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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 7

Learning from Mistakes: Flaking Accidents and Knapping Skills in the Assemblage of A.L. 894, (Hadar, Ethiopia)

Erella Hovers

Introduction

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

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

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

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

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

The Sample

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

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

Broken Artifacts: Flaking Accidents or Taphonomic Effects?

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

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

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

* *Small flakes <20 mm in maximum dimension.*
** *Number in parentheses is of whole artifacts out of the total for the type.*
*** *including one artifact classifiable as polyhedron, a unifacial chopper and a bifacial chopper.*

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

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

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

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

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

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

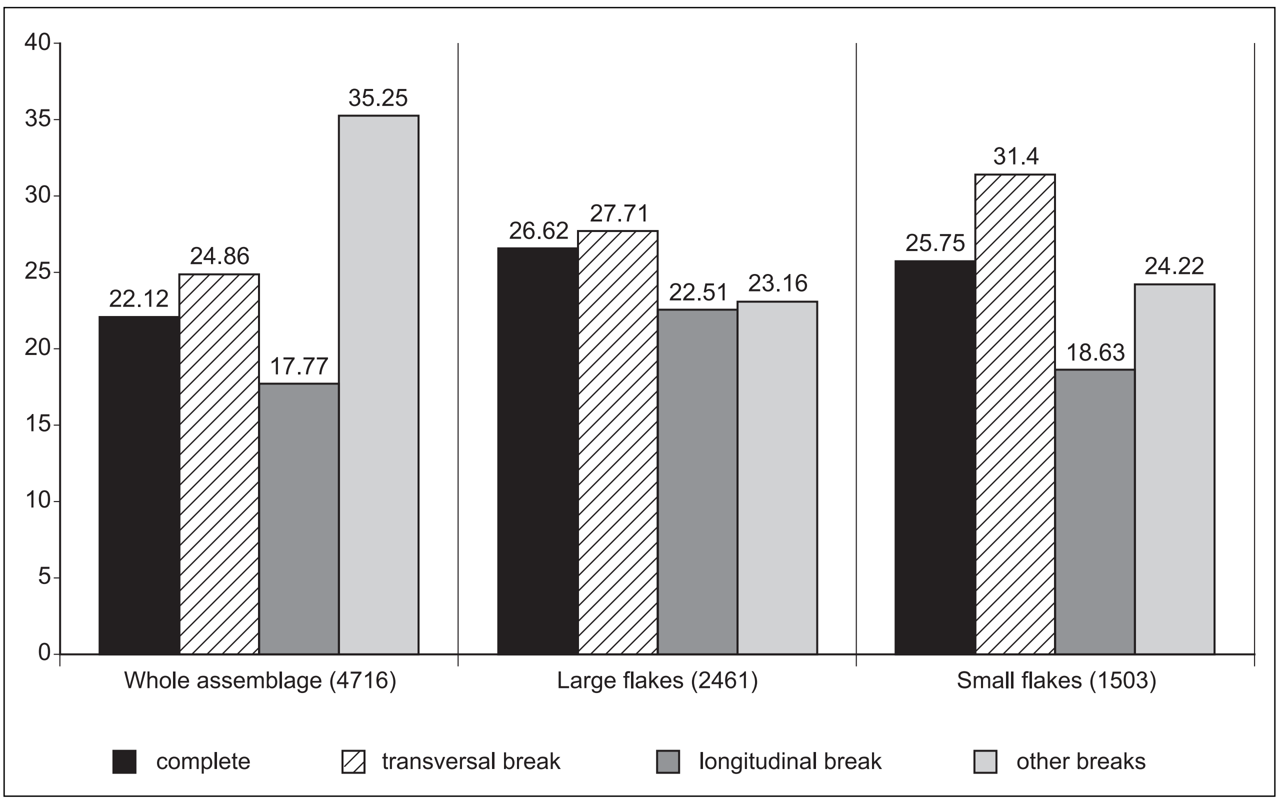

Figure 1. The distribution of breakage types. "Other breaks" is a catch-all category that includes combinations of break types as well as angular fragments, the origins of which cannot be traced reliably to knapping activities.

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

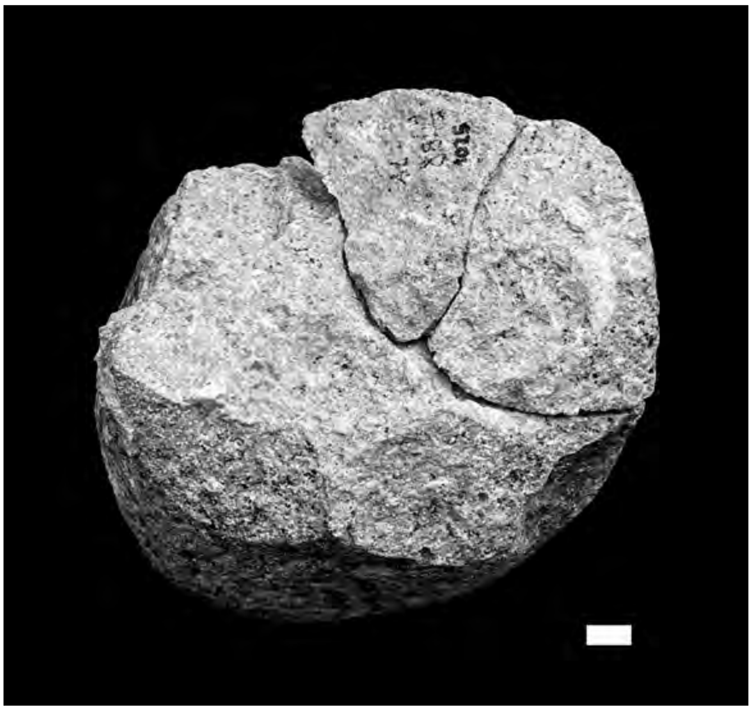

Figure 2. A core and a refitted Siret flake. Bar = 1 cm.

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

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

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

Stepped and Hinged Flakes and Knapping Skills

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Table 3. Effects of raw material on accidental flakes.

A. Frequencies of flakes with accidental scars by raw material

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

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

I. Whole flakes (all)

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

II. Whole large flakes

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

III. Whole small flakes

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

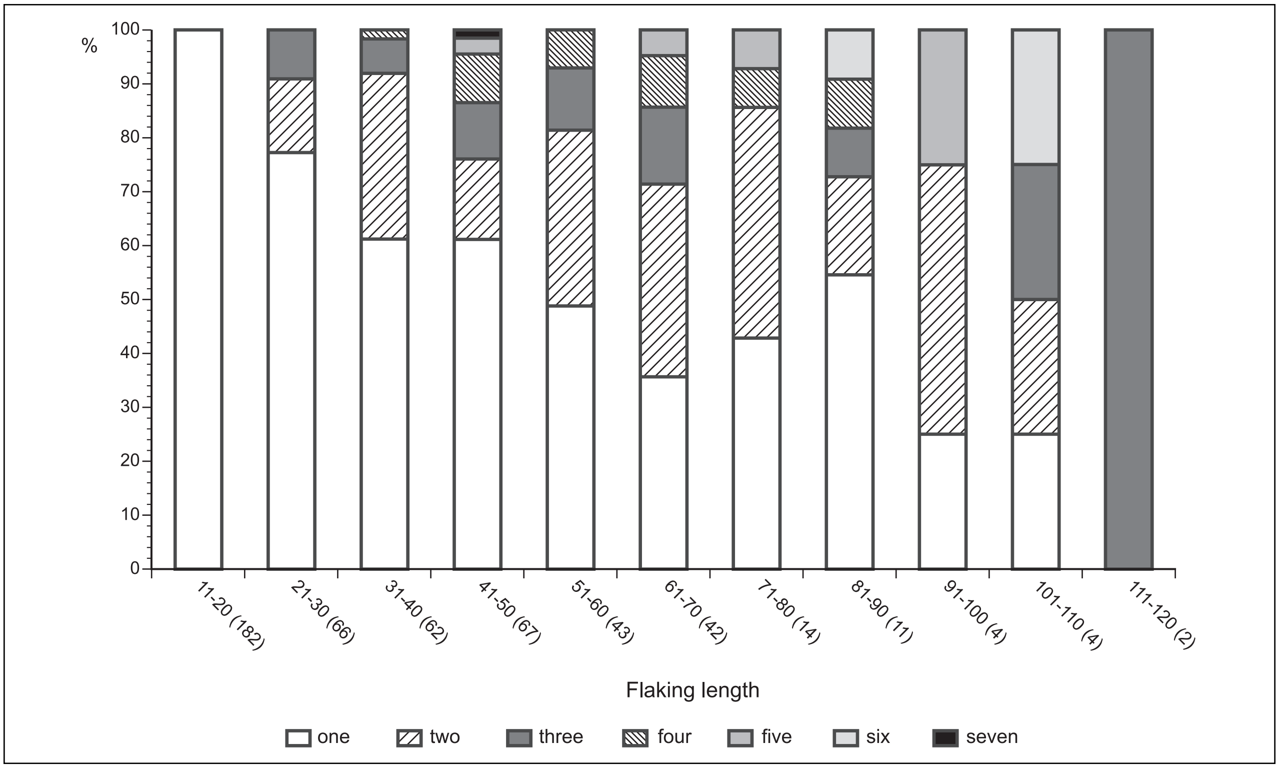

Figure 3. The distribution of accidental flake scars according to flaking length of whole large flakes. Regardless of size, single scars are the most frequent occurrences. Multiple scars are not necessarily associated with the longest items (though note the small sample sizes for some size categories).

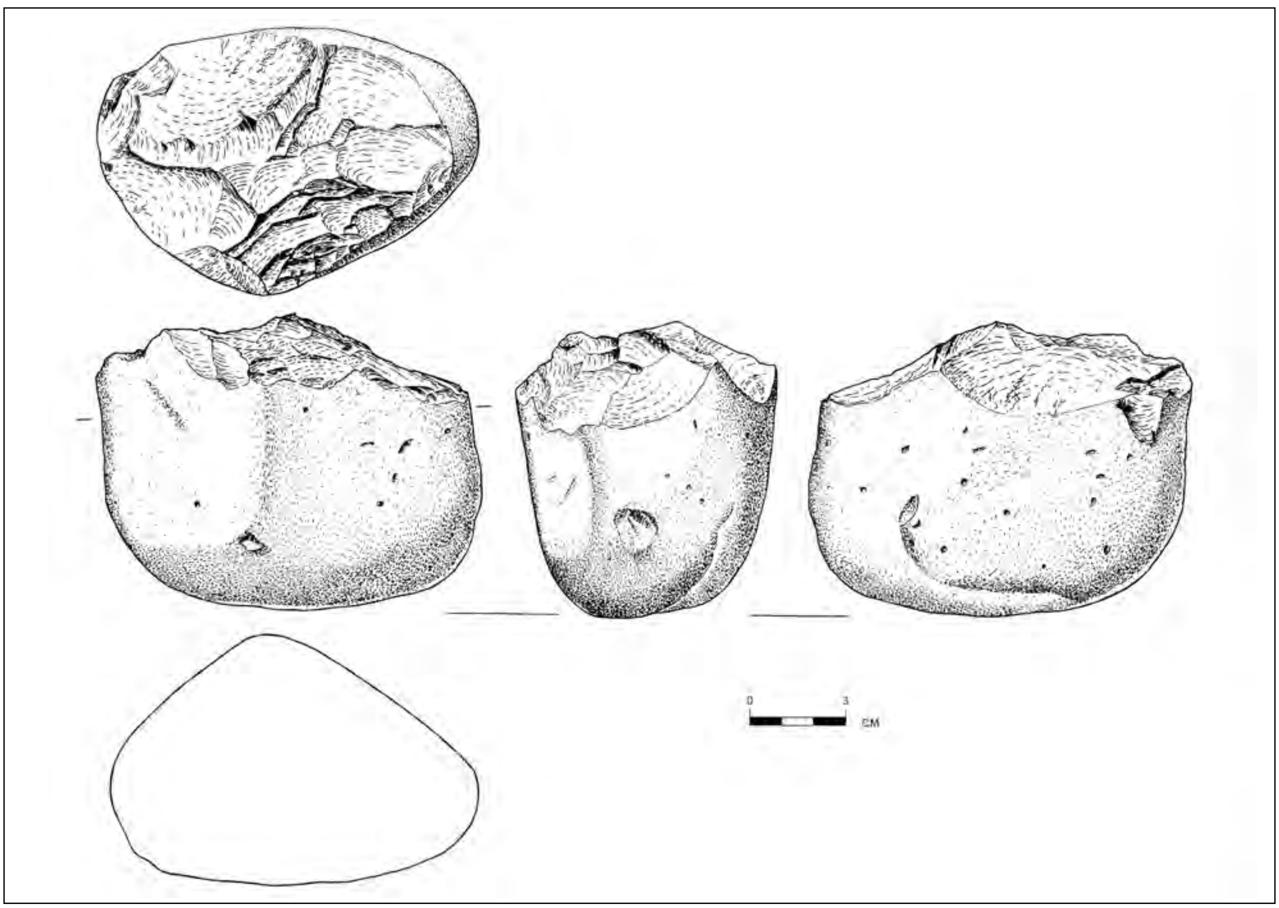

Figure 4. A discarded core. Note numerous small stepped scars concentrated in one part of the striking platform (best seen in the top view on the left).

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

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

* *flaking length, measured along the flaking axis*
** *flaking width, measured perpendicularly to flaking length*
*** *Thickness measured at half the flaking length*

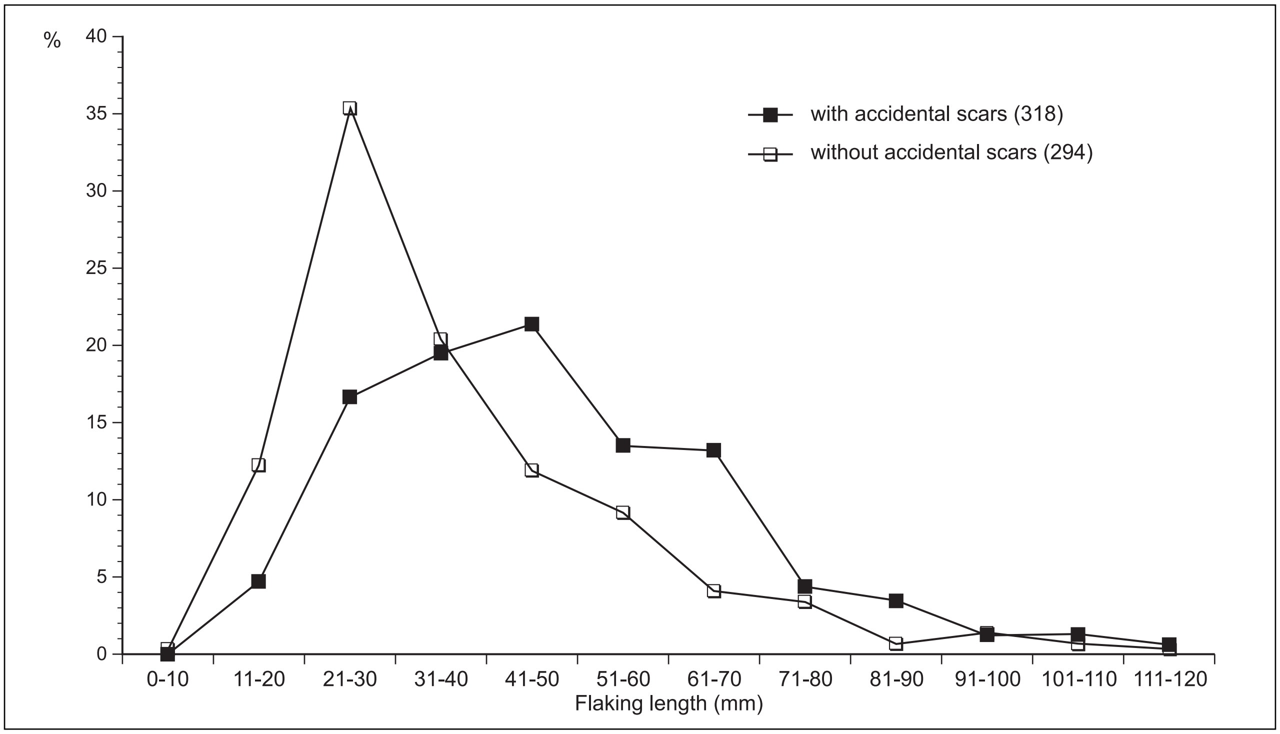

Figure 5. The distribution of flaking length of flakes with and without accidental dorsal face scars.

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

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

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

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

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

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

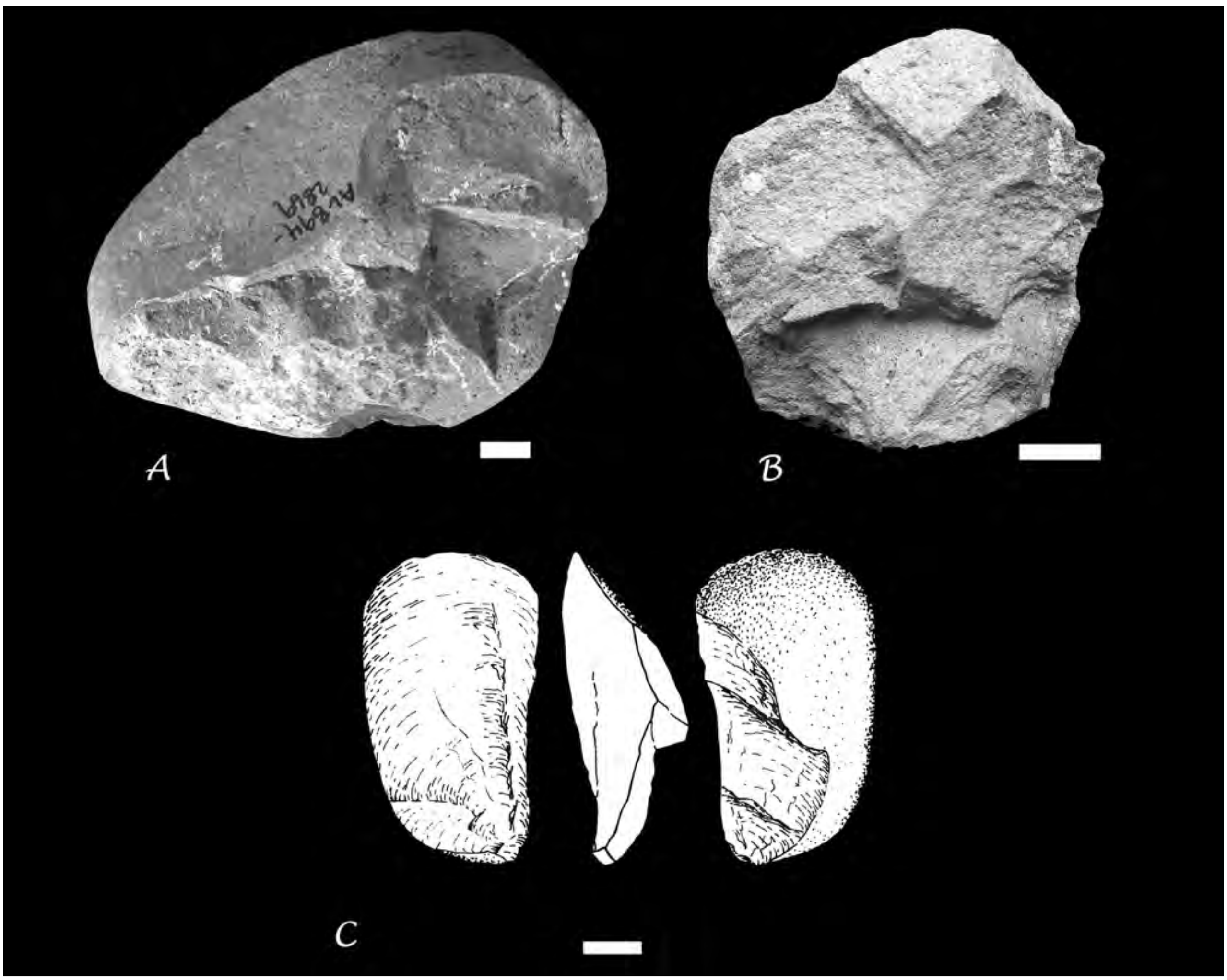

Figure 6. Examples of flakes with accidental scars in the A.L. 894 assemblage. ***A****. a series of scars from flakes terminating in step fractures, removed in an early stage of reduction, as indicated by the spatial distribution of cortex on its dorsal face. Accidental flaking thus occurred early on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

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

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

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

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

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

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

Table 6. Scar patterns on whole flakes.

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

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

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

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

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

Concluding Comments

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

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

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

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

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

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