CHAPTER 10

KNAPPING SKILL OF THE EARLIEST STONE TOOLMAKERS: INSIGHTS FROM THE STUDY OF MODERN HUMAN NOVICES

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ABSTRACT

Defining the knapping skill level and associated mental capabilities of the earliest stone toolmakers is a major objective for the archaeology of human origins. This requires that technological indicators of hominin knapping skill be identified and differentiated from raw material influences. To this end, products from two experiments with novice stone knappers were compared to a sample of artifacts from the site of EG10 in the Gona study area, Ethiopia (Semaw, 1997, 2000; Semaw *et al.* 1997). In the first experiment, three individuals were given cobbles of a highly distinctive variety of trachyte identical to that used by the Pliocene toolmakers at EG10. The continued availability of this material in the Gona study area provides an ideal opportunity for the experimental control of raw material influences. Data from a second experiment conducted as part of an unrelated research project (Stout, in prep., this volume) was also considered in order to provide an additional dimension of comparison. In this experiment, a single novice subject was given a variety of raw materials from a local (Martinsville, Indiana) quarry, including quartz, quartzite and limestone. Finally, an archaeological sample consisting of all surface and *in situ* EG10 artifacts manufactured in the distinctive "Gona trachyte" was taken. Comparison of these three samples revealed important raw material influences as well as material-independent differences in knapping techniques and flake attributes. The EG10 toolmakers were found to have employed a more uniform knapping technique and to have produced thicker flakes than modern human novices. These differences indicate a relatively high skill level among the EG10 hominins, and have important implications for the mental capabilities of the earliest stone toolmakers.

INTRODUCTION

Flaked stone artifacts dating from as much as 2.55 Ma. (Semaw *et al.*, 1997) provide some of our earliest and most fine-grained evidence of evolving hominid behavior and intelligence. Understanding this ancient evidence requires diverse actualistic studies in the modern world, including ethnographic (Stout, in press), replicative (Bordes, 1947; Crabtree, 1966; Callahan, 1979; Toth, 1985), mechanical (Speth, 1974; Dibble & Pelcin, 1995), biomechanical (Marzke *et al.*, 1998), and neurological (Stout *et al.*, 2000; Stout, this volume) research.

This chapter describes an application of the replicative approach to the question of Oldowan/Mode I (Clarke, 1969) knapping skill. Previous work (Toth, 1985) has established that the simple goal of flake production is sufficient to account for the vast majority of artifact types known from the earliest Stone Age. The question remains, however, as to the degree of skill and sophistication that was deployed by Plio-Pleistocene hominids in pursuit of this goal.

Isaac (1984) advocated a stepwise approach to understanding variation in early artifact assemblages, arguing that "among the known very early assemblages, raw-material and least-effort factors account for most differences, leaving very little if any residual variance on which to base either activity facies or culture-historic kinds of interpretations" (p. 161). The exact meaning of "least-effort" flaking was not, however, defined by Isaac, who instead called for the experimental investigation of flaking strategies "as responses to particular forms of raw material."

The residual approach has been very useful for Early Stone Age archaeologists, but tends to favor artificially exaggerated distinctions between social, functional and mechanical aspects of stone knapping. Stone knapping, like other primate tool-using behaviors (Boesch & Boesch, 1990; McGrew, 1992; van Schaik *et al.* 1999), is a goal-oriented activity that is learned and performed in a physical, social, and (in humans) cultural environment (Stout, in press). No knapping strategy, however simple, exists apart from the social environment in which it is learned, the raw materials in which it is executed and the functional purposes that it serves. One way in which to achieve a more integrated perspective is to consider stone knapping as a form of skilled action.

Isaac (1984) did not explicitly consider the issue of knapping skill but did emphasize the psychological significance of understanding the "design concept and motor patterns actually involved in making [stone tools]" (p. 161). Despite the simplicity of the goals and products of Mode I flaking, more or less complicated knapping processes and degrees of skill may be employed (Schick & Toth, 1993:133-134). With this in mind, researchers have begun to comment on the perceptual-motor sophistication apparent from early stone tools (e.g. Semaw, 2000; Ambrose 2001). Along these lines, Roche *et al.* (1999) describe a pattern of "unidirectional or multidirectional removals [from] a single debitage surface" at the Pliocene (ca. 2.34 Ma.) site of Lokalelei 2C in Kenya, which they argue is reflective of relatively advanced strategic and motor skill on the part of the toolmakers. In contrast, the high incidence of step fractures on artifacts from the similarly aged (ca. 2.35 Ma.) site of Lokalalei GaJh 5 has been seen as providing evidence of poorly understood and executed flaking techniques (Roche, 1989; Kibunja, 1994).

Technological case studies like these are essential in order to document the nature and diversity of early hominid knapping skills, but need to be interpreted in light of evidence from experimental replication. Quantitative and replicable experimental observations provide a consistent, external standard of comparison that is not available in the archaeological record itself. For example, Kibunja (1994) asserts that step fractures at Lokalalei GaJh 5 are indicative of unskilled knapping because his "surface observation" of raw materials and inspection of cores did not reveal any material flaws. Ludwig (1999; Ludwig & Harris, 1998), however, reports that his inspection of the GaJh 5 materials suggests that "subtle material flaws" did in fact play "a major role in the formation of these step fractures." This basic difference in qualitative evaluation leads to major differences in theoretical interpretation, but could be relatively easily and conclusively resolved through quantitative experimentation with authentic raw materials and knappers of known skill level.

Such an approach is adopted here with respect to the Pliocene site of EG10 from the Gona study area in the Afar region of Ethiopia (Semaw, 2000; Semaw 1997; Semaw *et al.* 1997). The site is well dated to between 2.52 and 2.6 Ma on the basis of $^{40}Ar/^{39}Ar$ and paleomagnetic evidence, making it one of several sites in the Gona study area that are the oldest known in the world. As such, EG10 is of special significance to researchers interested in the origins and evolution of stone knapping.

The Experiments

Rationale

Raw material variation is a major confounding factor in attempts to assess the skill-level of pre-historic Mode I (Oldowan) stone knappers. In the current study, it was possible to control for raw material influences by conducting experiments with raw materials identical to those from a selected archaeological sample. A further experiment with a single knapper and a variety of raw materials provided complementary insights into the effects of raw material variation with skill level held constant. By carefully differentiating between raw material and skill related influences, these experiments provided an empirical baseline for assessing the knapping skills evident at EG10.

Typically, evaluation of the skill-level of prehistoric knappers has been based upon qualitative assessments by experienced experimental knappers. Systematic and quantitative studies of skill-related variation are quite rare (e.g. Ludwig, 1999), although Schick & Toth (1993: 133-4) have made the more general observation that "the efficient [Mode I] flaking of stone…is a skill that can take a number of hours to master, even for a modern human." While it is impossible to directly study knapping skill acquisition in extinct hominin species, studies of modern humans (and other extant primates) offer an essential reference point. The current study evaluated the knapping products of novice modern humans in order to complement previous work with experienced human knappers and non-human primates (Schick *et al.*, 1999; Toth, 1985, 1997; Toth *et al.*, 2002, this volume; Wright, 1972).

Archaeological Context

The research presented here consists of the comparison of two experimental knapping samples with a subset of the artifacts recovered from EG10 by Semaw and colleagues (Semaw *et al.*, 1997). EG10 comprises a high-density scatter of lithic artifacts eroding out of fine-grained sediments on the east side of the Kada Gona drainage, and represents an excellent opportunity for experimental study due both to its sedimentary and stratigraphic context and to the nature of the raw materials used by the toolmakers. The fine-grained sedimentary context, the freshness of the artifacts, and the lack of vertical dispersion or apparent size sorting all suggest that the assemblage is relatively undisturbed. The site sits in floodplain silts stratigraphically above sands and a cobble conglomerate (the *Conglomerat Intermediaire* or "Intermediate Conglomerate" of Roche & Tiercelin [1977,1980]) all laid down by the same meandering channel. The cobble conglomerate below the EG10 site represents the remains of what, on the paleolandscape, would have been exposed cobble bars in this channel. Evidence of a channel cut-and-fill located between the sites of EG12 and EG13 (Semaw, 2000) further indicates that cobbles in the Intermediate Conglomerate were exposed in smaller feeder-channels on the floodplain itself. The EG10 artifacts, clearly made from river cobbles, almost certainly originated from either the axial channel or its tributaries. In fact, proximity to raw materials may have been an important factor leading to hominin activity at this site.

The Intermediate Conglomerate provides an exceptional record of the raw materials available to the EG10 hominids. One particularly distinctive raw material found both at EG10 and in the conglomerate is a variety of trachyte. The Gona trachyte is fine-grained, light brown or gray in color often with phenocrysts and dark brown cortex. It is a high-quality raw material with excellent fracture properties, and was clearly preferred by the EG10 hominids as shown by its disproportionate representation in the artifact assemblage compared with the cobble conglomerate (Semaw 2000). The distinctiveness of the Gona trachyte and its continued availability in the cobble conglomerates within the study area provide an ideal situation for the experimental control of raw material variation.

Methods

Two experiments in the Mode I production of flakes by modern human novices were carried out. The first took place during the 2000 field season in the Gona research area, Afar, Ethiopia. Cobbles (~ 80 - 160 mm in maximum dimension) of the distinctive "Gona trachyte" were selected by one of the researchers (D.S.) from conglomerates in the study area and made available to three novice experimental knappers. These individuals were familiar with the general appearance of the archaeological materials found in the area, but had never previously attempted to replicate them and had no prior instruction, either practical or theoretical, in stone knapping or artifact typology. They were asked to produce stone flakes like those they were familiar with from the study area. Knapping occurred in 2-3 approximately 15-minute long sessions per individual, amounting to a total of no more than one hour's experience for any one individual. All products were collected and analyzed, and are currently stored at the National Museum in Addis Ababa. This experiment allowed for exploration of variation in the flaking of a single raw material type between modern novices and the EG10 toolmakers.

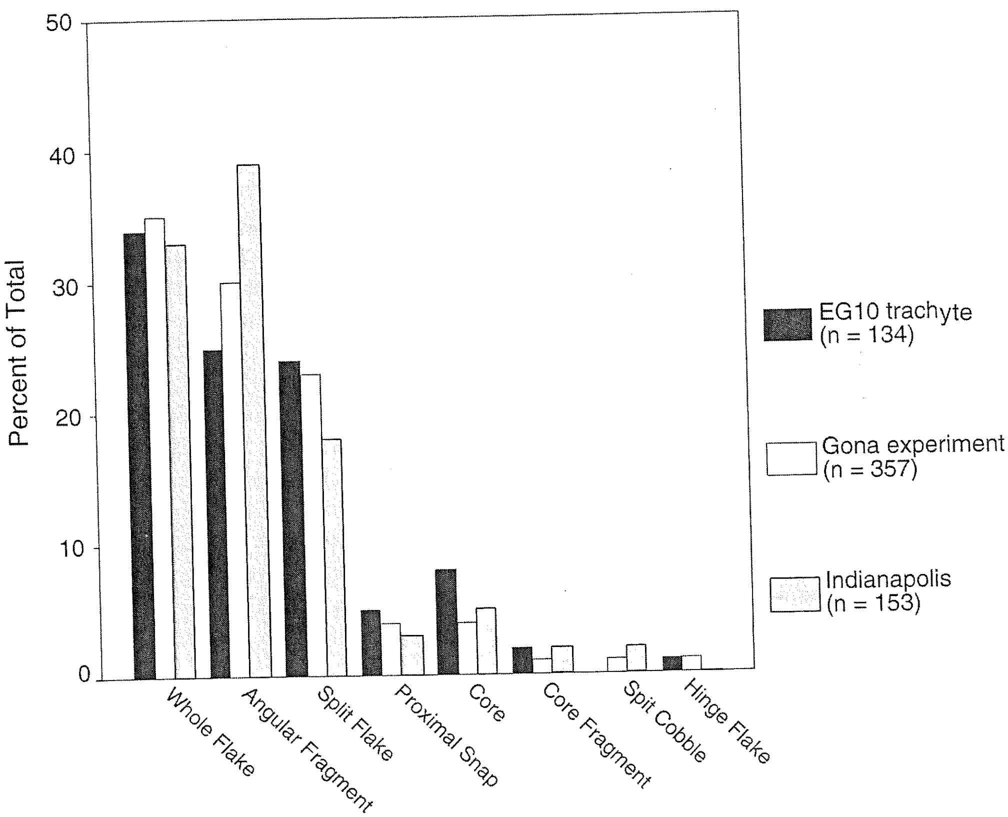
A second experiment took place in Indianapolis, Indiana in August, 2001, as part of an unrelated research project being conducted by one of the authors (D.S.). This project, involving the use of Positron Emission Tomography to explore the neural substrates of Mode I knapping skill (Stout, this volume), is still underway, but a small sample of the experimental artifacts thus far produced have been analyzed and are presented here. These artifacts were produced during a single 40-minute session by one novice stone knapper with no prior experience. In an important difference from the Gona experiment, raw materials made available to the knapper came from a local (Martinsville, Indiana) quarry. These included an assortment of limestone, quartz, and quartzite cobbles of approximately 100 - 200 mm in maximum dimension. This experiment allowed for exploration of raw material influences on flaking by a novice knapper, and comparison with the flaking of Gona trachyte by both modern novices and prehistoric hominins.

The experimental samples from Gona and Indianapolis were compared both with each other and with a sample taken from the EG10 archaeological collection stored at the National Museum in Addis Ababa. The archaeological sample included all *in situ* and surface artifacts > 20 mm in maximum dimension made in the distinctive "Gona trachyte" described above. Because raw material identification from small hand specimens is not always definitive, questionable cases were excluded from the sample.

A Student's t-test indicated that, of the metric attributes analyzed for this study, the only significant difference between *in situ* and surface flakes was the slightly more obtuse interior platform angle of the *in situ* flakes (110° vs. 103°, $p = 0.093$). Surface flakes also included a small percentage (17.2 %) with non-cortical platforms, which were completely absent from the *in situ* flakes. Neither of these differences would affect the conclusions and interpretations presented in this chapter.

For each sample, all artifacts > 20 mm in maximum dimension were analyzed. The resulting numbers and types of artifacts in each sample are summarized in Table 1, with relative frequencies represented in Figure 1. Data from the cores, core fragments and whole flakes will be dealt with here. Cores and core fragments were described in typological and qualitative terms, as well as by quantitative attributes. Quantitative core attributes recorded included length (defined as maximum dimension), breadth, thickness, # of flake scars (> 20 mm), # steps and hinges and % cortex remaining. The total number of detached pieces per core was recorded, as was the number of whole flakes per core. Whole flake

Figure 1: Frequency of Artifact Types



1. *Percentage representation of major artifact types in the three samples. Percentages are remarkably similar across samples with the exception of the greater representation of cores at EG10 and the higher proportion of angular fragments in the Indianapolis experiment. The latter is likely a reflection of differences in raw material - both in terms of fracture properties and expression of distinctive flake morphology.*

Table 1: The Experimental and Archaeological Samples

Sample	Cores	Core Fragments	Split Cobbles	Whole Flakes	Split Flakes	Proximal Snaps	Angular Fragments	Hinge Flakes	Total
EG10	11 (8%)	3 (2%)	0 (0%)	45 (34%)	32 (24%)	7 (5%)	34 (25%)	2 (1%)	134 (100%)
Gona Experiment	15 (4%)	5 (1%)	3 (1%)	126 (35%)	81 (23%)	16 (4%)	107 (30%)	4 (1%)	357 (100%)
Indianapolis Experiment	7 (5%)	3 (2%)	3 (2%)	50 (33%)	27 (18%)	4 (3%)	59 (39%)	0 (0%)	153 (100%)

attributes recorded included length (perpendicular to the striking platform), maximum breadth, maximum thickness, maximum dimension, platform thickness, platform breadth, external core angle, internal bulb angle, # dorsal scars, # steps and hinges, # platform scars, % dorsal cortex, % platform cortex and Toth's (1985) flake type. Artifacts from the Indianapolis experiment were also described in terms of raw material.

Unless otherwise noted, comparisons between samples were made using two-tailed Student's t-tests. Because many samples were not normally distributed, non-parametric Kolmogorov-Smirnov and Mann-Whitney tests were also employed. Results of these tests were consistent with those obtained using the parametric test, and did not suggest alternative interpretations.

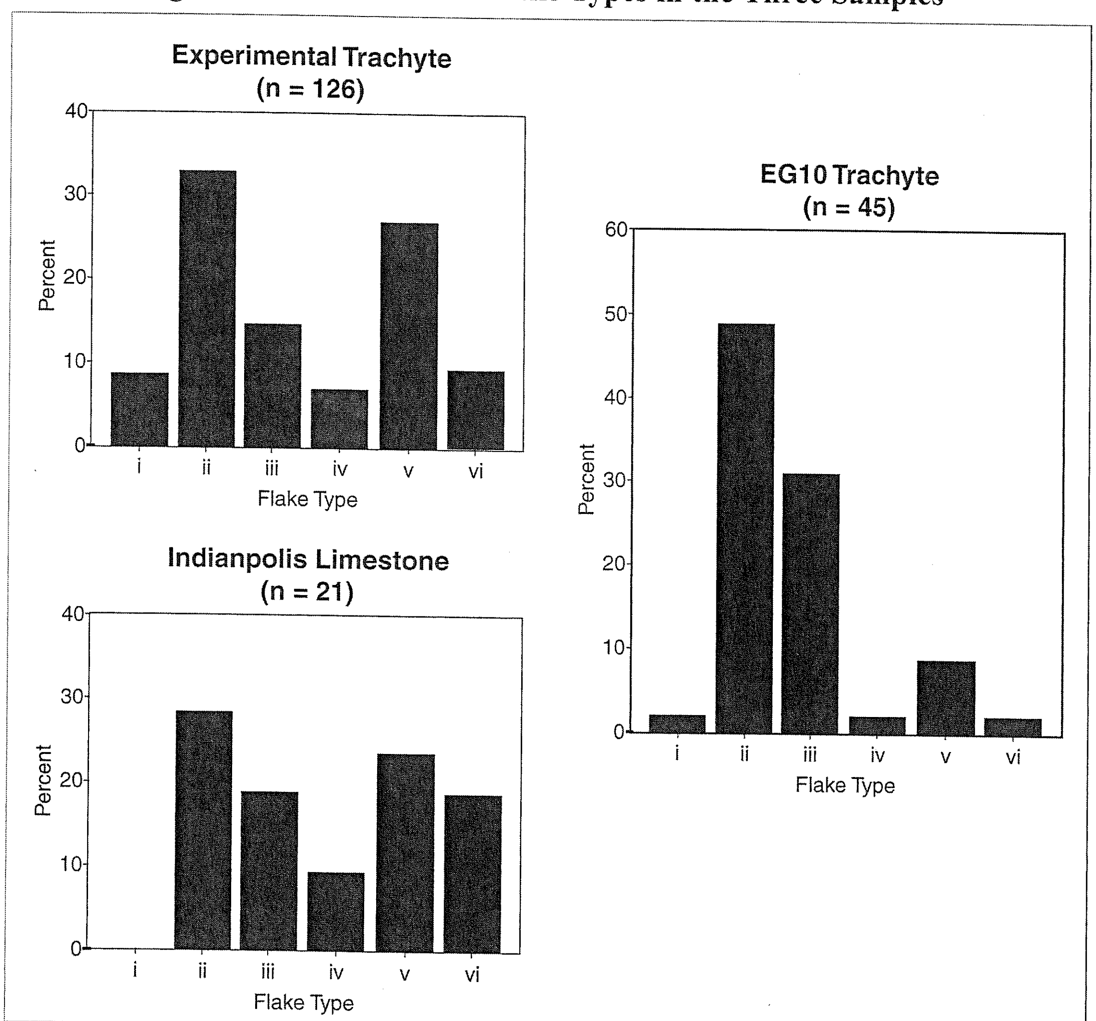
Results and Interpretation
Archaeological and Experimental Samples from Gona
Knapping Strategy

Comparison of the modern experimental sample from Gona with the archaeological materials from EG10 reveals important technological differences. To begin with, there is a difference in basic flaking strategy. The EG10 trachyte artifacts are dominated by the products of unifacial flaking, identifiable directly in terms of core morphology and indirectly in terms of flake attributes. Only one out of eleven EG10 trachyte cores examined for this study displayed flake scars indicative of bifacial reduction. In contrast, four out of fifteen experimental cores provide definitive evidence of bifacial reduction.

Also strongly indicative of unifacial flaking is the observed distribution of cortex on the whole flakes in the archaeological sample (Figure 2). In order to describe this patterning, the flake classification system of Toth (1985) is useful. This system recognizes six different flake types based on the presence or absence of cortex on the striking platform and dorsal surface: Types I, II and III have cortical platforms with completely cortical (I), partially cortical (II) or completely non-cortical (III) dorsal surfaces, while Types IV, V and VI have non-cortical platforms with completely cortical (IV), partially cortical (V) or completely non-cortical (VI) dorsal surfaces.

The EG10 trachyte whole flake sample is clearly dominated (86%) by Types II and III. The prevalence of cortical platforms demonstrates that the toolmakers were not exploiting scars from previous flake removals as platforms for subsequent removals. The unifacial reduction of four quartzite cobbles by one of the authors

Figure 2: Distribution of Flake Types in the Three Samples



2. *The relative frequency of Toth's (1985) flake types in the three samples under discussion. While both experimental samples show a similar distribution, the archaeological sample is exceptional in its near total domination by flake types II &III (flakes with cortical platforms and a partial [II] or total [III] absence of dorsal cortex). This reflects unifacial flaking of moderate to heavy intensity in the EG10 trachyte. The absence of whole flakes of type I from the limestone samples indicates that the relatively small number of cortical flake removals that did occur shattered to produce fragments rather than whole flakes.*

(D.S.) confirms this relationship between flake types and reduction strategy: of 26 whole flakes with intact platforms, none displayed non-cortical platforms. Instead, the sample consisted entirely of Types I (27%), II (50%) and III (23%). The relatively high representation of Type I flakes in this experiment reflects reduction much less exhaustive than that seen in the EG10 trachyte.

In the EG10 trachyte, the predominance of flakes with a partial (Types II & V, 61% of flakes) or total (Types III & VI, 33% of flakes) absence of dorsal cortex indicates moderate to heavy reduction intensity. Although some initial flaking may have occurred off-site (Schick, 1987), flakes types represented at EG10 clearly indicate substantial subsequent reduction. The dorsal morphology of EG10 Type II & V flakes, which display an average of 3 flake scars and only 27% cortex, is also indicative of relatively intense reduction. These trends, coupled with inspection of the EG10 trachyte cores, reveal a unifacial knapping strategy in which successive flakes were removed from the same area through reiterated strikes to the cortical surface of the core. This uniform strategy produces cores which are easily classified using Mary Leakey's (1971) typology, and which are dominated by unifacial side and end choppers (7 out of 11 or 64%). This strategy has the further effect of producing relatively spherical cores though preferential reduction of the long axis. The result is a ratio of mean core length:width:thickness that is approximately (1.6):(1.3):(1.0). In contrast, a random sample of 20 cobbles from one of the conglomerates exposed in the Gona study area produced a ratio of approximately (2.1):(1.4):(1.0).

The pattern of reduction evident from the Gona experimental cores and flakes is much different. Both bifacial and unifacial reduction are evident from inspection of cores, and knapping does not tend to be concentrated in any one region of the core. The experimental cores in general are much more difficult to classify according to Mary Leakey's (1971) typology, and many are best described as either "irregular polyfaceted" or "casual" cores using Isaac's (1977: 176-7) typology. Because there is no preferential reduction of the long axis, experimental cores tend to be more elongated, with a length:width:thickness ratio of (2.0):(1.5) :(1.0) that is very similar to that found in unmodified cobbles (above). The distribution of flake types (Figure 2) also shows a different pattern, with a much greater representation of flakes with non-cortical platforms (43.5% compared with 14% from EG10). A Chi-Square test confirms that the distribution of flake types in the two samples is significantly different ($p < 0.001$).

This difference in the pattern of flake type representation indicates that experimental subjects were much more likely to exploit scars from previous flake removals in selecting a striking platform. A majority (60%) of experimental whole flakes displayed dorsal surfaces that were partially cortical. On average, these flakes possessed cortex on 45% of their dorsal surface and 1.6 flake scars. Thus, although flakes with partially cortical dorsal surfaces dominated both experimental and archaeological samples, these partially cortical flakes displayed a much higher percentage of dorsal cortical surface area (45% vs. 27%, $p < 0.001$) in the experimental sample, as well as fewer flake scars (1.6 vs. 2.8, $p = 0.023$). These differences reflect a combination of less intense and less uniformly localized flaking by experimental subjects, with dorsal flake surfaces being less heavily modified by previous flake removals from the same part of the core.

Although it should be remembered that the stone artifacts recovered from EG10 include only those that "fell out" (Isaac 1984: 150) of the system of hominin tool transport and modification at this particular location, and which further survived subsequent site formation processes to be recovered by archaeologists, it would be difficult to construct a plausible scenario of transport and/or winnowing to account for the multifaceted and consistent pattern observed. Observed patterns in core morphology, flake type representation, percentages of dorsal cortex and numbers of dorsal flake scars all combine to produce a picture of reduction in the EG10 trachyte sample that is much different from that evident in the experimental sample. Whereas the EG10 toolmakers pursued a uniform strategy for the localized, unifacial reduction of trachyte cobbles, experimental subjects were more "opportunistic" in their approach, exploiting potential striking platforms wherever they occurred.

Flake Metrics

Despite these major differences in basic knapping strategy, whole flakes from the Gona experimental and archaeological samples are actually quite similar metrically (Table 2). In fact, the only significant differences are in the greater mean thickness of flakes and flake platforms in the archaeological sample. The fact that the two samples differ in thickness but not other measures suggests that the archaeological flakes are relatively as well as absolutely thicker. This is supported by the observation that the ratio of thickness to breadth is significantly greater in the archaeological sample and the ratio of maximum dimension to thickness is significantly less.

The Experimental Sample from Indianapolis

The small experimental sample from Indianapolis displays interesting commonalities and contrasts with the experimental sample from Gona, as well as with the archaeological materials from EG10. To begin with, it should be noted that the raw materials used in this experiment, predominantly limestone, quartz and quartzite, were quite different both from the fine-grained Gona trachyte and from each other. Raw material variation clearly exerted a major influence on the technological patterns observed in the Indianapolis sample.

Table 2: Flake Attributes

Attribute	Statistic	EG10 Trachyte	Gona Experiment	Indianapolis Limestone
Length (mm)	mean *s.d.* (range)	**42.5** *14.6* (18.2 – 73.8)	**40.2** *16.7* (9.8 – 97.0)	**42.6** *17.7* (9.6 – 90.4)
Breadth (mm)	mean *s.d.* (range)	**40.6** *14.3* (18.0 – 82.8)	**39.8** *16.9* (9.8 – 87.5)	**39.5** *11.0* (19.0 – 64.2)
Thickness (mm)	mean *s.d.* (range)	**16.0** *6.8* (5.7 – 36.0)	**12.8**** *7.7* (1.7 – 42.5)	**13.7** *7.5* (4.1 – 32.3)
Maximum Dimension (mm)	mean *s.d.* (range)	**51.8** *16.1* (26.3 – 86.9)	**52.7** *19.4* (20.5 – 109.0)	**53.1** *17.5* (25.5 – 94.6)
Platform Breadth (mm)	mean *s.d.* (range)	**27.1** *12.0* (4.0 – 62.0)	**27.5** *14.1* (4.0 – 70.5)	**20.6*†** *8.4* (8.7 – 38.8)
Platform Thickness (mm)	mean *s.d.* (range)	**12.5** *6.4* (0.1 – 34.5)	**10.1*** *7.1* (1.4 – 40.6)	**9.0** *6.4* (4.0 – 22.6)
External Angle (°)	mean *s.d.* (range)	**77** *15* (52 – 115)	**74** *16* (40 – 121)	**87*††** *17* (65 – 120)
External Angle (°)	mean *s.d.* (range)	**105** *17* (62 – 135)	**109** *15* (55 – 170)	**99*††** *18* (68 – 120)
Dorsal Scars (#)	mean *s.d.* (range)	**2.8** *1.8* (0 – 10)	**1.6**** *1.2* (0 – 6)	**2.9††** *1.8* (0 – 7)
Breadth/Length	mean *s.d.* (range)	**0.99** *0.3* (0.6 – 1.8)	**1.1** *0.4* (0.2 – 2.9)	**1.2** *1.0* (0.4 – 5.5)
Thickness/Breadth	mean *s.d.* (range)	**0.4** *0.1* (0.2 – 0.8)	**0.3**** *0.2* (0.1 – 1.7)	**0.3** *0.2* (0.2 – 0.9)
Max. Dim./ Thickness	mean *s.d.* (range)	**3.4** *0.7* (2.0 – 5.7)	**5.3**** *2.7* (1.8 – 18.0)	**4.5** *1.7* (1.9 – 8.8)

* *significantly different from EG10 trachyte at $p < 0.1$,*
** *significantly different from EG10 trachyte at $p < 0.05$,*
† *significantly different from Gona experiment at $p < 0.1$,*
†† *significantly different from Gona experiment at $p < 0.05$*

Table 2. Comparison reveals that flakes from the Gona experiment are significantly thinner than EG10 flakes, but of similar size and shape in plan view. Limestone flakes from Indianapolis differ from EG10 in the same way, but not significantly so. The Indianapolis sample differs from both of the other samples in platform breadth and platform angles, and from the Gona experiment in number of dorsal scars.

The degree of reduction seen on individual cobbles varied dramatically according to raw material. Thus, three cobbles of relatively soft and easily flaked limestone yielded 75 flakes and fragments > 20 mm in maximum dimension, while three quartzite cobbles yielded only 38. Two quartz cobbles produced 15 detached pieces. These differences in reduction intensity were also reflected in core morphology. The three limestone cobbles produced three relatively heavily reduced cores that were easily assigned to "typical" typological categories, including 2 unifacial choppers and one polyhedron. In contrast, three quartzite cobbles yielded 1 unifacial core, 1 "casual" core showing only a single flake scar, 3 core fragments and one split cobble. In an archaeological context, the artifactual nature of at least two of these quartzite pieces would be open to question.

Looking to flake characteristics, we find further evidence of material-related differences in reduction intensity. Limestone whole flakes (n = 21) have a much higher proportion of non-cortical platforms (types IV, V & VI = 52.4%), and a much lower proportion of completely cortical dorsal surfaces (types I & IV = 9.5%) when compared with quartzite flakes (n =19; types IV, V & VI = 26.3%; types I & IV = 47.3%). These differences clearly reflect the more intense reduction of the relatively easily flaked limestone cobbles. The intuitively puzzling absence of any type I flakes in the limestone whole flake sample results from a combination of reduction strategy/intensity and the fact that the small number of initial cortical removals that were executed on these three cores produced fragments rather than whole flakes.

Raw material differences also affected flake metrics, although not at a high level of significance for this small sample. Limestone flakes are larger on average than quartzite flakes in all measured dimensions (length, breadth, thickness, maximum dimension), but only at around an 85% confidence level or less. The greater mean weight of limestone flakes is, however, significant at the 90% level ($p = 0.086$). Other significant differences include the greater number of dorsal flake scars on limestone flakes ($p < 0.001$) and the sharper edge angles of limestone flakes ($p = 0.031$).

Giving due consideration to the importance of raw materials, the Indianapolis experiment may be compared with the experimental and archaeological samples from Gona. In fact, the Indianapolis limestone sample is quite similar to the Gona experimental sample, and the two differ in the same ways from the EG10 trachyte. On the other hand, the Indianapolis quartzite differs markedly from all other samples. Like the Gona experimental sample, the Indianapolis limestone displays evidence of relatively variable, "opportunistic" flaking, including some bifacial reduction. Although two of three limestone cores are classified as unifacial choppers, some bifacial reduction is evident on the third, a polyhedron. Furthermore, limestone flakes display a high percentage of non-cortical platforms (52.4%) similar to that observed in the Gona experimental flakes (43.5%) and much higher than that found in the EG10 trachyte (14.0%).

Qualitative inspection of limestone cores reveals that two of three (a unifacial side chopper and a polyhedron) display an opportunistic pattern of flake removals around the entire surface of the core, as seen in the Gona experimental cores, while the third (a unifacial end chopper) shows removals concentrated in a single area, as is characteristic of the EG10 trachyte cores. The Indianapolis limestone sample represents a mixture of reduction strategies that, considered as a whole, is more similar to the variable and opportunistic flaking seen in the experimental sample from Gona than to the uniform and localized flaking in the EG10 trachyte sample.

Steps and Hinges

It has recently (Ludwig, 1999) been argued that the frequency of steps and hinges on cores and dorsal flake surfaces is a good indicator of Mode I knapping skill. This measure produces interesting results in the current study, in which the number of steps or hinges per flakes scar observed on EG10 cores is significantly less than on the Indianapolis limestone ($p = 0.034$) or Gona trachyte ($p = 0.077$) experimental samples. These experimental samples, despite differences in raw materials, are not statistically distinguishable ($p = 0.429$). Following Ludwig (1999), these results would suggest greater knapping skill on the part of the Pliocene toolmakers as compared with modern human novices.

Discussion

Three major conclusions may be drawn from the results presented above. First, raw materials impose important constraints on knapping strategies and products. This is especially true for knappers of a low skill level. Second, when raw materials allow, technologically naïve modern human knappers tend to follow more variable and less patterned reduction strategies than those seen in the EG10 trachyte artifacts. Third, technologically naïve modern human knappers tend to produce flakes thinner than those known from EG10, even when working in the same raw material.

The Importance of Raw Materials

The importance of considering raw material variation in evaluating the skill or sophistication of stone knappers cannot be overemphasized. Many researchers have made this point in the past (e.g. Jones, 1979; Clark, 1980; Isaac, 1984; Ludwig & Harris, 1998) and it is particularly applicable in the case of Mode I technologies, where skill is defined by little more than the ability to efficiently detach flakes. In the current study, a single novice individual working over a 40-minute period produced artifacts of completely different character depending on the raw materials used. In contrast, novice knappers working only with Gona trachyte produced a set of flakes that differed from the archaeological sample only in thickness. The immediate success of experimental subjects at Gona reinforces the point that the Gona trachyte is a relatively easy material to work with, and may not have been particularly taxing for early toolmakers. Comparison of limestone and quartzite artifacts from the Indianapolis experiment further suggest that easily flaked materials do not provide as sensitive an index of knapping skill as do more challenging raw materials.

The selection of high-quality material in the first place, however, is itself revealing of the mental capabilities of the toolmakers. Schick & Toth (1993) and Stiles (1998) have previously described evidence of raw material selectivity in Lower Pleistocene Mode I artifact assemblages from Koobi Fora and Olduvai Gorge. Ongoing research at Gona is similarly revealing a high degree of raw material selectivity among late Pliocene stone toolmakers. Such selectivity has been taken as evidence of "relatively complex thought" (Stiles 1998: 133) or, more conservatively, as reflecting "some expertise" in distinguishing the quality of materials (Schick & Toth 1993: 125-6). In terms of mental capacity, the ability of the earliest stone toolmakers to understand and evaluate the suitability of materials for flaking and to locate, identify and preferentially collect higher quality materials is perhaps as significant as their ability to master the controlled fracture of stone.

Knapping Strategies

The particular knapping strategy employed by the EG10 toolmakers provides tantalizing evidence of perceptual-motor skill and mental sophistication. The trachyte artifacts from EG10 reveal a uniform reduction strategy of localized, unifacial flake removals. This differs from the more opportunistic and variable strategy adopted by experimental knappers both at Gona and in Indianapolis. The Gona experiment in particular, conducted with raw materials identical to those in the archaeological sample, indicates that the uniform patterning observed in the EG10 trachyte is underdetermined by material constraints and naïve approaches to least-effort flake production. Why and how did the EG10 hominins adopt this particular strategy?

The "residual approach" to early stone tools would suggest that, having accounted for raw material and least effort factors, explanations in terms of function and/or tradition should be considered. For example, localized, unifacial flaking might be a strategy used to produce certain useful artifact characteristics (e.g. thicker flakes), or to maximize the efficiency of flake production. Alternatively, it might represent an idiosyncratic "culture-historical" knapping tradition. From an evolutionary and psychological perspective, the knapping strategy might also be explained in terms of cognitive differences between the EG10 toolmakers and modern humans.

These potential explanations are not, however, mutually exclusive. To begin with, all stone knapping is cultural behavior, at least in the sense commonly used by animal behaviorists and Early Stone Age archaeologists (i.e. it is socially learned). The identification of a functional advantage for the mode of flaking employed with the EG10 trachyte certainly would not make this practice any less "cultural" in nature. Explanation of EG10 knapping practices in terms of function would also have important implications for the inferred mental capacities of the toolmakers. Selection of a particular, advantageous strategy implies technical intent and understanding beyond that often attributed to early Oldowan toolmakers (e.g. Wynn & McGrew, 1989), and it would be hard to dismiss the converse argument that the repetitive, unifacial strategy employed on the EG10 trachyte actually resulted from a lack of such understanding.

The argument from functional intent would, of course, be strengthened by evidence that the EG10 strategy is actually advantageous. For example, Roche *et al.* (1999) have argued that the unifacial reduction strategy pursued by Pliocene hominins at the site of Lokalelei 2C in Kenya was a particularly efficient one, producing up to 50 flakes per core (Roche & Delanges, 2001). It is impossible to know the exact number of flakes produced per trachyte cobble by the EG10 toolmakers, although the opportunistic strategy employed by Gona experimental subjects produced an average of 22.5 detached pieces per cobble. Further experimentation is needed to determine if a localized, unifacial strategy favors the production of more flakes per cobble. It must be remembered, however, that the reduction intensity observed at archaeological sites may be influenced by other factors, including raw material availability and the duration/intensity of occupation.

Instead of attempting to distinguish between overlapping functional, cultural and cognitive explanations, it makes a lot of sense to evaluate the EG10 artifacts in terms of acquired knapping skills. Such skills constitute demonstrated abilities, rather than residual explanations inferred through a process of elimination. Knapping skill acquisition (Roux *et al.*, 1995; Stout, in press) occurs through the discovery of dynamically stable behavioral solutions (cf. Bernstein, 1996; Thelen & Smith, 1994) to the inherently variable problems presented by lithic raw materials. Whereas skilled performance is embodied in the stable articulation of perception and action, skill learning is characterized by highly variable experimentation and exploration.

This is exemplified in the performance of the novice experimental knappers described in this chapter, who generally pursued "opportunistic" or exploratory knapping strategies and produced diverse, difficult-to-classify cores. In contrast, the EG10 toolmakers displayed a treatment of trachyte that was much more uniform and stable. A strategy of localized, unifacial flaking dominates the sample, cores are more easily classified into a small number of specific categories, and flake dimensions are less highly variable (Table 2). This uniform pattern is indicative of experienced performance, and implies that knapping was a habitual, skilled activity among the EG10 hominins. Future experimentation with novice and experienced knappers will be valuable in order to further test and refine this hypothesis.

Also of interest is comparative evidence of knapping skill acquisition in bonobos. Schick *et al.* (1999) report results from stone toolmaking experiments conducted with the bonobo Kanzi at a time when he had had 3 years (roughly 120 hours) of toolmaking experience. Although encouraged to practice hand-held, direct percussion, Kanzi independently adopted throwing as his preferred flaking technique. Schick *et al.* suggest that this was due to Kanzi's difficulties in producing sufficient percussive force though hand-held flaking. Using the relatively uncontrolled throwing technique, Kanzi produced 12 cores that were classified by Schick *et al.* as consisting of 8 (66.7%) casual or "minimally modified" cores, two bifacial end choppers, one two-edged bifacial end chopper and one heavy duty scraper. This extreme of variation in both technique and products is beyond that seen in novice human knappers (at least under experimental conditions), but nevertheless reflects a similar tendency toward behavioral exploration and variability during skill learning.

With further practice and encouragement, both Kanzi and his sister Panbanisha were able to develop more stable and controlled hand-held knapping skills (Toth *et al.* 2002, this volume). This generated a much more uniform pattern of core types, including an overwhelming majority (78.8%) of one-edged (63.6%) and two-edged (15.2%) unifacial cores, and 21.3% mixed bifacial/unifacial (15.2%) or exclusively bifacial (6.1%) cores. This shift to more uniform flaking techniques reflects the acquisition and stabilization of knapping skills by bonobos, and provides a remarkable parallel to observed differences between modern human novices and the EG10 toolmakers. Bonobos take longer to acquire knapping skill, and may never achieve parity with experienced humans, but the broad pattern of skill acquisition in both species appears quite similar. For both humans and bonobos, stable performance and uniform products are achieved through effortful practice. This would also have been the case among the Pliocene toolmakers of EG10.

Flake Metrics

One of the most fundamental aspects of stone knapping skill is the ability to combine force and accuracy during percussion (Stout, in press). This was a major stumbling block for Kanzi, leading him to adopt the much less controlled throwing technique. Because the amount of force (mass * acceleration) required in detaching a given flake is positively correlated with its mass (Dibble & Pelcin, 1995), flake metrics provide an indication of knapping forces employed. With raw material held constant, the production of larger flakes requires blows that are more powerful. Unless this increased force is accompanied by a compensatory decrease in accuracy (throwing being an extreme example), it constitutes an increase in perceptual-motor task difficulty (Fitts, 1954). Direct evidence of striking accuracy is a little more difficult to derive from artifacts, but platform dimensions and degree of battering can provide some indication.

Raw Material Influences

Out of the samples presented here, the experimental quartzite flakes from Indianapolis are the least massive, and weigh significantly ($p = 0.086$) less than limestone flakes produced by the same individual in the same knapping session. This difference in flake size clearly reflects the constraints of raw material, in that greater amounts of force are required to produce flakes of a given size in the fracture-resistant quartzite. Only blows that were relatively close to core edges resulted in successful fracture, producing small, thin flakes.

Another pattern attributable to raw material influences is the significantly steeper (closer to 90°) platform angles seen in limestone flakes compared with the experimental and archaeological Gona trachyte samples (Table 2). Sahnouni *et al.* (1997: 710) have previously noted the "special flaking qualities of limestone", and specifically its tendency to yield unusual platform angles. The pattern seen in this study is not identical to that reported by Sahnouni *et al.*, possibly due to differences in blank morphology and reduction intensity, but the idiosyncratic fracture mechanics of limestone are evident in both cases.

Flake Thickness

There is a significant difference in flake thickness between the archaeological and experimental trachyte samples (Table 2) that cannot be attributed to raw material. A similar but non-significant difference in thickness also exists between EG10 trachyte flakes and experimental limestone flakes. Although archaeological and experimental flakes are not appreciably different in length, breadth, maximum dimension, or platform angles, EG10 flakes are thicker and have thicker platforms. Flake weights for these samples are not available, but the observed differences in thickness nevertheless indicate that the EG10 flakes are more massive (cf. Dibble & Pelcin, 1995; Stout, in press).

There are several potential explanations for the difference in flake thickness between the archaeological and experimental samples, but a technological difference in flaking behavior is the most likely. Alternative explanations would involve some kind of preferential winnowing of relatively thin flakes from the archaeological sample, either through site formation processes or as a result of selective transport on the part of hominins. As previously discussed, artifact condition, sediment composition, artifact size distribution and the lack of preferential artifact orientation all indicate that EG10 is an undisturbed site. The preponderance of artifacts in the 15-25 mm size range at EG10 (Semaw, 1997: 106) argues against the probability that some flakes in the 20-90 mm range analyzed for this study were preferentially carried off due to minor differences in weight or shape. An explanation invoking the selective removal of thin flakes by hominins is more difficult to discount. The idea is plausible, but not very testable. Winnowing by hominin activity stipulates a form of behavior for which there is no other evidence and which presupposes undemonstrated mental sophistication and discriminative abilities. Nevertheless, it cannot be ruled out.

If the greater mean thickness of EG10 flakes is accepted as technological in origin, it indicates both that the EG10 toolmakers tended to strike further from core edges, and that they employed sufficient percussive force to detach the thicker flakes that resulted. At the same time, there is no evidence for a compensatory decrease in striking accuracy. Flaking is well controlled, producing the uniform unifacial pattern described above, and battering is, if anything, less pronounced in the archaeological sample than in the experimental materials. Platform thickness is also less variable in the archaeological sample (Table 2), further reflecting accuracy and consistency of percussion (i.e. striking at a consistent distance from core edges). The consistent production of thick flakes at EG10 provides further evidence of well-developed knapping skills, and particularly of the ability to combine force and accuracy during percussion.

This is not to say that Mode I knapping skill is necessarily defined by the production of thick flakes. In fact, highly skilled modern knappers working with Gona trachyte did not produce flakes as thick as those from EG10 (Toth *et al.* 2002, this volume). Technological habit and intent also become important factors here. What is significant is that the EG10 toolmakers imposed a bias on flake morphology (toward thicker flakes) that is not simply a reflection of raw materials and least-effort flaking. Experiments with bonobos (mean flake thickness = 10.4 [Toth *et al.*]), human novices (mean flake thickness = 12.8 mm [this study]), and human experts (mean flake thickness = 13.8 mm [Toth *et al.*]) using Gona trachyte all produced flakes thinner than those found at EG10 (mean thickness = 16.0 mm [this study]). Flake production at EG10 clearly did not follow an inevitable path of least resistance, and provides evidence of acquired knapping skill.

This leaves the question of why the EG10 toolmakers favored thicker flakes in the first place. Anecdotal evidence (Toth, pers. comm.) suggests that thicker flakes may be easier to hold during butchery and have edges that are more durable, but additional experimental work is needed in order to test these and other ideas. Although it is well known that early stone tools were used at least some of the time for carcass processing (Isaac, 1984; de Heinzelin *et al.*, 1999; Schick & Toth, 2001), and microwear evidence (Keeley & Toth, 1981) further indicates use in woodworking and cutting of soft plant material, many details regarding the function of Oldowan artifacts remain unknown. Tool-use experiments can at least provide insight into the potential relations between artifact characteristics and utility in various tasks.

Knapping Skill and Hominin Mental Capabilities

Comparison of experimental and archaeological samples indicates a relatively high level of knapping skill among the Pliocene toolmakers of EG10. Although the evidence does not reveal the specific combination of social, functional and cognitive factors that allowed for the development of this skill, it does suggest that knapping was an habitual activity associated with more than just a few hours of skill learning. Even modern humans require practice in order to achieve the kind of uniform and controlled knapping seen at EG10, and bonobos can take hundreds of hours to develop flaking skills that are even broadly comparable. It is most likely that the EG10 hominins fell somewhere between these extremes.

In humans and other apes, skill acquisition is a social process (Boesch & Boesch 1990; Inoue-Nakamura & Matsuzawa, 1997; van Schaik *et al.* 1999; Stout, in press). The mental demands of social interaction are widely appreciated (e.g. Humphrey, 1976; Byrne & Whiten, 1988; Dunbar 1992), and the acquisition of increasingly sophisticated knapping skills in prehistory provides an important indication of evolving social cognitive capabilities. The level of skill evident at EG10, though fairly low by human standards, suggests the presence of social contexts and mechanisms for skill acquisition beyond those seen in modern apes.

Research presented here and elsewhere (Stout *et al.*, 2000; Stout, this volume) is also beginning to reveal the perceptual-motor demands of Mode I knapping. Derived neural substrates for the effective coordination of perception and action may have been important in the development of the knapping skills seen at EG10. In any case, it is clear that some combination of social facilitation and/or perceptual-motor sophistication is necessary to explain the knapping skill of the EG10 toolmakers. Similar factors may also have underlain the raw material selectivity evident at EG10.

Conclusion

It would be inappropriate to attempt a general assessment of Oldowan hominin knapping skill and mental capabilities on the basis of artifacts from a single site or research area. To begin with, stone artifacts provide an indication only of minimum required competencies (Wynn 1989), and are unlikely to reflect the full extent of the makers' mental capabilities. This would be true even if evidence from all known sites were synthesized; it is certainly the case for this more limited investigation. Plio-Pliestocene hominin technological behavior is demonstrably variable over time and space. The relative importance of environmental, traditional, functional, population and even species level differences in explaining this variation remains to be evaluated, but it is clear that no one site can provide a full picture.

With this said, the narrowly focused investigation presented here does provide important information about the technological practices of at least one group of early toolmakers. What is sacrificed in breadth is gained in experimental control, increasing the utility of results and the robusticity of interpretations. Particularly important is the control achieved over raw material variation. Experimentation with Gona trachyte confirms its excellent flaking properties, and reveals that novice modern humans using this material are easily and immediately able to produce flakes comparable to those found at EG10. In contrast, artifacts produced by a modern novice on difficult-to-flake quartzite were quite distinct from the EG10 trachyte materials. Due to its high quality, the EG10 trachyte does not provide evidence of knapping skills that might have been evident (or demonstrably absent) in more difficult raw materials. On the other hand, evidence of the identification, selection and procurement of high-quality materials at EG10 and other Gona sites has much to reveal about the mental capabilities of the earliest stone toolmakers. It is even possible that the behavioral innovation leading to the first blossoming of knapped stone technology at Gona 2.5 million years ago lay as much in the selection of suitable raw materials as in the mastery of stone fracture mechanics.

Nevertheless, the trachyte artifacts from EG10 do provide important evidence of skilled flaking. The uniform reduction strategy of localized, unifacial flake removals employed at EG10 differs from the more opportunistic approach of novice knappers, and is indicative of experienced performance. This is also true of the production bias toward thicker flakes seen at EG10, which reflects consistent knapping practices that are underdetermined by raw materials and naïve approaches to least-effort flake production. The size and thickness of flakes from EG10 provide evidence of the skillful combination of percussive force and accuracy by the EG10 toolmakers.

The skill evident at EG10 is indicative of habitual knapping behavior associated with a relatively extended learning period. It is impossible to say exactly how long this learning period might typically have lasted, but it was most likely somewhere between the several hours required by modern humans and the hundreds of hours required by bonobos. This suggests the presence of relatively elaborate social contexts and mechanisms for skill learning, and has important implications for hominin social cognitive capabilities. It is striking that such skilled performance is evident from the very first appearance of stone knapping in the archaeological record.

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