# Exploring the Complexity and Structure of Acheulean Stoneknapping in Relation to Natural Language

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**ABSTRACT**

The intuition that there is a homology between sequenced action during stoneknapping and syntax in language is long-standing, but rarely explicitly analyzed. If valid, this proposed homology would allow paleoanthropologists to gain a handle on the timing and context of language emergence. Here, I present the results of three pilot studies performed to explore the methods such an analysis would require, as well as the issues that such an analysis would raise. The replication of an Acheulean handaxe was videotaped, then coded. This lithic reduction was analyzed using information theory, formal grammars, and Markov models. These three analyses found: (1) in terms of information entropy, the thinning phase of handaxe manufacture is as complex as many English language utterances; (2) the lithic reduction can be represented as a Context-Free Grammar (CFG), though in reality it only has limited embedding and is largely iterative in structure; and, (3) the lithic reduction also can be simulated by 'mindless' Markov models. These results raise a number of issues. First, it is not clear how to define and validate comparable units in stoneknapping and language. It is also not clear that the flow of actions performed by a stoneknapper can be easily segmented into discrete units. Second, in Studies One and Two, it was found that handaxe replication could be simulated by both a CFG and a Markov model instantiating a Finite State Grammar. The types of cognitive mechanisms capable of instantiating these are significantly different, with a CFG requiring memory resources not needed by the simpler Markov processes. These pilot studies indicate that it is possible to utilize these methods in the analysis of stoneknapping, but a number of basic conceptual and methodological issues remain to be clarified.

## INTRODUCTION: STONEKNAPPING AND LANGUAGE EVOLUTION

The hypothesis that the sequential structure of stoneknapping is homologous to syntax in language is long-standing (Holloway, Jr, 1969; Moore 2010) with support from neuroimaging studies of modern knappers replicating Acheulean technology (Stout and Chaminade 2012; Stout et al. 2008; Uomini and Meyer 2013). Both population-level cerebral asymmetries associated with language use and handedness (Holloway 1976; 1983) and the Early Acheulean technocomplex (Asfaw et al. 1992; Lepre et al. 2011) emerged approximately 1.8 ma. However, little work has been done to move beyond analogical and conceptual analyses to compare the structure of stone knapping to language. This paper is a contribution to the methodology of the structural analysis of stone knapping.

Are there deep structural similarities between language syntax and stoneknapping? If so, then stone knapping should exhibit an underlying grammar with actions organized into recursive, phrase-like structures that are in turn organized into overall sentence-like schemas (Figure 1). Such a structure would presumably mirror theoretical models of language and would require the hierarchical coordination of a diverse range of complex cognitive faculties (Barceló-Coblijn 2012).

In the 20th century, linguists working in generative grammar used formal languages to describe the underlying structure that all languages share. In particular, Chomsky (1959a) argued that a type of formal language called a context-free language (CFG, described below) captured all of the features required by the cognitive machinery powerful enough to generate the grammatical structures of observed ('natural') language. Chomsky's conclusions regarding the cognitive basis of language were motivated and limited by contemporary debates between behaviorists and cognitivists (e.g., Chomsky 1959b). More recent work viewing language as a dynamic system (Beckner et al. 2009; Christiansen and Chater 2008; Port 2010; Port and Leary 2005; Tomasello 2000, 2006) have profoundly challenged Chomsky's model of the language-capable brain. However, the comparison of sequential structures using formal languages remains a valid means of objectively comparing two sequential phenomena. If a CFG fits both natural languages and the actions involved in making a handaxe, this provides support for the intuitions of Holloway, Stout, and others.

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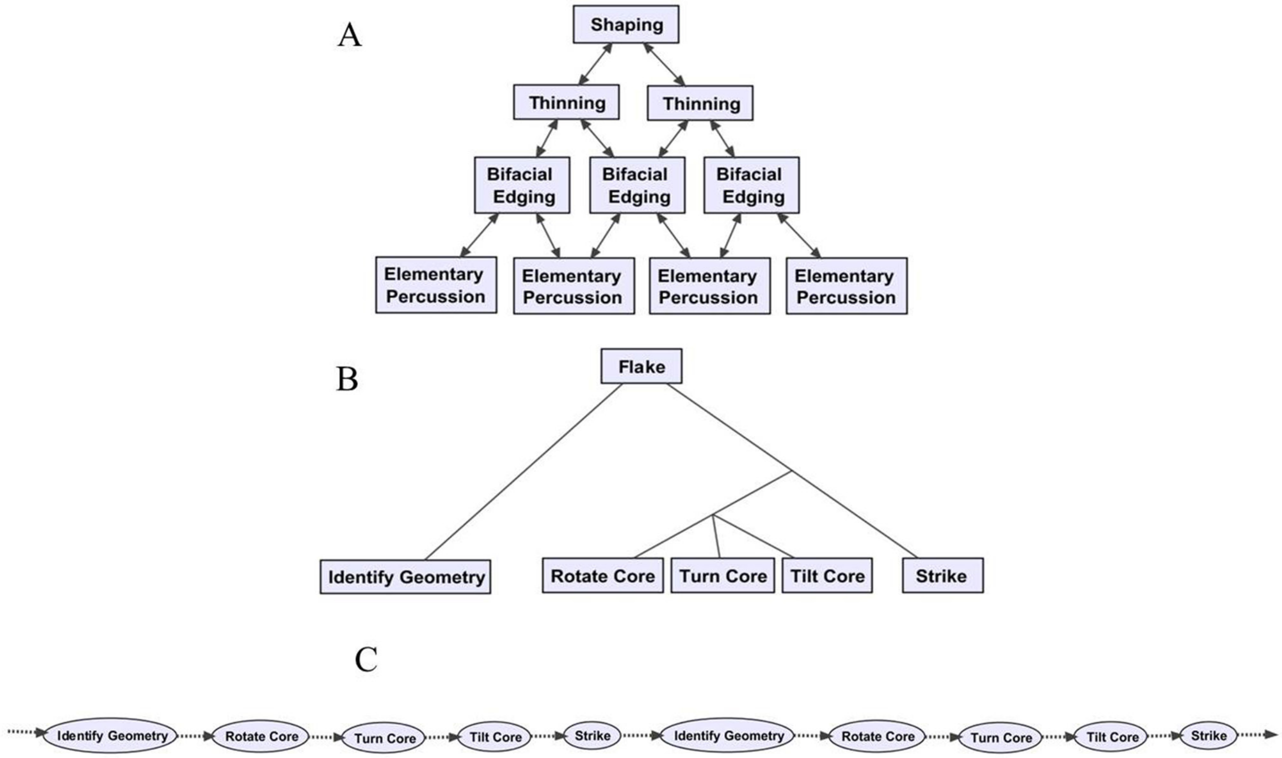


*Figure 1. The proposed hierarchical structure of stone knapping. (A) After Stout et al. (2008: 1941). Each level in the hierarchy represents a higher-level goal for the stone knapper. (B) After Moore (2011: 20). This represents the series of actions at the lowest level of (A). Moore refers to this as a basic flake unit, a term I apply as well. By analogy with language, a flake unit is homologous to a sentence. (C) The 'string-of-beads' model for stone knapping.*

There are alternative models for the cognitive structure of stoneknapping that do not require the complex cognitive machinery needed to implement a CFG. Wynn (1991) and Moore (2010; 2011) argue that this sequential structure could have been produced by a simpler mechanism that responded to changing stimuli in a manner analogous to a pigeon in a Skinner box conditioned to peck at a lever in response to a signal in order to receive a reward. Because the stimuli and response unfolds in time they are sequential, but this structure is not imposed by higher-level cognitive processes in the brain. Instead, such a sequence is a chain-like series of cause and effect followed by the knapper without planning. It should be noted that this argument is based on theoretical concerns. Wynn argued from a conceptual analysis of the components of both lithic reduction and language. Moore made an epistemologically argument based on principles of parsimony. Though limited, this study is the first empirical analysis of this issue.

These two models, the iterative chain ("string-of-beads") (see Figure 1) and CFG, may appear to be dichotomous. If this were the case, then a critical test could establish which of the two stoneknapping most resembles. In this pilot study, I analyze the sequence of actions used by a modern knapper replicating an Acheulean handaxe. The formal structure of stoneknapping is investigated using complexity measures, formal grammars, and simple Markov models. If the replication of an Acheulean handaxe is language-like in regard to the sequencing of actions, then observed sequence of action during the replication of a handaxe: (1) should exhibit levels of complexity similar to that seen in actual linguistic utterances; and, (2) a context-free grammar should fit the observed sequences better than a simpler finite state grammar implemented in a simple Markov model.

## STUDY 1: RELATIVE COMPLEXITY OF LANGUAGE AND STONE KNAPPING

### INTRODUCTION

Holloway (1969) proposed that the sequential structure of action in stone knapping reflects the same underlying structure as syntax in language. He writes:

> "Elements of a basic "vocabulary" of motor operations-flake detachment, rotation, preparation of striking platform, etc.-are used in different combinations to produce dissimilar tools, with different forms, and supposedly, different uses" (p. 54).

If this is the case, then the same metrics of relative complexity can be applied to both stoneknapping and a sample of utterances to determine how similar they are in terms of relative complexity.

There have been a number of attempts at finding a quantitative measure of technological complexity using graph theory (Mahaney 2013; Rugg 2011) or procedural

*Figure 2. The stoneknapper was videotaped for 40 minutes with a high definition digital video camera as he made an Acheulean handaxe out of a piece of high quality Texas flint. The study was performed at the Stone Age Institute in Gosport, Indiana, in 2010.*

units (Perreault et al. 2013).

These approaches focus on the cultural recipes (in the sense of Mesoudi and O'Brien 2008; Shore 1996) underlying a particular technology. While this is a valid and interesting approach to the problem, a recipe is an abstraction. The ability to assess the complexity of actual lithic reductions performed by stoneknappers would provide an additional perspective on technological evolution.

Information Theory provides the ideal means of approach to measure the complexity of sequential events. The concept of information entropy (Pierce 1980; Shannon and Weaver 1949) was developed by electrical engineers as a means of determining the most efficient way to encode information in bits for transmission over noisy channels. Information entropy measures uncertainty in a signal. If I were to say the word "dog," all other words in the language—such as "barks," "flies," "stoneknaps"—have a certain probability of following it. The more possibilities of subsequent words, the greater the listener's uncertainty. More complex signals, or sequences, have higher levels of uncertainty. Entropy is a measure of that uncertainty.

Information entropy can be applied to any sequential structure from computer programs (Linz 2011), genetic sequences (Lin 1991), life histories (Gabadinho et al. 2011), the English language (Shannon 1951a, b), or the actions performed during stone knapping. In this analysis, entropy is used to explore the relative complexity of the replication of an Acheulean handaxe co a sample compared to English language utterances. While there may be methodological and conceptual issues with this approach that I will discuss below, the goal of this analysis is to determine if this approach is potentially valid and informative.

## METHODS

An expert male stone knapper with over thirty years' experience working stone was videotaped for forty minutes replicating a cordiform Acheulean handaxe similar to those found at site of Boxgrove, United Kingdom (Figure 2). The knapper was not informed of the nature of the study so as to not influence his behavior. A nodule of high quality flint was used for this replication, as well a stone hammer and antler billet. A coding scheme was developed based on the observation of repeated technical actions performed by the knapper (Figure 3). Actions were defined simply, such as

**Action Schema defining a 'Flake Unit'**

(A) Rotation and placement of the blank
(B) Orientation, Platform Preparation, Flake Removal, Removal of Debitage

**Coding Scheme**

| Code | Action |
|---|---|
| a | Place blank on thigh |
| b | Orients lateral edge horizontally |
| c | Orients lateral edge, lowering distal edge |
| d | Orients lateral edge, raises proximal edge |
| e | Rotates lateral edge up, into view, while blank on thigh |
| f | Rotates lateral edge up, into view, after lifting blank (g) |
| g | Lifts blank. |
| h | Flips blank. |
| j | Touches platform with percussor ("aims" or "gauges") |
| k | Strikes blank. |
| l | "Chisel-like" platform preparation. |
| m | Abrasion with hammer. |
| o | Picks up debitage between fingers. |
| p | Sweeps away debitage with finger or percussor. |
| q | Set down hammer, pick up baton. |
| r | Set down baton, pick up hammer. |

**Examples of coded "flake units":**

"abjkkeop"

"ghabjkeop"

"gfhabdjjkeckkkep"

"ghadkep"

"gfabjjeckkepcjkepbjkep"

"gfhacecjkep"

"gharblllllllllllllllllllllllegfablllllllllllll
llegfablllllllllllllllegfhadmmmmmmmqdj
kepabjkjkjkjkjkepabjkegfabjkep"

"gfarbjllllllllllllefabjllllllllllegfhablllllllll
lllllegfablllllllllllllllllegfablllllllllllllllllllllll
llghabmmmmmmmmmmmmqebjkepabke
pabjkkkkkkegfabjkkghrfaqegfabjkepa
bjkkepegfabkkkkep"

*Figure 3: Coding scheme used in this study. In order to derive the grammar described in Study 2, the initial elements of the alphabet were specified. These included two non-terminal symbols (A and B) specifying the most basic components of a flake unit. It also included a coding scheme for each action performed by the knapper during each flake unit. These are terminal symbols. Coding resulted descriptions of all of the actions performed during each flake unit. Starting with the first two non-terminal symbols, the grammar in Figure 8 was derived. The coded actions also served as the basis for Study 1 and 3.*

*lifting* and *rotating* the core or tool blank, *placing* it, *orienting* the edge, *gauging* the blow, *striking*, and so on. The goal was to code repeated actions based on characteristics visually available to any observer, whether or not they had knowledge of stone knapping. These coded actions also were based on similar descriptions in Stout (2011), Moore (2010), and Holloway (1969). The proponents of both the action grammar and string-of-beads position agree on the fundamental units. Where they disagree is on how actions are linked to each other.

The component actions were coded with letters representing one of sixteen possible actions listed in Figure 3. The entire sequence was represented as a string of actions that were then segmented into *flake units* (Moore 2010; 2011). A flake unit includes all of the actions leading to the removal of a flake. It was observed that the knapper often prepared the core for a series of related removals. He then removed two or more flakes in quick succession. In doing so, he was effectively concatenating a series of flakes into a single flake unit. In those cases, this sequence was treated as a single unit.

These coded flake units were compared to a corpus of English language utterances transcribed from the 2nd US Presidential Debate in 2000 that were downloaded from the American National Corpus (Ide and Macleod 2001; Ide and Suderman 2002), an online archive for text-mining research. This corpus was segmented into sentences and punctuation removed. Both the stone knapping and language sequences were imported into the R 2.15.1 software (R Core Team 2012). Further processing and analyses were performed in the TraMiner package (Gabadinho et al. 2011; Gabadinho et al. 2009). Designed for analyzing life history sequences, TraMiner contains a number of analyses that can be applied to other forms of sequential data.

Shannon entropy was calculated for each flake unit and sentence. Entropy is being used as a relative measure of complexity and not an absolute measure. Shannon entropy is given by the formula:

$$H = -\sum p_i \log_b p_i$$

in which $p_i$ is the probability of an action or word occurring

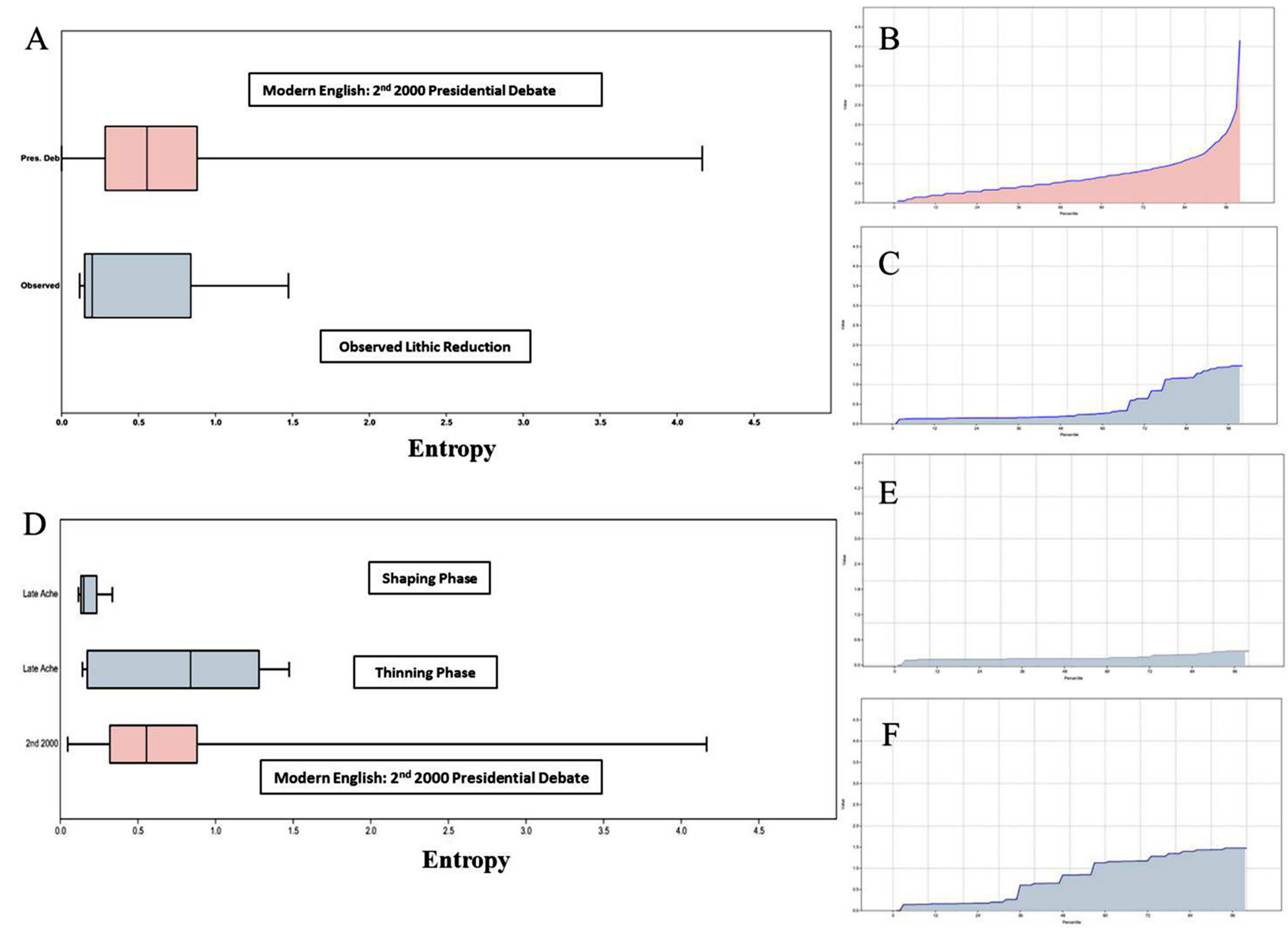


*Figure 4. (A) Boxplot of entropy scores (in bits) for replicated Acheulean flake units and sentences in the 2nd 2000 Presidential debate; (B) Cumulative distributions of entropy scores for the 2nd 2000 Presidential debate; and, (C) the entire Acheulean lithic reduction. Note the small number of higher scores in (B) over 1.47 bits. (D) Boxplot of entropy scores (in bits) for replicated Acheulean flake shaping and thinning phases units compared to sentences in the 2nd 2000 Presidential debate. (E) Cumulative distributions of entropy scores for Acheulean shaping; and, (F) the Acheulean lithic thinning phases. Note that (B) and (F) are visually more similar to each other than either is to (E), which is consistent with the Kruskal-Wallis results.*

at that point in the observed flake unit or sentence given the action or word preceding it. The resulting distribution of entropy values was not normal, so a three-sample Kruskal–Wallis test was performed over the aggregate samples to determine if the mean entropy differed significantly during the Presidential Debate, Acheulean Shaping phase, and Acheulean thinning phase.

## RESULTS

Overall, the knapper performed 2,683 actions organized into 46 flake units. This falls within the range of flake units for the knapping of a handaxe reported in Steele et al. (1995) and Chazan (2012). The 2nd 2000 Presidential debate had 1,086 total sentences.

Figure 4 shows the distribution of Shannon entropy for sentences from the Presidential debate ($M$=0.66, $SD$=0.50, range=0.04–4.16) and flake units during Acheulean shaping ($n$=23, $M$=0.18, $SD$=0.06, range=0.12–0.34) and thinning ($n$=23, $M$=0.78, $SD$=0.52, range=0.14–1.47) phases of the replication. There was a significant difference in the medians of the three samples, $H$=40.87, $p$<0.001. Post hoc Mann-Whitney pairwise comparison found no significance difference between the Presidential debate and Acheulean thinning, with mean ranks of 541.9 and 13.05 respectively (U=1.078E04, Z=-1.125, p=0.26). However, it did find a significant difference between Acheulean shaping and the Presidential Debate with mean ranks of 552.1 and 2.87 respectively (U=2901, Z=-6.31, p<0.001). There was also a significant difference between Acheulean shaping and thinning with mean ranks of 15.83 and 7.67 respectively (U=77, Z=-4.12, p<0.001).

While entropy values for the presidential debate vary through the entire series, those for stoneknapping show the expected initial shaping phase followed by thinning (Figure 5). The shaping phase (hard hammer) lacks the careful platform preparation of the later thinning phase (antler billet and hammerstone). There is a base flake unit present in shaping composed of *placing* the blank on the thigh ($a$),

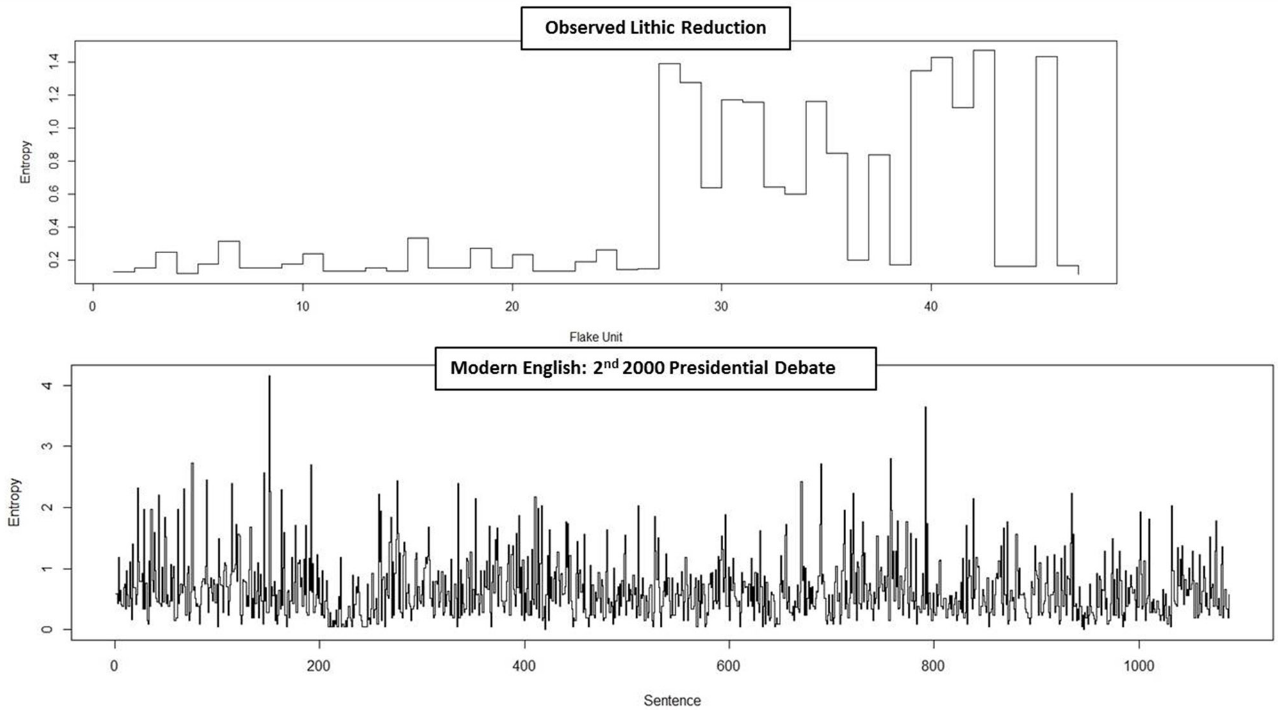


*Figure 5. Step plots of the entropy score for each sequence/sentence of the observed lithic reduction and the 2nd 2000 presidential debate. Entropy scores of the handaxe replication demonstrate the stark differences in complexity between the shaping and thinning phases.*

*orienting* the edge (*b, c, d*), *gauging* the blow (*j*), *striking* (*k*), and *sweeping* away debitage (*p*). This is obviously an invariant sequence. More variability, and thus higher entropy values, occurs during the thinning phase when additional platform preparation elements are added.

## DISCUSSION

In terms of information entropy, the earlier thinning phase of handaxe replication is less complex than the corpus of English language utterances and handaxe thinning. Handaxe thinning is not statistically different from the Presidential debate corpus. This latter result was completely unexpected. Natural languages such as English are theoretically infinite in their ability to recursively embed phrases within phrases (Bar-Hillel et al. 1961; Ogden 1968). In reality, there are practical limitations on working memory (Miller 1956) that the restrict the human capacity to understand or produce very long sentences. For generative linguists and many evolutionary psychologists (e.g., Fitch et al. 2005; Hauser et al. 2002; Pinker 1994; Pinker and Jackendoff 2005), it is this theoretically limitless recursivity that distinguishes language from all other animal communication systems. Figure 6 highlights this hypothesized design feature of natural language.

The greatest entropy value for the utterances is 4.16 bits while the greatest value for thinning a handaxe is 1.47. A flake unit is constrained to a *lift-placement-orient-strike-sweep debitage* structure. Additional platform preparation elements can only complicate the sequence so much until it becomes redundant and even counter-productive. Word order in language is not constrained in the same way, with *subject-object-verb*, *subject-verb-object*, and *verb-subject-object* being the most common word order (Tomlin 1986). While the perception and production of utterances are constrained by working memory capacity, phrase embedding in language can be more complex if there is a need for it to be. However, most of the time there may not be a need for higher levels of complexity.

This analysis and its methods raise important conceptual issues about research into the complexity and cognitive structure of stone knapping. It is not clear which units of action should be compared to particular linguistic structures, like phonemes, morphemes, sentences, or discourse. Is a flake unit comparable to a sentence? Looking at the graphical representations of knapping presented by Moore (2010) and Stout (2008, 2011) (see Figure 1), there does seem to be a similarity to the structure of a sentence—actions are grouped into phrase-like units that in turn are grouped into a sentence. However, does this graphical model map actually map onto stoneknapping or is it being imposed upon it? Hill (1972) speculated that stoneknapping was a simpler, shallower process than language. The actions out of which it is composed were homologous to consonants and not the morphemes that I have modeled them on in this pilot study. That said, the experimental work needed to determine what the appropriate units of analysis are has yet not been carried out.

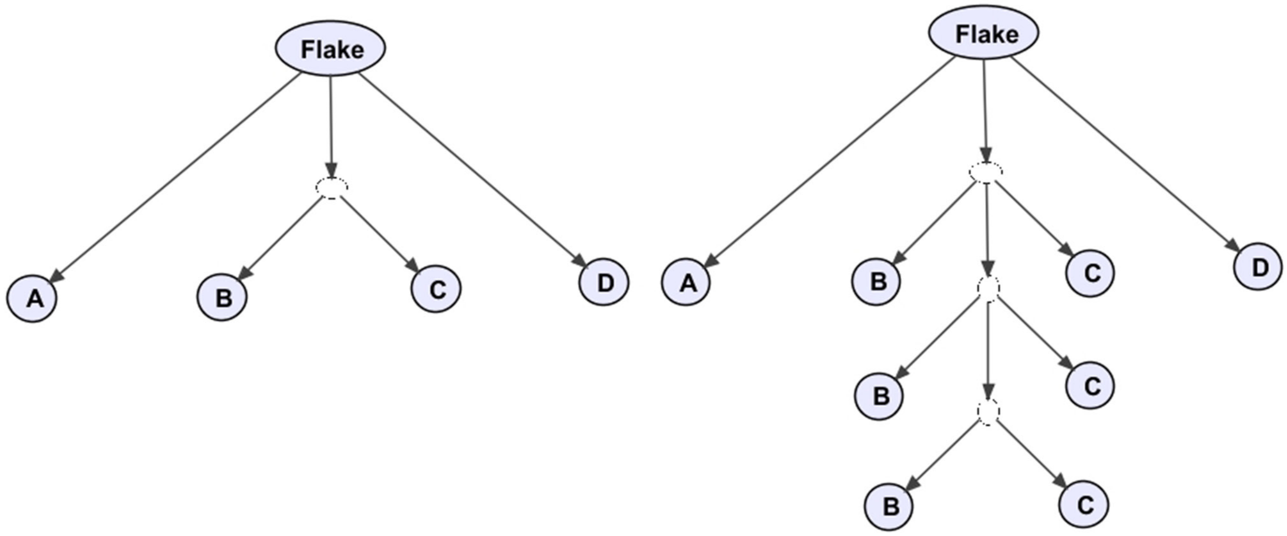


*Figure 6. The underlying theoretical recursive structure of a Context-Free Grammar modeling a flake removal. Generative linguists claim that this same structure occurs in natural language. (A) A, B, C, D represent components of the language. (B) Represents recursive embedding, in this case of B and C. Generative linguists claim that this is the defining trait of natural language. The ability to infinitely embed Bs and Cs independently of As and Ds represents the action of a 'pumping-lemma.' Grammars that satisfy this condition are referred to as context-free grammars (CFGs). Finite-state grammars, such as the string-of-beads in Figure 1C do not have this feature.*

## STUDY 2: CONTEXT-FREE ACTION GRAMMAR FOR STONE KNAPPING

### INTRODUCTION

The result that the thinning phase of handaxe replication may be as complex as many English utterances is surprising. However, that alone does not justify the homology of sequencing during stoneknapping and language syntax. Formal grammars were applied to describe and explore the underlying structure of handaxe replication. Formal grammars are used in generative linguistics and computer science to understand the behavior of languages and computer programs. Chomsky (1956) has proposed a hierarchy of possible formal grammars. Generative linguists argue that the actual languages that humans use, or *natural languages*, can be classified as context-free grammars (CFGs) (Chomsky 1959a). Simpler finite state grammars (FSGs) are realizable by simple Markov processes. According to the generative linguists, CFGs can recursively embed phrases into a sentence while FSGs cannot. For example, given the sentence "The knapper struck off the flake," a FSG can use conjunctions to concatenation phrases onto the end of a sentence:

> The knapper struck off the flake *and swept away the debitage*.

A CFG can recursively embed phrases within a sentence:

> The knapper, *who has worked stone for twenty years*, struck off the flake and swept away the debitage.

> The knapper, *who has worked stone, such as flint, for twenty years*, struck off the flake and swept away the debitage.

Such recursive embedding presumably requires a more complex cognitive mechanism than simple concatenation. It is this feature of recursivity that the many linguists and evolutionary psychologists believe is the crucial, distinguishing design feature of human language (see Figure 6) (e.g., Hauser et al. 2002). Sequential phenomena like natural language and stoneknapping can be described using formal languages without committing to the cognitive models supported by generative linguists. They provide a principled method of the comparison of the observable, surface features of a behavior. It does not follow that similar surface features require the same neurocognitive mechanisms to instantiate them. However, considerations of parsimony would support the hypothesis of shared cognitive resources.

Observation of Acheulean replication shows that there is possible embedding in the thinning phase. Archaeologists suggest that platform preparation is embedded recursively within the basic flake unit, leading to its flexible elaboration (Pelegrin 2005). A basic recipe is not executed in a mindless fashion, but, instead, components are flexibly managed, repeated, or skipped as the situation demands. This flexibility is one of the hallmarks of hierarchically structured cognition (Byrne and Russon 1998) and intelligence (Tomasello and Call 1997). The presence of this embedding means that it should be possible to derive a CFG to describe the replication of an Acheulean handaxe (Pastra and Aloimonos 2012). Elaborated operational chains appear archaeologically approximately 700 ka (Stout et

- Start with a structure constructed from terminal symbols
  - Follow a series of rules (a grammar) that define how to transform these into terminal symbols

| Starting Schema | Simple Grammar | Example Derivation |
|---|---|---|
| S | S → AB | S → AB |
| | A → aB | AB → aBB |
| | B → b | aBB → abB |
| | | abB → abb |

In this example we are given S and end with abb.

*Figure 7. Simple example of a formal grammar discussed in the text.*

al. 2014), so if it is possible to represent the replication of these lithic reductions as a CFG then it this may indicate language capacity among hominins at this date.

## METHODS

The same lithic reduction used in the earlier study was reanalyzed in this study.

A formal grammar is comprised of a series of states (*A,B,C* . . .), symbols (*a,b,c*. . .), and rules for generating symbols from states (Figure 7) (Linz 2011; Revesz 1991). For instance, the rule *A→aB* means "If in state *A* 'print' (or 'emit') *a* and go into state *B*". A series of states leads to the printing of strings like *abb*. The process halts when all states are exhausted (or when the system reaches a STOP state, a state not included in this analysis).

The 'strings' of action performed by the knapper were already segmented into flake units in the earlier study, providing the first element of structure in this grammar. At this point, a decision was made to structure flake units (*T*) into three phases—placement of the blank (*A*), the preparation and removal of the flake (*B*), and the sweeping away of the debitage (C). This gives the first rule, *T→ABC*. Obviously, this was the *imposition* of an *a priori* structure on the strings. After formulating this initial structure, each flake unit was analyzed to derive the rules for moving from one action to the next (Appendix). Additional states were only added as necessary. At this point, it was found that the *T→ABC* flake unit schema appeared to inadequately represent the observed action and the rule was shortened to *T→AB* (see Appendix). The resulting rules were checked against the observed strings to verify that it could generate all observed flake units (see Appendix).

## RESULTS

It is possible to generate a right-branching CFG capable of generating the observed flake units (Figure 8, see Appendix).

Overall, the resulting grammar demonstrates both recursive and chain-like behavior. First, it was common to concatenate (link in a chain-like manner) a series of flake removals onto a basic flake unit. The knapper would prepare a large region along the lateral edge of the blank, and then he would remove a series of flakes. This structure is captured by the rule B → EFCB. After proceeding through states E, F, and C, the knapper arrives at B and can reinsert EFCB (B → EFCB → EFCB → EFCB → EFCB . . .).

This can be repeated as often as is necessary. For example, Appendix Example 3 can be verbalized as "The stoneknapper performs the basic flake unit in which he removes a flake (1–13) and he removes another flake (14–20) and he removes another flake (21–29)."

Next, there were two rules for embedding repeated platform preparation sequences. During the thinning phase, the rule E → HIE allowed for the insertion of platform preparation (HIE) in the B → EFCB sequence. Then chisel-like platform preparation (H → ENCAH) and abrasion (I → EGCAI) could be repeated as often as was necessary in a chain-like manner. Appendix Example 4 can be verbalized as "The stoneknapper, carefully preparing his platforms (5–41), performs the basic flake unit in which he removes a flake (1–48) and he removes another flake (50–55) and he removes another flake (56–61) and he removes

**T → AB**
**A → aB | g | gD | λ**
**B → EFCB**
**C → eK | eL | λ**
**D → h | f | hD | fD**
**E → aM | M | HIE | λ**
**F → jJ | jC | jF | J**
**G → m | mG**
**H → ENCAH | λ**
**I → EGCAIO | λ**
**J → k | kJ | J**
**K → o | oL**
**L → p**
**M → b | bE | bG | c | cE | d | aCM | bCM | cCM**
**N → l**
**N → lN**
**O → qB**

*Figure 8. Context-Free Grammar capable of producing all of the flake units observed as a stoneknapper replicated an Acheulean hand axe.*

another flake (62–69)."

On paper, this grammar does satisfy the requirements of a CFG, it would be referred to as a 'pumping lemma' (Bar-Hillel et al. 1961; Ogden 1968). However, this result is slightly misleading. Remember that a CFG is potentially infinitely recursive according to generative linguists. However, in reality these sequences only demonstrate a single recursive level during the thinning phase. Platform preparation proceeds by concatenation (H → ENCAH → ENCAH → ENCAH . . . I → EGCAI → EGCAI → EGCAI . . .) one level 'below' the basic flake unit (T→AB → EFCB → EFCB → EFCB . . .) that also proceeds by concatenation (Figure 9). In other words, neither a 'string-of-beads' structure nor a recursive action grammar appears to be a valid way to conceptualize stoneknapping. Instead, it appears to be a 'string-of-beads' with limited embedding of another 'string-of-beads' sequence.

## DISCUSSION

It is possible to describe the operational sequence that produces an Acheulean handaxe as a CFG. As with the study of complexity above, this is a very interesting result. Perhaps more interesting is the finding that this bout of stoneknapping is both a limited recursive grammar and a 'string-of-beads.' If natural language is a CFG, then this means that stone knapping only shares structural features with it to a limited extent. Yet, there are three important issues that this study raises.

First, it cannot be claimed that this grammar is *the* grammar for the replication of an Acheulean handaxe. Theoretically, there are an infinite number of possible grammars that could have produced these flake units. In addition, the actions as coded in this study are not the only approach to identifying the component actions. For instance, should an action be coded as "orienting the blank" or as "orienting the blank to a particular degree in a particular relation to the knapper"? Arguments can be made for both approaches. Evolutionary cognitive archaeologists need to develop conventions to address this methodological issue.

Second, the definitions of actions, flake units, and an overall schema for a basic flake unit (*T→AB*) are necessary steps in formulating an action grammar. However, these units are imposed on the sequence following theoretically based assumptions. These are reasonable assumptions

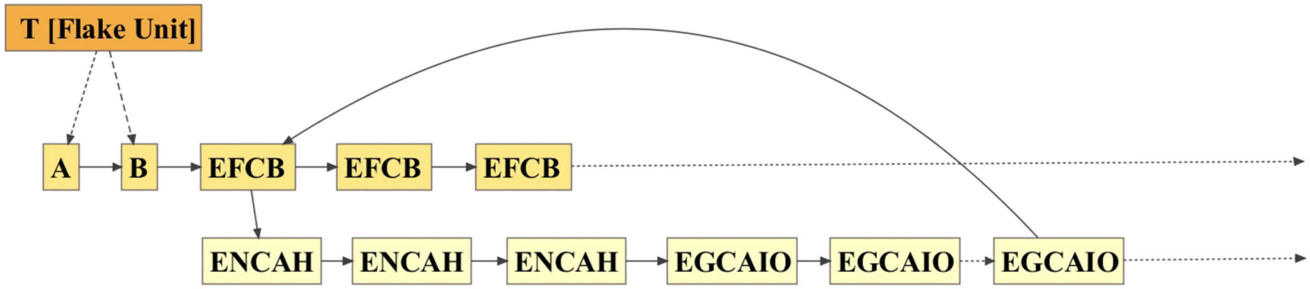


*Figure 9. The structure of a flake unit during Acheulean stone knapping. On paper, this reduction sequence can be described as a CFG (see Figure 8, Appendix) with theoretically infinite embedding (see Figure 6). However, the bout of stone knapping analyzed in this paper only demonstrates a single level of embedding within the basic flake unit. Both levels exhibit an iterative 'string-of-bead' structure.*

based on current experience and observation of stone knapping. Stone knapping is an ongoing flow of action that I segment into discrete units. However, it is not even clear that it is composed of discrete units. This facilitates the description of the process, but that could potentially be a distortion introduced by the methods of description used to record that data. Port (2010; Port and Leary 2005) argues that this is the case in some areas of linguistics. For example, he argues that phonemes have no neurocognitive reality as discrete units of sound but instead are artifacts of writing systems that represented this flow of sound as discrete letters. Being able to describe stone knapping in terms of discrete units does not mean that these descriptive units are real.

These two related issues bring me to a third, deeper theoretical issue. Comparisons to language assume that language is a well understood phenomena. However, this is not the case. First of all, not all linguists believe that natural languages require the powerful machinery of a CFG (Shieber 1987). Luuk and Luuk (2012) argue that simple iterative structures such as those described in this action grammar (B → EFCB, H → ENCAH, I → EGCAI) could reproduce most of the embedded structures in natural languages. Furthermore, any CFG can be described as a FSG. CFGs are favored because they do not make the assumption that a mindless process is responsible for generating a flexible linguistic behavior (i.e., Chomsky 1959b). In other words, they are favored due to overall theoretical considerations. Though Wynn proposed an iterative, string-of-beads structure to stoneknapping, he does not regard it as 'mindless.' On the other hand, Moore (2010, 2011) has explicitly claimed that the sequencing observed in stoneknapping could be mindless, performed by the kind of process that would compute a FSG. To test examine this claim, I performed the next study using Markov processes.

## STUDY 3: 'MINDLESS' MODELS OF STONE KNAPPING

### INTRODUCTION

As mentioned in the previous section, some linguists and neuroscientists contend that CFGs are too powerful for observed natural languages. In fact, a FSG can generate the same string of symbols as a CFG. However, they lack the additional phrase-structure present in a CFG.

Instead of deriving a FSG here, I examined the observed lithic reduction using Markov processes to simulate the observed sequences of actions performed by the stoneknapper. A Markov process can be thought of as a hypothetical machine, or automata 'emitting' or 'printing' strings of symbols as moves through a series of states probabilistically (Howard 2007). For each level of the Chomsky hierarchy of formal language there is a corresponding level in automata theory. CFGs are computed by pushdown automata equipped with a 'stack' onto which states such as the AB flake schema or the EFCB can be stored. FSGs are computed by Markov models. These automata lack the memory capacity that allows a pushdown automaton to recursively embed phrases into a string of symbols. With Markov processes, the only factor that determines the subsequent state is the state the system is in at the moment. A Markov process is modelled with two components, a transition matrix and an emission matrix. The transition matrix contains the probabilities of moving from one state to the next. The emission matrix contains the probabilities of emitting a particular symbol while in a particular state. In such a model, a state is comprised of both the condition of the stone knapper and the blank he is working. The emitted symbols represent the actions that he performed. In this third study, I used two simple Markov processes determine how well such a simple mindless process could simulate the sequenced actions performed by the stone knapper replicating an Acheulean handaxe.

### METHODS

The same coded lithic reduction used in the earlier studies was re-analyzed in this study. Two different Markov models were created for this analysis—a simple transition matrix model and a prior-knowledge model.

For the Simple Markov (SMM) model, I determined the probabilities for transition from one action to another in the observed sequence, creating a transition matrix. Each ac-

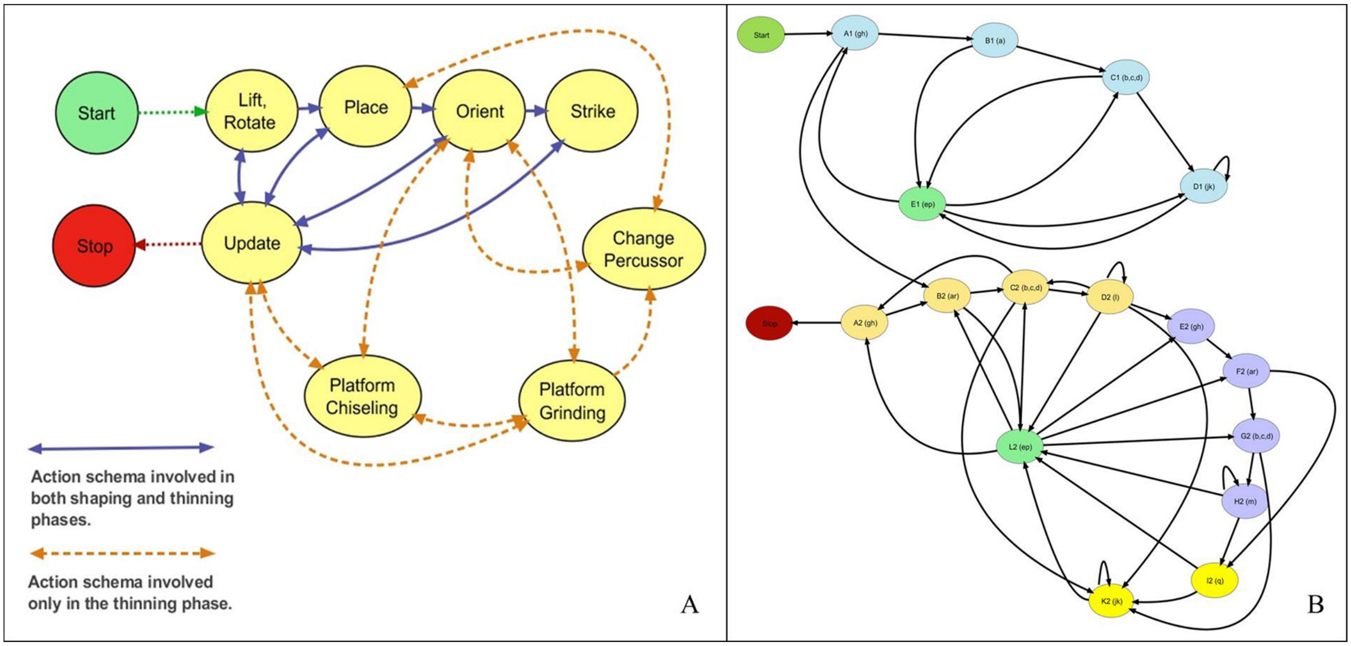


*Figure 10. (A) The component elements of the observed Acheulean replication. (B) The Prior-Knowledge (PK) Markov model used to test Moore's proposal of a mindless algorithm. The system transitions from one state (oval) to the next probabilistically, emitting a symbol (an 'action') when in each state. Note that the shaping (top loop) and thinning (bottom loop) phases are built into the model. Transferring from shaping to thinning is a low probability event, meaning that in most runs the model stayed in the shaping phase for a considerable amount of time before transitioning to the thinning phase. In this way, it replicated the procedure of making a bifacial tool.*

tion was treated as a state. There were no emitted 'symbols' and the strings generated represented the progression of the state transitions. The model was run in R 2.15.1.

Containing only the frequencies of observed actions, the simple Markov model does not actually approximate the 'string-of-beads' model proposed by Moore (2010 and, in a different sense, by Wynn [1991]). This model contains latent variables, or states, that occur sequentially and emit an evoked response (the observed action). A state refers not only to the condition of the core, but also to the condition of the mind of the knapper. A Prior Knowledge (PKM) model was constructed by the author using knowledge of the process by which Acheulean handaxes are made. In this model, the transition matrix contains theoretical probabilities for the transfer from one state to the next. An emission matrix contains the theoretical probabilities for the emission of a particular action or set of actions when the system is in that state. Theoretical values were used for this study simply to test the feasibility of system like this, built on empirically derived archaeological theories, to simulate strings of actions that resemble observed strings. The shaping and thinning phase were built into this model, with a transition between shaping and thinning modeled as a low probability event. See the discussion below for further comment on this approach. This model was run in R using the HMM package (Himmelmann 2010). The PKM model is presented visually in Figure 10.

The performance of these two simple Markov models was assessed both qualitatively and quantitatively. Observed actions and simulated strings were assessed in terms of five features. *Procedural coherence* (1) refers to the all of the strings in a single run of a model. If the run had a simple shaping phase followed by a thinning phase, then it was procedurally coherent. Thinning is defined by the presence of chisel-like platform preparation and abrasion or grinding platform preparation. Each string was classified as shaping or thinning based on the presence or absence of these features. *String coherence* (2) refers to each individual string generated by a model. If the string follows a coherent flake schema (core placement, orientation, striking, flake removal), even if it is atypical of an actual flake removal episode as performed by the observed knapper, it is considered coherent. *Chisel-like platform preparation/ grinding preparation reversal* (3) refers to the performance of these platform preparation techniques in a reversal of the expected order. *Chisel-like platform preparation exclusive* (4) refers to strings in which only this action is used to prepare a platform. *Grinding platform preparation exclusive* (5) refers to strings in which only this action is used to prepare a platform. Simple counts were made of the presence / absence of these features in both the observed and simulated action.

Next, I used two quantitative methods of determining how well the simulated strings approximated observed actions. Both methods use the concept of edit distance between strings. *Levenshtein Similarity* calculates the number of changes required to change one string of symbols, like "string," into another, like "strung" (1 change) or "apple" (6 changes). These changes include both deletions and replacements. The distance between two strings ($str_1$, $str_2$) is then divided by the length of the longest string (*max(A,B)*)

**TABLE 1. RESULTS OF THE QUANTITATIVE ANALYSIS OF THE OBSERVED LITHIC REDUCTION, SIMPLE MARKOV MODEL (SMM), AND PRIOR-KNOWLEDGE MARKOV MODEL (PKM).**

Procedural coherence refers to the presence of an initial shaping phase followed by a thinning phase. The SMM did not reproduce this feature. However, both the SMM and PKM produced coherent strings, meaning that they would result in the removal of a flake. Chisel-like (CPP) and Abrasion (APP) platform preparation reversal refers to the performance of abrasion before the chiseling of the edge. This reversal only occurred in the SMM. Both the observed lithic reduction and the SMM had strings/sequences in which only chiseling or only abrasion occurred, but these occurred at much higher frequencies in the SMM. These results indicate that the 'mindless' Markov models could simulate sequences similar to those performed by the stone knapper.

| Class | Procedural Coherence | String Coherence | CPP-APP Reversal (%) | CPP Only (%) | APP Only (%) |
|---|---|---|---|---|---|
| **Observed Lithic Reduction** | Yes | Yes | 0 | 0.02 | 0.11 |
| **Simple Markov** | No | Yes | 0.04 | 0.15 | 0.26 |
| **Prior-Knowledge Markov** | Yes | Yes | 0 | 0 | 0 |

and subtracted from 1 to give an approximate similarity measure:

$$1 - \frac{d(str_1, str_2)}{\max(A,B)}$$

The Levenshstein Similarity (Levenshtein 1966) was calculated between: a) all string pairs in the observed lithic reduction and between b) each simulated string produced by the Markov models and each string in the observed lithic reduction: a) provides a sense of the variability and self-similarity within the observed lithic reduction. b) provides a sense of how well each simulated string approximates the observed sequences of action. This analysis was performed in the RecordLinkage package (Borg and Sariyar, 2012) in R 2.15.1.

A second edit distance metric was also generated—OM distance. OM distance calculates both the number of replacements and deletions required to transform one sting of a particular class ("observed sequence, shaping phase" or "simple Markov model, thinning phase"). This provides an indication of how variable or self-similar each set of strings/sequences is. OM discrepancy was analyzed using Zapala and Schork's (2006) extension of a Discrepancy Analysis (Studer et al. 2010, 2011) for multiple variables. This analysis was performed in R 2.15.1 using the TraMiner package. The discrepancy matrix is used as a pseudo sum of squares, allowing the application of the $F$ statistic, reported here as pseudo $F$. A pseudo $r^2$ is also generated by the test, providing a further assessment of the strength of the effect. The effects of string/sequence class (observed x simple x prior knowledge) and phase (shaping x thinning) on discrepancy were assessed.

Finally, each observed or simulated sequence was analyzed using Gabadinho's complexity index (Gabadinho et al. 2010). This index calculates the complexity of a sequence relative to the maximum \possible complexity possible for that sequence given its length and the component alphabet. Gabadinho's complexity is calculated using this formula:

$$C(s) = \left(\frac{q(s)h(s)}{q_{max}, h_{max}}\right)^{.5}$$

where $s$ is the observed or simulated string, $q(s)$ is the number of transitions in the sequence, $h(s)$ is the within sequence entropy, $q_{max}$ is the maximum number of transitions, $h_{max}$ is the theoretical maximum entropy for this alphabet of coded actions:

$$h_{max} = -log \frac{1}{|A|}$$

Minimum values of zero can only be reached if the sequence is made up of only one state while maximum values represent a string with all possible component actions and maximum entropy.

## RESULTS

Results are presented in Table 1 and Figure 10. Qualitatively, the 'mindless' Markov models could simulate sequences similar to those performed by the stoneknappers. They also performed well quantitatively (Figure 11). The Levenshtein Similarity of observed shaping sequences to themselves was 0.59 while the distance of the SMM model to the observed lithic reduction was 0.50 and PKM model to OS was 0.64. During the shaping phase, the PKM model showed very limited variability. The increased variability of action in the thinning phase led to lower similarity values. However, sequence lengths and discrepancies indicate that these two simple models could have approximated the observed strings better. Overall, on average both the SMM and PKM strings were shorter with less variability or discrepancy than the actual observed sequences. The Discrepancy Analysis did find an effect for both string class

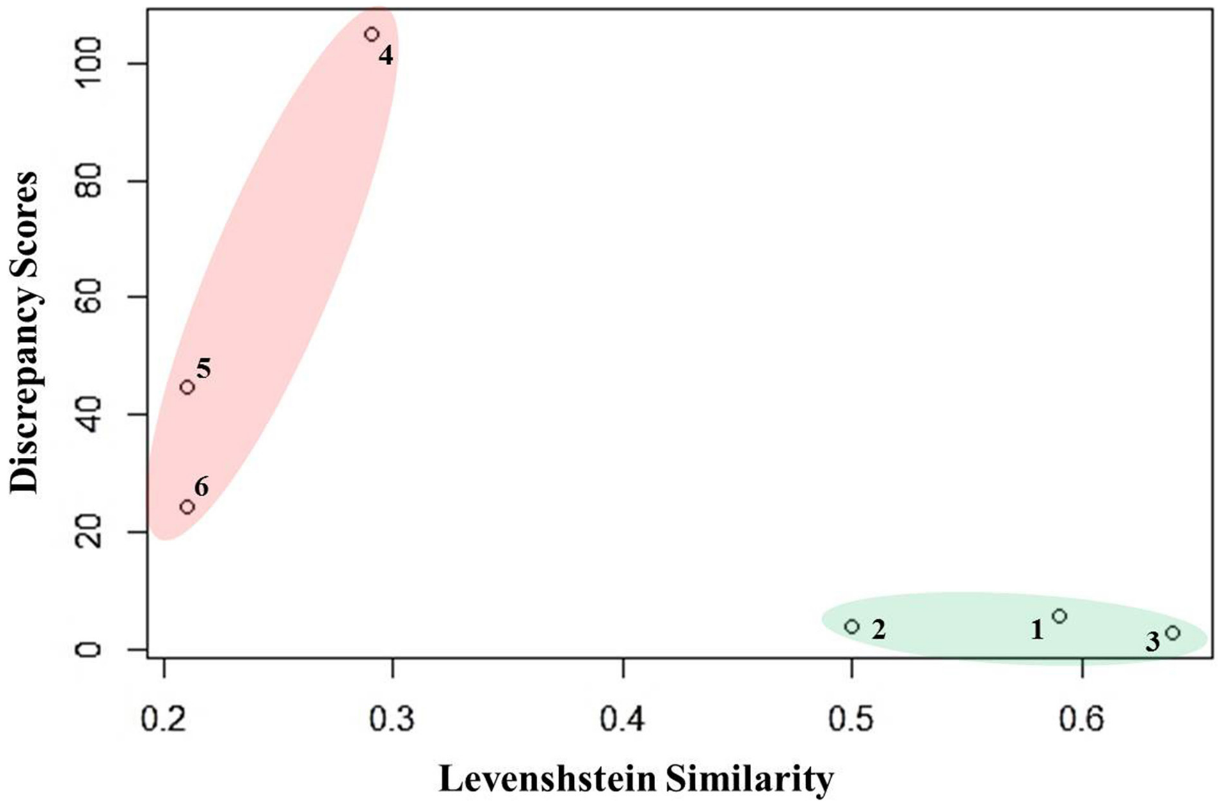


*Figure 11. Comparing the observed lithic reduction, the SMM, and the PKM using Levenshstein distance and Discrepancy Scores: 1 = Observed Shaping, 2 = SMM Shaping, 3 = PKM Shaping, 4 = Observed Thinning, 5= SMM Thinning, 6 = PKM Shaping, Blue = Shaping regions, Red = Thinning region. Again, the simple Markov models performed fairly well, with observed and simulated shaping and thinning strings clustering together. Shaping scores should show lower variability, thus lower similarity and discrepancy scores. Thinning strings should show increased variability. The statistical analysis performed on discrepancy scores found significant differences for string class (Pseudo F=90.27, Pseudo $r^2$=0.19, p<0.001) and phase (Pseudo F=99.87, Pseudo $r^2$=0.21, p<0.001). While the 'mindless' models successfully simulated many qualitative and quantitative features of the sequences of actions performed by the stoneknapper, these models can be improved markedly in future studies.*

(Pseudo $F$=90.27, Pseudo $r^2$=0.19, $p$<0.001) and phase (Pseudo $F$=99.87, Pseudo $r^2$=0.21, $p$<0.001).

Finally, an examination of the Gabadinho's complexity value demonstrates that the Prior-knowledge Markov Model captured the shaping and thinning phases of handaxe manufacture. Two runs are illustrated in Figure 12. Run 1 presents a shaping phase that is unrealistically short while Run 2 presents one that is unrealistically short. However, the models were able to capture this feature of the overall operational sequence.

## DISCUSSION

In Study 1, I was able to demonstrate that it is feasible to model the reduction of an Acheulean handaxe as a CFG. In this analysis, I was able to show that it is also possible to model the same sequences as a FSG using Markov models, though in this case the models could be significantly improved. Most of the features present in the observed strings were easily reproduced by a system lacking the higher level mechanisms required by the CFG mentioned above.

However, there are two issues with this study that should be highlighted. First, this study should be expanded and the models improved. The models were relatively crude. Note how the PKM model is structured with a shaping phase distinct from the thinning phase (see Figure 10). It could be argued that because the core has significantly changed its condition between these two phases, the states within the model are qualitatively different. To examine a core with a significant amount of cortex on it that the knapper will remove with a hard hammer may be fundamentally different from examining the core when you are removing thinning flakes with an antler billet. On the other hand, it may not be qualitatively different and all that actually changes after shifting from shaping to thinning are the relative probabilities of performing different actions as the reduction progresses. Other types of Markov models, such as time-varying Markov processes (Howard 2007), may be a more appropriate approach than that followed in this pilot study. In addition, Markov models can be derived directly from observed data or tuned based on observed data using machine-learning techniques such as the Baum-Welch algorithm.

The second issue is more theoretical. While it is possible to reproduce a sequence that mirrors the actions re-

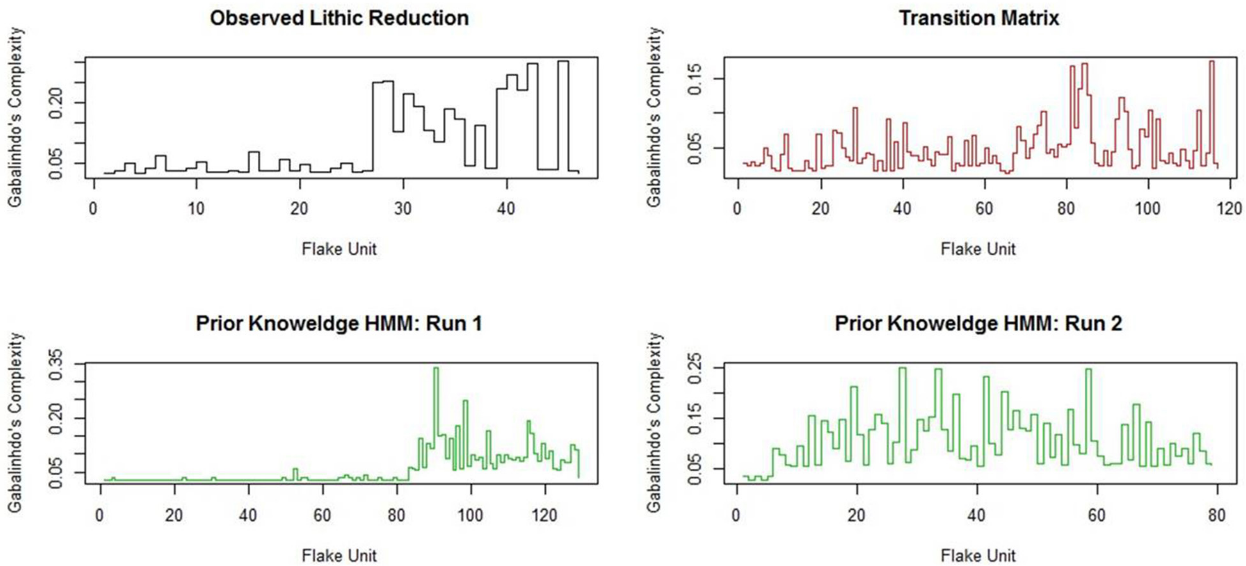


*Figure 12. Gabadinho's Complexity Index per string/sequence plotted over the course of the observed lithic reduction and representative runs of the 'mindless' Markov models. The observed lithic reduction demonstrates the expected shaping and thinning phases. As would be expected from Study 1, this increase in complexity is of one order of magnitude. PKM Run 1 and 2 also have this structure, though in the case of Run 2, the shaping phase is unrealistically short.*

produced during actual stone knapping, the concept of a state is problematic in that it combines the mental state of the knapper, the physical state of his body, and the state of the core. In other words, this may be a false simplicity.

## DISCUSSION: ISSUES AND POSSIBILITIES

These pilot studies provided three results:

1. The thinning phase of handaxe replication is as complex as many instances of spoken language.
2. Handaxe replication can be described using a Context-Free Grammar. It has a structure in which iterative units at two levels embed and concatenate actions onto a basic flake schema.
3. The observed actions of a stone knapper replicating a handaxe can be simulated by a Markov process.

As these studies found that both a CFG and Markov model fit the data well, the initial hypothesis that language and replicated Acheulean stone knapping display a homology in terms of a shared deep grammatical structure is not supported by this analysis. As I will discuss below, this result can be attributed to methodological issues.

The ultimate goal of these three pilot studies was to explore the issues involved in modelling stoneknapping as a cognitive process, especially in relation to natural language. To compare these two behaviors, researchers must be able to place them within the same analytical and theoretical framework. The use of information theory and formal grammars can provide such a framework, but their practical application raises a number of issues.

In order to construct this framework, it is essential to determine that valid units occurring at the same organizational level are being compared. At this point, it is not clear what a valid unit of action occurring during stoneknapping actually is. To validate the units being analyzed, it may be useful to have both expert knappers and non-knappers view videos of stone knappers at work and code it every time a new event (action) occurs. The analysis action using motion-tracking software, as in a series of studies by Bril and collaborators (Rein et al. 2013; Bril and Nonaka 2012; Bril et al . 2010; Nonaka et al. 2010; Foucart et al. 2005; Bril et al. 1996; Roux et al. 1995) could provide a more accurate and rigorous representation of the repetitive actions occurring as a knapper works. Neuroimaging studies of stone knapping may also help clarify this issue. Oldowan *debitage* activated bihemispheric parietal and cerebellar regions but not left lateralized frontal regions (Stout et al. 2011; Stout et al. 2008). Acheulean *façonage* (shaping) activates these regions as well as additional right lateralized frontal regions. Stout et al. (2008) have proposed that the additional activations in the right hemisphere indicate the hierarchical cognitive organization of stone knapping. Stout's studies support the modeling of handaxe replication as a context-free action grammar.

The action grammar and Markov models used in these studies grossly simplify the cognitive processes involved in stone knapping. Sensory and perceptual processes are simply assumed. The apparent action grammar of stone knapping has always attracted considerable attention, perhaps distorting understanding of the cognitive foundations of stone knapping and limiting research questions. Recent studies by researchers such as Blandine Bril and colleagues (Bril et al. 2010; Bril et al. 1996; Foucart et al. 2005; Nonaka and Bril 2012; Nonaka et al. 2010; Rein et al. 2013; Roux et al. 1995) have approached stone knapping through radically different theoretical and methodological means, helping to broaden understanding of the cognitive dimension of stone knapping considerably.

This is not to say that approaches similar to those presented in this paper are uninformative. To the contrary, they hold the promise of generating a deeper understanding of how stoneknapping is actually structured. Such an understanding is vital if evolutionary cognitive archaeologists are going to attempt to use technology as an index of cognitive evolution in the Pleistocene. The rich theoretical apparatus of formal languages and automata theory can be very useful in this regard. Consider the relationship between formal language and automata described earlier. An automata is a hypothetical computational mechanism, such as a Turing machine (Linz 2011; Turing 1936), capable of computing languages of different complexity. Finite state machines, automata instantiating Markov processes, are capable of computing FSGs. CFGs require a pushdown automaton. The crucial feature of a pushdown machine is the stack, which serves the role of storing memory. For instance, if given B, the system works on E while storing F, C, and B on the stack. This 'working memory' allows the system to hold the overall schema in mind while recursively embedding phrase-like platform preparation sequences. Analysis of the structure of Oldowan and Acheulean stone knapping, in relation to other lines of evidence, may indicate that Oldowan *debitage* does not require the neurocognitive equivalent of the pushdown stack while Acheulean *façonage* does.

This paper focused one dimension of the potential relationship between language and Acheulean lithic technology, the sequencing of verbal and technological actions. However, there are potential relationships along another dimension, social learning. More specifically, some researchers have asked if language is necessary to learn the skills and cultural recipes required for the production of an Acheulean handaxe. In an ethnoarchaeological study of contemporary stone knappers in Irian Jaya, Indonesia, Stout et al. (2002) found that adze makers worked in an intergenerational social context. They proposed that Acheulean knappers also may have transmitted technological knowledge in a similar way. Putt et al. (2014) have recently performed an experimental study in which novices were trained by an expert knapper using verbal and nonverbal cues. No significant difference was found between the handaxes and debitage produced by novices instructed differently. However, that study did not systematically control the content of the verbal interchanges between the novices and expert. Varying verbal strategies across groups may potentially yield different results. It is interesting, however, that this study reached ambivalent results regarding the role of language in the replication of Acheulean technologies.

The approaches piloted in these studies can provide a valuable and productive, though not unproblematic, framework for research into cognitive evolution during the Pleistocene. Future studies should address some of the issues raised here to move evolutionary cognitive archaeology forward from the analysis of surface features to deeper structural analyses.

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## APPENDIX

### EXAMPLE 1:

**Observed Sequence: ghabjkeop**

1. Intends to remove a shaping flake with a hard hammer
2. Lift blank from thigh
3. Flip blank in hand
4. Insert flake removal sequence EFCB
5. Place blank on thigh
6. Orients lateral edge horizontally
7. Gauges blow
8. Strikes
9. Rotates lateral edge up, into view
10. Picks up debitage between fingers
11. Sweeps away debitage
12. Deletes concatenating B
13. Completed flake unit

1. T → AB
. 2AB → gDB
3. gDB → ghB
4. ghB → ghEFCB
5. ghEFCB → ghaMFCB
6. ghaMFCB → ghabFCB
7. ghabFCB → ghabjJCB
8. ghabjJCB → ghabjkCB
9. ghabjkCB → ghabjkeKB
10. ghabjkeKB → ghabjkeoLB
11. ghabjkeoLB → ghabjkeopB
12. ghabjkeopB → ghabjkeopλ
13. ghabjkeopλ

**Analysis:** This is a simple flake unit without any concatenated or embedded units.

### EXAMPLE 2:

**Observed Sequence: ghadm$^4$epcjkeo**

1. Intends to remove a shaping flake with a hard hammer
2. Lift blank from thigh
3. Flip blank in hand
4. Insert flake removal sequence EFCB
5. Insert platform preparation sequence HIE
6. Delete chisel-like platform preparation sequence H
7. Insert abrasion sequence EGCAIO
8. Place blank on thigh
9. Orients lateral edge, raising
10. Abrasion
11. Abrasion [Repeat 2 more times]
12. Rotates lateral edge up, into view
13. Sweeps away debitage
14. Deletes AIO
15. Insert M
16. Orients lateral edge, lowering
17. Gauges blow
18. Strike
19. Strike
20. Picks up debitage between fingers
21. Deletes concatenating B
22. Completed flake unit

1. T → AB
2. AB → gDB
3. gDB → ghB
4. ghB → ghEFCB
5. ghEFCB → ghHIEFCB
6. ghHIEFCB → ghλIEFCB
7. ghλIEFCB → ghλEGCAIOEFCB
8. ghλEGCAIOEFCB → ghλaMGCAIOEFCB
9. ghλaMGCAIOEFCB → ghλadGCAIOeFCB
10. ghλadGCAIOEFCB → ghλadmGCAIOEFCB
11. ghλadmGCAIOEFCB → ghλadm$^2$GCAIOEFCB [Repeat 2 more times]
12. ghλadm$^4$CAIOEFCB → ghλadm$^4$eLAIOEFCB
13. ghλadm$^4$eLAIOEFCB → ghλadm$^4$epAIOEFCB
14. ghλadm$^4$epAIOEFCB → ghλadm$^4$epλ$^3$EFCB
15. ghλadm$^4$epλ$^3$EFCB → ghλadm$^4$epλ$^3$MFCB
16. ghλadm$^4$epλ$^3$MFCB → ghλadm$^4$epλ$^3$cFCB
17. ghλadm$^4$epλ$^3$cFCB → ghλadm$^4$epλ$^3$cjJCB
18. ghλadm$^4$epλ$^3$cjJCB → ghλadm$^4$epλ$^3$cjkCB
19. ghλadm$^4$epλ$^3$cjkCB → ghλadm$^4$epλ$^3$cjkeLB
20. ghλadm$^4$epλ$^3$cjkeLB → ghλadm$^4$epλ$^3$cjkeoB
21. ghλadm$^4$epλ$^3$cjkeoB → ghλadm$^4$epλ$^3$cjkeoλ
22. ghλadm$^4$epλ$^3$cjkeoλ

**Analysis:** This flake unit is somewhat atypical for this stoneknapper's shaping phase in that he embedded a platform preparation sequence within it (5–13). Most of the platform preparation sequence as not performed, only those aspects of the abrasion sequence of use to the knapper.

### EXAMPLE 3:

**Observed Sequence: gfhaejk$^2$epckepck$^2$ep**

1. Intends to remove a shaping flake with a hard hammer
2. Lift blank from thigh
3. Rotates edge up into view after lifting
4. Flip blank in hand
5. Insert flake removal sequence EFCB
6. Place blank on thigh
7. Rotates edge up into view while blank on thigh
8. Delete M
9. Gauges blow

10. Strike
11. Strike
12. Rotates edge up into view while blank on thigh
13. Rotates lateral edge up, into view
14. Concatenates with flake removal sequence EFCB
15. Inserts M
16. Orients lateral edge, lowering
17. Skip gauging blow, insert J
18. Strike
19. Rotates lateral edge up, into view
20. Sweeps away debitage
21. Concatenates with flake removal sequence EFCB
22. Inserts M
23. Orients lateral edge, lowering
24. Skip gauging blow, insert J
25. Strike
26. Strike
27. Rotates lateral edge up, into view
28. Sweeps away debitage
29. Deletes concatenating B
30. Completed flake unit

1. T → AB
2. AB → gDB
3. gDB → gfDB
4. gfDB → gfhB
5. gfhB → gfhEFCB
6. gfhEFCB → gfhaCMFCB
7. gfhaCMFCB → gfhaeMFCB
8. gfhaCMFCB → gfhaeλFCB
9. gfhaeλFCB → gfhaeλjJCB
10. gfhaeλjJCB → gfhaeλjkJCB
11. gfhaeλjkJCB → gfhaeλjk$^{2}$CB
12. gfhaeλjk$^{2}$CB → gfhaeλjk$^{2}$eKB
13. gfhaeλjk$^{2}$eKB → gfhaeλjk$^{2}$epB
14. gfhaeλjk$^{2}$epB → gfhaeλjk$^{2}$epEFCB
15. gfhaeλjk$^{2}$epEFCB → gfhaeλjk$^{2}$epMFCB
16. gfhaeλjk$^{2}$epMFCB → gfhaeλjk$^{2}$epcFCB
17. gfhaeλjk$^{2}$epcFCB → gfhaeλjk$^{2}$epcJCB
18. gfhaeλjk$^{2}$epcJCB → gfhaeλjk$^{2}$epckCB
19. gfhaeλjk$^{2}$epckCB → gfhaeλjk$^{2}$epckeLB
20. gfhaeλjk$^{2}$epckeLB → gfhaeλjk$^{2}$epckepB
21. gfhaeλjk$^{2}$epckepB → gfhaeλjk$^{2}$epckepEFCB
22. gfhaeλjk$^{2}$epckepEFCB → gfhaeλjk$^{2}$epckepMFCB
23. gfhaeλjk$^{2}$epckepMFCB → gfhaeλjk$^{2}$epckepcFCB
24. gfhaeλjk$^{2}$epckepcFCB → gfhaeλjk$^{2}$epckepcJCB
25. gfhaeλjk$^{2}$epckepcJCB → gfhaeλjk$^{2}$epckepckJCB
26. gfhaeλjk$^{2}$epckepckJCB → gfhaeλjk$^{2}$epckepck$^{2}$CB
27. gfhaeλjk$^{2}$epckepck$^{2}$CB → gfhaeλjk$^{2}$epckepck$^{2}$eLB
28. gfhaeλjk$^{2}$epckepck$^{2}$eLB → gfhaeλjk$^{2}$epckepck$^{2}$epB
29. gfhaeλjk$^{2}$epckepck$^{2}$epB → gfhaeλjk$^{2}$epckepck$^{2}$epλ
30. gfhaeλjk$^{2}$epckepck$^{2}$epλ

**Analysis:** This is a simple flake unit from the shaping phase with two additional concatenated flake removals (14–19, 20–28).

### EXAMPLE 4:

**Observed Sequence: ffhabl$^{5}$gfgabkep**

1. Intends to remove a shaping flake with a hard hammer
2. Blank already lifted, insert D
3. Rotates edge up into view after lifting
4. Rotates edge up into view after lifting
5. Insert flake removal sequence EFCB
6. Insert platform preparation sequence HIE
7. Insert chisel-like platform preparation sequence ENCAH
8. Place blank on thigh
9. Orients lateral edge horizontally
10. Chisel-like platform preparation
11. Chisel-like platform preparation [Repeat 3 times]
12. Delete C
13. Lifts blank
14. Rotates edge up into view after lifting
15. Deletes abrasion sequence I
16. Place blank on thigh
17. Orients lateral edge horizontally
18. Skips gauging blow, inserts J
19. Strike
20.Rotates lateral edge up, into view
21. Sweeps away debitage
22. Deletes concatenating B
23. Completed flake unit

1. T → AB
2. AB → DB
3. DB → fDB
4. fDB → ffB
5. ffB → ffEFCB
6. ffEFCB → ffHIEFCB
7. ffHIEFCB → ffENCAHIEFCB
8. ffENCAHIEFCB → ffaMNCAHIEFCB
9. ffaMNCAHIEFCB → ffabNCAHIEFCB
10. ffabNCAHIEFCB → ffablNCAHIEFCB
11. ffablNCAHIEFCB → ffabl$^{2}$NCAHIEFCB [Repeat 3 times]
12. ffabl$^{5}$CAHIEFCB → ffabl$^{5}$λAHIEFCB
13. ffabl$^{5}$λAHIEFCB → ffabl$^{5}$λgDHIEFCB
14. ffabl$^{5}$λgDHIEFCB → ffabl$^{5}$λgfgHIEFCB
15. ffabl$^{5}$λgfgHIEFCB → ffabl$^{5}$λgfgλ$^{2}$EFCB
16. ffabl$^{5}$λgfgλ$^{2}$EFCB → ffabl$^{5}$λgfgλ$^{2}$aMFCB
17. ffabl$^{5}$λgfgλ$^{2}$aMFCB → ffabl$^{5}$λgfgλ$^{2}$abFCB
18. ffabl$^{5}$λgfgλ$^{2}$abFCB → ffabl$^{5}$λgfgλ$^{2}$abJCB
19. ffabl$^{5}$λgfgλ$^{2}$abJCB → ffabl$^{5}$λgfgλ$^{2}$abkCB
20. ffabl$^{5}$λgfgλ$^{2}$abkCB → ffabl$^{5}$λgfgλ$^{2}$abkeLB
21. ffabl$^{5}$λgfgλ$^{2}$abkeLB → ffabl$^{5}$λgfgλ$^{2}$abkepB
22. ffabl$^{5}$λgfgλ$^{2}$abkepB → ffabl$^{5}$λgfgλ$^{2}$abkepλ
23. ffabl$^{5}$λgfgλ$^{2}$abkepλ

**Analysis:** This is a somewhat atypical elaborated flake unit from the thinning phase with an embedded platform preparation sequence (7–13). Abrasion was skipped by the stoneknapper (14–16).

### EXAMPLE 5:

**Observed sequence:**
**gfabl$^{20}$egfabl$^{23}$bl$^{11}$cl$^{49}$ghacm$^{8}$qcjk$^{2}$epjk$^{2}$jk$^{2}$ep**

1. Intends to remove a shaping flake with a hard hammer
2. Lift blank from thigh
3. Rotates edge up into view after lifting
4. Insert flake removal sequence EFCB
5. Insert platform preparation sequence HIE
6. Insert chisel-like platform preparation sequence ENCAH
7. Place blank on thigh
8. Orient lateral edge horizontally
9. Chisel-like platform preparation
10. Chisel-like platform preparation [Repeat 18 times]
11. Orient lateral edge up into view with blank on thigh
12. Lift blank from thigh
13. Rotates edge up into view after lifting
14. Insert chisel-like platform preparation sequence ENCAH
15. Place blank on thigh
16. Orient lateral edge horizontally
17. Chisel-like platform preparation
18. Chisel-like platform preparation [Repeat 21 times]
19. Delete AC
20. Insert chisel-like platform preparation sequence ENCAH
21. Insert M
22. Orient lateral edge horizontally
23. Chisel-like platform preparation
24. Chisel-like platform preparation [Repeat 9 times]
25. Delete AC
26. Insert chisel-like platform preparation sequence ENCAH
27. Insert M
28. Orient lateral edge, lowering edge
29. Chisel-like platform preparation
30. Chisel-like platform preparation [Repeat 47 times]
31. Delete AC
32. Lifts blank
33. Flips blank
34. Deletes embedding H
35. Inserts abrasion sequence EGCAIO
36. Place blank on thigh
37. Orient lateral edge, lowering edge
38. Abrasion
39. Abrasion [Repeats 6 times]
40. Deletes CA and embedding I
41. Set down hammer, pickup antler baton
42. Already on thigh, insert M
43. Orient lateral edge, lowering edge
44. Gauges blow
45. Strike
46. Strike
47. Rotates lateral edge up, into view
48. Sweeps away debitage
49. Concatenates with flake removal sequence EFCB
50. Inserts M
51. Orients lateral edge horizontally
52. Gauging blow
53. Strike
54. Strike
55. Deletes C
56. Concatenates with flake removal sequence EFCB
57. Deletes E
58. Gauging blow
59. Strike
60. Strike
61. Deletes C
62. Concatenates with flake removal sequence EFCB
63. Deletes E
64. Gauging blow
65. Strike
66. Strike
67. Rotates lateral edge up, into view
68. Sweeps away debitage
69. Deletes concatenating B
70. Completed flake unit

1. T → AB
2. AB → gDB
3. gDB → gfB
4. gfB → gfEFCB
5. gfEFCB → gfHIEFCB
6. gfHIEFCB → gfENCAHIEFCB
7. gfENCAHIEFCB → gfaMNCAHIEFCB
8. gfaMNCAHIEFCB → gfabNCAHIEFCB
9. gfabNCAHIEFCB → gfablNCAHIEFCB
10. gfabNCAHIEFCB → gfabl$^{2}$NCAHIEFCB [Repeat 18 times]
11. gfabl$^{20}$CAHIEFCB → gfabl$^{20}$eAHIEFCB
12. gfabl$^{20}$eAHIEFCB → gfabl$^{20}$egDHIEFCB
13. gfabl$^{20}$egDHIEFCB → gfabl$^{20}$egfHIEFCB
14. gfabl$^{20}$egfHIEFCB → gfabl$^{20}$egfENCAHIEFCB
15. gfabl$^{20}$egfENCAHIEFCB → gfabl$^{20}$egfaMNCAHIEFCB
16. gfabl$^{20}$egfaMNCAHIEFCB → gfabl$^{20}$egfabNCAHIEFCB
17. gfabl$^{20}$egfabNCAHIEFCB → gfabl$^{20}$egfablNCAHIEFCB
18. gfabl$^{20}$egfabNCAHIEFCB → gfabl$^{20}$egfabl$^{2}$NCAHIEFCB [Repeat 21 times]
19. gfabl$^{20}$egfabl$^{23}$CAHIEFCB → gfabl$^{20}$egfabl$^{23}\lambda^{2}$HIEFCB
20. gfabl$^{20}$egfabl$^{23}\lambda^{2}$HIEFCB → gfabl$^{20}$egfabl$^{23}\lambda^{2}$ENACHIEFCB
21. gfabl$^{20}$egfabl$^{23}\lambda^{2}$ENACHIEFCB → gfabl$^{20}$egfabl$^{23}\lambda^{2}$MNACHIEFCB
22. gfabl$^{20}$egfabl$^{23}\lambda^{2}$MNACHIEFCB → gfabl$^{20}$egfabl$^{23}\lambda^{2}$bNACHIEFCB
23. gfabl$^{20}$egfabl$^{23}\lambda^{2}$bNACHIEFCB → gfabl$^{20}$egfabl$^{23}\lambda^{2}$blNACHIEFCB
24. gfabl$^{20}$egfabl$^{23}\lambda^{2}$blNACHIEFCB → gfabl$^{20}$egfabl$^{23}\lambda^{2}$bl$^{2}$NACHIEFCB [Repeat 9 times]
25. gfabl$^{20}$egfabl$^{23}\lambda^{2}$bl$^{11}$ACHIEFCB → gfabl$^{20}$egfabl$^{23}\lambda^{2}$bl$^{11}$ $\lambda^{2}$HIEFCB
26. gfabl$^{20}$egfabl$^{23}\lambda^{2}$bl$^{11}$ $\lambda^{2}$HIEFCB → gfabl$^{20}$egfabl$^{23}\lambda^{2}$bl$^{11}$ $\lambda^{2}$ENCAHIEFCB
27. gfabl$^{20}$egfabl$^{23}\lambda^{2}$bl$^{11}$ $\lambda^{2}$ENCAHIEFCB → gfabl$^{20}$egfabl$^{23}\lambda^{2}$bl$^{11}$ $\lambda^{2}$MNCAHIEFCB
28. gfabl$^{20}$egfabl$^{23}\lambda^{2}$bl$^{11}$ $\lambda^{2}$MNCAHIEFCB →

gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cNCAHIEFCB

29. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cNCAHIEFCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$clNCAHIEFCB
30. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$clNCAHIEFCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{2}$NCAHIEFCB [Repeat 47 times]
31. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$CAHIEFCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λAHIEFCB
32. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λAHIEFCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λgDHIEFCB
33. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λgDHIEFCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghHIEFCB
34. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghHIEFCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλIEFCB
35. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλIEFCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλEGCAIOEFCB
36. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλEGCAIOEFCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλaMGCAIOEFCB
37. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλaMGCAIOEFCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacGCAIOEFCB
38. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacGCAIOEFCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacmGCAIOEFCB
39. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacmGCAIOEFCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{2}$GCAIOEFCB [Repeats 6 times]
40. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$CAIOEFCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$OEFCB
41. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$OEFCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qEFCB
42. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qEFCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qMFCB
43. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qMFCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcFCB
44. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcFCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjJCB
45. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjJCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjkJCB
46. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjkJCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$CB
47. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$CB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$eLB
48. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$eLB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epB
49. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epEFCB
50. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epEFCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epMFCB
51. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epMFCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbFCB
52. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbFCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjKCB
53. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjKCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjkJCB
54. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjkJCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$CB
55. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$CB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λB
56. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λEFCB
57. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λEFCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$FCB
58. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$FCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jJCB
59. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jJCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jkJCB
60. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jkJCB→
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jk$^{2}$CB
61. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jk$^{2}$CB→
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jk$^{2}$λB
62. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jk$^{2}$λB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jk$^{2}$λ EFCB
63. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jk$^{2}$λ EFCB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jk$^{2}$λ$^{2}$ FCB
64. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jk$^{2}$λ$^{2}$F CB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jk$^{2}$λ$^{2}$jJ CB
65. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jk$^{2}$λ$^{2}$jJ CB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jk$^{2}$λ$^{2}$jkJ CB
66. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jk$^{2}$λ$^{2}$jkJ CB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jk$^{2}$λ$^{2}$jk$^{2}$ CB
67. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jk$^{2}$λ$^{2}$j k$^{2}$CB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jk$^{2}$λ$^{2}$jk$^{2}$ eLB
68. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jk$^{2}$λ$^{2}$jk$^{2}$e LB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jk$^{2}$λ$^{2}$jk$^{2}$ epB
69. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jk$^{2}$λ$^{2}$jk$^{2}$e pB →
    gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jk$^{2}$λ$^{2}$jk$^{2}$ epλ
70. gfabl$^{20}$egfabl$^{23}$λ$^{2}$bl$^{11}$ λ$^{2}$cl$^{49}$λghλacm$^{8}$λ$^{3}$qcjk$^{2}$epbjk$^{2}$λ$^{2}$jk$^{2}$λ$^{2}$jk$^{2}$ epλ

**Analysis:** Typical elaborated flake unit from the thinning phase with embedded chisel-like platform preparation sequences (14–19, 20–25, 26–34), abrasion sequences (35–48), and concantenated flake removals (49–55,56–61,62–69).