

A biface and blade core efficiency experiment: implications for Early Paleoindian technological organization

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ABSTRACT

Early Paleoindians often are described as highly mobile hunter–gatherers who employed lithic technologies designed to minimize stone transport costs. We experimentally reduced blade and bifacial cores and found both reduction strategies to be equally efficient for the production of useable flake blanks. Further, when compared to similar core reduction experiments, the results of this study showed no significant differences in core efficiency between bifacial, prismatic blade, and wedge-shaped blade core reduction. Biface and blade cores with initial weights greater than 1000 g produced useable flakes as efficiently as informal cores. However, bifacial and blade core efficiency decreased with initial core weight. When considered in terms of Early Paleoindian technological organization, differences in core efficiencies suggest that Folsom groups employed core reduction strategies designed to minimize stone transport costs, but Clovis groups did not.

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1. Introduction

Understanding Early Paleoindian hunter–gatherer adaptations requires accurately linking the artifacts they left behind to the behaviors that produced those artifacts. Highly mobile Early Paleoindian groups such as Folsom and Clovis, transported toolstone considerable distances (Amick, 1996; Ferring, 2001; Hester, 1972; Meltzer, 2006) and they employed various strategies for reducing stone nodules and producing flake blanks for tools. Some overlap exists between their respective reduction strategies, but the two also significantly diverge. While a number of possibilities may explain why a particular prehistoric core reduction technique was preferred, many lithic technology experts studying mobile hunter–gatherers focus on the need to conserve stone, arguing that some tool production strategies are more efficient than others (Goodyear, 1993; Kelly, 1988; Kelly and Todd, 1988; Kuhn, 1994; Parry and Kelly, 1987). Until recently, however, assumptions about efficiency differences between tool production strategies lacked empirical evidence.

Experimental archaeology provides the inferences needed to explain these differences and bridge the gap between the present and the past. This paper builds on the growing body of core reduction efficiency research. We use controlled flaking experiments to empirically test whether differences in flake blank production efficiencies sufficiently explain the core reduction patterns evident in the Folsom and Clovis archaeological records on the Plains and Plains periphery.

As defined by Andrefsky (1998:12), a core is a piece of stone from which flakes are removed for use or modification. Cores can be reduced in various ways and five major core reduction strategies have been identified in Early Paleoindian lithic systems: bifacial, conical blade, wedge-shaped blade, discoidal, and informal. A bifacial core is flaked on two faces to create a single edge circumscribing the core, and this edge serves as the platform from which flakes are removed from two opposing sides (Andrefsky, 1998:15; Crabtree, 1972). Conical, or prismatic, blade cores have multiple blade removals around the circumference of the core; blade facets are oriented with the long axis of the core at approximate right angles to a single platform (Collins, 1999b; Collins and Lohse, 2004). Wedge-shaped blade cores have unidirectional or multidirectional blade scars usually detached from the narrow faces of the core and blade removals can occur on multiple faces emanating from one or more platforms (Collins, 1999b; Collins and

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Lohse, 2004). Similar to bifacial cores, discoidal cores are disc-shaped or ovoid with two faces that intersect at a single edge, which serves as the flake removal platform (Bradley, 1982:183; Frison and Bradley, 1980; Surovell, 2009:41). Unlike bifacial cores, however, flake removals are not restricted to two opposing edges. Flakes can be removed from the entire circumference of the discoidal core and one or two flake detachments may be used to remove a large portion of the core surface (i.e., a “Levallois-like” flake removal; Frison and Bradley, 1980). Informal cores, also referred to as generalized, blocky, amorphous, or expedient cores, have no standardized morphology and have several, opportunistic platforms from which flakes are removed in multiple directions (Bamforth and Becker, 2000; Parry and Kelly, 1987; Whittaker, 1994). While we recognize that these five reduction strategies are not mutually exclusive, we consider them separately to evaluate the relative blank production efficiencies of each.

1.1. Folsom and Clovis stone core technology

Folsom core technology includes bifacial cores, informal cores, and discoidal cores. Large bifaces have been recovered from Folsom sites including the Mitchell Locality at Blackwater Draw, NM (Stanford and Broilo, 1981); Hanson, WY (Frison and Bradley, 1980), Pavo Real, TX (Collins et al., 2003), Wilson Leonard, TX (Collins, 1998), and Shifting Sands, TX (Hofman, 1992). Folsom groups frequently used bifacial thinning flakes from these cores as flake tool and projectile point blanks (Hofman, 1992, 2003; LeTourneau, 2001; Stanford and Broilo, 1981; Wyckoff, 1996, 1999). Some of these large bifaces, termed ultrathins, were used primarily as knives (Jodry, 1999; Root, 1994; Root et al., 1999), but also served as cores for the production of tool blanks (Collins, 1999a; Hofman, 1999, 2003). Ultrathins are large and exceptionally thin, with straight longitudinal sections, bi-planar cross sections (transverse), and flake scar removals that terminate near the midline (Collins et al., 2003). There are, however, indications that flakes from these ultrathin bifaces were too thin for the production of Folsom points (Bamforth, 2003; Root, 1994).

Opportunistic use of raw material through informal core reduction was noted at Folsom sites such as Bobtail Wolf, ND (Root, 1994, 2000), Hanson, WY (Frison and Bradley, 1980), and Barger Gulch, WY (Surovell, 2009). In addition, some flake tools found at Stewart Cattleguard, CO (Jodry, 1999) and Agate Basin, WY (Bradley, 1982) may have been made on flakes from non-bifacial cores. No patterned reduction sequence was identified on these unprepared cores and Bamforth (2002) suggests that informal reduction was the primary strategy for Folsom tool blank production. Moreover, the recovery of informal core-struck flakes from sites that yielded few or no informal cores suggests these cores were transported by Folsom groups as part of the mobile toolkit (Bamforth and Becker, 2000:286). Surovell (2009) recently proposed, however, that the mobile Folsom toolkit consisted only of tools and flake blanks. This hypothesis holds potentially significant implications for understanding Folsom technological organization, but thus far has been tested only on a sample of four Folsom sites.

Discoidal cores have been reported from Folsom sites in Wyoming such as Hanson (Frison and Bradley, 1980), Agate Basin (Bradley, 1982), and Barger Gulch (Surovell et al., 2003; Surovell, 2009). Flakes from these cores may have been used as unifacial tools. To date, discoidal cores have not been identified from Folsom sites in the Southern Plains.

In Clovis assemblages, biface and blade cores are the most common core types. Informal cores also played a role in Clovis technology, but supporting data is limited at present. Clovis bifacial cores were recovered from several sites along the Balconnes Escarpment in Texas from quarry-camp sites like Gault (Collins,

2007) and Pavo Real (Collins et al., 2003), as well as from the Murray Springs site in Arizona (Huckell, 2007). Possible bifacial cores were identified in caches such as Anzick, MT, Crook County, WY, East Wenatchee, WA, Simon, ID, and Fenn (Kilby, 2008). Large Clovis bifaces are lanceolate in shape, biconvex in cross section and have flake scars that extend over the biface midline. More often than not, the flakes from these bifaces have pronounced curvature and were used for a variety of tasks (Collins, 2007; Hester, 1972; Huckell, 2007; Pevny, 2009; Wiederhold, 2004).

Clovis blade cores are either conical or wedge-shaped (Collins, 1999b). Conical cores were once considered to be the most common type of blade core, but at Clovis sites like Gault, wedge-shaped cores are more common (Collins, 1999b; Collins and Lohse, 2004; Dickens, 2005). Blade cores also were recovered from the Franey, NE, and Sailor-Helton, KS, caches (Kilby, 2008) and at the Pavo Real site, TX (Collins et al., 2003). Clovis blades from both types of blade cores were used primarily as cutting tools and scrapers (Collins, 2007; Hudler, 2003; Minchak, 2007).

Finally, Clovis knappers may have used informal cores for tool blank production (Hester, 1972; Frison and Stanford, 1982), but few informal cores have been recovered from secure Clovis contexts. Use of informal cores was inferred based on the recovery of normal flakes and a small core fragment from Murray Springs, AZ (Huckell, 2007). Informal cores also were identified in the Busse, KS, Franey, NE, and Sailor-Helton, KS caches (Kilby, 2008).

1.2. Technological organization and Early Paleoindian mobility

The link between hunter–gatherer mobility and stone tool-core reduction strategies lies in decisions regarding stone transport. Because toolstone sources are distributed unevenly across the landscape (Bamforth, 1986; Binford, 1980; Goodyear, 1989), highly mobile hunter–gatherers must devise strategies for carrying stone to ensure tools are on-hand to accomplish the necessary tasks while minimizing stone transport costs. Within Paleoindian studies, bifacial technologies have long been viewed as an ideal solution to this problem (Boldurian, 1991; Goodyear, 1989; Judge, 1973; Kelly and Todd, 1988).

Kelly (1988:719–21) outlines three potential roles that bifaces play. First, because they maximize flake tool cutting edge while minimizing transport weight, bifacial cores potentially could be used by hunter–gatherers exercising either residential or logistical mobility if those mobility patterns include extended time in material-poor areas. Bifaces also make ideal long use-life tools because they are durable and can be resharpened for multiple uses. Again, the decision to employ bifaces in this manner likely is tied to raw material availability. If material is scarce and residential mobility is low, Kelly predicts a high degree of biface maintenance and reuse should be evident. Finally, bifaces may be parts of complex, composite tools. Ethnographically, hunter–gatherers employing a high degree of logistical mobility frequently use complex composite tools. Bifaces compliment the organic components of these tool sets.

Kelly and Todd (1988) moved from a general consideration of the roles that bifaces could play to the specific roles that bifaces played in Early Paleoindian (specifically, Clovis and Folsom), technological organization. Kelly and Todd's (1988:237) high-tech forager hypothesis considers bifaces in the context of mobility and subsistence strategies, and they argue that Early Paleoindian technologies are dominated by bifaces because these highly mobile groups designed their lithic technologies to minimize stone transport costs. As a tool, the bifacial edge is durable and can be resharpened and reused, and they view Clovis projectile points as particularly good examples of bifaces designed as long use-life tools. Additionally, Early Paleoindians relied on bifaces as cores to

minimize stone transport weight. Because biface thinning flakes generally have a high edge-to-weight ratio, they argue, bifacial cores would produce more useable flake edge for tools than an informal core of equal weight.

Bifaces, however, are not the only potentially transport-efficient core reduction strategy. Kuhn (1994) convincingly argues that finished tools and individual flakes, not cores, are the most efficient way to transport stone if weight minimization is the primary concern. Macroblade (Bar-Yosef and Kuhn, 1999; Clark, 1987; Nelson, 1991; Sheets and Muto, 1972) and microblade technologies (Bamforth and Bleed, 1997; Bleed, 2002) also have been proposed as stone-conservative reduction strategies.

Most recently, Bamforth (2002, 2003) questioned the utility of the high-tech forager hypothesis as applied to Folsom and later Paleoindians. First, Bamforth (2003:210) argues that the competing design constraints for bifacial cores and bifacial tools make it unlikely the two were combined into a single multipurpose core/tool. Second, the flakes removed from late stage bifaces are extremely thin, fragile, and ill-suited for most tasks. Finally, informal cores (Bamforth, 2002, 2007) outnumber bifaces in many Late Paleoindian assemblages.

1.3. Previous core efficiency experiments

These opposing viewpoints raise an important question: which core reduction strategy provides the most efficient means for transporting stone? Recent experimental studies have attempted to answer this question. Three important core efficiency experiments are summarized in detail below, and they share the common goal of assessing relative core technology efficiencies by measuring and comparing the production of useable flakes. “Useable flakes” were defined in these studies as those flakes with dimensions greater than 25 mm. “Core efficiency” is measured one of three ways: by useable flake count, useable flake weight, or useable flake cutting edge. To control for initial core size differences, the total count of useable flakes is presented as a ratio of flake count to initial core weight. Likewise, the ratio of the total weight of useable flakes to initial core weight provides a measure of the percentage of initial core weight successfully converted to useable flakes. Finally, total useable flake edge informs on the production of readily useable tools.

To date, only Prasciunas (2004, 2007) has tested explicitly the core reduction efficiency expectations of Kelly and Todd's (1988) high-tech forager model through experimental replication. In her study, ten bifacial and ten informal cores were reduced to exhaustion to test which reduction strategy was a more efficient means of producing useable flakes. Prasciunas found no significant difference in the amount of useable flake edge produced by bifacial and informal core reduction. The weight of useable flakes produced via informal core reduction was significantly greater than bifacial reduction when initial core weight differences were controlled for. These results suggest that informal cores allow for the more efficient production of useable flake blanks than bifacial cores.

Two other experiments also bear mentioning, though neither was designed explicitly to investigate Clovis or Folsom technological organization. Rasic and Andrefsky (2001) present core and flake data from an experiment in which one bifacial and one blade core were reduced. They found the bifacial core produced more useable flake blanks. However, a greater percentage of initial core weight was converted to useable flake weight in blade core reduction. These results suggest bifacial reduction is a more efficient strategy for producing quantities of flake blanks, while blade reduction is more efficient for conserving stone weight. This study is potentially limited, however, by the dramatic difference between initial core sizes. The bifacial core was 10 times heavier than the blade core at the outset of the experiment. Due to significant technological

differences, bifacial reduction and microblade production efficiencies may not be directly comparable at the scale of a single core.

Finally, to better understand the Middle to Upper Paleolithic technological transition in Europe, Eren et al. (2008) conducted an experiment to compare discoidal and prismatic blade core reduction efficiencies. Seven discoidal and seven prismatic (conical) blade cores were reduced. Three major conclusions bear on the current study. First, discoidal reduction yielded more useable flake blanks per gram of material than blade reduction. Second, in discoidal core reduction a slightly higher percentage of the original core mass was converted successfully to useable flake blanks. Finally, neither technique yielded significantly more useable cutting edge. These results suggest that discoidal core reduction is a more efficient strategy than prismatic blade reduction for producing useable flake blanks.

2. Methods

Six bifacial and five wedge-shaped blade cores were reduced over the course of several days by one of the authors (WAD) for the current study. Although we are ultimately interested in better understanding Early Paleoindian technological organization, no attempt was made to exactly replicate Clovis or Folsom reduction techniques. Direct percussion was employed using copper billets of various sizes. A circular, industrial grinding stone was used to prepare platforms. To ensure uniform fracture and successful flake detachments, two varieties of high-quality, fine-grained Edwards chert from the Fort Hood area of central Texas were reduced. Unmodified pieces of chert were chosen based on the knapper's past experimental and archaeological experience; due to variation in nodule form, some pieces were destined to become bifacial cores and others wedge-shaped blade cores.

Prior to reduction, each chert nodule was weighed, measured (maximum length, width, and thickness), and photographed (Fig. 1). The primary goal of the experiment was to produce as many useable flakes as possible while maintaining the integrity of the core. Cores were deemed “exhausted” when no additional useable flakes could be detached. Cores that broke due to material flaws or knapper error prior to exhaustion ($n = 6$) are not included in this analysis. All debitage from each core reduction event was collected. To permit comparison to other studies (Eren et al., 2008; Rasic and Andrefsky, 2001), all flakes greater than 2.5 cm in any dimension were considered useable (Fig. 2). Prasciunas (2004, 2007) experimentally demonstrated that flake tool cutting efficiency significantly decreased below a 7 cm² size threshold. Individual flake measurement was used to identify flakes greater than 2.5 cm, and all useable flakes for each core were separated, counted, and weighed.

Because bifacial and wedge-shaped blade core reduction represent distinctly different strategies for unpacking stone nodules, we recorded two additional lines of data not considered in other studies. For all useable flakes, the presence or absence of cortex was noted. We also size-sorted all flakes less than 2.5 cm in maximum dimension into four classes (cm): ≥ 1.25 , 0.95–1.24, 0.625–0.94, and less than 0.625. Flakes in the first three groups were counted and weighed. Only weights were obtained for flakes in the smallest size class.

Although other studies also discuss useable flake edge as a possible measure of core efficiency, we did not record this variable for two reasons. First, Eren et al. (2008) show that flake resharpening can dramatically impact comparisons of useable flake edge. They found that blades have more initial cutting edge, but flakes from discoidal cores can undergo more resharpening events, providing more total cutting edge when the entire use-life of a tool is considered. Second, the useable flake edge measurement does



Fig. 1. Examples of Edwards chert nodules prior to knapping.

not account for the possibility of tool hafting. Hafting a flake blank immediately reduces the amount of exposed useable flake edge and limits the amount of edge available for resharpening. Therefore, for the current study, we focus on flake counts and weights.

3. Results

The mean initial core weights (Table 1, Column 3) for the blade (mean = 1449.82 g) and bifacial (mean = 1615.17 g) cores reduced

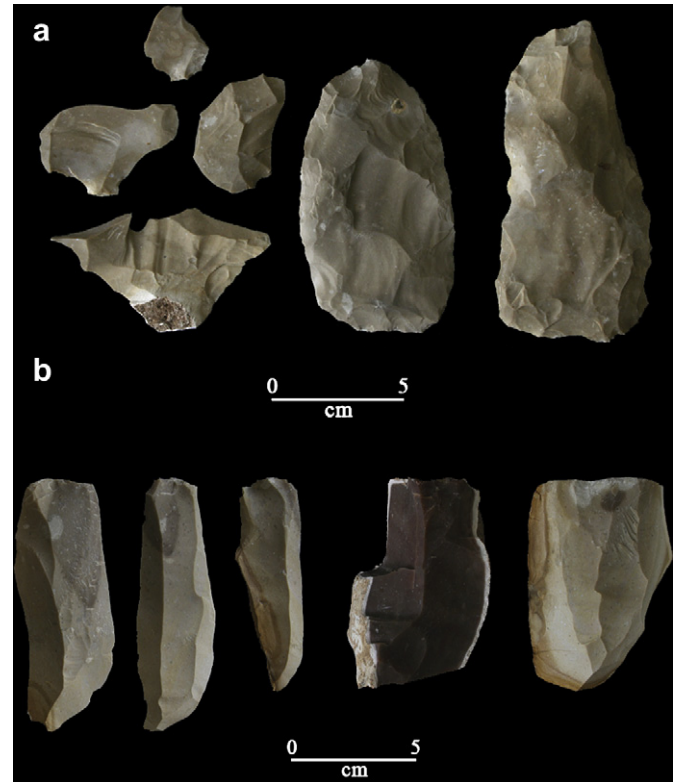


Fig. 2. Examples of experimentally reduced bifacial and wedge-shaped blade cores and some useable flakes produced by each reduction technique.

in the current study did not significantly differ ($p = 0.557$). Neither reduction technique produced significantly more useable flake blanks (Table 1, Column 5; $p = 0.092$). Controlling for initial core size differences (Table 1, Column 6), however, reveals bifaces did yield slightly significantly more useable flake blanks per 100 g of chert ($p = 0.05$). This is not unexpected given that the goal of wedge-shaped blade core reduction is to produce long blades, while bifacial reduction is not restricted by the same flake form goal. Moving from count to weight, there was no significant difference in the total weight of useable flakes produced (Table 1, Column 7; $p = 0.473$), and no significant difference in the percent of initial core weight converted to useable flake blanks (Table 1,

Table 1
Core weights and useable flake counts and weights for reduced wedge-shaped blade (WB1–5) and bifacial (Bf1–6) cores.

Core No.	Trajectory	Initial weight (g) (IW)	Exhausted weight (g) (EW)	Useable flake count (UC)	# Useable flakes per 100 g of core weight ((UC/IW) * 100)	Total weight (g) of useable flakes (UW)	Useable core weight percentage (UCWP) ((UW/IW) * 100)
WB1	Blade	1900.00	256.00	104	5.5	1505.00	79.21
WB2	Blade	1860.30	207.00	116	6.2	1532.20	82.36
WB3	Blade	1230.70	336.10	48	3.9	839.40	68.21
WB4	Blade	900.90	228.30	53	5.9	639.40	70.97
WB5	Blade	1357.20	382.80	42	3.1	948.70	69.90
Average		1449.82	282.04	72.6	4.9	1092.94	74.13
Bf1	Biface	1452.30	97.20	117	8.1	1065.10	73.34
Bf2	Biface	2196.20	129.40	154	7.0	1807.90	82.32
Bf3	Biface	2155.30	118.70	119	5.5	1787.70	82.94
Bf4	Biface	1333.10	88.30	112	8.4	1013.60	76.03
Bf5	Biface	1507.50	103.00	69	4.6	1284.10	85.18
Bf6	Biface	1046.60	115.00	84	8.0	743.70	71.06
Average		1615.17	108.6	109.17	6.9	1283.68	78.49

Column 8; $p = 0.262$). Taken as a whole, the results of this study demonstrate that bifacial and wedge-shaped blade core reduction techniques are equally efficient.

When measured as the number of flake blanks per 100 g of chert, bifacial and wedge-shaped blade reduction did not significantly differ in the production of useable cortical flakes (Table 2, Column 3). Measured as the percentage of the initial core weight, however, wedge-shaped blade core reduction yielded significantly greater useable cortical flake blanks. Cortical flakes produced during wedge-shaped blade core reduction are heavier than cortical flakes produced during bifacial core reduction.

Bifacial and wedge-shaped blade reduction produced equal counts and weights of flakes in size classes ≥ 1.25 , 0.95–1.24, and 0.625–0.94 cm, (Table 3). A significantly greater percentage of the initial core weight was converted to flakes less than 0.625 cm during bifacial reduction ($p = 0.016$) than during wedge-shaped core reduction.

Next, we compare the core reduction data presented by Prasciunas (2004, 2007) and Eren et al. (2008) to that from the current study (Table 4). Once again, we focus on useable flake counts and weights and, for now, keep each experimental data set separate. ANOVA reveals significant differences between the six core reduction groups in the quantity of usable flake blanks per 100 g of raw material ($p < 0.001$) and the percentage of initial core weight converted to useable flakes ($p < 0.001$).

To further investigate core reduction differences, the Bonferroni method for multiple comparisons was conducted at the 0.05 group confidence level. Looking first at the number of useable flakes produced per 100 g of raw material (Fig. 3), Prasciunas's bifacial cores yielded significantly more useable flakes than the bifacial cores from the current study and both blade core types. The informal cores produced significantly more useable flakes than the wedge-shaped blade cores. No significant differences in useable flake production per 100 g of material are evident when the bifaces from the current study, both blade core types, and the discoidal cores are compared.

Measuring efficiency as the percentage of the initial core weight converted to useable flake weight (Fig. 4), Prasciunas's bifacial cores are significantly less efficient than informal and discoidal cores, as well as the bifacial cores from the current study. No significant differences separate the bifaces from the current study, either blade core type, informal cores, or discoidal cores.

Finally, we examined separately the bifacial and blade core data. For bifacial cores, the number of useable flakes produced per 100 g

of chert is inversely proportionate to initial core weight ($r^2 = 0.588$, Fig. 5). Conversely, the percentage of the initial core weight successfully converted to useable flakes increases with initial core weight ($r^2 = 0.654$, Fig. 6). For blade cores, no relationship exists between original core weight and the number of flakes produced ($r^2 = 0.079$, Fig. 7). As with bifaces, however, a strong positive relationship exists between original core weight and useable flake weight percentage ($r^2 = 0.617$, Fig. 8).

4. Discussion

This study contributes new comparative data to the growing body of core efficiency experiments. This is the first study to directly compare the relative blank production efficiencies of bifacial and macroblade core reduction. This is the first blade core efficiency experiment to incorporate wedge-shaped blade cores. Larger initial core sizes were reduced than previous bifacial core reduction experiments. Finally, we move beyond other studies to include data on cortical flake and microdebitage production.

Prior to discussing the implications of the present study, we must acknowledge some limitations of core efficiency data as used in this paper.

- At present, the total sample size of knappers ($n = 3$) and the total number of cores reduced ($n = 45$) are admittedly small.
- Each of the experiments used different raw materials, and differences in stone quality surely affect reduction efficiency (Andrefsky, 2009; Bradbury et al., 2008).
- Flake shape and form varies with each reduction technique, and the utility of an individual flake may depend on the intended use or tool form. This renders measures of flake "utility" somewhat subjective.
- All "exhausted" cores in these studies could be further shaped and converted to some form of useable tool. Core "efficiency" may therefore include additional measures.
- Because we consider each reduction technique separately, these experiments do not account for the possibility that prehistoric knappers switched between two or more reduction strategies during the use-life of a single core (e.g., begin with bifacial reduction and then shift to informal reduction on the same core).

For these reasons and others, core efficiency experiments are an imperfect means to fully test hypotheses regarding past lithic technological systems. Experimental studies are, however, an important compliment to archaeological analyses. In spite of the limitations of the current experimental data set, we offer some new insights into technological organization gained through experimental core reduction and discuss the implications of these insights for understanding the Early Paleoindian lithic technology. Pending additional reduction experiments and more detailed comparisons to the archaeological record, our findings are best considered hypotheses that require further testing.

4.1. Implications

Following other studies, we present data on usable flake counts. These data appear to show that, if the goal is to maximize the number of useable flakes regardless of flake size or shape, then small-sized cores (informal or bifacial cores with initial sizes < 1000 g) are more efficient than cores (bifacial or blade) that began much larger (> 1000 g). With small core sizes, informal and bifacial cores appear to be equally efficient producers of quantities of useable flakes.

Table 2
Counts and weights of useable cortical flakes.

Core No.	Useable cortical flake count (UCC)	# Useable cortical flakes per 100 g of core weight ((UCC/IW) * 100)	Total weight (g) of useable cortical flakes (UCW)	Useable cortical flake core weight percentage (UCCWP) ((UW/IW) * 100)
WB1	65	3.42	1266.7	66.67
WB2	84	4.52	1272.9	68.42
WB3	42	3.41	783.5	63.66
WB4	47	5.22	612.3	67.97
WB5	40	2.95	915.1	67.43
Average	55.6	3.90	970.1	66.83
Bf1	62	4.27	827.9	57.01
Bf2	69	3.14	1448.2	65.94
Bf3	53	2.46	1521.8	70.61
Bf4	48	3.60	697.9	52.35
Bf5	29	1.92	1140.3	75.64
Bf6	45	4.30	613.4	58.61
Average	51	3.28	1041.6	63.36

Table 3
Size-class counts and weights of flakes less than 2.5 cm in maximum dimension. Size classes in cm.

Core No.	≥1.25 Count	≥1.25 per 100 g of core weight	≥1.25 Count	≥1.25 Weight	≥1.25 Core weight percentage	0.95–1.24 Count	0.95–1.24 Count per 100 g of core weight	0.95–1.24 Weight	0.95–1.24 Core weight percentage	0.625–0.94 Count	0.625–0.94 Count per 100 g of core weight	0.625–0.94 Weight	0.625–0.94 Core weight percentage	<0.625 Weight	<0.625 Core weight percentage
WB1	9	0.47	20	12.1	0.64	20	1.05	17.6	0.93	90	4.74	28.1	1.48	47.3	2.49
WB2	7	0.38	26	9.7	0.52	26	1.40	18.6	1.00	87	4.68	26.0	1.40	47.1	2.53
WB3	3	0.24	11	4.9	0.40	11	0.89	9.6	0.78	0	0	0	0	20.4	1.66
WB4	11	1.22	1	6.9	0.77	1	0.11	1.1	0.12	17	1.89	5.4	0.60	9.5	1.05
WB5	0	0	7	0	0	7	0.52	6.6	0.49	19	1.40	4.9	0.36	13.6	1.00
Average	6	0.46	13	6.72	0.46	13	0.79	10.7	0.66	42.6	2.54	12.88	0.77	27.58	1.75
BF1	19	1.31	52	34.4	2.37	52	3.58	46.7	3.22	187	12.88	67.4	4.64	92.6	6.38
BF2	14	0.64	72	13.4	0.61	72	3.28	47.5	2.16	230	10.47	66.3	3.02	96.9	4.41
BF3	15	0.70	56	21.7	1.01	56	2.60	43.9	2.04	181	8.40	57.9	2.69	78.3	3.63
BF4	8	0.60	55	11.1	0.83	55	4.13	36.1	2.71	167	12.53	47.3	3.55	81.4	6.11
BF5	6	0.40	28	9.1	0.60	28	1.86	22.6	1.50	82	5.44	24.7	1.64	44	2.91
BF6	7	0.67	59	8.9	0.85	59	5.63	40.7	3.89	167	15.96	49.4	4.72	70.6	6.75
Average	11.5	0.72	53.67	16.43	1.05	53.67	3.51	39.58	2.59	169	10.95	52.17	3.38	77.3	5.03

However, we do not view useable flake counts as a particularly informative measure of core efficiency. The large flakes produced from large cores could easily be broken to increase flake count numbers, thus negating the apparent efficiency advantage of small cores. We view useable flake weight as a more useful measure of core efficiency. For the following points, therefore, efficiency is defined only by useable flake blank weight as a percentage of the initial core weight. Viewed from this perspective, experimental core reduction efficiency comparisons reveal four main technological implications.

- 1) As demonstrated by Prasciunas (2004, 2007), if conserving stone transport weight is the primary goal, then informal core reduction is a more efficient strategy than bifacial reduction when the initial raw material package size is relatively small. We have shown, however, that as raw material size increases, bifacial, blade, and discoidal flake core reduction efficiencies approach that of informal core reduction.
- 2) For small core sizes, bifacial reduction is a relatively inefficient means to conserve stone transport weight. Larger cores are more efficient. Based on the significantly greater amount of smallest sized debitage produced during bifacial reduction in the present study, we surmise that the shaping necessary to prepare and maintain a bifacial core is costly, but that this cost is overcome at initial large core sizes because more weight-efficient biface thinning flakes can be removed.
- 3) Prismatic and wedge-shaped blade cores are equally efficient strategies for the production of useable flake blanks. For both blade core reduction strategies, core efficiency decreases with initial core size.
- 4) Finally, if only noncortical flake blanks are the desired product, bifacial core reduction may be a more efficient strategy than wedge-shaped blade core reduction. This hypothesis is extremely tentative, however, because no effort was made to maximize noncortical flake production in the current study.

These four points allow for new insights into Clovis and Folsom technological organization and highlight the importance of package size. If minimizing stone transport weight was the primary concern for Early Paleoindian knappers, raw material package size should have dictated core reduction strategies. Raw material package sizes differ between the Southern Plains and the Northern Plains and Rocky Mountains. On the Southern Plains, large tabular chert nodules outcrop across the vast Edwards Formation and in the less extensive Alibates Formation (Banks, 1990; Wyckoff, 2005). Groups with routine access to these sources need not rely heavily on other more size-variable outcrop or gravel sources in the region. In contrast, stone sources in the Northern Plains and Rocky Mountains are relatively more varied. While large nodules of stone are available at some locations, these outcrops are less extensive and more dispersed across the landscape (Frison and Stanford, 1982; Frison and Bradley, 1980; Miller, 1991). Outcrops with smaller-sized nodules and cobble sources in these regions potentially become a more important component of lithic economies.

Given these raw material availability differences, we might expect that different core reduction strategies were employed by Clovis and Folsom groups occupying the Southern Plains in comparison to the groups inhabiting the Northern Plains and Rocky Mountains. Groups in the Southern Plains with consistent access to large tabular nodules could reduce cores via informal, discoidal, bifacial, or either type of blade core reduction because all types of core reduction would be equally transport efficient. To the north, however, we should expect informal and discoidal reduction to dominate Clovis and Folsom core technologies if minimizing transport weight was truly a major concern.

Table 4

Data from previous core reduction efficiency experiments.

Trajectory	IW (g)	EW (g)	UC ^a	UC/IW ^a * 100	UW (g)	UCWP (percentage)	Study
Biface	503.30	131.41	44	8.74	353.82	70.30	Prasciunas (2004, 2007)
Biface	646.50	150.35	56	8.66	469.97	72.69	Prasciunas (2004, 2007)
Biface	218.40	125.41	29	13.28	112.57	51.54	Prasciunas (2004, 2007)
Biface	374.70	110.32	44	11.74	215.91	57.62	Prasciunas (2004, 2007)
Biface	405.00	170.27	35	8.64	202.49	50.00	Prasciunas (2004, 2007)
Biface	304.20	131.88	29	9.53	178.84	58.79	Prasciunas (2004, 2007)
Biface	245.00	160.69	31	12.65	108.91	44.45	Prasciunas (2004, 2007)
Biface	510.60	135.66	46	9.01	357.54	70.02	Prasciunas (2004, 2007)
Biface	457.90	132.48	55	12.01	310.37	67.78	Prasciunas (2004, 2007)
Biface	382.80	150.44	34	8.88	259.27	67.73	Prasciunas (2004, 2007)
Amorphous	417.10	46.72	43	10.31	370.27	88.77	Prasciunas (2004, 2007)
Amorphous	339.00	47.85	35	10.32	269.49	79.50	Prasciunas (2004, 2007)
Amorphous	258.10	55.90	16	6.20	192.13	74.44	Prasciunas (2004, 2007)
Amorphous	459.70	72.85	49	10.66	386.15	84.00	Prasciunas (2004, 2007)
Amorphous	606.00	36.65	45	7.43	528.45	87.20	Prasciunas (2004, 2007)
Amorphous	495.60	31.14	55	11.10	428.67	86.50	Prasciunas (2004, 2007)
Amorphous	979.20	72.49	70	7.15	875.29	89.39	Prasciunas (2004, 2007)
Amorphous	641.50	81.91	58	9.04	579.43	90.32	Prasciunas (2004, 2007)
Amorphous	563.80	67.55	64	11.35	505.18	89.60	Prasciunas (2004, 2007)
Amorphous	648.90	63.48	52	8.01	554.73	85.49	Prasciunas (2004, 2007)
Prismatic Blade	934.40	119.20	73	7.81	704.40	75.39	Eren et al. (2008)
Prismatic Blade	1469.20	174.60	109	7.42	1072.30	72.99	Eren et al. (2008)
Prismatic Blade	1208.40	210.60	72	5.96	830.90	68.76	Eren et al. (2008)
Prismatic Blade	1499.80	332.90	83	5.53	995.40	66.37	Eren et al. (2008)
Prismatic Blade	2375.10	200.60	91	3.83	1925.90	81.09	Eren et al. (2008)
Prismatic Blade	803.10	134.00	50	6.23	481.70	59.98	Eren et al. (2008)
Prismatic Blade	2411.10	169.70	141	5.85	1972.80	81.82	Eren et al. (2008)
Discoidal	980.40	57.30	71	7.24	785.70	80.14	Eren et al. (2008)
Discoidal	1361.90	105.10	101	7.42	1143.40	83.96	Eren et al. (2008)
Discoidal	697.10	56.50	57	8.18	463.70	66.52	Eren et al. (2008)
Discoidal	1311.10	96.90	94	7.17	1145.70	87.39	Eren et al. (2008)
Discoidal	1731.50	86.40	121	6.99	1550.60	89.55	Eren et al. (2008)
Discoidal	833.50	77.60	75	9.00	635.40	76.23	Eren et al. (2008)
Discoidal	2592.60	122.40	151	5.82	2266.60	87.43	Eren et al. (2008)

^a Note: Prasciunas (2004) uses a usable flake area threshold of 7 cm². For consistency, we instead tabulated all flakes greater than 2.5 cm in maximum dimension.

Returning to the archaeological record, Clovis groups throughout the Southern Plains, Northern Plains, and Rocky Mountains employed both bifacial and blade core reduction techniques (Collins, 1999a,b; Collins and Lohse, 2004; Ferring, 2001; Huckell, 2007; Kilby, 2008; Meltzer and Cooper, 2006), and both were clearly part of the mobile toolkit as demonstrated by their

occurrence in caches, specifically load-exchange caches (Kilby, 2008). Although some evidence suggests Clovis groups also used informal cores for flake tool production (Huckell, 2007; Kilby, 2008), informal reduction, the most transport-efficient technique, was never the dominant Clovis flake production strategy. The need to minimize stone transport costs does not solely explain why

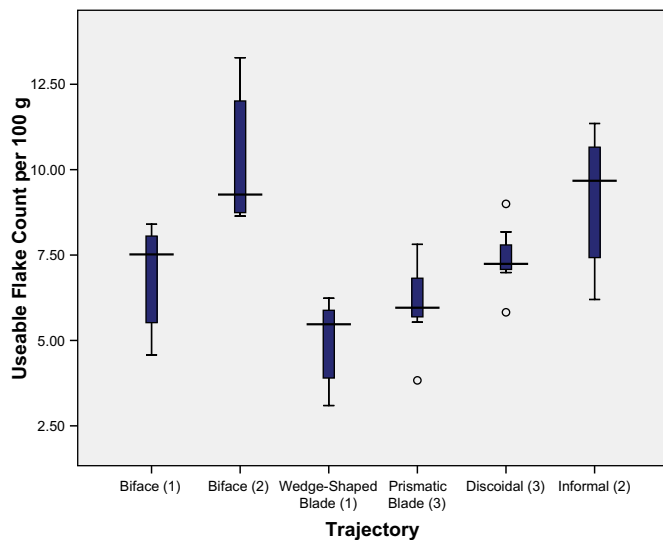


Fig. 3. Box plots showing the number of useable flakes produced per 100 g of raw material for each reduction method. Data: 1 = current study; 2 = Prasciunas (2004, 2007); 3 = Eren et al. (2008).

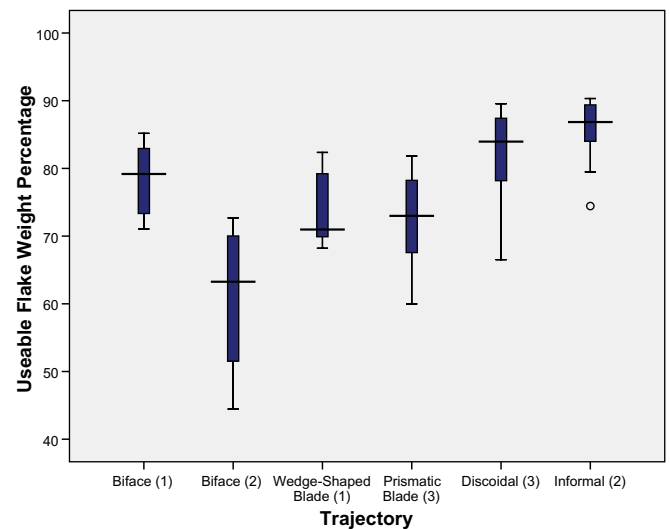


Fig. 4. Box plots showing total useable flake weight as a percentage of the initial core weight for each reduction method. Data: 1 = current study; 2 = Prasciunas (2004, 2007); 3 = Eren et al. (2008).

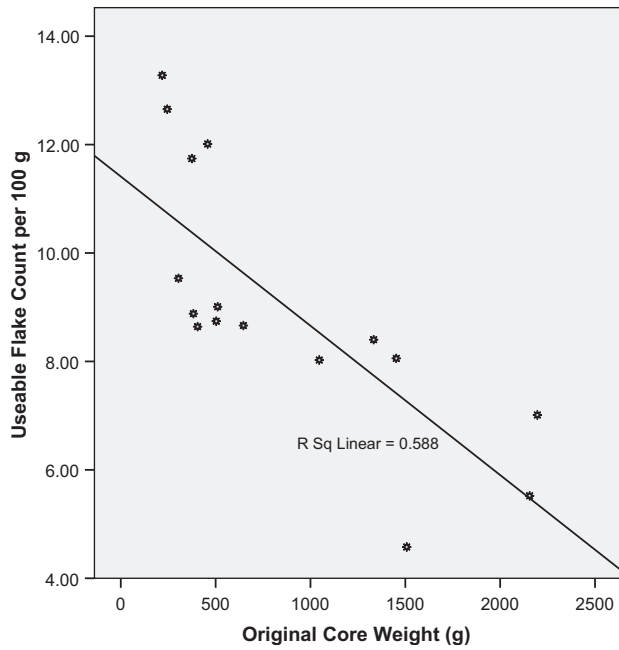


Fig. 5. Linear regression of the number of useable flakes produced per 100 g of raw material against initial core weight for bifacial cores.

Clovis knappers relied so heavily on bifacial, prismatic blade, and wedge-shaped blade core reduction techniques instead of informal reduction. We suspect, as some suggest, that Clovis groups were not always highly residentially mobile foragers (Anderson, 1990, 1995; Collins, 2007; Meltzer, 2002, 2004), and therefore Clovis core technologies were not designed to emphasize transportability over all other factors.

Clovis groups, however, do appear to have minimized stone transport costs by carrying flakes rather than cores in some circumstances. As noted previously, carrying individual flakes is the most weight-efficient way to transport stone (Kuhn, 1994). Blade

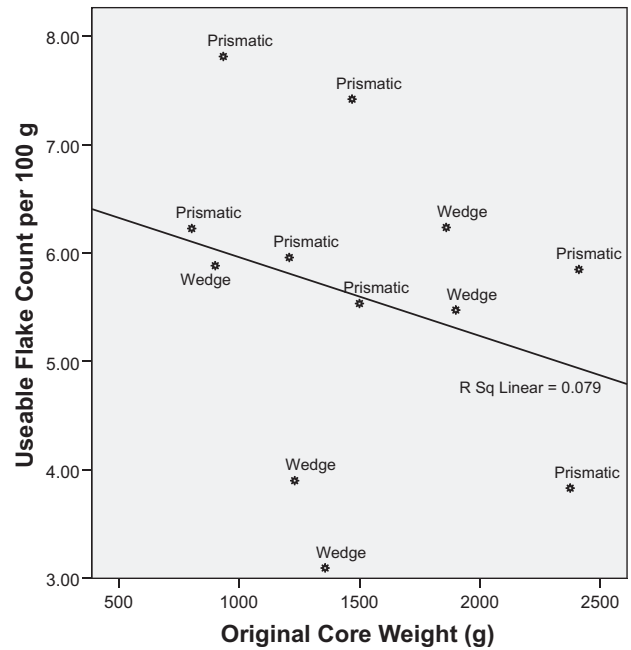


Fig. 7. Linear regression of the number of useable flakes produced per 100 g of raw material against initial core weight for prismatic and wedge-shaped blade cores.

and flake caches provide evidence that Clovis groups indeed transported stone in this manner (Kilby, 2008), and the nature of these caches strongly suggests they were associated with periodic logistical forays rather than continuous residential movement.

Folsom knappers, alternatively, appear to have routinely maximized stone transport efficiency. On the Southern Plains where large Edwards or Alibates chert nodules were accessible, Folsom groups readily utilized bifaces as cores for tools (Bement, 1999; Hofman, 1992, 2003; Hofman et al., 1990; Stanford and Broilo, 1981). Further north, however, where raw material sizes are more

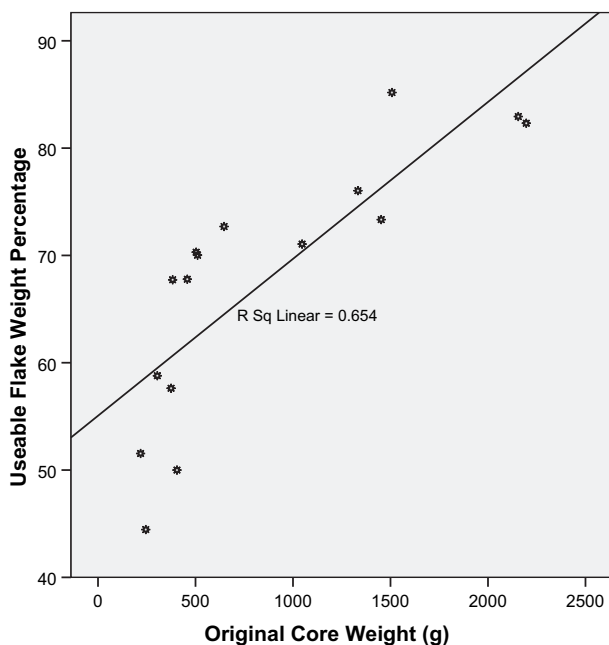


Fig. 6. Linear regression of total useable flake weight percentage against initial core weight for bifacial cores.

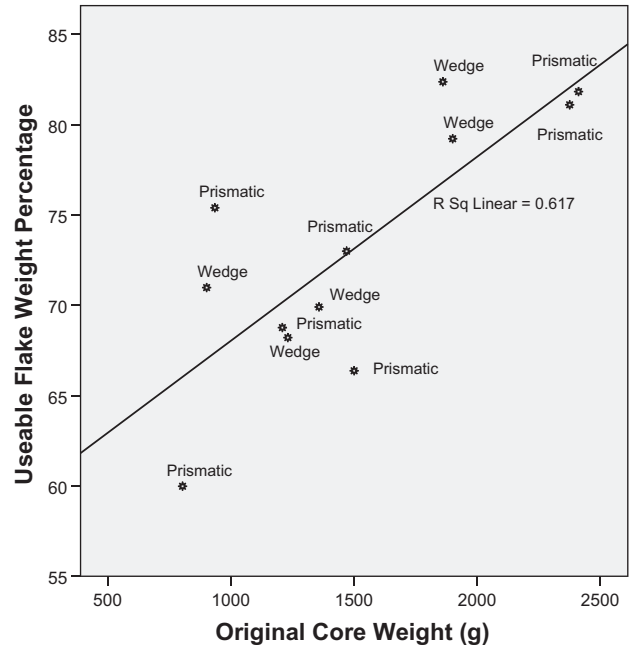


Fig. 8. Linear regression of total useable flake weight percentage against initial core weight for prismatic and wedge-shaped blade cores.

variable, Folsom knappers appear to have relied on more transport-efficient informal cores (Bamforth, 2002, 2003; Bamforth and Becker, 2000; Surovell, 2009) and discoidal cores (Bradley, 1982; Frison and Bradley, 1980; Surovell, 2009). The flexibility afforded by the option to efficiently produce tool blanks via bifacial, informal, or discoidal core reduction fits well with the long-held view of Folsom groups as highly residentially mobile hunter-gatherers concerned with conserving toolstone (Amick, 1996; Bement, 1999; Hofman, 1992, 2003; Hofman and Todd, 2001; Kelly and Todd, 1988; Meltzer, 2006).

5. Conclusions

Six bifacial and five wedge-shaped blade cores were reduced to exhaustion to experimentally compare core reduction efficiencies. Viewed solely in terms of transport weight costs measured by useable flakes produced, both reduction strategies are equally efficient. When compared to reduction experiments conducted by other researchers, no significant differences in core efficiency are evident between bifacial, prismatic blade, and wedge-shaped blade cores. For cores that began relatively large (>1000 g), bifacial and blade cores yield useable flakes as efficiently as informal cores. For smaller cores (<300–500 g), however, informal reduction is more efficient than bifacial reduction for the production of useable flake blanks.

These results have potentially important implications for understanding Early Paleoindian technological organization. Clovis and Folsom groups on the Plains had access to and made extensive use of the same lithic resources, yet their core reduction strategies appear to differ significantly. That Clovis knappers on the Plains routinely relied on bifacial and blade technologies over informal core reduction, regardless of raw material distribution or package-size variability, strongly suggests that minimizing transport weight was not the primary concern for these groups. Relative core efficiency differences cannot solely explain Clovis core reduction strategies. Further, while informal cores are often associated with sedentary groups employing expedient reduction techniques (Parry and Kelly, 1987), Prasciunas (2004, 2007) recently demonstrated that informal cores are more efficient than other core types for small initial raw material package sizes. This potentially alters the interpretation of Folsom technological strategies. While Folsom groups on the Southern Plains with access to large Edwards nodules routinely employed bifacial core reduction, relative differences in core efficiencies may explain why highly mobile Folsom groups shifted to the more transport-efficient strategies of informal and discoidal reduction in the Northern Plains and Rocky Mountains where raw material package size is more varied.

Thus far, only a few core efficiency experiments have been conducted. More experimental studies involving additional raw material types and sizes and variously skilled knappers are needed. Hypotheses regarding Early Paleoindian technological organization would also benefit from additional experiments designed to replicate Clovis and Folsom flake production and resharpening strategies. At present, core reduction experiments suggest that flake production efficiency differences may help explain Folsom technological strategies, however, we need to seek alternative explanations to fully understand Clovis technological organization.

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