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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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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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CHAPTER 13

The Importance of Actualistic Studies in Early Stone Age Research: Some Personal Reflections

Nicholas Toth and Kathy Schick

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 Research 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 "over-retouch"
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.

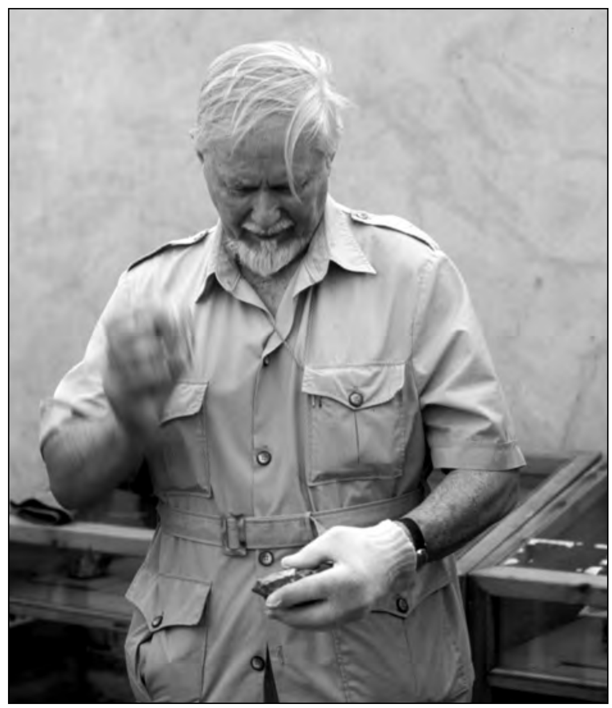

Figure 2. Actualistic pioneer: J. Desmond Clark. His experiments with stone tools included giving hunter-gatherers in Botswana actual prehistoric Acheulean quartzite handaxes and cleavers from Kalambo Falls, Zambia to use in butchering large mammals.

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.

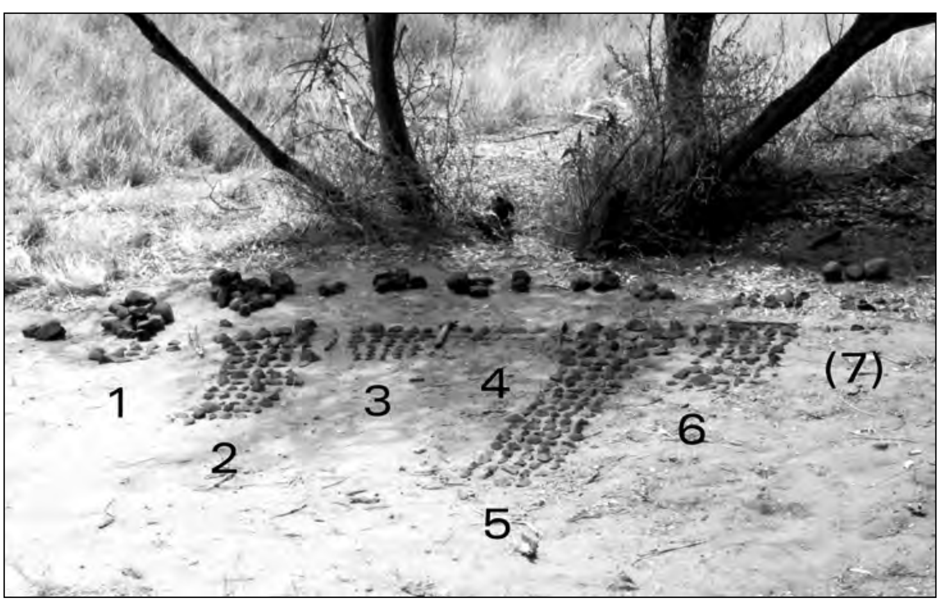

Figure 8. An "actualistic" bar graph of flake types (1 through 7) from an experimental primary flaking area, where all stages of reduction are represented. Percussors and cores made on cobbles and large flakes are at top. With more intensive reduction, there would be a shift to higher numbers of type 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.

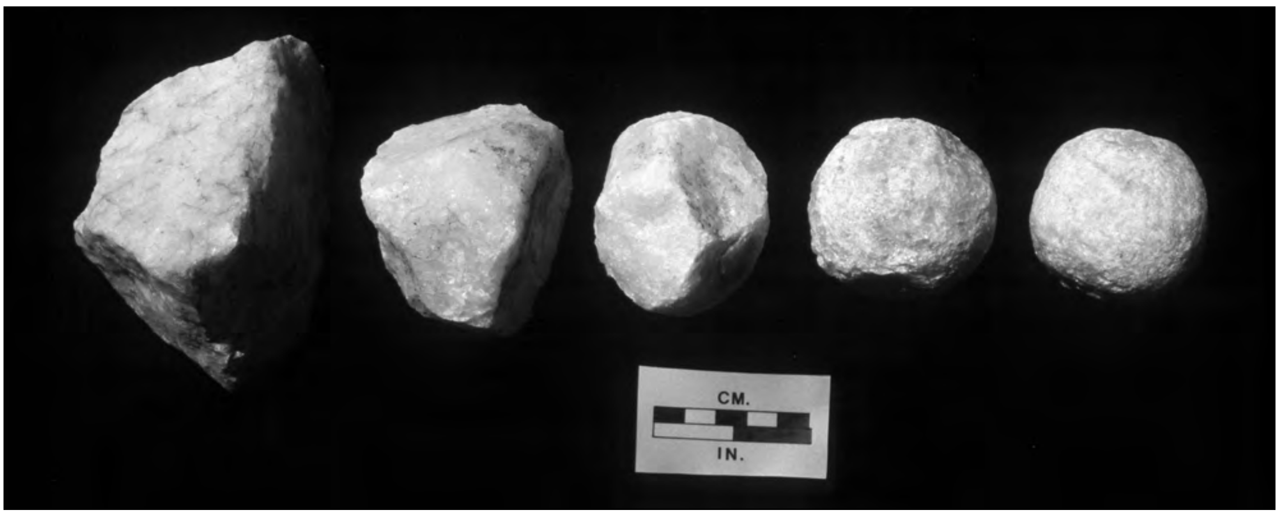

Figure 16. Experimental quartz spheroid production. From left, an unmodified block of quartz ; a polyhedral core ; a percussor used for one hour (subspheroid); a percussor used for two hours (spheroid); a percussor used for four hours (spheroid). These percussors become increasingly battered, rounded, 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.

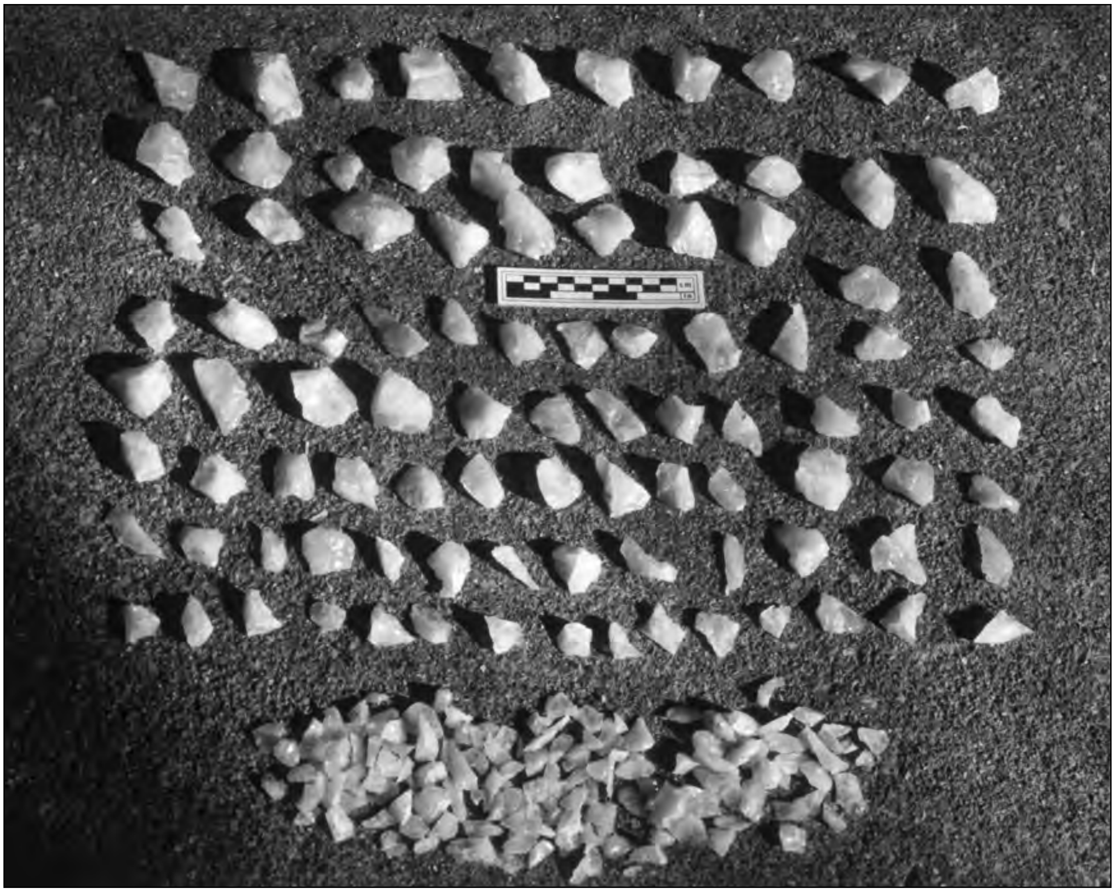

Figure 18. Extreme experimental quartz reduction. Such exhaustive lithic reduction produces large quantities of debitage but few recognizable cores, and could be one reason for the low core to debitage ratios regarding quartz at sites such as Bed II at Olduvai Gorge, Tanzania.

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.

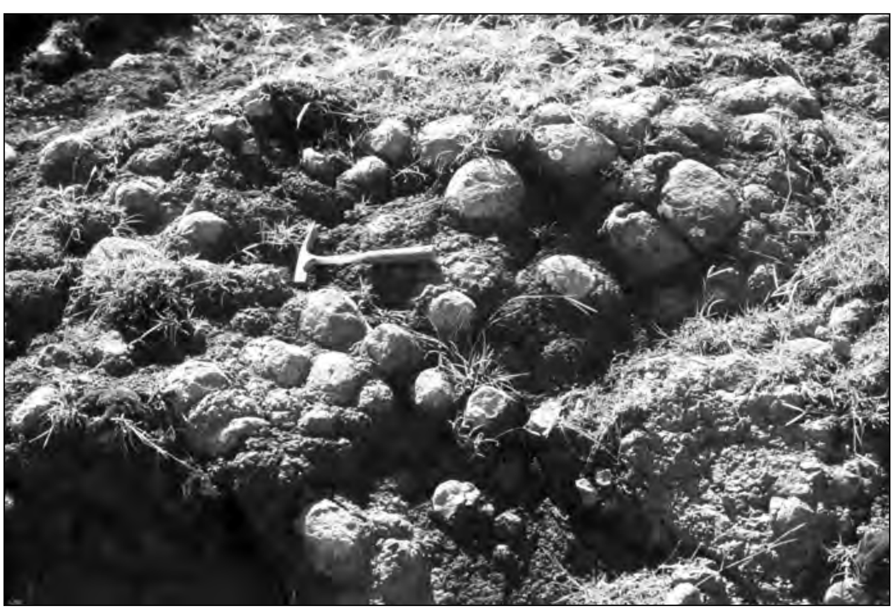

Figure 23. Spheroidal weathering in situ of basalt. These natural spherical clasts are about to erode out of the weathered basalt bedrock. Geological hammer for scale.

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.

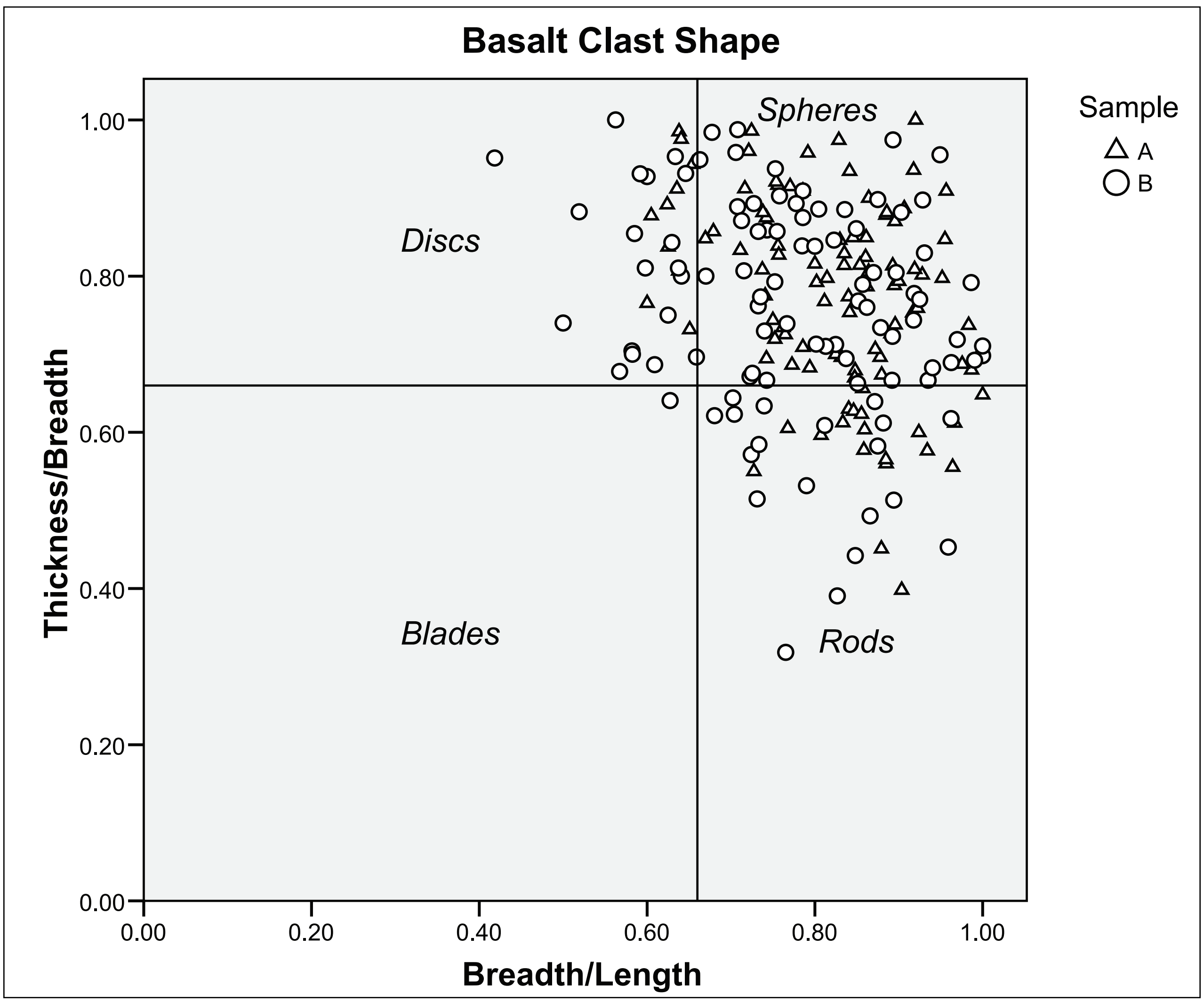

Figure 28. Scattergram of two natural clast samples (each sample is 100 nearest clasts greater than 60mm) plotted by breadth/length and thickness/breadth. Note the strong tendency for spherical clasts in each sample (a perfect sphere would be 1.00 for both ratios).

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.

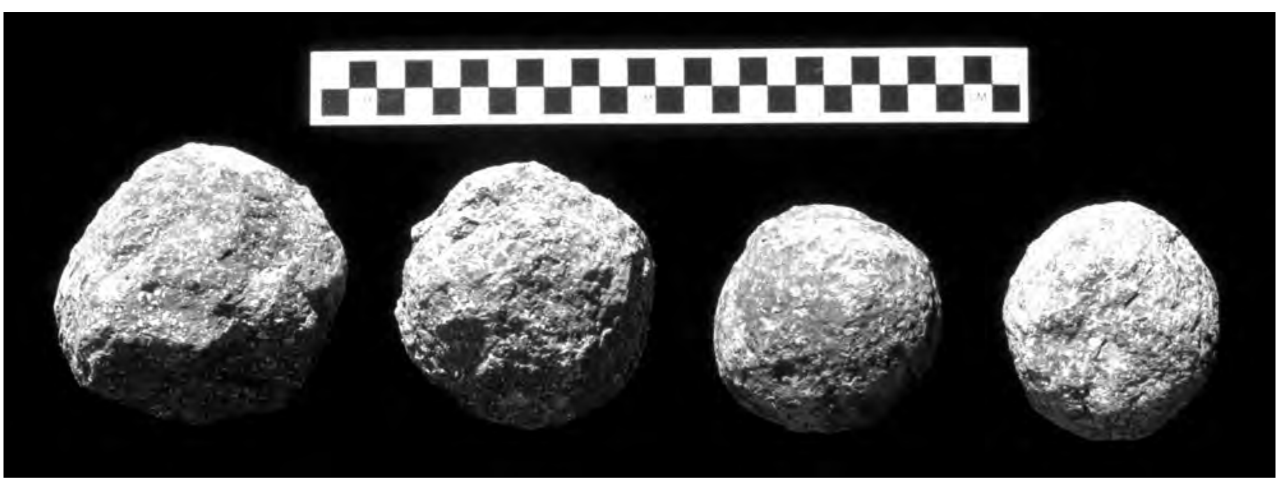

Figure 30. Formation of a battered basalt spheroid. From left: a natural spherical basalt clast; a percussor used to flake other stones for one hour; a percussor used for two hours; a percussor used for four hours. Note that sphericity changes little over time (a perfect sphere has breadth/length and 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.

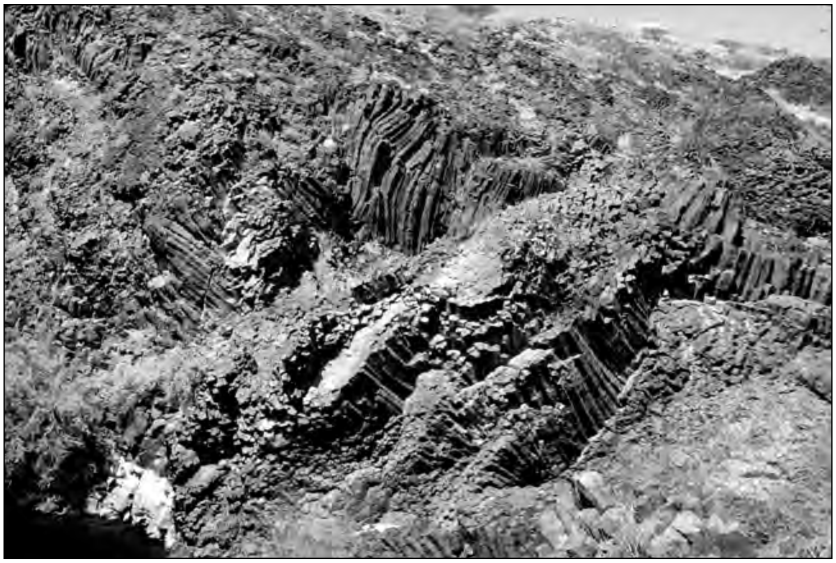

Figure 32. Columnar basalt formation in the eastern margin of Koobi Fora at Karsa, East Turkana, Kenya. These basalts tend to be fairly fresh and have not had the time to produce the classic spheroidal weathering seen at some localities. Lava spheroids are essentially absent at Koobi Fora sites.

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.

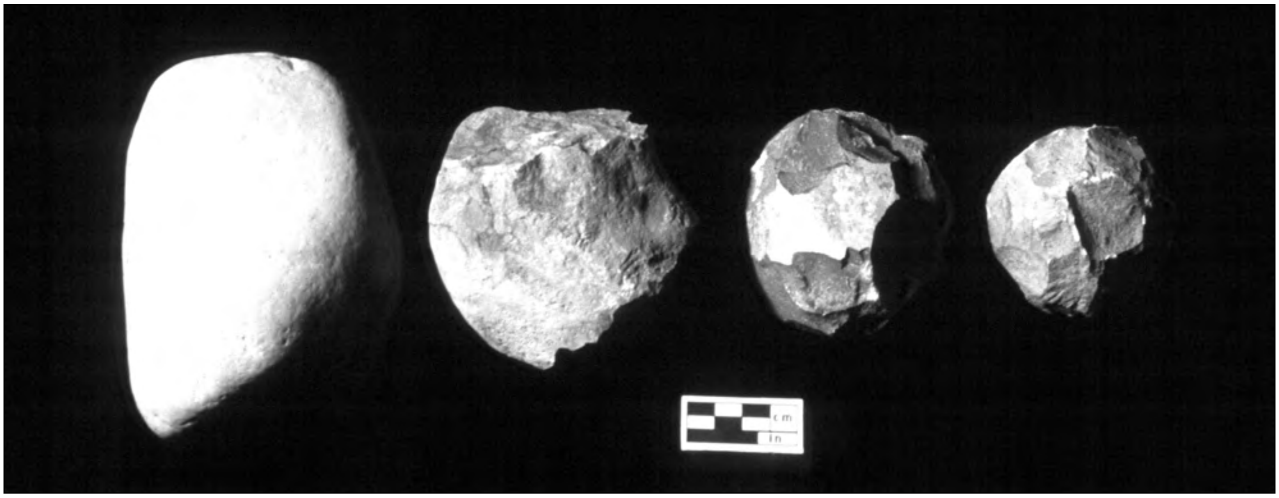

Figure 38. Experimental limestone facetted spheroid reduction. From left: an unmodified cobble; a two-edged chopper; a polyhedron; a facetted ball. Because of the unique properties of this limestone, there is a tendency for cores to become multifaceted and spherical in shape during flake production.

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).

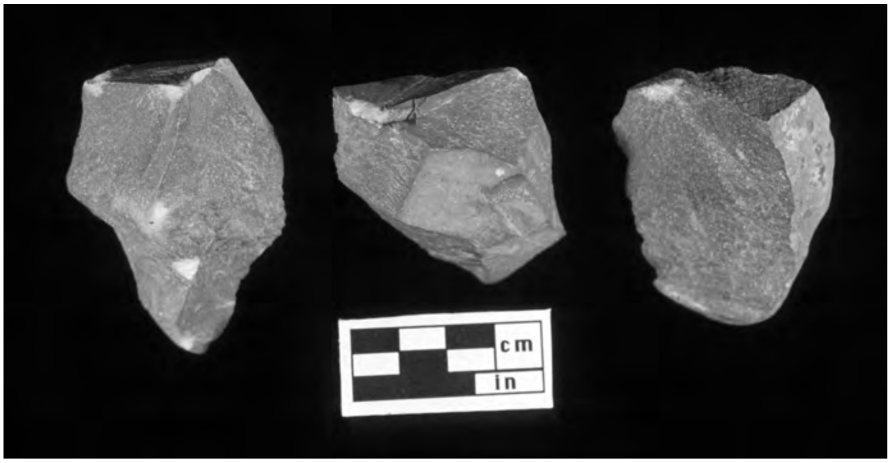

Figure 41. Limestone flakes: dorsal surfaces. Unlike most raw materials, the local limestones produce flakes with obtuse exterior platform angles (the angle between the striking platform and the dorsal surface), as it is possible to flake core edges of greater than 90 degrees. Flakes oriented with striking platforms at top.

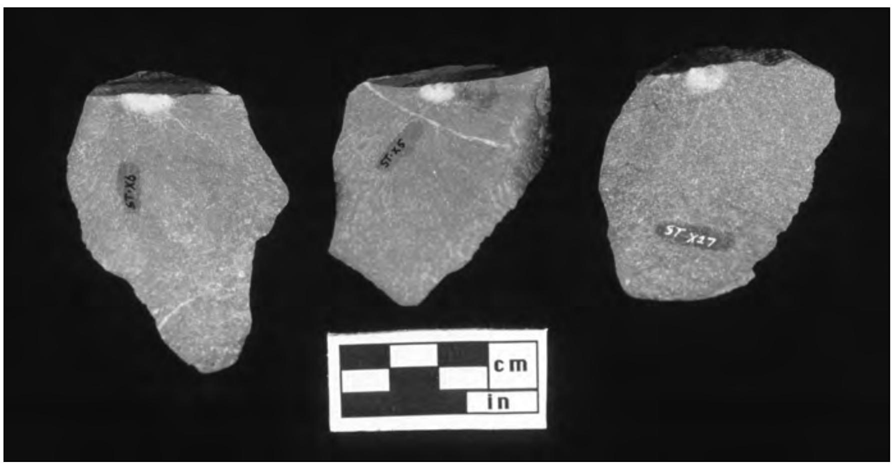

Figure 42. Limestone flakes: ventral surfaces. Again, unlike most other raw materials, the limestone produces flakes with acute interior platform angles (the angle between the striking platform and the ventral surface). Note the pronounced areas of crushing (usually 5 to 10 mm) at the point of percussion. Flakes oriented with striking platforms at top.

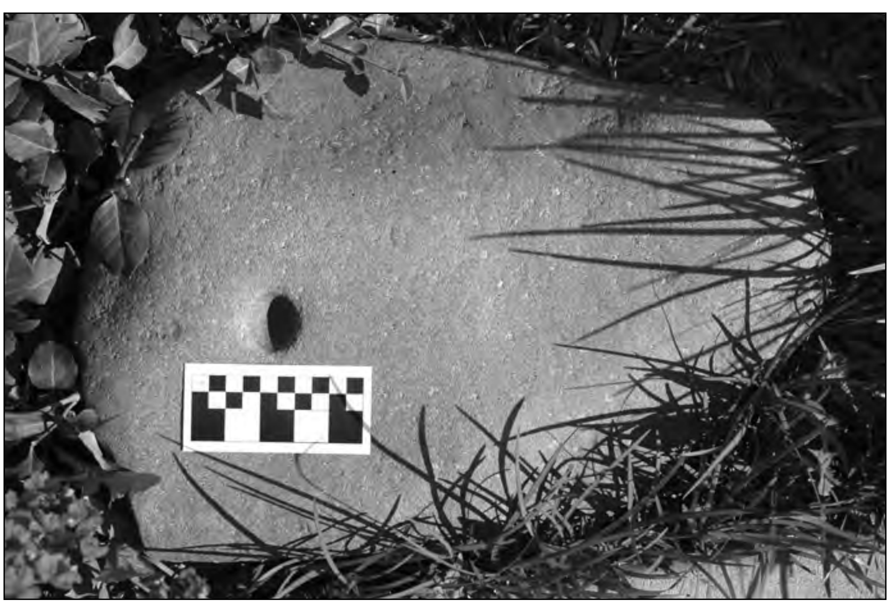

Figure 43. A large ethnographic mongongo nut-cracking stone from southern Zambia. The reverse surface of this specimen was a quern for grinding. Note the smooth pit from prolonged nut-cracking.

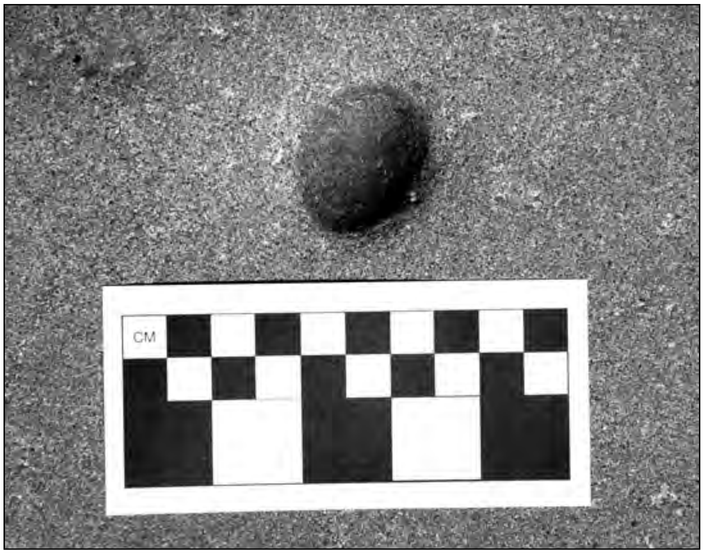

Figure 44. A close-up of the smooth pit (35 mm in maximum dimension) on the large ethnographic mongongo nut-cracking stone.

Figure 45. A smaller ethnographic mongongo nut-cracking stone from southern Zambia, showing another smooth pit (31 mm in maximum dimension).

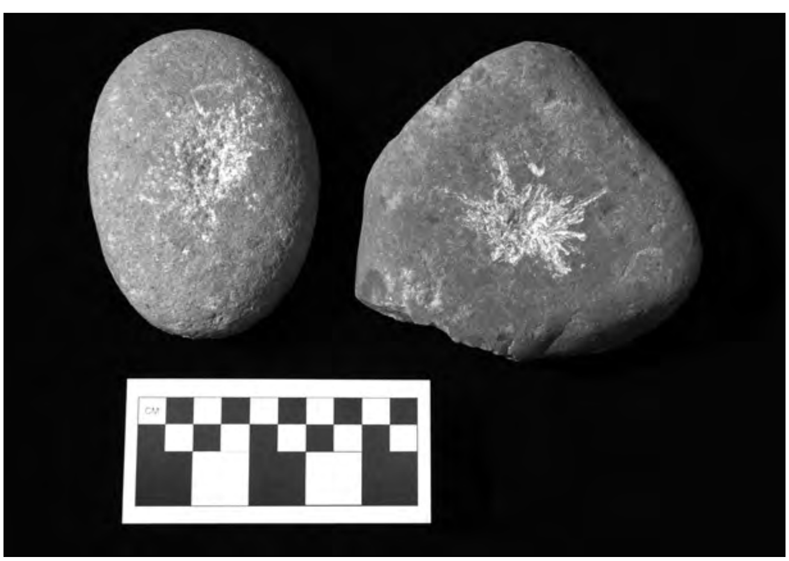

Figure 46. Two experimental bipolar anvils used in flaking cores. Note the rough pitted surface and the radial pattern of striae from contact with the base of bipolar cores.

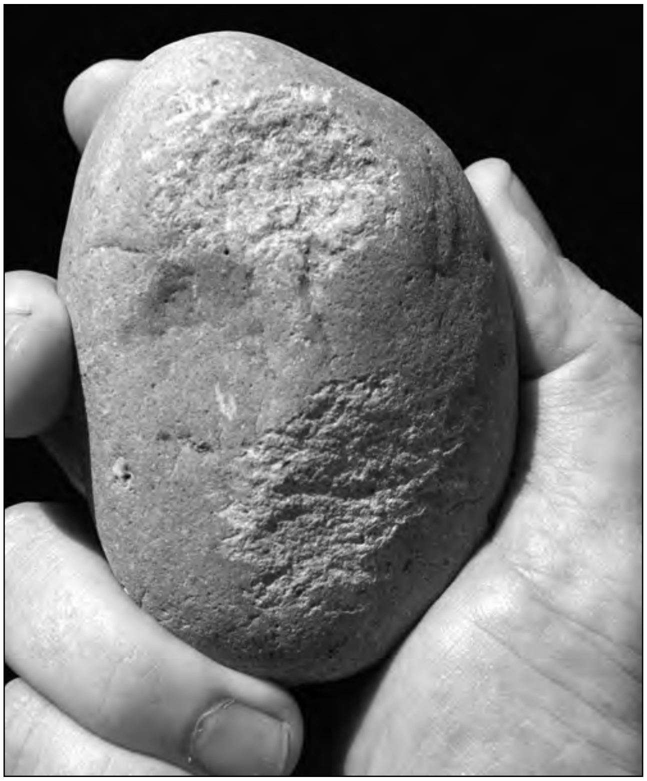

Figure 47. An elongated basalt bipolar hammer, showing two off-center rough pits from contact with bipolar cores. When humans use an elongated bipolar hammer, there is a tendency to produce an off-center pit about 1/3 the length from the end of the hammer. If the cobble is turned around, another pit 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.

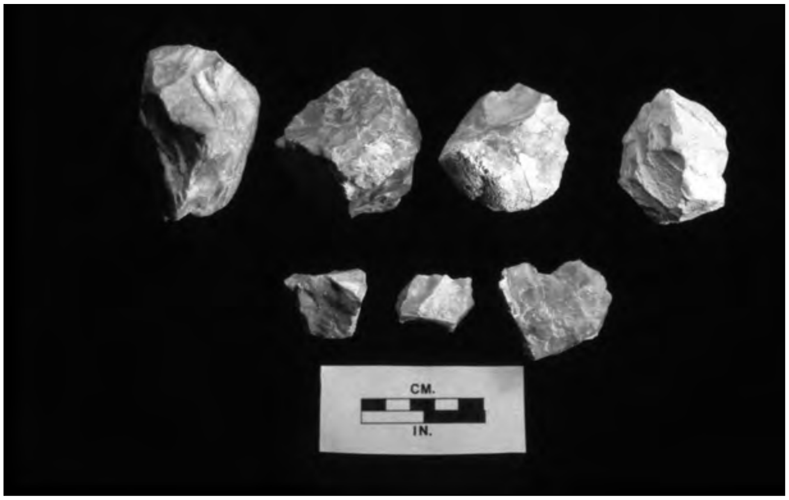

Figure 53. Chert cores from the site of Donggutuo. These cores tend to be heavily reduced and in the form of polyhedrons and discoids.

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.

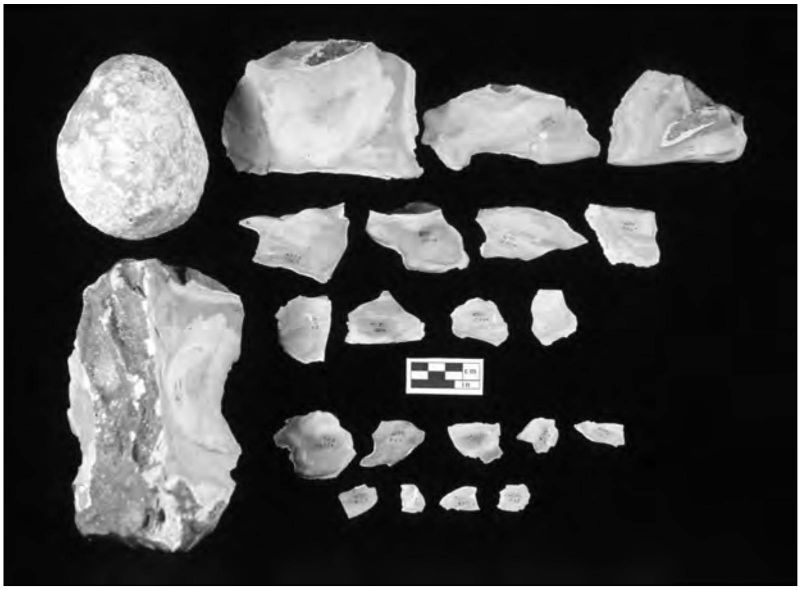

Figure 62. Flint artifacts produced by Kanzi after seven years of experience. Upper left: well-used hammerstone. Bottom left: core. The flakes tend to be much larger and the core is more heavily reduced than the previous figure. The flakes and fragments that were actually used for cutting activities 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.

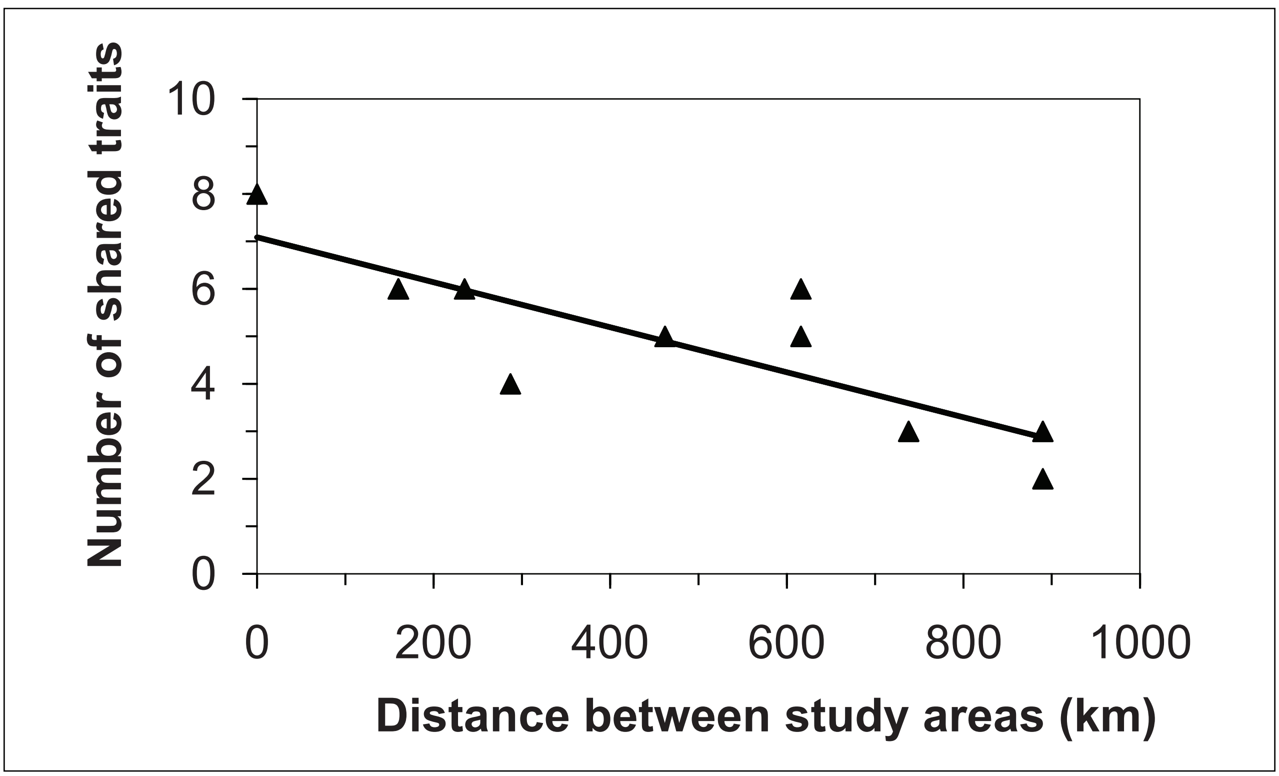

Figure 66. Do chimpanzee cultural traits cluster geographically? Here is a graph based on a study by the authors (Toth and Schick 2007, 2009; Whiten et al. 2009) showing the relationship of the number of shared chimpanzee cultural traits (habitual or customary, from the Whiten et al. 1999 paper) and 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.

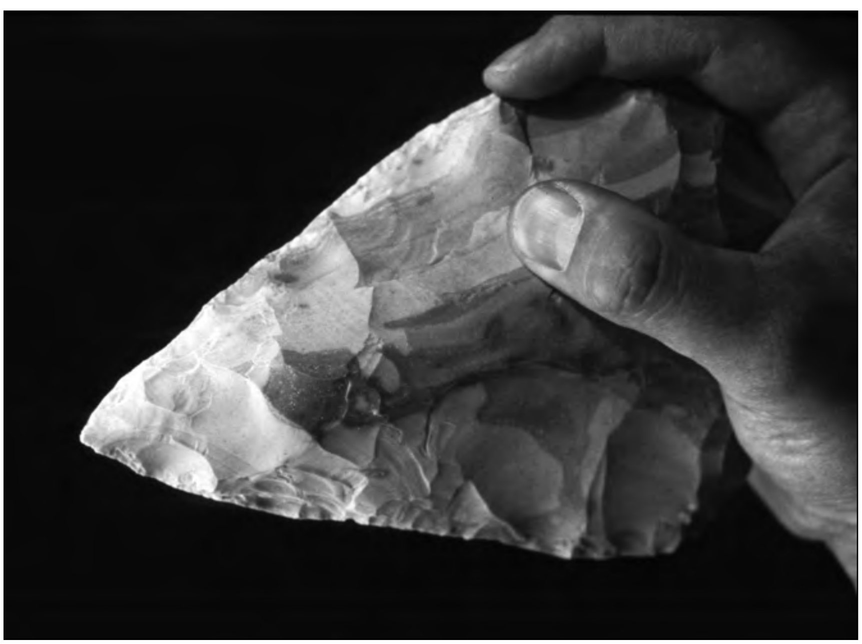

Figure 81. An experimental lanceolate flint handaxe made from the nodule in the previous figure. Soft hammer percussion.

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.

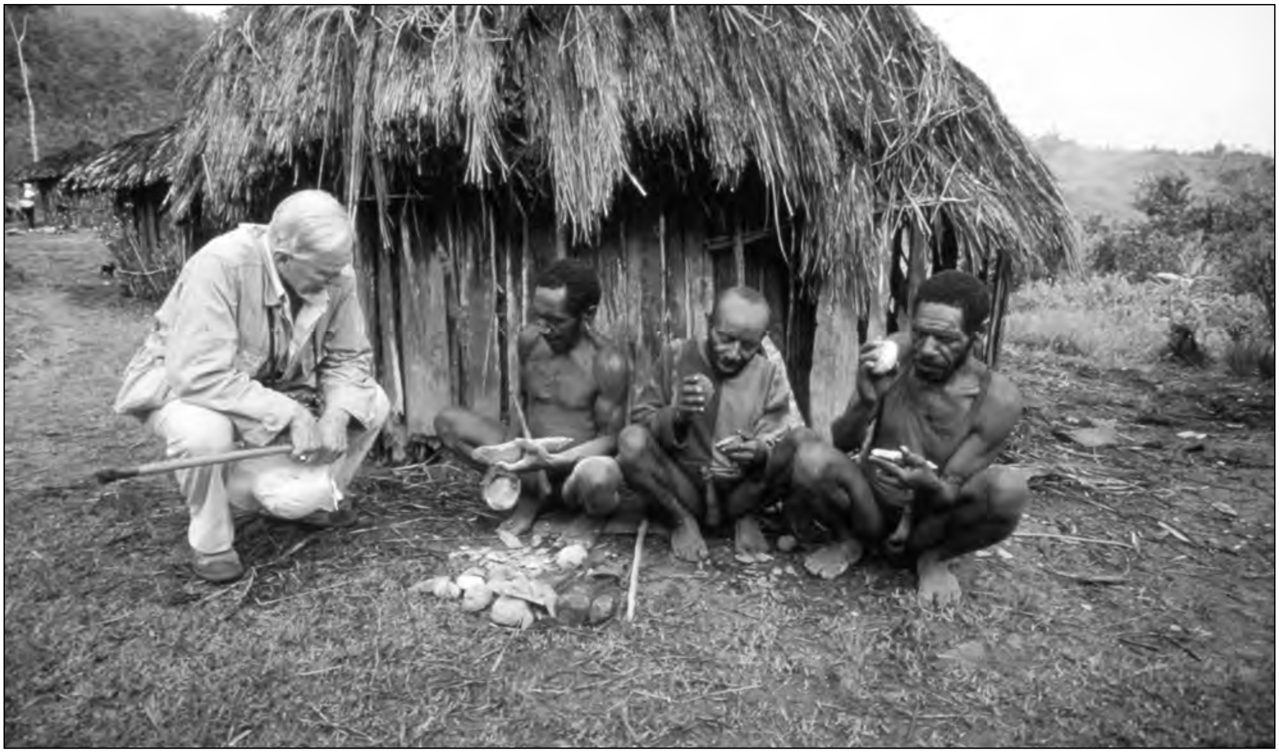

Figure 85. Prehistorian J. Desmond Clark with a group of adze-makers at Langda.

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.

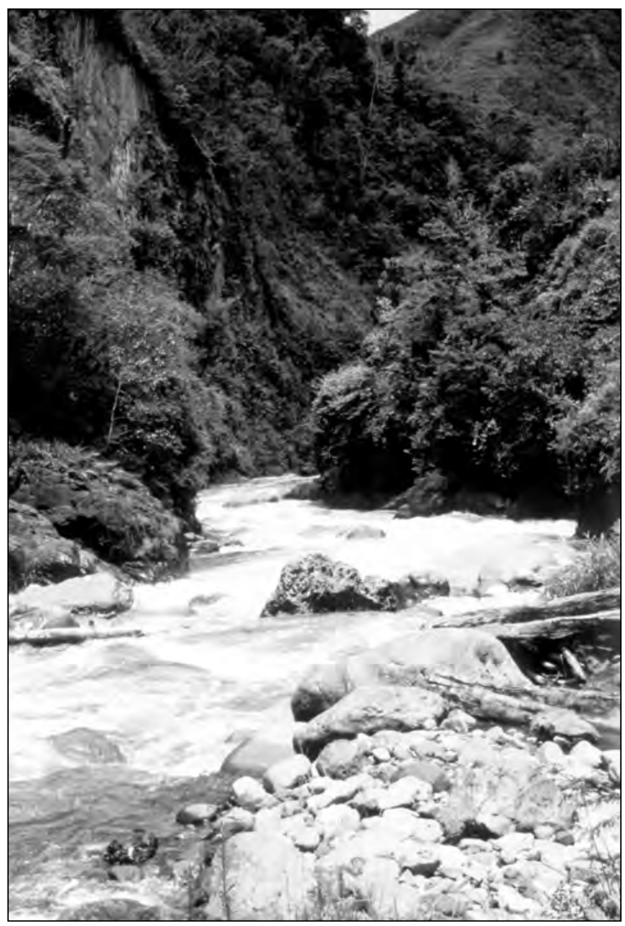

Figure 87. Lava boulders in the river at Langda. These boulders serve as the cores from which large flake blanks are struck for making the adzes.

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.

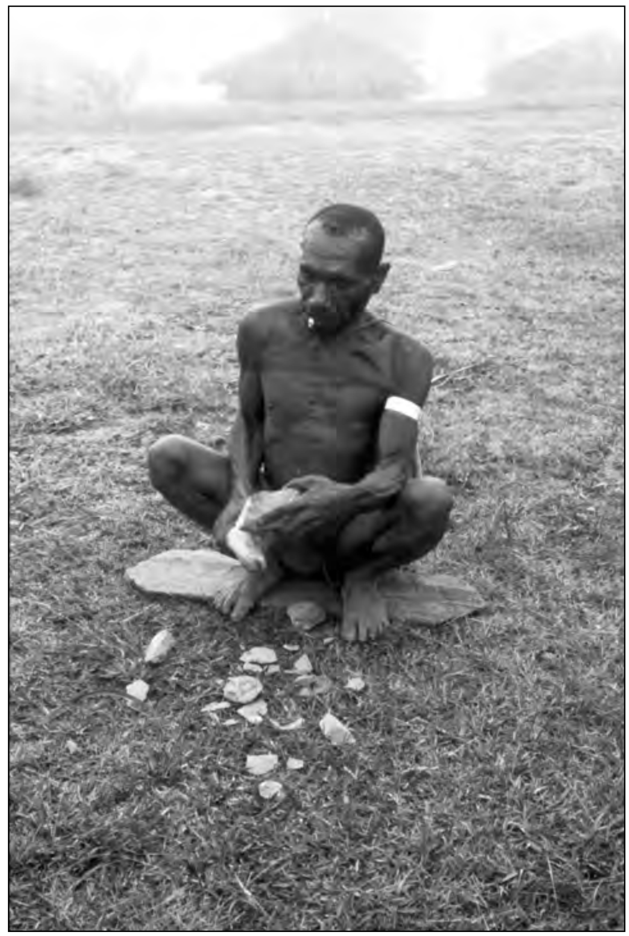

Figure 90. A Langda knapper making an adze by hard-hammer percussion. Note his posture and the wooden platform he is squatting on, and the array of debitage.

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.

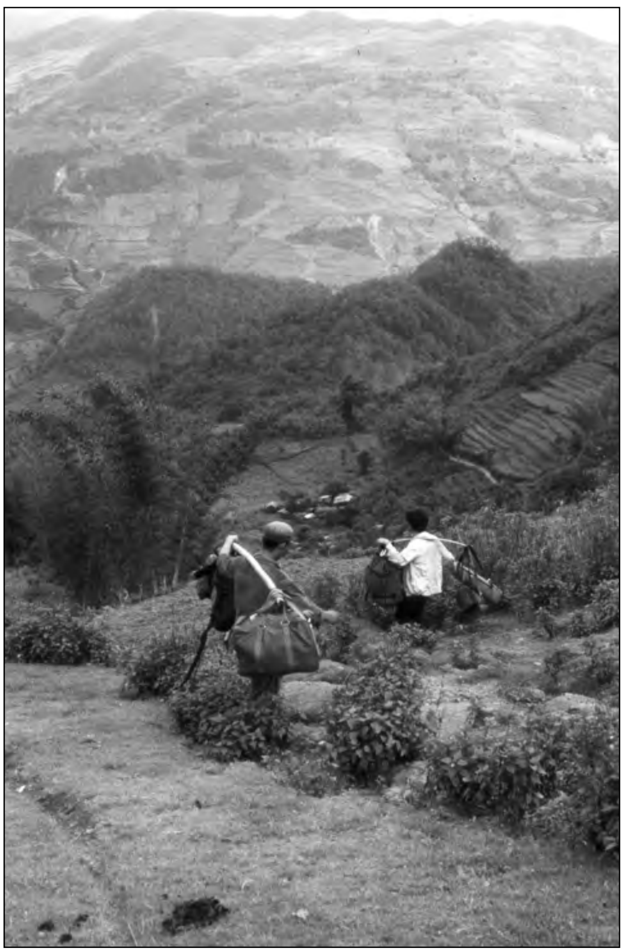

Figure 98. Looking down on the Kucong village in the mountains of Yunnan Provence, Southern China. Here a rich bamboo technology is still employed.

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.

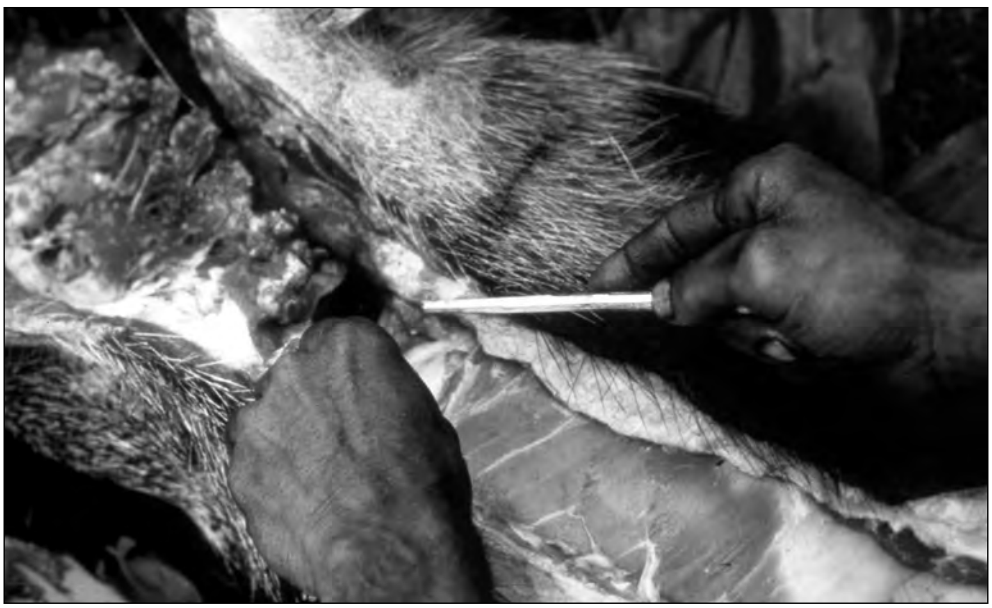

Figure 108. Pig butchery with a bamboo knives in Langda village, Irian Jaya, New Guinea. Split pieces of bamboo can make razor-sharp cutting tools.

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.

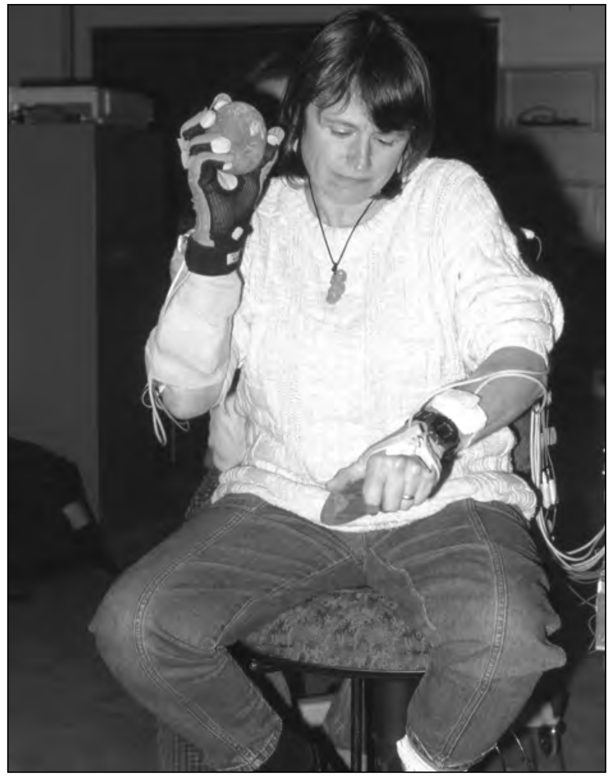

Figure 112. Measuring muscle activity in the hand and forearm of K. Schick during Oldowan flaking. Results of this study showed that the muscles involved in the"key grip" (pressing the thumb against the index finger) were critical to successful tool-making and tool-use, and that the flexor pollicis longus 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.

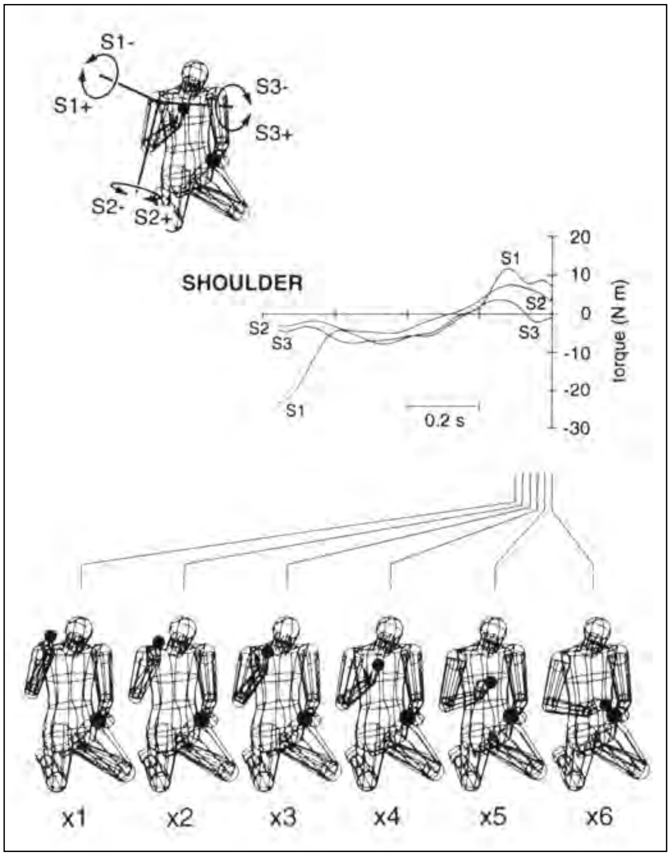

Figure 116. Kinesiological results of the Oldowan study. In Oldowan tool-making, the hammerstone was accelerated to a velocity of about 20 miles per hour just before impact, travelling a distance of just under a half meter (about a foot-and-a-half). Based on the weight of the hammerstone (625 gm), this 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.

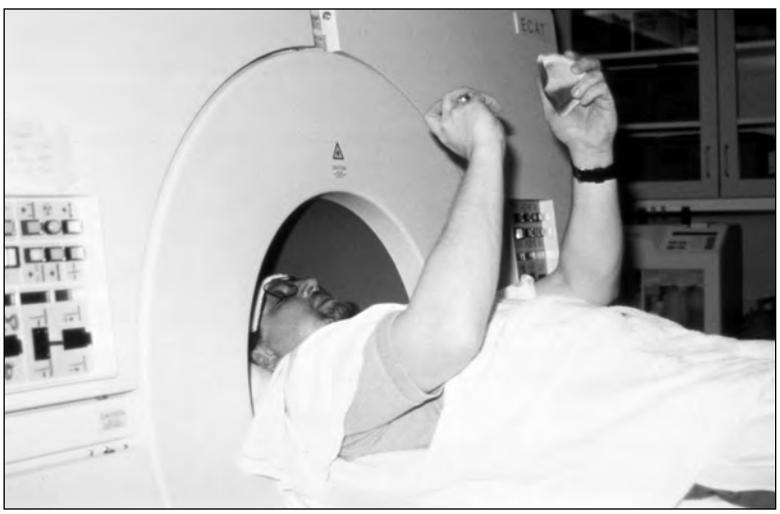

Figure 117. Positron emission tomography (PET) study of Oldowan artifact manufacture. In this early pilot study, the subject was injected with a fast-decaying radioisotope and was scanned in "real time" as he knapped in the machine.

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).

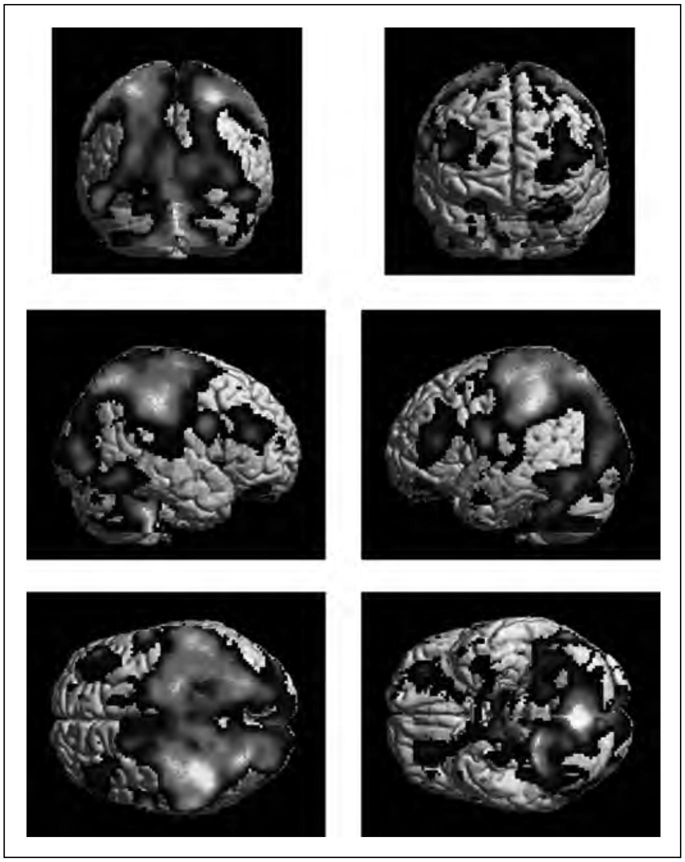

Figure 119. PET brain activity making an Acheulean handaxe. Lighter areas show more blood flow to neural areas.

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.

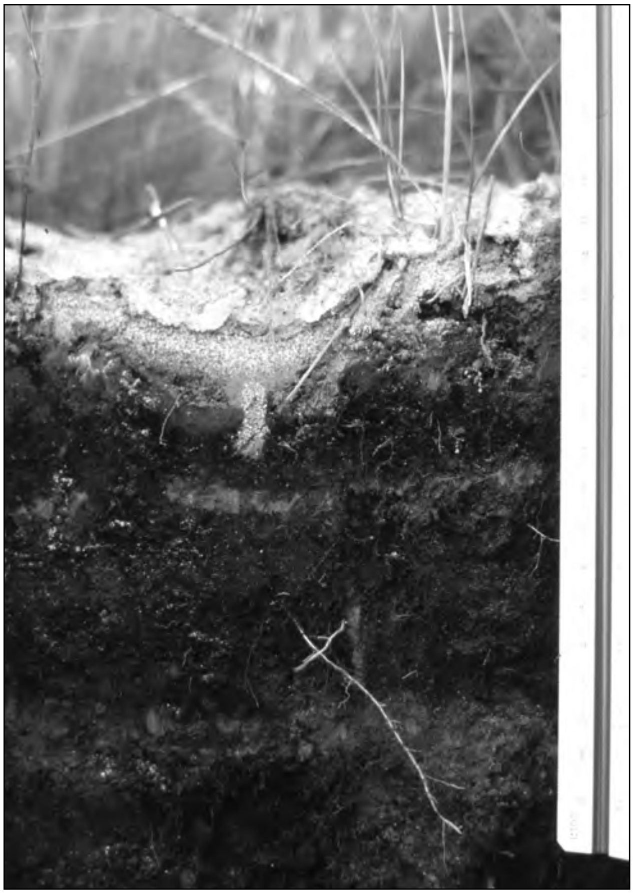

Figure 131. Study of aeolian volcanic ash deposition downwind of Mt. St. Helens three months after the eruption of 1980. An excavated section shows the lighter volcanic ash deposited on top of the darker soil horizon. At this distance from the eruption (about 40 miles) approximately four centimeters 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.

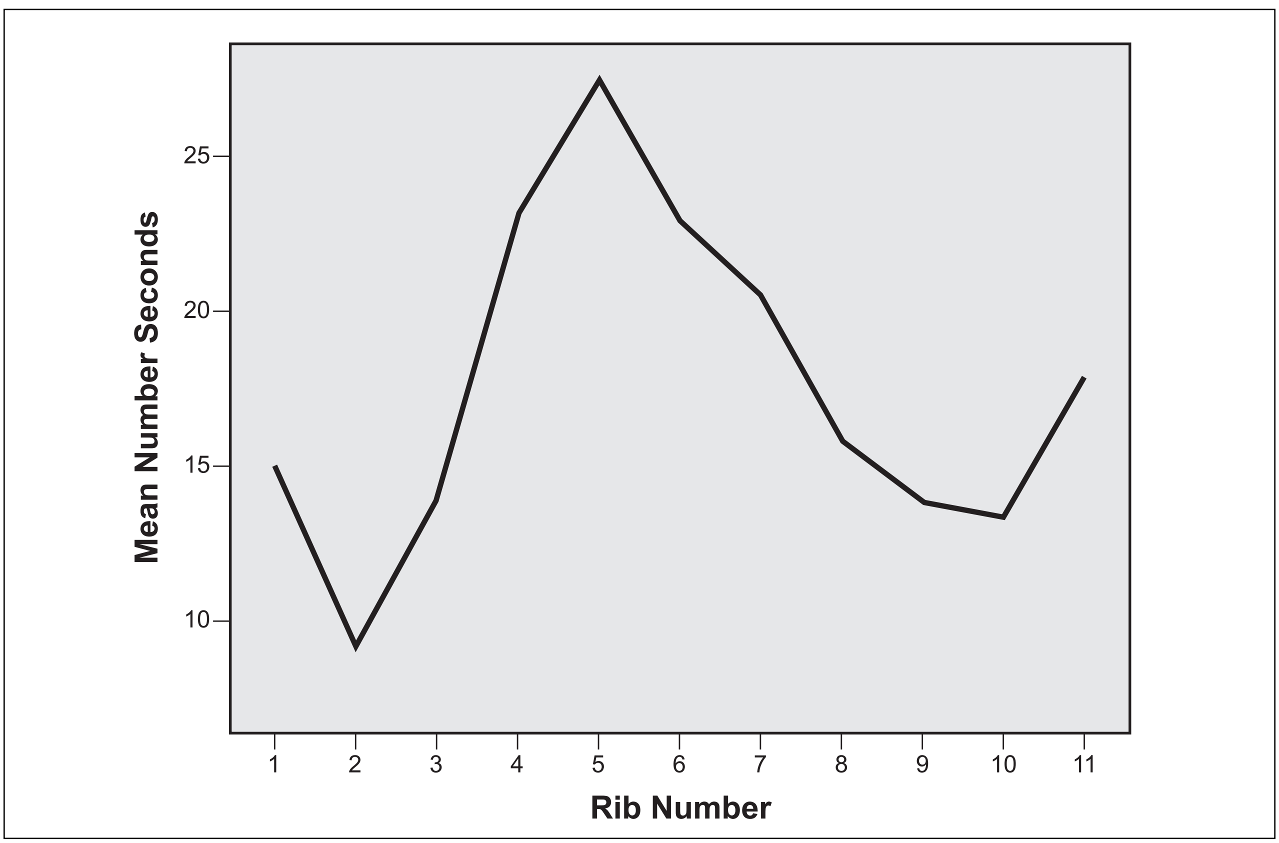

Figure 160. As an anatomical sequence of ribs was removed from a rack of ribs, some required more cutting time than others. This graph shows the average number of seconds per rib. Note that the fifth rib is especially difficult to remove, owing to its extreme curved morphology and its harder connective 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.

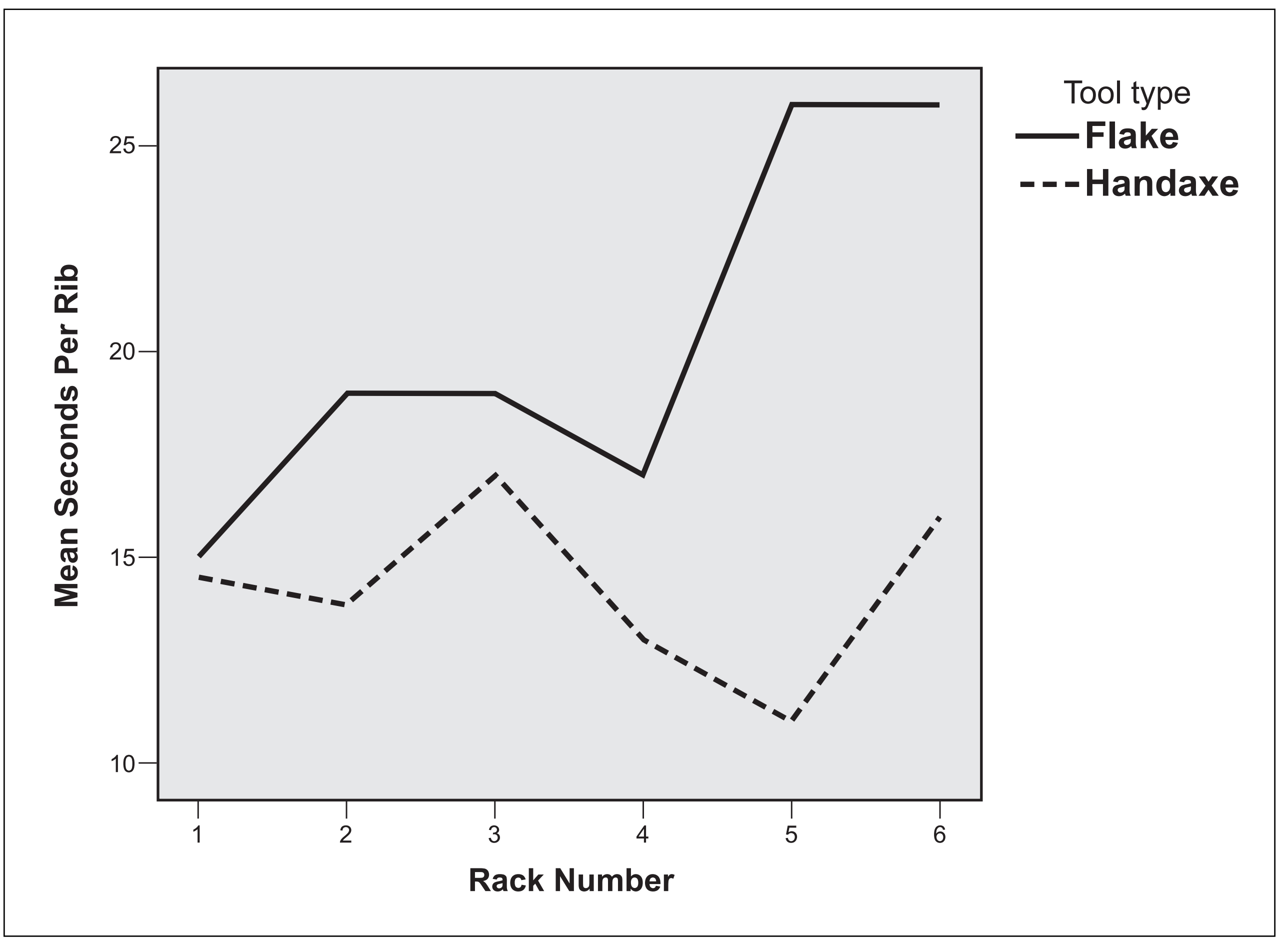

Figure 162. A comparison of the cutting ability of a flint handaxe versus a flint flake. Note the long duration of the cutting efficiency of the handaxe in comparison with the flake. The sharp flint flake dulled appreciably after cutting through four racks of ribs (or the disarticulation of approximately 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.

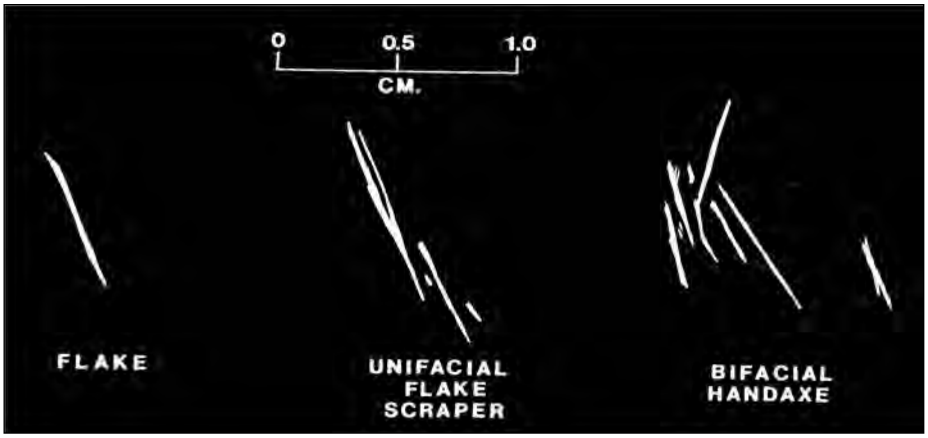

Figure 163. Cut-marks made with one unidirectional stroke from three different tool edges: an unmodified flake, a unifacial knife ("flake scraper"), and a bifacial handaxe. Note that the complexity of the cut-mark pattern increases with the sinuosity of the edge.

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.

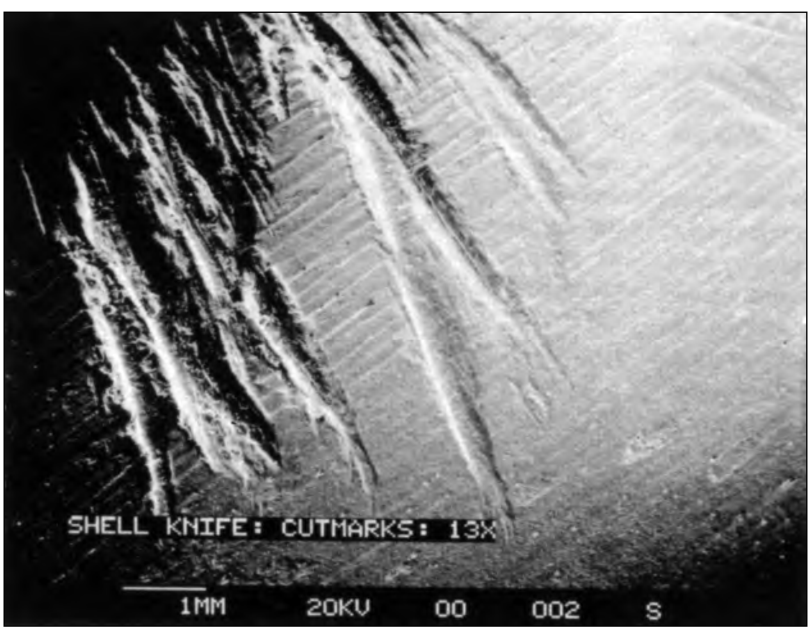

Figure 165. Cut-marks experimentally produced by the shell knife in the previous figure. These marks were produced on the metapodial of a goat during skinning. Such cut-marks are almost certainly indistinguishable in the archaeological record from those produced by a stone tool (unless small fragments 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 179. Excavations in progress at the Miocene Robbins quarry.

Figure 181. An equid pelvis showing toothmarks from a medium-sized carnivore (probably the canid Tomarctus) 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.

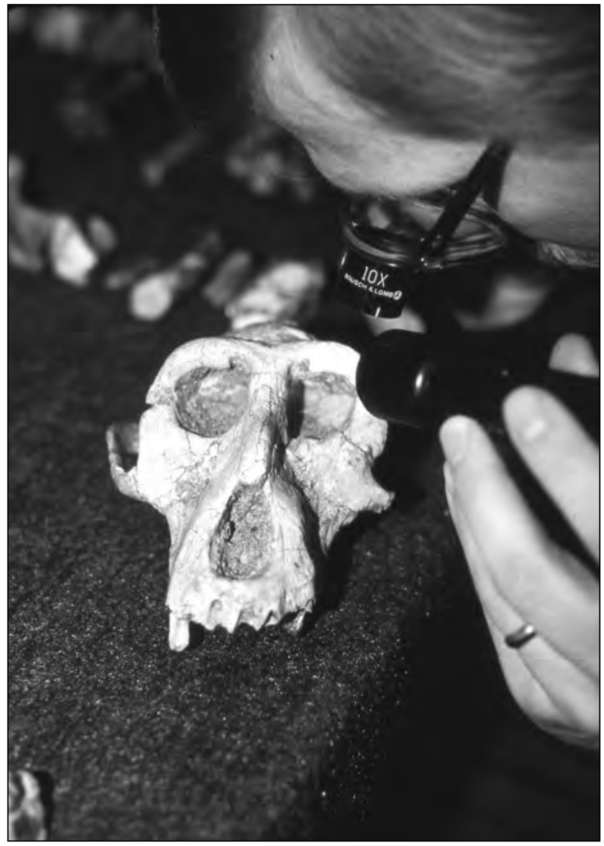

Figure 183. Examining the fossil cranium of a baboon from the Omo, Ethiopia for possible taphonomic traces of modification.

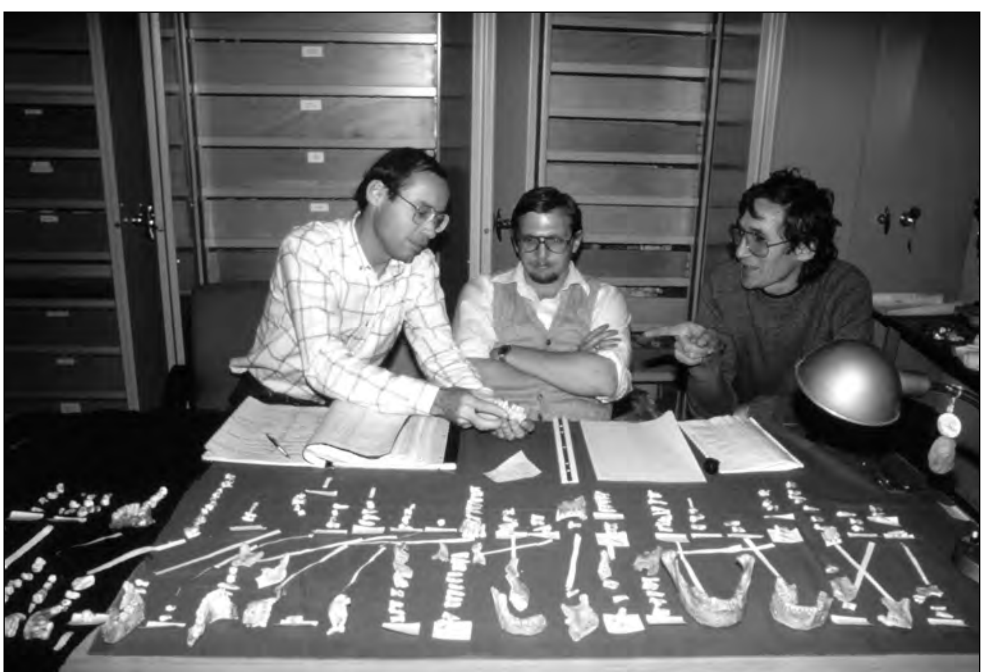

Figure 184. Tim White (left) and Nick Toth (center) study bone modification on the large sample of Neandertal fossils from Krapina, Croatia. Jakov Radovic on the right. Here the maxillary and mandibular fossils are shown.

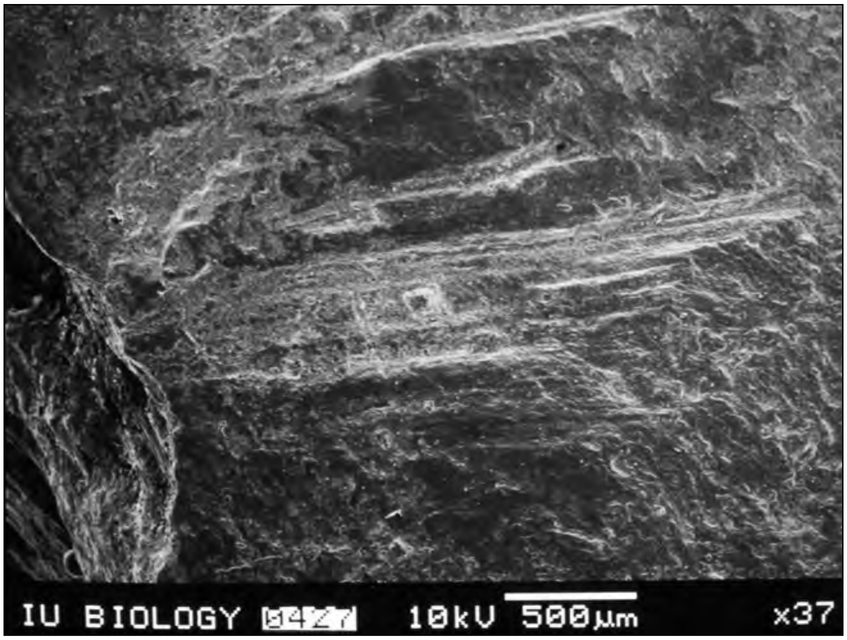

Figure 185. Cut-marks on hominin cranium Stw 53 at Sterkfontein cave, South Africa described by Travis Pickering, Tim White, and Nicholas Toth. Photomicrograph by N. Toth.

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.