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NUMBER 3

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THE CUTTING EDGE:

New Approaches to the Archaeology of Human Origins

Editors

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Stone Age Institute & Indiana University

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COVER CAPTIONS AND CREDITS

Top: Homo habilis Utilizing Stone Tools. Painting by artist-naturalist Jay H. Matternes. Copyright 1995, Jay H. Matternes. Inspired by a prehistoric scenario by K. Schick and N. Toth in Making Silent Stones Speak: Human Origins and the Dawn of Technology (1993), Simon and Schuster, New York. Pp.147-149.

Lower right: Whole flake of trachyte lava from the 2.6 million-year-old site of Gona EG-10, Ethiopia. Reported by S. Semaw (2006), "The Oldest Stone Artifacts from Gona (2.6-2.5 Ma), Afar, Ethiopia: Implications for Understanding the Earliest Stages of Knapping" in The Oldowan: Case Studies into the Earliest Stone Age, eds. N. Toth and K. Schick. Stone Age Institute Press, Gosport, Indiana. Pp. 43-75. Photo courtesy of Tim White.

Lower left: Prehistoric cut-marks from a stone tool on Sterkfontein hominin partial cranium StW 53. Reported by T. Pickering, T. White, and N. Toth (2000) in "Cutmarks on a Plio-Pleistocene hominid from Sterkfontein, South Africa". American Journal of Physical Anthropology 111, 579-584. Scanning electron micrograph by N. Toth.

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Dedication

To F. Clark Howell (1925-2007), professor, mentor, colleague, and friend. His scholarship, scientific contributions, influence, and encouragement to paleoanthropology are inspirations for the present and future generations of researchers.

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THE CUTTING EDGE: NEW APPROACHES TO THE ARCHAEOLOGY OF HUMAN ORIGINS

EDITED BY

KATHY SCHICK AND NICHOLAS TOTH

STONE AGE INSTITUTE PRESS, 2009

CONTENTS

INTRODUCTION

KATHY SCHICK AND NICHOLAS TOTH

"Science at the cutting edge, conducted by sharp minds probing deep into nature, is not about self-evident facts. It is about mystery and not knowing. It is about taking huge risks. It is about wasting time, getting burned, and failing. It is like trying to crack a monstrous safe that has a complicated, secret lock…"

Richard Preston (1996)
First Light: The Search for the Edge of the Universe.

"There's a pattern here to see, and the point will soon be clear to me…"

Stewart Copeland (1985)
"Serengeti Long Walk", from the film soundtrack, *The Rhythmatist*.

The co-evolution of hominin biology and technology has been a feature of the human lineage for at least the last two-and-a-half million years. During this time there have been both profound biological changes as well as profound technological changes, as manifested in the prehistoric human palaeontological and archaeological record. We believe that this unique reliance upon tools and technology was one of the primary factors in the evolutionary trajectory of the human lineage and the ability of our lineage to adapt to an astonishing range of environments and myriad of ecological niches over time.

For most of this time, the vast majority of our archaeological evidence for technology is in the form of flaked and battered stone artifacts and, where preservation has permitted, associated modified animal bones. While there is an great appreciation that a rich organic material culture was almost certainly also a part of early hominin material culture, such perishable tools artifacts (e.g. made of wood, bark, leaves, grass, hide, eggshell, tortoise shell, horn, gourd) rarely if ever survive in the early archaeological record. Thus stone technologies represent the major evidence for the evolution of early hominin tool-making and tool-using behaviors, for the role of tools in the lifeways and adaptations of evolving hominin forms, and potentially for the cognitive underpinnings of such complex behavior patterns in our ancestral lineage.

As tool-related behaviors have been so critical in the course of human evolutionary development, it is vital to palaeoanthropology to refine our understanding of the meaning and significance of early stone tool industries. In view of this need, in October of 2006 the Stone Age Institute hosted its third international conference, entitled "The Cutting Edge: New Approaches to the Archaeology of Human Origins." Many of the principal investigators of Early Stone Age (especially Oldowan) sites were invited to come to the Stone Age Institute, give presentations, and discuss major issues in the field as well as new methodologies that might be of use to other researchers. Our principal discussant was the late F. Clark Howell, who provided a valuable perspective gained from decades of palaeoanthropological experience. Participants included (showing their current affiliation), Rob Blumenschine (Rutgers University), David Braun (University of Capetown), Parth Chauhan (Stone Age Institute), Charles Egeland (University of North Carolina), Ignacio de la Torre (Institute of Archaeology, London), Henry de Lumley (Institut de Paléontologie Humaine, Paris), Manuel Dominguez-Rodrigo (University of Madrid), Leslie Harlacker (James Madison University), Jack Harris (Rutgers University), Erella Hovers (Hebrew University), Kathy Kuman (University of Witwatersrand), Travis Pickering (University of Wisconsin), Tom Plummer (SUNY Binghamton), Hélène Roche (CNRS, Nanterre), Mohamed Sahnouni (Stone Age Institute), Kathy Schick (Stone Age Institute), Sileshi Semaw (Stone Age Institute), Dietrich Stout (Emory University), Pierre-Jean Texier (CNRS, Valbonne), Nick Toth (Stone Age Institute), and David Zhvania (Georgia State Museum, Tbilisi, Georgia). In addition, we have invited another scholar from Spain who worked at the Institute recently on a predoctoral fellowship, Beatriz Fajardo, to also contribute to this volume.

In Chapter 1, Robert Blumenschine and colleagues discuss changes in raw material transport (quartzite) in lowermost Bed II times (c. 1.785- 1.745 Ma) at Olduvai Gorge, Tanzania that may be related to changes in landscape over time, notably in the pre-incision and post-incision phases. David Braun and John Harris examine in Chapter 2 technological variation in the KBS Member (c. 1.88-1.6 Ma) at Koobi Fora, Kenya that may be related to a shift towards drier conditions through time as well as the possibility of an increasing reliance on lithic technology and the emergence of *Homo erectus*. In Chapter 3, Parth Chauhan reviews the claims for early occupation on the Indian subcontinent, and concludes that, at our present state of knowledge, there is as yet no convincing evidence of a pre-Acheulean occupation of this area of South Asia. Ignacio de la Torre's examination of the technological strategies of hominins at Peninj, Tanzania (1.6-1.4 Ma) in Chapter 4 show that both early Acheulean and Oldowan-like lithic strategies were employed and were probably used by the same hominin groups in different environments.

In Chapter 5, Henry de Lumley and colleagues review the evidence of early archaeological sites in East Africa and Southern Europe, and suggest a "Pre-Oldowan" or "Archaic Oldowan" stage starting c. 2.55 Ma characterized by simple cores and flakes with little standardized retouch and a "Classical Oldowan" beginning c. 1.9 Ma with higher frequencies of small retouched tools as well as polyhedrons and spheroids. Erella Hovers in Chapter 6 examines early hominin knapping skills from the perspective of accidents as seen in broken, hinge and step flakes. She argues that such mistakes are an incidental part of the knapping process and not necessarily good indicators of skill, and that early tool-makers at Hadar site A.L. 894 (c. 2.36 Ma) were able to recover from such accidents and to continue reducing cores. In Chapter 7 Beatriz Fajardo reviews the evidence for an early occupation of Europe, focusing on sites at Orce (Barranco Leon and Fuente Nueva) in southern Spain. Kathy Kuman and Alice Field in Chapter 8 discuss the Oldowan Infill industry from Sterkfontein Cave (Member 5 East, ca. 2.0 Ma), South Africa and the influence of raw material on artifact form.

In Chapter 9, Travis Pickering and Charles Egeland experimentally assess the utility of cutmarks on animal bones and bone fragmentation in inferring hominin behavior, and stress that it is not the cutmark frequency, but rather the anatomical patterning of cutmarks that give the best evidence of hominin carcass use- most notably, cutmarks on midshaft fragments indicate processing of fully fleshed limbs and the probability that hominins had early access to carcasses. Mohamed Sahnouni and Jan Van der Made in Chapter 10 review the biochronology of sites in North Africa, and conclude that the sites of Ain Hanech and El-Kherba in Algeria are the earliest securely-dated sites in that region, dating to c. 1.8 Ma based especially on the forms of *Anancus* (mastodon), *Kolpochoerus* (pig), and *Dicerorhinus* (rhino) there. Semaw and colleagues in Chapter 11 look at variability in lithic assemblages at three sites dated to 2.6 million years old at Gona in Ethiopia (EG 10, EG 12, and OGS 7.) Of particular interest, OGS 7 shows evidence for strong selectivity on the part of hominins for higher-quality, finer-grained raw materials and more bifacial and polyfacial flaked cores.

In Chapter 10, Dietrich Stout and colleagues experimentally examine Oldowan lithic knapping skill acquisition in modern humans. Three developmental stages of skill acquisition were identified: 1) relatively uncontrolled; 2) controlled but minimally invasive core reduction; 3) expert with intensive core reduction, larger and more elongated flakes, and more acute exterior platform angles, which most closely resembles the early Oldowan prehistoric archaeological assemblages. Toth and Schick, in Chapter 12, draw upon over three decades of experimental archaeology and other actualistic studies to show how these approaches can shed light on our understanding and appreciation of the world's earliest archaeological occurrences and their behavioral and evolutionary significance.

The primary focus of the conference and this volume was the lithic technologies of Early Stone Age sites, and what they can potentially tell us about early hominin behavior and adaptation, in effect a complement to our Stone Age Institute conference and book on the analysis of animal bones from prehistoric sites, "Breathing Life into Fossils: Taphonomic Studies in Honor of C.K. Brain." This, our third edited volume, is the result of the "Cutting Edge" conference on early lithic technology. We would like to extend our heartfelt thanks to all of the participants who contributed chapters and for their patience during the production of this volume. We would also like to acknowledge the support of our advisory board members and other donors, whose generosity made this conference and publication series possible. We would like to especially thank Mila Norman, Leslie Harlacker, Melanie Everett, August Costa, Charles Egeland, and Blair Hensley-Marschand for all their help during the conference, and to Amy Sutkowski, who did the graphic design and layout for this volume.

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CHAPTER 1

Changes in Hominin Transport of Stone for Oldowan Tools Across the Eastern Olduvai Basin During Lowermost Bed II Times

Robert J. Blumenschine, Fidelis T. Masao, and Ian G. Stanistreet

Introduction

The Oldowan Industry was defined quantitatively by Leakey (1967, 1971) on the basis of frequencies of stone artifact forms in assemblages recovered from the Bed I through Middle Bed II sequence at Olduvai Gorge. Six excavations described by Leakey (1971) span most of this approximately 150,000 year interval of the Plio-Pleistocene. They are distributed across 3–4 km east-west extent of paleo-Lake Olduvai's eastern lake margin (Hay, 1976). Four of the excavations lie within approximately 1 km of the perennial portion of the paleo-lake, including the MNK Skull Site, the youngest Oldowan locality at Olduvai, and FLK *Zinjanthropus*, FLK North, FLK North North, the latter three separated by a total distance of about 200 m. Two other sites, HWK East and DK, are located in the middle and upper portions of the eastern lake margin to the toe of the alluvial fan (Figure 1). Ranging in area from about 30 m^2 to almost 300 m^2 (Harris and Capaldo, 1993), the excavations expose multiple stratigraphic horizons, some of which yielded low to very high density artifact assemblages comprising various proportions of raw materials, artifact types and manuports (Leakey, 1971; her Tables 6 and 7, Figure 117). Some of this variability has been related to presumed differences between site functions (e.g., occupations floor vs. butchery site; Leakey, 1971), but whether it has a behavioral, geographic, and/or temporal basis cannot be ascertained due to the small number of excavated occurrences dispersed over a large area and during a long time period.

Sampling a single discrete time interval across broad areas with a relatively high density of excavations allows potential geographically and behaviorally-based variability in artifact assemblages to be explored. Comparing a chronological series of such samples further permits exploration of temporal variability based possibly on changes in climate, landscapes, or hominin behavior and technology. Referred to most commonly as landscape archaeology (e.g., Ammerman, 1981; Rossignol and Wandsnider, 1992), such a sampling strategy is relatively common for recent time periods. It is undertaken recognizing that localized site-scale occurrences, the traditional focus of archaeological research, contain an incomplete variety of hominin activity traces (Isaac et al., 1981; cf. Binford, 1982, 1992; Ebert, 1992; Wandsnider, 1992), and are poorly understood units of behavioral analysis (Dunnell, 1992; Dunnell and Dancey, 1983; Ebert, 1992; Foley, 1981a, 1981b; Thomas, 1975).

Work conducted at Olduvai Gorge by the Olduvai Landscape Paleoanthropology Project (OLAPP) since 1989 (e.g., Blumenschine and Masao, 1991; Blumenschine et al., 2007 a, b) is one of several studies that seek to document penecontemporaneous variability in Early Stone Age artifacts across broad landscape scales in several East African sedimentary basins. Isaac and Harris (1975, 1978) initiated lateral sampling of isochronous surface remains on the Karari Escarpment in the Turkana Basin. Similar studies at East Turkana have followed that sample surface and in situ Oldowan and Developed Oldowan occurrences (Behrensmeyer, 1985; Stern, 1993, 1994; Rogers, 1996, 1997; Rogers and Harris, 1992; Rogers et al., 1994). At Olorgesailie, Potts (Potts et al., 1999; Sikes et al., 1999) has excavated Acheulian occurrences from four Middle Pleistocene strata. Lateral sampling of Early Stone Age occurrences has been initiated at Kanjera (Plummer et al., 1999; Ditchfield et al., 1999), and Peninj (Dominguez-Rodrigo et al., 2002). Some of

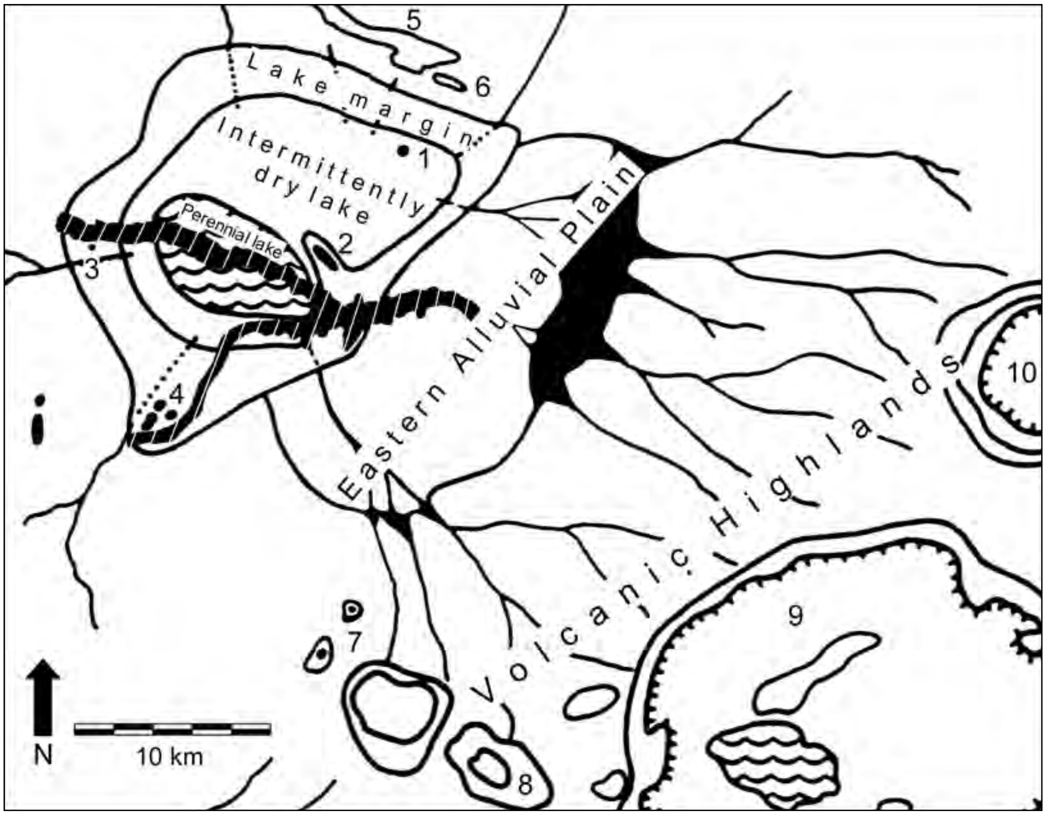


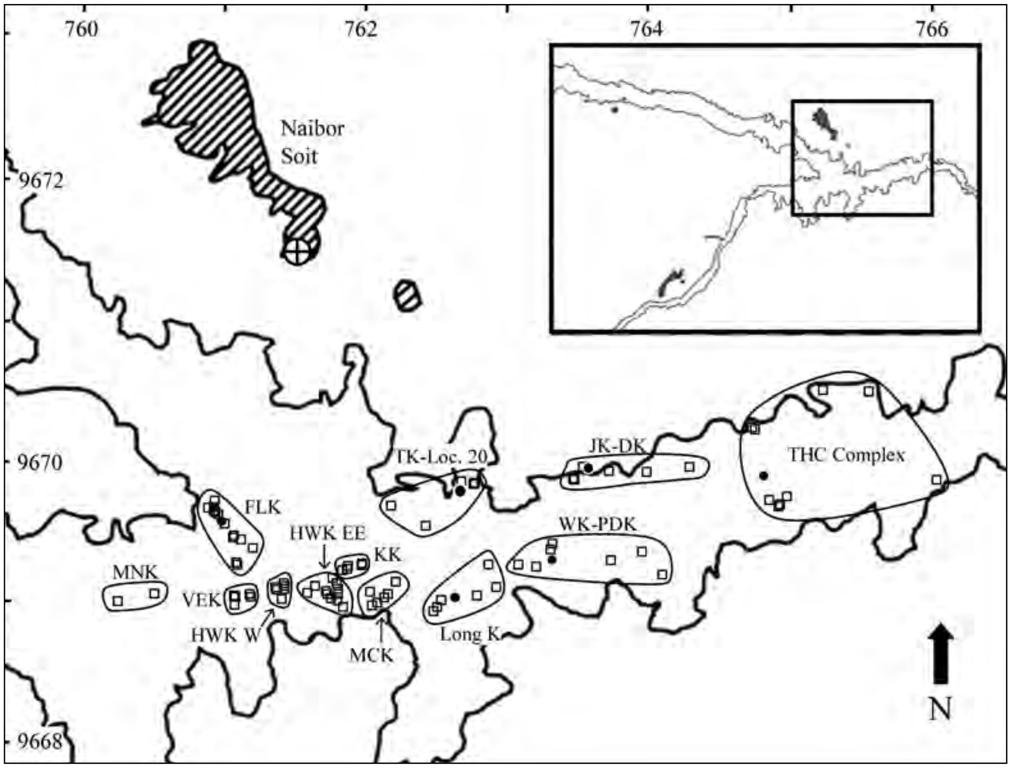
Figure 1. The Plio-Pleistocene Olduvai Lake Basin [modified from Peters and Blumenschine (1995, Figure 2); based originally on Hay's paleogeographic reconstruction (1976, Figure 38)], showing the location of present-day Olduvai Gorge (hatched). The center of the basin was occupied by a shallow, saline and alkaline lake with no outlet. During dry times, the lake was reduced to a perennial portion, expanding intermittently onto an intermediate flood zone and, during the wettest periods onto the Lake Margin (Hay, 1976). The phonolite volcanic neck, Engelosin (1), is located in the northeastern portion of the intermittently dry lake bed, and would frequently have been an island. Several metamorphic inselbergs are located in the lake margin zone, including Naibor Soit (2) in the Eastern Lake Margin north of the junction of the Main and Side branches of Olduvai Gorge; Naisiusiu (3) in the Western Lake Margin at the western end of the Main Gorge; and Kelogi (4), three hills in the Southwestern Lake Margin at the southern end of the Side Gorge. The Serengeti Plain lies to the west of the lake. To its north are exposures of the metamorphic basement complex, the southernmost inselbergs of which are Olongoidjo Ridge (5) and Engitati Hill (6). The broad Eastern Alluvial Plain abuts the Eastern Lake Margin, sloping gently up toward the volcanic Crater Highlands that define the eastern and southern margins of the basin. These highlands include Mt. Lemagrut (7), Mt. Sadiman (8), Mt. Ngorongoro (9) with its large caldera, and Mt. Olmoti (10), with a smaller caldera. Mt. Olmoti was the active volcano during Bed I and lowermost Bed II times (Hay, 1976).

these studies attempt to relate variability in landscape traces of hominin activity to depositional environment, proximity to stone material sources, and/or various proxies for vegetation structure.

OLAPP's landscape paleoanthropological work on the Oldowan has focused on several target intervals in Bed I and Lower Bed II. Through the 2007 field season, OLAPP has excavated 146 trenches into these intervals that sample various lake, lake margin and alluvial fan environmental settings distributed over ca. 130 km^2 of the central Olduvai Lake Basin (Figure 1).

Overall, the landscape assemblages of Oldowan artifacts display tremendous variability in the density of the occurrences and in aspects of their composition (e.g., Blumenschine et al., 2005; Tactikos, 2005).

Several factors have been correlated with landscape-scale variability in the Oldowan artifacts assemblages from OLAPP's best-developed sample, the eastern Olduvai Basin during lowermost Bed II times, defined by the interval between Tuff IF and Tuff IIA. Deocampo et al. (2002) found that a geochemical indicator of water freshness correlates positively and significantly with the weight density (g/m^3 of excavated deposit) of stone artifacts from the basal waxy claystone of lowermost Bed II in 22 OLAPP trenches in the eastern lake margin. Preliminary analyses by Blumenschine et al. (2005, 2007a) show that the weight density and functional diversity of stone artifacts from a large number of trenches in the eastern lake margin and alluvial fan for the whole of the lowermost Bed II interval correlates in theoretically expected ways to large mammal long bone shaft to end ratios, a measure of predation risk for hominins from large carnivores. Most recently, Blumenschine et al. (2007b) demonstrated that several aspects of the quartzite artifact a.



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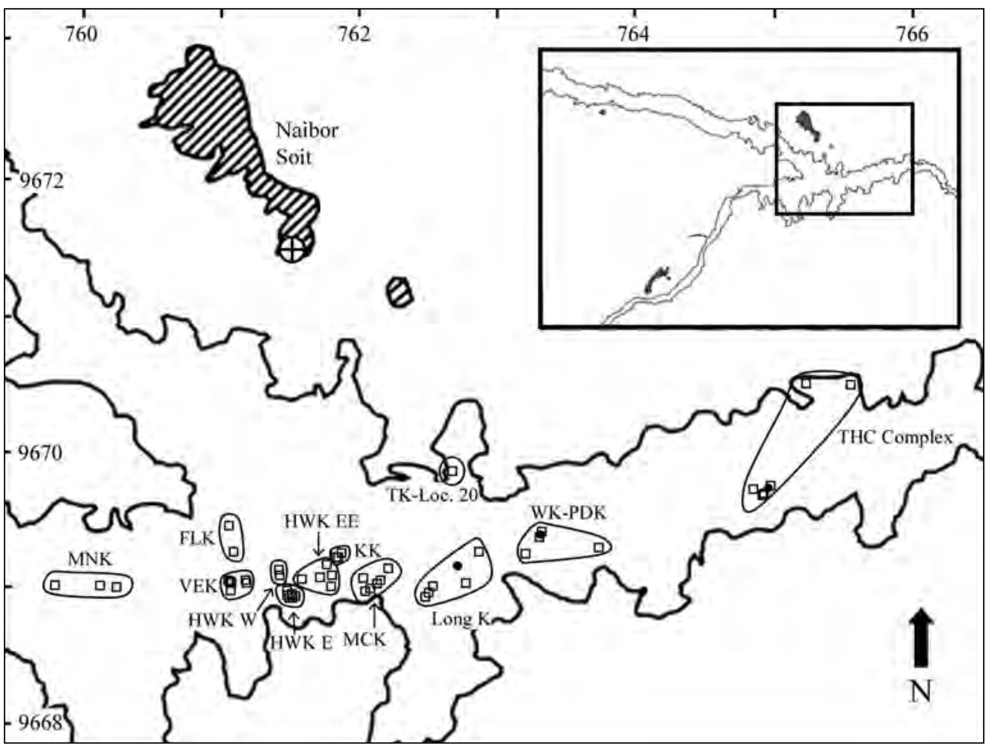


Figure 2. Grouping of trenches into geographic locales (e.g., FLK, MCK) used to investigate distancedecay effects for the a) pre-incision and b) post-incision intervals of lowermost Bed II. For the areally more extensive locales, the average trench location weighted by the weight of quartzite artifacts recovered is marked by a solid circle. The number and location of trenches, and the weighted average location of trenches differ for the two stratigraphic intervals in all locales. The location at the southeastern end of the main hill at Naibor Soit from which distance to each locale was calculated (Table 2) is indicated. Border tick marks are at 1 km intervals, in UTM units.

assemblages from 100 trenches sampling the lowermost Bed II eastern lake margin and alluvial fan (Figure 1) over a west-to-east distance of 6 km correlate in theoretically expected ways to distance from Naibor Soit, the inselberg of metamorphic basement rocks that was the likely source used by hominins to manufacture quartzite implements in this part of the Olduvai Basin.

In this paper, we explore effects of distance from stone material source on three characteristics of the quartzite artifact assemblages in the eastern Olduvai Basin (Figure 2) for two time intervals within lowermost Bed II. The time intervals precede and follow valley incision of the eastern basin, and are referred to as pre-incisional and post-incisional lowermost Bed II (Stanistreet, in prep.). This analysis has two major goals. The first is to determine if behavioral patterning following expectations of general distance-decay models of stone material transport can be detected over landscape scales for more discrete time intervals than we demonstrated previously. The second goal is to investigate changes in landscape-scale patterning of stone artifact assemblages that might be related in a preliminary way to landscape evolution and corresponding changes in Oldowan hominin land use. Detection of such changes would enhance future efforts to distinguish the theoretically two major sets of constraints on hominin land use: 1) the distributions of predation risk and resources requiring stone tools for extraction, and 2) transport costs of stone material to manufacture and use locations.

Sequence Stratigraphy of Lowermost Bed II

Introduction

As a concept, Sequence Stratigraphy was introduced to explain recurrent sedimentary cyclicities of similar periodicities related to base level changes encountered in marine basins (Vail, 1977; Van Wagoner et al., 1988). Subsequently, such stratigraphies have also been identified in continental basins (Shanley and McCabe, 1994; Ruskin and Jordan, 2007). A cyclic marine to continental Parasequence, related to a single rise and fall of sea-level, is the fundamental building block of a Sequence Stratigraphic framework. Their periodicities are typically of an order greater than tens of thousands of years, and are related to the forcing of Milankovitch climatic cycles (e.g., House and Gale, 1995.).

Lake-levels are the major base level influence in many continental basins, particularly apparent in Plio-Pleistocene basins of East Africa. In analogy with their marine counterparts, phases of pronounced lake level withdrawal or regression, alternating with phases of pronounced lake-level flooding or transgression, produce stratigraphic units that provide a detailed framework (Stanistreet, in prep.) in which to contextualize paleoanthropological finds. In the Olduvai Basin these units are sub-Milankovitch in period and are termed Lake Parasequences in order to distinguish them from their marine counterparts (Stanistreet, in prep.).

Also similar to marine basins, prolonged phases of lake withdrawal initiate erosional phases in its hinterland, represented by broad surfaces of degradation (Type II unconformity). If lake fall is pronounced for a prolonged period, which in the Olduvai Basin can extend to total drying up of palaeo-Lake Olduvai (Hay and Kyser, 2001; Stollhofen et al., 2007), downcutting by rivers sourcing in the Volcanic Highlands to the south and east (Figure 1) can incise a valley, with erosion surfaces cutting down deeply through the pre-existing stratigraphy (Type I unconformity). Such a total drying-up of the lake and major valley incision would occur during major synglacial aridity phases, associated with the weakening of the Indian Ocean monsoon on East Africa (Van Campo et al., 1982; Prell and Van Campo, 1986).

Lowermost Bed II Valley Incision

Surfaces that have the characteristics of Type I incision have already been described but not identified as such in the Bed I and Bed II stratigraphies at Olduvai Gorge. A particularly good example recognized by Hay (1976) is the widespread surface below the Lower Augitic Sandstone that defines the top of Lower Bed II, termed the Lower Discomformity. Hay (1976, his Figure 27a) portrays the westerly trending extent of the associated incised valley, which at FLK cuts out the whole of the Lemuta Member and Lower Bed II, through Tuff IF into topmost Bed I (Figure 3).

An earlier Type I unconformity is present within lowermost Bed II below the Lower Augitic Sandstone incision. This unconformity divides lowermost Bed II into 1) overlying postincisional wetland-related (Deocampo, 2002) successions dominated by siliceous earths and earthy claystones, developed particularly well, for example, at HWK and MCK (Figure 3 and 2) underlying pre-incisional waxy claystone dominated sequences related to lake transgressions, shown well at VEK, FLK and KK. This incision surface cuts out the whole of the underlying Bed II sequence at HWK East along the axis of a westerly trending incised valley, named Crocodile paleo-Valley, because of the commonness of teeth and feeding traces of these reptiles within its infill in some places (Njau, 2006). This incision surface has not been recognized by previous authors (Leakey, 1971; Hay, 1976; Ashley and Hay, 2002), leading to mistaken correlations.

Estimates of the durations of the pre- and post-incisional sequences are dependent on the reliability of bracketing dates of the tops and bottoms of each, and the lengths of time represented by missing sequence eroded from the sedimentary record. The base of the preincisional sequence is defined by the 1.785 Ma palaeomagnetic boundary between the Olduvai Subchron and Matuyama Reversal as outlined in Blumenschine et al. (2003). This corresponds well with the dating of the aridity that affected the region prior to and during the

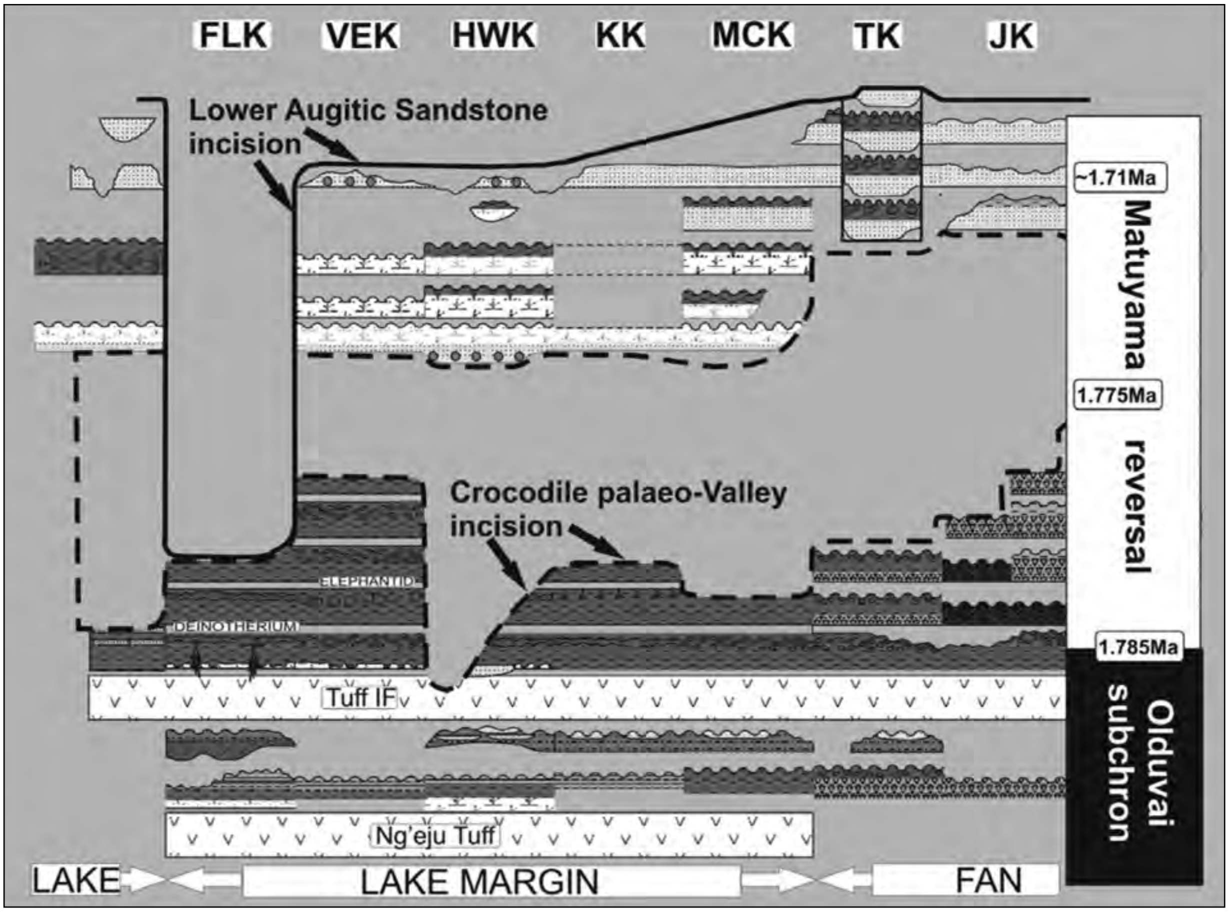


Figure 3. Sequence stratigraphic cross-section of the eastern Olduvai Basin for the interval between the upper part of Bed I through the Lower Augitic Sandstone showing the Crocodile Valley incision that divides lowermost Bed II into the lower pre-incision phase and the upper post-incision phase.

emplacement of Tuff IF (Stollhofen et al., 2007), which seems to coincide with a synglacial aridity affecting East Africa dated at 1.795 Ma by deMenocal and Bloemendal (1995) from windblown material in the offshore record. The top of the pre-incisional sequence is the date of the Crocodile Valley incision caused by the next synglacial aridity recorded at 1.775 Ma by deMenocal and Bloemendal (1995) in the offshore record. Thus, the duration of the pre-incisional sequence is presently best estimated at about 20,000 years.

The duration of the post-incisional sequence is less certain. The basal date is defined by the Crocodile Valley incision at dated at 1.775 Ma as discussed above. The top would be judged best from dating of Tuff IIA in the middle of the Lemuta Member, but dating of this tuff has proved to be problematic, and efforts to gain a reliable date are continuing. The potassium-argon biotite age of 1.71 Ma measured by Curtis and Hay (1972) is likely to be too young. However, the stratigraphic framework of the pre-incisional sequence (Figure3) is similar to the stratigraphic framework of the post-incisional sequence, suggesting that the duration of the latter can best be estimated to extend at least another 20,000 years.

Methods

Theory of Variability in Landscape Stone Artifact Assemblages

Blumenschine and Peters (1998) constructed a model that predicted the density, dispersion, and general composition of stone artifact assemblages from 11 landscape facets in the central Olduvai Basin during lowermost Bed II times. The predictions are based fundamentally on the hypothesized cover abundance of trees in each landscape facet, which is modeled to be inversely correlated to the intensity of predation hazard potentially encountered by hominins and directly correlated to the abundance and variety of food resources requiring stone tool use in each landscape facet. Higher-density occurrences with a broad functional range of stone artifact types are modeled to occur usually in safer, well treed landscape facets affording a variety of resources, while lower-density scatters of mainly knife-like flakes and flaking shatter are hypothesized for most landscape facets affording more open vegetation and higher predation risk.

In the model, stone transport costs from source to use locations also influence the landscape distribution of discarded or lost stone artifacts, because Oldowan hominins are conservatively modeled to lack carrying devices, thus creating severe limitations on transportable quantities of stone. Distance from stone source influences mainly the predicted relative abundance of tools made on different materials, where locally available quartzite is expected to dominate in assemblages near the central-basin source at the inselberg Naibor Soit, while artifacts made on lavas become more common toward the southeastern volcanic highlands (Figure 1). The model also predicts that quartzite artifact assemblage density would decrease with increasing distance from Naibor Soit, as would the degree of reduction of quartzite cores. Still, the influence of material transport costs on predicted landscape assemblages is not as great as those related to cover abundance of trees affording refuge or food.

The above predictions about stone material transport follow those of distance-decay models, borrowed from economic geography (e.g., Clark, 1979). When applied archaeologically, distance-decay models predict that as distance from a stone material source increases, artifacts made on that material should occur in lower quantities, both absolutely and relative to more local materials, and should be more thoroughly worked and used. Following Renfrew's (1969) pioneering analysis of the Early Neolithic obsidian trade in the Near East, quantitative demonstrations of distance-decay effects on stone artifact assemblages have been made for most periods of the Stone Age/Paleolithic, although their statistical strength is evaluated infrequently (see Blumenschine et al., 2007a for a review).

A recent test of hypothetical distance-decay effects on the quartzite artifact assemblages from the 13 geographic locales in the lowermost Bed II eastern Olduvai Basin showed that the proportionate weight of artifacts assemblages made up of quartzite is the assemblage characteristic most highly correlated with distance from Naibor Soit, the presumed source of the quartzite (Blumenschine et al., 2007a). Somewhat weaker, but still significant negative correlations with distance from Naibor Soit are also found for the weight density of quartzite artifacts and for the size and degree of reduction of quartzite cores. The finding suggests that transport costs of quartzite were relatively high, as might expected if hominins lacked carrying devices for stone (cf. Blumenschine and Peters, 1998), because the density and proportionate weight of quartzite assemblages approaches extinction at around 3-4 km from source in the most distant geographic locales sampled. The failure of distance from source to explain more than half of the variability in three of the four assemblage characteristics examined suggests that Oldowan hominin land use was also influenced by the modeled non-uniform landscape distributions of both resources requiring stone tools for extraction and predation risk (Blumenschine et al., 2007a).

Stone Artifact Sample Characteristics

The stone artifact assemblages reported here were recovered between 1989 and 2006 through excavation by OLAPP into lowermost Bed II in the Eastern Lake Margin and Eastern Alluvial Plain, traversing a west-east distance of approximately 6 km (Figure 2). The range of recovered artifacts includes forms described for the Oldowan at Olduvai by Leakey (1971). The current analysis is restricted to the eastern basin because Naibor Soit provides a local material source from which the vast majority of recovered quartzite artifacts appear to have been made (see Blumenschine et al., 2007a for a discussion).

Most of the excavations were 1–2 m wide step trenches through all or part of the target stratum. Trenches were located to maximize geographic coverage, constrained by the availability of minimally vegetated exposures that were not too steep to excavate. Trenches were located selectively over dense surface concentrations of artifacts and/or fossils in only a few cases, and trenching into outcrops lacking surface remains was not precluded.

The stone artifact samples for pre-incisional (n=2,961 from 50 trenches) and postincisional (n=3,235 from 82 trenches) lowermost Bed II (Table 1) form incomplete subsets of that reported previously for the whole of lowermost Bed II (n=8,167 from 100 trenches). Most of the artifacts excluded derive from the land-surface on top of Tuff IF in HWK East, which will be described in a future report. Further, the location of the incision surface dividing the lowermost Bed II sequence cannot be identified confidently from section drawings of some of the trenches excavated prior to 2000, leading to the exclusion in this analysis of artifacts from these trenches. Finally, the incision surface occurs within some individual levels yielding artifacts, such that these cannot be assigned with confidence to either the pre-incision or the postincision. These artifacts are also excluded from the current analysis.

The artifact sample for each time period is further subdivided into a series of geographic locales (Table 1, Figure 2), each named for the modern *korongo* (fluvially incised gully, named by the Leakeys) in which it is located. Trench assignments to geographic locales are based on a compromise between two competing needs of the distance-decay analysis: 1) ensuring close proximity of constituent trenches so that an accurate average distance of the locale from Naibor Soit can be obtained, and 2) ensuring artifact sample sizes from each locale that are adequate to support analyses. This compromise did not always yield satisfactory results for the sub-divided lowermost Bed II sample.

For the post-incisional sample, very small artifact numbers were recovered from TK-Loc. 20 (n=2 from 1 trench), WK-PDK (n=13 from 4 trenches), and THC Complex (n=14 from 6 trenches). These small samples result from a combination of the thinness of the post-incisional sequence in these locales and their extremely low artifact densities. Further, the tendency for lowermost Bed II to outcrop in cliff faces in WK-PDK and the THC Complex limit excavation locations greatly, resulting in the wide dispersion of trenches in these locales. No post-incision deposits occur in JK-DK. The absence of quartzite artifacts in MNK results from the inability to assign excavation levels to either the pre-incision or the

Table 1. Characteristics of the stone artifact sample from geographic locales listed west to east in the pre-incisional and post-incisional eastern lowermost Bed II Olduvai Basin (Figures 1 and 2). Two values are given for the number of trenches: those exposing the stratigraphic interval, and, in parentheses, those containing quartzite artifacts. Number of stone artifacts are those for which general stone material type was assigned.

Geographic Locale	No. Trenches	Excavated Volume (m^3)	No. Artifacts Total	No. Artifacts Quartzite
Post-Incision				
MNK	3 (2)	7.5	20	0
FLK	2 (1)	1.2	29	28
VEK	6 (6)	21.2	423	379
HWK W	2 (2)	8.1	247	231
HWK E	7 (7)	24.9	1,468	1,430
HWK EE	5 (2)	11.5	39	28
KK	3 (3)	4.9	67	58
MCK	6 (6)	36.0	562	300
TK-Loc. 20	1 (1)	1.2	2	2
LONG K	5 (5)	20.3	77	40
WK-PDK	4 (3)	8.8	13	9
JK-DK	0 (0)	0	0	0
THC-Complex	6 (2)	16.0	14	9
Total	50 (40)	161.5	2,961	2,514
Pre-Incision				
MNK	2 (2)	2.7	0	0
FLK	12 (1)	34.9	133	98
VEK	5 (6)	21.2	410	382
HWK W	7 (2)	15.3	365	343
HWK EE	12 (2)	13.2	876	865
KK	5 (3)	17.2	1,034	974
MCK	6 (6)	8.2	4	2
TK-Loc. 20	5 (1)	27.8	231	223
LONG K	6 (5)	11.9	75	45
WK-PDK	7 (3)	46.5	24	16
JK-DK	6 (0)	45.9	72	58
THC-Complex	9 (2)	22.1	11	6
Total	82 (63)	266.9	3,235	3,012

Table 2. Distances of the eastern basin geographic locales from the southeastern end of the main hill at Naibor Soit (761.50 easting, 9671.50 northing; Figure 2) for pre-incisional and postincisional lowermost Bed II. Distances are based on average UTM easting and northing values of trenches in each locale weighted by the weight of quartzite artifacts from each trench. For locales lacking quartzite artifacts, distance is the simple mean of UTM values for the trenches exposing the interval. Distances for a given locale can differ between the two stratigraphic intervals (and from those in Blumenschine et al., 2007a) because of differences in quartzite artifact weight.

Geographic Locale	Mean Easting (UTM km)	Mean Northing (UTM km)	Distance from Naibor Soit (km)
Post-Incision			
MNK	759.878	9668.776	3.17
FLK	761.058	9669.247	2.30
VEK	761.060	9669.008	2.53
HWK W	761.355	9669.093	2.41
HWK E	761.521	9668.965	2.54
HWK EE	761.672	9669.076	2.43
KK	761.751	9669.197	2.32
MCK	762.115	9669.089	2.49
TK-Loc. 20	762.761	9669.854	2.07
LONG K	762.771	9669.195	2.63
WK-PDK	763.278	9669.372	2.77
THC-Complex	764.924	9669.703	3.87
Pre-Incision			
MNK	760.326	9668.933	2.82
FLK	760.950	9669.595	1.98
VEK	761.057	9669.028	2.51
HWK W	761.355	9669.100	2.40
HWK EE	761.658	9669.050	2.46
KK	761.803	9669.213	2.31
MCK	762.016	9668.977	2.58
TK-Loc. 20	762.714	9669.830	2.06
LONG K	762.540	9669.019	2.69
WK-PDK	763.289	9669.269	2.86
JK-DK	763.573	9669.969	2.58
THC-Complex	764.768	9669.984	3.60

post-incision in trenches that had yielded the 14 quartzite artifacts reported for all of lowermost Bed II (Blumenschine et al., 2007a).

The pre-incision is poorly exposed at HWK E, with most pre-incision deposits having been eroded by valley incision. All lowermost Bed II artifacts in HWK E are restricted to the landsurface that developed on top of Tuff IF, which is not considered here, such that there is no pre-incision sample from this locale. As with the pre-incisional sample, none of the levels in trenches in MNK (n=0 artifacts from 2 trenches) could be assigned confidently to the preincision. Very small artifact samples characterize the pre-incision at MCK (n=4 artifacts from 6 trenches), and again the THC Complex (N=11 artifacts from 9 trenches) due to very low artifact densities.

Estimates of Distance from Source

The point on Naibor Soit used in the distance-decay analyses is the southeast end of the main hill (Figure 2). Two other locations along the main hill that were examined in the previous analysis for the whole of lowermost Bed II yield results similar to the southeastern end, and are not used here. For reasons that remain unknown, distance from the small hill at Naibor Soit, which was apparently the most accessible point on the inselberg when it was a peninsula in paleo-Lake Olduvai (Figure 1; Hay, 1976), did not yield significant results in the prior analysis.

The estimated straight-line distances of geographic locales from Naibor Soit are calculated using the average UTM coordinates of all trenches within a locale (Table 3), weighted by the total weight of quartzite artifacts from each trench. These distances for a given locale are in many cases different for the pre-incision and the post-incision samples due to the different series of trenches exposing each interval and their different yield of quartzite artifacts. The estimated distances would have been slightly less during lowermost Bed II times due to the subsequent accumulation on the inselberg's footslopes of approximately 30 m of sediment.

Assemblage Characteristics Used to Test Predictions

We use three of the four assemblage parameters reported previously to test the predicted distance-decay effects. The quantity of quartzite is measured by its weight density (g/m^3 of excavated deposit). Unlike the previous analyses for the whole of lowermost Bed II, weight densities are not transformed logarithmically, allowing the zero values for MNK obtained when lowermost Bed II sample is sub-divided to be graphed and incorporated into the statistical analyses. The relative abundance of artifacts made on quartzite is measured by its proportionate weight of artifacts made on all materials. The size of whole flaked pieces (cores) is measured by their mean maximum length. Unlike the previous report, we do not report on the degree of reduction of quartzite flaked pieces, which was expressed as the proportion of these that had been flaked unifacially around less than 50% of their circumference. This omission results from the small number of these minimally flaked cores from both the post-incision (n=20) and the pre-incision (n=13) samples.

Spearman's rank-order correlation is used to evaluate the strength of distance-decay relationships. This non-parametric method is appropriate for the small number of geographic locales into which assemblages are categorized. Correlations yielding probability values <0.05 are considered statistically significant. One-tailed probability values are reported because the direction of the relationships has been specified.

Results

The weight density of quartzite artifact assemblages varies over two orders of magnitude among geographic locales for both the pre-incision and post-incision intervals (Table 3). The range of values is greater for the post-incision (from a minimum of 0 g/m^3 at MNK to a maximum of 307 g/m^3 at MCK). The overall weight density of quartzite artifact assemblages for all locales combined is more that twice as great during post-incision times as during pre-incision times.

Weight densities tend to decrease with increasing distance of locales from Naibor Soit for both time intervals (Figure 4a). However, the relationship is significant only for the pre-incision, in which distance from Naibor Soit accounts for 84% of the rank-order variability in weight density (Table 4). The lack of a significant relationship during the post-incision results in part from the unexpectedly low weight densities encountered at the two localities closest to Naibor Soit, TK-Loc. 20 and FLK. These values are about two times lower than those in the preceding time period for TK-Loc. 20, and almost seven times lower for FLK. Conversely, MCK and VEK display unexpectedly high weight densities during the post-incision, having increased about 2.4 and 5.5 times over their respective values during the pre-incision.

The proportion of total artifact weight comprised of quartzite (Table 3) is again more variable for the post-incision (0% at MNK, 100% at TK-Loc. 20) than of the pre-incision (0.3% for THC Complex, 71% for HWK EE). For all locales combined, the proportionate weight of quartzite artifacts for the post-incision is about two-thirds that for the pre-incision, with most of the difference being accounted for by the large quantity of artifacts and manuports made on volcanic materials at MCK during the post-incision (Table 3).

The expected decrease in the proportionate weight of quartzite artifacts with increasing distance from Naibor Soit is obtained for both the early and late stages of lowermost Bed II (Figure 4b). The negative relationship is significant for both time periods, but the relationship is stronger for the pre-incision, with distance from Naibor Soit accounting for more than two-thirds of the variability in this assemblage parameter (Table 4). TK-Loc. 20 preserves expected high weight proportions of quartzite artifacts for both time periods, given its close proximity to Naibor Soit. Notably lower than expected values are seen at KK, HWK W and MCK for the post-incision, and at FLK during the pre-incision. Higher than expected values are seen at THC Complex for the post-incision, and at HWK EE for the pre-incision.

Variability in the mean maximum dimension of whole quartzite flaked pieces is less for the post-incision (46 mm at THC Complex, 63 mm at VEK and MCK) than for the pre-incision (34 mm at Long K, 76 mm at FLK), although this artifact type was recovered from fewer postincision locales (Table 3). The average size of these artifacts for all locales combined is similar for both

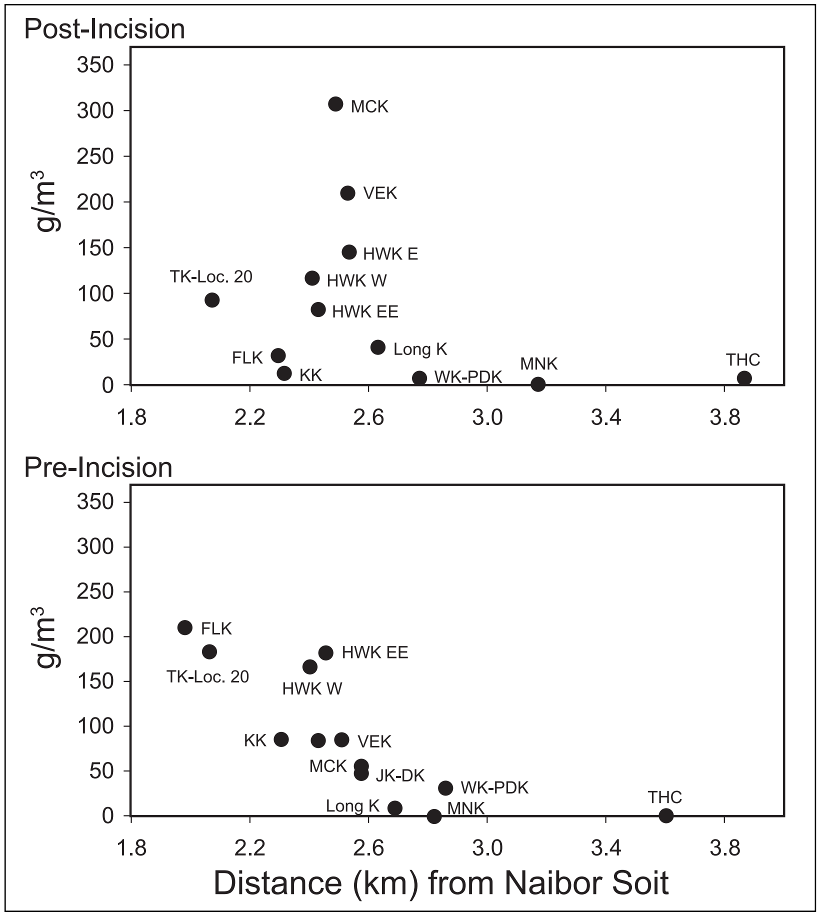
Table 3. Weights (g) and weight densities (g/m³ and log g/m³ of excavated deposit) of quartzite artifacts, the proportion of total artifact weight comprised of quartzite, and the mean maximum length (mm) of whole quartzite flaked pieces (FP) from geographic locales in pre-incisional and post-incisional lowermost Bed II. See Table 1 for excavated volumes.

Geographic Locale	Quartzite Artifacts Weight (g)	Quartzite Artifacts Weight density g/m³	Total Artifact Weight (g)	%Quartzite Artifact Weight	Total No. Quartzite FP	Mean Maximum Dimension (mm) of Quartzite FP
Post-Incision						
MNK	0	0	153	0.0	0	—
FLK	38	31.4	39	97.4	0	—
VEK	4,437	209.3	9,573	46.3	11	63.4
HWK W	940	116.3	4,370	21.5	5	49.0
HWK E	3,619	145.1	9,202	39.3	18	61.8
HWK EE	941	82.1	2,517	37.4	0	—
KK	58	11.9	1068	5.4	0	—
MCK	11,057	307.1	74,292	14.9	46	63.0
TK-Loc. 20	113	92.7	113	100.0	1	57.0
LONG K	816	40.2	7,706	10.6	4	50.3
WK-PDK	62	7.1	898	6.9	0	—
THC-Complex	104	6.5	561	18.5	1	46.0
Total	22,184	137.3	110,491	20.1	86	61.1
Pre-Incision						
MNK	0	0	0	—	0	—
FLK	5,256	210.2	12,118	43.4	13	75.6
VEK	2,322	86.0	6,699	34.7	10	49.8
HWK W	2,668	166.8	5,819	45.8	6	75.7
HWK EE	1,093	182.2	1,533	71.3	1	56.0
KK	2,482	85.6	6,900	36.0	14	48.9
MCK	111	55.5	450	24.7	1	63.0
TK-Loc. 20	1,098	183.0	1,617	67.9	4	53.5
LONG K	269	9.0	10,017	2.7	1	34.0
WK-PDK	249	31.1	1,269	19.6	3	40.7
JK-DK	617	47.4	4,585	13.4	3	51.3
THC-Complex	2	0.4	607	0.3	0	—
Total	16,167	60.6	51,614	31.3	56	58.3

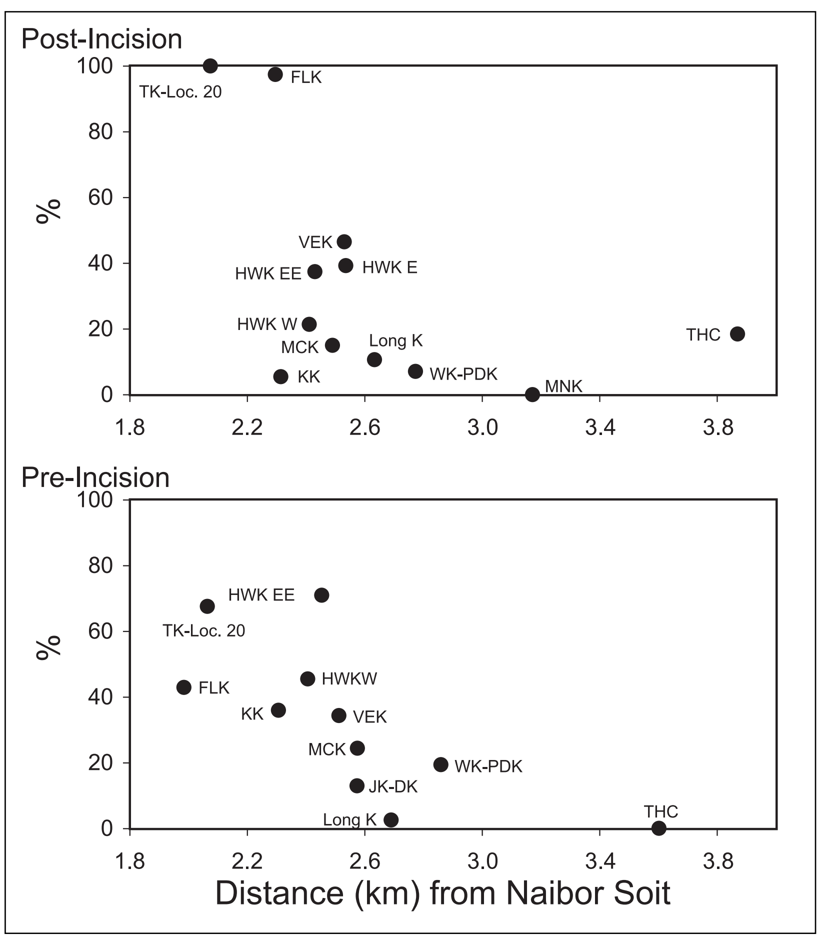
Table 4. Spearman's rank-order correlation statistics for the relationships between three artifact assemblage characteristics (Table 3) and distance from Naibor Soit (Table 2, Figure 2) of geographic locales for pre-incisional and post-incisional lowermost Bed II. Probability values are one-tailed, following predictions. Correlation statistics with probability values <0.05 are bold-faced.

Assemblage Characteristic	Stratigraphic Interval	No. of Locales	r_S	r^2_S
Weight density (g/m³) of quartzite artifacts	Post-incision	12	–0.41	0.16
	Pre-incision	12	**–0.91**	**0.84**
Weight proportion of quartzite artifacts	Post-incision	12	**–0.55**	**0.30**
	Pre-incision	11	**–0.83**	**0.69**
Mean maximum length of quartzite flaked pieces	Post-incision	7	–0.29	0.08
	Pre-incision	10	**–0.57**	**0.33**

a.


Post-Incision
g/m3
350
300
250
200
150
100
50
0
1.8
2.2
2.6
3.0
3.4
3.8
MCK
VEK
HWK E
TK-Loc. 20
HWK W
HWK EE
Long K
FLK
KK
WK-PDK
MNK
THC
Pre-Incision
FLK
TK-Loc. 20
HWK EE
HWK W
KK
VEK
MCK
JK-DK
WK-PDK
THC
Long K
MNK
Distance (km) from Naibor Soit

b.


Post-Incision
%
100
80
60
40
20
0
1.8
2.2
2.6
3.0
3.4
3.8
TK-Loc. 20
FLK
VEK
HWK EE
HWK E
HWK W
MCK
Long K
THC
KK
WK-PDK
MNK
Pre-Incision
HWK EE
TK-Loc. 20
FLK
HWKW
KK
VEK
MCK
WK-PDK
JK-DK
Long K
THC
Distance (km) from Naibor Soit

c.

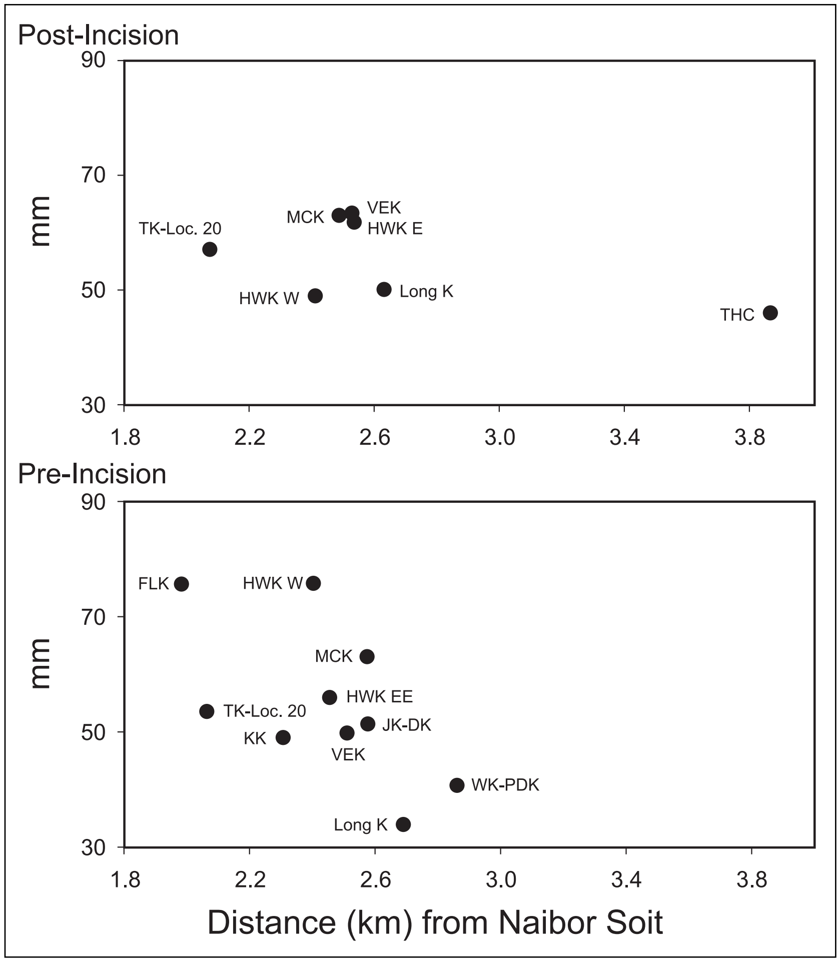


Figure 4a-c. The relationships between distance from the southeastern end of the main hill at Naibor Soit (Table 2) and three characteristics of stone artifact assemblages from the post-incisional and pre-incisional phases of lowermost Bed II (Table 4). The assemblage characteristics are a) weight density (g/m^3) of quartzite artifact assemblages, b) the proportion of total artifact assemblage weight comprised of quartzite, and c) the mean maximum dimension of whole quartzite cores.

time periods. For locales with good samples during both time periods, flaked pieces from VEK tend to be substantially larger, and those from HWKW substantially smaller during the post-incision.

The expected decrease in mean flaked piece size with increasing distance from Naibor Soit is seen for both time periods (Figure 4c). However, the relationship is significant only for the pre-incision, where distance from source accounts for one-third of the variability in flaked piece size (Table 4). For the pre-incision, larger-than-expected flaked pieces are found at HWK W, while unexpectedly small cores are found at TK-Loc. 20 and KK.

Discussion

The distance-decay effects documented previously for the whole of the lowermost Bed II interval (Blumenschine et al., 2007a) are shown here to be produced mainly by the sub-sample from the early, pre-incisional stage of this interval, for which significant distance-decay effects are obtained for the three assemblage parameters examined. Distance from source explains over two-thirds of the variation in the weight density and proportionate weight of quartzite artifact assemblages from the pre-incision. The weaker but still significant distance-decay effect for the size of quartzite flaked pieces is obtained despite very small numbers of flaked pieces during the pre-incision interval for most geographic locales.

Expected negative relationships obtained with distance from Naibor Soit exist for the three characteristics of the post-incision quartzite assemblages examined here, but only that for proportionate quartzite weight is significant. The absence of significant relationships for the other two variables is attributable in part to very small excavated volumes of post-incision deposits from FLK and TK-Loc. 20 (1.2 m^3 each). If the unexpectedly low weight densities of quartzite artifact assemblages from FLK and TK-Loc. 20 samples are excluded, the correlation between weight density and distance from Naibor Soit among assemblages from the remaining 10 geographic locales improves (r_s=–0.55, p=0.05). Still, distance from source during the postincision for this reduced sample explains substantially less of the variability in weight density (30%) than it does for the total pre-incision sample (84%). Excluding TK-Loc. 20 from the postincision analysis of flaked piece size (no quartzite flaked pieces were recovered from FLK) also improves the strength of the distance-decay relationship (n=6, r_s=–0.89, $p < 0.05$). Yet, if both FLK and TK-Loc. 20 are excluded from the analysis for proportionate quartzite assemblage weight, the relationship is no longer significant (n=10, r_s=–0.21, p=0.28).

Distance-decay effects apply most readily to hominin transport of stone material through uniform, two-dimensional Euclidean space following straight-line travel routes from source to use locations (Blumenschine et al., 2007a). However, for Oldowan hominins in the eastern Olduvai Basin during lowermost Bed II times, patchy landscape distributions have been modeled for critical landscape affordances such as predation hazards from large carnivores, potable water, refuge trees, and food resources involving stone use, discard and loss (Peters and Blumenschine, 1995). In this model, much of the patchy distribution of positive affordances coincides with the distribution of woodland, such as that expected to be concentrated along streams in the alluvial fan and the upper edge of the lake floodplain. Further, the negative affordance of predation risk is concentrated in more open vegetation contexts, such as on the mudflats of the lower lake floodplain and along marshes near stream mouths. In such complex ecological settings, costs of stone transport that underlie distance-decay expectations may become secondary to the avoidance of predation risk and the transport of stone materials to locales where resources are more abundant. The result would be diminished or negated distance-decay effects.

Observations of facies sequences in lowermost Bed II since 2000 by IS show that the landscape of the eastern lake margin prior to the Crocodile Valley incision would have been vastly different than during the infill of the valley, which on-lapped over the erosion surface.

Prior to the incision, the broad (up to ca. 3 km) lake margin of paleo-Lake Olduvai was exposed following lake withdrawals, on which calcareous soils formed that appear to have supported grassy woodland (Bennett et al., in review; cf. Sikes, 1994). Successive lake transgressions would have on-lapped onto the toe of the eastern alluvial fan system, resulting in the relative narrowness of the intermittently dry saline lake zone mapped by Hay (1976, his Fig. 31) in the east compared to other sides of the lake. The aggradation of the eastern alluvial fan deposits would have also resulted in the eastern lake margin being higher and drier than margins to the west, south and north of the lake. Hominin access between Naibor Soit and all unflooded areas of the eastern lake margin was likely to have been relatively unimpeded by geomorphic features, except at the times of the very highest lake-level stands when Naibor Soit formed an island (Hay, 1976), such as that immediately following the emplacement of Tuff IF tephra and its fluvial reworking (Stollhofen et al., 2007).

In contrast, following its incision, Crocodile Valley would have been a major westerly trending feature in the lake margin and distal portion of the alluvial fan. The center of the valley likely trended south through the eastern part of the THC Complex before bending westward, passing through Long K, the southern end of MCK, the three HWK locales, and toward MNK and the lake (Figure 2b). FLK, VEK, TK-Loc. 20, JK-WK and DK were located on the north side of the valley. Except during intervals of high lake-level that transgressed as far as the eastern end of Long K, the center of the valley appears to have been dominated by a stream-fed, freshwater marshland (cf. Peters and Blumenschine, 1995). The marshland would have extended from its junction with palaeo-Lake Olduvai at its western termination eastwards to or beyond MCK as far as the Long K Fault, which runs from the east side of Long K northeastward through JK. The eastward extent of the marshland would probably have depended on the intensity of dry and wet seasons within the range of variability at any one time. Eastward beyond the marshland, the center of the valley was occupied by narrow streams likely to have been lined with trees (cf. Peters and Blumenschine, 1995).

The creation of Crocodile Valley may have altered transport patterns of quartzite from Naibor Soit to use locations in the eastern Olduvai Basin. Valley incision provided for the establishment of an east-to-west trending wetland in the eastern lake margin that may have been a travel barrier over at least a portion of the lake margin and distal alluvial fan, at least during wet time periods. Localities on the north side of the valley would have been most accessible to Naibor Soit, but this resulted in high rates of quartzite artifact discard or loss only at VEK, possibly due to high predation risk and/or low availability of resources at the other northern locales. Nonetheless, the marshland may have impeded access to locales in the center of the valley, obviating straight-line transport routes for quartzite from Naibor Soit to use locations, increasing transport distances and associated costs, and in the process reducing the strength of the distance-decay effects seen for post-incision times compared to pre-incision times.

Perhaps more importantly, Crocodile Valley may have created a more patchy distribution of resources requiring stone tool use than had existed previously during pre-incision times. For example, scavengeable carcasses may have been concentrated along the edge of the marshland near the center of the valley in the lake margin. These as well as other affordances including plant foods, potable water, and refuge trees may have been concentrated along the riverine woodland expected for the streams on the distal alluvial fan, which may also have provided a relatively safe travel corridor for hominins (cf. Peters and Blumenschine, 1995). MCK and the west side of Long K may have provided the most abundant resources in exposed portions of the eastern basin. These are the westernmost of the locales dominated by earthy claystones during the post-incision, suggesting that the area lay at the interface of the lake margin's marshland and the streams of the alluvial fan. Such an ecotonal setting might have promoted the high rate of use, discard and/or loss of the quartzite artifacts as well as those made from various lavas in MCK (Table 3). In fact, the weight density of artifacts made on all materials at MCK is more than seven times greater than the average for the other locales during the post-incision. Preferential transport of quartzite and other materials for tools to MCK and other places affording concentrated resources would also reduce the strength of the distance-decay effects during post-incision times over that seen for the pre-incision.

Conclusions

Our results show that Oldowan hominin behavior at Olduvai Gorge can be detected at landscape scales for relatively discrete time intervals on the order of approximately 20,000 years during the Plio-Pleistocene. They also suggest that changes in behavioral patterning in the landscape distribution of artifacts are also detectable, and that these might be related to landscape evolution, reinforcing the need to invest heavily in the reconstruction of paleolandscapes at high temporal and spatial resolutions. The ability to detect these patterns is also dependent on production of adequate samples of stone artifacts recovered over large areas, which for the current analysis was generated during 12 seasons of excavation focused at least in part on lowermost Bed II in the eastern basin over a period of 17 years. The introduction in 2000 of sequence stratigraphy to Olduvai allowed the lowermost Bed II sample to be subdivided into pre 20 and post-incision components. It also leads to the possibility of reconstructing patterns of hominin land use across exposed portions of the lake margin and alluvial fan for intervals as short as ca. 4,000 years, the estimated duration of each parasequence during lowermost Bed II times (Stanistreet, in prep.). This unprecedented temporal resolution of traces of hominin land use at landscape scales can only be achieved with further excavation aimed at increasing sample sizes. Meaningful landscape paleoanthropology is a long-term, trans-generational effort (cf. Peters and Blumenschine, 1995), but one that has the potential to reveal aspects of ancestral hominin behavior undetectable through traditional, site-based excavation.

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CHAPTER 2

PLIO-PLEISTOCENE TECHNOLOGICAL VARIATION: A VIEW FROM THE KBS MBR., KOOBI FORA FORMATION

DAVID R. BRAUN AND JOHN W. K. HARRIS

INTRODUCTION

The earliest studies of Oldowan archaeology were aimed at defining the characteristics of the earliest traces of hominin behavior. These studies form the basis of further Oldowan studies in that they create the temporal and geographic structure of this industrial complex. More recent work begins to explore the variation within this structure. Most notably it is now understood that the Oldowan represents a technological system that is not as simple as it was once thought to be (Semaw 2000; Roche et al. 1999). It is now common to try and understand the Oldowan by investigating the intricate variability of tool forms (de la Torre 2004; Delagnes and Roche 2005). These studies have added a tremendous amount of understanding to our knowledge of stone artifact production at the onset of tool use (Stout 2002; Stout et al. 2005). However, studies of artifact form rarely link technological variability to the overall context of the archaeological sites (but see Rogers et al. 1994; Blumenschine et al. in this volume). The study of the Oldowan is more than just the study of the chipped stone artifacts but rather incorporates the land use and diet of hominins in a way that begins to explore "why" stone tools were made and discarded. These questions require not only an understanding of the paleoecology around these sites but also a model of hominin stone tool mediated behavior. Both of these factors are often lacking at Oldowan localities (although see Schick 1987; Blumenschine and Peters 1998).

In this study we present new excavations of Plio-Pleistocene archaeological sites in the Koobi Fora Formation and suggest possible hypotheses that may explain the variation across Oldowan landscapes. This study represents the initial description of the excavation of two artifact assemblages (FxJj 82 and FxJj 10) and a partial technological analysis of all Oldowan assemblages from the KBS Mbr. of the Koobi Fora Formation, northern Kenya (including FxJj 1 and FxJj 3). Here we combine new technological analysis of the KBS Mbr. sites with information regarding the paleogeography and paleoecology of the basin to explore patterns of landscape scale stone tool usage. Although the KBS Mbr. outcrops over hundreds of kilometers in the Lake Turkana Basin, previously excavated sites from the Koobi Fora Formation in this time period are restricted to a few localities in paleontological collecting areas 105, and 118 (Isaac and Harris 1997a; see Figure 1). Several surface localities were located, however large-scale excavation in the KBS Mbr. was limited to three specific sites: FxJj1, FxJj3, and FxJj10. Research on the archaeology of the KBS Mbr. is extensive (Leakey 1970; Isaac 1976, 1978, 1983, 1984; Isaac et al. 1971; Toth 1982, 1987; Rogers et al. 1994). Initial descriptions of artifact assemblages from the KBS Mbr. designated them as the KBS Industry on account of the decreased amounts of small scraper forms in these assemblages (Isaac and Harris 1978). Further interpretation suggested that the sites from the KBS Mbr. were merely a local variant of a broader entity described as the "Oldowan Industry" (Isaac and Harris 1997b). Assemblages in this time period were considered to be "least effort solutions" to a sharp edge.

This study represents the first excavations in the KBS Mbr. since 1973 when excavations ceased at FxJj 10 (Isaac and Harris 1997a). This new round of excavations in the KBS Mbr. was initiated for two major reasons. 1) The existing assemblages from the KBS Mbr. are some of the smallest Plio-Pleistocene assemblages to date. To compare inferences of behavior from the artifact assemblages from this time period to assemblages in other areas of the basin and different time periods, it was necessary to expand the sample. 2) Archaeological materials from the initial excavations in the KBS Mbr. are paleogeographically restricted. Given the known variability of behavioral signatures exhibited over large areas in the Okote Mbr. at Koobi Fora (Rogers et al. 1994) it is likely that the initial round of research in the KBS Mbr. did not document the full range of behavioral variability.

KBS Mbr.: An Overview

The KBS Mbr. was defined by Brown and Feibel (1986) and is delineated by the KBS tuff at the base and the Okote tuff complex at the top of the member (Brown et al. 2006)(see Figure 1). Radiometric ages on these tuffs provide a chronology of 1.88 to 1.6 Ma (McDougall and Brown 2006; Brown et al. 2006) for the entire member. Several small tuffaceous horizons within the KBS Mbr. allow for more detailed chronology but these horizons are usually not as laterally continuous (Brown et al. 2006). The KBS Mbr. is marked by high lateral and temporal variability. This time period is often modeled as a landscape dominated by lacustrine environments to the west and riverine environments to the north and east (Feibel 1988). The river systems that dominate this time period likely represent a paleo-Omo which was likely a perennial yet very dynamic river system. Feibel (1988) suggests the modified form of the Paleo-Omo river system at this time is likely due to increased uplift in the northeastern portion of the basin. Significant sediment input from river systems to the east (possibly a paleo-Il Eriet) probably modified the character

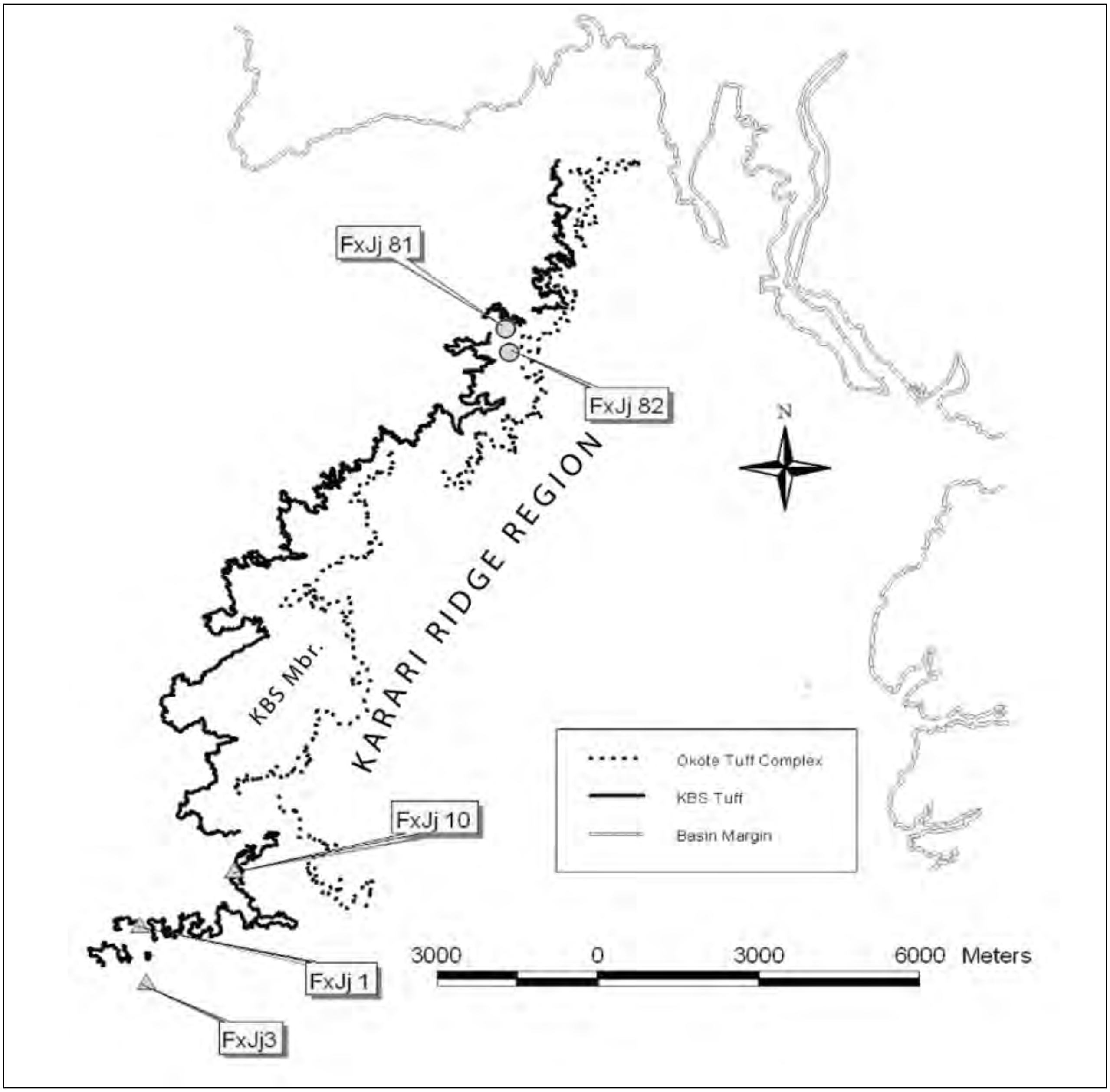

Figure 1. Map of the study region on the eastern shores of the Lake Turkana

of the Paleo-Omo (Feibel 1988; Gathogo and Brown 2006). The Karari Ridge (see figure 1) region of the basin represents a particularly dynamic landscape. Feibel (1988) interprets this area as slightly more upland and dry. Several caliche horizons in this area attest to this interpretation. Faunas from this time period suggest a drying trend with increased numbers of Alcelaphines and Antilopines towards the latter half of the KBS Mbr. (Behrensmeyer et al. 1997). Furthermore the KBS Mbr. is somewhat contemporaneous with a global gradual increase in grasslands possibly associated with the onset of Northern Hemisphere glaciation (deMenocal 1995; deMenocal and Bloemendal 1995; Quade et al. 2004). Despite this general trend there is significant within basin variability and there seems to be a generalized increase in mesic environments from the northeast to the southwest of the eastern side of the basin. In Area 105 where the sites of FxJj 1and FxJj3 are located, abundant fossils of hippopotamus and reduncine bovids suggest a wetter environment (Isaac and Behrensmeyer 1997). Similarly, evidence of broad leaf trees near FxJj 1 in the form of leaf impressions suggest substantial vegetation for some parts of the southwestern part of the study area (Isaac and Harris 1997a).

Previous Excavations in the KBS Mbr.

FxJj1

The site of FxJj 1 was the first site discovered in the Koobi Fora Formation. It was discovered during paleontological and geological survey in Area 105 in 1969 by Anna Kay Behrensmeyer. The site was then named the KBS site (Kay Behrensmeyer Site) and excavation occurred from 1969 through 1972 recovering a total of 138 in situ artifacts. The artifacts recovered from these excavations appear to have been deposited on the floodplain of a channel that is probably part of a southward prograding delta. Fine grained deposits that contain tuffaceous sediments directly below the archaeological horizon record the in fill of a paleo-channel. The site is situated in the bend of a channel that had largely been filed by tuffaceous sediment and must have been in flat swampy conditions. The archaeological collection from FxJj 1 includes smaller detached pieces and the flaked piece assemblage accounts for only 5 in situ and 7 surface finds. Many of the pieces preserve evidence of the outside surface of rounded river cobbles. The low incidence of refitting pieces and the lack of extremely small flaking debris led the Isaac to suggest at least minimal post-depositional water transport of the artifacts and bones at the site. The excavations also recovered numerous faunal specimens. Macromammal remains are dominated by reduncine bovids suggesting possible wetland environments nearby. The presence of fish, crocodile and hippopotamus bones indicates the presence of perennial water source. However, grasslands must have been adjacent to the site as alcelaphine bovids and hypsodont suids (*Metridiochoerus*) were also found at the site. Overall the site represents the infrequent, yet localized, discard of artifacts by hominins in a wet environment that was likely seasonally inundated and had extensive ground cover. The behavioral association between the bones and artifacts was never established with bone surface modifications, Stratigraphic association between the bones and artifacts argues that at least some of the bones are representative of hominin food refuse (Bunn 1997).

FxJj 3

This archaeological site was found in much the same context as FxJj 1. In the southern part of Area 105 there are several outcrops of a large channel system that has been choked by sandy tuffaceous sediment. Modern erosional gullies have exposed the cross section of these channels which is the context of the Hippo and Artefact Site (as it was originally named). The stratigraphic section is largely similar to the depositional context of FxJj 1, yet slight differences in the grain size of the sediments suggest less erosion of the land surface that hosted the discard of artifacts at FxJj 3. Extensive survey was conducted in the region around FxJj 3 to determine if the archaeological finds were transported by the hypothesized paleo-river system. The artifact and fossil bone collection appear to be an isolated event. The original surface finds included 64 artifacts and over 1000 fossil bones. The latter included much of one individual hippopotamus skeleton. Excavations confirmed that the area represented a localized patch of artifacts and bones of about 5 m in diameter. As at FxJj 1, the artifact collection is dominated by detached pieces which are relatively small. However, in the main and adjacent excavation, pebbles to cobbles (upwards of 4 cm in max dimension) were recovered. Along with the artifacts several fossil bones were recovered suggesting a similar environment to that proposed for FxJj 1. The presence of reduncine bovids, extinct pygmy hippopotamus, and two species of crocodile suggest a well watered environment. The behavioral association between the bones and the artifacts cannot be confirmed through bone surface modification studies. Isaac and Harris (1997a) suggests that the abnormally high incidence of bones in fortuitous association with the concentration of artifacts in the area is suggestive that the bones were somehow associated with the deposition of the artifacts. Alternatively, FxJj 3 may have been an area where fresh water was abundant which attracted both hominins and animals to this locale. At present there is no evidence which can determine which hypothesis is more likely. At most we can assume that hominins occupied an area that was seasonally wet (as indicated by the presence of vertisols) near a small channel in a prograding delta.

New Excavations in the KBS Mbr.

FxJj 82

The site of FxJj 82 is a large locality situated in deposits of the KBS Mbr. in Area 130 along the Karari Ridge region of Koobi Fora. The site is located southwest of FxJj 16 and almost due east of the hominin localities KNM-ER 1805 and KNM-ER 1806. The site was discovered during survey in Area 130 in October of 2001. A large carbonate ridge associated with the site is a conspicuous feature in northern Area 130 and caps the section at the KNM-ER 1805 and KNM-ER 1806 localities (Figure 2).

FxJj 82: Local geology

The KBS Mbr. in Area 130 has a complex stratigraphic history. Excavations at the KNM-ER 1805 emphasize that the stratigraphy is dominated by a series of cut and fill structures (Isaac and Harris 1997b). The KNM-ER 1805 and 1806 localities are associated with sediments 1-1.5 m above an orange tuffaceous sands and approximately 1 meter below the base of the Okote Tuff Complex (signaling the base of the Okote Mbr.)(Figure 3). The Okote Tuff Complex does not outcrop at the FxJj 38 locality and correlations were made between the base of the Okote Tuff Complex and the carbonate (caliche) horizon that overlays the artifact and fossil bearing horizons at FxJj 38. The FxJj 82 archaeological horizon appears to be lower than the KNM-ER 1805/1806 horizons. The artifacts and fossil horizons are associated with an orange pumiceous horizon. Geological sections exposed adjacent to the archaeological excavations show that the artifact horizon is approximately 5 to 6 meters below the base of the Okote Tuff Complex. Geological trenches (Geo Trench I, II, III, and IV) associated with the excavation shows that the Orange pumiceous horizon was secondarily incorporated a large soil horizon. Carbonate from this soil were subsequently affected by groundwater carbonate deposition that formed large mats of carbonate. This formed a carbonate horizon of variable thickness that incorporates the horizon where most of the artifacts and fossil bones were recovered from (Figure 4).

Recent studies of stratigraphy of the Koobi Fora Formation and correlations with the Shungura and Nachukui Formation have implications for the stratigraphic position and paleogeographic context of FxJj 82 (Brown et al. 2006; McDougall and Brown 2006). Although deposits near FxJj 82 record evidence of the KBS tuff (1.87 Ma) about 10.8 meters below the archaeological horizon there is considerable evidence in several locations in the Turkana Basin for substantial gaps in the sedimentary record in the Upper KBS Mbr. (Isaac and Behrensmeyer 1997; Brown et al. 2006). Furthermore the majority of the horizons in northern Area 130 that include tuffaceous sediment and pumice gravel appears to fill previous channels. This suggest that fluvial regime in Area

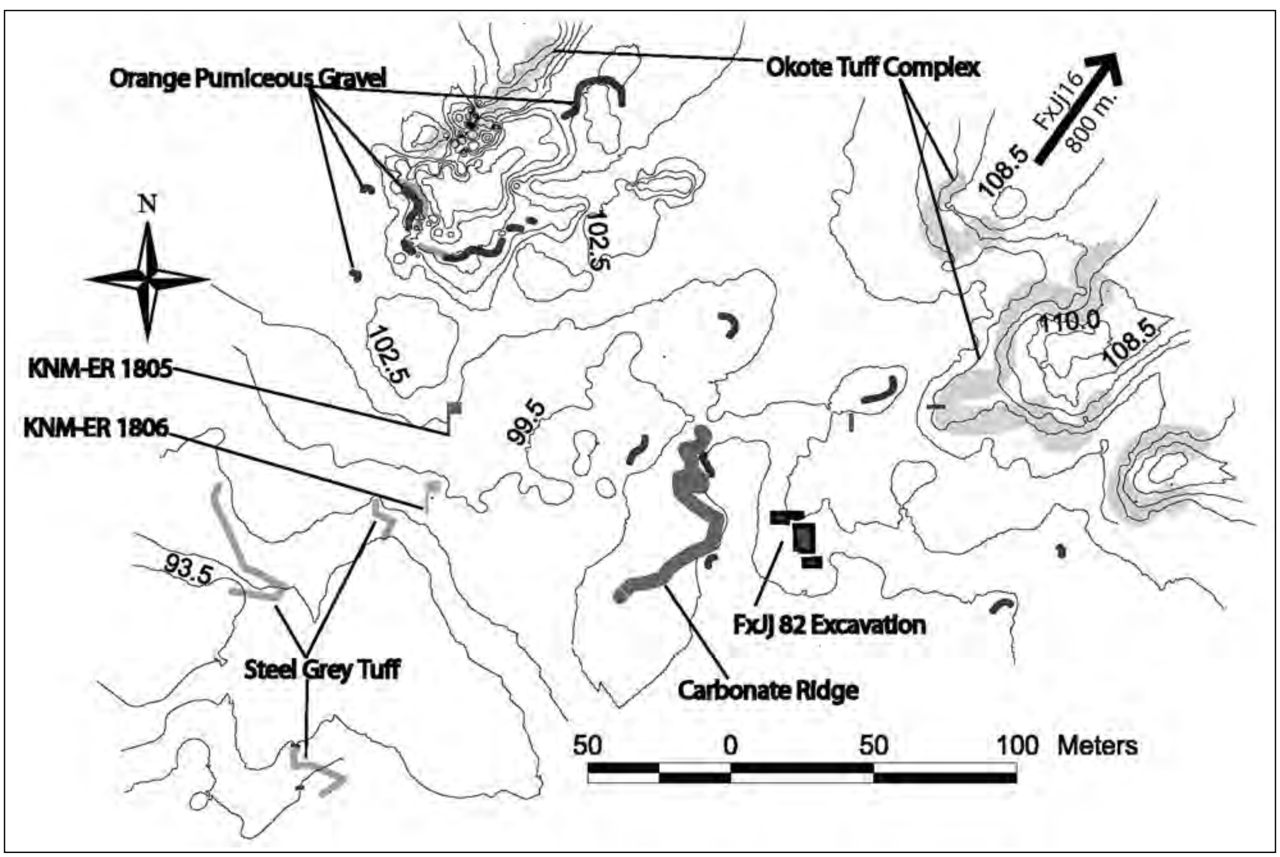

Figure 2. The region around FxJj 82 showing previous hominin finds and major stratigraphic markers.

130 during the upper KBS Mbr. was very dynamic. Geological Trench III records a large grey tuffaceous horizon approximately three meters below the archaeological horizon at FxJj 82 that is most likely the Steel Grey tuff described by Brown et al. 2006. In several locations in Area 130 this tuff is overlain by an orange pumiceous gravel that likely correlates with the similar horizon found in the excavation at FxJj 82. However, sediments north and west of the FxJj 82 excavation record instances where the steel grey tuff has been eroded away and the orange pumiceous horizon overlays the large cross bedded sand that underlies most of the sediments in this area. Based on the assumptions between local tephra and extensive studies of the tephra-stratigraphy (Brown et al. 2006; McDougall and Brown 2006) the archaeological horizon at FxJj 82 is approximately 1.64 Ma.

The site stratigraphy was divided into Layers 1, 2, 3, and 4 (Figures 4-More complete site stratigraphy is provided in Braun 2006)). Layer 1 is orange in color and includes several pumices of pebble to gravel size. This layer also includes several pebbles (< 4cm) of various felsic volcanic rocks and metamorphic rocks. Layer 1 has variable levels of carbonate concretions. Layer 2 is an indurated carbonate horizon that includes a matrix of sandy silt. The carbonate concretions often coalesce to form a mat of carbonate. In some areas this horizon records evidence of pedogenesis in the form of slickensides and slight mottling. Small clasts (3-8 mm) of felsic and mafic volcanics as well as metamorphic rocks are often found locked into the carbonate nodules. Layer 3 is similar to Layer 2 yet without the pebble and gravel component. This horizon is often difficult to distinguish in section because it often is incorporated into the carbonate horizons of layer 2. The relationship between layer 2 and 3 often appears unconformable. Despite artifacts in both horizons the two layers seem to be part of a complex series of small scale cut and fill events. Unfortunately, sedimentary structures are not easily visible in these sediments. They may have been obliterated by subsequent pedogenesis. Layer 4 represents low velocity deposition or overbank deposits in the form of silts. Lateral to the site this horizon appears to have undergone extensive pedogenesis. These four layers are present in all three trenches however they are often lenticular and cannot be found in each wall section. This is a testament to the dynamic sedimentary regime in Area 130.

FxJj 82:Paleoenvironment

The site of FxJj 82 is situated in an interesting position both paleogeographically and chronologically. The paleosol profiles from the upper KBS Mbr. have been used to document the onset of extensive grasslands in the early Pleistocene (Cerling et al. 1988). Changes in the macromammal fauna of the KBS Mbr. suggest changes in the overall ecology of the KBS Mbr. The loss of large arboreal colobines (*Rhinocolobus turkanaensis, Paracolobus mutiwa*) has been attributed to the loss of arboreal habitats through the KBS Mbr. (Feibel 1988).

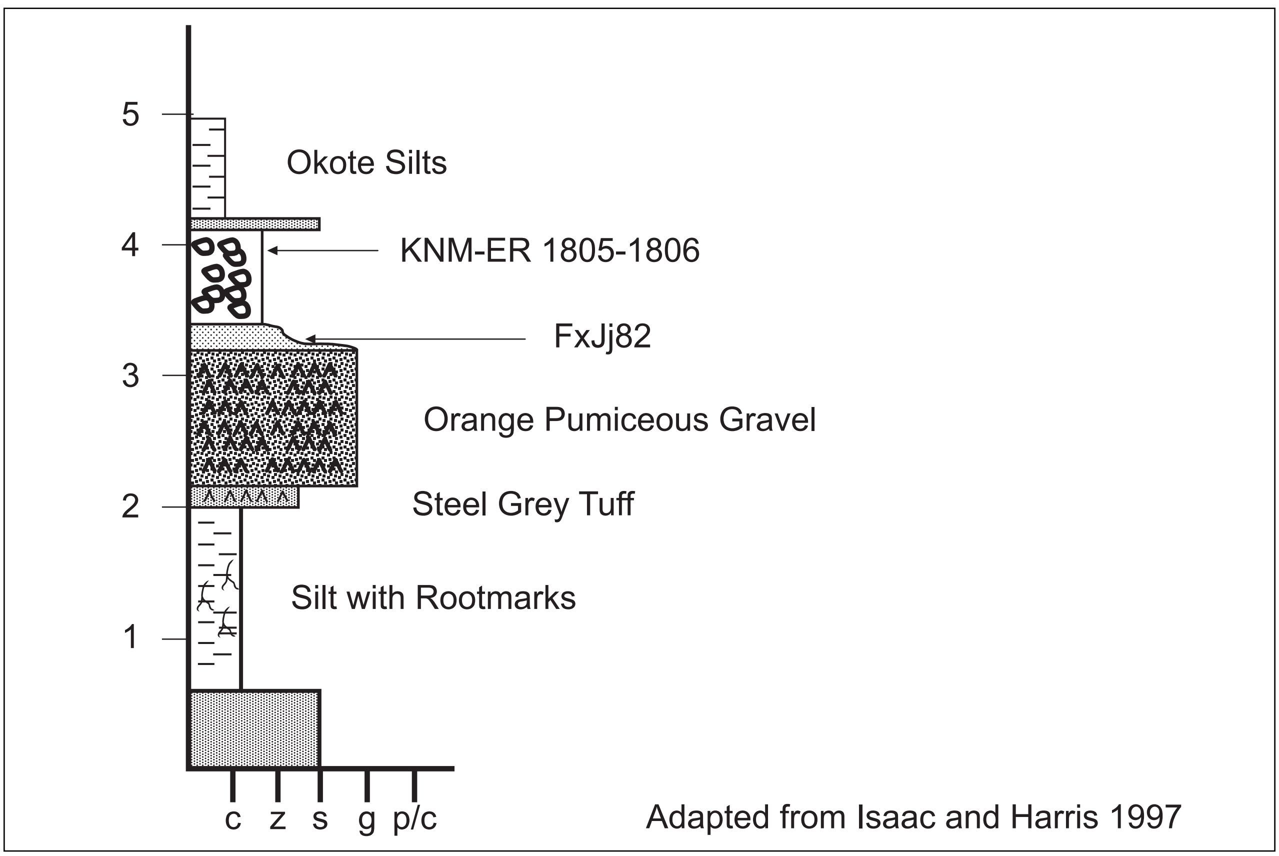

Figure 3. Stratigraphic column showing the relationship between FxJj 82 and the KNM-R 1805 and 1806 localities.

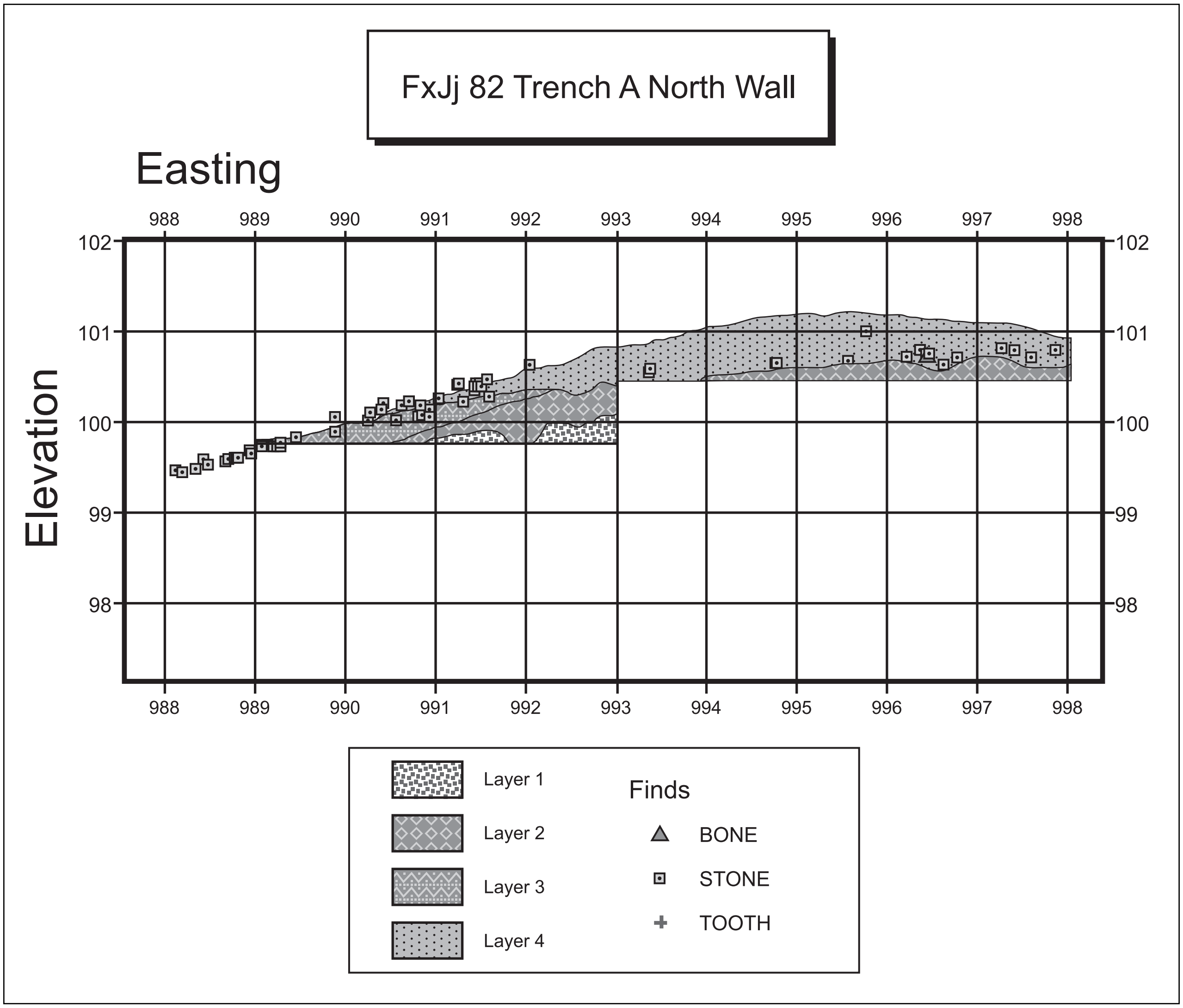

Figure 4. Site stratigraphy of the North Wall of FxJj 82 Trench A.

A steady decline in the abundance of reduncine forms toward the end of the KBS member further reinforces the generalized decrease in wetland habitats toward the end of the KBS Mbr. (Harris 1983). Feibel (1988) has suggested that the extensive caliche development in the Karari region at the upper part of the KBS Mbr. is the result of drier habitats due to the slightly elevated nature of this area. Pedogenic carbonate analysis by Wynn (2004) has suggested a rapid shift in environments toward modern values for stable carbon isotopic ratios at around 1.81 Ma. Wynn (2004) has argued that, mean annual precipitation in the Turkana basin decreased rapidly at about 1.65 Ma, especially relative to more humid conditions with higher precipitation rates in the earlier parts of the KBS Mbr. Finally, the fauna associated with FxJj 82 suggests an extremely variable habitat. The presence of several grazing antelopes (Antilopines, Alcelaphines) as well as hypsodont suids (*Metridiochoerus*) imply a xeric environment. However, the presence of elephant and rhinoceros bones suggest that sufficient vegetation was available to support a suite of large mammals. Based on the evidence of a variety of environmental proxies it appears that the landscape around Area 130 when hominins deposited artifacts at FxJj 82 was laterally variable and likely much drier than earlier periods of the KBS Mbr. Excavations at FxJj 82 recovered 541 artifacts, 264 non-artifactual stones and 141 bones. A listing of artifacts by raw material and artifact type can be found in Table 1. The faunal collection includes bovids (*Parmularis cf. altidens*; *Antidorcas* sp.) suids (*Kolpochoerus andrewsi*, *Metridiochoerus* sp.), equids, hippoptamids (*Hippopotamus gorgops*) and probiscideans.

FxJj 10

Initial excavations at FxJj 10 were conducted from 1972 through 1973. New excavations in 2003 were established in the areas were the highest density of artifacts were recovered during the 1973 investigations (Figure 5). A series of trenches were laid down over a large lateral extent to determine the extent of the archaeological horizon and the vertical dispersion of artifacts within this horizon. Trenches 1 and 2 were located directly next to the 1973 excavations and recovered the majority of the artifacts. Trenches 3 and 5-6 were located grid east of

Table 1. Raw material and typological breakdown of FxJj 82 collection (n=541)

Raw Material	Angular Fragment	Core	Snapped Flake	Split Flake	Whole Flake	Total
Asille Basalt	9.78	2.31	1.60	1.95	4.63	20.28
Chalcedony	3.38	.18	.54	0	1.42	5.51
Gombe Basalt	31.49	5.69	4.45	6.76	14.77	63.17
Rhyolite (Pantellerite)	4.80	.89	.71	1.24	1.42	9.07
Jasper	.71	.18	.18	0	.18	1.24
Quartz	.35	.18	0	.18	0	.71
Unknown	0	0	0	0	0	0

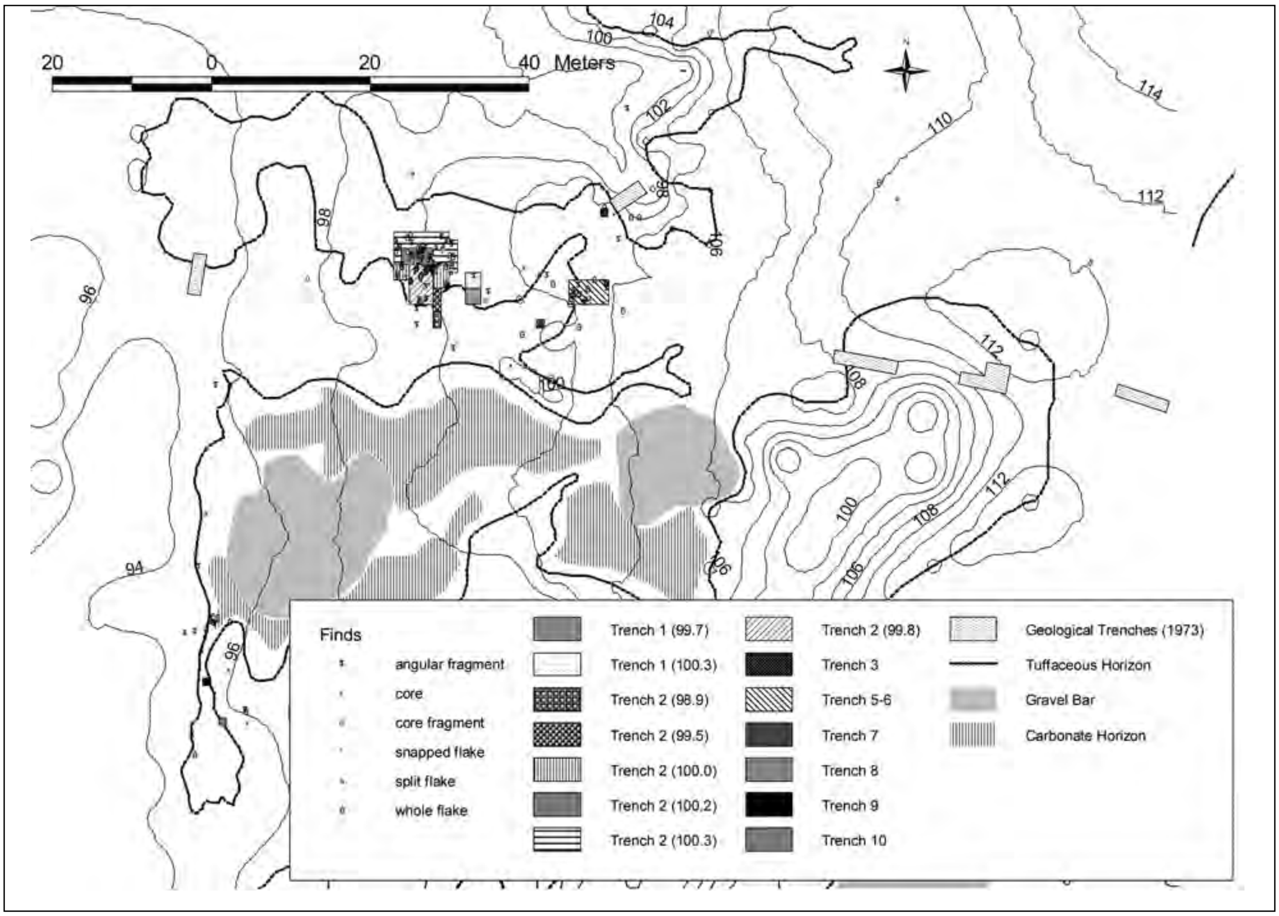

Figure 5. FxJj 10 excavations and surrounding Plio-Pleistocene deposits.

the main excavations and documented the southwesterly dip of all the horizons including the archaeological one. Even though the 2003 excavations were much larger in the area excavated (2003: 89 square meters; 1973: ~19 square meters) the number of artifacts recovered was comparable. The 1973 excavations recovered far more surface pieces than the 2003 excavations suggesting that the FxJj 10 locality was a very large archaeological occurrence that was subsequently eroded over a period of several years.

FxJj 10: Local geology

Paleontological area 118 where the excavation of FxJj 10 is located is not as well studied as some of the other regions of the Karari Ridge. The shallow exposures and numerous faults make the area more difficult to interpret. The initial description of the site assumed that the large fault about 100 meters south of the main excavations was responsible for the erosion that exposed outcrops of the KBS tuff (Isaac and Harris 1997a). It was assumed that the prominent tuffaceous horizon in Area 118 was the KBS tuff because of similar outcrops in nearby Area 105. However, subsequent analysis of the

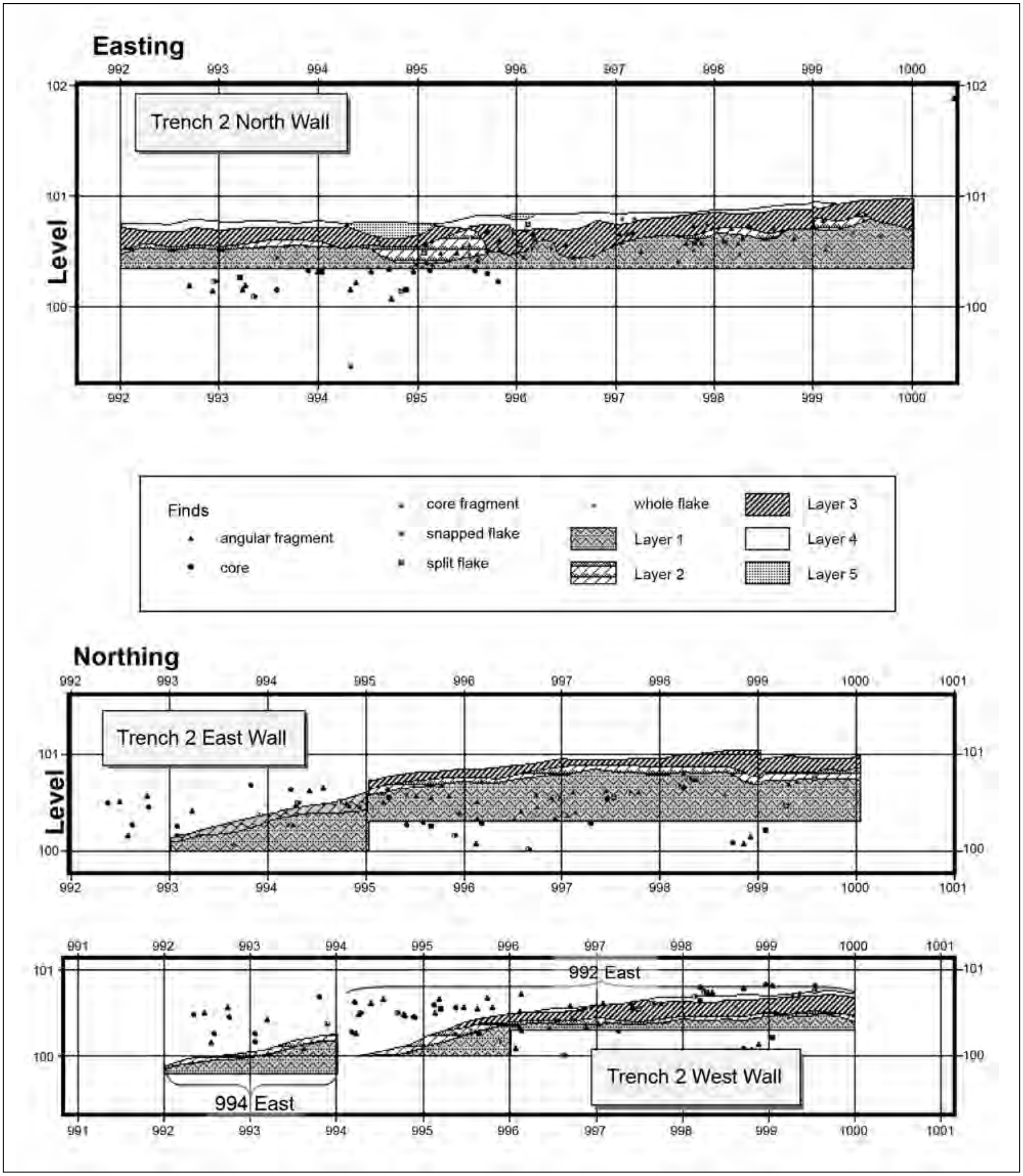

Figure 6. Wall sections of Trench 2 at FxJj 10

geochemistry of the tuffaceous horizons in Area 118 suggests that this horizon is actually the Orange Tuff (Feibel pers. comm.) This designation is further supported by evidence of an orange pumiceous horizon visually similar to the horizon seen in northern Area 130. This orange pumiceous horizon is found at the base of a channel in sediments approximately 120 meters south of the main excavations at FxJj 10. The area around FxJj 10 hosted a tributary of a relatively large fluvial system during late KBS Mbr. times. The appearance of tuffaceous horizons in this channel suggests this was a tributary of the axial river system (proto-Omo). As the Orange tuff at FxJj 10 forms the substrate on which artifacts are deposited, both FxJj 10 and FxJj 82 may represent relatively contemporaneous archaeological occurrences.

The archaeological horizon at FxJj 10 is positioned at about the level of the Orange tuff and is associated with a layer that has undergone extensive pedogenesis. The horizon that underlies the archaeological horizon is a sandy tuffaceous horizon that probably represents proximal floodplain deposits of the nearby channel. Soon after the deposition of the sandy tuffaceous horizon there was a cessation in deposition that led to the pedogenesis of the tuffaceous sandy horizon. A large discontinuous caliche horizon signals the possibility of somewhat xeric conditions in the region during this time. This paleosol horizon is the horizon in which the majority of the artifacts were found (Figure 6).

Although previous excavations had focused the recovery of *in situ* specimens at two trenches, the present study recovered *in situ* archaeological material over a large lateral area. None of the 10 trenches that were excavated in 2003 reached the density of pieces recovered in the 1973 excavations (e.g. 1973 Trench B: 16.5 artifacts per square meter/2003 Trench 2: 1.3 artifacts per square meter). However despite the broad area covered all but Trenches 3, 9 and 10 recovered artifacts. An area over 1000 square meters records evidence of hominin artifact discard at almost the exact same horizon. Original surface collections by Isaac and Harris suggested artifacts were associated with this horizon over an even larger area (Isaac and Harris 1997a: 109). Isaac and Harris (1997a) proposed a possible scenario where artifacts were frequently deposited in the area round FxJj 10 over a long period of time which resulted in a diffuse scatter of artifacts over a large area. The 2003 excavations support this scenario because many artifacts appear to be incorporated in the paleosol and these specimens can be found in situ over an extensive lateral area. During the hiatus in deposition after the floodplain of the nearby channel had been covered by tuffaceous sediments, pedogenesis began. This stable land surface was occupied by hominins repeatedly. Access to cobbles in the nearby channel allowed them access to raw material to make artifacts. These were subsequently incorporated into the paleosol. Intense chemical weathering, likely due to rapidly fluctuating wet and dry periods (seasonal inundation of the floodplain) caused the destruction of both bones and teeth and aided the formation of the extensive carbonate horizon.

The site stratigraphy is divided into five horizons. Layers 4 and 5 represent modern erosion and infill events that occurred during the exposure of the archaeological horizons in Area 118. Layer 4 is recently disturbed silts and clays that probably derive from Layers 2 and 3 and have subsequently slumped downwards off the sometimes steep erosional faces in Area 118. Layer 3 is a sandy silt horizon with some evidence of pedogenesis that has numerous carbonate nodules and some gravel lenses. Carbonate nodules often coalesce to form a solid caliche horizon. Layer 2 is a paleosol that is often discontinuous in the wall sections. It varies from increasing fractions of silt and sand across the length of the excavation but it is characterized by extensive pedogenic weathering including ped structures and mottling. Layer 1 is a silty tuffaceous sand that includes rare pumices. Archaeological finds are usually found at the contact between Layer 2 and 1. Many artifacts were found on the surface suggesting the vertical dispersion of artifacts prior to excavation was extensive. Indeed Isaac and Harris (1997a) comment on the relatively large vertical dispersion of elements in this excavation. This may be the product of soil process but also may be the result of post-depositional processes.

FxJj 10: Paleoenvironments

Unfortunately due to the intense weathering of fossils in Area 118 there are very little macromammal remains that can be used to determine the environments around FxJj 10. The original 1973 excavations recovered six fossils that were too weathered to determine their taxonomic affiliation. The 2003 excavation did not recover a single fossil specimen. Some fragments of enamel were recovered through screening but these were not diagnostic. Only one specimen had a morphology that would indicate that it was medium sized bovid. Considering that FxJj 10 is likely contemporaneous with the regional shift in climate indicated by Wynn's (2004) analysis of the Turkana Basin, it is very likely that Area 118 was experiencing xeric conditions around the time of the deposition of the Orange tuff. The extensive caliche horizon in the region may also lend credence to the designation of FxJj 10 as the hominin occupation of a dry habitat region.

The excavations at FxJj 10 during the 2003 field season recovered 161 artifacts. The typological and raw material breakdown of these finds can be seen in Table 2. The present analysis incorporates another 564 artifacts

Table 2. Raw Materials at FxJj 10 (n=725)

Raw Material	Angular Fragment	Core	Snapped Flake	Split Flake	Whole Flake	Total
Asille Basalt	1.89	.63	.42	.42	.84	4.20
Chalcedony	0	0	0	0	0	0
Gombe Basalt	46.12	5.66	10.06	6.92	25.78	94.55
Rhyolite (Pantellerite)	.42	0	0	0	.63	1.04
Jasper	0	0	0	0	0	0
Quartz	0	0	0	0	0	0
Unknown	0	0	0	0	0	0

from the 1973 excavations. Artifacts were not included in the analysis if significant chemical weathering made geochemical and technical analysis of the material impossible. The combined assemblage size of 725 artifacts is the largest assemblage in the KBS Member.

Raw materials in the KBS Mbr.

Although the igneous rocks in the Lake Turkana Basin include both felsic and mafic rocks the majority of artifacts in the Plio-Pleistocene sediments are made from basalts. These basalts can be geochemically divided into alkali and tholeitic basalts. Alkali basalts are distinguished from the more common tholeitic basalts by lower silica levels and higher alkali content. Rhyolitic rocks can also be found around the basin margin. These are mostly peraluminous rhyolites defined by Watkins (1982) as pantellerites. Associated with these rhyolites are large bands of chalcedonic cherts which are the product of hydrothermal activity leaching the silica from underlying silica rich rhyolitic rocks. These rocks outcrop in small patches in the extreme northern end of the sedimentary basin. All archaeological materials were subject to non-destructive ED-XRF testing to determine the trace element signature of the materials. This allowed the designation of different types of basalts (Figure 7). Rhyolitic rocks can easily be distinguished from basaltic rocks based on the presence of quartz and feldspar phenocrysts. However, Zr concentrations were also checked to confirm this distinction (see Braun et al. in press for further description of this analysis). Tables 3 and 4 show the composition of the original KBS Mbr. localities according the previously described raw material categories.

Debitage Products and Reduction Sequences

The stone artifact collections from the KBS Member represent hominin behaviors in diverse settings. New excavations and extensive raw material sourcing allow the technology of the KBS Member to be viewed in a manner which may reflect the uses and selective pressures acting on tool mediated behaviors. Although transport behaviors were not limited to certain portions of the technological system, previous refit studies have suggested that flaked pieces were the primary tool transported from locality to locality (Schick 1987). Whole flake assemblages may be the best example of behaviors that happened “on site.” Here we apply a multiple linear regression model that is based on a series of linear measurements of whole flakes and allows for a reasonably accurate description of the position of a whole flake in a reduction sequence (see Braun 2006 for complete description of the multiple regression model technique). The values for the predicted stage in reduction sequence are not intended to actually recreate the actual sequence number of flakes that were removed in antiquity. Rather the model is used to compare across assemblages in a

Table 3. Raw Materials at FxJj 1 (n=164)

Raw Material	Angular Fragment	Core	Snapped Flake	Split Flake	Whole Flake	Total
Asille Basalt	10.06	4.40	1.26	0	8.18	23.89
Chalcedony	0	0	0	0	0	0
Gombe Basalt	25.79	5.03	5.66	1.89	20.12	58.49
Rhyolite (Pantellerite)	1.89	2.51	0	0	5.03	9.44
Jasper	0	0	0	0	0	0
Quartz	0	0	0	0	0	0
Unknown	2.51	1.89	.63	.63	2.51	8.18

Table 4. Raw Materials at FxJj 3 (n=64)

Raw Material	Angular Fragment	Core	Snapped Flake	Split Flake	Whole Flake	Total
Asille Basalt	3.70	0	3.70	0	0	7.40
Chalcedony	0	0	0	0	0	0
Gombe Basalt	44.44	0	1.85	7.40	31.48	85.19
Rhyolite (Pantellerite)	3.70	0	3.70	0	0	7.40
Jasper	0	0	0	0	0	0
Quartz	0	0	0	0	0	0
Unknown	0	0	0	0	0	0

way that allows comparison of flake manufacture strategies at different sites.

Due to the small sample sizes in some assemblages it is necessary to use non-parametric tests to measure the significance of differences between assemblages. The Mann-Whitney test of two independent samples verified if the distribution between two samples is significantly different, but does not assume a normal distribution of the data. Box plots show that there are significant differences between assemblages in the KBS Mbr. (Figure 8). It appears that there is significant variation within the whole flake assemblages from those sites that are from the lower KBS Member (FxJj 1 and FxJj 3). In general all of the whole flake assemblages from FxJj 1 and FxJj 3 are from significantly earlier in an idealized reduction sequence than flakes from the latter part of the KBS Mbr ($p<.05$). This suggests that whole flake assemblages from sites in the older KBS Member sites were removed from cores that were not as extensively reduced. Furthermore it appears that at least for the assemblages at FxJj 1 there are no extreme outliers to suggest that there are cores being brought into these sites that are extensively flaked. The rhyolite assemblage from FxJj 1 does appear to have outliers that are from much later in the reduction sequence. It is possible that some of the rhyolitic material is being transported into this site.

Increased levels of reduction at FxJj 82 may be the result of increased transport behaviors due to ecological conditions that favor the use of more mobile toolkits. Previous studies have suggested that *H. ergaster* may have had an increased range size (Rogers et al. 1994; Anton and Swisher 2004). Extending the use life of a core by reducing it more exhaustively may have provided the mechanism for the expansion of home and day ranges in these hominins (Braun and Harris 2001, 2003).

Oldowan Technology at Koobi Fora: Synthesis

Oldowan technology represents the first attempt by early hominins to culturally mediate resource acquisition. In that sense it is vital to understand energetic input of technological organization because it should reflect the energetic benefits accrued from stone tool production

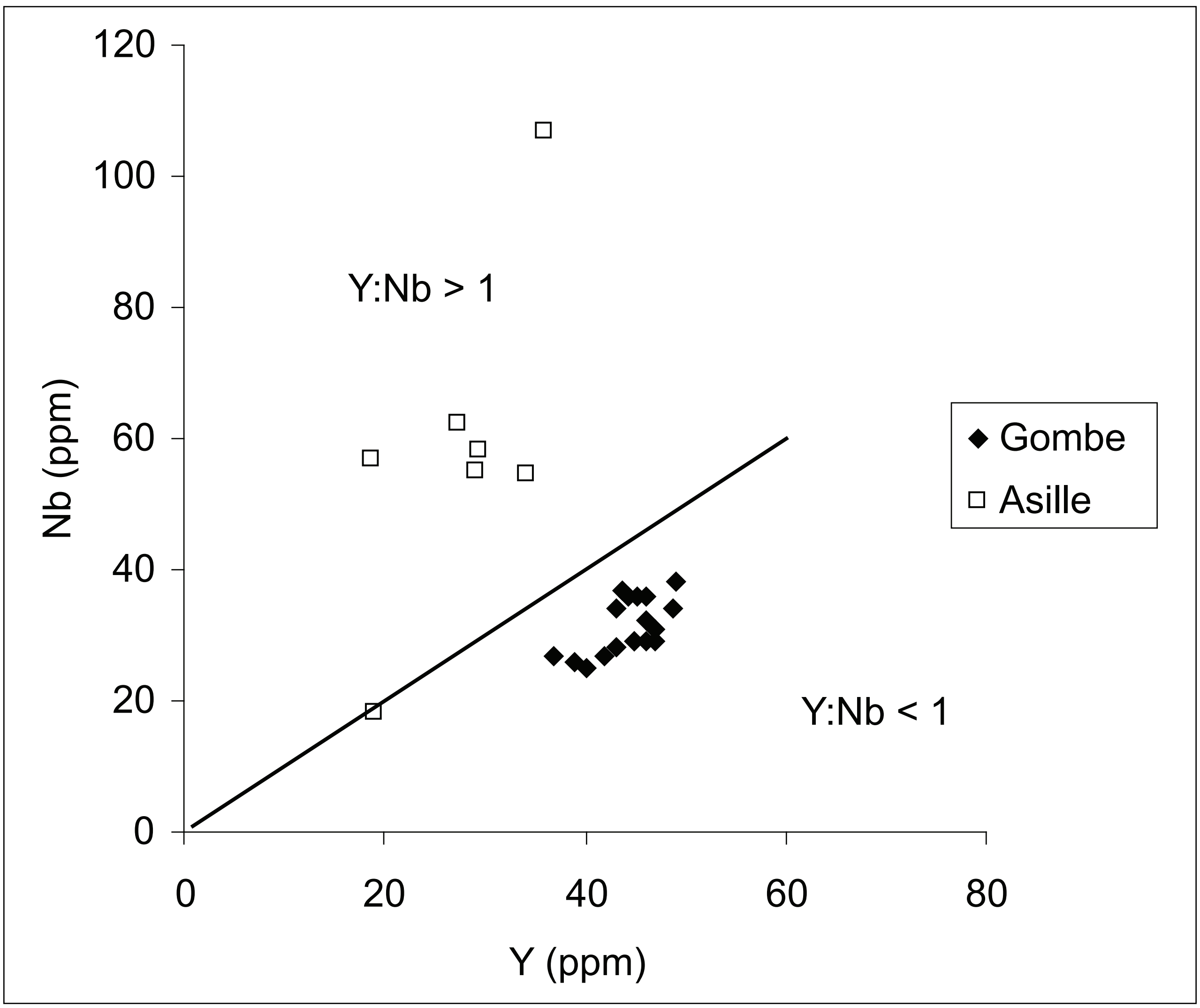

Figure 7. A ratio of Yttrium: Niobium separates the two major basalt groups found in the eastern Turkana Basin.

and use. In this sense the KBS Mbr. assemblages form a very interesting case study because the different factors that affect technological organization are well known (raw material availability and quality). Therefore it is possible to investigate simulate the affects of different ecological settings on patterns of stone tool use and discard. Stone tool technology may represent a method for Oldowan hominins to increase the efficiency of resource acquisition (Bousman 1993). Therefore, increases in the efficiency of stone tool manufacture and use may represent correlative increases in resource acquisition efficiency. Selective pressures acting on stone tool mediated resource acquisition should be directly reflected in attempts by Oldowan hominins to increase the efficiency of their technological organization.

As Oldowan tool kits are simple, modeling increases in efficiency is rather simplistic. Oldowan hominins can increase efficiency by increasing the use life of an artifact, thereby decreasing the time needed to procure new sources of raw material. There are two ways that Oldowan hominins can increase the use life of their technological system. They can increase the use life of a core by simply reducing it more extensively. Exhaustive reduction can be seen as a method of increasing the use life of a flaked piece. The predicted stage in reduction sequence values of whole flakes are a proxy for this behavior. These values record the intensity of core reduction when the detached piece was removed from it. Therefore it is possible that assemblages that exhibit flakes later in the reduction sequence represent cores that are nearing exhaustive reduction levels.

In the KBS Mbr. there are significant differences in the extent of flaked piece reduction between the earlier KBS Member assemblages and the assemblages from the later part of the KBS Mbr. The whole flake assemblage at FxJj 3 represents the least amount of reduction with median values close to 12 or 13, whereas FxJj 82 has median values closer to 24 or 29. Increased levels of reduction at sites later in the KBS Mbr. require further inquiry. One possible explanation may be variation in the requirement of stone artifacts in the behavioral repertoire across various ecological conditions in time and space

The extensive reduction that occurs at FxJj 82 may be the result of a greater need for artifacts and a subsequent attempt by early hominins to preserve their sources of raw material by extensively reducing them. The ability for hominins from the latter part of the KBS

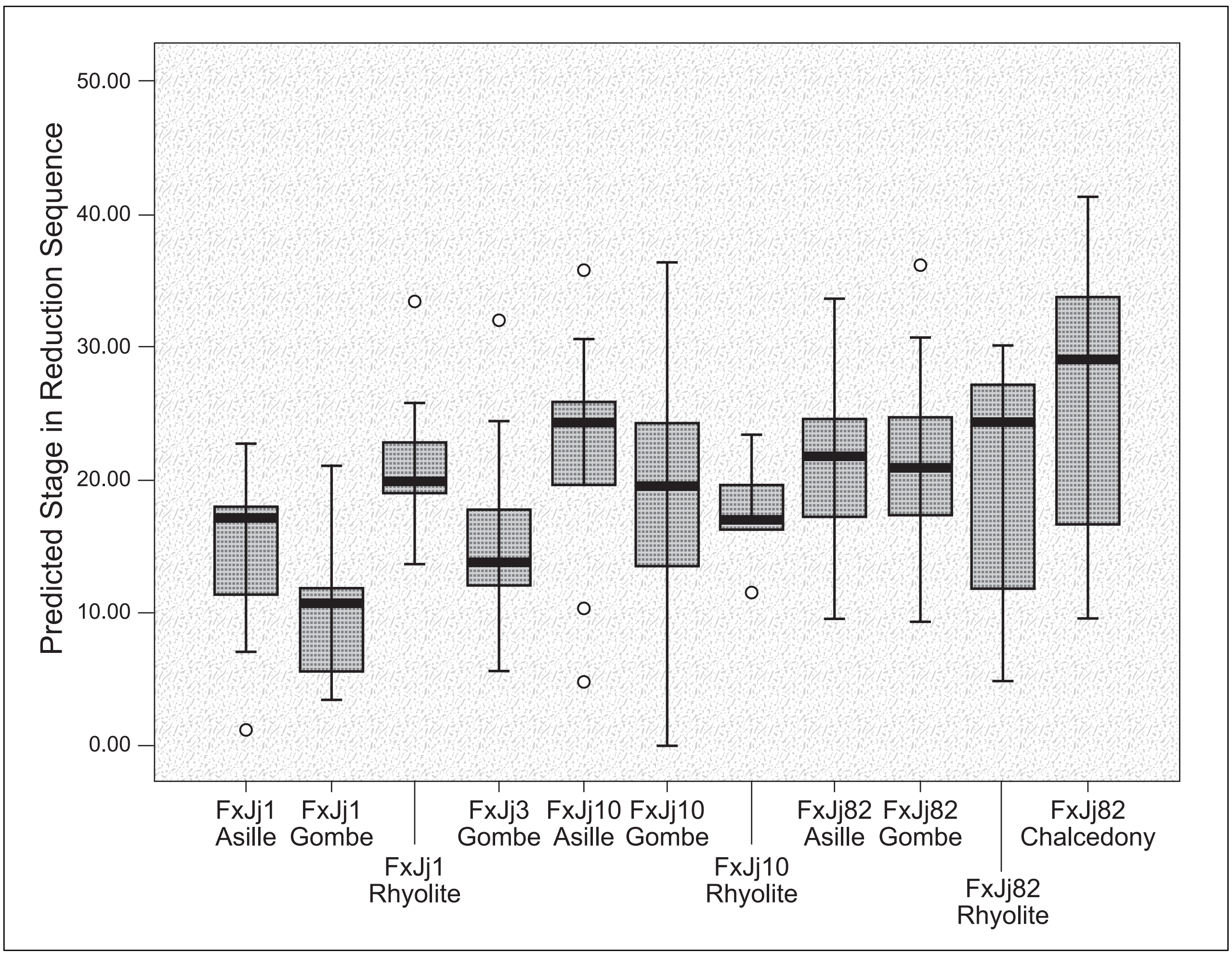

Figure 8. Box plots of predicted place in reduction sequence values for raw material specific assemblages of whole flakes from KBS Mbr. assemblages.

Mbr. to increase the length of time that a flaked piece stayed operable in a technological system may reflect the increased selection pressures for a conservative technological organization in later times in the KBS Member.

The greater effort made by hominins at FxJ10 and especially FxJj82 to conserve raw material sources and extend the use life of their sources of raw material may be a reflection of ecological differences. Although differences in raw material availability could explain the patterns seen in these assemblages, it is an unlikely explanation. FxJj10 and FxJj82 are both located near sources of raw material (Braun et al. in press). During the latter half of KBS Mbr. the basin margin drainage system would have had a higher competence due to increased uplift in the Lake Stephanie basin (Feibel 1988; Lepre 2001). The result would have been a higher incidence of clasts large enough to make artifacts during this time. Since raw material availability cannot explain this pattern, ecological differences may be the cause of variation. Paleoenvironmental data records an increase in xeric conditions towards the end of the KBS Mbr. At FxJj82 and FxJj10 there is proximate evidence to suggest xeric conditions in the form of carbonate horizons associated with soil horizons that were likely subject to intense seasonal variation. Wynn's (2004) analysis of soils during this time interval suggests a drastic drop in rainfall during this time. Macrofaunal evidence at FxJj82 in the form of hyposodont suids (*Metridiochoerus*) and arid adapted bovid species (Alcelaphini and Antilopini) suggest this site was surrounded by arid environments.

Discussion and Conclusion

Water stressed environments have a very different biological structure than more mesic environments. In Africa drier environments tend to have a significant grassland component. In these types of environments the biomass available for hominin consumption is shifted towards large mammals (Leonard and Robertson 2000). Hominins that lived in these environments would have had a limited selection of resources. It is possible that hominin occupation of grasslands required an increased reliance on mammal tissue. Ethnographic and experimental data suggests that certain butchery activities do not place intense raw material requirements on stone tool technologies (Shott and Sillitoe 2005). However, experimental data does suggest that skinning and disarticulation of even small sized animals can drastically reduce the utility of stone edges (Pobiner and Braun 2005). Therefore a technological organization that is focused on intense butchery activity would increase the need for stone artifacts in the behavioral repertoire of these early toolmakers. The potentially drier grassland environments of the later KBS Mbr. may have forced hominins to adapt more conservative tool use strategies. Alternatively, FxJj82 and FxJj10 may represent a greater reliance on stone tool technology because of the physiological requirements of a later hominin species (*H. erectus*). Increased density of artifacts at FxJj82 and FxJj10 may be signaling a more intense reliance on stone tool technology. The expected technological response to such conditions would be an increase in reduction of flaked pieces. The paleoenvironmental reconstruction of FxJj 1 and FxJj 3 in a back-delta swamp indicates that resources that did not require intensive stone tool use were more abundant (e.g. fruiting trees). It is possible that stone artifacts were not a vital resource for hominins in this environment. This may also explain the low density of pieces at FxJj1 and FxJj3 (Rogers et al. 1994).

Conclusions

The Oldowan assemblages in the KBS Mbr. of the Koobi Fora Fm. provide an interesting perspective on variation in the stone tool technology at the Plio-Pleistocene boundary. This study has provided a new perspective on the technology of the KBS Mbr. The earliest record of hominin behaviors on the eastern shores of Lake Turkana may be more complex than originally modeled by Isaac and Harris (1997a). Paleoenvironmental data indicators suggest that major changes occurred during the course of the KBS Mbr. that caused a change in the behavior of stone tool using hominins in the Turkana Basin at this time. Landscape scale variation in technological strategies allowed hominins to increase the use life of their toolkit in accordance with their requirement for stone tool mediated resources. This suggests that Oldowan technology reflects technological capabilities that allowed Plio-Pleistocene hominins to overcome variability in ecological conditions.

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CHAPTER 3

WAS THERE AN OLDOWAN OCCUPATION IN THE INDIAN SUBCONTINENT? A CRITICAL APPRAISAL OF THE EARLIEST PALEOANTHROPOLOGICAL EVIDENCE

PARTH R. CHAUHAN

INTRODUCTION

The Lower Paleolithic record of the Indian subcontinent has been traditionally divided into Mode 1 (pre-Acheulian) and Mode 2 (Acheulian) industries (Misra, 1987; Mishra, 1994; Petraglia, 1998; 2001; Gaillard and Mishra, 2001). These two traditions often occur independently as well as in shared geographic, geomorphologic, and stratigraphic contexts (e.g., de Terra and Paterson, 1939; see Sankalia, 1974; Jayaswal, 1982). The current geochronological evidence for archaeological and fossil evidence in Eurasia points to a late Pliocene or Early Pleistocene age for the earliest dispersal from Africa and involves the genus *Homo* (Larick and Ciochon, 1986; Anton and Swisher, 2004; Langbroek, 2004; also see Dennell and Roebroeks, 2005). However, the Paleolithic record of South Asia, a region that lies between the three sources of the earliest *Homo* fossils in Africa, the Republic of Georgia, and East Asia (Woldegabriel et al., 2000; Gabunia and Vekua, 1995; Gabunia et al., 2000; Swisher et al., 1994), does not clearly fit into this chronological framework and is conspicuously discontinuous (Dennell, 2003). Most of the Paleolithic localities have been dated through the Thorium-Uranium method and include a predominance of Acheulian sites in India (Mishra, 1992; Korisetter and Rajaguru, 1998; Chauhan, 2004, 2006). The majority of these occurrences appear to be late Middle Pleistocene in age, although some localities may be considerably older than 350 or 390 Ka, the maximum temporal limit of the Th-U method used. An older exception is the Early Acheulian site of Isampur in the Hunsgi Valley, recently dated to ca. 1.27 Ma using electron spin resonance on herbivore teeth (Paddayya et al., 2002). Unfortunately, this chronostratigraphic attribution remains tentative and requires more extensive study, especially when considering the possibility of geological reworking at the site (A. Skinner: pers. comm.) and current problems with ESR on Indian faunal specimens in specific depositional environments (e.g., Blackwell et al., 2007).

Following the early impact of the Clactonian evidence in England (see Dennell and Hurcombe, 1992), a pre-Acheulian technology based on pebbles and cobbles was also proposed for the Indian subcontinent in the form of the Soanian industry in what is now northern Pakistan (de Terra and Paterson, 1939). This industry was viewed as a distinct cultural phenomenon preceding and partly overlapping with the local Acheulian evidence in relation to Pleistocene glaciation phases. Their primary goal was to seek evidence of Pleistocene glaciation phases (after Penck and Brückner, 1909) and highlight its impact on early human cultures in the sub-Himayalan region (Sankalia, 1974; Dennell and Hurcombe, 1992; Dennell and Rendell, 1991). This model became a standard for subsequent prehistoric and Pleistocene research in India and prevailed for four decades (see Rendell et al., 1989). Later work by the British Archaeological Mission to Pakistan (BAMP) resulted in a major revision of de Terra and Paterson's interpretations. Most importantly, the concept of Soan terraces and the associated Soanian typo-technological sequence as recognized by de Terra and Paterson was deemed untenable because the Soan 'fluvial' terraces actually turned out to be erosional features (Dennell and Hurcombe, 1992). Subsequently, multiple lines of evidence including a comparison of Soanian and Acheulian technology (Gaillard, 1995), landscape geoarchaeology (Chauhan, 2008a), surveys of dated geological features (Soni and Soni, 2005) and

Figure 1. General locations of the pre-Middle Pleistocene paleoanthropological sites discussed in the text.

a comparative morphometric analysis (Lycett, 2007), clearly revealed that the majority of Soanian assemblages, if not all, represent a Mode 3 technology and relatively post-date the Acheulian (Gaillard and Mishra, 2001; Chauhan, 2003). Subsequent claims for a pre-Acheulian occupation have come from the Narmada Valley of central India and from the Siwalik Hills in the northern zones of Pakistan and India (Figure 1 and Table 1). This chapter represents a critical review of these occurrences and explores the possibility of a younger occupational history for the Indian subcontinent.

Narmada Valley

Central India is dominated by the Narmada River which flows through Madhya Pradesh and Gujarat from Amarkantak in the east to the Arabian Sea in the west–a total of about 1300 km. Numerous Quaternary geological and archaeological investigations have been conducted in the entire valley since the 19th century (see Kennedy, 2003). Prehistoric hominin occupation associated with the Narmada River appears to have occurred since at least the Middle Pleistocene, but potentially earlier (discussed later). Direct evidence of repeated human occupation is reflected by numerous sites ranging from the Lower Palaeolithic to the Chalcolithic Periods (Misra, 1997). The region is most famous for yielding the oldest fossil hominin evidence in the subcontinent at Hathnora, which is represented by an incomplete calvarium and two clavicles and a possible rib fragment (Sonakia, 1984; Sankhyan, 1997, 2005). The cranium remains to be accurately dated but has been variably attributed by different investigators as *Homo erectus, archaic H. sapiens or H. heidelbergensis* (Sonakia, 1984; Kennedy and Chiment, 1991; Sankhyan, 1997, 2005; Cameron et al., 2004). Because it possesses diverse but undiagnostic

Table 1. The earliest South Asian paleoanthropological sites as discussed in the text.

SITE	REPORTED AGE [DATING METHOD]	STRATIGRAPHIC CONTEXT	MATERIAL RECOVERED	REFERENCES	COMMENTS
Riwat	2.0-2.2 Ma? [PM, GS]	stratified in gritstone	3 to 23 cores and flakes (based on numerical ranking)	Rendell et al. 1987	requires corroboration through *in situ* fine-grained contexts
Pabbi Hills a	2.2 – 1.7 Ma? [PM, GS]	surface of fine-grained sediments	198 cores (various types), flakes, flake blades, scrapers, knife	Dennell, 2004	requires corroboration through *in situ* contexts
Pabbi Hills b	1.4-1.2 Ma? [PM, GS]	surface of fine-grained sediments	307 (same as above)	Dennell, 2004	requires corroboration through *in situ* contexts
Pabbi Hills c	1.2 - 0.9 Ma? [PM, GS]	surface of fine-grained sediments	102 (same as above)	Dennell, 2004	requires corroboration through *in situ* contexts
Uttarbaini	>1.6/>2.8 Ma? [FS]	stratified below dated ash horizon	not reported	Verma, 1991	requires confirmation, re-dating of ash
Jainti Devi ki Rao	EP-MP? [GS, BS]	stratified within Lower Boulder Conglomerate Fm.	150 Acheulian handaxes, cleavers, choppers, large flakes,	Sharma, 1977	requires confirmation, dating through *in situ* fine-grained contexts
Kheri-Jhiran	LP-EP? [GS, BS?]	stratified within Pinjore Fm.	>45 'Abbevillian' handaxes, choppers, scrapers, 'rounded pebble tools', a discoid	Verma, 1975	requires corroboration
Nadah	2.2 – 2.0 Ma? [GS, BS]	stratified (?) within Pinjore Fm.	*H. erectus* maxillary incisor	Singh et al. 1988	ambiguous; require diagnostic specimen(s)
Khetpurali & Masol	ca. 3.4 Ma? [ ]	eroded out from Tatrot Fm.?	hominid fossils: (mandibular, proximal femur, distal femur, patella, & post-cranial fragments, stone tools: (choppers, flakes?), other vertebrate fossils	Singh, 2003	represents false claims and substantiation
Durkadi	1 Ma? [GS, AT]	stratified in surface of conglomerate	650 artifacts (see Table 2)	Armand, 1979, 1983,	requires dating and corroboration through fine-grained contexts
Mahadeo Piparia	early MP? [GS, AT]	stratified in surface of conglomerate	>1215 but not all Lower Paleolithic	Multiple papers of A.P. Khatri; Supekar, 1985	requires dating and confirmation of context
Dhansi	>780 ka? [PM]	stratified in thin gravel horizon	5 cores, flakes, flake fragments	Patnaik et al. n.d.	requires confirmation of context and age

PM: paleomagnetism; GS: geo-stratigraphy; FS: fission track; AT: artifact typology; BS: biostratigraphy; LP: Late Pliocene; EP: Early Pleistocene; MP: Middle Pleistocene.

anatomical traits, Athreya (2007) has suggested that it be provisionally classified as *Homo* sp. indet.

Initial palaeomagnetic studies led by Agrawal et al. (1988) suggested that the Narmada Quaternary deposits fall within the Brunhes Chron (or, as presently dated, <0.78 Ma), while studies by the Geological Survey of India indicated an Early Pleistocene age for the oldest Quaternary sediments (see below). However, their respective studies were not applied to the same stratigraphic sections and because the Quaternary geology varies significantly across the entire basin, associated Lower Paleolithic sites are yet to be securely dated, including the ones discussed below. Based on the stratigraphic relationships, erosional unconformities, sedimentary mineralogy, granulometry, and structures, pedogenic characteristics, and tephra deposits, and palaeomagnetic signatures, the central Narmada Quaternary sequence have been divided into seven formations listed here from oldest to youngest: Pilikarar, Dhansi, Surajkund, Baneta, Hirdepur, Bauras and Ramnagar (Tiwari and Bhai, 1997). However, the author and his colleagues have recently demonstrated that the Pilikarar stratigraphic sequence cannot be defined as a geological formation (Patnaik et al., in press), thus provisionally qualifying Dhansi as the oldest Quaternary formation in the central Narmada Basin. This is provisionally based on Rao et al.'s (1997) paleomagnetic results which demonstrate that the latter formation at the Dhansi type-site belongs to the Matuyama Chron. Claims of pre-Acheulian evidence have come from two sites in the valley (Mahadeo Piparia and Durkadi) and preliminary observations at Dhansi suggest a Lower Paleolithic occupation prior to ca. 780 ka.

Mahadeo Piparia and Durkadi

In the 1960s, a pre-Acheulian lithic occurrence was reported in the form of the Mahadevian industry in the eastern part of the Narmada Valley. This industry was named after the site of Mahadeo-Piparia by Khatri (1963, 1966) who equated it to the Oldowan industry and interpreted it as a technological

Table 2. Fresh and rolled tool types from Durkadi. (Compiled from Armand, 1983)

TYPE	FRESH SPECIMENS	ROLLED SPECIMENS
HEAVY DUTY TOOLS:	**48**	**28**
Choppers:	37	23
Discoide	10	2
Side	19	19
Angular (on angle)	4	1
End	4	0
Proto-cleavers	1	0
Proto-handaxes	6	0
Handaxes	1	0
Heavy duty complex tools	4	2
Heavy hollow side-scrapers	0	4
LIGHT DUTY TOOLS:	**63**	**35**
Scrapers:	46	28
Round	5	4
Double side	2	1
Single side	33	19
Hollow side	1	2
Single end	5	2
Borers:	6	2
Angular (on angle)	5	2
End	1	0
Burins	1	0
Light duty complex tools	10	5
Other types of heavy or light duty tools	8	18
TOTAL TOOLS:	**119**	**82**
Prepared cores:	22	11
On-pebble	17	4
On-flake	5	7
Unprepared cores:	20	6
On-pebble	16	3
On-flake	4	3
Other types of cores	9	7
TOTAL CORES:	51	24
Prepared -platform flakes:	59	83
Plain	50	67
Faceted	9	16
Unprepared-platform flakes	63	49
Vertical	50	46
Horizontal	13	3
Other types of unworked flakes:	9	27
TOTAL UNWORKED FLAKES:	**131**	**158**
Percuter	0	2
Anvil	0	1
WASTE:	**62**	**17**
TOTAL DEBITAGE:	**244**	**202**
Non-classified artifacts	0	3
TOTAL ARTIFACTS	**363**	**287**

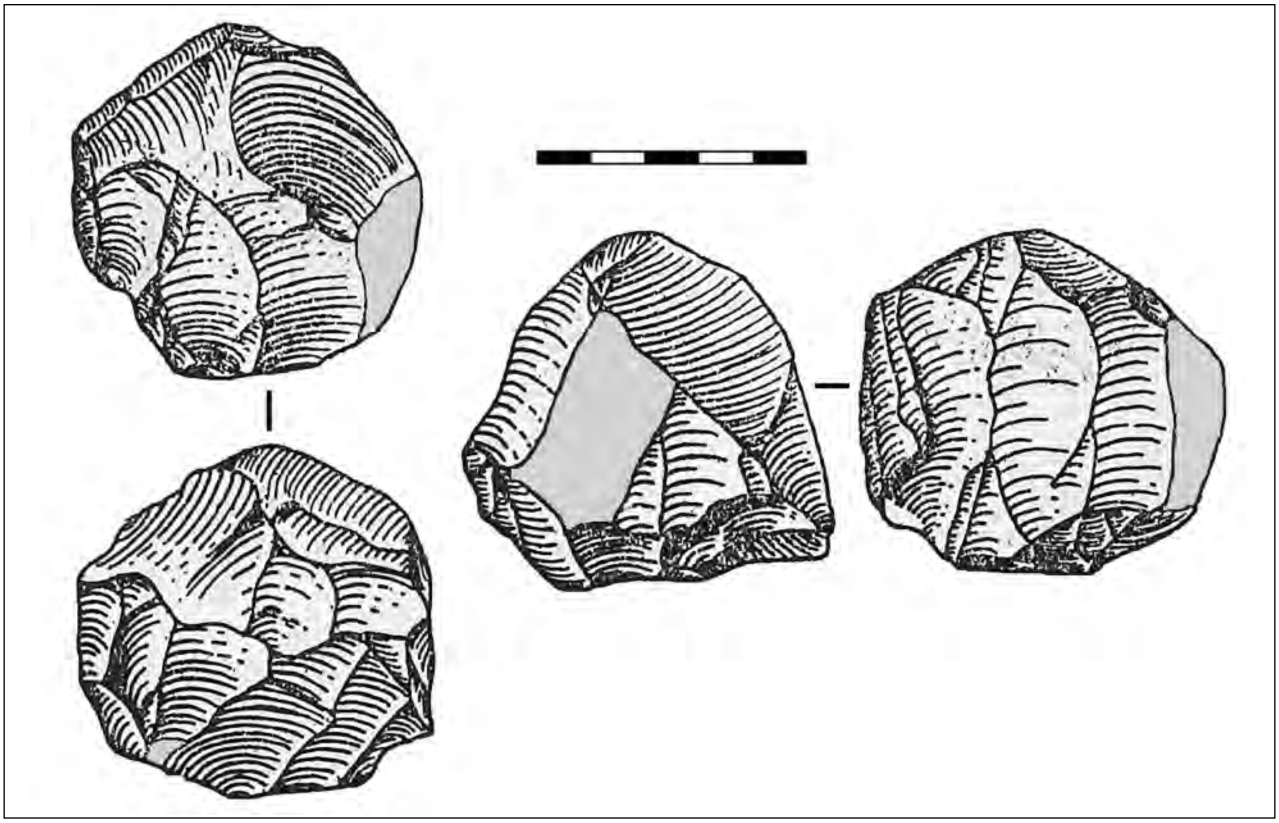

Figure 2. Polyhedron from Durkadi. (Modified after Armand, 1983)

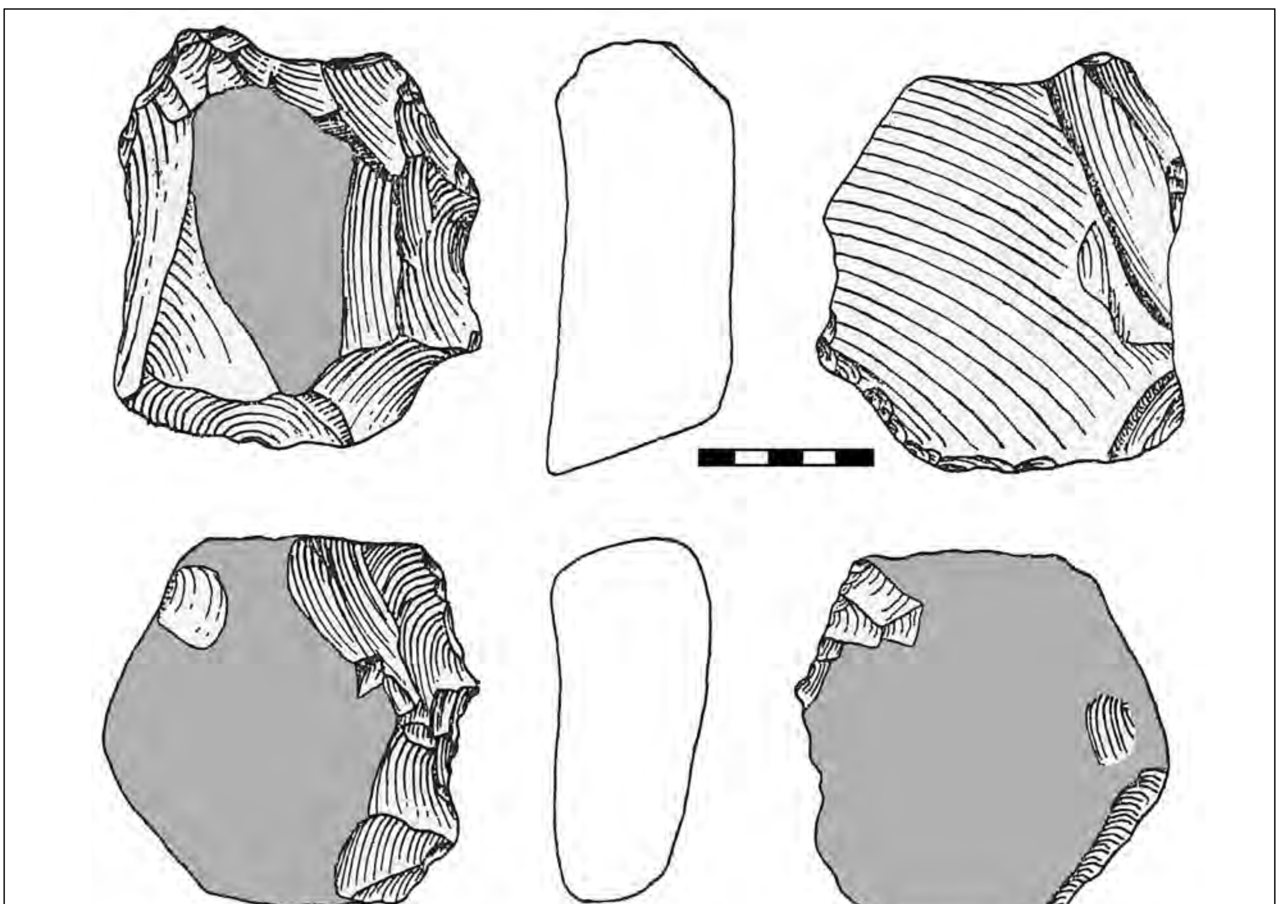

Figure 3. Core and chopper from Durkadi. (Modified after Armand, 1983)

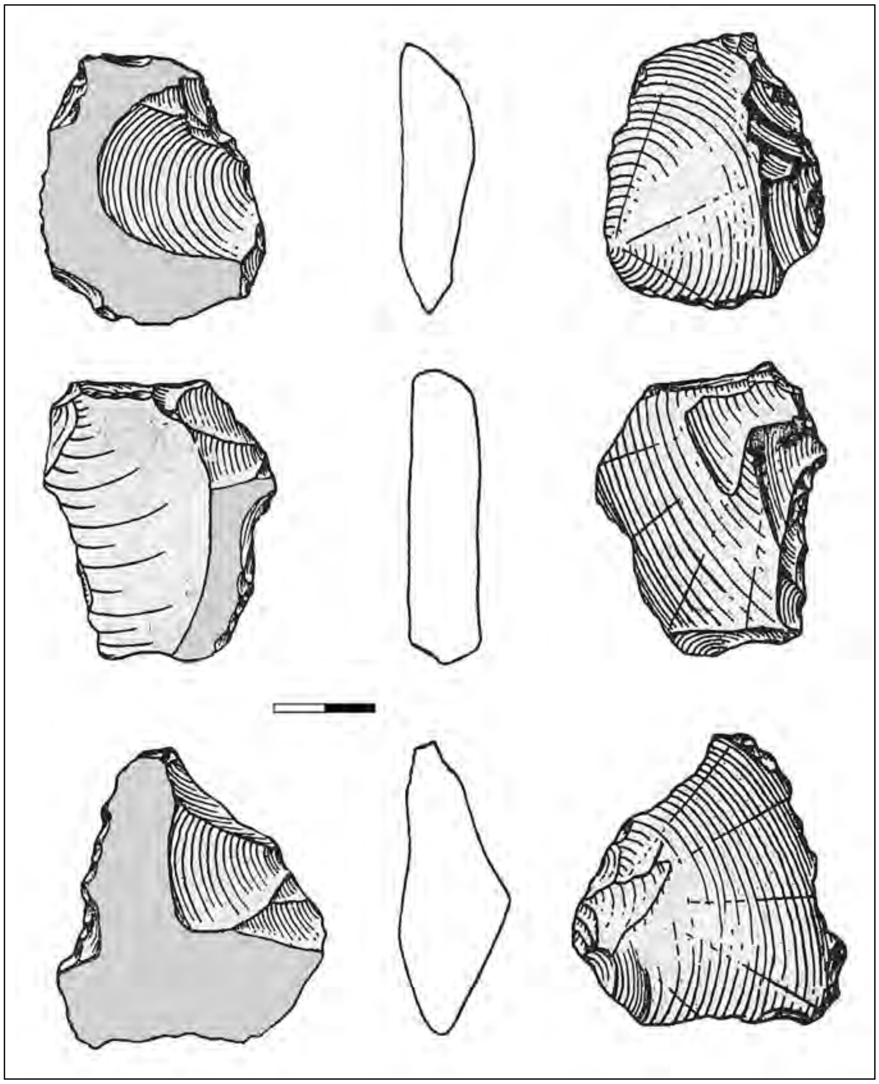

Figure 4. Flake specimens from Durkadi. (Modified after Armand, 1983)

predecessor to the Indian Acheulian. Later excavations and stratigraphic observations by Sen and Ghosh (1963) and Supekar (1968) refuted Khatri's claim of a Mode 1 to Mode 2 transition here. A similar claim to that of Khatri's was made more systematically through controlled excavations by Armand (1979, 1983, 1985) who defined the Durkadian industry at the site of Durkadi from excavated contexts 2 km south of the lower Narmada channel (Table 2). At both Durkadi and Mahadeo Piparia, a large amount of non-biface artifacts were recovered in stratified contexts and comprised of cores, choppers, flakes, "protobifaces", and other formal tool types (Figures 2 to 6). Both assemblages were recovered from within and over-lying the high-energy gravels of the Narmada River and many artifacts at both sites are relatively in fresh condition. This signifies the use of the conglomerate surface through multiple visits for clast acquisition and stone tool production prior to the surface's burial by fine-grained sediments, a key geoarchaeological feature at such sites associated with gravel or conglomerate contexts in the subcontinent (Chauhan, in press, a). While Mahadeo-Piparia was discerned to be early Middle Pleistocene in age (Khatri, 1963), Durkadi was interpreted to be about 1 Ma in age (Armand, 1983), based largely on geological stratigraphy and typology.

It is also now generally accepted that the South Asian Acheulian is a result of early migrations of the genus *Homo* from Africa sometime in the Pleistocene rather than being an indigenous or regional technological development (Sankalia, 1974). In other words, neither Mahadeo-Piparia and Durkadi, nor any other site in the Indian subcontinent, shows any convincing stratigraphic evidence for a technological transition from an Oldowan-type into the more sophisticated Acheulian technology (Jayaswal, 1982). Nonetheless, both Durkadi and a part of Mahadeo-Piparia remain typo-morphological anomalies within the South Asian Lower Paleolithic record and thus merit a reinvestigation to clarify their temporal and behavioral relationships (if any) with the regional Acheulian. Although these occurrences may not be as old as previously thought, they currently appear to represent some of the earliest typologically Mode 1 evidence in peninsular India. While Mahadeo-Piparia has yielded Acheulian bifaces and Middle Paleolithic elements in addition to the Mode 1 component (Supekar, 1985), Durkadi continues to be an exclusively Mode 1 site, despite Armand's (1983, 1985) report of 1 'proto-cleaver', 6 'proto-handaxes' and 1 'Abbevillian' or evolved Durkadian handaxe. These 8 specimens do not conform to the current typo-morphological definition of Acheulian bifaces as they lack bilateral and planform symmetry and adequate bifacial reduction (Figure 7). They also do not appear to resemble typical early developmental stages of the Acheulian as known from, for example, Olduvai Gorge, Konso-Gardula, Peninj and 'Ubeidiya (see Clark, 1998).

Dhansi

As mentioned earlier, the Dhansi Formation at the type-site is thought to belong to the Matuyama Chron based on paleomagnetic studies by Rao et al. (1997). Preliminary archaeological investigations here have recently yielded several Paleolithic aritfacts *in situ* from a thin gravel horizon at the bottom of the exposed type-

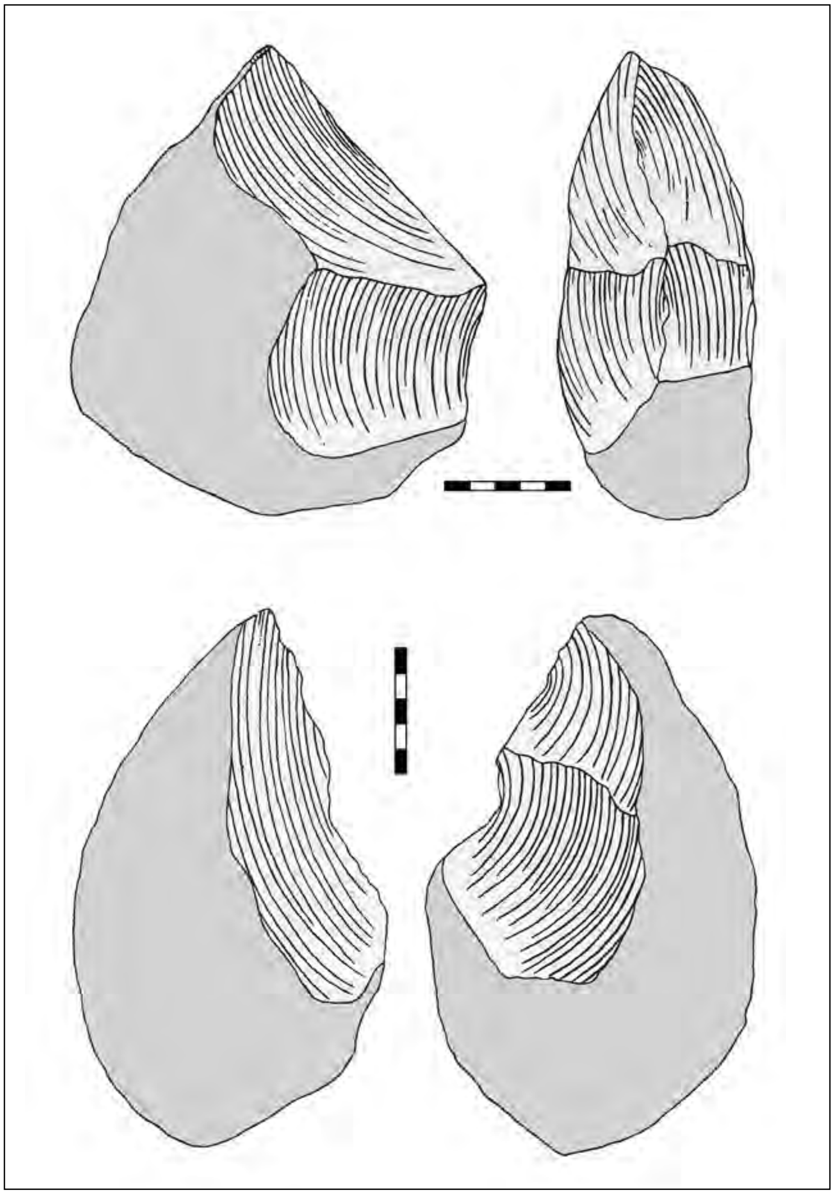

Figure 5. Cores/choppers from Mahadeo Piparia. (Modified after Khatri, 1963)

section. The specimens include a core/chopper, polyhedron and a few flakes or flake fragments in stratigraphic association with a highly-weathered fossil herbivore tooth recovered several meters away. Due to the potential significance of the site, a revision of the chronostratigraphic context of this site and additional excavations are currently underway. If Rao et al.'s (1997) paleomagnetic results ultimately prove to be accurate, the associated lithics may represent the first unequivocal evidence for an Early Pleistocene hominin occupation of the subcontinent. Elsewhere along the Narmada River, other exposures and sites possibly also of comparable age (provisionally based on soil color and morphology and lithic typology) also warrant careful archaeological and palaeontological reinvestigations. The remaining claims for pre-Middle Pleistocene palaeoanthropological evidence come from multiple locations in the Siwalik Hills of northern Pakistan (2) and northern India (4).

The Siwalik Hills

The Siwalik Hills or the Siwalik Foreland Basin consist of fluvial sediments deposited by hinterland rivers flowing southwards and southwestwards (Gill, 1983) from the Lesser and Greater Himalayas, when the region south of these mountains was originally a vast depression or basin (referred to as the foredeep) (Brozović and Burbank, 2000). They span from the western side of the Indus (northern Pakistan in the west) to the Bay of Bengal (Sikkim/Assam region in the east), covering a total length of approximately 2,400 km. The topography of the Siwalik Hills became a prominent feature on the landscape and reached its present elevation during Middle Pleistocene times (Kumar et al., 1994). The range is less than 13 km wide in places (average of 24 km), and it reaches an elevation between 900m and 1,200m. Quartzite pebbles and cobbles was the main raw material exploited by the hominin occupants of this ecozone at multiple temporal intervals throughout the entire Siwalik range (Dennell, 2007; Chauhan, 2008a). In addition to being located within the Boulder Conglomerate Formation of the Upper Siwalik Subgroup (Johnson et al., 1982), these localized quartzite clasts also occur in streambeds, on Siwalik surfaces of varying ages, and in the terrace sections of intermontane valleys. Paleolithic sites in the Siwaliks, situated within a range of eco-geographic contexts, have been traditionally divided into two types, Acheulian and Soanian,and are found in the form of sites, site-complexes, find-spots and numerous surface scatters (e.g., de Terra and Paterson, 1939; Stiles, 1978; Mohapatra, 1981; Chauhan, 2008a). However, claims made of the earliest occupation in the Siwalik region are reported to be considerably older than both these industries and have not been classified as Soanian, despite some broad morphological similarities.

Kheri-Jhiran (northern India)

From paleontological investigations in the Solan District of Himachal Pradesh, Verma (1975:518) reported a rich vertebrate fossil locality from the Pinjore Formation as well as "*closely associated* [emphasis mine] human artefacts–like crude handaxes, choppers, scrapers, light duty flakes and other pebble tools." This

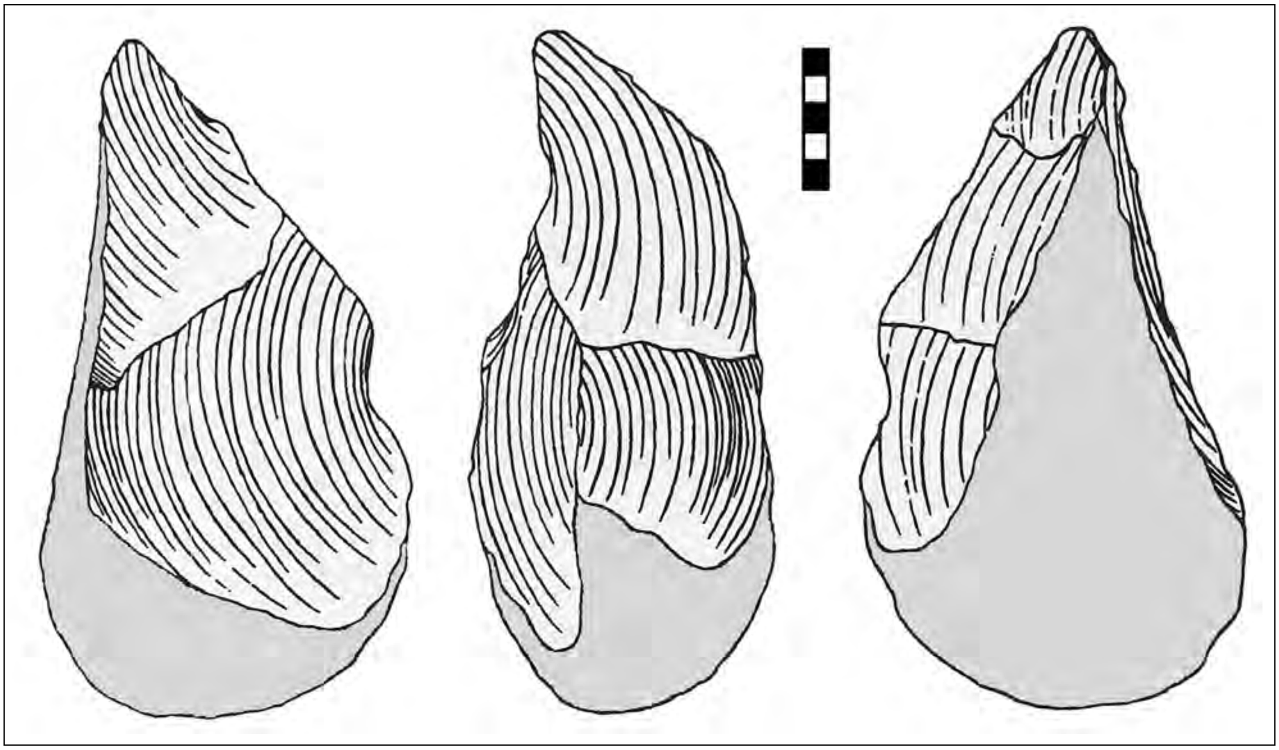

Figure 6. Pointed core/chopper from Mahadeo Pipari. (Modified after Khatri, 1963)

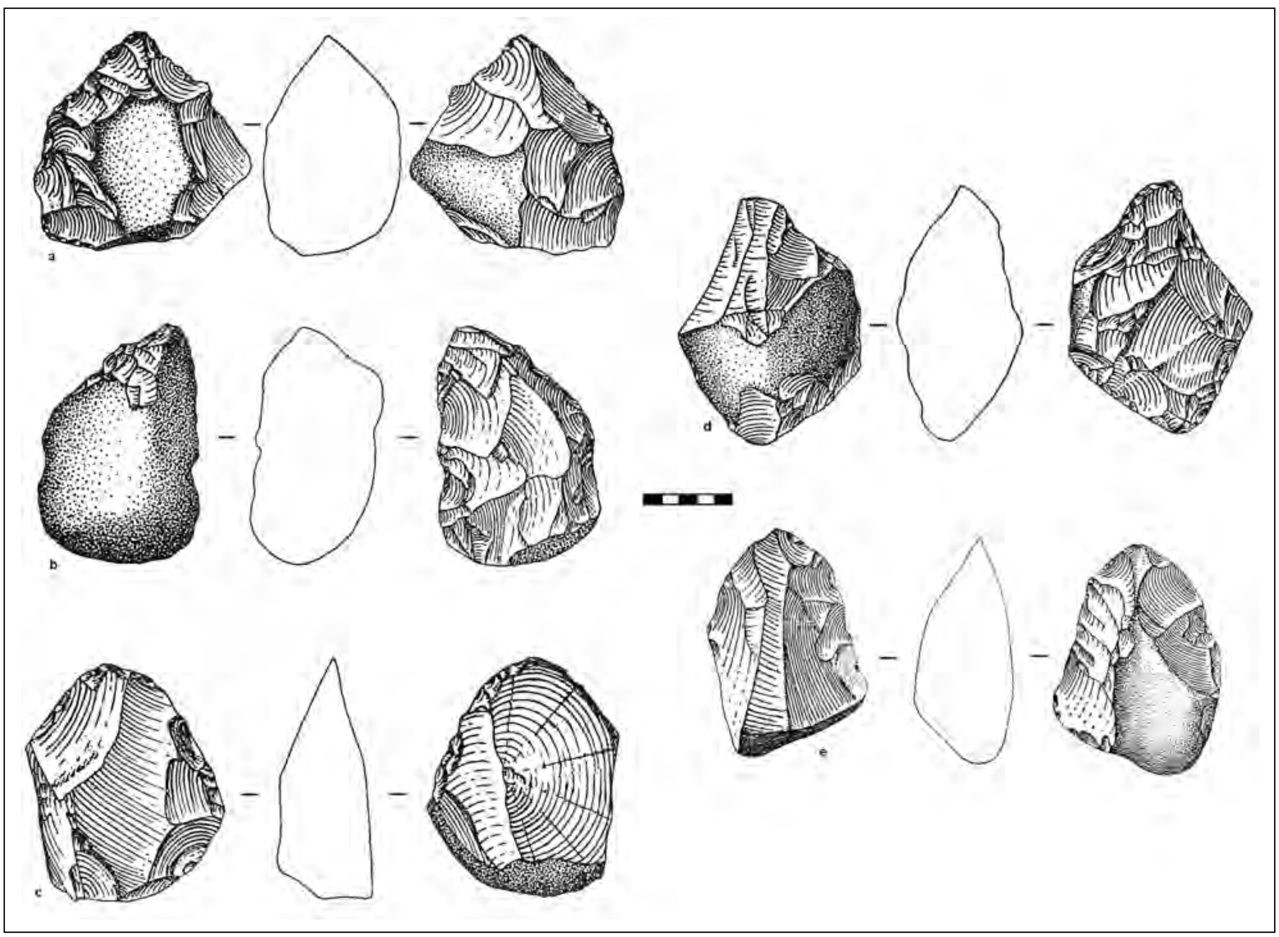

Figure 7. Some specimens from Durkadi classified as 'proto-handaxes' (a - d) and 'Abbevillian' handaxe (e) by Armand (1983).

locality, called GSI 107, is in the Kheri area and located about 30 km from the Pinjore type-section (Pinjore village). The Pinjore Formation here is thought to yield highly-fragmented but well-fossilized specimens of about a dozen different species within an area of 75 m^2. He reports about 45 fresh artifacts including ‘Abbevillian type’ handaxes, unifacial and bifacial choppers and scrapers, one discoid and several ‘rounded pebble tools’. The raw materials are pebbles and cobbles of quartzite and chert. The artifacts are described as lacking retouch and being of ‘crude typology’. Some of the artifacts were allegedly excavated *in situ* from the sandstone/conglomerate bed of the Pinjore Formation. The site also yielded about 50 unmodified quartzite pebbles (5–10 cm in diameter) in surface association with the vertebrate fossils. Twenty meters below GSI 107 and forty-five meters above, additional fossil material and ‘pebble tools’ are reported as well as a fourth occurrence 220 meters above GSI 107 and near the interface between the Pinjore Formation and the overlying Boulder Conglomerate Formation. This fourth occurrence is described as yielding several ‘crude’ specimens similar in nature to those from GSI 107, as well as two bifacial scrapers/choppers and a ‘multi-facetted’ discoid.

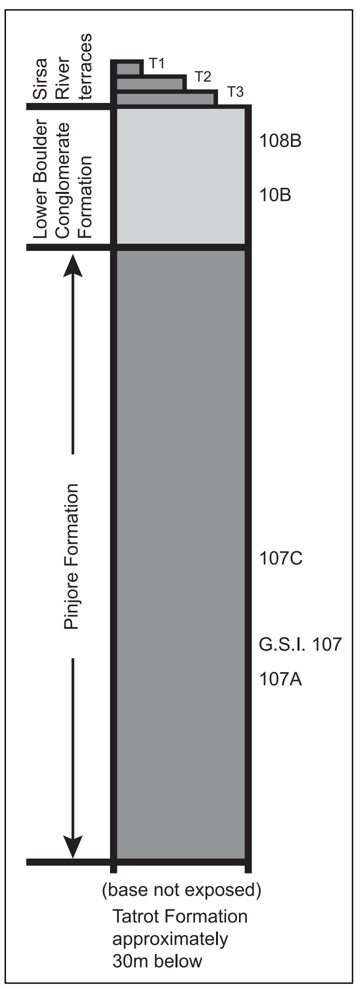

Figure 8. Schematic stratigraphic section at Kheri-Jhiran (redrawn from Verma, 1975).

The evidence is collectively interpreted to represent a “slow and gradual evolution in the culture and topology [typology?] of the artefacts through the long depositional history of Pinjors” (Verma, 1975:519). Although the Kheri-Jhiran section from which the paleoanthropological material is thought to derive is not adequately described, a schematic figure is provided by Verma showing the different occurrences of lithics and fossils within the section, all allegedly *in situ* (Figure 8). The photographs of four lithic specimens shown by Verma (1975:520) appear to be either pointed cores, core-fragments and/or pointed choppers. The flake scars are clearly visible and some of the illustrated artifacts morphologically resemble the pointed-core specimen from Riwat which may be of late Pliocene age (discussed later). However, the current descriptions in the text and associated illustrations are inadequate, thus reflecting the ambiguous nature of the Kheri-Jhiran assemblages and their stratigraphic contexts. Its current status can be viewed as being typologically undiagnostic, as most Paleolithic surface scatters in the Siwalik region are. The Kheri-Jhiran occurrences most likely represent contexts where lithic specimens (some of which may even include naturally-flaked clasts) have fallen from the Boulder Conglomerate Formation and/or from above it, suggesting their possible post-Siwalik age. Additionally, the surface association of vertebrate fossils and lithic specimens is a common occurrence in the Siwalik region (Chauhan and Gill, 2002; Chauhan, in press, b) and not a single such locality has been proven to represent evidence of butchery or hominin-modification. Nonetheless, the fact that Verma reports the material as being *in situ* and in association with vertebrate fossil material, this section and the surrounding area require further investigation.

Jainti Devi Ki Rao (Chandigarh area, northern India)

Near Chandigarh, Sharma (1977) reported a ‘habitation site’ from the Boulder Conglomerate Formation between Mullanpur and Parol on the northwestern bank of a seasonal stream called Jainti Devi ki Rao. From the geological and fossil vertebrate evidence, he assigns a Middle Pleistocene age to the material based on Upper Siwalik stratigraphy but also states that some or all of it may be Early Pleistocene. Interestingly, the investigator reports Acheulian bifaces in association with a prominent Mode 1 assemblage (‘pebble chopper/chopping-tool industry) as well as ‘large flake tools’. From two vertical sections of the Lower Boulder Conglomerate about 20 feet in vertical thickness, the investigator reports 150 artifacts including many specimens *in situ*, although the majority appear to be rolled. The assemblage includes unifacial and bifacial choppers, massive ‘borer-cum-choppers’ (possibly just pointed choppers), bifacial handaxes and cleavers and large flakes (many flakes being made by the Clactonian technique). From the facetted platforms on some specimens, a prepared-core technology or the Levallois technique also appears to be present, with increased frequency in the younger context at the site. Based on the variable technology of the lithic industries and associated states of preservation, Sharma (1977:94) invokes broader environmental changes and recognizes an associated gradual evolution (similar to Verma, 1975) of the behavioral evidence in this area from the Abbevilian to the Acheulian and beyond: “*Small flake-blade tools (along with the handaxe-cleaver and chopper industries_ appear only in the later phases-the Upper Pleistocene and post-Pleistocene-indicating an Upper Palaeolithic culture in the region that is perhaps derived from the local Lower Paleolithic cultures*.”

This scenario is presented using the Lower Paleolithic evidence from the Boulder Conglomerate Formation combined with typologically younger lithic evidence from the nearby post-Siwalik terrace deposits (i.e. younger than the Boulder Conglomerate Formation) about 10-15 feet in height. From this younger context, Sharma reports 100 artifacts including flakes, blades and abundant debitage as well as a continuation of some Lower Paleolithic types (choppers, handaxes, cleavers) but with decreased frequency, made on flakes and in fresh condition unlike those from the Boulder Conglomerate Formation. The post-Siwalik flakes are of various dimensions and morphology and their striking platforms show no signs of preparation, though secondary working and retouch appears to be prominent. The blades only occur in the post-Siwalik alluvium and are described to be technologically more refined (e.g., thin, elongated, prepared platforms but no retouch) and thought to belong to the Upper Paleolithic of Panjab. Unfortunately, Sharma does not provide any photographs of the site or figures and tables for the lithics; a detailed stratigraphic description and figure are also lacking. The large amount of rolled specimens and the mixed nature of the lithic material may preclude the site as being primary context or even a 'habitation site' as no evidence of refitting specimens is provided. Instead, the occurrence may be a result of frequent post-depositional processes such as seasonal fluvial activity from the monsoons, erosion through tectonic processes and colluvial action–all common in the Siwalik region (Chauhan and Gill, 2002). In addition, it has long been proven that the rolled vs. fresh condition of artifacts is not always a reliable indicator of the relative comparative age of the material. For example, older artifacts may have rolled less and thus be more fresh than younger artifacts from the same site that may have rolled over a longer distance or to a greater degree. Also, a linear model of lengthy technological evolution in the Siwaliks is highly unlikely. Rather, the Paleolithic record in the entire Siwalik region and the subcontinent in general is notably discontinuous (Dennell, 2003) and the variable presence of Mode 1, Acheulian and Soanian assemblages clearly suggests intermittent occupation (Chauhan, 2008a). Although there are significant deficiencies in the report by Sharma (1977), the area and particularly suitable outcrops of the Boulder Conglomerate Formation merit a survey for primary-context Paleolithic occurrences (preferably those capped by fine-grained sediments). Unlike the Pinjore Formation, the Boulder Conglomerate Formation contains a vast amount of quartzite clasts (along with the dominant sandstone clasts) for the production of stone tools which may have stimulated an increase in hominin occupation of the Siwalik frontal zone compared to Pinjore times (Chauhan, 2008a). The location of sites in such contexts may yield valuable information regarding not only raw material exploitation and transport behaviors but also pinpoint the initial timing of colonization by incoming hominin groups (i.e. earliest Acheulian of South Asia).

Toka (northern India)

In the Toka area in southern Himachal Pradesh, Verma and Srivastava (1984) reported Paleolithic artifacts eroding out from the Tatrot sediments of Pliocene age and in association with vertebrate fossils (see Gaillard and Mishra, 2001 for a similar argument elsewhere in the Siwalik Hills). Despite the lack of excavations or *in situ* occurrences, they concluded that the artifacts on the Upper Siwalik slopes (but lacking on Lower Siwalik exposures) as well as some assemblages on the nearby Markanda terraces are eroding out from the ancient Siwalik surfaces. The investigators sought support for their observations from the previous work of Verma (1975) and Sharma (1977) (both discussed earlier): "The tool types recovered from both these stratigraphic levels indicate the pre-existence of the culture and suggest the possibility that the artefacts occurring in the Siwalik outcrops in the Markanda Valley have their provenance in the Tatrot Formations" (Verma and Srivastava, 1984:17). In conclusion, they state: "The occurrences indirectly suggest that the toolmaker lived in this region during the Upper Pliocene times, contrary to the earlier belief that the stone tools are confined to the terrace deposits only and the early man appeared in the Siwalik region during the Middle Pleistocene" (Verma and Srivastava, 1984:19).

As a part of my doctoral research, basic geological attributes were examined at Toka to hypothesize about site formation processes and reassess its stratigraphic context, partly in light of these claims. The resulting observations (Chauhan and Gill, 2002) refuted Verma and Srivastava's claims through several types of evidence: 1) the concerned artifacts are Soanian (i.e. a combination of Modes 1 and 3) rather than being pre-Acheulian, 2) they derive from post-Siwalik Upper Pleistocene contexts capping the Tatrot sediments, 3) the post-Siwalik artifacts happened to be deflated on the underlying Tatrot sediments instead of eroding out of them, and 4) artifacts and vertebrate fossils are also mixed and thus not contemporaneous with each other. This was all confirmed through two test-trenches on a post-Siwalik terrace as well as a pre-existing water pipeline trench across a part of Toka through exposures of the Tatrot Formation (Chauhan, 2008a). Where artifacts were found within Tatrot sediments or seemingly eroding out of them, they actually represented results of re-burial and/or re-exposure through colluvial action, monsoon-related surface runoff, or downslope displacement (Mohapatra and Singh, 1979; Chauhan and Gill, 2002).

In contrast, the contextual integrity of the artifacts appears to be associated with the post-Siwalik sedimentary layers *above* the Tatrot beds, implying a considerably younger age as Verma and Srivastava (1984:17) originally considered, but then negated, from observations at 75 localities (of only 5 to 15 artifacts at each location): "Close association of stone artefacts and vertebrate fossils throughout the area under examination poses an intriguing problem as whether to accept them to be of a common stratigraphic level or taking one (fossils) as Pliocene in age and the artefacts of a later period, and accidental. This however, seems highly improbable." From general observations by the author, this "close" but misleading association of stone artifacts and vertebrate fossils appears to be a result of winnowing and deflation from erosion and seasonal fluvial processes on the underlying Tatrot sediments (the source of the fossils) and post-Siwalik sediments (the source of the artifacts) in addition to the lack of post-Siwalik sedimentation (i.e., the lack of artifact burial) at different places on the site. Ultimately, it is presumed that the archaeological material is not older than the associated post-Siwalik raw material source (i.e. Tirlokpur Nadi) since the Tatrot Formation exposures here and elsewhere do not contain any quartzite clasts (Gill, 1983).

Uttarbaini (northern India)

A claim of an Early Pleistocene lithic occurrence has also been made from the Jammu-and-Kashmir region of northern India. Here, Verma (1991) reports artifacts *in situ* from below a tuffaceous layer which was initially dated to 1.6±0.2 Ma and then re-dated to 2.8±0.5 by Ranga Rao et al., (1988) using the fission-track method. However, this claim has not been verified through further detailed investigations including excavations and the application of other geochronological techniques. Not only does the ash require re-dating, but the context of the artifacts and their archaeological integrity for that matter, also need to be confirmed. For example, no photographs of the section, the stratified ash or the artifacts are provided, and a description of the assemblage composition is also lacking. Nonetheless, this alleged occurrence warrants a systematic survey of the area in light of the ash deposits whose inconsistent age may be more accurately constrained using the well-established Upper Siwalik biochronology (Nanda, 2002; Dennell, 2004) in addition to re-dating.

Riwat and the Pabbi Hills Assemblages (northern Pakistan)

The best-studied but also the most controversial pre-Acheulian lithic evidence in South Asia is currently known from the Siwalik Hills of northern Pakistan and includes the ca. 2.0 Ma site at Riwat (Rendell et al., 1989) and the 2.2–0.9 Ma old Mode 1 assemblages from the nearby Pabbi Hills (Hurcombe, 2004). The work was carried out by the British Archaeological Mission to Pakistan (BAMP) which lasted almost two decades and also yielded the oldest securely-dated Acheulian in the subcontinent at Dina and Jalalpur (Rendell and Dennell, 1985) and a unique post-Siwalik Paleolithic site (Rendell et al., 1989). The lithics at Riwat were first noticed in 1983 and then studied during subsequent visits over a decade. The site is a part of the Soan Syncline, a landscape-level geological feature that dips at an angle of about 10-15^{o} on its southern edge (Rendell et al., 1989). Previous paleomagnetic applications (Burbank and Johnson, 1982) had suggested that the Syncline formed in the late Pliocene or between 1.9 and 2.1 Ma. Additionally, a volcanic tuff from the overlying horizontally-bedded fluvial sediments subsequently indicated an age of 1.6±0.2 Ma through K/Ar. According to Dennell (2007), scientists have never questioned the age or the dating of the Soan Syncline stratigraphic sequence, which implies that the tilted artifact-bearing horizon was established prior to the folding and is considerably older than the overlying ca. 1.6 Ma old horizontal strata. Later work by Rendell et al. (1987, 1989) sought to confirm the late Pliocene age of the concerned strata and also demonstrated that the artifact-bearing horizon was a prominent stratum of the Soan Syncline rather than being channel fill of a younger age. Through the collection of 280 samples from 71 sampling locations (with mean spacing of 1.7 meters), they confirmed the magnetic polarity to belong to the Matuyama Chron (see Dennell, 2007). The stratigraphic context of the Riwat assemblage is the lower gritstone/conglomerate horizon (LGC) in the syncline.[1]

Riwat

To distinguish between naturally-flaked clasts–a common feature in conglomeratic deposits–and genuine artifacts, the investigators developed a methodology based on experimentation and ranked the various artifacts based on length, breadth, thickness, flake features, number of directions of flake removal, percentage of remaining cortex, positive/negative scars, evidence of retouch, edge roundedness and post-depositional damage (Rendell et al., 1989). Ultimately, 23 flaked quartzite specimens were initially collected and ranked (see Table 7.2 in Rendell et al., 1989: 110) after observing over 1000 cobbles within the LGC, but only three specimens have been promoted as being the most convincing artifacts and thus have received the most attention (Figure 9). Specimen R001 was first observed in 1983 to be imbedded in a gritstone/comglomerate horizon near the base of an erosional gully. This large core has eight or nine flake scars in three different directions and the size of the flake scars are thought to be comparable to Oldowan evidence from Bed I of Olduvai Gorge (Dennell, 2007). It is worth noting however, that the overall dimensions and morphology of the actual core is rather large and pointed, respectively, unlike typical Oldowan cores which are generally smaller and amorphous. Except for the cortical butt, the remainder of the specimen exhibits flaking on its two faces, also not common in the Oldowan in general. Specimen R014 was extracted from a gritstone block that had fallen from the same horizon nearby and is represented by a large flake struck from a

1 An upper gritstone is 100–200 ka and the overlying loess yielded a TL date of 74.3 8.3 ka. A hemispherical disc core and a rolled handaxe were collected from this upper gritstone horizon.

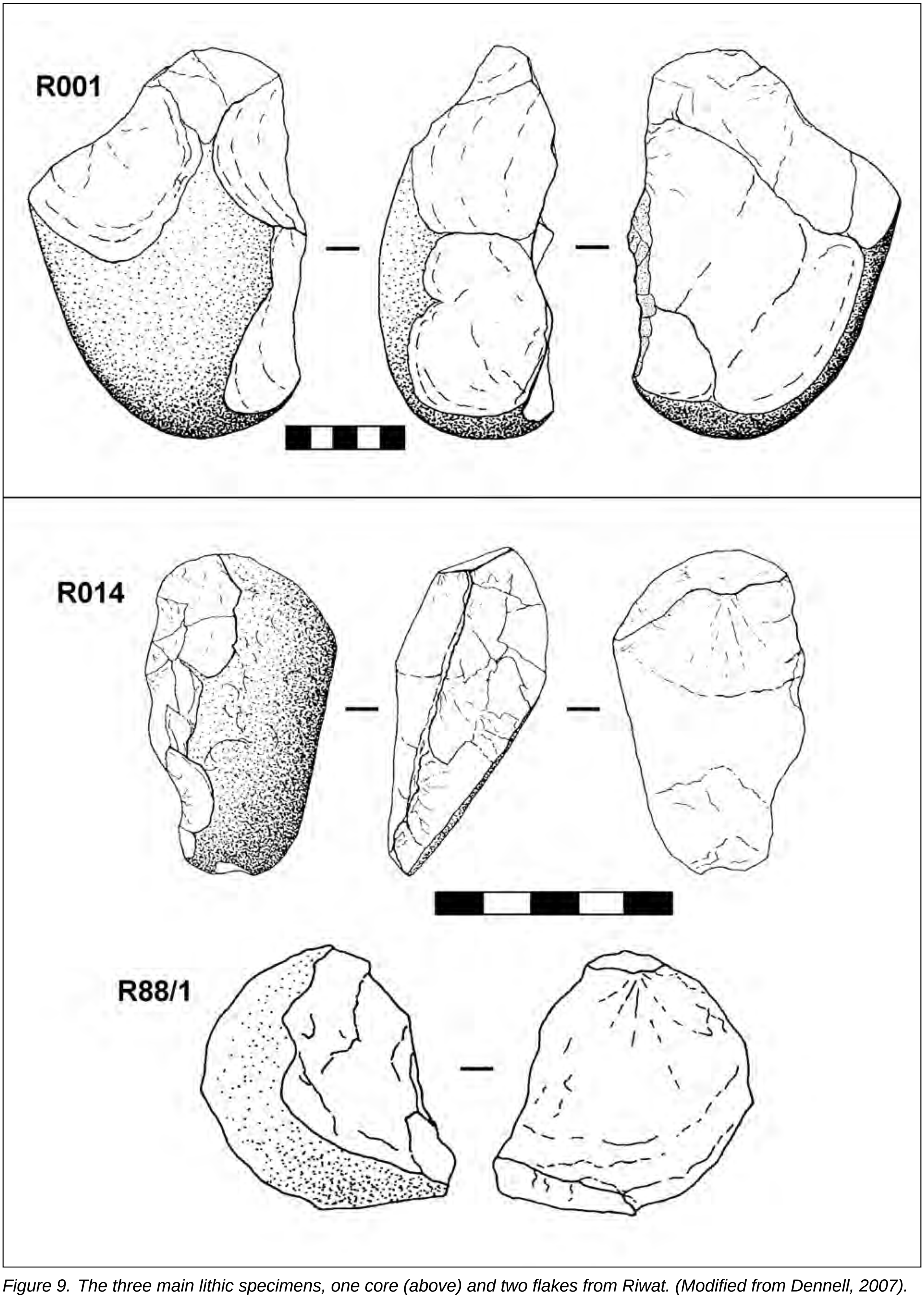

Figure 9. The three main lithic specimens, one core (above) and two flakes from Riwat. (Modified from Dennell, 2007).

Table 3. The Pabbi Hills assemblage composition (modified from Hurcombe, 2004).

Artifact type	Quantity	%	Retouched	Quartzite	Flint	other rock pieces
proto-biface	1	0.3		1		
straight edged core tool	5	0.8	3	5		
flake blade core	6	1.0		6		
high action core tool (HACT)	14	2.3		14		
microcore	6	1.0			6	
squared core	10	1.6		10		
bipolar core	4	0.7		4		
shattered wedge core fragment	51	8.4		50		1
irregular core	30	4.9		30		
split cobble	16	2.6		16		
unifacial core	16	2.6		6		
bidirectional/bifacial core	48	7.9		48		
simple disc core (discoid)	23	3.8		22		1
complex disc core (discoid)	14	2.3		14		
polyhedron	3	0.5		3		
TOTAL CORES/CORE-TOOLS	**247**	**40.7**	**3**	**239**	**6**	**2**
shatter-split flake	2	0.3		2		
angular flake	11	1.8		11		
irregular flake	110	18.1	1	105	1	4
(decortication flakes)	(21)					
split flake	64	10.5		60	3	1
(decortication flakes)	(4)					
double bulb flake	5	0.8		5		
rounded simple flake	76	12.5	1	75	1	
(decortication flakes)	**(39)**					
rounded complex flake	13	2.1		12		1
straight-edged flake	37	6.1	3	37		
flake blade	14	2.3	2	14		
scraper	6	1.0	6	5	1	
HACT flake	6	1.0		6		
knife	1	0.2	1	1		
TOTAL FLAKES/FLAKE TOOLS	**345**	**56.8**	**14**	**333**	**6**	**6**
TOTAL CHIPPED STONE	**592**	**97.5**	**17**	**572**	**12**	**8**
ring stone	2	0.3		1		1
rubbing stone	1	0.2		1		
rubbing stone flake	2	0.3				2
polished stone fragment	6	1.0		2		4
TOTAL GROUND/POLISHED	**11**	**1.8**	**0**	**4**	**0**	**7**
hammerstone flake	1	0.2		1		
hammerstone	3	0.5		3		
TOTAL HAMMERSTONES	**4**	**0.7**	**0**	**4**	**0**	**0**
TOTAL SPECIMENS	**607**		**17**	**580**	**12**	**15**
% in assemblage			2.8	95.6	2.0	2.5

cobble. It possesses a prominent bulb of percussion as well as ripple marks and eight flake scars from three different directions. The third specimen, R88/1, is a fresh Type-5 flake (Toth, 1985) with a prominent bulb of percussion and with evidence of additional flaking from three directions and has positive and negative flake scars on each respective side. It was recovered from a freshly-eroding vertical section and 50 m from Specimen R001. Two additional specimens (R88/5 and R88/6) were originally counted as artifacts but were later discounted because they were thought to derive from post-Siwalik colluvial fill in the area. Overall, 1,264 clasts were plotted and studied in the LGC, however no additional artifacts were recovered. Therefore, in addition to the ca 2.0 ma age requiring substantiation, the Riwat sample is meager and comes from a gravel horizon (i.e. secondary context) and thus, offers little behavioral information. On the other hand, the Pabbi Hills evidence offers paleoanthropologists greater behavioral and technological information, in spite of its surface context.

Pabbi Hills assemblages

In comparison to the Riwat evidence, the Pabbi Hills assemblages (Hurcombe and Dennell, 1993) are considerably richer and have often been overshadowed by the former. Following the work at Riwat, the main research objectives of BAMP in the Pabbi Hills was to pinpoint the context of the artifacts, confirm the Early Pleistocene age of much of the material, and distinguish between artifacts and naturally-fractured stone in the region. Only one find spot is reported and the rest of the specimens are surface occurrences distributed across the Siwalik landscape. The find spot is that of a stone tool on the surface of an escarpment of Sandstone 14. It fit in an *in situ* socket located in a secondary channel context above from the location it was recovered. A total of 607 specimens were interpreted to hominin-produced (Table 3; Figures 10 & 11) but their density of occurrence was observed to be very low: out of 211 locations where flaked-stone was recovered, isolated pieces occurred in 45% of the cases and no more than 3 specimens were found in 78% of the instances (Dennell, 2007).

The fluvial channel that deposited the sediments in the region was a part of a large floodplain environment and helped in establishing the depositional history of the area as well as possibly explained the absence of certain types of artifacts. Some of the possible debitage specimens collected weighed as little as 1 gm. The investigators (see Dennell, 2004) have also attempted to chronologically divide the entire assemblage based on the specimens' surface association with the underlying sediments and associated biochronology and stratigraphic correlation. For example, 102 specimens were distributed on sediments dated to 0.9–1.2 Ma; 307 specimens were collected from the surface of Sandstone 12, interpreted to be between 1.2 and 1.4 Ma; and 198 specimens were collected from a surface interpreted to be between 2.2 and 1.7 Ma. Approximately 41% are cores and 58% are flakes and the majority of specimens (96%) were produced on quartzite with 2.8% of all specimens showing deliberate retouch (Hurcombe, 2004). Six micro-cores, four hammerstones and six fragments of polished stone axes were made on flint and are thought to possibly belong to the Neolithic or a later phase.

Thought to be typologically comparable to most typically-African Oldowan assemblages, the investigators (see Dennell, 2004, 2007) maintain their interpretations and defend the contextual and behavioral integrities of the Pabbi Hills evidence using the following lines of argument: a) except for the Neolithic-like specimens, there is a virtual lack in the region of artifacts from younger time periods such as the Acheulian and Middle or Upper Paleolithic, b) the archaeological evidence cannot be road or rail ballast because the latter is generally smashed, not flaked and the artifacts were found at higher elevations and several kilometers from the nearest road/railway, c) there is no evidence of lithic or fossil material eroding/deflating from younger contexts and d) it is unlikely (from the currently-observable erosional processes) that such old artifacts and fossils could have remained on the surface of these formations throughout the Middle and Upper Pleistocene; thus they have eroded out in recent decades from the underlying sediments. Similarly, Dennell (2007) also attributes the lack of fossil hominin material in the otherwise rich vertebrate fossil evidence from northern Pakistan to such possible factors as: i) taphonomic bias towards the preservation of larger mammals (Dennell, in press), ii) seasonal flash floods, iii) water-borne infections and illnesses, and iv) episodic major flood events every two to three decades–hypothesized from modern analogs and thus having implications on raw material availability and procurement.

Claims of Pre-Middle Pleistocene Hominin Fossils

The majority of human fossil material in the subcontinent comprises Late Pleistocene and Holocene specimens of *H. sapiens* from various parts of India and Sri Lanka (Kennedy 1999; 2001). The *Homo* calvarium from Hathnora in the central Narmada Valley in central India is thought to be of at least late Middle Pleistocene age and currently represents the oldest hominin fossil evidence in the Indian subcontinent (Sonakia and Biswas, 1998). Two other finds alleged to be older have generally been ignored in published reviews, probably because of their doubtful status as hominin fossils. For the sake of being comprehensive and unbiased, they are formally included as a part of this critique of the earliest claimed South Asian evidence. The two finds are of Early Pleistocene and late Pliocene age respectively and both come from Nadah and Khetpurali in the Siwalik region near Chandigarh in northern India.

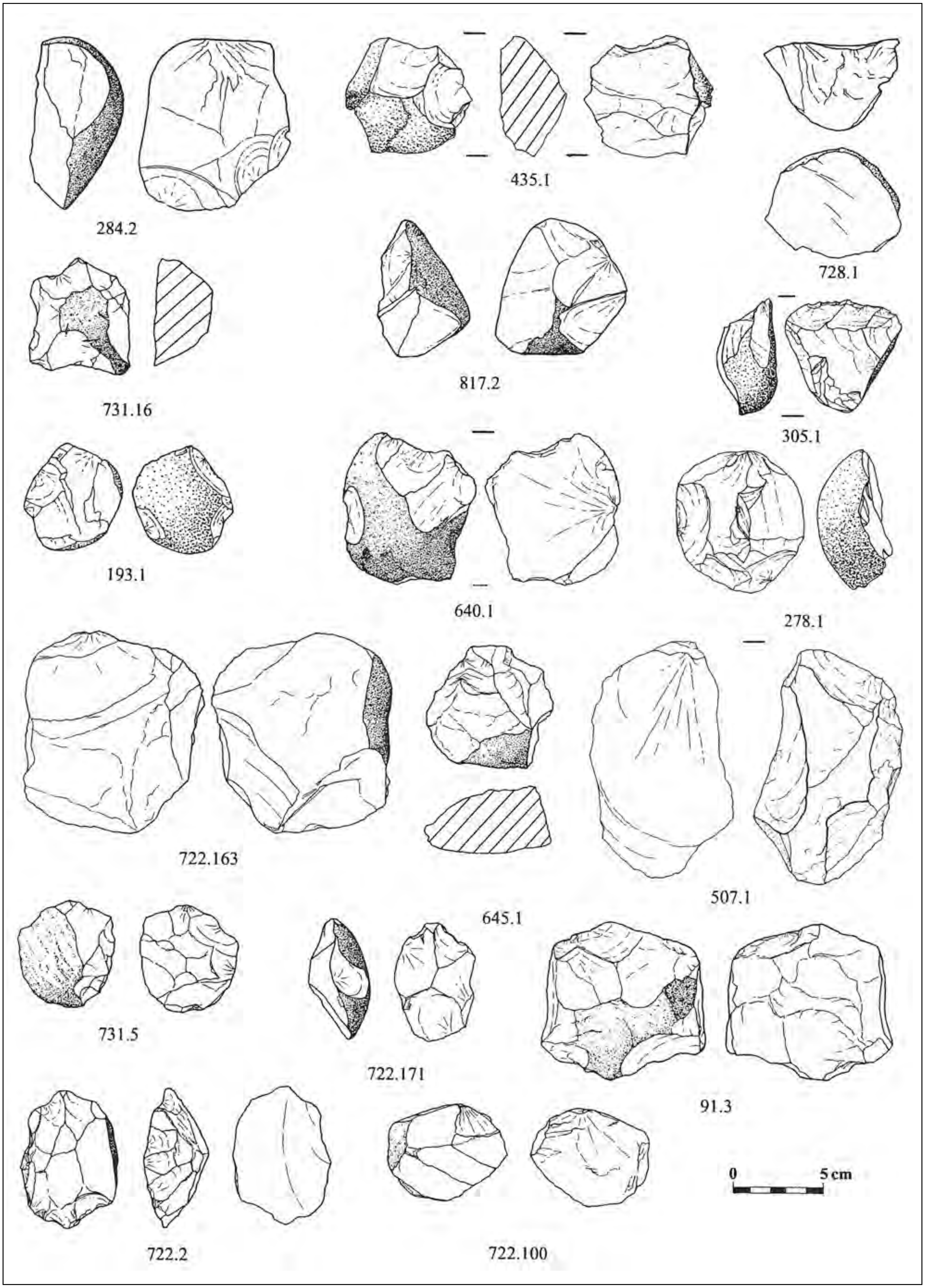

Figure 10. Select core specimens from the Pabbi Hills (Source: Hurcombe, 2004)

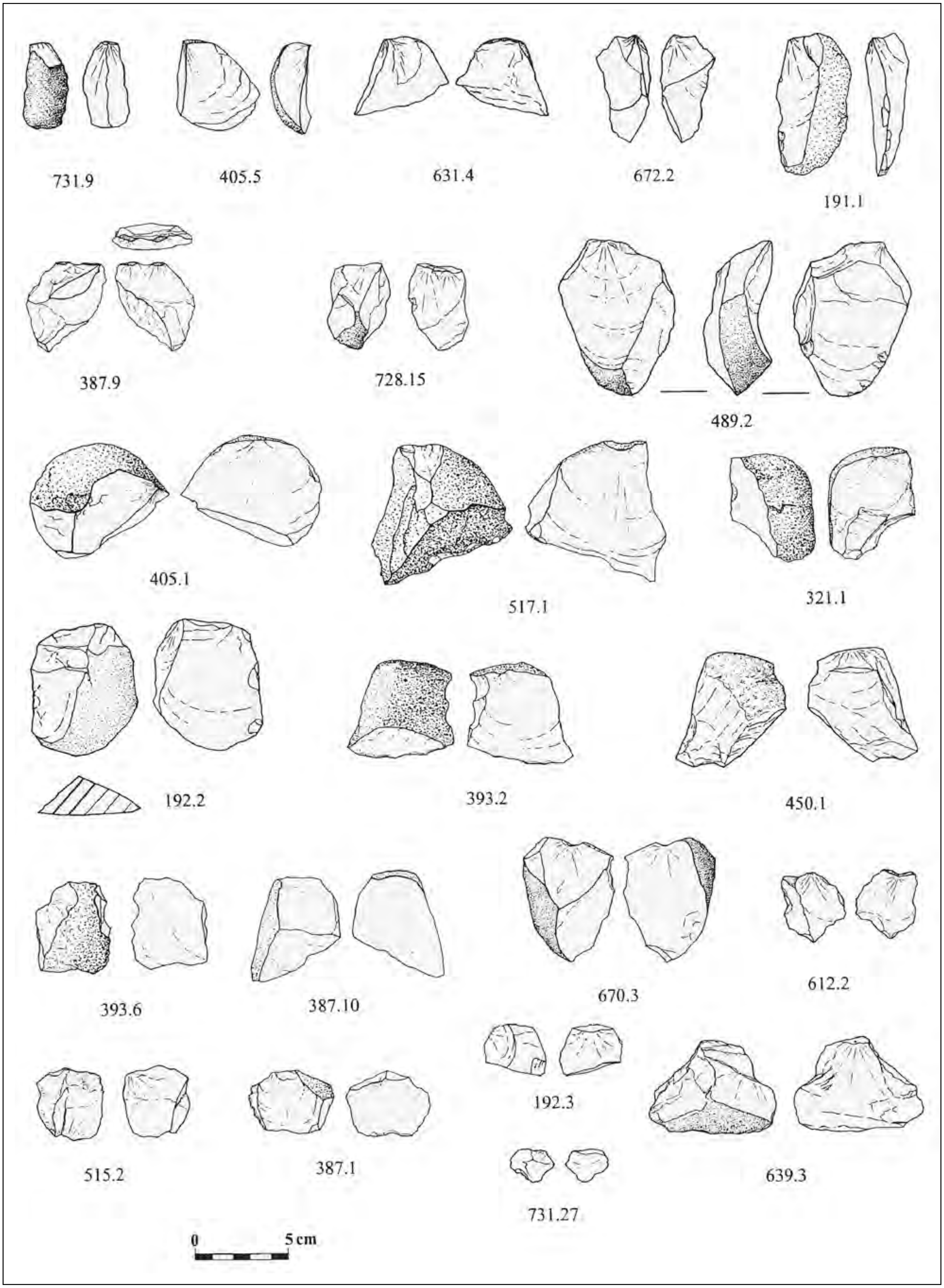

Figure 11. Select flake specimens from the Pabbi Hills (Source: Hurcombe, 2004)

Nadah

The hominin specimen from Nadah is represented by a left maxillary central incisor recovered from the Pinjore Formation and attributed to *Homo erectus* (Singh et al., 1988). Although the lead author mentions the discovery by him of 'at least' three teeth thought to belong to three different individuals, the primary focus in their paper is on the one incisor. The specimen was discovered in 1985 from a buff-colored mudstone stratum 200 m from the base of the section and the basal portion of the Pinjore Formation and 0.5 km south of Nadah village. The other two incisors were recovered from 100 m away from the main specimen. The stratigraphic sequence here is approximately 275 m in total vertical length and consists of gray and greenish sandstones inter-bedded with brown and purple siltstone as well as cemented conglomerate and hard sandstone. Based on associated biostratigraphy and comparative stratigraphy of the Tatrot-Pinjore contact, the specimen is estimated to be 2.0 to 2.2 Ma old. Singh and colleagues describe the tooth in great morphological detail and attempt to systematically prove the hominin classification of the specimen. They list several key features to invalidate it as a Siwalik hominoid but do not systematically compare the specimen with other mammalian species. Features thought to be characteristic to hominids are highlighted by the authors as: i) a distinct occlusal abrasion pattern; ii) arched occlusal contour; iii) axial curvature of the longitudinal axis of the root and crown; iv) Pattern-3 prism of enamel structure; and v) mesiodistal and labiolingual metric data falling in the then-known range of other hominid dental evidence (see Table I in Singh et al., 1988: 570). Given the often ambiguous morphological overlap between certain hominin teeth and other mammalian species, the purported incisor(s) from Nadah remains circumstantial; it cannot be accepted as hominin until more diagnostic fossil specimens are recovered. At the very least, this specimen may represent a primate incisor if not hominin (A. Sahni: pers. comm.).

Khetpurali and Masol

Most recently, Singh (2003) has also reported hominid mandibular and post-cranial fragments in association with stone tools from the Tatrot Formation near Khetpurali Village. From available paleomagnetic dating results on the known Upper Siwalik Formations, he proposed an age of ca. 3.4 Ma for the evidence. All fossil and lithic specimens are reported to have eroded out from a brown siltstone bed approximately 10 meters from the base of the Tatrot Formation which is thought to be 220 meters thick here. An additional 50 vertebrate taxa were also recovered at and around this locality. The mandibular fragment comprises a lower right first molar (M1) and the alveoli of the 3rd and 4th premolars and Singh highlights several features including i) the low position of the mental foramen below the mesial root of M1; ii) pattern of worn enamel and dentine; and iii) the transversely thick horizontal rami as well as other related details such as a facet on the cusp and the width of the root. M1 is thought to be metrically double the size of that tooth in *Homo sapiens*. Later work allegedly yielded more hominid fossils including a similar mandibular ramus with the P3, P4, M1 and alveoli of the canine present, a proximal-end of a left femur, the distal-end of a left femur and a right patella (from a brown clay at the basal portion of the Tatrot section near Masol village).

Unfortunately, not only are the descriptions parochial, but the fossil specimens are presumably classifiable as various large vertebrates rather than hominin. The associated lithic illustrations are also of poor quality and lack a photographic scale. There are also no comparative tables or related data (i.e. geochronology, sedimentation, metric data for the fossils and lithics and so forth) that are normally found in the current literature regarding paleoanthropological finds of such significance. Lower Paleolithic artifacts of a Mode 1 nature (including quartzite and ivory) are mentioned but the investigator does not provide any qualitative or quantitative details of the material except that they are made from quartzite pebbles and comprise unifacial and bifacial choppers. In that respect, they can easily be (and probably are) significantly younger Soanian assemblages that derived from younger contexts nearby. Overall, these localities reported by Singh (2003) do not appear to merit further scientific attention except for their geological and vertebrate paleontological aspects.

Discussion and Conclusion

The foregoing review and critique of the South Asian pre-Acheulian palaeoanthropological evidence has included claims of both lithic and hominid-fossil occurrences from northern Pakistan and two separate regions of India, respectively. There are numerous other core-and-flake lithic assemblages in peninsular India, but because they remain undated and were reviewed elsewhere (Chauhan, in press, a), they have not been discussed in detail in this paper. These assemblages are known from the Konkan coast, Karnataka, Uttar Pradesh, Bihar and West Bengal, Orissa, Andhra Pradesh and northeastern India (Jayaswal, 1982). They comprise varieties of cores, discoids, choppers, core-scrapers, flakes, scrapers, notches, polyhedrons, sub-spheroids, unifaces, occasional *atypical* bifaces and debitage. Most are made from pebbles and cobbles and are associated with gravel deposits, suggesting that such clasts and associated tools were not transported over long distances.

Most of those assemblages are small and come from surface or secondary contexts and remain typological un-diagnostic. From general observations regarding their geological contexts, reduction strategies, comparative stratigraphy and overall assemblage compositions, most of the core-and-flake assemblages in peninsular India appear to be younger than the early Middle Pleistocene, with some possible Mode 1 exceptions in the Narmada

Valley that may be older than the Brunhes-Matuyama boundary such as Dhansi and Durkadi (Chauhan, in press, a) and other localities in Maharasthra. Some Early Acheulian assemblages in western and southern India may also be of comparable age (e.g., Mishra, 1995; Paddayya et al., 2002; Deo et al., 2007), but these occurrences also require further corroboration.

Despite the still controversial nature of the Riwat and Pabbi Hills lithic evidence, it remains the best-studied among all the claims discussed in this paper. The Pabbi Hills material is morphologically and dimensionally more similar to classic Oldowan assemblages than is the Riwat evidence. However, because the Riwat assemblage is meager and comes from a gravel context, and the Pabbi Hills evidence comes from surface contexts, both remain circumstantial and require corroboration through excavated sites in fine-grained primary contexts. Indeed, Dennell (2007:41) himself states: "However, apart from a small amount of material *that remains controversial* [emphasis mine] from Riwat (Dennell et al., 1988) and the Pabbi Hills, Pakistan (Dennell, 2004; Hurcombe, 2004), there is no incontrovertible evidence that hominins were living in the northern part of the Indian subcontinent in the Early Pleistocene, even though it is the obvious corridor route between Southwest and Southeast Asia." The evidence for possible early occupation at Riwat and/or Pabbi Hills does not necessarily suggest the presence of comparable evidence in peninsular India (see Dennell, 2003).

The current absence of such assemblages in peninsular India may be attributable to a suite of factors: i) Plio-Pleistocene sediments are not well preserved/exposed in the region and/or ii) behavioral evidence is deeply buried under alluvium such as the Indo-Gangetic plains (Misra, 2001), and iii) Early Pleistocene evidence (if any exists) has been misinterpreted as being younger because it remains un-dated or because it not expected in the archaeological record. The most parsimonious or plausible explanations is that hominins were not present in peninsular India and possibly the entire Indian subcontinent. Regarding the Pabbi Hills evidence, Dennell (2007: 60) states: "*As none of this material was found in situ, the case for dating it to the Early Pleistocene remains circumstantial. Nevertheless this type of field survey data forms an important part of the archaeological literature, and those readers who might reject this evidence on the grounds that it was found on the surface might reflect how much other data collected by field surveys elsewhere should also be rejected*." However, it cannot be overstated that the most reliable chronological frameworks for early hominin occupation throughout the Old World have primarily come from well-excavated sites in fine-grained stratified contexts that were directly dated on an absolute scale.

The other pre-Acheulian occurrences in the Siwalik Hills (e.g., Uttarbaini) and Narmada Valley (e.g., Durkadi, Dhansi) of northern and central India respectively, require re-investigations of their stratigraphic contexts and the precise age of the behavioral evidence. The sites of Kheri-Jhiran and Mahadeo Piparia appear to respectively represent a mixture of various lithic industries–Mode 1, Acheulian and younger assemblages. However, they still merit a proper investigation, particularly absolute dating of the associated deposits, to confirm or eliminate the possibility of pre-Acheulian occupation at these locations. The claims of hominid fossils and stone tools from late Pliocene and late Miocene contexts at Nadah and Khetpurali (Singh et al., 1988; Singh, 2003) respectively, cannot be accepted as valid finds, most of which still require substantiation.

Based on the current paleoanthropological evidence in the Indian subcontinent and other surrounding regions (e.g., central Asia, SE Asia), a shorter chronology for the earliest hominin occupation in Asia is better supported than the currently-claimed longer chronologies in these respective regions. For example, this general review has demonstrated that there is currently no convincing evidence of hominin occupation prior to the Middle Pleistocene in the Indian subcontinent. This is broadly and tentatively supported by the lack of late Pliocene/Early Pleistocene stone tools in SE Asia (Corvinus, 2004) and the need for better chronological and contextual control, including re-dating at key site localities such as the Nihewan Basin (e.g., Zhu et al., 2004) and the reportedly-earliest hominid fossil localities in SE Asia (Swisher et al., 1994). In other words, our knowledge of the earliest timing of hominin colonization of Asia remains unclear and requires clarification at various levels. For instance, Dennell (2007) marshals such evidence as the lack of suitable raw material in the Indo-Gangetic foredeep of South Asia (Misra, 1989; 2001), the seasonal availability of raw material, and a high number of carnivores (as a major predation risk to hominins) to explain and interpret the seemingly marginal occupation of early hominin groups in this region.

In other words, late Pliocene/Early Pleistocene smaller-brained hominins may have been represented by only small populations that did not venture frequently into areas containing limited lithic resources due to a smaller home-range size and short-distance transport (of raw materials) behavior. They may have adapted through multiple options: i) utilizing small clasts, ii) curation of raw materials and finished tools, iii) caching, iv) replacing stone with other material and v) avoidance of 'stone-poor' areas (Dennell, 2007: 49). On the other hand, early Middle Pleistocene larger-brained hominins groups may have better coped with such ecological challenges and thus been able to colonize this zone as well as pass through the Indo-Gangetic plains into peninsular India. If these inferences turn out to be accurate, they may partly explain the virtual dearth of Early Pleistocene Oldowan and Acheulian occupation in the Pinjore Formation of the Siwalik Hills as well as in contemporaneous contexts of peninsular India and, possibly other parts of Asia.

Obviously, much more research is required to test and confirm such hypotheses. However, until we have absolute dates from excavations in primary fine-grained contexts, we cannot reject the possibility of a shorter chronology of hominin occupation for South Asia. Based on the most unequivocal information available, the earliest occupation of the Indian subcontinent appears to be by Early Acheulian hominins at the Brunhes-Matuyama polarity transition or slightly earlier.

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CHAPTER 4

Archaic Stone Industries from East Africa and Southern Europe Pre-Oldowan and Oldowan

Henry de Lumley, Deborah Barsky and Dominique Cauche

Over recent years, many discoveries have renewed our knowledge about the oldest stone industries and also about the behaviour and lifestyle of the hominids that made them, not only in East Africa, but also in the Near East, in Trans Caucasia and in southern Europe.

If the first tool-making hominids appear in East Africa as early as 2.55 million years ago, they are present in the Levant a little over 2 million years ago, as early as 1.81 million years ago at the gates of Europe in Trans-Caucasia, and a little over 1.4 million years ago on the Mediterranean coasts of Europe (Figures 19 and 21).

Pre-Oldowan or Archaic Oldowan

The Gona and Ounda Gona sites in Ethiopia, dated to a little over 2.5 million years old, have yielded lithics characterized largely by knapping products (Figure 1): flakes and angular fragments (de Lumley, 2006; Semaw, 2000 and 2005; Semaw et al., 1997 and 2003). Manufactured pebbles are rare. Bipolar knapping on an anvil was often practiced while hand-held knapping methods employed were sometimes unifacial, bifacial or even multifacial. Core exploitation was relatively intense, with numerous, generally small sized flakes removed from each piece. The assemblage does not include standardized small retouched tools shaped by secondary retouch modifying the edge of a flake or angular fragment.

The Lokalalei 1 and 2C sites in Kenya, in the Nachukui Formation dated to 2.340 million years old, discovered and studied by Hélène Roche and Pierre-Jean Texier, offer an industry similar to that from the Gona sites (Roche et al., 1999; Delagnes et al., 2005). The assemblages comprise mainly non-retouched flakes, angular fragments and cores (Figure 2).

Refits of flakes onto cores allowed define a systematic reduction sequence resulting in the production of numerous, generally small-sized flakes. For some cores as many as fifty pieces were refitted. As is the case for the Gona region sites, the Lokalalei assemblages do not comprise any standardized, small retouched tools on flakes or debris, with the possible exception of a few pieces.

The archaic stone tools from the Omo Valley, such as those from Omo 71 and Omo 84, dated to around 2,4 million years old, as well as those from Omo 57 and Omo 123, dated to around 2.34 million years old, discovered and studied by Jean Chevaillon, yielded very numerous small quartz flakes, with an average size of 2 to 3 cm, most often showing reduced or null striking platforms and flat inner surfaces, bearing witness to the frequent use of bipolar knapping on an anvil. However, pebble tools and percussion instruments are rare or absent. There are no small retouched tools. Yet flake edges often show irregular use retouch and chips attesting to their use.

Locally available raw materials, mainly quartz and some basalt, were used in the fabrication of the stone tool assemblage from the Fejej FJ-1 site in the southern Omo area of Ethiopia, around five kilometres from the Kenyan border (Barsky et al., 2006; de Lumley et al., 2004a and 2004b; Chapon, 2007). Pebbles used were collected from the environment immediately surrounding the site; a few hundred meters at the most. Both bipolar knapping on an anvil and hand held techniques were used during knapping reduction sequences which were mainly unifacial, sometimes bifacial and rarely multifacial.

The assemblage is mainly composed of small-sized flakes and angular fragments (Figure 3). Pebble tools are

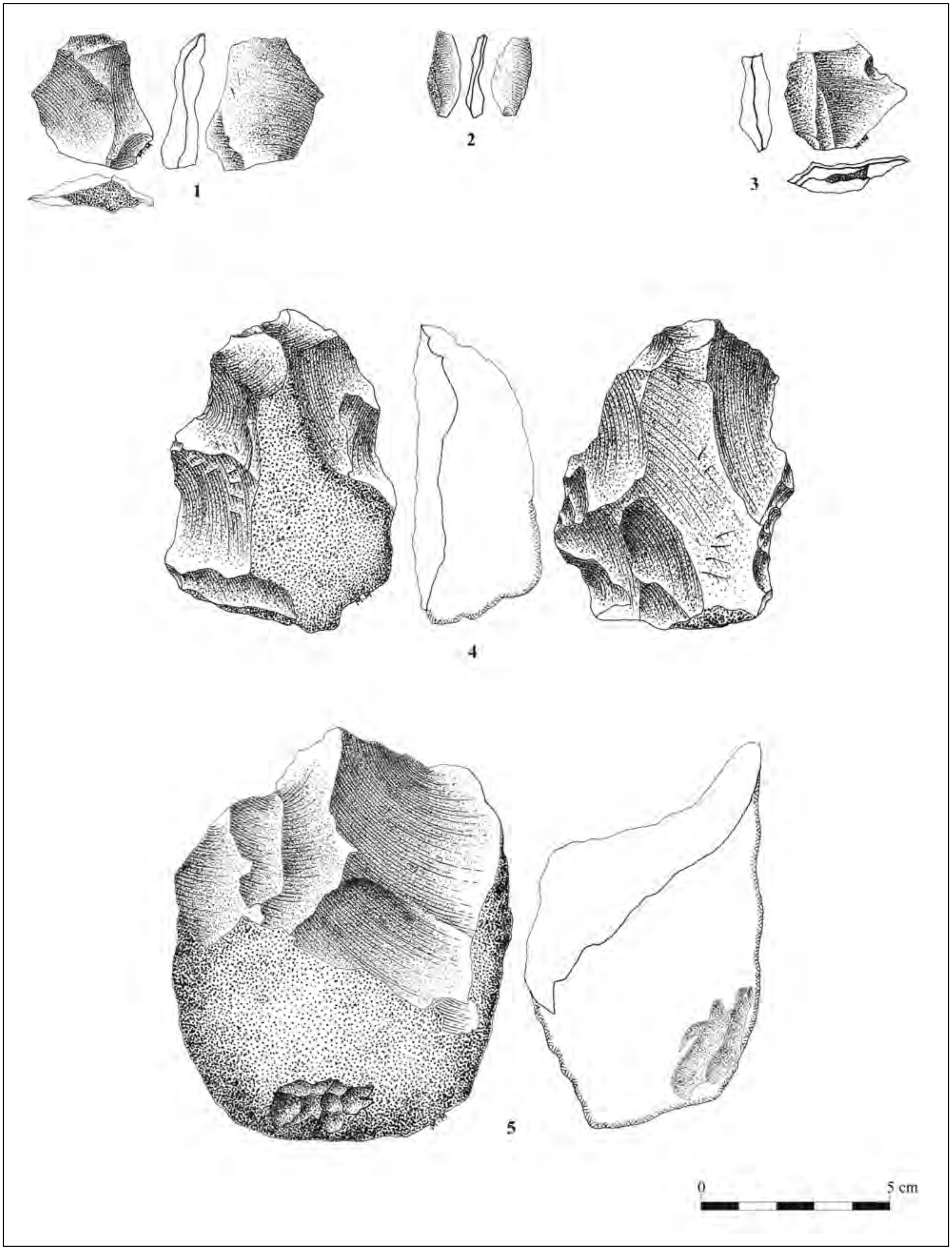

Figure 1. Gona EG 10, Hadar, Ethiopia. 2.55 million years. Pre-Oldowan *or* Archaic Oldowan*.*
1 to 3: flakes; 4: core; 5: chopper

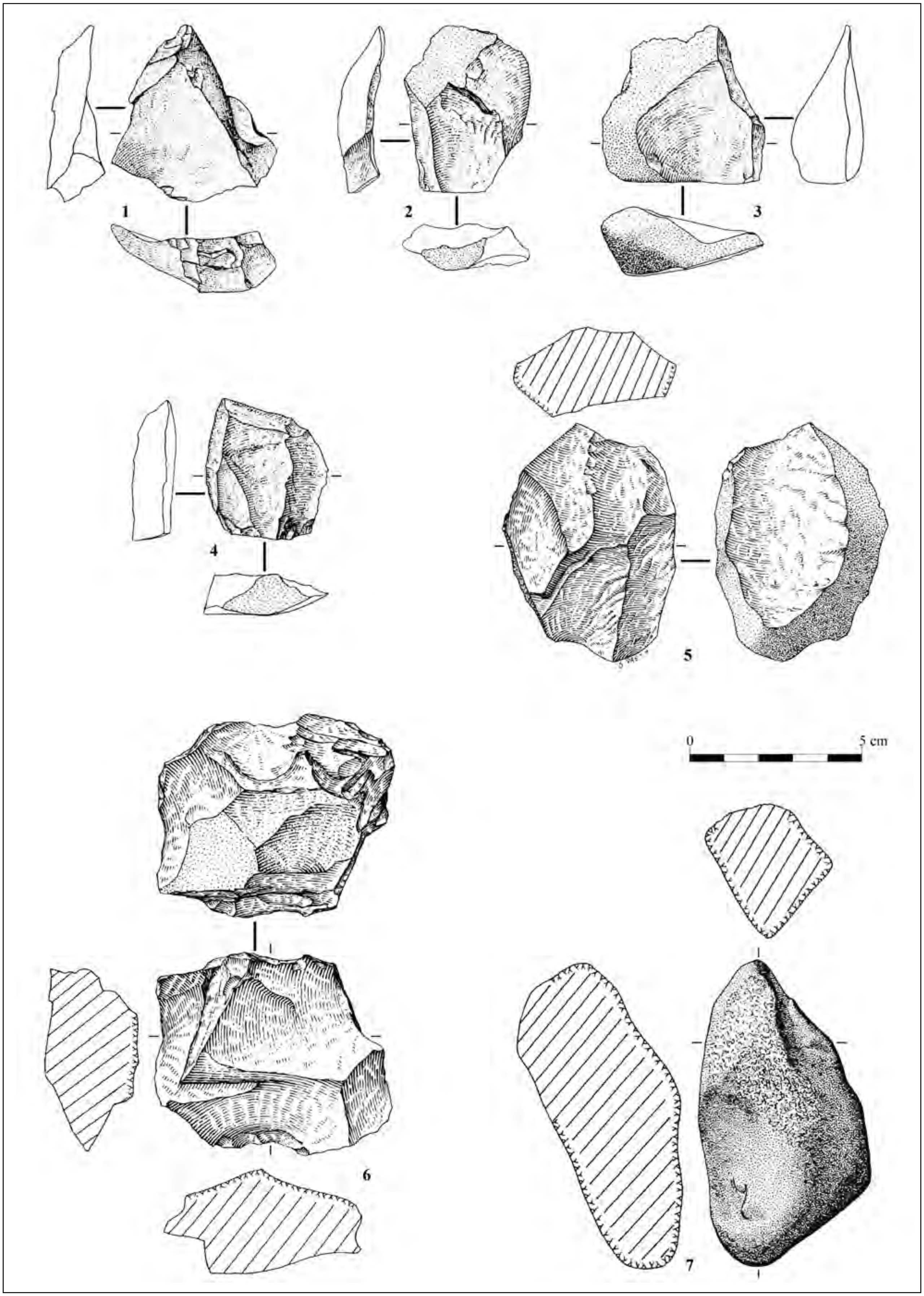

Figure 2. Lokalalei 2C, West Turkana, Kenya. 2.2 million years. Pre-Oldowan *or* Archaic Oldowan*.*
1 to 4: flakes; 5 and 6: cores; 7: percussion instrument. (from A. Delagnes et H. Roche, 2005).

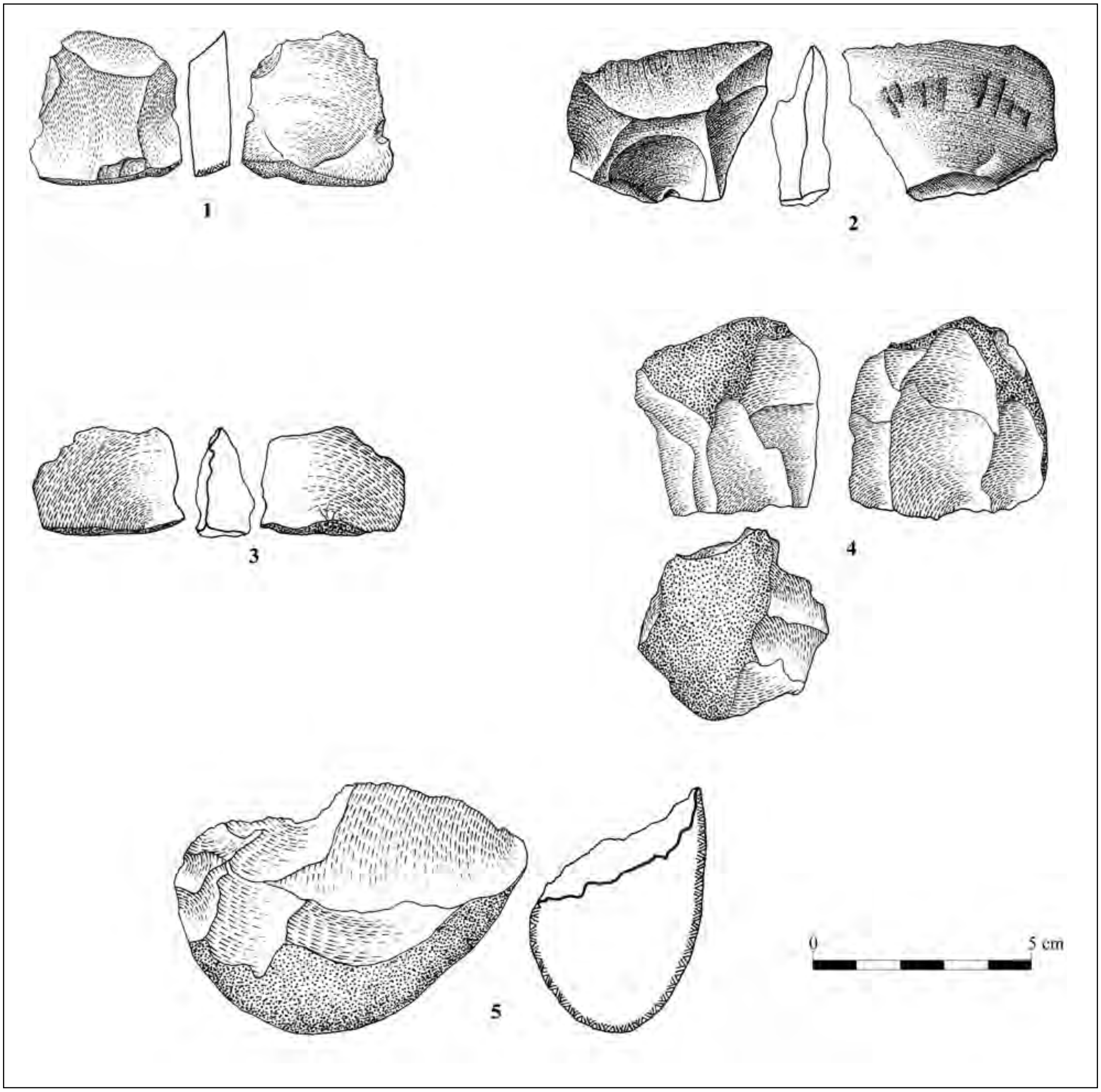

Figure 3. Fejej FJ-1, South Omo, Ethiopia. 1.96 million years. Pre-Oldowan *or* Archaic Oldowan*.*
1 to 3: flakes; 4: core; 5: chopper.

rare: choppers (pebbles showing a bevelled cutting edge shaped by one or several removals on a single face), a few core-scrapers (*rostro-carénés*; massive choppers with abrupt, narrow and convex cutting edges) and rare chopping tools (pebbles showing a bevelled cutting edge shaped by one or several removals on both faces). At this site, once again, there are no intentionally shaped small retouched tools on flakes or angular fragments.

In East Africa, presently known lithic assemblages dating to before around 1.9 million years ago show common characteristics (de Lumley, 2006; de Lumley, 2004a and 2004b). Such industries, dated to between 2.55 and 1.9 million years ago, have also been discovered in Ethiopia, in the Hadar region (AL666) and in the Omo Valley (Ftji1, 2 and 5, Omo 71, 84, 57 and 123) and at Kanjera South in Kenya (Plummer et al., 1999). The tools were essentially made from quartz or volcanic rock types collected from the area immediately surrounding the site. Knapping was generally executed using the hand held technique most often with unifacial and unidirectional removals, sometimes with multipolar or centripetal removals. Bifacial knapping was rarely practiced. Multipolar orthogonal knapping is also present. Bipolar knapping on an anvil was quite often used. It is important to underline that this type of percussion; bipolar simultaneously in two opposite directions, does not necessarily signify a poorly mastered knapping technique, but rather a very efficient way to extract flakes or sharp fragments, from small crystalline pebbles. Thus, knapping methods and techniques for flake production were chosen in accordance with the quality of raw materials and/or initial bloc or pebble morphology. It is thus that humans chose essentially cubic blocks offering natural striking platforms.

Generally cores were abandoned after the extraction of only a few flakes, especially when raw materials were of poor quality. However, when rocks were of finer quality, for example fine grained basalt, reduction sequences were systematically more intensive, as Fejej FJ-1, and even up to fifty flakes for a core at the Lokalalei 2C site (Roche et al., 1999).

Relative abundance of raw materials near each site, their nature, the morphology and size of available pebbles or blocs all had a determinant influence on the technological characteristics of each stone series.

These archaic lithic assemblages are essentially composed of non-retouched flakes, some cores or pebble tools, notably choppers and a few chopping tools. Flakes seem to have been the main objective sought out by the knappers. Their non-modified edges sometimes show chips attesting to their use. Flakes were often broken during their production probably because of violent blows with a hard hammer instrument or during bipolar on an anvil knapping technique. Flakes obtained, generally small sized, show numerous knapping accidents: longitudinal fractures along or parallel to the knapping axis, and fractures transversal or oblique to the knapping axis.

In all of these assemblages, even the oldest, as at Gona, hominids had acquired quite elaborate knapping strategies attesting to their technical prowess, and their relatively developed level of comprehension of raw material bloc geometry and of the physical parameters essential to knap hard rocks, as well as anticipatory faculties. They had acquired and mastered knapping processes according to certain constant technological principles. The invention of the tool, 2.55 million years ago, is a major cultural leap for humanity, with which begins the real history of Mankind.

We have proposed to group together these archaic industries under the name “Pre-Oldowan” or “Archaic Oldowan” in order to underline the absence or extreme scarcity of small retouched tools which characterizes them (Barsky et al., 2006; de Lumley, 2006 and 2007; de Lumley et al., 2004a and 2004b). In the case of retouched tools, an edge is modified by tiny, continuous, adjacent or overlapping removals, to obtain a predetermined shape. The term “Pre-Oldowan” is not meant to designate a single, homogenous and well defined cultural entity, but rather a cultural evolutionary stage within which there are not yet stereotyped and standardized small tools made by retouch that modified the initial form of flake, fragment or core clasts. It is a practical denomination for designating a cultural milieu wherein the technological (chaine opératoires) and typological (resulting tool types) characteristics are more archaic than in the Oldowan *stricto sensu* or Classical Oldowan. It connotes a behavioural parallelism amongst diverse human groups present in East Africa between 2.55 and 1.9 million years ago.

A drier milieu and the consecutive extension of a savannah type environment constrained some hominids to consume larger quantities of grains, thus favouring the development of large teeth (Paranthropus), while others were oriented towards ever increasing meat consumption. They were scavengers who, with the help of their primitive tools, collected meat left on large Herbivore carcasses abandoned by large Carnivores (Dominguez-Rodrigo et al., 2005; Semaw et al., 2003). They also gathered not only vegetables, but also small animals such as rodents, reptiles and amphibians.

Classical Oldowan

Although a decisive step for human evolution, these archaic tools were rudimentary. Growing sophistication in tool making was soon to accompany the progressive evolution of the human brain.

Around 1.9 million years ago in East Africa, at Olduvai in Tanzania, but also in Kenya and Ethiopia, more evolved stone industries appear. They too are characterized by a predominance of flakes, unifacial, bifacial or multifacial cores and some pebble tools (choppers, chopping-tools) (Figures 4 to 7). Small tools also make their appearance, with intentionally retouched edges modifying the initial form of the flake or fragment support. These are end scrapers, scrapers and denticulates, that is to say, flakes or fragments upon which adjacent notches were intentionally made in order to form a saw-like edge (Figures 4 to 7). Other types of tools also appear, such as polyhedrons (globular shaped tools made by small removals forming facets) (Figure 7, n° 11) and spheroids (perfectly spherical stones intentionally made but whose use remains unknown). It is this stone industry, found at Olduvai Gorge at several sites dated to between 1.9 and 1.7 million years old that Louis, and then Mary Leakey named “Oldowan” (Leakey, 1971; de la Torre et al., 2005).

Oldowan culture was to spread throughout the entire African continent: its traces are found not only in Olduvai’s Bed I between 1.9 and 1.6 million years ago, but also in Ethiopia, at the Gombore I site in Melka Kunturé, at sites dated to 1.7 million years ago, in Algeria at Ain Hanech, dated to around 1.8 million years old, and even in south Africa, at Sterkfontein 5 and at Swartkrans.

“Classical Oldowan”, dated to between 1.9 and 1.6 million years old, is characterized by the predominance of non-modified flakes, the presence of unifacial and sometimes bifacial or multifacial cores, pebble tools which are present in low but significant proportions polyhedrons and spheroids and especially small retouched tools (end scrapers, scrapers, denticulates) (de la Torre et al., 2005). These elements denote type-specialization which is progressively to become more and more standardized.

The Classical Oldowan marks the acquisition of a new stage in human cognition, within which specific

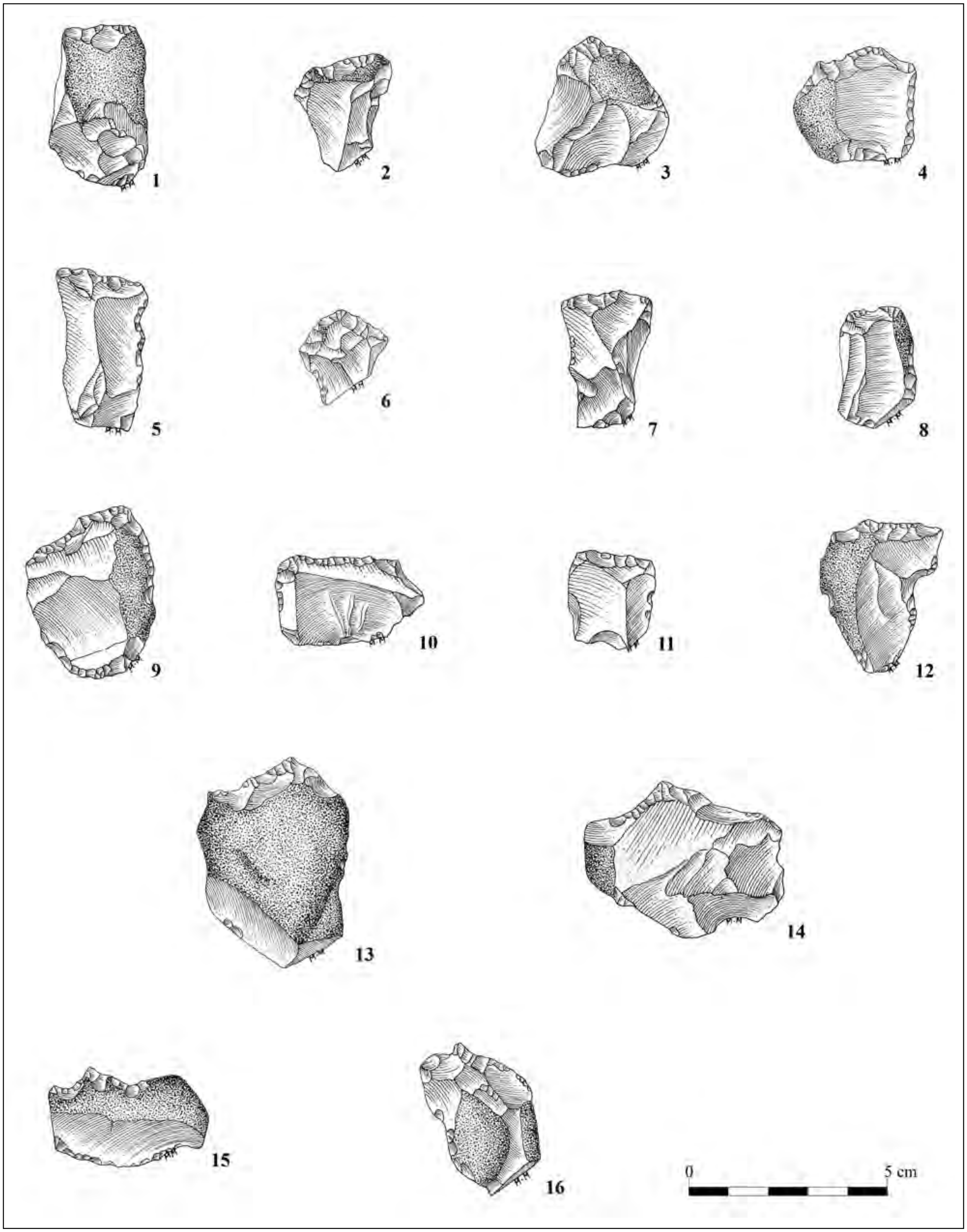

Figure 4. Olduvai, Tanzania. Bed 1, Site FLK North, Sandy Conglomerate. 1.75 million years. Oldowan sensu stricto or Classical Oldowan*. Small retouched tools on chert flakes.*
1 to 11: scrapers; 12: scraper + notch; 13 to 16: becs made from two continuous retouched notches.

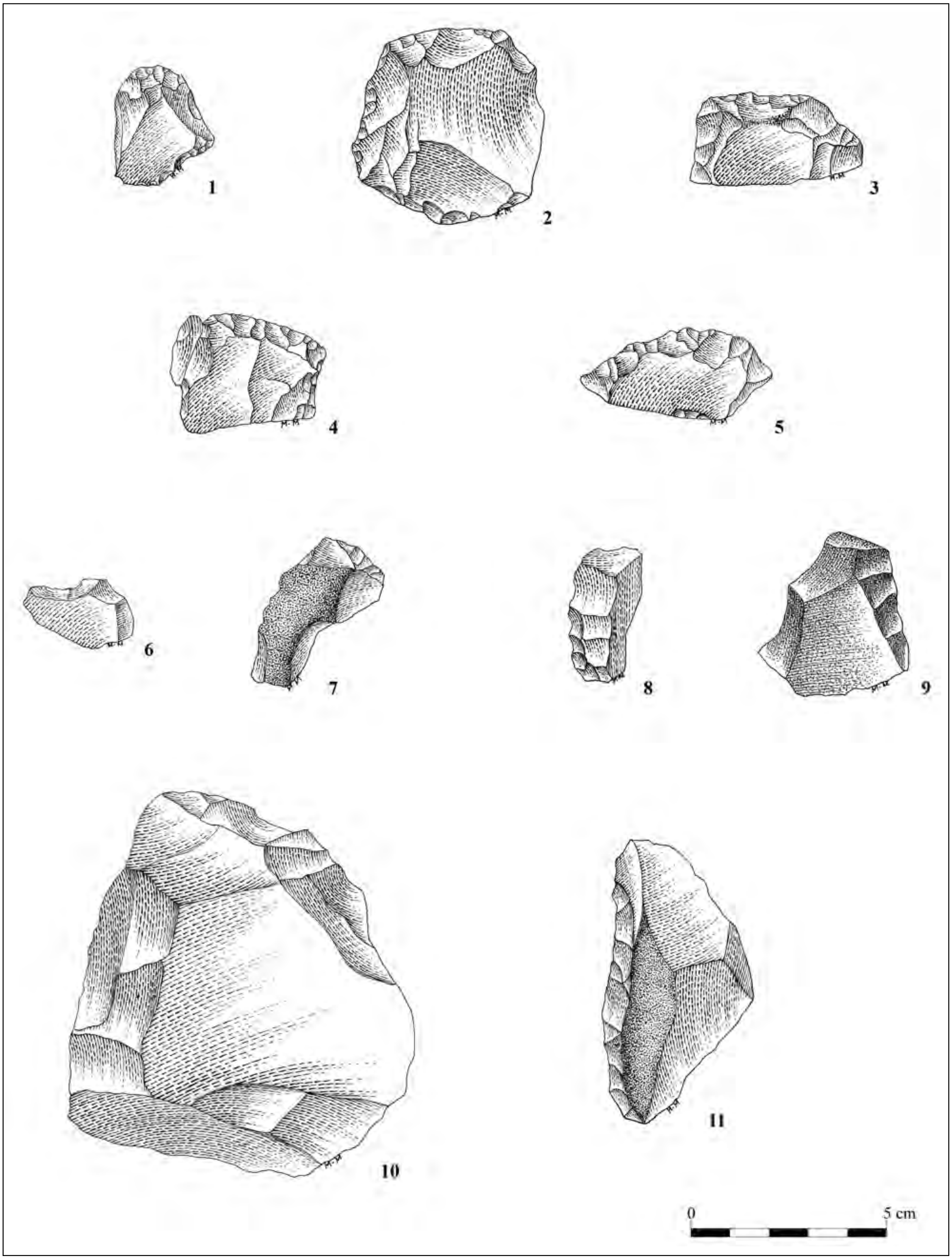

Figure 5. Olduvai, Tanzania. Bed I, site FLK NN 1. 1.75 million years. Oldowan sensu stricto or Classical Oldowan.
Small retouched tools on quartz flakes.
1 and 7: end scrapers; 2 to 5 and 9 to 11: side scrapers; 6: notch; 8: denticulate scraper.

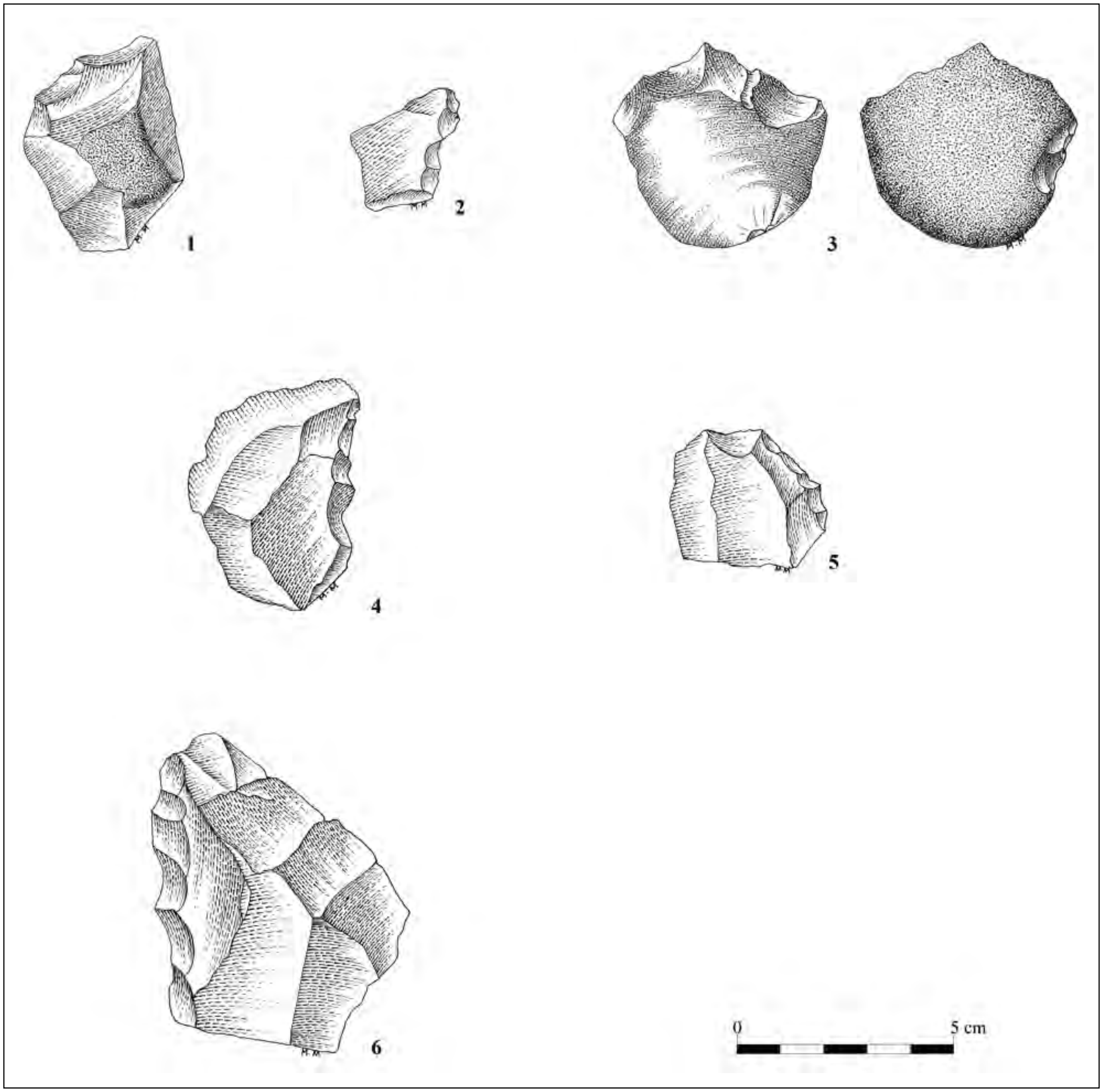

Figure 6. Olduvai, Tanzania. Bed I, site FLK North, levels 1 to 3. 1.75 million years. Oldowan sensu stricto or Classical Oldowan. *Small retouched tools on quartz flakes (n°s 1, 2 and 4 to 6) and volcanic rock (n° 5). 1, 2 and 5: scrapers; 3, 4 and 6: denticulates.*

small-sized tools were fashioned using voluntary retouch, and a certain standardization of manufactured tools is achieved.

These early artisans lived at lake edges or alongside small water sources or marshes, convenient for water supply and scavenging. Though they continued to scavenge, the desire for meatier alimentation led hominids to practice their first hunting activities. The growing diversity of their stone tool-kit denotes a specialization in their activities. Scrapers and end scrapers were probably used to work skins, thus suggesting that they began to dress themselves, denticulates and other tools with wide deep notches may have been used for wood working. But what were polydhedrons and spheroids used for? They may have served as primitive bolas for capturing large herbivores by immobilizing their legs.

The Pre-Oldowan Outside of Africa

According to our knowledge to date, australopithecines appear to have been confined to Africa. However, it was very early after their emergence that the first human tool making artisans left the African cradle of humanity (Figures 19 and 21).

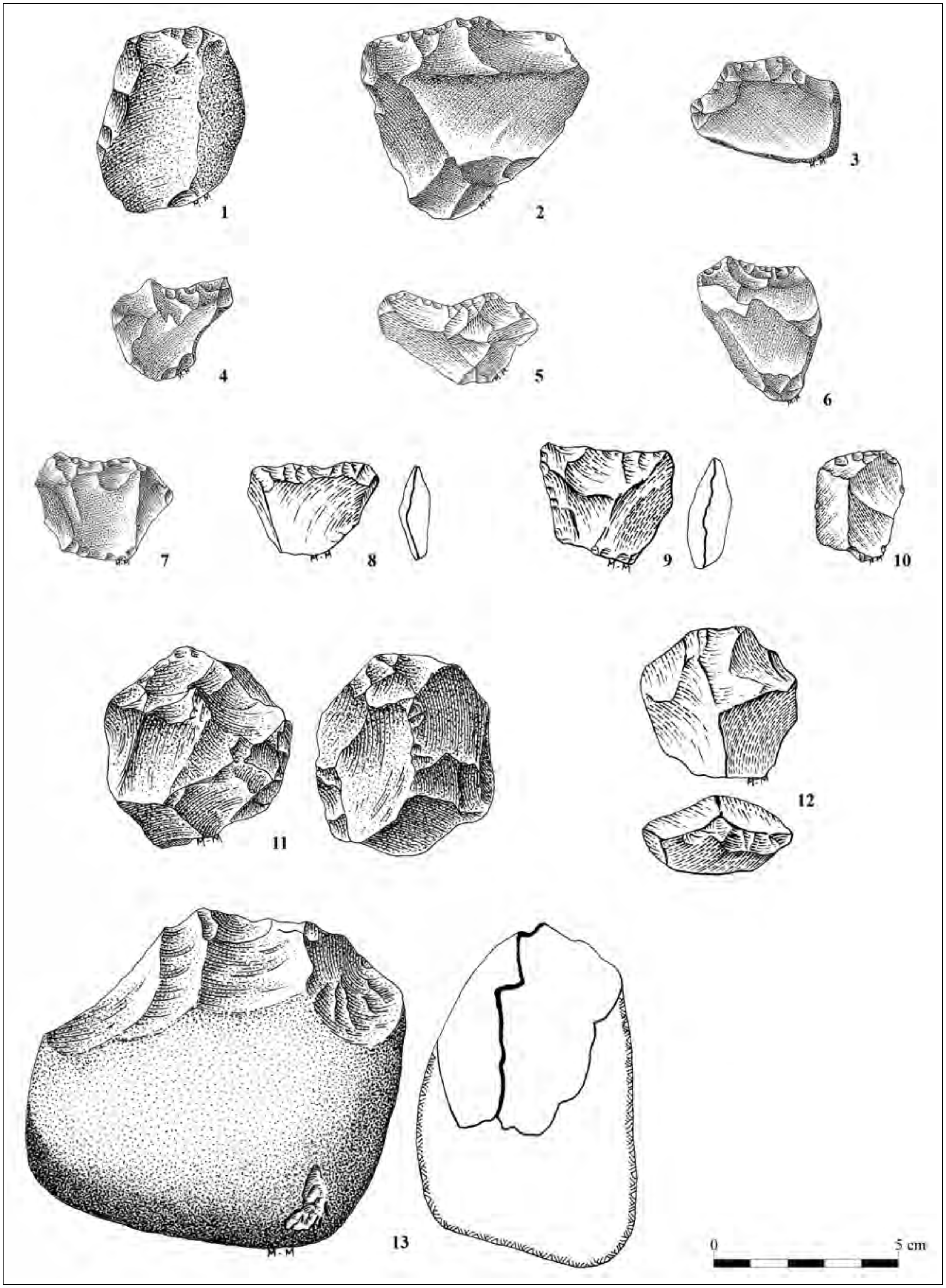

Figure 7. Olduvai, Tanzania. Bed I, site DK. 1.8 million years. Oldowan sensu stricto or Classical Oldowan. *Small retouched tools on flakes, quartz (n°s 8 to 10) and volcanic rock (n°s 1 and 4 to 7). 1: scraper adjacent to an end scraper; 2 to 9: scrapers; 10: end scraper; 11: polyhendron; 12: discoidal core; 13: chopping tool.*

Yiron, Israël

The Yiron site, located north-west of Haifa in Israel, symbolizes this large dispersion. Reported by Avraham Ronen as early as 1980, this site indicates to paleontologists that stone tool manufacturers lived in the Levant more than 2 million years ago (Ronen, 1991 and 2006; Ronen et al., 1980).

The plateau is composed of a thick layer of basalt flow covering gravels trapped in red clays. The basalt flow has been dated by potassium-argon to 2.450 million years old. Stone tools, a few flint pieces, were discovered in the gravel just beneath the basalt (Figure 8). Up to date, too few objects have been found to allow for a precise diagnostic of this industry. It is characterized by the predominance of non-retouched flakes, bifacial cores and the absence of standardized small retouched tools on flakes. It appears therefore very similar to the Pre-Oldowan industries from East Africa.

Dmanissi

At the crossroads between Africa, Asia and Europe, Georgia is situated between the Black and Caspian seas, in the prolongation of the Rift Valley and the Palestinian corridor, beyond the Zagros and Anatolian mountain ranges and the Small Caucasus. It was the launching point from which early humans migrated towards Europe and Asia.

At the Dmanissi site, 85 kilometers south of Tbilissi at an altitude of 100 meters, on the southern slopes of the Small Caucasus, a Lower Pleistocene fauna, a Pre-Oldowan stone industry and numerous hominid remains were discovered in a well dated stratigraphical context (Lordkipanidzé et al., 2007; Celiberti et al., 2004; Gabounia et al., 2000 and 2002; de Lumley, 2006; de Lumley et al., 2002 and 2005). This site attests to Man's arrival at the gates of Europe around 1.810 million years ago, thanks to the geochronological 40Ar/39Ar dating method.

Today in ruins, the medieval city of Dmanissi, near the village Patara Dmanissi, was built on a basaltic spur at the confluence of two rivers; the Mashavera, which circles it to the north-west, and the Pinezaouri, to the south-east. Constructed during the IXth and Xth centuries, the city prospered between the XIIth and XIVth centuries, before its destruction in the second half of the XIVth century by Tamerlan, a Turkish Muslim conqueror, at the head of the Golden Horde.

The prehistoric site was discovered beneath the medieval city. Excavations brought to light trash pits in the foundation basements. In 1991, a hominid mandible was found in one of these, in very ancient deposits within which it had been buried. Following this discovery, other human remains were found at Dmanissi. Excavations under the direction of David Lordkipanidzé have revealed five skulls, four mandibles and around twenty postcranial remains. They are the oldest known human remains yet to have been found in Eurasia.

The Dmanissi spur is covered by a thick volcanic lava flow composed of basalt, covering Pliocene fluvial deposits. This lava, coming from the Dzavacheti of Empeliki Mountains west of the site, flowed through the Mashavera paleo-valley. Heading towards the north-east, it constituted an obstacle against which lakes were formed. An age of 1.850 million years was obtained from the lava flow using the potassium-argon method.

A layer of volcanic ash (bed VI) covers the basalt flow. The hominid remains were found in this level, and it has been dated using the ^{40}Ar/^{39}Ar method to 1.810 million years old. Subsequently, river and flood silty sands covered the layer of ash. The paleomagnetic limit Olduvai-Middle Matuyama, around 1.770 million years, was identified in the deposits, 80 centimetres above the layer of ash. The archeological deposits at Dmanissi which yielded the human remains, dated to between 1.810 and 1.750 million years, thus accumulated over a period of less than 60,000 years (de Lumley et al., 2002).

Paleo-vegetation in the area may be reconstituted through the study of the rare pollens, phytoliths and carporests. It evokes a mosaic type landscape, with large, mainly grassy open spaces and dispersed forest areas, a gallery type forest along riversides and denser forest covering the nearby mountains (Messager, 2006). It is similar to that familiar to early African hominids.

The large mammalian fauna includes canids (*Cansis etruscus, Vulpes alopecoides*), bears (*Ursus etruscus, Ursus* sp.), hyenas (*Pachycrocuta perrieri, Pachycrocuta* sp.), felines (*Lynx issiodorensis, Panthera gombaszoegensis*) and notably sabre tooth tigres (*Meganteron meganteron, Homotherium crenatidens*). Among the herbivores present at the site: elephants (*Mammuthus meridionalis*), horses (*Equus stenonis, Equus* sp. aff. *altidens*), rhinoceros (*Dicerorhinus etruscus*), cervids (*Cervus perrieri, Cervus* sp., *Eucladoceros* aff. *senezensis, Cervus* (*Dama*) cf. *nestii major*), small bovids (*Paleotragus* sp., *Dmanisibos georgicus, Galagoral meniginii sicenbergii, Capra* sp., *Sorgelia* sp., *Ovibovini*), antilopes (*Gazella* sp., *Antilopini*) and even, among the birds, ostriches (*Strutho dmanisensis)*.

This faunal assemblage may be dated according to the evolutionary stage of the different species to the transition period between the Tertiary and Quaternary periods (Plio-Pleistocene boundary) dated to around 1.8 million years ago.

It comprises African species such as giraffe (*Paleotragus* sp.) and ostrich, Eurasian species such as some horses, elephants rhinoceros and deer, as well as sabre tooth tigers which were widespread during this period in Africa as in Eurasia, clearly indicating that Georgia is situated at the crossroads between two major geographical ensembles (Africa and Eurasia), with the Levant hyphenating these two large spaces.

Sedimentological, paleobotanical and paleontological data allow to reconstitute the environment within which these early humans lived at the gates of Europe: a savannah landscape with some trees and sectors of forest

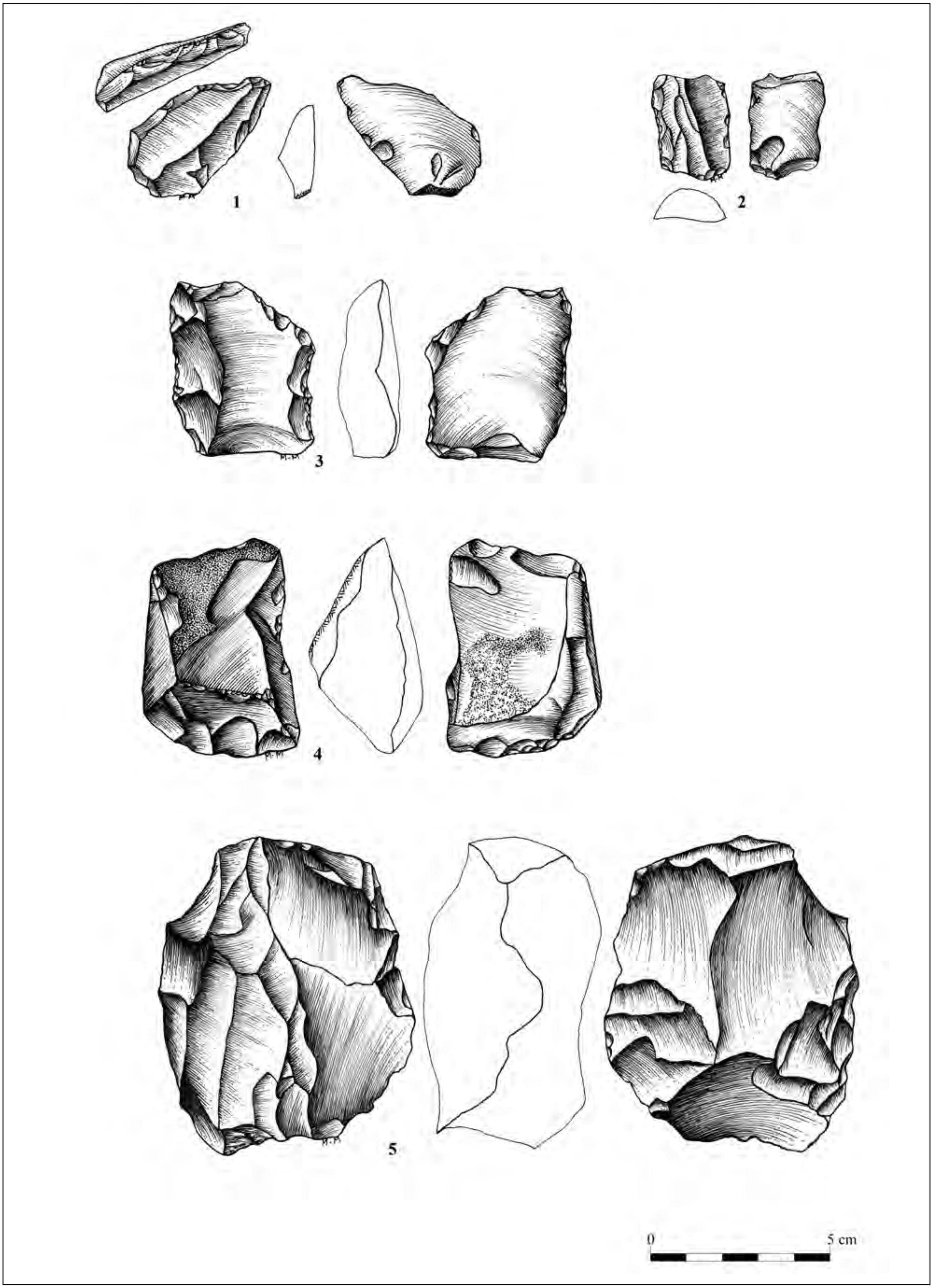

Figure 8. Yiron, Haifa Region of Israël. More than 2 million years. Pre-Oldowan or Archaic Oldowan. *Flint lithic industry. 1 to 3: flakes; 4 and 5: cores.*

cover, under a hot and humid subtropical climate. The hominids who lived on the southern slopes of the Small Caucasus 1.8 million years ago rediscovered their ancestral ecological niche. Fauna there was abundant, while in East Africa the climate grew progressively drier.

The hominid remains include, five skulls, four mandibles and around twenty post-cranial remains, belonged to at least five individuals of both sexes and of varying ages: one adolescent 13 or 14 years old, a pre-adult, two adults and one toothless elder. They were quite small, around 1.50 meters tall, with a cerebral volume of 600 to 770 cm^3 (de Lumley et al., 2006).

Their anatomical characteristics, most notably metrical, indicate that the Dmanissi hominid remains may be an intermediary form between, on the one hand, *Homo habilis-rudolfensis* and, on the other hand, *Homo ergaster* which appeared in East Africa as early as 1.8 million years ago. They do however appear closer to the former group, particularly to *rudolfensis* ER 1470 found in Kenya. Several characteristics differentiate them: their skull has a greater transverse diameter (euroneuryon), less however than that of *Homo ergaster,* a petro-tympanic disposition at the base of the skull in posterior rotation, as well as very strong canine pillars.

The relative gracility of their face, narrowness of their occipital portion and the architecture of the base of their skull clearly distinguishes them from *Homo erectus*, whose predecessors appear to have been *Homo ergaster*.

All of the anatomic characteristics of the Dmanissi hominids combined led Marie-Antoinette de Lumley to attribute the Dmanissi hominids to a new species: *Homo georgicus* (de Lumley et al., 2006).

An abundant stone industry (Figure 9) was also found at Dmanissi, among the fauna and human remains. It is very archaic (Celiberti et al., 2004; de Lumley, 2006; de Lumley et al., 2005). The raw material is essentially composed of volcanic rock pebbles, with some metamorphic rocks as well, all collected from the nearby Mashavera and Pinezaouri alluvials. Raw material supplying was strictly local–there are no rocks brought from any distance away.

Rocks selected are of fine and of varying quality, and hominids chose pebbles with angular morphology, presenting natural planes, most favourable for knapping and shaping.

The lithic assemblage is characterized by a large number of non-modified whole or broken pebbles, perhaps manuports, that is to say, objects brought to the site in their natural state. Many show angular morphology, with triangular or quadrangular sections. Their relatively modest dimensions (75×55×35 mm for the whole pebbles), less than those of the pebble tools (83×73×45 mm), may indicate a choice of larger clasts for the latter.

The assemblage is also characterized by numerous non-modified knapping and shaping products–flakes and fragments–a relative frequency of cores, alongside the larger unifacial or bifacial and more or less elaborate pebble tools. Percussion tools include pebbles showing marks from knapping blows or bone fracture, as well as pebbles with isolated convex negative scars typical of accidental removals. Small flakes less than length 20 mm long are very scarce and there are no retouched flakes. There are no standardized small tools shaped by intentional retouch.

All stages of knapping and shaping operational chains are represented at the site, from whole pebbles up to finished products (non-modified flakes or pebble tools) including knapping residues (cores and fragments) and even percussion instruments. The flakes themselves carry traces of the different knapping stages; from entirely cortical dorsal surfaces (test flakes corresponding to first removals detached from a pebble and thus conserving a cortical surface), to non-cortical flakes (flakes detached within the volume of the blocks). Their presence, as well as that of numerous cores, suggests that knapping took place on the site, *in situ*. A refit of a flake onto a chopper, both from the same layer, also shows that shaping took place on-site. The edges of broken pebbles, pebble tools, cores, fragments and flakes often show irregular use retouch.

The relatively low proportion of non-cortical flakes (less than a third) in association with numerous partially exploited cores with only a few removal scars, underlines non-intensive support exploitation. Most of the non-cortical flakes coming from within the volume of the pebbles are in fine grained tuff, a more exhaustive use of this finer quality rock type. Furthermore, a large number of flakes with cortical striking platforms also conserve, at least partially, the cortical surface of the pebble from which it was knapped on their outer side. This may be explained by the summarily knapped clasts and pebble tools most of which show a single removal negative (primary choppers) or sometimes choppers with a few removals. The orientation of removal scars conserved on the flakes' outer sides confirms the frequency of unipolar knapping. Flakes resulting from more complex knapping strategies are rare. Likewise, flakes show relatively few removal scars (average of 2.1) also underlining minimal exploitation of knapped or shaped clasts.

Knapping was done with a hard percussion instrument using mainly hand held or occasionally bipolar on anvil techniques. Cores are characterized by a dominance of unifacial knapping, few removals and the frequent use of unprepared cortical striking platforms. However, presence of bifacial, multifacial or prismatic cores indicates that the Dmanissi knappers were able to apply more complex knapping strategies and thus possessed well mastered knapping techniques. More numerous removals are visible on some cores, notably those in finer quality raw materials.

Pebble tools and percussion instruments largely dominate the assemblage. Many whole or broken pebbles show traces of their use as percussion tools, either for breaking bones or for knapping or shaping other stone artefacts. Such traces consist of chipped areas or

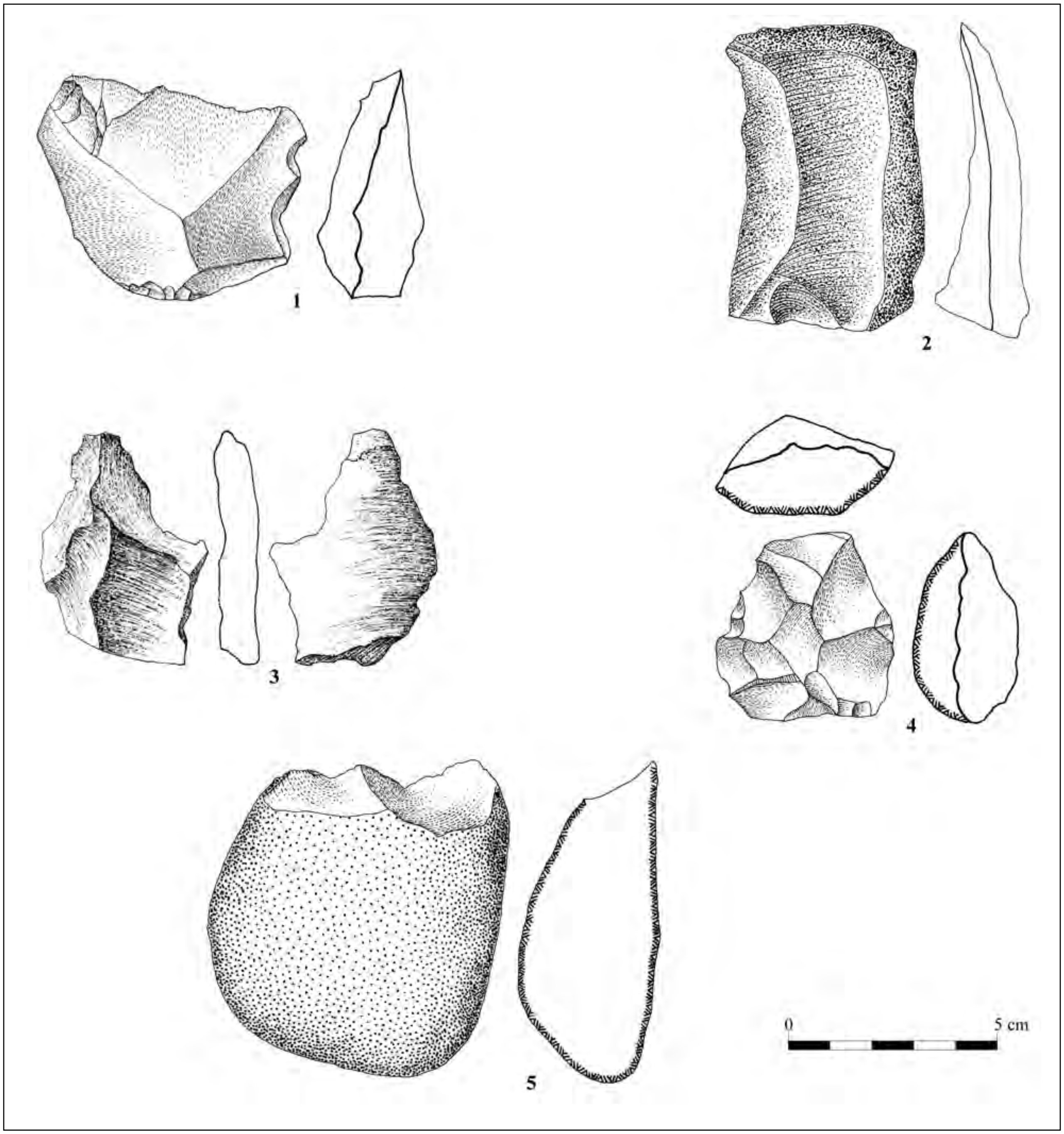

Figure 9. Dmanissi, Georgia. 1.81 million years. Pre-Oldowan or Archaic Oldowan. *Lithic industry in diverse rocks. 1 to 3: flakes; 4: core; 5: chopper.*

cupula, or, more often, accidental single convex edged removal scars. Percussion instruments are most often thick pebbles with traces typically located on the lateral edges. Isolated convex removal scars have nearly right-angled striking angles (average of 86 degrees), in other words, the knapping platform is sub parallel to the main pebble axis.

Pebble tools found in the different layers of the Dmanissi stratigraphical complex attest that the clasts were selected according to their size; favouring large pebbles; either thick and angular or flatter and angular. Nearly two thirds of the pebble tools show a single concave removal negative. These are primary choppers whose cutting edge was shaped by only one short removal, with a more acute angle (average of 79.5 degrees) than observed on pebbles with convex edged removal scars. Choppers, usually non-converging, are more elaborate; shaped by few removals (an average of only 3.3), delineating an angled cutting edge (average of 79 degrees). The few core-scrapers present in the assemblage were made on larger clasts by more numerous removals (average=4.3). Chopping-tools are rare, made from thick, large pebbles. On the average they show only five removal scars and the angle of their cutting edge is the most acute among the pebble tools (average of 69.2 degrees).

On the other hand, small standardized tools shaped by intentional retouch on flakes or fragments were not found in the stone tool assemblage from Dmanissi. Their cutting edges do however often show irregular, marginal micro-retouch or isolated irregular retouch, such as dense notches, which may be continuous or sometimes even overlapping, localized on parts of the edges and attesting to the intensive use of these pieces.

Among pieces showing irregular retouch, isolated notches are most frequent (56.2 %). Only about a quarter of the pieces affected show continuous irregular retouch located on an edge and evoking a scraper or a sort of end scraper. Some flakes (seven pieces) show a single removal on one or the other of its faces.

In short, the Dmanissi stone assemblage (Figure 9) is characterized by the following traits :

- a strong proportion of whole or broken pebbles (manuports)
- numerous non-modified knapping products (flakes and fragments), most of which conserve a cortical surface
- cores with a limited number of scars, made from selected angular clasts (pebbles with natural planes)
- primary choppers (pebbles with single concave flake scars) dominate among the macro-tools and there are some more elaborate choppers (notably non-pointed), whereas percussion instruments are most frequent
- many pieces, especially flakes and fragments, with traces of intense use wear such as notches, or dense, continuous or overlapping irregular retouch, attesting to their intensive use
- absence of standardized small tools shaped by intentional retouch

The stone industry from Dmanissi has numerous points in common with the oldest stone industries known in Africa such as those from Kada Gona (EG 10 and EG 12, 2.550 million years old); Lokalalei 2C (2.340 million years old) and Fejej FJ-1 (1.9 million years old):

- local raw material selection
- better quality raw materials were more exhaustively knapped
- selectivity in choice of pebble morphology
- abundance of non-modified knapping products (flakes, debris, cores)
- frequent production of sharp-edged objects (essentially flakes, but also pebble tools) for cutting meat and disarticulating animal carcasses
- mastery of rock fracturing methods
- use of hand held and bipolar knapping on an anvil techniques
- parallel use of several knapping strategies
- predominance use of unidirectional, unifacial knapping strategies
- presence of pebble tools, mainly with unifacial removal scars (choppers) with little morphological standardization
- absence or extreme rarity of small tools shaped by intentional retouch
- high proportion of flakes, fragments and broken pebbles with tiny retouch or irregular retouch, notably dense notches, resulting from intensive use

Pirro Nord, Foggia Province, Southern Italy

The Pirro Nord site, also known as the Cava dell'Erba, is located in southern Italy's Foggia Province, on the Apricena Commune, northeast of the Gargano massif. The area has been known for a long time as a very rich paleontological site; its karstic cavities were brought to light during quarrying and have yielded remains of mammals characteristic of the Lower Pleistocene.

In September 2006, at the occasion of the XVth International Congress of Prehistoric and Protohistoric Sciences, Marta Arzarello and her collaborators reported the discovery, among the faunal remains, of a few stone pieces (Figure 10), attesting to the arrival of prehistoric humans on the Mediterranean coast of southern Europe as early as 1.4 million years ago.

The site is a vast karstic network of galleries and fissures, largely produced by erosion. The fauna discovered in these galleries is very rich: more than one hundred species of vertebrates have been found. Carnivores, notably felines, are dominant (*Homotherium crenatidens*, *Megantereon whitei*, *Acinonix pardinensis*, *Lycaon lycaoanoides*), bear (*Ursus etruscus*) and giant hyena (*Pachycrocuta brevirostris*). Among the herbivores there are bison (*Bison deguilii*), horse (*Equus altidens*, *Equus* cf. *Equus stenonis*), rhinoceros (*Stephanorhinus hundsheimensis*) and cervids (*Praemegaceros obscurus*, *Axis* sp.). A specimen of African monkey has also been found (*Theropithecus* sp.).

This faunal assemblage is characteristic of the Lower Pleistocene and dates the site to around 1.4 million years old. It is later than the beginning of the Lower Pleistocene, as indicated by the presence of *Stephanorhinus hundsheimensis*, and earlier than the Vallonnet site, which has been dated to 1.070 to 1 million years old and where *Ursus deningeri* and *Bison schoetensacki* have been found. Among the bird remains discovered, the coexistence of such species as the great bustard (*Otis tarda*), the bustard (*Tetrax tetrax*) and the sand grouse (*Pterocles orientalis*) suggest an open environment, arid, but with seasonally humid areas. This landscape corresponds to that favoured by large herbivores.

A few pieces knapped from flint were found in three fissures: three cores and some flakes. They were

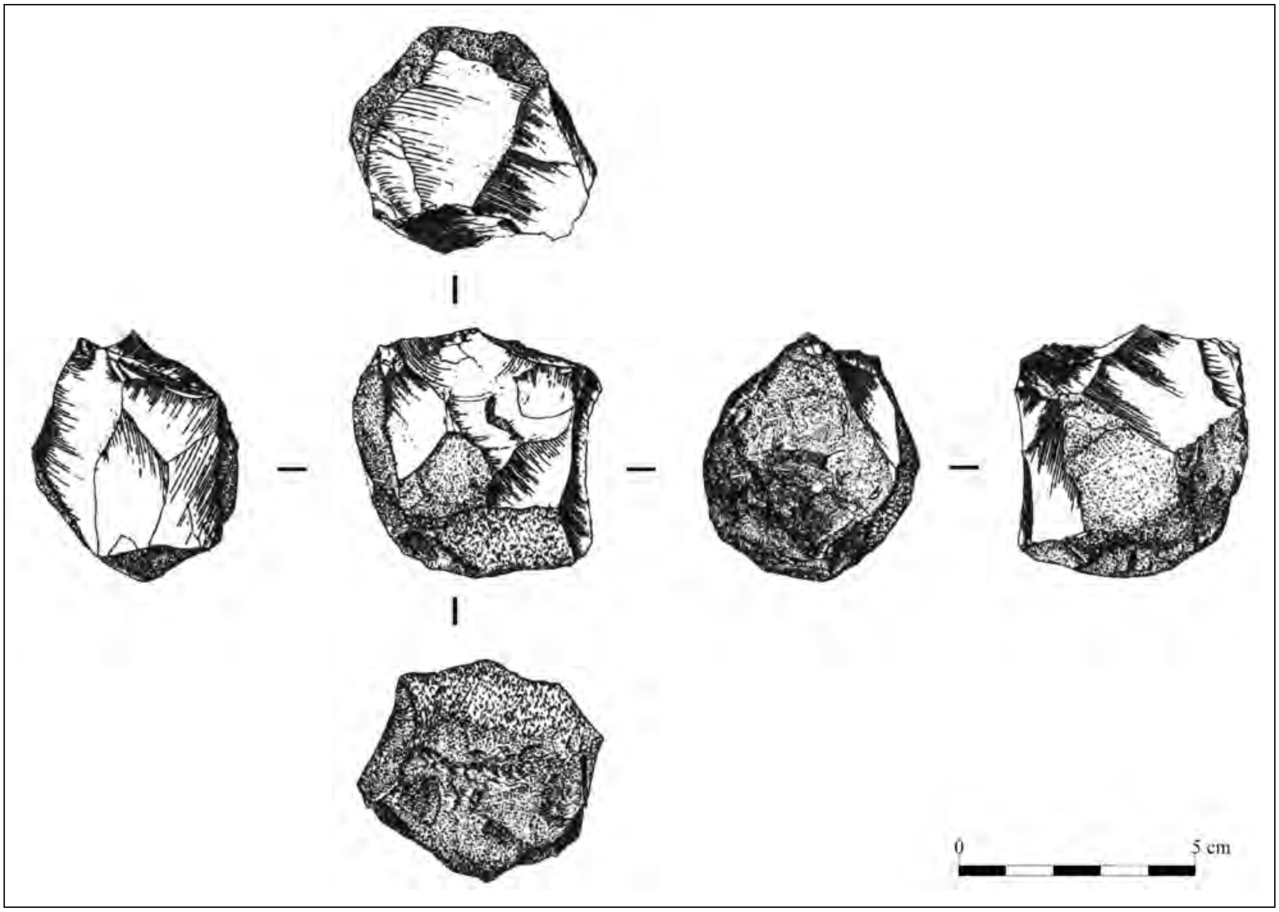

Figure 10. Pirro Nord. Foggia Province, Italy. 1.4 million years. Pre-Oldowan or Archaic Oldowan*. Flint core. (from M. Arzarello et al., 2006).*

knapped by violent percussion using the hand held technique. No small flakes with intentional retouch were found. However, the edges of some of the flakes show micro retouch attesting to their use. The industry is like other "Pre-Oldowan" industries older than Dmanissi, Yiron and some East African assemblages (Fejej, Lokalalei and Gona). The Pirro Nord assemblage is characterized by the production of non-modified flakes. Raw material is local testifying to a limited area of transport.

This recent discovery of a prehistoric site 1.4 million years old from southern Italy is a milestone for the arrival of hominids in southern Europe, on the Mediterranean shore of southern Europe.

The great Guadix-Baza paleo-lake, Orce, Andalucia

Barranco León and Fuente Nueva 3

In 1976 the team from the Miguel-Crusafont Paleontological Institute in Sabadell, near Barcelona, discovered a rich stone industry among the large mammal fossils in the Guadix-Baza Basin in Andalusia, northeast of Granada. The Barranco León and Fuente Nueva 3 sites, just 4 kilometres apart, are located to the east of the town of Orce, around 115 kilometres to the north east of the Provincial capital and 80 kilometres from the seashore (de Lumley, 2006; Martinez-Navarro et al., 2003; Toro et al., 2002, 2003a and 2003b). These two sites are of exceptional interest as examples of typical Pre-Oldowan butchery sites demonstrating, once again, that early humans made tools because they had become meat-eaters.

The Barranco León site was first made known by Jordi Agusti and excavated in 1994 by Josep Gibert. Excavations were later taken up by Isidro Toro Moyano. Fuente Nueva 3 was discovered in 1991 by Alain Bocquet and excavated from 1995 by Josep Gibert and Alain Turq. Excavations were later undertaken by Isidro Toro Moyano.

Two deeply embanked valleys cut into the Guadix-Baza basin Plio-Pleistocene formations that are over 100 meters thick. Important natural stratigraphical sections have been left by erosion. They show the evolution of an ancient lake, the Baza paleo-lake, which covered the basin from the end of the Miocene up the Middle Pleistocene, between 7 million years and 300,000 years ago, before drying up, when waters feeding this endoreic basin were captured by the Guadalquivir.

This basin, extending over around 3,000 km^2, was formed during the Miocene, about 10 million years ago (Middle Tortonian) following tectonic phenomena. Once linked to the Mediterranean Sea and the Atlantic Ocean, it was first inundated by the sea which, at the end of the

Miocene, leaving progressively thinner clayey deposits. By the Messinian, around 6 million years ago, during the Miocene-Pliocene transition, connections between the Mediterranean and the Atlantic were permanently closed and the basin became endoreic, that is to say, fed only by continental waters, and so became a lake. It was then progressively filled in by continental deposits during the Pliocene, and throughout the Lower and Middle Pleistocene.

During the middle of the Middle Pleistocene the Guadalquivir captured drainage waters and the basin was opened up once again, it became exoreic, as this Andalusian river emptied into the Atlantic Ocean to the west of Gibraltar. Its Plio-Pleistocene formations were then truncated by a glacis, and then deeply cut into by erosion, the base of the level then being lowered to 500 meters, after which the Baza paleo-lake dried up permanently.

Numerous paleontological sites have been discovered in the upper layers of this formation on the border of the paleo-lake, most notably Venta Micena, dated to 1.5 million years ago, as well as the Barranco León and Fuente Nueva 3 archeological sites, both dated to around 1.2 million years old. These last two sites have also revealed stone industries and numerous bone remains. These two Andalusian sites are very rich, not only for information they furnish about fauna, but also for their contribution to what we know about the early inhabitants of Europe on the Iberian Peninsula.

The fauna is very abundant and these sites have been dated according to the biochronology of large mammals and microvertebrates. The sites have also been dated by magnetostratigraphy. The sedimentary deposits give a negative paleomagnetic reading which, taking into account the fauna's evolutionary stage, corresponds to the Middle Matuyama inversion (1.780 to 1.070 million years), preceding the direct Jaramillo episode (1.070 million years to 984,000 years). In fact, the large and micro mammals are at the same evolutionary stage and they are very close in age. They are older than those from the Vallonnet Cave site, dated to between 1.070 million years and 980,000 years, with the appearance of the deer (*Megaceroides* cf. *verticornis*) and the archaic bear (*Ursus deningeri*), species absent from both of these Spanish sites, which may therefore be dated to around 1.2 million years old.

Fauna from Barranco León (Martinez-navarro et al., 2003) includes saber-toothed tigers (*Homotherium* sp.), giant hyenas (*Pachycrocuta brevirostris*), bears (*Ursus* sp.), an archaic wolf (*Canis mosbachensis*), foxes (*Vulpes* sp., *Alopex* cf. *praeglacialis*), badgers (*Meles* sp.), archaic elephants (*Mammuthus meridionalis*), hippopotamus (*Hippopotamus antiquus*), deer (*Megaceroides* aff. *obscurus*, *Pseudodama* sp.), bison (*Bison* sp.), small bovids (*Hemitragus* cf. *albus*), horses (*Equus altidens*, *Equus* cf. *bressanus*), rhinoceros (*Stephanorhinus hundsheimensis*), porcupines (*Hystrix* sp.), rabbits (*Oryctolagus* cf. *lacosti*), and many rodents (*Allophaiomys* aff. *lavocati*, *Allophaiomys* sp., *Castillomys crustafonti* sp., *Apodemus* aff. *mystacinus*).

The fauna from Fuente Nueva 3 (Martinez-Navarro et al., 2003) includes saber-toothed tigers (*Machairodontinae* indet.), giant hyenas (*Pachycrocuta brevirostris*), bears (*Ursus* sp.), an archaic wolf (*Canis mosbachensis*), foxes (*Vulpes* sp., *Alopex* cf. *praeglacialis*), badgers (*Meles* sp.), archaic elephants (*Mammuthus meridionalis*), hippopotamus (*Hippopotamus antiquus*), deer (*Megaceroides* aff. *obscurus*, *Pseudodama* sp.), bison (*Bison* sp.), small bovids (*Ammotragus europaeus*, *Hemitragus* cf. *albus*), horses (*Equus altidens),* rhinoceros (*Stephanorhinus hundsheimensis*), porcupines (*Hystrix* sp.), and rodents (*Allophaiomys* aff. *lavocati*, *Allophaiomys* sp., *Mymomys savani*).

The stone industries from both sites (Figure 11) are very similar, concerning the raw materials used, and the types of pieces realized and the knapping techniques used (Toro et al., 2003a and 2003b; de Lumley, 2007). They attest to a human presence in southern Europe as early as the middle of the Lower Pleistocene.

The rocks used as clasts for these tools are mainly flint and limestone, collected in the environment immediately surrounding the sites where they are abundantly available as blocks, pebbles, nodules or plates. Different types of flint of varying quality, as well as marly limestone or limestone silicified to different degrees have been identified.

Rock exploitation apparently began at the source where the materials were collected by some initiating blows. An under-representation of flakes from the early stages of the operative schemas is seen: entirely cortical or with few removal scars on their dorsal face, suggests that this activity took place away from the sites. The scarcity of possible refits of considerable size confirms that most of the knapping was not performed in the same area where the meat was consumed.

Different types of more or less massive percussion tools–whole or broken pebbles, stones and pebbles with isolated convex removal scars–are numerous. Traces of their use are conserved on their surfaces as crush-marks, cupules, or isolated removal scars. The surfaces of the limestones are chemically altered, often impeding observation of any such traces. These implements apparently served early humans frequenting the swampy area on the edge of the Baza paleo-lake for breaking large herbivore bones and as percussion instruments for shaping and knapping stones.

Large tools on pebbles or stones are very rare in both sites among numerous knapped flakes. They are mainly pebbles with single concave removal scars ("primary choppers"), while in both sites there are few choppers with edges shaped using a series of continuous removals. Other types of choppers, irregular and of poor quality are also rare.

Flake knapping is thus the main characteristic of the Barranco León and Fuente Nueva 3 assemblages. It took place using hand held or bipolar on anvil techniques. Small series of unidirectional removal scars are

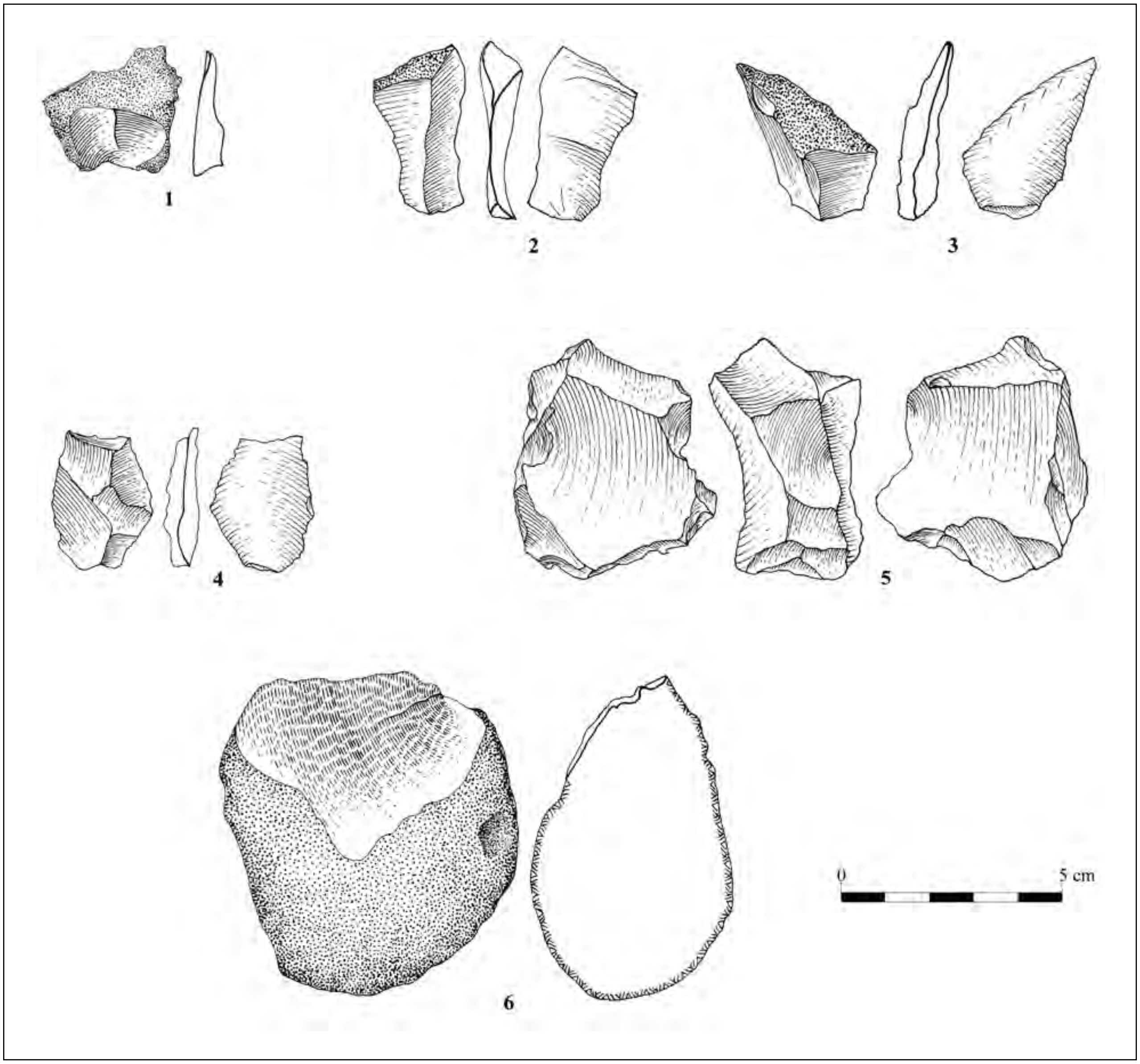

Figure 11. Barranco León and Fuente Nueva 3, Orce, Guadix-Baza basin, Andalucia, Spain. 1.2 million years.
Pre-Oldowan or Archaic Oldowan.
1 to 4: flakes; 5: core; 6: pebble with an isolated concave removal negative (primary chopper).

often observed on the cores. Core scars are sometimes also centripetal or crossed, on one or two sides of a clast, or multifacial in orthogonal series, leading to the production of cores with globular or polyhedron morphology. Some of the flakes obtained were themselves subsequently knapped. The latter, as well as overall core reduction strategy, reveals a desire to optimize raw material exploitation, especially for finer quality rocks such as some of the flint.

Angular fragments are also numerous, resulting from the percussion of relatively poor quality rocks, with mineral inclusions or lithoclases transformed into planes during knapping.

Most of the flakes conserve little of the original cortical surfaces from pebbles or nodules while others were knapped from the interior of the clast and conserve no cortical surface at all. The latter were obtained from the central mass of the raw material and are often small with a low extension (length) index. The model sought after was a small, more or less square flake, on the average 2 to 3 centimetres long. The frequency of small flakes may be explained by frequent use of the bipolar on an anvil technique which produces chipping on the transversal flake edges, posed directly onto the anvil, and the detaching of small fragments.

Cores are remarkably rare compared to flakes. At Barranco León, a total of 252 flakes larger than 2 cm were counted in comparison to only 18 cores. Such a ratio (14 flakes for one core) seems impossible given the poor quality of some of the rocks used. At Fuente Nueva 3, a total of 300 flakes larger than 2 cm in comparison to 21 cores giving a ratio of around 16 flakes for each core, even less probable for poor quality rocks. It therefore appears likely that a large proportion of the non-modified flakes, especially those larger than 2 cm, and also the cores, were transported to the site at least partially flaked.

However, numerous exhausted polyhedron, globular or cubic cores from which no further flakes could have been produced, knapped using either hand held or bipolar on an anvil techniques, as well as flake-cores from which small flakes were produced, seem to suggest that much of the knapping did take place on-site, according to needs, to carry out certain activities. There are mainly very small flakes knapped on-site from small cores (very reduced) or from other flakes. In fact, frequent irregular retouch on these small flakes show that their edges were rapidly used and they probably had to be replaced often.

However, numerous cores showing intense exploitation and from which no further flakes may be obtained are seen; polyhedrons, globular or cubic cores knapped using either hand held or bipolar flaking on an anvil, seem to indicate that a large number of pieces were obtained on the site, according to needs, for some activity.

Many pieces, be they broken or shaped pebbles, angular stones, cores, fragments or (especially) flakes, show traces on their more-or-less sharp cutting edges of irregular use retouch and micro retouch. However, intentional retouch for the elaboration of standardized small tools was not practiced by Orce's early humans.

The quasi-exclusive use at Barranco León and Fuente Nueva 3 of local raw materials can be seen; all coming from sources accessible within a range of 5 kilometres, suggest that these two sites were not habitation sites. They seem to have been areas for a specific activity for which hominids used nearby rocks.

This system of exploitation of rock resources is particularly interesting. The behaviour of these early humans is, in this respect, very opportunistic.

Quaternary conglomerates near the sites, accessible 500 meters to 5 kilometres away, furnished nodules of limestone and flint. Collection of these materials could have taken place during daily foraging in search of food.

Although this kind of exploitation of stone resources may appear simplistic or even instinctive, selective behaviour did preside in the choice of raw materials. Pebbles with summarily rolled surfaces and, consequently few fissures, seem to have been selected. Among the latter, limestone was carefully selected for the production of large tools while nodules of silicious rocks (flint and radiolarite) were reserved for flake production. This selectivity shows that hominids practiced a reasoned use of raw materials, taking into account their physical properties, in spite of their simple acquisition approach. It proves that these early humans were perfectly adapted to their environment and that they had already adopted a behavior that was efficient in its industrial enterprises.

The presence of stone artefacts among the large mammal bones, sometimes preserved in anatomical position, such as the hippopotamus at Barranco León or the elephant at Fuente Nueva 3, as well as apparently human-caused breakage and some traces of butchery on bones, leads to believe that the stone tools were destined to be used for processing the carcasses of these animals.

The relative scarcity of pebble tools and their small size precludes the idea of a site reserved for disarticulating and cutting up of large mammal carcasses killed by humans or which were bogged down in the swamps.

The predominance of non-modified flakes, most often small in size, on the average 10 to 25 mm long at Barranco León and 20 to 40 mm long at Fuente Nueva 3, seems to suggest that they were used for cutting up and scraping meat remaining on animal carcasses abandoned by large carnivores in the swampy areas around the Baza paleo-lake (Figure 12). Humans competed with hyenas for the carcasses. They practiced secondary scavenging : they followed satiated carnivores and obtained the pieces of meat still remaining on the bones using their small flakes.

The technological (operative schemas) and typological (resulting tool types) characteristics of the stone industry, as well as the behaviour of the early humans from Barranco León and Fuente Nueva 3, fit these sites within the Pre-Oldowan cultural horizon.

La Sima del Elefante, Sierra d'Atapuerca, Spain

Around 500 kilometres to the northwest of the Guadix-baza basin, the Atapuerca Sierra, near Burgos, in the Castille-León Province, is an imposing karstic massif with numerous cavities which sheltered remarkable prehistoric sites covering all periods of human history in Europe (Carbonell I Roura et al., 1995 and 2001; Carbonell I Roura et al., 2008; Cuenca-Bescos et al., 2004; Garcia et al., 2008; Huguet et al., 2007; Pares et al., 2006; Rofes et al., 2006; Rosas et al., 2001 and 2006).

Amongst these sites, La Sima de l'Elefante is a cavity opened up by the trench of an old railway track (la *Trinchera del Ferrocaril*). It is a vast cave, rich in large mammal faunal remains–such as elephants–from which comes the name of the site. It was in-filled by sandy clays rich in stones over 15 meters thick. The lower levels are very old; magneto-stratigraphical studies have established that they were deposited prior to the geomagnetic polarity change Matuyama-Brunhes, dated to 770,000 years ago. Results from the *cosmogenic nuclide* method gave a date of 1.13 ± 0.16 and 1.22 ± 0.14 million years (Carbonell et al., 2008).

Fauna from these levels includes archaic cervids, primitive bison, hippopotamus, rhinoceros, macaques, turtles, beavers and other rodents and insectivores for which numerous remains have been found. The evolutionary stage was determined by paleontological studies, particularly by the rodents, including an archaic form of *Iberomys huescarensis*, *Allophaiomys lavocati* and *Catillomys rivas*, and the insectivores, especially *Beremendia fissidens* and *Asoriculus gibberodon*, all suggest a date of Lower Pleistocene, earlier than 1 million years old.

Presence of hippopotamus, beavers and turtles sug-

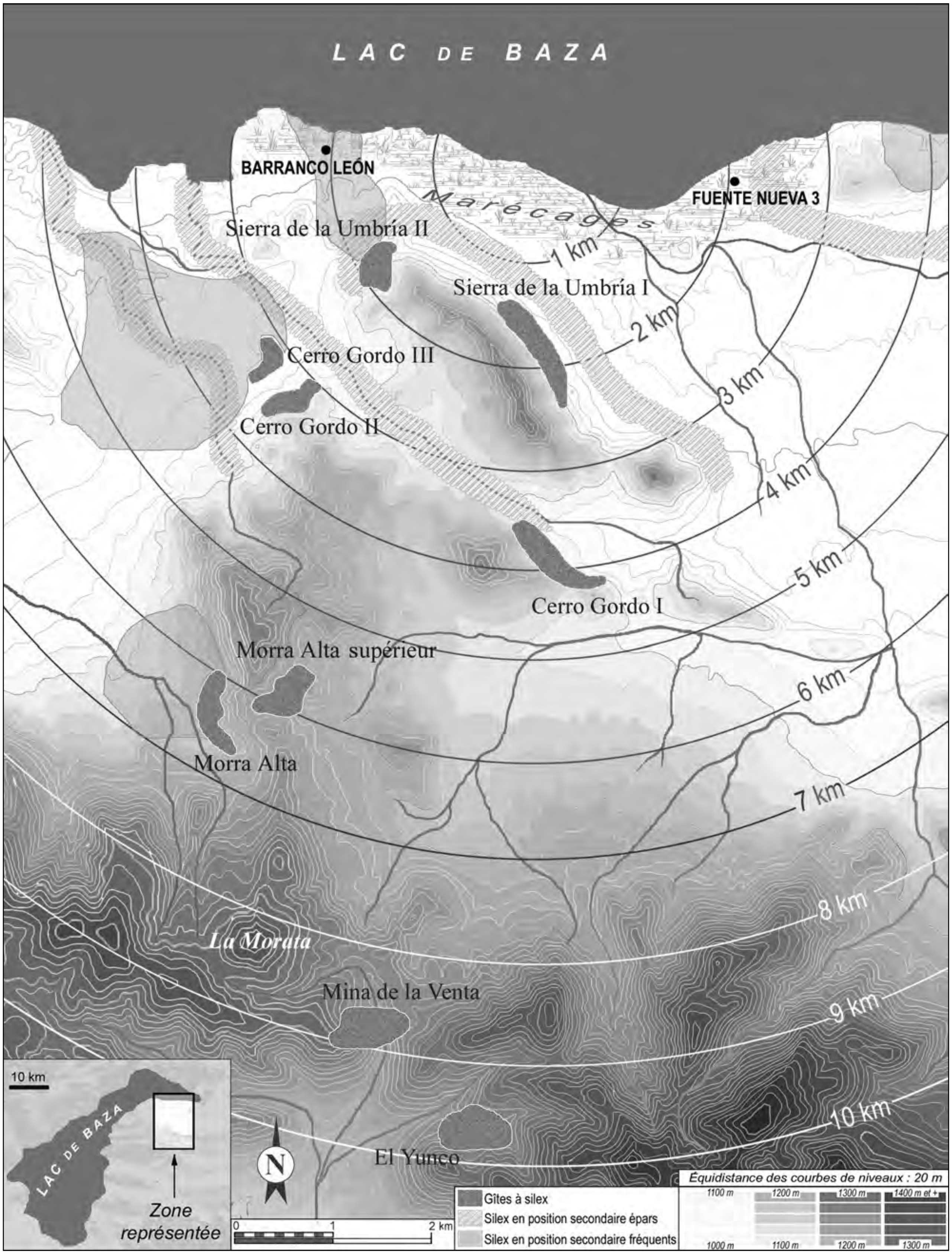

Figure 12. The Pre-Oldowan site Barranco León and Fuente Nueva 3, Orce, Guadix-Baza basin, Andalucia, Spain, were located in a swampy area between the southern edge of the large Baza paleo-lake and a Jurassic limestone massive, rich in flint.
In the swampy area, on the Baza lake-edge, prehistoric humans indulged in scavenging around 1.2 million years ago.

gest a humid landscape with rivers and swamps. During excavations in 2000, Eudald Carbonell's team brought to light the first flake knapped from flint: it is proof that hominids stayed at the Atapuerca Sierra more than a million years ago.

Since then, other non-modified knapped flint flakes have been recovered. None of these flakes had been transformed by intentional, regular retouch. They are non-modified flakes. These tools appear to correspond with those from other sites with Pre-Oldowan industries.

In July 2007 an isolated premolar and the lower portion of a hominid mandible, belonging to the same individual, was attributed to *Homo antecessor* (Carbonell et al., 2008), were discovered.

Thus, a little over 1 million years ago in the Guadix-Baza basin at Barranco León and Fuente Nueva 3 as well as at La Sima del Elefante in the Atapuerca Sierra, the earliest inhabitants of Europe lived in a humid, wooded environment, at a lake's edge in the Andalusian basin or near the rivers and swamps of the Castilian Sierra.

Who were the artisans of these primitive stone tools? Were they similar to Dmanissi's *Homo georgicus*, at the gates of Europe, or were they closer to the European forms of *Homo erectus*, *Homo heidelbergensis* that we find later at the Ceprano site in Italy (*Homo cepranensis*) or at Gran Dolina (*Homo antecessor*), another cave site in the Atapuerca Sierra, around 880,000 years ago? Ongoing excavations in the Guadix-Baza basin and the Sima d'Elefante site may soon provide answers to this question so fundamental to understanding the morphological evolution of the earliest inhabitants of Europe. The hominid remains found in June and July in the lower levels of the Sima del Elefante yield the first answers to this question.

The Vallonnet Cave site, Roquebrune-Cap-Martin, Alpes-Maritimes

The Vallonnet Cave at Roquebrune-Cap-Martin in the Alpes-Maritimes is located on the western slopes of Cap Martin, around 800 meters from the Mediterranean seashore (de Lumley et al., 1988). It opens up onto the right-hand side of a small ravine, the Vallonnet, which descends towards Menton Bay. It is a small cavity carved into a Jurassic dolomitic-limestone massif, pitched, enveloped in a Miocene conglomerate made up of pebbles and sandy concretions. The low and narrow porch joins a 5 meter long corridor which opens onto a 4 meter wide chamber. Stratigraphical and sedimentological studies of the deposits have defined five ensembles.

The base of stratigraphical ensemble I is made up of a stalagmitic floor dated to between 1.4 and 1.370 million years old. Pollen analysis in the deposits evokes a forest landscape with Mediterranean essences dominated by plane trees.

Above this level, stratigraphical ensemble II is made up of marine sands rich in foraminiferous, marine mollusc shells and fish bones amassed by a transgressing sea which dismantled the existing continental in-fill. This marine beach is slightly older than 1.070 million years. Among the fish, the presence of diodon (globe fish) and, among the molluscs, the presence of species typical of warm seas, indicate a tropical or subtropical sea. The latter data, in association with that from the fossil pollen analysis, suggests a relatively warm, dry climate with mild winters.

With a thickness of 1.5 meters, stratigraphical ensemble III is the most important of the series deposited in the cave. It is composed of continental deposits made up of clayey-silty sands rich in stones and pebbles from the conglomerate overhanging the cave. This relatively homogenous continental in-fill has been sub-divided into three main layers which were subsequently sub-divided into several human or carnivore occupation levels. Many bones brought into the cave by humans and/or by carnivores have been found in these deposits. Pollen analysis in this stratigraphical ensemble suggests an open landscape made up of composites, mainly chicories, clusters of trees, and a sort of scrubland passing gradually into deciduous-leafed oak forests dominated by white oak. The relatively dry climate observed at the beginning of this ensemble becomes more humid later on. Magnetostratigraphical studies show that this ensemble corresponds with the Jaramillo geomagnetic polarity episode within the larger reverse polarity period of Matuyama. This episode, situated between the two reverse geomagnetic polarity events that are the Middle and Upper Matuyama, is dated to between 1.070 and 1 million years ago.

A little over 1 million years ago, the entranceway corridor's existing infill was emptied by erosion and only the deposits located deep in the chamber of the cave were preserved.

Stratigraphical ensemble IV is a thick stalagmite floor that was formed and that sealed what remained of the geomagnetically reverse deposits thus preserving them from further erosion. It was formed later than 1 million years ago (Upper Matuyama) and has been dated using electron spin resonance to between 900,000 and 890,000 years old.

Palynological analysis suggests a deciduous forest comprising a variety of species suggesting a colder and especially more humid climate than at present.

The deposits making up this upper ensemble V consist of silty-sandy plastic clays, extracted from earlier deposits and accumulated during the different humid phases of the Quaternary period.

Nearly one hundred knapped stone tools were found in the sandy-clayey-silty sediment of ensemble III (Figure 13) among Quaternary faunal remains. They are dispersed over sixteen carnivore and human occupation levels identified as different archeostratigraphical units by Anna Echassoux (2004) on computerized vertical projections allowing a view of the archeological material on profiles 25 centimetres wide.

Six units were identified in the lowest layer C, five in the middle layer B2 and five in the upper layer B1.

These archeostratigraphical units were not only human occupations. Research carried out has not revealed any particular pattern in the site. The Vallonnet Cave served as a den for large carnivores, mainly bear, and felines such as panther and saber-toothed tigers; large hyenas broke many of the bones (Essachoux, 2004). Large carnivores brought numerous herbivore carcasses into the cave: deer, bison, small bovid, rhinoceros, horse, wild boar. Apart from the carnivores, humans could have also frequented the cave, leaving their tools behind.

Large mammal fauna is very abundant and includes more than twenty-five species. Carnivores account for a third of the material which is characteristic of the end of the Lower Pleistocene and which includes some archaic species: macaque (*Macaca sylvanus florentina*), felines like the Eurasian jaguar (*Pantera gomaszoegensis*), cheetah (*Acinonyx pardensis*) or the giant hyena (*Pachycrocuta brevirostris*), southern elephant (*Mammuthus meridionalis*), rhinoceros (*Stephanorhinus hundsheimensis*, horse (*Equus stenonis*), pig (*Sus*), deer (*Cervus nesti vallonnetensis*), musk ox (*Praeovibos*).

Other, more evolved species, announce the Middle Paleolithic: an archaic wolf (*Canis mosbachensis*), an archaic fox (*Alopex praeglacialis*), the cave lynx (*Lynx spelaea*), a bovid (*Bison shoetensacki*) and thar (*Hemitragus bonali*).

The evolutionary stage of each species of this well dated fauna (from 1.070 to 1 million years old), delimits the Vallonnet stratigraphical horizon which has become a referential milestone in Europe for biochronology.

Paleoecological affinities evoke different landscapes: the numerous deer remains suggest forest areas, while bison and small bovids evoke more open spaces.

Stone tools (Figure 13) left by humans during their short stays in the cave–a hundred odd pieces–were knapped from pebbles collected in the Roquebrune Miocene conglomerate (de Lumley et al., 1988). Three pieces were knapped from translucent beige flint pebbles which come from 700 meters to the north of the cave at Ciotti, near Menton. Limestone was most often used for the manufacture of these tools, as well as a few sandstone and some rare fine quartzite and flint pebbles. The assemblage is mainly composed of pebbles used as percussion instruments (showing isolated convex removals), pebble tools, cores and non-modified flakes.

Percussion tools are by far the most numerous. Pebbles showing single concave removals (primary choppers) are frequent, although are poorly manufactured. Pebble tools showing multiple removals (choppers, chopping-tools) are significant but most of them are of poor quality and without standardization. Many cortical flakes present in the collection were produced by accidental breakage of percussion instruments with isolated convex removals. Those produced from intentional production of pebble tools are also well represented. Finally, flakes from cores are rare. A core showing multidirectional orthogonally oriented removal scars and another with bipolar unifacial scars have been unearthed. All flakes are non-modified; none were transformed by intentional retouch.

The middle portion of a bison femur (*Bison shoetensacki*) showing a series of removals and apparently having served as a percussion instrument (Figure 14), and around ten deciduous deer antlers were brought into the cave and used as tools. While tooth marks present on most of the bones attest to their transport and breakage by carnivores, characteristic spiral-type breaks resulting from intentional human percussion on fresh bone are visible on others.

Some bones show parallel, fine, short, obliquely oriented striation marks from meat cutting with a stone implement. The high proportion of percussion tools, whole or broken pebbles and pebbles with convex edged removals, gives this industry a particular character and bears witness to the dominant human activity practiced in the Vallonnet Cave. These tools may be associated with numerous intentionally broken large herbivore bones found in the cave, while a few knapped flakes, especially those in flint, bear witness to meat cutting activity.

Around one million years ago humans occasionally came to Vallonnet Cave to scavenge carcasses abandoned there by large carnivores, breaking the bones and consuming the marrow.

At sites where the presence of early humans is attested to by archaic stone industries, large herbivore bones are often associated with large feline remains such as saber-toothed tigers (*Homotherium* and *Megantereon megantereon*), or Eurasian jaguars (*Panthera gombaszoegensis*). Did early humans who had become meat eaters follow large carnivores who, once satiated, left behind carcasses of large herbivores, just like the giant hyenas did (*Pachycrocuta brevirostris*) ? There apparently was real competition between hyenas and humans for scavenging.

These humans, more scavengers than hunters, left no traces of domestic arrangement in the Vallonnet Cave. No evidence has yet been discovered to suggest that they had domesticated fire. With Pirro Nord, Barranco León and Fuente Nueva 3 and the Sima del Elefante, the Vallonnet Cave is among the oldest known evidence of a human presence in Europe in a well-dated stratigraphical context.

Ca'Belvedere di Monte Poggiolo, Emilei-Romagne, Italy

In Emilia-Romagna, on the eastern slopes of the Apennines, between Rimini and Bologna, numerous Lower Paleolithic sites were found rich in non-modified flakes, cores and pebble tools: Ca'Belvedere di Monte Poggiolo, Ca'Romanina and Rio Sanguinario. Ca'Belvedere, discovered in 1984 and studied by Carlo Peretto, is the principal site.

Stratigraphical studies of the site identify, at the base, a thick layer of greyish-blue clayey sediment deposited by a coastline sea and overlain by a level of pebbles. Nonetheless, magnetostratigraphical studies have

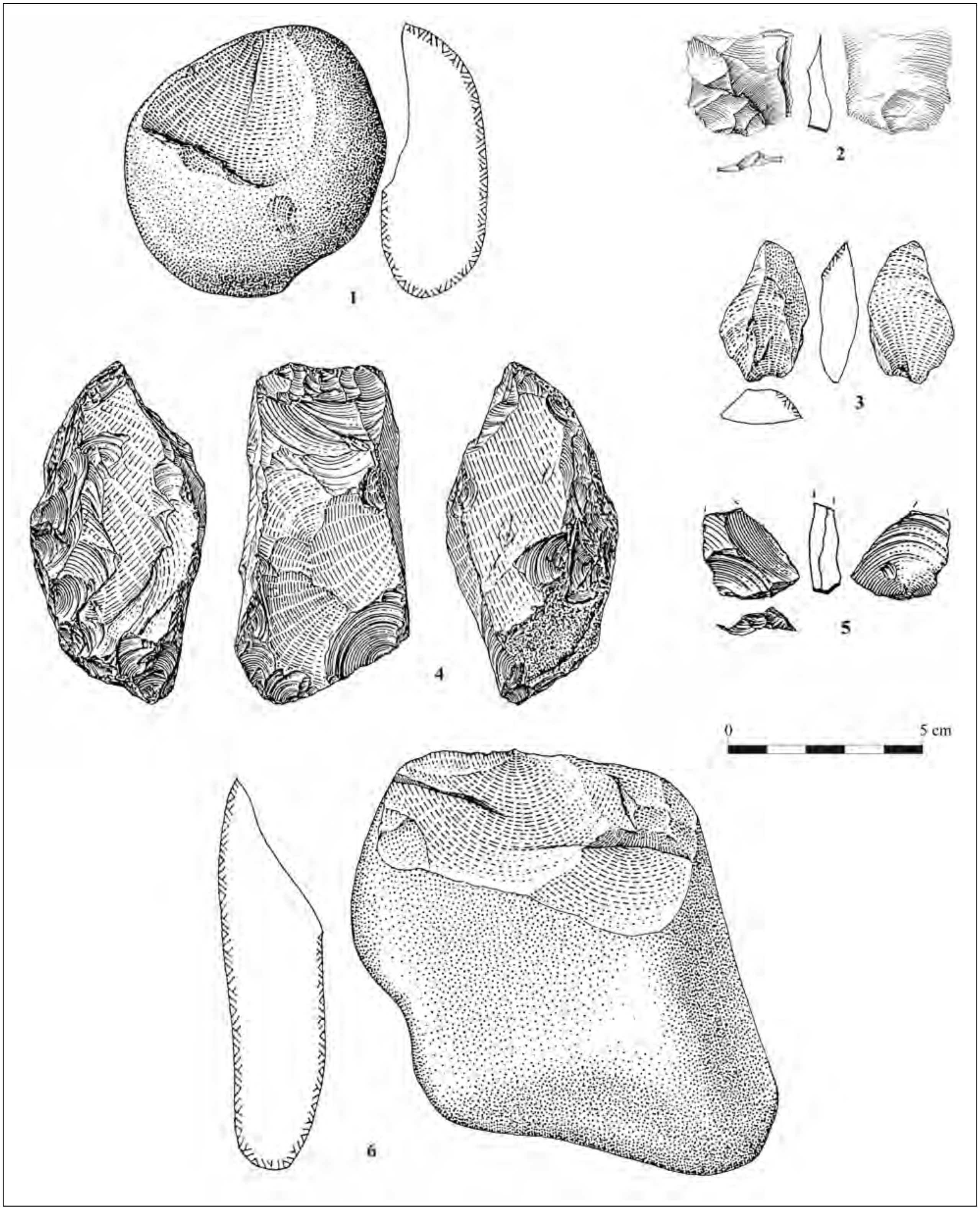

Figure 13. Vallonnet Cave, Roquebrune-Cap Martin, Alpes-maritimes, France. Between 1.7 and 1 million years. Pre-Oldowan or Archaic Oldowan*. Limestone industry.*
1: Pebble with an isolated convex edged removal negative (percussion instrument); 2, 3 and 5: flakes; 4: core; 6: chopper.

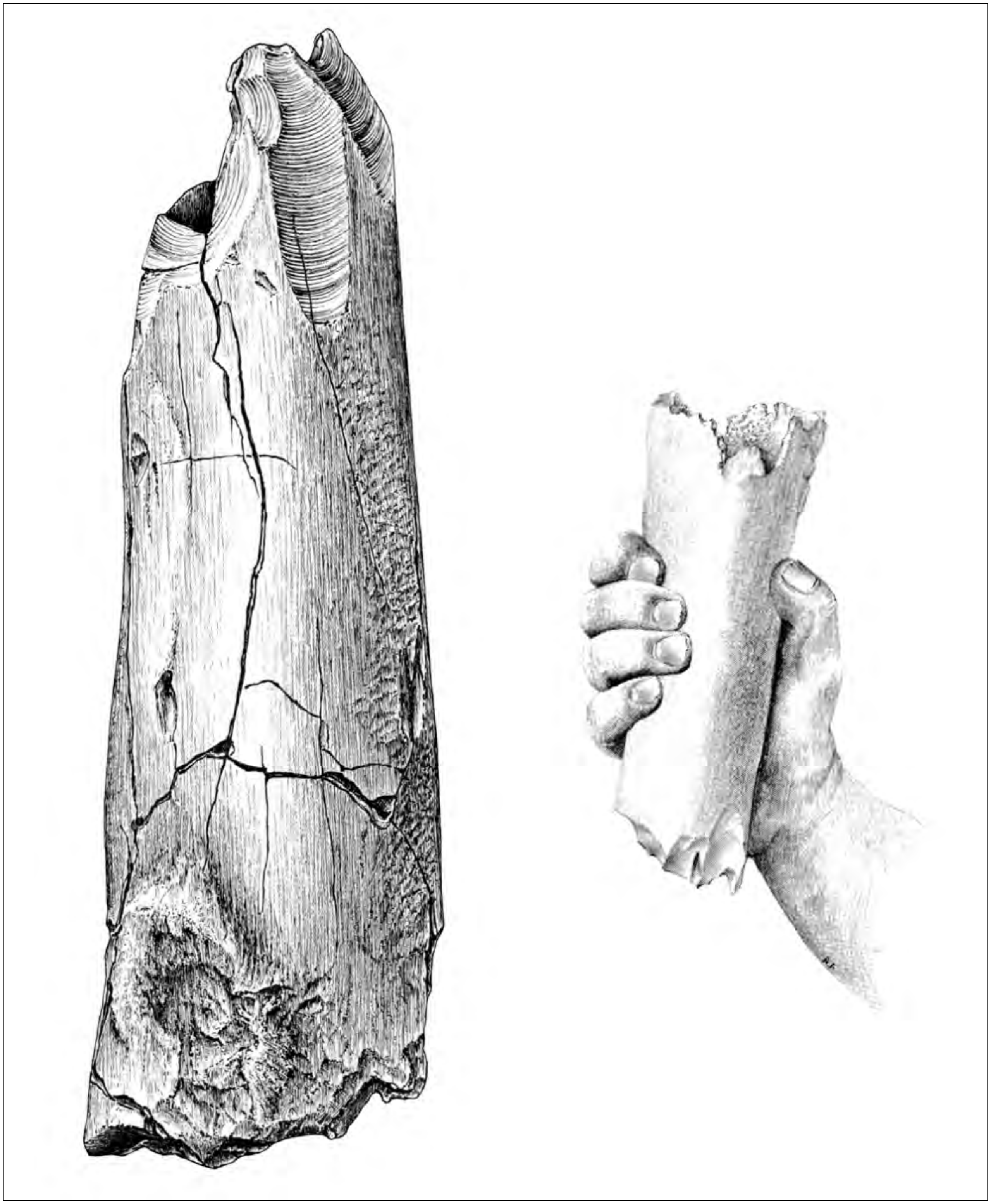

Figure 14. Vallonnet Cave, Roquebrune-Cap Martin, Alpes-maritimes, France. Between 1.7 and 1 million years.
Pre-Oldowan or Archaic Oldowan.
Bison schoetensacki diaphysis fragment that served as a percussion instrument, showing a series of invasive removals.

revealed a reverse geomagnetic polarity allowing to date these deposits to the Upper Matuyama epoch, between one million and 780,000 years ago. Unfortunately, fauna was not preserved: it is therefore difficult to precisely date the site.

A very rich stone tool industry comprising thousands of pieces (Figure 15) was discovered on this shoreline. It is characterized by abundant flake production, almost all obtained from flint pebbles. Cores are numerous, showing use of mainly unifacial, sometimes bifacial and rarely multifacial knapping methods.

Large tools are represented by choppers, most of which show single removal scars, and there are some chopping-tools. Contrary to what one generally observes in archaic Pre-Oldowan industries, flakes from this site sometimes show retouch, at the limit of regular retouch, dominated by notched tools, bringing to mind non-standardized small tools which may have served for cutting meat.

Numerous flakes have been refitted onto one another or onto the cores from which they were extracted, attesting to complete on-site exploitation. These refits help in reconstituting knapping technology used by the artisans at this site. There is a very simple technique using mostly single removals; flakes obtained may sometimes show irregular use retouch. In addition, analysis of spatial distribution of the flakes shows that certain areas of the site were preferred.

The Latium Rift

In central Italy, between Rome to the north and Monte Cassino to the south, the Apennines to the east and the Lepini mountains to the west, the Latium rift was covered with large lakes during the Lower or Middle Pleistocene. Ancient volcanoes were identified along this rift by ashes deposited over time in the Quarternary formations and that allow for radiometric dating. The chemical composition of these ashes makes them characteristic chronological milestones interstratified in the Quaternary deposits.

Archaic stone tools were discovered at several locations by Italian Paleontologists, notably Italo Biddittu, Aldo Segre and Eugenia Segre-Naldini, at Colle Marino, Arce, Fontana-Liri and Castro dei Volsci (Biddittu, 1971, 1972, 1983 and 1984; Biddittu et al., 1992; Cauche et al., 2004). The levels comprising these stone tools are sandwiched between deposits containing Lower Pleistocene faunal remains below and more recent levels above which seem to correspond to eruptive activity known in the Latium. The oldest of these levels has been dated by potassium-argon to 0.7 million years.

It is difficult to date these sites. Because of the acidity of the sediment, fauna has mostly disappeared. However, at Colle Marino, a humerus fragment from a large hyena, *Pachycrocuta brevirostris*, was found, as at Vallonnnet, Barranco León and Fuente Nueva 3.

The prehistoric stone tools of the Latium are characterized by frequent percussion instruments–pebbles or blocks showing traces of percussion activity and pebble tools–as well as numerous flakes and debris. As at Ca'Belvedere, some flakes and debris show retouch that may have been intentional, especially notches.

The Oldowan in Europe

In East Africa, especially at Olduvai, humans voluntarily retouched flakes and fragments to shape them into small tools as early as 1.9 million years ago. The retouch modified the natural edges into notches, denticulates, scrapers and end scrapers. Along with polyhedrons and spheroids, these small tools characterize the Oldowan culture.

Fabrication of such small tools appears much later in Europe (Figure 21), where they appear only around 900,000 years ago. Although present at Olduvai at DK1 (Figure 7) and FLK NN1 (Figures 4 to 6) 1.9 to 1.8 million years ago, they have been identified at some southern European sites, such as at Terrassa in Catalonia around 0.9 million years ago, at Ceprano in Italy (Figure 16) and at Gran Dolina in Spain (Figure 17) only around 0.8 million years ago and again in Italy at La Pineta in Isernia (Figure 18) only around 0.62 million years ago (Figure 20).

The temporal discrepancy (Figure 21) between the emergence of this large cultural horizon in Africa and its appearance in Europe is considerable: one million years. This temporal gap leads one to believe that the spatial diffusion of these new acquisitions was extremely slow. The passage between Pre-Oldowan and Oldowan industries thus marks a new stage in the development of human cognitive capacities and represents an important cultural advancement.

Terrassa, Catalonia, Spain

The Terrassa site in Catalonia, particularly rich in stone industry and in fauna, is located 30 kilometres to the northeast of Barcelona at the edge of a small river, the Val Paradis. It was unearthed in geomagnetically reverse deposits corresponding to the Upper Matuyama. The fauna is slightly more recent than that from Vallonnet and dates the site to around 900,000 years old. It includes a Eurasian jaguar (*Panthera gombaszoegensis*), a gracile rhinoceros (*Stephanorhinus hundsheimensis*), a stenonian horse, a suid close to the one from Vallonnet, a cervid (*Pseudodama nestii vallonnetensis*) and antique elephant (*Elephas antiquus*).

The stone tools include a few poorly worked pebbles, numerous flakes and a few intentionally retouched small tools on flakes or debris.

Ceprano, Latium, Italy

The Campo Grande di Ceprano site is located in central Italy, in the Latium, around 100 kilometres southeast of Rome (Ascenzi et al., 1996 and 1997; Mallegni et al., 2003). The site is of particular interest because a human skull was discovered there in 1994 by Italo Bid-

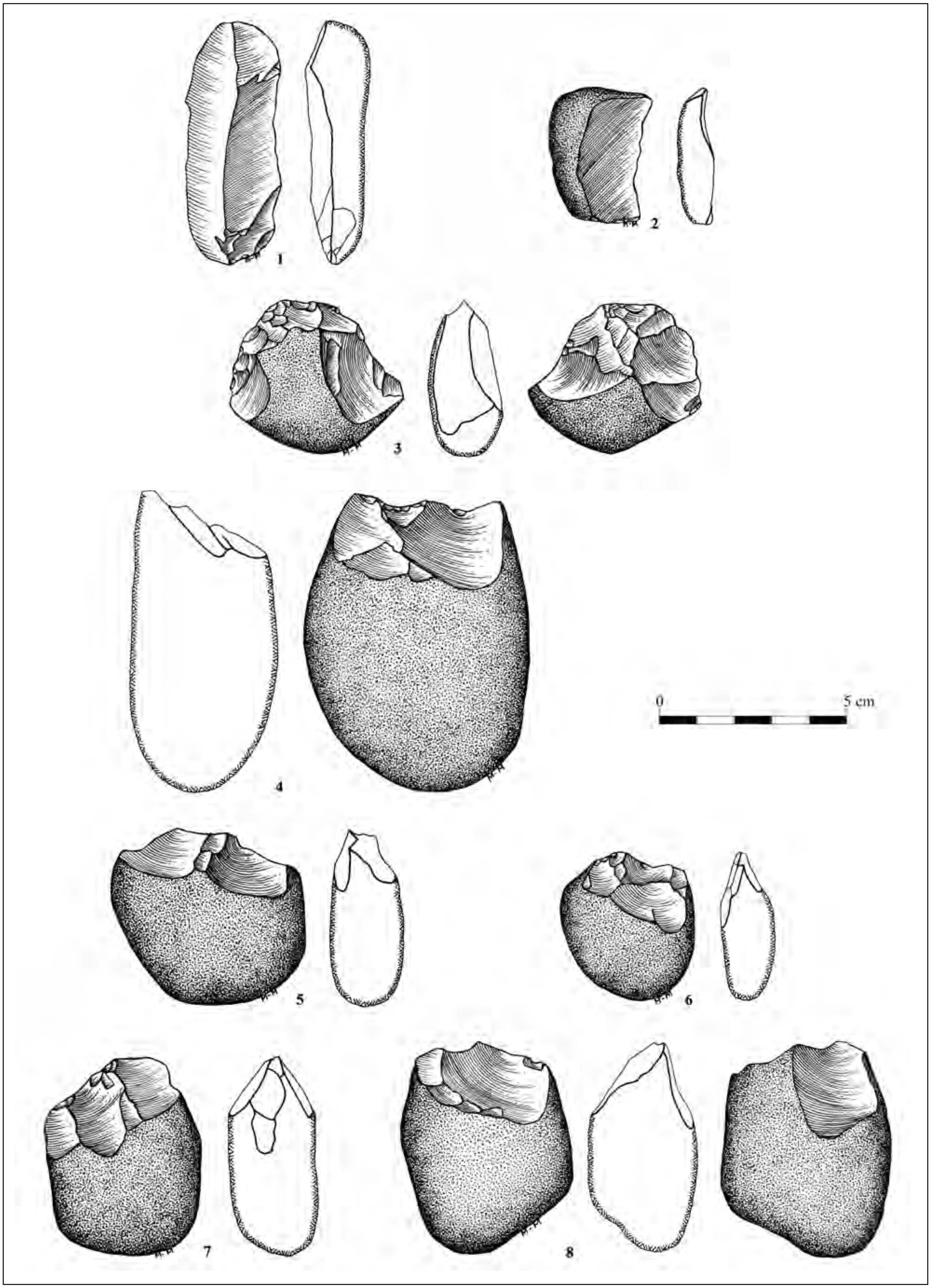

Figure 15. Ca'Belvedere di Monte Poggiolo, Emilie-Romagne, Italy. Around 1 million years. Pre-Oldowan or Archaic Oldowan. *Flint industry.*
1 and 2: flakes; 3: core; 4: chopper; 5 to 8: chopping tools.

dittu. The skullcap was found isolated in clay flows during roadwork, and is the oldest human skull presently known from Mediterranean Europe.

The skullcap was discovered during roadwork, isolated in clay flows. These clayey deposits cover fluvial sand formations, rich in fresh water molluscs. They show reverse geomagnetic polarity and appear to be slightly earlier than the Matuyama-Brunhes dated to 780,000 years ago.

The massive, low skullcap bears relief marks above the orbits and temporal crests. The latter end in a torus showing a parietal postero-inferior angle similar to that observed on most *Homo erectus*. Its morphology is very different from *Homo georgicus* who lived 1.8 million years ago. In spite of a large variability, it appears close to that of the African and Eurasian *Homo erectus*. It is close to the European Anteneandertals (*Homo heidelbergensis*), and thus has been attributed to a new species (*Homo cepranensis)* (Mallegni et al., 2003).

One million years separate *Homo georgicus* from Ceprano Man (*Homo cepranensis*). Is there an evolutionary link between them or did a new population come to Europe from Africa or Asia? The question remains to be answered.

Archaic stone tools were found in association with large mammal bones including elephant (*Elephas antiquus*), rhinoceros (*Stephanorhinus hundsheimensis*), hippopotamus (*Hippopotamus* sp.), cervis (*Pseudodama nestii vallonnensis*).

The lithics (Figure 16) were knapped from a large variety of raw materials–flint, jasper, silicified breccia, quartz, quartzite, limestone–collected as pebbles or plates, and are characterized by a large number of knapped flakes, cores and pebble tools (Cauche et al., 2004). Core reduction was intense with frequent directional changes. Most flakes show little or no cortical residue.

Some flakes or fragments were intentionally retouched into scrapers, denticulates and side scrapers or shaped into notches, becs and short thick points shaped by adjacent notches. These small tools denote a diversity of specialized activities corresponding perhaps to a higher level of cognition for Oldowan humans.

Gran Dolina, TD 6, Atapuerca Siera, Spain

The Gran Dolina site is located in the Atapuerca Sierra, Castille-León Province, near the Sima del Elefante. This huge cavity, like that of the Sima del Elefante, was opened up during railway construction work to build the Trinchera del Ferrocaril (Carbonell et al., 1995 and 2001).

The lower levels (from the base to the top) TD 4, TD 5 and TD 6, immediately underlying the polarity change limit Matuyama-Brunhes, are earlier than 780,000 years old. Level TD 6, familiarly called the "Aurora Strata" is rich in fauna including rhinoceros (*Stephanorhinus etruscus*), elephants (*Mammuthus* sp.), horse (*Equus altidens*), cervids (*Cervus nestii vallonnetensis*, *Cervus elaphus*, *Eucladoceros giulii*), bison (*Bison* cf. voigtstedtensis) and large carnivores such as saber-toothed tigers (*Homotherium latidens*), Eurasian jaguar (*Panthera gomaszoegensis*), lynx (*Lynx* sp.), as well as very numerous rodents (*Allophaiomys chalinei*, *Pliomys espiscopalis*, *Mimomys savani*). This faunal ensemble is characteristic of the end of the Lower Pleistocene (800,000 years).

Nearly a hundred human remains were discovered in this level, including a frontal, a maxillary, a mandible, a parietal and numerous teeth and post-cranial elements: ribs and vertebra. All of these bones come from six individuals; two children , two adolescents and two young adults.

Some traits allow to characterize them: they are relatively slender, there is a depression on the maxillary, their tooth relief is relatively complex with numerous cusps and deep grooves, and the molars have multiple roots. These characteristic traits led Jose Bermudez de Castro, Juan Luis Arsuage and Eudald Carbonell to name them *Homo antecessor* (Carbonell et al., 1995).

These fragmentary human remains show striation marks from meat removal and spiral-type fractures typical of fresh bone breakage. It would appear that the site was a lair for hominids who scavenged large herbivore and human remains, more specifically young individuals.

The stone industry (Figure 17) discovered among these human and faunal remains was knapped from diverse rocks: limestone, fine and coarse grained quartzite, quartz, flint and sandstone. They must have been collected as pebbles or blocks.

Flakes dominate, indicating an important knapping activity. Cores are also numerous, confirming the latter hypothesis. Knapping was almost exclusively done using hand held percussion in several directions: centripetal, orthogonal or simply unipolar. The few flakes showing intentional retouch (Figure 17, n^{os} 4 to 6) to make scrapers and denticulates or to shape notches, link this assemblage to the Oldowan.

La Pineta, Isernia, Italy

The La Pineta site, south of the town of Isernia in the Molise Province of central Italy, is located 150 kilometres to the northeast of Naples (Peretto, 1994). The natural Isernia basin constitutes a vast depression once occupied by a large lake at the beginning of the Quaternary period. A thick layer of white lacustrine clays were left by the lake and then covered by sand and gravel. Travertine is interstratified at the top of this formation. Several layers containing volcanic ash allow to precisely determine the age of this site.

In the sand and gravel layers with travertine, two archeological levels rich in fauna and stone industry were uncovered over a large area by Carlo Peretto. Radiometric dates using two argon isotopes (^{40}Ar /^{39}Ar) enable to attribute an age to these two archeological levels of between 620,000 and 604,000 years. The clayey upper levels, situated above the archeological layers, have been dated to 504,000 and 474,000 years. The very abundant

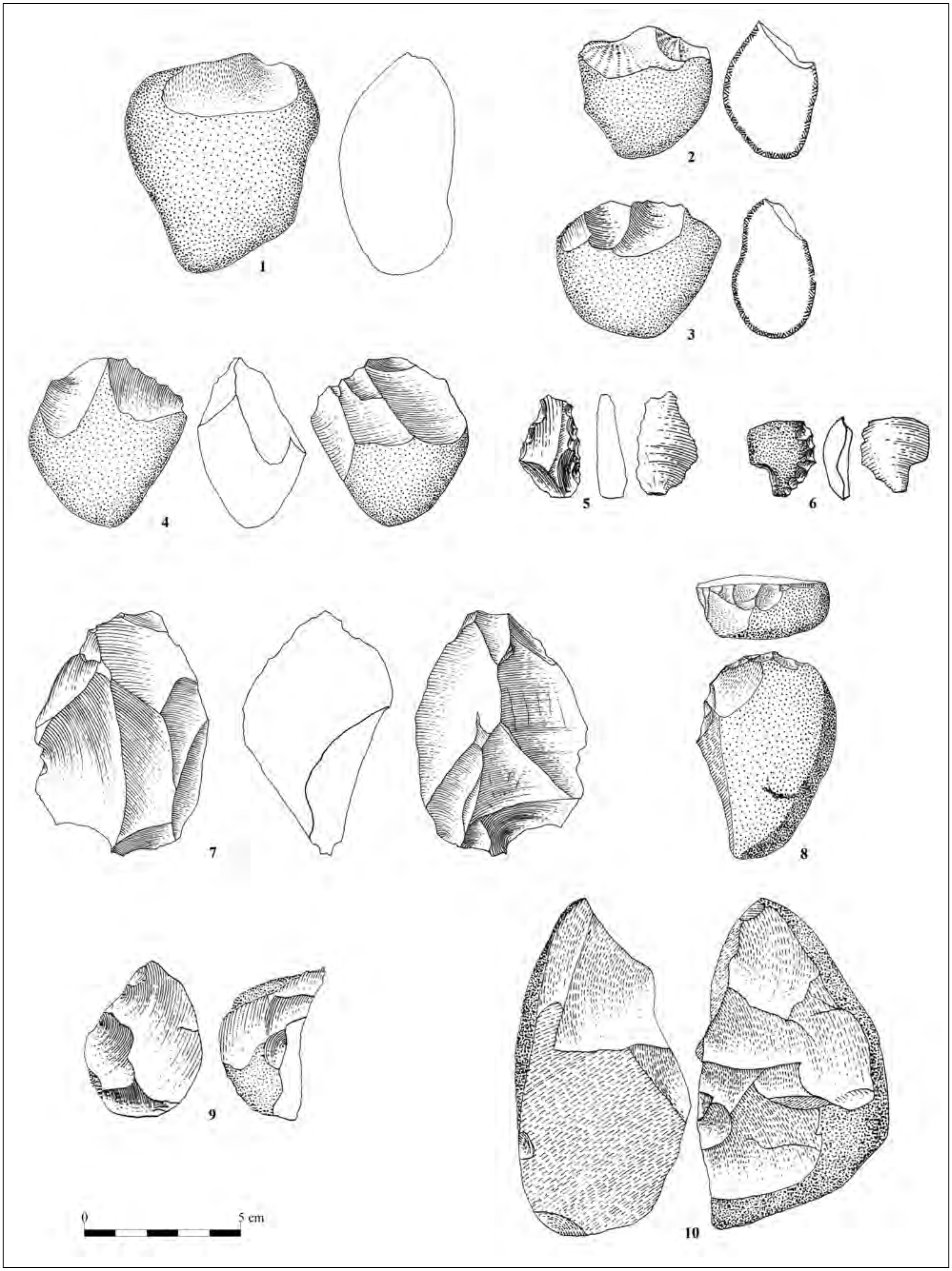

Figure 16. Campo Grande di Ceprano, Latium, Italy. Around 800,000 years. Oldowan sensu stricto or Classical Oldowan. *Industry in diverse rock types.*

1: pebble with an isolated concave removal negative (primary chopper); 2 and 3: choppers; 4: chopping tool; 5 and 6: denticulated scrapers; 8: end scraper; 7, 9 and 12: cores.

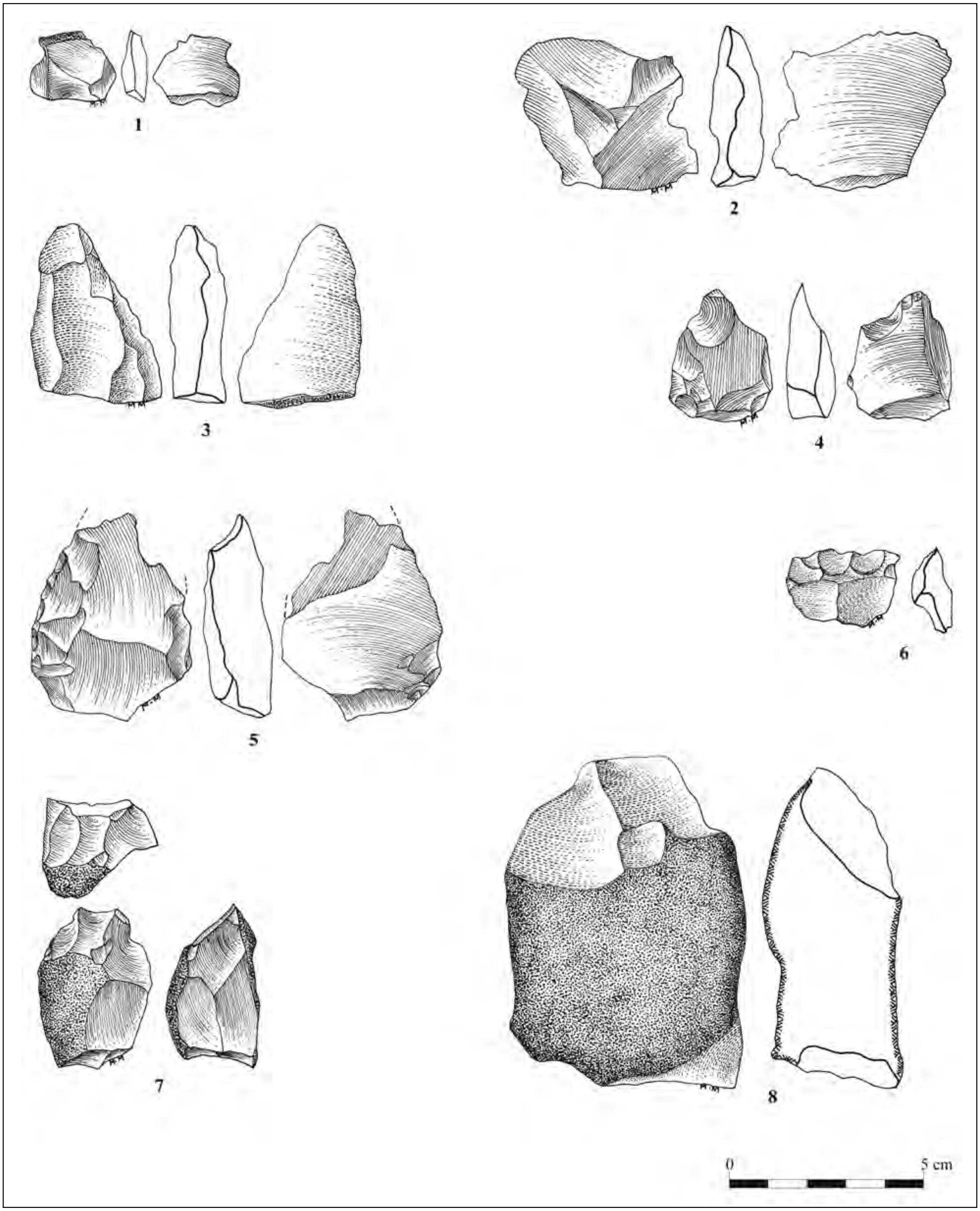

Figure 17. Atapuerca, Gran Dolina, level TD 6, Castille León, Spain. Around 800,000 years. Oldowan sensu stricto or Classical Oldowan.
1 to 3: flakes; 4 notched tool; 5: scraper; 6: denticulate; 7: core; 8: chopper.

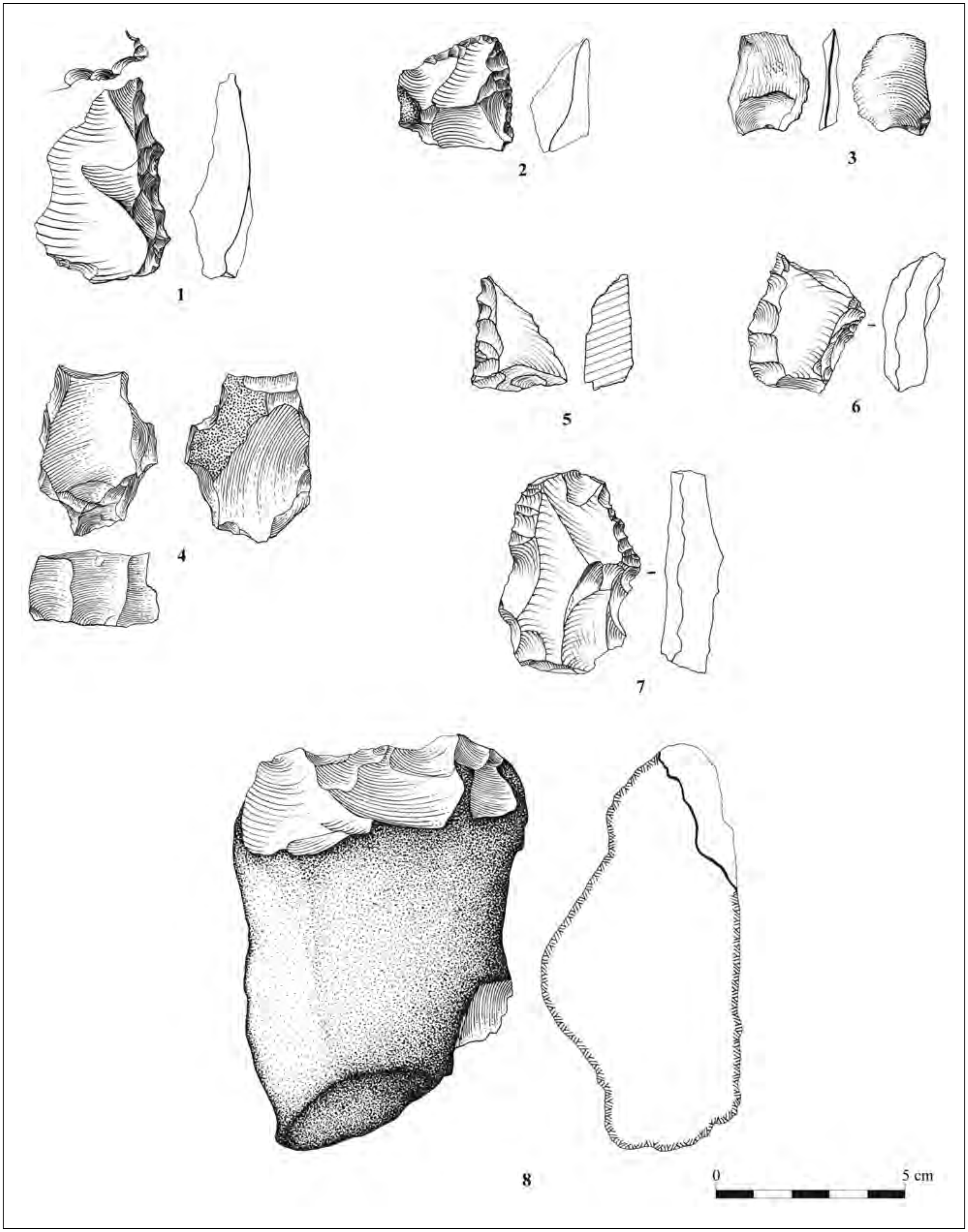

Figure 18. La Pineta, Isernia, Molise Province, Italy. 620,000 years. Flint industry.
1 and 6: denticulated scrapers; 2: double convex edged dejeté *scraper; 3: flake produced from another flake; 4: core; 5: scraper; 7: denticulate; 8: chopper.*

fauna includes bison (*Bison schoetensacki*), rhinoceros (*Stephanorhinus hundsheimensis*), elephants (*Elephas (Palaeoloxodon) namadicus*), bear (*Ursus deningeri*), hippopotamus (*Hippopotamus* cf. *antiquus*), wild boar (*Sus scrofa*), small bovids (*Hemitragus* cf. *bonali*), cervids (*Megaloceroides solilhacus, Cervus elaphus acoronatus, Dama dama* cf. *clactoniana, Capreolus* sp.) and a large feline, the lion (*Panthera leo fossilis*). This fauna is characteristic of the morphological species evolution at the beginning of the Middle Pleistocene.

Within this faunal assemblage, numerous cervid bones and the presence of hippopotamus remains suggest a humid forest landscape.

The stone tools from this site (Figure 18) are very numerous, with several thousand pieces. The products were essentially knapped from flint and some limestone. Two main operative schemas may be distinguished. For the shaping of pebble tools, humans chose limestone, but they preferred flint for knapping flakes. Pebble tools are relatively rare but well made. Flakes are most numerous in the assemblage. Most of the flintknapping took place using bipolar on an anvil technique but hand held knapping was also practiced. Unidirectional percussion predominates, without excluding the use of bipolar percussion. Many flakes were further reduced as cores.

This industry is characterized by intentionally retouched small tools, mainly on flint flakes. The collection includes mainly notched tools, scrapers and end scrapers. This making of small tools on flakes (Figure 18, n°s 1, 2, 5 and 7) by successive notches or continuous raised retouch, that is to say, wide, concave and sub vertical or more or less abrupt micro removals, is one of the principal traits of the la Pineta assemblage. This type of shaping is practically unknown in more archaic industries (Pre-Oldowan) but present in Classical Oldowan.

Most of the bones, dispersed over a large surface area, are broken and rarely found in anatomical connection. They often show intentional fractures (on fresh bone) for marrow extraction. Striation marks on the bones indicate that meat was cut off of them. Some bison, elephant and rhinoceros skulls were opened, suggesting that the brains of these large herbivores were consumed. It appears that this was a scavenging site where humans were attracted by the carcasses of drowned animals. The pebble tools may have served for butchery activities such as disarticulating large herbivore carcasses, while the flakes and small tools may have served to remove and cut up flesh.

No particular spatial pattern has been detected at the site. An accumulation of travertine blocks surrounded by flint flakes may suggest a natural area where hominins could have withdrawn to a dry place after having scavenged in the surrounding muddy swamps.

Conclusions

In East Africa, stone industries earlier than 1.9 million years present common characteristics. They are essentially knapped from quartz or volcanic rocks, raw materials collected close to the sites. Most of the knapping was realized by hand held technique, using unifacial, unipolar knapping, or sometimes multipolar or centripetal removals. Bifacial knapping was rare. Multipolar orthogonal knapping was also used. Bipolar knapping on an anvil was quite often used (Omo 57, Omo 123, FtJi1, FtJi2, FtJi5, Fejej FJ-1) (de Lumley et al., 2004; de Lumley, 2006 and 2007). It is important to underline that bipolar on an anvil knapping was not necessarily a poorly mastered technique but rather the best way to extract flakes or fragments from small pebbles in crystalline rocks. Methods and techniques of flake production are often tied to the quality of raw materials and to initial block or pebble morphology. Generally, cores were abandoned after the extraction of a few flakes, especially when raw materials were of poor quality. Nonetheless, when rocks were of fine quality, for example fine grained basalt, reduction sequences were longer, up to fifty flakes for a core at Lokalalei 2C. The apparent technological differences between these assemblages reflect, for a large part, differences in available raw materials. Relative availability of raw materials in the immediate environment of each site, their nature, morphology and the size of available pebbles or blocks, conditioned the technological characteristics of each lithic series.

The lithic assemblages are mainly composed of non-modified flakes, some cores and pebble tools, mainly choppers and rare chopping-tools. For these sites flake production seems to have been the main objective of the knappers. The non-modified flake edges are sometimes chipped, indicating their use. Flakes are often broken as a result of the violent blows using a hard percussion instrument, either by hand held or bipolar on anvil techniques. Flakes obtained were small and often present knapping accidents: longitudinal breaks along (Siret type accidents) or parallel to the knapping axis, or breaks that are transversal or oblique to that axis.

Industry from these sites whose age is between 2.55 to 1.90 million years old present the following common characteristics :

- local rock selection
- choice of raw materials for which the best ones were more exhaustively knapped
- selectivity in choosing pebble or block morphology
- presence of numerous percussion instruments
- well-mastered rock fracture
- use of both hand held and bipolar knapping on an anvil techniques
- presence of pebble tools, generally unifacial (choppers) and pebbles with single removals (primary

choppers) probably used for disarticulating animal carcasses

- parallel use of several well mastered knapping strategies and, mainly unifacial knapping using unidirectional removals, more rarely multipolar or centripetal and sometimes bifacial or multifacial orthogonal knapping. The methods used generally follow a least effort strategy
- dominance of unifacial cores
- abundance of non-modified knapping products (flakes, fragments and cores)
- dominance of non-modified flakes, generally small sized and without pre-determined form, probably used for cutting meat
- abundance of flakes broken from knapping with violent blows
- frequency of remnant cortex on flakes whose striking platforms are also most often cortical or non-prepared
- absence or extreme rarity of small intentionally retouched tools on flakes or fragments
- a high proportion of irregular marginal micro-retouch on flake, debris, pebble tool and broken pebble edges, especially dense notches.

We have proposed (de Lumley et al., 2004; de Lumley et al. 2005; de Lumley, 2006 and 2007) to group together these archaic industries under the name *Pre-Oldowan* (or *Archaic Oldowan*) to designate lithic assemblages which are characterized by the absence or extreme scarcity of small retouched tools. The term *Pre-Oldowan* does not designate here a single homogenous, autonomous and well defined culture, but simply a cultural evolutionary stage where standardized, stereotypical small tools on flakes and fragments with retouch that modifies the original form of their edges are not yet made while such tools are present in the Oldowan levels DK 1 (1.9 myrs.) and FLK NN (1.8 myrs.) at Olduvai, where there are a relatively significant amount of true end scrapers, scrapers and denticulates made from quartz (Figures 4 to 7), associated with polyhedrons and spheroids (Leakey, 1971; de la Torre and Mora, 2005).

In a large sense it is possible to distinguish two stages of Oldowan that are probably tied to the level of cognition attained by early humans.

1. the *Pre-Oldowan* or *Archaic Oldowan*, like at Gona EG 10 and EG 12, Ounda Gona OGS-6 and OGS-7, Lokalalei or Fejej FJ-1, sites with an age between 2.5 and 1.9 million years, where stone industries are characterized by the dominance of non-modified flakes, mostly unifacial cores, some pebble tools, numerous percussion instruments and the absence of standardized small retouched tools on flakes or debris.
2. The *Oldowan s. s. (sensu stricto)* or *Classical Oldowan*, like at Olduvai DK 1 and FLK NN 1, with an age of between 1.9 and 1.6 million years, also characterized by the dominance of non-modified flakes, presence of unifacial and sometimes bifacial cores, pebble tools, percussion instruments, and where standardized small retouched tools appear (end scrapers, scrapers, denticulates), as well as polyhedrons and spheroids.

Pre-Oldowan industries are characterized by a very strong dominance of non-modified flakes, a large proportion of cores, the presence of pebble tools, a relative abundance of percussion instruments and the absence of standardized intentionally retouched small tools. They correspond with an early stage of hominid cultural evolution whose degree of cognition did not yet allow them to realize specific small sized tools or for relative standardization in their tool manufacture.

The term *Pre-Oldowan* is a practical denomination to designate a cultural horizon whose technological and typological characteristics are more archaic than those of the Oldowan s. s. or Classical Oldowan and correspond to comparative behaviour between diverse groups of hominids living in East Africa between 2.55 and 1.9 million years ago.

Outside of Africa, archaic Pre-Oldowan industries are present at Yiron in the Levant, as early as 2 million years ago and at Dmanissi in Georgia 1.81 million years ago.

They are present in Mediterranean Europe as early as 1.2 million years ago at Barranco León and at Fuente Nueva 3 in Andalucia, as early as 1.1 million years ago at La Sima del Elefante in the Atapuerca Sierra, between 1.07 and 0.984 million years ago at the Vallonnet Cave site in the Alpes-Maritimes and at Ca'Belvedere di Montepoggiolo in Italy around 1 million years ago.

An important time-lag thus separates these assemblages from Classical Oldowan assemblages in East Africa and Mediterranean Europe where standardized small retouched tools on flakes or fragments were sometimes made, as well as spheroids: DK 1 at Olduvai around 1.9 million years ago, FLK NN 1 at Olduvai around 1.8 million years ago, Terrassa in Catalonia around 0.9 million years ago, Ceprano in Itay and Gran Dolina TD4 TD 5 and TD 6 in Spain around 0.8 million years ago and at la Pineta at Isernia around 0.65 million years ago.

The large chronological gape separating the emergence in Africa of these major cultural horizons tied to the development of cognitive capacities of hominids and their presence in Europe bring to light the very slow spatial diffusion of these new cultural acquisitions.

If all these archaic stone industries, called here Pre-Oldowan or archaic Oldowan, whose technological and typological characteristics correspond to the earliest stage of human cultural evolution tied to the attainment of a certain cognitive level, are very similar, they may nonetheless present a certain variability conditioned by the environment and human adaptation to milieu.

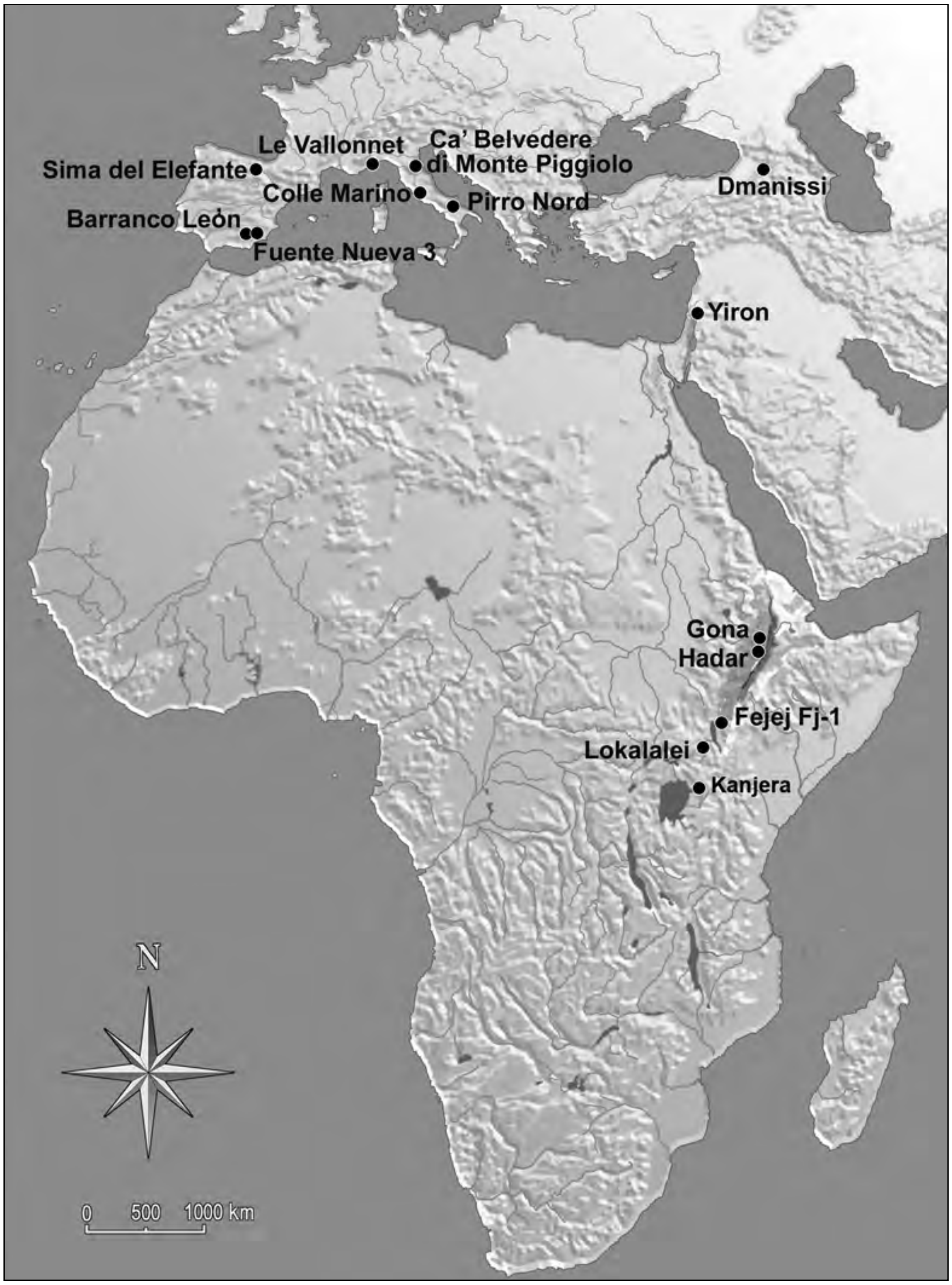

Figure 19. Sites with Pre-Oldowan *or* Archaic Oldowan *type industries, without small, intentionally retouched tools, corresponding to a behavioural and cognitive parallelism.*

Thus the industry from Gona EG 10 and EG 12 was essentially knapped from trachyte, rhyolite and basalt pebbles of excellent quality abundant in the Gona alluvials, those from Fejej FJ-1 in quartz pebbles relatively numerous in the alluvials of water courses from the Hamar mountain range, those from Dmanissi in various rock types from the Mashavera and Pinezaouri rivers, while those from Barranco León and Fuente Nueva 3 were made from flint nodules from nearby Jurassic limestone bordering the Guadix-Baza basin (Celiberti et al., 2004; de Lumley et al., 2005).

Well made pebble tools are quite well represented at Gona EG 10 and EG 12, at Fejej FJ-1 and at Dmanissi, but are very rare in the Barranco León and Fuente Nueva 3 assemblages because of the absence of alluvial layers with pebbles in the environment near the sites. Pebbles are replaced by Jurassic limestone blocks whose edges show irregular use wear attesting to their use as cutting instruments.

A common structure between lithic assemblages is tied to a specific cognitive level, where non-modified small flakes dominate, most probably used for cutting or scraping meat off bones abandoned by scavengers, and by the absence or extreme scarcity of small retouched tools on flakes or fragments, but a relative variability due to environmental constraints; thus may be viewed the ar-

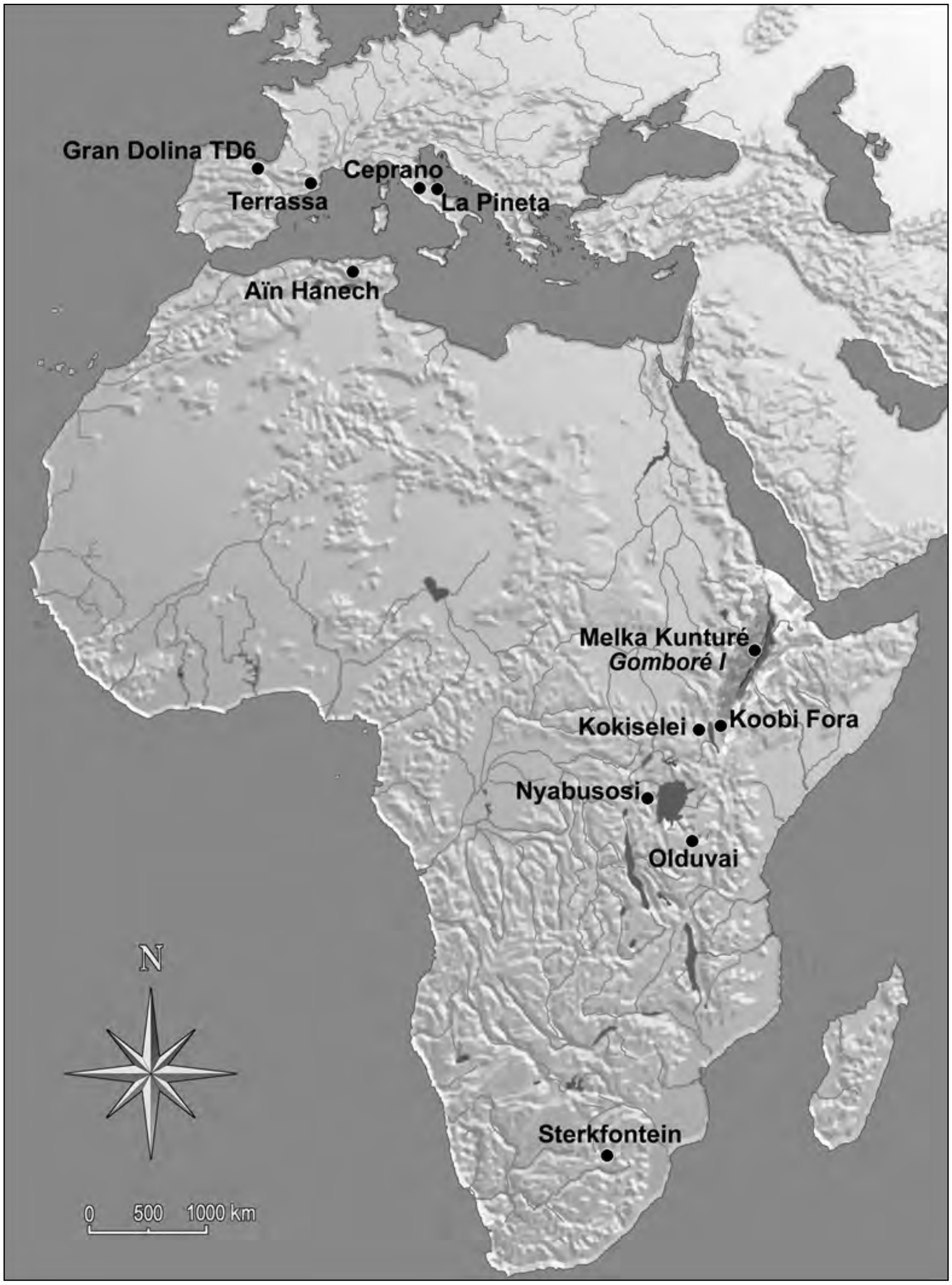

Figure 20. Sites with Oldowan sensu stricto *or* Classical Oldowan *type industries, with small, intentionally retouched tools, corresponding to an identical behavioural and cognitive stage.*

chaic stone industries from East Africa up to the shores of Mediterranean Europe.

With the emergence of conceptual thought as early as 2.55 million years ago, hominids were capable of conceiving and manufacturing a model. That model was small non-modified flakes for cutting up meat or pebble tools for slicing. With the slow conquest of the world by early humans, this cognitive capacity was to be diffused up to the gateways of Europe, at Dmanissi 1.81 million years ago and in Mediterranean Europe, in the Guadix-Baza basin at Barranco León and Fuente Nueva 3 and the Sima del Elefante at Atapuerca 1.2 million years ago.

Pre-Oldowan lithic assemblages, as well as the Oldowan lithic assemblages which followed them in time, each correspond to behavioural and cognitive parallelisms of hominids groups present in diverse regions of the world and that may be largely separated in time (Figure 21).

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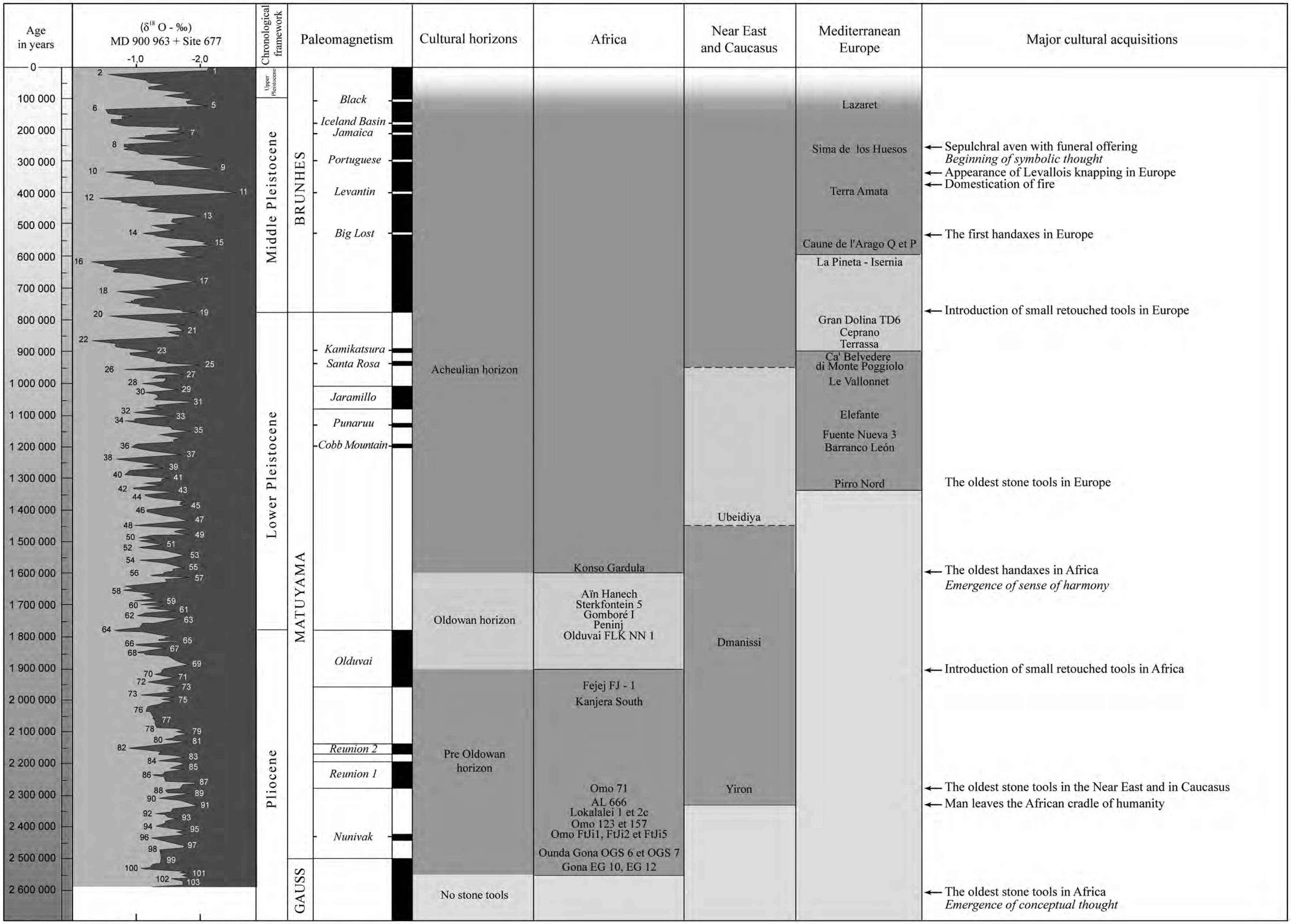

Figure 21. Main major cultural sequences in Africa, the Near East, Trans Caucasia and southern Europe in their geochronological and paleoclimatic Quaternary framework. Important temporal gaps separating the emergence of different cultures, corresponding to identical behavioural and cognitive stages tied to a certain cognitive level, may be observed in different large regions of the world.

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CHAPTER 5

TECHNOLOGICAL STRATEGIES IN THE LOWER PLEISTOCENE AT PENINJ (WEST OF LAKE NATRON, TANZANIA)

IGNACIO DE LA TORRE

ABSTRACT

This chapter summarizes the lithic technology of two areas from Peninj, the North Escarpment and the Type Section. The purpose of this work is to introduce a comparative overview of the technological strategies in both regions. Such strategies may be studied from two prospects, that of the core reduction sequences, and through the understanding of lithic resources management in the landscape context. Combining both perspectives, hominin adaptations in the Lower Pleistocene at Peninj are explored, as well as the cultural status of the analyzed sites.

INTRODUCTION

As yet, three archaeological areas have been recognized at Peninj (Figure 1); the North Escarpment, the Type Section and the South Escarpment. Situated 8 km away from the Type Section, the North Escarpment is the most distant area from Lake Natron. In this location, Isaac (1965, 1967) excavated RHS (named afterwards Mugulud, Isaac n.d.). The South Escarpment is situated over the Sambu Escarpment, about 4 km southwest from the Type Section. Isaac (1965, 1967) excavated there the Acheulean site of MHS (afterwards named Bayasi, Isaac nd). The third area is the Type Section (named by Isaac as Maritanane), in which the Peninj delta flowed during the Lower Pleistocene. Recent works at Peninj have been focused on the Type Section, with papers already published on its palaeoenvironments, technology and zooarchaeology (Domínguez-Rodrigo et al., 2001, 2002; Mora et al., 2003; de la Torre & Mora, 2004; de la Torre et al., 2003, 2004).

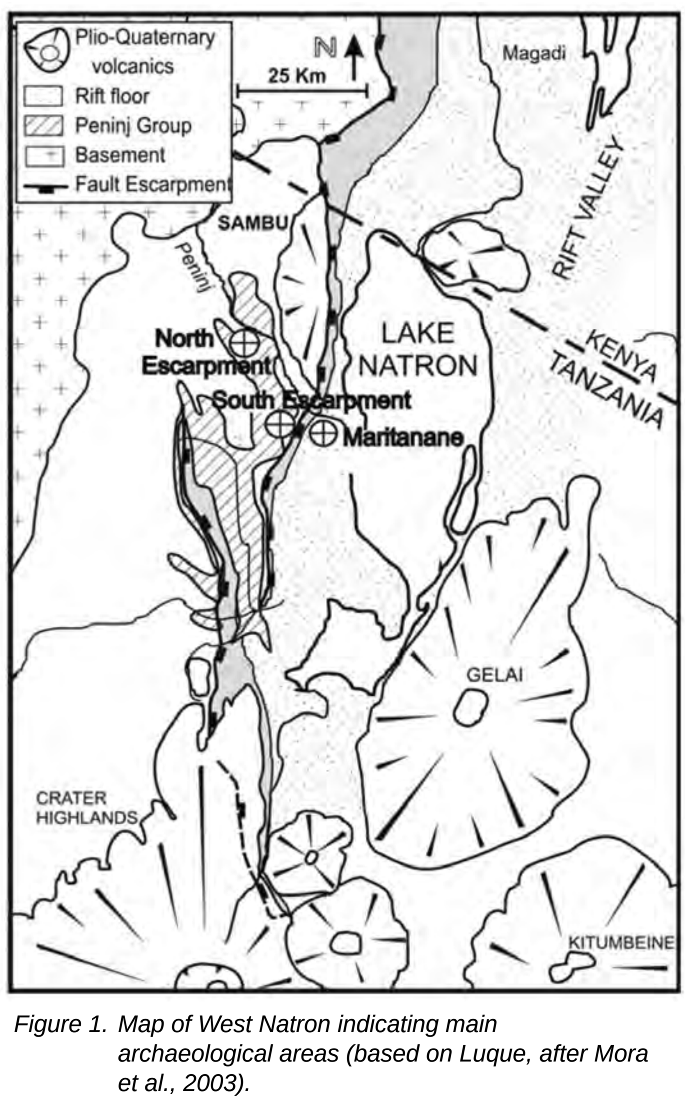

Figure 1. Map of West Natron indicating main archaeological areas (based on Luque, after Mora et al., 2003).

This work summarizes technological and cultural features from two of these zones, North Escarpment and Type Section. Up to now, the North Escarpment was only known by the short descriptions that Isaac (1965, 1967) provided on the site originally named RHS. Nonetheless, artefacts recovered by Isaac were not studied systematically until de la Torre´s (2004) review, in which preliminary results of new excavations at the site were presented. Previous publications on the technology of the Type Section (de la Torre & Mora, 2004; de la Torre et al., 2003, 2004) were restricted to the so-called ST site Complex (Domínguez-Rodrigo et al., 2002), which is just a small area within the Type Section. Following de la Torre´s (2004) study of materials at North Escarpment including Isaac´s collections and artefacts from modern excavations and at Type Section adding unpublished data from the ST Site Complex and further assemblages from this area the purpose of this work is to introduce a comparative overview of the technological strategies in both regions. Such strategies may be studied from two perspectives, that of the core reduction sequences and through the understanding of lithic resource management in the landscape context. Combining both perspectives, an exploration is possible of hominin adaptations in the Lower Pleistocene at Peninj as well as of the cultural status (Oldowan vs. Acheulean) of analyzed sites.

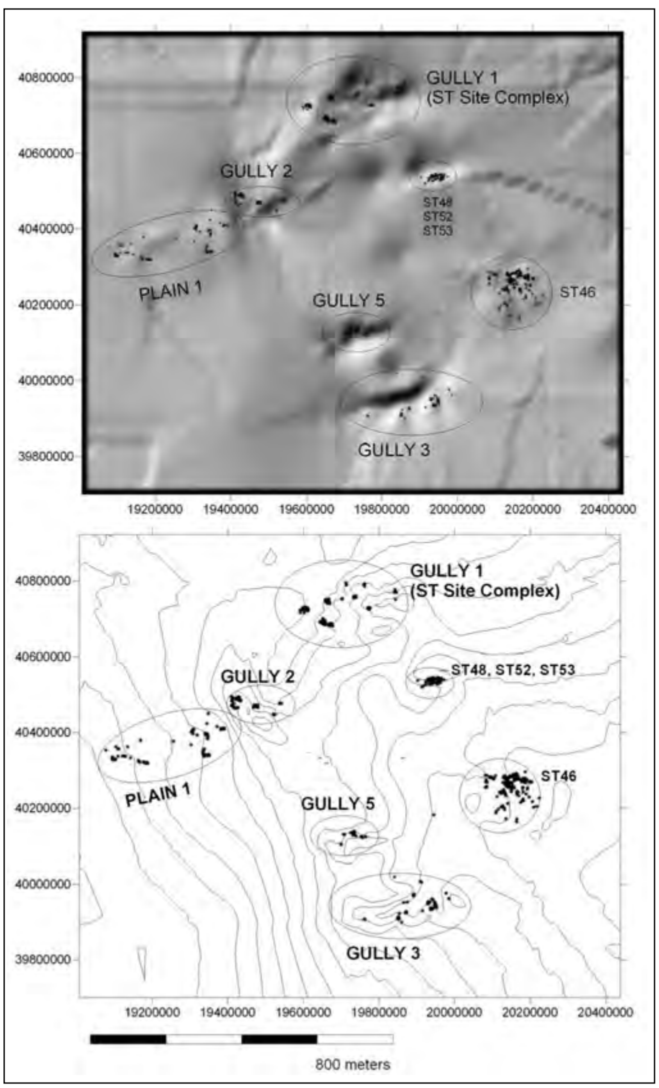

Figure 2. Location of sites in Maritanane.

Stratigraphic and Archaeological Contexts

Most of the archaeological and palaeontological sites at Peninj are located in the Upper Sandy Clays (USC) of the Humbu Formation, which are widely distributed across much of the Peninj Group outcrops, both over the Sambu Escarpment (in which North and South Escarpments are located) and in the Type Section (Maritanane area). Thickness of USC Member is variable, ranging between 4 and 20 m. The base of the Moinik Formation (which is just overlying Humbu Formation) has been dated between 1.37 myr (Isaac & Curtis, 1974) and 1.33 (Manega, 1993), suggesting an average age for

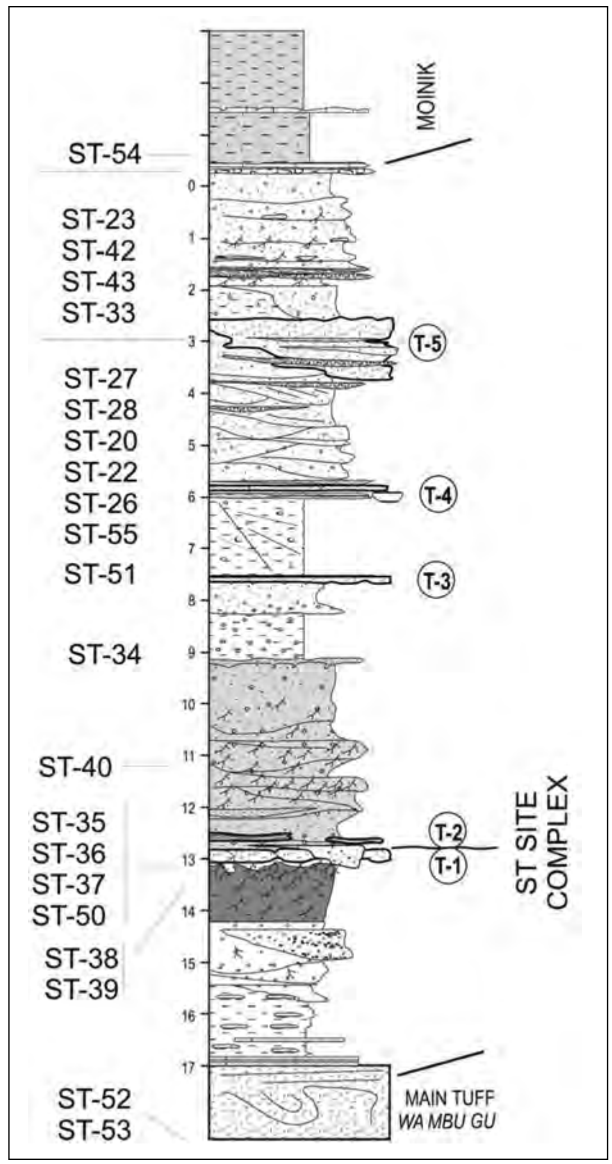

Figure 3. Stratigraphic column of the Upper Sandy Clays with position of mentioned sites in this chapter (based on Luque, after de la Torre, 2004).

sites in the Peninj USC of 1.5-1.4 myr.

In the Maritanane/Type Section, the most relevant area is the so-called ST Site Complex, situated in an upper position of the USC. The ST Site Complex is the densest patch of archaeological remains at the Type Section, also being the most homogeneous in stratigraphic terms, with all archaeological sites situated just above Tuff 1 see a detailed description in Mora et al., 2003. Nonetheless, in the Type Section there are also other gullies in which the Humbu Formation is exposed (Figure 2). In these outcrops bone and artefact densities are lower than in the ST Site Complex. These occurrences are mostly in sediments overlying the Main Tuff, and are located at a range of stratigraphic positions, at the level of the ST Site Complex, but also with some below and many above this horizon. Therefore, small artefact scatters have been identified in localities above Tuff 2, Tuff 4, Tuff 5 (Figure 3) and even in sediments from the Moinik Formation (de la Torre, 2004).

Density of each site is variable within Maritanane (Table 1); only assemblages above Tuff 1 (i.e. sites from the ST Site Complex and ST37, in Gully 2) have substantial numbers of stone tools. Excluding assemblages with artefacts from mixed stratigraphic levels (ST46 and ST48), the rest of the "STs" showed in Table 1 are just surface scattered stone tools which do not constitute archaeological sites as such. To sum up, there are only a few archaeological patches in the area known as the ST Site Complex (most of them actually surface concentrations), and a surface scattering of isolated fossils and stone tools is dispersed through the rest of the Type Section. Therefore, in Maritanene there are no further equivalents to the ST Site Complex, neither in terms of density nor total number of items. In spite of documenting bones and/or scattered artefacts in every outcrop from the USC (although usually on the surface and not in stratigraphy), in the Type Section those remains are dispersed across the landscape, not making conspicuous patches. Beyond Gully 1 (ST Site Complex), the denser patches of bones and stone tools are located in Gully 2 and Plain 1, although these do not reach the volume of materials found at the ST Site Complex. At any rate, it may be interesting to point out that several of the scatters above Tuff 1 show technical features very similar to those from the ST Site Complex, formerly considered as Oldowan (de la Torre et al., 2003).

No further sites associated to Tuff 1 have been recorded yet at Maritanane. Besides small scatters such as ST41, ST51, ST52 and ST53, the rest of the assemblages are clearly Acheulean. Both in Gully 3 and Gully 5, situated stratigraphically on the top of the Humbu Formation (below and above Tuff 5), the scarce stone tools found so far are handaxes and knives typical of Mode 2. Those artefacts, alongside the handaxes recorded at ST46 and

Table 1. Lithic collections from Peninj analyzed in this work.

Site	Number of pieces	Stratigraphic position	Area
ST51	3	Below Wambugu Tuff	Maritanane
ST52	7	Below Wambugu Tuff	Maritanane
ST53	2	Below Wambugu Tuff	Maritanane
ST38	3	Below T-1	Gully 2
ST15	12	Above T-1	ST Site Complex
ST2A	7	Above T-1	ST Site Complex
ST2C-E	146	Above T-1	ST Site Complex
ST2D	3	Above T-1	ST Site Complex
ST2G	5	Above T-1	ST Site Complex
ST3	71	Above T-1	ST Site Complex
ST30	86	Above T-1	ST Site Complex
ST31-32	70	Above T-1	ST Site Complex
ST4	91	Above T-1	ST Site Complex
ST6	11	Above T-1	ST Site Complex
ST35	6	Between T-1 and T-2	Gully 2
ST36	16	Between T-1 and T-2	Gully 2
ST37	54	Between T-1 and T-2	Gully 2
ST50	7	Between T-1 and T-2	Gully 2
Plain 1	13	Between T-1 and T-2	Gully 2
ST40	6	Above T-2	Gully 2
ST34	15	Between T-2 and T-3	Gully 2
ST20	4	Below T-5	Gully 3
ST22	3	Below T-5	Gully 3
ST55	2	Below T-5	Gully 3
ST28	2	Below T-5	Gully 4
Gully-5	2	Below T-5	Gully 4
ST33	4	Above T-5	Gully 2
ST23	2	Above T-5	Gully 3
ST42	8	Above T-5	Gully 3
ST43	3	Above T-5	Gully 3
ST54	11	Moinik	Maritanane
Gully-3	3	Indetermined	Gully 3
ST46	96	Mixed	Maritanane
ST48	30	Mixed	Maritanane
Mugulud (EN1)	508	Above Wambugu	North Escarpment

ST48, suggest that during the sedimentation of the upper part of the Humbu Formation, transporting of large cutting tools to the delta of the Peninj river was a recurrent behaviour. Raw material types and the big size of blanks among handaxes suggest that their catchment area was distant from Maritanane, contrasting with the small cores and flakes found at the ST Site Complex. This tendency towards an input of high-quality basalts and big sized blanks increases in a site placed in the overlying Moinik Formation, at ST54, huge flakes in fine-grained lava have been shaped through systematic soft-hammer *façonnage*, to produce finely trimmed bifaces.

It is not well understood when and how input of handaxes to the Type Section started, although it does seem that at the top of the Humbu Formation this became a systematic pattern. Whether this is due to diachronic issues (the ST Site Complex underlies sites from Gully 3, Gully 5 and Moinik Formation) or to a change in the use of landscape is still a rather difficult question to address.

The scattered distribution of several sites with low densities of archaeological remains at the Type Section contrasts with the pattern observed in the North Escarpment, in which there are very few sites across the landscape (Figure 4); RHS-Mugulud (named recently as EN1), already discovered by Isaac, is the only relevant site recorded as yet. Further assemblages such as EN2, EN3, EN4 and EN5, in the surrounding area of Mugulud (see Figure 4), bear far fewer artefacts than the latter. Being the single significant site in the North Escarpment, Mugulud is particularly relevant since in this specific part of the landscape there is an outstanding concentration of stone tools. Therefore, in less than 200 square meters and in a discrete temporal span (on the top of the Humbu Formation or perhaps at the base of the Moinik Formation), this single site contains more than 160 kilograms of lithic materials. On the contrary, in the entire Type Section–a region with several square kms and with archaeological evidences across all the upper half of the Humbu Formation–aggregates total slightly more than 80 kilograms of stone tools. This significant imbalance among the Type Section and North Escarpment may be considered from two complementary points of view, technology and use of landscape. Both will be reviewed in forthcoming sections, as well as the debate on the status of those industries, clearly Acheulean at Mugulud, but not as obviously Oldowan in the Type Section, such as suggested by de la Torre et al. (2003).

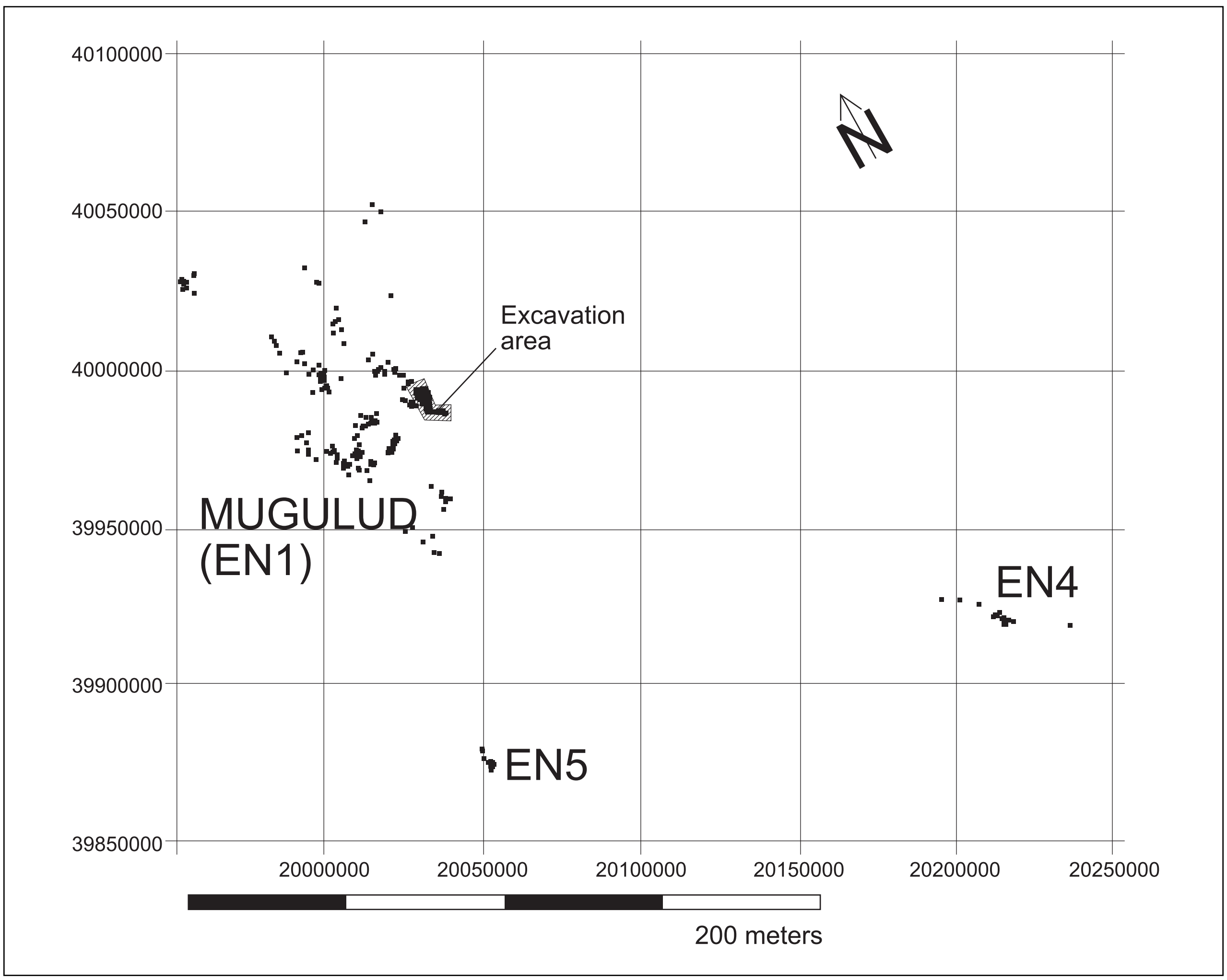

Figure 4. Location of main sites in the North Escarpment.

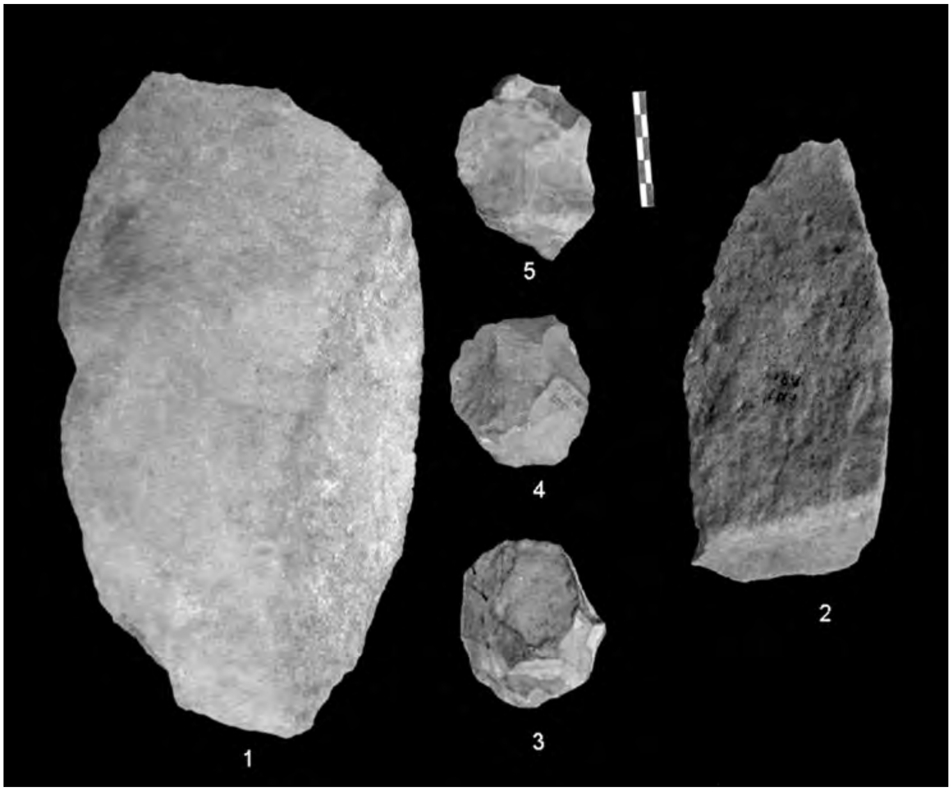

Figure 5. Lithic examples from recent excavations in Peninj. (1-2) Large cutting tools from the North Escarpment. (3-5) Hierarchical bifacial centripetal cores from Maritanane.

TECHNOLOGY AND *CHAÎNES OPÉRATOIRES* AT PENINJ

In Peninj both small-sized *débitage* and typically Acheulean large cutting tools are found. Examples from Figure 5 show that dichotomy; pieces 1 and 2 are flakes resulting from the production strategy of large blanks in the North Escarpment. Examples numbered 3-5 are cores from which even smaller flakes are detached in the Type Section. Given the very size of stone tools such as those from Figure 5, it becomes difficult to support the idea that there is a single *chaîne opératoire*. But size is not the unique argument, and the analysis of knapping methods provides further insights on this issue:

Reduction sequences of small-sized *débitage*

Exploitation types of small-sized cores in the ST Site Complex at Peninj have been already described elsewhere (de la Torre & Mora, 2004; de la Torre et al., 2003, 2004). Therein, the most relevant knapping method is the so-called hierarchical bifacial centripetal method. This system is not only found at the ST Site Complex, but also in other assemblages from Maritanane, and even in the North Escarpment. Examples from the Type Section (Figures 6-9) and Mugulud in the North Escarpment (Figures 10-12) display most of the technical features considered by Boëda (1994: 255) as typical of the Levallois method, such as:

1. Volume of the core is divided into two asymmetrical, secant (intersecting) surfaces with opposing convexities.
2. Those surfaces are 'hierarchized'. The main one is used to obtain flakes through a centripetal structure, and the other side is used to prepare the flake removals on the main surface of the core.
3. The secondary plane (knapping platform) shows secant flakes to the edge dividing the core in two sides, being therefore perpendicular with respect to the flaking axis on the main surface.
4. Angles of the flake removals on the main surface are parallel or sub-parallel to the plane created by the intersection of both surfaces.
5. The technique used in this method is based on direct percussion with hard hammer.

In previous works (i.e. de la Torre et al., 2003, 2004) it has been suggested that, despite reservations imposed by the chronological leap, the hierarchical bifacial centripetal method is following Boëda´s (1993, 1994) criteria similar to the centripetal recurrent Levallois method typical of the Middle Palaeolithic. Thus, in Peninj's cores there is a hierarchical structure of the surfaces, with a plane of intersection in which secant scars to an edge serve as striking platforms for knapping onto the main surface. Moreover, the main surface of Peninj cores shows a more or less centripetal pattern, in which scars are parallel or subparallel to the plane of intersection. Finally, the structure of the knapping surface is not interchangeable along the entire reduction process.

All of this led us to propose in previous works that the hierarchical bifacial centripetal method is the result of a precise technological knowledge, mental template

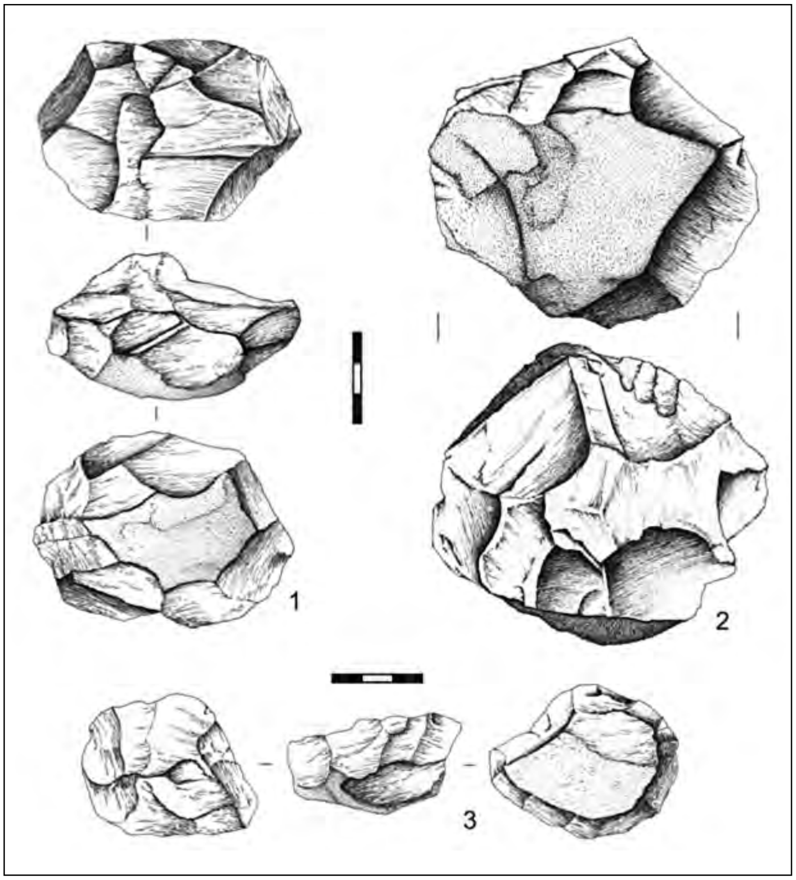

Figure 6. Hierarchical bifacial centripetal lava cores from ST4 in different reduction stages (drawn by Noemi Morán).

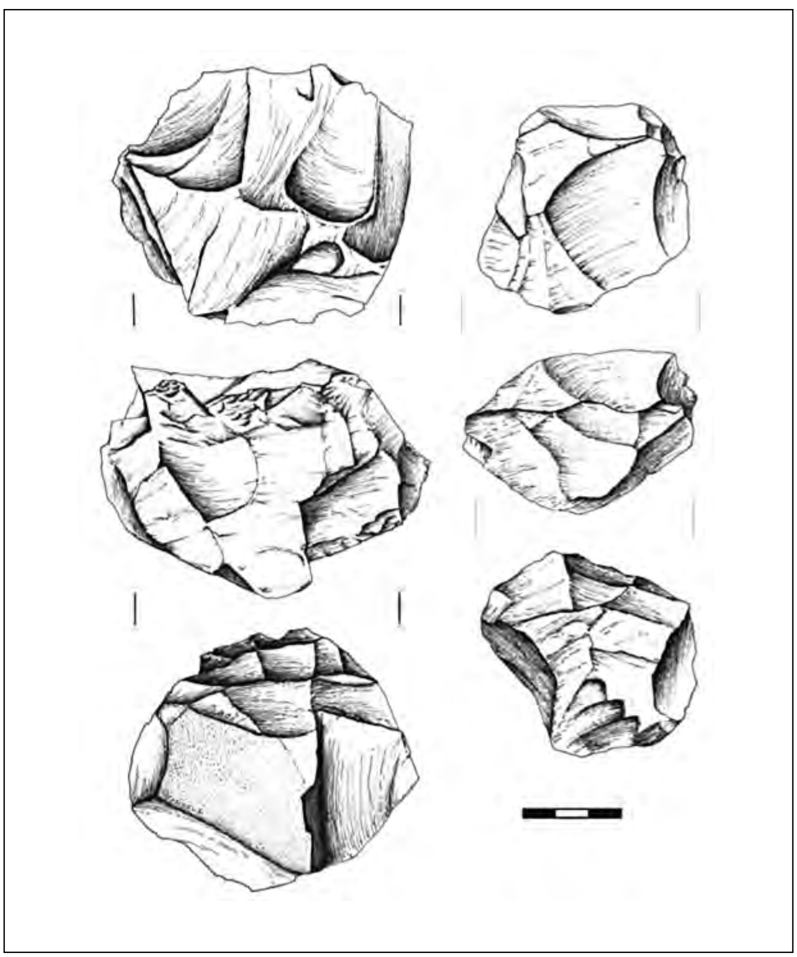

Figure 7. Hierarchical bifacial centripetal lava cores from ST31- ST32 (drawn by Noemi Morán).

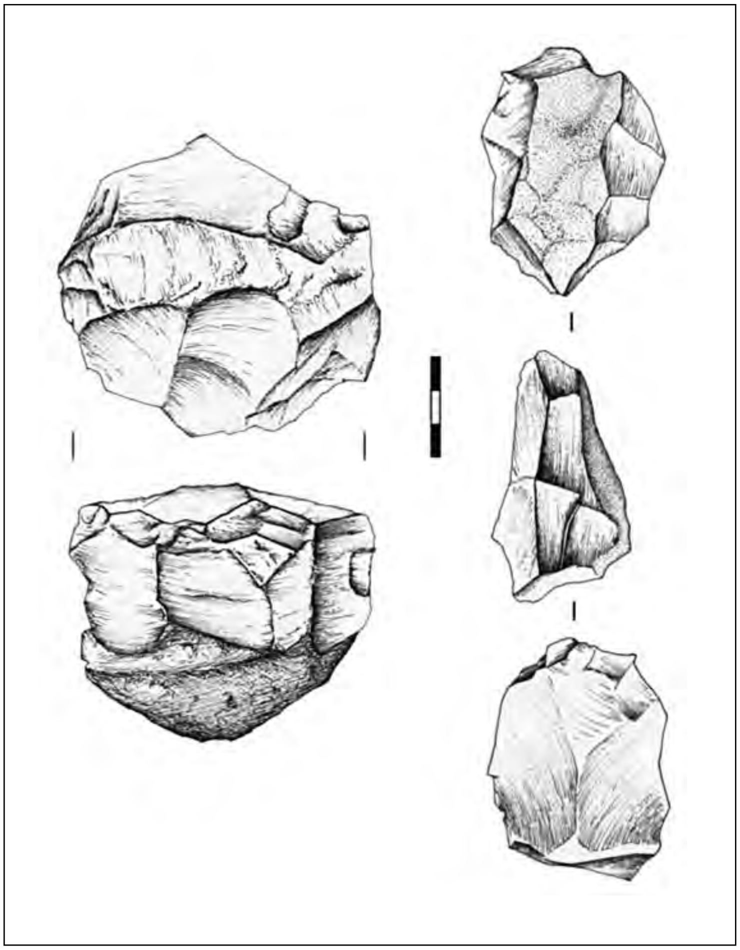

Figure 8. Hierarchical bifacial centripetal cores from ST2 in different stages of reduction (drawn by Noemi Morán).

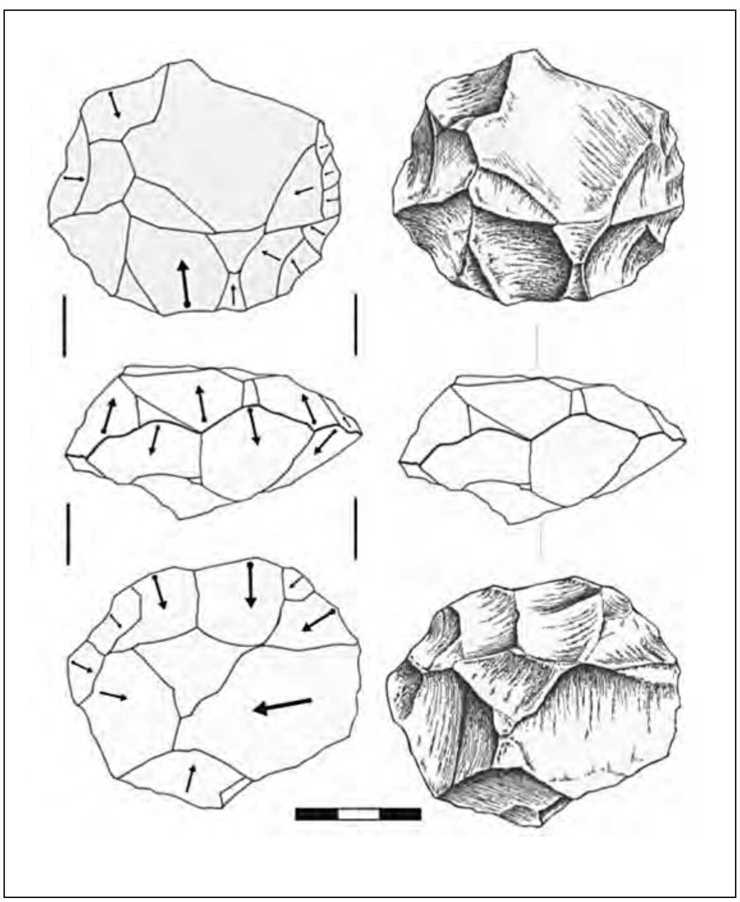

Figure 9. Hierarchical bifacial centripetal core from ST51 (drawn by Noemi Morán).

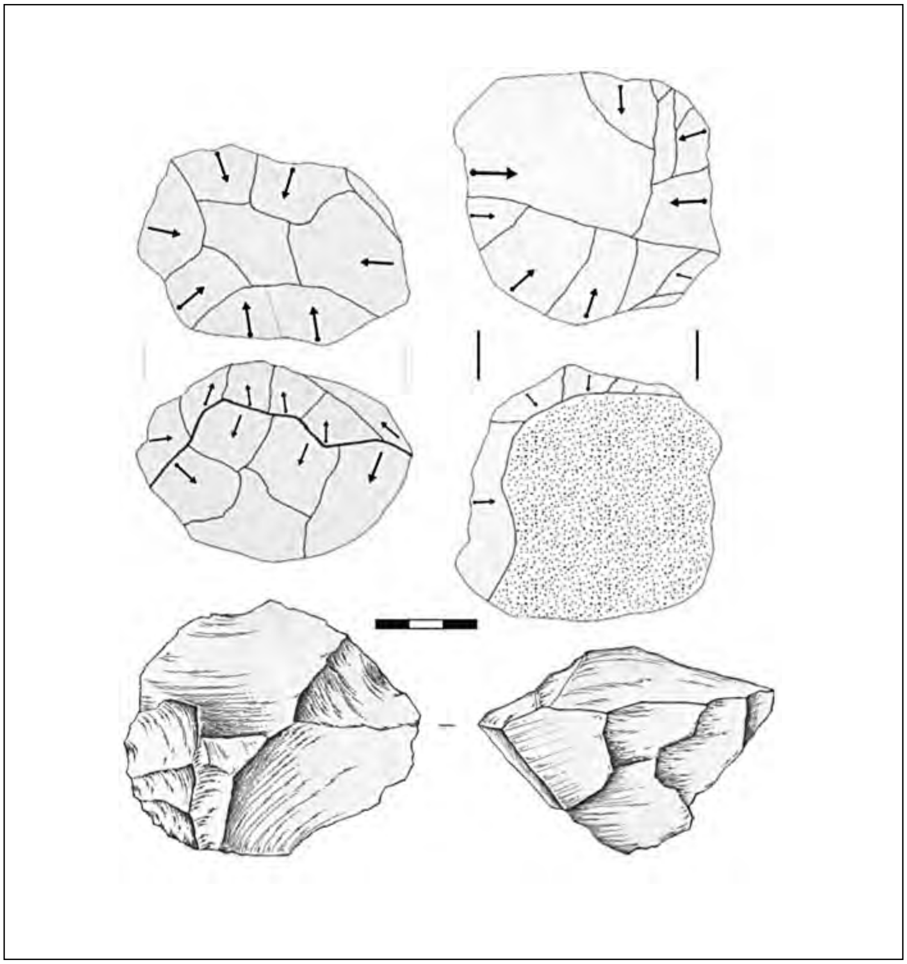

Figure 10. Hierarchical bifacial centripetal cores in Mugulud from recent excavations.

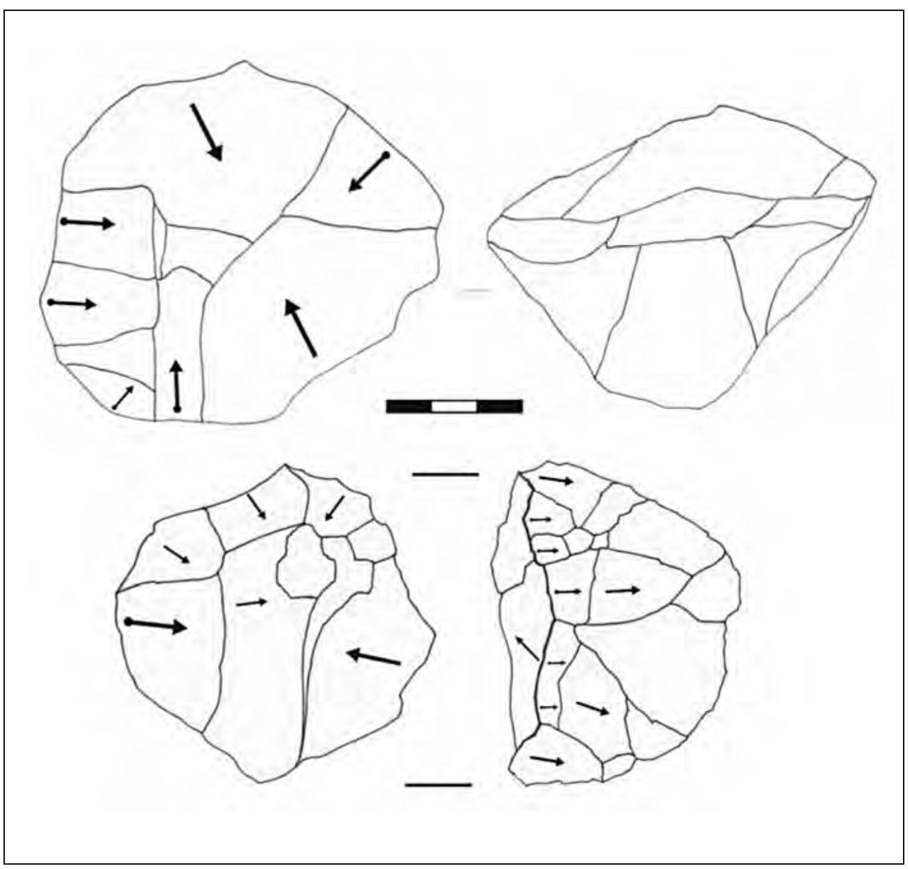

Figure 11. Diacritic schemes of bifacial centripetal cores in Mugulud, from Isaac's excavations.

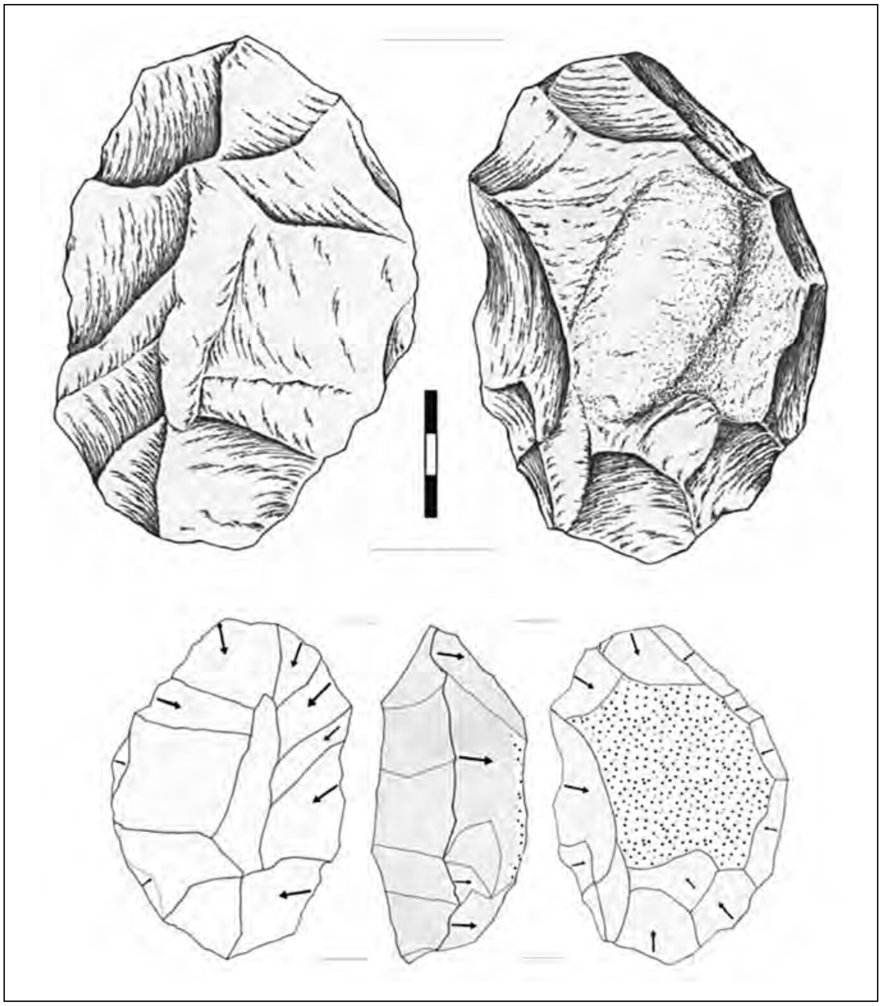

Figure 12. Hierarchical bifacial centripetal core from Mugulud (drawn by Noemi Morán).

and planning of knapping sequences. However, is it enough for including this technology within the Levallois method? New works on this topic make it even more difficult to address the issue about what Levallois method truly is. Slimak (2003), Pasty (2003) and Guette (2002) criticize Boëda´s (1993, 1994) definition of centripetal recurrent Levallois system for being too restrictive. Following Slimak (2003), there are only two real differences between Levallois and discoid methods. First is the management of convexities, which is peripheral in the discoid system and lateral–distal in the Levallois case. The second one would be the configuration of the knapping plane, which is secant among discoid strategies and parallel in the Levallois. Lenoir and Turq (1995) pointed out the similarities between the centripetal recurrent Levallois and the discoid method; following these authors, possible differences would be the non-invasive extractions in the discoid method and, as Slimak (2003) also suggests, that the knapping plane is oblique in relation to the edge of the core. At any rate, Lenoir and Turq (1995) claim that differences between Levallois and discoid methods are neither conceptual or technical, but lie on the degree of predetermination, which at the same time is conditioned by lateral and distal convexities, which respectively determine thickness and length of flakes.

Whereas Boëda (1993, 1994) stressed the immutability of Levallois method along the knapping process – which would maintain a rigid and unchangeable structure during the whole reduction – both Lenoir and Turq (1995) and Slimak (2003) propose that the exploitation of a single core can be carried out changing from a discoid method to a centripetal recurrent Levallois one, and vice versa. Actually, presence of hierarchical surfaces within the discoid method is systematically recognized (i.e. Mourre, 2003; Pasty, 2000, 2003; Terradas, 2003), therefore all the criteria considered by Boëda (1993, 1994) as exclusive from centripetal recurrent Levallois method can be identified also among discoid systems.

Because of all of this, Lenoir and Turq (1995) suggest that the term Levallois *sensu stricto* should be constrained to the lineal (preferential flake) method and the unidirectional and bidirectional Levallois systems. In this sense, Slimak (2003) insists on the conceptual differences between the Levallois *sensu stricto* and discoid methods; notion of the recurrence in the *débitage* constitutes the structural criterion of the discoid concept, whereas in the Levallois method there is a stage of preparation of convexities for subsequently detaching the Levallois flake. Following Slimak (2003), these are the grounds for the differences between both systems; discoidal knapping implies a continuous rhythm of *débitage* in which there is no hierarchical preparation of convexities along the production stages of the predetermined products. On the contrary, Levallois method is characterized by a discontinuous rhythm, with alternation between stages of full *débitage* and phases of preparation of convexities. Therefore, the distinction between both concepts would lie on the identification of the specific knapping rhythms, and not on the classification of cores. In sum, in the Levallois method the exploitation of *débitage* surfaces would be restricted by the bifacial edge itself; after a knapping sequence, the volumetric structure needs to be rejuvenated, being a discontinuity on the *débitage* rhythm that discoid technology does not show (Slimak, 2003). In other words, whereas a Levallois core requires of a complete rearrangement after every flaking sequence, the discoid method allows a sustained reduction, which lasts as long as the volume of the core permits (Terradas, 2003).

A review of recent works on the topic (Slimak, 1998-1999, 2003; Mourre, 2003; Lenoir & Turq, 1995; Terradas, 2003, etc), agrees on proposing that most of the criteria suggested by Boëda (1993, 1994) for defining the centripetal recurrent Levallois method, are already contained in the discoid technique. Therefore, it appears to be a consensus on fading away differences between centripetal recurrent Levallois and discoid methods, reminding earlier claims along those lines (i.e. Pigeot, 1991). In this case, the key criterion for distinguishing between discoid and Levallois would be the management of lateral and distal convexities on the main surface in the latter method (Terradas, 2003; Mourre, 2003; Slimak, 2003; *contra* Boëda, 1993, 1994; Guette, 2002).

When Boëda´s criteria have been applied to the Peninj cores in previous paragraphs, lateral and distal convexities were omitted from the list of features displayed by this industry. In the centripetal recurrent Levallois method *sensu* Boëda (1993, 1994), every scar on the main surface predetermines the following one, so that convexities are maintained through the recurrence of knapping. However, when applying a more restrictive definition of Levallois concept, the requisite of lateral and distal convexities on the *débitage* surface can not be applied to the Peninj technology. Although cores are generally found in their exhausted form (in which knapping surfaces usually have lost convexities), the preparation of lateral and distal convexities typical of Levallois is not consubstantial to the hierarchical centripetal bifacial method defined at Peninj. As aforementioned, this industry displays hierarchical surfaces, the main one focused on obtaining 4-5 cm long flakes, the other dedicated to the preparation of striking platforms. Extractions are centripetal on the *débitage* surface, as well as parallel or subparallel to the configuration plane. By contrast, negatives in the preparation surface are longitudinal, parallel to each other and with secant angle with respect to the intersection plane. All of that, altogether with the recurrent pattern displayed by flakes, led us to propose elsewhere (de la Torre & Mora, 2004; de la Torre et al., 2003, 2004) similarities between the hierarchical bifacial centripetal method at Peninj and the centripetal recurrent Levallois method *sensu* Böeda (1993). If the latter actually is a variant from the discoid method (Pigeot, 1991; Slimak, 1998-1999, 2003; Terradas, 2003; Lenoir & Turq, 1995; Mourre, 2003, etc.), the Peninj technology would also be. In spite of cores such as the one in Figure 12, in which there seems to be some preparation of convexities – also identified in several examples from BK in Olduvai (de la Torre & Mora, 2005) – that is not the general pattern. In sum, the reduction sequences of small-sized *débitage*, following the most recent literature, should be included within the definition of discoid method.

Does this mean a re-evaluation of the technical and cognitive implications already proposed for the Peninj technology? Probably not. Actually, the aforementioned discussion is rather a terminological dispute concerning the status of the centripetal recurrent method as discoid or truly Levallois. As far as technical abilities for predetermination, division of hierarchical surfaces, planning of reduction sequences, volumetric management of cores, etc, are recognized as typical of discoid systems; cognitive, technical and manual skills among knappers are very similar to those underlying the preferential Levallois method. At the risk of being simplistic, the main difference would rest upon the management of knapping sequences for obtaining single products (preferential method) and the systematic exploitation of surfaces (recurrent methods of all kinds). That is to say, upon the continuity of discontinuity of rhythms on the knapping as proposed by Slimak (2003).

Because of these terminological nuances, it would perhaps be advisable to follow more general definitions for describing this technical system, such as that of simple preparation cores as proposed by White and Ashton (2003). Cores studied by these authors are said to display all Boëda´s technical requirements of Levallois method, except for lateral and distal convexities. Thus, White and Ashton (2003) claim some kind of intentionality in the production of flakes, but do not identify predetermination as required for obtaining really standardized flakes. At any rate, and as mentioned elsewhere (de la Torre & Mora, 2004; de la Torre et al., 2003), the specific denomination for the knapping method identified at Peninj may be irrelevant, as far as the complexity of underlying technical process is assumed. Should the Peninj industry be included in the centripetal recurrent Levallois *sensu* Böeda (1993), in the discoid system (as conceived by Lenoir & Turq, 1995; Pigeot, 1991; Terradas, 2003; Mourre, 2003; Slimak, 2003, etc.) or among methods of simple preparation (following White & Ashton, 2003), technology at Lake Natron required remarkable manual and cognitive abilities, as had been already suggested by Texier (1995) for the geographically and chronologically similar assemblages at Nyabusosi.

Beyond questions of terminology identifying, to which techno-culture the hierarchical bifacial centripetal method belongs is the key issue. In this work, Oldowan is considered as a technology based on knapping of small-sized flakes (usually 3-5 cms) from the *débitage* of cores of limited dimensions. This technology is characterized in Olduvai Bed I by relatively simple knapping methods, in which there is not usually preparation of cores, and in which reduction sequences are short and poorly organized (de la Torre & Mora, 2005), as is it at Koobi Fora (Toth, 1985). At Peninj, assemblages from the ST Site Complex at Maritanane have been assigned in previous works to the Oldowan (Domínguez-Rodrigo et al., 2002; de la Torre et al., 2003), precisely because of the production of small-sized flakes detached from equally small cores. As already seen in Figure 5, neither the target of knapping nor the size of artefacts in the ST Site Complex is comparable with those at the North Escarpment Acheulean.

However, while the ST Site Complex industry displays targets typical of the Oldowan – focused upon making regular flakes through free-hand *débitage* – knapping methods for obtaining such products are quite different from those identified at Olduvai Bed I (de la Torre & Mora, 2005). In fact, the ability to exploit the entire volume of a piece through a structured bifacial method followed through a complete knapping sequence – which is what defines reduction in ST Site Complex cores – shares the same technical scheme usually attributed to the Acheulean. Several authors have specifically linked Acheulean technology with Levallois or Levallois-like methods (i.e. Pigeot, 1991; Tuffreau, 1995; De Bono & Goren-Inbar, 2001; White & Ashton, 2003, etc). Therefore, it could be possible that knappers from sites initially considered as Oldowan at the ST Site Complex were the same ones that display an Acheulean technology in the Escarpments. This hypothesis was already outlined in a previous work (de la Torre & Mora, 2004: 204-205), but was discarded perhaps too rashly, thus the ST Site Complex industry was considered as Oldowan.

A plausible hypothesis for explaining differences between the North Escarpment Acheulean and the industry of the ST Site Complex maintains that technological divergences are explained for the same human groups occupying different ecological niches. The behavioural meaning of this proposal will be explored below, but now it is relevant to focus on its technical connotations; conceptually, the onset of the Acheulean meant the appearance of standardized designs (Isaac, 1986; Wynn, 1993), efficiency in the working of *débitage* surfaces (Pigeot, 1991), and in sum the involvement of bifacial structures into the recurrent and systematic management of raw materials.

Boëda (1991) and Pelegrin (1985) point out that any knapping structure (including in such a structure all the required knowledge, as well as the methods and technical skills within a concrete system) is extremely stable; anarchical behaviours do not exist, and any documented variant is just due to individual operational capabilities or to problems derived from a specific raw materials. Therefore, any particular knapping structure is the result of the technical background by a determined group or culture (Boëda, 1991; Pelegrin, 1985).

This perspective leads to a reinterpretation of the Peninj record, dissecting the technological characteristics across each area; at the ST Site Complex, knappers exploited small cores aimed to obtain short and thin flakes. Input and output of handaxes should not be excluded, as some possible biface trimming flakes could suggest in ST30 and ST4 (de la Torre & Mora, 2004; de la Torre, 2004). Anyway, tool-making was clearly focused on the production of small and (usually) unretouched flakes. This *débitage* was carried out through a variety of reduction methods, among which the hierarchical centripetal bifacial system stands out quantitatively and qualitatively. This strategy requires the application of a particular technical knowledge, which is systematically repeated in cores from various sites and in examples discarded at several reduction stages. Therefore, it seems obvious that specialized knapping methods were used in a recurrent manner at the ST Site Complex.

In the North Escarpment the same *débitage* methods were being applied to the production of small-sized flakes; configuration of cores and reduction sequences are identical to those from the Type Section, pointing towards the use of the same technological strategies. Thus, there is a shared knapping general structure (*sensu* Boëda, 1991), that arranges the organization of technology across the entire western side of Lake Natron, and in which reduction methods such as the hierarchical bifacial centripetal method would be the expression of a unique background of technical knowledge.

If the existence of the same technical knowledge in both regions is accepted, and it is also assumed that the same humans could occupy both areas, the single difference between the ST Site Complex and the North Escarpment would be functional. This does not raise interpretative problems upon landscape use by humans from Peninj, as is discussed below. However, it does mean a contradiction with respect to some implications proposed by ourselves on the evolution of technology; de la Torre et al. (2003) suggested that classic Oldowan knappers developed technical strategies more complex than previously thought. Therefore, de la Torre et al. (2003) proposed–erroneously, as recognized by de la Torre & Mora (2005)–that even in the earliest sites at Olduvai technical methods similar to those of Peninj existed. As clarified by de la Torre & Mora (2005), however, Olduvai *débitage* systems similar to those from Peninj are common only after the emergence of Acheulean in Middle Bed II.

At Lake Natron, where archaeological sites earlier than the beginning of African Acheulean at 1.6-1.5 ma have not been discovered yet, assemblages containing large cutting tools and those with only small-sized cores and flakes overlap chronologically. Indeed, technical knowledge seems to be identical; artisans from the ST Site Complex had the cognitive, technical and manual skills typical from the Acheulean, although these were applied in a different manner than at the North Escarpment. Actually, it is probable that both assemblages were manufactured by the same humans. If this view is followed, the former proposal by de la Torre et al. (2003) on the possible existence of predetermined *débitage* systems in the Oldowan prior to 1.6 ma (that is, earlier than the onset of the Acheulean) would be dropped; complex knapping in the delta of Peninj river (ST Site Complex) would be made by the same artisans than those from the Acheulean in the middle river course (North Escarpment), and the differences between the industry from these places would be a functional response to distinct environments, both being integrated within the same background of technical knowledge and tradition. This hypothesis is based upon the shared characteristics of technical process for knapping simple flakes from small cores in both the North Escarpment and the ST Site Complex. Besides, altogether with this small *débitage*, at the North Escarpment there is a complementary *chaîne opératoire* focused on the production of large cutting tools, which will be described in the next section.

The *chaîne opératoire* for the production of large cutting tools in the North Escarpment

The Acheulean production at Peninj is based upon the flaking of big blanks that often are secondarily modified into retouched large cutting tools (de la Torre, 2004). In terms of the *chaîne opératoire*, this means the incorporation of an intermediate stage between the process of fabrication and use of artefacts; yet in the Oldowan production the system is immediate (a flake is obtained from a core, and is used directly), in the typical Acheulean technical system the process has at least three stages (flaking of blank, secondary modification of it and then use). There are further implications on the nature of the Acheulean *chaîne opératoire*; given the massive size of cores, it is assumed that there is generally a chronological and spatial division between the obtaining of large flakes and their introduction into the sites. This spatial and temporal division could not only affect to the obtaining of large blanks, but also to their shaping; as pointed out by Toth (1991) referring to the African Acheulean, the most optimum strategy would be making handaxes on the quarry itself, since the weight of raw material to be transported is reduced, so are the risks of breakage of blanks during knapping. Likely this strategy was common at Mugulud, in which a great part of retouched blanks were introduced partially or totally manufactured. This actually is a further argument to explain low densities of *débitage* identified at this site (Table 2).

Therefore, it is difficult to evaluate what exactly the specific methods of obtaining of large blanks were, as well as the degree of standardization at their production. At any rate, both the few cores recovered and the scarcely preserved butts on those large flakes indicate that percussion platforms were prepared, and that these belong to bifacial systems. Such knapping strategy should have been similar to that described by Toth (2001), in which previous scars were used for preparing striking platforms. Anyway, more structured methods should not be excluded; at Mugulud several cleavers have been found, and it is conventionally accepted that those artefacts are predetermined blanks. Texier and Roche (1995) point out that blanks for making bifaces do not necessarily have to come from structured cores; however, they propose that knapping of a cleaver is linked to the conceptual progress implicit in the introduction of predetermination within the *chaîne opératoire*. Therefore, whereas in the making of a handaxe the predetermination concept is optional, in the case of the cleaver such conceptual scheme is omnipresent, and actually is necessary for the obtaining the bit, the key element among cleavers (Texier & Roche, 1995). Taking this into account, it could be considered that at Mugulud some of the cores for the production of large blanks should have been, at least in some cases, relatively prepared.

At any rate, following the highly skilled configuration of knapping sequences among small-sized *débitage* cores, it appears evident that artisans from Mugulud had a precise technical knowledge which was applied efficiently to obtain specific products. In the case we are now dealing with, such products were large flakes, wider than longer and characterized by large butts and great thickness. The very existence of some intermediate flakes which are thin but show lengths and widths similar to those of the large cutting tools, suggests that the great thickness of the latter is an intentional choice by knappers. In the case of large cutting tools, artisans were aiming to obtain heavy and blunt tools, being careless in the waste of raw material or the effects regarding the cores, whose knapping surfaces would have been badly structured after the removal of such flakes.

Table 2. Lithic categories at Mugulud, including Isaac's collections stored in Dar-es-Salaam Museum and those from recent excavations (figures follow de la Torre, 2004).

	Total	
	n	**%**
Test cores	4	0.8
Cores	22	4.3
Core fragments	2	0.4
Large cutting tools	83	16.3
Small retouched pieces	5	1.0
Hammerstones	20	3.9
Unretouched blanks for LCT	14	2.7
Flakes	101	19.9
Flake fragments	178	35.0
Frags. <20 mm	7	1.4
Angular fragments	39	7.6
Battered frags.	9	1.8
Unmodified pieces	24	4.7
Total	508	100.0

Once those large flakes were obtained, they usually served as blanks in which secondary modification of edges was performed. However, reference to bifaces is not accurate in the case of Mugulud. Edwards (2001) suggests that large flakes at Kalambo Falls could be obtained in less than a minute, but that the *façonnage* of any of its bifaces takes hours. That is not the case in Mugulud at all; as among the large flakes in EF-HR at Olduvai (Leakey, 1971; de la Torre & Mora, 2005), in Mugulud retouch is restricted to the edge of pieces, the volume of pieces not being shaped (Figure 13). Both EF-HR at Olduvai and Mugulud at Peninj could be included among what Böeda et al. (1990) call "*chaînes opératoires des pieces bifaciales supports*". This denomination has an insightful technical meaning, and describes accurately the traits displayed by the large cutting tools in the Early Acheulean at Olduvai and Peninj; at both sites, blanks show two secant surfaces, wherein one is convex and the opposite is flat. Therefore, volume is based on two asymmetrical surfaces, in which a simultaneous *façonnage* is nearly impossible. The shaping of blanks is mainly performed from the flat surface, which in both EF-HR and Mugulud corresponds to the ventral face of flakes, and from such face the entire volume of the piece is shaped, fulfilling criteria defined by Böeda et al. (1990) for those *chaînes opératoires des pieces bifaciales supports* with flat-convex sections.

This knapping technique responds to determining factors imposed by the method in which those blanks are obtained; whereas transforming a convex surface into a flat one is relatively easy, the opposite is extremely difficult (Böeda et al., 1990). This could explain, for example, the reason why authentic bifaces at Isenya are poorly shaped on their ventral faces (Roche et al., 1988; Texier & Roche, 1995), or why at Kalambo Falls transformation of a flake into a well-shaped handaxe is a complex and consuming task (Edwards, 2001). Neither at EF-HR (de la Torre & Mora, 2005) or at Mugulud is there a symmetrical distribution of volume among artefacts, and therefore it could be supported that "*le façonnage de pièces plano-convexes constitue la finalité technique du schéma opératoire*" (Böeda, 1991: 57).

To sum up, in the Early Acheulean at Mugulud the concept of bifacial symmetry does not exist, a notion that we do find in more recent Acheulean sites. Large

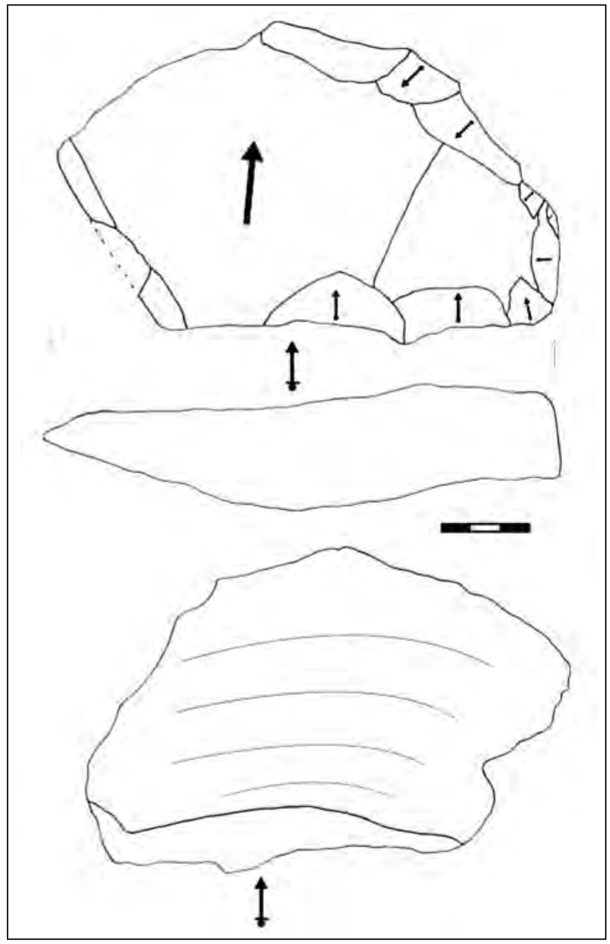

Figure 13. Diacritic scheme of a lava knife from recent excavations in Mugulud, whose retouch is limited to the transversal distal part of the dorsal face.

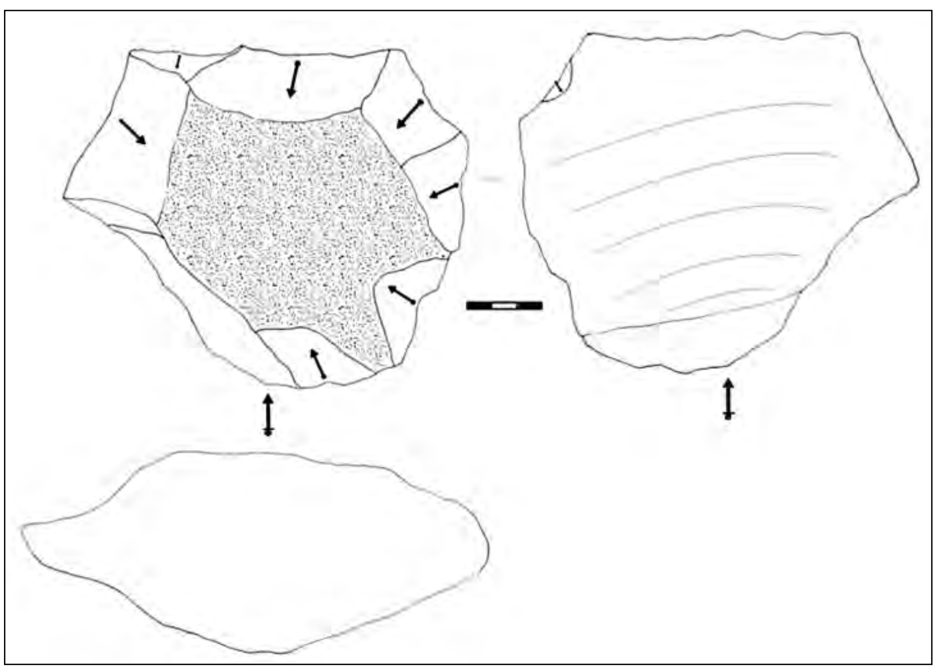

Figure 14. Diacritic scheme of a lava knife from recent excavations in Mugulud. It is a large flake with no retouch on the ventral face and a few blows on the distal-transversal part of the dorsal face, which made a denticulate edge opposite to the blunt part formed by the butt.

cutting tools from Mugulud at Peninj, as well as those from EF-HR at Olduvai, actually are not bifaces but huge side scrapers with (generally) unifacial retouching and pointed forms, however in which there is not shaping of the overall volume, but just a non-invasive working of the edges of pieces (Figure 14). Perhaps that was the reason which led Isaac (1972; Isaac, in VVAA, 1967) to stress the technical similarities between EF-HR and Mugulud. Leakey (1971) also underlined the resemblance between both assemblages, at the same time she discussed differences between Mugulud and BK in Olduvai (Leakey, in VVAA, 1967).

This last point is rather relevant and leads to a further reflection; at BK there are real bifaces, which show a whole management of surfaces, a systematic *façonnage* and the existence of bifacial symmetry (de la Torre & Mora, 2005). Those traits are not present among any of the earlier Acheulean sites in Olduvai such as EF-HR or TK. Are those traits a technical evolution? Or were the artisans from EF-HR and Mugulud not interested in stylistic issues of that kind? Although at Mugulud there are no real bifaces, in a later site from Peninj, ST54 (Figure 15), there are authentic bifaces which actually show exquisite manufacture. Whether this responds merely to a stochastic variation, as suggested by Isaac (1977), or it does reflect an increase of technical skills is a question beyond the scope of this work. Now the point is to analyze what the landscape use strategies were at Peninj.

Technology and Landscape in Peninj Sites

In order to evaluate landscape use in Peninj from a technological point of view, there are two main aspects to be addressed. As reviewed above, one is the dichotomy between the technical systems from the North Escarpment and those from the Type Section. A complementary perspective to be addressed in this section is the study of the configuration of sites and their distribution across the landscape, together with the relationships of those sites with the availability and characteristics of lithic raw materials.

Raw material management

At Peninj it is possible to locate some of the source areas for basalts, nephelinites and quartz found at the sites. Through X-ray diffraction analyzes several types of basalts (basanites, hawaiian basalts, aphitic and aphiric basalts) and piroxenic nephelinites were identified. The original source area for quartz is the metamorphic hills of Oldoinyo Ogol, located to the west of the Peninj Group. Primary source areas for basalts are the Sambu volcano and the Hajaro lavas, whereas most of nephelinites probably come originally from the Pliocene hills of the Shirere and Mozonik volcanos.

However, it is one thing to identify raw material primary source areas, and another to locate the exact spots where hominins could have been supplied from. In the North Escarpment it is assumed that basalt blocks from which large cutting tools are made were abundant in the vicinity of Mugulud. This site, located on the piedmont of Sambu volcano, should have been surrounded by outcrops and lava flows that, because of their weathering, produced large blocks that could be used as cores. Therefore, the immediate abundance of huge basalt blocks at the North Escarpment facilitated obtaining of large blanks. In Mugulud, both hammerstones and small-sized *débitage* cores are mainly made of quartz (de la Torre, 2004). This quartz appears in the site as rounded cobbles of 10 cm in diameter, and probably were collected in a nearby (but still unidentified) stream channel. Its primary source area was the Oldoinyo Ogol Hills and their metamorphic substrate. The scarce nephelinites from Mugulud also appear as rounded cobbles, which we assume also were collected from a local stream channel. In this case the primary source area is more difficult to establish, since topographically those nephelinites were unlikely to come naturally from the Mozonik volcano or the Shirere Hills, located downstream on the Peninj River. There are actually conspicuous differences between nephelinites from the Type Section and those from the North Escarpment, being coarser-grained, less compacted and with bigger pyroxenes. Finally, at Mugulud there are also basalt small rounded cobbles, with similar sizes to the quartz and nephelinites. These small lava cobbles seem to belong to a different variety of basalt than that used for large cutting tools, and actually were managed for alternative tasks, including their use as hammerstones and small-sized *débitage* cores.

Primary raw material source areas should have been similar in the Type Section, being the Oldoinyo Hills (the original location of quartz) and the Sambu volcano and its lava flows for the basalts. At the North Escarpment, the source of nephelinites probably were the Shirere Hills and the Mozonik volcano. At any rate, whereas in the North Escarpment it is assumed that primary sources of raw material procurement were near the site of Mugulud – because of its proximity to the Sambu volcano and its location in the middle course of the Peninj river, which in this area would carry cobbles of considerable size – in the Type Section specific spots of raw material supply are more difficult to determine. First, because of the landscape configuration during the formation of sites: paleotopographic reconstructions of Maritanane (Luque, 1996) suggest a low-energy deltaic environment. Therefore, it is unlikely that there were contemporaneous cobble streams where hominins could get raw material supplies from. An alternative is that some fluvial channels belonging to the lower part of the stratigraphic sequence were exposed during the formation of archaeological sites. This would not be very common either, since the Upper Sandy Clays constitute an agradation phase and not a stage of erosion of underlying sediments.

The other main problem for the identification of raw material procurement sources is the current disposition of sedimentary exposures; contrary to other parts of the

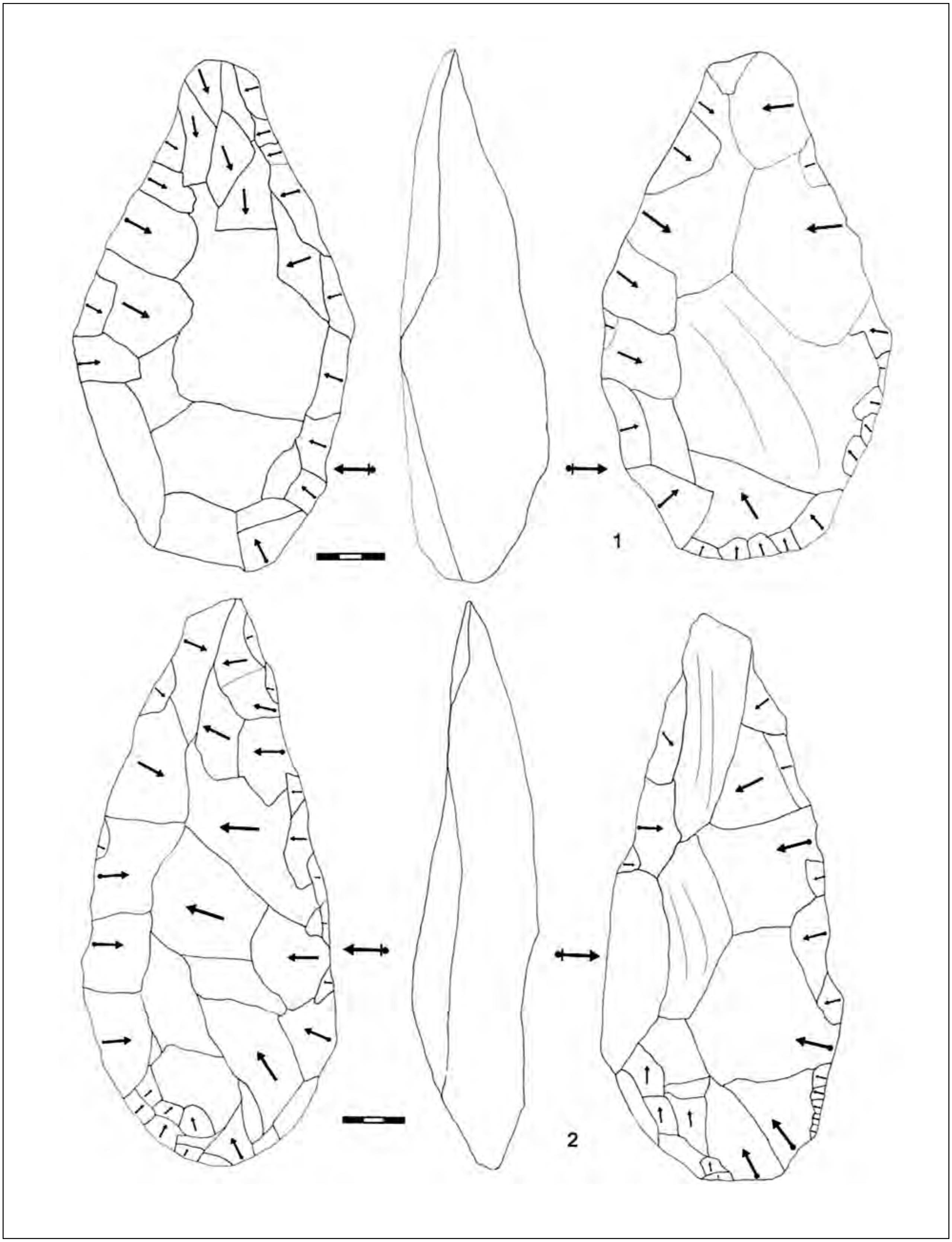

Figure 15. Basalt bifaces from ST54 in Maritanane. (1) The blank is a large (1800 grams and 230 mm length) flake, bifacially worked aiming to create two symmetrical volumes. (2) Exceptionally large flake (more than 2000 grams weight and 300 mm length), which is shaped by flat and invasive retouch, probably with soft hammer.

Peninj Group, the Type Section is a quite small sedimentary area, in which unearthed Plio-Pleistocene sediments are not abundant. Actually, zones such as the ST Site Complex are located on the limits of exposures. Therefore, it could be the case that stream channels where hominins obtained raw materials were a few hundreds of meters away from the sites, and nonetheless we were not able to find them because of the absence of modern exposures.

At this stage, neither experiments nor surveys in search of possible source of raw materials (see de la Torre, 2004) have permitted to establish firmly where the specific spots of lithic procurement were. At any rate, it is possible to provide a general view of the management of lithic raw materials: in the North Escarpment, located in a landscape where big blocks of basalt were abundant, technological processes were focused mainly on the obtaining of large blanks. It has already been mentioned that the intentional great thickness of pieces, as well as the abundance of huge unutilised fragments, etc., suggest an absolute lack of concern on the conservation of raw materials. In other words, artisans at Mugulud were

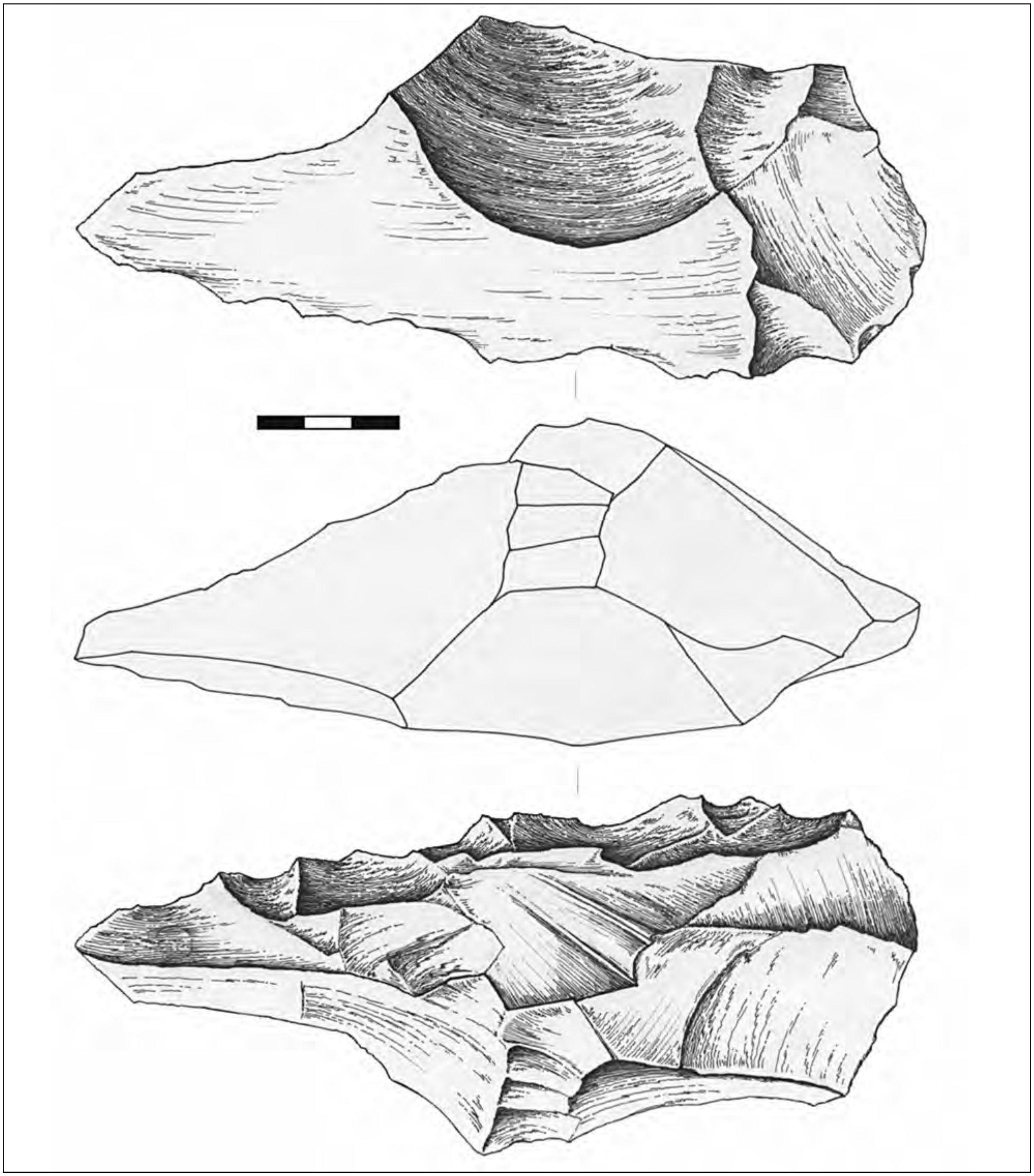

Figure 16. Large cutting tool on flake from ST28 (drawn by Noemi Morán).

not interested at all on maximizing the output of raw materials; their main goal was obtaining huge blanks which afterwards were shaped. Obviously, this behaviour should have been closely related to the immediate abundance of huge basalt blocks that were an almost unlimited resource for raw materials.

The palaeoecological setting of the Type Section, around 8 kilometers to the southeast from the North Escarpment, was very different, being a deltaic environment with low-energy sediments in which raw material availability should have been severely limited. A solution to this scarcity could be the input of artefacts from the Escarpments. This seems to have been the option in some cases, such as in ST23, ST28 (Figures 16-17) and ST54 (see again Figure 15). The large cutting tools and bifaces found at these sites should have been imported from the middle and upper course of the Peninj River, since at Maritanane suitable blocks for obtaining those blanks were not available. Such a strategy, however, has not been observed so far in the sites situated just above Tuff 1, in which sites from ST Site Complex and those from the Gully 2 denote an alternative solution: artefacts in these sites have no petrographic similarities with those from the Escarpments, and up to now no large

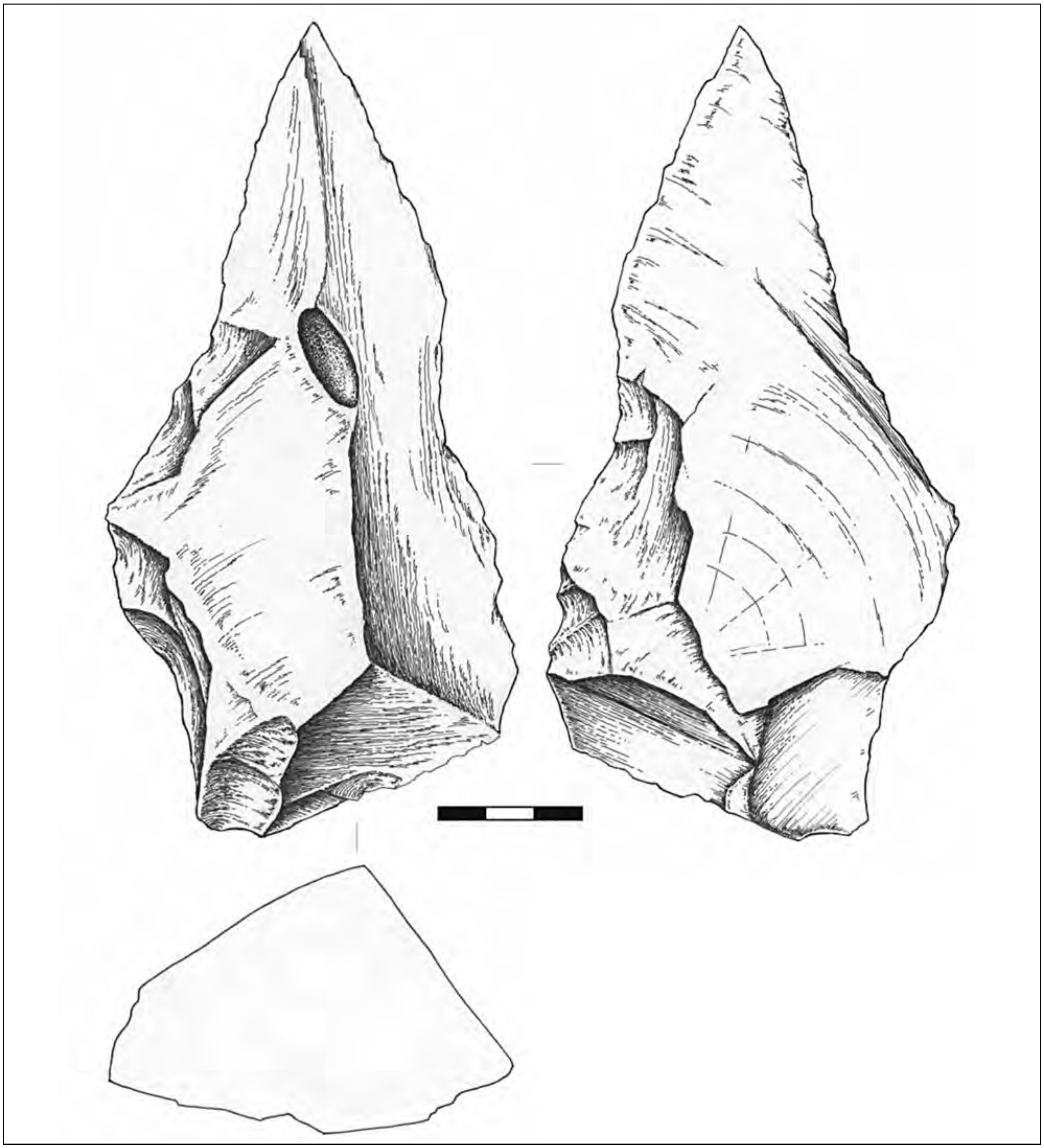

Figure 17. Another example of large cutting tool from ST28 (drawn by Noemi Morán).

cutting tools have been found. Independent of whether or not the same people made large cutting tools in the Escarpments, hominins who occupied Tuff 1 at the Peninj delta were focused on the management of tiny cores. Only small-sized cobbles would be available in a distal stream course such as that of Peninj in the Type Section, and moreover those cobbles should not have been abundant. Response by hominins to such raw material scarcity seems to have been carefully planned; cores were knapped quite often until exhaustion, and usually following a well-reasoned reduction method that would maximize returns of a scarce resource in Maritanane, the lithic material. By this way, availability of raw materials would be a primary factor for understanding the type of technology used in each region at Peninj. But it was probably not the unique reason, so in the following section more functionally-related options are also addressed.

The configuration of sites in the landscape of Peninj

Pollen analyzes (Domínguez-Rodrigo et al., 2001) suggest an open herbaceous landscape for the Type Section, whereas the location of Mugulud in the margins of a fluvial channel indicates that this site could have been situated in a more closed environment. Therefore, it is probable that trophic pressure was higher in the Peninj delta in which the Type Section sites were deposited, and where the herbaceous landscape should have been intensely occupied by carnivores. This could be an important factor to understand why at just a single site such as Mugulud there is a huge accumulation of artefacts, while in the entire Type Section the total of knapped stone tools (including all sites and chronologies) does not add up to even half of that at Mugulud; as a hypothesis, probably more closed environment in the North Escarpment could have been a place to develop longer term activities than at the less secure Type Section, where occupation would be more episodic and dispersed.

Isaac (1977: 86) was convinced that the tendency of Acheulean sites to be associated with seasonal streams was independent of preservation factors that could accumulate artefacts in particular locations, and referred expressly to Mugulud (then RHS), underlining its palaeogeographic similarities to Isimila, Kalambo Falls, Olorgesailie and the Acheulean sites at Olduvai. Potts et al. (1999) agree with such an interpretation, and assume that, although the role of hydraulic processes on the formation of Acheulean sites should not be ruled out, such natural causes do not either explain the outstanding concentrations found in many of the sites at Olorgesailie. The same can be applied to Mugulud; this site was, beyond any doubt, affected by hydraulic agents (see taphonomic discussion in de la Torre, 2004). However, the channel at Mugulud probably had no hydraulic competence sufficient to accumulate large cutting tools which, moreover, do not usually show rounded edges. Therefore, we should not be tempted to explain the outstanding concentration of Mugulud just as a mere post-depositional aggregation. Hominins were intentionally accumulating in that particular spot a huge quantity of large cutting tools, resulting in a lithic collection with more than 160 kilograms.

Behaviour in the Type Section was radically different. As shown in Table 1, most of the "STs" are made of collections of less than a dozen of pieces. This does not necessarily mean these are disturbed sites or scarcely informative spots. On the contrary; Isaac (1981; Isaac et al, 1981) would insist on the importance of taking into account the lithic scatters across the landscape besides the relevance of bigger concentrations. In exposures such as those from Tuff 1 at Maritanane, which can be followed horizontally or in section across several hundred of m^2, documentation of isolated artefacts in the landscape permits the reconstruction of the so-called "background scatter of artifacts" (Isaac, 1981: 136), which was actually the main objective of Isaac (n.d.) in his late research program in Peninj. When this frame of reference is applied to the record from Maritanane, it is observed that most of the "STs" correspond to what Isaac et al. (1981) called intermediate levels of artefact dispersal across the landscape, those in which there is a range of 3-20 stone tools per 25 m^2 (Table 1).

In fact, even the densest concentrations of artefacts in Maritanane – which usually are surface findings, with very few materials in situ (i.e. those from the ST Site Complex) – do not reach the category of real sites in the classification by Isaac et al. (1981). Therefore, even the main sites at the Type Section can be included under the category of minisites; Isaac et al (1981) put FxJj64 as a good example of minisite, wherein only 83 artefacts and 353 bone fragments had been recovered, a figure just slightly smaller than that of ST4, the most important site in Maritanane. Thus, it is obvious that the artefact density in the Type Section is singularly low, even when compared with studies based not on big sites but on artefact dispersals across the landscape, both during the beginnings of the Lower Pleistocene (Blumenschine & Masao, 1991; Isaac et al., 1981; Rogers, 1996) and the final part of this period (Potts et al., 1999). Curiously, in spite of the general dispersion of scattered artefacts across the Type Section's landscape, the densest concentrations are focused on a particular point of the area; although being in absolute terms a low density of artefacts (mainly if compared to Mugulud), the 28 kilograms from the ST Site Complex are a conspicuous patch in the landscape clearly distinct from the rest of Maritanane.

There are then three different realities in the Peninj record. One is the huge concentration of Mugulud, where hominins systematically discarded artefacts until a patch of more than 160 kilograms was deposited. In the Peninj delta, landscape use was different, and follows two models; one is that of scattered pieces across the landscape of intermediate levels of density (following terminology by Isaac et al., 1981), and includes both assemblages supposedly Oldowan (mainly those from

Gully 2) and distinctively Acheulean (Gullies 3 and 4). Together with this scattering of artefacts, in a particular spot of Maritanane – the ST Site Complex – patches of artefacts related to a small-sized *débitage* technological strategy appear.

What is the functional explanation for these differences on the use of landscape? In the case of the Type Section, most of the artefacts, independently of the density of the patches, usually appear associated with bone remains. This is particularly evident at the ST Site Complex, in which some of the bones show cutmarks (Domínguez-Rodrigo et al., 2002). Therefore, it is assumed that humans visited the Peninj delta in search of animal resources, which in such an open environment should have been abundant.

Functionality for the Mugulud Acheulean site is nonetheless more difficult to specify. At this site, the few recovered bones were probably transported by the channel and their association with stone tools is accidental (see de la Torre, 2004). Consequently, it seems difficult to address why such a huge concentration of artefacts formed on this very spot of the landscape.

Conclusions

Two technological strategies have been identified in the Lower Pleistocene sequence at Peninj. The first involves a typical Acheulean use of landscape, and is located at Mugulud in the North Escarpment; on the piedmont of Sambu volcano, surrounded by big blocks of basalts and probably in a relatively closed environment, hominins were knapping and accumulating stone tools near the margin of a channel. Reasons why those humans made such a great concentration of artefacts – which follow very precise manufacturing methods based on the obtaining of large cutting tools – are unknown.

At any rate, it seems clear that functionally the site was concerned with a thick-edged use of lithics, yet stone tools at Mugulud are usually heavy-duty artefacts in which there was no stinting of raw material. Indeed, the great amount of raw material invested in obtaining large blanks is surprising; there are examples of large thin flakes which indicate knappers were technically skilled in obtaining big blanks with no wasting of raw material or exhaustion of cores. However, that does not seem to have been a concern, and artisans preferred to overexploit knapping surfaces in order to flake massive and thick blanks. The evident waste of raw material was possible because of the proximity of lava raw material sources. This strategy should have been related to the particular activities carried out on the spot, which required a thick-edged use of artefacts. Such heavy- duty tasks – whatever they were – probably were not exclusive, since in Mugulud there is also a *chaîne opératoire* of small-sized flake production which may have been applied to alternative activities, and which are suggesting a prolonged use of the same spot in the landscape.

The Peninj delta in Maritanane shows a different scene from the one at the middle course of the river at the North Escarpment. The open landscape in the Type Section and the inherent trophic pressure of such environments probably did not encourage a prolonged occupation of the area. Also, being the distal part of the fluvial system, raw material availability would have been scarce, making it more difficult to wander across the area. A solution was importing artefacts from the Escarpments, as appears to be the case of the few handaxes found from Tuff 4 onwards. However, during the main occupation of Type Section–that is, such immediately overlying Tuff 1–humans adapted to the limitations of the surrounding environment, and therefore exploited small pebbles locally. Moreover, this exploitation was systematic, using efficient and well-reasoned reduction methods, which allowed artisans to maximize a scarce resource such as lithic raw material in the delta region. This resulted in an apparently typical Oldowan industry, made of small sized cores and flakes, with only a few retouched tools and with no presence of typical *façonnage* processes such as those characterizing the Acheulean.

It is not possible to say exactly whether these hominins were the same as those who formed the Acheulean sites at the Escarpments, although this is a very plausible hypothesis. Chronologically, all mentioned sites are in the same time interval, around 1.6-1.4 ma (Isaac & Curtis, 1974). It could be argued that Mugulud (positioned at the top of the Humbu Formation or at the base of Moinik Formation) is slightly more recent than some of the non-handaxe bearing sites from the Type Section (i.e. the ST Site Complex, over Tuff 1), and that Maritanane assemblages were late Oldowan examples, whereas the North Escarpment witnessed the onset of the Acheulean technology. However, in the South Escarpment – around 3-4 kilometres away from the Type Section – Domínguez-Rodrigo et al. (1997) claim the existence of Acheulean sites older than the supposedly Oldowan-like assemblages from the ST Site Complex. Therefore, it does not seem feasible to explain these technical differences through diachronic issues, nor to ascribe each technology to a particular hominin species.

Actually, both at the South and the North Escarpments small-sized *débitage* methods are very similar to those documented in the Type Section, implying a shared technical knowledge. This leads to a functional differentiation in order to explain the technological variability among Maritanane and the Escarpments; at the Peninj delta river, where raw material sources were scarce, hominins who also occupied the Escarpments were focused on obtaining small flakes, most likely linked to carcass processing. This occupation in the Peninj delta, judging by the densities of archaeological remains, should have been short-term, although repetitive; the ST Site Complex, wherein there are different concentrations placed on the same stratigraphic position and within a particular perimeter, indicates that humans usually occupied that specific area when they would come down to the delta of the Peninj river. As I have argued in this work, a detailed study of their technology can be used to show that such hominins shared the same technical skills as those of the Acheulean sites and, most probably, were the same groups using alternative technologies in different environments.

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CHAPTER 6

The Oldest Occupation of Europe: Evidence from Southern Spain

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Abstract

Research into the early phases of human dispersion out of Africa into Eurasia, especially into Western Europe, has increased in the last decade, involving both fieldwork at already-known sites and the discovery of new localities, and now points to a very old occupation of this region. This paper presents an updated version of the actual state of knowledge of this question, complementing the discussion of technological characteristics of the oldest European archaeological assemblages presented by Fernando Díez-Martín in volume 2 of this series. It gives special emphasis to lesser-known sites in the southeast Iberian Peninsula, Barranco León and Fuente Nueva 3, which provide some of the best well-preserved paleontological and archeological evidence for the Early Pleistocene in Europe.

When and Why Did Humans Colonize Eurasia?

Palaeoanthropological studies started with the assumption that Africa was the birthplace for genus *Homo* and that the first species leaving the continent to start the colonization of Eurasia was *Homo ergaster or early Homo erectus* around 1.7-1.9 Ma. This species is associated with hot, dry conditions, and preferred the grasslands, open scrub, and woodlands of East Africa after 1.7 Ma, avoiding environments that also contained permanent water (Dennell, 2003).

For many years, questions concerning possible causes for hominid migration have been explored. Vrba (1995) and deMenocal (1995) have suggested that major evolutionary events in East Africa are directly related to climatic conditions. Cooler, dryer conditions developed after 2.8 Ma and intensified at 1.7 and 1.0 Ma, with a pronounced dry period between 1.8-1.6 Ma. Those climatic events coincided with faunal changes occurring between 2.0 and 1.6 Ma, especially in suids (White, 1995). Changes in the regional vegetation from forest and grasslands to sparse dry steppe, and in the climate from sub-humid to semiarid/arid, are explanations for the migration of hominids to the north. Assuming hominids were primarily carnivores and scavengers, annual ranges would increase northwards during periods of aridity when food resources were diminished.

When Did Humans Arrive in Western Europe?

Over the past 20 years, acceptance of the presence of early Paleolithic sites in Europe has been questioned, leading to the formation of the three following chronological hypotheses for the first dispersals of humans in Europe (Dennell, 1983; Carbonell et al., 1995).

1. *Young Europe* or *Short Chronology* (Roebroeks 1994; Roebroeks & van Kofschoten, 1994; Roebroeks & Tuffreau 1995). This hypothesis is supported by a lack of evidence regarding hominin fossil remains older than 0.5 Ma, the lack of clearly hominin-made lithic artifacts from sites older than 0.5 Ma, a lack of evidence of hominin occupation associated with *Mymomis savini* in early Pleistocene sites in Europe, and all the claimed findings from before 0.5 Ma. deriving from coarse, secondary deposits (Roebroeks, 1994; Carbonell et al., 1995). Thus, according to this hypothesis, the clear settle-

ment of Europe began 0.5 Ma, and any earlier, more sporadic occupation could be accepted only if an Early Pleistocene site in primary context were to be discovered (Roebroeks, 1994).

2. *Mature Europe* (de Lumley, 1976; Colotori et al., 1982; Cremaschi & Peretto, 1988; Carbonell et al., 1995) This hypothesis supports the presence of clearly hominin-made lithic assemblages in the Early Pleistocene, including after Vallonet (France) and Monte Poggiolo (Italy) along with somewhat younger sites such as Isernia la Pineta (Italy) dated to the early Middle Pleistocene, and sites such as Mauer (Germany) dated to at least 0.6 Ma. These open-air and cave sites found in Europe and claimed to date to between 1.0 and 0.7 Ma present the possibility of an older occupation in the continent, although the lack of hominin remains still hasn't fully convinced the scientific community.

3. *Old Europe* (Bonifay, 1991; Gibert & Palmquist, 1995; Carbonell et al., 1995). This hypothesis is supported by the discovery of the hominin fossils at Dmanisi (Republic of Georgia), the supposed *hominin* remains at Venta Micena (Orce, Spain), and several sites in the French Massif Central, such as Saint-Elbe, with lithic assemblages dated to more than 2.5 Ma. (Bonifay, 1991), and Chilhac, dated between 1.8-2.0 Ma (Guth, 1974; Bonifay, 1991). This hypothesis argues that the first human settlement in Europe in the late Pliocene-Late Pleistocene emerged through two possible routes, the Strait of Gibraltar or the Palestine Corridor, simultaneous with the origin of genus *Homo* in Africa.

Two major limitations exist in the development of Eurasian Lower Paleolithic research. First, the chronology of most of the archaeological sites in Eurasia is based largely on biostratigraphic studies and, in those few instances where it is available, palaeomagnetic studies. The second limitation is in the different taxonomic systems used in the study of the stone artifact assemblages. The more traditional system of the French typology school (empirical and descriptive) is used by some of the prehistorians (e.g. de Lumley, 1988), while a technological system of classification according to a Système Logique Analytique (SLA) (or 'Analytical Logical System') (Carbonell, 1992) is used by others, with a similar problem also affecting paleontological studies in Europe and Asia.

Almost all of the research on prehistoric Europeans exhibits a somewhat limited approach to the paleontological and archaeological record. For instance, it has focused on a restricted geographical area of reference (i.e. Europe) and has been limited to the remains of specimens of the genus *Homo*. It would appear, however, from recent years of research on the oldest African sites, that for a more coherent approach, focusing only on the chronological aspects or the anatomical characteristics of Eurasian hominids is not sufficient. Only with a general view that includes the technological and functional skills of the hominins, derived from the study of lithic assemblages as well as the climate and ecology of the area, will we be able to understand the first occupations outside of Africa.

The oldest occurrences described in the European sample were in the French Massif Central, which contained very small assemblages of artifacts or even isolated lithic pieces, most of them described as geofacts produced by volcanism in the region (Raynal et al., 1995; Diez-Martin, 2006). Other sites, Chilhac III (attributed to an age of 1.8 Ma.) and Soleihac (0.9 Ma.), published in the early 1990s as archaeological sites, present problems with regard to the dubious nature of their artifacts and the possible disturbed nature of their stratigraphic context (Chavaillon, 1991; Villa, 1991; Raynal et al,, 1995; Diez-Martin, 2006).

The case of Vallonet cave (de Lumley et al., 1988; Yokoyama et al., 1988) is different: there is strong evidence for its date of 0.9 Ma., based on biostratigraphic, palaeomagnetism and ESR, but the nature of the lithic assemblage presents problems. At the moment, the collection consists of 94 pieces, most of them in limestone and sandstone, with sporadic presence of quartzite and flint. All of the materials exhibit different degrees of alteration on their surface and have been found in deposits that contain sand and natural limestone cobbles. Currently, the two theories that attempt to explain the origin of this assemblage are:

1. Natural processes of sedimentation such as wave action could have produced natural fractures in pebbles (Roebroeks & van Kolfschoten, 1994);

2. The archaeological accumulation might be the mixture of different assemblages in a secondary context, based on the relative homogeneity of the assemblage and its lack of patterned spatial distribution within the stratigraphy as well as studies of post-depositional site formation (Villa, 1991; Raynal et al., 1995; Fajardo, 2004).

In 1998, El Aculadero (Querol & Santonja, 1983) was considered to be the most compelling proof of the oldest human settlement in the Iberian peninsula. Upon reconsideration of the geomorphological sequences in the area, however, this site is now placed at the end of the Pleistocene (Raposo & Santonja, 1995).

All of this controversy concerning the evidence for the *Mature Europe* and the *Old Europe* hypotheses helps reinforce the concept of the *Short Chronology* hypothesis, supporting the idea that around 0.5 Ma. *Homo heidelbergensis* occupied the continent, bringing in an already well-developed Acheulean technological complex. This is corroborated by several documented Acheulean sites across Europe. The discovery of the site of Dmanisi (Republic of Georgia), however, and its strong evidence of hominid migration into Eurasia at a very early date, has generated renewed hope of finding old sites in Western Europe.

The scenario in Western Europe changed in 1995 with the publication of the hominid remains now as-

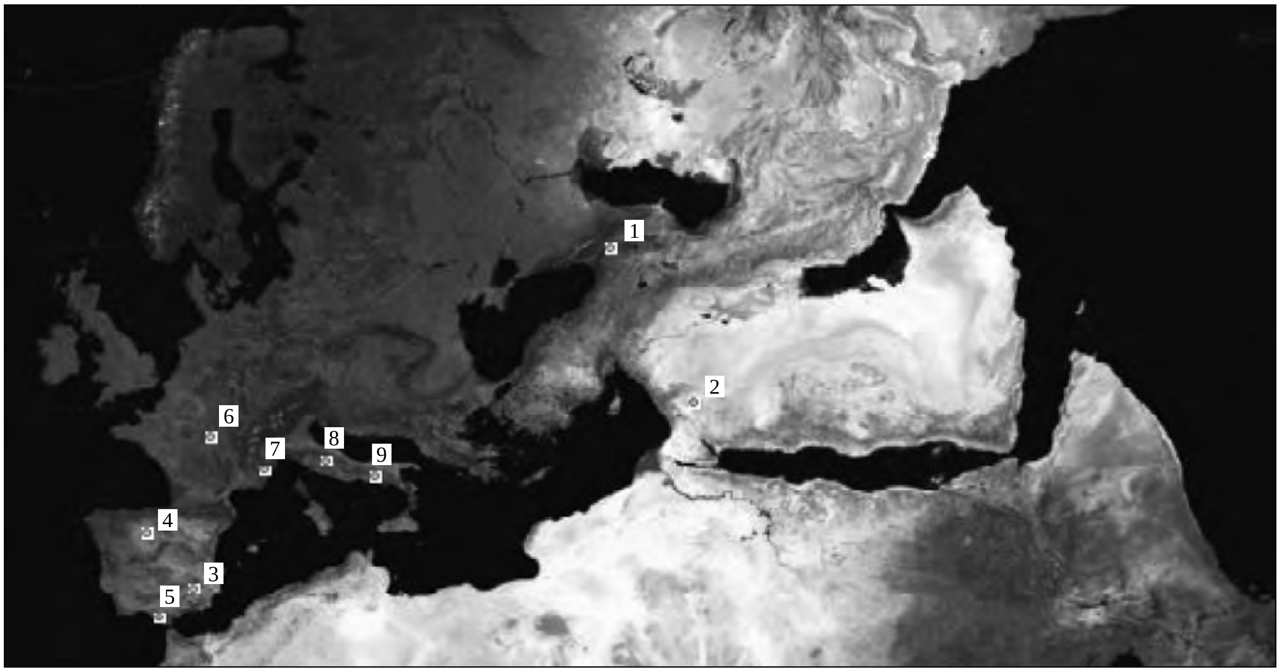


Figure 1. The oldest sites in Western Europe cited in the text: 1: Dmanisi (Republic of Georgia), 2: Ubeidiya and Yiron (Israel), 3: Barranco León and Fuente Nueva 3 (Spain); 4: Sierra de Atapuerca, TD 6 and Sima del Elefante (Spain); 5: El Aculadero (Spain); 6: French Massif Central (France); 7: Le Vallonnet (France); 8: Monte Poggiolo (Italy); 9: Ceprano (Italy).

cribed to a new species, *Homo antecessor* (Bermudez de Castro et al., 1997) from Atapuerca site TD6 (in Northern central Spain, Duero basin), dating to more than 780,000 years ago (Carbonell et al., 1995). In view of the hominid's age and its association with a rich faunal and lithic assemblage (Carbonell et al., 1999) in a cave context at Aurora stratum, the *Mature Europe* hypothesis, or the *Long Chronology* idea supported by the Atapuerca team, was strengthened (Carbonell et al., 1995). Further support of this hypothesis was added with the discovery in 1994 during the construction of a road of a human skull fragment in Ceprano (Italy), with characteristics reported at first to be like those of *Homo erectus* (Ascenci et al., 1996, 2000). Recent studies place the Ceprano specimen as a bridge between *H. ergaster/erectus* and *H. heidelbergensis* (Manzi et al., 2001; Diez-Martin, 2006). The hypothesis that this Italian fossil might be the first adult cranial specimen of *H. antecessor* is also possible (Diez-Martin, 2006).

According to Aguirre and Carbonell (Aguirre & Carbonell, 2001), three migration waves out of Africa can be identified with actual paleoanthropological data:

1. The first *Out of* Africa wave: Appearance of *Homo erectus (sensu strict)* in Indonesia in the same period as the creation of the Sunda Sea, in the later Olduvai magnetic subzone (Watanabe and Kadar, 1985; Semah, 1997). This is corroborated by the dating of earliest land mammal faunas of Java, near the end of the Olduvai event. The change in temperature recorded after 1.9 Ma points to colder and more arid conditions. The first appearance of *H. ergaster* occurred between 1.8-1.7 Ma.

2. The second *Out of* Africa wave: Appearance of Dmanisi hominids in the Republic of Georgia by 1.8 to 1.6 Ma), somewhat after the appearance of *H. erectus* in Indonesia. From a morphological point of view, the Dmanisi mandible is closer to the African *H. ergaster* and shows progressive *modern* traits not seen in *H. erectus* mandibles of Java (Rosas and Bermudez de Castro, 1998).

Around 1.7-1.6 Ma, open vegetation and increased aridity are recorded in Africa, and at around 1.5 Ma the sea level rises, the climate warms, woodlands in Africa improve, and lakes expand. The Eburonian cool climate vegetation interval is recorded in European mid-latitudes between 1.8 and 1.5 Ma. Between 1.8 and 1.6 Ma. important changes are recorded in the paleoanthropological register in Eastern Africa, with the evolution of *H. ergaster* and disappearance of *H. habilis*, and the first appearance of the Acheulean technological complex.

3. The third *Out of* Africa wave: The movement of hominids with Acheulean technology into Israel, as indicated by archaeological evidence of hominids at the site of Ubeidiya. The faunal assemblages at the Ubeidiya site included faunal elements from upper Olduvai Bed II, indicating an age older than 1.25 Ma as well as Eurasian species, and the archaeological evidence shows the appearance of Acheulean Technological complex in western Asia by this time.

A few early Pleistocene sites with hominid remains have been found in Eurasia, which can be usefully divided into three geographical areas for the purpose of this discussion (Arribas et al., 1999). As Europe is a political entity defined by historical attributes, and hominids probably wouldn't have the same conception of frontiers that we have now, we have to consider Eurasia as a geographical unit for the study of the first human dispersal out of Africa. The paucity of hominin and archaeological remains in this vast area can be explained two ways. First, taphonomic processes may be an important factor, as there is currently little representation of late Pliocene-Early Pleistocene assemblages in fine-grained sedimentary context. Secondly, and most importantly, insufficient fieldwork in deposits of suitable age in this region could also play a major role (Figure 1).

1. East Eurasia

The latest radiometric ages of several human remains of *Homo erectus* from Java, using the single-crystal Ar/Ar method (Swisher et al. 1994), have yielded dates between 1.6 and 1.8 Ma. This would suggest that the first occupation of this area was in the latest Pliocene, coinciding with the arrival in Java of several species of mammals that had originated in Asia (Satir fauna, 1.7 Ma, Semah, 1997; Arribas et al., 1999). The earliest finding in Java include the Modjokerto cranium, dated to 1.81±0.04 Ma, and the earliest specimens of Sangiran, dated about 1.6-1.7 Ma. The reexamination of the Bapang Formation (Kabuh, South East quadrant of the Sangiran), where almost 80 specimens of *H. erectus* were found, initially dated to between 1.51 and 0.08 Ma, are now suggested to date to before 1.5 Ma. Different teams do not agree with those dates, however (Semah et al., 2000), and argue a younger date of 1.3-1.0 Ma for the first appearance of hominids in Java.

At Longupuo Cave at Wushan, Sichuan Province in China (Wanpo et al., 1995) has yielded a mandible and teeth originally attributed to *Homo* but which probably represent an ape (Swartz, 1996; Wu, 2000). Ambiguous lithic pieces (two specimens) have also been reported for this site. Palaeomagnetic, biostratigraphical and geochronological (ESR) studies placed the levels in the late Pliocene, corresponding with the normal Olduvai event (1.96-1.78 Ma).

The presence of hominids at Dongyaozitou and Renzingdong at approximately 1.5 Ma. are regarded as not proven (Bar-Yosef et al 2001). The earliest nonambiguous well-dated evidence of hominids in China appears at Xiaochangliang at 1.36 Ma in the form of large assemblages of artifacts (Zhu et al., 2001).

2. Central Eurasia

Ronen (Ronen, 2006) has claimed that the earliest evidence of Out of Africa is in Israel, evidenced by a small series of flint artifacts (flakes, a core and retouched flakes) found in a gravel bed in 1980 at Yiron, dated between two basalt beds at 2.4 Ma. The site of Ubeidiya (Israel) situated south of the Lake of Galilee in the Erq el-Ahmar formation provides important assemblages of lithic artifacts representing early Acheulean technology as well as fauna remains dated biostratigraphically to around 1.4-1.3 Ma. Other sites such as Gesther Benot Yaaqov (GBY, in the northern Jordan Valley) are dated to approximately 0.8 Ma and also represent the Acheulean technological complex.

The strongest evidence of earliest settlements in Central Eurasia is in the Plio-Pleistocene site of Dmanisi (Republic of Georgia in the Caucasus region). An age for the site has been derived through K/Ar dating of the basalts below the deposits to be approximately 1.8-1.6 Ma, with magnetostratigraphy placing it in the Olduvai event and biostratigraph information supporting this date. The discovery of remains of several hominids include complete skulls of different individuals, which have been classified as an early type of *H. ergaster* or a new taxon, *Homo georgicus* (Gabunia et al., 2000; Lordkipanidze, et al., 2007). These hominids are associated with more than 4,000 lithic artifacts from six different beds. These artifacts have been classified by de Lumley et al. (2005) according to their technological and typological characteristics, particularly the absence of small retouched tools, as a "Pre-Oldowayen" cultural horizon (Lumley de et al., 2004). This is in line with the somewhat outmoded notion that tool-makers between 2.6-2.0 Ma such as at Gona sites in Ethiopia (EG10, EG12) have less knapping skill than later Oldowan tool-makers (Chavaillon 1976; Kibunjia et al. 1992; Kibunjia 1994: Piperno 1989, 1993; Roche 1989). The application of this concept to younger assemblages at Dmanisi seems to be non-evolutionary, in view of the evidence that early *Homo* originated in Africa and that the oldest lithic assemblages known at Gona in Ethiopia are classified as Oldowan technology rather than "Pre-Oldowan" (Semaw, 2000).

3. Western Eurasia

The oldest lower Pleistocene sites currently known are located below the lower limit of the Jaramillo Normal Subchron (>1.07Ma.) in the Orce-Venta Micena sector of the Guadix-Baza Basin, Barranco León and Fuente Nueva 3 (discussed below). In the Guadix-Baza Basin, other younger sites have been discovered, such as Cullar-Baza 1 dated to 0.8-0.7 Ma. and la Solana del Zamborino dated to the Middle Pleistocene.

Homo antecessor remains and Mode 1 stone tools have been found in the karstic site of Atapuerca (Burgos, Spain) at the Gran Dolina (A-TD 4-6) locality. These were found stratified in beds which, according to palaeomagnetic studies, are located below the Bruhnes-Matuyama reversal, indicating an age greater than 0.78 Ma (Carbonell et al., 1999; Pares et al., 1995). Another Atapuerca locality at Sima del Elefante (A-TE) (Carbonell, et al., 1999; Pares et al., 2006) corresponds to the Jaramillo subchron (0.990-1.070 Ma.), where stratigraphied deposits also contain Mode I artifacts. Thus, the lithic industries of Atapuerca suggest continual on long-term hominid occupation of southwestern Europe at the end of the Lower Pleistocene.

Some lithic artifacts made from flint were discovered in secondary stratigraphic context localized in three

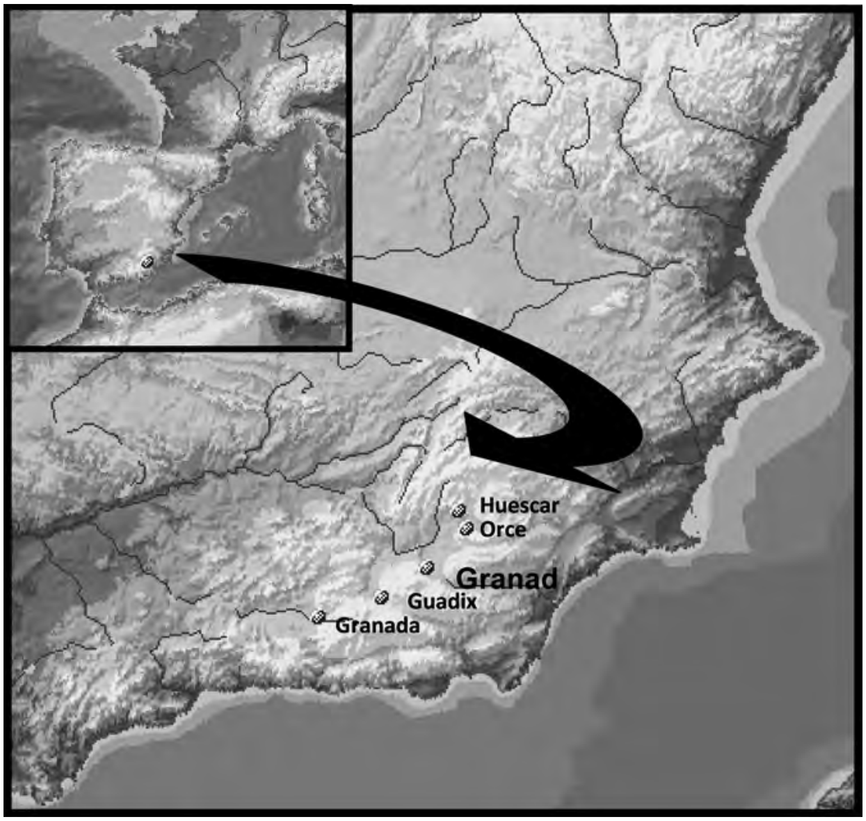


Figure 2. Locale of the Guadix-Baza basin (After Toro et al., 2003).

different fissures at the Pirro Nord site in southern Italy and are dated between 1.3-1.7 Ma. (listed in the bibliography as a paleontological site, Apulia, Italy). The lithic industry currently consists of only three cores found in different fissures, plus some flakes found associated with an Early Pleistocene vertebrate fossil assemblage. In the absence of studies into the process of formation at the site, *the disarticulated, sometimes worn, or deeply abraded bones suggest fluviatile transport and preburial effect* (Arzarello et al., 2007), and also in view of the small size of the lithic assemblage, it would appear too early to consider this site as the oldest in Western Europe.

The Case of the Early Stone Age at Orce, Barranco León and Fuente Nueva 3

One of the best examples of early occupation of western Europe is localized in the Betic Range of southern Spain, in the Guadix-Baza Basin at Orce (Figure 2). Some prehistorians believe that early Paleolithic assemblages in Europe have little value, as they are composed of small assemblages, and their ascription to Oldowan or Mode 1 (Clark, 1969) technologies is too ambiguous for the limited sample of tool-kits (Villa 1983, 2001; Kuman, 1998). Recent fieldwork at the archaeological Orce sites (Barranco León and Fuente Nueva 3), however, have increased the number of artifacts found in one representative sample, providing evidence that these artifact assemblages can be associated with the Oldowan technological complex.

The Orce-Venta Micena sector (eastern part of the Guadix-Baza Basin) is at present a plateau situated at 900 m above sea level surrounded by the Massif mountains to the North and South. The badland system caused by erosion allows access to the 100 m thick sedimentary beds and supplies evidence of an ancient lake that existed from Pliocene times (Agustí et al., 2000; Martínez Navarro et al., 1997; Toro et al., 2003).

The research in the Guadix-Baza basin has been embroiled in debate since the 1982 discovery of a purported hominid cranial fragment (VM-0), unearthed while prospecting for beds with micromammals for dating this basin. According to its discoverers, the specimen can be attributed to *Homo sp*. and represents the oldest fossil hominid in Europe (Gibert et al., 1983; Martinez-Navarro, 2002). After this discovery, systematic prospecting was carried out looking for other ancient sites in the basin. Further archaeological sites were discovered at Barranco León and Fuente Nueva 3 among others.

The specimen (VM-0, called *la galleta*) was published before it was fully cleaned, and initially only the external surface was studied. Controversy surrounding the fragment caused poor scientific reception of these sites, also complicated by the fragmentation of the original team. The research in this area continued after 1999 under the direction of Isidro Toro (Director of Granada Archaeological Museum), Jordi Agustí (a participant in the discovery of the polemic fragment, VM-0) and Bienvenido Martinez-Navarro (ICREA, Area de Prehistoria, Universitat Rovira i Virgili-IPHES).

The latest research by Martinez-Navarro concludes that the anatomy and size of the VM-0 specimen indicate it is the juvenile female of a large ruminant species (Martinez-Navarro, 2002). Currently, the only evidence of definitive human presence in the Early Pleistocene in the Orce region consists of the lithic artifacts recovered from Barranco León and Fuente Nueva3 (Martınez-Navarro et al., 1997; Oms et al., 2000; Toro et al., 2003; Fajardo, 2004). Bitterness over the controversy is still alive, however, so that even now, more than twenty years later, many focus on the problematic human nature of the fossil fragment rather than on the direct evidence of human occupation contained in the lithic assemblages from Barranco León and Fuente Nueva 3.

The geology of the Guadix-Baza basin (southeast of the Iberian Peninsula) became known in the 1970s,

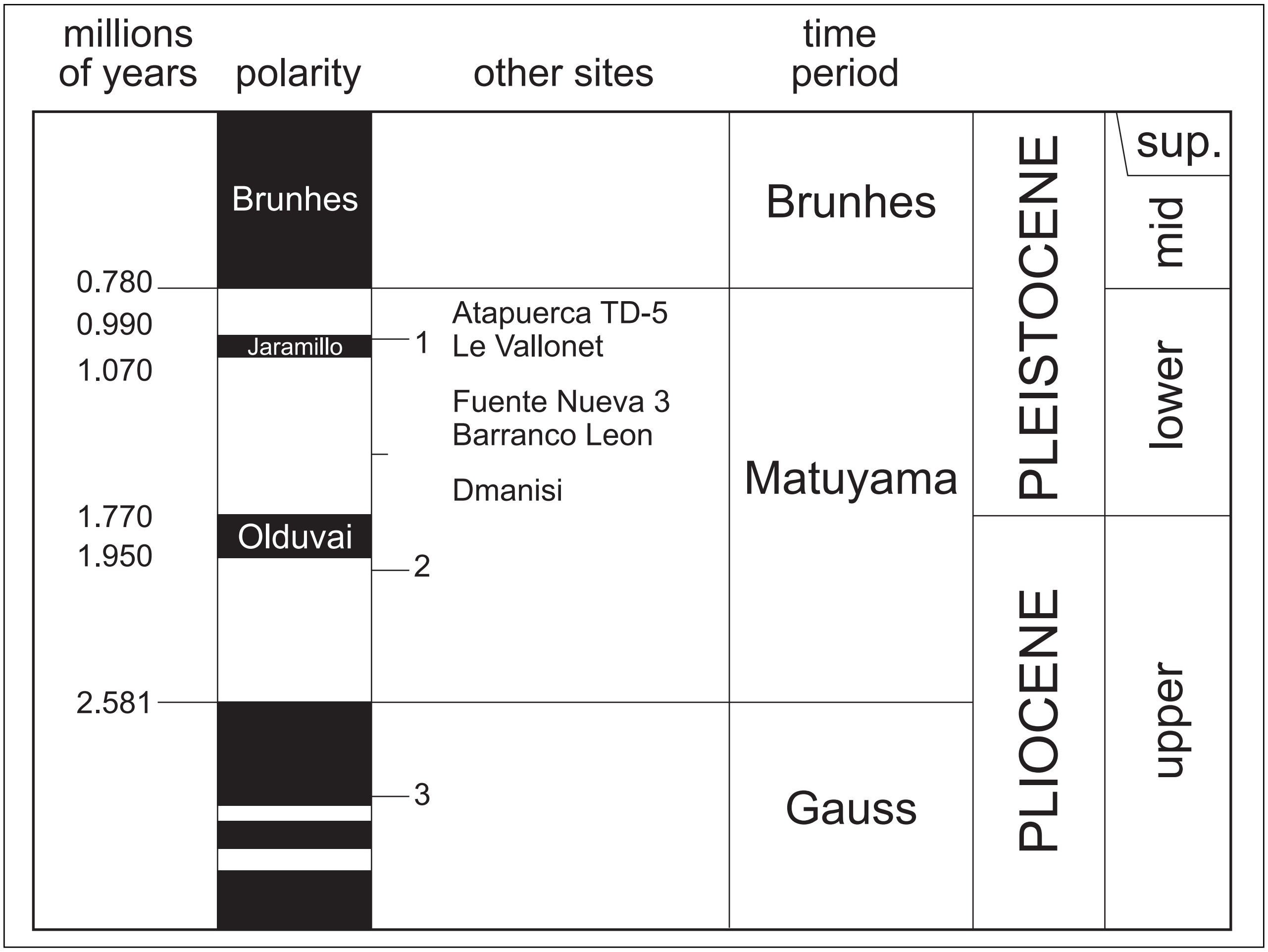


Figure 3: Correlation between the sections of Barranco León and Fuente Nueva 3 and the paleomagnetic time scale (Oms 2003).

thanks to the work of Prof. Juan Antonio Vera (Vera, 1970). The author divided the depression into two main areas–the basins of Guadix and Baza. The first, Guadix, is dominated by a torrential fluvial system, mainly with sedimentary input from the Sierra Nevada. The second, Baza, is dominated by a lake system with evaporitic sediments (limestone, gypsum and salt). This depression has been capped since the late Miocene, but retains an exceptional Pliocene paleontological record as well as an archaeological and paleontological record from the Lower Pleistocene to the Late Middle Pleistocene. More recent lake sediments within this depression has yielded a locality with Acheulian lithic assemblages, La Solana Zamborino (Botella et al., 1979; Martinez-Navarro et al., 2003). The basin was captured at the Upper Pleistocene by a tributary of Guadalquivir River (Calvache et al., 1997).

Dating and fauna

Barranco León and Fuente Nueva 3 are open-air sites located in a lacustrine/wetland context and contain lithic artifacts associated with a fauna largely composed of big mammals. Several conclusions can be reached from the biostratigraphic register (Figure 3) and palaeomagnetic analysis from both Barranco León and Fuente Nueva 3. First, the two deposits are within sections of dominant reverse polarity. This gives them an age before the Brunhes Normal Chron and places them in the Matuyama Reversed Chron (an assignment to earlier reversed Subchrons are ruled by the biostratigraphic data). Secondly, the magnetic and biostratigraphic evidence indicate that these deposits are older than reversed Jaramillo Subchron but more recent than normal Olduvai Subchron (Figure 4) (Oms et al., 2000, 2003).

Faunal remains from the new excavations are currently under study, but preliminary data from one indicating the presence of species has been published (Martinez-Navarro et al., 2003; Martinez-Navarro et al., in prep). Large mammals show a faunal break at the Plio-Pleistocene boundary, marked by the arrival of African and Asian species. In the excavated faunal assemblage, we can find bones modified by the action of carnivores (specifically from one very big hyena, *Pachycrocuta brevirostris*) and also hominid cutmarks.

More than 3,000 faunal remains are present in both sites. Preliminary study of the materials up to 2003 shows that 52.9% at Barranco León are identifiable, and 45.7% at Fuente Nueva 3. Both sites show a quite similar faunal composition (Table 1) and similar skeletal element representation, although there are some key differences

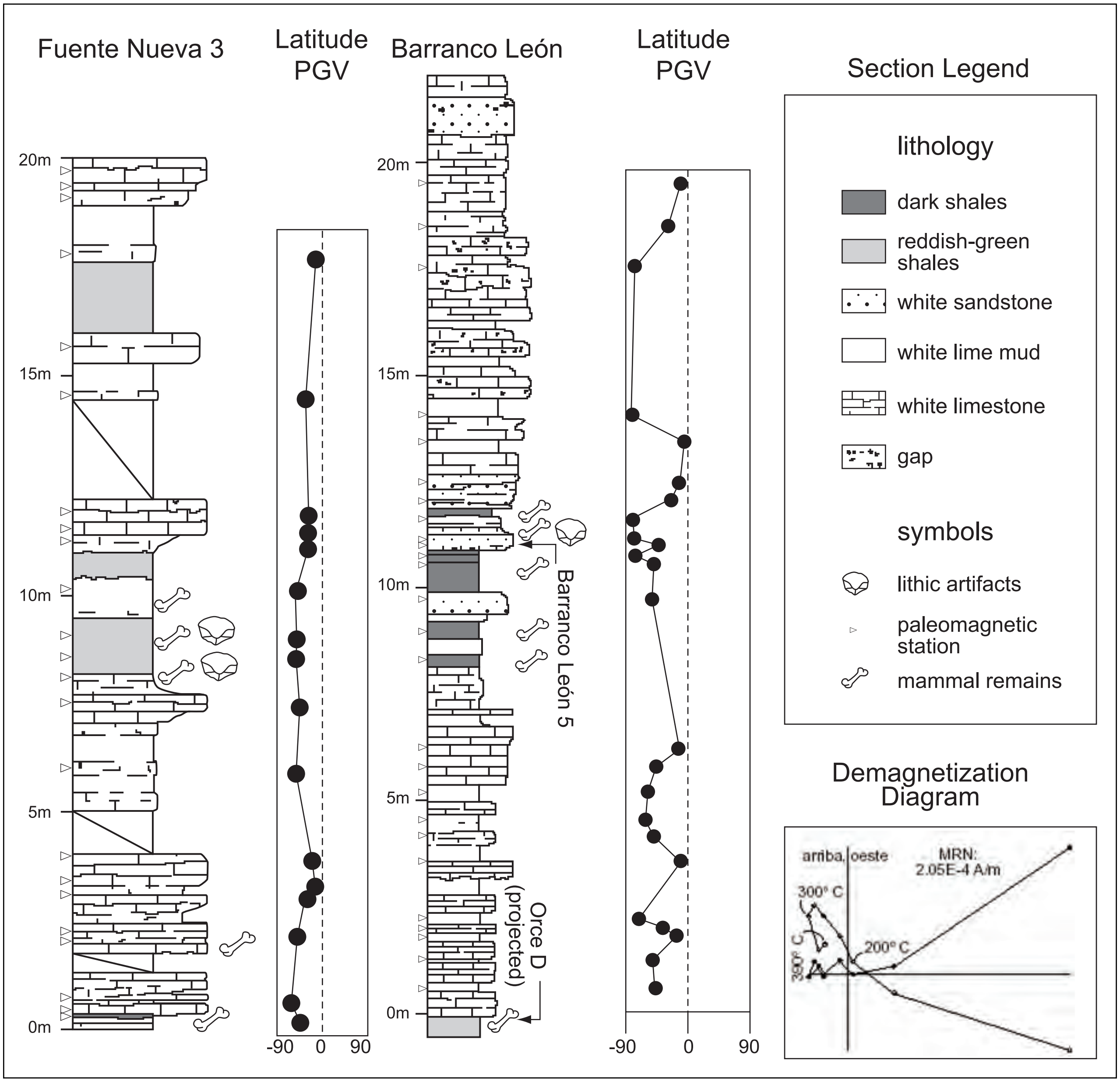


Figure 4. The stratigraphic sections at Barranco Leon and Fuente Nueva-3 showing the locations of paleomagnetic samples taken, the mammalian localities, and the archaeological sites. (after Oms et al., 2000).

between the two localities in the former, primarily in the relative abundance of different megaherbivore species. In Barranco León, *Mammuthus meridionalis* is practically absent, while at Fuente Nueva 3 it is one of the best represented species, especially in the Upper Bed. *Hippopotamus antiquus*, however, is abundant in Barranco León but scarce in Fuente Nueva 3.

Taphonomic state of the materials

The statistical probability of the faunal differences between these sites being due to a sampling error is practically nil. These differences in faunal components are almost certainly related to real faunal differences tied to the very different environments of these two sites–a lacustrine environment with occasional clastic sedimentation in the case of Barranco León, and a lacustrine/wetlands environment with areas of pools in the case of Fuente Nueva3 (Espigares et al., in press).

The faunal remains at Fuente Nueva 3 show little evidence of hydraulic transport. Very few remains have polished or rounded surfaces, and some articulated elements have even been found in this locality. The analysis of bone orientation is not possible, as only a small number of remains are available for such analysis, so such study awaits retrieval of a larger data set (Espigares et al., in prep). On the other hand, at Barranco León, in the lower part of Bed D represented by sands (D2) and gravels with pebbles (D1), including some of great size, are numerous faunal elements with polished or rounded surfaces as well as stone artifacts in D1 that show pati-

Table 1: Animal species at Barranco León and Fuente Nueva 3 according to Martinez-Navarro (in prep)

Fuente Nueva 3	**Barranco León**
Homo sp. (Only lithic assemblages)	*Homo* sp. (Only lithic assemblages)
Ursus sp.	*Ursus* sp.
Canis mosbachensis	*Canis mosbachensis*
Lycaon lycaonoides	*Lycaon lycaonoides*
Vulpes cf. *praeglacialis*	*Vulpes* cf. *praeglacialis*
Pachycrocuta brevirostris	*Pachycrocuta brevirostris*
Felidae indet.	Cf. *Homotherium* sp.
Lynx sp.	
Felis cf. *silvestris*.	
Meles sp.	*Meles* sp.
Pannonictis cf. nestii	cf. *Pannonictis*
Mustelidae indet. (small size)	
Mammuthus meridionalis	
Stephanorhinus hundsheimensis	*Stephanorhinus hundsheimensis*
Equus altidens granatensis	*Equus altidens granatensis*
	Equus suessenbornensis
Hippopotamus antiquus	*Hippopotamus antiquus*
Bison sp.	*Bison* sp.
Ammotragus europaeus	
Hemitragus cf. *albus*	*Hemitragus* cf. *albus*
Praemegaceros cf. *verticornis*	*Praemegaceros* cf. *verticornis*
Metacervocerus rhenanus	*Metacervocerus rhenanus*
	Oryctolagus cf. *lacosti*
Erinacenae indet.	Erinacenae indet.
Crocidura sp.	*Crocidura* sp.
Sorex minutus	Sorex minutus
Sorex sp.	*Sorex* sp.
Galemys sp.	*Galemys* sp.
Asoriculus gibberodon	*Asoriculus gibberodon*
Allophaiomys aff. *lavocati*	*Allophaiomys* aff. *lavocati*
Allophaiomys sp.	*Allophaiomys* sp.
Mimomys savini	*Mimomys savini*
Castillomys crusafonti	*Castillomys crusafonti*
Apodemus aff. *mystacinus*	*Apodemus* aff. *mystacinus*
Hystrix sp.	*Hystrix* sp.

The spatial distribution of fossil remains at Barranco León does not reveal patterning in either a horizontal or vertical sense, as both bones and lithic remains are fairly uniformly distributed in the deposit. In Fuente Nueva 3, however, stone artifacts are especially concentrated in the Lower Bed but are scarce within the Upper Bed (although the fact that the Lower Bed has been excavated more extensively than the Upper Bed could potentially help bias this apparent pattern). The relative abundance of coprolites of *P. brevirostris* in the different levels of this site would indicate a relatively greater impact of hominids in the Lower Bed as opposed to relatively greater impact of carnivores in the Upper Bed. Overall, the accumulation of remains presents evidence of modification through a variety of means, including anthropic, carnivore and rodent activity as well as by purely diagenetic processes (Espigares et al., in press).

nation. The analysis of orientations of elements in Bed D1 indicates a prominent SW-NE orientation, in line with the paleocurrent in the area. The upper part of the layer, however, contains much finer-grained sediments, primarily fine sands, indicating lower-energy deposition. This is supported by the presence of conjoining artifacts as well as some bones in anatomical connection and coprolites.

Stratigraphic position

Barranco León

The site of Barranco León (Figure 5) is at the moment the oldest site yet found in the Guadix-Baza Basin. It is situated 3 km of east of Orce within a ravine that runs from north to south, from the base of the bell tower of Sierra of Umbría to Cañada de Vélez,

The stratigraphy proposed by Anadón & Juliá (Anadón & Juliá; 2003) is the following:

The observable succession from the bottom of the ravine to the top of the plain can be traced along a gentle slope in the lower, more northerly part of the ravine, where primarily fine-grained, marly lutite sediments, reddish and whitish, are exposed (Red detritic member). Above these layers are carbonates containing quartz sand, silt and clay, which form the steeper parts of ravine (Upper muddy limestone member). Within these strata the archaeological Bed BL 5 (Turq et al., 1996) has been identified, in which the following sedimentary sequence can be observed in the excavation trench and in nearby

Figure 5. Barranco León September 2007 (B. Fajardo).

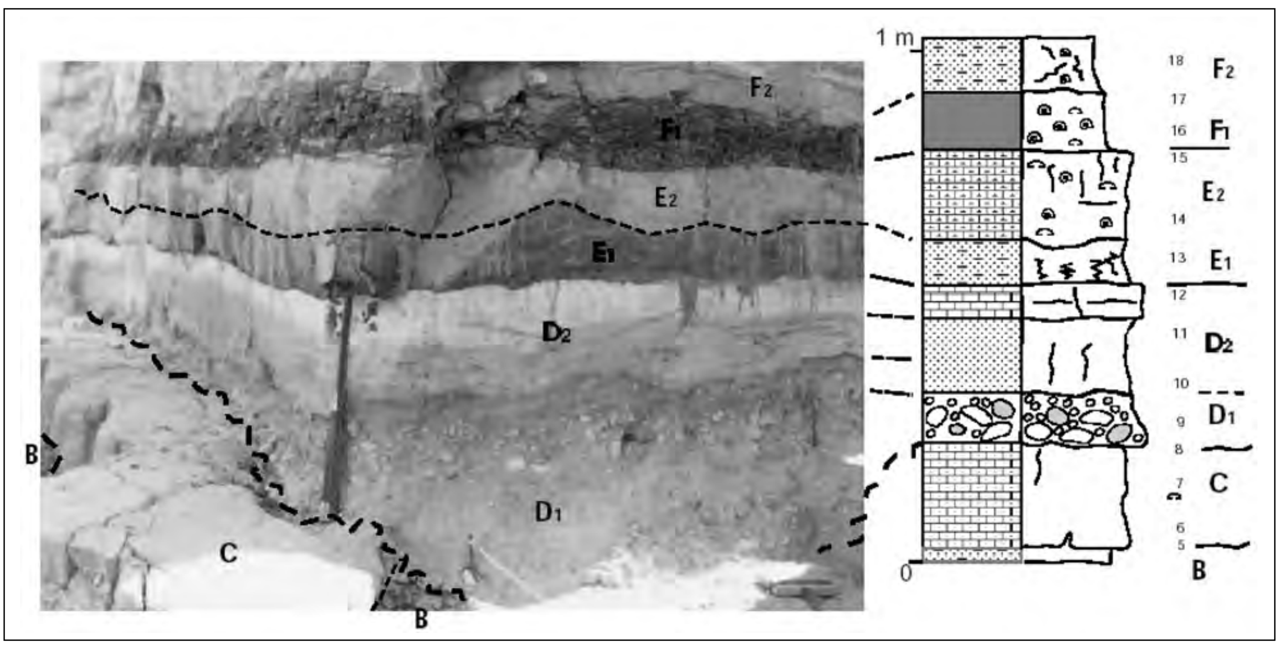


Figure 6. Synthetic stratigraphy of Barranco León (after Toro et al. 2003).

outcrops, from the bottom to the top (Figure 6):

A) (Not shown in Figure 6). Bed of variable prominence around one meter in thickness, exposed in the southern excavation area and composed of calcarenite-calcisiltite with plentiful gastropods. This Bed corresponds to the base of the Bed "d" of the profile LD of Anadón & Juliá (1987) and is situated at the level of sands and blackish and reddish luttites in the big extension trench (Beds L 2-3 according to Anadón & Juliá, 1987).

B) 25-32 cm of variable thickness, formed by sandy beds of different colors, grey, green, blackish, with inclusions of the sandy lutites with quartz. Sands consist of grains of quartz and feldspars. Certain beds show laminations and ferruginous spots.

Figure 7. Fuente Nueva 3, (after Toro et al., 2003)

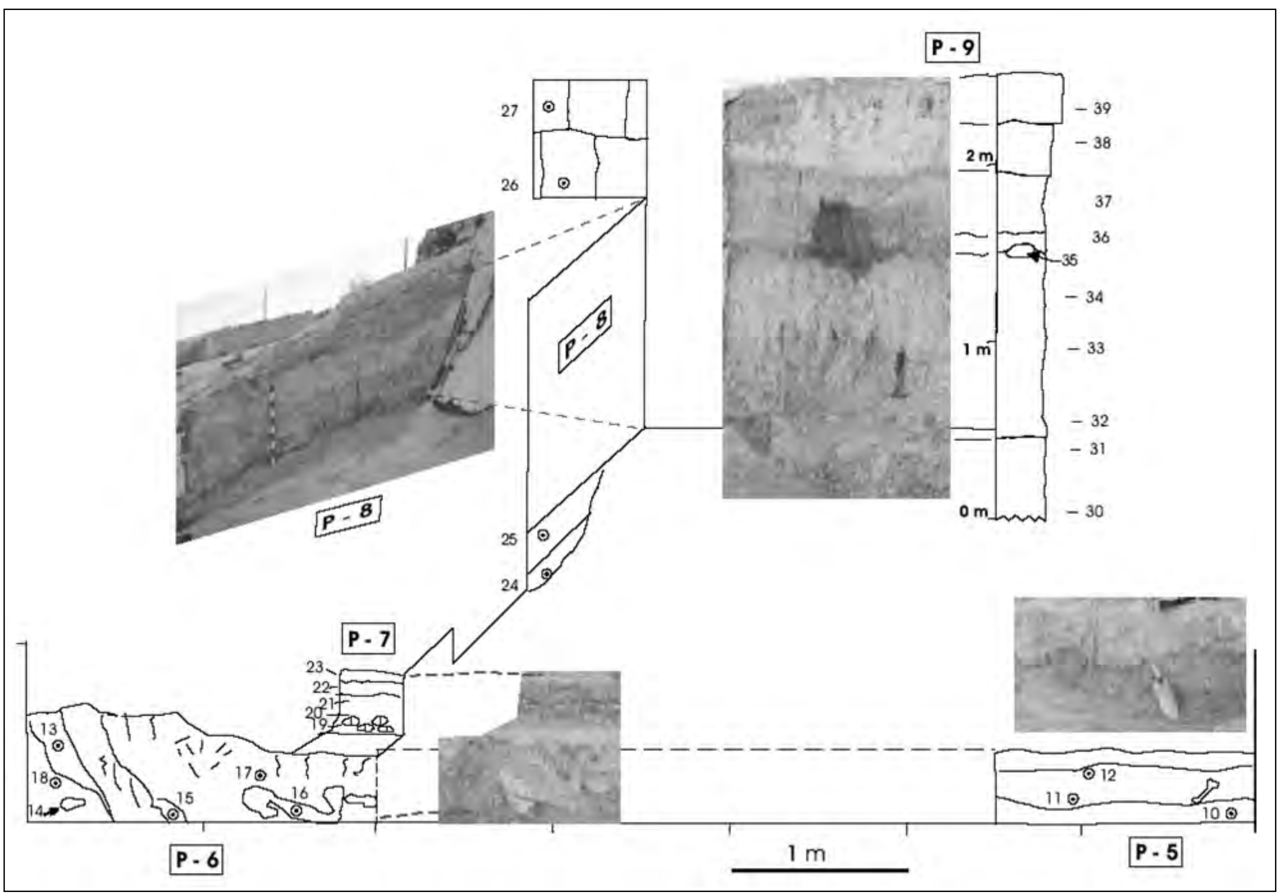


Figure 8. Synthetic stratigraphy of Fuente Nueva 3 (after Duval et al., in prep.).

Figure 9. Mammuthus meridionalis *from the Upper Bed of Fuente Nueva 3. (After Toro et al., 2003).*

C) 20-30 cm, calcisiltites in beige calcarenites with ostracods and numerous bivalves (Spaeriidae). There are visible vertical tracks of bioturbation and some faunal remains of isolated vertebrates.

D) 5-65 cm, Turq et al., 1996 correlated by Turq et al., (1996) with the Bed BL-5 described by Turq and Gibert (Gibert et al., 1998). In the area of the excavation, this bed can be divided into two sub-beds, the lower one, D1, characterized by variable sandy gulleys and irregular erosive basal contact. Above, is the sub-Bed D2, 22 cm of sands with gray quartz bioclastics, which present yellowish irregular spots which end in a bed of white limestone full of ostracods and gyrogonites of charophytes (casts of stonewort fruit).

E) 32-35 cm, this can be subdivided into two beds. The uppermost, E1, consisted of a basal bed of sands made up primarily of quartz and feldspar, reddish, ochre and greenish colors, about 5 cm thick. Bed E2, approximately 27 cm thick, is a layer of gray, marly-calcareous sediment with numbers of gastropods, ostracods and gyrogonites of charophytes.

F) 22cm, a layer of blackish lutites and gastropods (F1, 12 cm thick.) topped by a 10 cm layer of gray green, finely stratified quartz-bioclastic sands. At its upper contact with the overlying bed are small white nodulary concretions.

G) Beige bioclasitic calcareous sands, with a high percentage of large siliciclastic rocks as well as scattered shells of ostracods.

Fuente Nueva 3

The site of Fuente Nueva 3 (Figure 7) is situated approximately 8 km to the east of Orce, in the extension of the Fuente Nueva excavation, close to the ruins of a church and old fountains after which the site is named.

The deposits are characterized by carbonate deposits and major secondary oxidations which make reading the stratigraphic sequence difficult. At the base, 11 sedimentary layers can be grouped into five lithostratigraphic units, containing two layers of human occupation. The sequence is made up of fine-grained carbonate deposits (clays to fine sand). At the base is a limestone (ULS I), followed by the marly-calcareous deposits (ULS II) which contain the lower archaeological bed. The ULS III, with the upper archaeological Bed, constitutes a sedimentary break in the sequence, with beds of relatively hardened. At the top is a very thick marly deposit (ULS IV) capped by layers of limestone (ULS V), (Figure 8). (Duval, et al., in prep).

Table 2: General breakdown of the lithic assemblages.

Artifact categories	BL		FN3 N. INF		FN3 N. SUP	
	N	%	N	%	N	%
Nucleus	23	1.80	25	2.72	0	0
Whole flakes	191	14.95	230	25.03	25	12.14
Flake fragments	99	7.75	108	11.75	22	10.68
Angular fragments	4	0.31	77	8.38	39	18.93
Hammerstones	14	1.10	33	3.59	4	1.94
Modified pieces	23	1.80	32	3.48	3	1.46
Unmodified pieces	75	5.87	67	7.29	25	12.14
Retouched pieces	26	2.03	12	1.31	1	0.49
Anvils	0	0.00	10	1.09	0	0
Debris	823	64.40	325	35.36	87	42.23
Total	1278	100.00	919	100.00	206	100

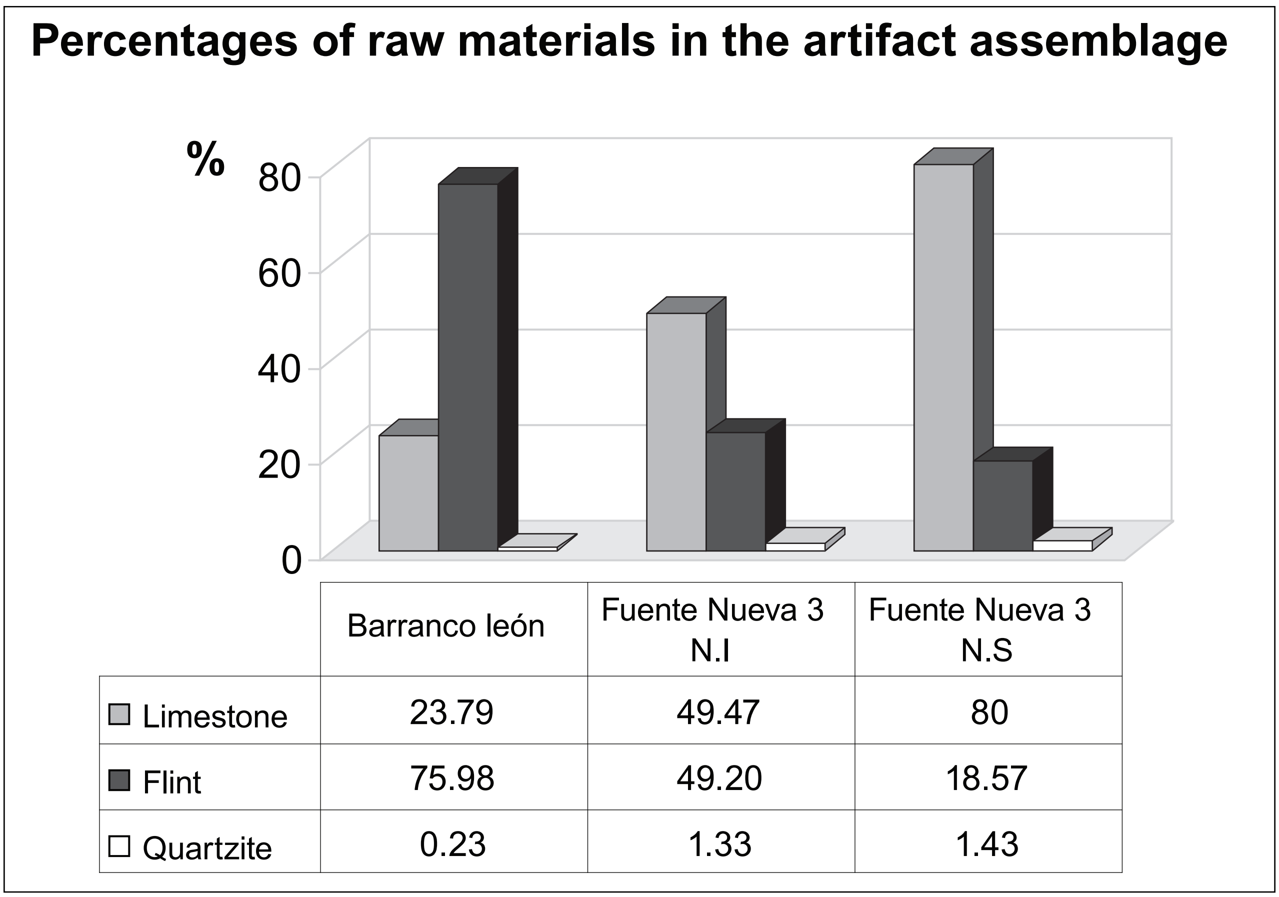


Figure 10. Raw materials distribution in the lithic assemblage of each site.

Overview of the Oldowan Lithic Assemblages from Barranco León and Fuente Nueva 3.

The systematic archaeological and geological survey and excavation at Barranco León and Fuente Nueva 3 sites (Orce, Spain) during the last decade led to the discovery of well-flaked stone artifacts, which are currently some of the oldest known from Europe, along with a faunal assemblage, stratified within fine-grain sediment.

At Barranco León the area of excavation is 40 m^2 with a 0.6 m depth of deposit for Beds D1 and D2 combined. At Fuente Nueva 3, the excavation area in the Upper Bed comprises 65 m^2 (with 8 m^2 occupied by the

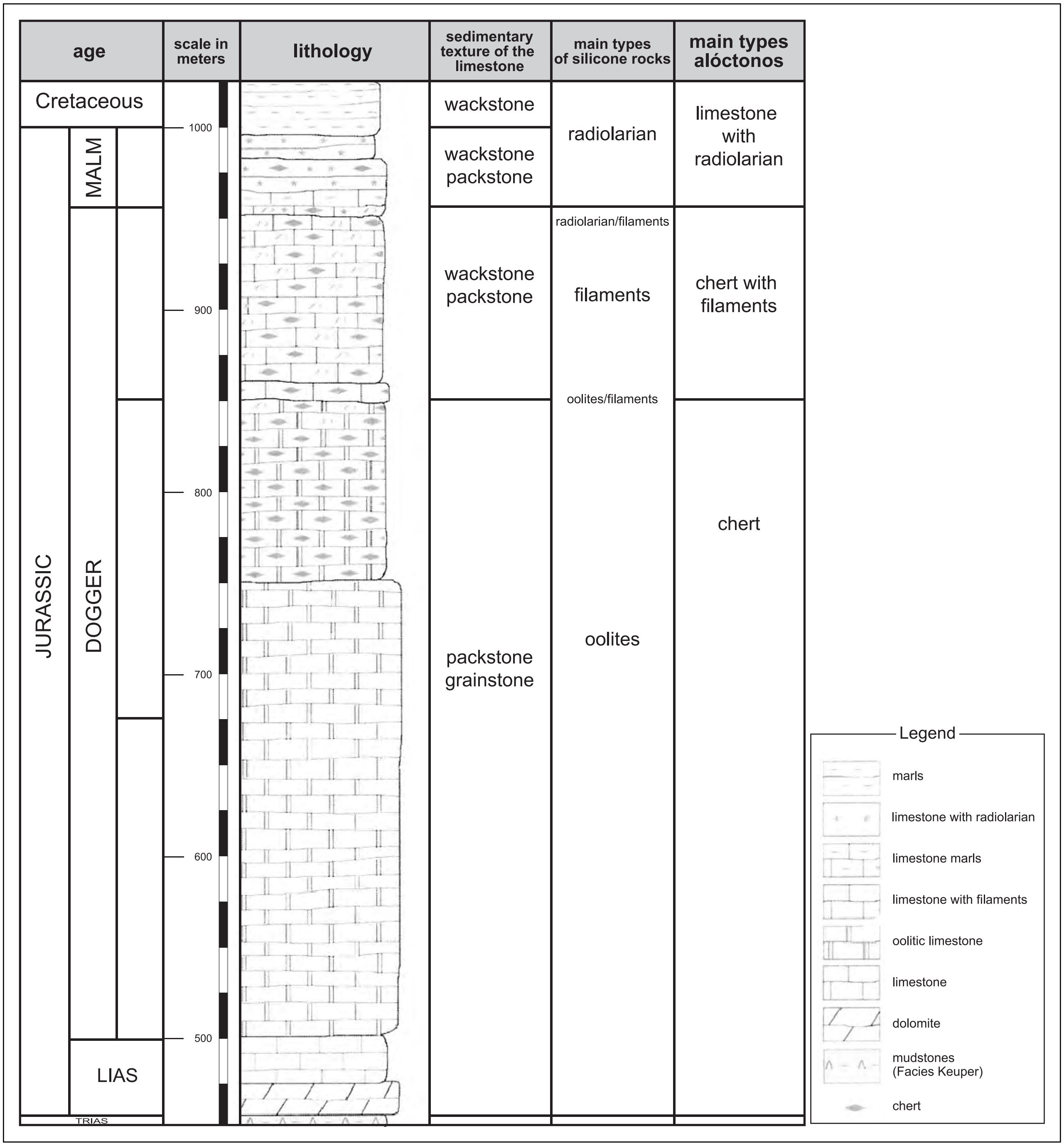


Figure 11. Synthetic stratigraphy of montain system south of the sites at Sierra de Orce and Sierra de Maria (after Ramos Millán et al., 1991).

skeleton of a *Mammuthus meridionalis*) (Figure 9) with a deposit depth of 0.30 m), and the excavated area in the Lower Bed extends 50 m^2 with a 0.5 m depth of deposit.

The composition and characteristics of the artifact assemblages from Barranco León and Fuente Nueva 3 are broadly similar to other Lower Pleistocene assemblages assigned to the Oldowan Industrial Complex or Mode I technology, characterized by a low degree of standardization (simple core forms and débitage). Both assemblages consist of cores, hammerstones, whole and broken flakes, a high density of angular fragments, as well as a few retouched pieces. The majority of the artifacts fall into the débitage category, including whole and broken flake debris and angular fragments. Flint and limestone were the best represented raw materials, and a few pieces of quartzite are also present. The raw material sources for the Orce tool-making hominids, accessible from nearby ancient streams, were small cobbles and tabular fragments.

In spite of the simplicity of the technology and the accidents of débitage, the tool-makers managed to produce good quality flakes. This is evident not only in terms of the technical mastery of flaking, but also in terms of the choice of good quality raw materials, which denotes

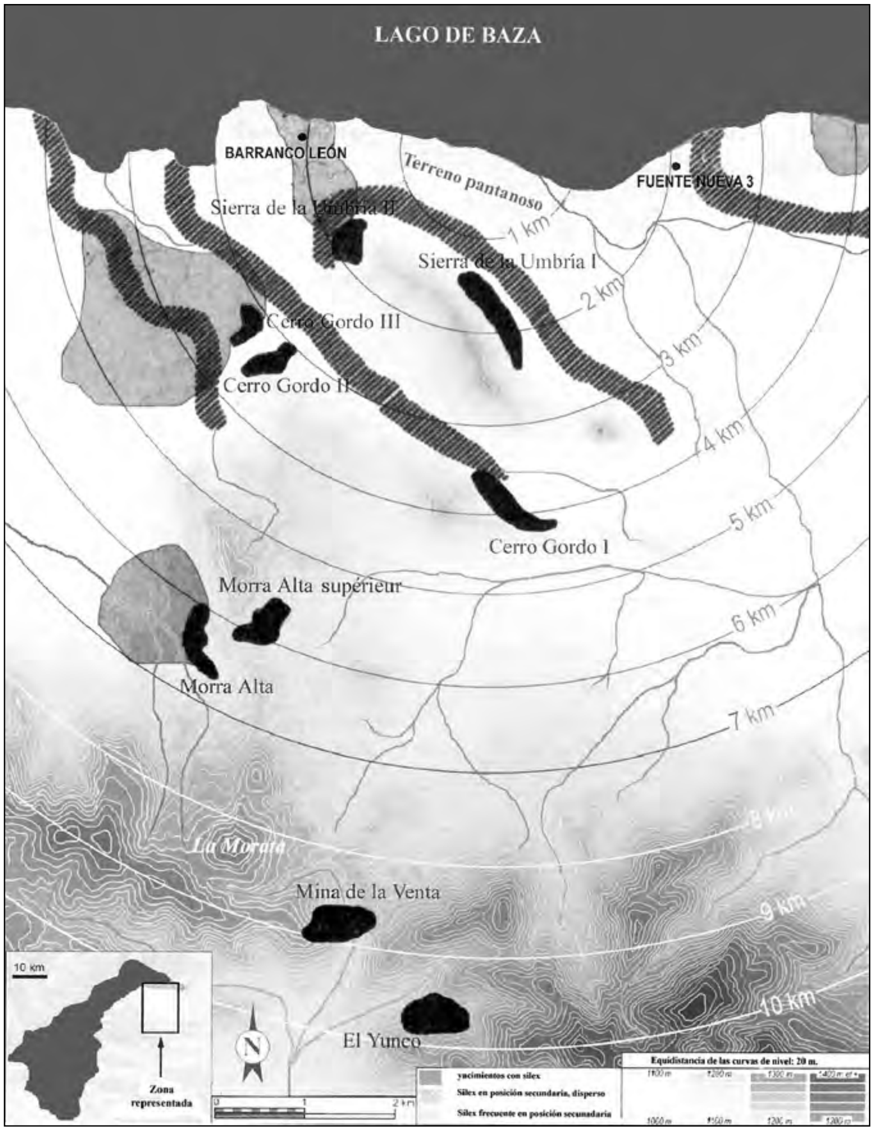


Figure 12. Zones of Jurassic flint and localization, (in black) of flint in secondary position (in gray), in the hydrographic area and in the slope deposits (after Toro et al. in prep).

knowledge of the properties of stone sources available. The flakes define the finality of the production, and of the relatively simple strategies of débitage.

The Barranco León lithic assemblage is composed of 1,278 pieces, the Fuente Nueva 3 Lower Bed assemblage of 919 pieces, and the Fuente Nueva 3 Upper Bed assemblage of 206 pieces (Table 2). These assemblages are composed of technological types in the following categories: cores, whole flakes, flake fragments, angular fragments, hammerstones, modified pieced, unmodified pieces, retouched pieces, anvils and debris. The presence of small pieces < 2 cm in the assemblages of both sites suggests minimal disturbance by depositional or post-depositional process at the sites.

Raw materials

Most of the artifacts present at Barranco León and Fuente Nueva 3 are made of flint and limestone, with the exception of a few quartzite pieces, and manufactured through hard hammer percussion (n=961, 75.20% in flint, n=290, 22.69% in limestone and n=3, 0.23% in quartzite in Barranco León, and for Fuente Nueva 3 N=371, 50.96% in inferior Bed and for the Superior Bed n=168, 80% in limestone; n=39, 18.57%, in flint and n=3, 1.43% in quartzite) (Figure 10).

The flint, which formed during the Jurassic period, is present in different colors and textures. The original form of the flint used was in the form of tabular pieces. Overall, the flint was of poor quality, coarse grained, and in a variety of colors ranging from yellow to green. The green flint is the best quality and is the most abundant in the Barranco León assemblage. In the case of Fuente Nueva 3, the most abundant flint is white in color, indicating that it had been leached of most of its silica by post-depositional processes not yet identified. The Jurassic limestone present in both sites is of two different qualities - marly limestone and siliceous limestone.

Both types of raw material are found in geologi-

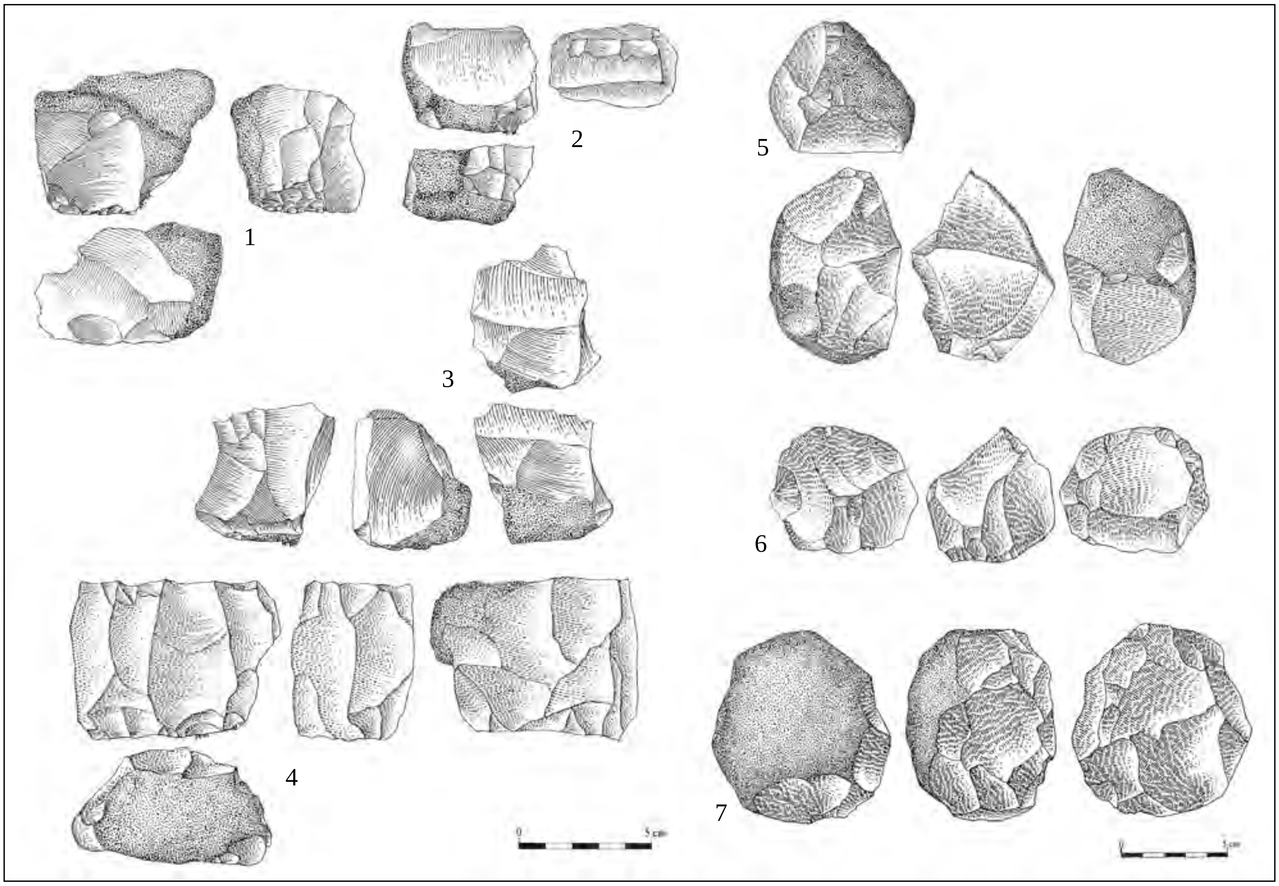


Figure 13. Cores from Barranco León: 1-4 cores in flint, 5-7 cores in limestone, made by direct percussion with hard hammer, except number 4, which was produced by bipolar technique with an anvil. The size difference between both raw materials is clearly evident.

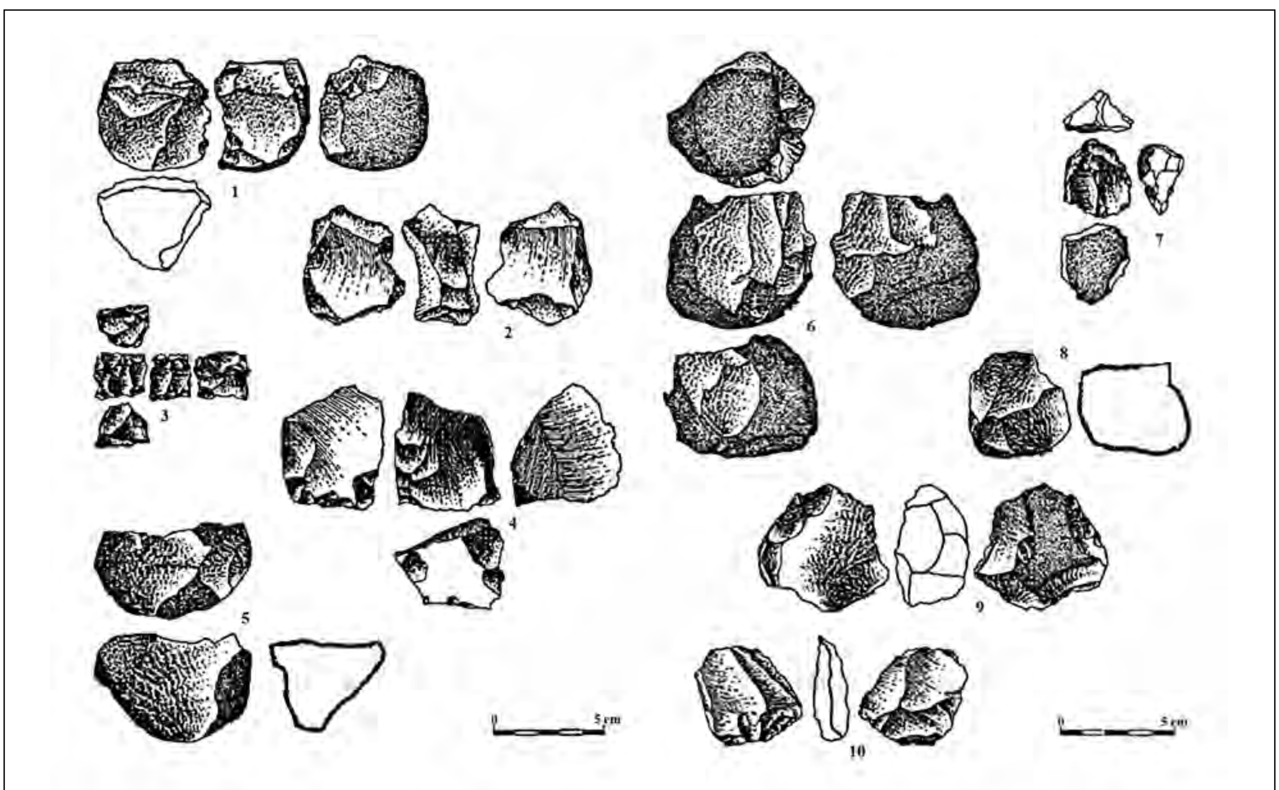


Figure 14. Cores from Fuente Nueva 3. 1: core in quartzite; 2, 3, 4, 7, 9, 10: cores in flint; 5, 6, and 8: cores in limestone.

Table 3. Whole flake dimensions (in mm) and weight (g) at Barranco León, at Fuente Nueva 3 N. I, and at Fuente Nueva 3, N.S.

	Statistics	Mean	Std. Dev.	Range
Barranco León (n=191)	Length	26.98	11.02	6-65
	Breadth	22.27	9.36	1-55
	Thickness	8.72	4.55	1-26
	Weight in grams	7.36	9.48	1-83
	Ratio L/B	1.35	1.03	0.38-15
	Ratio B/T	3.02	1.83	2-17
Fuente Nueva 3, N.I. (n=230)	Length	34.47	15.19	7-131
	Breadth	30.38	16.92	7-121
	Thickness	10.82	7.39	1-55
	Weight in grams	22.01	91.03	1-1086
	Ratio L/B	1.26	0.47	0.15-3.57
	Ratio B/T	3.44	2.08	0.93-16
Fuente Nueva 3, N.S. (n=25)	Length	30.92	14.48	9-65
	Breadth	28.08	12.59	6-59
	Thickness	9.64	6.74	2-30
	Weight in grams	23.37	3.16	1-236
	Ratio L/B	1.21	0.58	0.47-3
	Ratio B/T	3.65	1.93	1.13-9.5

cal primary context in the mountain system south of the sites, in the Sierra de Orce and the Sierra de Maria (figure 11), within 2 km of the sites, but the hominids probably used raw materials available from nearby ancient streams (Figure 12).

Comparison of frequencies of raw materials between Barranco León and Fuente Nueva 3 Inferior Bed, and Superior Bed is somewhat problematic. First, there is significant difference in the excavated area of the two sites, and secondly, there was selective recovery of artifacts in the first years of fieldwork by different teams working at the sites after their discovery. We can see different overall distributions of raw materials between Barranco León and Fuente Nueva 3, with limestone more prevalent in the latter site, but in both cases the débitage is predominantly flint. The percentage of retouched pieces is low, but most of these are made of flint. Relatively small proportions of cores are found in the assemblages of both sites, and cores are in fact absent in the Superior Bed of Fuente Nueva 3. The dimensions and technological patterns observed in the cores are largely dependent upon the original form and quality of the raw material, with the final typological assignment also corresponding to the different stages of flaking. Hard-hammer direct percussion is the only technique used by the hominins at Orce sites, with the application of this technique always adapted to the size and original form of the raw material.

Twenty-three cores are identified at Barranco León and twenty-five at the Inferior Bed of Fuente Nueva 3. The dimensions are variable, depending on the original form and quality of the raw material, and there are no stereotypical forms. In general, the cores made of limestone are bigger than those of flint, probably the result of more intensive flaking of the finer-quality flint. Most of the cores preserved the residual cortex. The number of scars varies among cores produced through unidirectional, bidirectional or multidirectional methods. Most cores can be classified (according to Mary Leakey's typology) as choppers, subspheroids and polyhedrons (Figure 13, 14).

A total of 198 whole flakes are present at the assemblage of Barranco León (Figure 15) (92.2% in flint, 6.5% in limestone and 1.4% in quartzite); 229 at Fuente Nueva 3, 204 in the Inferior Bed (79.41% in flint, 19.12% in limestone and 1.47% in quartzite) and 25 in the Superior Bed (60% in flint and 40% in limestone). The general dimension of the flakes is small and, as we can see in table 3, they are not standardized in shape.

Following the flake types of N. Toth (Toth, 1985):

- Type I: Cortical platform and cortical dorsal surface.
- Type II: Cortical platform and partially cortical dorsal surface.
- Type III: Cortical platform and non cortical dorsal face.
- Type IV: Non cortical platform with total cortical dorsal surface.
- Type V: Non cortical platform with partially cortical dorsal surface.

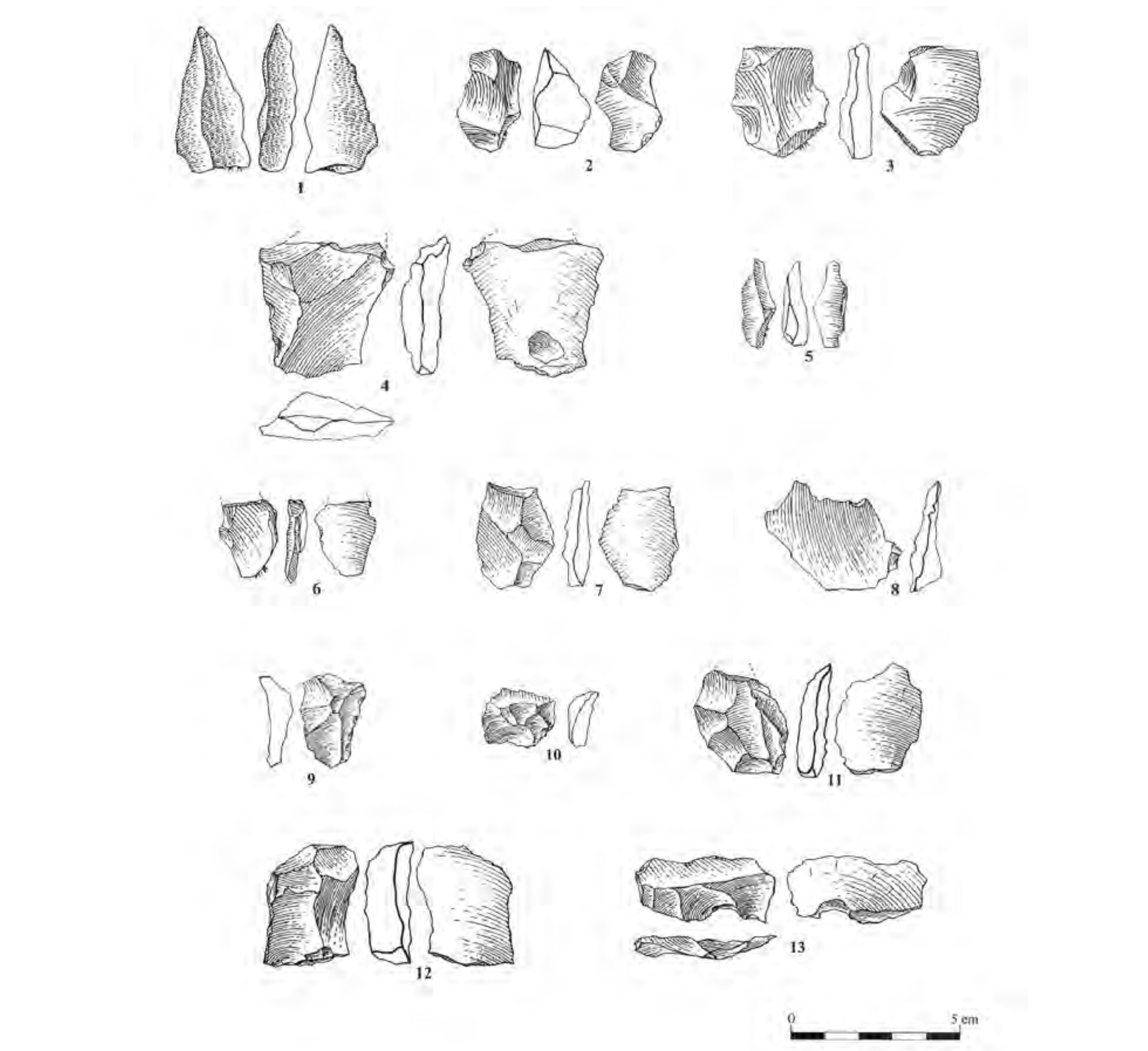


Figure 15. Examples of flakes from Barranco León. Note the relatively small size and the lack of standardization.

Type VI: Non cortical platform with non cortical dorsal surface.

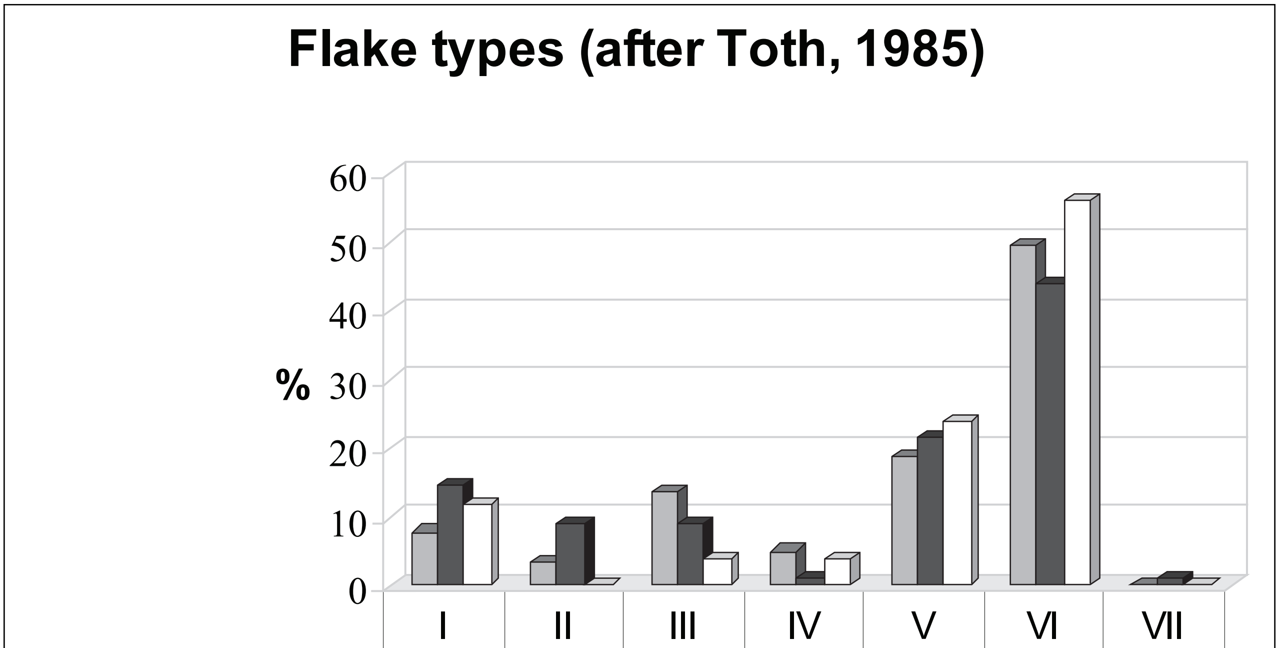
Type VII: Indeterminate.

We can see that in general all flake types are represented, but types V and VI are the most abundant (figure 16). This indicates that the earliest stages of flaking were possibly carried out away from the site, which can be interpreted as a sign of hominid transport of better quality raw materials after they had tested their flaking characteristics in the nearby ancient streams. The sites are not totally excavated, however, and further fieldwork to be necessary to investigate whether there are signs of intra-site transport of the rock between episodes of flaking.

The retouched pieces are not very well represented in either assemblage– 49 pieces in total (2.03% of the assemblage at Barranco León, and at Fuente Nueva 3, 1.3% of the assemblage in the Inferior Bed and 0.49 of the assemblage at the Superior Bed) (Figure 17). Also, they are not visibly standardized in terms of the choice of a blank, the application of the retouch, or in stylistic forms produced. They are primarily made in flint and include types such as scrapers, denticulates and notches. Several pieces show retouch on sharper edges, which may also be produced through use, as indicated by experimental and micro-wear studies, and may not represent deliberate retouch as such.

Summary

Presently, the sites of Barranco León and Fuente Nueva 3 are the oldest and most well preserved in Western Europe in open-air context. The continuation of research work in the area of Guadix-Baza Basin is one of the keys to help us understand the dispersal and evolution of our ancestors–the first adventurers who peopled



	I	II	III	IV	V	VI	VII
BL (n=217)	7.83	3.23	13.82	5.05	18.89	49.77	0.00
FN3,N. I (n=204)	14.71	8.82	8.82	0.98	21.57	44.12	0.98
FN3 N. S. (n=25)	12	0	4	4	24	56	0

Figure 16. Flake type breakdown from each site.

this part of the European continent.

Several conclusions can be extracted from the preliminary analysis of the lithic assemblages from Barranco León and Fuente Nueva 3. These conclusions can be traced to the characteristics observed in the first Oldowan assemblages recognized in Africa, and show opportunistic and non-systematic reduction patterns viewed as a least-effort system for the production of sharp edges (Toth, 1985; Isaac, 1997).

- Flint and limestone are the two best represented types of rocks used to manufacture the artifacts. They were available in the alluvial formations of the paleo-channels that fed the lake, in the form of small cobbles or tabular fragments. There is no evidence of stone transport over great distances to the sites, but it is obvious that the hominids were selective of the shapes of the raw materials.
- Two principal techniques used for knapping were hard-hammer percussion and direct unipolar and bipolar technique (using an anvil). The choice of technique, is related to the sharpness and quality of the original form of the raw material.
- The final morphology of the artifact assemblage is not related to a stylistic conception, rather, it depended on the original form and quality of the raw material. The high quality flint allowed more intensive core reduction.
- The flint cobbles and tabular fragments appear to have been favored for production of flakes with sharp cutting edges. Limestone was also used for to produce core forms, battered precursors and débitage, but in lower proportion and with less intensity.
- The study of the cores and the flakes shows a lack of prepared platforms, indicating a relatively opportunistic character to these assemblages.
- The goal of these hominids seems to be the production of flakes. The distribution of flake populations (according to Toth's flakes types; Toth, 1985) together with the high proportion of debris, broken flakes and conjoined pieces found recently in preliminary work, shows that the débitage was *in situ*. Though all flake types are represented, the most abundant represent the final stages of flaking. That is most likely a result of probable transport of raw material from the paleo-channels to the sites after testing their potential.
- The proportion of retouched artifacts is low but present, and they do not show stylistic standardization. Forms present may be categorized primarily as denticulates and notches.
- Considering the Oldowan hominids as opportunistic omnivores (Schick & Toth, 2006), the high propor-

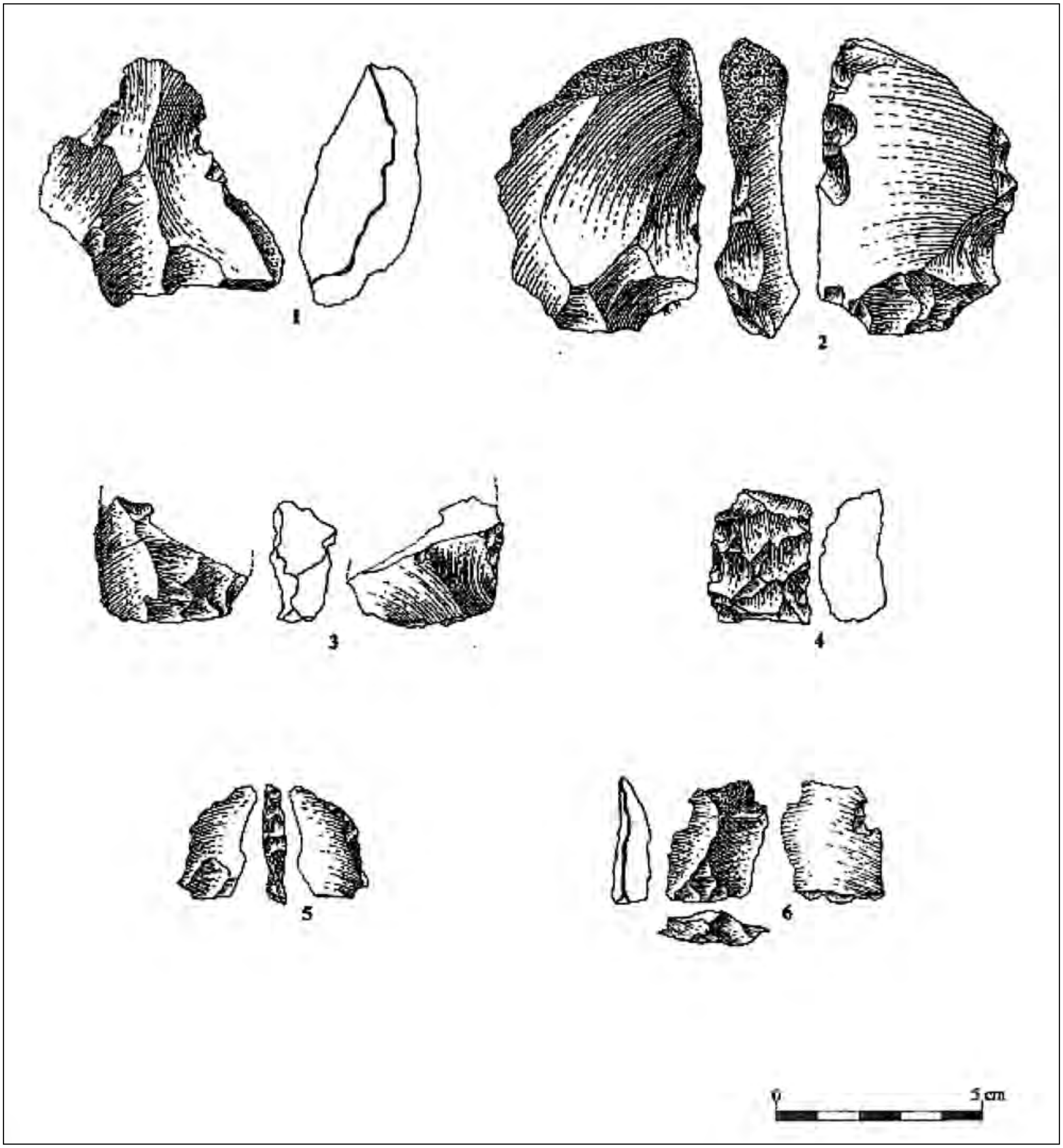


Figure 17. Some examples of retouched pieces in flint from Fuente Nueva 3, Inferior Bed.

tion of both herbivore and carnivore animal bone remains, together with the presence of the big hyena *Pachycrocuta brevirostris* and lithic artifacts, would indicate these localities to be probable scavenger sites.

- Study of the patterns of cut-marks, tooth marks and patterns of fractured bones (in progress) will need to be undertaken in order to determine if hominids here had primary or secondary access to the carcasses left behind by predators.

The proportions of animal remains including both herbivores and carnivores, the open-air context of these sites on the border of the lake, and the association of the bones with the artifact assemblages would support an interpretation of these Orce localities as scavenger sites. Ongoing taphonomic studies will help address the question as to whether hominids had primary or secondary access to the herbivore remains at these sites.

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CHAPTER 7

LEARNING FROM MISTAKES: FLAKING ACCIDENTS AND KNAPPING SKILLS IN THE ASSEMBLAGE OF A.L. 894, (HADAR, ETHIOPIA)

ERELLA HOVERS

INTRODUCTION

Identifying and understanding the skill levels involved in the knapping of the early stone tools and the mental capabilities underlying them is a major part of human origins archaeology. This is by no means a simple task. The actual execution of stone knapping involves a multitude of factors that interact in complex ways. Stone knapping is defined by the physics of fracture mechanics and by hominin anatomy. Raw materials respond to parameters such as hammer velocity and flaking angles, whose application to the stone depends in large part on the anatomical build of the tool-maker and his dexterity (e.g., Speth, 1972, 1974, 1975; Dibble and Whittaker, 1981; Sullivan and Rozen, 1985; Cotterell and Kamminga, 1987; Amick and Mauldin, 1997; Marzke, 1997; Marzke et al., 1998; Pelcin, 1997a, 1997b, 1997c; Tocheri et al., 2008; Toth et al., 2006, and references therein). Different raw materials respond variably to the forces applied to them and factor into many of the patterns observed in the early assemblages (e.g., Stout and Semaw, 2006). Thus stone knapping involves dynamic interactions between multiple elementary movements of the shoulder, arms, hands and fingers, and their constant integration with perceptual information and sequential planning as the process advances (Biryukova et al., 2005; Roux and David, 2005; Stout and Chaminade, 2007). These defining components of lithic "design space" (Moore, 2005) interact with the goals of any given knapping session, combined with individual expertise and idiosyncratic preferences of the knapper (which may influence, for example, the choice of raw material and of the type of hammerstone) and with technological traditions (i.e., available technological knowledge and social conformity, which would dictate the *preferred* manners of geometrically organizing core surfaces and exploiting them; Hovers, 1997, 2004).

The experience and skill of a knapper are expressed in the integration of perception and motor abilities, end-goals and technological background into a coherent, dynamic process of decision-making and action. In such a complex process, flaking accidents–i.e., uncontrolled removal of flakes–are practically unavoidable. While the resultant flakes (here referred to as "accidental flakes") may be functionally useful and can be applied in various tasks, they still represent episodes of (conscious or unconscious) misjudgment on the part of the knapper. Thus the presence of accidental flakes has been referred to as a proxy of the levels of inherent and/or acquired skills of prehistoric hominins (e.g., Kibunjia, 1994; Delagnes and Roche, 2005; Shea, 2006).

The question of knapping skills and their identification in the material record attains special interest in the context of studying Oldowan lithics. It pertains to defining explicitly the differences between hominin and ape stone tool-making (Toth et al., 2006; Mercader et al., 2007), assessing the levels of expertise required to produce the very early (and, according to some, technologically simple) lithic artifacts, and to the question of the evolution over time of technical capabilities in various hominin genera and within the genus *Homo*.

In the following discussion I present data and some interpretations of the occurrence of accidental flakes in the lithic assemblage of A.L. 894, located in the Makaamitalu Basin of the Hadar Research Area (Ethiopia). The site, dated 2.36 Ma or slightly older (Campisano, 2007), is found in clayey-silts representing crevasse splay deposits on the proximal flood plain of the paleo-Awash river (Hovers et al., 2002, 2008). The rich lithic assemblage from this locality possibly represents palimpsests of several occupations. The presence of numerous refits (Davidzon and Hovers, n.d.) suggests, however, that burial occurred relatively fast and with minimal geological disturbance. This large assemblage provides an opportunity for a detailed analysis of flaking accidents and their implications for understanding the skill of the tool makers.

The discussion focuses on two categories of products originating from flaking accidents. One includes incomplete flakes due to breakage. The second consists of hinge/step flakes and of hinge/step flake scars on cores and on the dorsal faces of flakes. Both types of accidental flakes pertain to "glitches" in the physical aspects (e.g., hammer mass and velocity, which can be gauged from experimental and actualistic studies; Toth et al., 2006, and references therein) and/or in perception-motor control during the process of knapping (e.g., tilting and rotating of the core to control flaking angles and distribution of mass on the core's surface, respectively). Yet these two categories of accidental flakes also differ in significant ways. Snapping or splitting of flakes often results in regular, feather terminations, and do not alter the *core's* configuration or geometry (Crabtree, 1968 in Cotterell and Kamminga, 1987:700). While the knapper may perceive of the products themselves as useless for future tasks, detachment of such flakes often does not entail special treatment to salvage the core. To the contrary, the removal of accidental flakes that distort the core's surface geometry requires that a knapper responds to a new situation. He needs to first evaluate the situation and make a decision whether knapping can go on unhindered, whether the core is beyond salvation, or whether it should and can be rectified. If the latter decision is made, the knapper applies his skills in order to control the damage and enable the continuation of the knapping process. Hinge/step flakes, and their negative on flakes and core surfaces, are interesting because they allow a better understanding of problem-solving capacities and a dynamic process of technological decision-making.

The Sample

The assemblage consists of flaked and detached pieces (following the terminology of Isaac and Harris, 1978, reiterated and expanded by Isaac and Harris, 1997). The artifacts are made on volcanic rocks, primarily rhyolite, basalt and trachyte, all of which had been selected from the nearby conglomerates in the Makaamitalu basin (Goldman and Hovers, in press). Striking platform and bulb characteristics of the detached items are consistent with hard hammer percussion (Hovers, n.d.).

Flakes were further divided into whole and broken artifacts (Table 1, Figure 1). The location of breaks was noted, so that broken flakes were divided into several categories: snapped (when the break is more or less parallel to the striking platform on either the distal or proximal part of the flake), lateral breaks (when the break was more or less perpendicular to the platform), and split flakes (see below). Medial snaps of flakes were classified as flake fragments. Additionally, lithic pieces that could not be linked reliably to anthropic flaking were classified as angular fragments. (Their likely origin from either flakes or blocks could be inferred from their thickness values.) The few natural pebbles (in the size range of 3-5 cm) are excluded from the following analyses.

Broken Artifacts: Flaking Accidents or Taphonomic Effects?

Regardless of their size group, the majority (73.8% of N=3973) of detached pieces had been broken by flex-

Table 1. The composition of the A.L. 894 assemblage.

Category	N	% in Catetory	% of Total Assemblage
Detached Elements			
Flakes (whole)	648	16.31	13.42
Flakes (broken)	1802	45.36	37.32
Small flakes (whole)*	387	9.74	8.02
Small flakes (broken)	1121	28.22	23.22
Tools	13 (7)	0.3 (0.67)	0.3
Cores-on-flakes	2 (1)	0.1 (0.1)	0.04
Total	3973 (1043)	100.0 (100.0)	82.32
Flaked Elements			
Cores			
*Whole***	*20*	*40.00*	*0.41*
broken	*26*	*52.00*	0.54
Tested cobbles	*4*	8.00	0.08
Total	50	100.0	1.034
Debris			
Angular fragments			
possibly from flakes	752	93.42	15.58
from cores	53	6.58	1.10
Total	805	100.0	16.68
Assemblage Total	**4828**		**100.00**
Natural Pebbles	54		

* *Small flakes <20 mm in maximum dimension.*

** *Number in parentheses is of whole artifacts out of the total for the type.*

*** *including one artifact classifiable as polyhedron, a unifacial chopper and a bifacial chopper.*

ion. (The elevated frequencies of broken artifacts in the total assemblage are due to the inclusion of angular fragments.) Frequencies of breaks among large flakes are not related to raw material properties (X^2=5.72, p=.0572, DF=2). When all flake sizes and angular fragments are examined, the differences in breakage frequencies are statistically significant (X^2=11.53 , p=.0036, DF=2), suggesting that basalt (78.9% incomplete items) shattered into smaller pieces more often than rhyolite (74.9% incomplete items) and especially compared to trachyte (65.4% items) (see also Goldman and Hovers, in press).

Three different scenarios can account for the formation of flexion breaks.

1) Flakes break during *tool modification*. This happens when retouch thins the flake such that it cannot sustain further application of force or pressure. This is a highly unlikely explanation in the case of A.L. 894, given that none of the broken artifacts in the assemblage bear remnants of retouch scars. Additionally, the low frequency of retouched items in the assemblage (Table 1) indicates that modification of lithic blanks into tools was rarely practiced at this particular locality (although it is possible that some such artifacts were transported away from the site).

2) Flakes may break during *knapping* when hammer force and velocity or impact angles are miscalculated in relation to raw material characteristics and/or core geometry. As a rule, lithic analysts perceive higher ratios of complete to broken artifacts as an expression of better control over hammer and raw material properties, i.e., a reflection of higher skill levels. In the context of Oldowan lithic production, Toth et al. (2006) argued for the opposite interpretation, suggesting that the efficient reduction of a core's mass (a high flake: core ratio) necessitated higher hammer velocities, which could be achieved through higher degrees of expertise yet would still have led to elevated levels of shattering of both flaked and detached pieces.

3) Broken flakes are taphonomic phenomena that occurred post-depositionally due to the pressure in vertic soils and/or trampling. Such processes evidently operated at A.L. 894 (Hovers, 2003). In this assemblage incomplete flakes that formed through unsuccessful flaking or due to taphonomic breakage cannot be distinguished morphologically from one another (with the exception of split flakes, see below). Contextual evidence sometime helps in making this distinction. Where cracked flakes were found undisturbed (Hovers, 2003: figs. 1-2) the taphonomic nature of their breakage was easily recognizable. However, if the broken parts of a flake had been spatially dissociated from one another, the agent of fragmentation could not be identified, and such pieces were identified as either "broken flake" or as "angular fragments" (according to the criteria mentioned above).

The only broken flakes in the A.L. 894 assemblage that can be assigned with certainty to accidental flaking are split ("Siret") flakes (Siret, 1933) (see example in Figure 2). In these cases the break occurs along the flaking axis (i.e., more or less perpendicular to the striking platform) and halves the bulb of percussion (i.e., all

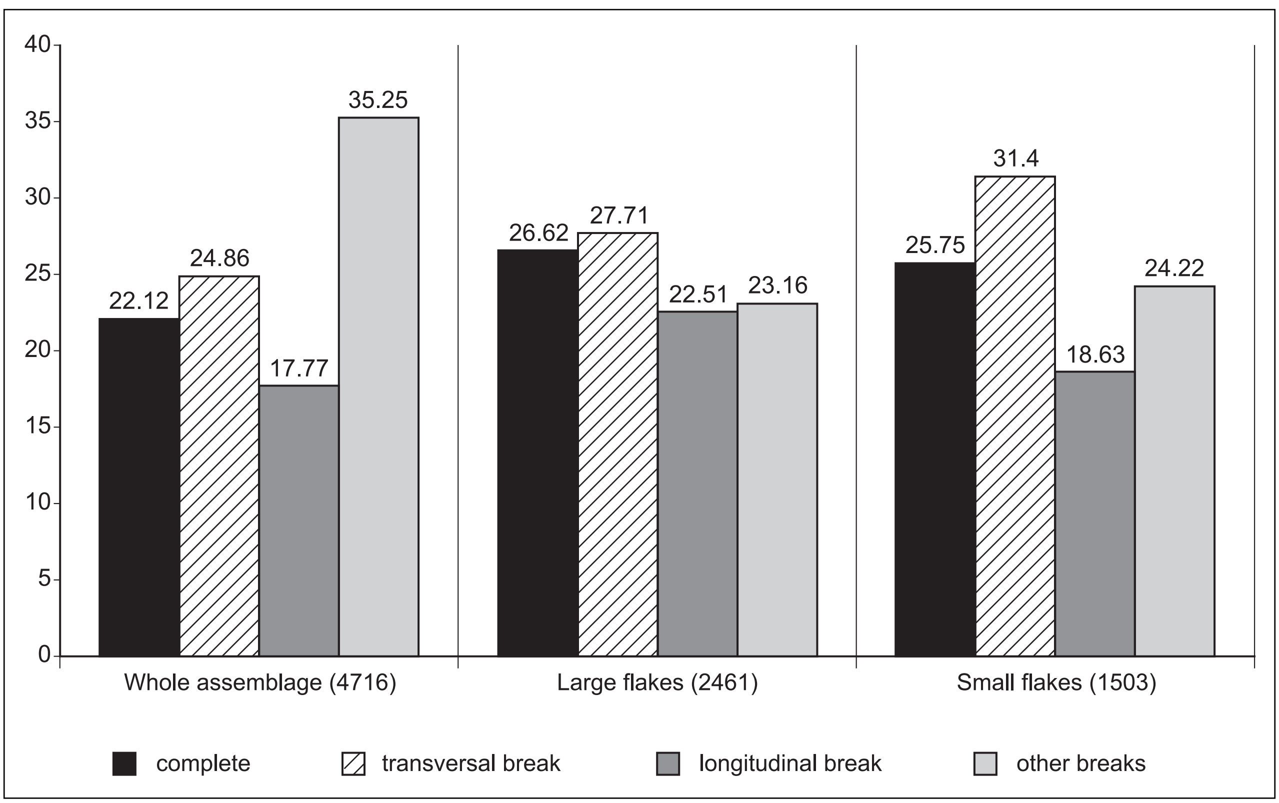

Figure 1. The distribution of breakage types. "Other breaks" is a catch-all category that includes combinations of break types as well as angular fragments, the origins of which cannot be traced reliably to knapping activities.

Siret breaks are also laterally-broken flakes, but not the other way around). This type of flaking accident is specifically associated with hard hammer percussion (Inizan et al., 1992). Only 142 such items (3.6% of the detached pieces) were found in the A.L. 894 assemblage. The ratio of split to whole flakes (0.14) in A.L. 984 is intermediate between comparable ratios in a Bonobo assemblage and the Gona assemblage (0.09 and 0.33, respectively) and is much lower than that recorded for modern humans (0.64) in the comparative study of Toth et al. (2006:169). In fact the ratio at the Hadar site is closer to that of the Bonobo assemblage than to any of the hominin samples discussed by these authors.

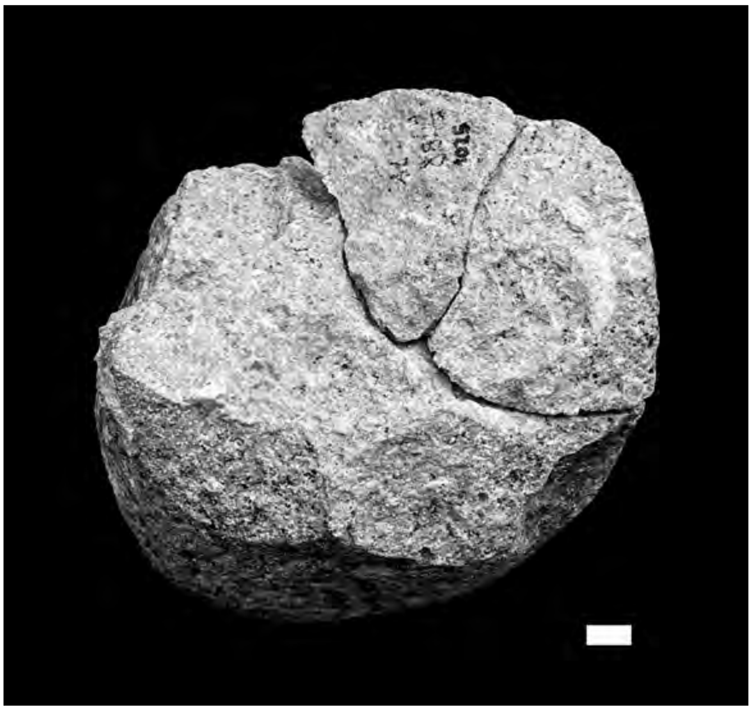

Figure 2. A core and a refitted Siret flake. Bar = 1 cm.

Within the interpretative framework suggested by Toth et al. (2006), one would expect from the ratio of split to whole flakes that frequencies of whole flakes in the assemblage of A.L. 894 be higher than in any of the Gona and modern samples, due to inferred lower hammer velocities leading to less shatter during core reduction. Yet the frequency of whole flakes in the A.L. 894 assemblage (26.2%) is lower than in the Bonobo, Gona and modern human samples (54.9%, 37.7%, 39.7%, respectively) discussed by Toth et al. (2006:168).

Of the several potential explanations for the apparent discrepancy between the ratio of split to whole flakes and assemblage composition, two are most pertinent to the current discussion. Refitting studies of the A.L. 894 assemblage (Davidzon and Hovers, n.d.) indicate that partly-reduced cores were exported out of the locality, and it is possible that usable, large flakes were also removed from the site, thus inflating the proportion of broken to whole flakes. Secondly, this discrepancy may underline the role of taphonomic processes in elevating the proportion of incomplete flakes in the assemblage.

This analysis is helpful in demonstrating that, contrary to an implicit assumption of many workers, proportions of broken items in an assemblage are far from being a straightforward reflection of the skills of their authors. This probably pertains to lithic assemblages of all periods; because of the special interest of researchers in the knapping skills of Oldowan stone tool makers, this caveat is especially meaningful in the context of Oldowan studies.

Stepped and Hinged Flakes and Knapping Skills

A brief overview of the fracture mechanics of hinged and stepped flakes

When a striking force is applied to a core, a fracture begins to propagate from the striking platform towards the distal end of the core. Flake terminations sometimes deviate from a smooth, gradual propagation fracture separating a flake from a core surface (ending in feather termination), and step and hinged flakes are formed. This occurs when propagation force drops below a critical value. This value is set anew with each blow by the mass, shape and raw material type of both the core and the hammer, as well as the force with which impact is applied.

Step flakes happen either when there is insufficient energy to complete a fracture (i.e., almost immediately when the propagating force drops below a critical value) or when the propagation crack intersects with a flaw in the raw material that effectively blunts it (Cook and Gordon, 1964; Cotterell and Kamminga, 1987). Bending then diverts the force to the face of the core, causing a *step* termination, i.e. a 90-degree break of the flake's distal end that is mirrored by a "step" on the negative on the core's surface.

A *hinge* termination occurs when flakes are formed near the surface of the core. It is relatively frequent in cores with flattish surfaces, where the width of the propagating flake increases as it is spalling off the core. If the energy required to keep crack propagation is unavailable, the velocity of propagation decreases, immediately followed by a turn of the crack towards the core surface. A hinge termination is formed, and the detached flake exhibits a typical blunt tip and a more-or-less rounded cross-section (Cotterell and Kamminga, 1979, 1986, 1987). Decrease in propagation velocity followed by hinge formation may occur due to the curvature of the core's surface (see above); miscalculated positioning of hammer and core in relation to one another, leading to high exterior platform angles and higher frequencies of hinge or plunging (overshot) terminations (Dibble and Whittaker, 1981); an underestimate of the force that needs to be applied in order to remove a flake; or a wrong choice of hammerstone (Callahan, 1979; Sollberger, 1994; Pelcin, 1997a, 1997b).

Often a succession of hinge flakes is formed on a core. This happens because when a flake is removed from a hinge scar-bearing surface, its thickness must increase suddenly when the crack tip intersects with the edge of the scar and its force decelerates suddenly. Because increasing the crack velocity can only be done by manipulating the hammerstone location on the striking platform, it is impossible to change this velocity instantaneously, the result being that propagation velocity decreases and a second hinge is likely to form (Cotterell and Kamminga, 1987).

The formation of hinge and step flakes affects the core so that the knapper needs to make a purposeful decision about his course of action if the technological problem is to be solved and knapping continued. Indeed, the presence of hinge and step scars on core surfaces is often cited as a cause of discard (e.g., Ludwig, 1999; Barkai et al., 2005; Delagnes and Roche, 2005). Yet how hinge/step formation influences the process of lithic production before core discard has rarely been examined. The following analysis deals with the hinge flakes themselves as well as with their marks on cores and on the flakes that were removed subsequent to the formation of hinge/step terminations.

Hinge and step flaking accidents in the A.L. 894 assemblage

There are only 172 large hinge flakes in the assemblage. These constitute 7.6% of the detached items (N=3973) and 3.6% of the total assemblage (N=4828). (Step flakes are more difficult to identify because they are similar to snapped flakes; their presence in the assemblages was not quantified). The frequencies of raw material types within this group (71% are made on rhyolite, 24% on basalt, and 3% on trachyte) are practically identical to the frequencies of raw material types among all the detached pieces. Eighty (46.5%) of the hinge flakes also bear accidental flake scars on their dorsal faces, representing sequential (albeit not necessarily consecutive) episodes of accidental removals. Whole

Table 2. Frequencies and statistics of accidental scars on cores and flakes.

	Cores	All flakes	Large flakes	Small flakes
Frequency of items with accidental scars	22 (75.86%)	1066 (28.56%)	844 (36.73%)	213 (15.19%)
Frequency of items w/o accidental scars	7 (24.14%)	2666 (71.44%)	1454 (63.27%)	1189 (84.81)
			X^2=197.88, p<0.0001, DF=1	
Mean N of accidental scars+	1.65±1.73 (N=22)	1.42±0.83 (N=1059)	1.49±0.90 (N=838)	1.14±0.44 (N=213)
			ANOVA F-value 31.39, p=<0.0001, DF=1	
Mean N of accidental scars*	N/A	1.64±1.04 (N=383)	1.74±1.09 (N=318)	1.19±0.56 (N=64)
			ANOVA F-value 15.39, p=0.0001, DF=1	
Mean ratio of hinged to stepped scars+	N/A**	0.10±0.32 (N=889)	0.12±0.35 (N=709)	0.04±0.22 (N=174)
			ANOVA F-value 7.08, p=0.0079, DF=1	
Mean ratio of hinged to stepped scars*	N/A**	0.16±0.38 (N=327)	0.19±0.41 (N=273)	0.04±0.16 (N=53)
			ANOVA F-value 7.13, p=0.0080, DF=1	
Mean ratio of all accidental to regular scars+	0.22±20 (N=22)	0.42±0.17 (N=1058)	0.41±0.17 (N=838)	0.45±0.19 (N=212)
			ANOVA F-value 9.02, p=0.0027, DF=1	
Mean ratio of all accidental to regular scars*	N/A	0.40±0.17 (N=383)	0.40±0.16 (N=318)	0.43±0.18 (N=64)
			ANOVA F-value 1.34, p=0.2479, DF=1	

+ on flakes bearing accidental scars
** whole flakes with accidental scars*
*** only stepped scars were observed on cores*

hinge flakes (N=79) are thicker (X=17.62±71.06 mm) than regular flakes (N=569; X=10.81±6.83 mm), shorter (X=37.46±12.72 mm; 42.26±20.49 mm, respectively) and narrower (X=34.95±14.42; X=37.09±18.62 mm, respectively). These differences are to be expected, given the differences in fracture mechanics between flakes of the two types.

The evidence for hinge and step flakes in the A.L. 894 assemblage comes mainly in the form of their negatives on the dorsal faces of flakes and on cores. Negatives of accidental flakes occur on ca. 75% of the cores and on nearly a third of the flakes in the assemblage (Table 2). The number of accidental scars on dorsal faces ranges between 1-7, but tends to be low (median and mode are both 1; see Figure 3). Negatives resulting from the removal of step flakes outnumber those originating from detachments of hinge flakes. The ratio between the two types of accidental flake scars may suggest that tool-makers at A.L. 894 tended to knap curved (most likely convex) core surfaces, since flat-surface cores are more likely to lead to the formation of hinge flakes.

Raw material lithology does not seem to have biased in any significant way the frequencies of flakes bearing accidental scars, nor the frequencies of accidental flake removals as reflected by the ratio of accidental to "regular" removals (Table 3).

Table 2 exhibits some interesting size-related patterns. The frequencies of accidental scar-bearing blanks differ significantly between the two size categories, with much fewer instances recorded on small flakes. Where such scars exist on small flakes they are less frequent, and the ratio of hinge to step scars is lower compared to large flakes (these differences are statistically significant; see ANOVA results in Table 2). Conversely, the ratio of accidental to regular scars is similar or even slightly elevated in small flakes in comparison to the large flake category. These patterns hold when only unbroken ("whole") flakes are considered, though the values vary slightly (Table 2).

By definition small flakes are peripheral–they begin and terminate in close proximity to the core's periphery, on the striking platform, and are not invasive onto the core's surface. Because of their small sizes, these flakes almost never bear the diagnostic end part of earlier, large and disruptive hinge/step scars; hence by default they do not represent attempts to correct major disruptions to the geometry of a core's flaking surface. This in turn suggests that small flakes bearing accidental scars are not likely to represent conscious attempts of the knapper to remove the residues of accidental flakes from the core's surface. Their lower frequency among accidental scar-bearing flakes may be a result of probabilities dictated by fracture mechanics principles. Similarly, the higher mean number of accidental flake scars on large

Table 3. Effects of raw material on accidental flakes.

A. Frequencies of flakes with accidental scars by raw material

	Among all flakes with accidental scars	**Among whole flakes with accidental scars**
Basalt	201 (30.92)	79 (47.59)
Rhyolite	644 (30.87)	241 (39.97)
Trachyte	32 (35.56)	18 (51.42)
	X^2=0.89, *p*=0.6412, DF=2	X^2=4.43, *p*=0.1092, DF=2

B. Effect of raw material type on mean number of accidental flakes

I. Whole flakes (all)

RM	**N**	**Mean N of accidentals ±s.d.**	**Ratio of accidental to regular scars**
Basalt	79	1.67±1. 07	0.42±0.19
Rhyolite	241	1.63±1.04	0.40±0.16
Trachyte	17	2.23±1.39	0.44±0.19
ANOVA results: F-value 2.48, *p=0.0851*, DF=2			ANOVA results: F-value 0.74, *p*=0.4799, DF=2

II. Whole large flakes

RM	**N**	**Mean N of accidentals ±s.d.**	**Ratio of accidental to regular scars**
Basalt	61	1.80±1.15	0.41±0.17
Rhyolite	205	1.73±1.09	0.41±0.16
Trachyte	16	2.31±1.40	0.46±0.18
ANOVA results: F-value 2.04, *p*=0.1319, DF=2			ANOVA results: F-value 0.77, *p=0.4665*, DF=2

III. Whole small flakes

RM	**N**	**Mean N of accidentals ±s.d.**	**Ratio of accidental to regular scars**
Basalt	17	1.24±0.56	0.47±0.23 (N=17)
Rhyolite	36	1.14±0.42	0.39±0.12 (N=36)
Trachyte	1	1.00	0.17 (N=1)
ANOVA results: F-value 0.30, *p*=0.7390, DF=2			ANOVA results: F-value 2.57, *p=0.0866*, DF=2

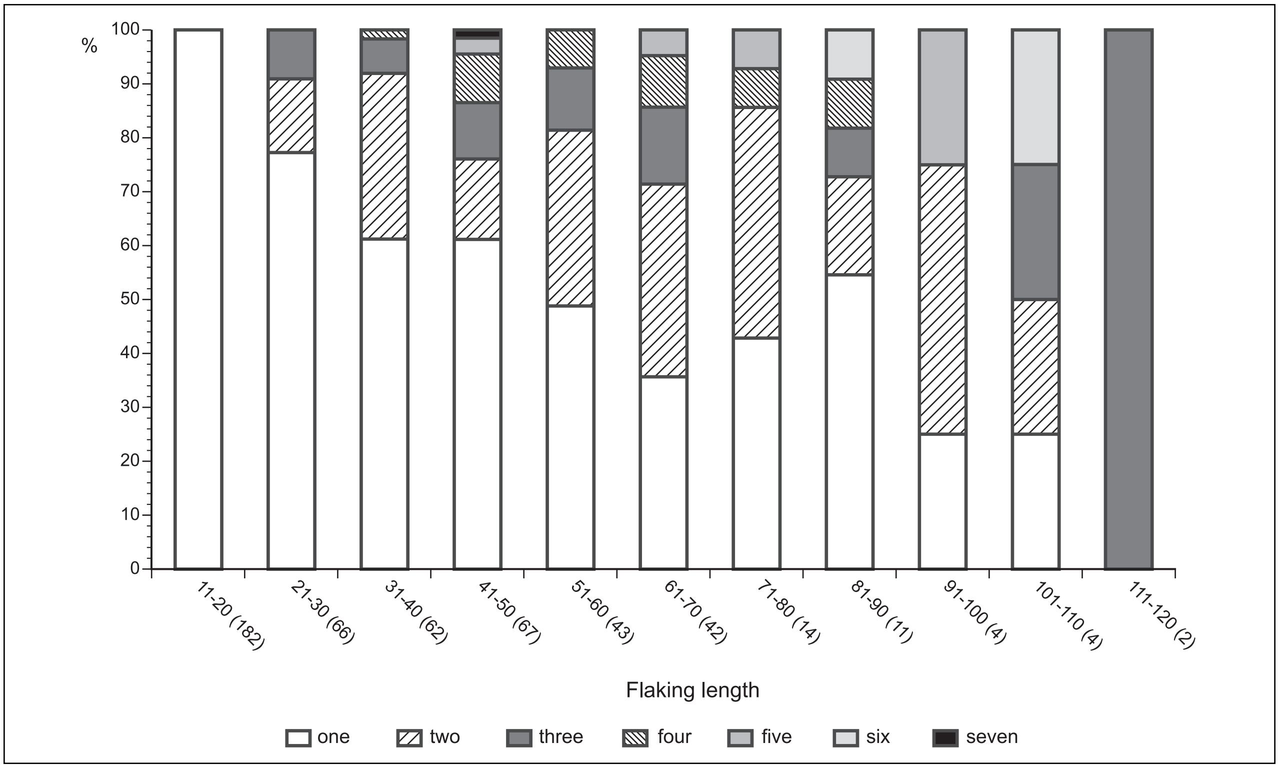

Figure 3. The distribution of accidental flake scars according to flaking length of whole large flakes. Regardless of size, single scars are the most frequent occurrences. Multiple scars are not necessarily associated with the longest items (though note the small sample sizes for some size categories).

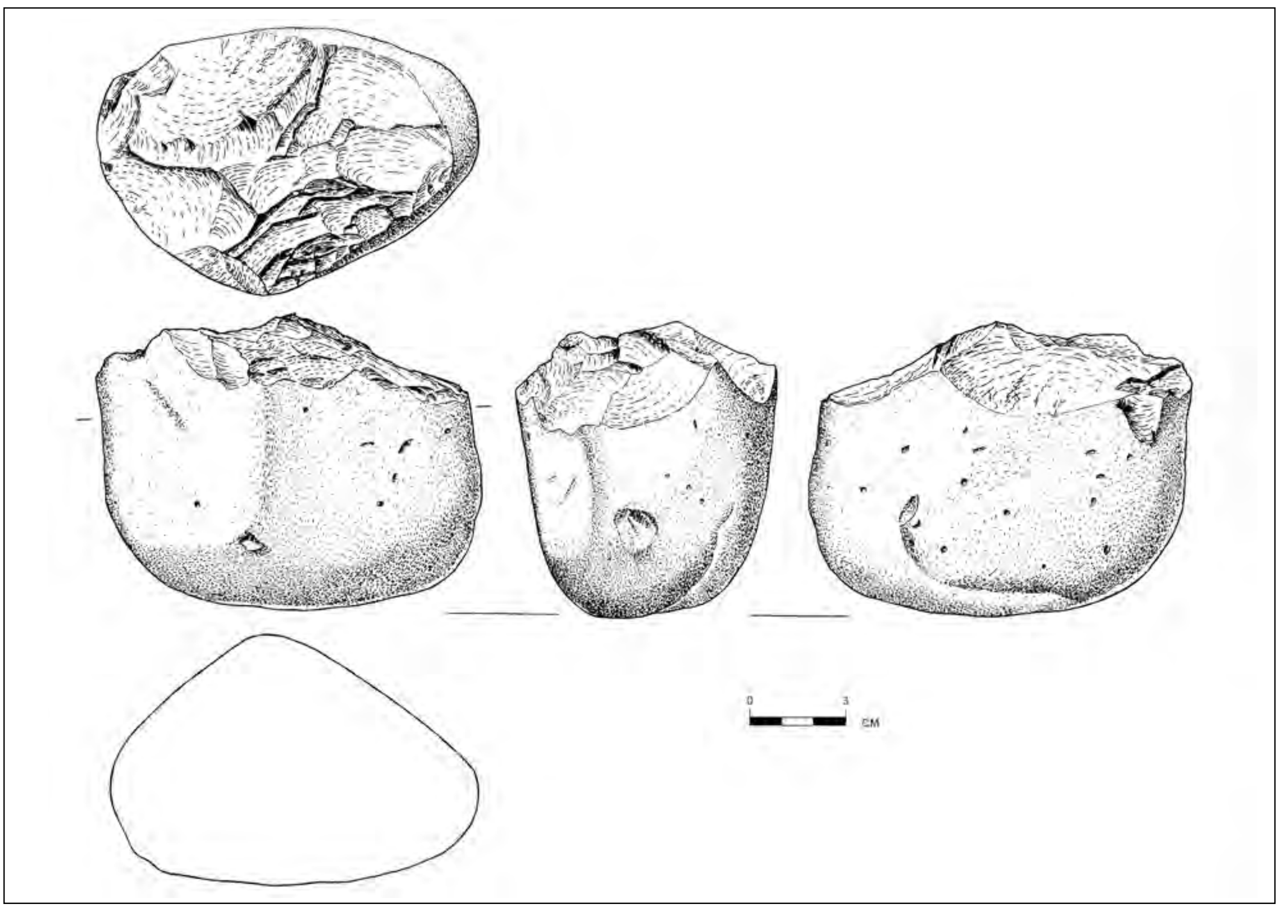

Figure 4. A discarded core. Note numerous small stepped scars concentrated in one part of the striking platform (best seen in the top view on the left).

Table 4. Dimensions, striking platform characteristics and number of dorsal face scars on whole flakes.

	With accidental scars	w/o accidental scars	Mann-Whitney test results
Length*	45.57±19.77 (318)	36.12±18.51 (294)	U 30584.0, *p*<0.0001
Width**	41.45±17.85 (317)	31.07±16.26 (293)	U 29690.0, *p*<0.0001
Thickness**	12.06±6.73 (314)	8.86±5.87 (292)	U 29812.0, *p*<0.0001
Striking Platform length	29.59.±16.97 (270)	24.23±14.08 (228)	U 24633.0, *p*=0.0001
Striking Platform depth	9.90±5.24 (275)	8.83±5.07 (250)	U 29803.5, *p*=0.0085
Exterior angle	88.03±12.68 (261)	83.94±13.01 (236)	U 25316.5, *p*=0.0006
Interior angle	96.69±12.74 (256)	94.59±13.22 (236)	U 27419.0, *p*=0.0767
Mean number of dorsal scars	4.62±2.42 (319)	2.26±1.31 (297)	U 16932.0, *p*<0.0001

* *flaking length, measured along the flaking axis*

** *flaking width, measured perpendicularly to flaking length*

*** *Thickness measured at half the flaking length*

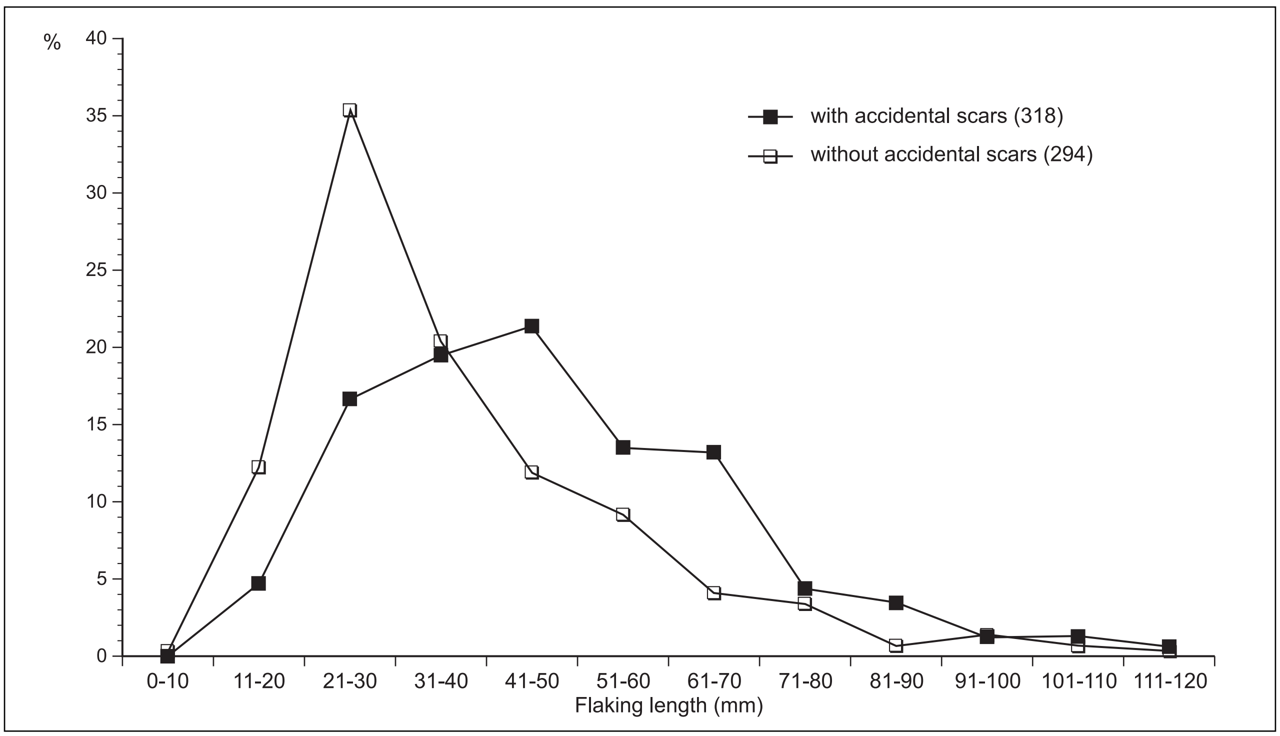

Figure 5. The distribution of flaking length of flakes with and without accidental dorsal face scars.

accidental scar-bearing flakes (2.63 as opposed to 1.91 on small flakes) can be seen as a result of their larger surface area.

Explanation of the very low ratio of hinged to stepped scars on small flakes, on the other hand, is more likely tied with particular technological steps taken by a knapper. This ratio may be attributed to repeated blows aimed at the same location on the core's striking platform when a knapper fine-tunes his perception-motor coordination before hitting the core. If the core's geometry is already damaged after previous flaking, a series of small step (but not hinge) flakes results. Small flakes removed in the process are likely to bear a relatively high number of stepped scars (e.g., Figure 4).

These characteristics of small flakes are possibly related to the process of rectifying core geometry. But as a

Table 5. Distribution of cortex on dorsal faces of flakes with and without accidental flake scars.

% Cortex cover*	Total		On flakes without accidental scars		On flakes with accidental scars	
	N	%	N	%	N	%
None	124	20.0	63	21.65	58	18.24
1-25%	248	40.0	100	34.36	147	46.23
26-50%	165	26.61	79	27.15	81	25.47
51-75%	49	7.90	29	9.97	20	6.29
76-99%	34	5.48	20	6.87	12	3.77
Total	620	100.00	291	100.00	318	100.00
X^2=11.65, p=0.0201, DF=4						

** excluding fully cortical flakes (N=29) and flakes with "indeterminate" percentage of cortical cover (N=3)*

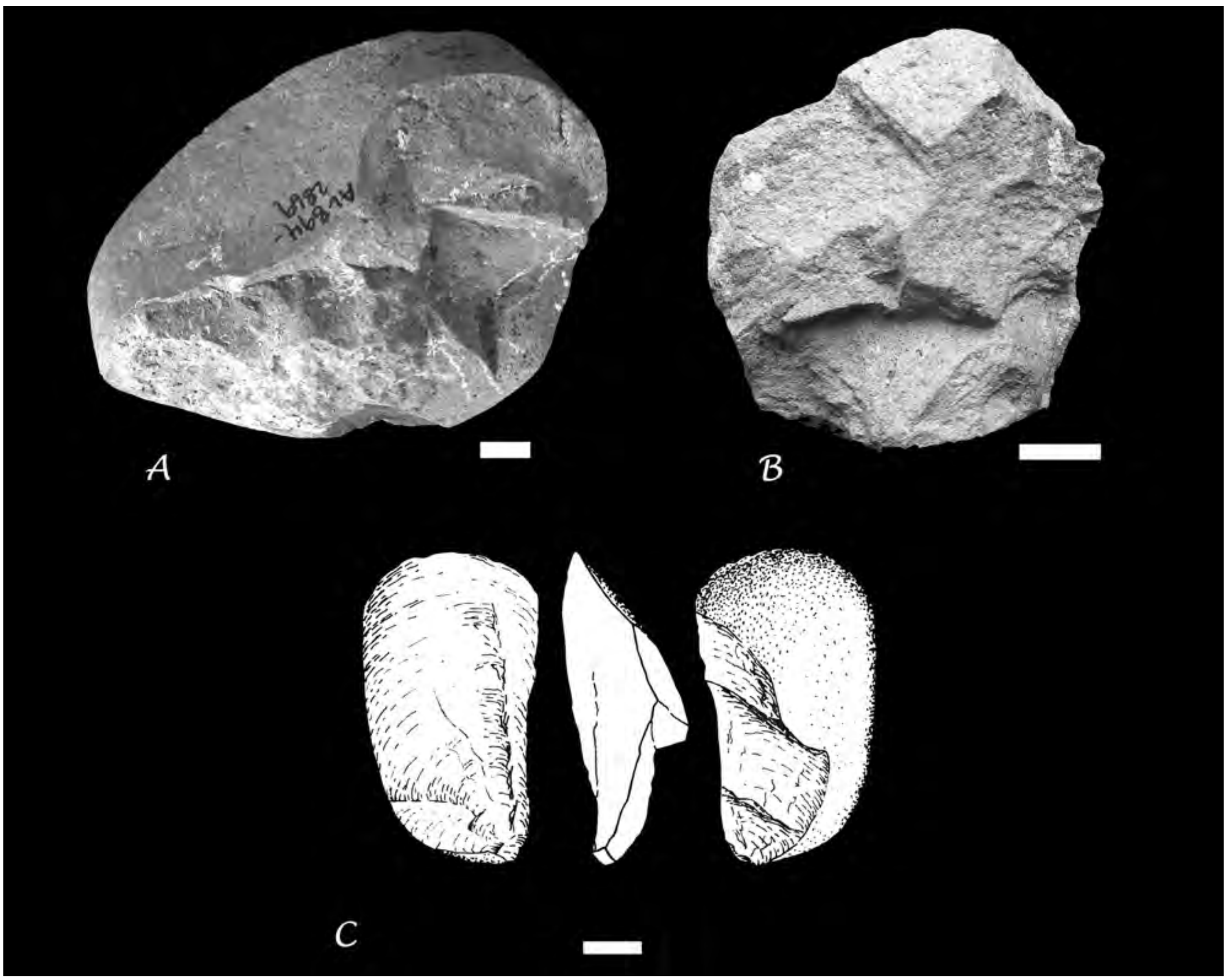

Figure 6. Examples of flakes with accidental scars in the A.L. 894 assemblage. **A**. *a series of scars from flakes terminating in step fractures, removed in an early stage of reduction, as indicated by the spatial distribution of cortex on its dorsal face. Accidental flaking thus occurred early on in the reduction sequence.* **B**. *a cortex-free dorsal face suggests that this flake was removed in relatively advanced stages of reduction. Two step termination flakes had been removed from different directions following rotation of the core during knapping. The spatial relationship of the scars on this dorsal surface suggest that the flawed flakes, too, had been removed during advanced stage of core exploitation.* **C**. *three views of a partially cortical flake. Note the step scar nested in the negative of an earlier hinge termination scar. These accidental removals clearly occurred in the early stages of reduction, as indicated by the spatial distribution of the cortex on the dorsal face. Bar = 1 cm in each case.*

direct result of their small size such flakes are less informative about technological problem-solving as it is perceived for the purpose of this paper. The following thus focuses mainly on whole, large flakes in the assemblage.

If a flake is removed so that its surface bears negatives of accidental scars (and step scars at that), the hammer must be placed on the striking platform in a manner that ensures that the velocity of the blow is sufficient to propagate the crack over and across the obstacle presented by the negative of the miscalculated blow (Cotterell and Kamminga, 1987). This in turn tends to produce relatively large flakes. Accordingly, in the A.L. 894 flakes bearing accidental scars exhibit several characteristics that distinguish them from other flakes in the assemblage. These flakes tend to be longer, wider and thicker than flakes without accidental removals (the differences are statistically significant, though variation is considerable for all dimensions; Table 4, Figure 5). These differences correspond to the differences in mean values of exterior platform angle (Table 4), consistent with the latter's significance in determining flake dimensions during hard hammer percussion (Speth, 1972, 1974, 1975; Dibble and Whittaker, 1981; Pelcin, 1997c).

With the obvious exception of fully cortical flakes, removed at the very initial stage of exploiting a surface of a cobble, accidental scars are associated with varying degrees of cortical cover on flakes detached during all stages of core reduction (Figure 6). Still, they occur more often on flakes with restricted distributions of dorsal face cortex (Table 5) and with a higher total number of flake scars on their dorsal faces (Table 4). The latter two traits are obviously complementary.

Accidental flake scars occur in practically every combination of flaking directions on the dorsal faces of flakes, but this co-occurrence is not random. While under-represented on flakes removed off core surfaces that had not been extensively worked (resulting in flakes with plain dorsal face scar patterns) or from cores that had been worked mainly from a single direction (unipolar scar patterns), accidental flake scars are unproportionally abundant on flakes with bipolar and crossed scar patterns, derived from the surfaces of cores that had been rotated during reduction (Table 6; see Figure 6B).

In and of themselves, the data and observations presented here are not helpful for determining whether core reduction sequences were carried out as pre-planned processes from the outset of each such sequence. It is also unhelpful in determining whether flaking occurred as a continuum, propelled onwards merely by the changes in core mass location on the core due to earlier removals. Accidental flakes tended to occur during later phases of the reduction process, after a core had been rotated during knapping and its surface geometry had been affected by scars and ridges extending from various section of the striking platform. Some of the distinct patterns and relationship between various traits may seem related simply to the larger dimensions (hence larger surface areas) of accidental scar-bearing flakes (see Braun et al., 2005 for a similar argument with regards the effect of surface area on "flake erasure rates" in Oldowan cores). Evidently some accidental removals remained on the core surface and knapping continued unhindered (hence the mean number of accidental flakes is higher than 1; Table 2). Yet the treatment of accidental scars can be shown to be a *purposeful* technological act.

In general, flaking at A.L. 894 was unipolar, i.e. flakes were mostly removed from a single direction by hard hammer blows. When flawed flake terminations occurred, they were sometimes invasive, causing the formation of high stone mass in the center of a core's surface, which could not be removed by continued flaking from the same direction. The combination of characteristics described above suggests that knappers solved such technological problems by diverting from the motor-habit patterns that typified the "regular" knapping process. Cores with large surfaces would have been rotated (again?) at this point to achieve better access to the area of high mass. Cores with relatively small surface areas could sometimes be managed by removing flakes from the same direction (Figure 7).

Table 6. Scar patterns on whole flakes.

	w/o accidental flake scars		With accidental flake scars	
	N	**%**	**N**	**%**
Bipolar	33	11.22	75	23.54
Centripetal	3	1.02	24	7.55
Crossed (opposed & side)	0	0.00	2	0.63
Crossed (unipolar & side)	27	9.18	65	20.44
Crossed (ridged)	1	0.34	3	0.94
Convergent	10	3.40	13	4.09
Opposite	3	1.02	1	0.31
Plain	33	11.22	1	0.31
Side	11	3.74	10	3.15
Unipolar	167	56.80	124	38.99
TOTAL	260	100.00	248	100.00
X^2=94.48, p<0.0001, DF=10				

* *"Indeterminate" scar patterns as well as some scar patterns that occurred in extremely low frequencies were omitted from this analysis. Still, results of the X2 test are dubious due to existence of cells with too low expected values.*

Figure 7. A refitted set of flakes from a small basalt cobble. The flake with a step termination and the subsequent flake that removed the step scar from the core surface (the latter shown in detail in Figure 6C) were detached from the same direction, a procedure that was applied more often to cores with small surfaces. See text for further details.

Either way, the high external angles of flakes with accidental scars suggest that cores were titled so as to change the impact angle, such that hammer velocity and impact force would lead to the spalling of a large flake and removal of the problematic area on the core. Refitting analyses (Davidzon and Hovers, n.d.; Figure 7) provide support of this reconstruction of technological sequences, indicating that cores were often rotated *in order* to detach a large flake sufficiently invasive to rectify the damage caused by earlier accidental detachments. In addition, the A.L. 894 data suggest that core reduction did not automatically stop due to the removal of accidental flakes. Knappers of this assemblage while obviously operating within the limitations of fracture mechanics, were also clearly exercising an ability to over-ride (at least to a degree) the limitations of raw material characteristics and manipulate the constraints of fracture mechanics.

The cores in the A.L. 894 assemblage are too few for a full formal analysis; it is in these elements of the assemblage that indications for a lower degree of skill can be found. While most cores bear accidental flake scars, their ratio to regular flake scars is low (Table 2). Step and hinge scars seem to have occurred as the last attempt of knappers to exploit a core after the angle between the striking platform and flaking surface of the core became too blunt for further successful removals of flakes. Sometimes this happened when the cores were still large (Figures 2, 4). Cores were not discarded due to accidental flake scars but because knappers were unable to maintain appropriate knapping angles. The accidental flake scars on cores are the result of this process, not its cause.

Concluding Comments

Researchers have focused on broken, hinge and step flakes as proxies for knapping skills. Some basic measures such as frequencies of accidents (expressed by a number of assemblage composition variables and/or flake traits) have been applied as a coarse measure for the level of knapping skills. A few studies (e.g., Nichols and Allstadt, 1978; Ludwig, 1999; Ekshtain, 2006; Toth et al., 2006) have gone beyond this point and provide a comparative framework for discussion.

The ratio of accidental to regular scars on cores in the assemblage of A.L. 894 (0.22±0.20) is similar to that seen in the Gona assemblage (0.18±0.15) and lower than both the Bonobo (0.26±0.21) and modern human (0.31±0.16) samples described in the only available comparative study by Toth et al. (2006:188). Conversely, the same ratio on flakes is much higher in the Hadar assemblage (0.42±0.17) than reported by Toth et al. (2006:208) for Bonobo (0.14± 0.23), modern humans (0.10±0.20) and Oldowan knappers at Gona (0.05±0.12). Toth et al. attributed the difference between human and Bonobo cores to differences in core shape. The difference between the Gona assemblage and the human sample, in the ratio of accidental to regular scars on both cores and flakes, was related to the degree of core reduction, since in the replication study the cores were not fully reduced. Continued knapping brought this ratio in the modern human sample to lower values than those recorded at Gona. Following this continued reduction, the ratio on flakes was brought down to values similar to those seen in the Gona assemblage. The experimental data thus support the hypothesis of extensive reduction of the archaeological sample, suggesting that frequencies of accidental scars are not necessarily a reflection of technological skill.

Using the experimental data to scale the findings from A.L. 894, two behaviors seem to be represented. The ratio of accidental to regular scars on cores suggests that those were heavily reduced, similar to the Gona cores. By the same token, the much higher ratio on flakes represents, according to this model, light to moderate reduction levels. These discrepancies are likely linked to the role of the site in a broader settlement/mobility system and the transport of artifacts over the landscape (Hovers, n.d.). The lithic assemblage of A.L. 894 (as indeed any other assemblage) should be treated as a component of an open, dynamic system rather than as a self-contained unit.

The quantitative approach applied to the assemblage has shown that details of flake size and physical conditions are not immaterial for understanding knapping skills. Moreover, this study suggests that the presence or expression of accidental removals is not an indication of knapping skills, nor a measure of their level. Flaking accidents are part and parcel of all knapping processes, be they of relatively simple (e.g., Oldowan) or relatively complex (e.g., Middle Paleolithic Levallois [Ekshtain, 2006], Neolithic Naviform [e.g., Khalaily et al., in press]) flaking technologies. It is the manner by which knappers responded to new situations formed by knapping accidents that speaks to their expertise. Novices and experienced knappers alike will detach accidental flakes, but only the latter are adept sufficiently to rectify the outcome and continue core reduction. Thus, interpretations of knapping accidents as child's play, the training of novices or culture-driven inaptitude should be qualified with rigorous quantitative analyses.

In the assemblage of A.L. 894 artifacts conventionally defined as "accidents" reveal knappers' ability to extend the knapping process after accidents had occurred, indicating high skill levels and at least short-term technological foresight. These interpretations are consistent with the notion that very early tool-makers were cognizant of flaking mechanics (Semaw, 2000; Delagnes and Roche, 2005; Stout and Semaw, 2006; Toth et al., 2006). Whether these relatively expert assemblages reflect the earliest stone tool-making, or whether an earlier, Bonobo-like Pre-Oldowan preceded it (Toth et al., 2006:215) remains an open question that challenges paleoanthropologists and primatologists alike. At the same time, the nuanced complexity that is revealed through the study of flaking accidents may indicate that lithic tool making might have emerged in a "window of opportunity" situation, when the necessary mental and anatomical abilities finally became synchronized. This hypothesis is difficult to test directly. Certainly additional information about the identity of tool-makers in various contemporaneous localities can help here, since it is less likely that such synchronization would occur as a parallel process in many hominin genera or even species.

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CHAPTER 8

THE OLDOWAN INDUSTRY FROM STERKFONTEIN CAVES, SOUTH AFRICA

K. KUMAN AND A.S. FIELD

INTRODUCTION

The earliest archaeological deposits in southern Africa have thus far been found in South Africa, within the dolomitic limestone cave infills of Gauteng Province (Figure 1). Absolute dating techniques are still poorly developed for most of these underground cave breccias, and currently Oldowan period artifacts have only been identified by the age of associated fauna. Of the 14 sites in this geological setting, six or possibly seven preserve Plio-Pleistocene artifacts from *ca* 2 to 1.0 My in age; and of these, only two or possibly three sites have deposits of Oldowan age: Kromdraai B has only two certain artifacts and is *ca* 1.9 My by palaeomagnetic dating; Sterkfontein has 3,500 artifacts that are of similar age; and the Lower Bank of Member 1 at Swartkrans is believed to date to *ca* 1.7 or 1.8 Ma (see Kuman 2007 for references and details). The purpose of this paper is to describe the Oldowan industry from Sterkfontein and its implications for hominid behaviour. Fortunately, the Sterkfontein Oldowan is the best preserved of all the Plio-Pleistocene assemblages from the Gauteng sites, and despite its cave infill context, it is informative because of its largely intact nature and large sample size. The assemblage was excavated in the early 1990s by R.J. Clarke from Member 5 East of the Sterkfontein Formation (Partridge 1978; Partridge and Watt 1991).

The Sterkfontein Formation refers to six massive and complex infills or members, with Members 1 to 3 contained in an underground system of caverns (Clarke 2006), and Members 4 to 6 exposed at the surface through erosion of the cave roof. Since this terminology for the cave infills was developed by Partridge (1978), deposits in the Jacovec Cavern (the lowest situated cavern in the system) have also been identified as one of the earliest infills (Partridge et al. 2003). Along with Members 2 and 4, it has yielded *Australopithecus* fossils. Member 5 is younger but of Plio-Pleistocene age and contains Oldowan and early Acheulean artifacts in a complex stratigraphic relationship (see Kuman and Clarke 2000). Member 6 overlies Member 5 West and is of mid-Pleistocene age but lacks artifacts. The Post-Member 6 Infill and the Lincoln Cave deposits are of late to mid-Pleistocene age and contain Middle Stone Age artifacts, along with some older material re-worked from Member 5. There are additional caverns with infills in the underground system that have not yet been excavated, but one exception is the Name Chamber. It directly underlies the Oldowan Infill in Member 5 East and contains artifacts that eroded from this deposit and filtered down into this underlying chamber (see later discussion).

The subject of this paper is the archaeology of the Oldowan Infill in Member 5 East, which is the second of at least four sequential infills contained in the Member 5 breccias (Clarke 1994; Kuman 1994a; Kuman and Clarke 2000). Initially published as dating about 1.7 to 2.0 Ma on fauna, the age of this infill has been confirmed at the older end of this range, with an absolute date of *ca* 2 Ma now achieved on a manuport (Granger *et al.*, in preparation). This paper presents the details of the complete assemblage, as defined stratigraphically in Kuman and Clarke (2000), and it provides an updated and revised analysis of the sample initially presented in Field (1999).

The reason for the rarity of Oldowan archaeology in southern Africa is the restricted geological circumstances under which such early sites are preserved. These are all underground 'keyhole' sites, capturing ma-

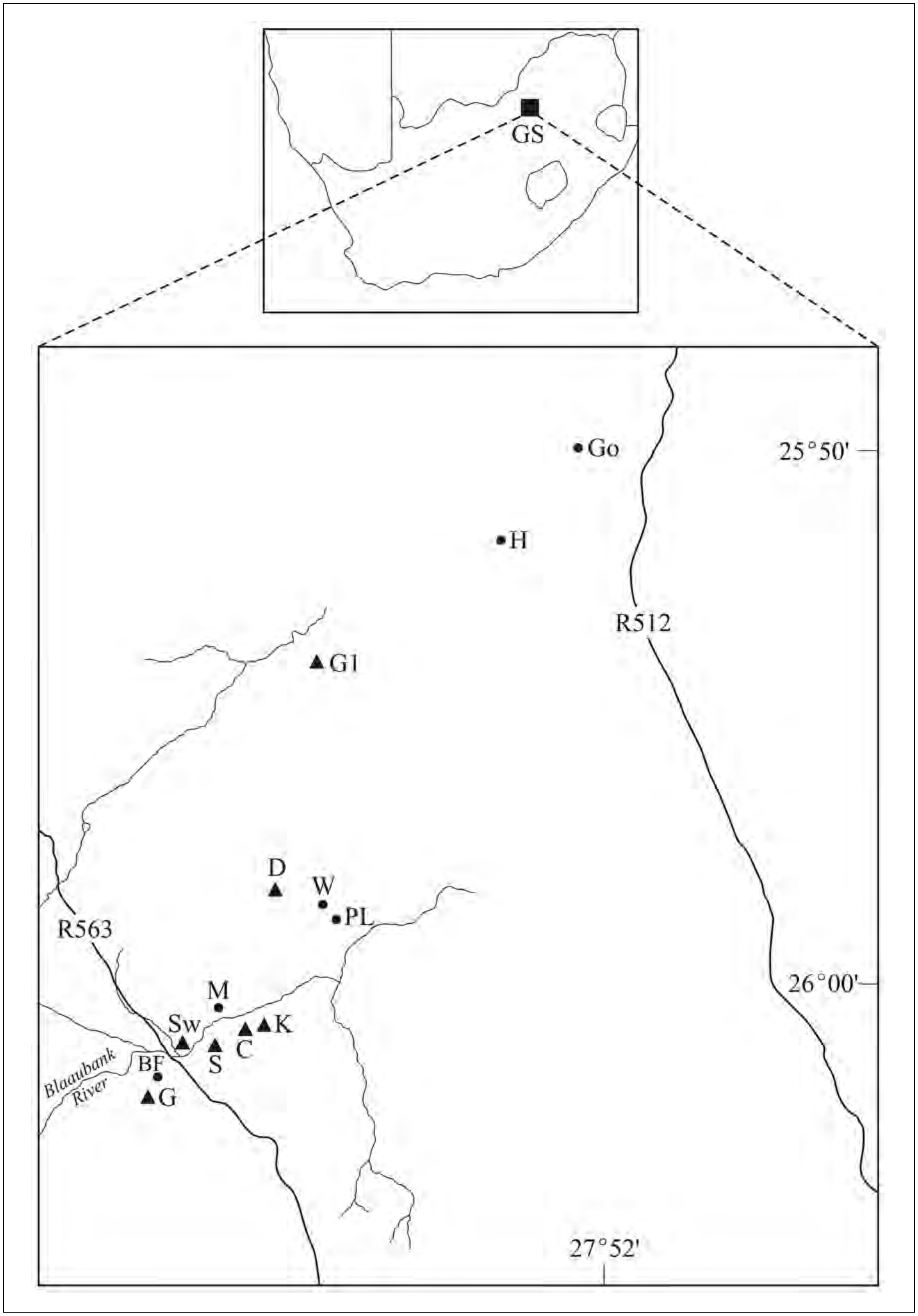

Figure 1. The suite of early sites in Gauteng Province (GS), designated as a UNESCO Cradle of Humankind World Heritage Site in South Africa, is located about 50 km northwest of Johannesburg. Sites indicated with a triangle contain artifacts of Plio-Pleistocene age: G (Goldsmith's), Sw (Swartkrans), S (Sterkfontein), C (Coopers), K (Kromdraai), D (Drimolen), and Gl (Gladysvale). PL (Plover's Lake) contains Middle Stone Age artifacts. BF (Bolt's Farm), M (Minaar's), W (Wonder Cave), H (Haasgat), and Go (Gondolin) have thus far not produced artifacts, nor has Motsetse, which is not shown.

terial from surface occupations around cave entrances that led to talus slope deposits through steep shafts, up to 15-20m deep. The Sterkfontein Oldowan Infill is no exception, having entered the system through a narrow opening immediately west of the australopithecine breccias of Member 4 (Kuman 1994a). Taphonomic analysis by Pickering (1999) indicates the associated fauna accumulated largely as a death-trap assemblage, with only some minor contribution from slope wash processes.

A notable fact is that all but a few artifacts at the Gauteng sites are found in close proximity to the Blauubank River gravels (see Figure 1). Only four artifacts have been found at sites distant from these gravels (3 at Drimolen and 1 at Gladysvale), and given their early age, this pattern is not unexpected (Kuman 2003). The three richest sites (Sterkfontein, Swartkrans and Kromdraai) all lie within 300m of the closest Blauubank gravels and within 500m of the modern-day river. With the largest early Pleistocene artifact assemblages, Sterkfontein must have provided the most comfortable occupation site in the valley, attracting repeated visits that resulted in large accumulations during both the Oldowan and early Acheulean periods (Kuman 1994a,b, 1998). Details of the stratigraphy and associated hominid fossils for Sterkfontein are provided in Kuman and Clarke (2000), and the Member 5 faunal assemblages are presented in Pickering (1999).

Assemblage Characteristics and Site Formation

The Sterkfontein Oldowan (Table 1) has been classified using the typology of Leakey (1971), with modifications as published by Kuman (1996, 1998) and Field (1999). *Small Flaking Debris* is defined as all material less than 20 mm in maximum length. It is not discussed further in this paper, but Field (1999) provides more detail on the traits of the Oldowan debitage. With the exception of one retouched flake that is 18 mm long, all other material that is 20 mm or more in maximum length has been categorized as follows:

Terminology

Complete flakes are whole enough to provide all technological information. Some occasional pieces may present minor modern or ancient damage, but this does not interfere with the measurements or technological attributes. *Incomplete flakes* include all flakes that lack a platform or are not complete enough to provide accurate measurements. Where platform information was available, however, this information was recorded in Field (1999). The incomplete flake category includes flake fragments, a category that is often used by other researchers for flakes or flake portions which lack platforms. *Core trimming flakes* are complete flakes with angular cross-sections, suggestive of some form of platform correction to assist with continued flaking of the core. There is only one example, and it is included in the complete flakes. *Core rejuvenation flakes*, with clear evidence of actual platform removal, are not present in this assemblage. *Chunks* are angular, blocky-shaped fragments. They are often produced through the fragmentation or shatter of thick flakes, but they are distinguished from flake fragments by their blocky volumes. *Retouched pieces* are flakes, chunks or flake fragments with clear evidence of secondary trimming on one or more edges. *Core tools*, as a category, include core forms that appear to be intentionally shaped for some use, or alternatively, a core that shows evidence of utilization on one or more edges. In this assemblage, there is only one core tool, a protobiface that could also be termed a pointed chopper. *Cores* are cobbles or other forms with clear evidence of removals, with either freehand or bipolar (hammer and anvil) technique. *Core fragments* are broken cores, lacking enough surface to be classified into any of the core types. *Manuports* are cobbles (or pebbles) that do not generally occur naturally on the landscape near the site. They are transported from the river gravels within 300-500 m of the site and lack any signs of use, including battering. While they are common in the early Acheulean breccias at Sterkfontein, there are only 10 specimens in the Oldowan, and three possible manuports.

For the core types, the following definitions apply:

Bipolar cores show clear evidence of being flaked with a hammer and anvil technique. Such cores do not show any negatives for a bulb of percussion on dorsal scars, and they typically have planed or slightly convex fracture surfaces, often with evidence of crushing at the point/s of impact. Flakes and fragments removed with this technique, which is most common in quartz materials, may show a variety of attributes: crushing at the point/s of impact, shattered platforms or very thin platforms, and more occasionally, spalled flakes and segment-shaped core fragments (*i.e.*, shaped like the segments of an orange). We have defined these attributes for the bipolar technique through extensive experiments in flaking of the local vein quartz.

Casual Cores possess only one or two removals and may represent testing of raw materials or just minimal flaking, for whatever reason. The scars on such cores should have a negative bulb of percussion to indicate freehand flaking. Cobbles possessing unintentional removals—*e.g.*, spalls removed when a cobble is used as a hammerstone—do not usually show a clear negative of bulb of percussion in these raw materials. *Chopper-Cores* are cores flaked (unifacially or bifacially) along an edge, an end, or a combination of the two, and although they may suggest an attempt at radial flaking, the removals do not continue along enough of the circumference to be classified as radial or discoidal flaking. *Discoidal Cores* are both radially and bifacially flaked around most of the circumference, and there is only one such example (in quartz) in this assemblage. *Polyhedral Cores* are extensively flaked from three or more platforms in differing directions, while *Irregular Polyhedral Cores* are defined in the same way but are less extensively flaked, which results in a less spherical and more irregular form.

Assemblage Characteristics

Table 1 shows that the assemblage is dominated by vein quartz (90.5% of all material), but it also includes some chert (6.7%) and quartzite (2.8%).

If all material <20mm and the unworked cobbles are excluded from the count, quartz still dominates at 79.7%, with chert at 5.7% and quartzite at 14.6%. And if only the 24 cores are considered (Table 2), quartz contributes 71%.

The size profile of the assemblage is dominated by small flaking debris, defined as all artifacts <20 mm in size, and comprising 82% of all measurable material (Table 3 and Figure 2). This compares well with experimental replications in the local raw materials (Table 4). In exhaustive flaking experiments of cores in quartz and quartzite directed by J. McNabb (see Kuman et al. 2005; also Field 1999 for a similar study), the proportion of small flaking debris under 20 mm maximum size was 85%; the local chert (which forms in association with the dolomite) flakes in a similar manner to quartz, but we did not include it in the experiments because chert does not figure prominently at Sterkfontein until the Middle Stone Age (Kuman 1994a). The vein quartz is brittle and shatters easily, producing a higher proportion of small flaking debris than quartzite (87% v. 79% respectively). In experiments replicating East African assemblages in lava at Koobi Fora, Kenya, Schick (1987) recorded means of 60 to 75% for material <20 mm in size. These figures are somewhat lower than ours for three reasons. First is the difference in raw materials. Secondly, the Koobi Fora experiments were intended to reproduce specific core types rather than to exhaust a core's potential. Thirdly, Schick quantified material beginning at 5 mm size, while we included material from 4 mm. In sum, Schick's and our own experiments demonstrate that a well-preserved assemblage produced by tool manufacturing should be characterised by 60% to 87% of flaking debris <20mm in size.

Details of the <20 mm size category, however, vary. While our overall experiments produced 65% and 20% respectively in the <10 and <20 mm size intervals, Schick records 28% and 41% for these categories, which is a reversal in dominance of the 10 to <20mm size interval to our own figures. This discrepancy may be due to the more exhaustive flaking of our cores, as well as to raw material differences or other unknown factors. Regardless of the reasons though, the 10 to <20mm size interval in the Sterkfontein Oldowan appears to be over-represented. It is unlikely to be due just to the export of some of the larger flakes from the site. The Sterkfontein material is a long-term accumulation that is in a re-deposited context, and it was undoubtedly somewhat altered by those natural processes that swept material into the cave shaft. Although it does not represent a pristine manufacturing assemblage, it does nonetheless indicate that knapping took place near the opening to the cave.

Table 4 also shows that the smallest component (<10 mm size) is under-represented, and as 2mm sieve mesh was used for the excavation, this under-representation is not a recovery problem. Work by D. Stratford (2008) has now accounted for the paucity of this smallest component of the Oldowan assemblage. At some point in the history of the Oldowan Infill assemblage, breccia was decalcified, and re-working of the deposit resulted in the loss of a portion of the artifacts down an underlying shaft into a lower chamber. This is the Name Chamber, which directly underlies the Oldowan breccia, connecting with it via a 12m-long shaft (Clarke 1994). Today the Old-

Table 1. Artifact types and raw materials for the complete Oldowan assemblage, including manuports. Apart from the small flaking debris, all material in the other categories is ≥20mm in maximum length, with the exception of one retouched flake which is 18mm.

	quartzite	chert	quartz	Total	%
Small flaking debris <20mm	9	204	2744	**2957**	**84.17%**
Complete flakes	20	7	57	**84**	**2.39%**
Incomplete flakes	38	22	231	**291**	**8.28%**
Chunks	11	0	120	**131**	**3.73%**
Retouched pieces	1	1	5	**7**	**0.20%**
Core tools	1	0	0	**1**	**0.03%**
Cores	7	0	17	**24**	**0.68%**
Core fragments	1	1	3	**5**	**0.14%**
Manuports	7	1	2	**10**	**0.28%**
Manuports?	2	0	1	**3**	**0.09%**
TOTAL	97	236	3180	3513	100.00%
%	2.76%	6.72%	90.52%	100.00%	

Table 2. Core types and their raw materials from the Sterkfontein Oldowan assemblage. There are no cores in chert.

	Raw Material Types			
Core Types	Quartzite	Quartz	Total	%
Bipolar Core	0	3	**3**	**13%**
Casual Core	0	2	**2**	**8%**
Chopper Core	3	1	**4**	**17%**
Discoidal Core	0	1	**1**	**4%**
Polyhedral Core	0	6	**6**	**25%**
Irregular Polyhedral Core	3	3	**6**	**25%**
Single Platform Core	1	1	**2**	**8%**
Total	7	17	24	100%
%	29%	71%	100%	

Table 3. Size profile of the Oldowan assemblage by raw material, with size intervals in mm. N=3492, which excludes damaged artifacts that could not be measured. Q is quartz, Ch is chert, and Qz is quartzite.

	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-99	100+	N
Ch	24	175	16	5	6	4	1	1	0	0	0	232
	10.3%	75.4%	6.9%	2.2%	2.6%	1.7%	0.4%	0.4%	0.0%	0.0%	0.0%	100.0%
Qz	0	9	15	24	12	12	5	1	4	5	2	89
	0.0%	10.1%	16.9%	27.0%	13.5%	13.5%	5.6%	1.1%	4.5%	5.6%	2.2%	100.0%
Q	321	2343	374	82	26	8	10	1	3	0	3	3171
	10.1%	73.9%	11.8%	2.6%	0.8%	0.3%	0.3%	0.0%	0.1%	0.0%	0.1%	100.0%

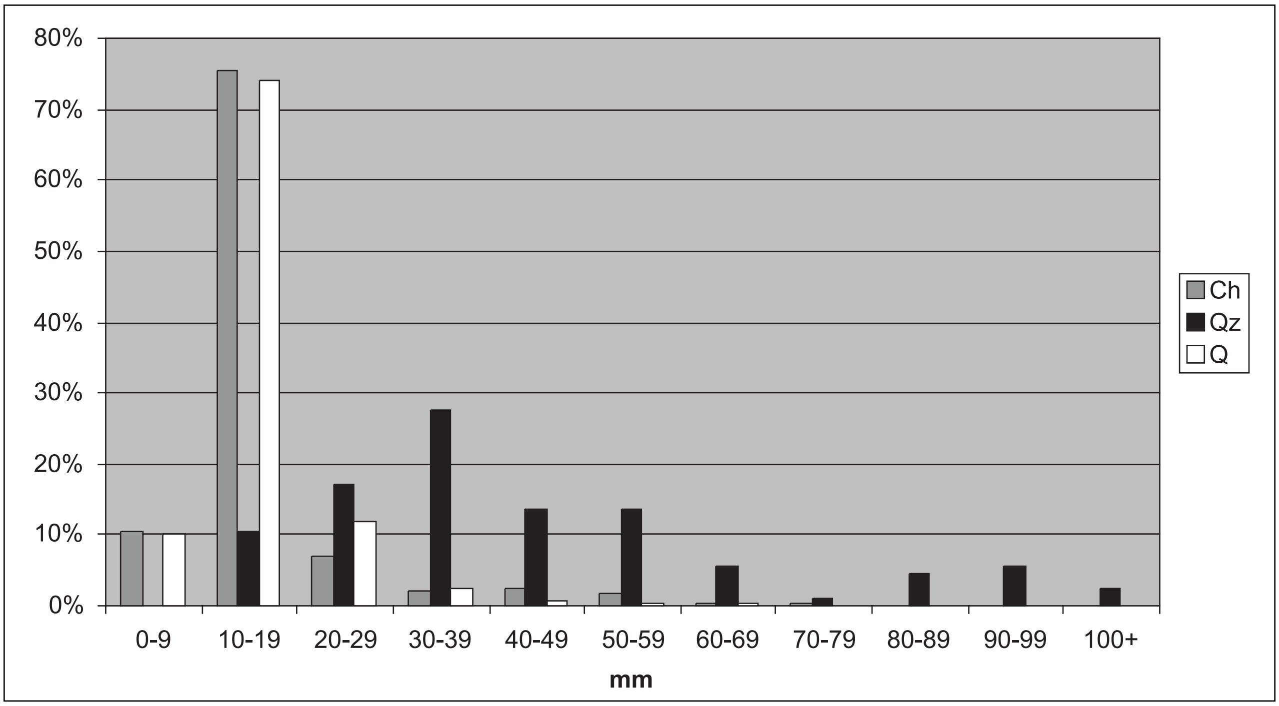

Figure 2. Size profile of the Oldowan assemblage by raw material type. Some material that could not be measured accurately is excluded.

Table 4. All measurable Oldowan artifacts, excluding manuports, compared with data from the experimental flaking of quartz and quartzite (Kuman et al. 2005).

Experiments	**Quartz**		**Quartzite**				**Combined**	
Size categories	N	%	N	%			N	%
4-9 mm	10295	**69%**	4631	**57.6%**			14926	**65%**
10-19 mm	2749	**18%**	1745	**21.7%**			4494	**20%**
20 and above	1933	**13%**	1670	**20.8%**			3603	**16%**
Total	14977	**100%**	8046	**100.0%**			23023	**100%**
Oldowan	**Quartz**		**Quartzite**		**Chert**			
Size categories	N	**%**	N	**%**	N	**%**	N	%
4-9 mm	321	**10.1%**	0	**0.0%**	24	**10.3%**	345	**9.9%**
10-19 mm	2343	**73.9%**	9	**10.1%**	175	**75.4%**	2527	**72.4%**
20 and above	507	**16.0%**	80	**89.9%**	33	**14.3%**	620	**17.8%**
Total	3171	**100.0%**	89	**100.0%**	232	**100.0%**	3492	**100.0%**

owan Infill is exposed at the surface through erosion of the dolomite cave roof, but it was once an upper chamber that overlay the lower chamber (or Name Chamber), in the modern underground cave system.

Stratford's analysis of artifacts excavated from a portion of the Name Chamber talus confirms that this latter assemblage is dominated by smaller artefacts. As material eroded out of the Oldowan breccia, it filtered down the shaft leading to the Name Chamber talus below, but it was mainly the smaller component that was able to pass through the restrictions created by rubble blocking the specific feeding shaft (Stratford 2008). This analysis has been confirmed by the stratigraphic and sedimentological details of the Name Chamber talus slope (*ibid.*). Our conclusion is that the Oldowan assemblage was once a largely complete occupation assemblage, with some portion of it re-worked and eroded into the underlying shaft.

Future analysis of the abraded component of the Oldowan assemblage is expected to demonstrate areas of re-worked breccia within the infill, which may show bias in certain size categories. The great majority of the assemblage, however, is in fresh condition. Artifacts derive from the area around the cave entrance, which correlates with the fact that there would have been relatively little higher ground from which weathered and abraded artifacts could have entered the site's catchment. Quartz, the dominant material, is resistant to weathering and it generally needs abrasion to obtain a weathered appearance. Thus the quartz component that is not fresh (and particularly the abraded component) suggests that the assemblage underwent some mechanical abrasion, either on the immediate landscape or in the process of re-working within the cave infill.

We conclude that most of the assemblage must have accumulated within a limited catchment area around the cave entrance, with hominid activities presumably taking place under shade trees. This is a logical conclusion because the surface fissures associated with cave shafts normally are marked by denser vegetation and trees due to greater moisture (Kuman 1994b). The assemblage composition points to a relatively stable land surface minimally affected by erosion. Sedimentological analysis by Partridge (1993) shows a higher clay and silt content for this breccia than for any other infill in Members 4 and 5, which include breccias that are both older and younger than the Oldowan Infill. If this phenomenon is not purely attributable to internal cave processes, it could indicate locally moist conditions that reflect more advanced pedogenesis of sediments entering the cave at this time (*ibid.*). Supporting evidence for this possibility may come from a study of carbon isotopes analysed from faunal teeth by Luyt and Lee-Thorp (2003), who conclude that a moderately wooded environment was present during the Oldowan accumulation. The combination of this environmental data and the good assemblage preservation thus suggests that catchment of artifacts around the cave entrance was aided by a stable, fairly well-vegetated land surface. It is not surprising then that Pickering's (1999) taphonomic study of the fauna indicates that a death-trap-like opening existed at this time. Local vegetation could have obscured a cave shaft, which was also relatively narrow because it formed early in the history of the Member 5 cave openings.

Raw Material Properties and Hominid Selection

Only 152 pieces in the assemblage have cortex that directly indicates the source of raw materials (Table 5). Of this informative portion, however, 72% have river gravel cortex, indicating a significant degree of manuport and artifact transport into the site from the nearby gravels. Of the cores, core fragments and one core tool, at least a quarter have cortex which indicates they were made on material sourced from the gravels. In addition, virtually all the quartzite artifacts without cortex can be added to the total of gravel-sourced pieces. Quartzite is not found around the caves today (Kuman 1996), and there is little evidence that there are remnant deposits from earlier times. In contrast with quartzite, chert in the Sterkfontein valley occurs as thin layers interbedded within the dolomite, and it can be found both at the caves and in the gravels. Quartz formed as veins within the dolomite and other local rocks, and hence it is also found both at the caves and within the gravels. As both chert and quartz are resistant rocks, they often litter the landscape in areas where the dolomite has decayed through weathering and dissolution.

Although shapes for chert are more rounded in the gravels than on the landscape, the quality of the chert is generally comparable between the two sources, but chert was a minor raw material in the Sterkfontein Oldowan. For quartz, however, it is much more difficult to find sizeable, good quality pieces on the landscape than in the gravels, where there is a variety of available sizes, from pebble to cobble grade. Vein quartz may have been preferred for some activities because it produces very sharp flakes with a clean cutting edge. Our flaking experiments show that it is brittle and fractures easily, regardless of shape. It is not so common in the gravels

Table 5. Raw material sources determined by cortex type for the entire Oldowan assemblage.

	Gravel cortex	Hillslope cortex	Indeterminate	N
Raw Material				
Chert	2 (0.8%)	4 (1.7%)	230 (97.5%)	236
Quartzite	55 (56.7%)	n/a	42 (43.3%)	97
Quartz	52 (1.6%)	39 (1.2%)	3089 (97.1%)	3180
Total	109	43	3361	3513

as quartzite, and hence it may have been selected for its ease of fracture, or alternatively for tasks that required a razor-sharp cutting edge. The chert also flakes easily, but this particular type of chert, formed interbedded with dolomite, produces flake edges with a somewhat rougher texture than that of vein quartz. This could explain its limited use at Sterkfontein, but it is more prominent at nearby Swartkrans (Field 1999), where chert and silica-enriched dolomite are more common on the immediate landscape around the cave. Hence the use of quartz and chert at Sterkfontein may be reflecting some combination of factors relating to the task at hand and raw material availability.

As both quartz and chert were flaked on site, they appear to represent an expedient use of these stones, probably for some activity that required sharp rather than robust edges. Our student butchery experiments over the years have shown that quartz makes very efficient cutting tools, even if a number of flakes has to be used because of their generally smaller size and brittle edges. The Oldowan quartzite, on the other hand, shows a size profile that does not indicate flaking on site (Figure 2, Table 3). There is a lack of small flaking debris in quartzite, with most quartzite pieces occurring in the 20 to 59 mm size intervals, and there is a wider range of artifact sizes present in quartzite than in quartz and chert. This suggests transport of this material, rather than differential capture for this sub-assemblage, particularly because all three materials are likely to have been subjected to the same depositional conditions. Transport may also have been desirable because it is easier to produce whole flakes from quartzite than from quartz. Field's (1999) experiments resulted in 40% of removals as whole flakes from quartzite cores versus 5% for quartz.

Where flaking method is evident, it is dominated by the freehand technique, but there is some evidence for the bipolar (hammer and anvil) method. However, vein quartz can be particularly difficult to assess quantitatively, as its high degree of shatter deletes most diagnostic bipolar traits. Freehand flaking probably dominates because cobbles are more common than pebbles in the gravels (pebbles are <64mm in size).

Cobble shapes for all raw materials are rarely spheroidal but occur in a range of other forms, which can be described as: blocky angular, blocky rounded, rounded polyhedral, wedge, disc, and tabular-disc (Kuman 1996; Field 1999). The lack of well rounded cobbles reflects the short transport distance these gravels have undergone, with the source of the Blaaubank River only about 24 km distant (Kuman 1996).

To summarize, all three raw materials are readily available in the area, and the situation is unlikely to have differed during the Oldowan occupation of the valley. Although quartz and chert may vary in their relative abundance around individual sites, they are both ubiquitous on the landscape and in the gravels. As some raw materials were clearly sourced from the gravels, we also know that these terrace deposits were accessible during the Oldowan. Therefore, environmentally influenced shifts in access to the three rock types are not a factor for the archaeology, and curated *v.* opportunistic use of raw materials can be interpreted with some confidence. There is good indication that hominids were not merely using the raw materials immediately available at the site but were transporting many rocks, as well as some pre-flaked quartzite, into the site. Quartz was often selected from the gravels, where it is not the most common material, probably for its ease of fracture and sharp flake edges. The lack of cores in chert and its availability on the landscape suggest that this material was most often accessed near to the site. These patterns thus indicate that the Sterkfontein hominids practiced both an expedient and a curated (*i.e.*, transported) use of stone at the site.

Typological Classification and the Influence of Raw Materials

The typological classification of the assemblage (Table 2, and see Figures 3 to 9 for representative types) shows that retouched pieces are only 0.2% (N=7), which means that an expedient strategy dominates. Manuports are also poorly represented at 0.3%, which is typical for most Oldowan period sites. A variety of core types is present, but polyhedral cores dominate (50% of 24 cores). This is due to two factors—the dominance of a non-organised flaking strategy that exploits any available surface on cobbles with varying platform opportunities; and the prominence of vein quartz, which in these gravels is found in a variety of shapes and which, during flaking, can shatter into exploitable portions or chunks. Some of quartz cores have been made on chunks. As a result of this tendency for quartz to shatter, extremes occur in quartz core sizes, which range from 30 to 120 mm (Table 6).

The only discoidal core is one in quartz. Our experiments showed that discoids are fairly easy to make on these cobble shapes, but continued flaking can transform them into polyhedrons (Kuman *et al.* 2005). Of the four chopper-cores (Fig. 3), only one quartzite example (No. 1) approaches the classic type of Oldowan chopper flaked on the edge of a cobble (as per Leakey 1971); the two other quartzite chopper-cores (Nos. 2-3) resemble radially flaked cores on split or fractured blanks; the blank for the quartz example (No. 4) cannot be determined. The few chopper-cores therefore highlight the limitations of the classic Leakey typology and the value of a *chaine opératoire* approach, which pays more attention to the raw material shapes, blank forms, and flaking process (*e.g.*, Toth 1985). Of the 24 cores, several also have irregular fracture surfaces that suggest pieces may have been thrown or split prior to flaking. This feature fits with the opportunistic technology, but it could also be due to flaws within the quartzite.

There is no edge damage or macroscopic wear that suggests any of the cores was used as a core tool. How-

*Table 6. Details of the 24 cores in the assemblage, with measurements in mm. Length, Width and Thickness have been provided so that core volumes could be analysed (Field 1999). In one case (No. 2502), the Maximum Length differed with the orientation of the core used for volumetric measurements.'Irreg. Fracs.' refers to the number of irregularly fractured surfaces. 'Reduction' is the degree of core reduction for freehand cores (1, minimally reduced with more than 2 platforms remaining; 2, partially reduced with 1-2 platforms remaining; 3, fully reduced with no remaining platforms). Cortex is estimated as 0 (none), 1 (up to 25%), 2 (up to 50%), 3 (up to 75%) and 4 (more than 75%). *3303 is a rolled complete polyhedron that appears to have been imported to the site as a manuport. **44 lacks details because it could not be located.*

Catalogue No.	Type	Max Length	Length	Width	Thick-ness	Scar No.	Longest scar	Irreg. Fracs.	Reduc-tion	Cortex
Quartzite										
4920	chopper	85	85	79	40	12	49	2	2	1
2502	chopper	94	89	64	51	3	56	1	2	4
2932	chopper	94	94	86	55	15	63	1	1	1
8854	polyhedron	69	69	45	35	10	32	0	3	1
8841	polyhedron	89	89	59	35	3	61	0	3	1
3019	polyhedron	91	91	81	57	4	49	1	3	2
2789	single platform	55	55	41	25	5	25	0	1	2
Quartz										
6212	bipolar	103	103	63	53	n/a	n/a	.	.	3
3708	bipolar	58	58	46	44	n/a	n/a	.	.	0
2771	bipolar	30	30	26	22	n/a	n/a	.	.	1
2693	casual core	34	34	25	19	1	23	0	2	0
8911	casual core	68	68	60	42	1	51	0	2	0
3977	chopper	66	66	47	39	8	49	0	3	0
3065	discoid	63	63	50	40	15	43	0	3	0
3705	polyhedron	105	105	91	57	4	50	0	1	4
4965	polyhedron	120	120	99	70	25	84	0	3	0
2487	polyhedron	36	36	31	29	3	30	0	3	1
2457	polyhedron	42	42	40	34	10	29	0	3	1
2772	polyhedron	42	42	33	22	8	28	0	3	0
2629	polyhedron	45	45	42	27	8	34	0	3	0
7334	polyhedron	62	62	46	38	8	47	0	3	0
2903	polyhedron	75	75	62	50	6	61	0	2	2
3303*	polyhedron	84	84	74	66	.	.	.	.	.
44**	single platform	44	.	.	.	.	.	.	.	1

ever, the one protobiface (Fig. 4, No. 5) has been classed as a core-tool because the removals concentrated at one end of the piece give it a pointed 'functional' end. Although the artifact can clearly be called a protobiface because these removals appear to be shaping the tip, it is also possible that this shape is the fortuitous result of flaking the more acutely angled end of the cobble.

Finally for the typological analysis, we re-iterate that vein quartz tends to produce a high proportion of incomplete flakes, due to its tendency to shatter. Although the archaeological sample sizes for chert and quartzite are small, there is a clear pattern that shows a much greater dominance of incomplete flakes for quartz for material $\geq$20mm:

	Quartzite	*%*	*Chert*	*%*	*Quartz*	*%*
Complete flakes	20	34%	7	24%	57	20%
Incomplete flakes	38	66%	22	76%	231	80%
Total	58	100%	29	100%	288	100%

This is corroborated by the experimental data, and although we have not included chert in the quantified experiments, our flaking experience suggests a generally similar pattern to quartz, as the chert is friable and tends to shatter. The data on quartzite, however, is not representative of a full knapping sequence and thus is not so useful.

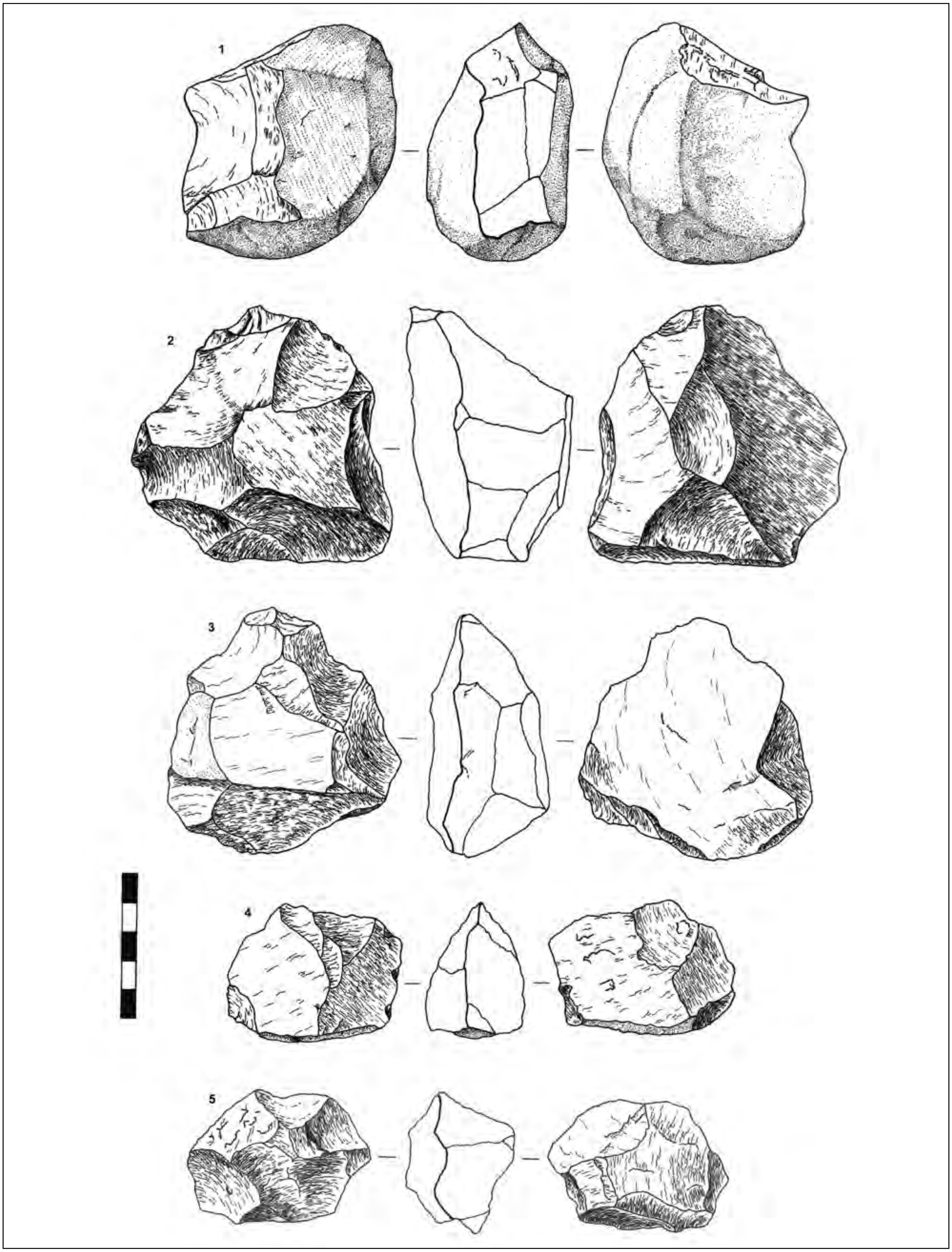

Figure 3. Chopper-cores and discoid: No. 1, a unifacial chopper-core in quartzite (#2502), made on a cobble with an irregular fracture at top; No. 2, a partly bifacial chopper-core in quartzite (#2932), with a radial flaking pattern and an irregular fracture formed by a planed surface that probably followed a natural flaw in the rock; No. 3, a unifacial chopper-core in quartzite (#4920), with a radial flaking pattern and made on a large flake or cobble fragment, with two irregular fracture surfaces; No. 4, a bifacial chopper-core in quartz (#3977); No. 5, a bifacial discoidal core in quartz (#3065).

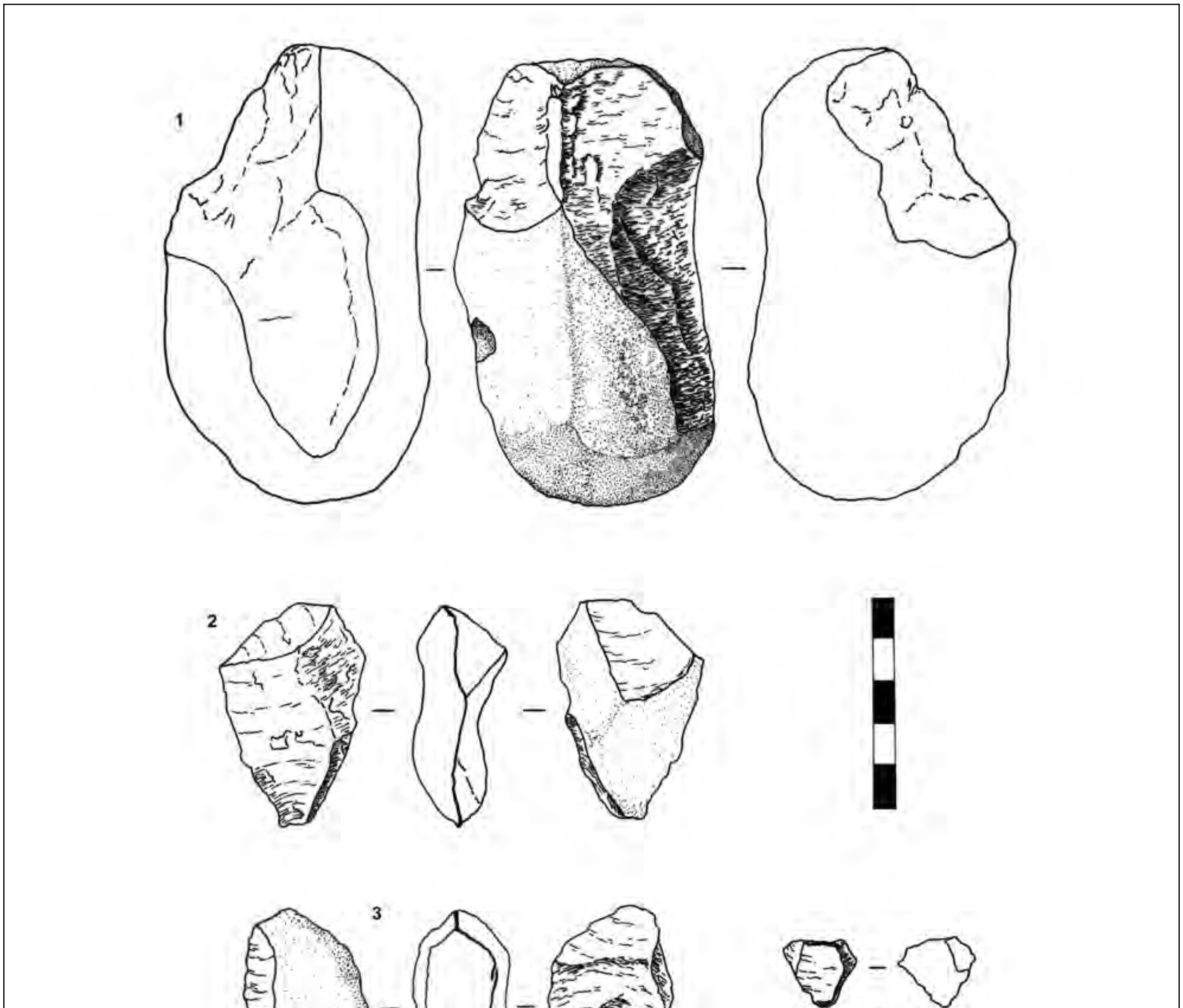

Figure 4. Bipolar pieces and protobiface: No. 1, a bipolar core on a quartz cobble (#6212), with fractured surfaces probably produced by a single blow; Nos. 2-4, quartz bipolar core remains or fragments; No. 5, a protobiface in quartzite (#2371).

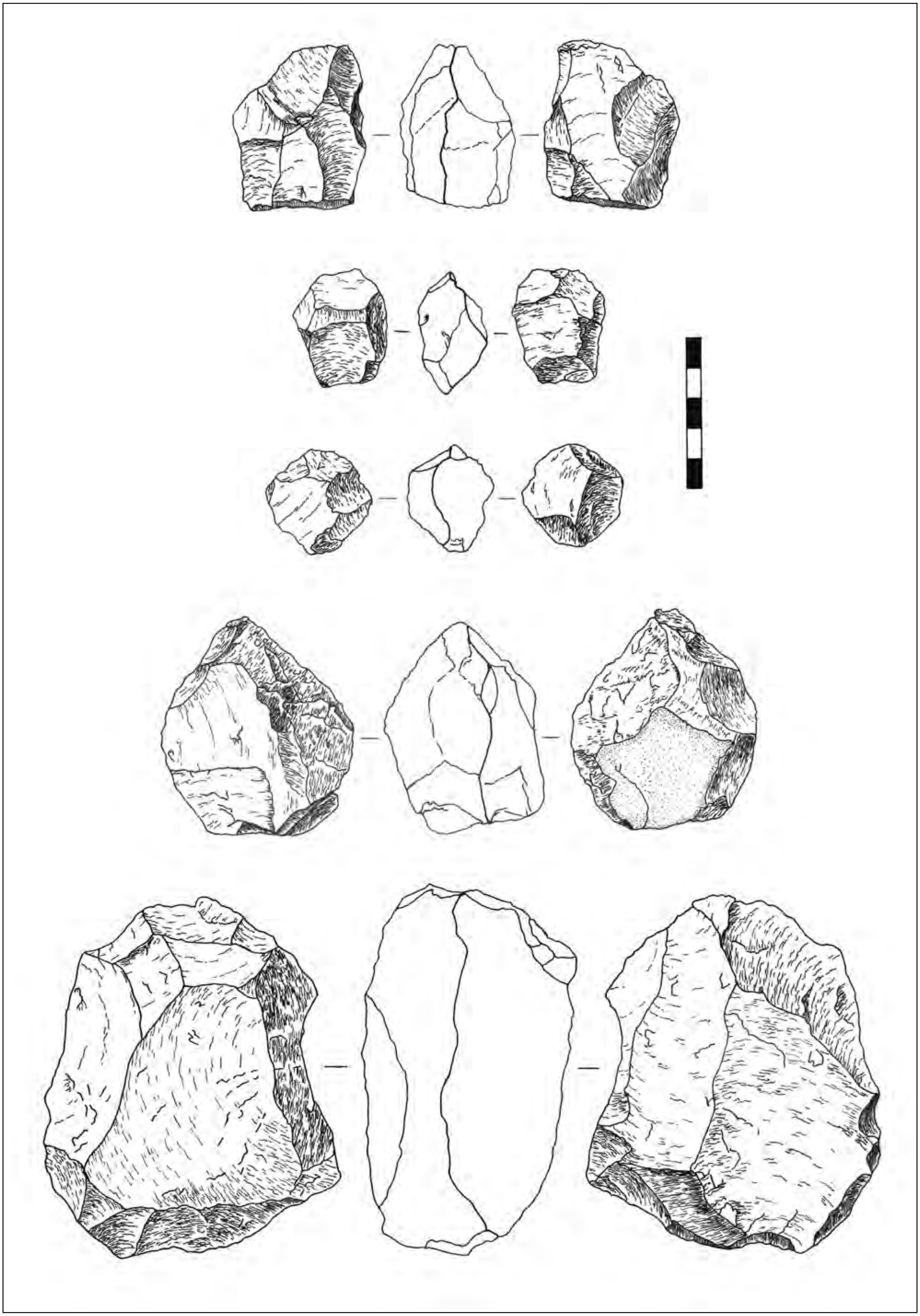

Figure 5. Polyhedral cores in quartz (in sequence from top: #'s 7334, 2772, 2487, 2903, 4965).

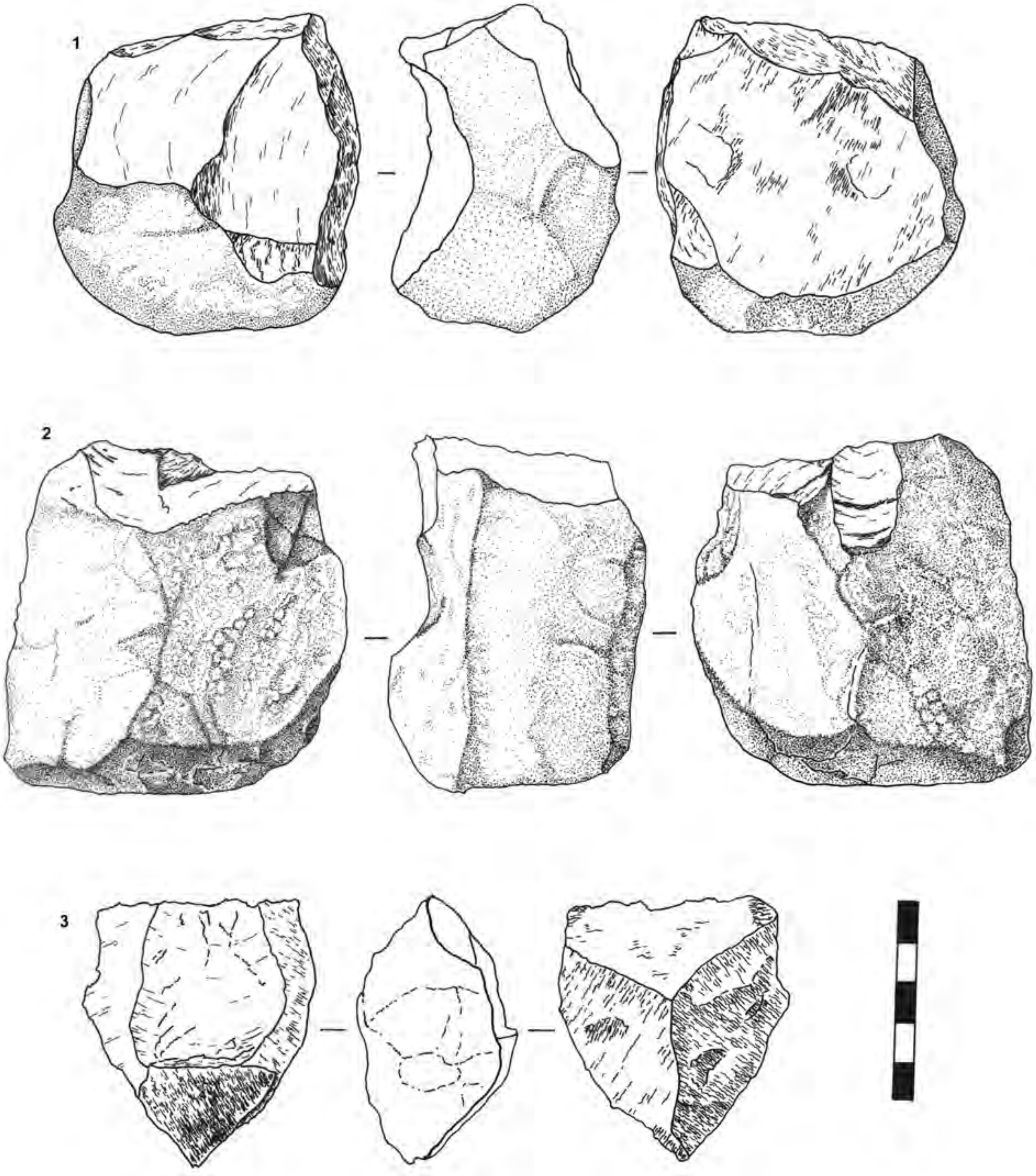

Figure 6. Polyhedral and casual cores: No. 1, polyhedral core in quartzite (#3019), with an irregular fracture visible in profile and 3rd views; No. 2, polyhedral core in quartz (#3705), with removals concentrated at top end; No. 3, casual core in quartz (#8911), made on a chunk.

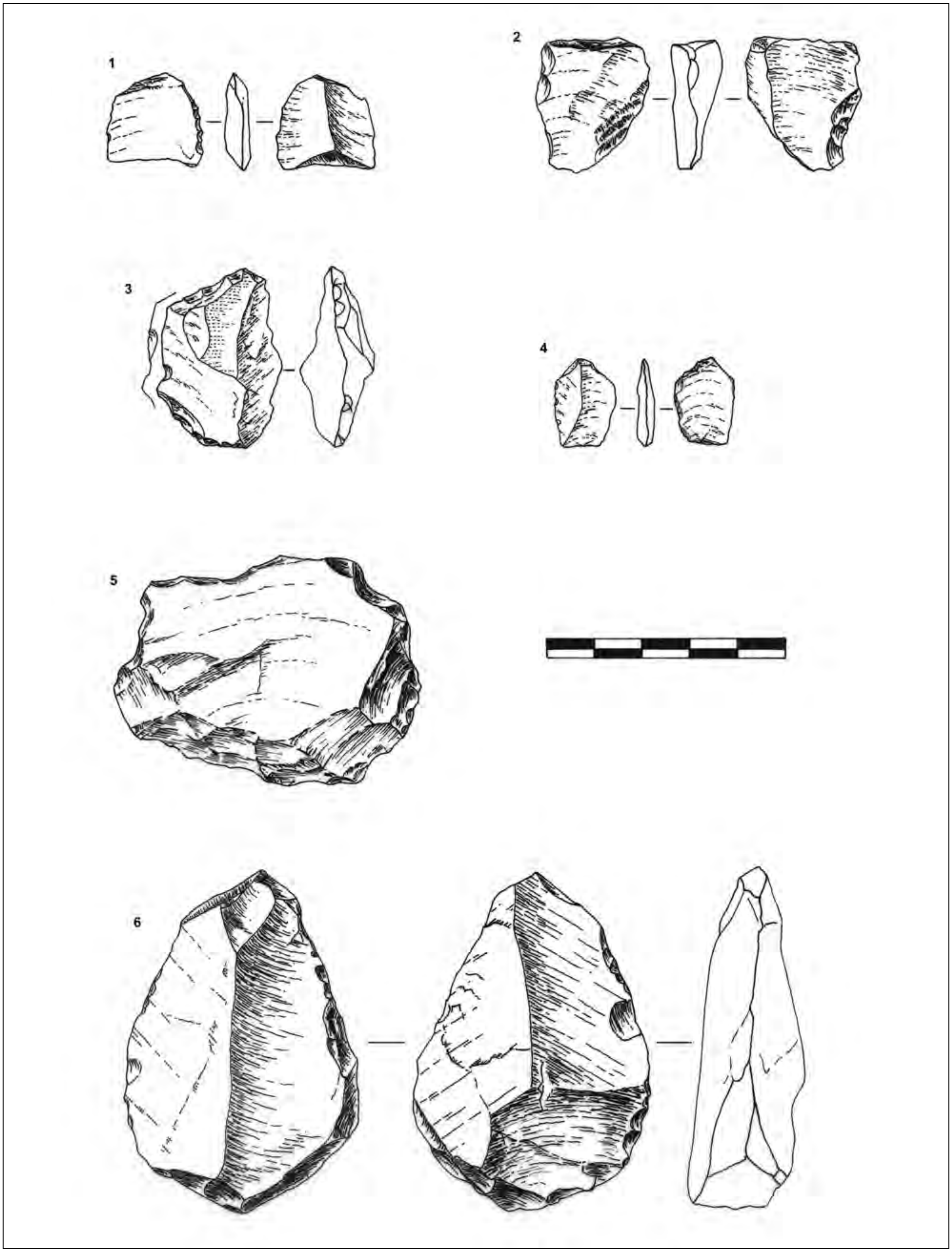

Figure 7. Retouched pieces. No. 1, distal portion of an incomplete flake with marginal retouch (#2647, quartzite); No. 2, proximal portion of an incomplete flake with inverse-obverse retouch on one edge (#3206, quartz); No. 3, an incomplete flake with denticulated retouch along most of the unbroken perimeter (#6121, quartz); No. 4, a complete flake with fine marginal retouch (or utilization?) on the ventral face (#7430, quartz); No. 5, a flake with abrupt edges showing ventral retouch (at right) (#7229, poor quality quartz); No. 6, a flake with sporadic retouch (#3228, chert, ventral face is the middle view).

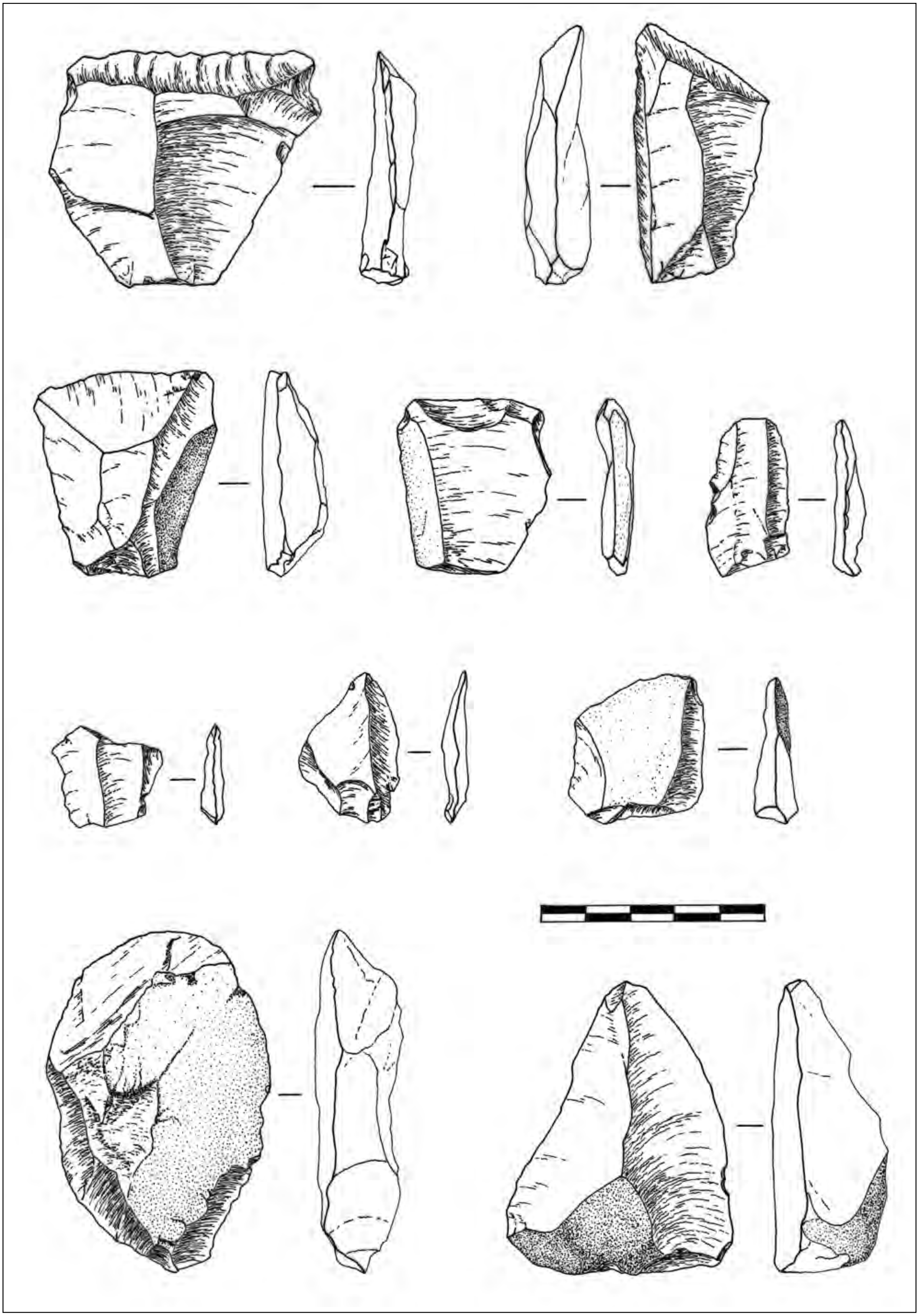

Figure 8. Complete flakes in quartzite.

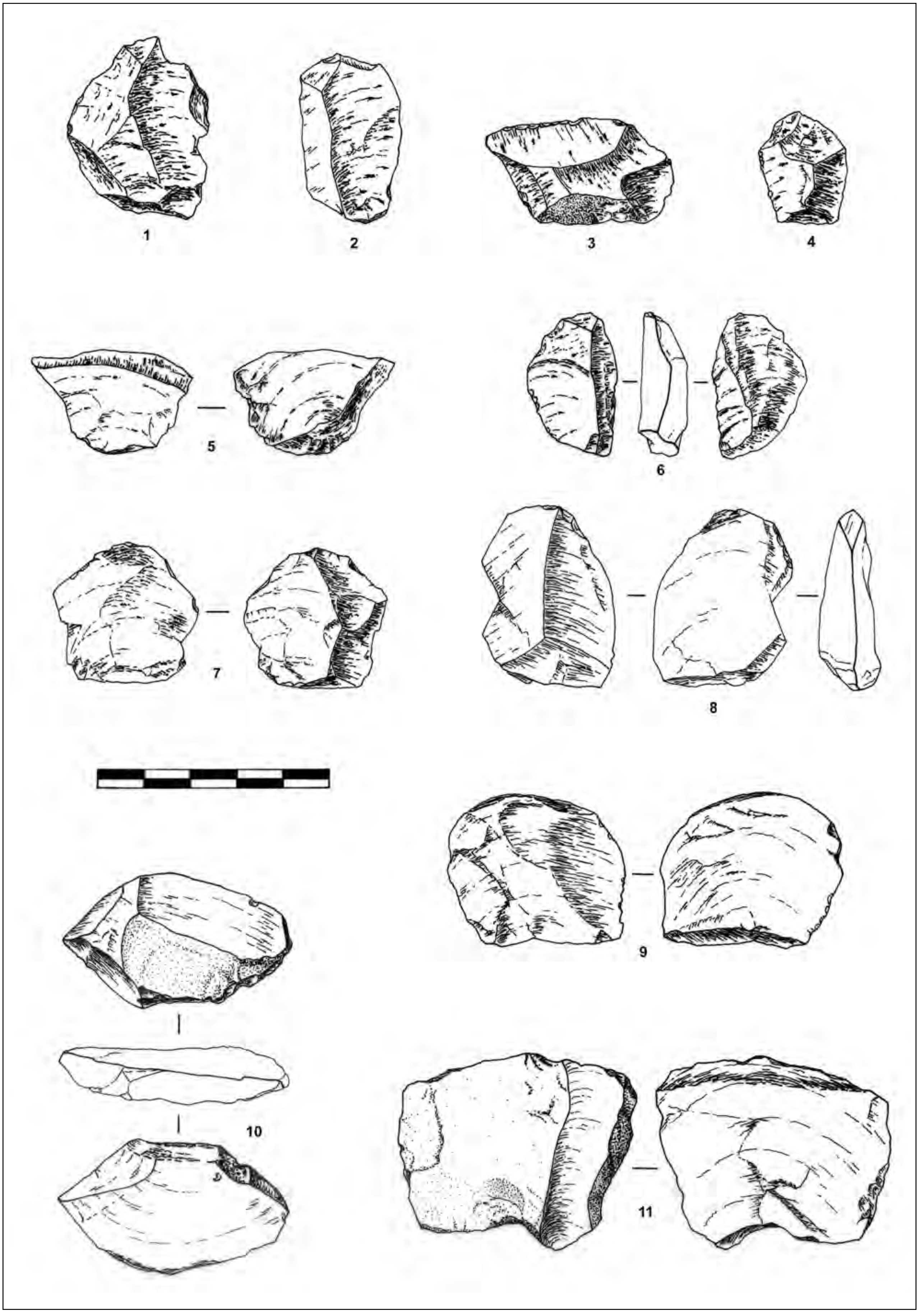

Figure 9. Complete flakes in quartz and chert. Nos. 1-7 in quartz, Nos. 8-11 in chert.

Examples of complete flakes in the three raw materials are provided in Figs. 8 and 9. Fig. 7 illustrates six of the retouched pieces. Retouch varies from sporadic removals to more consistent but marginal or nibbling edge working, and none is invasive, highlighting the casual nature of the assemblage.

Technological Analysis

A variety of technological attributes was analyzed for the sample used by Field (1999) to gain insight into the industry. Our results on this slightly smaller sample are summarized below, and Field (1999) may be consulted for further details:

Flake shapes

Flake shapes were recorded for 84 pieces, with the striking platform at base, as:

	convergent	*divergent*	*irregular*	*parallel*	*Total*
Quartz	40	9	6	7	62
Quartzite	5	5	3	4	17
Chert	4	1	0	0	5
Total	49	15	9	11	84
	58%	18%	11%	13%	100%

The majority of shapes is convergent (58%), but the chert and quartzite samples are too small to compare raw material trends. For the more reliable quartz sample, 65% are convergent. This attribute probably only reflects the manner in which quartz tends to detach with the simple flaking patterns evident in this assemblage.

Flake dorsal scars

The mean number of dorsal scars on complete flakes (≥20mm, with obvious bipolar flakes excluded) is slightly higher for quartzite than for quartz or chert:

	Mean	*Range*	*N*
Chert	2.5	1 to 5	6
Quartzite	3.4	2 to 6	16
Quartz	2.3	1 to 7	54

Although the sample size for quartzite is small, this difference could reflect the greater degree of flaking of quartzite off-site. The low mean numbers of dorsal scars in general correlates with the simple flaking patterns that dominate this assemblage. Dorsal Scar Patterns on whole flakes were also recorded for 86 pieces lacking cortex as: Unidirectional from the Platform, Opposed to the Platform, Transverse to the Platform, Unidirectional and Transverse to the Platform, Irregular, Radial or Converging. The patterns are overwhelmingly simple, reflecting the kind of flake types that would result from the dominance of polyhedrons and chopper-cores:

	Uni-directional	*Op-posed*	*Trans-verse*	*Uni-Trans-verse*	*Irreg*	*Ra-dial*	*Con-verg*	*Total*
Quartz	40	2	5	6	6	0	5	64
Quartzite	6	1	2	5	2	0	0	16
Chert	4	0	1	0	0	1	0	6
Total	50	3	8	11	8	1	5	86
	58%	3%	9%	13%	9%	1%	6%	100%

Flake terminations

Of 90 whole flakes for which flake terminations could be recorded, only seven had hinge terminations, with the remainder showing feathered terminations. This pattern is due to the dominance of quartz, which produces many incomplete flakes. If flakes terminate in a step in this material, they appear to be incomplete flakes and are classed as such, resulting in an elevated ratio of incomplete flakes. For every quartz complete flake, there are 4.56 incomplete flakes.

Cortex

The amount and position of cortex on whole flakes is used as an indication of degree of reduction (Villa 1983; Toth 1985). Flakes have been classed according to the six types described by Toth (1985) as successive stages of core reduction:

Cortex Location	*1: full/ platform and dorsal*	*2: platform and part dorsal*	*3: platform and no dorsal*	*4: dorsal and no platform*	*5: part dorsal and no platform*	*6: none*	*N*
Chert	0	0	1	0	2	3	6
Quartzite	2	0	1	0	6	9	18
Quartz	1	4	4	0	10	47	66
Total							90

The six chert flakes are too few to provide meaningful information. However, 83% of the 18 quartzite flakes fall into Types 5-6, consistent with the expectation that quartzite was largely flaked off-site. On the other hand, 86% of the 66 quartz flakes also fall into Types 5-6, even though quartz was clearly flaked on-site. This must be due to the brittle nature of vein quartz, which provided non-cortical fragments and chunks that would have been used as cores for on-site flaking, reducing the number of cobbles needing to be imported. 74% of all cores have less than 25% cortical surface remaining. However, the proportions of cortex on cores is not particularly informative of reduction in this assemblage, as quartz can be flaked as chunks, and there are few quartzite cores and none in chert. The amount of remaining cortex would also be influenced by cobble shape as much as by degree of reduction.

Core reduction

Scar counts on freehand cores range between 1 and 25 removals at time of core abandonment. There are only two casual cores (defined as a minimally flaked core with only 1-2 removals), which are both made on quartz. Chopper-core scars range from 3 to 15, and the only discoid in the assemblage is in quartz, with 15 removals. For the polyhedral cores, the most completely worked examples are all in quartz, with up to 25 scars. Overall and regardless of type for freehand cores, the quartzite cores average 7.8 scars, while the quartz cores average 8.7 scars. In our experiments, we also achieved up to 25 scars by core abandonment, but the mean was 10.5 scars. The experimental cores were, however, fully reduced, which is not always the case with the archaeological specimens. A more accurate measure of core reduction for the Oldowan cores is the number of remaining 'flakeable' platforms. We recorded this attribute based on our subjective but mutual decision that a platform could continue to be used. The result was that the majority of the Oldowan cores has no potential for further flaking, showing a relatively extensive use of materials, particularly for quartz.

Striking platform facets

Striking platforms of flakes are predominantly simple, with 1.2 being the mean number of facets for quartz flakes (N=43), 1.4 the mean for quartzite flakes (N=14), and 1.5 the mean for chert flakes (N=5). Although sample sizes are small, this pattern is not unexpected for the types of cores dominating the assemblage.

Flake platform angles

For non-cortical flakes, the mean angle formed between the striking platform and the ventral surface is greatest in quartz at almost 97°, but sample sizes for chert and quartzite are very small:

Material	*Mean*	*N*
Quartz	96.7°	45
Chert	92.4°	5
Quartzite	95.5°	13
Total		63

The range of values is also great—from 48° to 136°. Such a wide range could relate to the casual nature of the industry, or even to the ease with which quartz flakes, thus creating more variability.

Conclusions

Although we currently have only one certain site (dominated by quartz artefacts) to provide insight into Oldowan hominid behaviour in southernmost Africa, some interesting conclusions are evident in the Sterkfontein assemblage. Where it is possible to distinguish the source of raw materials from the cortex remaining on artifacts, the majority was brought into the site from the nearby gravels. Better quartz could be obtained from the gravels than from the landscape, and this shows a degree of selectivity, despite the expedient use of quartz at the site. Although chert was only occasionally used, both quartz and chert show near-complete size profiles, indicating they were flaked on-site. This fact and the paucity of retouched tools support an interpretation of the assemblage as generally expedient. Quartz may have been favoured because it was easy to flake and produced very sharp (if brittle) edges. The chert sample is small, but this rock is easily obtained on the landscape near the site and similarly appears to represent an expedient use of stone which was flaked on-site. Quartzite, on the other hand, creates more robust flake edges than these more brittle rock types. It was less commonly flaked on site and was largely transported, perhaps for use in certain tasks or even as an individual preference. Therefore the dominance of quartz at Sterkfontein should be viewed as a site-specific pattern that could be activity-related, random, or idiosyncratic to the site or the individuals involved. In addition to the selection of quartz from the gravels, there is evidence for transport of quartzite into the site as this material is not found on the hillslopes today, and it is unlikely that it was present in any significant amounts in the past. Transport for some pre-flaked quartzite tools is also a pattern, as there is a preference for medium-size quartzite flakes.

This overall pattern of selection, transport and curation at Sterkfontein shows forethought and appreciation of raw material properties, which mirrors Oldowan behavioural patterns in a variety of East African sites (*e.g.*, Stout et al. 2005). Many Oldowan sites show transport of raw materials over some distance, pre-flaking of cores, transport of flakes, or selection for specific raw material quality or flaking properties (see Plummer 2005 and Schick and Toth 2006 for syntheses). At least one early Oldowan site also shows a degree of selectivity for manageable rock shapes and maintenance of shape through the flaking process (Delagnes and Roche 2005). After 1.5 Ma, there is indication of some organised flaking strategy (De La Torre *et al.* 2003), which is a logical development following on the cognitive sophistication seen in earlier assemblages (e.g., De La Torre 2003; Delagnes and Roche 2005; Semaw 2006). While simple flaking patterns dominate at Sterkfontein and organized flaking patterns are not particularly evident in the small number of cores, much of this 'simplicity' can be explained by raw material shapes and flaking properties. There is also ample evidence for well-controlled flaking of the better raw materials in the assemblage, as well as a tendency for radial and alternate flaking of even the simplest type, *i.e.*, chopper-cores. More sites will be needed to provide a fuller picture of the range of early hominid behaviour in southern Africa, but the Sterkfontein industry does show a strong consistency in cognitive abilities with the Oldowan in other parts of Africa.

Although the majority of Oldowan cores appears to be relatively intensively worked, this attribute bears a significant relationship with raw material. As with core and dorsal scar counts, such traits should be assessed for each material. Experiments with flaking the local rocks have been invaluable for assessing raw material properties and shapes. Because the brittle vein quartz is easy to flake, it was easier to reduce cobbles and cores more fully than to transport new material to the site.

It is possible to produce all of the basic Oldowan core types on the local cobbles, which tend to have facetted or polyhedral and blocky shapes, but polyhedral cores dominate. This is also true for the Sterkfontein early Acheulean assemblage, in which quartzite was used for the majority of cores. With our less extensive experience of knapping than the Oldowan hominids would have possessed, we found the discoid the easiest core type to reduce fully because, when the two platforms are established, they can more easily be maintained. However, many of the Oldowan polyhedral cores are well reduced (as well as those in the Acheulean). This may be correlated not only with raw material, but also with skills in core reduction that come with greater practice and dependence on stone tool technology. While there are smaller numbers of complete flakes in quartz than in quartzite, quartz shows higher average scar counts on cores. These observations correlate with the tendency of quartz to shatter more readily than quartzite, and once again this highlights the importance of raw material comparisons for understanding technological attributes. The assemblage is characterized by relatively small average flake sizes.

The Sterkfontein Oldowan is only one assemblage, with characteristics that may be activity-related or due to individual biases, and it is clear that much more data is needed for a fuller picture. However, the assemblage is informative enough to allow us to conclude that the southernmost expression of this industry shows traits comparable with the East African pattern. We hope that renewed excavations in Member 1 at Swartkrans, which began in 2006 with a team led by T.R. Pickering, may help to round out this picture a little more.

Acknowledgments

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CHAPTER 9

Experimental Zooarchaeology and Its Role in Defining the Investigative Parameters of the Behavior of Early Stone Age Hominids

Travis Rayne Pickering and Charles P. Egeland

Introduction

In the past quarter century, zooarchaeologists have made significant contributions to our understanding of Early Stone Age (ESA) hominids. This work has been advanced in the field and laboratory, and includes: (1) the demonstration of functional linkages—in the form of butchery marks—between the world's oldest lithic technology and the reduction of animal carcasses into their constituent edible parts (e.g., Blumenschine, 1995; Bunn, 1981, 1982, 1997; Bunn and Kroll, 1986; Domínguez-Rodrigo et al., 2002, 2005, 2007; de Heinzelin et al., 1999; Pickering et al., 2004, 2007; Potts and Shipman, 1981); (2) some provisional idea of hominid dietary choices through the taxonomic identification of bones with butchery marks (compiled in Blumenschine and Pobiner, 2007). These two basic inferences have received wide-spread acceptance and, considering the vital role of diet in an animal's survival and fitness, they serve as foundational braces in models of early hominid socioecology. However, higher-order inferences, such as those concerning foraging efficiency, food sharing and group organization also are desired and have been attempted by applying actualistic results to the interpretation of zooarchaeological data. In particular, ethnoarchaeology has been one important contributor in these efforts (e.g., Bartram, 1993; Bunn et al., 1988), but we do not discuss that approach here. Instead, this chapter begins with a review of our experimental contributions to an understanding of ESA hominid carcass foraging. We summarize and discuss the implications of new datasets generated in our recent experimental programs. These results and others have been important in demonstrating that laboratory research plays a relevant role in ESA zooarchaeology. It does this first by helping to establish the interpretive limitations of actualistic results for application to an archaeological record formed in the very remote past—a record, which itself is severely limited due to preservational and other biases. Second, by recognizing these limitations, experimental zooarchaeology continues to act as catalyst in developing more apposite methods for creating models of the adaptive behaviors of our early African ancestors. We close the chapter with an opinion about the area in which these methods reside, and urge a renewed research focus in it.

Butchery Marks

The intensity by which hominids processed animal carcasses is of considerable interest to ESA zooarchaeologists. This is in no small part because carcass processing intensity probably relates directly to the over-arching issue of hominid-carnivore competition. Competition is widely recognized as an integral component of ecological communities and how they are structured, maintained and transformed (Cody and Diamond, 1975; Diamond and Case, 1986; Roughgarden, 1983; Tilman, 1982); it is at this level of inference that we could begin to have a much richer understanding of early hominid adaptations and behavior.

There are at least three zooarchaeological predictions of processing intensity that have been proposed: (1) the variable utilization of differently nutritionally ranked carcass parts (low processing intensity would be indicated by use of just the highest ranked parts, while high processing intensity would, in addition, see the use of

Table 1. Summary of essential parameters for carcass processing intensity experiments[1]

Cutmark experiment	
Hypothesis	number of defleshing cutting strokes applied to ungulate limb and cutmark frequency will covary positively
Sample	*Equus cabullus* 3 complete, fully fleshed forelimbs; 6 complete or nearly complete, fully fleshed hindlimbs. *Bos taurus* 5 complete, fully fleshed forelimbs; 2 complete, fully fleshed hindlimbs
Methods	carcass units completely defleshed using obsidian and chert flakes; number of cutting strokes required to accomplish the above counted; bones collected and cleaned; number of cutmarks (each discernable striation) counted
Test implication	Hypothesis falsified[2]
Percussion mark experiment	
Hypothesis	number of demarrowing hammerstone blows applied to ungulate limb and percussion mark frequency will covary positively
Sample	*Odocoileus virginianus* 36 complete, defleshed humeri; 38 complete, defleshed radii
Methods	bones broken across stone anvils using stone hammers until medullary cavity breeched to minimal extent that all marrow could be removed with a 12-inch pharmaceutical spatula; number of blows necessary to accomplish the above counted; bone fragments collected and cleaned; number of percussion marks counted
Test implication	Hypothesis falsified[2]

[1]Detailed methods and results for the cutmark experiments are described in Egeland (2003), and for the percussion mark experiments in Pickering and Egeland (2006).
[2]See Figure 1 for graphic summary of results.

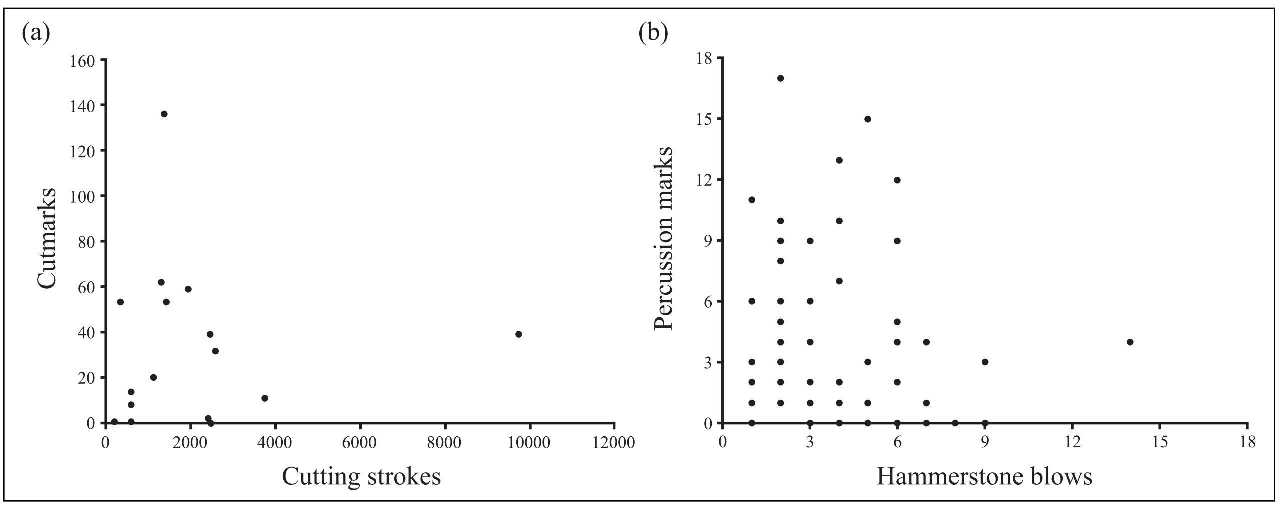

Figure 1. Bivariate scatterplots showing no significant positive correlations between (a) the number of defleshing cutting strokes and cutmark frequency on horse and cow bones (r_s = 0.081, p > 0.10) (data from Egeland, 2003), and (b) between the number of hammerstone blows and percussion mark frequency on white-tailed deer bone fragments (r_s = −0.234, p = 0.045) (data from Pickering and Egeland, 2006). Note that skeletal elements and bone specimens from the experiments that do not preserve surficial marks are not graphed in (a) and (b).

low ranking parts); (2) the extraction of marrow and/or grease in addition to meat; (3) the increased investment in removing one particular type of carcass tissue (e.g., not only defleshing major muscle masses, but also small scraps of meat adhering to bone). Among others, three of the primary zooarchaeological measures to test these predictions are: (1) skeletal part profiles; (2) quantification of bone fragmentation; (3) frequencies of butchery marks. Our most recent experimental work relates directly to the third measure and we discuss it here.

The often epiphenomenal nature of butchery marks has been highlighted most explicitly by Lyman (1992, 1994, 1995, 2005). His work on the topic, however, was largely comparative (sensu, Klein and Cruz-Uribe, 1984; i.e., it has concentrated on inter-taxonomic and inter-site comparisons of strictly archaeological materials), rather than actualistic. Inspired by Lyman's results, our efforts to discover meaningful linkages between hominid behavior and butchery damage have been, in contrast, wholly experimental.

We conducted two sets of experiments. The first, by Egeland (2003), operated under the hypothesis that the number of defleshing cutting strokes applied to a muscled ungulate limb bone (limb bones = humeri, radioulnae, femora, tibiae, metapodials [see, Pickering et al., 2003]) and cutmark frequency will covary positively—with the underlying assumption that high intensity defleshing is conducted with more cutting strokes than is low intensity defleshing. Second, Pickering and Egeland (2006) hypothesized positive covariation between the number of hammerstone blows and percussion mark frequency during the demarrowing of an ungulate limb bone. The critical parameters of both experiments are outlined in Table 1, and Figure 1 presents our results. In sum, there is not a statistically significant positive correlation between cutting strokes and cutmark frequency, nor is there one between hammerstone blows and percussion mark frequency. These experimental results falsify both hypotheses. They also lead to a conclusion that agrees with that of Lyman (2005), based on his comparative analyses: the production of butchery marks is largely contingent and fortuitous. In the wake of this conclusion, Lyman (2005) still counsels some optimism, arguing that "well-founded interpretations of frequencies of cut-marked remains [might be possible, but also] may require unique kinds of contextual data." We, however, remain more dubious. At least in the context of ESA archaeofaunas, in which hominid input into the systems is usually minimal in even the "best" assemblages (e.g., Bunn, 1982, 1997; Domínguez-Rodrigo et al., 2007; Pickering et al., 2004, 2008), linking butchery mark frequency causally to carcass processing intensity is a long shot for success.[1]

A potentially more ESA-applicable observation on butchery mark frequency emanating from our combined experimentation is that 77.0 % of the total limb bone minimum number of elements (MNE) demarrowed display at least one percussion mark (Pickering and Egeland, 2006) and 87 % of the total limb bone MNE defleshed displayed at least one cutmark (Egeland, 2003). We believe these results provide a baseline standard against which an ESA archaeofauna might be compared to assess its hominid contribution. If independent data lead to the hypothesis that the fauna is primarily hominid-derived, our results predict that in that case at least 75% of the total limb bone MNE should be butchery marked. In doing so, the experimental approach highlights the inferential utility of the MNE as a zooarchaeological measure of skeletal element abundance. Previous work by Rapson (1990), Bartram (1993) and Abe et al. (2002) has emphasized butchery mark frequency data based on number of identified specimens (NISP) counts are highly sensitive to differential bone fragmentation, whereas MNE-based counts are much less so and thus preferable for most behavioral analyses.

Bone Fragmentation

The MNE played another essential role in falsifying the hypothesis that high levels of ungulate limb bone fragmentation necessarily indicate a high intensity of carcass processing (Pickering and Egeland, 2006). A standard zooarchaeological measure of bone breakage is the fragmentation ratio NISP:MNE. Our hammerstone fragmentation of ungulate humeri and radii (see Table 1) resulted in markedly different NISP:MNE ratios for the two elements, even though each individual bone was broken to the minimal extent necessary for marrow removal. In other words, even though processing intensity was held constant in each case, the radius sample (NISP:MNE = 21.3) is more heavily comminuted than is the humerus sample (NISP:MNE = 13.1). Two other measures of bone breakage, including distribution of fragment sizes (Figure 2) and the proportion of epiphyseal (humerus n = 74; radius n = 91) to non-epiphyseal specimens (humerus n = 401; radius n = 720) corroborate the same significant difference between humeri and radii, with greater reduction of radii. We conclude that the variable that best explains this disparity is the more robust structure of the radius diaphysis compared to the thin-walled shaft of the humerus. More effort was required to breech radii sufficiently to attain the goal of complete marrow extraction. It is important to stress that in this case effort is *not* synonymous with intensity, the latter of which was held constant as breaking each bone to the *minimal extent necessary for marrow removal*. Thus, as demonstrated in so many other contexts (e.g., Brain, 1967, 1969; Lyman, 1984; Carlson and Pickering, 2003), it is an intrinsic property of bone that is mediat-

[1] We note here that studies by Pobiner and Braun (2005) and Domínguez-Rodrigo and Barba (2005) found positive correlations between cutmark frequencies and the size of the carcass that is butchered. So, we admit that cutmark frequencies do seem to hold some explanatory power for at least one component of understanding early hominid carcass foraging, and are thus not completely epiphenomenal.

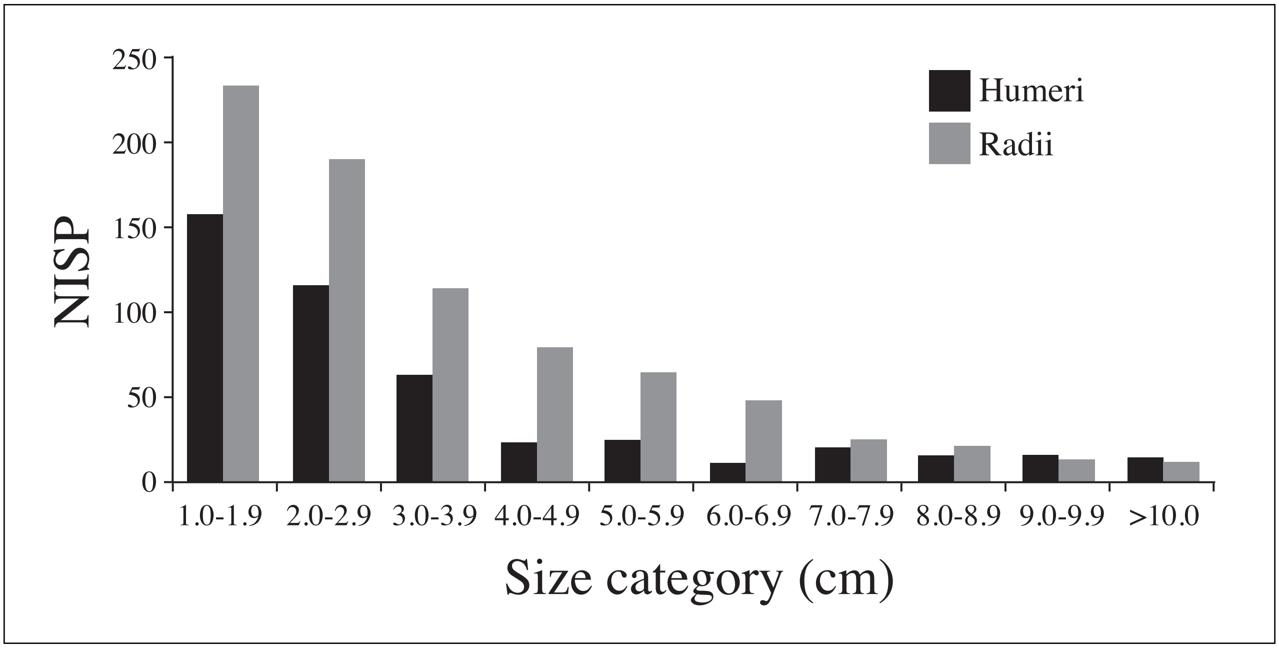

Figure 2. Inter-element distribution of fragment sizes for hammerstone-percussed humeri and radii (data from Pickering and Egeland, 2006). The radius sample contains a higher number of small fragments than does the humerus sample, corroborating the assertion that the former is more heavily comminuted than is the latter. NISP = number of identified specimens.

ing a zooarchaeological pattern of bone specimen representation. Such phenomena obscure or at least confound any underlying behavioral patterning (in this case, carcass processing intensity) in a fauna.

Return to a Previous Direction

Our experimental results summarized above conclude pessimistically about the probable success of using butchery mark frequencies and bone fragmentation to accurately infer the intensity by which Plio-Pleistocene hominids utilized ungulate carcasses. It thus seems to us that this avenue for investigating hominid-carnivore competition in the earliest ESA leads to a dead end. However, we certainly do not mean to imply that the dynamics of prehistoric competition are inexplicable. Indeed, many previous experimental efforts, as well as other approaches, have been devoted to modeling hominid-carnivore competition. One of the best known of these earlier studies is that of Blumenschine (1988).

His research maintained a focus on surface marks on ungulate limb bones. A concentration on these skeletal elements is particularly useful from an archaeological standpoint because their midshaft portions have been shown to better survive the rigors of density-mediated attrition than most other element portions; thus, limb bone presence in an archaeofauna (calculated by shaft inclusive methods of quantification) very likely reflects their original abundances with considerable fidelity (Bunn, 1982, 1986; Cleghorn and Marean, 2007; Marean and Cleghorn, 2003; Pickering et al., 2003).

Blumenschine's field experiments, carried out in the Serengeti and Ngorongoro (Tanzania), simulated two general scenarios. In the first scenario provisioned ungulate carcasses are processed completely and exclusively by human experimenters using cutting tools or by wild carnivores (referred to, respectively, as "hominid-only" and "carnivore-only"). When carnivores (mainly hyenas) process complete limb bones they break them open to access marrow and grease. This results in tooth mark frequencies on midshaft segments of between 50%–80% (Blumenschine, 1988, 1995; Capaldo, 1995, 1997). Hominid-only samples derive from both experimental and ethnoarchaeological settings. Data generated on those samples indicate that hominid butchery results in cutmark and percussion mark frequencies that range between 15%–40% (Blumenschine and Selvaggio, 1988, 1991; Bunn, 1982; Domínguez-Rodrigo, 1997, 1999a; Domínguez-Rodrigo and Barba, 2005; Lupo and O'Connell, 2002; Pickering and Egeland, 2006; Pobiner and Braun, 2005). Blumenschine's second scenario simulates the sequential utilization of carcasses in "dual-" or "multi-patterned" models (Blumenschine and Marean, 1993; Capaldo, 1995). When human hammerstone breakage and marrow extraction is followed by carnivore ravaging, limb bone midshaft segments are tooth-marked at rates of only 5%–15% (Blumenschine, 1988, 1995; Blumenschine and Marean, 1993; Capaldo, 1995, 1997). The reason for this is relatively straightforward: hammerstone-broken midshafts no longer contain nutrient-rich marrow and therefore scavenging carnivores have little or no reason to put them between their jaws and incidentally tooth-mark them. Therefore, tooth mark frequencies on midshaft fragments can be used to differentiate primary from secondary access to ungulate carcasses by *bone-crushing carnivores*.

That the data of Blumenschine and his colleagues derive mainly from hyenas is important given that Domínguez-Rodrigo et al. (2007) demonstrate that tooth mark frequencies similar to "hominid-to-carnivore" models can be produced when felids rather than hyenas are the primary agent of carcass modification. Felids, especially medium-sized leopards and cheetahs, impart many fewer tooth marks on midshaft sections because they lack the bone-crushing ability of hyenas. This issue of potential equifinality in carnivore tooth mark frequencies highlights the need to consider taxon-specific variability in carcass modification abilities among carnivores. In addition, it stresses that *only hominid-imparted surface marks* can be used to directly infer the nature of hominid involvement with carcasses.

With the demonstrations that butchery mark frequencies are a doubtful source of accurate behavioral inferences, we return to our well-published assertion that it is the *anatomical patterning of butchery marks* that is instead of primary importance in faithfully modeling hominid carcass use. Specifically, defleshing cutmarks on limb bone midshafts of ungulates are good evidence for the butchery of fully fleshed limbs and, by extension, early access to carcasses (Bunn, 1982, 1986, 1991, 2001; Bunn and Kroll, 1986; Domínguez-Rodrigo 1997, 1999a, 2002; Domínguez-Rodrigo and Pickering, 2003; Pickering and Domínguez-Rodrigo, 2007; Pickering et al., 2004, 2008). Observations of abandoned lion kills—on which flesh scraps are never or rarely present on the previously meat-bearing midshafts of humeri, radii, femora and tibiae—strengthen this claim (Domínguez-Rodrigo,1999b). Thus, hominids relegated to passively scavenging felids kills would have no reason to impart cutmarks on bone sections (i.e., humeri, radii, femora and tibiae midshafts) that are usually completely defleshed by those primary-access felids. Cutmarks on pelves and ribs, the flesh of which is also consumed early in the carnivore consumption sequence (Blumenschine, 1986), are also indicative of early access by hominids to animal carcasses.

There is no longer any excuse to consign the importance of these observations. First, they have been tested actualistically and, unlike mark frequency data, are upheld as inferentially utilitarian. Second, the ESA archaeological record preserves an abundance of durable limb bone midshaft specimens, as well as other pertinent fossils. The very earliest zooarchaeological traces from Gona and Bouri, Ethiopia, at 2.6 – 2.5 million years (Myr.) ago, are scant, but we still believe it is telling that the few butchered specimens recovered so far from that time include ungulate upper and intermediate limb bone midshafts, as well as a rib with cutmarks on its ventral surface (Domínguez-Rodrigo et al., 2005; de Heinzelin et al., 1999). The minimalist nature of these Pliocene occurrences has led some researchers to conclude that early access to carcasses by hominids was only firmly established in the Early Pleistocene (Bunn, 2007). Although we certainly agree that the Pliocene sample of butchered ungulate remains is small and that early access is undoubtedly reflected in some Early Pleistocene assemblages, it is perhaps significant in this context that renewed analyses of the Early Pleistocene Bed I occurrences at Olduvai Gorge reveal FLK *Zinj* as the only assemblage between 2.5–1.5 Myr. ago with evidence of *systematic* butchering of carcasses by hominids (Domínguez-Rodrigo et al., 2007). These data indicate regular and early access to carcasses at 1.8 Myr. ago. We therefore suggest as an alternative that it might have been the *regularity* with which hominids acquired carcasses and not necessarily the *method* of access that differed between the Pliocene and the Early Pleistocene (and beyond).

Regardless, it still seems to us that this rather basic approach—a focus on the anatomical patterning of cut- and percussion marks—to the interpretation of hominid butchery damage stills holds the most potential to elucidate accurately the question of hominid-carnivore competition in the ESA. In at least one sense, the characterization of early hominid foraging capabilities and strategies provided by the approach are quite unambiguous and specific in being unclouded by reference to surficial bone damage imparted by other taphonomic agents and processes. As such these characterizations serve as an appropriate base upon which a sophisticated model of early hominid socioecology and cognition can be built.

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CHAPTER 10

The Oldowan in North Africa Within a Biochronological Framework

Mohamed Sahnouni and Jan van der Made

Abstract

Much of the Plio-Pleistocene data on the Oldowan is primarily from sites in East Africa. However, although North Africa is well underexplored compared to East Africa, there is a fairly good Oldowan record in this part of the African continent. There are a number of localities in sealed stratigraphic sequence with Oldowan artifacts that provide evidence of early human presence in North Africa. Yet, unlike East Africa, they lack a sound absolute chronological framework. Therefore, dating of the North African Oldowan depends on associated faunas with taxa of biostratigraphic significance. Using the well dated East African fossil records, faunas from North Africa and East Africa are compared to help dating the North African Plio-Pleistocene localities, especially those yielding Oldowan occurrences such as Ain Hanech and El-Kherba in Algeria. Dated minimum to 1.77 Ma, Ain Hanech and El-Kherba document clearly Oldowan artifacts associated with a savanna-like fauna, indicating that early hominins geographically ranged in wider areas outside East and South Africa.

Introduction

The primary information on early hominin behavior and adaptation derives chiefly from a number of Plio-Pleistocene sites in East Africa. Modern investigations undertaken at Olduvai in Tanzania (Leakey, 1971; 1975, Potts, 1988) and at Koobi Fora in Kenya (Bunn et al., 1980; Harris, 1978; Isaac, 1972; 1978) have allowed archaeologists to concentrate on the horizontal aspect of the accumulation of the archaeological materials, study its spatial distribution, and attempt to understand its behavioral significance. In fact, excavations of Oldowan sites in primary context have allowed archaeologists to address major questions regarding early hominin way of life, such as food acquisition, significance of concentrations of stone artifacts and fossil bones, the role of lithic technology in hominin adaptation and intelligence. These questions have generated heated scientific debates, such as the hunting/scavenging (Binford, 1981; Bunn, 1981, Bunn & Kroll, 1986), “home base” and “food sharing” hypothesis (Isaac, 1978), and site formation processes of paleolithic sites relative to hominin activities (Schick, 1986, 1987).

In contrast, North African Early Palaeolithic was regarded as providing scanty evidence and little information on a scarce early human presence in this part of the African continent. For example, Desmond Clark (1992: 33) wrote “the great majority are surface occurrences that cannot be tied to a stratigraphic sequence”. Actually, this situation primarily was a consequence of lack of systematic investigations and less emphasis on understanding of past human behavior. Current studies have shown that there are a number of Early Palaeolithic sites in North Africa that are in sealed stratigraphic sequences providing ample possibilities for tackling early hominin behavior and adaptation in this region of the African continent. In fact, the sites of Ain Hanech and El-Kherba in Algeria, encased in fine-grained sediments, permit to address various aspects of hominin behavior, including manufacture, use and discard of artifacts; acquisition and processing of animal carcasses; and vertical and horizontal distribution patterns of archaeological remains.

Unlike East Africa, the North African Plio-Pleistocene paleontological and archaeological localities suffer from the lack of an accurate chronological framework due to the absence of radiometrically dateable materials. Absolute dating techniques are possible only for the Middle and Upper Pleistocene deposits. Consequently, the dating of the Plio-Pleistocene deposits depends primarily on associated faunas with taxa of biochronological significance. In contrast, the East African Plio-Pleistocene fossil records are derived from a radiometrically well dated lithostratigraphic background, offering a precise biochronological framework that can be used for dating other African fossil deposits that are devoid of radiometric dates but have yielded the same or close relative taxa found in East Africa. Using this approach, North African faunas are compared with their East African corresponding taxa to help dating the Plio-Pleistocene localities in North Africa, particularly those yielding Oldowan occurrences such as Ain Hanech and El-Kherba. Ain Hanech and El-Kherba yielded a number of large mammal taxa of biochronological significance that are well dated in East Africa, including *Equus*, *Anancus*, and particularly *Kolpochoerus*, as well as a less understood "*Dicerorhinus*". Indeed, Ain Hanech and El-Kherba *Kolpochoerus* is the same one that is found in the Koobi Fora KBS Mb, Shungura H, and Olduvai Bed I, which was after about 1.8 Ma a different species.

There are a number of localities with Oldowan artifacts that provide evidence of early human presence in North Africa. The localities are assigned traditionally to Pre-Acheulean (~Oldowan), which is divided into Ancient Pre-Acheulean and Evolved Pre-Acheulean. The entire Pre-Acheulean was correlated to Moulouyen and Saletian climatic cycles correlated to the Lower Pleistocene. This chapter examines the Oldowan record in North Africa in light of the new investigations carried out in the major archaeological areas of Casablanca in Atlantic Morocco and Ain Hanech in northeastern Algerian, and their implications on early hominin behavior and adaptation. In particular, the work at Ain Hanech has succeeded in establishing the timing and understanding of the characteristics of the earliest human occupation of this part of the African continent. Ain Hanech documents clearly Oldowan artifacts (*sensu* Leakey, 1971), indicating that early hominins geographically ranged in wider areas outside East and South Africa.

Stratigraphic Background

The stratigraphic framework of prehistoric North Africa is based upon inferred correlations of sea-level sequences between the Atlantic costal sites and the Mediterranean deposits, especially the area between Rabat and Casablanca (Morocco), which provides continuous deposits rich in faunas and prehistoric lithic industries. Indeed, the Casablanca coastal area offers the most extensive Pleistocene stratigraphic sequence. Quarry exploitation opened for building materials have exposed a series of fluctuating high and low sea levels interbedded with terrestrial sediments reflecting changes in climate. The stratigraphic sequence has been studied by several geologists. Neuville and Rhulman (1941) studied the Sidi Abderrahman Quarry and established the stratigraphic chronology of Atlantic Morocco for dating the prehistoric industries known from the region. Choubert et al. (1956) proposed a general stratigraphic framework for the Moroccan continental Pleistocene deposits; and Biberson (1961a, 1971) redefined its major components. The stratigraphic framework in the Atlantic coast consists of a series of seven marine cycles, interbedded with six terrestrial episodes named after stratigraphic description of type-localities (Figure 1). The marine cycles include, from the oldest to the youngest, Moghrebian, Messaoudian, Maarifian, Anfatian, Harounian, Ouldjian, and Mellahian. The terrestrial cycles are Moulouyan, Saletian, Amirian, Tensiftian, Presoltanian, and Soltanian. The "Pebble-culture" or Pre-Acheulean industries are dated to Moulouyan and Saletian continental episodes (Biberson, 1971: 74). Although this stratigraphic system was defined for Atlantic Morocco, it became increasingly a classic scheme and a wide spread Quaternary relative chronological framework for the entire Maghreb.

A number of researchers questioned the validity and the relevance of this stratigraphic system to the Atlantic Coast. For instance, Beaudet (1969) criticized the validity of the Saletian stratotype. He argued that on one hand the type locality represents an older deposit, and on the other, in some localities two similar lithologies occur making it difficult to determine which of these corresponds to the Saletian. Based on a revised study of the Casablanca sequence, Texier et al. (1986) highlighted the weaknesses of the system, including: ambiguity of the pluvial-arid alternate principle, complexity of correlating the Moroccan climatic episodes with the European glaciations, and not taking into account the local Quaternary uplift and isostatic movements controlling the deposition of the successive episodes. To resolve these weaknesses, they recommended abandoning the entire old scheme and suggested an alternative lithostratigraphy for the Pleistocene sequence, incorporating four main formations (Texier et al., 1994). These formations include, from the oldest to the youngest, Oulad Hamida Formation (thereafter Fm), Anfa Fm, Kef el Haroun Fm, and Dar Bouaza Fm (Lefèvre & Raynal, 2002; Texier et al., 2002). The Lower Paleolithic sites, which consist basically of Acheulean occurrences, spanned from Oulad Hamida Fm to Kef el Haroun Fm (from ca. 1 Ma to 163 Ka [Rhodes et al., 2006]).

In the Sahara, the alternating erosion-sedimentation cycles in the absence of any other chronological and biostratigraphical criteria, such as dateable volcanic material and preserved fauna, served as a guide to build up a stratigraphic framework for the succession of the prehistoric industries of the Saoura in the Northwestern Saharan region (Alimen, 1978; Chavaillon, 1964). Six erosional and depositional cycles have been identified. The "pebble culture" is correlated with the Mazzerian episode (Early Pleistocene), and the Acheulean with the Taouritian and Ougartian episodes (Middle Pleistocene).

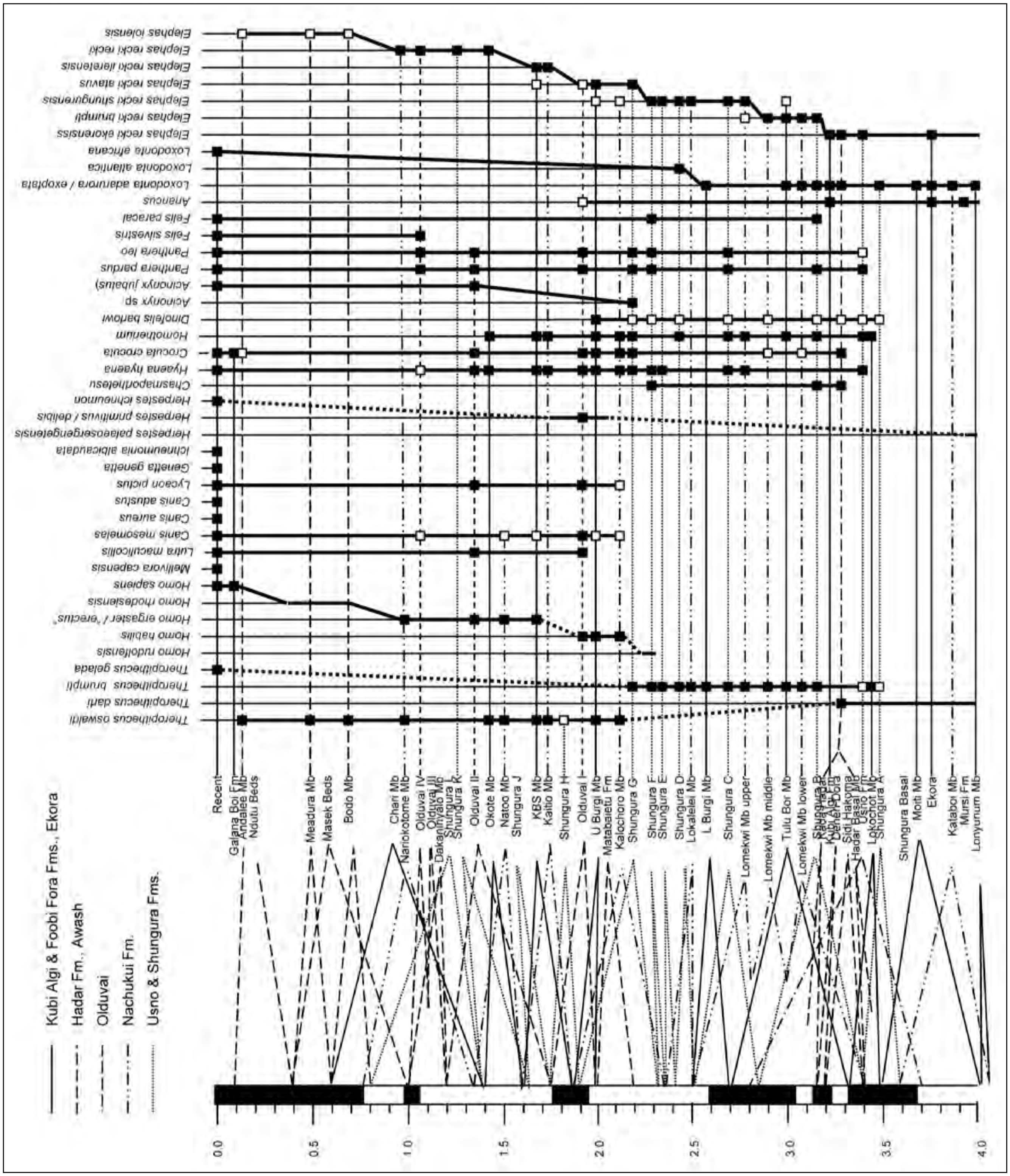
CYCLES MARINS		CYCLES CLIMATIQUES		INDUSTRIES PRÉHISTORIQUES				HOMMES FOSSILES DU MAROC
Europe	Maroc Atlantique		Europe	Civilisations	Familles	Stades	Gisements-types	
Versilien	Mellahien				Ibéromaurusien		Grotte de Taforalt	H. de Taforalt
		Soltanien	Würm final		Atérien		Dar-es-Soltan	H. de Tanger (?)
Néotyrrhénien	Ouljien				Moustérien		Jebel Irhoud	H. du Jebel Irhoud
		Présoltanien	Würm inférieur		Acheuléen évolué	St. VIII	Cap Chatelier (niv. D_2)	H. de Témara
Tyrrhénien	Harounien					St. VII	Sidi Abderrahman-Extension (niv. E)	H. de Rabat
		Tensiftien	Riss				Grotte des Littorines	H. de Sidi Abderrahman
						St. VI	(niv. D_0)	
Paléotyrrhénien = Milazzien II	Anfatien			Civilisation du Biface	Acheuléen moyen	St. V	Grotte des Ours (niv. G_0)	
						St. IV	Sidi Abderrahman-Extension (niv. F)	
		Amirien	Mindel			St. III	Carrière de la STIC	
					Acheuléen ancien	St. II	Sidi Abderrahman-Anc. Exploit. (niv. M)	
						St. I	Sidi Abderrahman-Anc. Exploit. (niv. M)	
Milazzien I = Sicilien II	Maarifien				*Pebble-Culture évoluée*	St. IV	Sidi Abderrahman-Extension (niv. G)	
Sicilien I		Salétien	Günz	Civilisation du Galet aménagé		St. III	Souk-el-Arba du Rharb	
Emilien	Messaoudien					St. II	Carrière Déprez (Casa)	
Calabrien		Moulouyen	Donau		*Pebble-Culture ancienne*			
						St. I	Tardiguet-er-Rahla	
Précalabrien	Moghrébien	Villafranchien inférieur	Biber (?)					

Figure 1. Quaternary continental and marine cycles and associated lithic industries and hominins of Morocco after Biberson 1964.

Biochronology of the North African Plio-Pleistocene Localities

The North African Lower and Middle Pleistocene deposits suffer from the absence of a precise chronological framework due to lack of dateable tuffs. Uranium-series, optically stimulated luminescence (OSL), and electron spin resonance (ESR) dates are most applicable only for late Middle and Upper Pleistocene sites. As a result, the dating of the North African Pleistocene deposits relies primarily on biostratigraphic correlation. In contrast, the East African fossil record comes from a lithostratigraphic context well dated radiometrically and by palaeomagnetism, providing an excellent biochronological framework for comparison with other African regions devoid of sound dating context. Therefore, the Plio-Pleistocene faunas from North Africa and East Africa are compared here.

Figures 2a and 2b display the stratigraphic ranges in East Africa of those large mammals, which also occur in North Africa or their close relatives. On the left, the stratigraphic units of main East African sequences and their assumed ages are shown. On the right, the presence of the large mammals in these stratigraphic units is indicated by solid squares, open squares in the case of uncertainty (cf., aff., indet., sp., ?), and their inferred time ranges by thick lines. The occurrences are taken from the literature. Occasionally, there are contradictions in the published literature, or one author cites certain taxa in a unit, but these are not mentioned at all by another author. In such cases, generally we follow the latest or more specialized literature. In other cases, there is controversy whether a series of species or subspecies represent anagenetic stages of a lineage (and thus are never coeval) or whether they are taxa with overlapping ranges (e.g. in *Elephas* and some Suidae). Figures 3a and 3b show the stratigraphic distribution of the North African large mammals (squares) compared to temporal ranges of the same or similar taxa from East Africa (thick lines). Presence of *Homo*, if inferred from lithic industry and


Elephas iolensis
Elephas recki recki
Elephas recki ileretensis
Elephas recki atavus
Elephas recki shungurensis
Elephas recki brumpti
Elephas recki ekorensis
Loxodonta africana
Loxodonta atlantica
Loxodonta adaurora / exoptata
Anancus
Felis caracal
Felis silvestris
Panthera leo
Panthera pardus
Acinonyx jubatus
Acinonyx sp
Dinofelis barlowi
Homotherium
Crocuta crocuta
Hyaena hyaena
Chasmaporthetes
Herpestes ichneumon
Herpestes primitivus / delibis
Herpestes palaeoserengetensis
Ichneumia albicauda
Genetta genetta
Lycaon pictus
Canis adustus
Canis aureus
Canis mesomelas
Lutra maculicollis
Mellivora capensis
Homo sapiens
Homo rhodesiensis
Homo ergaster / "erectus"
Homo habilis
Homo rudolfensis
Theropithecus gelada
Theropithecus brumpti
Theropithecus darti
Theropithecus oswaldi
Recent
Galana Boi Fm
Andalee Mb
Ndutu Beds
Meadura Mb
Masek Beds
Bodo Mb
Chari Mb
Nariokotome Mb
Olduvai IV
Shungura L
Shungura K
Olduvai II
Okote Mb
Natoo Mb
Shungura J
KBS Mb
Kaitio Mb
Shungura H
Olduvai I
U Burgi Mb
Matabaietu Fm
Kalochoro Mb
Shungura G
Shungura F
Shungura E
Shungura D
Lokalalei Mb
L Burgi Mb
Shungura C
Lomekwi Mb upper
Lomekwi Mb middle
Tulu Bor Mb
Lomekwi Mb lower
Shungura B
Sidi Hakoma
Hadar Basal Mb
Usno Fm
Lokochot Mb
Shungura A
Shungura Basal
Moiti Mb
Ekora
Kataboi Mb
Mursi Fm
Lonyumun Mb
Kubi Algi & Koobi Fora Fms., Ekora
Hadar Fm., Awash
Olduvai
Nachukui Fm.
Usno & Shungura Fms.
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

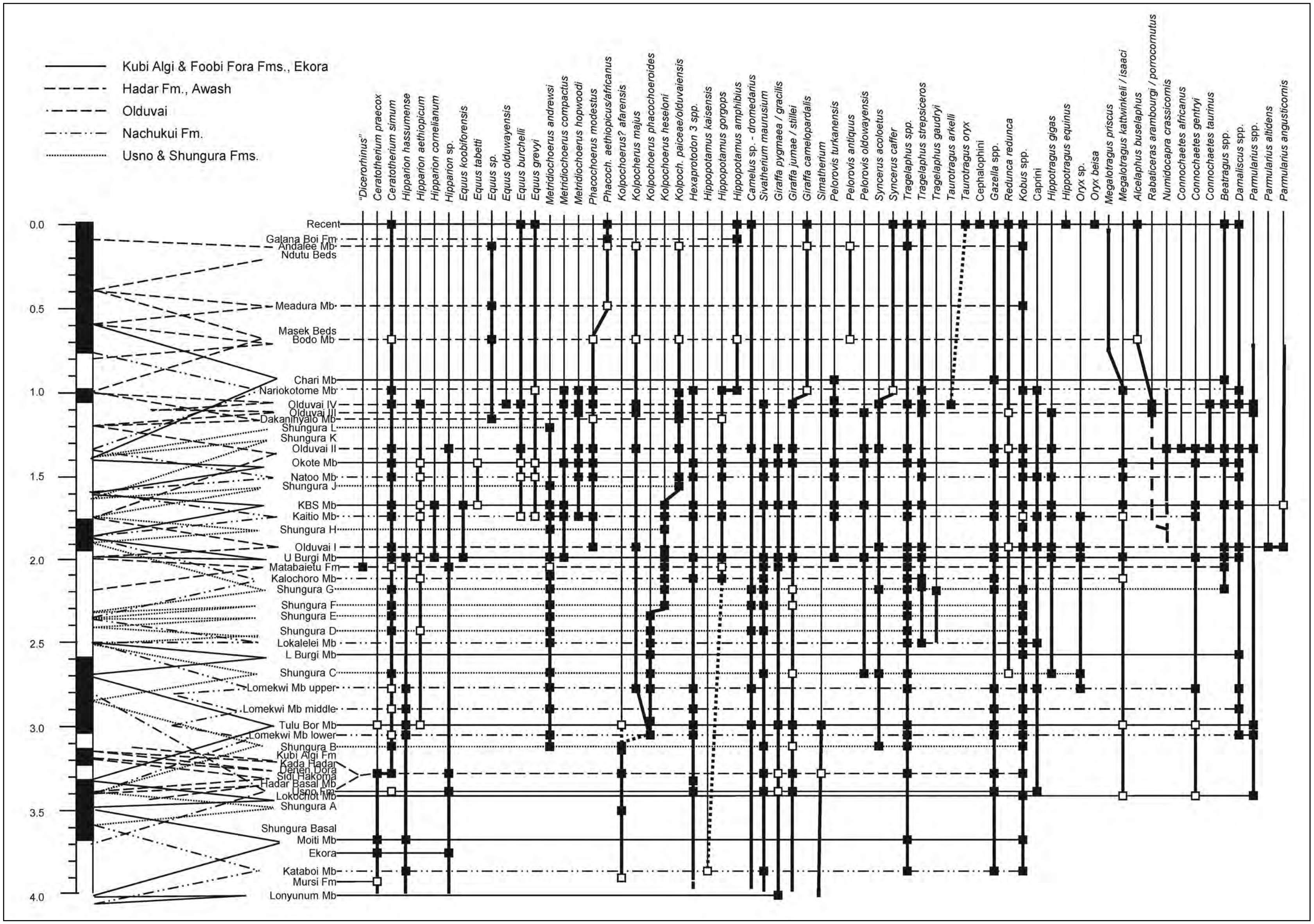


Figure 2a & 2b. The temporal distribution in the main East African sequences of the large mammals that occurred in North Africa based on Cooke (1985), Feibel, Harris & Brown (1991), Kalb et al. (1982), Rook (1994), Sahnouni et al. (2004), Turner et al. (1999), Vrba (1996; 1997). Solid squares indicate presence; open squares indicate possible (?) or imprecise (cf., aff.) presence. Thick lines indicate temporal ranges as inferred from presence and absence data in the figure and, occasionally, other information (e.g. Vrba 1996; 1997) and ancestor descendant relationships. Stippled thick lines indicate uncertainty.

cut marks, is indicated by open squares. The North African sites are arranged in such a way that a minimum of their taxa are situated outside the temporal ranges as established for East Africa.

Prior to correlating East African and North African faunas, it is constructive to stress some methodological considerations. A first comparison between figures 2 and 3 reveals that some taxa have very different ranges in North and East Africa. For instance, *Loxodonta* disappeared at the end of the Pliocene from the East African sequences (Figure 2b), but is again present in the recent faunas. The genus occurs in several Pleistocene sites in North and South Africa, from where it presumably recolonized East Africa. Similar patterns are observed in *Connochaetes* and *Oryx*. Obviously, the first and last appearances of these taxa cannot be used to correlate between East Africa and North Africa. This may also occur on a smaller temporal scale with other taxa. There is no way to know *a-priori* in which taxa this occurs, and the common way to detect this is when a correlation based on a particular taxon is in conflict with another means of correlation.

It is commonly read that two sites have to be of the same age because they share a particular species. However, there are also authors who claim that a mammal species may last 2.5 Ma (e.g. Van Dam et al., 2006). Obviously, the more we know about the evolutionary and biogeographical context of a taxon, the more precise the correlations that are based on that species. First appearance by dispersal and last appearance by (local) extinction of common taxa may provide very sharp datum planes. However, one needs to know the area in which these datum planes are applicable. For this method, rare taxa tend to be of little use (unless many of them disperse or go extinct at the same time, which to some extent tend to confirm the pattern). By contrast, even in a rare taxon, anagenetic evolution may provide important information, but the transition between one and another stage tends to be gradual. There is again the risk that diachronic evolution may occur, which should be detected by contradictory evidence. Some authors use the "grade of evolution" and compare samples of species that belong to different but related lineages. This is a questionable procedure, because it supposes that evolution proceeds in different lineages at a similar rate. However, in a well understood phylogenetic context, it can be stated that two samples from divergent lineages are younger than the last sample of a common ancestral form. Below are discussed, in chronological order, the Plio-Pleistocene localities with taxa of biostratigraphic interest:

Ahl al Oughlam, Lac Ichkeul, and Ain Brimba

Ahl al Oughlam (formerly Carrière Déprez) in Morocco, and Lac Ichkeul (near Bizerte) and Ain Brimba (near Chott Djerid) in Tunisia are landmark sites of the North African Upper Pliocene. The rich locality of Ahl al Ouglam has *Hipparion*, but no *Equus*. It does have a *Canis*, which appeared in Africa at the same time or slightly earlier than *Equus*. The alcelaphine bovid *Beatragus* from Ahl al Oughlam was interpreted as a little bit more primitive than the *Beatragus* from East Africa (Geraads & Amani, 1998), which ranges there from the Matebaietu Fm at 2.6 Ma till recent (Vrba, 1997). The absence of *Oreonagor* in Ahl al Oughlam is not indicative of an age, since the related taxa *Connochaetes* and *Megalotragus* as well as the ancestral "*Damalops denenedorai*" (see Vrba, 1997) are also absent. The suid *Kolpochoerus phacochoeroides* is well represented in Ahl al Oughlam (Geraads, 1993; 2004b) and has an evolutionary level that is comparable to that of *Kolpochoerus* from the Shungura Members (thereafter Mbs) C-F with ages comprised between roughly 2.8 and 2.3 Ma.

Early reports on the faunas from Lac Ichkeul and Ain Brimba were published by Arambourg and Arnould (1949), and Arambourg and Coke (1958), respectively. Arambourg (1970, 1979) described more in detail the material of both sites and concluded to an Early Villafranchian age. Like Ahl al Oughlam, these localities have *Hipparion*, but no *Equus*. The absence of *Equus* might indicate that they are older than the first appearance of that genus in Africa. *Machairodus* is close to but more primitive than *Homotherium*, which is present from about 3.5 Ma onwards. *Machairodus africanus* is thus a primitive element in the fauna from Ain Brimba. These faunas may be close in age to Ahl al Oughlam.

Ain Boucherit and Ain Jourdel

Ain Boucherit and Ain Jourdel are paleontological sites in northeastern Algeria. Pomel (1893-1897) described the first fossil remains collected at Ain Boucherit in the course of road works. Arambourg (1970, 1979) explored further the site and studied its fauna. Based on proboscideans and equids, he assigned the occurrences to the Lower Villafranchian, and correlated it with Shungura Mbs A, B, C, and D, and Kaiso deposits, implying an age between 3.7 and 2.5 Ma (p. 135). Other authors estimated Ain Boucherit age to 3.4-2.7 Ma (Coppens, 1972, Pl. 2), 2.7-2.5 Ma (Vrba, 1996, 1997), about 2.3 Ma (Sahnouni et al., 2002), and about 1.8 Ma (Geraads et al., 2004b).

Sahnouni et al. (2002) collected more fossils from the Ain Boucherit fossil-bearing stratum and studied its stratigraphy. The stratum is contained in Unit Q of the newly defined Ain Hanech Fm by Sahnouni and de Heinzelin (1998), 13 m below the Ain Hanech and El-Kherba Oldowan deposits (Unit T). The magnetostratigraphic study of the Ain Hanech Fm indicates a shift from reversed polarity in Unit P, Q and R to normal polarity in Unit S and T containing the Ain Hanech Oldowan deposit. Given the character of the fauna, the normal polarity most likely corresponds to the Olduvai (N) subchron dated between 1.95 and 1.77 Ma. The Ain Boucherit faunal assemblage comes from Unit Q, which being located lower in the formation and having a reversed polarity, is thus older than the Oldowan subchron.

The Ain Boucherit and Ain Jourdel taxa biochronologically relevant comprise *Hipparion, Anancus, Equus, Canis,* alcelaphines, and *Elephas*. The presence of the equid *Hipparion* and the proboscidean *Anancus* is confirmed by the recent collections. While *Hipparion* is less informative, *Anancus* indicates an approximate minimum age of about 2-1.8 Ma (as discussed under Ain Hanech below).

The horse *Equus* and *Canis* originated in North America and spread to the Old World. *Equus* arrived in Europe just before the end of the Gauss chron (2.581 Ma) (Alberdi et al., 1997; Lourens et al., 2004) and *Canis* around 2 Ma (Torre et al., 1992). The oldest well dated record of *Equus* in Africa is in Shungura Member (thereafter Mb) G (Churcher & Hooijer, 1980) around 2.3 Ma. However, there are old sites that are not well dated, and which might push down the first appearance in Africa to the European age. The first African record of *Canis* seems to be older than in Europe and might be in Ahl al Oughlam (Geraads, 1997) or some of the South African sites. The suggested age for Ain Boucherit by Sahnouni et al. (2002) is inspired by the fact that the fossil bearing stratum is located below the Olduvai subchron and the first known African record of *Equus*.

The alcelaphines include *Oreonagor tournoueri* and *Parmularius altidens*. While Geraads et al. (2004b) claimed that *Oreonagor* from Ain Boucherit is more advanced than that of Ain Jourdel, Vrba (1997), who carried out a detailed study of the phylogeny of the Alcelaphini, apparently believed this to be just the other way around estimating an age of 2.7-2.5 Ma for Ain Boucherit and 1.8 Ma for Ain Jourdel. In her cladogram and resulting tree, *Oreonagor tournoueri* originates after/from "*Damalops denendorai*" and before *Connochaetes gentryi*. The former species has its last occurrence in the Kada Hadar Mb and Shungura Mb B around 2.9 Ma. The latter species has its first appearance in the Upper Lomekwi Mb of the Nachukui Fm around 2.5 Ma. This probably induced Vrba (1996, 1997) to estimate Ain Boucherit age to between 2.7-2.5 Ma.

The presence of the alcelaphine bovid *Parmularius altidens* in Ain Boucherit and Olduvai Bed I suggested to Geraads et al. (2004b) that both localities would be contemporaneous, e.g. 1.8 Ma. However, the occurrence of one species in two sites does not necessarily indicate that these sites have exactly the same age. In Vrba's (1997) tree, *Parmularius altidens* is a descendant of *P. braini*, and *P. altidens* is an ancestor of *P. angusticornis* and *P. rugosus*. The last presence of *P. braini* is in Makapansgat Mb 3 with an estimated age of 2.8-2.6 Ma. The first occurrence of *P. angusticornis* is in Olduvai Bed I at about 1.8-1.75 Ma and that of *P. rugosus* at Olduvai Bed II, at 1.75-1.66 Ma. If the model is correct, the total range of *P. altidens* must be thus between some 2.8-2.6 and some 1.75 Ma, which indeed is more or less the case (from Shungura Mb C at 2.6 Ma till the Okote Mb at 1.6-1.39 Ma). As for *P. altidens* in Ain Boucherit, Vrba (1996, 1997) estimated its age to 2.7-2.5 Ma, which is not in contradiction with the other data on the Alcelaphini.

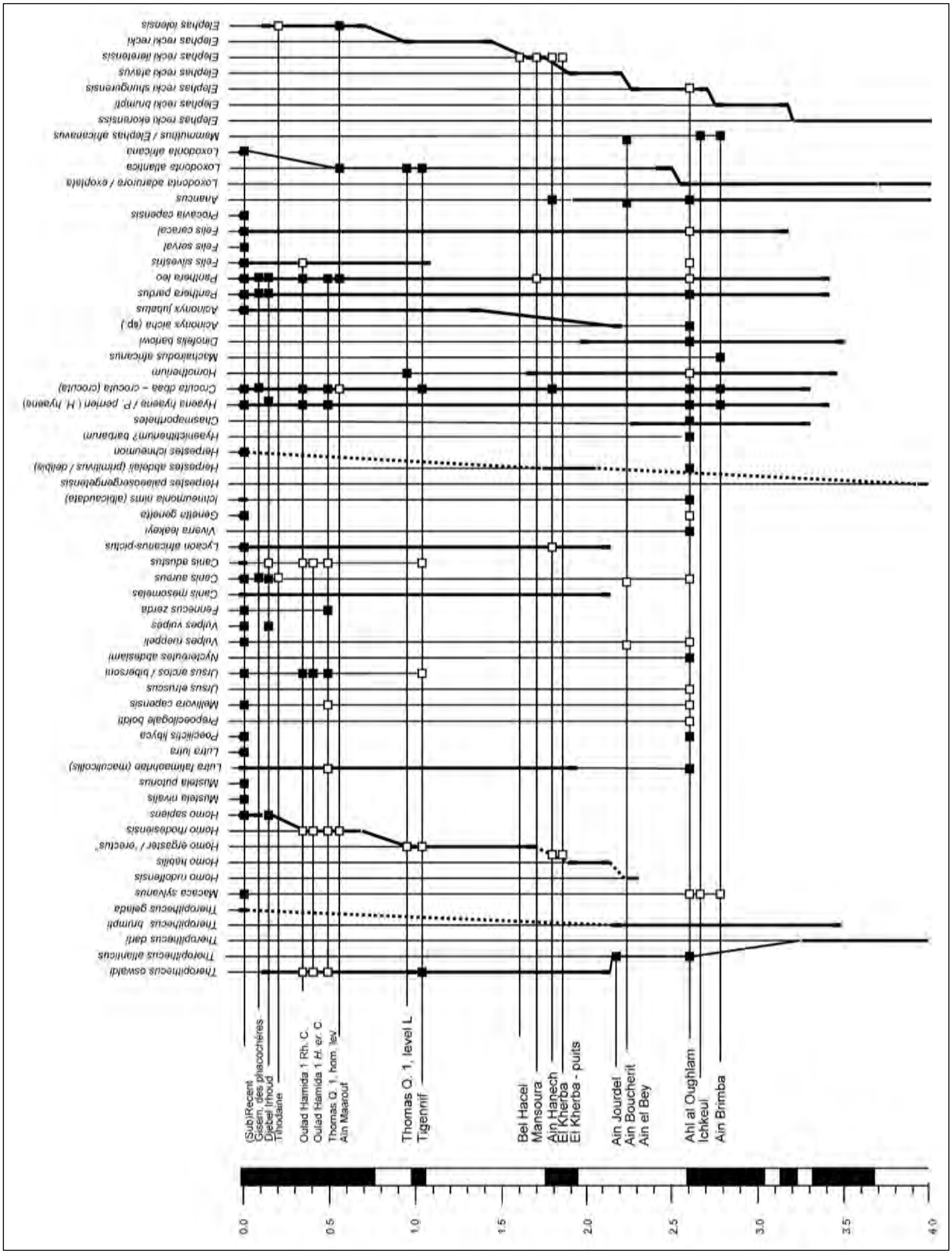
Arambourg assigned some specimens from Ain Boucherit to *Elephas africanavus* and considered this species anterior to *Elephas moghrebiensis*, which he defined on material from Ain Hanech. It has been suggested, however, that it belongs to the genus *Mammuthus* and that it gave rise to the Eurasian *Mammuthus meridionalis* (e.g. Coppens et al., 1978). Geraads & Metz-Muller (1999) seem to be more inclined to maintain the species in *Elephas*, but are of the opinion that the material from Ain Boucherit is too poor for a reliable determination.

Biochronology points to an age between 1.8-2 Ma and 2.3-2.6 Ma for Ain Boucherit. Its position in sediments with reversed polarity below Ain Hanech in sediments with normal polarity correlated to the Olduvai subchron, narrows this down to between 1.95 and 2.58 Ma. Ain Jourdel does not have a particularly rich fauna (Figures 3a & 3b), but, like Ain Boucherit, it has *Hipparion* and *Equus* and thus is younger than the appearance of the latter genus in Africa. Besides, it has several bovids that are present also in that locality. An age close to that of Ain Boucherit seems likely.

Ain Hanech, El Kherba, and El Kherba-Puits

The sites of Ain Hanech and El-Kherba are key Plio-Pleistocene fossil localities in north-eastern Algeria (see further information provided in the Oldowan section below). Arambourg (1957) analyzed the fauna he excavated from Ain Hanech. Renewed investigations at Ain Hanech by Sahnouni et al (1996, 2002) yielded more faunal material and led to the discovery of the rich locality of El-Kherba. El-Kherba-Puits is a locus within a short distance (110 m) south of El-Kherba. The faunal list is provided in figures 3a and 3b.

Arambourg (1957, 1970, 1979) believed that Ain Hanech; Olduvai Bed I; and the Shungura Mbs H, I and J follow an important faunal break between 2.5 and 1.8 Ma marking the onset of the Upper Villafranchian (Arambourg, 1969). Other sites, that were believed to be of similar age, are Laetolil (Tanzania), Makapansgat, Taung and Sterkfontein (South Africa). Coppens (1972) placed Ain Hanech in his biozone VI dated between 2.7 and 1.4 Ma, and Vrba (1996, 1997) estimated its age to 1.8 Ma. Sahnouni et al. (2002) showed that Ain Hanech is dated between 1.95 and 1.77 Ma based on paleomagnetic and biochronological evidence. Geraads et al. (2004b) cast doubt on the suggested age by Sahnouni et al. (2002), arguing that it might be only 1.2 Ma. Sahnouni et al. (2004) reiterated the age of 1.8 Ma for Ain Hanech, but again Chaid-Saoudi et al. (2006) consider that it is close chronologically to Ubeidiya, which is widely assumed to date to ca 1.4 Ma. Thus, there are two hypotheses on the age of Ain Hanech: 1.4-1.2 Ma and 1.9-1.8 Ma. Below we go over the discussion of Ain Hanech and El-Kherba age and add new biostratigraphic elements.


Elephas iolensis
Elephas recki recki
Elephas recki ileretensis
Elephas recki atavus
Elephas recki shungurensis
Elephas recki brumpti
Elephas recki ekorensis
Mammuthus / Elephas africanavus
Loxodonta africana
Loxodonta atlantica
Loxodonta adaurora / exoptata
Anancus
Procavia capensis
Felis caracal
Felis serval
Felis silvestris
Panthera leo
Panthera pardus
Acinonyx jubatus
Acinonyx aicha (sp.)
Dinofelis barlowi
Machairodus africanus
Homotherium
Crocuta dbaa – crocuta (crocuta)
Hyaena hyaena / P. perrieri (H. hyaena)
Chasmaporthetes
Hyaenictitherium? barbarum
Herpestes ichneumon
Herpestes abdelali (primitivus / delibis)
Herpestes palaeoserengetensis
Ichneumonia nims (albicaudata)
Genetta genetta
Viverra leakeyi
Lycaon africanus-pictus
Canis adustus
Canis aureus
Canis mesomelas
Fennecus zerda
Vulpes vulpes
Vulpes rueppeli
Nyctereutes abdesalami
Ursus arctos / bibersoni
Ursus etruscus
Mellivora capensis
Prepoecilogale bolti
Poecilictis libyca
Lutra lutra
Lutra libyca (maculicollis)
Mustela putorius
Mustela nivalis
Homo sapiens
Homo rhodesiensis
Homo ergaster / 'erectus'
Homo habilis
Homo rudolfensis
Macaca sylvanus
Theropithecus gelada
Theropithecus brumpti
Theropithecus darti
Theropithecus atlanticus
Theropithecus oswaldi
(Sub)Recent
Gisem. des phacochères
Djebel Irhoud
Tihodaine
Oulad Hamida 1 Rh. C.
Oulad Hamida 1 H. er. C
Thomas Q. 1, hom. lev
Ain Maarouf
Thomas Q. 1, level L
Tigennif
Bel Hacel
Mansoura
Ain Hanech
El Kherba
El Kherba - puits
Ain Jourdel
Ain Boucherit
Ain el Bey
Ahl al Oughlam
Ichkeul
Ain Brimba
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

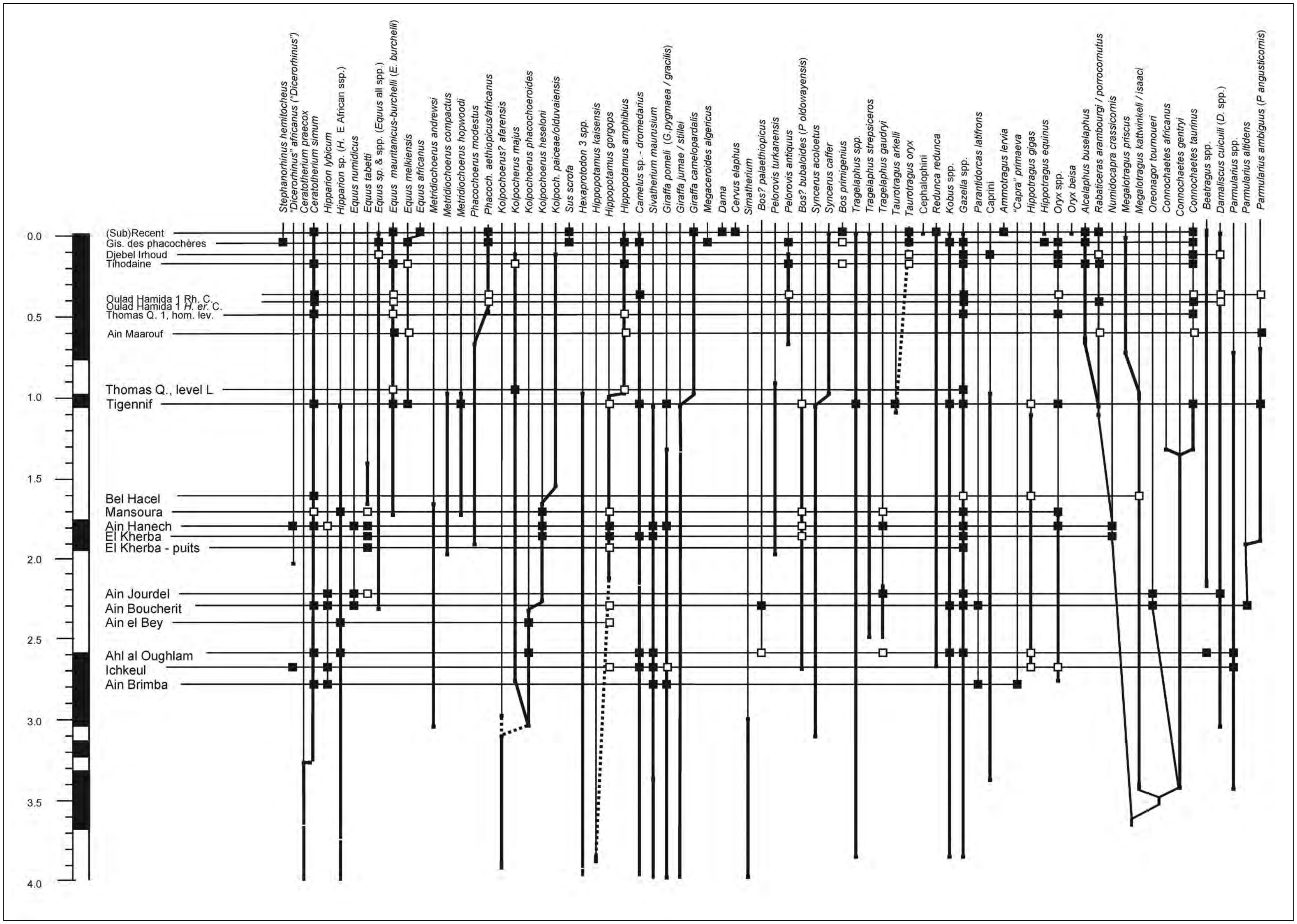


Figure 3a & 3b. The temporal distribution of the large North African mammals compared to that of the same or similar species in the main East African sequences based on data from Amani & Geraads (1998), Arambourg (1979), Chaid-Saoudi et al. (2006), Eisenmann (2006), Geraads (1981, 2002), Geraads et al. (1998), Hadjouis (1985), Kowalski & Rzebek-Kowalska (1991), Sahnouni et al. (2004), Thomas (1977), Vrba (1996, 1997), and personal observations and interpretations of the literature. Solid squares indicate presence; open squares indicate possible (?) or imprecise (cf., aff.) presence. Thick lines indicate temporal ranges in East Africa (from Figures 2a & 2b) of the same species or of closely related or similar species (indicated between brackets). Lines of intermediate thickness are based on the North African material.

Arambourg (1957) included the mastodon *Anancus* in the Ain Hanech faunal list. Yet, later (1970, 1979) he considered it dubious listing it as a surface find, due likely to the chronological implications of its presence in this site. Geraads et al. (2004b) used its presumed absence as an argument for a young age of Ain Hanech. Nonetheless, the recent excavations confirmed the presence of *Anancus* at Ain Hanech with an *in situ* tooth. The proboscidean *Anancus* was wide spread in the Old World, going extinct in Europe around 1.8-2 Ma with a last occurrence at Le Coupet (France) (Arambourg, 1969; Geraads & Metz-Muller, 1999). Its last record in East Africa seems to be at Olduvai Bed I (Coppens et al., 1978) or even in Bed II (Arambourg, 1979). However, the occurrences at Olduvai are not mentioned by Turner et al. (1999) and otherwise the latest East African records are from the Nachukui Apak Mb (Tassy, 2003), Kanapoi, Ekora, Laetolil, the Mursi Fm, and Kubi Algi Fm (Coppens et al., 1978). It is also present at Makapansgat (Cooke, 1993), and from the Vaal river gravels at Waldecks Plant near Barley West (Windsorton, South Africa) from a terrace that is younger than a terrace with *Equus* (Fraas, 1907). There are several North African Late Pliocene sites such as Lac Ichkeul, Fouarat, Ahl al Oughlam and Ain Boucherit (Arambourg, 1970, 1979; Geraads & Metz-Muller, 1999), suggesting that *Anancus* did not survive longer in Africa than in Europe.

Arambourg (1970) defined the species *Elephas moghrebiensis* on material from Ain Hanech. Coppens et al. (1979) included the species in *Mammuthus meridionalis*. Yet Geraads and Metz-Muller (1999) considered it a North African form of *Elephas recki* that corresponds to the East African *E. recki ileretensis*, and Geraads et al. (2004b) used its temporal range for discussing North African biostratigraphy. Whether the different subspecies of *Elephas* are really distinct in morphology and whether or not these have different time ranges and really form an anagenetic lineage (e.g. Maglio, 1972; Cooke, 1993) is a matter of debate (e.g. Todd, 2001). However, according to Feibel et al., (1991), *E. r. ileretensis* occurs in the KBS Mb of the Koobi Fora Fm and in the Kaitio Mb of the Nachukui Fm, both of which are of earliest Pleistocene age.

Arambourg (1957) included the three toed horse *"Stylohipparion" libycum* without reservation in the Ain Hanech faunal list. Yet, in a later publication, he listed this taxon as very rare, arguing that the teeth (an upper and a lower M2) might have been reworked from the underlying deposit (Arambourg, 1970: 85). He probably believed that *Hipparion* is too old for Ain Hanech. Geraads et al (2004b: 753) used the alleged absence of *Hipparion* from Ain Hanech as an evidence for a younger age. Nonetheless, the upper cheek tooth is especially very indicative of the presence of *Hipparion*, and in view of the flat lying sediments, reworking from a considerably older deposit seems unlikely. In Europe, *Equus* replaced *Hipparion* around 2.6 Ma, but in East Asia and Africa both genera overlapped for a considerable time. While the first appearance of *Equus* in Africa is in Shungura Mb G (ca. 2.3 Ma) (Churcher & Hooijer, 1980), *Hipparion* is still present in the Kaitio, Okote and Natoo Mbs and in Olduvai Beds I to IV (Arambourg, 1979; Feibel, et al., 1991) for more than 1 Ma after the appearance of *Equus*. In addition, in South Africa *Hipparion* survived well into the Pleistocene. Therefore, the presence or absence of the genus *Hipparion* at Ain Hanech is irrelevant for discussing the age of the site.

Ain Hanech is the type locality of *Equus tabeti*. *Equus* cf. *tabeti* was found in the KBS and Okote Mbs (Eisenmann, 1983), with ages ranging from 1.4 to over 1.8 Ma. Feibel et al (1991) cited *E.* cf. *tabeti* in the same members, while Geraads et al., (2004b) mentioned *Equus numidicus* and/or *E. tabeti* from Shungura Mbs G and H lower (2.12-2.04 to 1.88±0.02 Ma [Howell et al, 1987: 667]). In any case, forms similar to *E. tabeti* appeared in East Africa roughly between 2.3-1.9, and 1.4 Ma.

There is also a larger *Equus* species at Ain Hanech attributed by Sahnouni et al. (2002, 2004) to *E. numidicus* based on its morphological and metrical resemblances with the specimens from the older deposit of Ain Boucherit. In contrast, Geraads et al. (2004b) viewed it as a "zebra-like" form and assigned it to *Equus* cf. *mauritanicus*. *Equus mauritanicus* is present in Tighenif (formerly Ternifine) and the North African Middle Pleistocene, and its alleged presence at Ain Hanech was used by Geraads et al. (2004) to date this site to the early Middle Pleistocene. *E. mauritanicus* from Tighenif is believed to be close (Eisenmann, 2006) or identical to the plains zebra *Equus burchelli* (Churcher & Richardson, 1978). *Equus* cf. *burchelli* is present in the Kaitio, Natoo, and Okote Mbs respectively of the Nachukui Fm and Koobi Fora Fm (Feibel et al., 1991; Eisenmann, 1983), with ages spanning from 1.8 to 1.4 Ma. Though Eisenmann (2006) discussed the first appearances of the different types of equids, she did not mention the older presence of a plains zebra. Whatever the affinities of the larger equid from Ain Hanech, an age close to the Plio-Pleistocene transition cannot be excluded.

Arambourg (1970) named the rhinoceros *Dicerorhinus africanus* on the basis of an M^3 and a mandible with $M_{2\text{-}3}$ from Lac Ichkeul in Tunisia. This was at a time when European species, attributed now to *Stephanorhinus*, were assigned to *Dicerorhinus*. The material from Lac Ichkeul was said to be more brachyodont than *Stephanorhinus etruscus*, but evidently it is poor for assessing its affinities. A fragment of a very low crowned lower molar from Ain Hanech suggests the presence of a similar rhino. Kalb et al. (1982) reported a "*Dicerorhinus*" from the Matabaietu Fm. The records of a rhino with resemblances to "*Dicerorhinus*" suggest a Late Pliocene age for Ain Hanech.

The pigs or Suidae are considered to be of great biostratigraphic interest and have been intensively studied in East Africa (Maglio, 1972; Cooke, 1976, 1978a-c, 1979, 1985, 1997, 2007; White & Harris, 1977; Harris & White, 1979; and Harris, 1983). Despite nomenclatorial changes, the evolution of *Kolpochoerus* in East Africa seems to be essentially clear. There are, however, different opinions on whether the same species are found in North Africa (Sahnouni et al., 2002, 2004), or whether there are endemic species (Geraads, 1993, 2004b). Even though Geraads et al. (2004b) recognised different species in North Africa and believed that the evolution of *Kolpochoerus* in this region of Africa is imperfectly understood, Geraads (1993) and Chaid-Saoudi et al. (2006) used the enlargement trend in the East African third molar to estimate the ages of North African sites. In spite that the M_3 of *Kolpochoerus* from Mansourah is of simple morphology, Chaid-Saoudi et al. (2006) claim that it is geologically young, and compared it with those from Konso (southern Ethiopia) to argue that the North African *Kolpochoerus* represents a different lineage. Suwa et al. (2003) considered the Konso *Kolpochoerus* as endemic, because they believed it is morphologically primitive or simple compared to specimens from Shungura and Koobi Fora Fms. However, the variations in the presence or absence of a terminal cusp in the last lobe of the M_3, or the variation in its size, if such a cusp is present, are similar to those observed in the sample of recent *Sus scrofa vittatus*, that was studied by Van der Made (1991) for sexual bimodality, or in the Spanish *Microstonyx* (Van der Made et al., 1992). We believe that endemism in North African *Kolpochoerus* is not demonstrated, and that, if variation, that is to be expected in a representative sample, is taken into account, the specimens from North Africa and Konso fit well in the East African evolutionary trends (Figure 4). Thus the most parsimonious model is that the same species were present in both East Africa and North Africa.

Kolpochoerus is represented in Ain Hanech and El Kherba by teeth with low crowns, and short M_3 and M^3 that do not have many distal lobes. These specimens were assigned to the species *K. heseloni*, and suggest that these localities are comparable in age to Olduvai Bed I and Shungura Mb H and are older than Olduvai Bed II and Shungura Mb J (Sahnouni et al., 2002, 2004; Van der Made, 2005). The transitions of Olduvai Bed I to II and Shungura H to J are around 1.7 Ma.

The antelopes *Parantidorcas* and *Oreonagor* are present at Ain Boucherit, but their absence at Ain Hanech was given much importance as an argument for a much younger age for the latter site (Geraads et al., 2004b). However, these species are very rare and are nearly only known from the former site (Vrba, 1996, 1997). In our opinion, presence/absence of extremely rare species should not be used in stratigraphy.

The giraffe *Sivatherium* was discussed by Geraads et al. (2004b) in Ain Hanech biochronology. Nevertheless, it is really irrelevant here since it appeared well before the end of the Pliocene and lived on till after 1 Ma ago.

Arambourg (1979) named the species "*Oryx el eulmensis*" based on material from Ain Hanech. This should be emended as *Oryx eleulmensis* (ICZN, 1999, article 11.9.5). In contrast, Geraads et al (2004b) regarded it as the living species *Oryx gazella*, which differs from older forms in the degree of compression of the horn cores. In this character, the Ain Hanech specimen plots between, on the one hand, material from the KBS and Upper Burgi Mbs, and, on the other hand, Tighenif and the living species; so that it could cluster either way. The variation of all the material from the Koobi Fora Fm, Ain Hanech, and Tighenif fits in the variation range of a single bovid species from one locality (Sahnouni et al., 2004: 765), precluding biostratigraphic use.

Arambourg (1979) described some Ain Hanech material as *Crocuta crocuta*. Some authors assigned African fossils of well over 2.5 Ma and up to nearly 4 Ma to *Crocuta crocuta* (Turner & Antón, 1998; Turner et al., 1999; Feibel et al., 1991), while others recognize various Late Pliocene species (e.g. Geraads, 1997). A principal component analysis by Geraads et al. (2004b) shows that there is a wide range of variation in the larger Middle-Late Pleistocene and recent samples of *Crocuta*, while the much smaller Early Pleistocene and Pliocene samples have a lesser range of variation. This suggests that these forms are not well enough known in this respect to draw far reaching conclusions.

Arambourg (1979) named the species *Bos bubaloides* and *Bos praeafricanus* from Ain Hanech. Geraads and Amani (1998) assigned material from Ahl al Oughlam to *Pelorovis? praeafricanus*, transferring thus the species tentatively to the genus *Pelorovis*. Hadjouis and Sahnouni (2006) named *Pelorovis howelli* from El Kherba based on a skull with complete horn cores. Geraads et al. (2004b) assigned a skull from the earliest Middle Pleistocene of Asbole (Ethiopia) to *Bos* after comparing it with *Bos* and *Pelorovis*. Martínez-Navarro et al. (2007) proposed that *Bos* (as in Asbole and Europe) evolved from *Pelorovis* and suggested that *P. howelli* and *B. bubaloides* are close to or identical to *Pelorovis oldowayensis*. This latter observation finds some support in the metacarpal, which was chosen by Arambourg (1979) as the syntype of *B. bubaloides*. This metacarpal has a robusticity similar to that of *P. oldowayensis* from Olduvai (Figure 5). It is also larger, but not too large to preclude a synonymy. The latter species has a temporal distribution from about 2.5 to 1.3 Ma (Vrba, 1996), while the earliest record of what certainly is *Bos* is dated close to 1 Ma (e.g. Trinil, Java; Van den Bergh et al., 2001).

Arambourg (1949) described the genus and species *Numidocapra crassicornis* from Ain Hanech. Vrba (1997) considered that this species is an alcelaphine, which is also present in Olduvai Bed II, Anabo Koma and Bouri, and proposed an evolution from *Numidocapra* to *Rabaticeras* and *Alcelaphus*. Though *N. crassicornis* persisted alongside *Rabaticeras*, this scenario implies that *Numidocapra* appeared before the first *Rabaticeras* (dated roughly to 1.8 Ma at Swartkrans).

In summary, of the taxa discussed above, *Anancus*, the *Dicerorhinus*-like rhino, and *Kolpochoerus* are the most relevant biostratigraphically. They falsify the 1.2-

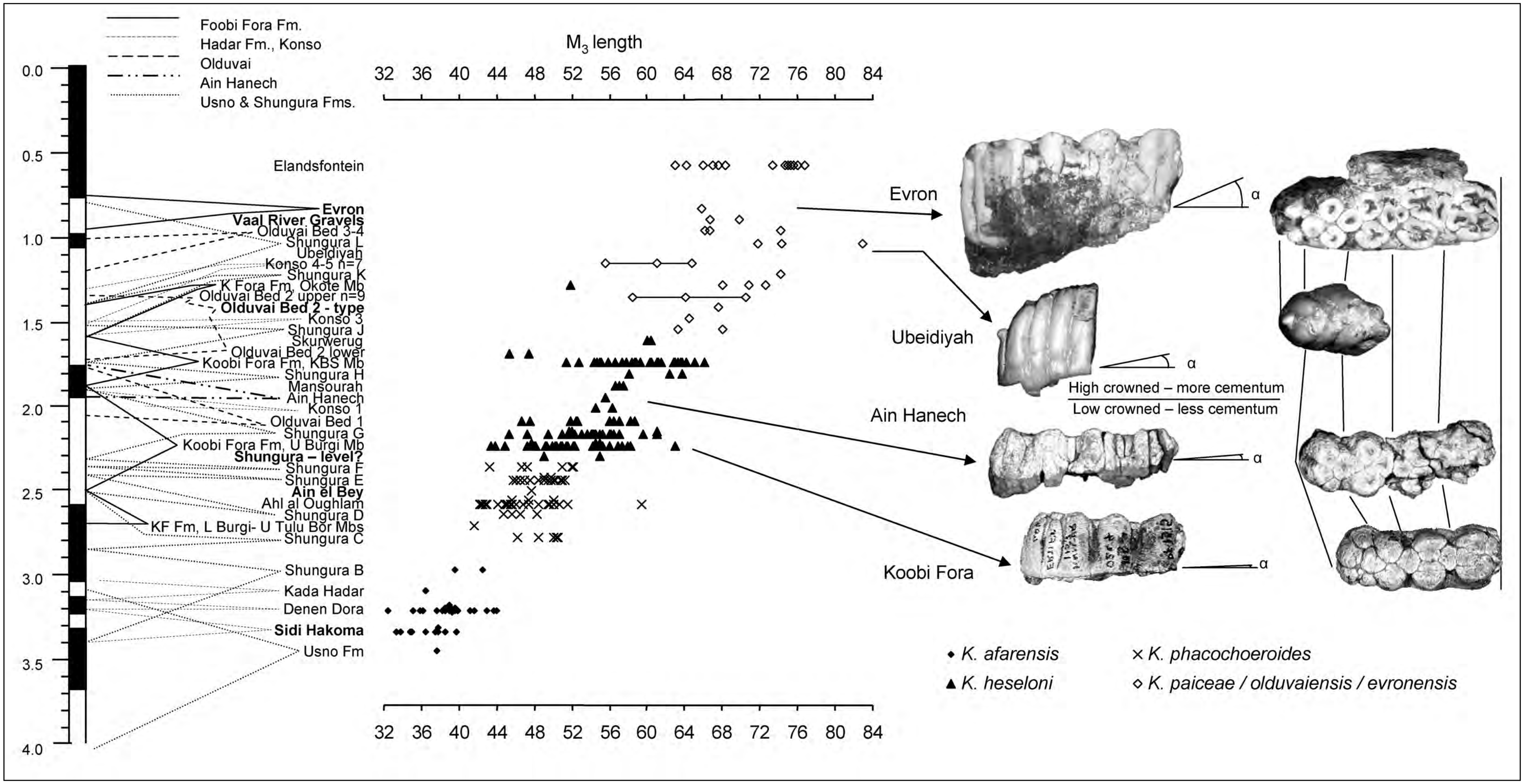


Figure 4. The evolutionary changes in morphology and length in the third lower molar of Kolpochoerus. *On the left are the age in Ma, palaeomagnetism and samples (localities, formation, member, biozone). Data from Koobi Fora Fm, Harris (1983): (*M. compactus *zone corresponds to the Okote Mb;* M. andrewsi *zone corresponds to KBS Mb;* N. scotti *zone corresponds to Upper Burgi Mb; zone C corresponds to the Lower Burgi Mb and the top of the Tulu Bor Mb); Usno Fm & Shungura Fm, Cooke (1976); Ahl al Oughlam & Ain el Bey, Geraads (1993, 2004); Ain Hanech, Sahnouni et al. (2002); Skurwerug, Olduvai Bed 1, Vaal River Gravels & Elandsfontein, Hendey & Cooke (1985); Olduvai Bed 2, Leakey (1943); Evron, Hebrew University of Jerusalem (HUJ). On the right are four specimens:* Kolpochoerus heseloni *from the* N. scotti *zone or Upper Burgi Mb at Koobi Fora (Kenya National Museums, KNM ER1153) and from Ain Hanech (collection),* Kolpochoerus paiceae/olduvaiensis/evronensis *from Ubeidiyah (HUJ K25) and holotype from Evron (HUJ). The morphological changes include increase in crown height and deposition of cementum, the increase of the angle between the crown base and the occlusal surface, and the addition of distal lobes and cusps.*

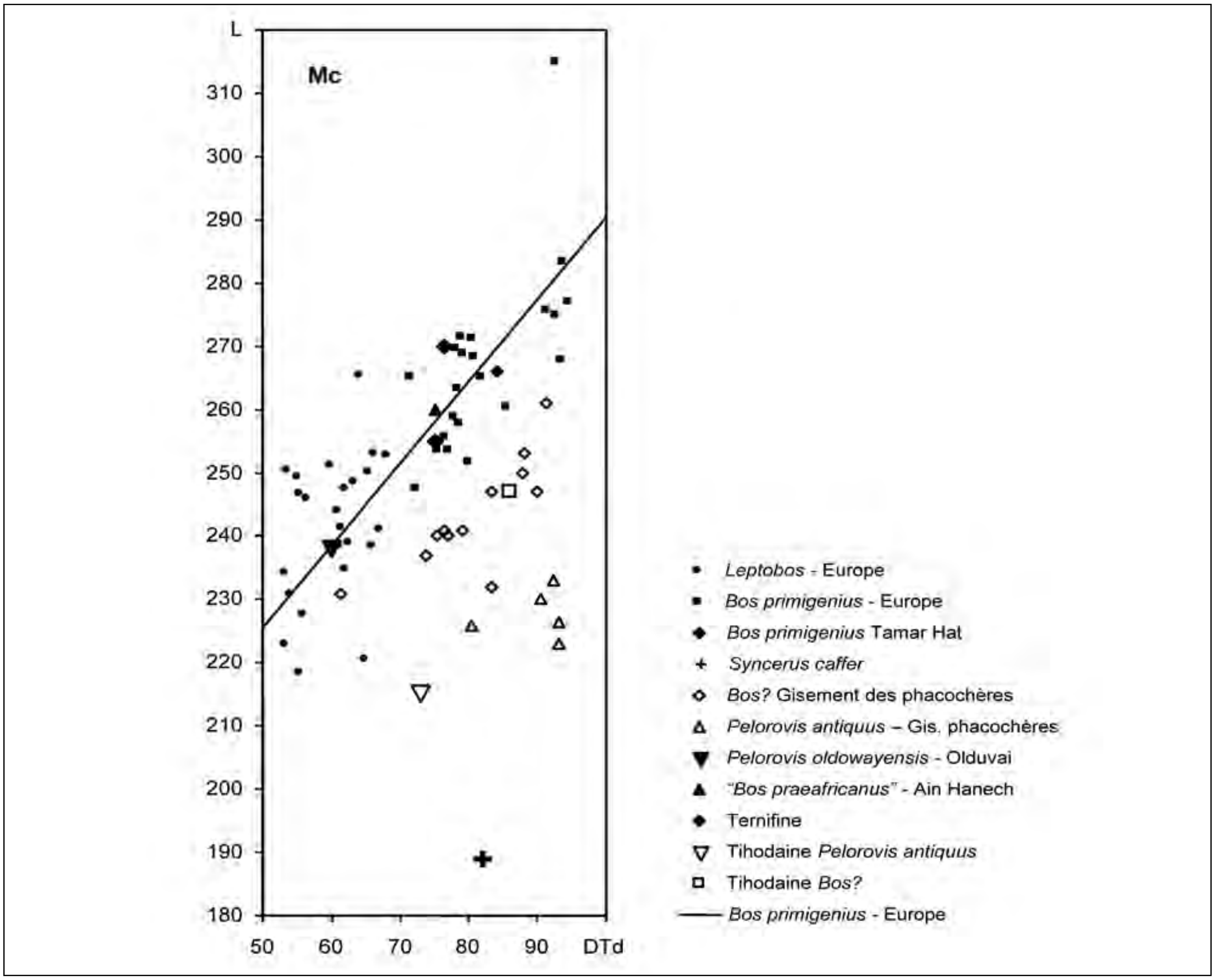


Figure 5. Bivariate plot of the metacarpals of selected Bovidae *using distal width (DTd) versus length (L).* Leptobos *de Villaroya (IPS), Montopoli (IGF), Senèze (MNHN), Olivola (IGF), Valdarno (Bologna);* Bos primigenius *from Miesenheim (Monrepos), Ariendorf (Monrepos), Plaidter Hummerich (Monrepos), Neumark Nord (Halle), Taubach (IQW), Lehringen (HMV), Pinilla del Valle (UCM), Villa Seckenberg (SMNS) and Can Rubau (Gerona);* Bos primigenius *from Tamar Hat (Geraads, 1981);* Pelorovis oldowayensis *from Oduvai Bed I (Gentry, 1967);* Pelorovis antiquus *(or* Syncerus antiquus*) from the Gisement des phacochères (Hadjouis, 1985, 2002); recent* Syncerus caffer *(NNML);* "Bos? bubaloides" *from Tighenif (Geraads, 1981);* "Bos praeafricanus" *from Ain Hanech (Arambourg, 1979).*

1.4 Ma hypothesis, but do not contradict the 1.8-1.9 Ma hypothesis, corroborating the Olduvai subchron polarity evidenced at Ain Hanech.

Mansoura

During the second half of the 19th century and the beginning of the 20th century faunal remains were collected in the Mansourah area in the vicinity of Constantine though not much attention was given to local stratigraphy (Bayle, 1854; Thomas, 1884; Joleaud, 1918). Half a century ago, stone artefacts were collected at Mansourah and a sketchy stratigraphy was reported (Laplace-Jaurechte, 1956). Chaid-Saoudi et al. (2006) studied fauna from the earlier collections housed in Algiers, Constantine and Rabat, but artifacts from the Laplace collections, housed in Les Eyzies (France). There is thus no guarantee that conclusions on the age, drawn from that fauna, apply to the lithic industry, nor that the fauna comes from a single site or level.

Chaid-Saoudi et al. (2006) concluded that the fauna from Mansourah is Early Pleistocene in age and slightly older than that of Ain Hanech, arguing that the latter fauna lacks the Tragelaphini and Reduncini, which for Mansourah indicate an earlier age. The form belonging to the Reduncini was described as *Kobus* aff. *kob*, an extinct subspecies of *Kobus kob* or a new species. *K. kob* is a living species, and it is hard to see, how fossils of insecure taxonomy, but close to a living species can be an argument for an old age. They assigned the tragelaphine from Mansourah to *Tragelaphus* cf. *gaudryi*, while they assume that *T. gaudryi* (present in Ain Boucherit and Ain Hanech) gave rise in North Africa to *T. algericus*, present in Tighenif. So, *Tragelaphus* is assumed to have been present all the time, though there is no precise documentation of the transition from one species to the other. How can the presence or absence of a form of this lineage, but of imprecise specific affinities, be used in precise biostratigraphy?

We agree with Chaid-Saoudi et al. (2006), that the Mansourah faunal list as presented shares several taxa with Ain Hanech (Figures 3a & 3b), in particular the suid, which we believe to be *Kolpochoerus heseloni* (Figure 4); and that the age of the Mansourah fauna (if indeed homogenous) may be close to that of Ain Hanech, which in our opinion is around 1.8-1.9 Ma old.

Tighenif and Thomas Quarry level L

Tighenif and Thomas Quarry Level L are important North African Late/Middle Pleistocene localities. The locality of Tighenif (formerly Ternifine, formerly Palikao) in northwestern Algeria was discovered in 1870 in the course of sand quarry exploitation where vertebrate fossil bones and lithic artifacts were collected. Subsequently, Pomel (1878, 1893-1897) described the first mammalian fossils. Initially, Arambourg (1951) correlated the site to the Riss, but later gave a faunal list and indicated an older age between 1.23 and 0.23 Ma. In 1954-1956 Arambourg carried out large scale excavations that led to the discovery of the oldest North African *Homo erectus* remains associated with a rich fauna and Acheulean assemblage (Arambourg & Hoffstetter, 1963). He dated the fauna to the base of the Middle Pleistocene and correlated the site to Olduvai Upper Bed II (Arambourg, 1979). Geraads (1981, 2002) re-analyzed the Bovidae and published a revised faunal list. Further investigations on the site were carried out including the results of a plaeomagnetic study with normal polarity of the lower deposits, indicating either the Brunhes Epoch or the Jaramillo Event (Geraads et al., 1986). Vrba (1997) assumed an age of about 0.7 Ma, but this is not based on her phylogenetic tree of the Alcelaphini, which would allow an age of 1.5 Ma for Tighenif as well. Taxa from Tighenif are shown in figures 3a and 3b and those that may have stratigraphic interest are discussed below:

Metridiochoerus is closely related to the living a wart dog. Different views on the evolution of this suid have been published (Cooke, 1976, 1978a, 1978c, 1985; White & Harris, 1977; Harris & White, 1979; Harris, 1983). *Metridiochoerus hopwoodi* (*M. nyanzae* for Cooke) occurs last in East Africa in the Nariokotome Mb of the Koobi Fora Fm and in Olduvai Bed IV (Harris, 1983; Turner et al., 1999). Its occurrence in Tighenif suggests thus an age of not less than about 1.0-0.8 Ma.

The Giant sable antelope (*Hippotragus* cf. *gigas*) is cited last in East Africa in Olduvai Bed III and in the Natoo Mb of the Nachukui Fm (Harris, 1983; Turner et al., 1999), with ages of just over 1 Ma.

A large bovid, represented only by some foot bones including metacarpals, was assigned to *Bos?* cf. *bubaloides*, a species present in Ain Hanech (Geraads, 1981). As discussed above, this form might be identical to *Pelorovis oldowayensis*. The metacarpals from Tighenif are similar in proportions and size to those from Ain Hanech, but also similar to those of European *Bos primigenius*. On one hand, in Europe, the earliest *Bos* appeared around 0.5 Ma, maybe 0.6 Ma (Petronio & Sardella, 1998). *Bos primigenius* is present in Gesher Benot Yakov, which may be earlier than in Europe, and a *Bos* was reported from Asbole (Geraads et al., 2004b). On the other hand, the last record of *Pelorovis oldowayensis* in East Africa is in Olduvai Bed III at about 1.3 Ma (Vrba, 1996).

Despite the common practice to place Tighenif in the Middle Pleistocene, there is no well documented species that indicates such an age. In fact, several species suggest rather a late Early Pleistocene age. In combination with the normal palaeomagnetic polarity detected in the sediments of this locality, the biostratigraphic data suggest a correlation with the Jaramillo event rather than to the basal Middle Pleistocene.

Level L at Thomas Quarry 1 constitutes the oldest archaeological deposit of the long Acheulean sequence of Atlantic Morocco. It yielded an Acheulean industry associated with a small faunal assemblage. The sediments signal probably a reversed polarity, while OSL dating points out a maximum age of 989±208 Ka for Unit L (Rhodes et al., 2006). Although the fauna is not very informative in terms of biostratigraphy (Figures 3a & 3b), it suggested an Early Pleistocene age to Geraads (2002), either after (p. 47, fig. 2) or before the Jaramillo Event (p. 49), and even up to 1.5 Ma (Geraads et al., 2004b). The following taxa were discussed by that author in relation to the age of level L:

The gerbilid *Ellobius* and *Gazella atlantica* are present in Tighenif (early Middle Pleistocene for Geraads) and Middle Pleistocene sites. The presence of similar gazellas in both Level L and Tighenif is not taken as an indication of similar age while the absence of gerbilid in Level L is interpreted as an indication that Level L is older than Tighenif. The absence of evidence is thus valued more than the presence of evidence.

An upper third molar of *Kolpochoerus* is similar to that of the type of *K. maroccanus* (of unknown age [Geraads, 2002]) and *Kolpochoerus majus*. *K. majus* is known to have survived well into the Middle Pleistocene (Cooke, 1976, 1978a, 1978c, 1985; White & Harris, 1977; Harris & White, 1979); nevertheless Geraads (2002) argued that the genus is not known from the Middle Pleistocene of North Africa and that its presence in level L points to an Early Pleistocene age.

Several species of small mammals are represented by poor material. While this material is different from that of other sites in the quarry, its biochronological value is limited, since the material does not allow for a precise taxonomic assignment.

None of these are really good biostratigraphic criteria for dating Level L, but we are willing to accept a late Early Pleistocene age for that level, mainly because of the reversed paleomagnetics and the OSL dates.

In conclusion to the biostratigraphical study of the North African Plio-Pleistocene localities, the faunas can be clustered into the following chronologies:

1. Ahl al Oughlam, Lac Ichkeul, and Ain Brimba are Late Pliocene about 2.5 Ma or older;
2. Ain Boucherit, Ain Jourdel, and Ain el Bey are Late Pliocene between about 2.58 and 1.95 Ma;
3. Ain Hanech, El-Kherba, El-Kherba Puits, and Mansourah are latest Pliocene-earliest Pleistocene between about 1.95 and 1.6 Ma; the first two localities belonging to the Olduvai subchron; and
4. Tighenif and Thomas Quarry Level L are late Early Pleistocene in age, the former site being correlated to the Jaramillo subchron (0.99-1.07 Ma); while the latter with reversed paleomagnetism and a date of 989±208 Ka might most probably be a little younger.

Pre-Acheulean or Oldowan

A terminological issue that is essential to be addressed in this chapter is whether or not the North African lithic assemblages preceding the Acheulean tradition should be designated as Pre-Acheulean or Oldowan. Because of the inadequacy of then used terminology, the Pan-African Congress held in Tenerife (Spain) in 1963 adopted the resolution "to reexamine entirely all terms relating to technique, typology and cultures in Africa and to make precise recommendations for a standardized African nomenclature" (Cuscoy, 1965: 91). "Pebble culture" was among the terms that the congress recommended to be replaced. Subsequently, it has been decided at the Wenner-Gren conference at Burg Wartenstein, (Austria) that the term "Pebble-Culture" to be replaced by Oldowan to refer to industries that precede the pre-bifacial technology. However, instead of the Oldowan, the term Pre-Acheulean was proposed by North Africanist prehistorians for North Africa, arguing that the term Oldowan is impossible to apply to Moroccan "Pebble Culture" levels and because North African assemblages are not found in a sealed context, e.g. "living floor" (Bishop & Clark, 1967: 866-867).

Yet, the term Pre-Acheulean has a chronological connotation, and the arguments advanced against the use of the term Oldowan in North Africa are no longer valid. In fact, recent studies showed that the presence of Pre-Acheulean industries in Atlantic Morocco is not authentic (Raynal & Texier, 1989), and the Oldowan industry truly occurs both chronologically and typologically in North Africa, e.g. Ain Hanech and El-Kherba (Algeria). At these two sites the Oldowan industry is found in a sealed context and detailed study has clearly shown that the North African Lower Palaeolithic assemblages from Ain Hanech are very similar to the Oldowan stone tools recovered from Upper Bed I and Lower Bed II at Olduvai in Tanzania (Sahnouni, 1998). Therefore, in accordance with the recommendations of the Burg Wartenstein conference, we propose here that the term Oldowan should replace the Pre-Acheulean for North African assemblages predating the Acheulean.

Oldowan in North Africa

The earliest lithic artifacts attributed to Mode I are presently known in Eastern Africa, and are dated to roughly between 2.6-1.5 Ma. Major sites include: East Gona 10 (EG10), East Gona 12 (EG12), and Ounda Gona South 7 (OGS7) (Gona, Ethiopia) (Semaw et al., 1997, 2003), Lokalalei (West Turkana, Kenya) (Roche et al., 2003), Koobi Fora, East Turkana) (Isaac, 1997), Olduvai Gorge, Tanzania (Leakey, 1971, 1975) Melka Kunture, Ethiopia (Chavaillon & Piperno, 2004). South African sites that yielded Mode I artifacts include Sterkfontein (Kuman et al., 2005) and Swartkrans (Clark, 1993). These artifacts are generally assigned to the Oldowan Industrial Complex, named for Olduvai Gorge in northern Tanzania. The Oldowan technology is simple but required mastering by early hominins of some fundamental stone flaking techniques. The Oldowan assemblages incorporate cores and core-tools (choppers, polyhedrons, subspheroids, spheroids), debitage, and less-frequent retouched pieces as well. Similar assemblages are known from the earliest archaeological sites in the Maghreb, including Ain Hanech. These assemblages were generally referred to as "Pebble Culture" and sometimes as Pre-Acheulean. Most of the sites are located in Morocco and in Algeria (Figure 6). Outside of Algeria and Morocco, rare and/or doubtful finds have been reported in Tunisia and Egypt. In Tunisia only a single bifacially flaked core/chopper, encountered within a sandy-clay deposit has been reported (Gragueb & Ouslati, 1990). In the Egyptian Nile Valley there are reports of Pre-Acheulean stone tools in the Early Pleistocene (Biberson et al., 1977), but they seem of doubtful authenticity (Vermeersch, 2001, 2006). These so called "Pre Acheulean" sites are environmentally located in three distinct areas, namely High Plateaus of Algeria, the Sahara, and possibly Atlantic coast of Morocco (Figure 6).

Ain Hanech and El-Kherba

The major Oldowan sites are formed within basin deposits of the Algerian High Plateaus. These include Ain Hanech and El-Kherba, Mansourah, and Monts Tessala. Ain Hanech and El-Kherba are located on the edge of the eastern Algerian Plateau. Ain Hanech was discovered by Arambourg (1970, 1979), and yielded a Plio-Pleistocene fauna associated with Oldowan artifacts. Beginning in 1992-93 Sahnouni and colleagues have re-investigated this major site. These new studies have involved investigations bearing on stratigraphy, dating, nature of the association of broken up bones and stone artifacts, lithic assemblages, and overall behavioral implications of the archaeological occurrences. The preliminary results are accessible in a number of publications (Sahnouni, 1998; Sahnouni & de Heinzelin, 1998; Sahnouni et al., 2002,

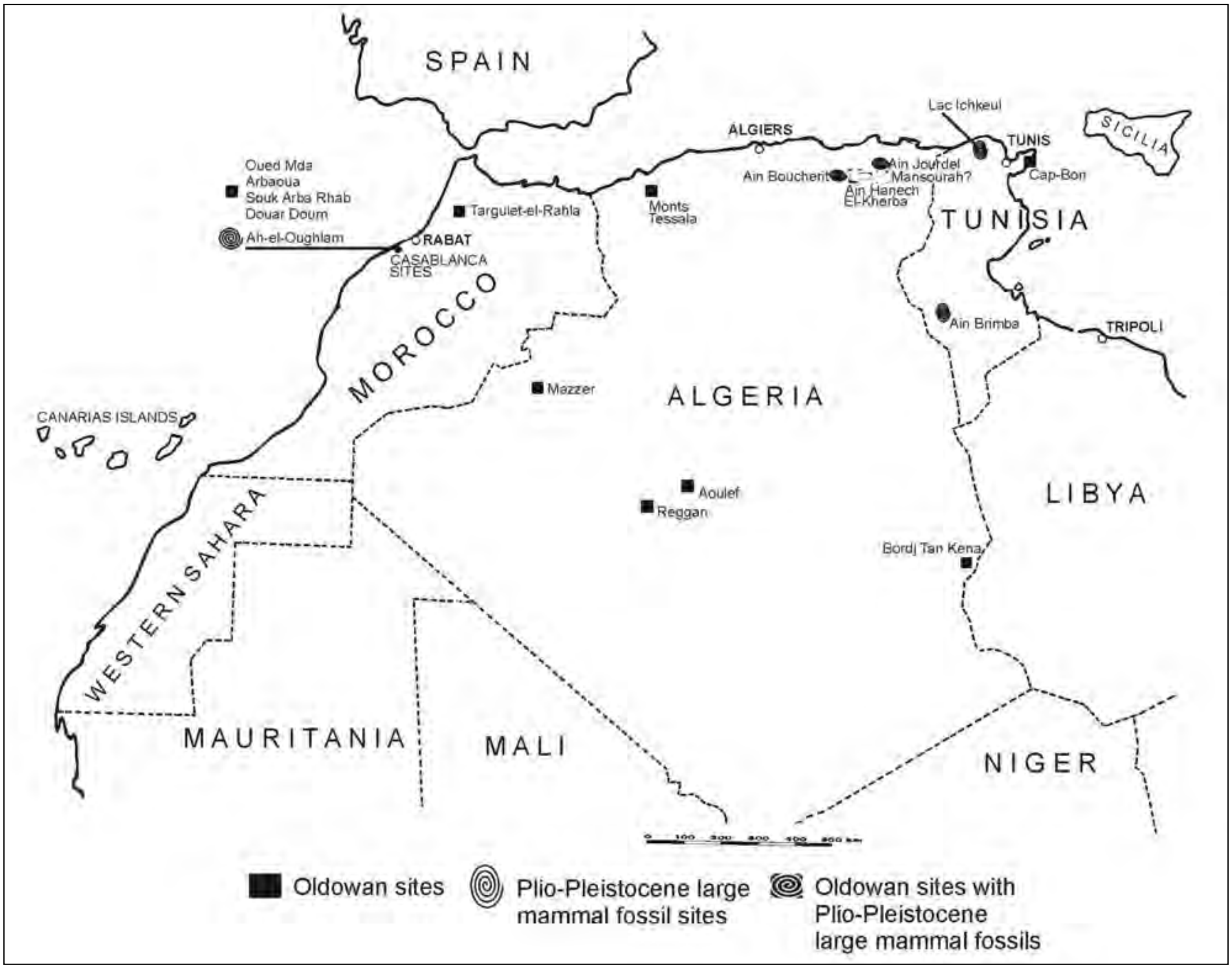


Figure 6. Map showing major Oldowan and Plio-Pleistocene sites in Northwest Africa. Note that the only Oldowan sites with clearly associated Plio-Pleistocene large mammal fossils are Ain Hanech and El-Kherba in Algeria.

2004), and only a summary is provided here. Ain Hanech is not a single site but rather a Plio-Pleistocene site complex stretching over an area of approximately one Km^2. The localities include Ain Boucherit, Ain Hanech, El-Kherba, and El-Beidha. Ain Boucherit is a Late Pliocene paleontological locality and the oldest in the region (see section above) (Arambourg, 1970, 1979, Sahnouni et al., 2002). Ain Hanech is located near a small local cemetery in a sedimentary outcrop cut by the deep ravine of the intermittent stream of Ain Boucherit. El-Kherba and El-Beidha are newly discovered archaeological localities, and are situated in the immediate vicinity south of the site of Ain Hanech. While the investigations are well underway at Ain Hanech and El-Kherba, the locality of El-Beidha has yet to be fully explored. The Acheulean occurrences are entirely independent of the Oldowan, and belong to the calcrete deposits located 6m higher sealing the entire formation.

Three distinct archaeological levels have been identified at Ain Hanech. They yielded Oldowan assemblages associated with Plio-Pleistocene faunas (Sahnouni et al., 2002). They are from the youngest to the oldest A, B, and C. Levels A and B comprise a gravel layer at the bottom, abruptly overlain by a silty stratum. These deposits suggest an alluvial floodplain cut by a meandering river channel. Level C is easily discernable as it is separated from level B by 0.50 m of sterile deposits. It is 50 cm thick and consists of dark sandy clay with pebbles and cobbles, and black flint fragments. A test excavation yielded a few fossil bones and 15 lithic artifacts.

Major excavations were undertaken mainly at Ain Hanech and El-Kherba. The excavated areas total 118 m^2 x 1.50 m depth at Ain Hanech and 80 m^2 x 1.40 m depth at El-Kherba. At both localities a rich assemblage was recovered. A total of 2475 archaeological remains was recovered at Ain Hanech, including 1242 fossil bones and 1232 stone artifacts >2 cm. At El-Kherba the excavations yielded a total of 631 specimens, including 361 fossil bones and 270 stone artifacts. The materials are contained in all three levels sealed in a fine sedimentary matrix.

Made primarily of limestone and flint, the lithic assemblages incorporate a full range of Oldowan artifact categories, including core-forms (Figure 7), unifacial and bifacial choppers, polyhedrons, subspheroids, spheroids, whole flakes, and retouched pieces (chiefly scrappers and denticulates) (Figure 8). Several simple flakes and retouched pieces were utilized in cutting meat as ev-

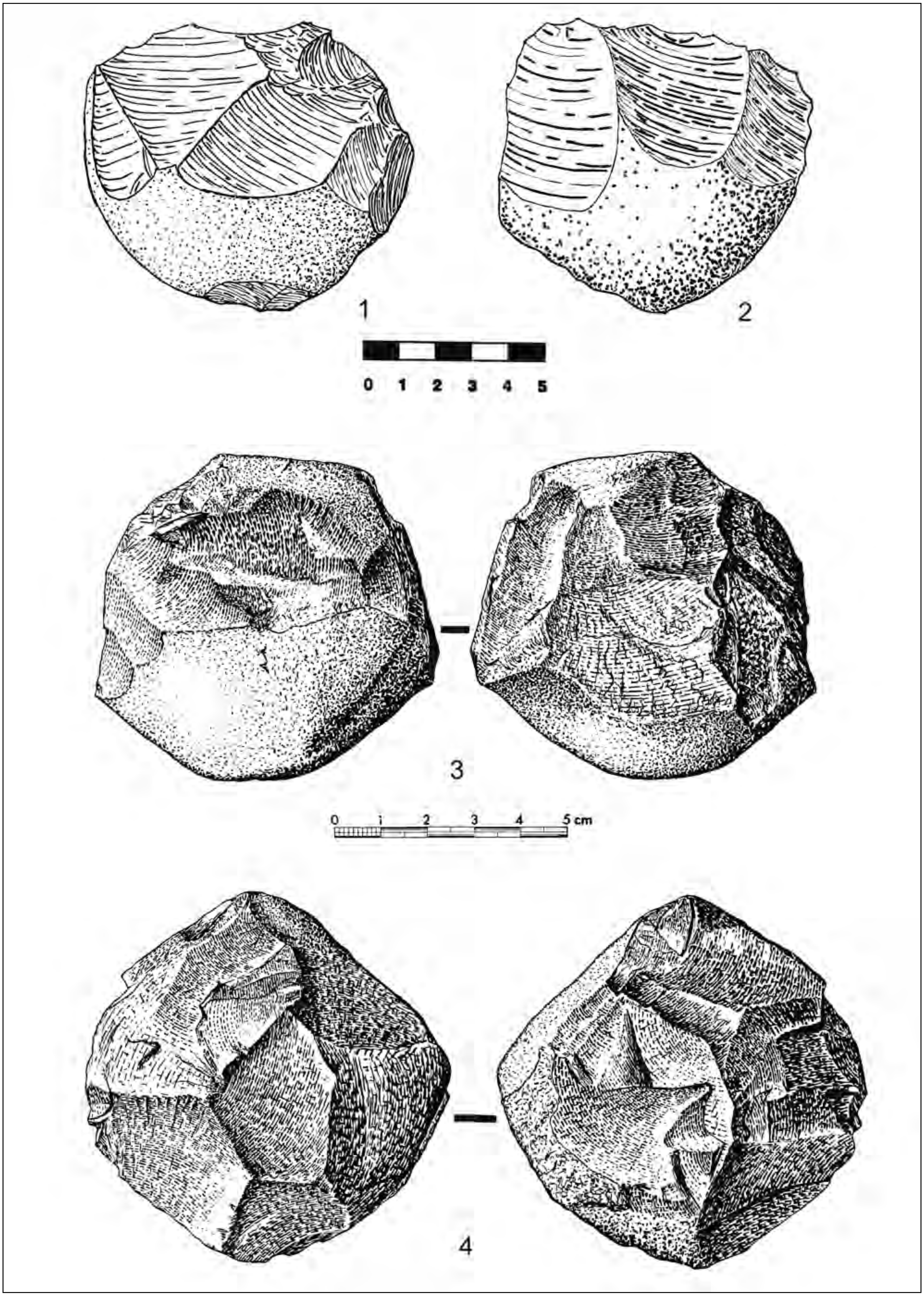


Figure 7. Examples of core-forms from Ain Hanech (3, 4) and El-Kherba (1, 2) sites in northeastern Algeria (1 and 2 drawn by de Heinzelin, 3 and 4 modified after Biberson [1967])

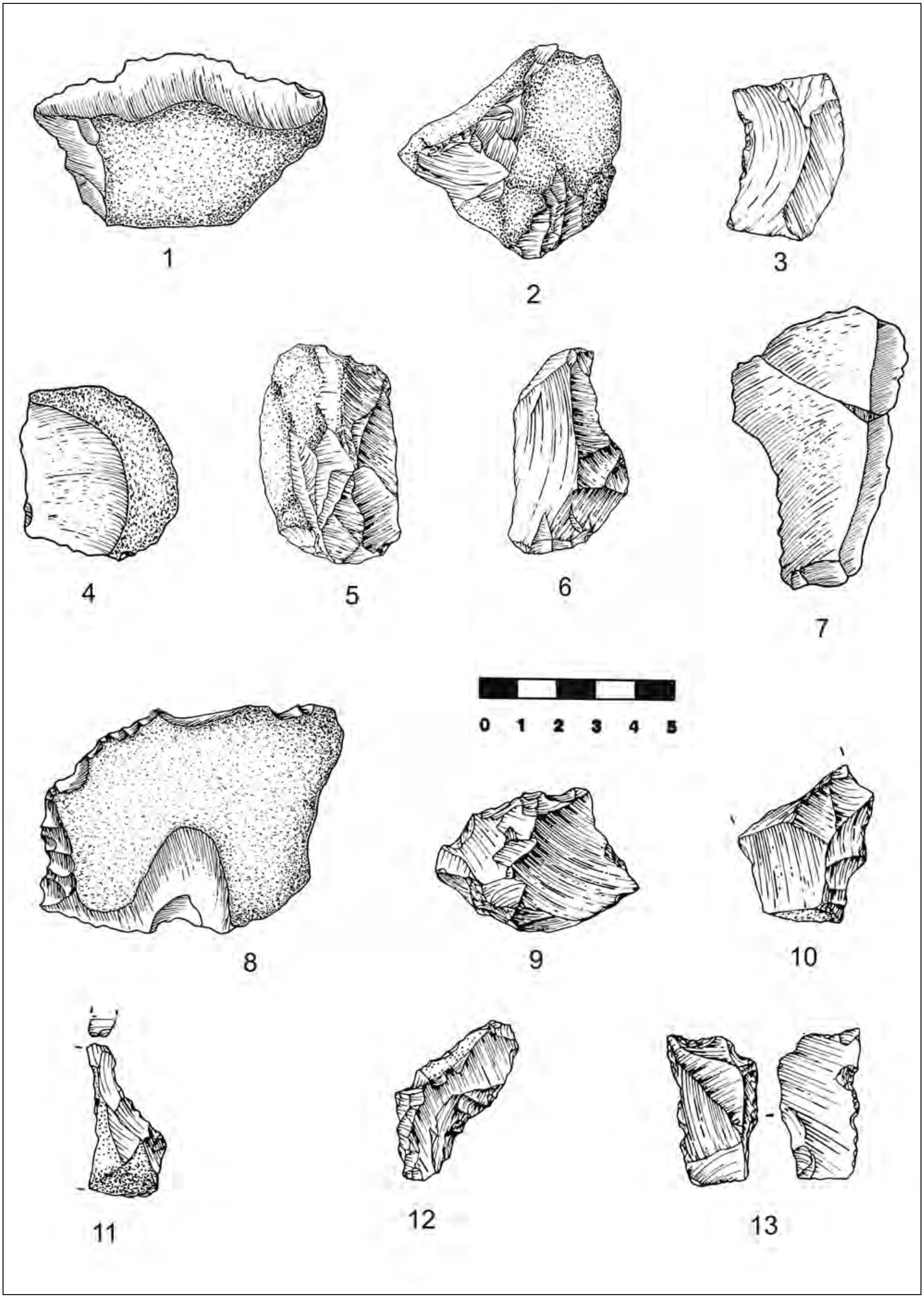


Figure 8. Whole flakes and retouched from Ain Hanech (1 to 5 and 7 to 10) and El-Kherba (6 and 11 to 13) sites (from Sahnouni's excavations).

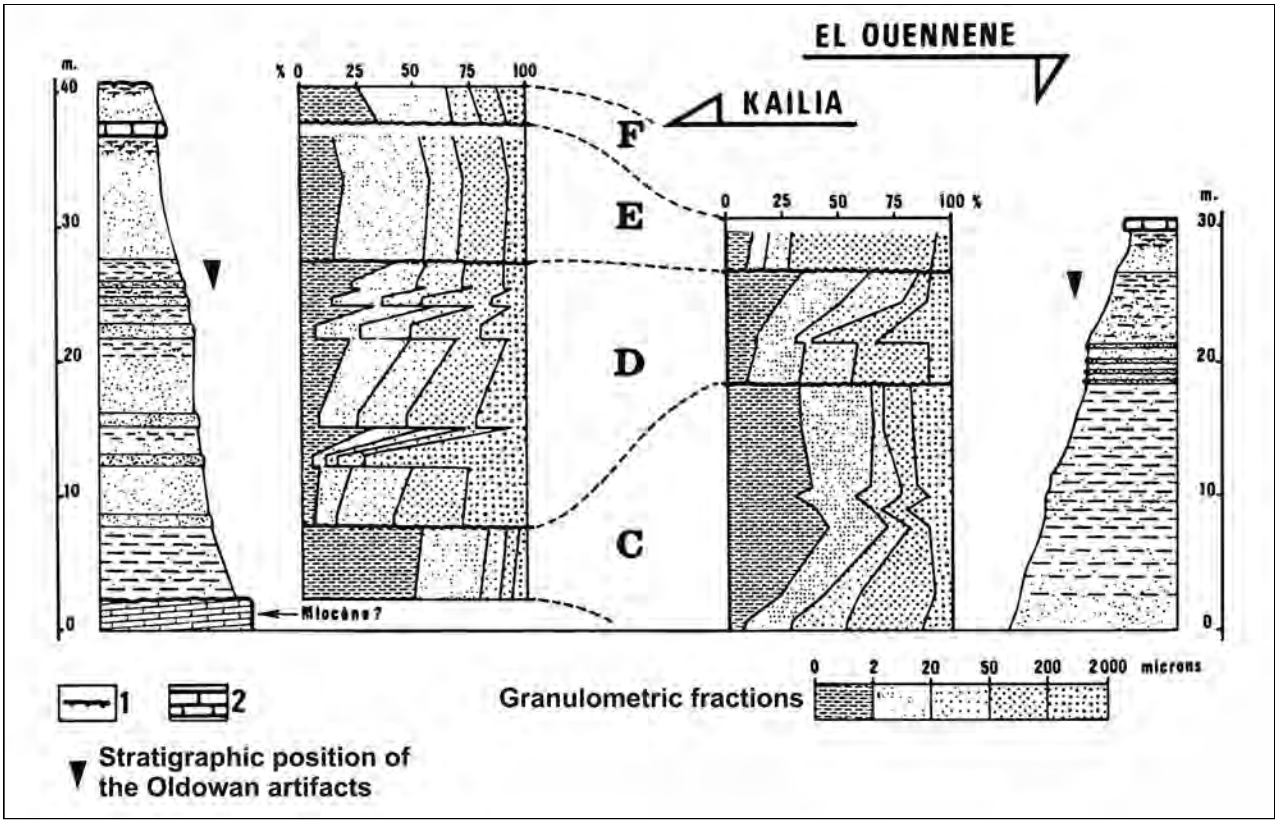


Figure 9. Stratigraphic section showing the in situ position of the Oldowan assemblages in Formation D found at Monts Tessala (western Algeria) modified after Thomas (1973).

idenced by the presence of meat polishes on their edges. The lithic artifacts from Ain Hanech and El-Kherba are very similar to those known from Olduvai upper Bed I and lower Bed II, especially in terms of flaking patterns and resultant artifacts forms.

Mansourah

Mansourah in the vicinity of Contantine yielded approximately 500 lithic artifacts most of which were collected *in situ* from three different stratigraphic layers; from top to bottom, red silts, silty sands with cobbles, and travertines (Laplace-Jauretche, 1956). The travertine deposit yielded Oldowan-like artifacts, consisting of fresh polyhedrons-cores made of quartzite and flakes made of quartzite and flint. A collection of 11 pieces made by R. P. Poyto and published by Camps (1964), also included bifacial choppers, polyhedrons, spheroids, bifaces, and tools on large flakes. However, Camps did not precise their stratigraphic provenience. Jolaud (cited in Laplace-Jauretche, 1956) and Arambourg (1970: 18) assigned the travertine deposits to the Upper Villafranchian (=Early Pleistocene). Nevertheless, Laplace-Jauretche (1956) did not report unambiguously the finding of large fauna associated with the Oldowan artifacts. Therefore, the remote antiquity of the Mansourah industry as proposed by Chaid et al. (2006) is doubtful. The silty sand deposit overlaying the travertines strata yielded typical Acheulean materials made primarily of quartzite and flint, including bifaces, trihedrons, polyhedrons, and large flakes.

Monts Tessala

The two archaeological localities of Douar Kailia and Douar El Ouennene in the Monts Tessala area of northwestern Algeria have yielded *in situ* Oldowan artifacts (Thomas, 1973). The localities are situated at the limits of the sub-coastal valleys and the southern Tell (Tessala and Oulad Ali Mounts) of the Oran region. Douar Kailia is located between the villages of Oued Tlelat and Taferaoui, and Douar El Ouennene is located to the North West of the town of Sig.

Stratigraphically, the artifacts were contained in a detritic deposit comprising sometimes heterometric gravels wrapped in a clear sandy or silty matrix (Formation D) (Figure 9). The deposit is sealed by a paleosol. Thomas (1973) correlated the deposit with the Moroccan Saletian stage, which is a pluvial cycle dated to the Lower Pleistocene.

The lithic assemblage (Figure 10) totaling 237 pieces include 48 artifacts recovered from Kailia and 187 from El Ouennene. The artifacts were fresh and made primarily of limestone (97%) and Jurassic or Cretaceous sandstone. The assemblages comprise unifacial and bifacial choppers (8.51%); polyhedrons and/or cores (14.04%); whole flakes (69.78%); retouched flakes (2.55%); and percussors and split cobbles (5.1%). Following Biberson's classification system, Thomas assigned the industry to the "Pebble Culture" stage III or IV.

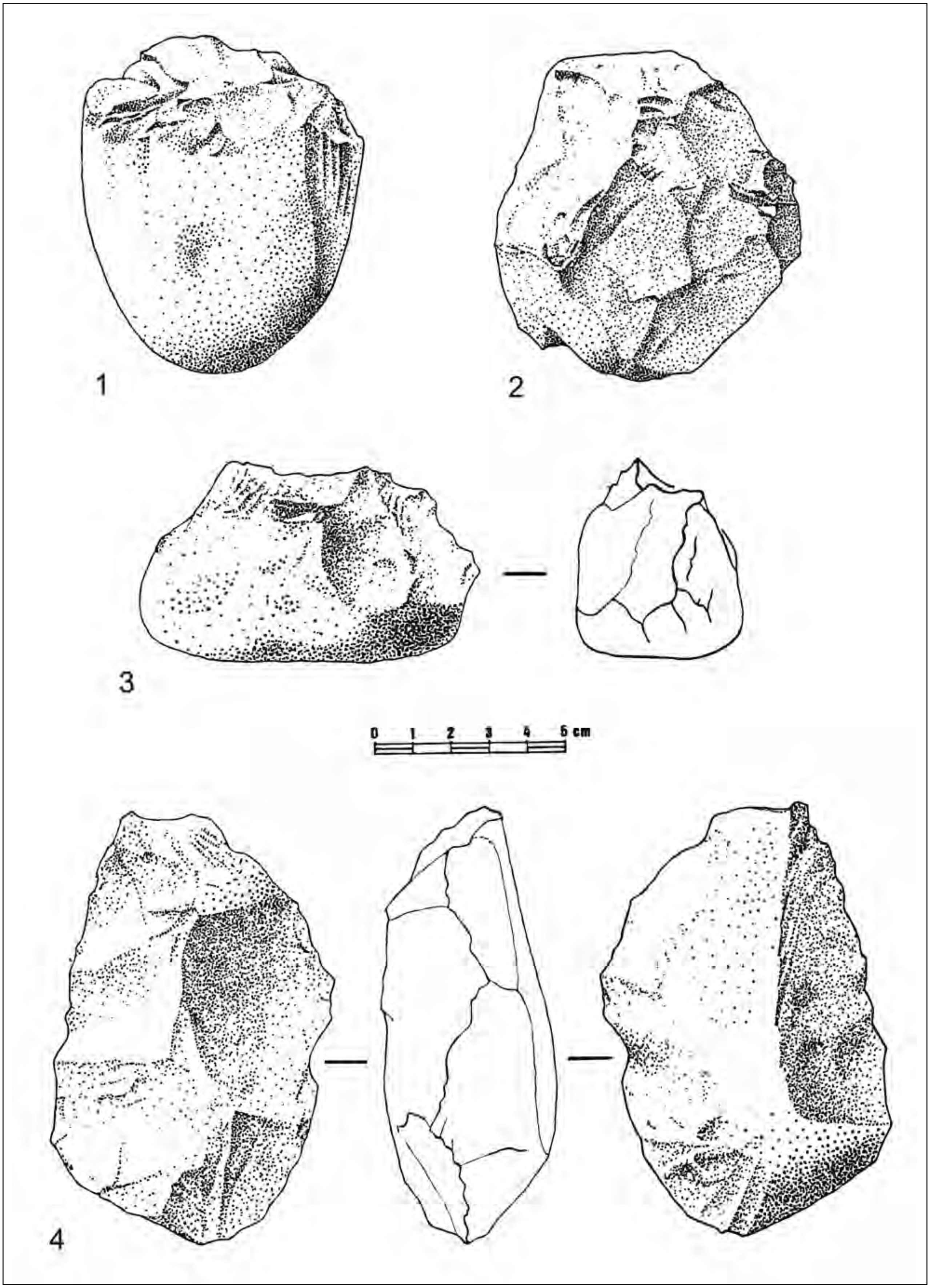


Figure 10. Examples of Oldowan artifacts from Monts Tessala (western Algeria) modified after Thomas (1973), including 1 and 3: bifacial choppers, 2: polyhedron, and 4 a proto-biface. Note that Monts Tessala assemblages might depict a transitional phase between the Oldowan and Acheulean in North Africa.

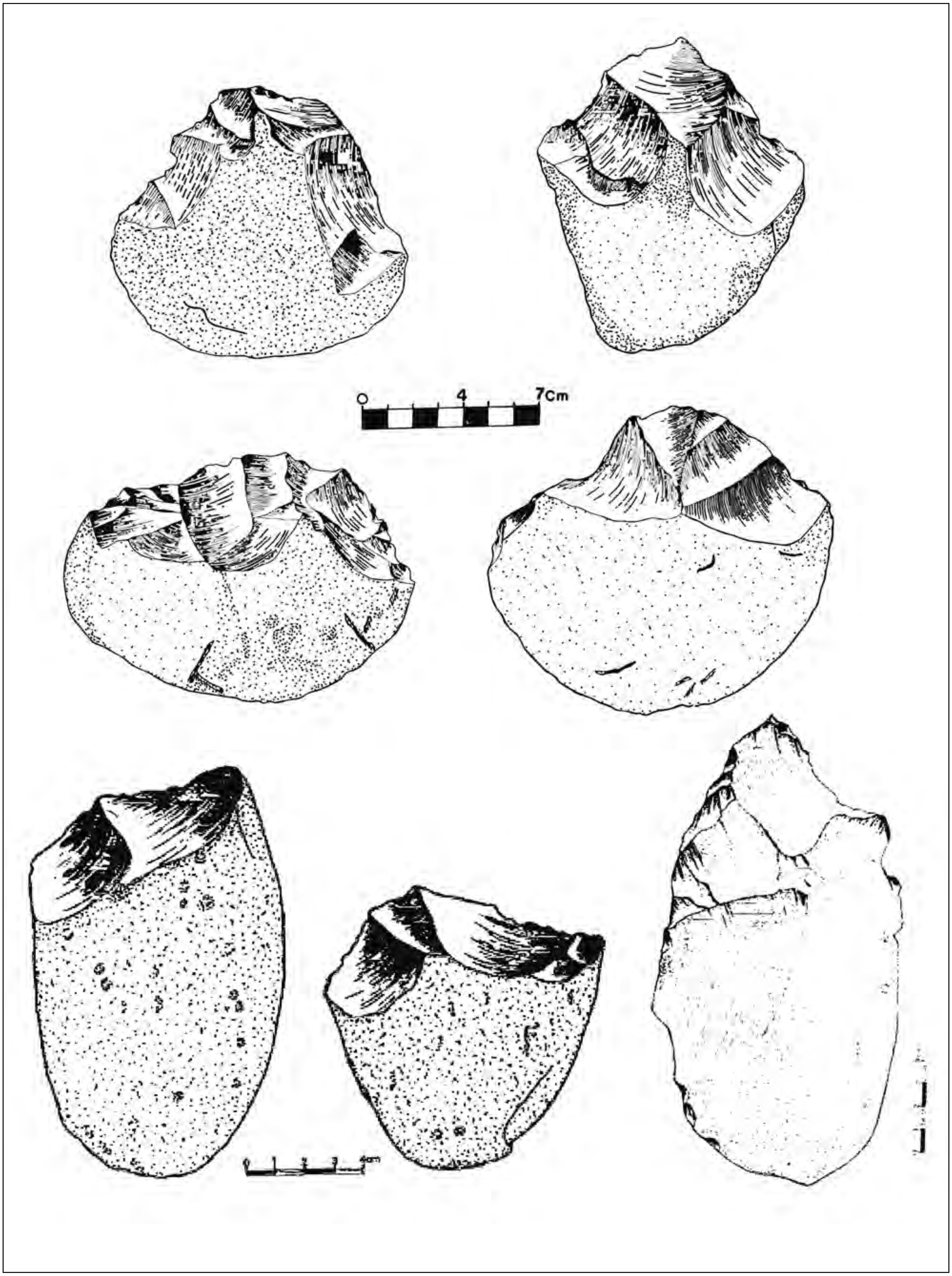


Figure 11. Example of Oldowan artifacts from the site of Bordj Tan Kena in northeastern Algerian Sahara modified after Heddouche (1980, 1981). Note that the assemblage might represent a transitional phase between Oldowan and Acheulean in the Sahara.

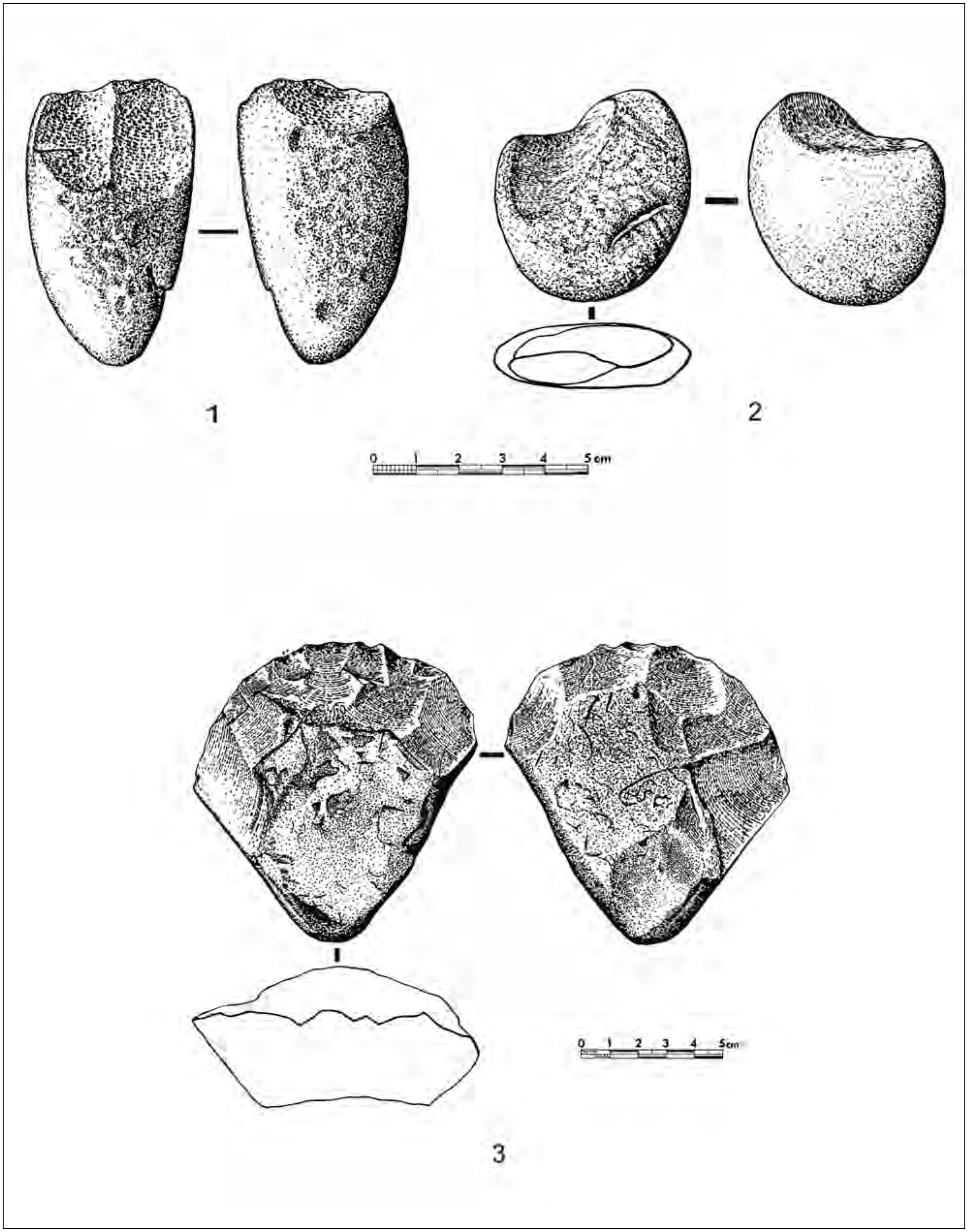


Figure 12. Example of Oldowan artifacts from the Sahara modified after Biberson (1967), including 1 and 2 choppers from Aoulef in the Algerian Central Sahara, and 3 a bifacial chopper from Mazzer in Algerian Northwestern Sahara.

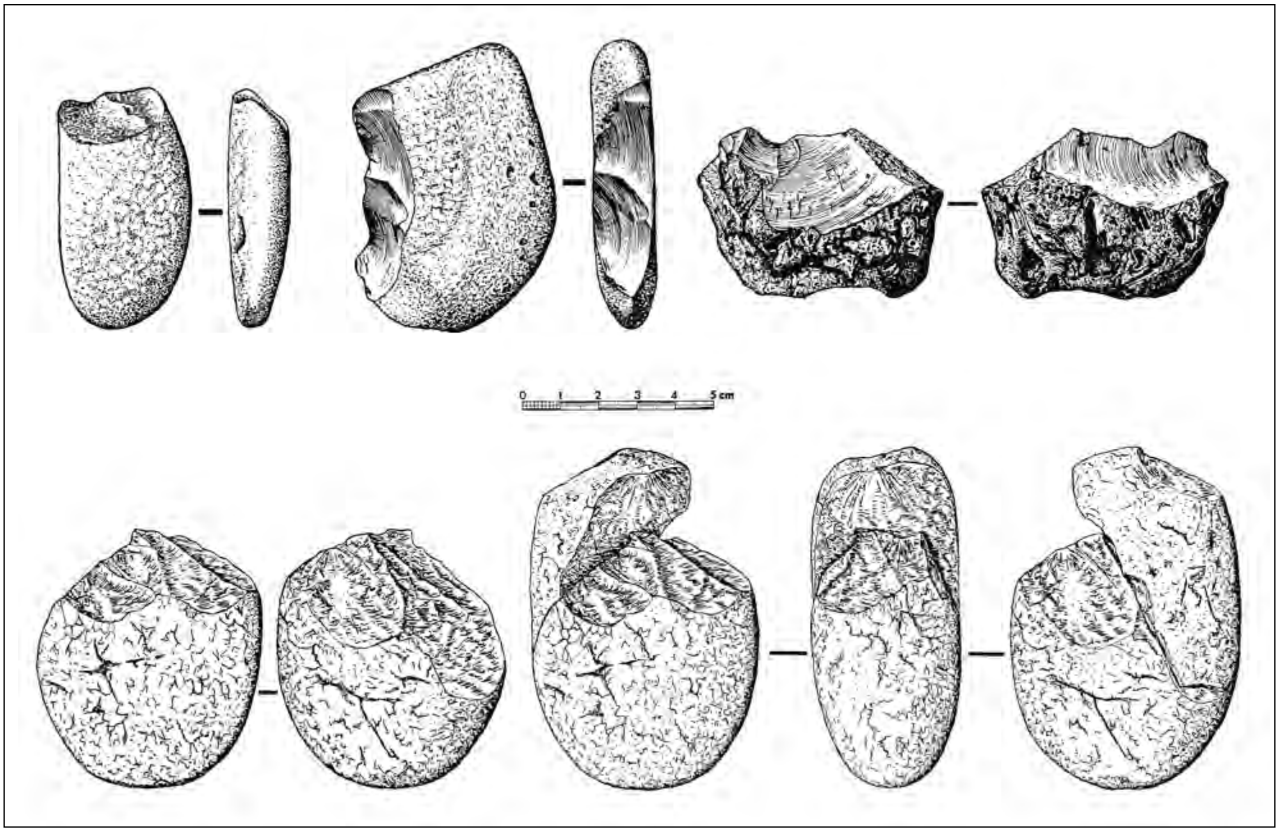


Figure 13. Unifacial and bifacial choppers from the site of Reggan in the Algerian Central Sahara modified after Ramendo (1963, 1964) and Biberson (1967). Note the nicely refitted flake with the chopper.

The Sahara

Oldowan-like artifacts have also been found in at least four localities in the vast Algerian Saharan landmass. These include Aoulef (Hugot, 1955) and Reggan (Ramendo, 1963) in the Central Sahara; Saoura (Alimen & Chavaillon, 1962) in the Northwestern Sahara; and Bordj Tan Kena (Heddouche, 1980, 1981) in the Northeastern Sahara. While the specimens from Aoulef and Reggan are surface collections, those from the Saoura region and Bordj Tan Kena were excavated *in situ.* At this latter site (9° 20 E, 26° 32 N) Heddouche (1980, 1981) has excavated 154 "pebbles tools" (Figure 11) from a Glacis type deposit (Glacis 4). However, not a single flake was reported associated with the flaked cobbles, which raises the issue of site integrity. The assemblage incorporates unifacial and bifacial choppers, discoids, bifaces, and a trihedral pick made of quartzite. Because of the abundance of bifacial choppers, Heddouche assigned the industry to the later stages of the Evolved Pre-Acheulean of Biberson's classification system.

The Aoulef and Reggan collections comprise 90 and 321 specimens, respectively. The artifacts include a range of types: unifacially, bifacially, multifacially flaked pebbles, discoids, and whole flakes made of variable raw materials (quartz, quartzite, sandstone, flint, fossil wood, and eruptive rocks) (Figure 12). Interestingly, the surface collection from Reggan includes a flake that refits nicely with a bifacially-flaked chopper made of quartz (Ramendo, 1964) (Figure 13). If the flake was not removed as a result of post depositional processes, these conjoined pieces suggest that the assemblage may have not been heavily disturbed by natural agencies.

In the Saoura region, Alimen and Chavaillon (1962) collected 110 "pebble tools" *in situ* from several localities contained in alluvial and lacustrine deposits correlated to the Mazzerian depositional cycle (=Early Pleistocene). Made primarily of quartzite and quartz; the "pebble tools" included split pebbles, and unifacial and bifacial choppers with an alternate flaking reduction (Figure 12 [3]). Sediment and pollen analyses indicate that the climate was fairly humid during the Mazzerian episode (Alimen, 1981).

Atlantic Moroccan sites

Large quarries on the Moroccan Atlantic coast, exploited for building materials, have exposed a series of marine deposits interbedded with terrestrial sediments. A series of sites located in the vicinity of the town of Casablanca have been investigated by Biberson (1961a). These sites include Arbaoua, Oued Mda, Douar Doum, Terguiet el-Rahla, Carriere Deprez, Sheneider Quarry (lower and upper), Chellah, Souk Arba-Rhab, and Sidi Abderrahman (niveau G).

Mode I assemblages recovered from these localities allowed Biberson (1961b) to construct a typological chronological sequence showing the evolution of the Pre-Acheulean industry through time. He divided the

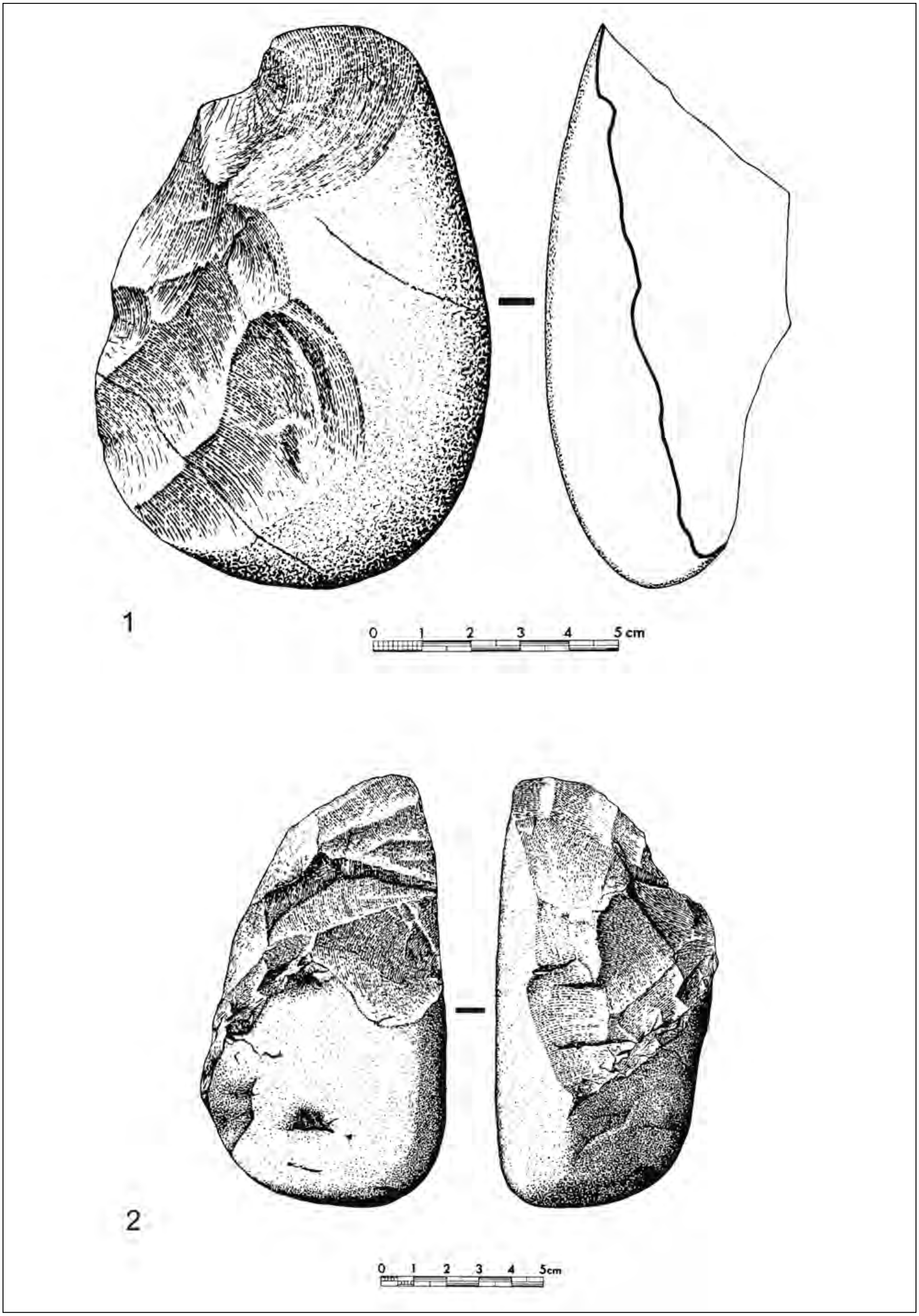


Figure 14. Oldowan artifacts from the site of Targuiet el-Rahla in Morocco modified after Biberson (1967).

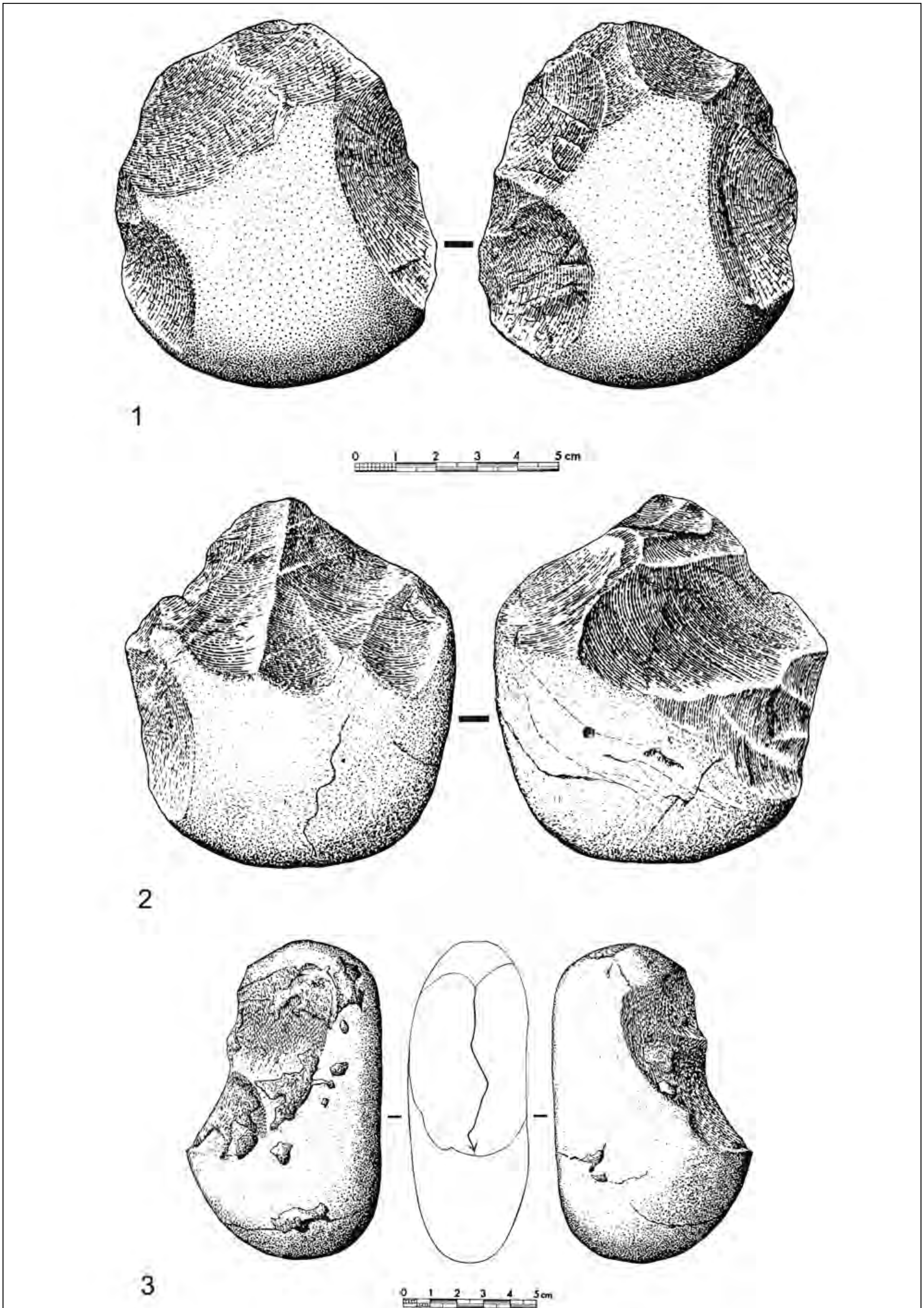


Figure 15. Bifacial choppers from the site of Souk Arba-Rhab modified after Biberson 1967.

Pre-Acheulean (previously labeled as "Pebble-Culture") into four successive stages. Stage I includes the oldest artifacts from simple technological gestures (unidirectional). This stage is illustrated by the site of Targuiet-el-Rahla (Figure 14). Stage II incorporates "pebble tools" characterized by bi-directional flaking. The site of Carriere Deprez in Casablanca (presently Ahl Al Oughlam) represents this stage. In stage III the multidirectional technique appeared where the artifacts are considered to be more evolved. This stage is represented by the site of Souk-el-Arba du Rhab (Figure 15). The last stage (IV) is represented by level G of the Sidi Abderrahman sequence, and is characterized by the emergence of the first Acheulean elements. Stages I and II constitute the Ancient Pre-Acheulean while stages III and IV Evolved Pre-Acheulean forms (Biberson, 1976).

Recently, researchers revised Biberson's stratigraphic sequence casting doubts on the antiquity of his "Pebble Culture" (Raynal & Texier, 1989; Raynal et al., 2004). The researchers claim that assemblages of "Pebble Culture" Stage I are either surface finds or reworked materials. Artifacts assigned to the "Pebble Culture" stage II were recovered from high energy deposits. Materials of the "Pebble Culture" Stage III are from polycyclic colluviums. "Pebble Culture" Stage IV is reclassified as Acheulean by these researchers instead of the "Pebble Culture" tradition as defined by Biberson. In addition, new investigations at the site of Ahl Al Oughlam in Casablanca (Morocco) indicate that the assemblages assigned to "Pebble Culture" Stage II by Biberson appear to be pseudo-artifacts generated by high energy deposits (Raynal et al., 1990). The authors concluded that the earliest human occupation in Morocco is estimated to a maximum of 1 Ma (Raynal et al., 1989, 2002a-b).

Conclusions

This article examined the Oldowan in North Africa within a biochronological framework. Despite the fact that North Africa is well underexplored relative to East Africa, there is a fairly good record of Oldowan in this region. The record consists mainly of stone assemblages found in stratigraphic contexts but it usually lacks associated fauna except for the sites of Ain Hanech and El-Kherba in Algeria. The fauna is crucial for dating North Africa earliest archaeological sites in the absence of suitable dateable materials where, unlike East Africa, there are no volcanic rocks to provide sound radiometric ages. Uranium-series and OSL dating are applicable only to the sequence around the end of the Lower Paleolithic. As it was applied to the dating of the South African cave sites, East African well dated fossil records can help dating the North African Plio-Pleistocene localities with similar taxa or their close relatives but devoid of radiometric ages. Indeed, the comparative biostratigraphical study of large fossil mammals permitted to date the North African Plio-Pleistocene faunas. The faunas range successively from approximately 2.5 Ma or older to 1.0 Ma. Ain Boucherit, situated stratigraphically below Ain Hanech, has a fauna that dates to between 2.3 Ma and 1.95 Ma. Ain Hanech and El-Kherba faunas, the only ones clearly associated with Oldowan stone artifacts, date to 1.9-1.8 Ma. This age is corroborated by the presence of three taxa biostratigraphically pertinent, including the proboscidean *Anancus*, the suid *Kolpochoerus*, and the "*Dicerorhinus*" like rhino, and by the paleomagnetic normal polarity dated to the Olduvai subchron. Tighenif and Thomas Quarry Level L, with Acheulean assemblages, are contemporaneous dating to around 1.0 Ma.

So far, the most secure data on the earliest hominin occupation in North Africa are provided by the sites of Ain Hanech and El-Kherba. The Ain Hanech and El-Kherba archaeological evidence shows that the human presence in this part of the African continent dates back to 1.8 Ma, and the earliest artifact tradition was the Oldowan, (Sahnouni, 2005; Sahnouni & de Heinzelin, 1998; Sahnouni et al., 2002, 2004) *sensu stricto* East African Oldowan (e.g., Leakey, 1971, Semaw et al., 1997). This long chronology model for an early human occupation in North Africa fits relatively well in the generally accepted scenario regarding hominin dispersal into the northern hemisphere. The current evidence indicates that early hominins colonized the Eurasian landmass by 1.8 Ma. Indeed, the oldest presence of hominins out of Africa is documented in the Caucasus at the site of Dmanisi in the Republic of Georgia. Dmanisi is dated to 1.8 Ma, and has yielded several hominin fossils associated with an Early Pleistocene fauna and Oldowan-like artifacts (Gabunia & Vekua, 1995; Gabunia et al., 2000, 2001; Lumley et al., 2005). Mode I artifacts from Majuangou (Nihewan basin, China) are dated to 1.6 Ma (Zhu et al., 2004). Earliest hominins in Indonesia are dated to 1.81 Ma (Swisher et al., 1994), although their chronological placement is still being debated (Klein, 1999: 272). There is now evidence showing that Oldowan-like artifacts older than 1 Ma have been found in southern Europe, and this new evidence is pushing back the dates for human presence a bit earlier than previously known. The new European archaeological sites with earlier dates include: 1) Pirro Nord site in Italy (with an assumed age of 1.3 Ma) (Arzarello et al., 2007), 2) Barranco Leon (1.3 Ma) (Toro-Moyano et al., 2003) and Fuenta Nueva 3 (1.2 Ma) (Turq et al., 1996) at Orce (Guadiz-Baza basin, Southern Spain), 3) Le Valonnet cave near Nice (Southern France) dated to Jaramillo Normal subchron (0.99-1.07 Ma) (Lumley et al., 1988), 4) Ca'Belvedere di Monte Poggiolo in Italy dated to 0.9 Ma (Peretto et al., 1999), and 5) Atapuerca near Burgos in Spain, with archaeological materials dated to 0.8 Ma (Carbonell et al., 1995).

The other major problem is the lack of contextual information, making the occurrences unsuitable for inferring Oldowan hominin behavior. In fact, most of the Oldowan sites have been discovered and studied without systematic archaeological survey and excavations. The sites have been located either casually or coincidentally in the course of urban development. A few of the sites, encountered following geological or paleontological expeditions, have been investigated without a real archaeological perspective or appreciation. As a result, most of the materials have been casually collected, with mostly the "pebbles tools" being systematically selected and examined. These selected artifacts constituted the basis for a proliferation of typological and classificatory systems, where mostly each lithic assemblage has its specific type-list (Alimen & Chavaillon, 1962; Biberson, 1967; Heddouche, 1981; Hugot, 1955; Ramendo, 1963). In addition, the lithic artifacts encountered are abraded to varying degrees, making them of doubtful authenticity. They were often collected from the surface or from high energy deposits as shown by Raynal and Texier (1989) in the case of Atlantic Morocco.

For a long period of time the earliest North African sites were viewed to be in secondary context, which largely eliminates the possibility to identify early hominin behavioral patterns (Clark, 1992). Recent research indicates that this major difficulty was not due to the absence of sites in primary context, but rather it was primarily because much of the emphasis by Palaeolithic researchers until the 1960s was on culture-history and to little systematic investigations have been undertaken to shed light on behavioral patterns. However, this is changing gradually with modern investigations on key localities being more systematic since the late 1980s-1990s. Where major systematic investigations took place in North Africa includes our investigations of the Oldowan site of Ain Hanech. These sites were investigated in primary context with fresh artifacts and well-preserved fauna, and have yielded relevant behavioral information for a better understanding of early hominin adaptation in northern Africa. For example, the Oldowan site of Ain Hanech can be viewed as a spot for short-term occupations by early hominins near a shallow river embankment, where raw materials were accessible from nearby river beds, and plenty of game for acquiring meat. The technology used by Ain Hanech hominins is simple (Mode I Technology), expedient, and characterized by a low degree of standardization. There is no evidence for long distance raw material transport. The industry is primarily composed of core-tools/choppers, flakes, fragments, and occasional retouched pieces that are the main characteristics of early stone artifact assemblages assigned to the Oldowan. Bones belonging to different animal taxa such as equids, large and small bovids, hippo, and elephant were recovered in association with the lithic artifacts. One taxon, i.e. Equidae, appears to dominate the faunal assemblages. Whole flakes and retouched pieces were used to process soft animal tissue, suggesting that meat was a major component of early hominin diet in North Africa. An in depth study is underway for documenting subsistence patterns, the strategy employed for meat acquisition, and breaking bones for marrow.

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CHAPTER 11

INSIGHTS INTO LATE PLIOCENE LITHIC ASSEMBLAGE VARIABILITY: THE EAST GONA AND OUNDA GONA SOUTH OLDOWAN ARCHAEOLOGY (2.6 MILLION YEARS AGO), AFAR, ETHIOPIA

SILESHI SEMAW, MICHAEL J. ROGERS, AND DIETRICH STOUT

ABSTRACT

The 1992 systematic archaeological excavations of the two East Gona sites (EG-10 and EG-12) resulted in the discovery of the oldest known stone artifacts dated to ~2.6-2.5 million years ago (Ma) (Semaw, 2000, 2005, 2006; Semaw et al., 1997). Trachyte and rhyolite dominate the EG artifact assemblages, followed by basalt and aphanitic volcanics. Artifacts made of fine-grained raw materials such as vitreous volcanics are present, but few in numbers (Stout et al., in prep).

Our continued systematic survey and excavations in the years 1999 and 2000 in the Ounda Gona South (OGS) area produced additional 2.6 Ma stone artifacts at OGS-6 and OGS-7 (Semaw et al., 2003). At the OGS sites, in addition to trachyte and rhyolite, artifacts were made on a greater variety of raw materials including latites and aphanitic volcanics which were well represented in the assemblages. Moreover, vitreous volcanics were more extensively used at OGS-7 than at the EG sites (Stout et al., 2005). The two OGS sites have a minimum age of 2.53±0.15 Ma based on the $^{40}Ar/^{39}Ar$ date of a tuff located stratigraphically directly above OGS-7. Further, the age of the two OGS sites was corroborated with the identification of the Gauss-Matuyama paleomagnetic transition (2.6 Ma) at the level of the OGS-7 excavation. The OGS sites are important for yielding additional stone assemblages that are contemporary with the artifacts excavated from the EG sites, and for providing the opportunity for investigating Late Pliocene hominin toolmaking activities, the variations in the stone assemblages, and patterns of resource exploitations at 2.6 Ma. The most informative artifacts and associated fragmentary fauna were recovered *in situ* from OGS-7, and the materials were excavated within fine-grained sediments. The OGS-6 excavation also yielded *in situ* artifacts, but with no associated fossilized bones. However, at OGS-6, a freshly eroded bone with definite cutmarks was identified from the surface providing direct evidence that the earliest stone artifacts may have been used for accessing animal resources (Semaw et al., 2003; Domínguez-Rodrigo et al, 2005; also see de Heinzelin et al., 1999).

The cobbles from the underlying conglomerates near both the EG and the OGS sites, the probable stone raw material sources used for making the artifacts, were sampled yielding interesting results (Stout et al., 2005, 2008, in prep.). Rhyolite was the most dominant of the raw materials in the cobbles sampled from both the EG and OGS areas. Latites at OGS, and basalt and trachyte near the EG sites, make up the second most prevalent materials in the associated cobble conglomerates in each area. Rhyolite and trachyte dominate the EG assemblages whereas rhyolite, latite (quartz latite) and aphanitics were fairly represented in the OGS assemblages. Most interestingly, vitreous volcanics, which were totally absent from the OGS cobble samples, were frequently used for making the OGS artifacts.

Detailed study of the Gona artifacts shows that a complex scenario of raw material sourcing and selectivity, and different modes of core reduction was already in place at 2.6 Ma. Further extensive sampling and experimental knapping studies will be important to firmly understand the reasons for the differential selectivity of raw materials by the contemporary hominins that lived in the EG and OGS areas. Nonetheless, it has become clear that the earliest toolmakers, even at the threshold of artifact manufacture and use at 2.6 Ma were already selective and preferred raw materials that are fine-grained and

more flakable. The OGS sites are providing new clues on the stone tool behavior of the first toolmakers, and the evidence confirms that by 2.6 Ma they were far more sophisticated in their planning, foresight and modes of artifact manufacture than was previously recognized.

Key Words: Oldowan, East Gona (EG), Ounda Gona South (OGS), earliest stone tools, raw material selectivity, Late Pliocene artifact assemblage variability

Introduction

The EG sites are located east of the Kada Gona, one of the major rivers from the easternmost part of the Gona study area that feeds into the Awash. The 2.6 Ma EG archaeological sites outcrop about 5 Km upstream from the confluence with the Awash River. The Ounda Gona is a tributary of the Kada Gona from the west, and the 2.6 Ma OGS archaeological sites are located south of the river (Figure 1). The two Late Pliocene sites of OGS-6 and OGS-7 were excavated in 2000 and yielded substantial archaeological materials with major implications for understanding the beginnings of early hominin stone tool behavior, and their ancient habitats. OGS-7 has yielded the most informative artifact assemblage and associated fauna, and more concentrated geological and archaeological investigations were carried out at the site.

Our studies show that the OGS stone artifacts, both in terms of composition of raw materials and modes of core reductions, are somewhat different from the contemporary archaeological materials recovered previously from the EG sites (Semaw et al., 2003; Stout et al., 2005). Our investigations, although preliminary, show that the types of raw materials used, and their differential flaking properties may have played an important role in determining the morphology and characteristics of the lithic assemblages excavated from the two areas. How did the use of different raw materials influence artifact form and size? How variable are the assemblages from the two areas of EG and OGS? Is the evidence sufficient to explain the reasons for the differences seen between the stone assemblages recovered from the EG and OGS areas? This paper explores the role that raw material proximity, accessibility and its flaking-quality may have played in the different modes of core reduction seen at the EG and the OGS sites. Further, we provide preliminary assessment of the assemblage variability seen during the initial stone manufacture and use at 2.6 Ma, and during the Oldowan documented at Late Pliocene-Earliest Pleistocene sites elsewhere in Africa.

Only the *in situ* archaeological materials excavated from EG-10, EG-12 and OGS-7 are analyzed here because these sites have yielded the largest sample of stone artifacts recovered within well-constrained geological/geochronological context. Artifacts greater than 20mm in maximum dimension are treated in more detail. The raw materials used for making the EG stone artifacts were reanalyzed by one of us (DS) following the more elaborate identifications used for the OGS-7 stone assemblages in Stout et al. (2005). The detailed identification of the cobble samples from both the EG and OGS areas indicate differences in the flaking-quality and proportion of the raw material types accessed in the two areas (Stout et al., 2005, in prep). Further systematic and extensive sampling of the cobbles/raw materials, and experimental knapping studies are needed for understanding the raw material selectivity and artifact manufacture practiced by the earliest toolmakers, but our preliminary investigations indicate intriguing and more complex behavior was already in place even during the initial stages of the production of stone artifacts at 2.6 Ma.

Initial research at Gona

The palaeoanthropological importance of the ancient artifact-rich and fossiliferous deposits exposed within the middle reaches of the Afar Rift was first recognized by Maurice Taieb (see Taieb et al., 1976). His initial explorations in the late 1960s laid the groundwork for the systematic investigations undertaken in the Afar during the subsequent four decades. Taieb's preliminary geological reconnaissance survey showed the presence of laterally-extensive artifact and fossil-rich Plio-Pleistocene deposits outcropping along the main course of the Awash River and its major tributaries. Subsequent systematic and extensive field investigations in the Afar led to the discovery of the Hadar, the Middle Awash, the Gona and the Dikika, and recently the Woranso-Mille study areas. Decades of fieldwork at these major sites has produced remarkable fossil hominins and archaeological materials (Kalb et al., 1982a & b; Johanson et al., 1982; Clark et al., 1984, 1994, 2003; White et al., 1994, 2003, 2006; WoldeGabriel et al., 1994, 2001; Renne, et al., 1999; Kimbel et al., 1994, 1996; Semaw, 2000, 2005, 2006; Semaw et al., 1997, 2003, 2005; Quade et al., 2004, 2008; Asfaw et al., 1999, 2002; de Heinzelin et al., 1999; Haile-Selassie, 2001; Haile-Selassie et al., 2004, 2007; Alemseged et al., 2006; Wynn et al., 2006; and references therein).

The archaeological significance of the Gona deposits was first noted in the early 1970s with the discovery of low density surface exposed artifacts from localities named Afaredo-1, and Kada Gona 1, -2, -3 and -4 (Corvinus, 1976; Corvinus & Roche, 1976; Roche & Tiercelin, 1977, 1980). The Afaredo and Kada Gona occurrences were located in the deposits exposed east of the Gona River, just north of the EG sites excavated later by Semaw et al. (1997). The initial fieldwork by Roche et al. (1977, 1980) in the Kada Gona documented artifacts traced between two conglomeratic layers named the Intermediate Cobble Conglomerate (ICC) and the Upper Cobble Conglomerate. The ICC is located just below the EG-10 and EG-12 excavations, and probably it was the source of the raw materials used for making the EG artifacts (Semaw, 2000, 2006; see also Semaw et al., 2003; Stout et al., 2005). Initially, Roche & Tiercelin (1977, 1980) recognized four volcanic tuffs (ashes I-IV) in the stratigraphic sections exposed at East Gona, and three of

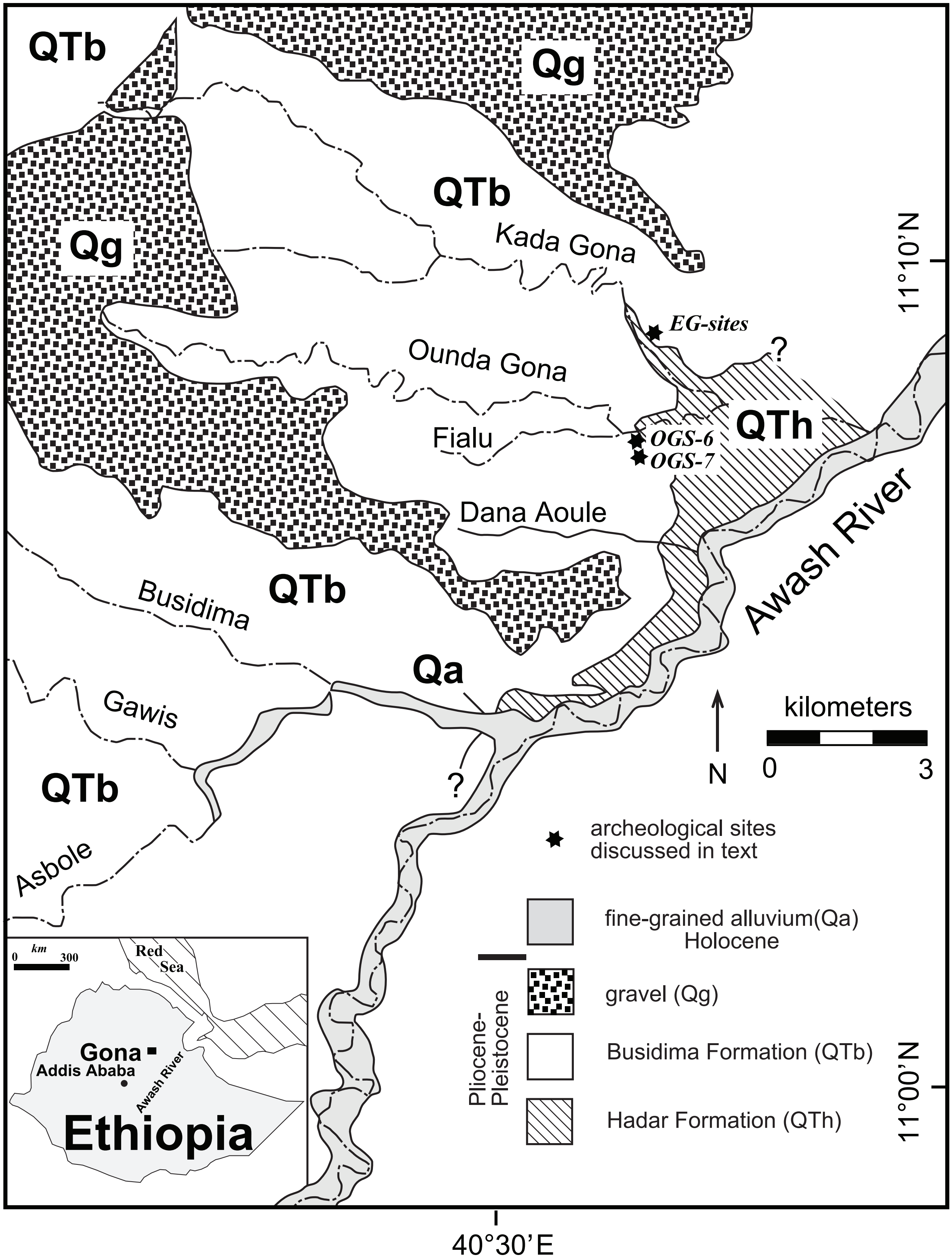

Figure 1. A map of the Gona Palaeoanthropological Research Project Study Area. The East Gona and the Ounda Gona South excavated sites are located in the easternmost part of the Gona study area (after Semaw et al., 2003; map modified by J. Quade).

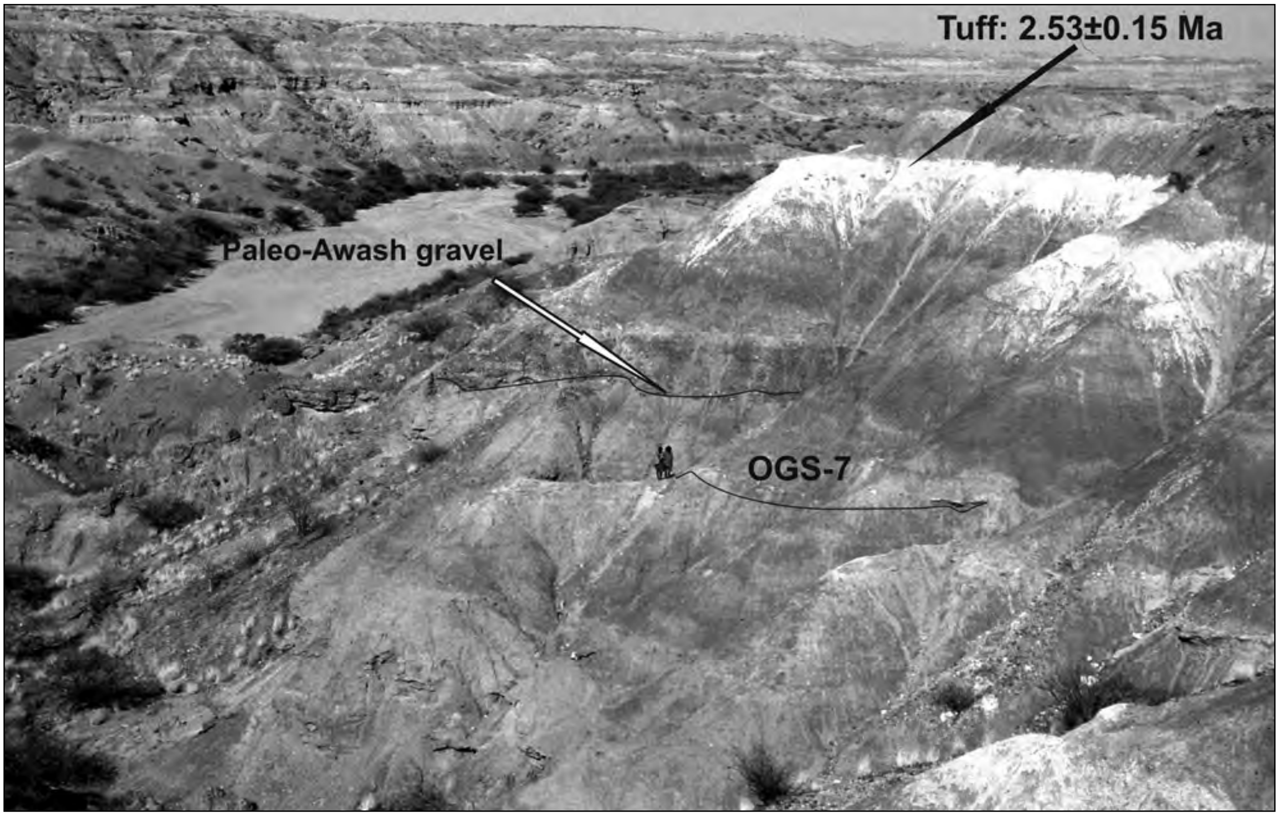

Figure 2. A photo showing the OGS-7 archaeological site with the prominently exposed tuff $^{40}Ar/^{39}Ar$ dated to 2.53±0.15 Ma, the stratigraphic position of the OGS-7 excavation and the cobble conglomerate (paleo-Awash gravel) sampled for this study (after Semaw et al., 2003).

these were later renamed as Artifact Site Tuffs (AST-1, -2 & -3) by Walter (1980). These tuffs were too altered for radioisotopic Ar/Ar dating, but still useful as markers for correlating the archaeological sites in the Kada Gona and associated drainages. The Afaredo and Kada Gona artifacts found in the early 1970s were at the time estimated to 2.5 Ma based on the supposed correlation of the BKT-2 tuff from the Hadar Formation with the AST-2 tuff exposed at East Gona (Walter, 1980; Walter & Aronson, 1982; but see Semaw et al., 1997). The BKT-2 has been re-dated to 2.9 Ma (Kimbel et al., 1994), and the age was later confirmed with the discovery of the Green-marker tuff at East Gona, which was also dated to 2.92 Ma by $^{40}Ar/^{39}Ar$. The Green-marker tuff is a correlative of the BKT-2 from Hadar and stratigraphically located several meters below the EG archaeological sites (Semaw et al., 1997).

In situ stone artifacts from systematic excavations within the Kada Gona drainage were first documented in 1976 from a locality identified at West Gona, later renamed as WG-1 (Harris, 1983; Harris & Semaw, 1989). The WG-1 artifacts were of low density, and like the Afaredo and Kada Gona sites, the 2.5 Ma age for West Gona was again an estimate based on the supposed stratigraphic correlation of the artifact-bearing layer with the BKT-2 tuff from Hadar. Recent geological investigations indicate that the artifact-bearing deposits at WG-1 and the adjacent archaeological localities at West Gona (except probably for WG-5 which may be EG-10 & -12 age) lie stratigraphically above the EG sites, and probably date to ~2.4-2.3 Ma (Quade et al., 2004, 2008).

The East Gona Archaeological Localities of EG-10 and EG-12 and the Stone Artifacts: Brief Summary

EG-10 and EG-12 were discovered in 1992, and the surface and *in situ* artifacts from both sites combined number more than 3,000. The two sites were excavated within fine-grained deposits securely dated between 2.6-2.5 Ma (for details see Semaw et al., 1997). Within the upward-fining stratigraphic sequence exposed at East Gona, the Intermediate Cobble Conglomerate (ICC) is located just below EG-10 and EG-12, and prominently exposed near the two sites. The ICC also extends laterally within the Kada Gona and associated drainages and it may have been the closest source of the cobbles used for making the EG stone artifacts. The AST-2.75 tuff (discovered in 1993), located ~5-7 meters above the EG sites, was dated to 2.52± 0.075 by $^{40}Ar/^{39}Ar$, and assisted in resolving the age of the oldest Gona artifacts (Semaw et al., 1997). Paleomagnetic analyses of the sediments sampled along the stratigraphic sections exposed near EG-10 and EG-12 placed the Gauss-Matuyama transition dated to 2.58 Ma (McDougall et al., 1992) within the ICC, also corroborating the age of the overlying tuff. Hence, the EG-10 and EG-12 artifacts are securely dated between 2.52 -2.6 Ma, with the excavated layers closer to the maximum age.

The EG-10 and EG-12 stone assemblages consist of cores/choppers and *débitage* (whole and broken flakes and angular fragments), representing the main artifacts known in the Oldowan or Mode 1 core/flake Industry (M. Leakey, 1971; Clarke, 1969). A majority of the EG cores were unifacially-worked using the hand-held percussion technique as the main mode of core reduction. A large number of the cores were made on trachyte and rhyolite cobbles and most were identified as unifacial side choppers (*sensu* M. Leakey, 1971). Although unifacial-flaking was dominant, a large number of specimens were also bifacially-worked and some were identified as core scrapers, including one partial discoid from EG-10 and a heavily reduced small polyhedral core recovered from EG-12.

Artifacts identified as *débitage* comprise about 97% of the stone assemblages of EG-10 and EG-12. The whole flakes from both sites were well-struck and show clear platforms, prominent and pronounced bulbs of percussion and smooth release surfaces. Like the cores, a majority of the whole flakes were made of trachyte and rhyolite, and mainly side-struck. EG-10 and EG-12 contain a large number of split flakes and angular fragments, and again the pieces were dominated by trachyte and rhyolite. Although unifacial working was the main mode of flaking, bifacial/polyfacial working was also practiced, confirming that the makers were skilled knappers with clear understanding of the mechanics of conchoidal fractures on stones, and that the hominins were capable of manipulating the cores for acute flaking angles. Retouched pieces (though whether deliberate or accidental is unclear), are present, but rare.

The OGS-7 Archaeological Locality, Ounda Gona South

The Late Pliocene deposits exposed in the Ounda Gona South (OGS) area, located ~ 3-5 km south-southwest of the EG sites were systematically surveyed in 1999, and the presence of archaeological sites lower in the stratigraphy at OGS was first noted with the discovery of a high density of Oldowan artifacts and fauna on the surface at the locality named OGS-6 (Figure 1). Intensive survey of the immediate area in 2000 produced OGS-7, the most informative of the OGS sites (Semaw et al., 2003). OGS-7 was found in the Fialu (40° 31' 42.758'N, 11° 6' 3. 479'E), one of the major streams feeding into the Ounda Gona. Both sites were excavated in 2000, and OGS-7 yielded the highest and densest concentration of artifacts and associated fauna *in situ*. OGS-6 also yielded a limited number of excavated artifacts and a surface eroded bone with evidence of definite cutmarks (Semaw et al., 2003; Domínguez-Rodrigo et al., 2005). Although the bones were poorly preserved, the OGS-7 excavated materials provide the oldest documented associations of artifacts and fragmentary fauna dated close to 2.6 Ma, and the most informative artifact assemblage for investigating and understanding the raw material selectivity of the first toolmakers.

Stratigraphy and dating

During the 2000 survey, surface exposed artifacts at OGS-7 were found eroding out of a steep-walled section, which also showed the relationships of the artifact-bearing horizon to the overlying dated tuff, and the entire stratigraphic sequence at the site (Figure 2). The archaeological site is situated within the newly designated Busidima Formation and stratigraphically lies immediately above the geological disconformity widely documented at Gona (Quade et al., 2004, 2008). The disconformity is stratigraphically located below the fluvial sediments associated with the paleo-Awash, and above the lacustrine and deltaic sediments preserved in the post-Hadar-age deposits (<2.9 Ma). Penecontemporaneous lacustrine and deltaic sediments are also exposed at East Gona just below the ICC and above the Green-Marker tuff dated to 2.92 Ma. The disconformity is laterally-extensive and well-exposed in both the OGS and EG areas, and it is estimated between 2.9-2.7 Ma (see Semaw et al., 1977, 2003; Quade et al., 2004, 2008). At OGS-7, above the disconformity are a series of ~5-8 m thick upward fining sections with conglomerates at the base, followed by rhyzolith-rich sands and bedded silts capped by paleo-vertisols (Semaw et al., 2003; Quade et al., 2004). Figure 3a shows the stratigraphic sequence at OGS-7. Stratigraphically OGS-7 is placed within the middle of the second upward fining cycle. The excavated artifacts and fragmentary fossilized fauna are confined to a <10cm-thick fine vertisol, and the materials were uncovered resting flatly on a local contact between coarse sand below and bedded silt above.

The volcanic tuff prominently exposed ~7 meters directly above the OGS-7 excavation was dated by $^{40}Ar/^{39}Ar$ to 2.53±0.15 Ma, and the Gauss-Matuyama chron geomagnetic polarity transition (GPTS) dated to c. 2.58 Ma (McDougall et al., 1992; Cande & Kent, 1995) was traced at the level of the site (Figures 2 and 3b). Thus, the age of the OGS-7 archaeological materials is well-constrained between 2.6-2.53 Ma. The artifact-bearing horizons at both OGS-6 and OGS-7 are extensive and can be traced laterally between the two sites, which are separated by only about 300 meters; hence, both sites are dated to the exact same age (Semaw et al., 2003). Further, the stratigraphic position of the EG and OGS sites appear to be similar suggesting that the toolmakers in both the EG and OGS areas may have shared a contemporary landscape, but probably with diverse habitats and varied access to raw material sources.

The OGS-7 Excavation and Archaeology

The OGS-7 archaeological site was found on a steep-walled section with the dated tuff prominently exposed directly above it (Figure 2). About 200 artifacts (including surface scrapes) were collected from the surface, and more than 700 excavated artifacts (with a large number

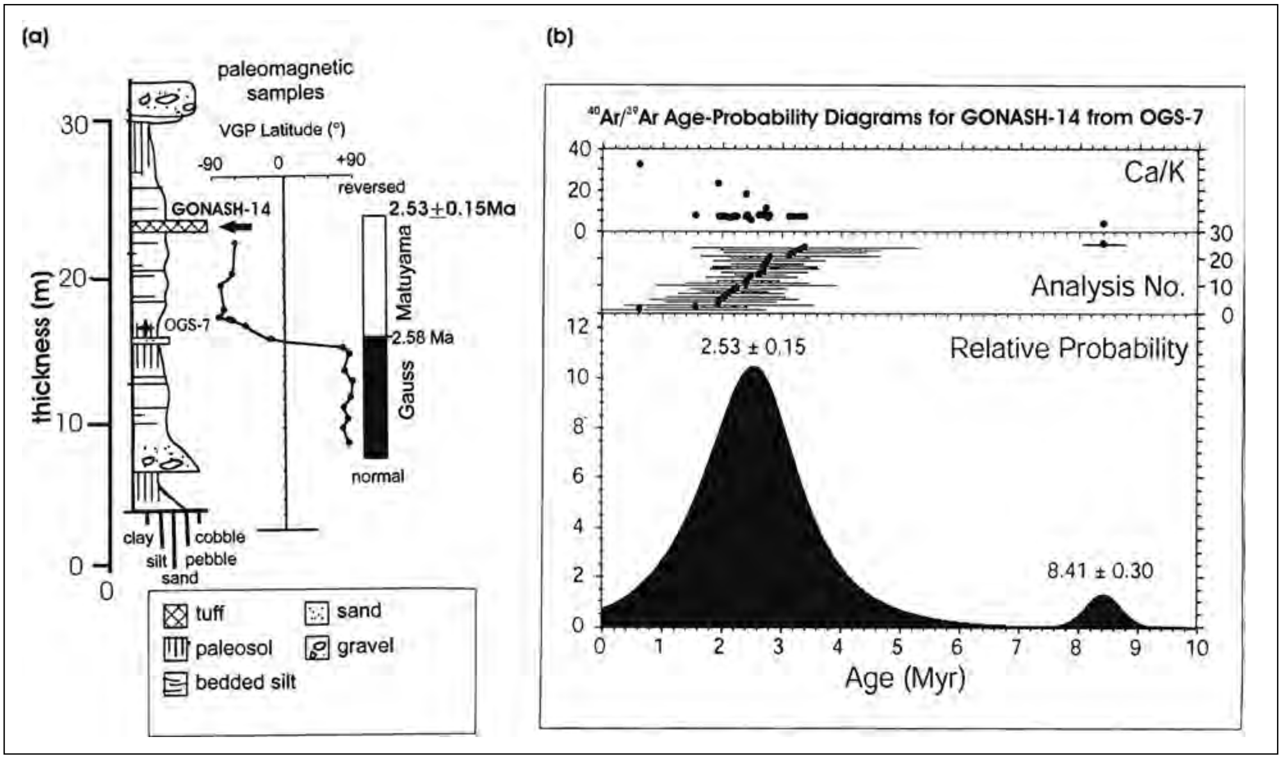

Figure 3. The stratigraphy and paleomagnetic analysis of OGS-7. a) Site-mean virtual geomagnetic polarity (VGP) latitude is plotted against stratigraphic level; negative VGP latitude indicates reversed polarity, b) $^{40}Ar/^{39}Ar$ spectra on GONASH-14 (after Semaw et al., 2003).

measuring <20 mm) and fossilized bone fragments were recovered *in situ* within fine-grained sediments. Figure 4 shows some of the *in situ* artifacts excavated within fine-grained sediments. Over 25 meters of overburden lie in the steep exposures above OGS-7 and only a portion (4m × 0.65m) of the site was excavated. Because of the steep exposures, excavations were undertaken on steps cut for standing, and the archaeology team dug into the wall slowly succeeding to uncover only a portion of the site. Despite the difficulty of removing the overburden, and the small size of the area excavated, the materials recovered at OGS-7 were of very high density (at least 162 artifacts/m^2 and 13 bone fragments/m^2 piece-plotted only). Figure 5 shows the horizontal and vertical distribution of the excavated artifacts. The artifacts were very fresh and vertically restricted within <10cm-thick layer with no preferred orientation, implying an undisturbed archaeological association. The artifacts consist of typical Oldowan choppers/cores and *débitage* (whole flakes, broken flakes and angular fragments) made of a variety of raw materials including trachyte, rhyolite, latite, aphanitic and vitreous volcanics. More than ~97% of the artifacts fall into the *débitage* category. Although the artifacts were very fresh, the fauna were very fragmentary probably due to hominin-induced breakage and damage, and possibly as a result of pre-fossilization weathering.

A variety of raw materials were used for making the artifacts, but unique for OGS-7 is the presence of a large number of *débitage* made of vitreous volcanic (12%), a fine-grained raw material type rare for any of the Gona assemblages dated to 2.6-2.5 Ma. Vitreous volcanics were totally absent from the cobble samples randomly collected within the associated conglomerate (the most likely source of the clasts used for making the artifacts), and none of the OGS-7 cores were identified to this raw material. In contrast, all of the remaining raw material types utilized for making the OGS-7 artifacts were identified within the cobbles sampled from the conglomerate associated with OGS-7.

All of the cores from OGS-7 were bifacially/polyfacially-worked, heavily-reduced and smaller in size, except for 1 unifacial (centripetal), but intensively worked specimen, attesting to the sophisticated understanding of conchoidal fracture on stone and superb knapping skills of the makers. Most striking at OGS-7 is also the presence of a considerable number of well-struck, knife-like whole flakes and some deliberately retouched pieces made of fine raw materials. The fossilized bones excavated from OGS-7 were fragmentary and poorly-preserved for documenting stone tool-induced modifications, and *in situ* bones with evidence of cut marks have yet to be excavated from the oldest 2.5-2.6 Ma sites at Gona. However, a bovid calcaneus with definite cut marks was found on the surface at OGS-6 (Domínguez-Rodrigo et al., 2005). The OGS-6 cut-marked bone was recovered along with a large number of freshly exposed artifacts. The fossilized bones excavated from OGS-7 were tightly clustered (horizontally and vertically) with the artifacts. A bone flake with a clear striking platform and diagnostic bulb of percussion was also recovered

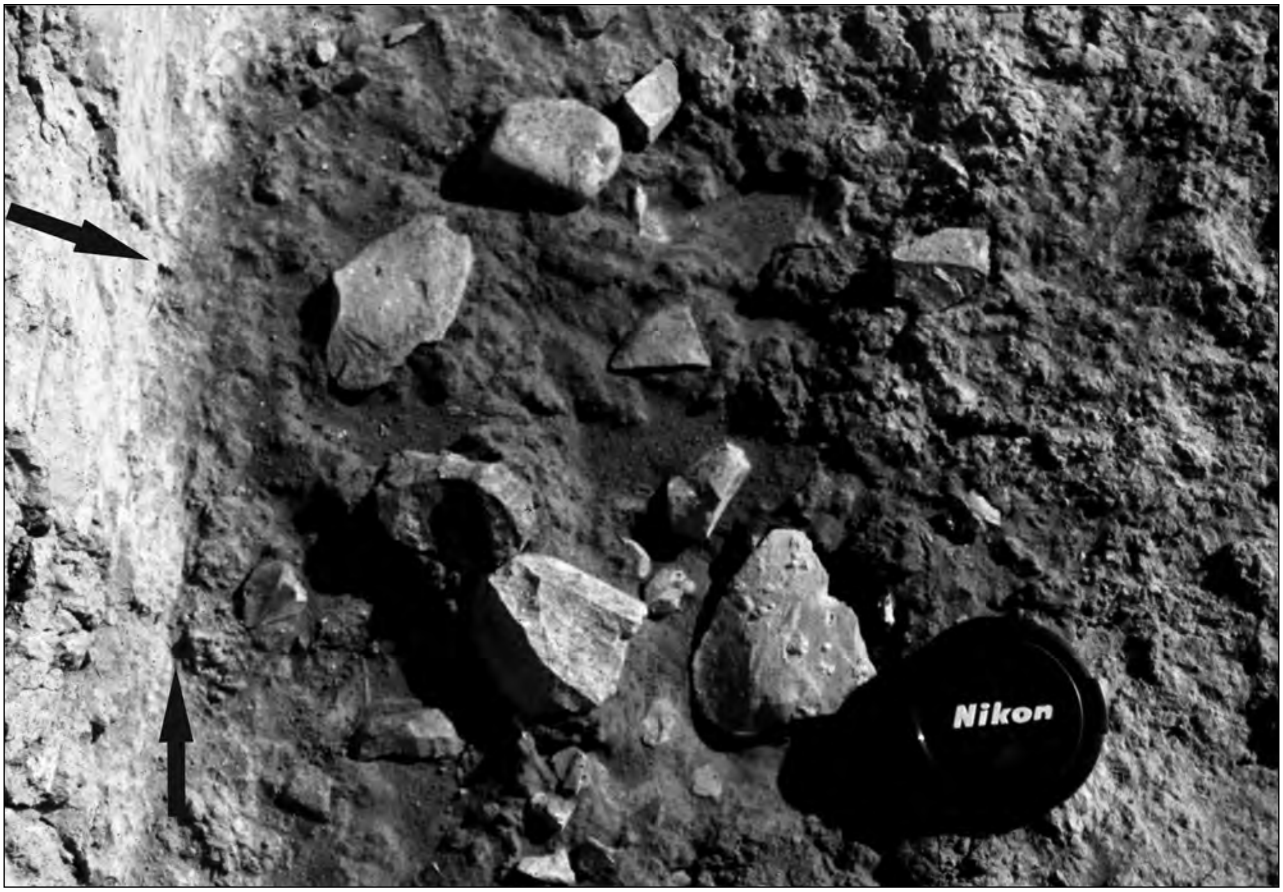

Figure 4. The OGS-7 "excavation floor" showing the in situ artifacts and fragmentary bones recovered in fine-grained sediments. (the excavation wall is shown by the arrows)

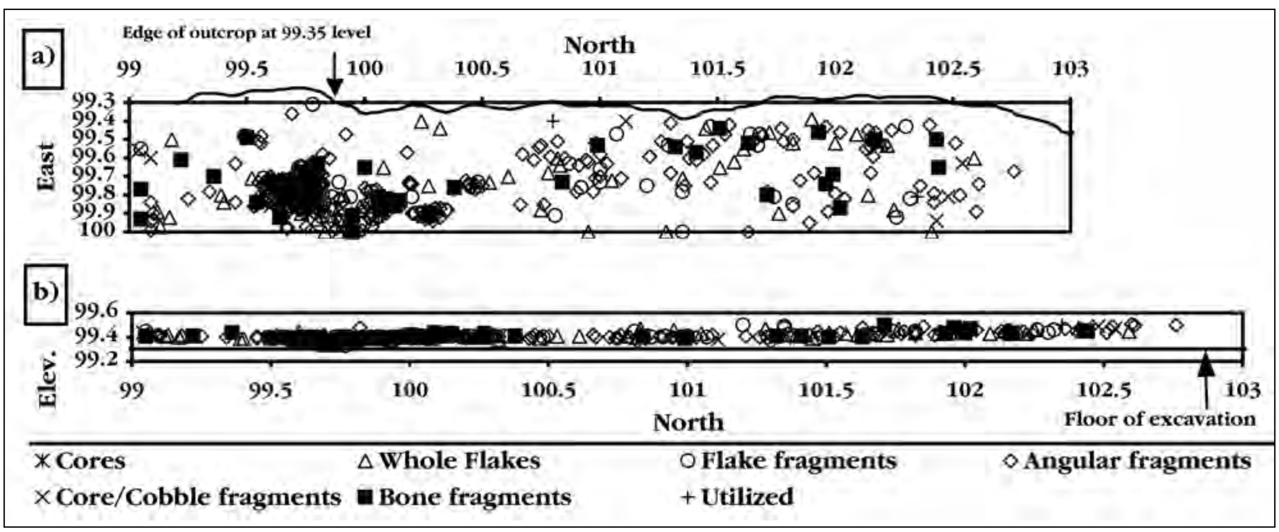

Figure 5. Artifacts and bone piece plot showing, a) the horizontal and b) the vertical distribution of the excavated materials at OGS-7.

in situ in association with the OGS-7 excavated stone artifacts pointing to hominin activities related to carcass processing. Stone tool cut-marked bones are also known from contemporary deposits at Bouri, in the Middle Awash (de Heinzelin et al., 1999). The Bouri excavated bones lack associated stone artifacts, but the cut mark evidence clearly shows that ancestral hominins by ~2.6-2.5 Ma used sharp-edged flaked stones for processing animal carcasses for meat. Despite the fragmentary nature of the excavated bones, and lack of *in situ* cut-marked bones at Gona, the association between artifacts and broken fossilized remains of ancient animal bones with clear evidence of damage induced by hominin activities at 2.6-2.5 Ma has been unequivocally established for the first time with the evidence from OGS-6 and -7.

The Stone Raw Materials Used at the Earliest Sites at Gona

Most of the Plio-Pleistocene archaeological sites at Gona, including OGS-7, are located near conglomerates, the probable cobble sources exploited for the raw materials used for making the stone artifacts. The cobbles were deposited along the main course of the ancestral Awash and would have been accessible on cobble bars in the main channel, especially during the dry season (Quade et al., 2004). Clasts may also have been exposed in tributary channel cuts on the nearby floodplains. One of us (DS) undertook systematic and random sampling of the cobbles from the conglomerates exposed just below and laterally to the OGS-7 excavation to assess the availability of cobbles suitable for knapping and to determine the selectivity of the toolmakers (for details see Stout et al., 2005, in prep). Figure 6 shows the raw material types identified from the cobble samples from EG13 (~100-200 meters from EG-10 and EG-12) and OGS-7 and the composition of the raw materials used for making the artifacts.

The cobbles in the samples (random and systematic from the conglomerate exposed near OGS-7) included trachyte, rhyolite, latite and aphanitic volcanic materials, and only one-fifth of those systematically sampled were > 5cm in maximum dimension, i.e. of a size suitable for knapping. Artifacts made of vitreous volcanics are abundant at OGS-7, but such materials were absent from the cobble samples. Of the 116 cobble samples systematically excavated from the conglomerate associated with OGS-7, "31% were identified as trachyte, 26% as rhyolite, 26% as latite, 11% as aphanitic lava and the remaining as indeterminate (6%). The random outcrop sample was dominated by latite (41%) and rhyolite (34%), with a smaller percentage of basalt (18%) and trachyte (7%), but no chert clasts [vitreous volcanic] were recognized" (Semaw et al., 2003, p. 175).

The OGS-7 site is undisturbed post-depositionally and preserves a high percentage of *débitage* (~97%) for contrasting the types of raw materials sampled in the conglomerate, and to determine the selectivity of the hominins. "The raw material composition of the OGS-7 excavated *débitage* (29% latite, 20% trachyte, 14% rhyolite, 12% chert [vitreous volcanic] and 25% others including aphanitic) contrasts strongly with the availability of raw materials in the conglomerate" (Semaw et al., 2003, p. 175).

In fact, no significant correlations were detected between the frequency of the raw material types identified in the cobble samples and in the OGS-7 *débitage* (see Semaw et al., 2003; Stout et al., 2005 for details).

The heavy utilization of vitreous volcanics (12% of the *débitage*) is striking with almost every vitreous volcanic flake produced from a different original nodule. However, no vitreous volcanic cores were recovered from the excavation, and such materials were completely absent from the associated cobble samples. It remains most likely that the toolmakers obtained these materials locally (although precise transport distances remain unclear), however, the failure to recover a single vitreous volcanic clast from a combined sample of 216 cobbles indicates an extremely low rate of occurrence. Thus, the presence of abundant artifacts made of vitreous volcanics and other raw materials that were not identified in the cobbles sampled near OGS-7 implies that the homi-

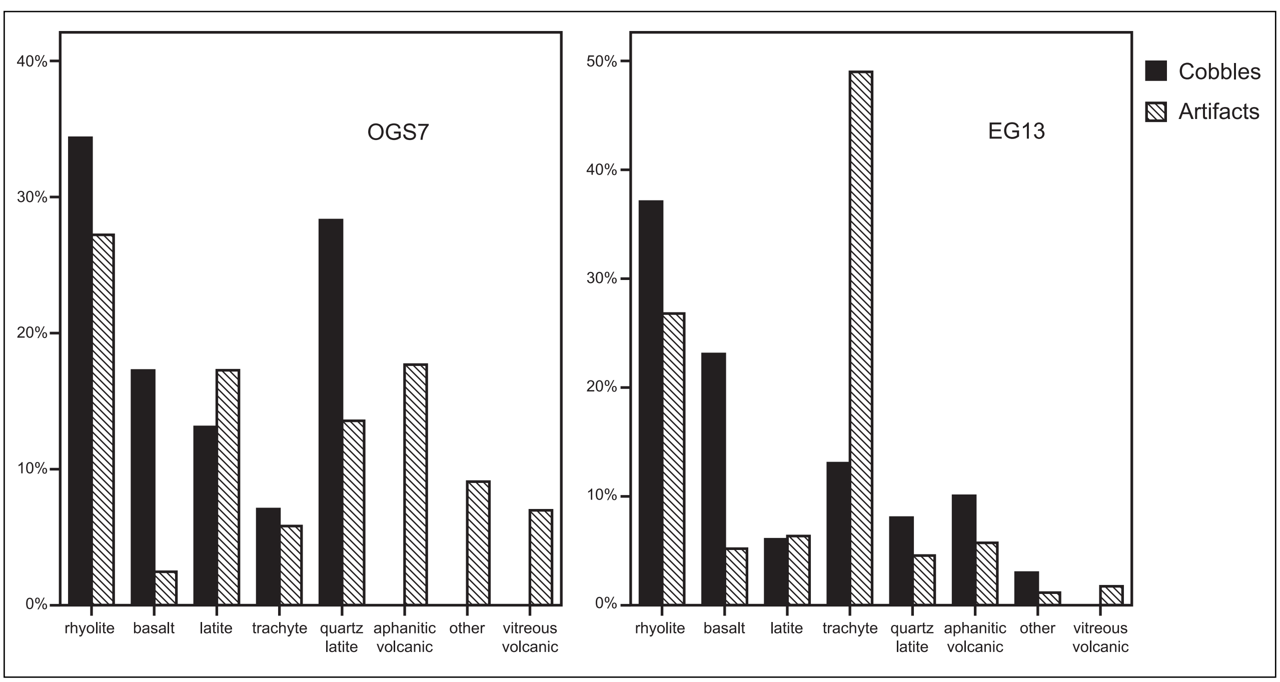

Figure 6. The distribution of raw material types in the conglomerate samples and actual artifacts from OGS-7 and EG13 (after Stout et al., 2005).

nins practiced a high level of selectivity for good-size (fist-size) and better-flaking quality cobbles accessed from nearby sources.

In contrast, the EG-10 and EG-12 artifacts were predominantly made of trachyte and rhyolite cobbles selected from the nearby gravels associated with the ICC. The ICC was the closest source of raw materials and fist-sized cobbles suitable for making artifacts were accessible from ancient channels located near EG-10 and EG-12. The toolmakers had to travel only a short distance to acquire these cobbles. Stout et al. (2005) carried out random sampling of the cobbles found eroding from the ICC near EG13. The preliminary study of Stout et al. (2005) shows that a majority of the cobbles sampled from the ICC were rhyolite and basalt (~60% of the samples) with trachyte cobbles making up just over 10%, and other raw materials such as latite and vitreous volcanics making up the remainder. Interestingly, a majority of the EG13 (nearly 50%) stone artifacts were made of trachyte, and close to 30% on rhyolite, and the remainder on basalt and other raw materials, a pattern of selectivity similar to EG-10 and EG-12 (Stout et al., 2005). Figures 7-9 show the artifact breakdown by raw material types. The EG-10 and EG-12 raw materials were recently reanalyzed by one of us (DS) following the criteria outlined in Stout et al. (2005). Trachyte and rhyolite dominate the EG assemblages, followed by latite, aphanatic and vitreous volcanics. The distribution of detached pieces raw material types at EG-10 and EG-12 is statistically indistinguishable (n=445, Pearson's Chi Square =7.65, df=8, p=0.469), but differs significantly from that seen at OGS-7 (n=620, Pearson's Chi Square=179.7, df=8, p<0.001). The detached pieces make up ~97% of the total assemblages from each of the EG and OGS sites, and the results clearly show the differing patterns of raw material selectivity between the two areas.

Further systematic and exhaustive sampling and experimental work on the cobbles exposed near the EG and OGS sites is needed to conclusively determine the composition of the raw material types accessible in the conglomerates. The initial analyses of Stout et al. (2005, in press) indicate that the toolmakers in both areas show selectivity for particular raw materials for making the Oldowan stone artifacts. However, why the major em-

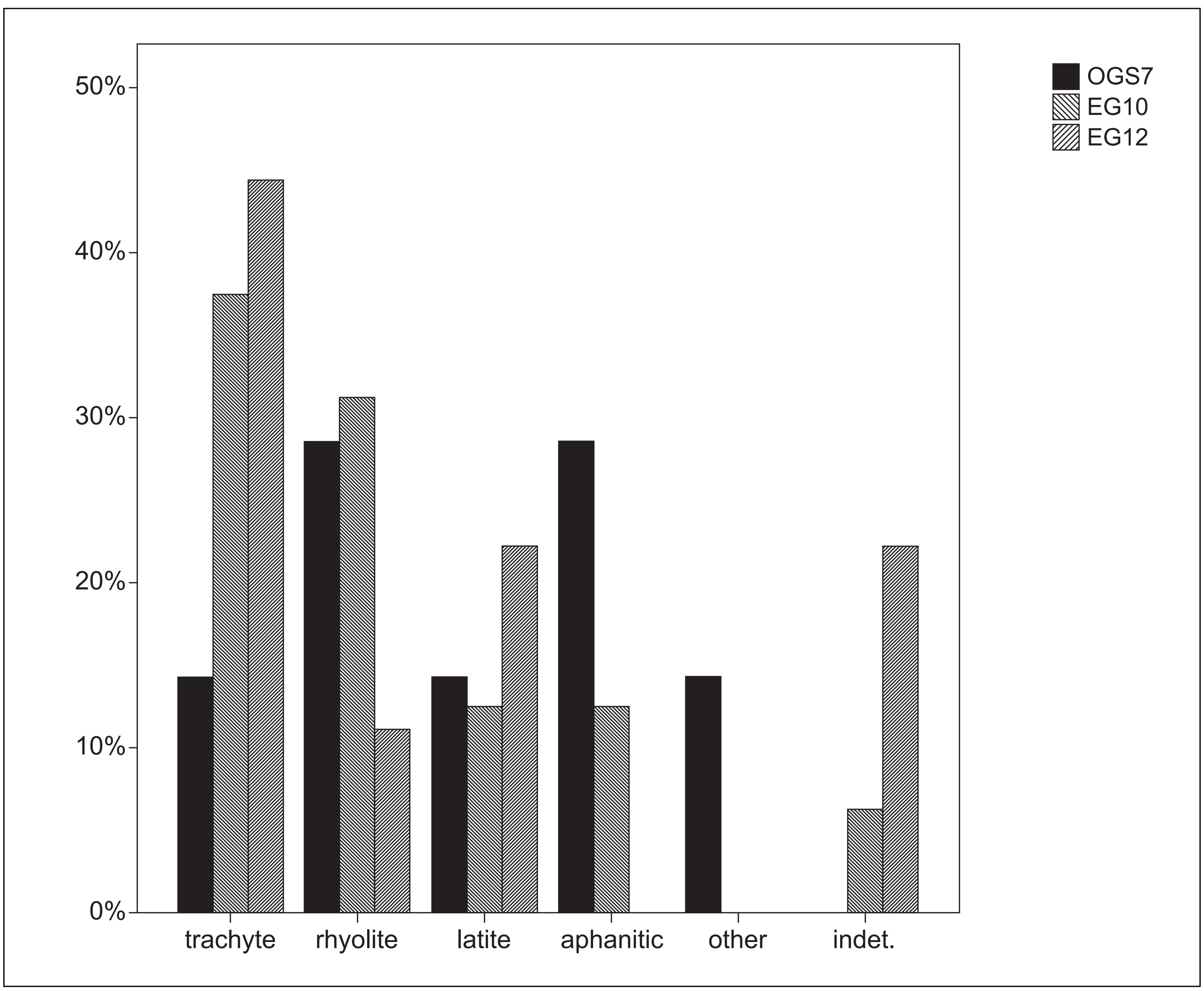

Figure 7. Percentage frequency of the raw material types used for making the EG-10, EG-12 and OGS-7 excavated cores.

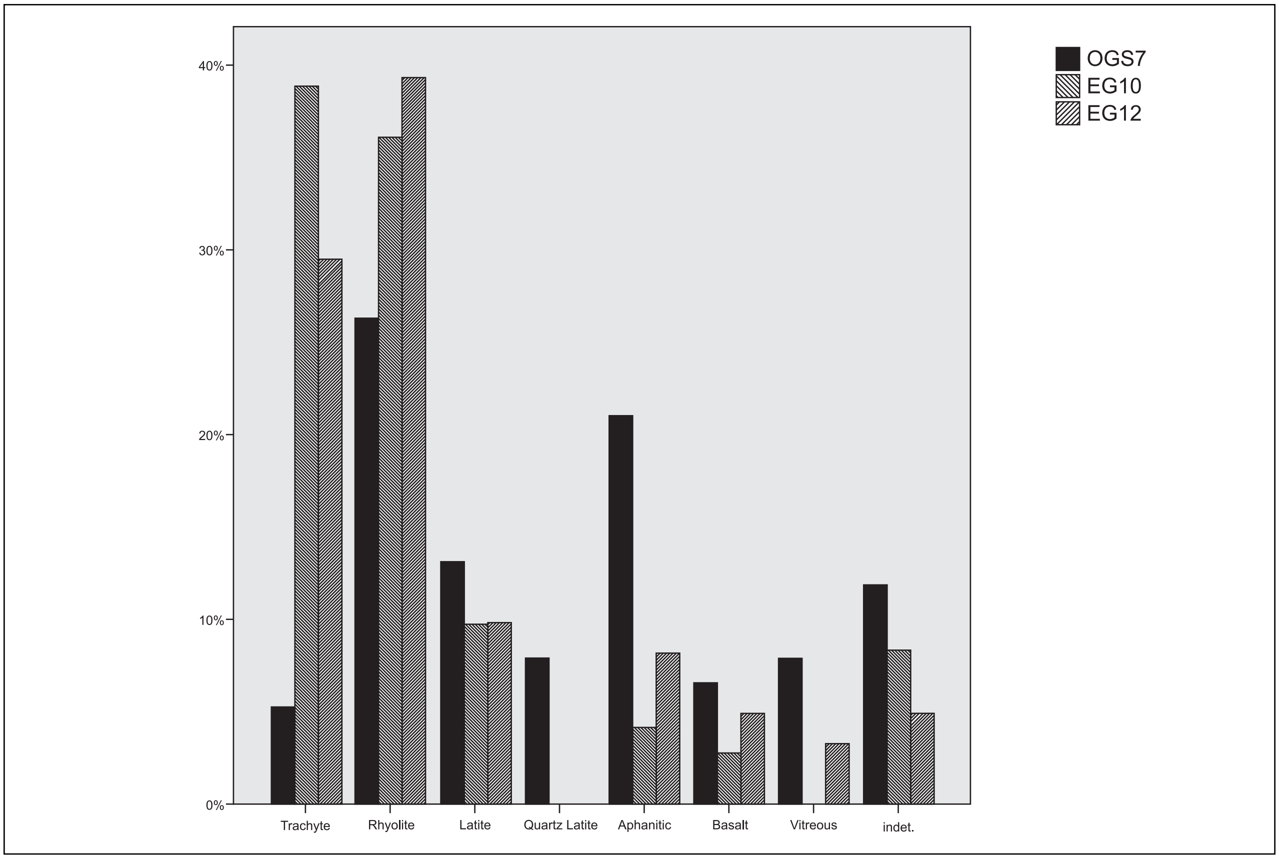

Figure 8. Percentage frequency of the raw material types used for making the EG-10, EG-12 and OGS-7 excavated whole flakes (after Stout et al., in prep).

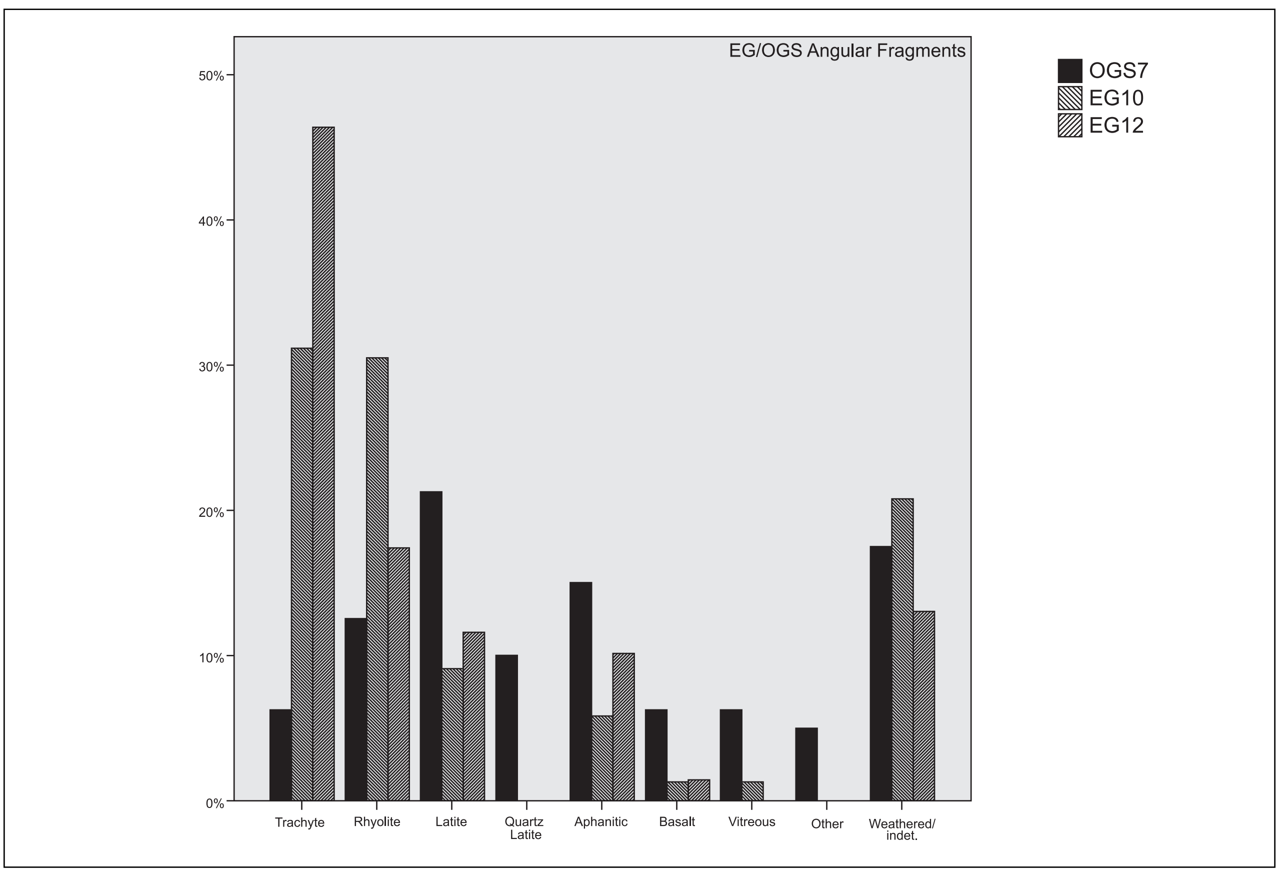

Figure 9. Percentage frequency of the raw material types used for making the EG-10, EG-12 and OGS-7 excavated angular fragments (after Stout et al., in prep).

Table 1. Percentage composition of all surface and excavated artifacts from OGS-7, EG-10 & EG-12. Data modified after Semaw, 2006. (n) = number of artifacts. The description of the artifacts follows M. Leakey's (1971) terminologies. Isaac et al's (1981) artifact categories are shown in parantheses. Note: The OGS7 artifact count includes only the specimens >20mm.

	OGS7		EG10		EG12	
	Surface	**Excavated**	**Surface**	**Excavated**	**Surface**	**Excavated**
All Lithics (n)	53	269	1549	687	309	444
All Artifacts (n)	53	269	1549	685	308	445
Manuports (Unmodified Stones)	0	0	0	0	0	0
Split Cobbles	0	0	0	1	1	0
Cores/Choppers or Tools (Flaked Pieces)	1.90	2.60	1.1	2.19	1.3	2.03
Débitage (Detached Pieces)	98.11	97.40	98.9	97.81	98.7	97.97
Utilised Materials (Battered & Pounded Pieces)	0.00	0.00	0.00	0.00	0.00	0.00
% Artifacts	100	100	100	100	100	100
Cores/Choppers or Tools (Flaked Pieces) (n)	1	7	17	16	4	7
Cores/Choppers	100.00	100.00	88.24	73.33	100.00	88.89
Discoids	0.00	0.00	5.88	20.00	0.00	0.00
Core Scrapers	0.00	0.00	5.88	6.67	0.00	11.11
% Total	100.00	100.00	100.00	100.00	100.00	100.00
Débitage (Detached Pieces)	52	262	1532	670	304	436
Whole Flakes	19.23	29.01	18.01	24.48	30.92	33.94
Angular Fragments	65.38	55.34	74.28	60.45	54.93	51.83
Split Flakes	5.77	10.69	5.42	8.36	12.17	9.86
Snapped Flakes	9.62	4.97	0.72	3.43	0.66	2.06
Split & Snapped Flakes	0.00	0.00	0.07	2.69	0.00	0.00
Core/Cobble Fragments	0.00	0.00	1.50	0.59	1.32	2.31
% Total	100.00	100.00	100.00	100.00	100.00	100.00
Utilised Materials (Battered & Pounded Pieces)	0	0	0	0	0	0

phasis was placed on trachyte at the EG sites and why other more fine-grained raw materials were selected/preferred (or used) at OGS-7 is an issue that needs further investigation.

The evidence from OGS-7 strongly corroborates earlier observations made regarding the sophisticated artifact manufacture, the raw material selectivity, and the effective knapping strategies of the hominins responsible for producing sharp-edged cutting flakes recovered from the EG sites (Semaw et al., 1997). The overall archaeological evidence from OGS-7 further reinforces the fact that the first toolmakers were more advanced in their decision-making and stone crafting behavior than previously recognized.

Characteristics of the EG and OGS Stone Assemblages

The Cores: Flaking modes, and the extent of core reductions

A large number of cores have been excavated from the East Gona archaeological sites, including 16 from EG-10, and 7 from EG-12. Table 1 shows the artifact composition of the EG and OGS-7 artifacts. A majority of the EG cores are unifacially-flaked (EG-10 ~70%, and EG-12 ~50%). Following M. Leakey (1971), most of the EG cores could be classified as unifacial side choppers. A large number of the EG cores/choppers are not as heavily-worked (compared to OGS-7). However, a number

Table 2. Basic measurements of the excavated cores

		OGS7	EG10	EG12
No. of Cores/Choppers		7	16	7
Maximum Dimensions				
	Mean	62.57	82.75	74.11
	Std	7.61	10.16	9.5
	Range	(45-70)	(68-106)	(58-87)
Length				
	Mean	44.14	83.33	74.45
	Std	13.68	10.34	8.72
	Range	(28-67)	(69-105)	(58-93)
Breadth				
	Mean	59	60.90	59.73
	Std	8.54	9.18	8.06
	Range	(45-70	(44-80)	(49-77)
Thickness				
	Mean	37	45.27	43.73
	Std	8.2	12.36	7.74
	Range	(22-49)	(30-69)	(25-53)
Total Scars				
	Mean	6	10.27	8.91
	Std	1.6	3.74	3.45
	Range	(3-8)	(6-21)	(3-15)
Largest Scars/ Dimensions				
	Mean	50.71	48.07	45.45
	Std	7	11.79	8.40
	Range	(41-60)	(30-65)	(33-60)
B/L				
	Mean	0.77	0.73	0.77
	Std	0.3	0.08	0.09
T/B				
	Mean	0.8	0.74	0.71
	Std	0.4	0.16	0.14

Table 3. Basic attributes of the excavated whole flakes

		OGS7	EG10	EG12
No. of Artifacts		73	114	62
Maximum Dimensions				
	Mean	44	42.18	40.94
	Std	15.5	15.56	13.85
	Range	(20-82)	(20-85)	(20-71)
Length				
	Mean	39.1	37.38	34.50
	Std	14.3	15.34	12.84
	Range	(13-80)	(14-78)	(15-66)
Breadth				
	Mean	37.1	34.63	35.55
	Std	14.1	13.74	13.23
	Range	(13-74)	(14-77)	(19-66)
Thickness				
	Mean	12.7	13.18	12.13
	Std	5.07	6.26	5.76
	Range	(3-26)	(3-33)	(4-30)
Dorsal Scars				
	Mean	2.2	3.07	3.00
	Std	1.5	1.72	1.54
	Range	(0-5)	(0-10)	(0-8)
Platform Breadth				
	Mean	23.23	22.86	24.56
	Std	10.67	11.37	13.27
	Range	(8-64)	(4-60)	(5-58)
Platform Thickness				
	Mean	9.1	10.21	10.10
	Std	4.2	6.04	5.65
	Range	(1-19)	(2-34)	(2-29)
Breadth/Length				
	Mean	0.99	0.96	1.08
	Std	0.34	0.26	0.30
Thickness/Breadth				
	Mean	0.36	0.39	0.34
	Std	0.14	0.11	0.11

Table 4. Maximum dimension, in situ angular fragments, and split flakes

	OGS7	EG10	EG12
Angular Fragments			
Count > 20mm	84	181	91
MD Avg.	30.48	27.02	26.81
STD	9.48	7.6	8.56
Range	(64-20)	(77-20)	(62-20)
Split Flakes			
Count > 20mm	26	46	38
MD Avg.	31.58	37.93	38
STD	8.4	11.99	12.4
Range	(26-20)	(73-22)	(77-21)

of the specimens were multifacially/polyfacially-flaked, heavily-reduced, and include polyhedral and discoidal cores (Figures 10-12). In addition, one 'Karari-like' core scraper was recovered from the EG-10 excavation (Figure 13). In contrast, six of the seven excavated cores recovered from OGS-7 were multifacially/polyfacially-worked, heavily-reduced (retaining only <25% cortex), and most can be identified as bifacial side choppers (with some polyhedral cores), and one as end chopper. Figures 14 and 15 show heavily-worked cores from EG-10 and OGS-7. Examples of two of the heavily-reduced cores excavated from OGS-7 are shown in Figure 16. Only one of the excavated cores from OGS-7 can be identified as a unifacial centripetal core. The maximum dimensions on the cores show the heavy-reduction of the OGS-7 cores (Table 2, Figure 17). Actually, the maximum dimension recorded for a flake from OGS-7 is greater than the maximum dimension of the largest core (82mm for the flake vs. 70mm for the core), which is not the case for the EG sites, where the maximum dimension of the cores is definitely larger than the flakes, as expected (see Tables 2 & 3).

A majority of the EG cores were made on trachyte (~55%) and the remaining on rhyolite and aphanitics. In contrast, most of the OGS-7 cores were made on rhyolite (~30%) and aphanitic volcanics (~30%), and the remaining on trachyte, latite and other (~14% each). Interestingly, none of the cores from OGS-7 (excavated or surface) were identified as vitreous volcanics, but 12% of the *in situ débitage* were of this raw material type. Based on observations of the color and texture of the *débitage*, at least four or five vitreous volcanic nodules may have been used at OGS-7, however, none of these flaked pieces were recovered at the site. Interestingly, EG-12 has yielded one core made on a glassy latite, but the number of *débitage* on this raw material from the EG sites is very low. The cores from the EG sites were predominantly unifacial and the evidence seems to be persuasive that this mode of core reduction may have been the dominant stone working technique in the EG area.

In terms of flake scars, the EG-10 cores have ~10 scars on average, whereas the OGS-7 cores retain an average of ~6 flake scars (Table 2). The relatively low number of flake scars recorded for OGS-7 may be due to the exhaustively-worked nature of the cores resulting in the removal of previous flaking scars in the course of the heavy-reduction process. The absence of vitreous volcanic cores at OGS-7 raises important questions. Based on our preliminary work at OGS-7, it can be argued that this raw material was sought after for its fine-grained property and better-flaking quality, and the cores were exhaustively-reduced for generating the most flakes. Fur-

Figure 10. Photo showing the EG-10 and EG-12 cores. The top row shows bifacially-flaked cores, and the bottom row examples of unifacially-flaked cores. The two cores on the top row are made on trachyte, and the third one on rhyolite. The two cores in the bottom row are made on trachyte, and the third on aphanitic volcanics. All the specimens (except for the larger piece in the bottom row) are excavated.

Figure 11. Photo showing the opposite faces of the cores in Figure 10.

ther, the cores that were already flaked at the site were probably conserved and transported by the hominins for further reductions at other yet undiscovered 'activity areas' across the ancient landscape. However, we need to expand the OGS-7 excavation to verify the validity of this suggestion. The less-exhaustively worked nature of the EG cores corresponds with the great abundance of suitable-size trachyte and rhyolite cobbles that were easily accessible and readily available in the ICC.

The nature of the cores from the EG and the OGS sites provides important clues on ancestral human behavior regarding conservation and transport of raw materials. The evidence from the EG and OGS sites strongly indicates that the heavy/moderate reduction and the size of the cores appear to correspond with the proximity and easy access to good-flaking raw materials. The heavy-reduction of the cores seen at OGS-7 is a good example of early hominin selectivity of raw materials with excellent flaking-quality, and exploitation of fine-grained raw materials to the maximum, possibly due to the relative scarcity of the most-favored raw material types. These finer-grained materials tend to be sharper, harder, and more durable than the coarser-grained lavas (N. Toth, pers. comm.).

Rounded-cobbles usually identified as hammerstones at other Early Pleistocene assemblages in East Africa are not known from either the EG or the OGS sites. However, a few of the cores from the EG sites show pitting/pounding marks on their cortical butt probably a result of use as hammerstones or possible use for pounding activities related to processing of animal carcasses such as for breaking bones for marrows. There are a few cores from OGS-7 that also have cortical butts that could have been used for the same purpose. Toth et al. (2006) point out that heavy-reduction of cores is an indicator of good flaking skills, and the overall archaeological evidence attests that the OGS-7 toolmakers were proficient knappers. The preponderance of side choppers is also listed by Toth et al. (2006) as an indicator of good knapping skills, and all the Gona sites contain a large number of specimens identified into this category (with a few number of end choppers), again confirming the superb knapping skills of the 2.6 Ma toolmakers at Gona.

The débitage

Whole flakes

A majority of the whole flakes both from the EG and the OGS sites show clear platforms, bulbs of percussion and smooth release surfaces. The flakes were well-struck showing that the makers were skilled knappers and understood the flaking property of the raw materials used (Figures 18-20). Like the cores, the EG-10 and EG-12 whole flakes are dominated by trachyte and rhyolite, with the remaining on aphanitics and latite (Figure 8). Just a few (<5%) were made of vitreous volcanic, basalt and other raw materials. In contrast, the OGS-7 whole flakes were predominantly made of rhyolite, trachyte, latites,

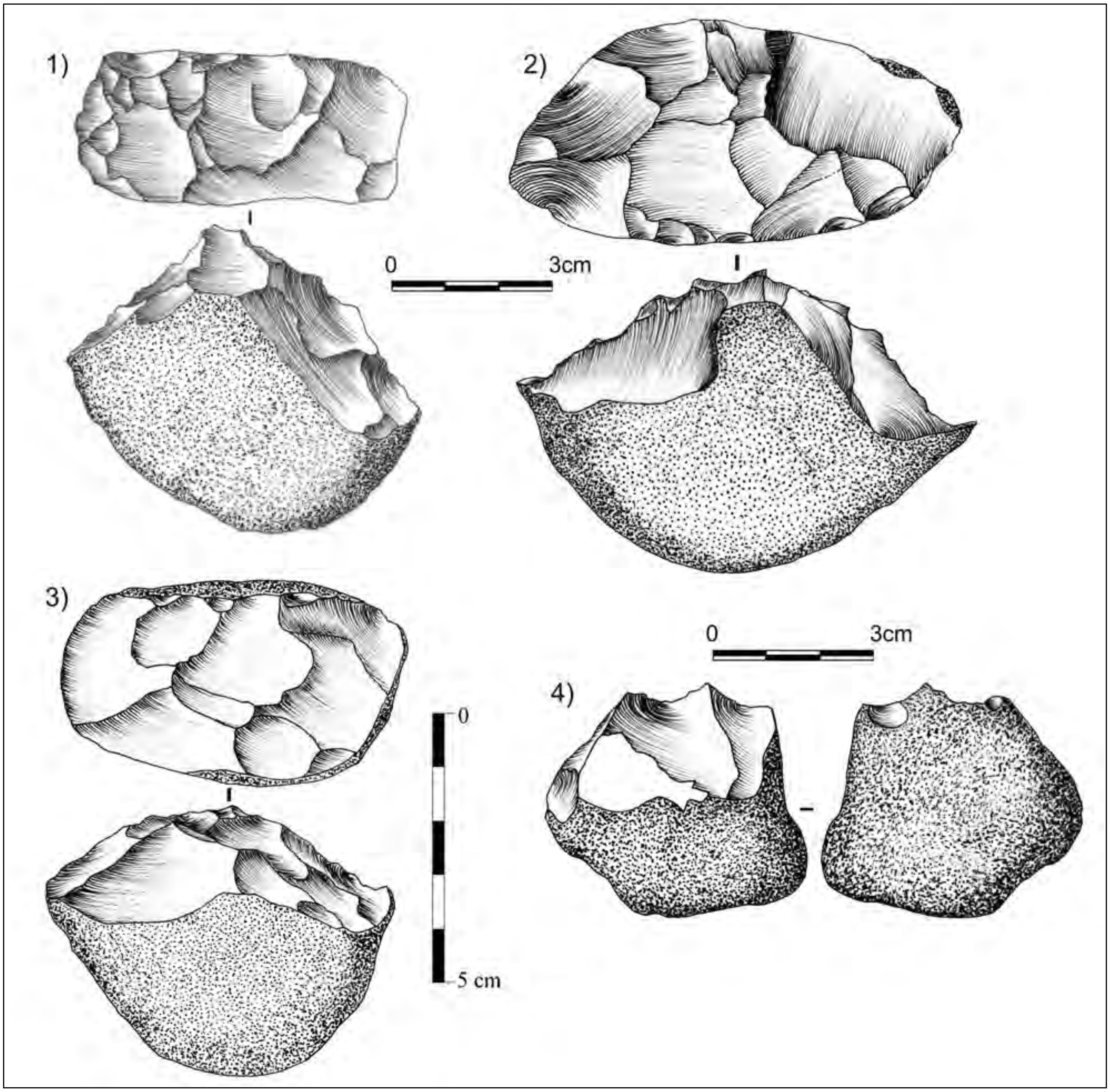

Figure 12. Drawings of excavated cores. 1 & 2, from EG-10, and 3 & 4, from EG-12. Note: these represent the typical cores excavated from the EG sites. Artifact drawings by D. Cauche.

aphanitic and vitreous volcanics, all represented in fair proportions. As shown in Figure 8 trachyte and rhyolite clearly dominate the raw materials on the whole flakes excavated from the EG sites, but the predominance of rhyolite at OGS-7 is not as marked. The flakes recovered from both the EG and OGS-7 assemblages average ~ 40mm (Table 3). Figure 21 shows the size frequency of the EG and OGS-7 whole flakes, and Figures 22 and 23 show some of the Gona flakes (including the cut-marked bone recovered from OGS-6) attesting the superb skill of the makers.

Flake types

Flake types are good indicators of the prevalent mode of core reduction represented in an assemblage, i.e. they provide the means for determining whether or not an assemblage is dominated by unifacial or bifacial-flaking (Toth, 1985, 1987). As shown in Figure 22, the most dominant flake types at EG-10 and EG-12 are flake type 3 (~45%) followed by type 2. In contrast, type 6 dominates at OGS-7 (>40%) followed by type 5. Interestingly, flake type 1 is missing from both the EG-10 and EG-12 whole flakes, but at OGS-7 flake type 1 comprises over 5% of the whole flakes. OGS-7 also has better representation of flake type 4 (~5%) compared to EG-10 (0%) and EG-12 (~1%). Generally, the flake types represented at EG-10 and EG-12 show that unifacial flaking of the cores was the dominant mode of reduction at both sites. In contrast, the higher percentage of type 6 and type 5 flakes at OGS-7 suggests predominantly bifacial

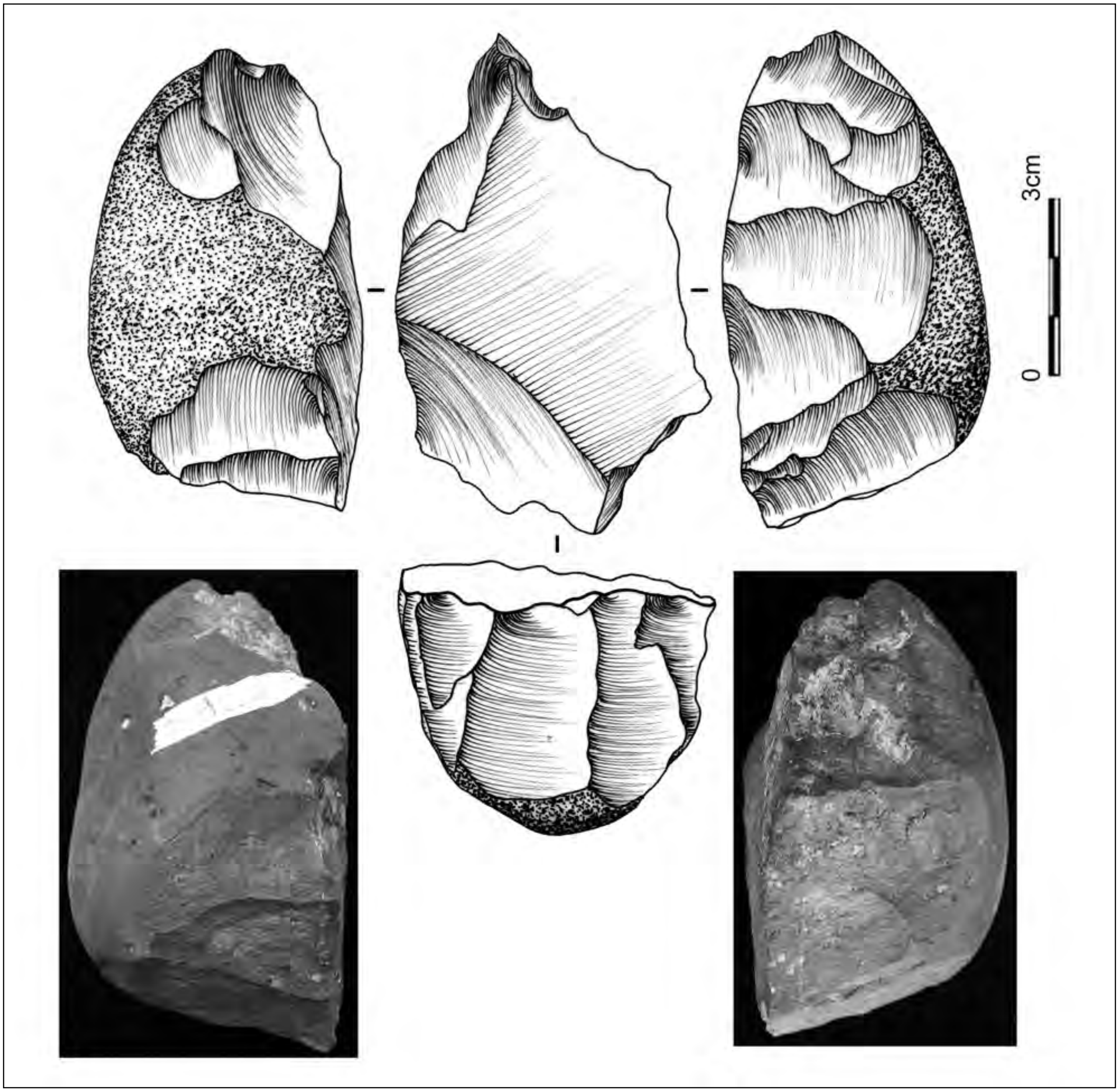

Figure 13. Drawing and photo of a "Karari-type" single-platform core (on trachyte) excavated from EG-10. Artifact drawings by D. Cauche.

reduction of the cores. The high incidence of flakes type 3 and type 2 at the EG sites clearly shows that a majority of the cores were unifacially-reduced through consecutive flake removal carried out by targeting the cortical surface of the cores. At OGS-7, flake type 6 and 5 dominate the whole flakes which is consistent with intensive bifacial and polyfacial reduction of cores.

Angular fragments and broken flakes

EG-10 has produced the highest number of artifacts, and as expected a large number of angular fragments as well (Table 4). Like the cores and the whole flakes trachyte and rhyolite dominate the angular fragments at EG-10 and EG-12 followed by latite and aphanitic volcanics (Figure 9). As shown in Figure 9, various raw materials are again more evenly represented in the OGS-7 angular fragments, with a fair proportion of latites and aphanitics as well as some rhyolite and vitreous volcanics.

Overall, a relatively large number of split flakes are documented at both the EG and the OGS sites, and until recently the implication of this pattern at Gona was unclear. However, recent experimental work by Toth et al. (2006) showed that higher percussive force results in the production of a large number of split flakes, and that the Gona hominins were applying appropriate force in striking large flakes from the cores (for details see Toth et al., 2006).

The Gona assemblages also consist of core fragments and snapped flakes, but these are relatively small in number. However, it is possible that some of the core fragments actually may be exhausted cores, and further experimental work may provide clues on the extent of

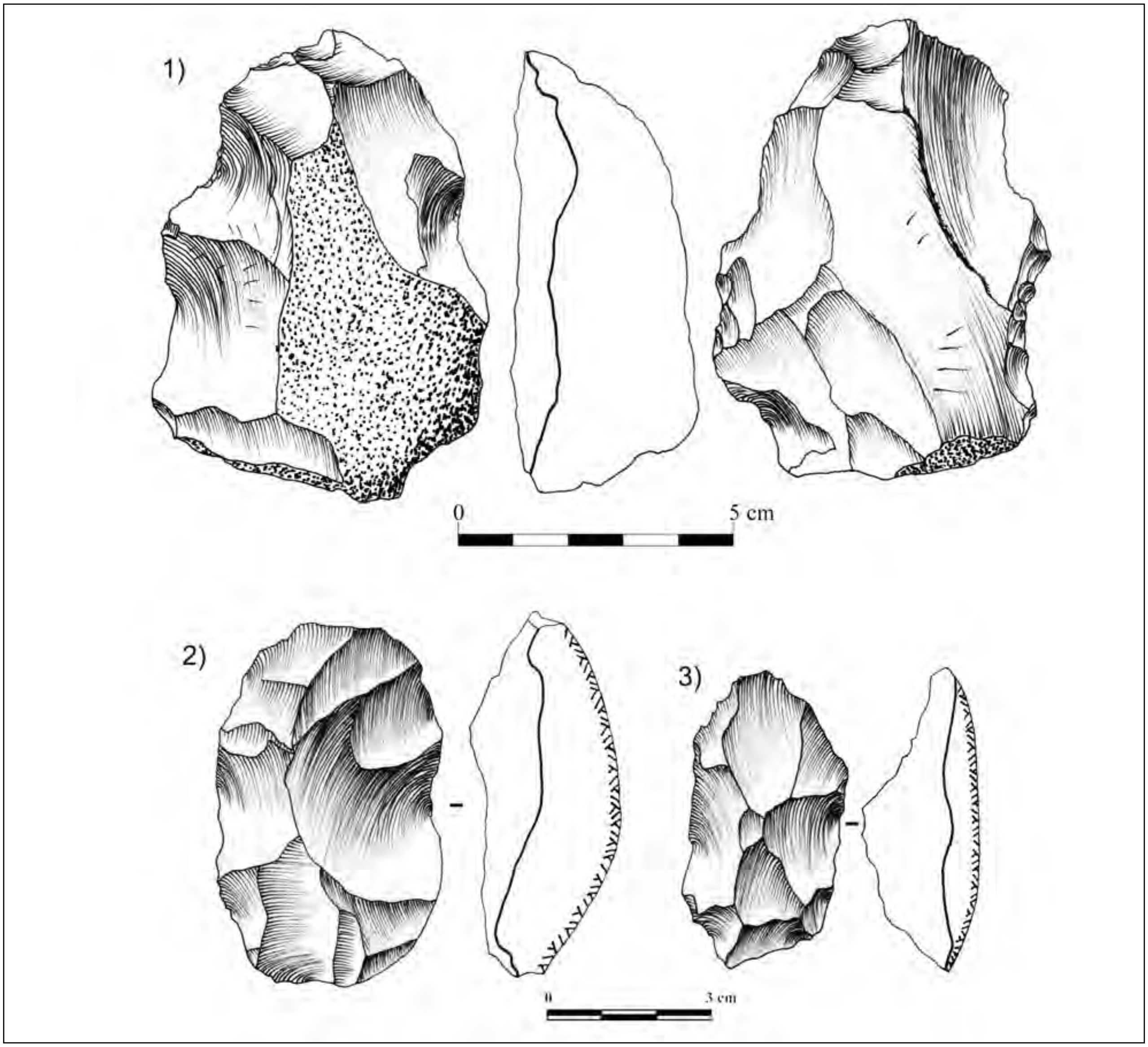

Figure 14. Drawings of cores from EG10 and OGS7. 1) Bifacially flaked “irregular discoid” on rhyolite from EG-10, 2 & 3) exhaustively-flaked unifacial cores on rhyolite from OGS-7 surface and excavation. Artifact drawings by D. Cauche.

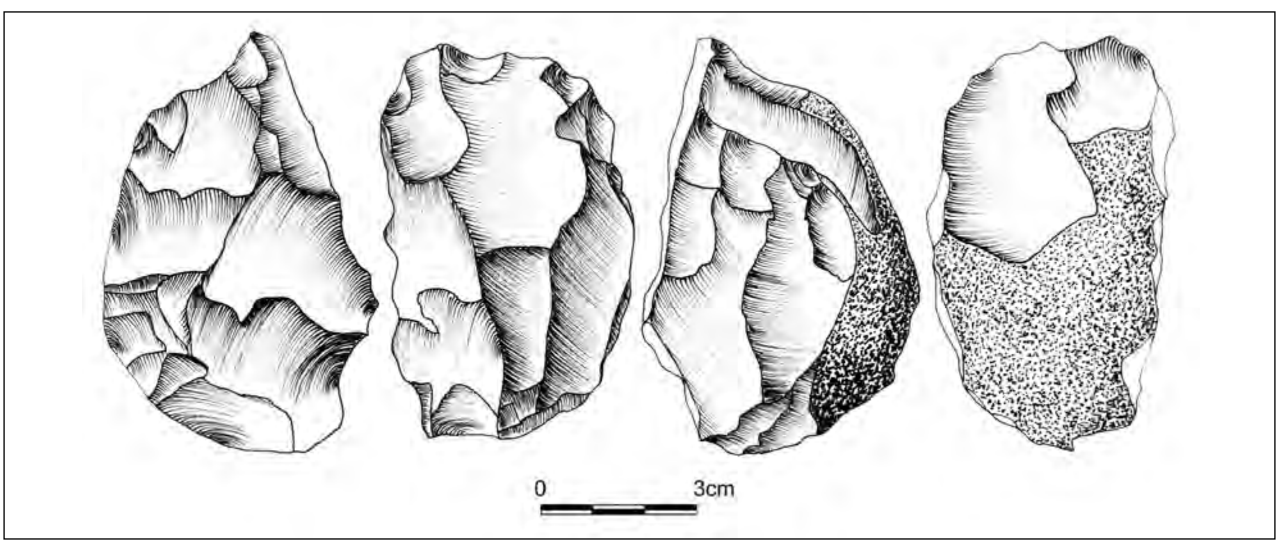

Figure 15. Drawings of a polyfacially and heavily-flaked excavated core on trachyte from EG-10. Artifact drawings by D. Cauche.

core reduction possible on the different raw materials accessible at Gona, on the characteristics of heavily-worked cores, and how to recognize those in an assemblage.

Late Pliocene-Early Pleistocene Hominin Artifact Transport?

As shown in Figure 22, OGS-7 has better representation of all of the flake types (Toth, 1985, 1987) compared to the EG sites where type 1 and type 4 flakes are missing. Despite the limited excavation at OGS-7, a much higher density of stone artifacts were recovered from the small area opened at the site. Further, the OGS-7 "excavation floor" appears to be littered with flaking debris, and it is likely that the assemblage represents much of the flaking that was conducted on site. Analysis of the EG-10 and EG-12 whole flakes by Toth et al. (2006) suggests active transportation of flakes from the EG sites probably for use elsewhere on the landscape. At OGS-7 all the flake types are fairly represented and this may not be apparent, but other lines of evidence indicate possible transport of artifacts may have been practiced at OGS-7 as well. In the case of OGS-7, it is likely that the cores made of fine-grained vitreous volcanics were transported by the hominins for further reduction over other parts of the ancient landscape. Again, further excavation at OGS-7 will be important for investigating the artifact transport behavior of the toolmakers.

The fact that hominins may have been transporting artifacts away from the densest concentrations, i.e. large sites (or traditionally referred to as 'workshops') is indicated by the composition of the artifacts from the EG and OGS sites. Isaac et al. (1981) have suggested that small sites ('mini sites') may provide clues regarding hominin activities away from larger sites ('maxi sites'), the focus of most research by Palaeolithic archaeologists. It is possible that the absence of a single core made of vitreous volcanics at OGS-7, in part, may have been due to the transport of these valuable cores into other yet to be discovered 'activity areas'. In addition, the manufacture of such a large number of artifacts that are still in fresh condition is intriguing. One would expect to find a large number of 'retouched pieces' or specimens damaged as a result of utilization, but only a few such possible pieces are found at most Late Pliocene sites (e.g., Gona, Lokalalei, Omo, etc.; see Delagnes & Roche, 2005; Chavaillon, 1976; Merrick, 1976; Merrick & Merrick, 1976). As suggested by Toth et al. (2006) there is a strong likelihood that 'favored specimens' may have been transported away from the larger sites and utilized elsewhere over different parts of the ancient landscape. Most likely such utilized specimens (retouched pieces or specimens with evidence of edge-damage) may be discovered at low-density archaeological sites or 'mini-sites' of Isaac et al. (1981). This is a possible scenario and will be the focus of further field investigations at Gona.

Discussion

Continued investigation of the Gona archaeological sites, study of the stone artifacts from EG-10 and EG-12 and comparison with the stone assemblages excavated from OGS-7 is providing important clues on yet unrecognized complex behavior of the first toolmakers. Previous study of the EG-10 and EG-12 archaeological materials has clearly shown that the earliest toolmakers had excellent mastery and control of fractures on stones and that the hominins produced thousands of artifacts during the initial stages of stone manufacture and use ~2.6 Ma (Semaw, 2000, 2006; Semaw et al., 1997). The OGS sites, located ~3-5 Km to the west/southwest of the EG sites, have yielded additional important information revealing more complex hominin raw material selectivity and transport behavior ~2.6 Ma.

Our investigation of the technological aspects of the earliest stone assemblages at the EG and OGS sites clearly indicate that no marked trends exist at Gona or elsewhere in East Africa for Late Pliocene-Early Pleistocene core reduction strategies to have gradually evolved from unifacial to bifacial/polyfacial stone working. Our recent studies also show that the behavior of the earliest toolmakers was much more complex than previously recognized. The evidence from Gona confirms that the first toolmakers practiced both unifacial and multifacial/polyfacial core reduction techniques just at the beginning of stone tool manufacture and use ~2.6 Ma, and selected for high quality raw materials. The degree of core reduction (minimal or exhaustive) seems to be related to the fine-grained nature and flaking-quality of the raw materials, and transport of artifacts over different parts of the ancient landscape may have been part of the overall technological repertoire. Although the final shape of the artifacts appear to be highly influenced by the size, flaking-quality, abundance and distances traveled to sources of raw materials, unifacial reduction of cores may have been the norm at the EG sites while bifacial/polyfacial working of cores was heavily practiced by the contemporary toolmakers at the OGS sites. It is unclear as of yet what influence, if any, cobble shape may have played in the difference.

Detailed study of the EG and OGS stone assemblages shows that the makers of the Gona artifacts at 2.6 Ma were proficient knappers, had clear understanding of stone fracture mechanics, and sophisticated skill and coordination for creating sharp-edged cutting stone flakes used for processing animal carcasses. In particular, the archaeological evidence from OGS-7 indicates that the hominins were economical where raw materials such as vitreous volcanics (with good-flaking quality) were scarce. Compared to the cobble source associated with the EG sites where fist-sized trachyte clasts were abundant and easily accessible, the situation at OGS-7 is unclear regarding how far the hominins had to travel to procure vitreous volcanics. The absence of any vitreous volcanic clasts from both the random and systematic

Figure 16. Photo of exhaustively-flaked cores from OGS-7 on trachyte and rhyolite respectively, both excavated.

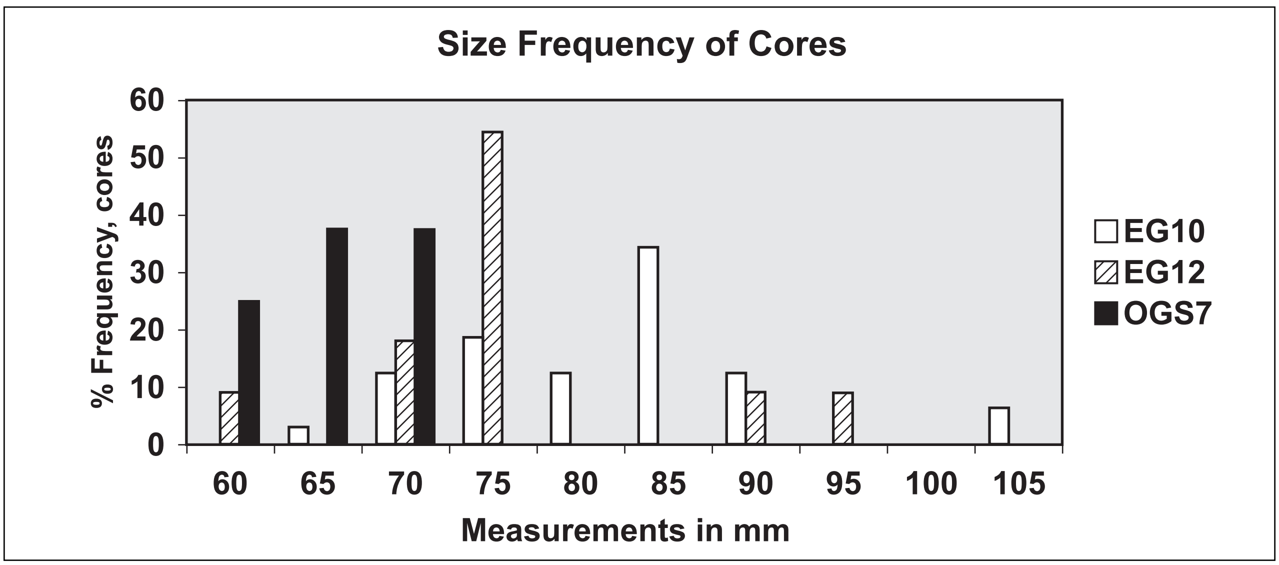

Figure 17. Size distribution of the excavated cores.

samples in the conglomerate associated with OGS-7, and the absence of even a single core made on this raw material from the OGS-7 excavation (or the surface) strongly suggests that the hominins were exhaustively reducing the vitreous volcanic cores and/or conserving and transporting them across the ancient landscape for further flaking at activity areas located away from the densest concentrations (sites) where initial flaking took place. At OGS-7, despite the small area excavated and the relatively small number of artifact recovery (i.e. compared to the EG sites), all of the six flake types were recovered implying some presence of all of the reduction stages on site (Toth, 1985, 1987). In contrast, flake types 1 and 4 are missing from the EG assemblages implying possible transport of artifacts away to other activity areas.

Based on the comparison of the excavated EG stone assemblages with the artifacts generated through experimental knapping of the cobbles sampled from the ICC, Toth et al. (2006) pointed out that early hominins at the EG sites were probably transporting selected large flakes away from the sites for further use over different areas of the ancient landscape. The evidence from OGS-7 reinforces Toth et al.'s (2006) observations with the difference that here the hominins appear to have transported cores rather than flakes. Toth et al. (2006) sampled unmodified cobbles selected from the ICC (on the basis of external appearance, like smooth cortex, size and shape), and imported the samples (through permission granted by the Ethiopian Antiquities and the Ministry of Mines) intact to the US for experimental knapping. Subsequent

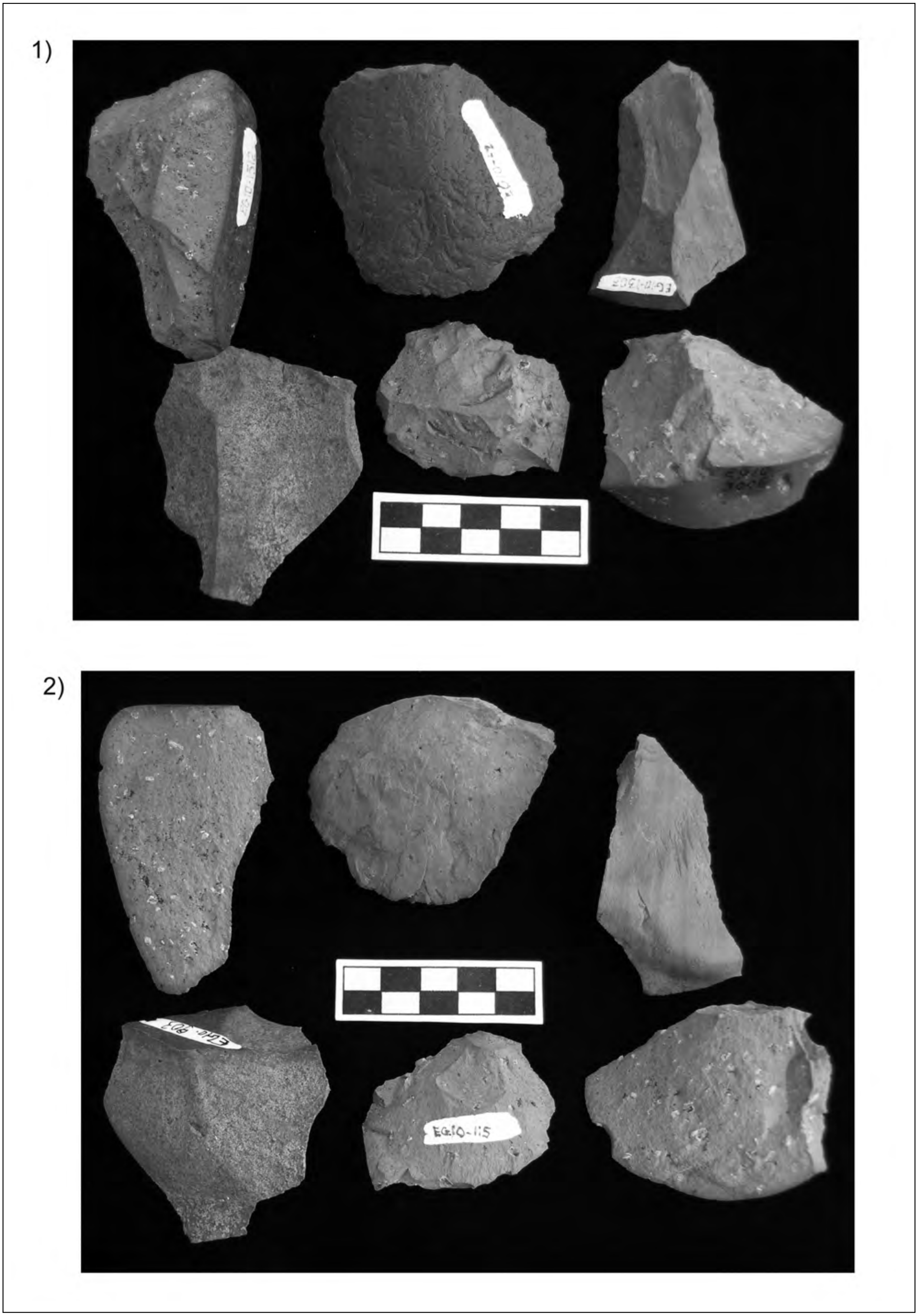

Figure 18. Photo of whole flakes from EG-10 & EG-12, made mainly on trachyte, rhyolite, aphanitic and vitreous volcanics.

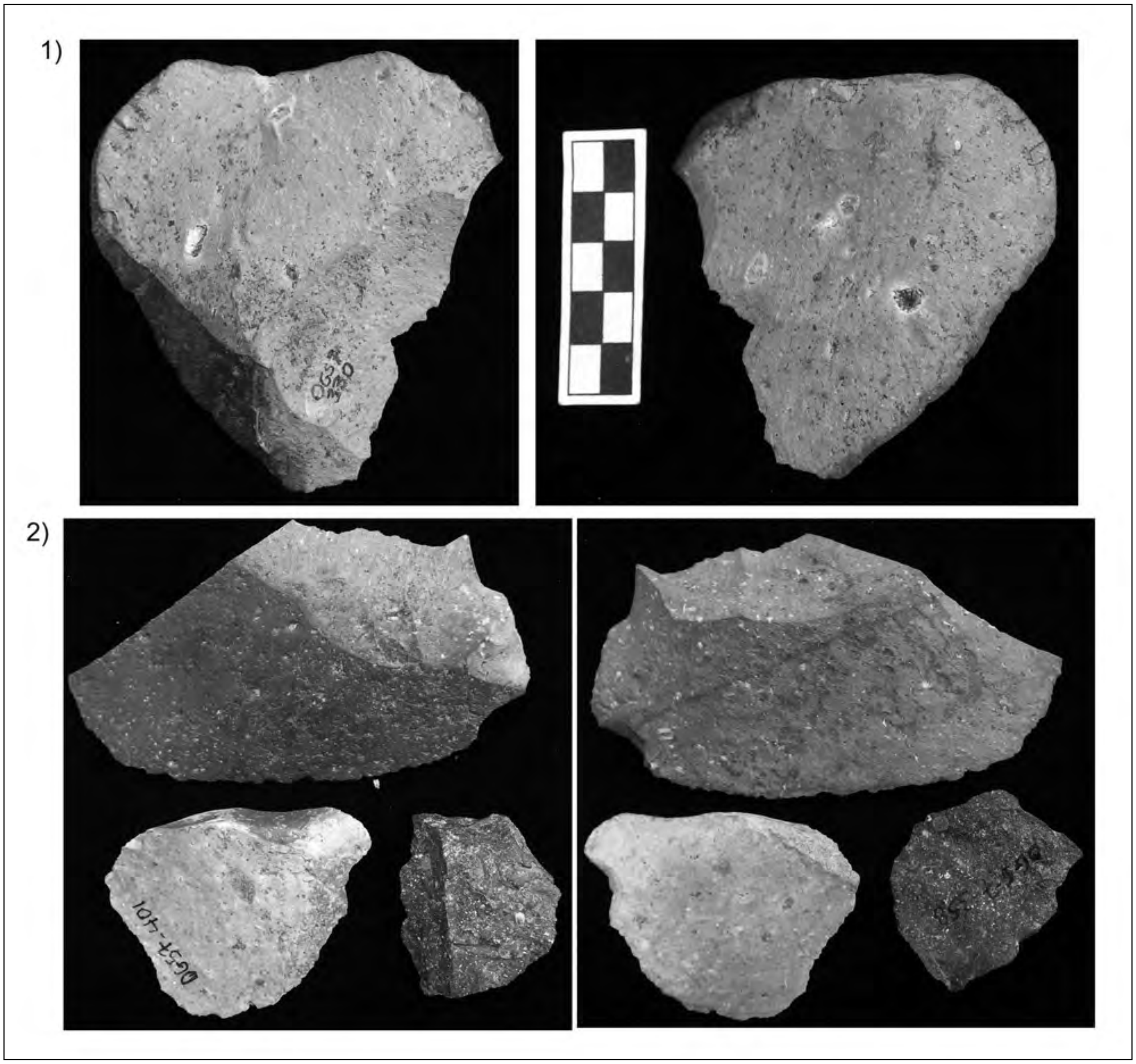

Figure 19. Photo of excavated whole flakes from OGS-7. 1) A large whole flake on trachyte from OGS-7 (actually larger in maximum dimension than any of the OGS-7 excavated cores), 2) examples of the whole flakes excavated from OGS-7. OGS-7-401 is made on vitreous volcanics, the larger piece on trachyte and the smallest piece on latite.

experimental knapping showed that about 75% of the cobbles selected from the ICC were of good-to-excellent flaking-quality, strongly suggesting that the Gona hominins were 'test-flaking' the cobbles at the gravel sources, and selecting for raw materials with "excellent" flaking-quality before transporting the cores for extensive knapping over the floodplains where the sites were formed. The Gona hominins at 2.6 Ma were highly selective and clearly utilized better-flaking-quality raw materials, and the evidence from OGS-7 supports earlier observations made regarding the sophisticated behavior and planning shown by the first toolmakers at the EG sites (Semaw et al., 1997).

Some researchers have suggested that high incidence of steps/hinges indicate low level of knapping skills (e.g., Kibunjia, 1994). The experimental knapping of the Gona cobbles by Toth et al. (2006) casts doubt if any relationships exist between steps/hinges and the level of hominin knapping skills. More instances of steps/hinges were recorded from the results of the knapping experiment conducted on the Gona cobbles by modern humans, i.e. compared to the number of steps/hinges counted on the Gona artifacts.

The use of different raw materials and proximity to sources may explain why different modes of flaking were practiced contemporaneously at EG and OGS, but it is also possible that factors related to group norms, microhabitats and tool function may have impacted the extent of core reductions seen in the two areas. Thus, investigations of aspects of the ancient environment ~2.6 Ma will be the goal of our future research. Experimental replication study of artifacts is a great tool for unravel-

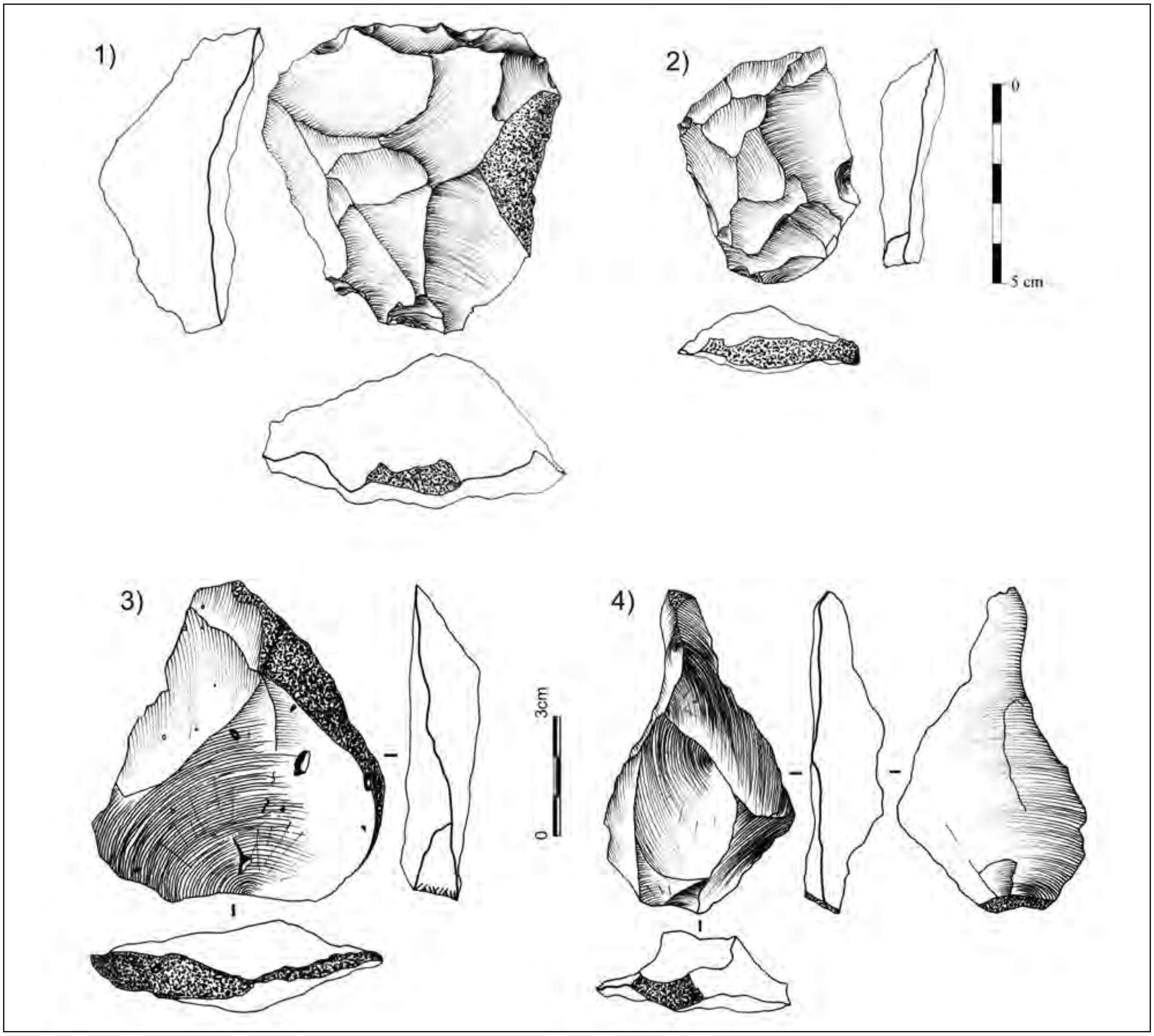

Figure 20. Drawings of excavated whole flakes. 1 & 2) from EG-10, both on trachyte, and 3 & 4 from OGS-7, both on trachyte. Note: whole flake #1 is the largest flake excavated from EG-10, and the maximum dimension of whole flake #3 from OGS-7 is larger than any of the cores recovered (excavated/surface) at the site. Artifact drawings by D. Cauche.

ing some of the intricacies in the toolmaking behavior of the Gona hominins, and further such investigations will be critical to firmly understand the meaning of the variations seen in Oldowan assemblages between 2.6-1.7/1.6 Ma (e.g., Toth, 1985, 1987; Toth et al., 2006; Schick & Toth, 1994; Sahnouni et al., 1997; Jones, 1994).

The Earliest Stone Technology

Currently, a large number of Oldowan archaeological localities with dense concentrations of artifacts dated to 2.6-2.5 Ma are documented at Gona through the field investigations carried out between 1999 and 2007. These earliest archaeological occurrences are distributed across a much wider area (~10-15 Km) west/southwest of the EG sites. Relatively younger Oldowan sites dating ~2.3-2.0 Ma are also known in the deposits prominently exposed in the eastern part of the study area. Further, the deposits that are older than 2.6 Ma have been targeted during the past several years, and the very rare pockets of sediments surveyed in the 2.9-2.6 Ma time interval in the Kada Gona, Ounda Gona and Dana Aoule drainages have not produced any traces of archaeological materials, i.e. flaked stones (modified stones) or bones damaged by a hominin agent. The geological disconformity and the scarcity of fossil-bearing sediments between 2.9-2.7 Ma at Gona or elsewhere in Africa unfortunately hinders the resolution of the issue of whether or not hominins made and used stone artifacts earlier than 2.6 Ma.

However, the sophisticated understanding of stone fractures and advanced knapping skills shown by the Gona toolmakers strongly suggests that ancestral hominins probably began experimenting on the use of stones as tools prior to 2.6 Ma. The appearance of thousands of flaked stones in the deposits dated to 2.6 Ma may not be an indication of ancestral hominin behavioral threshold

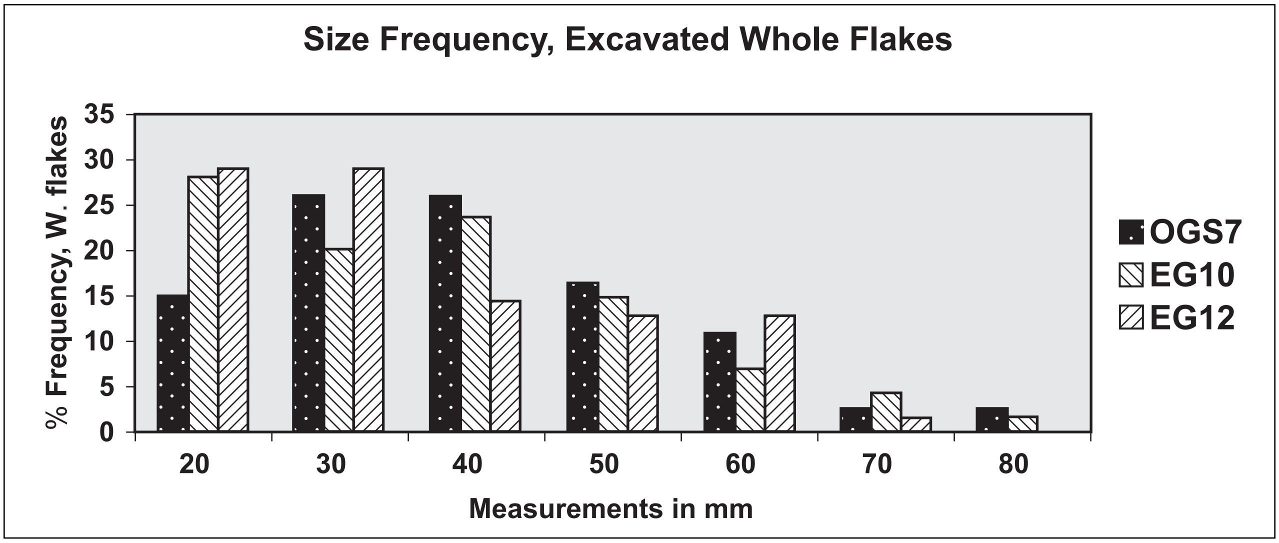

Figure 21. Size frequency of excavated whole flakes.

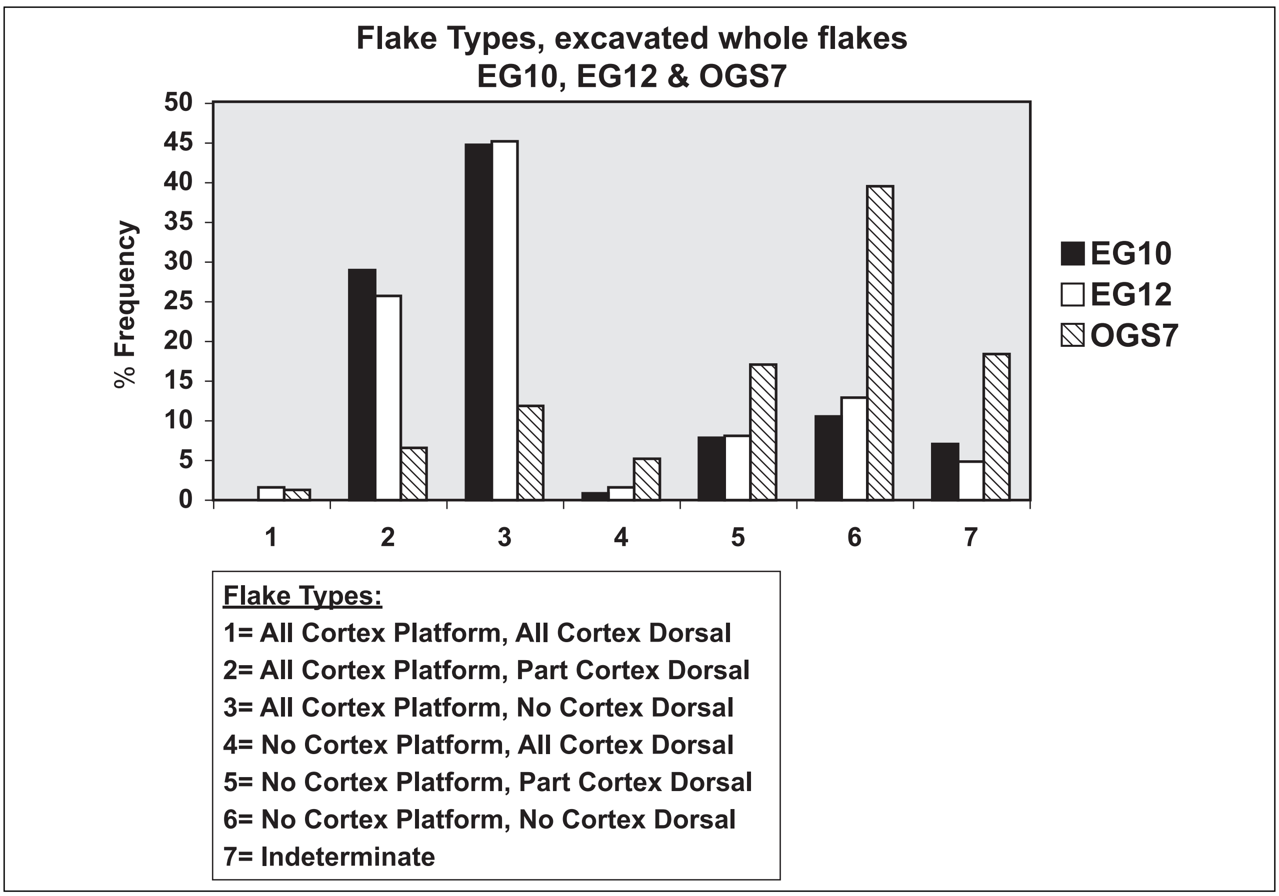

Figure 22. Flake Types, excavated whole flakes from EG-10, EG-12 and OGS-7.

at this particular time, but the earliest preservation and documentation of such evidence in the geological record at Gona. The evidence from Gona, both from the EG and OGS sites indicates that the advent of thousands of flaked stones by 2.6 Ma into the geological record seems abrupt and the manufacture and use of stone artifacts widespread across much of the ancient Gona landscape. Early hominins by 2.6-2.5 Ma were adept in manipulating stones, and the practice appears to have been widespread based on the large number of archaeological sites documented at Gona and the stone tool cutmarked bones recovered at Bouri, located c. 90 Km south in the Middle Awash (Semaw et al., 1997, 2003; Semaw, 2000, 2006; de Heinzelin et al., 1999; Asfaw et al., 1999).

Did hominins use modified stones prior to 2.6 Ma? What would these artifacts look like? Further investigations and empirical data are needed from the older deposits (2.9-2.6 Ma) to answer these questions con-

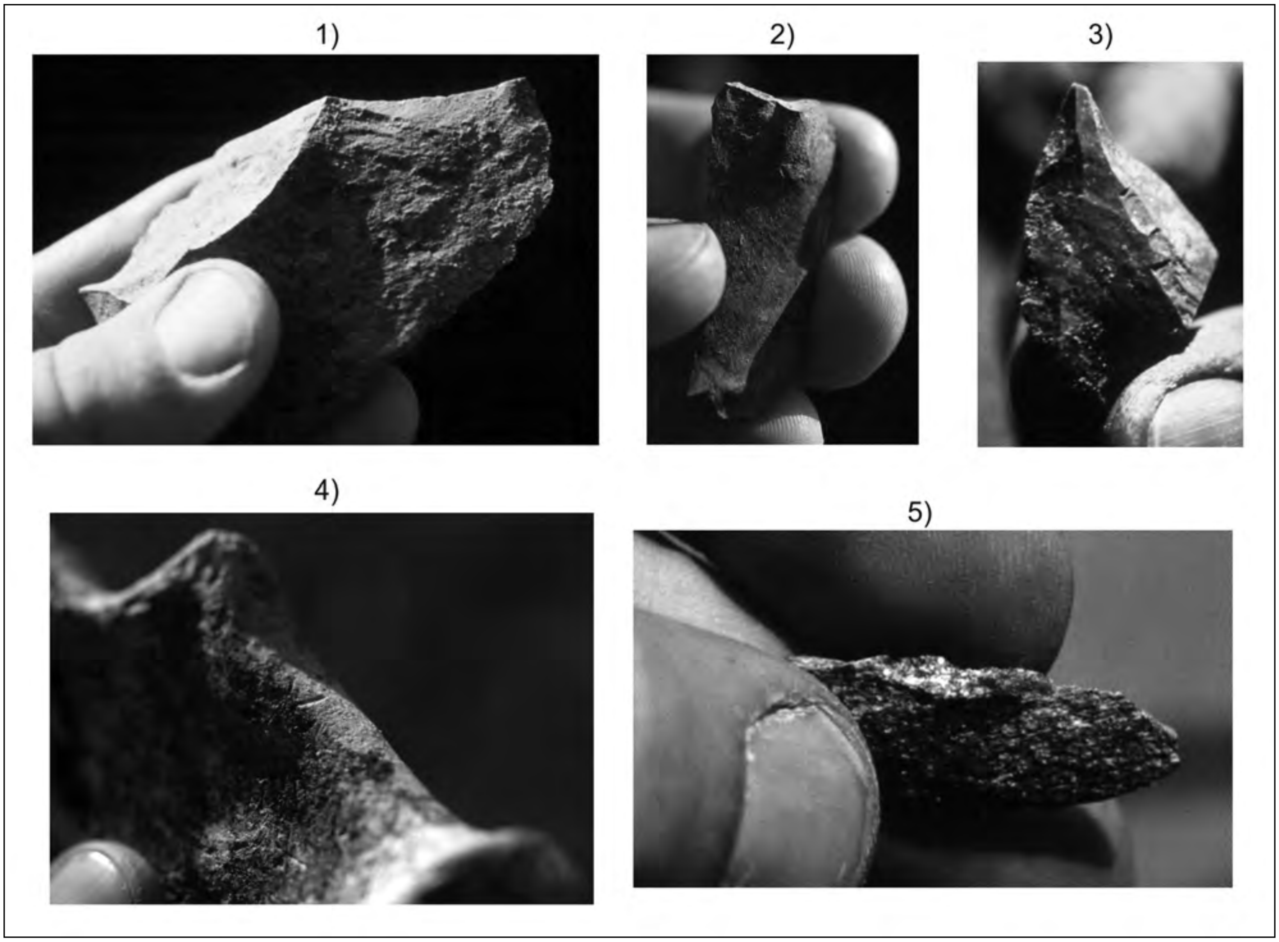

Figure 23. Photos showing, 1) knife-like flake- OGS-7, 2) blade-like flake- OGS-6, 3) pointed-piece- OGS-7, 4) cut-marked bone- OGS-6, & 5) bone-flake- OGS-7. All of the specimens were excavated, except for the cut-marked bone.

clusively. However, based on our investigations of the Gona deposits, currently the earliest evidence for ancestral hominin use of stone artifacts dates back just to ~2.6 Ma. It can be argued based on the sophisticated nature of the earliest artifacts from Gona, the large number of archaeological sites already documented across a wide area, and the high density concentrations of artifacts at these sites that ancestral hominins may have began using modified stones as early as 2.9 Ma, but not prior to 3.0 Ma. To date, there are no archaeological indications for the use of any modified stones by *Australopithecus afarensis*.

This hominin species lasted in the geological record up to 2.9 Ma at Hadar, and a major gap still exists in the hominin fossil record up to 2.6 Ma in East Africa (Kimbel et al., 1994). *Au. aethiopicus and Au. garhi*, and probably early *Homo* are the three penecontemporaneous hominin species overlapping with early stone tools in East Africa (Walker et al., 1986; Hill et al., 1992; Schrenk et al., 1993; Suwa et al., 1996; Kimbel et al., 1994, 1996; Asfaw et al., 1999; Prat et al., 2005), and further hominin discoveries along with possible flaked stones within the deposits dated between 2.9 Ma and 2.6 Ma will be critical to determine if stone toolmaking hominins existed from this least known time interval. Up to now, no artifacts or modified bones have been reported from any of the early hominin study areas that are older than 3.0 Ma like Hadar, Middle Awash, Gona, Woranso-Mille, and Dikika in Ethiopia; or from any of the early hominin sites known elsewhere in East Africa such as Alia Bay in Kenya and Laetoli in Tanzania. Thus far, the lack of any traces of stones or bones modified by a hominin agent (e.g., Blumenschine & Selvaggio, 1988; Bunn et al., 1980; see also Goren-Inbar et al., 2002) from any of these sites renders the possibility of early hominin use of flaked stones prior to 3.0 Ma unlikely.

A number of researchers have argued for ancestral hominin use of tools prior to 2.6 Ma (e.g., McGrew, 1993, Mercader et al., 2002; Panger et al., 2002). The close genetic relationships between the African great apes (particularly chimpanzees) and humans, and the capacity of modern chimpanzees in manipulating tools, both in the wild and in controlled environments, are used as strong indications for ancestral hominin use of tools prior to 2.6 Ma. It is likely that ancestral hominins may have been capable of using/throwing unmodified stones, and manipulating such perishable items as wooden clubs, tree branches, etc. for defense against predators, etc. prior to 2.6 Ma, but these materials do not fossilize as well as flaked stones and the use of such simple tools remains difficult to prove archaeologically, and probably remains speculative.

The recent study by Toth et al. (2006) of the results from the experimental stone knapping of the Gona cobbles by chimps (bonobos) and by modern humans, and comparison of the experimentally-generated materials with the artifact assemblages excavated from Gona dated to 2.6 Ma showed that chimps are capable of knocking flakes off similar cobbles used by the first toolmakers, but the chimp-generated assemblages exhibit important differences from the Oldowan stone technology. Toth et al. (2006) concluded that- "If such a bonobo assemblage were discovered in a prehistoric context, with so many distinct differences from early Oldowan artifact assemblages in so many attributes, particularly ones associated with skill, it might be assigned to a "Pre-Oldowan" stage of technology." Toth et al.'s (2006) chimp-generated assemblages provide a useful guide for archaeologists who pursue further field investigations for traces of possible artifactual remains that may have been left by ancestral hominins prior to 2.6 Ma.

The results from Toth et al.'s (2006) analysis cast much doubt on the validity of earlier conclusions reached by Mercader et al. (2002) on the purported similarity between the chimp-generated "artifacts" from West Africa and the Omo and Koobi Fora archaeological assemblages. In fact, Mercader et al. (2007) have more recently come around to the view that the accidental thrusting percussion by-products of chimpanzee nutcracking are indeed distinct (and distinguishable) from the controlled flaking products of hominins (p. 3046). The prevalence of bashing technologies at some Oldowan sites may be underappreciated (Mora & de la Torre, 2005), however, the earliest assemblages from Gona display clear evidence of highly controlled and systematic flaking aimed at the production of sharp edges.

The earliest Gona stone assemblages consist of artifacts typical of the Oldowan tradition with cores and *débitage* (whole and broken flakes, and angular fragments), and the toolmakers utilized stone working techniques (mainly hand-held-percussion) similar to Early Pleistocene Oldowan assemblages documented from elsewhere in Africa (Semaw, 2000, 2005, 2006; Semaw et al., 1997, 2003). Our investigations of the EG and OGS stone assemblages show that the earliest toolmakers were more complex in their raw material selectivity, and stone manufacture and use behavior with the production of unifacially as well as bifacially/polyfacially-reduced cores that are typical of most Oldowan assemblages known from the Early Pleistocene. The Gona stone assemblages are classified into the Oldowan Industry because of the similarity in the techniques of artifact manufacture and comparability in the composition of the stone assemblages with other Early Pleistocene sites known in Africa. The Oldowan stone technology persisted for almost a million years with little or no change until the advent of the more standardized Acheulian artifact tradition dated to ~1.6/1.7 Ma (Beyene, 2003, 2004, 2008; Beyene et al., 1997; Roche, 2005; Suwa et al., 2007; Semaw et al., in prep). The long duration of the same manufacture techniques of the core/flake dominated stone assemblages between ~2.6-1.7 still reinforces earlier suggestion of "technological stasis" for the Oldowan Industry (Semaw et al., 1997).

The Oldowan, the earliest artifact tradition

A number of researchers have proposed a "Pre-Oldowan" stage of stone technology, along with several presumed 'facies,' for characterizing the evolutionary stages of the stone assemblages recovered in Africa within the deposits that are older than 2.0 Ma (e.g. Roche, 1989, 1996, 2000; Piperno, 1989; Kibunjia, 1994; see Semaw, 2006 for earlier treatment of this issue). Among the major proponents of the "Pre-Oldowan," some still uphold this supposed stage of stone technology, and the idea seems to linger in the archaeological literature with newer perspectives added to it (e.g., Roche, 2000, 2005; de Lumley et al., 2004, 2005; Barsky et al., 2006). The "Pre-Oldowan/Oldowan" dichotomy and the presence/absence of different stages of stone technology during the Late Pliocene-Earliest Pleistocene is becoming an issue, and currently the idea has extended even beyond Africa to include the stone assemblages recovered from the earliest archaeological sites known in Eurasia (de Lumley et al., 2005). Therefore, it is timely to address the issue of the "Pre-Oldowan" again, and to evaluate some of the shortcomings of its use for classifying Late Pliocene-Early Pleistocene archaeology.

Despite Roche et al.'s (1999) discovery of a large number of refitting pieces (with evidence of 'sophistication') at Lokalalei 2C (LA2C) in West Turkana, and dated to 2.34 Ma, Roche (2000, 2005) continues to argue for the presence of different stages of stone technology during the Late Pliocene-Earliest Pleistocene. Roche and colleagues argue that these earliest stone assemblages evolved from a "Pre-Oldowan" to an "Oldowan" stage some time ~ 1.9/1.8 Ma. Although the LA2C artifacts were argued to be more 'sophisticated,' i.e. based on the large number of refitting pieces recovered from the site, there is still lack of sufficient explanations regarding why some of the LA2C artifacts at 2.34 Ma look more sophisticated compared to the artifacts recovered even within the same site, and to the pene-contemporaneous artifact assemblages excavated earlier from Lokalalei 1 (LA1), located just one Km distance north of LA2C (Kibunjia, 1994; Kibunjia et al., 1992; Roche et al., 1999, 2003; Delagnes & Roche, 2005). Both sites are dated to ~2.34 Ma, but LA2C may be slightly younger (~2.3 Ma, see Brown & Gathogo, 2002; McDougall & Brown, 2008), though, still not significantly younger than LA1.

The Lokalalei researchers, justifiably, had a great appreciation of the data generated from the LA2C refitting pieces, and the information these specimens provided regarding the sequence of core reductions carried out at the site. They recognize the diversity/variation within the Late Pliocene stone assemblages based on the differences attested in the success/failure of the flake productions at the two sites of LA2C and LA1. Further, they recognize the differential accessibility/availability of the raw materials, and they also note the differential flaking quality of the raw materials available for the toolmakers in the two areas. However, they attribute the variations/differences mainly to hominin skills, or lack thereof, when comparing the LA2C and LA1 assemblages. Explaining why some cores did not have "organized *débitage*," i.e. why some were less intensively exploited at LA2C, Delagnes & Roche (2005) note that

> "most of these cobbles are angular specimens, their shape being quite similar to that of the cores on which an organized *débitage* was carried out. On the other hand, most of them are medium grained trachyte, a less homogeneous raw material than the phonolite that represents the dominant raw materials used at Lokalalei 2C…The reason for the premature abandonment of these specimens very likely lies in the poor flaking quality of the raw material" (Delagnes & Roche, 2005, pp. 444-445).

The differences in the flaking-quality of the medium-grained trachyte and basalt (poor-flaking-quality) vs. phonolite (good-flaking-quality) has been recognized, and interestingly out of the six major refitting pieces recovered from LA2C, five were made on phonolite and only one of the major refitting pieces on basalt. They recognize that some of the LA2C cores did not have "organized *débitage*" (i.e. the cores were less intensively exploited) because of the low flaking quality of the raw materials (e.g., medium-grained trachyte and basalt). However, in comparison to LA1, they argue that raw materials do not account for this difference. It is puzzling why the role of the raw materials is not considered as a major possible contributing factor for explaining the differences in the LA2C and LA1 stone assemblages, and why total emphasis was placed only on the "differential knapping skills" of the toolmakers. From our point of view, it is simply evidence of stone reduction (behavioral) flexibility, similar to what we see at the EG vs. OGS sites at Gona. Obviously, from their published information the flaking-quality of the different raw materials accessed by the toolmakers has greatly impacted the extent of core reductions and the success/failure of flake productions.

The researchers attribute the entire success/failure to the stone manipulating ability of the toolmakers despite the obvious effect of the variations due to the flaking-quality of the raw materials used. Comparing the two sites of LA2C and LA1, it is argued that the technology of the LA1 artifacts showed "clumsiness and poor manual dexterity" (Roche, 2005, p. 37) whereas the sophisticated LA2C artifacts exhibit "high level of manual dexterity" (Roche, 2005, p. 39). Who made the LA2C stone assemblages? Does this imply two different hominin species were responsible for the LA2C stone assemblages? Delagnes & Roche's (2005) section on the raw materials makes reference to the shape and size of the original cobbles accessed by the toolmakers, the transport of unmodified or flaked cobbles to the site and close proximity of the basalt sources, though, they provide little discussion regarding the differential flaking property of the raw materials playing a major role impacting the variations seen in the assemblages recovered at LA2C (Delagnes & Roche, 2005, pp. 464-465).

According to Roche (2005) the "Pre-Oldowan" lasted between 2.6-1.9 Ma, and it was characterized by "simple expedient flaking, more organized *débitage*, and occasional retouching" (p. 37), and what differentiates it from the succeeding "Oldowan" (1.9-1.7/1.6 Ma?) is the appearance of "polyhedral and spheroidal shaping" in the latter. A number of studies (e.g., Sahnouni et al., 1997, Schick and Toth, 1994) have shown the effect of the differential flaking-quality of the various types of raw materials accessed by Early Pleistocene hominins in influencing the final shape of the stone assemblages. Schick and Toth (1994) have experimentally demonstrated how quartz chunks, after several hours of use as percussors, tend to transform into artifacts traditionally labeled as battered spheroids, and Sahnouni et al. (1997) have shown how extensively flaked limestone cobbles tend to transform into cores traditionally labeled as facetted spheroids. Preliminary investigations by Stout et al. (2005) have clearly illustrated the raw material selectivity of the earliest toolmakers at Gona, and Semaw et al. (2003, also this chapter) have shown how the quality of raw materials influenced the flaking modes of the 2.6 Ma artifact assemblages excavated at the two penecontemporaneous East Gona and Ounda Gona South sites.

We believe that Oldowan hominins (2.6-1.7/1.6 Ma) produced cores and stone flakes with sharp cutting edges used for processing animal carcasses. Why would the hominins deliberately design "polyhedral and spheroidal" artifacts at 1.9/1.8 Ma? Roche (2005) argues that during the so called "Pre-Oldowan" stage the flakes were the main artifacts that the hominins sought after (the cores being the waste), and during the Oldowan stage (1.9/1.8 Ma) the emphasis shifted more on the cores (at this time the flakes becoming the waste). What were the function of the "Pre-Oldowan" flakes and the adaptive role of the "polyhedral and spheroidal" shaped artifacts during the "Oldowan?" To date, no substantial and clear explanations have been provided by Roche and colleagues as to why hominins were making these stone artifacts, and no discussions are available on their functions and the adaptive role tool use may have played for the Late Pliocene toolmakers.

As discussed above, the Gona hominins at 2.6 Ma produced unifacially and bifacially/polyfacially-worked cores. Therefore, "the polyhedral and spheroidal" criteria for distinguishing the so called "Pre-Oldowan" from the Oldowan, and the arbitrary boundary of 1.9/1.8 Ma for separating the two "artifact traditions" does not seem to be meaningful, and is not supported by the existing archaeological data. Clearly, spherical specimens do appear in the archaeological record by 1.9/1.8 Ma, mainly at Olduvai Gorge, at Ain Hanech, and slightly later at Melka Kunture (M. Leakey, 1971; Sahnouni et al., 1997; Piperno et al., 2004), but these occurrences are exceptions to the rule and not universal. Experimental evidence indicates that the existence of these spherical specimens both at Olduvai and at Ain Hanech at 1.9/1.8 Ma, and other Early Pleistocene sites is probably a result of the use of limestone and quartzite. If such a behavioral succession from the so called "Pre-Oldowan" to the Oldowan stage existed in the archaeological record (as proposed by Roche, 2005), spherical specimens should have been found at several other sites dated to 1.9/1.8 Ma in East Africa, and should have been documented irrespective of the flaking-quality of the raw materials used for making them. For example, the archaeological sites at Koobi Fora (East Turkana, Kenya) dated to 1.9/1.8 Ma do not document any such specimens because hard basalt was the primary raw material used (Isaac & Harris, 1997). Further, at the contemporary site of Fejej from Ethiopia, also dated to 1.9/1.8 Ma, quartz and basalt were the primary raw materials used, and no spherical specimens are reported there (de Lumley et al., 2004; Barsky et al., 2006). Although Roche (1989, 2000, 2005) advocated a "Pre-Oldowan" stage, later publications (Delagnes & Roche, 2005) seem to deemphasize its significance, though arguing that the variations still reflect different stages of hominin skills and competence in manipulating cores during the Late Pliocene.

Currently, de Lumley et al. (2004, 2005; see also Barsky et al., 2006) also have joined in support of the "Pre-Oldowan" argument claiming the presence of such a technological phase in Africa and Eurasia. de Lumley and colleagues base their argument on the presence/absence of "retouched pieces" in Plio-Pleistocene stone assemblages, and use this as a criterion for differentiating the supposed technological stages, i.e. by classifying sites where retouched pieces are absent as "Pre-Oldowan" and sites with retouched pieces as "Oldowan," and implying the latter to be technologically more advanced. Interestingly, retouched pieces (not clear if systematic or edge-damaged), although few in number, are present in the 2.6 Ma excavated Gona assemblages (EG-10 and OGS-7), and even Roche (2005; see also Delagnes & Roche, 2005) recognizes the presence of occasional retouched pieces (e.g., ~21 pieces at LA2C) in Late Pliocene assemblages. Most of the Late Pliocene/Earliest Pleistocene Oldowan stone assemblages in Africa document only a small number of retouched pieces (e.g., Olduvai) except for Ain Hanech where a relatively large number of retouched pieces are documented at 1.8 Ma (Sahnouni & de Heinzelin, 1998; Sahnouni et al., 2002). Of the relatively large number of retouched pieces recovered at Ain Hanech, most were made on flint (Sahnouni & de Heinzelin, 1998). Even at Olduvai, a majority of the retouched pieces appear only after the hominins began exploiting chert (M. Leakey, 1971, but see de la Torre & Mora, 2005). However, some of the pieces from Olduvai were probably not intentionally retouched.

> "Indeed, most of the chert pieces from FLK North SC [Sandy Conglomerate] are excellently preserved. Nonetheless, the edges of the chert pieces, sharper than most of the quartzes and lavas, are also more sensitive to damage (pseudo-retouching in this case) produced by the sediment itself. Most of the so-called retouched pieces Leakey (1971) describes present a very marginal modification on the edges, which is irregular, not systematic. Therefore, and although several are subject to equifinality, we believe the majority are not clear enough to be considered retouched pieces" (de la Torre & Mora, 2005, p. 85).

A majority of the stone artifacts from the Late Pliocene-Early Pleistocene sites in East Africa have not been subjected to microwear analyses, and it is still not clearly determined whether or not hominins used un-retouched flakes and/or just the retouched pieces for processing animal carcasses or for other activities related to subsistence, etc. However, some of the Koobi Fora and Ain Hanech excavated artifacts were analyzed for microwear polishes, and it was discovered that both un-retouched flakes and retouched pieces bear evidence of meat-polish (Keeley & Toth, 1981; Sahnouni & de Heinzelin, 1998). Therefore, there is no need for *a priori* assumption that Late Pliocene/Earliest Pleistocene hominins used only the retouched pieces. At Ain Hanech, further reanalysis of the retouched pieces is planned to determine whether or not most of the specimens identified as retouched pieces were intentional and systematic (Sahnouni, *pers. com.*).

What does the presence of "retouched pieces" in an Oldowan assemblage signify? Are these pieces formal tools like those known at later times? The number of retouched pieces particularly during the Late Pliocene and the Earliest Pleistocene was insignificant, and begs the question of whether or not the "retouched pieces" occasionally found at Oldowan sites are clearly identified to be a result of intentional hominin action or if edge-damaged specimens resulting from use or others from bioturbation and trampling could have been mistakenly identified as retouched pieces (see de la Torre & Mora, 2005). Further, how much of the retouching was influenced by hominin selectivity of certain raw materials for this purpose? Nonetheless, the fact remains that, 1) the Late Pliocene sites including Gona and LA2C contain occasional retouched pieces, and 2) the number of "retouched pieces" found at several of the Earliest Pleistocene sites in Africa including Olduvai Gorge is insignificant (e.g., de la Torre & Mora, 2005).

To date, the only Early Pleistocene archaeological site in Africa with relatively large number of retouched pieces is Ain Hanech, and a majority of the retouched pieces are on flint, a fine-grained raw material compared to the limestone available for the toolmakers (Sahnouni et al., 2002). In most cases, archaeological investigations show that non-local raw materials procured from further distances tend to be heavily-reduced and more retouched pieces were made on them compared to raw materials available from nearby sources (see recent review by Blumenschine et al., 2008). In conclusion, 1) there is lack of rigorous study and strength in de Lumley et al.'s (2004, 2005) argument, and 2) classifying younger Oldowan archaeological sites in Europe lacking retouched pieces as "Pre-Oldowan" (e.g., Elefante and Fuente Nueva 3, dated to ~1.4-0.9 Ma) and older sites in Africa with a small number of retouched pieces as "Oldowan" (e.g., Olduvai dated to 1.9/1.8 Ma) appears to us to be anachronistic, and de Lumley et al.'s criteria of presence/absence of retouched pieces for differentiating the supposed "Pre-Oldowan" from the Oldowan (*sensu stricto*) unnecessarily compounds the issue.

As was suggested by Toth et al. (2006), the term "Pre-Oldowan" may suit possible modified stones yet to be found in the deposits that are older than 2.6 Ma, i.e. if and when the existence of such hominin-modified materials (stones/bones) is proven archaeologically through future field investigations; and if these yet to be found modified materials are actually different from the Oldowan (*sensu stricto*). Palaeolithic archaeologists are gaining a better understanding of the earliest phase of ancestral human stone technology and behavior through field and laboratory investigations undertaken over the past two decades, and in particular our study at Gona has clearly shown that, to date, there is no such "Pre-Oldowan" stage of stone technology.

Like Roche and colleagues, we recognize the presence of assemblage variability in the Oldowan Industry during the Late Pliocene-Earliest Pleistocene (2.6-1.7/1.6 Ma.). However, we attribute these variations mainly to differences in raw material proximity, availability, and flaking quality and the interaction of these variables with predominant modes of core reductions. For the simple Oldowan (Mode I) Industry, the discovery by some group of hominins of conchoidal fractures on stones and the invention of sharp-edged cutting flakes was the major behavioral breakthrough (Isaac, 1976). Once this discovery was made, i.e. in the case of the Oldowan (2.6-1.7/1.6 Ma), there is no reason to assume that any one group of hominins were capable of removing only one or two flakes during the earliest phase of artifact manufacture, and such other superior group (species) of penecontemporaneous hominin species to have been more knowledgeable and skilled to remove tens of flakes from a core. The current evidence clearly shows that once hominins understood that striking one cobble (the core) with another one (used as a hammerstone) results in the creation of sharp-edged cutting knives, following acute angles, unifacial/polyfacial-working of cores and the success/failure of flake productions appear to have been largely dependent on the flaking-quality of the raw materials accessible to hominins. Quoting Isaac's (1976) statement on a similar issue will be appropriate here:

> "Distinctive features of stone artifact assemblages can be attributed to differences in the traditions or cultures of the hominids that made them. Clearly before this is done it is desirable to distinguish features which may have been induced largely by *differences in raw materials*, and differences which may reflect *varied activities* by the same people at different times and places. The distinctiveness of the Shungura industries *vis-à-vis* Olduvai and Koobi Fora may be an example of differences induced by contrasting raw materials, which therefore cannot be interpreted as necessarily indicative of other cultural or developmental stage differences." (Isaac, 1976, p. 496, original emphasis).

The variability seen between the EG and OGS assemblages appears to be somehow similar to the above observations made by Isaac (1976, p. 496) on the lithic variability earlier witnessed at Omo, Olduvai and Koobi Fora, which he explained to have been a result of the use of different raw materials. Roche and colleagues attribute the success/failure of flake productions at the Lokalalei sites solely to differential manual dexterity and hominin skills. In the EG and OGS assemblages we see no such evidence of differential success/failure, despite substantial differences in the raw materials selected and reduction methods employed. There seems to be no reason to assume that this variability reflects the different abilities of different toolmaking species. Even if the possibility of differential skills existed among Late Pliocene hominins, as assumed by Roche and colleagues (see Harmand, 2007), it would still be difficult, if not impossible to attribute particular Oldowan stone assemblages between 2.6-1.7/1/6 Ma to any one particular hominin species and to prove this archaeologically.

Currently, there is no evidence for associating early *Homo* with the earliest Oldowan artifacts (2.6 Ma) at Gona. Hominin species known from East Africa at this time include *Au. aethiopicus* and *Au. garhi*, actually with *Au. garhi* being a somewhat more compelling candidate as an early toolmaker on the basis of its cranial anatomy, proposed ancestry to early *Homo* and proximity to the earliest archaeological traces (Asfaw et al., 1999). As always, such attributions represent only our current best knowledge and remain subject to further fossil discoveries. Somewhat later, early *Homo* does emerge as a likely toolmaker, and there are currently two Late Pliocene archaeological sites (LA1α at West Turkana and A.L. 666 at Hadar), dated to ~2.3 Ma, that represent stratigraphic associations of early *Homo* with Oldowan artifacts (Prat et al., 2005; Kimbel et al., 1996). However, these assemblages are no more skilled or "sophisticated" than those known from 2.6 Ma, and there is no evidence that phylogenetic change was associated with technological change ~ 2.3 Ma.

Interestingly, the LA1α early *Homo* molar was found ~100 meters south of LA1, a site argued to contain artifacts produced with "poor manual dexterity," and the artifact assemblage is close in age to the LA1α hominin (Roche et al., 2003; Prat et al., 2005). Following the discovery of this molar, Roche and colleagues (see Prat et al., 2005) conclude that early *Homo* is the best candidate for making the LA1 artifacts. If this is accurate, and if different hominin species are responsible for the variability between the two Lokalalei assemblages (LA1 and LA2C), the question is then who made the "more sophisticated" but slightly younger artifacts excavated from LA2C?

Isaac's (1976, p. 496) cautionary note seems relevant to Roche and colleagues' interpretation of the lithic assemblages from the two Lokalalei sites. Again, we believe that the variability witnessed in the two Lokalalei stone assemblages to a large extent appears to have been a result of the diverse quality of the raw materials, and probably not related to differential knapping skills of Late Pliocene hominins. Further, our argument is supported by the fact that the makers of the Gona stone tools, which are at least 250,000 years older than those of Lokalalei, were already accomplished knappers at 2.6 Ma, and based on current data, the most likely candidate responsible for the stone assemblages would be *Au. garhi* (Asfaw et al., 1999; de Heinzelin et al., 1999).

The main goal of the Late Pliocene-Earliest Pleistocene toolmakers was the production of sharp-cutting flakes (resulting in core/flake assemblages) which were mainly made with the hand-held percussion. Core/flake assemblages with occasional retouched pieces (some associated with cutmarked bones) are the hallmark of the Oldowan (Mode I) Industry (M. Leakey, 1971; Clarke, 1969), and this is why we still argue for "technological stasis" in the Oldowan (Semaw et al., 1997; Stout et al., in prep). We believe the major distinction in terms of manual dexterity, mental template, and imposition of form and symmetry on stone artifacts did emerge with the larger-brained hominin (probably early *Homo erectus/Homo ergaster*), contemporaneous with the Early Acheulian Industry. The Acheulian was obviously qualitatively as well as quantitatively different from the Oldowan stone technology and the transition was probably rapid (Isaac, 1969; Semaw et al., in press). During the Early Pleistocene, archaeological sites become more abundant and widely documented across Africa, and some are associated with a large number of cutmarked bones (e.g., Bunn, 1983, Bunn et al., 1980; Potts, 1988; Potts & Shipman, 1981; but see Domínguez-Rodrigo et al., 2007).

The fact that the first toolmakers were "sophisticated" in their artifact manufacture and raw material selectivity was originally proposed by Semaw et al. (1997). Besides the clear archaeological evidence for the sophisticated knapping skills of the Gona hominins, Semaw et al. (1997, 2003) have shown the presence of variations in Late Pliocene stone assemblages, and that this appears to be primarily a result of the differential flaking quality of the raw materials available to the toolmakers. However, more experimental work is needed on the various stone raw materials used during the Plio-Pleistocene to firmly determine what role the flaking quality of the various raw materials accessed by early hominins played in influencing the variations we see in Oldowan stone assemblages. Again, experimental investigations with the raw materials used by the Lokalalei hominins appears to be a necessary step towards a better understanding of the reasons for the variations seen in the Lokalalei stone assemblages.

Based on current understanding, the use of the term "Oldowan" is appropriate for classifying the Plio-Pleistocene core/flake (Mode I) dominated stone assemblages (*sensu* M. Leakey, 1971). To date, evidence for a "Pre-Oldowan" phase is non-existent and the use of this term is unwarranted.

The archaeological evidence from Gona has clearly shown that the stone raw material selectivity, artifact transport and use behavior of Late Pliocene toolmakers was much more complex than generally understood. Further research is needed for understanding the paleohabitats of the earliest toolmakers, and for gaining a better grasp of their land use and patterns of resource exploitations over different parts of the ancient landscape. Nonetheless, the Oldowan still remains the earliest known phase of ancestral hominin manufacture and use of flaked-stones until the presence of hominin modified stones/bones is proven/shown in the deposits that are older than 2.6 Ma.

Summary

Based on our recent study of the EG and OGS archaeological materials, current understanding of the earliest stone artifacts ~2.6 Ma, and Late Pliocene stone assemblages can be summarized as follows:

a) The first toolmakers had extraordinary mastery of conchoidal fractures on stones, and they preferentially selected fine-grained raw materials for making the earliest documented stone artifacts at 2.6 Ma,

b) The materials from OGS-7 show strong evidence for hominin selectivity of raw materials with excellent flaking-quality such as vitreous volcanics. In addition, artifacts may have been selectively transported across the ancient landscape for further use at activity areas away from the densest concentrations (sites) where initial flaking activity took place (see also Toth, et al., 2006).

c) The makers of the Late Pliocene-Earliest Pliocene stone artifacts were primarily after sharp-edged cutting implements; and to a large extent, the final shape of the artifacts appear to have been influenced by the proximity and the flaking quality of the various raw materials accessed by the toolmakers (Toth, 1985, 1987; Toth et al., 2006). However, the factors that may have influenced the modes of flaking (unifacial-dominated at EG vs. bifacial/polyfacial-dominated at OGS) and differing reduction intensity at the two Gona areas may need further research.

d) The variability seen in artifact assemblages at EG/OGS and at Lokalalei indicates that Oldowan hominins were capable of some behavioral flexibility with respect to lithic reduction.

e) The earliest stone tools at Gona were used mainly for processing animal carcasses for meat (Domínguez-Rodrigo et al., 2005; Semaw et al., 2003; see also de Heinzelin et al., 1999).

f) The EG and OGS artifacts consist of unifacial, bifacial and polyfacial cores, and *débitage*, as is typical of the Oldowan tradition. The toolmakers utilized similar stone working techniques (mainly hand-held-percussion), the same stone knapping techniques also used for making most other Early Pleistocene Oldowan assemblages known from elsewhere in Africa (Semaw, 2000, 2006; Semaw et al., 1997, 2003). Thus, the archaeological evidence points to almost a million years of "technological stasis" for the Oldowan Industry. Evidence for a "Pre-Oldowan" phase is so far non-existent, and the use of the term is unwarranted.

g) Site frequency and artifact densities and the occurrence of retouched pieces all probably increased through time and became much higher during the Earliest Pleistocene, but the Oldowan artifacts made between 2.6-1.7 Ma were still technologically within a continuum and with no significant departures seen in the stone working techniques and composition of the artifacts from the earliest stone artifacts recovered at Gona. Artifacts made of substantially larger cobbles and flakes, and with controlled design, predetermined shape and symmetry were unknown within the Oldowan; and bifaces and cleavers emerged by ~1.7/1.6 Ma with the advent of the Acheulian tradition in Africa (Asfaw et al., 1992; Beyene, 2003, 2004, 2008; Beyene et al., 1997; Roche, 2005; Suwa et al., 2007; Semaw et al., in press).

The overall archaeological evidence from Gona shows a more complex behavior was already in place even during the initial stages of stone artifact manufacture at 2.6 Ma, including greater foresight and planning involving selectivity of fine-grained raw materials with good-flaking quality, and probably transport of selected artifacts out of the high density sites into other activity areas over different parts of the ancient landscape. Although the extent of core reductions was highly influenced by the flaking-quality of the raw materials and proximity to sources, the differences seen at the EG and OGS-7 sites in the choice of raw materials and the prevalent core reductions, unifacial at EG vs. bifacial/polyfacial at OGS indicate the possibility of local norms, although other factors related to raw material size, shape and type cannot be ruled out. The earliest toolmakers already had skills and foresight as complex as Early Pleistocene hominins and it seems appropriate to classify the Gona and all the simple core/flake assemblages dated between c.2.6-1.7/1.6 Ma into the Oldowan (*sensu* M. Leakey, 1971).

The Bouri archaeological site dated to 2.5 Ma from the Middle Awash, 90 Km to the south of Gona, has yielded excavated fossilized bones with evidence of stone tool cutmarks, but without associated artifacts (de Heinzelin et al., 1999). Therefore, the Gona sites with the oldest documented associations between artifacts and broken fauna, and the materials from Bouri provide complementary and direct evidence attesting that the earliest stone tools were definitely used for processing animal carcasses for meat.

Concluding Remarks

The Gona sites preserve the earliest known archaeological evidence for the advent of flaked stones in the geological record, but the sophisticated techniques of artifact manufacture and the presence of a high density of archaeological materials distributed over a wider area may be suggestive of possible earlier beginnings of stone tools probably as early as 2.9 Ma. The archaeological and faunal record between 3.0-2.6 Ma is incomplete at Gona and elsewhere hindering our understanding of the initial beginnings and the ecological settings for the behavioral changes seen in Late Pliocene hominins. The question of what triggered the beginnings of the use of flaked stones, and why early hominins resorted to a novel means of adaptation by incorporating meat in their diet can be answered only with detailed investigations and understanding of the environmental settings of sites within deposits dated between 2.9-2.6 Ma.

Global climate changes roughly between 2.8-2.5 Ma associated with astronomical forcing have been linked to faunal evolutionary changes and the origin of diverse hominin lineages, and have also been cited as among the driving forces triggering changes in hominin behavior that led to the beginnings of the use of stone artifacts (e.g., Vrba, 1995; deMenocal, 1995; Kingston et al., 2007). Much of the evidence for climatic fluctuations and its relations with global climatic change are well-documented in marine cores (deMenocal, 1995). Current data from Pliocene localities dated between 2.7-2.55 Ma in the Baringo Basin (Kenyan Rift) is providing evidence for orbitally mediated environmental changes impacting terrestrial fauna (Kingston et al., 2007). Because of the disconformity the time interval between 2.9-2.7 Ma is not well-represented at Gona, and lacking any archaeological or faunal evidence for detecting effects of global climate (Quade et al., 2004, 2008). Although establishing causal links are difficult due to limiting factors related to sedimentation and the influence of volcano-tectonics, the time interval between 2.9-2.7 appears to have been a critical time period in human evolution with the disappearance of *Au. Afarensis* from the geological record, and the emergence of a diversified hominin lineage and the beginnings of the use of stone artifacts in East Africa (e.g., Walker et al., 1986; Hill et al., 1992; Schrenk et al., 1993; Suwa et al., 1996; Kimbel et al., 1994, 1996; Semaw et al., 1997, 2003; Asfaw et al., 1999; de Heinzelin et al., 1999). Recent studies at Hadar within sediments dated between 3.15-2.9 Ma show significant increase in arid-adapted fauna likely related to climatic oscillations associated with climatic variability, but still difficult to establish cause-effect relationships between global climate changes and human evolution (Campisano & Feibel, 2007).

Future discoveries are needed of possible archaeological materials from deposits dated between 2.9-2.7 Ma, which also coincides with the climatic shifts known to occur globally and the local changes documented regionally; faunal, geological and isotope studies may also help resolve some of the major questions regarding the beginnings of the manufacture and use of flaked-stones (e.g., Vrba, 1995, 1999; Wesselman, 1995; de Menocal, 1995; Shackleton, 1995; Behrensmeyer et al., 1997; Levin et al., 2004; Bobe & Behrensmeyer, 2004; Campisano & Feibel, 2007; Kingston et al., 2007; Potts, 2007). Therefore, further research combining geology, fauna and archaeology will be critical for determining the driving force(s) that pushed ancestral hominins to invent cutting tools by flaking stones, for assessing why ancestral hominids resorted to a novel means of adaptation by utilizing animal resources in their diet and for testing various environmental hypotheses of this consequential event in human evolution (cf. Potts, 2007). The best clues, most likely, may still lie in the few pockets of deposits dated between 2.9-2.7 Ma at Gona or elsewhere in Africa (Rogers & Semaw, in press).

The current archaeological evidence from Gona shows that stone artifacts made an abrupt appearance in the geological record by c. 2.6 Ma, and so far any traces of modified stones or bones confirmed to be a result of hominin involvement, and from well-controlled geological context are unknown in the deposits that are older than 2.6 Ma (but see de Heinzelin, 1983). The archaeological evidence from our recent investigations at Gona reinforces earlier suggestions made on the sophisticated techniques and skills seen in the stone tool manufacture practiced ~2.6 Ma (Semaw et al., 1997). Our preliminary observations also indicate that the intended function, proximity/distance to raw materials sources, availability, size and the flaking quality of accessible raw materials may have played a prominent role in hominin selectivity of raw materials and its effect on the final forms of the artifacts. Although no hominids were discovered from the Late Pliocene deposits at Gona, it is likely that *Au. garhi* discovered with the Bouri archaeological materials could have been the first toolmaker (Asfaw et al., 1999). Further investigations are needed to shed light on the reasons behind the differences seen in the assemblages of the two areas, but environmental differences and idiosyncratic norms and behaviors in the selection of raw materials and the extent of reduction of the cores may have dictated the final forms of the artifacts found at different parts of the ancient landscape.

The presence of fossilized fauna modified by ancestral hominins at the OGS-6 and OGS-7 archaeological sites, albeit fragmentary and very small in number, and the absence of such evidence at the EG sites is intriguing. It is still unclear if the absence of bones at the EG sites was a taphonomic bias related to the lack of preservation or a direct reflection of the differences in the tool use behavior of the hominins that lived in the two areas. On the outset it may seem that the OGS hominins exploited resources more effectively for activities related to animal butchery compared to the lack of evidence for fossilized bones and related activities at the EG sites. However, it will be difficult at this stage to attribute such differences between the two areas to a more effective use of stone material sources as well as better exploitation of animal carcasses at OGS vs. at EG. Only ~ 3m^2 has been excavated at OGS-7 because of the large amount of overburden above the site, and if major differences exist between the EG and OGS areas, the full picture can be understood only with further expansion of the EG and OGS excavations and recovery of additional archaeological materials *in situ*, and continued investigations of the raw material sources and the ancient environments in the two areas.

The discovery of sharp cutting tools made on stones ~2.6 Ma (or probably even earlier) was a major technological breakthrough which greatly facilitated access to new food sources like meat. The behavioral threshold crossed with the invention of flaked stones some time in the Pliocene has changed the course of human evolution forever, eventually leading to the expansion/enlargement of ancestral hominin brain through a complex mechanism of feedback interplay of continued tool use ultimately resulting in human dependency on technology.

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Appendix 1

The Gona palaeoanthropological study area

The Gona Project was organized and the international research team began large-scale palaeoanthropological investigations in 1999. The Gona Palaeoanthropological Research Project study area is located in the west-central Afar Rift and covers an area of >500 Km^2 badlands with fluvio-lacustrine fossiliferous and artifact-rich deposits. The major rivers and their tributaries drain regions of the study area and seasonally flow into the Awash, also cutting through ancient sediments and exposing Plio-Pleistocene artifacts and fossilized fauna. Cobble conglomerates and interbedded tuffaceous markers are prominent through out much of the stratigraphic sequence providing local markers for correlating sites and the materials critical for dating the fossil and artifact-rich deposits.

To the east of Gona is the contiguous Hadar study area well-known for yielding a wealth of fossil hominins attributed to *Australopithecus afarensis* (including the famous fossil skeleton known as 'Lucy'). The foothills of the Gona Western Escarpment mark the boundary of the Gona study area to the west. The fossiliferous deposits in the Gona Western Escarpment are patchy, but contain important Late Miocene fauna and hominins dated to $\geq$ 5.6 Ma. The Early Pliocene deposits exposed in the adjacent Gona Western Margin have also yielded abundant hominins dated between 4,5-4.3 Ma and attributed to *Ardipithecus ramidus* (Semaw et al., 2005). The Bati-Mile road limits the northern extent of the Gona study area.

The eastern and southeastern portion of the study area in the Kada Gona, Ounda Gona and Dana Aoule drainages contain >80m thick sediments with Plio-Pleistocene fossil fauna, and artifact-rich deposits with multiple Oldowan levels within the 2.6-c. 1.5 Ma time interval. Successive layers of several Acheulian occurrences estimated between 1.7-0.5 Ma are documented in the Dana Aoule, Busidima and Gawis drainages. Further to the east the deposits at Gawis and Ya'alu are rich with Late Acheulian, surface scattered Middle Stone Age, and Late Stone Age sites. The deposits that contain Early and Late Acheulian stone artifacts have also yielded several hominin fossils (Semaw et al., in prep; Simpson et al., 2008). The Asbole and further upstream the Dera Dora Rivers mark the southern limit of the study area. The deposits exposed towards the southwestern part of Gona contain Mid-Late Pleistocene archaeology and fauna. The fossil and artifact-rich deposits outcropping in the Gona study area are now providing windows of opportunities for systematic archaeological, palaeontological, and geological field investigations, and the research team has carried out successive fieldwork between 1999 and 2007.

CHAPTER 12

Understanding Oldowan Knapping Skill: An Experimental Study of Skill Acquisition in Modern Humans

Dietrich Stout, Kathy Schick and Nicholas Toth

Abstract

Variation in knapping skill is a potential source of variability in Oldowan artifact assemblages thought to have important cognitive, behavioral and evolutionary implications. However, a uniform method for assessing Oldowan knapping skill has yet to be adopted. Research presented here builds upon previous experimental and archaeological work in pursuit of increasingly systematic, detailed and empirically informed models of skill-related variation. Lithic products from six technologically naïve subjects, knapping before and after a controlled practice period, and from three experienced academic knappers were collected and analyzed as part of a broader experimental study of skill acquisition. Results revealed skill-related variation related to core reduction intensity, debitage productivity, frequency and morphology of fragments, flake metrics, and flake types, as well as modulation of these variables by raw material type and blank morphology. From this artifactual variation, three behavioral stages of skill acquisition were identified: I) an initial phase of relatively uncontrolled wedging fracture, II) a rapidly achieved phase of controlled but minimally invasive flaking, and III) expert performance with intensive core reduction through invasive flake removals. Of these, expert performance is most similar to patterns reported from early Oldowan artifact assemblages. These results highlight relevant variables and relationships to be considered in the archaeological evaluation of Oldowan knapping skill, and suggest the presence of substantial hominin investments in knapping skill acquisition already at this very early date.

Introduction

Assessing variation in hominin stone tool making skill is an increasingly important objective for Early Stone Age archaeology. In recent years, knapping skill has emerged as a key piece of evidence in a wide range of debates, including those over the existence of a "pre-Oldowan" technological stage (Roche, 1989; Semaw, 2000), the likelihood of hominin tool making prior to the earliest known occurrences (Panger et al., 2002; Semaw et al., 2003), the nature of variability in Plio-Pleistocene artifact assemblages (Delagnes & Roche, 2005; Kimura, 2002; Ludwig & Harris, 1998), the number of species involved in stone tool-making (Delagnes & Roche, 2005), and the sophistication of early hominin cognition and culture (de la Torre, 2004; Hovers, 2003; Ludwig & Harris, 1998; Roche, 2005; Semaw, 2000) in comparison to that of modern apes (Mercader, 2004; Pelegrin, 2005; Schick et al., 1999; Wynn & McGrew, 1989). However, no uniform method has been adopted for evaluating Oldowan knapping skill.

Major contributions to the subject have come from qualitative descriptions of East African Plio-Pleistocene lithic assemblages, including the reconstruction of reduction sequences (Delagnes & Roche, 2005) and strategies (de la Torre, 2004; de la Torre et al., 2003), as well as attribute-based evaluations of flaking skill (Ludwig & Harris, 1998; Semaw, 2000). In practical terms, this work has strongly supported the view (Semaw et al., 1997) that late Pliocene hominins were fully competent Mode I stone knappers. The adoption of an interpretive, "*chaîne operatoire*", approach by several of these studies (de la Torre, 2004; de la Torre et al., 2003; Delagnes & Roche, 2005) has also sought to introduce a new level of detail to the description and interpretation of Plio-Pleistocene technological behavior. This offers exciting possibilities for the reconstruction of specific knapping actions and strategies (Martinez-Moreno et al., 2003) while raising substantial new challenges for the study of behavioral variability. A suitably detailed comparative and explanatory framework is essential if we are to avoid producing a series of interesting but idiosyncratic case studies (Martinez-Moreno et al., 2003).

In this context, skill may be seen as one of many potential sources of inter-assemblage variability. Some of the assemblage characteristics putatively associated with knapping skill variation in the literature have included reduction intensity and efficiency (de la Torre, 2004; Delagnes & Roche, 2005; Ludwig & Harris, 1998; Semaw, 2000), flake size and morphology (de la Torre, 2004; Ludwig & Harris, 1998; Semaw, 2000), platform angles (Roche, 2005; Semaw, 2000), proportions of whole flakes vs. fragments (Hovers, 2003), frequency of hinge and step fractures (Kibunjia, 1994; Ludwig, 1999; Ludwig & Harris, 1998), standardization of knapping methods and products (de la Torre, 2004; de la Torre et al., 2003; Delagnes & Roche, 2005; Ludwig & Harris, 1998), and selectivity of raw materials (de la Torre, 2004; Ludwig & Harris, 1998; Stout et al., 2005). More recently, a systematic comparative study of Mode I knapping by Oldowan hominins, modern apes, and experienced modern humans (Toth et al., 2006) identified sixteen specific criteria for evaluating skill in Oldowan assemblages, including core type frequencies, scar counts, remnant cortex, and edge angles, as well as debitage type, frequency, mass, shape, and external platform angles. Importantly, results from this study also demonstrated the influence of broader behavioral patterns, such as test flaking at raw material sources, off-site core reduction, and the selective removal of artifacts, on relevant assemblage characteristics.

From such findings it is clear that a wide range of ancillary factors condition the expression, preservation and identification of even the most robust indicators of knapping skill. These include raw material characteristics and availability (de la Torre, 2004; Delagnes & Roche, 2005; Isaac, 1984; Ludwig & Harris, 1998; Semaw, 2000), artifact transport and discard patterns (Potts, 1991; Schick, 1987; Stiles, 1998; Toth, 1987), broader adaptive contexts (Blumenschine & Peters, 1998; Braun & Harris, 2003)[tackticos], site formation processes (Hovers, 2003; Petraglia & Potts, 1994; Schick, 1991), and even the "particular skills" (Gowlett, 2004) of individual lithic analysts. Thus, specific criteria used to assess knapping skill will frequently be incommensurate across sites. For example, reduction intensity is clearly related to skill but is also likely to be influenced by local raw material availability (Toth et al., 2006). For this reason, evaluation of relative knapping skill across assemblages has remained largely subjective (Plummer, 2004).

In order to move beyond such subjective assessments, it is necessary to develop more systematic, detailed and empirically informed models of skill-related variation. Ideally, such models would incorporate multiple interacting behavioral and environmental factors in order to assess demonstrated (i.e. minimum required) knapping skill at assemblage, regional and chronostratigraphic scales (Toth et al., 2006). Controlled knapping experiments with subjects of variable skill levels provide one major avenue for the development of such models. Logically, such studies may involve cross-sectional comparisons between groups and/or longitudinal investigations of skill acquisition within groups.

Cross-sectional studies are particularly useful in establishing an overall comparative framework and identifying relevant variables. Using such an approach, the aforementioned inter-species comparative study (Toth et al., 2006) situated archaeologically observed Oldowan knapping along a continuum between modern ape and human capabilities, suggested characteristics that might be expected in a hypothetical "pre-Oldowan" technological stage, and identified 16 specific indicators of knapping skill through a systematic assessment of 42 separate artifact attributes.

Longitudinal studies can complement such research by providing a window on the dynamics of skill acquisition, including novice performance, patterns of change through time, and amounts of practice required to achieve particular levels of skill. This last point is of considerable interest because the amount of practice time required for novices to replicate specific artifact forms might in principle be used as a quantitative measure of skill in archaeological assemblages (Toth, 1991). Prehistoric investments in technical skill acquisition may also have important cognitive, social and behavioral implications (Stout, 2002, 2005b).

Unfortunately, only a handful of experimental studies of Mode I knapping skill have been conducted (Ludwig, 1999; Ludwig & Harris, 1998; Toth et al., 2006) and none has directly investigated the process of skill acquisition. As a result, we still know very little about the behavioral dynamics, cognitive requirements and material correlates of Mode I knapping skill acquisition. For this reason, we undertook a multidisciplinary study of Mode I tool making skill acquisition in technologically naïve subjects, combining functional brain imaging (Stout & Chaminade, 2007), video-based operational analysis, and quantitative lithic analysis in order to gain a cohesive picture of the cognitive, behavioral and artifactual changes associated with skill acquisition. Lithic analyses, presented here, were aimed at identifying objective, quantitative indices of developing knapping skills that might be useful in modeling patterns of skill-related variation in the early archaeological record.

Experimental Design

Six novices with no prior stone knapping experience and three experienced academic knappers were recruited to participate in the study. Each novice subject participated in two Mode I knapping experiments (before and after practice) and each expert in one.

All knapping experiments were conducted under controlled conditions at the PET Imaging Center of the Indiana University School of Medicine, Department of Radiology. Subjects were seated in a chair with an array of stone cobbles available within easy reach on a cart to their left. Cobbles were collected at a gravel quarry in Martinsville, Indiana, and included a wide range of sizes, shapes and materials. Selection of cobbles (both hammerstones and cores) from those provided was an important component of the experimental task.

Subjects were instructed to use the cobbles on the cart to produce sharp stone flakes that would be "useful for cutting." This is in keeping with the current consensus that Oldowan knapping was primarily directed at the least effort production of sharp edges (Braun & Harris, 2003; Delagnes & Roche, 2005; Isaac, 1984; Potts, 1991; Toth, 1985), although it does not address the hypothesis that some core forms were intentionally shaped (Roche, 2005). At the outset of each experiment, a radiological tracer was administered through a venous catheter in the foot. Subjects were then left alone to perform the task for 40 minutes, after which time all lithic products were collected. A drop cloth was used to ensure 100% collection, and all experiments were video taped for operational analysis. As described elsewhere (Stout & Chaminade, 2007), brain activation data were collected following task completion.

After completion of the first experiment, each novice subject independently completed four weekly, uninstructed, 1-hour tool making practice sessions held at the Center for Research into the Anthropological Foundations of Technology (CRAFT) in Bloomington, Indiana. Subjects were provided with the same range of cobbles available during the experiments, as well as sheets of vinyl and pieces of wood with which to test the cutting ability of tools produced. Following completion of the practice regime subjects participated in a final tool making experiment with conditions and instructions identical to those in the pre-practice session.

Lithic Analysis

For each experiment, all lithic products greater than 25mm in maximum dimension were identified by raw material, technologically classified, and analyzed according to relevant technological attributes (Table 1, all analyses performed by DS). Previous research (Toth et al., 2006) has identified variables relating to reduction intensity, debitage productivity, flake size, and edge angles as being particularly relevant to knapping skill. In order to maximize the comparative utility of the analysis, an effort was made where possible to use variables that were quantitative rather than qualitative, continuous rather than categorical, and objective in the sense of being relatively easy to define, observe and replicate without reference to the particular expertise of the analyst.

Raw material classification

The first step in analysis was classification of the lithic raw materials. Nodules used in the study were collected from a gravel quarry in Martinsville, Indiana and included blocks of local sedimentary bedrock as well as glacial outwash from the White River. A wide array of rock types were represented in the sample, including micritic, silicified and variably fossiliferous limestones, siltstone, chert, quartz, quartz sandstone, quartzite, and various grades of metabasalt. Individual specimens within types further displayed substantial variation in technologically relevant characteristics including density, homogeneity, grain size, weathering, and the occurrence of internal flaws, inclusions and/or preferential fracture planes. This high level of variability resembles that observed in some East African Pliocene raw material sources (Stout et al., 2005), and presents similar difficulties for summary description and analysis.

In the current study, a highly conservative "lumping" approach was ultimately adopted, with each artifact being placed into one of three categories reflecting broad variation in flaking properties: 1) sedimentary (primarily limestone), 2) vein quartz, and 3) metamorphic (primarily quartzite and metabasalt). Chert, initially treated as a separate category, accounted for only 2.2% of the total number of artifacts and was ultimately grouped with other sedimentary rocks for analysis. A further 78 pieces (3.7%) were classified as unidentifiable or "other."

This inclusive classificatory scheme was adopted in order to maximize the robusticity, replicability and broader relevance of the results obtained. Information is necessarily lost regarding more specific raw material effects within categories, however any surviving trends and relationships will be those least sensitive to such variation. This is consistent with the goals of the current study, which focus on generalized model building rather than specific replication.

Nodule reconstruction

In order to avoid disturbing the experimental subjects, no attempt was made to separate the products of individual nodules during knapping. However, conjoining (assisted by the distinctive appearance of many nodules) allowed for over 95% of detached pieces to be assigned to their original nodule. In this way, each sample was treated as an idealized archaeological assemblage with 100% artifact representation.

Technological classification

Individual artifacts were initially classified into the basic technological categories proposed by Isaac (1984): flaked pieces, detached pieces and pounded pieces (Table 1). In order to provide additional descriptive detail, flaked pieces were further classified using the modified version of Mary Leakey's (1971) typology developed by Toth (1985; 1982). Although categorical and qualitative, these classifications are easily defined and reproduced

Table 1. Variables used in lithic analysis

Technological Classification		**Technological Attributes**		
Flaked and Pounded Pieces*	**Detached Pieces**	**Cores**	**Whole Flakes**	**Angular Fragments**
Battered cobble	Whole Flake	Length (mm)**	Maximum Dimension (mm)	Length (mm)**
Casual core	Split Flake	Breadth (mm)	Length (mm)	Breadth (mm)
Unifacial chopper	Proximal Snap	Thickness (mm)	Breadth (mm)	Thickness (mm)
Bifacial chopper	Angular Fragment	Mass (g)	Thickness (mm)	Mass (g)
Unifacial discoid		Remaining Cortex (%)	Mass (g)	
Bifacial discoid			Platform Breadth (mm)	
Core scraper			Platform Thickness (mm)	
Polyhedron			Exterior Platform Angle (EPA)	
Split cobble			Flake Type	

** Only types actually present in the sample are listed*
*** For cores and angular fragments, length is defined as the maximum dimension*

by different analysts and provide a rough indication of both mode and intensity of reduction (Toth, 1985; Toth, 1982).

Detached pieces were classified as whole flakes, split flakes (longitudinal fracture), proximal snaps (transverse fracture, with striking platform preserved) and angular fragments (no striking platform). Although it is sometimes possible to further differentiate angular fragments as flake fragments (distal snaps, midsections, etc.) or angular shatter (e.g. "chunks"), this introduces an additional level of subjectivity to the analysis and was not attempted here. Instead, the ratio of maximum dimension to thickness was used to provide an objective and continuous measure of fragment laminarity vs. chunkiness.

Technological attributes

Technological attributes recorded for all artifacts > 25mm in maximum dimension are listed in Table 1.

Cores

Cores were analyzed according to linear dimensions, mass, and % cortex coverage. Length was defined as the maximum dimension, with breadth as the maximum dimension orthogonal to length and thickness as the maximum dimension perpendicular to the plane defined by length and breadth. Core mass was measured to the milligram.

With regard to skill, it was considered that the most important variables potentially represented by cores were flaking mode (reflected in technological classification) and reduction intensity. Reduction intensity has been linked with flake scar counts (Potts, 1991; Toth, 1982), however this relationship is complicated by the effects of initial core size and the deletion of scars by subsequent flake removals (Braun et al., 2005). Exact scar counts may also be difficult to replicate (Andrefsky, 1998), particularly in coarse and/or shatter-prone materials. Experience with conjoining in the current experimental sample clearly showed that apparent scar counts were frequently misleading regarding the actual number and pattern of detachments, particularly in the novice samples.

For these reasons, the simpler measure of percent cortex coverage (estimated to the nearest 5%) was adopted. Although subject to some of the same limitations as flake scar counts, this measure is easily defined, rapidly recorded and reasonably predictive of reduction intensity. In the current sample, % cortex predicted the total number of detached pieces per nodule with an $r^2 = 0.48$.

Whole flakes

Whole flakes were analyzed for linear dimensions, platform dimensions, external platform angle, mass, and flake type. Linear dimensions and mass provide information regarding flake size and shape, both of which have been linked with knapping skill (Ludwig, 1999; Ludwig & Harris, 1998; Semaw, 2000; Stout, 2002; Toth et al., 2006). Length was defined as the distance from the point of percussion, perpendicular to platform breadth, to the distal margin of the flake, while breadth and thickness were defined as maximum dimensions orthogonal to length. These particular definitions were selected because they are easily defined, measured and replicated, and because they reflect information about flake shape not captured by measurements like "maximum flake length" (Andrefsky, 1998). Ratios were used as a quantitative and continuous means to assess variation in flake shape, including laminarity (maximum dimension/thickness), elongation (breadth/length), and skewing (displacement of the maximum dimension away from the axis of either length or breadth).

Flake platform dimensions (breadth and thickness) are theoretically interesting because they are (at least potentially) under the control of the knapper and are causally related to flake size (Dibble, 1997; Dibble & Pelcin, 1995; Speth, 1972). Manipulation of platform dimensions is one way in which skilled knappers might exert control over the knapping process. Platform breadth was defined as the distance between the lateral margins of the flake along the striking platform. Platform thickness was defined as the distance along the platform surface between the dorsal and ventral margins at the point of percussion.

External Platform Angle (EPA) is another important variable that may be manipulated by knappers in order to influence the size and shape of flakes (Dibble, 1997; Dibble & Pelcin, 1995; Speth, 1972), and the amount of force required to successfully initiate fracture (Dibble & Pelcin, 1995). Selection and maintenance of appropriate core angles is an important factor in knapping success (Pelegrin, 2005), and a relationship between EPA and knapping skill level has been documented in previous ethnographic and experimental research (Ludwig, 1999; Stout, 2002). Unfortunately, flake platform angles are notoriously difficult to define and measure in a reliable fashion (Andrefsky, 1998; Cochrane, 2003; Dibble, 1997). Mode I flakes do have the advantage of relatively large and simple platforms compared to some more recent technologies (Cochrane, 2003), however they frequently display highly irregular and convex dorsal surfaces. For this reason, measurements taken to well-defined and consistent dorsal landmarks (for example, to a point located below the platform at a distance equal to platform thickness [Dibble, 1997]) may be less effective in Mode I flakes. In particular, such measures (Figure 1a) may fail to capture physical relationships influencing Mode I flake size and shape. As explained by Dibble and Pelcin (1995), the relationship between EPA and flake size may be conceptualized in simple geometric terms, with increases in EPA producing triangular flake cross sections of increasing height and area (figure 1b). Although cross sections of real flakes inevitably deviate from this geometric ideal, the underlying relationships are expressed by a right triangle drawn between the striking platform and dorsal flake surface (Figure 1c). The base (striking platform) and hypotenuse of this triangle form an EPA that is determined by the overall distribution of mass in the flake, rather than by the flake's proximal dorsal morphology. This angle is reflective of the underlying mechanics of flake removal and, in more subjective terms, approximates judgments of effective edge angle made by knappers confronted with superficially irregular core morphologies.

Unfortunately, dorsal convexities frequently make it impossible to measure this angle directly on flakes. In the current study, measurements (to the nearest 5°) were taken by aligning the goniometer arm along a line parallel to the hypotenuse and tangent to the dorsal surface (Figure 1c). Although this angle captures important technological information, the method of its measurement is clearly dependant on the individual skills of the analyst. Until a better method is developed, perhaps through the use of digital image analysis, a degree of subjectivity and imprecision in this measure is unavoidable.

In order to assess the accuracy of the current method of measurement, a replication study was conducted with a random sample of 96 flakes from 10 different nodules. Re-measurement yielded a difference in the mean EPA of 0.5° with no change in the median value, confirming

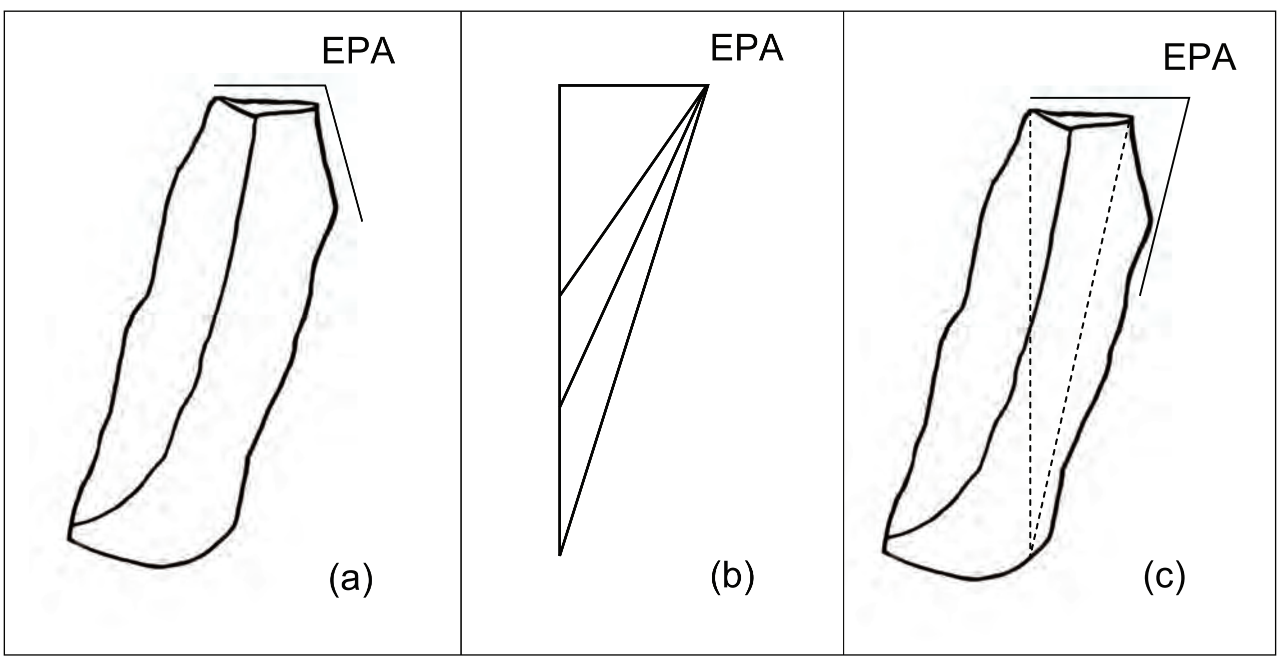

Figure 1. Measuring the External Platform Angle on a large type IV flake from the expert sample: (a) a direct measurement, (b) underlying geometric relationship of EPA to flake size, (c) method of measurement adopted in this study.

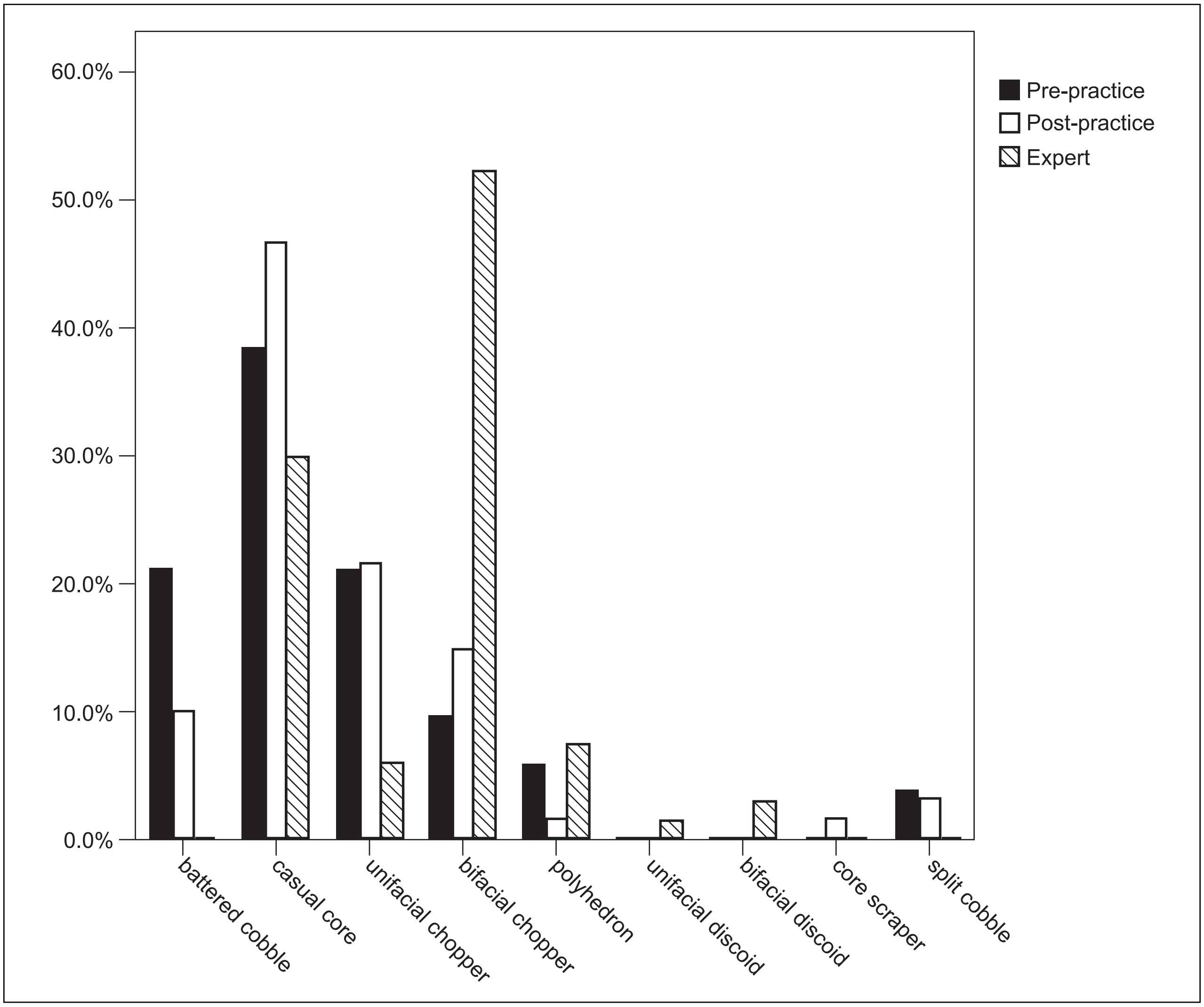

Figure 2. Core type representation in novice and expert samples

the replicability of the central tendency. The mean error was 4.9° with a median and a mode of 5.0°. This likely reflects the fact that measurements were taken to the nearest 5.0°.

Angular fragments

Angular fragments were analyzed for linear dimensions and mass. Due to the lack of technological landmarks, length was defined as the maximum dimension, with breadth as the maximum dimension orthogonal to length and thickness as the maximum dimension perpendicular to the plane defined by length and breadth. Mass was measured to the milligram.

Other fragments

The other fragment categories used in this study were split flakes and (proximal) snapped flakes. Split and snapped flakes were analyzed for maximum dimension, length, breadth, thickness and mass in the same fashion as whole flakes, with the obvious difference that some measures (breadth for split flakes, length for snaps) were being taken to broken edges rather than intact margins. In addition proximal snaps were analyzed for platform dimensions and EPA. Fragments that were both split and snapped were treated as angular fragments.

Statistical Analyses

All statistical analyses were conducted using SPSS©. Variables analyzed for this study include both categorical (e.g. core and debitage types) and ratio (e.g. artifact counts, flake metrics) data. The significance of variation between samples in the distribution of categorical data was tested using Pearson's Chi-Square. In the case of ratio data, there was no strong reason to expect homogeneity of variance on any of the variables being examined. Thus, following Ruxton (2006), it was decided to apply the unequal variance (Welch) t'-test for all significance testing on ratio data. It is also quite typical for debitage metric attributes to be heavily skewed by a preponderance of small pieces. This was the case in the current study, and many sample distributions were found to be significantly non-normal (1-sample Kolmogorov-Smirnov test, $p < 0.05$). In these cases, data were ranked before application of the t'-test (Zimmerman & Zumbo, 1993), and median values used to report central tendency.

Table 2. Productivity by Experience and Raw Material

Experience	Raw Material	Cobbles	WF	AF	Flake Fragments SF	Flake Fragments PS	DP
Pre-Practice (n=6)	Sedimentary	21	95 31%	178 58%	31 10%	4 1%	308
	Quartz	11	16 39%	24 58%	1 2%	0 0%	41
	Metamorphic	20	84 57%	49 33%	14 9%	1 1%	148
	Total	*52*	*195* *39%*	*251* *51%*	*46* *9%*	*5* *1%*	*497*
Post-Practice (n=6)	Sedimentary	27	98 45%	83 38%	34 15%	5 2%	220
	Quartz	13	33 28%	55 47%	26 22%	2 2%	116
	Metamorphic	19	67 53%	29 23%	24 19%	7 6%	127
	Total	*59*	*198* *43%*	*167* *36%*	*84* *18%*	*14* *3%*	*463*
Expert (n=3)	Sedimentary	10	117 38%	119 38%	61 20%	14 5%	311
	Quartz	7	34 49%	29 41%	6 9%	1 1%	70
	Metamorphic	48	263 42%	213 34%	118 19%	27 4%	621
	Total	*65*	*414* *41%*	*361* *36%*	*185* *18%*	*42* *4%*	*1002*

**Table does not include the small number of artefacts classified as "indet/other"*

Results

Analysis of the technological attributes described above produced evidence of skill-related variation in core reduction, flake productivity, frequency and morphology of fragments, flake metrics, and flake types. Important raw material effects were observed, as well as skill effects that are relatively independent of raw material.

Core reduction

The frequency distribution of core types (Figure 2) showed little change in novices before and after practice (Pearson Chi-Square 5.57, df = 6, p = 0.473), but in experts reflected a much greater representation of bifacial and more heavily reduced (polyhedral, discoidal) forms (Pearson Chi-Square 60.99, df = 16, $p < 0.001$). The same pattern is seen in the percentage of cortex ocverage, which is indistinguishable among novices, but significantly less in experts (median = 60%) compared to pre-practice (median = 75%, $t' = 3.52$, df = 98.51, p = 0.001) and post-practice (median = 78%, $t' = 4.18$, df = 123.03, $p < 0.001$) novices. This difference is also significant in each raw material category consider separately. The only apparent trend within novices is a decrease in battered cobbles and concomitant increase in casual cores (i.e. indicating greater success in removing at least one or two flakes) following practice (Figure 2).

Productivity

Artifact productivity by experience level and raw material type is reported in Table 2. Among novices, practice was not associated with any significant changes in overall productivity, whether measured in terms of to-

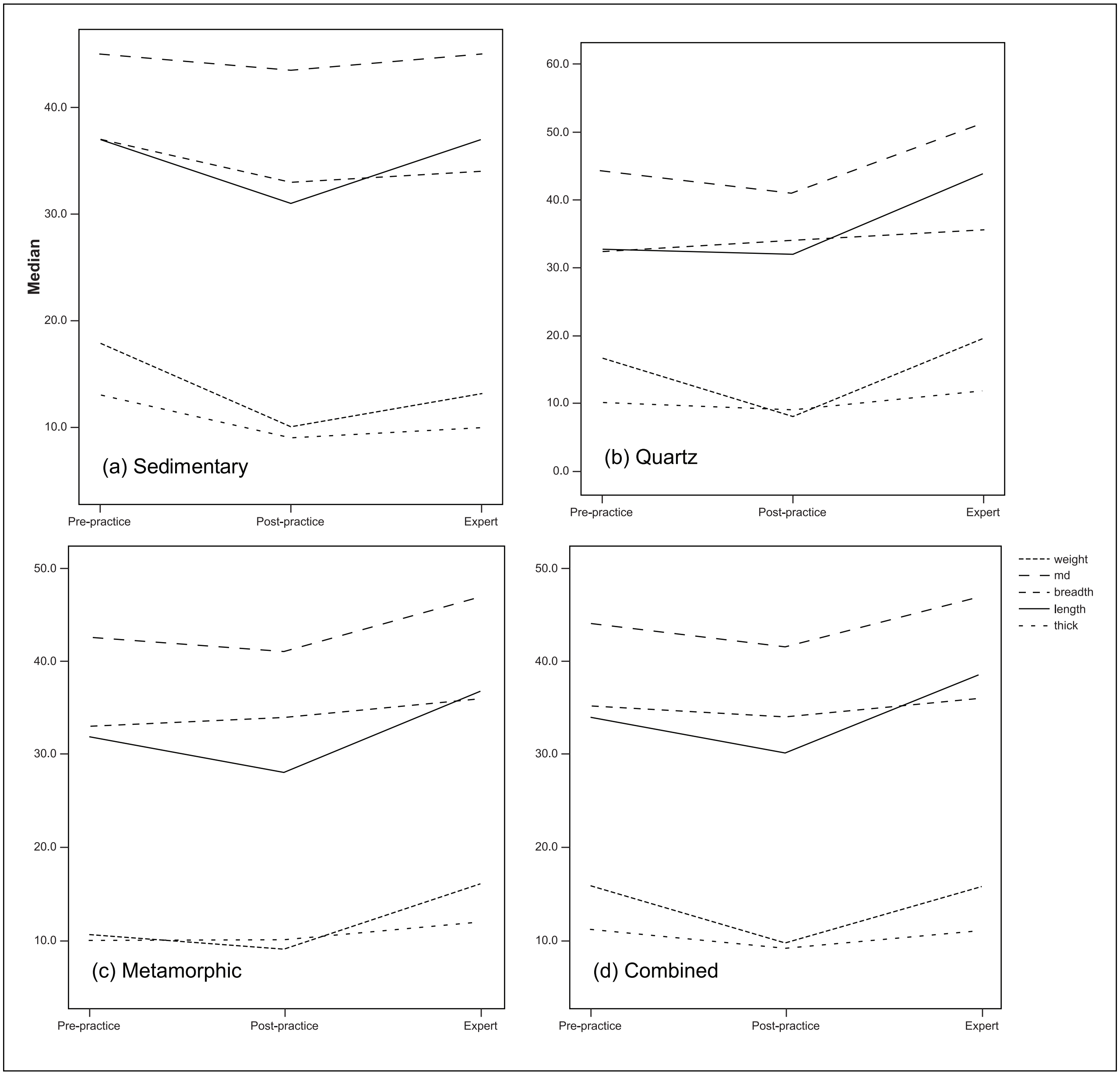

Figure 3. Effects of experience on flake size in different raw materials.

tal cobbles modified, pieces detached, whole flakes produced, pieces detached per cobble or whole flakes produced per cobble. There was also no major alteration in the proportions of sedimentary, quartz and metamorphic cobbles modified (0.40:0.21:0.39 vs. 0.46:0.22:0.32).

In contrast, expert subjects modified significantly more cobbles than pre-practice ($t' = -3.26$; $df = 2.49$; $p = 0.062$) and post-practice ($t' = -5.55$; $df = 4.11$; $p = 0.062$) novices, detached more pieces (pre: $t' = -4.15$; $df = 3.46$; $p = 0.019$ / post: $t' = -4.55$; $df = 2.68$; $p = 0.025$) and produced more whole flakes (pre: $t' = -3.51$; $df = 2.54$; $p = 0.051$ / post: $t' = -3.61$; $df = 2.24$; $p = 0.058$). Changes in productivity per cobble in the total sample were not significant, however this likely reflects raw material differences relating to the much greater percentage of metamorphic cobbles (72%) modified by experts. Experts did produce significantly more whole flakes (pre: $t' = -2.73$; $df = 22.71$; $p = 0.012$ / post: $t' = -3.06$; $df = 17.78$; $p = 0.007$) and detached pieces (pre: $t' = -3.38$; $df = 28.91$; $p = 0.002$ / post: $t' = -5.97$; $df = 28.16$; $p < 0.001$) per sedimentary cobble and per quartz cobble (whole flakes: $t' = -3.51$; $df = 15.98$; $p = 0.003$/ $t' = -2.24$; $df = 17.34$; $p = 0.039$; detached pieces: $t' = -2.43$; $df = 14.60$; $p = 0.028$/ n.s. in comparison to post-practice). Increased productivity of flakes and detached pieces per metamorphic cobble was significant at a lower threshold (whole flakes: $t' = -1.78$; $df = 28.84$; $p = 0.085$/ $t' = -1.87$; $df = 26.27$; $p = 0.073$; detached pieces: $t' = -1.76$; $df = 30.98$; $p = 0.089$/ $t' = -2.03$; $df = 32.37$; $p = 0.050$).

Fragments

In the sample of all novice fragments, practice was associated with a significant decrease in mass, absolute thickness and an increase in laminarity (maxi-

Table 3. Median values for all fragments

Raw Material	Experience	Max. Dim.	Breadth	Thickness	Max. Dim./ Thickness	Mass	% SF
Sedimentary	Pre-practice	37.7	27.5	13.6	3.9	8.9	1.4
	Post-practice	39.0	26.7	13.3	4.1	8.0	7.6
	Expert	38.0	27.8	13.6	4.0	7.4	18.5*
Metamorphic	Pre-practice	40.7	26.5	13.8	3.8	7.0	5.8
	Post-practice	39.4	26.4	11.6	4.3	5.9	0.0
	Expert	39.0	23.9	10.2*	4.5*	6.0	11.0
Quartz	Pre-practice	41.0	25.8	11.9	4.2	8.1	0.0
	Post-practice	40.5	26.3	10.2	4.7	6.5	7.7
	Expert	39.0	21.9†	8.7	4.6	4.3*	20.0*
Combined Sample	*Pre-practice*	*37.0*	*23.0*	*11.0*	*3.4*	*8.5*	*0.0*
	Post-practice	*37.0*	*23.0*	*10.0**	*3.8**	*7.0**	*0.0*
	Expert	*35.0*	*22.0***	*9.0**	*4.0**	*6.1**	*13.6**

** Significantly (p<0.05) different from pre-practice novices*
† Significantly (p<0.05) different from post-practice novices
*** Significantly (p<0.05) different from pre- and post-practice novices*

Table 4. Median values for whole flakes

Raw Material	Experience	Max. Dim.	Length	Breadth	Breadth/ Length	Thick-ness	MD/ Thick-ness	Mass	Plat-form Breadth	Plat-form Thick-ness	EPA
Sedimentary	Pre-practice	49.8	38.0	37.6	1.08	14.0	3.84	20.6	26.0	10.0	80.0
	Post-practice	45.0*	32.0*	35.0*	1.06	11.0*	4.52*	13.0*	21.0	8.0	80.0
	Expert	45.0	37.0†	34.0	1.09**	10.0	4.33*	13.0	22.0	7.0	75.0**
Metamorphic	Pre-practice	41.9	31.7	33.1	1.09	10.0	4.17	10.7	20.0	7.0	90.0
	Post-practice	41.0	28.0	35.0	1.15	11.0	4.25	11.6	23.0	8.0	85.0*
	Expert	50.0**	40.0**	36.5	0.93**	12.0	4.33	19.6**	23.0	7.0	80.0**
Quartz	Pre-practice	45.8	33.0	31.8	1.14	10.3	4.44	16.8	20.5	6.5	80.0
	Post-practice	39.0	32.5	32.0	1.04	10.0	4.29	8.0	21.0	5.0	85.0
	Expert	52.5	44.5†	35.5	0.92†	12.0	4.10	21.8	18.0	4.0	85.0
Combined Sample	*Pre-practice*	*45.6*	*35.0*	*35.6*	*1.10*	*11.9*	*4.00*	*17.0*	*22.8*	*8.0*	*85.0*
	Post-practice	*42.5*	*31.0**	*35.0*	*1.08*	*10.5**	*4.48**	*18.4**	*22.5*	*7.0*	*80.0**
	Expert	*49.0†*	*40.0***	*36.0*	*0.93***	*12.0†*	*4.30*	*16.7†*	*22.0*	*7.0*	*80.0**

** Significantly (p<0.05) different from pre-practice novices*
† Significantly (p<0.05) different from post-practice novices
*** Significantly (p<0.05) different from pre- and post-practice novices*

mum dimension/thickness). Expert fragments differed significantly from post-practice novice fragments only in breadth, perhaps reflecting the increased production of split flakes. The proportion of split flakes relative to the total number of pieces detached per cobble showed a progressive increase from pre-practice (mean rank = 68.7) to post-practice (mean rank = 78.4) to expert (mean rank = 91.0), however this difference was only significant in the comparison of experts to pre-practice novices ($t' = -2.66$, $df = 81.86$, $p = 0.01$). Split flakes in general were larger (maximum dimension: $t' = -2.69$, $df = 609.76$, $p = 0.007$) and relatively thinner ($t' = -4.54$, $df = 651.15$, $p < 0.001$) than angular fragments.

Analysis by raw material category inevitably reduced sample sizes, particularly in the case of the quartz and novice metamorphic samples (Table 2). Within individual raw material categories, changing median values (Table 3) are consistent with skill-related changes in fragment size and shape, but generally fail to achieve significance at the $p < 0.05$ threshold. Exceptions include the decreased mass of expert quartz fragments relative to pre-practice novices, and the decreased absolute and relative thickness of expert metamorphic fragments compared to those of pre-practice novices. The percentage of split flakes increases significantly in experts compared to pre-practice novices for sedimentary and quartz, but not for metamorphic, cores.

Whole flakes

Metrics

Analysis of the total sample of whole flakes (Table 4; Figure 3d) indicates a significant decrease in the length, thickness, relative thickness, mass and EPA of novice flakes following practice. Expert flakes reverse this trend toward reduced size, returning to pre-practice values for mass, maximum dimension and thickness, as well as being both longer and more elongated (breadth/length) than either sample of novice flakes. No significant trends were observed in platform dimensions; however the novice samples did have a much higher percentage of flakes lacking well-defined platforms (i.e. having broken, linear or punctiform platforms) on which measurements could be taken. These account for 16% of pre-practice flakes, 23% of post-practice flakes and 9% of expert flakes. The EPA of expert flakes was statistically indistinguishable from the post-practice condition.

As in the fragments, trends in flake size and shape seen in the total sample appear to be reflected within raw material categories (Figure 4a-c) although apparent differences are not always statistically significant in these reduced samples (Table 4). Quartz in particular is characterized by small sample sizes, and achieves significance only in comparisons of expert length and elongation to post-practice novices.

Among sedimentary flakes, maximum dimension, length, breadth, thickness, relative thickness and mass are all significantly reduced in post-practice flakes compared to pre-practice flakes. Expert sedimentary flakes show no significant differences in size from pre-practice novices, but are relatively thinner and more elongated. Expert sedimentary flakes also have a lower EPA than either novice sample.

Among metamorphic flakes, the only significant difference between pre- and post-practice novices is a reduction in EPA. Expert metamorphic flakes show a further reduction in EPA, as well as significantly greater maximum dimension, length, elongation, and mass than either novice sample.

Shape

Variation in the ratio of flake breadth to length at all skill levels is unimodal and continuous, providing no evidence of discrete morphological categories. In novice flakes, both before and after practice, breadth/length ratios cluster around 1.0, with median values of 1.08 and 1.10 respectively. In each case, more than half (62%, 60%) of flakes display a breadth greater than or equal to length. As described above, expert flakes are significantly more elongated, with length exceeding breadth in 55% of flakes (median = 0.94). In all samples, flake maximum dimension rarely exceeds the hypotenuse of a triangle formed by length and breadth (pre-practice = 9%, post-practice = 12%, expert = 12%), reflecting an infrequent occurrence of “skewed” flake shapes. There are no significant differences between any of the samples on this ratio.

Flake types

As may be seen in Figure 4, pre- and post-practice novice samples are dominated by flakes with cortical platforms (Types I-III) while experts show an increased representation of Type V. There is no significant difference between novice flake type distributions (Pearson Chi-Square = 8.84, $df = 5$, $p = 0.116$), however the expert distribution is significantly different from both pre-practice (Pearson Chi-Square = 14.17, $df = 5$, $p = 0.015$) and post-practice (Pearson Chi-Square = 42.13, $df = 5$, $p < 0.001$) novices. The same pattern ($p < 0.05$) is present in the sedimentary and metamorphic samples considered separately. Unfortunately, the quartz samples are too small (pre-practice = 16, post-practice = 27, expert = 34) for separate evaluation.

A one-way ANalysis Of VAriance on ranked data shows a significant interaction ($p < 0.005$) of flake type with each of the metric variables and ratios presented in Table 4. As shown in Figure 5, this reflects the relatively large size of types I, II and V relative to types III, IV, and VI. Among this first group, linear, mass and ratio differences between experience levels reported in Table 4 remain significant at $p < 0.05$ (novices vs. experts) and $p < 0.10$ (pre- vs. post-practice) thresholds. However, this is not the case in the second group, in which only the greater length and elongation of expert flakes vs. post-practice novices remains significant ($p < 0.05$). The proportion of the total sample represented by these two groups of flakes is essentially constant across experience levels (pre-practice: 0.68/0.32, post-practice: 0.68/0.32, expert: 0.67/0.33).

EPA behaves differently across flake types in experts as compared to novices (Figure 6), specifically in the much more acute EPAs of expert non-cortical platform flakes (types IV – VI). This pattern, coupled with the greater representation of non-cortical platform flakes in the expert sample, accounts for the reduced EPA of expert vs. novice flakes seen in Table 4. When non-cortical platform flakes are removed from the analyses, these differences disappear.

Discussion

Expert performance

The most striking patterns observed in the current study are the vastly greater debitage productivity and core reduction intensity of experts compared with novices. Half the number of experts produced more than twice the number of detached pieces in the same amount of time (Table 2), removed a significantly greater percentage of cortex from each core, and produced many more highly modified core forms (Figure 2). Somewhat surprisingly, 4 hours of practice did not result in any increase in the overall productivity or reduction intensity of novices and was actually associated with a decrease in the size of flakes (Table 4; Figure 3). This is in stark contrast to experts, who produced flakes that were not only more numerous, but also larger and more elongated. This is important because the greater size and invasiveness of flakes detached by experts is directly related to their increased productivity and reduction intensity.

In order to establish and maintain viable (i.e. relatively flat) knapping surfaces on a Mode I core, it is necessary to strike invasive flakes (Delagnes & Roche, 2005), ideally traveling more than half way across the surface. In contrast, the removal of small, non-invasive flakes from core edges leads to a progressive rounding of surfaces, creation of more obtuse edge angles, and premature exhaustion of the core. The production of sufficiently invasive flakes is itself dependant on the perceptual-motor and strategic skills of the knapper, who

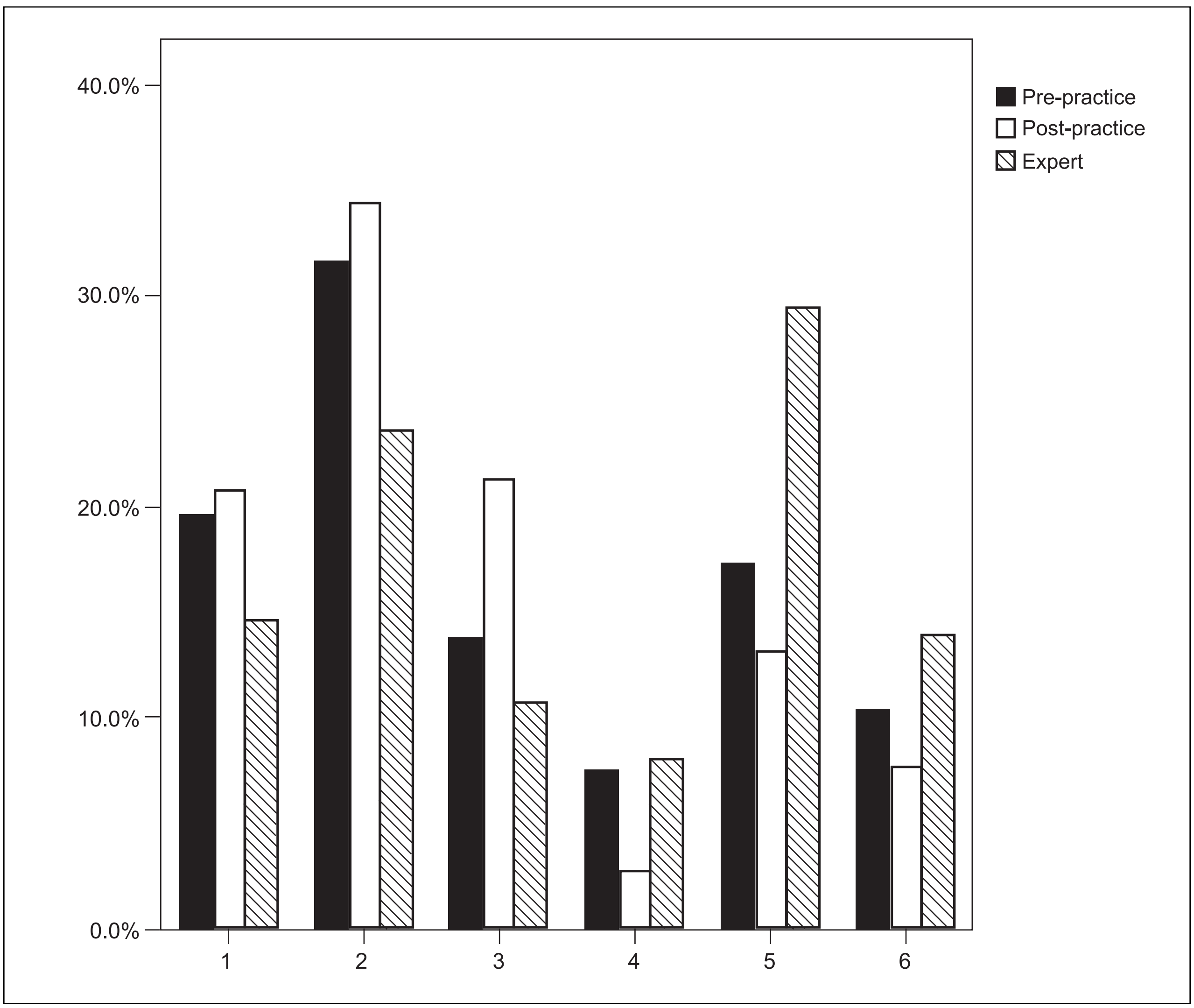

Figure 4. Flake type representation in novice and expert samples

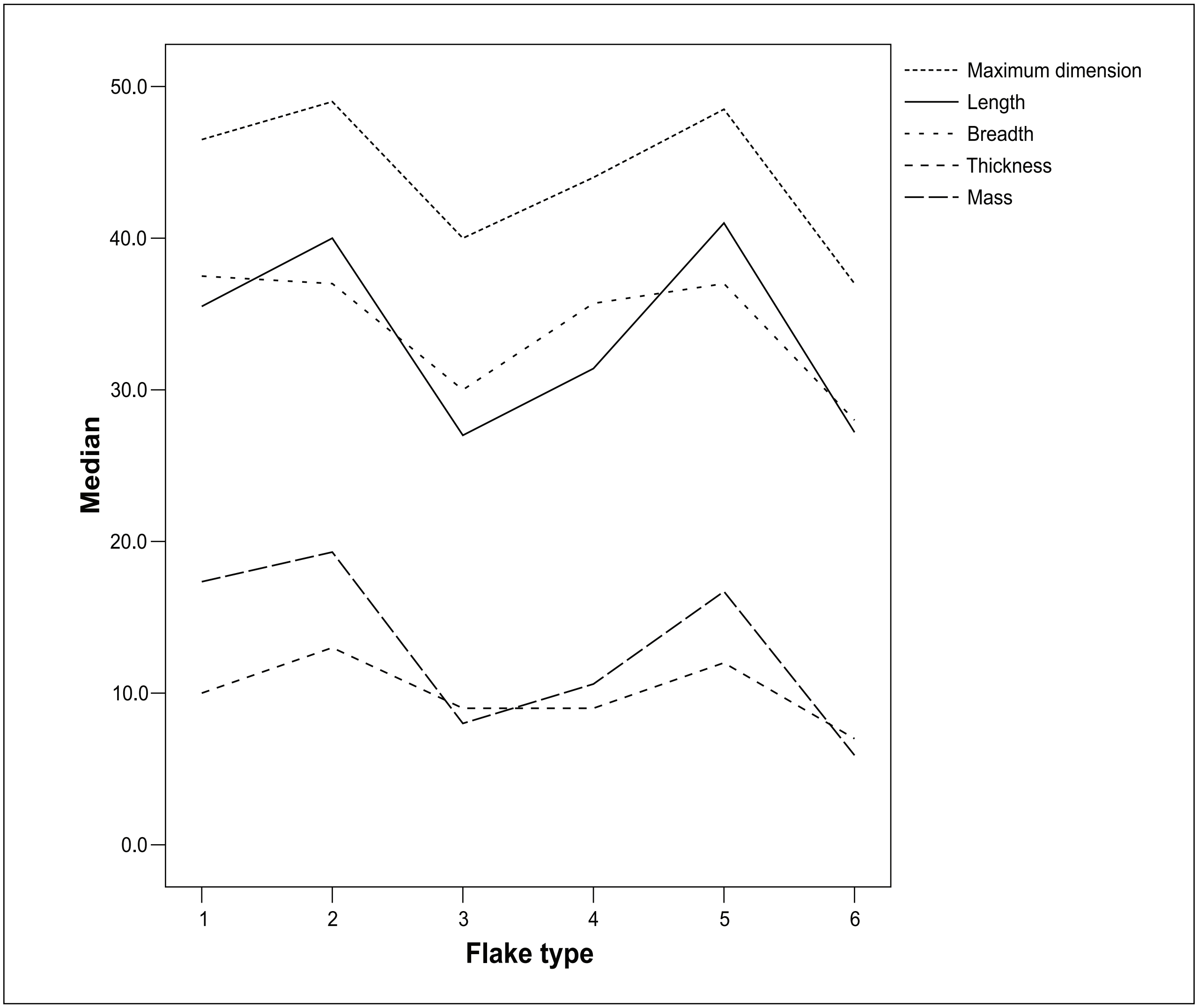

Figure 5. Relationship of flake type to flake size.

must accurately deliver sufficient force to appropriately selected targets.

All other things being equal, detachment of increasingly large flakes requires increased percussive force (Dibble & Pelcin, 1995). This may be achieved through an increase in strike velocity, an increase in hammer mass, or some combination of the two. Unless accompanied by a proportional decrease in accuracy, such changes constitute an increase in the motor difficulty of the task (Fitts, 1954), and require commensurate increases in perceptual-motor skill. However, invasiveness is also a function of the shape of flakes, as flakes that are massive but short (i.e. relatively broad and/or thick) may still fail to invade the center of the knapping surface. Flake thickness is related to platform thickness ($r^2 = 0.52$ in the current sample) while relative elongation is a function of the EPA (Figure 1b) together with the topography of the knapping surface. The latter relationship reflects the fact that flakes will travel longitudinally along ridges but tend to spread laterally across flat surfaces (Whittaker, 1994).

Expert knappers were able to manipulate all of these variables in order to produce larger, longer, and more numerous flakes and more heavily reduced cores. Particularly striking is the greater prevalence of bifacial cores (Figure 2) and non-cortical platform flakes (Figure 4) in the expert sample. This reflects that fact that, through controlled flake removals, experts proactively created viable flaking surfaces rather than simply exploiting the natural surfaces of the core. This allowed experts to produce advantageous (75±5° [Pelegrin, 2005]) edge angles (Figure 6) for bifacial flake removals and to maintain large median sizes in non-cortical platform flakes (Figure 5).

Novice performance

Novice subjects were clearly challenged by the basic physical requirements of flake detachment, and never developed the perceptual-motor skill required for the bold, invasive flaking seen in experts. Because of this constraint, novices were unable to exert the same degree of control over flake size and shape and thus had little control over core form. The relatively brief period of practice encompassed by the experiments instead documents an earlier and more fundamental step in skill acquisition: the transition from relatively uncontrolled

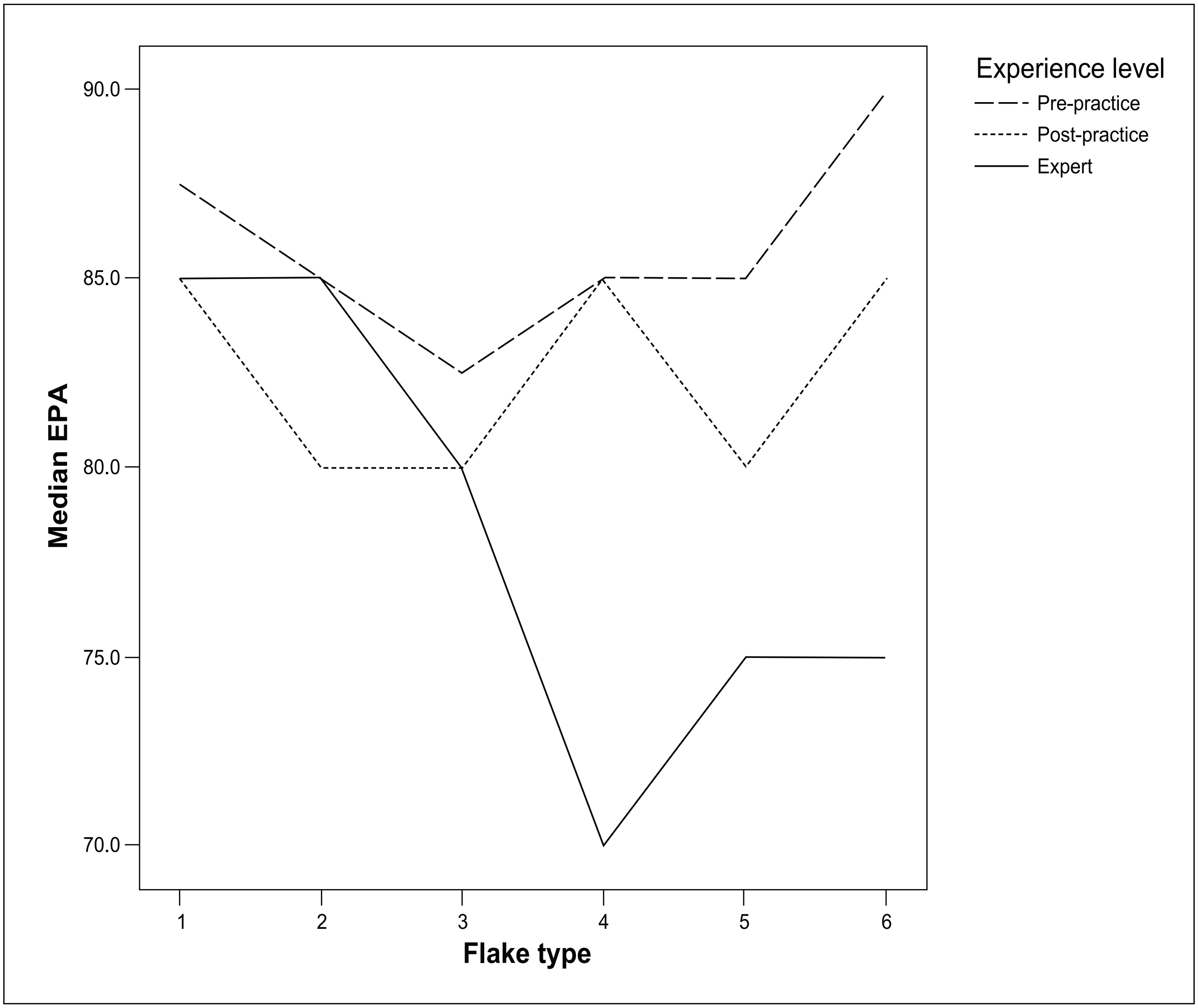

Figure 6. Relationship of flake type to External Platform Angle by experience level.

fracture of rock using brute force to more intentional flake production based on the deliberate exploitation of core morphology (Figure 7).

As described by Pelegrin (2005), it is possible to fracture rock without any particular regard to core morphology, so long as the percussive force applied is great enough. Indiscriminate blows, if directed away from core edges or toward obtuse angles, will commonly result in the initiation of wedging (Cotterell & Kamminga, 1990) or "split" fractures and tend to produce large numbers of amorphous angular fragments with only the occasional flake or flake fragment. More consistent production of conchoidal flakes is achieved through Hertzian fracture initiated near acute core edges (Cotterell & Kamminga, 1990), a technique which requires greater percussive precision, bi-manual coordination and technical understanding (Pelegrin, 2005). In the current study, an increased reliance on conchoidal fracture technique following practice is indicated by proportional decreases in the production of angular fragments, seen within each raw material category as well as in the combined sample (Table 2).

This shift in technique was also associated with significant changes in flake morphology in sedimentary and metamorphic materials, including reductions in flake size, thickness and EPA that relate directly to the requirements of Hertzian fracture. No such changes were documented in quartz, which may reflect the particular fracture properties of quartz (e.g. Knight, 1991) or simply the small size of the quartz sample.

The sedimentary sample was dominated (80%) by blocks of limestone bedrock offering relatively acute natural edge angles and forgiving fracture mechanics (Sahnouni et al., 1997). As a result, it was often possible for pre-practice novices to initiate fracture with blows struck a considerable distance from core edges and to produce large, relatively thick conchoidal flakes (Table 4; Figure 3) along with prolific angular fragments (Table 3). After practice, greater control was achieved by striking closer to core edges, preferentially producing smaller, thinner flakes accompanied by less than half as many angular fragments. Due to clast shape and fracture properties, EPA does not appear to have been an important constraint on sedimentary flake production and only

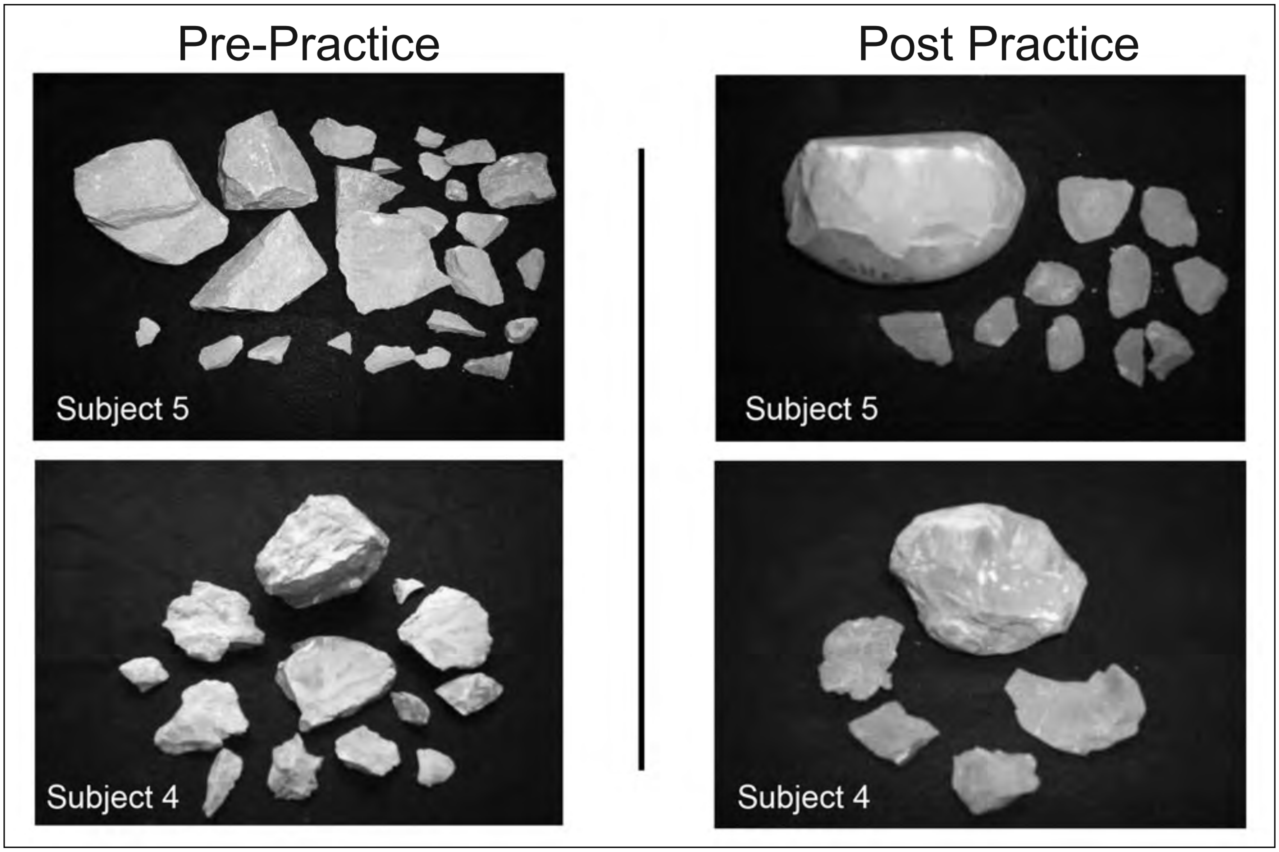

Figure 7. Representative nodules from the novice sample showing a shift to less productive but more controlled flaking following practice.

decreased significantly with the introduction of bifacial flaking by experts.

Pre-practice novices attempted a similarly uncontrolled approach to metamorphic clasts, but produced far fewer flakes per cobble ($t' = 2.14$, $df = 77.00$, $p = 0.035$). This is because the denser, water-rounded metamorphic cobbles offered fewer acute edge angles, and blows directed away from core edges typically failed to initiate fracture. As a result, the large, thick flakes typical of the pre-practice sedimentary sample were not produced, and no significant reduction in flake size was seen following practice. Post-practice novices instead adapted to the constraints of the raw material by restricting their attentions to more acute edge angles (Table 4). These projecting edges were more easily fractured, but rapidly exhausted by the short, non-invasive flake removals of novices. In fact, rounding off of edges led to early abandonment and low productivity in many post-practice metamorphic cores (Figure 7).

In all materials, post-practice novices adopted more controlled knapping techniques that minimized the amount of physical effort required to produce sharp cutting edges. This was achieved by exploiting relevant aspects of core morphology to produce small flakes and flake fragments through Hertzian fracture, reducing the force required to initiate fracture and producing proportionately more cutting edge per blow.

Brain activation

The shift to more controlled knapping techniques among novices corresponds to practice-related changes in brain activation identified through Positron Emission Tomography. Functional brain imaging results are described in greater detail elsewhere (Stout & Chaminade, 2007), but include increased activation of posterior visual association areas relating to object recognition, spatial attention and visual search following practice. These changes likely reflect increased attention to technologically relevant aspects of core morphology, including the edge configurations and angles necessary for the successful initiation of Hertzian fracture. A significant shift in the localization of activation in premotor cortex is also seen following practice, in an area relating to object prehension. This reflects changes in the handling of the core and hammerstone, likely corresponding to the learning of effective grips for the precise bimanual percussion required in conchoidal flaking. Modulation of activation in prefrontal areas relating to strategic action organization was not observed, perhaps reflecting novices' failure to exert control over core morphology and the reactive, opportunistic nature of their flaking. Ongoing imaging research with expert knappers will test this hypothesis.

Table 5. Learning stages and material correlates

Learning Stage	Experience	Technique	Potential Indications
I pre-practice novice	0 – 40 minutes	split fracture	High proportion of angular fragments; relatively thick flakes; steep EPAs (approaching 90°)
II post-practice novice	280 – 320 minutes	marginal conchoidal flaking	Proportionally more flakes and flake fragments; small, relatively short flakes; more acute (80°-85°) EPAs; rounded "prematurely" exhausted cores
III expert	multiple years	intensive bifacial reduction	Large, relatively thin and elongated flakes; increased representation of non-cortical platform flakes with optimal (75±5°) EPAs; heavily reduced bifacial cores

Archaeological implications

Results presented here document three stages of knapping skill acquisition associated with characteristic changes in assemblage composition and flake morphology (Table 5). These are: I) an initial phase of relatively uncontrolled wedging fracture, II) a rapidly achieved phase of conchoidal but minimally invasive flaking, and III) expert performance with intensive bifacial core reduction through invasive flake removals. These stages outline a modern human learning trajectory in which the basic requirements of conchoidal flaking are quickly learned, but reliable production of large flakes and controlled core reduction require more substantial investments in perceptual-motor skill acquisition. Further research with more prolonged practice periods will be required to trace in greater detail the process of expert skill acquisition, and to identify any further intermediate stages.

These observations are based on the performance of modern humans under experimental conditions, and care must be taken in applying them to the early archaeological record. For example, it is possible that greater upper body strength among Pliocene hominins would have made wedging fracture a more viable technique in a wider range of clast sizes, shapes and compositions. Conversely, differences in hand morphology (Marzke, 2005; Panger et al., 2002), manual dexterity (Maier et al., 2005), or brain organization (Stout & Chaminade, 2007) might have made the mastery of controlled Hertzian fracture more challenging. For example, hand morphology appears to be an important constraint on the knapping performance of modern bonobos (Savage-Rumbaugh & Fields, 2006). There is, however, currently no evidence to suggest similar constraints in early hominin toolmakers.

Raw material differences are another major concern, and results from the current study exemplify the influences that variable blank morphology and composition can have on artifact form and frequency (e.g. Tables 3 & 5). Previous research has similarly indicated an influence of initial cobble morphology on the occurrence of steps and hinges (Toth et al., 2006). Nevertheless, some rather robust trends were seen across raw materials, especially with respect to the increased productivity, reduction intensity and flake elongation of experts. The first two stages of skill acquisition in novices were most consistently distinguished from each other by a decrease in angular fragment production, as well as by more material-specific decreases in flake size, thickness and EPA.

Specific replication studies are required in order to properly assess individual sites (e.g. Toth et al., 2006), however it seems clear that the efficient and productive flaking reported in Late Pliocene archaeological assemblages (de la Torre, 2004; Delagnes & Roche, 2005; Ludwig & Harris, 1998; Semaw, 2000) has much more in common with expert performance than with earlier stages of skill acquisition. This is consistent with the findings of a previous study (Toth et al., 2006) showing that Pliocene archaeological assemblages from Gona, Ethiopia cluster with the products of experience modern knappers in terms of assemblage composition, core typology, flake shape, and flake elongation.

Interestingly, flakes from Gona were also found to have significantly higher EPAs than the modern experimental sample. This difference may reflect a somewhat lower level of skill in the selection and maintenance of optimal edge angles, analogous to the performance of novices in the current study. However it was not accompanied by similar deficits in flake size, elongation, or core reduction intensity. Relatively high EPAs in the Gona sample may also be related to differences in initial cobble shape and/or flake type representation arising from 1) the selection of thinner, easier-to-flake cobbles by the Gona hominins, 2) the influences of off-site flaking and selective hominin removal of useful flakes on archaeological assemblage composition, and 3) a somewhat greater incidence of bifacial flaking in the experimental sample (Toth et al., 2006). Results from the current study illustrate the influence that both clast form (e.g. angular limestone blocks) and flake type (Fig. 4) can have on EPA values.

In contrast to the experimental replication of the Gona assemblages (Toth et al., 2006), subjects in the current study were not instructed to conform to a predominantly unifacial flaking mode. In fact, the most salient difference between the modern experts in this study and Late Pliocene toolmakers was a strong preference for bifacial reduction on the part of the modern knappers. Such bifacial reduction appears to be relatively infrequent at early archaeological sites, although it is clearly present to at least some degree already in the earliest known occurrences (Semaw, 2000; Semaw et al., 2003).

It is possible that this emphasis on unifacial flaking reflects cognitive differences on the part of Pliocene toolmakers, for example in the ability to plan and execute contingent action sequences. However, the broader behavioral context of early sites, including selective raw material procurement (Stout et al., 2005) and the extensive transport of flaked materials about the landscape (Toth et al., 2006), seems to argue against this. Furthermore, the unifacial strategies of Pliocene knappers appear quite effective in producing useful flakes and reducing cores (Delagnes & Roche, 2005; Toth et al., 2006). Possible environmental, technological, and/or cognitive factors promoting unifacial reduction strategies among Pliocene toolmakers remain poorly understood and should be a focus for future research.

Despite this intriguing difference, research with modern subjects of variable skill levels strongly supports the emerging consensus that Late Pliocene hominins already displayed fairly advanced knapping skills. In fact, the general absence from the early archaeological record of anything resembling the first two stages of skill acquisition identified here is striking. While the high productivity of expert knappers in the current study does suggest that evidence of novice or inexpert knappers could easily be lost amid the products of more accomplished individuals, it is also clear that at least some such accomplished individuals were usually present in Oldowan toolmaking populations.

Many Oldowan sites do display a relatively high proportion of fragments, however this is likely due to site formation processes unrelated to knapping (Hovers, 2003), and is generally not coupled with other indicators of uncontrolled fracture (such as incomplete core reduction) seen in pre-practice novices. Wedging fracture may characterize accidental assemblages associated with percussive activity (Mercader et al., 2007; Mercader et al., 2002), and the prevalence of such activities in the Oldowan also may be underappreciated (Mora & de la Torre, 2005). Nevertheless, many Oldowan assemblages provide clear evidence of intentional flake production with controlled fracture and intensive reduction (e.g. de la Torre, 2004; Delagnes & Roche, 2005; Semaw, 2000; Semaw et al., 2003).

In contrast, modern bonobos do appear to flake stone in a relatively uncontrolled fashion analogous to the first stage of human skill acquisition described here, but with lesser hammerstone velocities than are typical of humans (Harlacker, 2006; Toth et al., 2006). This lower velocity knapping may reflect differences in hand morphology that make controlled percussion without injury to the fingers more difficult (Savage-Rumbaugh & Fields, 2006) and/or to differences in the neural regulation of visually guided prehension (Stout & Chaminade, 2007). Because behavior is a property of whole organisms, it is most likely that integrated neural and somatic factors are involved.

In any case, the outcome is that bonobo subjects did not produce the large amounts of chunky angular shatter seen in pre-practice human subjects pursuing a "brute force" approach to knapping. This is because low velocity blows directed away from core edges failed to initiate wedging fractures. For this reason, pieces actually detached tended to be very thin whole flakes with steep (~85) EPAs, each reflecting a large number of less fortuitous accompanying blows that failed to initiate fracture (Toth et al., 2006). This pattern in most closely analogous to that seen in the pre-practice metamorphic sample of the current study, in which subjects also produced a relatively high proportion of whole flakes (Table 1) which exhibited thin cross-sections and steep EPAs (Table 2). Following a relatively small amount of practice, however, these human subjects shifted to the selective exploitation of more acute core angles. This adaptation has not (yet) been seen in the products of bonobo knappers.

Comparative studies with modern apes and humans of can thus begin to define a range of knapping skill levels, from the accidental to the expert, which may be used to better understand variation within the Oldowan and even to model hypothetical "pre-Oldowan" stone technologies (Panger et al., 2002; Toth et al., 2006). For example, the rapidity with which modern humans learn to exploit the principles of conchoidal fracture suggests that a relatively prolonged (i.e. archaeologically visible) transitional phase of tool production through uncontrolled split fracture would only have been likely in the context of substantial manipulative and/or perceptual-motor differences from modern humans. Experimental studies of knapping-related prehension (Marzke, 2005) and brain activation (Stout & Chaminade, 2007) provide some further indications as to the likely nature of any such differences. At the current time, however, paleontological evidence does not support the presence of such differences in hominins ca. 2.5-3.0 Ma (Holloway et al., 2004; Marzke, 2005), and archaeological evidence for a pre-Oldowan phase of uncontrolled percussion is lacking.

Stage II (post-practice) skill perhaps provides a more likely model for unskilled knapping, either as part of a "pre-Oldowan" industry or as a dimension of variation within the Oldowan. One possible archaeological example is provided by Lokalalei 1 in Kenya, where it has been argued that relatively small flake scars on cores and a high incidence of flaking "accidents" indicate poorly developed knapping skills relative to Lokalalei 2C (Delagnes & Roche, 2005; Kibunjia, 1994). However it has also been argued that this difference arises from "subtle material flaws" (Ludwig & Harris, 1998) at Lokalalei 1, and potentially relevant differences in blank morphology have been described (Delagnes & Roche, 2005). It is, of course, quite difficult to demonstrate that low reduction intensity necessarily corresponds to a lack of ability rather than a lack of incentive, however the case may be strengthened if a broader pattern of premature core exhaustion through inefficient flaking and edge rounding may be shown, as in the current post-practice sample. Currently available descriptions and illustrations of the Lokalalei 1 cores (Delagnes & Roche, 2005; Kibunjia, 1994) do not yet clearly indicate such a pattern. As previously discussed, other early Oldowan sites clearly display knapping that is most closely analogous to fully expert, "Stage III", modern humans.

Conclusions

The most important conclusion of the current study is that variation in knapping skill is associated with measurable, quantitative variation in assemblage composition and artifact morphology. Three stages of skill acquisition were identified, differentiated by measures of reduction intensity, debitage productivity, and relative frequency of angular fragments, as well as by flake size, morphology, and EPA. These stages reflect a rapid development from uncontrolled split fracture to deliberate, but non-invasive, conchoidal flaking and ultimately to intensive bifacial reduction.

These findings corroborate the results of a previous cross-sectional comparison of modern apes, experienced humans, and Pliocene hominins, which identified measures of reduction intensity, debitage type, flake morphology and platform angles as key indicators of knapping skill (Toth et al., 2006). The specific patterns of skill acquisition observed in this longitudinal study are also consistent with ethnographic (Roux et al., 1995; Roux & David, 2005; Stout, 2002, 2005b) and brain imaging (Stout, 2005a; Stout & Chaminade, 2007) research emphasizing the fundamental role of perceptual-motor skill acquisition in the development of knapping proficiency. Though preliminary, broad similarities between Late Pliocene archaeological assemblages and the products of modern human experts suggest substantial investments of time and effort in knapping skill acquisition already at this very early date. This, in turn, may have implications for the social context of Oldowan technology (Savage-Rumbaugh & Fields, 2006; Stout, 2005b).

These findings also support and extend the conclusions of more qualitative investigations of Oldowan knapping skill, and it is hoped that complementary application of interpretive and quantitative/experimental methods in the future will yield further insights. In this context, site-specific replication studies and the production of comparable descriptive and quantitative data from multiple sites are essential. The current study calls particular attention to the importance of studying fragments, including both typological and metric analyses, and to the value of whole flake linear dimensions, shape indices and exterior platform angles in assessing Mode I knapping skill.

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CHAPTER 13

THE IMPORTANCE OF ACTUALISTIC STUDIES IN EARLY STONE AGE RESEARCH: SOME PERSONAL REFLECTIONS

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ABSTRACT

This chapter emphasizes the importance of actualistic studies (studies of modern phenomena to gain a better understanding of phenomena in the prehistoric past) in Early Stone Age research, personally drawing on over three decades of research. This retrospective of research includes experimental archaeological studies of stone artifact manufacture and use, ethnoarchaeology, primatology, brain imaging, cognitive science, kinesiology and biomechanics, electromyography, taphonomy, and geoarchaeology.

INTRODUCTION

Actualistic studies allow researchers to examine the relationships between observed processes (e.g. animal butchery with stone tools; soft hammer flaking) and archaeological products (e.g. cut-marks and hammerstone striae on bones; refined handaxes and characteristic bifacial thinning flakes). The best Palaeolithic archaeological projects tend to have a strong experimental component that addresses specific questions that emerge from specific excavated sites.

We have reviewed the prehistoric evidence for the archaeology of human origins in a number of publications, including Schick and Toth, 1993, 1994, 2001, 2003, 2006, 2009; Toth and Schick, 1986, 2006b; 2007b; 2009a, 2009b, 2009c; and Whiten et al., 2009. This chapter will focus on our work in actualistic studies, and how they have helped us in the interpretation of early archaeological sites. There are many other researchers that have been involved in a wide range of actualistic studies, but here we will focus on our own research over more than three decades as a personal odyssey and narrative.

EARLY HISTORY OF ACTUALISTIC RESARCH INTO EARLY STONE TOOLS IN AFRICA *(FIGURES 1-3)*

In the history of Early Stone Age research in East and Central Africa, three figures stand out as early advocates of actualistic studies in Palaeolithic research. Louis Leakey (Figure 1) was one of the first African prehistorians to learn to make stone tools. J. Desmond Clark (Figure 2) also knapped stone tools and even gave actual Acheulean artifacts to hunter-gatherers from Botswana to see the feasibility of these tools for animal butchery (see Howell, 1965). Glynn Isaac (Figure 3), along with Clark, nurtured a generation of students, including ourselves, to pursue actualistic studies in our archaeological pursuits. In South Africa, prehistorian and naturalist C.K. Brain conducted a range of actualistic studies focusing on taphonomic patterns at the Transvaal cave sites (see Pickering et al., 2007.)

Today there are a growing number of scholars engaged in actualistic studies focusing on early hominin Plio-Pleistocene archaeological sites in Africa and Eurasia. These studies of modern phenomena to help in the interpretation and understanding of the prehistoric past include experiments in stone artifact manufacture and use; lithic microwear analysis; bone modification and other taphonomic studies, isotopic studies of soil carbonates, bones and teeth; experiments in archaeological site formation; primate tool use research; ethnoarchaeological research; ethological studies; geoarcheological studies; biomechanical studies; brain imaging studies; and ecological studies. Here we will review actualistic research and related inquiries in which we have personally been involved over the past three decades.

Experimental Studies of Early Technologies at Koobi Fora (*Figures 4-10)*

(Bunn et al., 1980; Schick and Toth, 1993; Toth, 1982, 1985a, 1985b, 1987a, 1987b, 1991, 1997).

The Koobi Fora (East Turkana) archaeological sites, dating from approximately 1.9 to 1.4 million years ago, were the focus of a long-term experimental replicative and functional program. All of the major raw materials used by the early hominins here were available in the modern stream beds in the same area, which enabled realistic comparisons and contrasts between the archaeology and the experimentation. Major conclusions reached in this research were:

1. The types of cores generated by Mode 1 or Oldowan flaking are highly influenced by the types of raw material, as well as the size and shape of the blanks (cobbles, chunks, flakes or fragments) used for reduction. Lava, ignimbrite, quartzite, and limestone cobbles tend to produce chopper-dominated assemblages, while quartz and chert cobbles tend to produce polyhedral core forms. Using larger flakes as blanks for cores tend to produce discoids and heavy-duty scrapers with further reduction;

2. The success in reducing cobbles is often a function of one large flake being removed from a core, creating new acute angles in core morphology that can be exploited for further reduction. Such success is not only a function of the cognitive ability to identify appropriate core striking platforms but also the biomechanical ability to deliver a well-placed, powerful (high velocity) blow from a percussor to that core surface;

3. Many Oldowan core forms were probably not intentional target forms in the minds of the hominin toolmakers, but rather a by-product of flake production. Again, the type of raw material, the size and shape of the blank, and the degree of reduction will have great effect on the final core form;

4. Retouched flakes are often resharpened cutting tools made on edges that had dulled through use. A denticulate retouched edge in coarser-grained raw materials such as lavas or quartzites can produce very functional rejuvenated cutting edges;

5. For reducing small cores (50 g), the ideal hammerstone is about twice the weight (100 g) of the core. For medium sized cores (500 g), the ideal hammerstone is about the same size as the core. For large cores (3000 g), the ideal hammerstone is about half the core weight (1500 g);

6. The reduction of Oldowan cores will produce predicable flake patterns (flake types 1-6), and departures from that pattern (for example, sites dominated by flake types 3 and 6) are often an indication that later stages of flaking are preferentially represented. Many Oldowan sites tend to be characterized by later stages of flaking, implying that earlier stages occurred somewhere else;

7. Throwing one cobble against another to initiate fracture will produce a diagnostic fracture pattern with a pronounced crushing at the point of percussion and a very flat release (ventral) surface without prominent bulbs of percussion. Such fracture will often split cobbles neatly in half. Such fracture patters can also be produced when a hammerstone accidentally breaks, but normally there will be a pronounced area of battering on the cortical surface around the point of fracture;

8. The pattern of a predominance of flakes with cortex on their right dorsal side (when the striking platform is oriented at the top) may be an indication of preferential right-handedness in these early tool-using populations. Interestingly, it is with the contemporaneous hominin fossils attributed to early *Homo* that human-like asymmetries associated with right-handedness in modern populations are seen in fossil cranial endocasts, including a strong left parietal/right frontal petalias and a pronounced Broca's area.

Experiments in Flaking Quartz and Spheroid Production (*Figures 11-19)*

(Schick and Toth, 1993, 1994).

Battered and facetted stone balls of "spheroids" have been the subject of much speculation for well over a century. While doing research in Zambia, we had access to large amounts of quartz that had formed in veins in the bedrock through hydrothermal activity in the past and were now exposed and eroding out in angular chunks. Quartz can be the dominant raw material in many parts of Africa and elsewhere, and we examined the patterns that were produced by Oldowan knapping. Among our conclusions were:

1. Quartz is a raw material that batters easily. Percussors, cores, and even the dorsal surfaces of flakes can exhibit marked battering from lithic reduction. This battering thus can result as a function of the knapping process and does not necessarily represent some type of food processing or other tool-using behavior;

2. Reduction of quartz will often produce cores dominated by polyhedrons, discoids, heavy-duty scrapers, and subspheroids/spheroids. Further reduction of these cores may produce very high proportions of debitage yet few recognizable cores, dramatically lowering the core/debitage ratios, i.e., a great deal of debitage but relatively few recognizable cores. Such

patterns are seen at many quartz-dominated assemblages in the Oldowan;

3. The use of a quartz chunk or core as a percussor in knapping will, over time, produce a heavily battered and highly rounded and spherical form that would be classed as a "spheroid" (if it does not break during knapping). After four hours of knapping such a quartz percussor will be battered over its entire surface and be very spherical in shape. Many of the spalls produced in the early phases of spheroid formation (usually smaller flakes and fragments) will also exhibit marked battering on their dorsal surfaces;

4. Such quartz spheroids may simply be by-products of the knapping process and not intentional target pieces in the minds of the hominin tool-makers. On the other hand, a subspherical percussor may be carried around or cached and re-used because it is comfortable to hold and resistant to fracture as battering proceeds, and thus may have been intentionally selected and curated by hominins for long-term use;

5. In more recent archaeological times (e.g. Neolithic and Iron Age of Africa), similar spheroid forms can be produced by the use of "sharpening stones" to rejuvenate a quern surface by pecking to roughen the grinding area when it becomes too smooth for efficient grinding. This equifinality shows that repeated impact quartz percussors on stone for different purposes can produce similar end products. This pattern can has been observed on a microscopic scale as well, since quartz sand grains in an aeolian context (e.g. Kalahari sands) can also produce "microspheroids" by countless random impacts through wind action.

Experiments in the Production of Basalt Lava Spheroids *(Figures 20-34)*

At early archaeological sites such as in Bed 1, Olduvai Gorge, in the Middle Awash of Ethiopia, and at Ubeidiya, Israel, battered spheroids made in basalt lava can be found. While doing research in the volcanic highlands of Ethiopia, we addressed the question of lava spheroids (assisted by Tadewos Assebework). Among our conclusions were:

1. One can expect to have battered lava spheroids in areas where spheroidal weathering of columnar basalts is common, and these spheres weather out and are exposed on the surface (e.g. Olduvai Gorge). Spheroidal weathering of basalt occurs when columnar basalts develop transverse fractures at right-angles to the columns. The resultant rectangular or square fragments begin to weather into clay on the corners and edges and slowly become more spherical in shape over time;

2. Natural spherical clasts of lava can make excellent percussors. Usually a softer exterior will quickly wear away until a harder, denser interior is exposed. Often there will be subtle pits in the spheroid where its surface made contact with a core during knapping. After a few hours of knapping, a near-perfect spherical percussor can be produced;

3. In areas with fresher basalt lavas that have not had time to weather spheroidally, battered spheroids will be rare or absent, and hammerstones with battering on selected cortical surfaces will be common (e.g. at Koobi Fora).

Experiments in the Production of Limestone Facetted Balls *(Figures 35-42)*

(Sahnouni et al., 1997).

While visiting the early Stone Age site of Ain Hanech in Algeria, we had the opportunity to flake the same types of limestone cobbles that were flaked by the early hominin tool-makers here. Fine-grained limestone, as at Ain Hanech, has some unusual flaking properties. Replicative experiments led us to some major conclusions:

1. The softness of the limestone (unlike flint, lava, quartzite, etc.) creates unique fracture patterns where external platform angles (the angle formed by the striking platform and the dorsal surface of the flake) tends to be obtuse, while internal platform angles (the angle formed by the striking platform and ventral or bulbar surface) tends to be acute. A pronounced area of crushing normally forms on the ventral surface at the point of percussion, and the size of the area of crushing is a function of the hammerstone impact force (the more force, the larger the area of crushing);

2. The core forms produced by flaking limestone cobbles at Ain Hanech include choppers, polyhedrons, and facetted subspheroids/spheroids. The unique fracture pattern of the limestone tends to create a subspherical core morphology with many obtuse angles and many visible points of percussion from hammerstone blows (which might be mistaken for utilization by an archaeologist not familiar with this raw material);

3. A facetted subspheroid or spheroid core that is subsequently used as a percussor will develop profound battering on its surface from prolonged use, starting on the ridges and then slowly spreading to the flake scar surfaces. Within an hour more than 50 percent of the surface can be battered, and within a few hours of use the entire surface will exhibit battering and the limestone percussor will have become much more rounded and spherical in shape.

Experiments and Ethnographic Examples of Pitted Artifacts (*Figures 43-48*)

Pitted artifacts are sometimes found in the prehistoric record. We conducted a range of experiments to see the ways such pits could form. Our conclusions were:

1. Nut-cracking tends to produce anvils that exhibit smooth pits over time. Such pits, as they develop, actually make it easier to hold a nut in place in order to crack it with a stone hammer. Harder-shelled nuts will produce pitting at a faster rate than softer-shelled nuts;
2. Bipolar flaking of pebbles or thick flakes produces anvils with rough pits in the center, sometimes with a radial pattern of striae from the center of the pit. Rough pits form on hammerstones as well during bipolar flaking. If a hammerstone is elongated, there is a tendency to produce two off-set rough pits, approximately at 1/3 and 2/3 of the total length of the cobble.
3. It has been observed that the type of sporadic pitting on some cortical surfaces of lava cores from Gona, Ethiopia (ca. 2.6 million years old) can sometime be seen on cobbles of the same raw material on the modern land surface there, sometimes with the fragments that formed the pits still in place. It appears that some type of "potlidding" takes place naturally, possibly due to quick changes in temperatures (which can get to over 125 degrees F in the region today).

Chert Versus Lava Cores in China (*Figures 49-55*)

(Clark and Schick, 1988; Schick, 1994; Schick and Dong, 1993; Schick et al., 1991; Xie et al., 1994).

While doing archaeological fieldwork in the Nihewan Basin of northeastern China (focusing on the sites of Donggutuo, Feiliang, and Cenjiawan estimated to be about 1.3 million years old), we had the opportunity do conduct replicative knapping experiments with the range of raw materials that were available to early hominins here. In prehistoric times, Precambrian basement rock outcrops protruded above the depositional land surface like islands, and were the major source of raw material, normally obtained as angular chunks with an identifiable cortex. Most of the major sites in this area were within a hundred feet of such outcrops. These Precambrian rocks contain cherts that range in flaking quality from excellent to poor, as well as quartzites, and limestones. Basalt lava cobbles were also available in nearby channel systems, but are rare at the archaeological sites. The results of our replicative experiments were:

1. High-grade cherts produced artifacts with clear signs of conchoidal fracture (bulbs of percussion, bulbar (eraillure) scars, ripples, fissures, negative scars, etc.) and a higher proportion of whole flakes to fragments; as chert quality decreased, it would become harder to see the tell-tale signs of conchoidal fracture, and the proportion of fragments, especially angular fragments, relative to whole flakes, rose accordingly. Hominins here usually selected higher-quality cherts to knap;
2. The knapping of higher-quality chert chunks tended to produce a range of heavily-reduced cores, many of which would be classified as polyhedrons, discoids, and casual cores;
3. The flake type distribution at most of these sites suggests that all stages of knapping were well-represented at the archaeological sites here; perhaps Precambrian outcrops were exposed over much of the palaeolandscape so that transport and curation of stone were not as critical in foraging behavior;
4. When rare basalt cobbles were flaked, classic Oldowan "choppers" were the most common core form, unlike the more easily-fractured chert. Such a dichotomy of such core forms can also be seen at Olduvai Gorge, where the chopper-dominated assemblages are associated with lava-dominated sites in Bed 1, and where polyhedron and discoid dominated assemblages are associated with quartz-and chert-dominated assemblages in Bed 2. At Kalambo Falls in Zambia, artifacts that were assigned to classic "core-tool" forms like choppers and core scrapers tended to be made from quartzite cobbles, while smaller, more reduced "cores" tended to be made out of the chert-like silicified mudstone. It is likely that at these sites raw material size, shape, and flaking characteristics greatly influenced core morphology.

Experiments in Ape Stone Technology and Gona Technology (*Figures 56-65*)

(Savage-Rumbaugh et al., 2006; Schick and Toth, 1993; Schick et al., 1999; Toth and Schick, 2009a, 2009b; 2009c; Toth et al., 1993, 2006; Whiten et al., 2009).

For the past two decades we have been leading an experimental program to study the stone tool-making and tool-using capabilities of modern apes, focusing on bonobos or "pygmy chimpanzees". In collaboration with cognitive psychologists Sue Savage-Rumbaugh and Duane Rumbaugh and their colleagues, first at the Language Research Center in Atlanta and then at the Great Ape Trust of Iowa, we have been studying skill acquisition in a male bonobo, Kanzi (now 29 years old), and his half-sister, Panbanisha (now 24 years old). Panbanisha's son Nyota (now 11 years old) is just beginning to acquire knapping skill.

Our strategy for getting Kanzi and Panbanisha to flake stone was to model for them (show them how we strike off sharp flakes and use these flakes to cut through a rope to open a food award box or cut through a membrane to get into a food drum) and then give them raw material to learn, primarily by trial-and-error. Since a food reward was the "payoff" in these experiments, motivation was not a major problem.

We were also able to obtain unmodified lava cobbles from the ancient 2.6 million-year-old river gravel conglomerates at Gona, Ethiopia, the exact raw material early hominins (perhaps *Australopithecus garhi*). We flaked the Gona cobbles to produce a sample manufactured by modern humans and also gave Gona cobbles to the bonobos, Kanzi and Panbanisha. In this way we were able to do a three-species comparison of skill: bonobos vs. Gona hominins (represented by Gona sites EG 10 and EG 12) vs. modern humans.

The results of these experiments were:

1. When the bonobos first started knapping stone, they did not understand that you have to strike a blow near the edge of a cobble-core, ideally striking near a thin edge to detach a flake. This understanding seemed to slowly emerge after several months of trial-and-error practice, and was only mastered after several years;

2. Kanzi's first flaked products were small flakes and large cores with small flake scars and battered edges (reminiscent of naturally-damaged rocks in high-energy environments). After significant practice, however, the bonobos are able to produce stone artifacts that are clearly recognizable as deliberately flaked products;

3. The bonobos tended to be the outgroup in our three-species assessment of knapping skill, while the Gona tool-makers either were intermediate between the bonobos and modern humans or grouped with the modern humans, depending upon the criterion of skill;

4. This relatively lower level of skill in the bonobos may be a function of different cognitive as well as biomechnical capabilities;

5. The Gona hominin tool-makers had apparently evolved the cognitive and biomechanical abilities to flake stone efficiently and were very competent stone tool-makers by 2.6 million years ago.

6. It was clear for this analysis that later stages of cobble reduction are preferentially represented at the Gona sites analyzed. We estimated that on average cobble cores were reduced by between one-third and one-half of their original mass at some other location before these cores were carried to the excavated sites (the dorsal cortex on Gona flakes averaged 12%, while both the human and bonobo flakes averaged about 40%, with all of the flakes represented). These experiments thus highlight salient aspects of patterns of stone tool manufacture and transport among the earliest known stone tool-makers, including:

    a. The Gona hominins were reducing cores at some other locations (perhaps closer to the river conglomerates), where flakes of the earlier stages of reduction would have been represented;

    b. The Gona hominins transported partially reduced cores to the excavated sites where they were further flaked;

    c. The Gona hominins left behind substantially reduced cores and later stages of debitage, but probably removed some of the larger, sharper flakes from these sites (and probably some of the larger cores) to be used at some future locality.

Observations of Wild Chimpanzee Cultural Patterning *(Figure 66)*

(Toth and Schick, 2007a, 2009c;
Whiten et al., 1999, 2009).

In a seminal paper about wild chimpanzee material culture at different study sites, Whiten et al. (1999) identified 36 different cultural traits that were shared by some but not all chimpanzee groups in East and West Africa. We decided to see if there might be a geographical patterning to these cultural traits by examining the number of shared cultural traits relative to distances between study areas . In this analysis, geographical barriers such as rivers, lakes, and mountain ranges were not considered, and all distances were calculated as point-to-point measurements. Our results showed:

1. On a Pan-African, species-wide level, there was no statistically significant pattern between the number of shared cultural traits and the distance between sites; with the last common ancestor of West African and East African chimpanzees estimated to be as much as 2 million years ago, it is likely that there has been a lot of convergence (independent invention) of cultural traits that do not share an evolutionary history;

2. On a subspecies level (comparing West African sites to other West African sites of *Pan troglodytes verus*, and East African sites to other East African sites of *Pan troglodytes schweinfurthii*), however, a highly statistically significant pattern emerged. Sites in closer proximity shared more cultural traits, while sites further away shared fewer cultural traits. Less than half of the maximum number of shared traits (less than four out of eight) was found to be shared

between groups separated by more than 700 kilometers (about 450 miles);

3. We used this patterning of a 700 kilometer cutoff of shared cultural as a model for Early Stone Age sites between 2.6 million and 1.5 million years ago in Africa and Eurasia. Although there may not always have been depositional contemporaneity between these archaeological sites, it is likely that these locales often had hominins on the ground there, even in nondepositional periods. We also realize that early tool-making bipedal hominins were not knuckle-walking chimpanzees, and that their typical environmental settings and foraging patterns were almost certainly significantly different than those of chimpanzees. Nonetheless having an appreciation of distances between sites and the probability of having shared traits may help us identify subtle forms of commonality in the material culture of early hominins through time.

Experimental Replication of Acheulean Forms *(Figures 67-82)*

(Schick and Toth, 1993, in press; Toth, 1982; Toth and Schick, in press).

The Acheulean Industrial Complex is characterized by new artifact forms, namely large handaxes, cleavers, and picks, which can be made on large flake blanks or on large cobbles or nodules. The Acheulean appears to have emerged between 1.7 and 1.5 million years ago in Africa, became widespread in Africa outside of dense tropical forests of the Congo basin, and ultimately spread to the Near East, Western Europe, and the Indian subcontinent. In much of Eastern Europe and East Asia, the Acheulean is not well represented. Although there are a number of large bifacial tool sites in China and Korea, they appear to be sporadic and atypical of the Acheulean phenomena elsewhere.

We have conducted a wide range of experiments in replicating Acheulean technology. Some of our major conclusions are:

1. Quarrying large lava flakes from boulder cores to be used as blanks for handaxes or cleavers can be accomplished with a large, hand-held hammerstone, but much greater impact forces (and larger flakes) can be generated by *throwing* a large hammer against a boulder-core. This technique of throwing is especially useful in initiating fracture in a massive boulder;

2. In five consecutive hours of quarrying large flakes, it was possible to produce 97 flake blanks suitable for handaxes, cleavers, or picks from twenty boulder cores. These boulder cores were giant versions of discoids (7 specimens), bifacial choppers (5 specimens), polyhedrons (5 specimens), and core fragments (2 specimens). An average of about five large flakes suitable for Acheulean tool production was obtained per boulder core. The flake type breakdown of these large flake blanks was as follows: Flake type 1: (4 specimens); Flake type 2: (9 specimens); Flake type 3: (0 specimens); Flake type 4: (6 specimens); Flake type 5: (62 specimens); Flake type 6: (8 specimens); Flake type 7 or indeterminate: (8 specimens). Thus, the flake blanks for Acheulean tool manufacture predominantly had non-cortical platforms and partially cortical dorsal surfaces. About one in five flakes was deemed an excellent blank for a cleaver. Forty-eight of these large flakes were end-struck, and forty-one were side-struck. (The others were either flake large fragments or equidimensional);

3. Early Acheulean handaxes and cleavers can be made by hard-hammer percussion, while many later Acheulean forms may have been made using soft hammers of wood, bone, ivory, or antler (or even a softer hammerstone). Soft hammer technology is usually associated with careful platform preparation, producing thinning flakes with multi-scar (facetted) striking platforms;

4. Flint handaxes could be made on large flake blanks, on water-worn cobbles, or from nodules that have eroded out of limestone or chalk bedrock. The ideal cobble or nodule shape for handaxe manufacture is a large, elongate, flat disc;

5. The size and morphology of handaxes and cleavers can be greatly influenced by the size and the shape of the flake blanks, cobble, or nodule.

6. The final form of a handaxe or cleaver, although influenced by raw material, represents a preconceived notion of that final form or "mental template". By later Acheulean times there is clear evidence of stylistic norms at many sites, and a predominance of certain forms (e.g. ovate, lanceolate, ficron) and/or technological strategies (e.g. tranchet blow, Kombewa flake, Tabalbalat-Tachenghit cleaver-flake).

The Langda Adze-Makers of Irian Jaya, New Guinea *(Figures 83 -97)*

(Schick and Toth, 1993; Stout, 2002; Toth et al., 1992).

Some of the last traditional flaked stone technologies are found in the mountains of Irian Jaya, New Guinea. With J. Desmond Clark and Giancarlo Ligabue (and later investigated by Dietrich Stout), we studied the material culture of traditional stone adze-makers in the village of Langda. The most common raw material for flaking is a metamorphosed lava quarried from large river boulders in the valley 800 meters below Langda village. Adze-making is a high-status, specialized craft normally taught from father to son. Although these people are modern horticulturalists with a ground stone adze technology, earlier stages of adze technology, notably the quarrying of large flakes from boulder-cores and the early stages of adze reduction have some interesting parallels with Acheulean technology. Among the observations that were made about the Langda adze-makers were:

1. The Langda adze-makers quarry large flake blanks for adzes from boulders by a variety of techniques, including large hammerstones held in both hands; by throwing a large hammer on a boulder core, sometimes from an appreciable height by standing on a gigantic boulder; and by fracturing large rocks by the use of fire (the latter producing spall blanks, but not technically percussion flakes). These quarrying techniques are some of the few ethnographic models we have for Acheulean large flake quarrying;

2. Different stages of adze manufacture can take place on different types of the landscape. Quarrying is always at the river, the source of the raw material, and often the early stages of roughing-out the adze take place at the river as well. A hut located part of the way up the mountain path to the village provides a resting or sleeping place and a place for further reduction. Adze blanks or rough-outs are usually wrapped in leaves to cushion them (and the carrier), and transported in woven net carrying devices carried on the back. The final stages of adze knapping (and subsequent grinding and hafting) normally take place back at Langda village;

3. The early stages of adze reduction can be reminiscent of Acheulean bifacial handaxes, but as flaking progresses, the adzes develop three flaked edges and a triangular cross-section. The bits are carefully shaped with a broad edge while the butt end is normally pointed in form;

4. The flakes produced in adze manufacture are all made with stone hammers, but because of careful platform preparation and skilled knapping these flakes would be classified as “soft hammer” flakes by many archaeologists, with facetted and thin striking platforms, thin overall morphology, shallow dorsal scars, and a diffuse bulb of percussion, often with a slight lipping on the proximal ventral margin;

5. Knapping is a very social enterprise, and adze-makers usually work in groups positioned in a line several feet apart from the next knapper. There is a great deal of talking and gesticulating during knapping, and of showing adzes and sometimes the refitting flakes to other knappers.

Actualistic Studies of the Use of Bamboo *(Figures 98-109)*

(Jahren et al., 1997; Schick, 1994).

Some prehistorians have stressed the possible importance of bamboo as a major raw material in Eastern and Southeast Asia. Some have also suggested that this reliance on bamboo as a cutting tool could have been responsible for the retention of simple Mode 1 industries even into the later Pleistocene of East Asia.

With J. Desmond Clark, we visited a Chinese minority group called the Kucong who lived in the village of Manjiu in the mountains of Yunnan Province in southern China and had a very rich bamboo technology. We recorded over fifty uses of bamboo, including construction material for houses including roofing tiles, containers (buckets, storage bins, bowls, cups, wash basins), steamers, strainers, cutting tools including bamboo machetes, fencing, baskets, fire saws, shovels, aqueduct pipes for moving water, troughs, lashing material, sleeping mats, hats, ladders, stools, goat bells, smoking pipes, fishing poles, walking sticks, flutes, and weaponry such as arrow shafts, spears, and crossbows. From an Early Stone Age perspective, bamboo could have provided raw material for cutting or slashing tools, containers, spears or digging sticks, simple structures, or (probably later in time) fire production, lashing, and simple woven baskets and mats. Figures 98 to 104 show various aspects of Kucong bamboo technology.

We then examined the feasibility of working bamboo from an early Stone Age perspective (Figures 105-107) and found the following results:

1) To work bamboo efficiently (chopping, splitting), it was critical to have at least a Mode 1 (Oldowan-like) technology;

2) Chopping a thick bamboo stalk required a heavy, acute-edged core such as a chopper;

3) A medium-sized flake, when struck with a hammerstone, made an efficient wedge to split lengths of bamboo to produce cutting edges or to make strips of bamboo for other types of material culture (lashing, weaving, etc.). The resultant flake wedges often exhibited edge-damage on opposite sides or ends reminiscent of some “outils écaillés” found in the prehistoric record.

The adze-makers in Langda village, Irian Jaya, New Guinea (discussed in the previous section) produce thousands of lava flakes and fragments during their cumulative knapping episodes, but it is interesting that when they butcher a pig they choose a split stick of bamboo as a butchery knife for its superior cutting edge (Figure 108 and 109). They can resharpen a bamboo knife by simply tearing a thin strip of the side with a thumbnail.

Such a reliance on bamboo as a raw material might partially explain the dominance of simple Mode 1 industries in parts of East Asia, but it is likely that we are also seeing major cultural spheres separating groups having handaxe and cleaver technologies and those having simpler Oldowan-like technologies.

Actualistic Studies of Hand/ Forearm Muscle Activity *(Figures 110-114)*

(Marzke et al., 1998).

In collaboration with bioanthropologist Mary Marzke of Arizona State University and hand surgeon Ron Linsheid of the Mayo Clinic, we served as subjects and investigators to study the hand and forearm muscles employed in stone tool manufacture and use. Forty needles, each about three inches long, were inserted into the right and left hands and forearms (some needles inserted almost all the way through the hand) to insert wires to measure electrical muscle activity by electromyography (EMG) during Oldowan and Acheulean stone tool manufacture and use. The results of this study, which monitored the activity of 17 hand muscles of the dominant and non-dominant hand in stone tool-making experiments and functional experiments in using a range of tools of stone and other materials, included:

1) The hand muscles involved in the strong precision pinch grips involved in holding the hammerstone and the core (pressing the thumb towards the forefinger when holding an object tightly) were of great importance in many tool-making and tool-using activities. These were primarily the intrinsic muscles in the area of the thumb/index finger and the fifth (little) finger;

2) The muscles controlling the little finger was, to the surprise of the investigators, often employed in these activities and had a stabilizing effect;

3) The flexor pollicus longus muscle was not of prime importance in the stone tool-making activities measured, despite the fact that some anthropologists had pointed to the attachment markings of this muscle on fossil hominin thumb bones as a strong indicator of stone tool behavior.

Kinesiology *(Figures 115-116)*

(Dapena et al. 2006; Harlacker, 2009).

In collaboration with kinesiologist Jesus Dapena, who studies the biomechanics of collegiate and Olympic athletes, we examined the joint torques of a human subject during Oldowan knapping. Two slow-motion cameras were set up at angles and recorded Toth knapping, which allowed three-dimensional analysis. All images of the knapper were digitized at established anatomical points and analyzed for biomechanical patterning. The results showed:

1) The hammerstone traveled 0.48 meters to impact and reached a maximum velocity of 9 meters per second (20.1 miles per hour), while the core was brought up to meet the hammerstone at 1.3 meters per second (2.9 miles per hour), so that the combined impact speed was 10.3 meters per second (22.6 miles per hour). This was more than twice the hammerstone velocities generated by bonobo knappers (Harlacker, 2009);

2) Based on the weight of the hammerstone used in this experiment (625 grams), a kinetic energy of 25.3 Joules was produced just before impact. This was the equivalent to the kinetic energy of a baseball being thrown at 42 miles per hour;

3) Study of joint torque showed that the extensor, internal rotator, and adductor muscles of the shoulder and extensor muscles of the elbow of the right arm were employed to bring the hammerstone down to meet the core; the flexor, external rotator, and abductor muscles of the elbow were then employed after impact to brake the downward motion of the hammerstone and to help accelerate its upward motion in preparation for the next blow;

4) From a kinesiological perspective, this activity did not require great strength; the elbow joint torque (20 N · m) was the equivalent to a person holding a 5 kilogram weight behind the head with the forearm in a horizontal position. A typical baseball pitch generates shoulder torques 5 to 23 times greater than the shoulder torques used in Oldowan knapping. On the other hand, Oldowan knapping does require substantial speed to accelerate the hammerstone over a relatively short distance.

Brain Imaging Studies and Cognition *(Figures 117-119)*

(Stout et al., 2000, 2006, 2009; Toth and Schick, 1992, in press).

In 1989 (published in Toth and Schick, 1992), we first proposed the use of positron emission tomography (PET) to investigate the brain imaging patterns produced by knapping stone from different stages of human technology. In collaboration with Dietrich Stout, we conducted a pilot study investigated the brain imaging patterns from making Oldowan artifacts, and subsequently another study comparing and contrasting brain activity in Oldowan and Acheulean tool-making. These results showed:

1) Knapping of stone produces brain activity in a broad arc in both hemispheres from the cerebellum through the occipital and parietal lobes and to the posterior frontal lobes. For a right-handed knapper making Oldowan artifacts, there is stronger activity in the left hemisphere (controlling the right hand), especially in the primary motor and somatosensory cortex around the central sulcus;

2) The neural areas involved in tool-making partially overlap with language areas, suggesting a co-evolution of tool-making and language employing some of the same areas. It is also consistent with the emergence of populational-level lateralization (including preferential right-handedness) and expansion of association cortex during the course of human evolution;

3) Knapping later Acheulean tools, compared to Oldowan knapping, produced much more symmetrical patterns of brain activity between the hemispheres (especially more activation of the right hemisphere's primary somatosensory and motor), more extensive and intense

activation overall. This bilateral activation may be due to the cognitive demands of positioning the handaxe in the left hand for the blows being struck by the hammerstone held in the right hand (in the case of a right-handed knapper);

4) There is notably significantly more activity in three neural areas of the right hemisphere during Acheulean handaxe manufacture: the supermarginal gyrus (Broadmann area 40), the ventral precentral gyrus (Broadmann area 6), and the inferior prefrontal gyrus (Broadmann area 45);

5) The activation of the right prefrontal cortex during Acheulean tool-making is of especial interest, as this area is involved in coordinating flexible, goal-driven behavior.

We have also tried to identify and quantify the differences in cognitive decisions required in Oldowan technology (probably produced by later *Australopithecus* and early *Homo)* and late Acheulean technology, based upon extensive replication experiments over many years. The number of cognitive decisions required to make a late Acheulean handaxe compared to producing Oldowan cores and flakes increases more than fourfold as listed below:

Oldowan Technology: Cognitive Decisions

1. Select hammer
2. Select cobble (core)
3. Test cobble (accept/reject)
4. Identify thin edge (overhang)
5. Point of impact
6. Angle of impact
7. Force of impact
8. Unifacial/bifacial flaking
9. Seek out acute angles
10. Follow areas of high mass (follow ridges)
11. Selecting best flakes for cutting

Late Acheulean Technology: Additional Cognitive Decisions

12. Select large hammer
13. Select boulder-core
14. Produce large flake blanks
15. Discoidal reduction of core
16. Select best flake blanks
17. Create continuous edge (hard hammer) with alternate, bifacial reduction
18. Center edge relative to mass (hard hammer)
19. Identify long axis of biface
20. Even out mass/gross thinning (hard hammer)
21. Select soft hammer
22. Prepare platforms to steepen angle (by faceting with hard hammer) and centering edge relative to the thickness of biface to set up soft hammer blows
23. Isolate high point of striking platform
24. Abrade platforms (hard hammer)
25. Identify areas of high mass (where flakes will detach)
26. Select area of impact on edge (soft hammer)
27. Correct angle of soft hammer impact
28. Correct force of soft hammer impact
29. Spacing blows (with soft hammer)
30. Select edge to flake
31. Select face to flake
32. Consider planform shape/symmetry
33. Consider cross-section shape/symmetry
34. Shape butt
35. Dull edge around butt for comfort when holding
36. Thin tip
37. Shape tip
38. Remove spurs/overhangs
39. Recover from steps/hinges, often by removing flakes from the opposite direction
40. "Balance" of shape & thinning as reduction proceeds
41. Keep edges sharp as flakes detach, do not "overretouch"
42. Straighten out sinuous edges
43. Even out possible mistakes (to maintain bilateral symmetry)
44. Avoid end shock (tip breaks off) by not hitting too hard on butt end
45. Avoid transverse fracture (across breadth) by not hitting too hard
46. Support biface with leg or hand to help absorb shock

Studies in Archaeological Site Formation *(Figures 120-135)*

(Schick, 1984; 1986, 1987a, 1987b, 1991; 1992; 2001; Schick and Toth, 1993).

How can early Palaeolithic sites be transformed before final burial and incorporation in the geological record? A program of setting out simulated Early Stone Age sites in a wide range of depositional environments was conducted, including river floodplains and channels, lake margins, and deltas. We also conducted experiments in flumes (artificial river systems where the water velocity and sediment load could be controlled) to see the detailed dynamics of stone artifacts moving with water flow. Such experiments can help prehistorians understand the types of disturbance that can happen to a Stone Age site before final burial, especially by water action of river flooding or lake transgressions, and whether a given archaeological site retains much of its behavioral integrity pertaining to the spatial array of stone artifacts and fossil bones.

Criteria for assessing the degree of disturbance/non-disturbance at Palaeolithic sites include:

1) Assemblage composition: For a given technology and raw material, there tends to be a predictable breakdown of the proportion of cores to flakes to fragments. As water action proceeds, the proportion of cores and whole flakes goes up, while the proportion of fragments (snaps, splits, and angular fragments) goes down. Within whole flake population, as water action proceeds, the proportion of flake types 3 and 6 (with no dorsal cortex, often representing later stages of flaking) goes down, while flake types 1, 2, 4, and 5 (with dorsal cortex) goes up;

2) Size distribution of flaked stone artifacts: Knapping stone, for a given technology and raw material, produces a predictable breakdown in the size fraction of debitage. The smaller the size class of debitage, the larger the number of actual artifact pieces. As water action proceeds, the smaller size classes tend to be winnowed away, preferentially leaving larger size fractions. (Of course at even higher water velocities all artifacts may be swept away);

3) Orientation of artifacts: The spatial orientation of artifacts at a pristine Stone Age site should show random orientation of artifact or bone long axes and a near-horizontal planar orientation of flatter objects. As water action proceeds, there is a tendency for artifacts with long axes to orient themselves parallel or perpendicular to water flow (which can be shown graphically with a rose diagram) and a tendency of flatter objects to dip in the direction of stream flow;

4) Spatial distribution of artifacts: Individual knapping episodes tend to produce concentrations of artifacts (many of them refitting) in an area of about one square meter, with occasional outliers outside of this area. As water action proceeds, many of these refitting pieces will be swept downstream. There is a tendency of larger pieces to cluster in sets with water action, and smaller pieces resting under larger pieces. In a large-scale excavation, it may be possible to see a pattern of larger artifacts upstream and smaller pieces downstream.

We also investigated the deposition of volcanic ash (tuff) after the eruption of Mount St. Helens in Washington State in 1980 (Figures 131-133) and the possible effect of scavengers on bone assemblages from animal carcass processing (Figures 134-135). The Mount St. Helens eruption rapidly spewed massive amounts of ash (a cubic kilometer) into the atmosphere in a column 80,000 feet high, which spread across the United States within three days and around the world within about two weeks. Beyond the devastation locally in the vicinity of the mountain (from avalanches and landslides, violently powerful and superhot lateral blasts, volcanic mudflows, and pyroclastic flows of hot rock and ash), significant deposits of volcanic ash blanketed about 22,000 square miles in the region. Although the ash fall was deeper closer to the eruption, with a depth of ten inches observed ten miles away, still significant amounts were observed at some distance, with a one-inch depth at 60 miles and a half-inch as far as 300 miles downwind. Such ash falls in East Africa during early hominin evolution often contributed substantially to the rapid deposition of sites and fossils, not just from air fall, but from the rapid addition of so much sediment into the regional stream systems from surface runoff of such ash fall deposits on the broader landscape.

Functional Studies *(Figures 136-162)*

(Keeley and Toth, 1981; Toth, 1982, 1987a, 1987b, 1985b, 1991; Toth and Schick, 1993, in press).

We have experimentally tested the efficiency of a range of Oldowan and Acheulean replicated tool forms for a number of activities that may have been carried out by Early Stone Age hominins, including nut-cracking (Figure 136), woodworking (Figure 137-140), digging (Figure 141), and animal butchery (Figure 142-158.)

Some of the major conclusions drawn from these functional feasibility studies are:

1) For nut-cracking, simple cobble hammers and anvils could have been employed. With prolonged use, smooth pits can form on both the hammer and anvil. Similar artifacts have been observed with wild chimpanzees in West Africa, as well as wooden hammers and tree root anvils;

2) For chopping a wood sapling or branch to make a spear or digging stick, a heavier core or large flake with an acute edge is ideal. Larger choppers, heavy-duty scrapers, handaxe butts, and flake cleavers are especially efficient for wood-chopping. Cleavers used for such activities usually show edge-damage in the form of small step-fractures along the bit;

3) For shaping wood (e.g. sharpening a spear or digging stick) roughing-out a point can be accomplished with a heavy, acute-edged core (chopper, heavy-duty

scraper) or a flake used as a chisel in conjunction with a hammerstone (such a flake will often show marginal use-flaking reminiscent of some *outils écaillés*. Final shaping can be done with a flake, flake scraper, or simply by grinding against a rough surface such as a coarse sandstone block or outcrop;

4) For digging (to obtain water, underground vegetable resources, or burrowing animals), normally nonlithic materials worked best. Sharpened wooden digging sticks, broken and pointed limb bones, and animal horns could service as digging tools. For very hard soil, a tool such as an Acheulean trihedral pick worked well, but prolonged use created a "soil polish" on the tip which is rarely if ever seen on archaeological specimens;

5) For animal butchery (hide slitting, dismembering, and meat cutting) an unmodified flake worked well; as it dulled, denticulate retouch with a hard hammer could rejuvenate the edge. Thinner, acute-edged discoids were also good butchery tools. Acheulean cleavers and handaxes were also excellent butchery tools, especially for larger mammals;

6) For breaking long bones to extract edible marrow and skulls to extract brains, a simple stone hammer and anvil was ideal. Heavy cores could also be used as hammers to break bones, often leaving chop-marks at points of percussion. Bone modification included negative scars or notches, bone flakes, hammerstone striae, and many spiral-fractured bone shaft fragments.

Quantifying Meat-Cutting Efficiency *(Figures 159-162)*

(Toth and Schick, 2006a, in press).

We attempted to develop a methodology to quantitatively assess the meat-cutting capabilities of different Palaeolithic artifact types in different raw materials. After some thought we decided that 5-pound racks of pork ribs from the supermarket provided a standardized and relatively inexpensive way to test tool efficiency. This provided a substantial amount of animal tissue (meat, fat, cartilage, and bone). Each rib was cut off of a rack with a stone tool, and the time required to sever the rib was recorded. For an individual rack of ribs (usually eleven cutting episodes to separate twelve ribs), a mean number of seconds per rib was assigned to each tool. In this pilot study we found that:

1. Finer-grained materials such as flint produced a more efficient cutting edge than quartzite or lava; a large flake, being heavier and with a longer cutting edge, was a much more efficient meat knife than a smaller flake;
2. Artifact types of the same raw material showed very similar results in cutting efficiency;
3. Both refined and crude handaxes had similar cutting efficiency (although the crude handaxe weighed about two-and-a-half times as much);
4. When cutting through successive racks of ribs, flint handaxes and flakes started off having similar cutting efficiency, but the flake dulled after four racks while the handaxe showed no sign of dulling after six racks (and only one of the two sides of the handaxe had been used); also, handaxes were much more ergonomic tools, being larger and having a comfortable butt end to hold onto;
5. Denticulates were intermediate between flakes and handaxes in their long-term cutting efficiency over the course of disarticulating six racks of ribs;
6. Early Stone Age groups that habitually butchered medium to large mammals would likely develop either large bifacial handaxe/cleaver technologies like the Acheulean or flake denticulate technologies (essentially jagged-edged scrapers made up of a sequence of single-scar notches) like the Developed Oldowan, Tayacian, Nihewan industries, etc.

Bone Modification Studies *(Figures 163-185)*

(Pickering et al., 2000, 2007; Schick and Toth, 1993; Schick et al., 1989, 2007; Toth, 1982, 1985b, 1987a; Toth and Schick, in press; Toth and Woods, 1989; White and Toth, 1989, 1991, 2007).

It is important to be able to recognize various types of bone modification from a range of possible agents, including early Stone Age hominins, carnivores, rodents, and trampling, etc. Some of our work with bone modification (e.g. carnivore feeding experiments) was carried out to sharpen our analytical skills in interpreting bone modification patterns, but not necessarily to produce a scientific report.

This has included examination of cut-marks from different types of tool edges (Figure 163). Simple flake knives tend to produce single striations, while unifacially- and bifacially-retouched serrated tool edges tend to produce more complicated cut-mark patterns, often with multiple striae, some intersecting, from a single stroke.

The feasibility of using molluscan shell knives for animal butchery in lake margin areas without easy access to stone was investigated by Toth and Woods (1989). A retouched mollusc shell (using another shell as a hammer to produce the retouch) can produce a surprisingly sharp edge that can be used to butcher an animal and produce cut-marks on the bones (Figure 164-165).

Over the years we have experimentally investigated tooth-mark and fracture patterns on bones produced by a range of carnivore and other agents (Figures 166-172) to improve our analytical skills in studying prehistoric bone assemblages. Such experiments are important in showing the types of patterning of tooth-marks, notching, and fracture from a range of animal species.

We excavated and analyzed a recent striped hyaena den (Figure 173) in the eastern desert of Jordan. (A detailed analysis of this den was reported by Schick et. al, 2007). Results of this analysis included:

1) This excavated den contained almost 5,000 bone and tooth specimens representing at least 54 individuals of 16 taxa including camel, dog, gazelle, goat/sheep, donkey, human, horse, fox, stork, hare, and hedgehog. The proportion of carnivores in this assemblage was high (26% of the MNI and 31% of the NISP);

2) This assemblage had a high proportion of limb shaft fragments, similar to that of many Plio-Pleistocene archaeological sites. Measurement of shaft fragment thickness (modal value of 3 mm) suggested that most of these fragments were from smaller mammals. Bones of weathering stage 0-1 were dominated by green fracture, while bones of weathering stage 3 were dominated by dry fracture;

3) Element representation showed that smaller animals (smaller in size than the hyaenas) had higher cranial/postcranial ratios and higher axial/appendicular ratios, suggesting that these animals could have been brought in as whole carcasses, while the bones of larger animals were likely brought in as individual limbs or skulls;

4) The tooth-mark patterning, notches, and fracture patterning was generally consistent with a hyaena-sized carnivore. There were very few cut-marks from human tool-users, very little evidence of burning, and very few examples of rodent gnawing;

5) That tooth-mark frequencies on shaft fragments markedly decreased as bone weathering progressed, from 20.8 tooth-marks per 100 sq. cm for weathering stage 0-1 to 1.4 tooth-marks per 100 sq. cm for weathering stage 3;

6) About 96% of the bones were buried; these included most of the fragmented bones and teeth. The 4% on the surface tended to be larger and more complete bones, often more weathered from exposure to the elements.

On Santa Cruz Island, one of the Channel Islands of the coast of southern California, we studied the effects of feral pigs scavenging on the carcasses of feral sheep (there are presently no scavenging carnivores on the island). Analysis showed that crania, innominates, and long bones preferentially survived, while vertebrae, ribs, and phalanges were under-represented (Figures 174-177). Although this setting is unusual, with no major scavenging carnivores present, it can show the types of patterning one might expect from pigs scavenging on carcasses. Tooth-marks were present but much less frequent than typical carnivore ravaging, probably because pigs tended not to fracture the long bones of the sheep.

We excavated a Miocene site in the Mojave Desert of southern California (Figures 178-182) as a test case to see if this faunal assemblage (high-density concentrations of mammalian bones from a number of taxa in a volcanic ash context) mimicked pattering attributed to early hominin modification in a clearly non-hominin context (Schick et al., 1989). Results showed that bone modification was consistent with a medium-sized canid (probably the Miocene form *Tomarctus*).

Tim White and Nicholas Toth conducted a survey of fossil hominin remains for evidence of the presence or absence of hominin-induced bone modification (e.g. White and Toth, 1989, 1991, 2007 (Figure 184). Analysis of the early *Homo* partial cranium Stw 53 at Sterkfontein Cave, South Africa and estimated to be about 2 million years old showed cut-marks on the maxilla (Pickering et al., 2000). This is the earliest evidence of cut-marks on a fossil hominin bone known (Figure 185).

Recent Stone Technology *(Figures 186-190)*

Although technically outside the scope of this chapter, we nonetheless have a strong interest in recent uses of knapped stone. Historical examples include millstones for grinding grain (Figure 186), threshing sledge blades for processing wheat and other grains (Figure 187), gunflints for generating the spark to ignite a gunpowder charge (Figure 188, as described in the excellent monograph by Skertchly, 1879), knapped building materials for architecture (Figure 189), and snapped glass microtome blades used as knives for cutting thin sections of tissue samples for transmission electron microscopy or TEM (Figure 190).

In terms of the time extent of human technology, the vast majority of the human technological record - well over 99 percent of the time span that hominins have used recognizable tools – is constituted nearly entirely of worked stone. With the rise of complex societies in many parts of the world, stone was supplanted by metal (copper, then bronze, then iron) as a principal raw material for tools. During the age of European exploration in the 15th through 19th centuries, however, a number of societies retained the use of stone as a principal raw material, including many in Subsaharan Africa, Oceania, and the Americas.

Conclusion

The use of actualistic studies in prehistoric research can greatly increase our analytical abilities to understand and explain patterns in the prehistoric past. Experimental archaeology, geoarchaeology, ethnography, ethology, biomechanic, and neurology can yield important insights into the prehistoric record and help us understand the complex relationships between *processes* and the *products* that are found in the archaeological, palaeontological, and geological record.

Here we advocate the use of such actualistic studies in Early Stone Age research and encourage students of palaeoanthropology to become deeply involved in actualistic research as well as conventional field work and analysis. Such involvement will greatly increase one's analytical abilities and help to develop methodologies that will help us gain a much better and more realistic understanding of the prehistoric past.

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Figure 1. Actualistic pioneer: Louis Leakey. Leakey was one of the first African archaeologists to conduct experimental archaeology into Early Stone Age manufacture and use. Photo by Glynn Isaac.

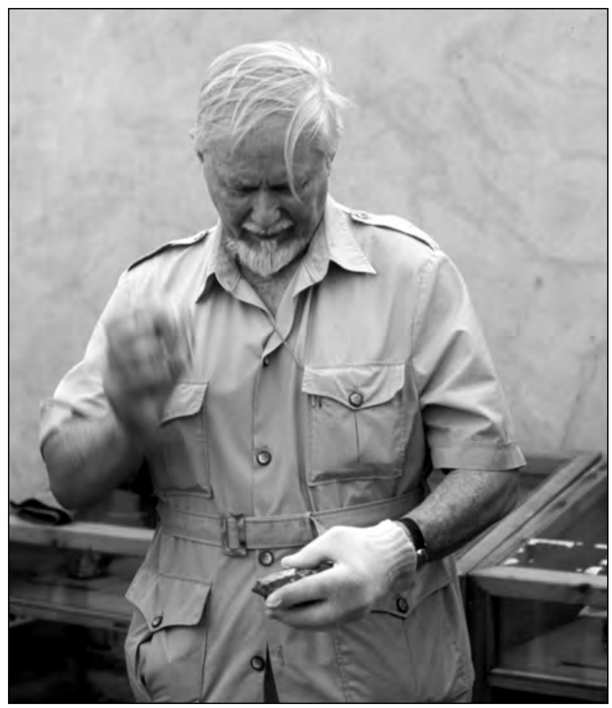

Figure 2. Actualistic pioneer: J. Desmond Clark. His experiments with stone tools included giving hunter-gatherers in Botswana actual prehistoric Acheulean quartzite handaxes and cleavers from Kalambo Falls, Zambia to use in butchering large mammals.

Figure 3. Actualistic pioneer: Glynn Isaac. In 1977, Isaac invited the authors to participate in the Koobi Fora Research project and conduct experiments in stone artifact manufacture and use, as well as in archaeological site formation studies. Here he is kneeling on the excavated floor of Oldowan site FxJj50 (ca. 1.5 million years old) with the stone artifacts and fossil animal bones put back in their original spatial position.

Figure 4. The landscape at East Turkana (Koobi Fora) Kenya, showing stratigraphic deposits dating to approximately 1.9 million years ago in this area.

Figure 5. Examining modern raw materials in the Bura Hasuma streambed at East Turkana, Kenya. As in the prehistoric past, the cobbles in the stream in this area are predominantly basalt lava, with lower proportions of ignimbrite, chert, quartz, silicified wood, and limestone.

Figure 6. Experimentally knapping a replica of an Oldowan bifacial chopper by using two basalt cobbles, one cobble serving as the percussor (hammerstone) and the other cobble being flaked into the chopper-core. Note the spatial array of flakes and fragments that have been detached by hard-hammer percussion.

Figure 7. Experimental examples of typical Oldowan artifacts that are found at East Turkana, all made in basalt. Top row, from left: battered cobble hammerstone, unifacial chopper, bifacial chopper, polyhedron, core scraper (made on large flake), discoid (made on large flake). Bottom row, from left: retouched flake scraper, six flakes.

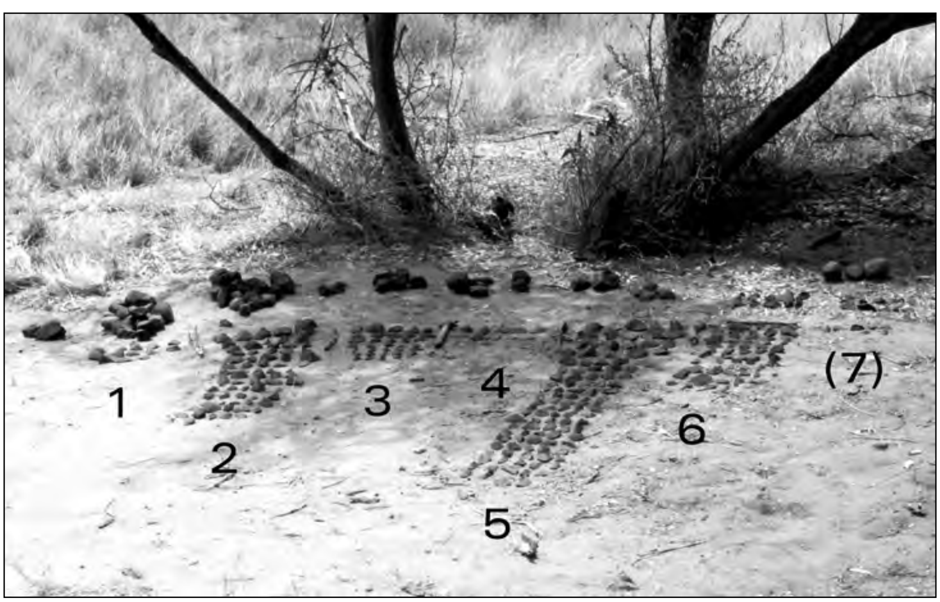

Figure 8. An "actualistic" bar graph of flake types (1 through 7) from an experimental primary flaking area, where all stages of reduction are represented. Percussors and cores made on cobbles and large flakes are at top. With more intensive reduction, there would be a shift to higher numbers of type 3 and type 6 flakes.

Figure 9. A graded series of hammerstone weights used experimentally to determine the ideal weight of hammerstone for a given core weight. For a small core weighing 50 grams, the ideal hammerstone weighed 100 grams (twice as much); for a core weighing 500 grams, the ideal hammerstone also weighed 500 grams; for a mega-core weighing 3000 grams, the ideal hammerstone weighed 1500 grams (half as much).

Figure 10. "Split cobble" fracture produced by throwing one cobble against another. Fracture is characterized by a pronounced area of crushing at the point of impact and a very flat release surface, without a prominent bulb of percussion. Hammerstones can also break in this manner, but will normally show more cortical battering near the point of percussion.

Figure 11. Early Stone Age quartz spheroid from central Zambia. The artifact is almost perfectly spherical and is battered over the entire surface. Maximum dimension: 67mm. Weight: 403 grams.

Figure 12. A quartz spheroid from an excavation at Olorgesailie, Kenya associated with Acheulean handaxes and cleavers.

Figure 13. A landscape in central Zambia. Here quartz can form in veins in the basement bedrock, later eroding out as angular chunks or blocks.

Figure 14. Using a quartz percussor (spheroid) experimentally to flake a quartz core. Such a percussor became increasingly battered, rounded, and spherical over time through its use as a hammerstone.

Figure 15. An experimental quartz percussor (spheroid), a polyhedral core, and associated debitage. The dorsal surfaces of some of these flakes and fragments show battering: this battering may be due to spalling of the percussor surface as well as from impact of the percussor on core surfaces during flaking.

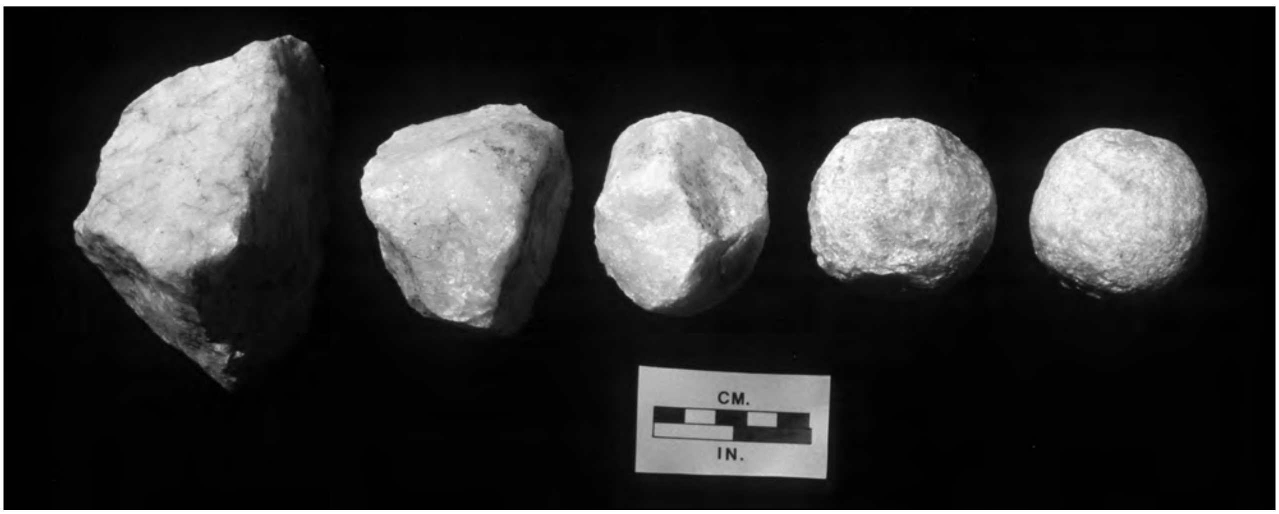

Figure 16. Experimental quartz spheroid production. From left, an unmodified block of quartz ; a polyhedral core ; a percussor used for one hour (subspheroid); a percussor used for two hours (spheroid); a percussor used for four hours (spheroid). These percussors become increasingly battered, rounded, and spherical over time. These latter, spheroidal forms can be arrived at as a by-product of flaking rather than as intentional target forms, although a heavily battered and well-rounded spheroid makes a very comfortable and very stable (not liable to fracture unexpectedly) percussor.

Figure 17. Experimental quartz cores made as by-products of flake production, from angular blocks of the raw material. These core forms would be typed by archaeologists as polyhedrons, subspheroids (and even spheroids), and discoids, although classic Oldowan choppers are rare. All of the core surfaces exhibit some battering from the impact of a quartz percussor (from unsuccessful blows to fracture the stone), though these surfaces are not as extensively battered as that on the percussor itself. These cores could have been reduced much further if needed.

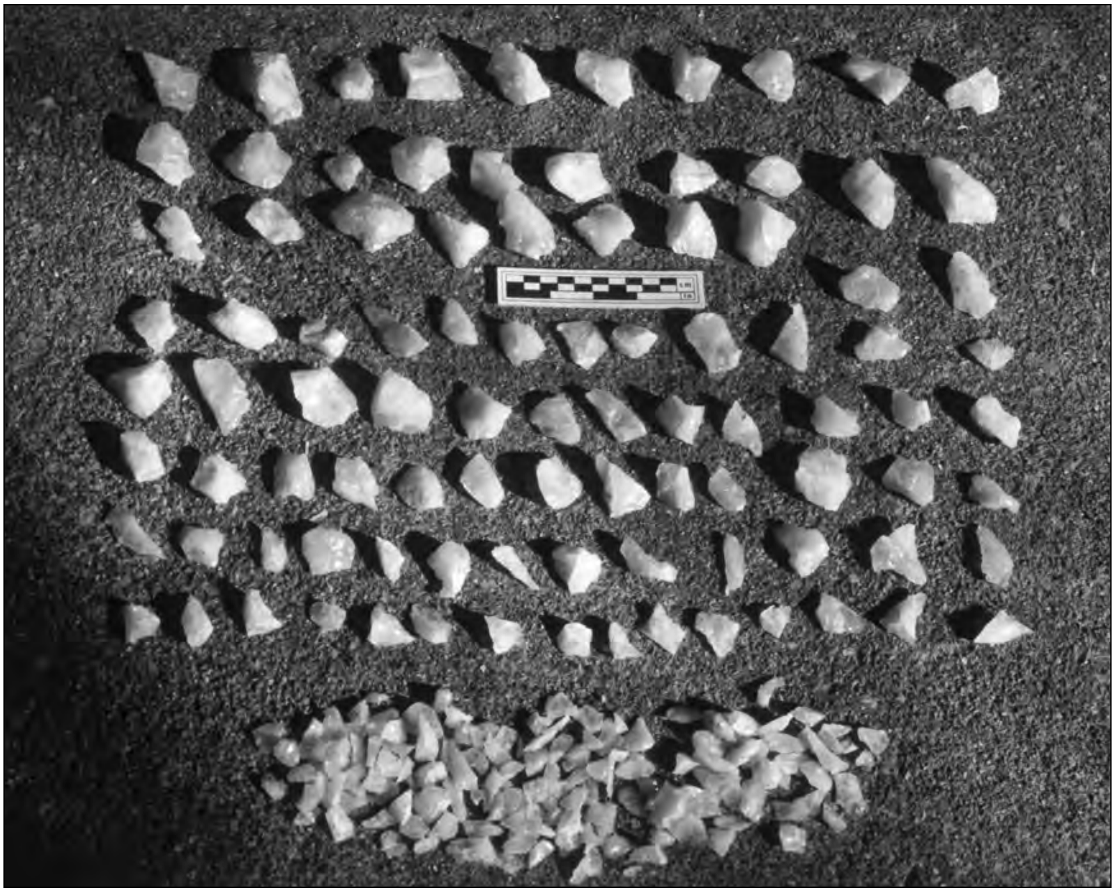

Figure 18. Extreme experimental quartz reduction. Such exhaustive lithic reduction produces large quantities of debitage but few recognizable cores, and could be one reason for the low core to debitage ratios regarding quartz at sites such as Bed II at Olduvai Gorge, Tanzania.

Figure 19. Recent prehistoric querns and spherical "sharpening stones" from central Zambia. Such artifacts are associated with agricultural societies (Neolithic and Iron Age). Ethnographically, it has been observed that when the surface of a quern becomes too smooth for efficient grinding, the surface is pecked with these stones to roughen them again. Such "sharpening stones" become increasingly battered, rounded, and spherical over time. Although these artifacts are not produced in the exact same manner as Early Stone Age spheroids, such long-term percussion produces very similar end products.

Figure 20. A large battered basalt spheroid (surface find) from Olduvai Gorge, Tanzania. Maximum dimension 85 mm.

Figure 21. A basalt spheroid (76 mm) from the Middle Pleistocene site of Dawaitoli A6 in the Middle Awash of Ethiopia, flanked by two lava subspheroids.

Figure 22. The area near Debre Birhan in the Ethiopian volcanic highlands (elevation approximately 2500 meters) where the basalt spheroid experimental study was conducted. Note the naturally-occurring spherical clasts that have eroded from bedrock can be seen in the foreground.

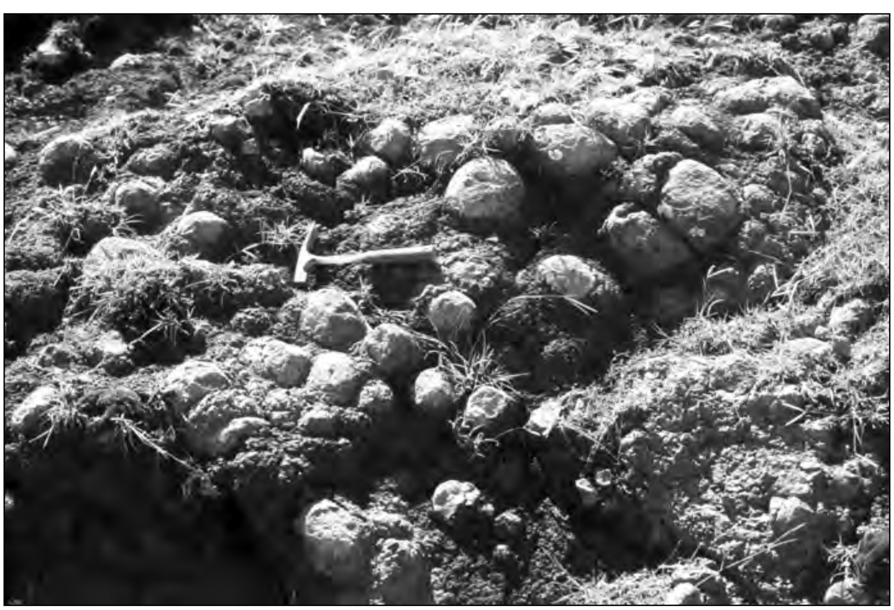

Figure 23. Spheroidal weathering in situ of basalt. These natural spherical clasts are about to erode out of the weathered basalt bedrock. Geological hammer for scale.

Figure 24. Close-up of a row of natural basalt spheres in situ. Camera lens-cap for scale.

Figure 25. Small gulley with numerous natural spherical clasts, as well as larger boulders, that have eroded from the bedrock.

Figure 26. Six eroded naturally spherical basalt clasts showing the classic "onion ring" exfoliation.

Figure 27. A sample of 100 natural basalt clasts greater or equal to 60 mm found on a fairly flat erosional surface. With a random throw of a hat to determine a central point, the nearest hundred clasts were sampled on the surface (the area sampled was a circle with an approximately ten-meter radius). Note how spherical many of these natural clasts are in shape.

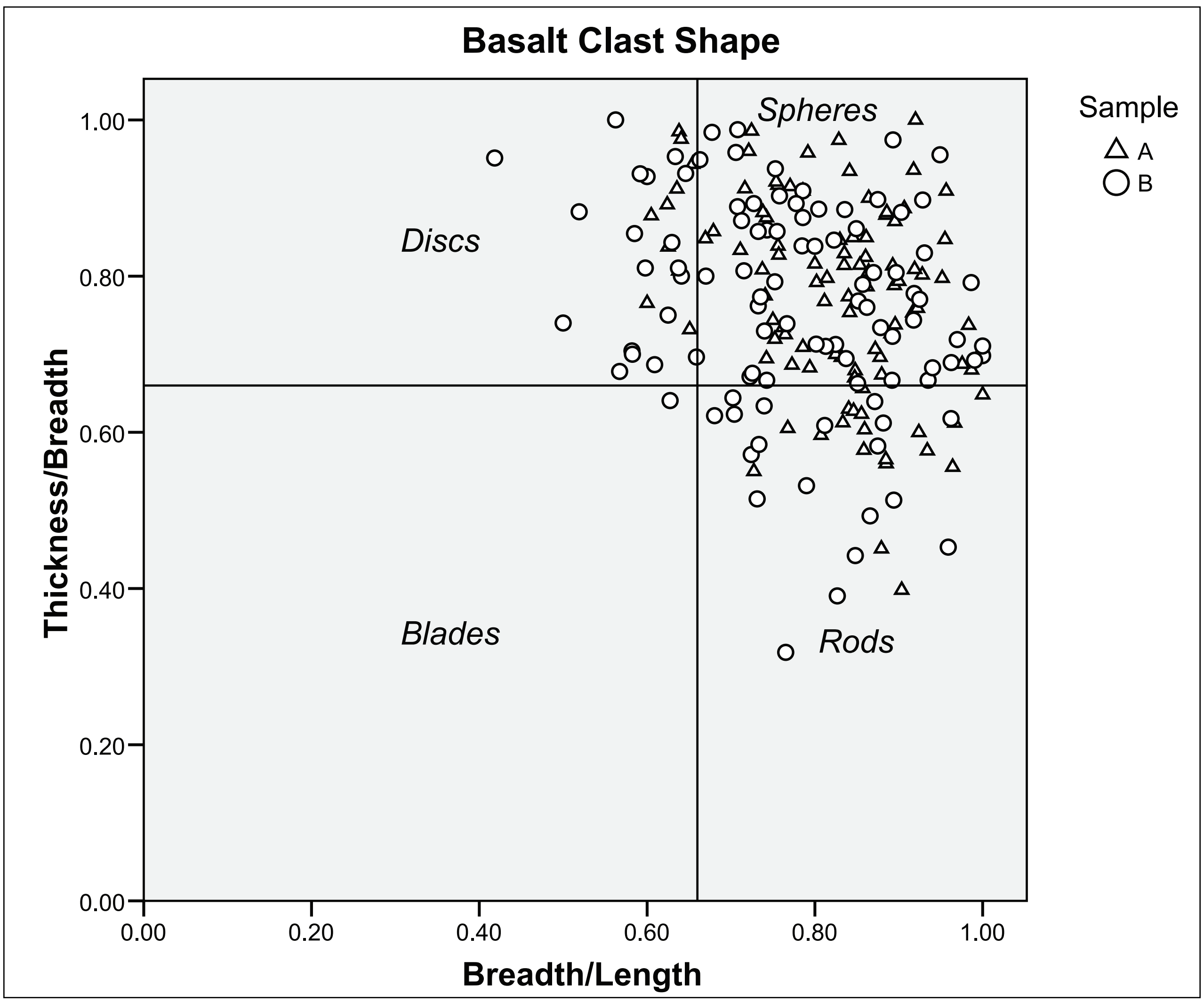

Figure 28. Scattergram of two natural clast samples (each sample is 100 nearest clasts greater than 60mm) plotted by breadth/length and thickness/breadth. Note the strong tendency for spherical clasts in each sample (a perfect sphere would be 1.00 for both ratios).

Figure 29. Natural spherical basalt clasts ideal for use as percussors. These eroded surface clasts were collected in ten minutes of search time.

Figure 31. A close-up of a battered basalt spherical clast that was experimentally used as a percussor for four hours (maximum dimension: 70 mm.) The surface is covered with thousands of small pits from individual impacts. The softer exterior has been worn away down to the denser, harder interior. The hand grip is typical of that used during hard-hammer percussion.

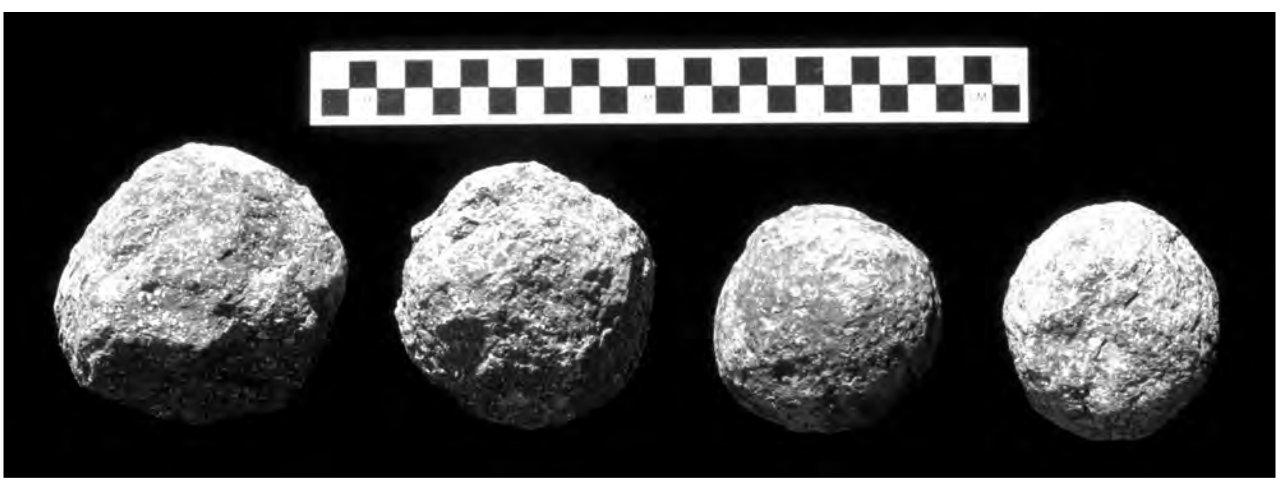

Figure 30. Formation of a battered basalt spheroid. From left: a natural spherical basalt clast; a percussor used to flake other stones for one hour; a percussor used for two hours; a percussor used for four hours. Note that sphericity changes little over time (a perfect sphere has breadth/length and thickness/breadth ratios of 1.00), but the size and weight tend to decrease over time as the softer, more friable exterior is worn away as percussion proceeds.

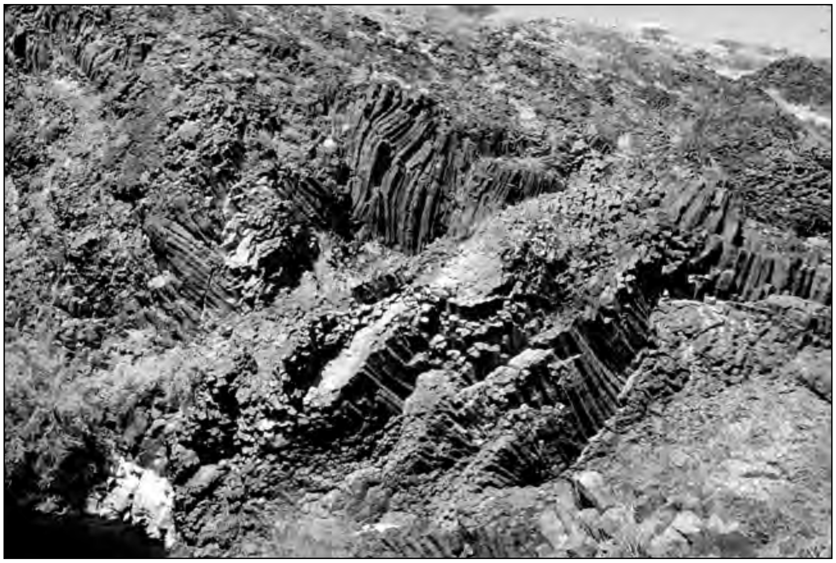

Figure 32. Columnar basalt formation in the eastern margin of Koobi Fora at Karsa, East Turkana, Kenya. These basalts tend to be fairly fresh and have not had the time to produce the classic spheroidal weathering seen at some localities. Lava spheroids are essentially absent at Koobi Fora sites.

Figure 33. A small archaeological basalt hammerstone, upper left (weight : 222 g; maximum dimension: 64 mm) made on a hard-cortex basalt cobble, and other artifacts from the Oldowan site FxJj 3 ("HAS") at Koobi Fora, Kenya, approximately 1.9 million years old, associated with the partial skeleton of a hippopotamus. Battered lava spheroids are essentially absent from the archaeological sites in this region, as the available clasts for percussors tended to be hard-cortex river cobbles. This hammerstone was likely used to detach flakes from small cores.

Figure 34. A large archaeological basalt hammerstone (weight: 1,332 g; maximum dimension: 116 mm) made on a hard-cortex basalt cobble from proto-Acheulean site FxJj 33 at Koobi Fora, Kenya, approximately 1.4 million years old. This hammerstone was likely used to detached large flakes (largest at this site 195 mm) from mega-cores (largest 220 mm).

Figure 35. A prehistoric limestone spheroid from Ain Hanech, Algeria. Maximum dimension 87 mm. Photo courtesy of Mohamed Sahnouni.

Figure 37. Stratigraphic section exposed at Ain Hanech, showing conglomerate levels representing ancient river gravels. These gravels were the source of the limestone cobbles and flint pebbles used by early hominins at this site. Photo courtesy of Mohamed Sahnouni.

Figure 36. The landscape around Ain Hanech, Algeria. Excavated sites dating to approximately 1.8 million years ago contain low proportions of limestone "facetted balls" and occasional battered spheroids.

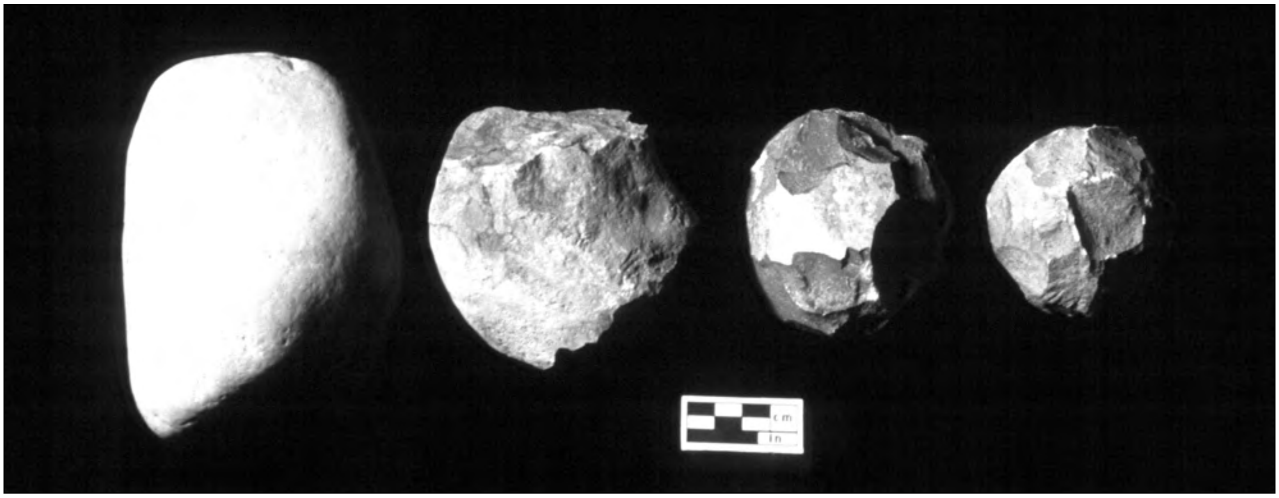

Figure 38. Experimental limestone facetted spheroid reduction. From left: an unmodified cobble; a two-edged chopper; a polyhedron; a facetted ball. Because of the unique properties of this limestone, there is a tendency for cores to become multifaceted and spherical in shape during flake production.

Figure 39. Two experimental faceted limestone spheroidal cores, produced as a by-product of flake production. Note light-colored points of impact from a hammerstone.

Figure 40. An experimental limestone facetted spheroidal core (seen in figure 39, right). After it was produced through extensive reduction of a limestone cobble, it was then used as a percussor to knap other cores for one hour. It is battered on well over 50 percent of its surface, the battering spreading first from the tops of higher ridges. If such a percussor is used for three or four hours of knapping, it can become an almost perfect battered sphere (unless it breaks during knapping).

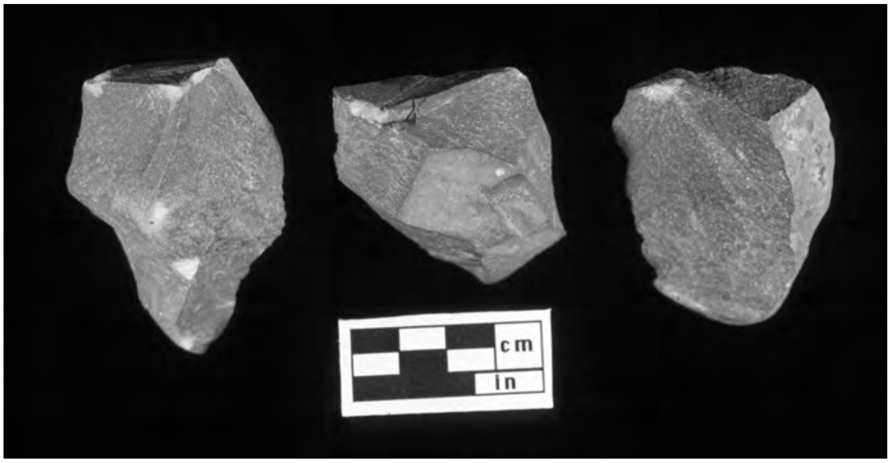

Figure 41. Limestone flakes: dorsal surfaces. Unlike most raw materials, the local limestones produce flakes with obtuse exterior platform angles (the angle between the striking platform and the dorsal surface), as it is possible to flake core edges of greater than 90 degrees. Flakes oriented with striking platforms at top.

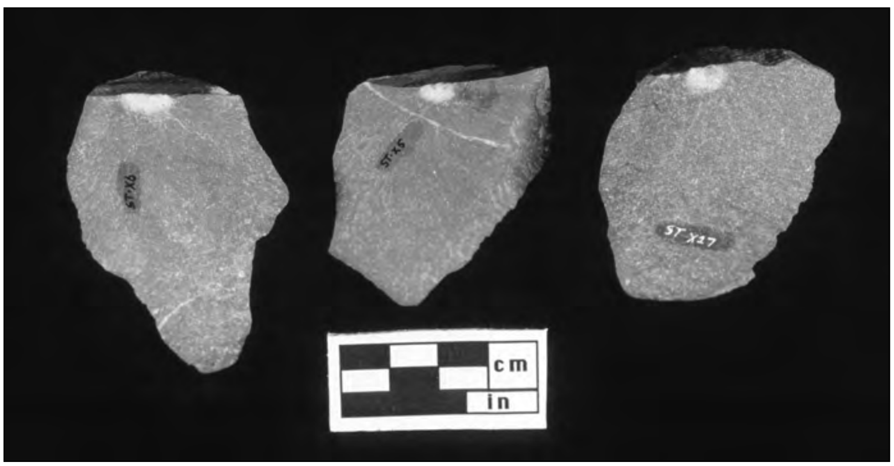

Figure 42. Limestone flakes: ventral surfaces. Again, unlike most other raw materials, the limestone produces flakes with acute interior platform angles (the angle between the striking platform and the ventral surface). Note the pronounced areas of crushing (usually 5 to 10 mm) at the point of percussion. Flakes oriented with striking platforms at top.

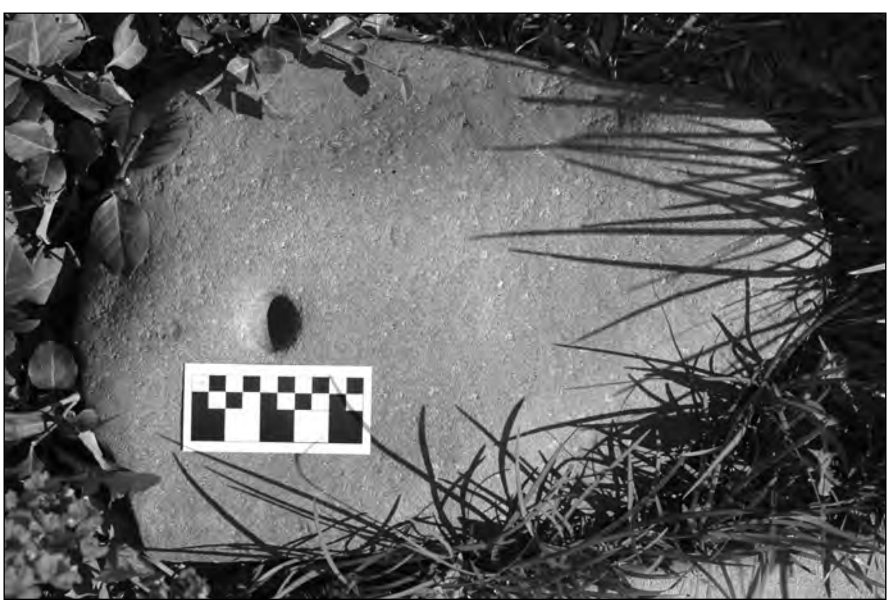

Figure 43. A large ethnographic mongongo nut-cracking stone from southern Zambia. The reverse surface of this specimen was a quern for grinding. Note the smooth pit from prolonged nut-cracking.

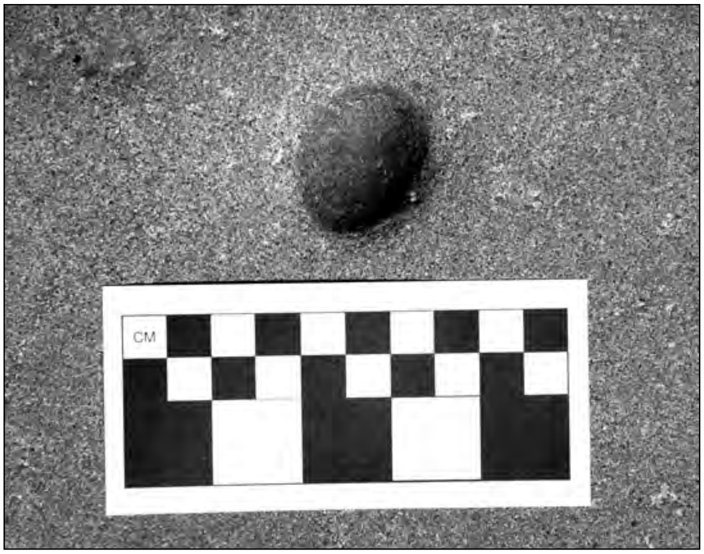

Figure 44. A close-up of the smooth pit (35 mm in maximum dimension) on the large ethnographic mongongo nut-cracking stone.

Figure 45. A smaller ethnographic mongongo nut-cracking stone from southern Zambia, showing another smooth pit (31 mm in maximum dimension).

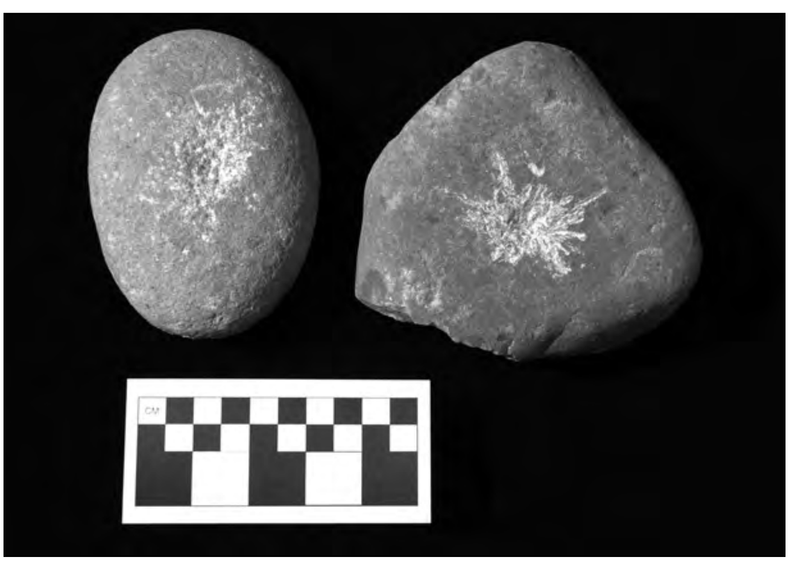

Figure 46. Two experimental bipolar anvils used in flaking cores. Note the rough pitted surface and the radial pattern of striae from contact with the base of bipolar cores.

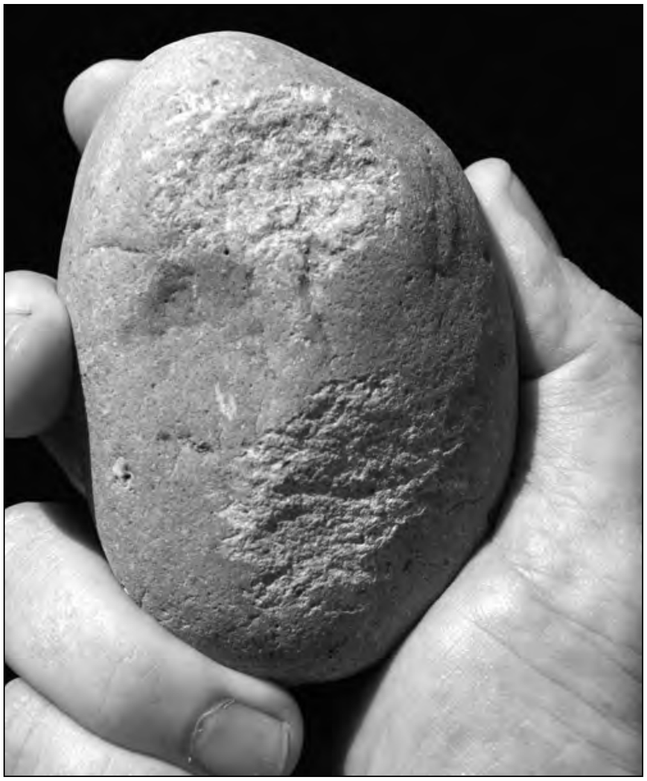

Figure 47. An elongated basalt bipolar hammer, showing two off-center rough pits from contact with bipolar cores. When humans use an elongated bipolar hammer, there is a tendency to produce an off-center pit about 1/3 the length from the end of the hammer. If the cobble is turned around, another pit will form. This will finally produce a pitted bipolar hammer with rough pits at approximately 1/3 and at 2/3 of its length.

Figure 48. Another elongated bipolar hammer, limestone, showing two off-center rough pits.

Figure 49. The Plio-Pleistocene outcrops in the Nihewan Basin, northeast China. The group of people on the outcrop marks the site of Feiliang, estimated to be about 1.3 million years old, excavated by Xie Fei, Desmond Clark, and the authors.

Figure 50. Precambrian bedrock outcrops (right and left) in the Nihewan basin. In the early Pleistocene, such outcrops rose above the prehistoric land surfaces, with the near-horizontal sediments being deposited against them. These Precambrian outcrops contain cherts and quartzites that were exploited by early hominins here for stone tools. Most sites in this area are located within a few hundred meters of such outcrops.

Figure 51. Excavations at Donggutuo site, estimated to be about 1.3 million years old. Excavations by Wei Qi and his colleagues began here in the early 1980's.

Figure 52. Conducting experimental knapping of a range of raw materials from the Nihewan Basin.

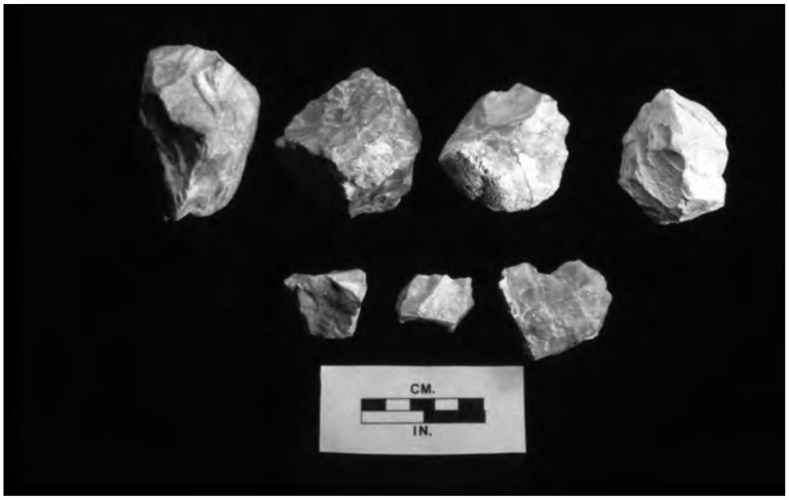

Figure 53. Chert cores from the site of Donggutuo. These cores tend to be heavily reduced and in the form of polyhedrons and discoids.

Figure 54. A refitted set of chert flakes and fragments onto a small core from the site of Cenjiawan in the Nihewan Basin, estimated to be about 1.3 million years.

Figure 55. A basalt lava bifacial chopper from the site of Donggutuo. When the rare lava cobble was flaked here, the resultant core was usually a typical chopper form. Tougher raw materials (lava at Olduvai Gorge in Tanzania and Donggutuo, quartzite at Kalambo Falls in Zambia) tended to produce chopper-dominated cores ("core tools"), while raw materials that were easier to flake (chert at Olduvai Gorge and Donggutuo, silicified mudstone at Kalambo Falls, quartz at Olduvai Gorge) tended to produce core assemblages dominated by heavily-reduced polyhedral and discoidal cores.

Figure 56. A portrait of Kanzi, a bonobo or "pygmy chimpanzee", Pan paniscus. Kanzi has now been flaking stone for two decades.

Figure 57. The first day with Kanzi, May, 1990. Nick Toth demonstrates how to detach sharp flakes from a core and use them to cut through a cord in order to open a box with a food reward. By the end of this day Kanzi was cutting through the cord with flakes that Toth had made and attempted (unsuccessfully) to make his own flakes by hitting two cobbles together.

Figure 58. Kanzi throwing on cobble against another to produce fracture.

Figure 59. Kanzi flaking a core positioned on the ground.

Figure 60. Kanzi flaking a core by freehand direct percussion with a hammerstone.

Figure 61. The first flint artifacts produced by Kanzi after a month of experience: the flint core (upper right) and three flakes (bottom). The hammerstone he used is in the upper left. The flakes are small and the core shows non-invasive scars.

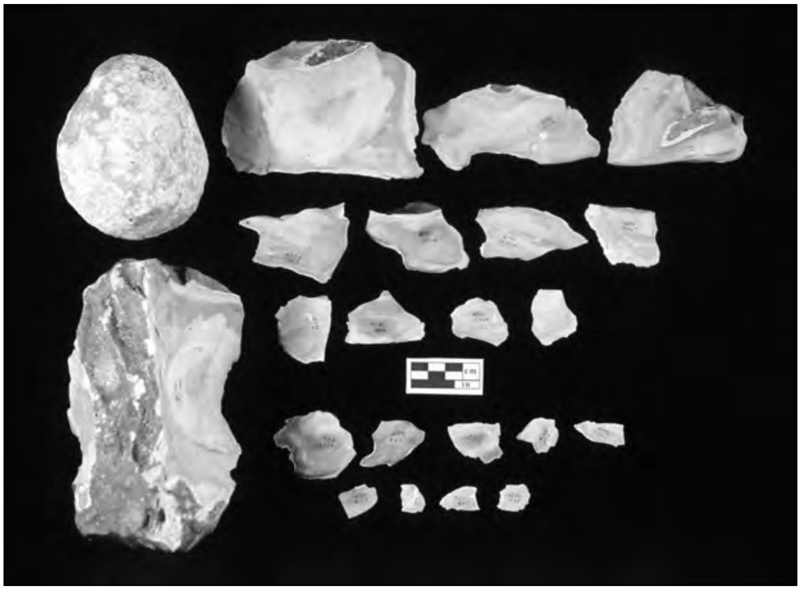

Figure 62. Flint artifacts produced by Kanzi after seven years of experience. Upper left: well-used hammerstone. Bottom left: core. The flakes tend to be much larger and the core is more heavily reduced than the previous figure. The flakes and fragments that were actually used for cutting activities are above the scale; the flakes and fragments that were not used (mostly smaller debitage) are below the scale.

Figure 63. Cores produced by Kanzi and his sister Panbanisha from Gona volcanic cobbles, especially trachytes. These specimens would be easily be recognized as artifactual by any competent Palaeolithic archaeologists, although the bonobo cores are not as heavily reduced and their edges are more battered from hammerstone impact as compared to the archaeological cores from the Gona prehistoric sites.

Figure 64. A large trachyte lava flake (right, 155 mm) and cobble-core produced by Kanzi. This flake is large enough to serve as a blank for a small handaxe.

Figure 65. Kanzi cutting through a cord with a flint flake to open the box for a food reward. In other experiments, he would cut through a plastic membrane of a drum to get a food reward in a drum.

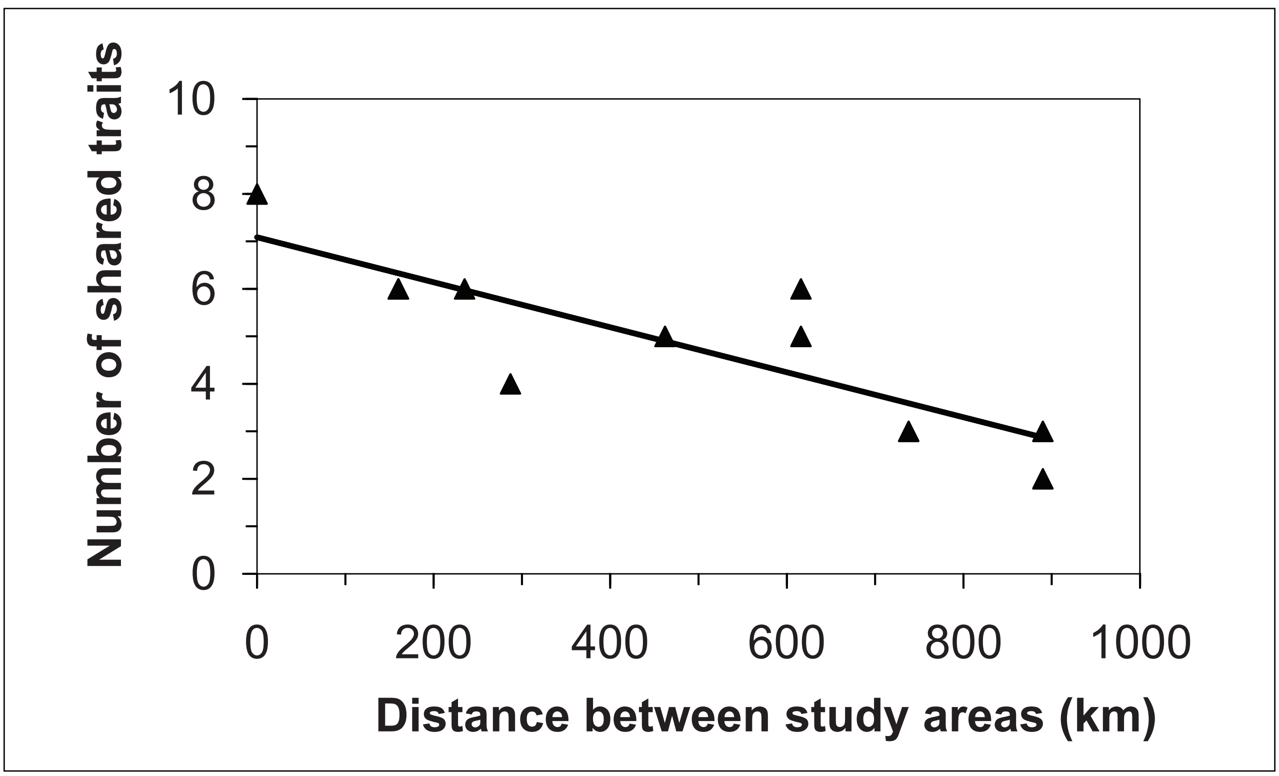

Figure 66. Do chimpanzee cultural traits cluster geographically? Here is a graph based on a study by the authors (Toth and Schick 2007, 2009; Whiten et al. 2009) showing the relationship of the number of shared chimpanzee cultural traits (habitual or customary, from the Whiten et al. 1999 paper) and distances between pairs of chimpanzee groups of the same subspecies. Groups in closer proximity share more traits than groups separated by greater distances, and the number of shared traits drops by more than half (fewer than four) at a distance of about 700 kilometers. A Pearson r-squared value of 0.702 was derived for the 11 pairs of 7 groups. Among the East African chimpanzee groups (10 pairs) the Pearson r-squared value was 0.687 and the Mantel test p=0.014.

Figure 67. Experimental quarrying large basalt flakes from boulder cores in the volcanic highlands of East Turkana (Koobi Fora), Kenya. A large, hand-held percussor was used to detach flakes. Such large flakes can be knapped into Acheulean handaxes, cleavers, picks, and knives.

Figure 68. An experimental basalt boulder core and the large flake detached from it that would serve as a blank for a handaxe. (Koobi Fora, Kenya).

Figure 69. In five hours of experimental quarrying, 97 flake blanks were struck from boulder cores. These blanks could be made into handaxes, cleavers, and picks. (Koobi Fora, Kenya).

Figure 70. Top row: Experimental Acheulean artifacts made from large basalt flakes at Koobi Fora, Kenya. From left: ovate handaxe, lanceolate handaxe, cleaver, and pick. Bottom row: quartz spheroid, flake scraper, and three biface trimming flakes.

Figure 71. Two large experimental basalt side-struck flakes that served as blanks for cleavers. (Koobi Fora, Kenya).

Figure 72. Throwing one basalt boulder against another to produce large flakes. This technique can generate much higher impact forces than using a hand-held hammerstone. (Koobi Fora, Kenya).

Figure 73. A large basalt cortical flake (type 1) experimentally struck from a large boulder by throwing. The thrown hammer is in the foreground. Such a large flake blank could be used to strike a Kombewa flake from its ventral surface. (Koobi Fora, Kenya).

Figure 74. Looking down on the striking platform of a large basalt flake that has been experimentally detached from a boulder core. The thrown hammer can be seen at the bottom right (Ethiopian volcanic highlands).

Figure 75. A large basalt flake experimentally detached from a large boulder core, ideal for a cleaver or handaxe (Ethiopian volcanic highlands).

Figure 76. An experimental quartzite cleaver made on a large flake struck from a boulder-core at Kalambo Falls, Zambia. Hard hammer percussion.

Figure 78. Three flint handaxes and one cleaver made from four of the large flakes seen in figure 77 (penny for scale). The large ovate handaxe at bottom right was used in an experimental butchery of an elephant that died of natural causes (see figure 79). Soft hammer percussion.

Figure 77. Experimental reduction of one large flint boulder (maximum dimension 63 cm) that produced numerous large flake blanks for handaxes and cleavers at Ambrona, Spain. They are shown in the sequence of removal, starting from the upper right and progressing clockwise. The heavily-reduced polyhedral core (below hand) and various hammerstones (some broken) are in front of knapper.

Figure 79. Resharpening the large flint ovate handaxe with an antler soft hammer during an experimental elephant butchery.

Figure 80. A tabular flint nodule from the eastern desert in Jordan ideal for handaxe manufacture. One flake has been removed to inspect the quality of the raw material.

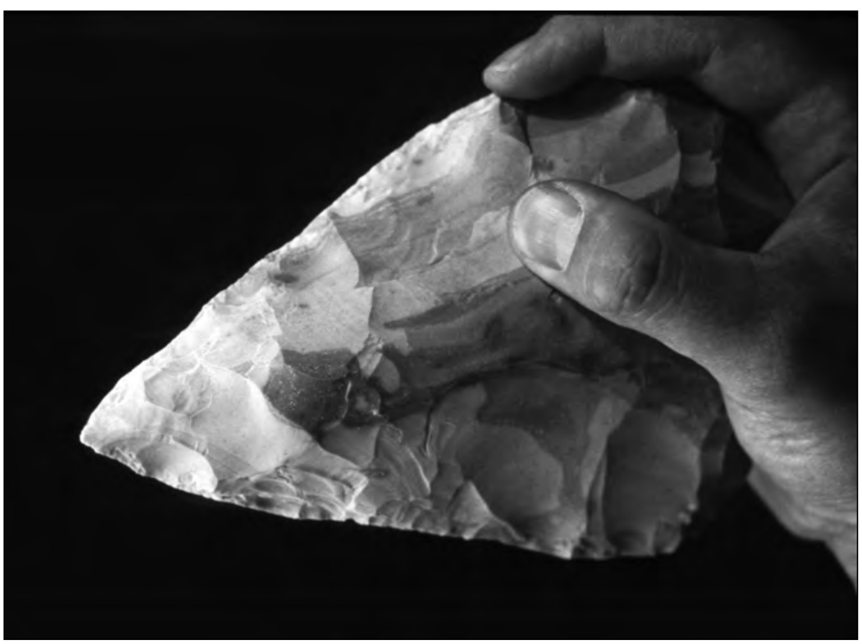

Figure 81. An experimental lanceolate flint handaxe made from the nodule in the previous figure. Soft hammer percussion.

Figure 82. A large experimental limestone handaxe made by Kathy Schick within sight of the Zhoukoudian "Peking Man" site in northeastern China, produced from raw material found in the local river valley. Hard hammer percussion. The absence of Acheulean artifact forms in much of East Asia is not due to the lack of appropriate raw materials for handaxes and cleavers.

Figure 83. A portrait of an expert adze-maker from Langda village, Irian Jaya, New Guinea. These stone knappers are members of a specialized craft guild in this region, and the skill of adze-manufacture is normally passed from father to son.

Figure 84. A view of a hut at Langda village. This village is situated on a plateau of a mountain ridge at an altitude of about 2000 meters.

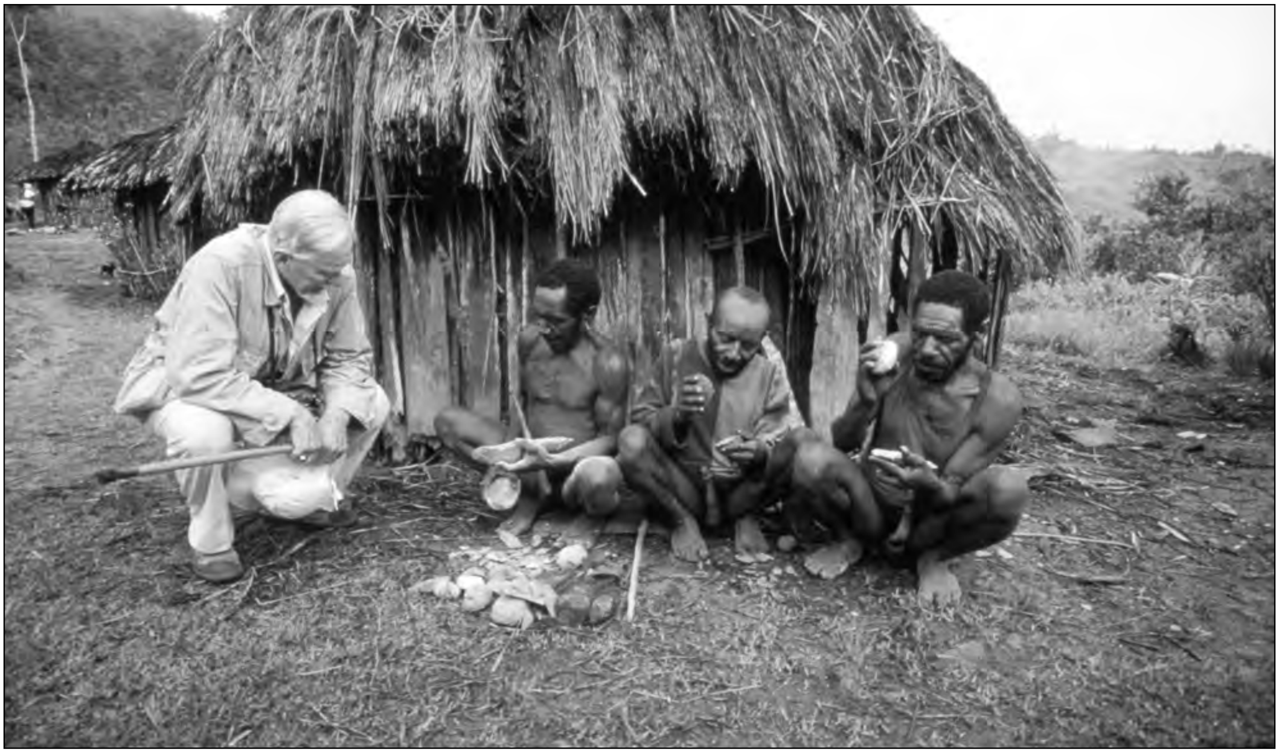

Figure 85. Prehistorian J. Desmond Clark with a group of adze-makers at Langda.

Figure 86. The raw materials used by the Langda adze-makers are located in the river valley about 800 meters below the village in altitude. Steep paths wind down from the village to the river.

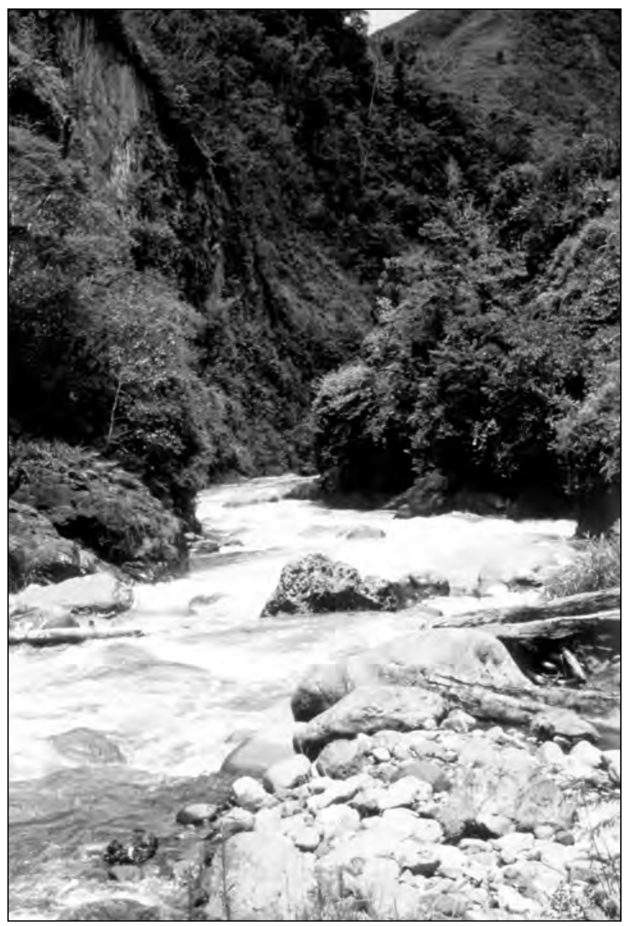

Figure 87. Lava boulders in the river at Langda. These boulders serve as the cores from which large flake blanks are struck for making the adzes.

Figure 88. Quarrying a large flake from a boulder core, using a large stone hammer held in both hands. In this quarrying technique, the hammer is swung between the legs to initiate fracture. Other quarrying techniques include holding a large hammer in one hand, throwing (sometime from an appreciable height by standing on a massive boulder) and fracture by fire. Photo courtesy of the Ligabue Research Center, Venice.

Figure 89. A group of knappers roughing-out adzes from large lava flake blanks by hard-hammer percussion. They employ extensive platform preparation, and many of the flakes they detach would be classified as "soft hammer" flakes by many archaeologists. Note the large handaxe-like perform in the foreground as well as the heavily reduced adzes on the ground, ready for grinding and subsequent hafting. Photo courtesy of the Ligabue Research Center, Venice.

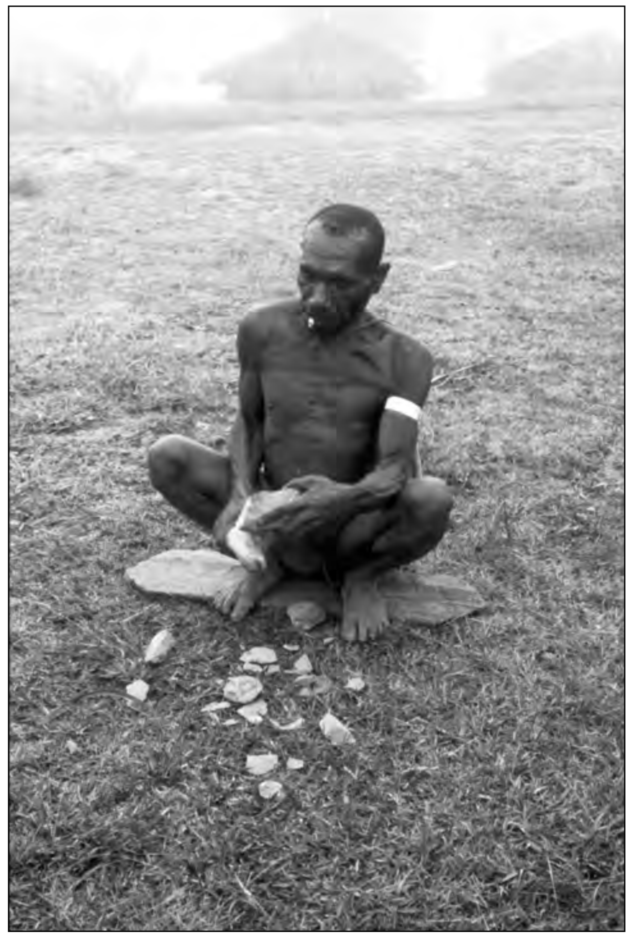

Figure 90. A Langda knapper making an adze by hard-hammer percussion. Note his posture and the wooden platform he is squatting on, and the array of debitage.

Figure 91. Another Langda knapper making an adze.

Figure 92. A view over the shoulder of the Langda knapper. Note the spatial pattern of flakes and fragments between his legs. A similar spatial pattern of debitage is seen at the Acheulean site of Boxgrove in England.

Figure 93. Two Langda knappers grinding the flaked adzes on quartzite grindstones, using water as a lubricant.

Figure 94. A Langda knapper hafting a ground adze to a t-shaped handle using vine as a lashing material.

Figure 95. Two Langda villagers chopping down a tree with adzes.

Figure 96. A range of discarded adzes found in Langda village. They include broken specimens and heavily resharpened and reduced specimens.

Figure 97. A montage of material culture associated with Langda adze-making. Included are hammerstones, flake blanks, flaked and ground adzes, wooden handles, and vine.

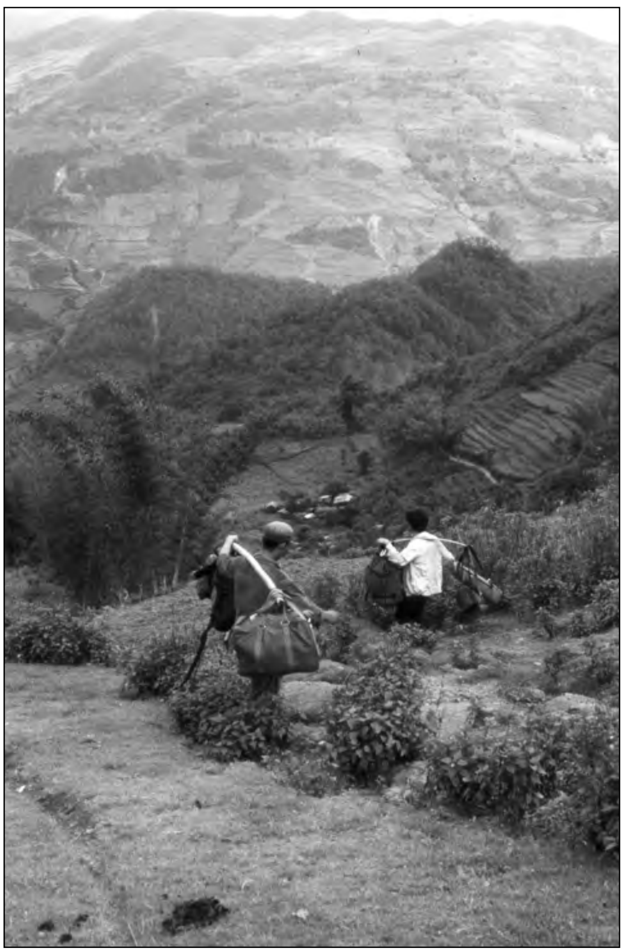

Figure 98. Looking down on the Kucong village in the mountains of Yunnan Provence, Southern China. Here a rich bamboo technology is still employed.

Figure 99. Portrait of a Kucong elder.

Figure 100. A Kucong man chopping down a large bamboo stalk with a metal cleaver-knife. This stalk can serve as a raw material for baskets, containers, pipes, etc. The authors documented over 50 different uses of bamboo in this village.

Figure 101. Splitting bamboo with the metal cleaver-knife.

Figure 102. Once a bamboo stalk has been cut and an initial split made with a tool, the bamboo stalk can be split further by hand. By pulling vigorously in opposite directions, very long strips of bamboo can be created.

Figure 103. Making a basket from split bamboo strips.

Figure 104. Some simple containers made out of bamboo sections.

Figure 105. Experimentally chopping bamboo with a flint bifacial chopper. Palaeolithic hominids exploiting bamboo for a range of purposes would still need a minimal stone technology (Mode 1) in order to obtain segments of the bamboo stalk suitable for tool use or manufacture .

Figure 106. Experimentally splitting bamboo with a flake wedge and hammerstone. By this method, strips of split bamboo can produce sharp cutting edges.

Figure 107. The experimental flakes used to split bamboo and wood become modified from hammerstone impact and contact with the bamboo, exhibiting light retouch on opposite sides or ends. These tools are reminiscent of “outils écaillés” from the Early Stone Age (the lighter retouched examples as opposed to the heavily reduced bipolar cores). Ventral side of flakes shown.

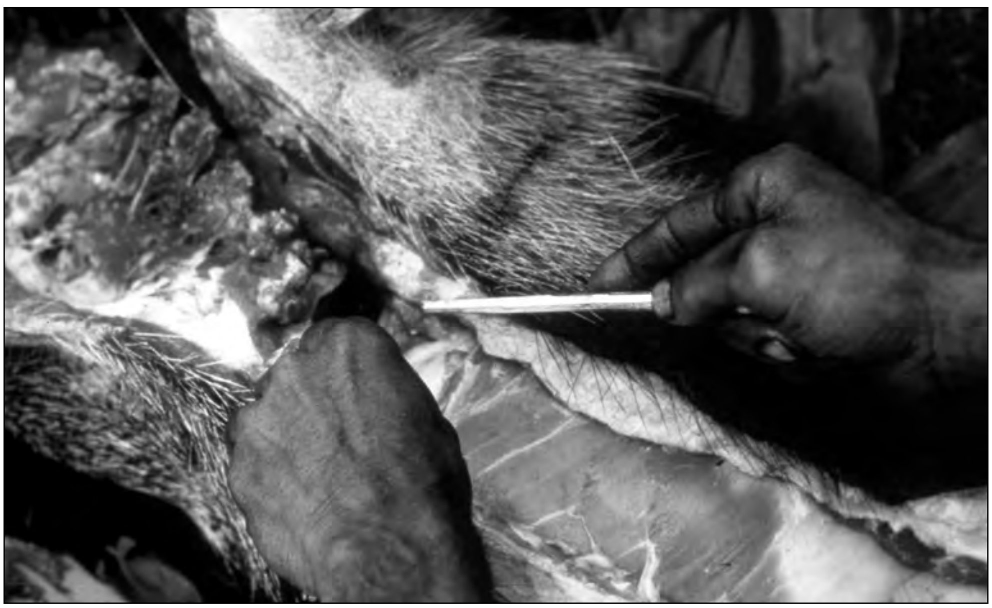

Figure 108. Pig butchery with a bamboo knives in Langda village, Irian Jaya, New Guinea. Split pieces of bamboo can make razor-sharp cutting tools.

Figure 109. Resharpening a bamboo knife in Langda village by simply peeling off a thin strip with the thumbnail.

Figure 110. Researching hand and forearm muscle activity at the Mayo Clinic in Rochester, Minnesota. A surgeon inserts one of forty 3-inch needles into the forearm of N. Toth in order to insert a wire to measure electrical activity of a specific muscle by electromyography (EMG). Some of these needles were inserted all the way through the hand from the outer (non-palmar) side to measure hand muscle activity just under the palm (having wires exposed from the palmar side of the hand would have put them in contact with the core and hammerstone and ripped them out). This research was carried out in collaboration with bioanthropologist Mary Marzke of Arizona State University and hand surgeon Ron Linscheid of the Mayo Clinic.

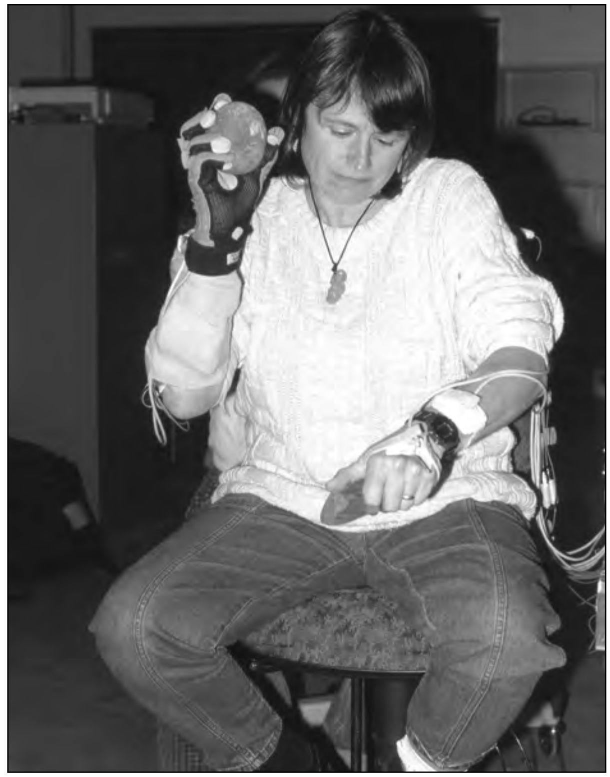

Figure 112. Measuring muscle activity in the hand and forearm of K. Schick during Oldowan flaking. Results of this study showed that the muscles involved in the"key grip" (pressing the thumb against the index finger) were critical to successful tool-making and tool-use, and that the flexor pollicis longus muscle (which bends the thumb at the first joint) was not as important for tool-making and tool-using as some anthropologists had maintained.

Figure 111. Measuring muscle activity in the hand and forearm of N. Toth during Oldowan flaking.

Figure 113. Measuring muscle activity in the hand and forearm of N. Toth during Acheulean handaxe manufacture. (The resultant handaxe is now framed and on display at the Mayo Clinic in Rochester, Minnesota).

Figure 114. Performing CT-scans of N. Toth's hands at one-millimeter sections. Toth, who by this time had been flaking stone (especially Oldowan and Acheulean technologies) for well over two decades, showed unusual and hypertrophied development of the muscles between the thumb and index finger in both hands, but especially in the left hand which holds the core in a tight, vice-like grip. The radiologist and technicians wondered what this subject did for a living.

Figure 115. Nicholas Toth and kinesiologist Jesus Dapena investigating the biomechanics of Oldowan knapping with a basalt hammer and core.

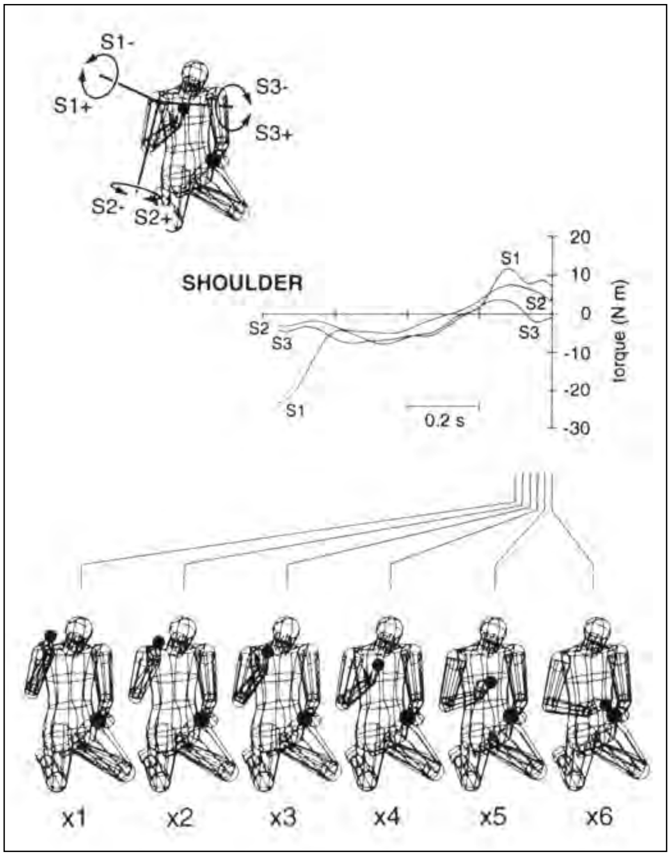

Figure 116. Kinesiological results of the Oldowan study. In Oldowan tool-making, the hammerstone was accelerated to a velocity of about 20 miles per hour just before impact, travelling a distance of just under a half meter (about a foot-and-a-half). Based on the weight of the hammerstone (625 gm), this implied a kinetic energy of 25 Joules, the equivalent of a baseball being thrown at 42 miles per hour. Although overall upper limb strength was not critical in this activity, speed was important to generate the energy required to knap basalt efficiently.

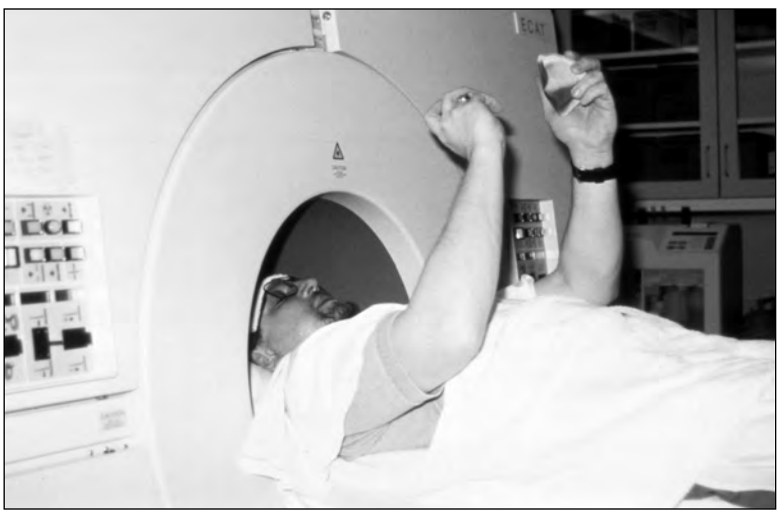

Figure 117. Positron emission tomography (PET) study of Oldowan artifact manufacture. In this early pilot study, the subject was injected with a fast-decaying radioisotope and was scanned in "real time" as he knapped in the machine.

Figure 118. PET study of late Achulean handaxe manufacture. The subject was injected with a slower radioisotope, knapped for 45 minutes, and then scanned for 45 minutes. (This was also done for Oldowan flaking and the control state).

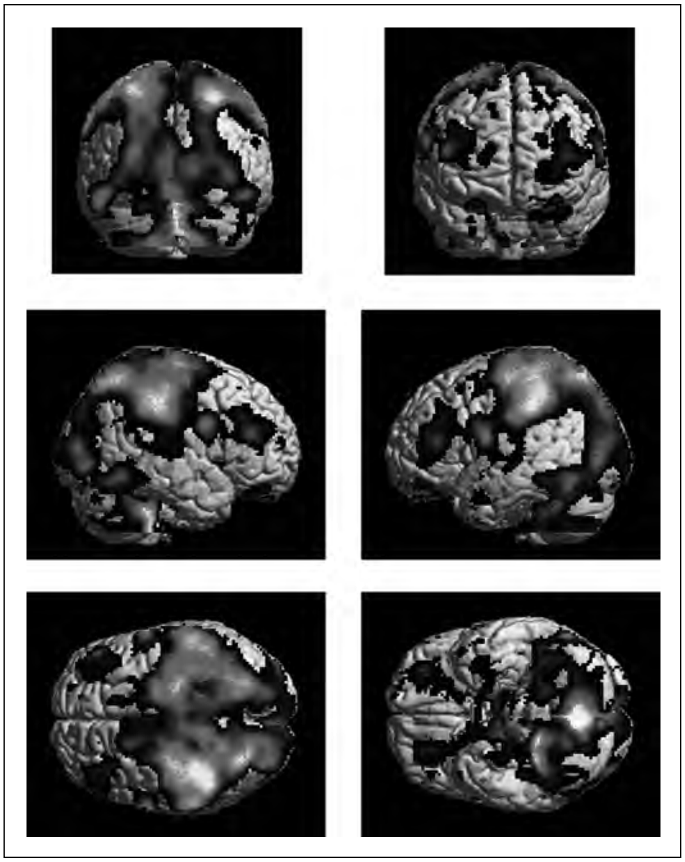

Figure 119. PET brain activity making an Acheulean handaxe. Lighter areas show more blood flow to neural areas.

Figure 120. Creating simulated archaeological sites in order to study experimental site formation processes at Koobi Fora, East Turkana, Kenya. Lava artifacts are painted with yellow paint for easy identification, and a sample is coated with aluminum foil so that they can be found with a metal detector after burial.

Figure 121. Studying the spatial scatter of flakes and fragments from an experimental Oldowan knapping episode at Koobi Fora.

Figure 122. One experimental assemblage of stone artifacts and animal bones set out on a stream floodplain at Koobi Fora.

Figure 123. A floodplain experimental "mega-site" of 100 square meters and over 1,000 stone tools and animal bones (including much of the skeleton of a giraffe) was subsequently excavated after flooding and burial.

Figure 124. A seasonal flood of a stream at Koobi Fora. The floodplain (bottom left) is being inundated by water. Note the "standing waves" in the stream.

Figure 125. An experimental lake margin site about to be inundated by wave action at Lake Turkana. This site was later excavated when the lake level receded.

Figure 126. Searching for buried experimental artifacts in a stream channel context with the use of a metal detector at Koobi Fora.

Figure 127. Excavation of an experimental delta site on Lake Turkana.

Figure 128. Flume studies of stone artifact and bone transport by water in the Department of Engineering at the University of California, Berkeley. Sediment load and stream velocity can be controlled in this flume.

Figure 130. The results of water action in the experiment shown in Figure 129. "Upstream" (top) and successive "downstream" sorting of artifacts is based on their weight, size, and shape. Smaller, lighter artifacts are preferentially winnowed downstream, while larger, heavier artifacts tend to be transported smaller distances.

Figure 129. A simple teaching exercise in water action on stone artifacts conducted at the University of Capetown, South Africa. Students pour buckets of water on an experimental flaked assemblage of stone artifacts.

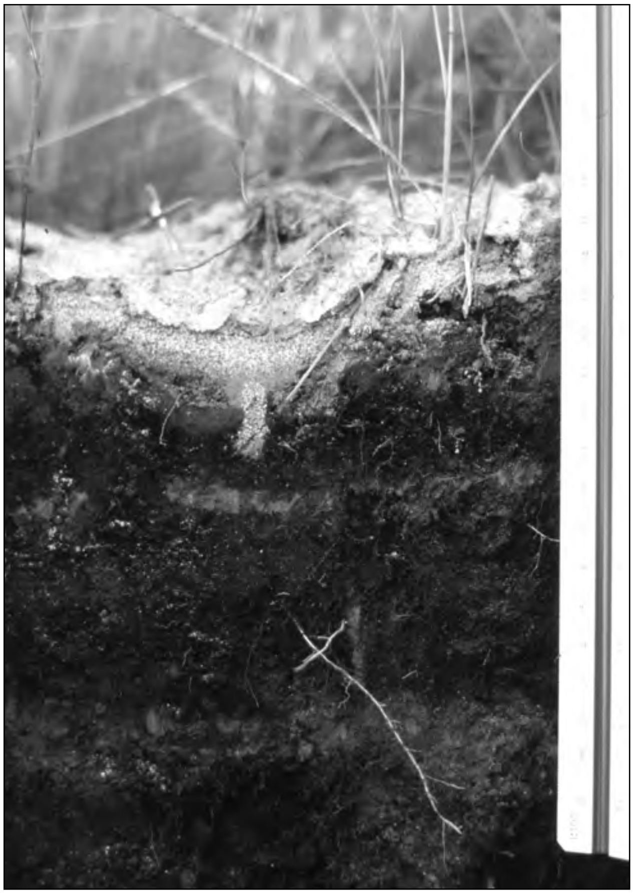

Figure 131. Study of aeolian volcanic ash deposition downwind of Mt. St. Helens three months after the eruption of 1980. An excavated section shows the lighter volcanic ash deposited on top of the darker soil horizon. At this distance from the eruption (about 40 miles) approximately four centimeters of ash were deposited, following the natural topography. Three major strata of ash can be seen, with a more consolidated layer in the middle. This field trip and study of the Mt. St. Helens area was organized by Glynn Isaac.

Figure 132. Excavation of cross-bedded fluviatile ash deposits of the Mt. St. Helens eruption near Yakima, Washington state. Approximately 1.5 meters of ash and sediment were deposited in this ash-choked river system soon after the eruption.

Figure 133. “Here but for the grace of God could be your home”. Sign put up along the Toutle River downstream of Mt. St. Helens where homes and vehicles were buried by massive floods of ash-choked water. Fifty-seven people lost their lives in this eruption.

Figure 134. An experiment in site transformation. A goat that was processed with stone tools had the skull and broken limb bones set out with the artifacts. Within an hour crows had flown off with many of the shaft fragments.

Figure 136. Experiments in nut-cracking. Mongongo nuts are cracked between a lava hammer and anvil. Repeated use produced characteristic smooth-pitted anvils.

Figure 135. By the next morning, almost all of the bones (except for the skull, upper right) had disappeared, probably carried off by hyaenas or dogs. There has been slight disturbance of some of the stone artifacts (probably having had organic residues licked off by carnivores), but they were all still in the general area.

Figure 137. Chopping a sapling with a lava bifacial chopper. Such a sapling could serve as a digging stick, a spear, or a skewer for carrying chunks of meat.

Figure 138. Sharpening a wooden branch by scraping with a lava flake to make a spear or digging stick.

Figure 139. An experimental wooden spear made with stone tools. Manufacture of such an artifact takes about one hour.

Figure 140. A spear or digging stick that required little or no modification. An oryx horn was slid onto an unmodified tree branch.

Figure 141. Experiments in digging with wood, bone, and horn. Digging for water, underground plant foods, insects, or burrowing animals are tasks in which non-lithic materials are often better suited than stone tools.

Figure 142. Seasonal floods could have produced scavenging opportunities for early hominins. During the wildebeest migration at Masai Mara Park in southern Kenya, numerous animals drown crossing rivers and are swept downstream. Here a fairly fresh wildebeest, a casualty of the migration, floats in the Mara River.

Figure 143. Two fairly fresh wildebeest carcasses ended up in an eddy of the Mara River, along with many defleshed bones on the river bank. A Marabou Stork checks out one of the carcasses.

Figure 144. Through either hunting or confrontational scavenging, hominins with a very simple flaked stone technology could have rapidly detached the meaty limbs of a larger mammal (in this case an oryx) using simple stone flakes and removed these limbs to a safe place for consumption.

Figure 145. Slitting the hide of a wildebeest that died of natural causes with the use of a simple basalt lava flake knife (Lake Natron, Tanzania). Flaked stone tools would have allowed early hominins to efficiently process carcasses acquired through hunting, confrontational scavenging, or "bonanzas" such as scavenging of animals that drowned trying to cross rivers during migrations.

Figure 146. Cutting through the joint between the humerus and radio-ulna on a large bovid with a lava flake. Such stone knives made disarticulation of animal carcasses into easily transported parcels possible. (Koobi Fora, Kenya).

Figure 147. A Dassenech tribesman experimentally cutting a rack of ribs from the vertebral column with a flake knife. (Koobi Fora, Kenya).

Figure 148. Cutting meat from the mid-shaft of a femur from a medium-sized bovid, creating multiple cut-marks on the midshaft. A strong pattern of cut-marks on midshaft fragments is one strong argument that early hominins had access to carcasses with significant flesh on them.

Figure 149. Cutting meat off the distal humerus of a large bovid, creating oblique cut-marks. A statistically significant pattern of oblique cut-marks (upper left to lower right, relative to the long axis of the limb shaft or shaft fragment) could be a strong indication of preferential right-handedness in early hominins. (Koobi Fora, Kenya).

Figure 150. A defleshed wildebeest carcass at Masai Mara Park in Kenya. The skull and long bones were still intact. Such an occurrence could have provided food resources (marrow and brains) for scavenging hominins with a simple stone hammer and anvil technology. Bone fracture from such processing would leave characteristic robust scarring or notching on shaft fragments, bone flakes, a high frequency of spiral fracture, and hammerstone striae. There was no remaining meat on the carcass, so that in a prehistoric context one would not expect cut-marks from stone knives.

Figure 151. Breaking a femur of a small bovid with a basalt lava hammer and anvil in order to access the edible marrow inside. (Koobi Fora, Kenya).

Figure 152. Fracture of the limb bone of a large bovid large bovid by hammer and anvil percussion for marrow processing. (Nairobi, Kenya).

Figure 153. Breaking a goat skull with a basalt lava chopper-core to gain access to the brains.

Figure 154. Slitting the thick (ca. 2 cm) hide of an elephant that died of natural causes with a small basalt lava flake. A simple flaked stone technology would have allowed early hominins to gain access to the meat of even the largest terrestrial mammals. Since scavengers such as hyaenas normally wait until megafaunal carcasses start putrifying before they feed on them, hominins could have had early access to natural deaths of elephants, rhinos, and hippos.

Figure 155. Kathy Schick cutting through the hide of an elephant that died of natural causes with a medium-sized flint flake.

Figure 156. The beginning of the experimental butchery with stone tools of an elephant that died of natural causes.

Figure 157. The elephant butchery in the previous figure, after approximately four hours of processing (hide removal and meat-cutting).

Figure 158. Cutting through massive quantities of meat in an experimental butchery of an elephant that died of natural causes. Hundreds of kilograms of meat could be processed from one side of this elephant. Such fresh megafaunal carcasses could have been an important, if sporadic, source of food for early hominins.

Figure 159. In a study of the meat-cutting efficiency of different stone tools, five-pound racks of pork ribs were used. Each rib was removed sequentially by cutting through the connective tissue (meat, fat, and cartilage). While removing individual ribs with stone tools was not necessarily an activity of early hominins, it did provide a control in this experimental program and realistically tested the meat-cutting abilities of different types of stone tools as well as different raw materials. The number of seconds required to remove each rib was recorded. Here the first rib is being removed using an experimental replica of a late Acheulean handaxe.

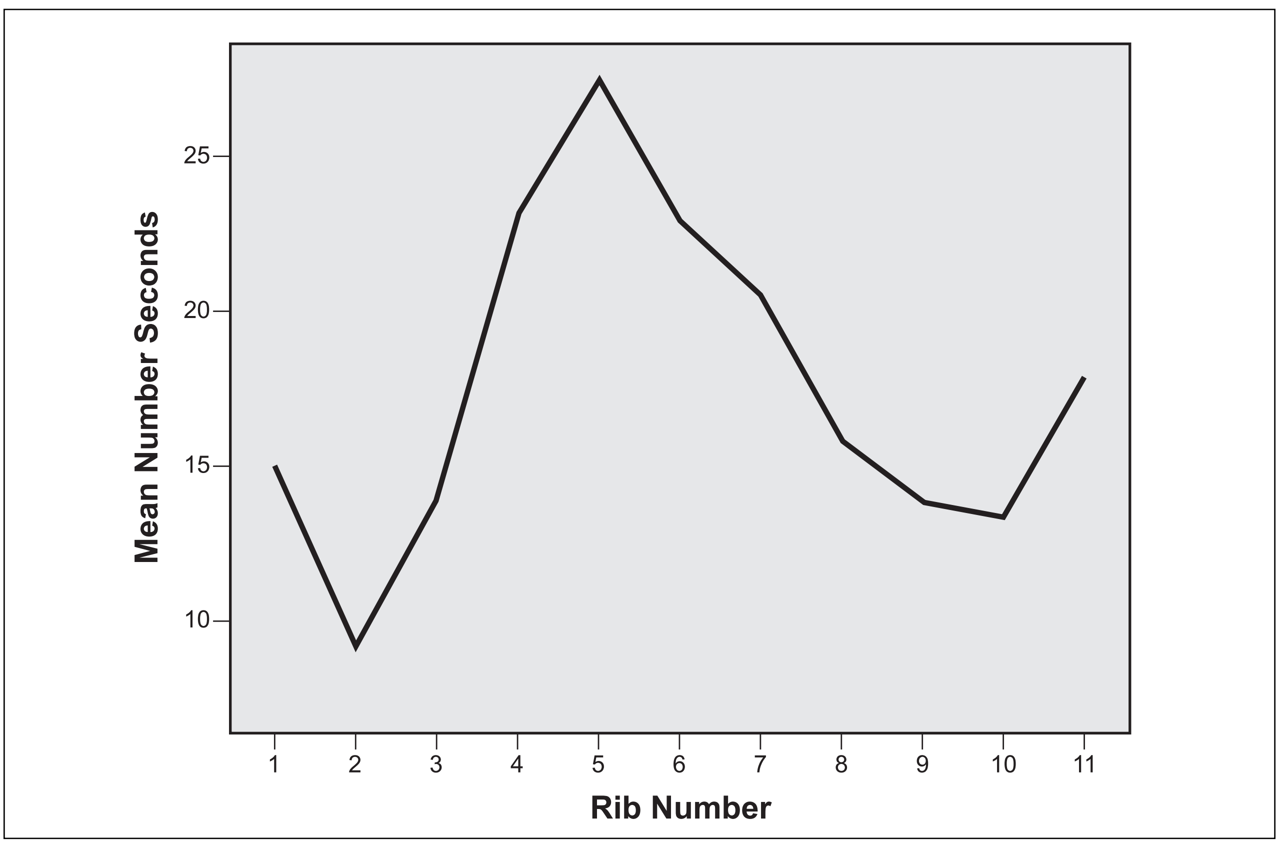

Figure 160. As an anatomical sequence of ribs was removed from a rack of ribs, some required more cutting time than others. This graph shows the average number of seconds per rib. Note that the fifth rib is especially difficult to remove, owing to its extreme curved morphology and its harder connective tissue where it meets the sternum. A mean number of seconds per rack of ribs (usually eleven ribs are cut off per rack) is calculated for each experimental trial.

Figure 161. The results of the pilot study into meat-cutting efficiency. The approximate mean number of seconds per rib is noted. 3 seconds per rib: a professional steel meat-cutting knife (factory sharp). 8 seconds per rib: a large, cleaver-like flint flake. 15 seconds per rib: (top) a thin flint flake and a late Acheulean handaxe; (bottom) a late Acheulean flint handaxe and an early thick Acheulean flint handaxe. 21 seconds per rib: a flint denticulate flake. 28 seconds per rib: (top) a thick flint flake; (bottom) a flint discoidal core, a thin quartz flake. 37 seconds per rib: two thin basalt lava flakes. 46 seconds per rib: a thin quartzite flake (medium-grained). 67 seconds per rib: two thin trachyte lava flakes.

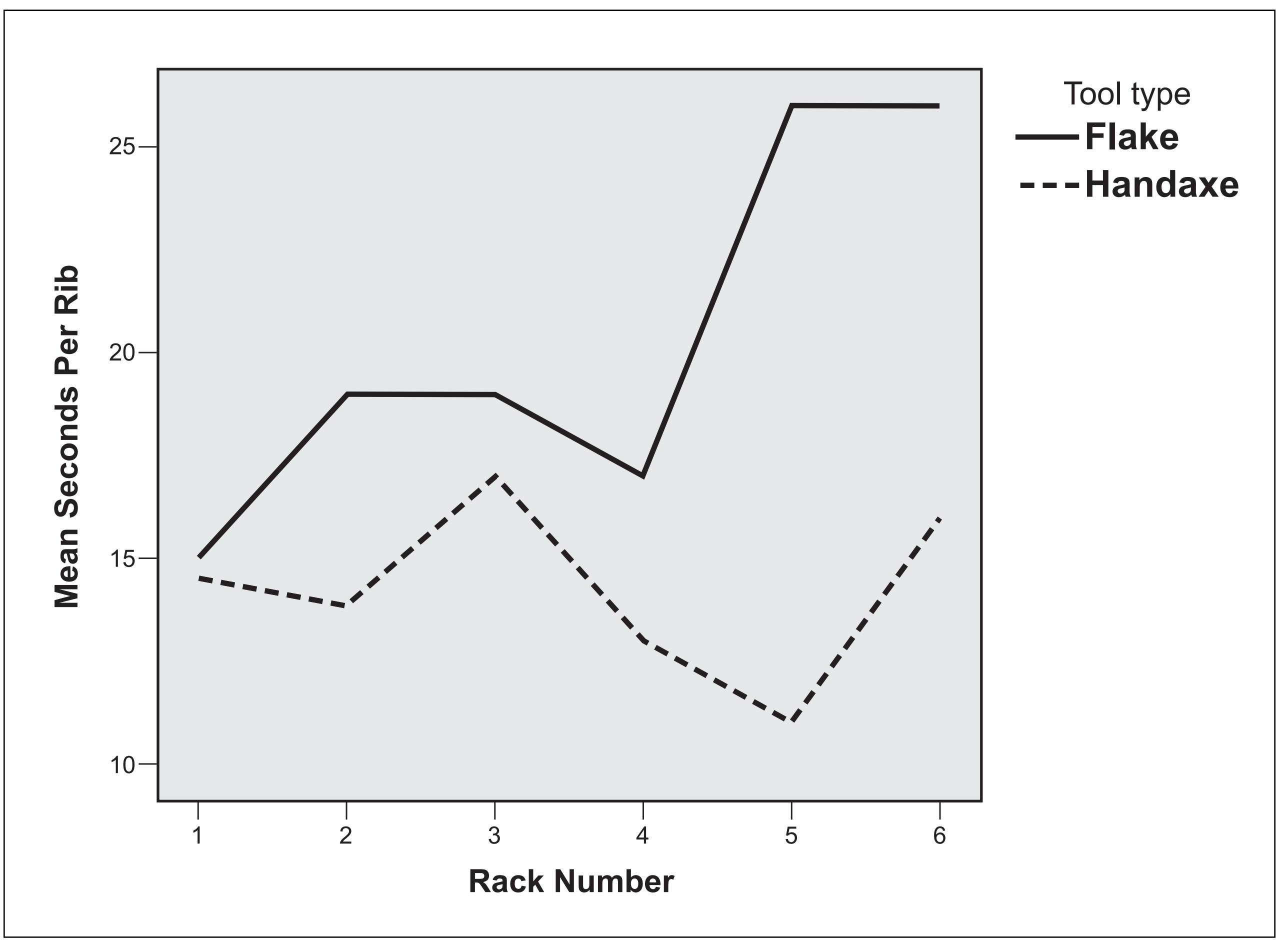

Figure 162. A comparison of the cutting ability of a flint handaxe versus a flint flake. Note the long duration of the cutting efficiency of the handaxe in comparison with the flake. The sharp flint flake dulled appreciably after cutting through four racks of ribs (or the disarticulation of approximately 44 ribs), while the efficiency of the handaxe persisted through the processing of six racks of ribs, with the use of only one of the two edges of the tool.

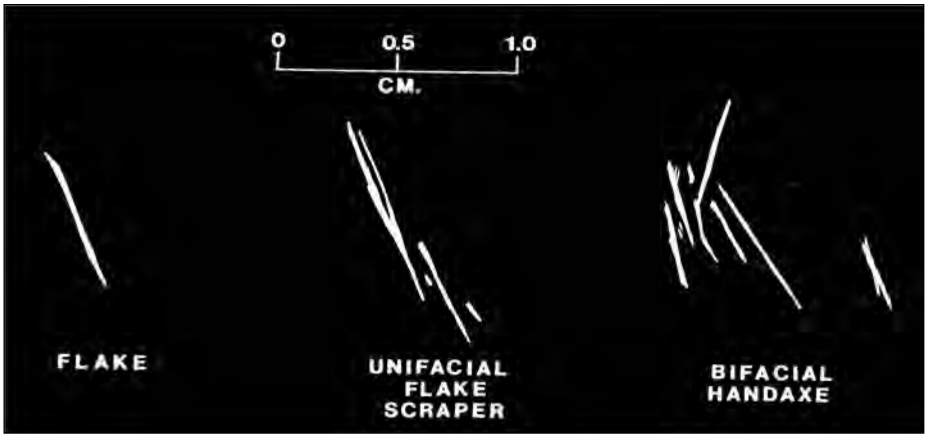

Figure 163. Cut-marks made with one unidirectional stroke from three different tool edges: an unmodified flake, a unifacial knife ("flake scraper"), and a bifacial handaxe. Note that the complexity of the cut-mark pattern increases with the sinuosity of the edge.

Figure 164. A molluscan shell knife, unifacially retouched with a shell hammer of the same size. In areas where stone was not locally available, but molluscan shells were (e.g. a lake margin environment), such shell cutting implements could have serviced as butchery tools.

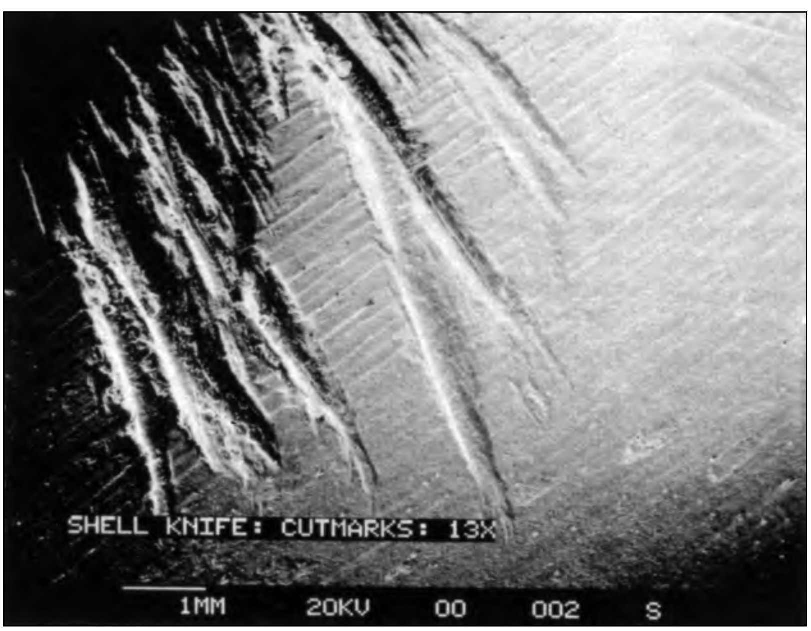

Figure 165. Cut-marks experimentally produced by the shell knife in the previous figure. These marks were produced on the metapodial of a goat during skinning. Such cut-marks are almost certainly indistinguishable in the archaeological record from those produced by a stone tool (unless small fragments of shell were imbedded within the striations).

Figure 166. Studying bone modification from deciduous canid dentition on a lamb femur. Kodiak was the authors' four-month-old Alaskan Malamute.

Figure 167. Studying bone modification from adult canid dentition (same dog as previous figure) on a lamb femur. Kodiak as a four-year adult, weighing 110 pounds.

Figure 168. Studying bone modification on a cow bone during lion feeding.

Figure 169. Studying bone modification on a cow bone during tiger feeding.

Figure 170. Studying bone modification on a cow bone during striped hyaena feeding.

Figure 171. Studying bone modification on a cow bone during Cape Hunting Dog feeding.

Figure 172. Bone modification study: an Andean Condor feeding on a lamb bone.

Figure 173. Study of wild striped hyaena bone modification on a range of collected animal bones (camel, dog, gazelle, goat/sheep, donkey, human, horse, bird, etc.) from a recent hyaena den the authors excavated in the eastern desert of Jordan.

Figure 174. Santa Cruz Island, one of the Channel Islands off the coast of Santa Barbara, California. In this unusual setting, feral pigs scavenge the remains of culled feral sheep.

Figure 175. Study of pig scavenging and bone modification on sheep bones on Santa Cruz Island. All the bones were collected within a radius of 50 meters from a central point. The assemblage is dominated by skulls, pelves, and limb bones, with vertebrae, ribs, and phalanges especially under-represented. Limb bones tended to be complete and unbroken.

Figure 176. A dead sheep carcass on Santa Cruz Island was monitored for three days to see the ravaging effect of a group of feral pigs.

Figure 177. After three days, all that was left in this area was the head and parts of the axial skeleton, with all of the limbs transported by the pigs to some off-site destinations.

Figure 178. The 15 million-year-old Miocene fossiliferous deposits in the Mud Hills near Barstow, California. This site, representing a dense collection of modified mammalian bones in a volcanic ash deposit, was used as a test case to see if any of the bone modification at the site mimicked hominin modification. Except for dense concentrations of diverse mammalian taxa, it did not.

Figure 181. An equid pelvis showing toothmarks from a medium-sized carnivore (probably the canid Tomarctus) at the Miocene Robbins quarry.

Figure 179. Excavations in progress at the Miocene Robbins quarry.

Figure 180. A close-up of the Miocene excavations at the Robbins quarry, showing an equid mandible and metapodials (Merychippus).

Figure 182. Nick Toth (foreground) and Tim White clean a fossiliferous layer of the outcrop over a distance of 150 meters to examine the variation in in situ bone density from a natural erosion transect.

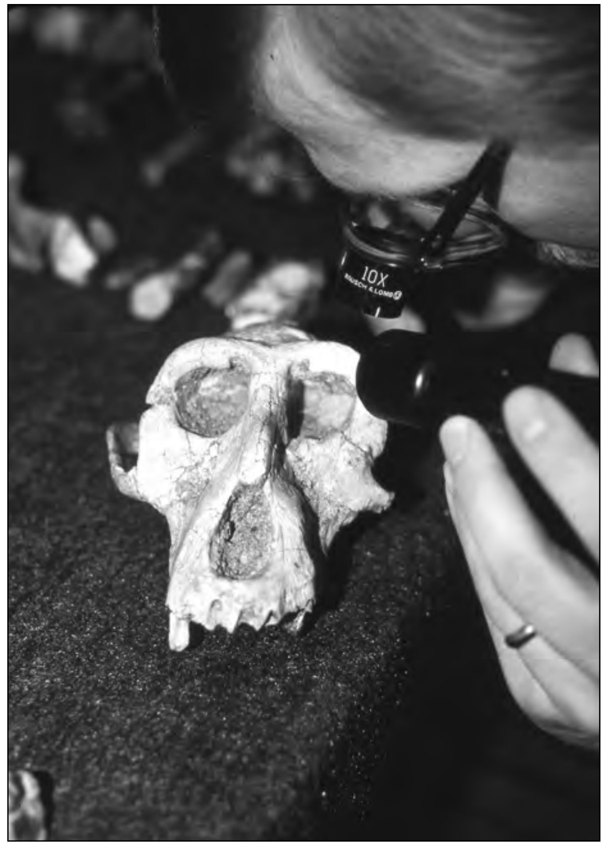

Figure 183. Examining the fossil cranium of a baboon from the Omo, Ethiopia for possible taphonomic traces of modification.

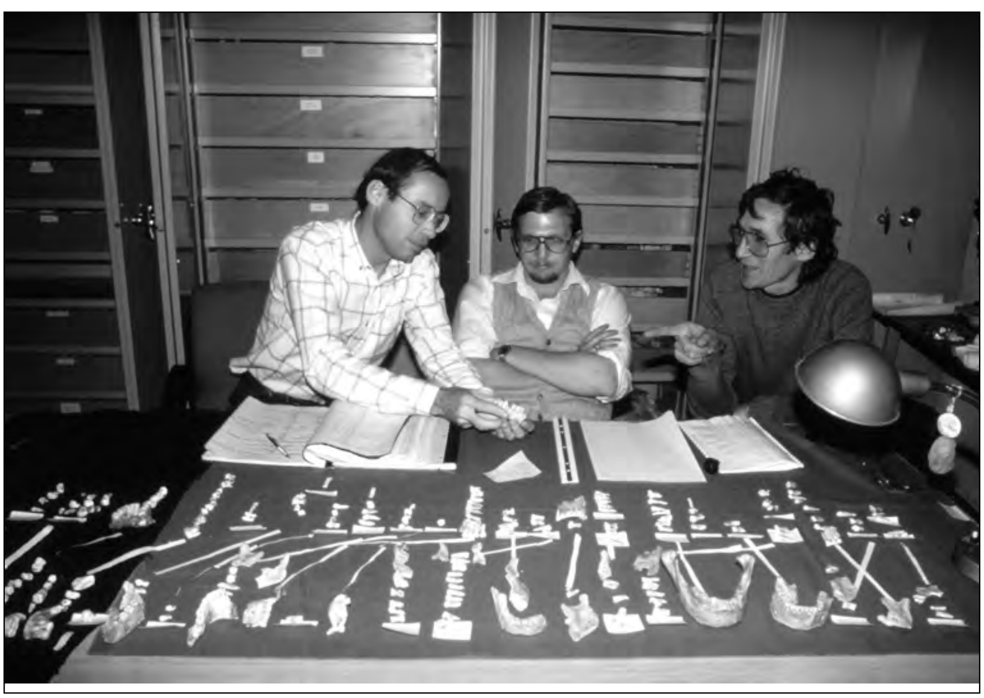

Figure 184. Tim White (left) and Nick Toth (center) study bone modification on the large sample of Neandertal fossils from Krapina, Croatia. Jakov Radovic on the right. Here the maxillary and mandibular fossils are shown.

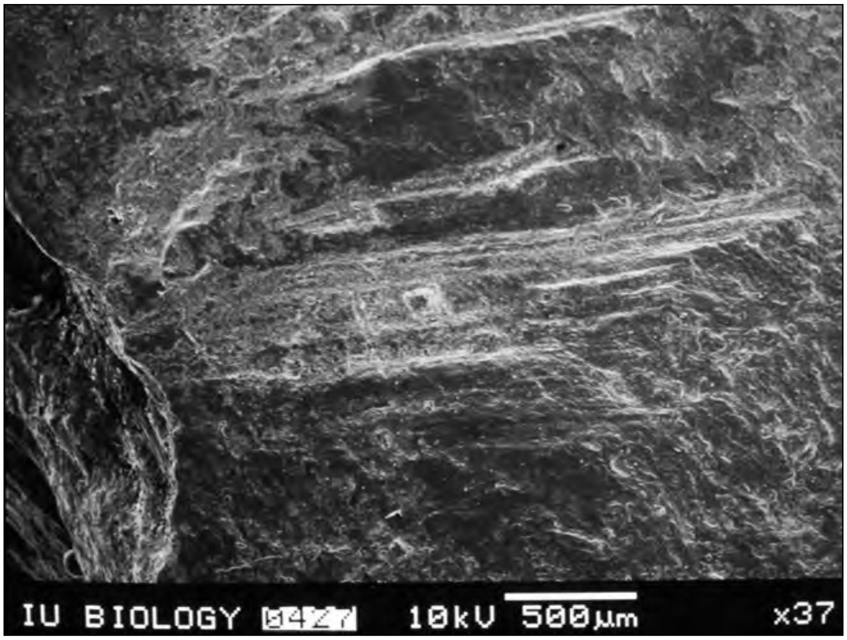

Figure 185. Cut-marks on hominin cranium Stw 53 at Sterkfontein cave, South Africa described by Travis Pickering, Tim White, and Nicholas Toth. Photomicrograph by N. Toth.

Figure 186. Recent stone technology: a medieval millstone made out of a solid piece of flint from the Perigord region of southwest France. Such millstones were used to crush cereal grains to make flour or to crush walnuts to make oil. This millstone must have come from a geological formation containing a massive seam of flint that was over 30 cm thick.

Figure 187. Recent stone technology. A wheat-threshing sledge from Burgos, Spain, made from an old wooden door with flint blades hammered into its working surface. Such sledges were normally dragged by a cow or a horse in order to slice up harvested cereal crops put on the ground and help separate the wheat from the chaff before winnowing. The blades can develop a “sickle gloss” with prolonged use. Such artifacts are known from Europe and the Middle East.

Figure 188. Recent stone technology. A close-up of the lock mechanism on a black- powder, muzzle-loading flintlock Kentucky long rifle replica built by the authors. The gunflint, secured in the jaws of the hammer, was knapped by using the methods of the 18th and 19th century flintknappers of Brandon, England. The gunflint is actually a hafted scraping tool (a rectangular, retouched geometric "microlith" made from a midsection of a blade) employed to scrape white-hot particles of iron from the gun's metal frisson, and thus ignite the gunpowder charge in the pan. When the gunflint's working edge becomes dulled over time it can be resharpened by light retouch. Archaeologist J. Desmond Clark once shot this rifle using its iron sights, and was able to hit a one-inch bulls-eye on a target at a distance of 50 yards. For an authoritative study of the Brandon flintknappers, see Skertchly, 1879. The rise of flintlock rifles, starting in the latter 17th century, created a new need for knapped flint, and a re-emergence of flaked stone technologies. Gunflints were produced on an industrial scale in many parts of Europe and elsewhere until the introduction of the percussion-cap gun in the 19th century.

Figure 189. Recent stone technology. A knapped basalt core used as building stone in a church in Pullman, Washington.

Figure 190. Recent "stone" technology. Glass microtome blanks that are snapped into sharp knives for cutting thin sections of tissue samples for transmission electron microscopy (TEM). Photo courtesy of SPI Supplies.