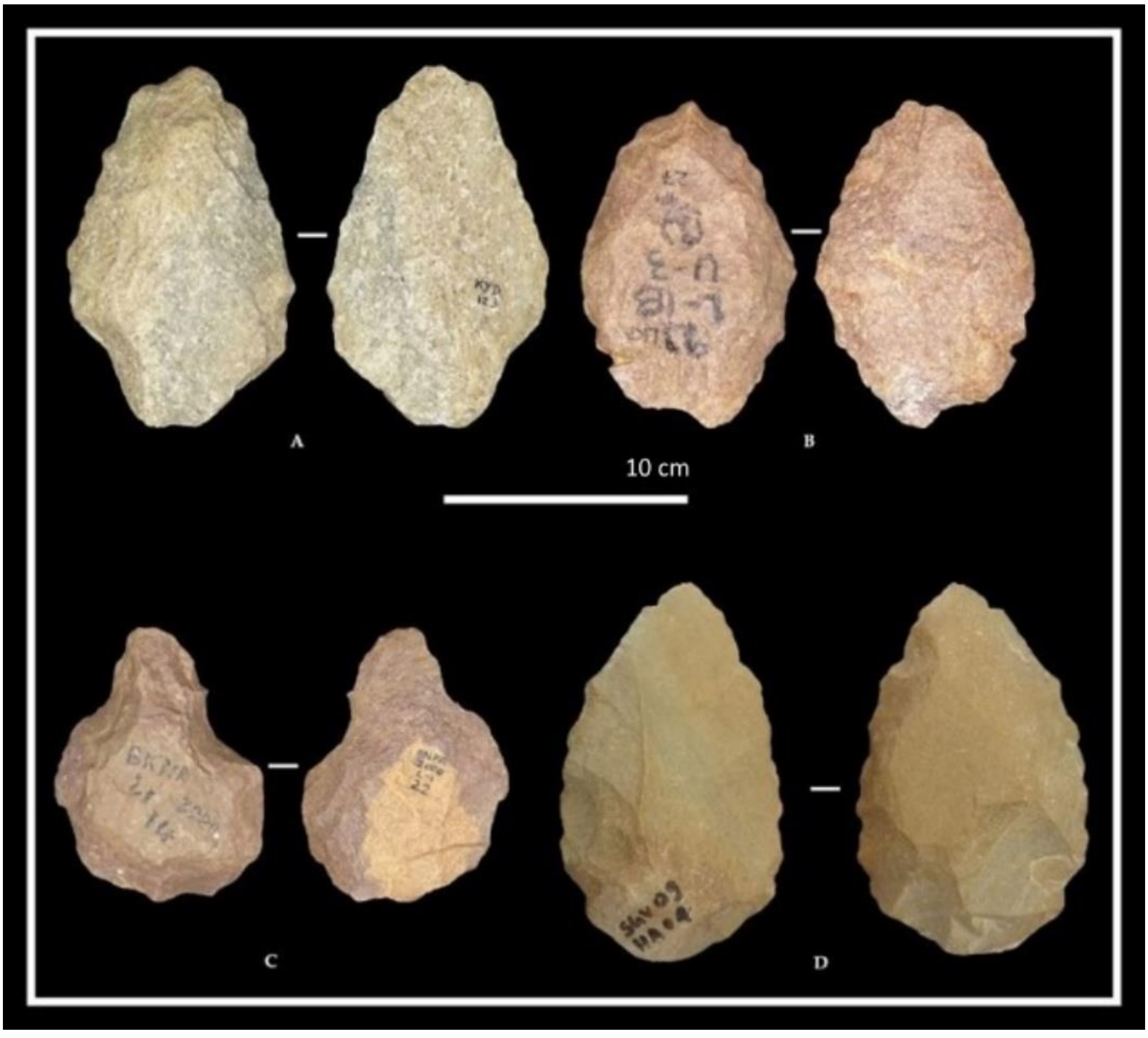

Figure 4. Handaxes with different retouch types – Khyad (A), Lakhmapur (B), Benkaneri (C) and Singadivakkam (D).

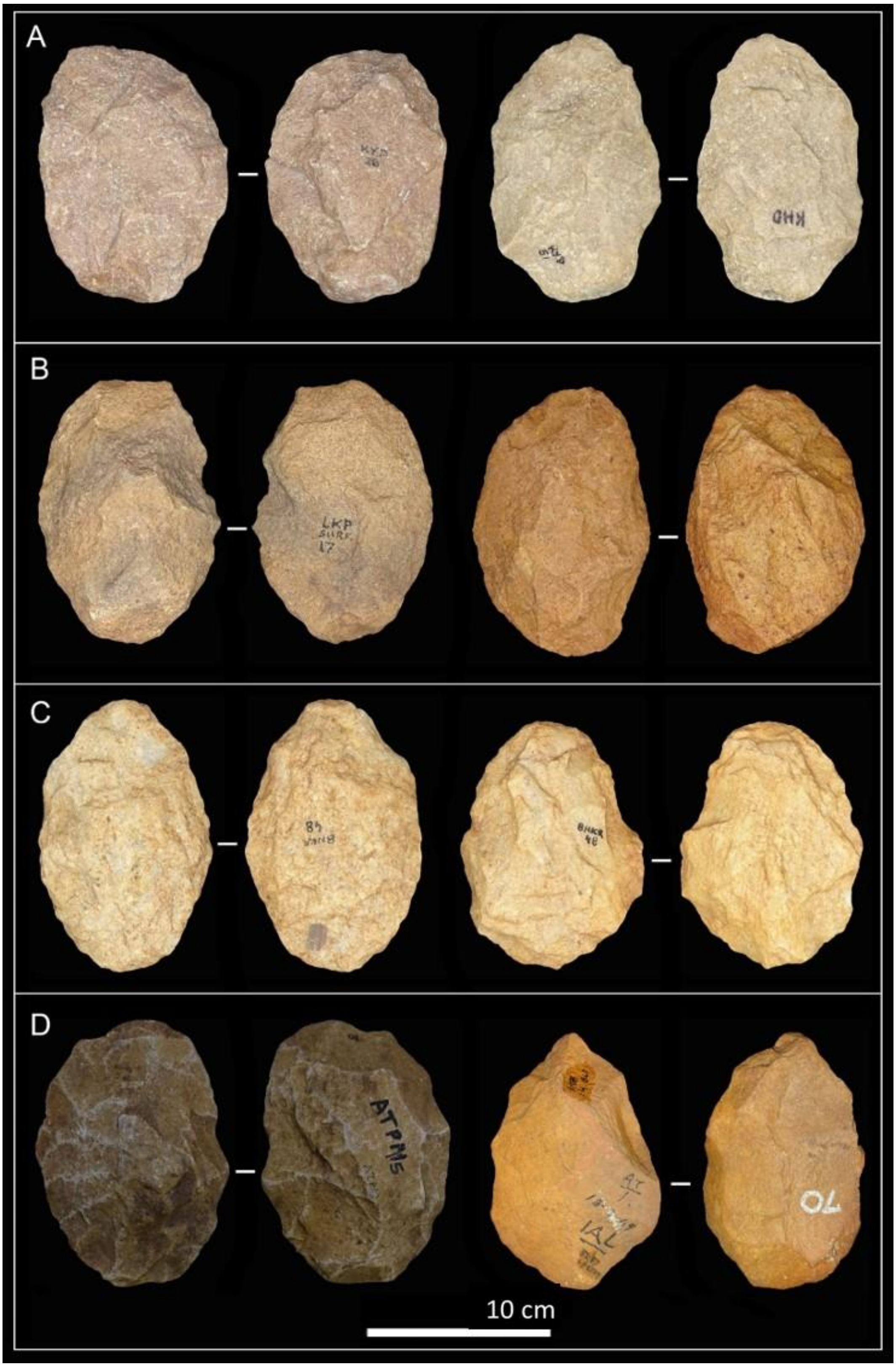

Figure 5. Ovates from Khyad (A), Lakhmapur (B), Benkaneri (C), Attirampakkam (D).

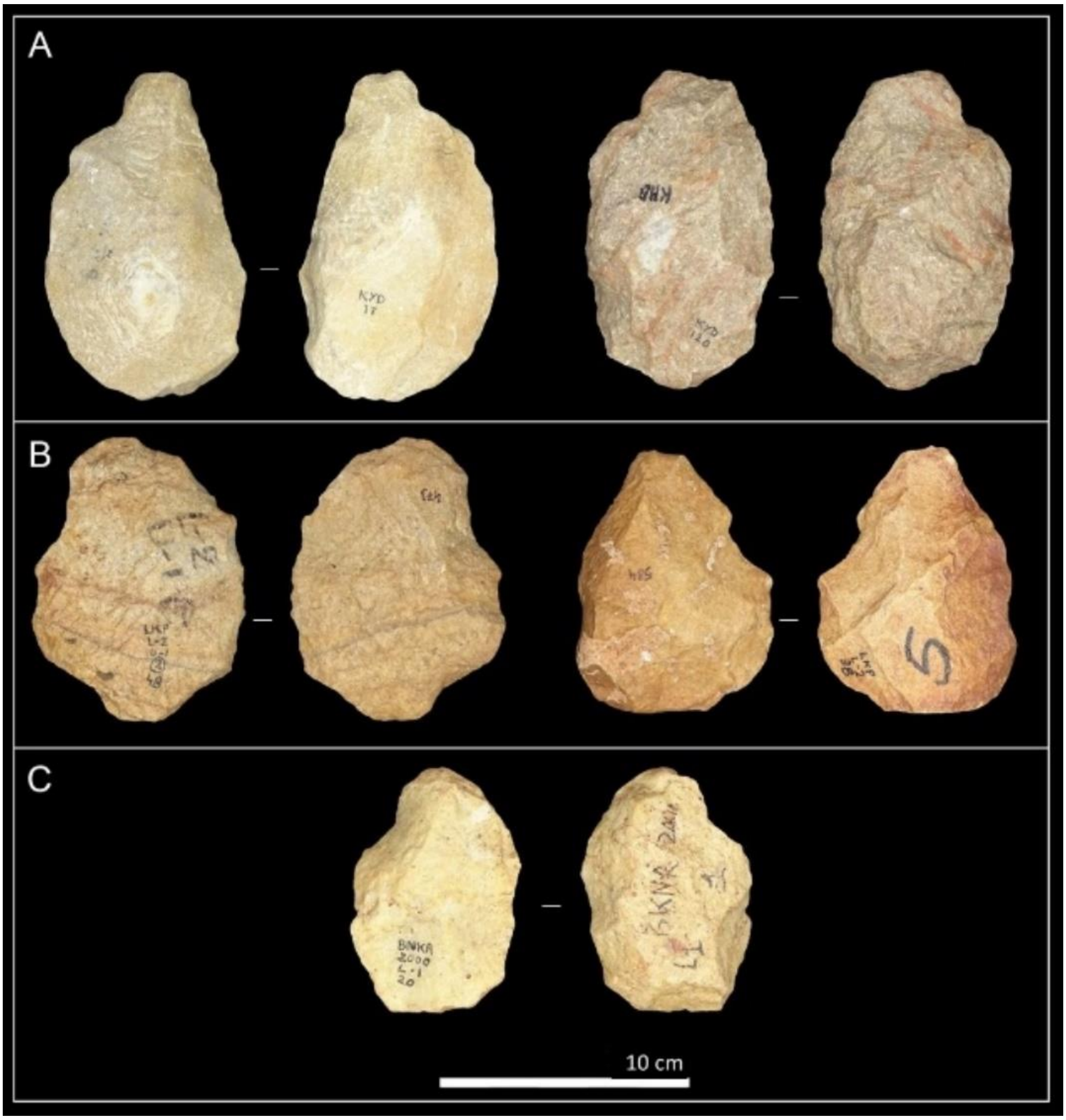

Figure 6. Irregular ovates from Khyad (A), Lakhmapur (B) and Benkaneri (C).

Figure 7. Elongated ovates from Khyad and Lakhmapur (A), Benkaneri and Attirampakkam (B).

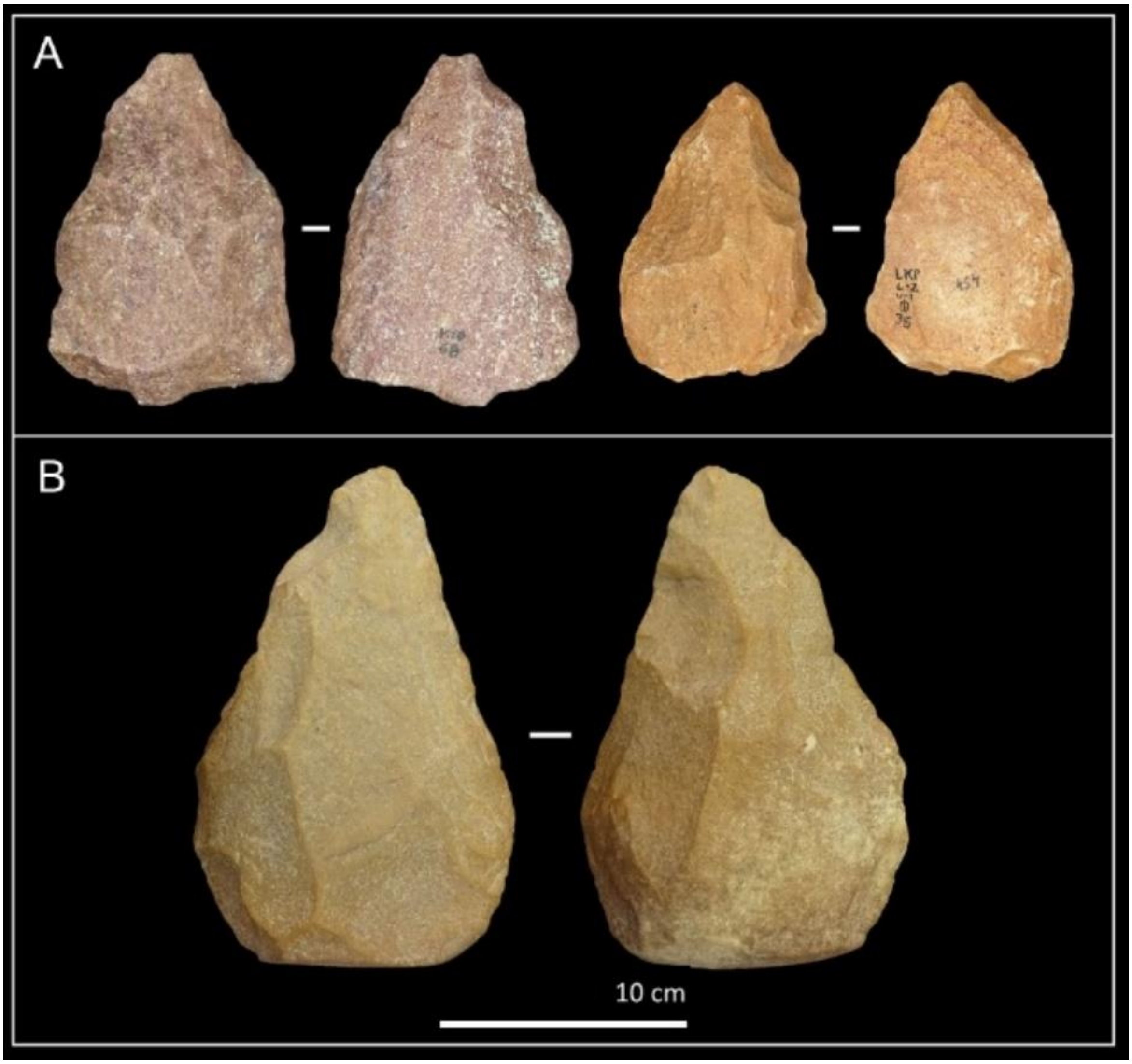

Figure 8. Triangular shaped handaxes from Khyad and Lakhmapur (A) and Singadivakkam (B).

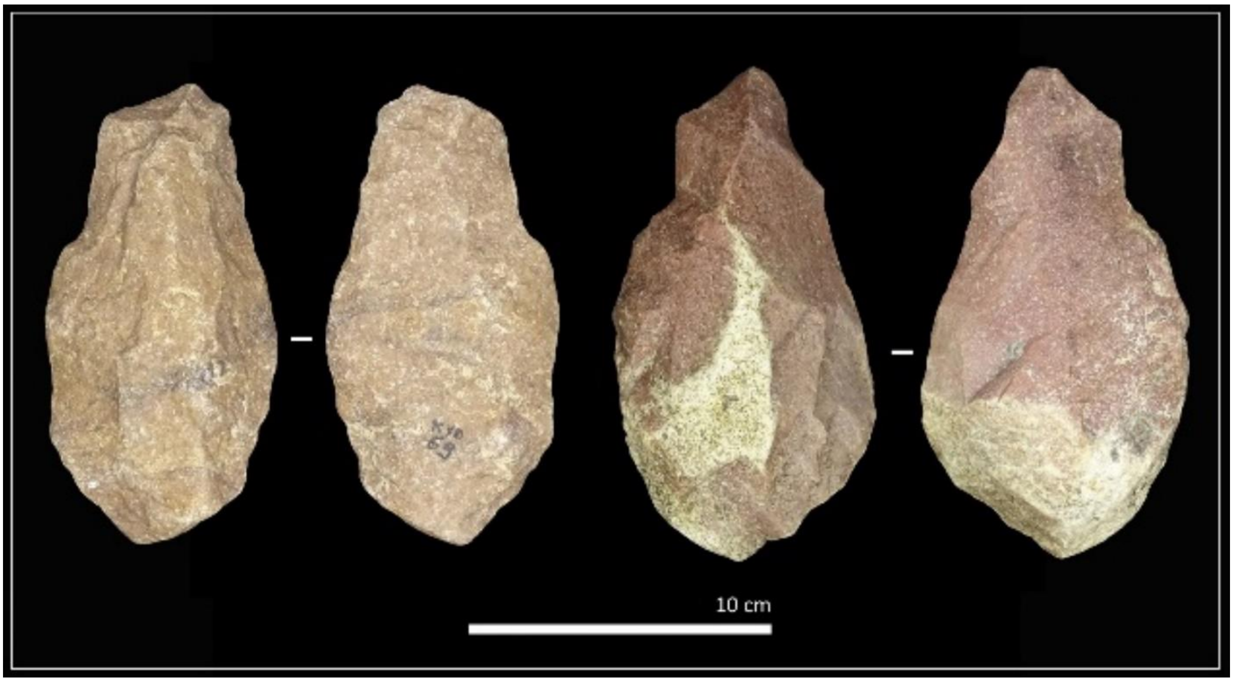

Figure 9. Handaxes with transversal edge from Khyad.

Figure 10. Composite cleavers from Khyad (A and B).

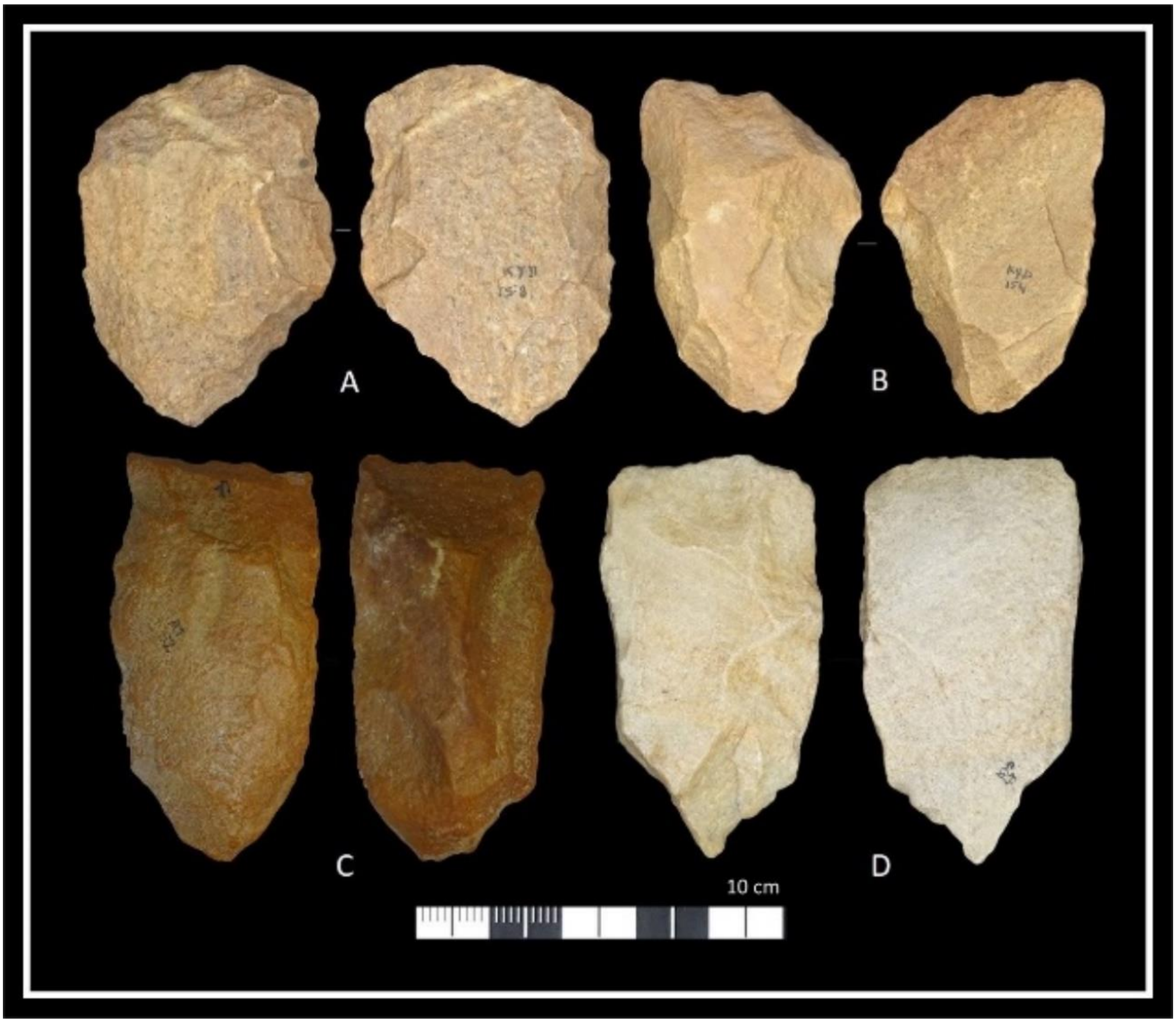

Figure 11. Different cleavers with V proximal morphology from Khyad (A, B. D) and Attirampakkam (C).

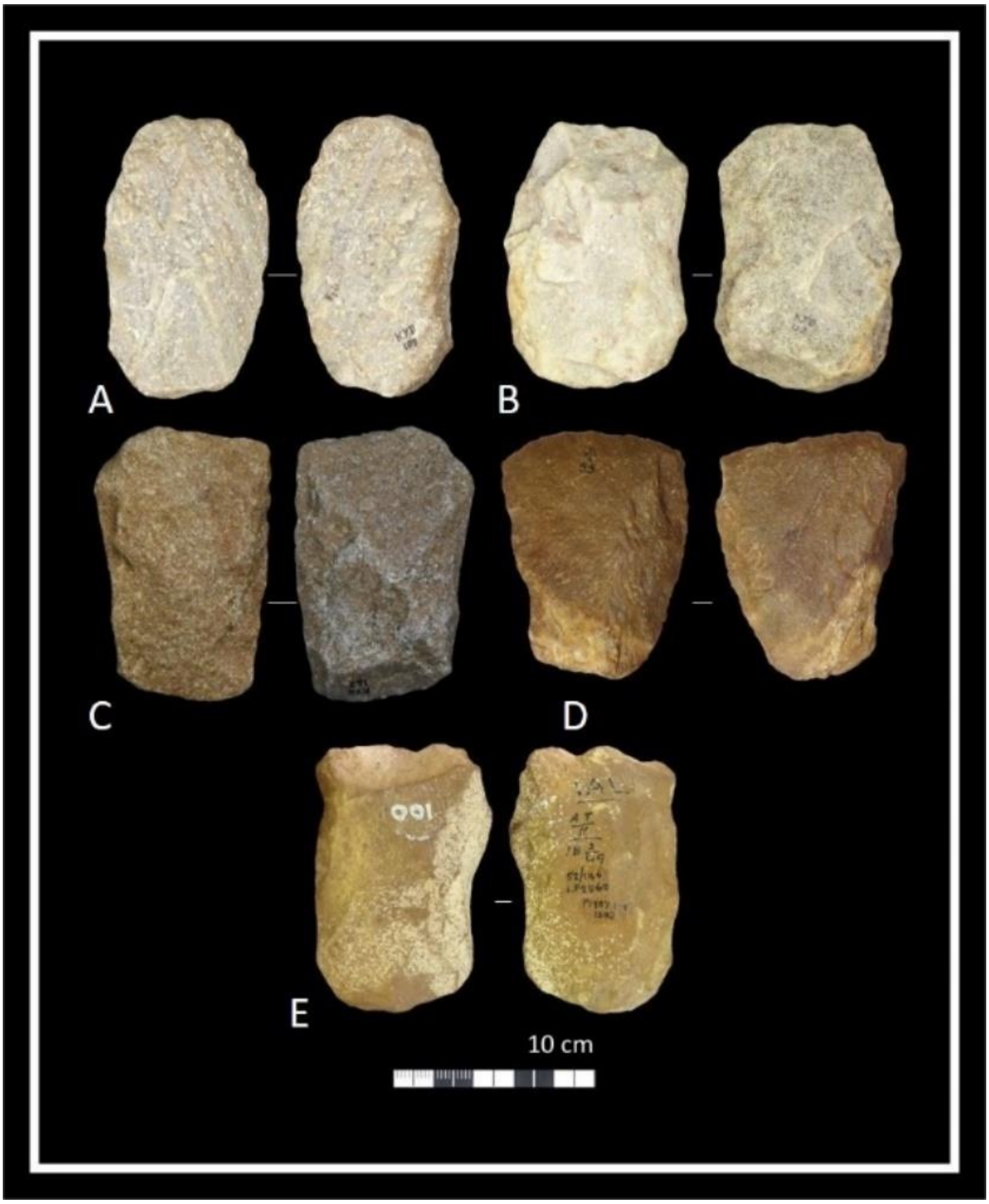

Figure 12. Cleavers with square ended proximal morphology - Khyad (A, B, C) and Attirampakkam (D and E).

Figure 13. Cleavers with convergent distal ends –Khyad (A and B) and Benkaneri (C).

Figure 14. Cleavers with convex distal morphologies – Khyad (A) and Benkaneri (B)

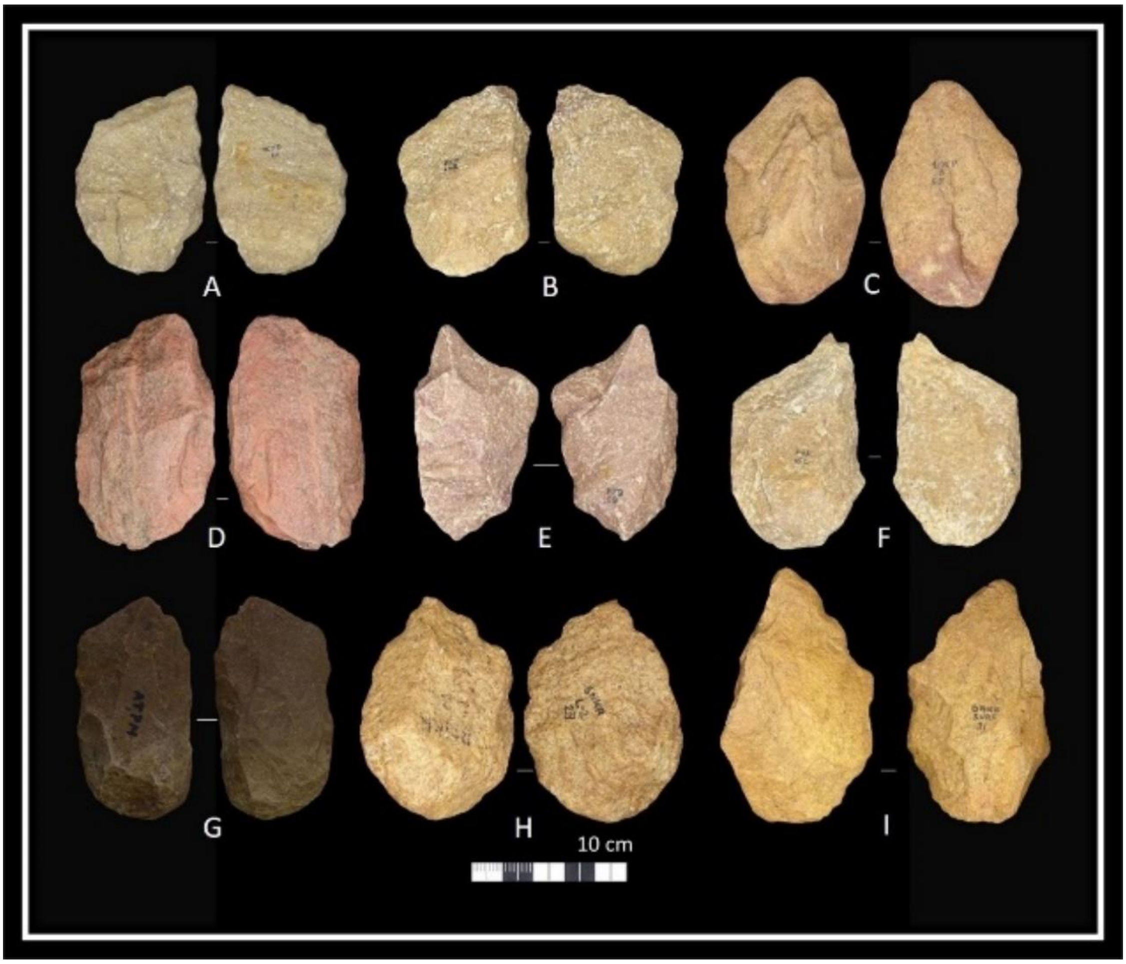

Figure 15. Cleavers with diagonal cutting edge from Khyad (A, B, E, F), Lakhmapur (C), Benkaneri (D, H, I), Attirampakkam (G).

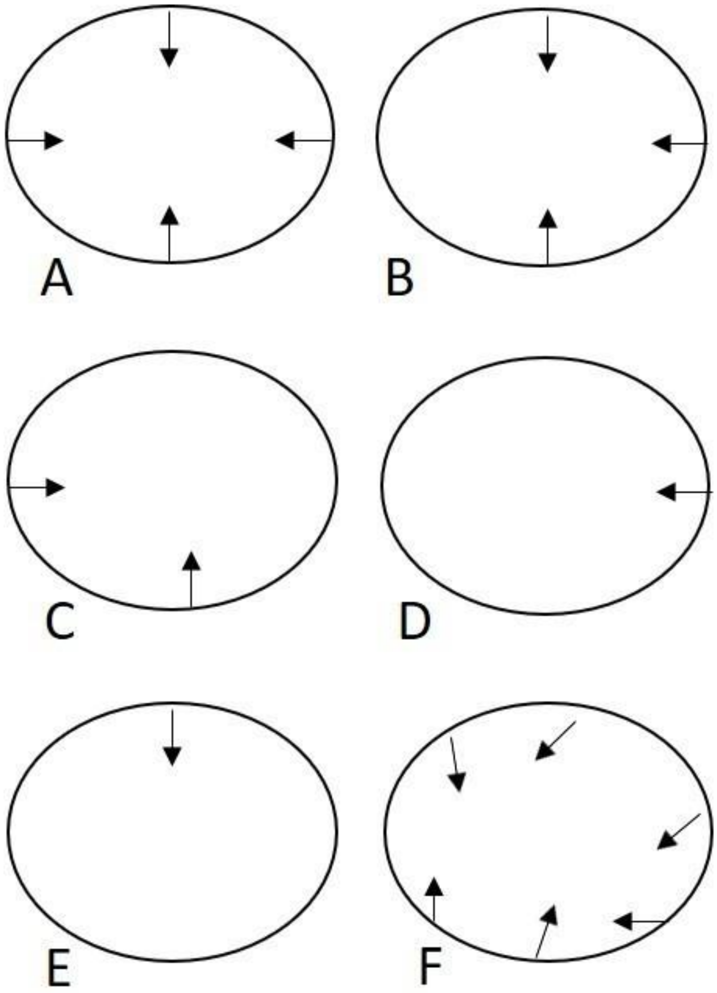

Figure 16. Shaping removal patterns; A (convergent/radial/centripetal), B (Three-directional), C (bidirectional), D (unidirectional), E (unipolar longitudinal) and F (multi-directional).

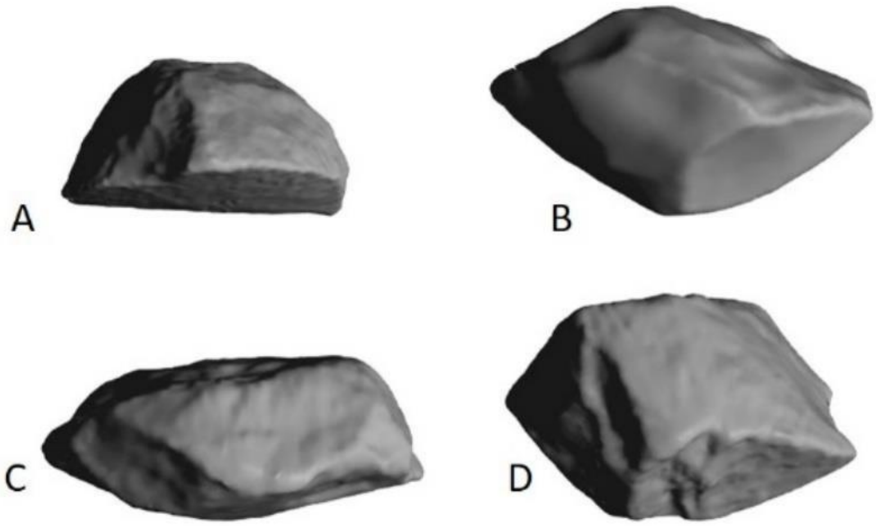

Figure 16. Cross-sectional morphology – Plano-convex (A), Biconvex (B and D), Biplanar (C).

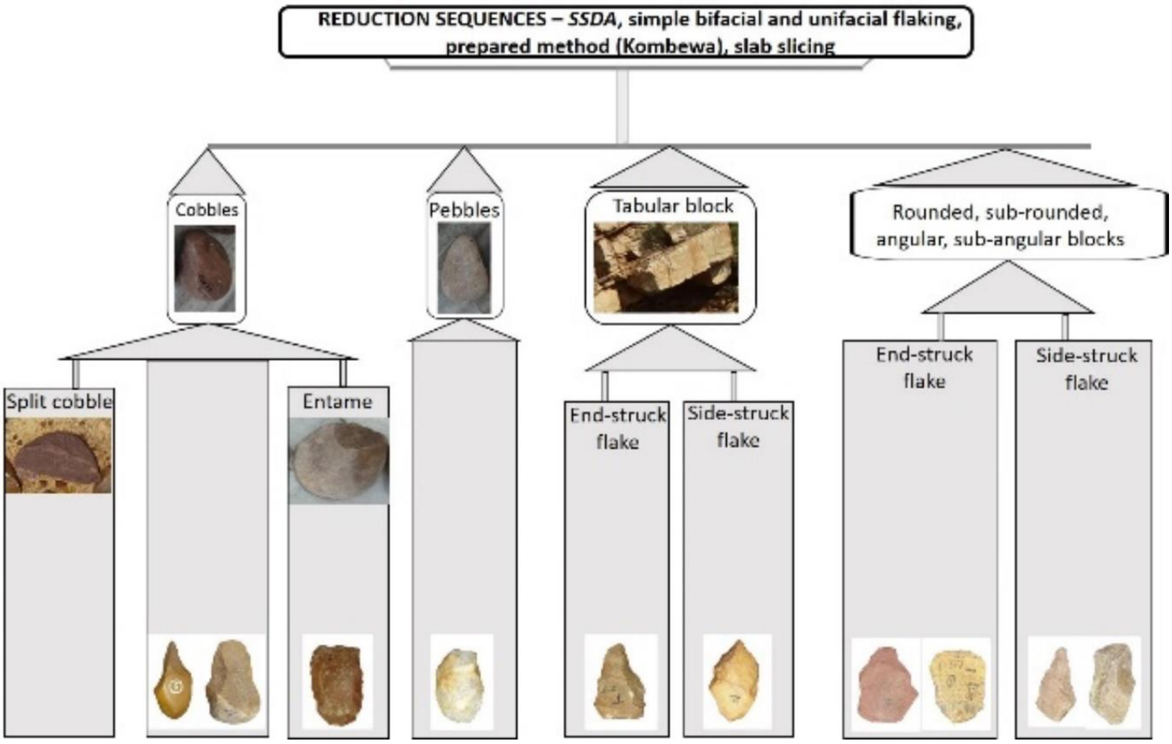

Figure 17. Schema of diverse reduction sequences noted at all the sites from Malaprabha Valley and Tamil Nadu.

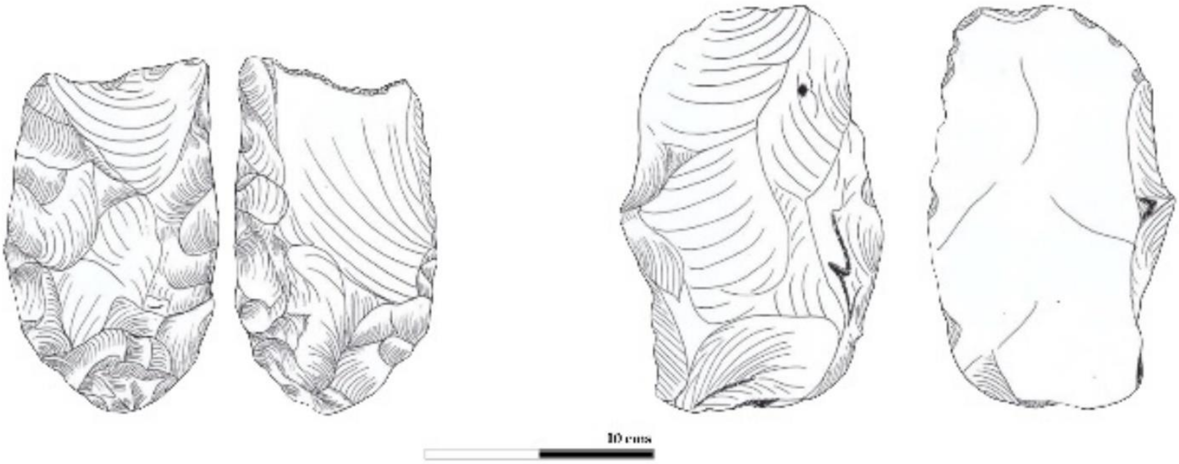

Figure 18. Cleavers from Khyad (Source: Jinu Koshy).

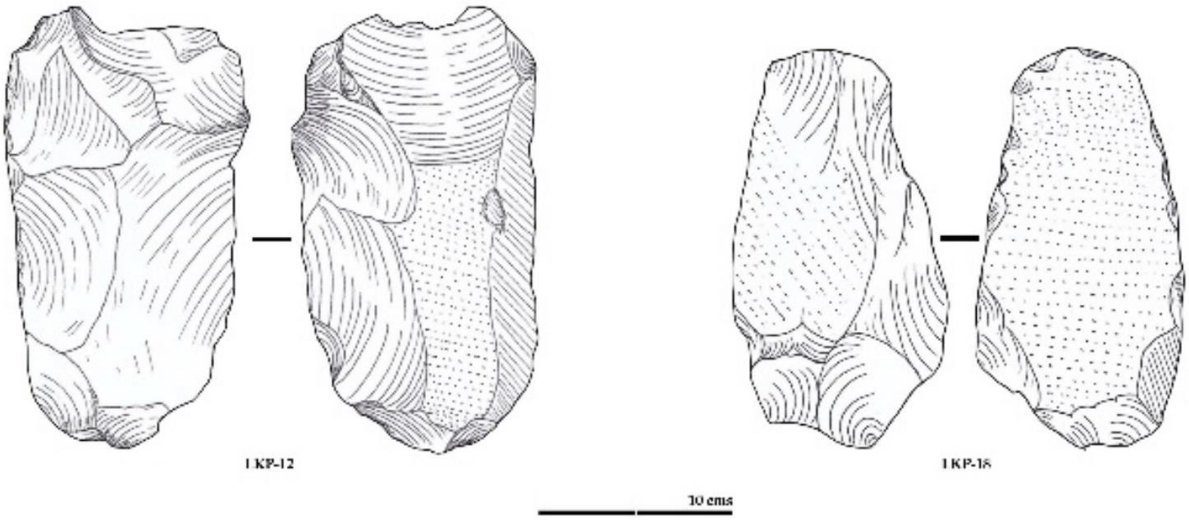

Figure 19. Cleavers from Lakhmapur (Source: Jinu Koshy).

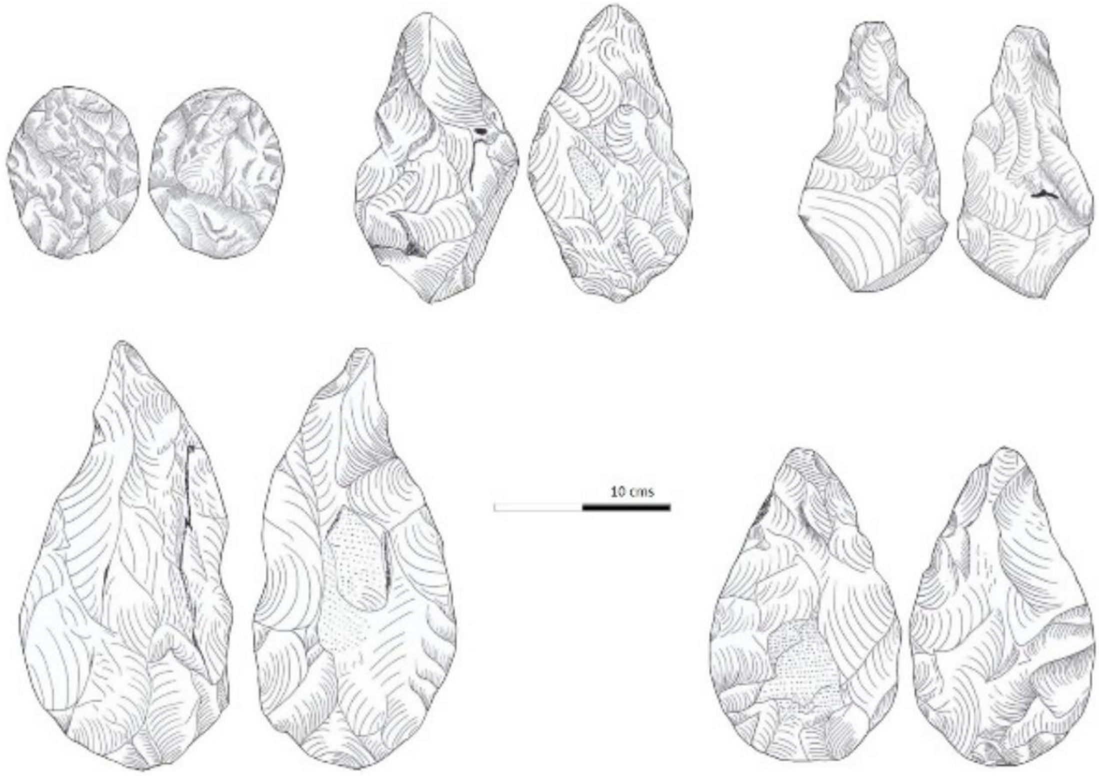

Figure 20. Handaxes from Lakhmapur (Source: Jinu Koshy).

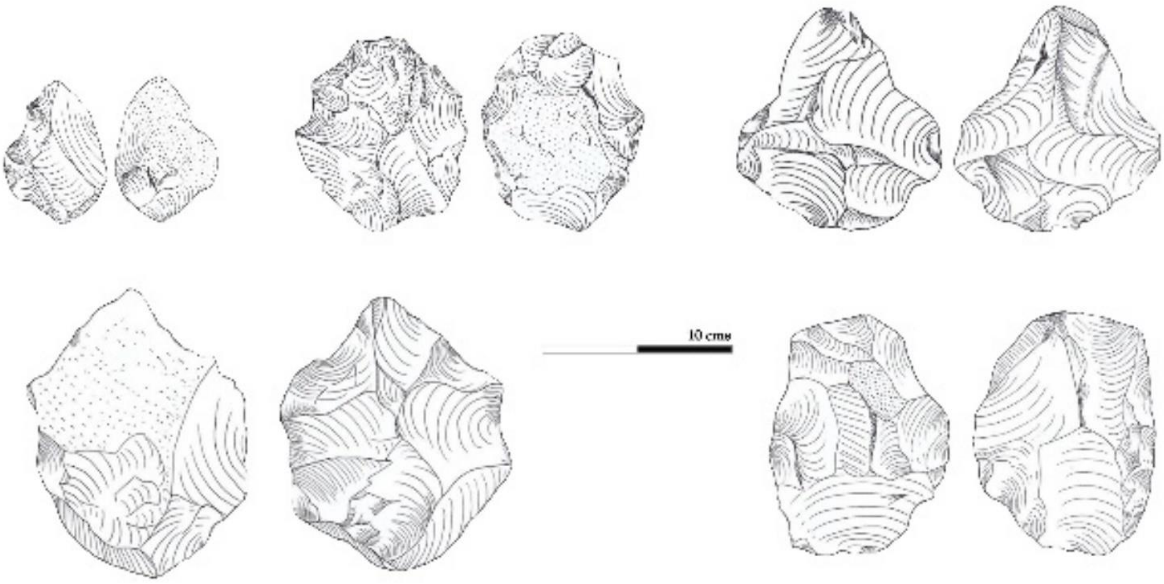

Figure 21. Handaxes from Benkaneri (Source: Jinu Koshy).

APPENDIX IV – PLATES

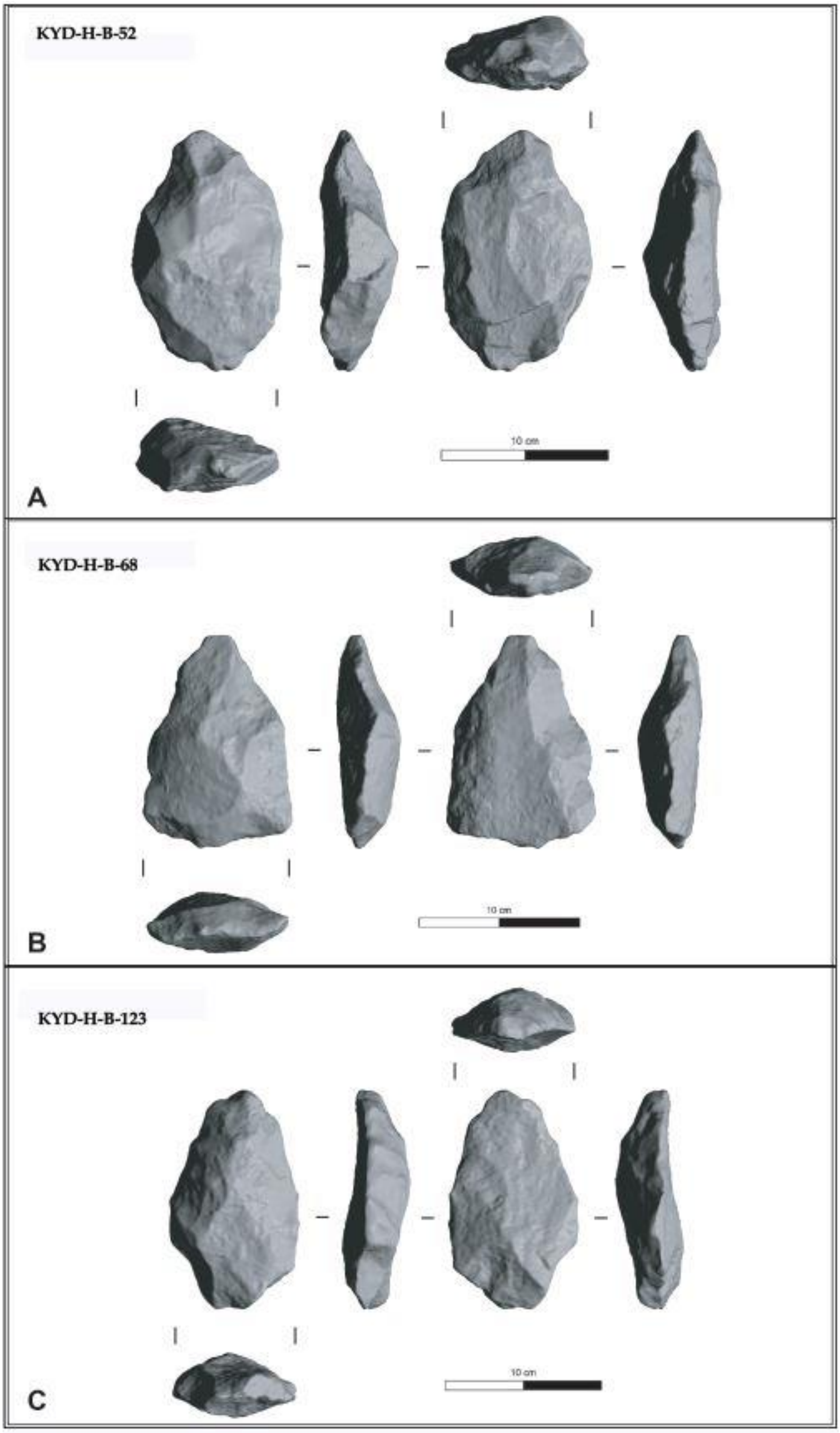

Plate A. 3D images of bifacial handaxes from Khyad.

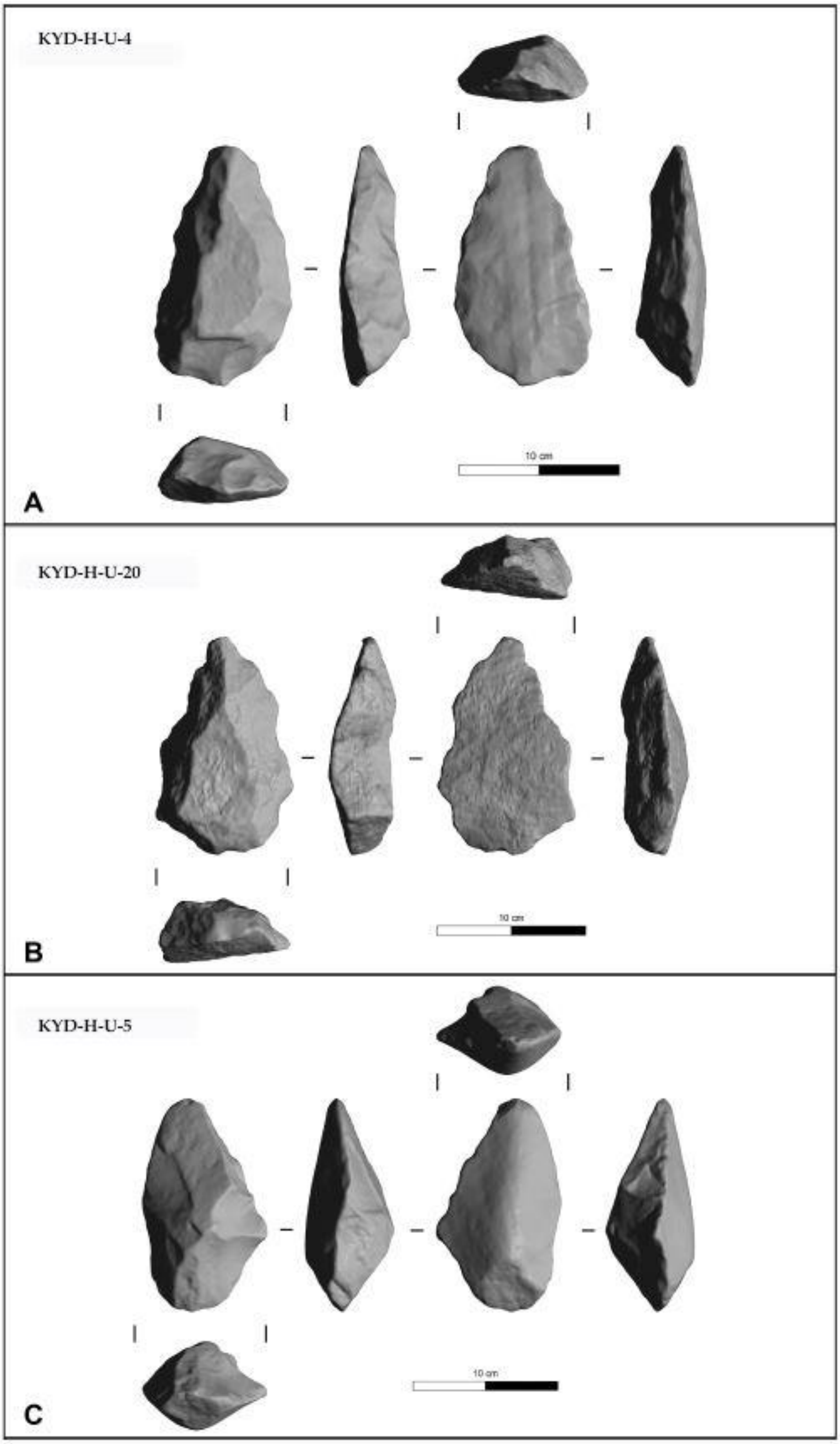

Plate B. 3D images of unifaces from Khyad.

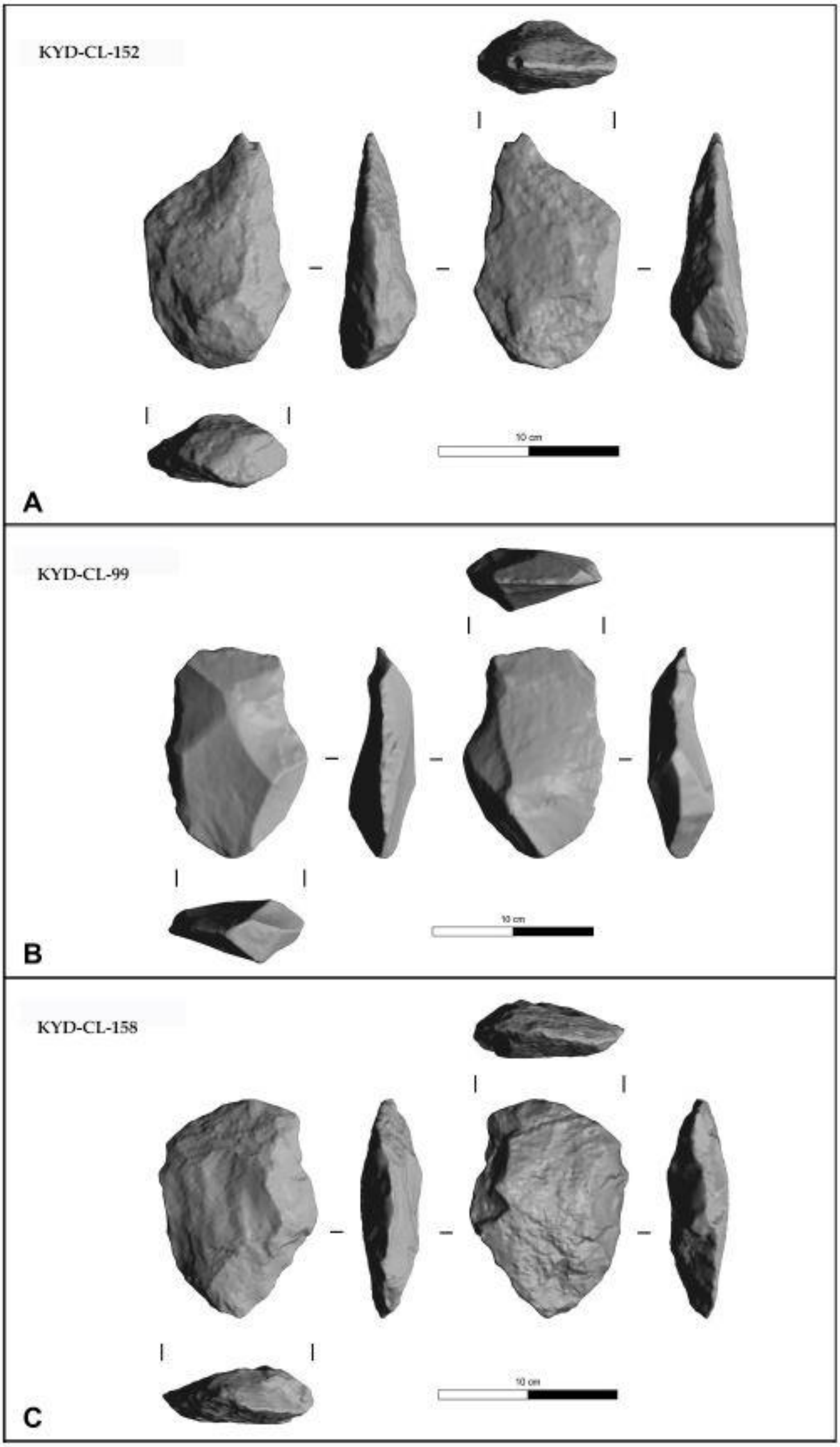

Plate C. 3D images of cleavers from Khyad.

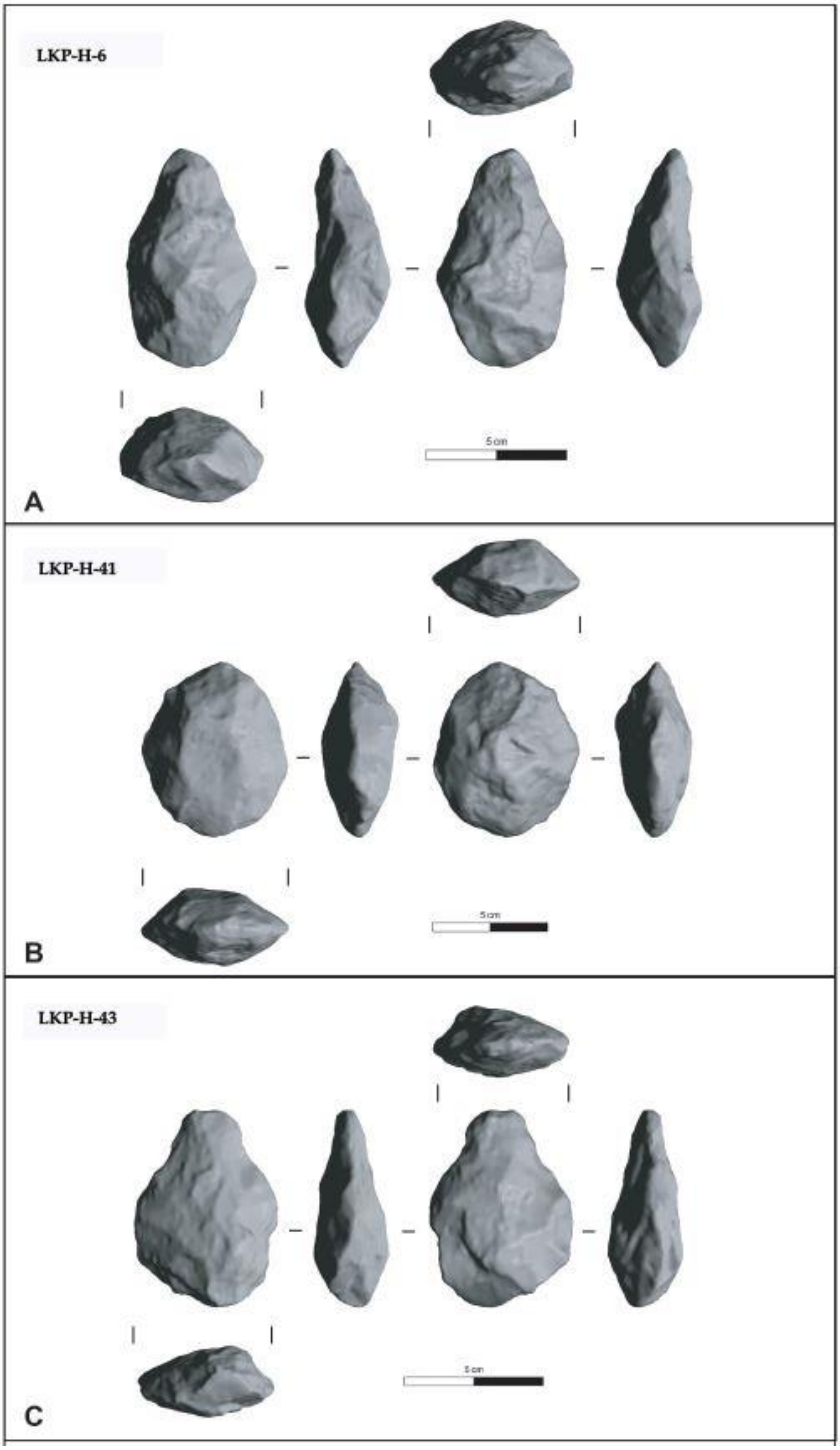

Plate D. 3D images of handaxes from Lakhmapur.

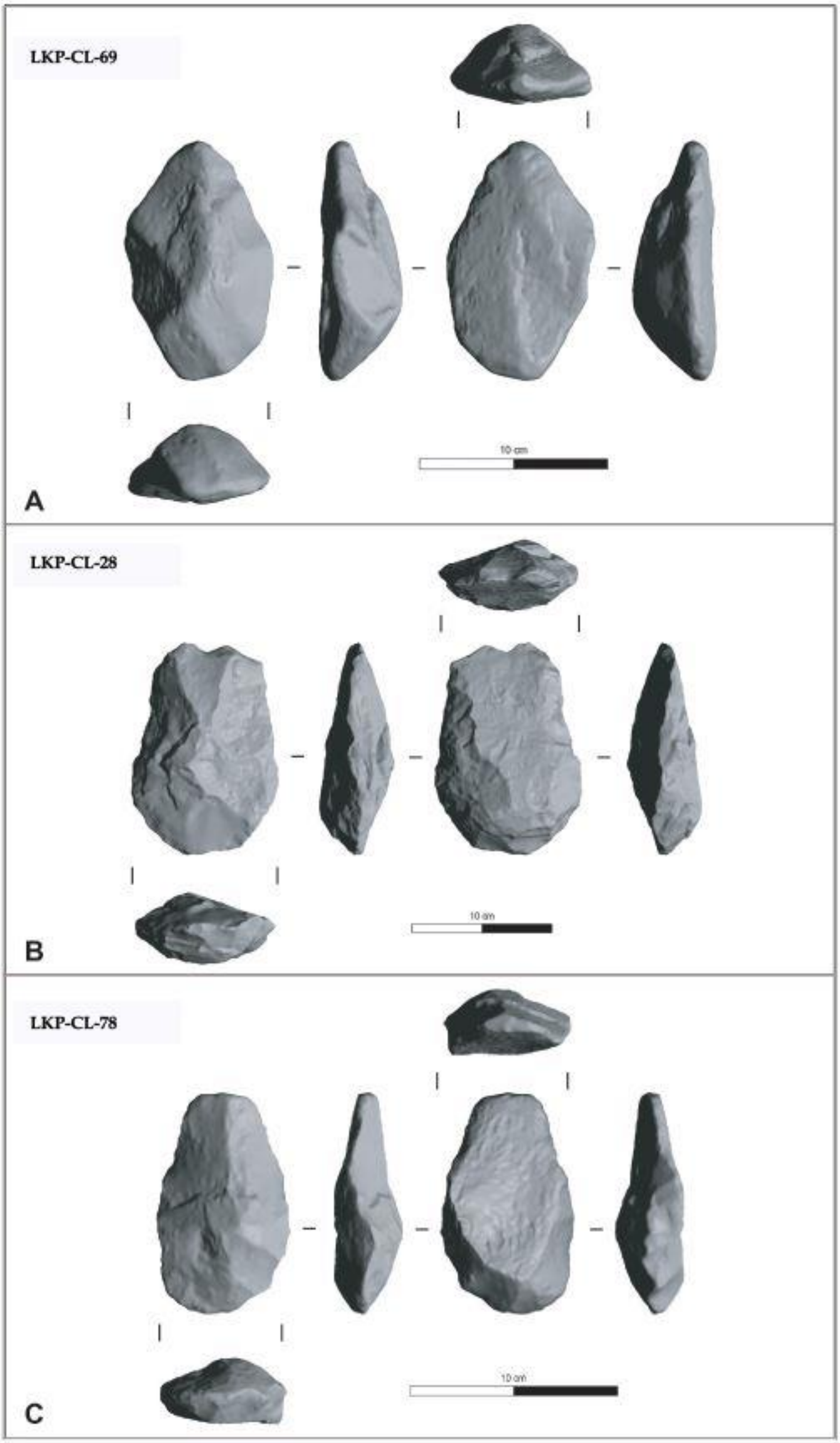

Plate E. 3D images of cleavers from Lakhmapur.

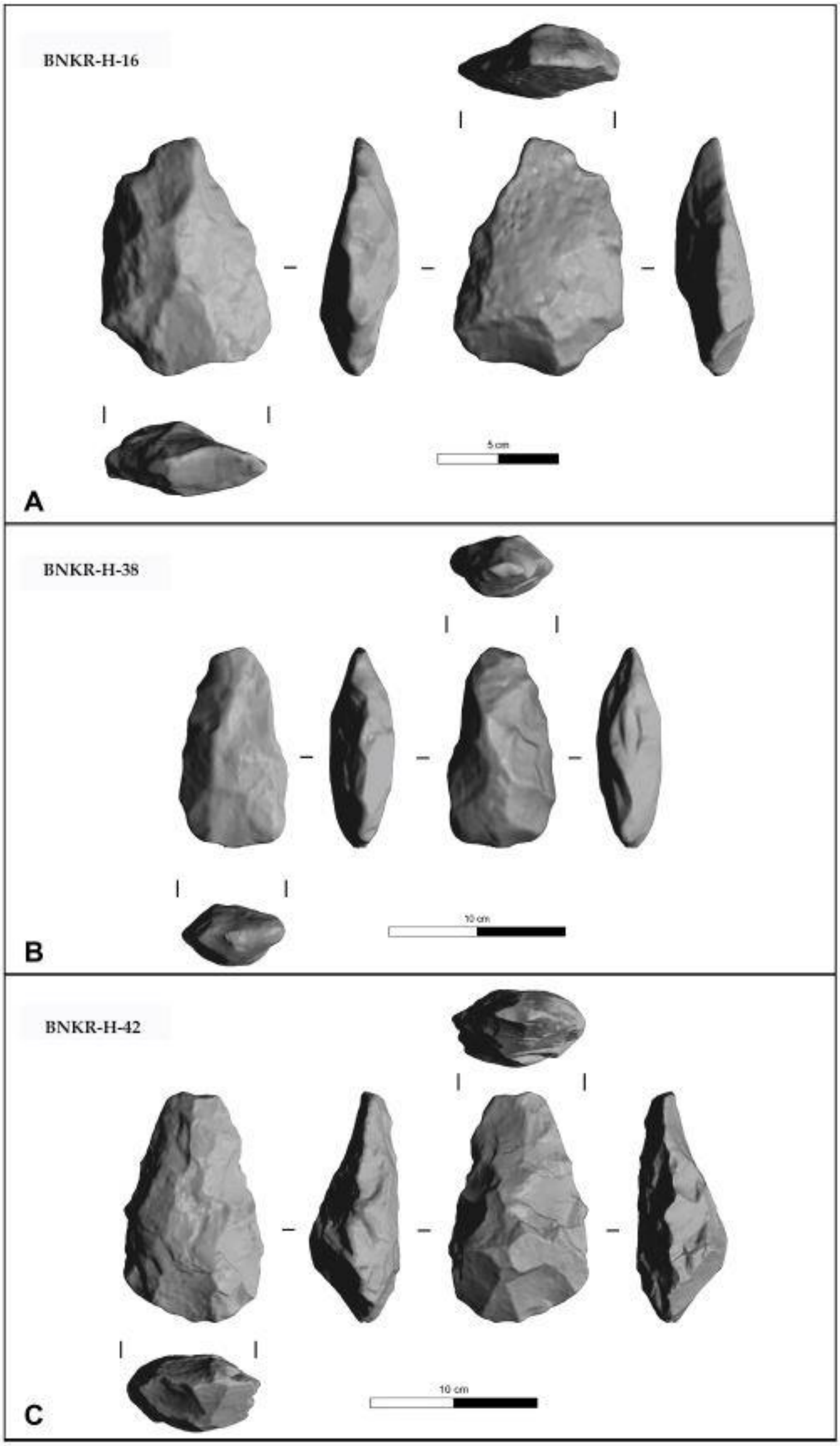

Plate F. 3D images of handaxes from Benkaneri.

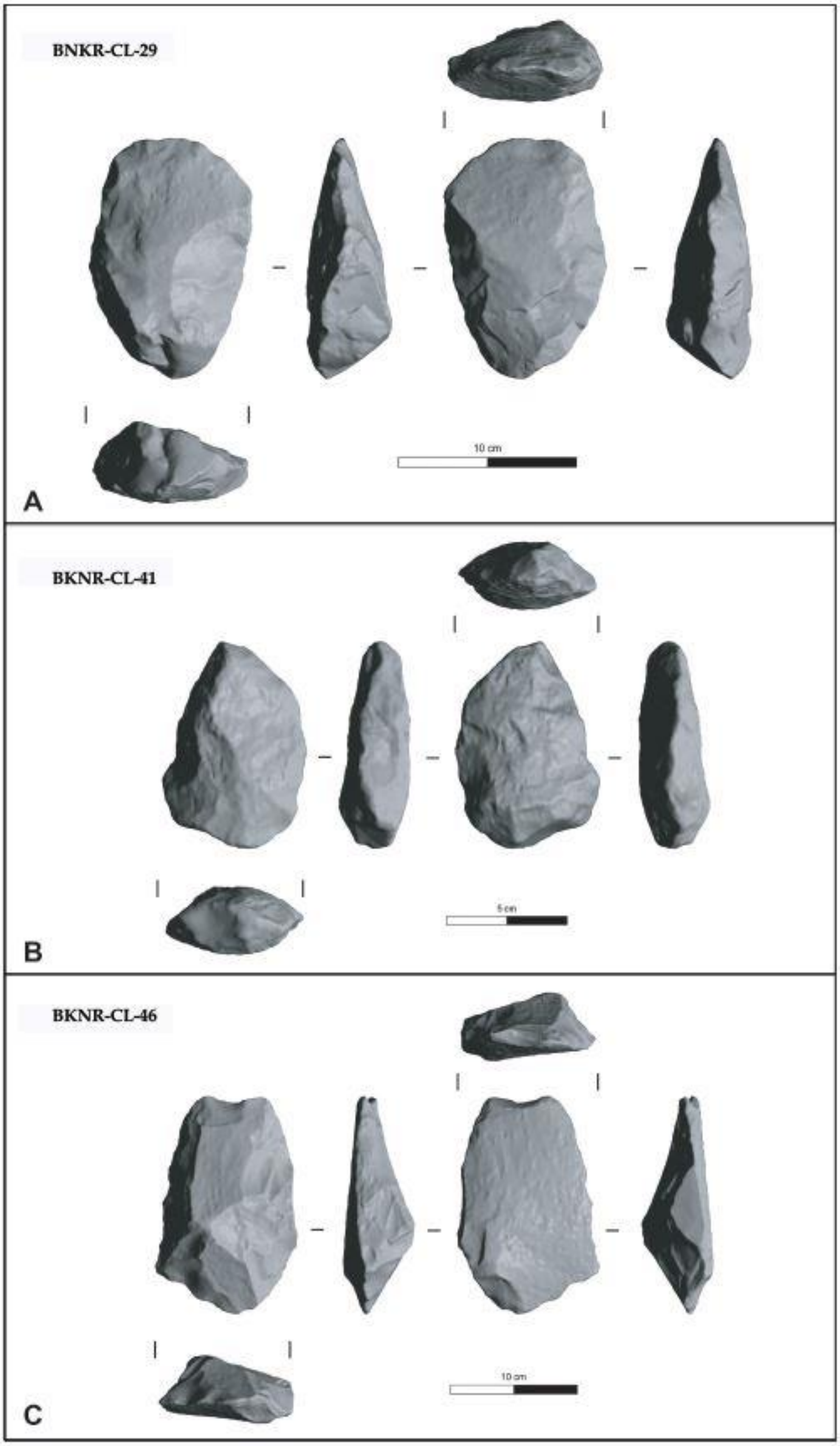

Plate G. 3D images of cleavers from Benkaneri.

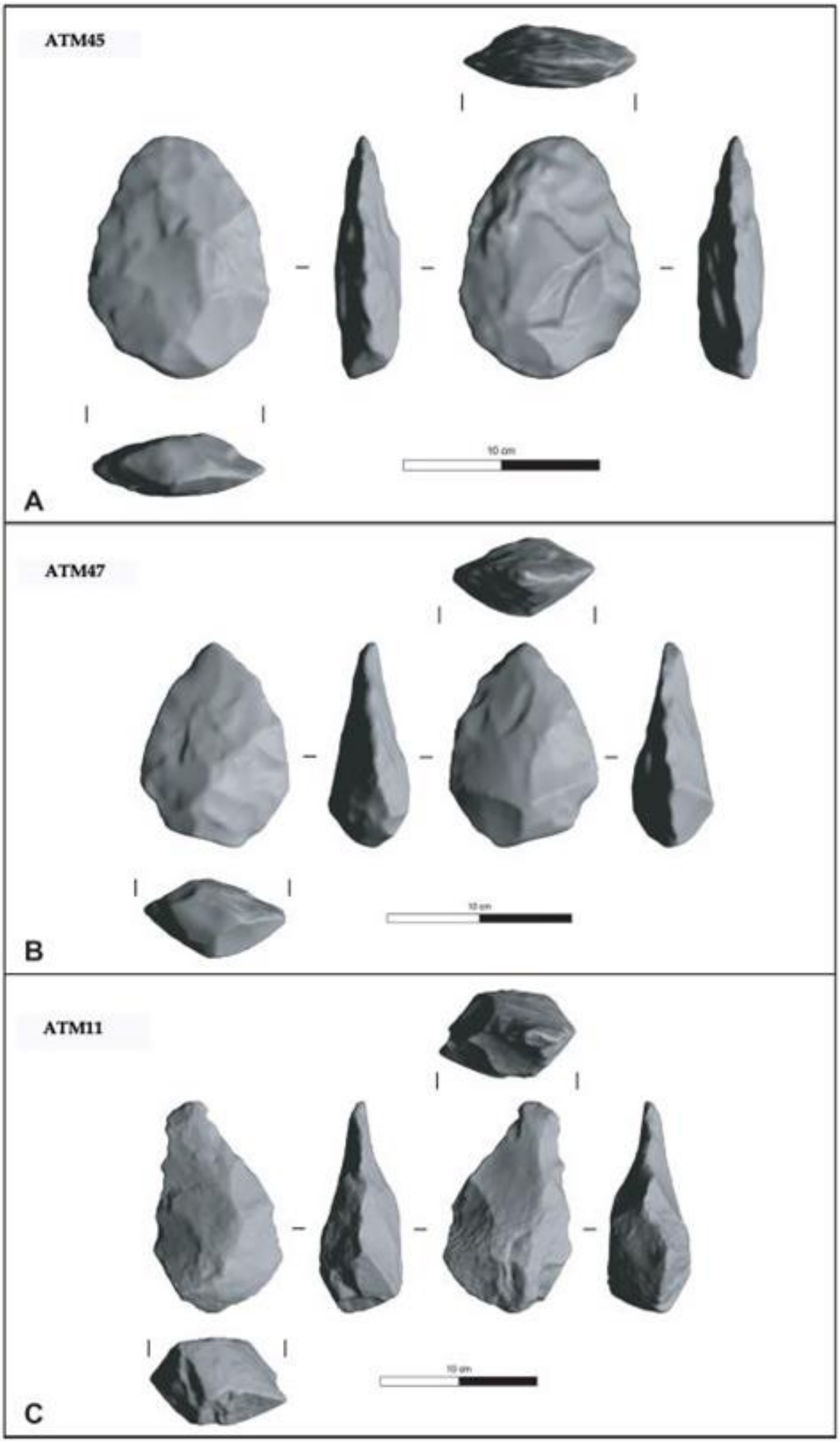

Plate H. 3D images of handaxes from Attirampakkam.

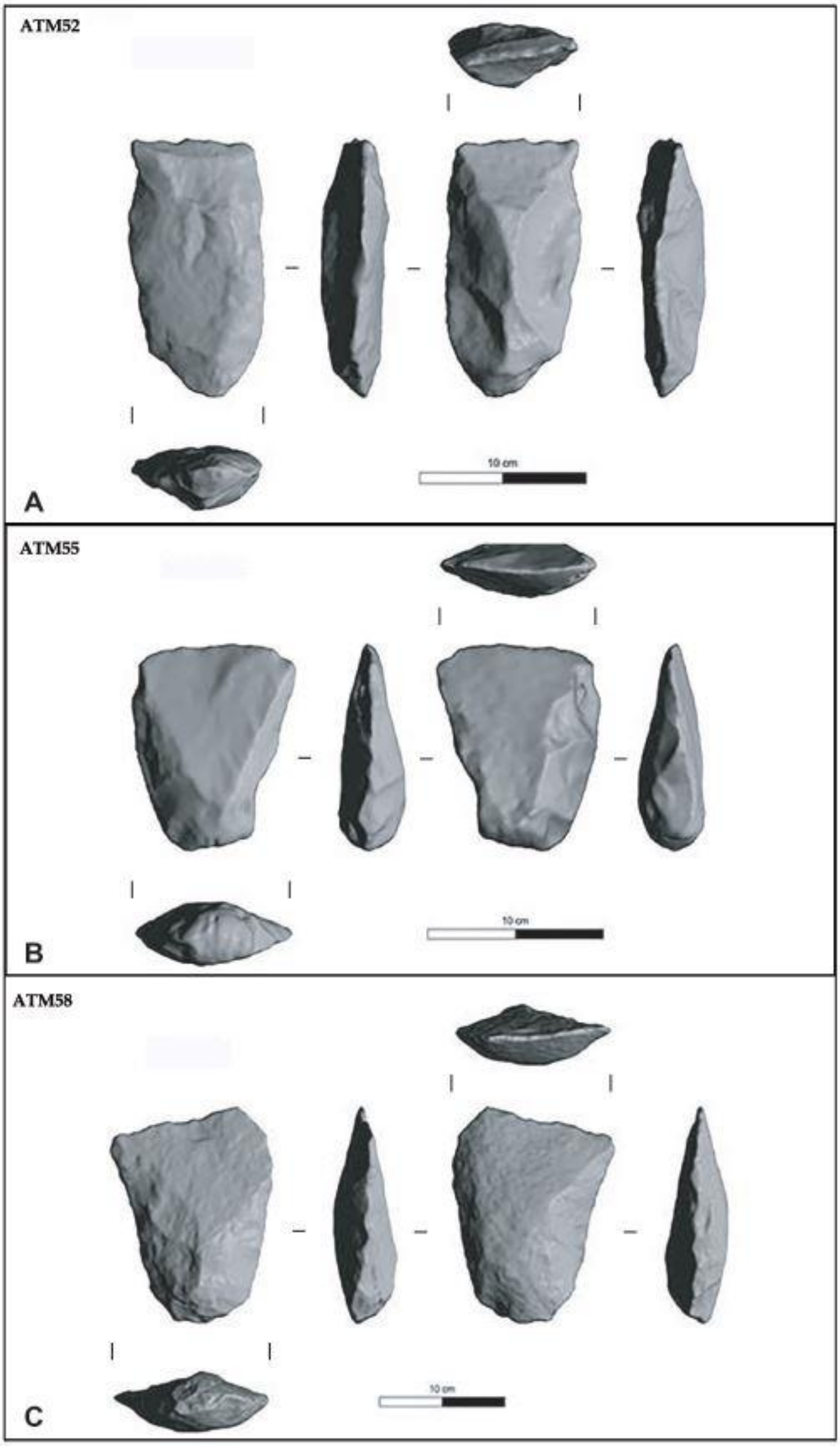

Plate I. 3D images of cleavers from Attirampakkam.

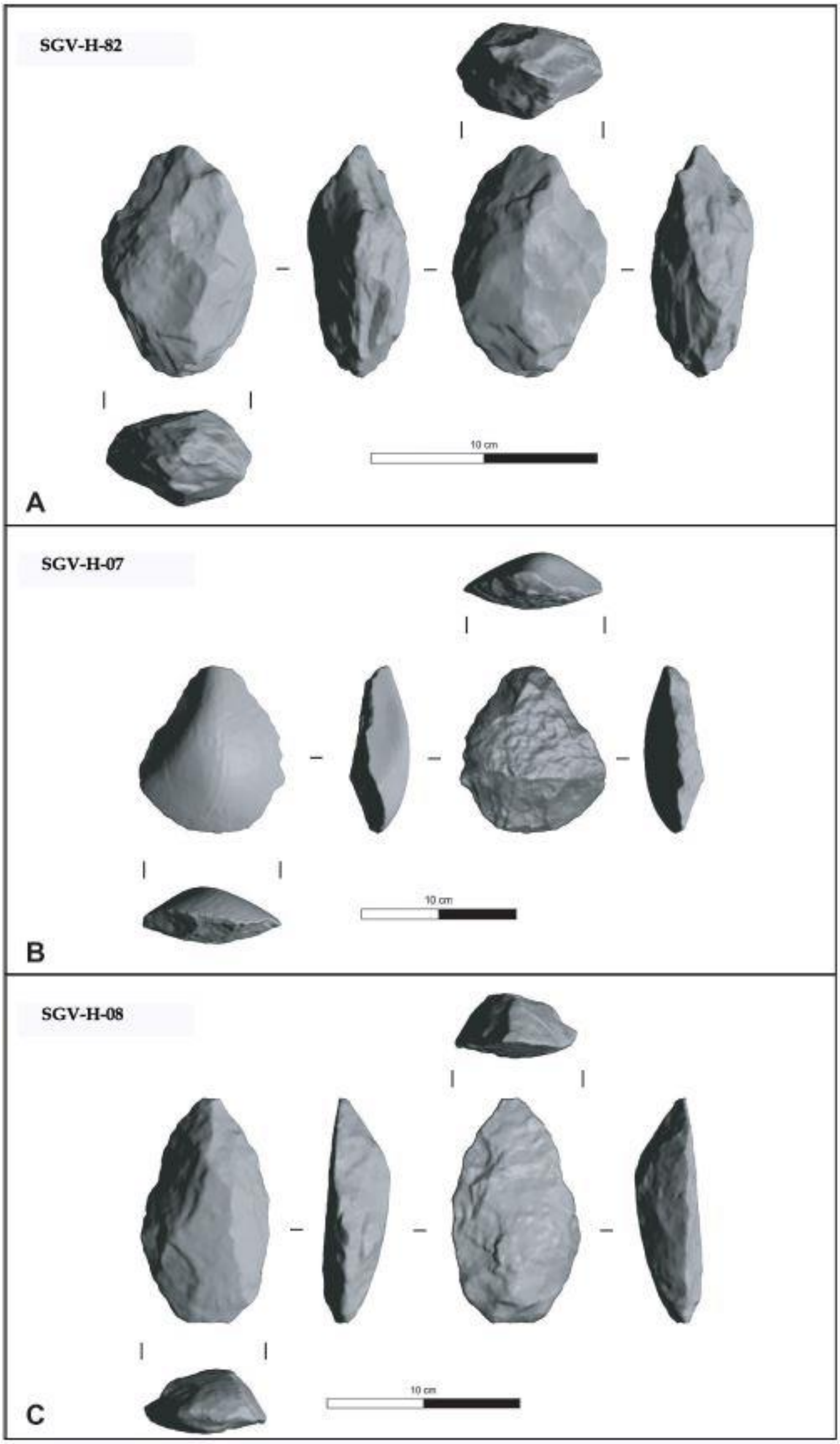

Plate J. 3D images of handaxes from Singadivakkam.

"I am sometimes asked what is the point of my research? Mostly I reply that there is no point beyond understanding. However, if I were to suggest a more utilitarian purpose to this research, it would be that cooperative, not competitive, social interactions, are what gives humanity our unique cognitive and cultural abilities, and we would do well to remember that." Shipton, 2013: 87

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