Experimental production of bending and radial flake fractures and implications for lithic technologies

Thomas A. Jennings*

Center for the Study of the First Americans, Texas A&M University, 4352 TAMU, College Station, TX 77843, United States

ARTICLE INFO

Article history:
Received 21 July 2011
Received in revised form
26 August 2011
Accepted 27 August 2011

Keywords:
Bend break
Radial break
Experimental archaeology
Paleoindian
Paleolithic
Pseudoburin
Lithic technology
Flake fracture

ABSTRACT

Bend and radially broken flake tools have been identified in Paleolithic and Paleoindian assemblages, and their presence raises important questions. Were these breaks intentionally produced to serve as tool edges or were broken flakes simply scavenged? More importantly, can we distinguish between intentionally produced breaks and those produced incidentally? Experimental archaeology can help answer these questions. In this paper, three sets of experimentally produced bend and radial flake breaks were compared. Flakes were intentionally broken by percussion, and these breaks were compared to those produced during bifacial core reduction and by flake trampling. The presence of point of impact markers, near ninety degree break angles, and an assemblage with high percentages of bend and radial breaks distinguish intentional fracture from incidental fractures produced during bifacial reduction. High percentages of radial breaks distinguish intentional fracture from trampling. Finally, it may not be possible to identify intentional breaks in a bifacial reduction assemblage severely affected by flake-on-flake trampling.

© 2011 Elsevier Ltd. All rights reserved.

1. Introduction

Flaked stone technologies are dominated by tools made by striking cores to remove flake blanks which are then either used as is or retouched into formal tools. Because of their relative scarcity compared to other tool classes, intentionally broken bend or radial flake fracture tools have received less attention in lithic analysts. Bend and radial fractures used as tools, intentionally produced by striking the center of bifaces or flakes, have been identified in Paleolithic and Paleoindian technologies (Bergman et al., 1987; Ferring, 2001; Frison and Bradley, 1980; McAvoy and McAvoy, 2003; Surovell, 2009; Waters et al., 2011). The thick, damage-resistant edges created by these breaks are ideal for but not restricted to scraping and engraving tasks (Barton et al., 1996; Crabtree, 1977; Deller and Ellis, 2003; Frison and Bradley, 1980; Root et al., 1999). While the production process of bend or radially broken bifaces and flakes has been described (c.f. Bergman et al., 1987; Deller and Ellis, 2003; Miller, 2006; Root et al., 1999), few studies have directly compared intentionally produced breaks to incidental breaks. Lithic analysts rely on core reduction and tool production and use strategies to define cultures, reconstruct adaptations, and identify shared or individual knapping signatures. Recognizing an intentionally produced bend and radial break technology can provide an additional line of evidence to help understand the knapping strategies, technological organization, and site-level activities of a single group of people or help distinguish the technological signatures of one culture from another. As a first step towards defining criteria diagnostic of bend/radial break production technologies, this paper presents the results of an experimental program comparing bend and radial breaks produced by intentionally striking flakes to breaks produced incidentally during bifacial core reduction and breaks produced by flake trampling.

1.1. The mechanics of bend and radial breaks

Lithic experts distinguish between three types of fracture initiation and two types of fracture propagation (Andrefsky, 2005; Bonnichsen, 1977; Cotterell and Kamminga, 1987; Crabtree, 1972; Odell, 2003). Hertzian and bending initiations result in stiffness-controlled propagations, while wedging initiation produces compression-controlled propagation. The final phase is termination. With Hertzian and bending initiations, flakes can terminate in feather, hinge, or step terminations, while wedging typically results in axial termination (Odell, 2003). For this paper, the most important termination is stepping. Step terminations occur when...
bending forces act perpendicular to the initial fracture and represent a second fracture event independent of the first Hertzian or bending initiation. Hertzian and bending initiations are the most common during many controlled lithic reduction and flake production techniques (i.e. bifacial reduction, blade production), while wedging is typically associated with bipolar reduction.

In addition to core reduction, these same mechanisms of fracture can be used to break individual flakes. For Cotterell and Kamminga (1987:Figure 15), percussion applied to the center point of a flake can result in fracture either by bending or compression forces. If there is no opposing force directly under the point of impact, bending fracture will cause the flake to snap transversely. In some cases, bending induced transverse fractures, also referred to as snap fractures, have virtually no propagation phase, and the force travels straight down from the impact point creating a ninety degree fracture angle. Deller and Ellis (2003) also suggest that snap fractures can result from classic Hertzian cone initiation in which a cone began to form prior to median/lateral fracture propagation. However, they note that even on percussion produced snap breaks, cones of force are often absent making it impossible to determine whether the force was produced by bending or Hertzian fracture.

Alternatively, if an opposing force is placed directly opposite the impact recovery type bend fractures can be produced from the striking surface (Cotterell and Kamminga, 1987). Compression fracture results in what have been termed radial breaks which are produced when the percussive force causes the flake to split into three or more pieces (Deller and Ellis, 2003). These also can exhibit lips and cones of force (Deller and Ellis, 2003) as well as ring cracks, crushing, and erasure scars at the point of force (Moore et al., 2009). Radial fractures can also accompany perversive fractures when propagation follows radial fissures (Miller, 2006).

1.2. Distinguishing intentional from incidental fracture

Flintknapping experiments have revealed how bend and radial fractures occur, and archaeological analyses demonstrate that prehistoric knappers used bend and radial fractured bifaces and flakes for tools. Yet the question remains, were these breaks intentionally created by prehistoric knappers for tool use, or did tool users simply select incidentally broken fragments for use? Experimental archaeology has the potential to help answer this question, but experiments explicitly designed to replicate bend and radial breaks are few, with radial breakage of bifaces receiving the most attention.

Bergman et al. (1987) produced experimental breaks by placing flakes on an anvil and using a hammer indenter. The features they consider diagnostic of intentional breakage are points and cones of percussion, incipient cones, and dorsal crushing at the point of impact. Importantly, use of a hard hammer is more likely to produce these features than soft hammer, and twenty-five percent of the breaks in their experimental sample had no evidence of contact features. Finally, they suggest other features, including wedge-shaped fracture lines, lips, and conchoidal fracture marks, are common to intentional breaks but also occur on accidental breaks during core reduction. Root et al. (1999) report experimental breakage of bifaces and flakes by radial fracture. Although they do not present experimental data in detail, they do note that Hertzian initiations and edge lips are rare, and radial break edges are “near 90°” angles. Jones (2002) experimentally produced bend and radial breaks by placing flakes on a stump and tapping the flake center with a hammerstone but does not describe the fragments or breaks. Deller and Ellis (2003) refer to experiments in which they broke bifaces via bend/snap and radial fracture but also do not present detailed experimental data. They identify several traits which they suggest demonstrate unequivocal evidence of intentional breakage, and these include occasional Hertzian cones, ring cracks, and lipping of the fracture edge. Miller (2006) experimentally broke bifaces, some of which broke by radial fracture, but the focus of this experiment was replicating perversive fractures rather than bend or radial fractures.

The above bend and radial fracture experiments have identified potential markers of intentional breakage, but they fall short of providing systematic comparisons between intentionally produced breaks to those produced incidentally. Under the umbrella of use-wear analysis, innumerable other experiments have been designed to identify tools and distinguish between intentional and natural damage, but these experiments focus primarily on microscopic edge damage and use-wear rather than larger-scale bend or radial flake breakage (Andrefsky, 2005; Odell, 2003). Likewise, numerous core reduction and flake production experiments have been designed to replicate various aspects of prehistoric technologies, but because these studies often focus on other questions, few report the incidence of bend and radial flake breakage produced during the reduction process. Important exceptions include the work of Root et al. (1999) and Tallavaara et al. (2010). In their core reduction experiment, Root et al. (1999), found that only 30 of 622 flakes larger than 5.6 mm exhibited radial fractures. Tallavaara et al. (2010) experimentally produced 413 flakes and recorded the incidence of accidental bending and radial fractures. The 201 fragmented flakes were produced by combinations of 152 bending and 125 radial fractures. They show that knapping skill, indenter type, and relative flake thickness significantly impact fracture rate.

Previous experiments have provided important data on the frequency and attributes of bend and radial breaks produced intentionally and incidentally. This paper builds on these studies by providing new data on how often radial breaks are produced by processes other than intentional breakage, specifically by bifacial core reduction and trampling, and refining criteria for distinguishing intentional breaks from incidental fractures.

2. Methods

To compare bend and radial fractures produced intentionally and incidentally, three flake fracture experiments were conducted. First, flakes were intentionally fractured by striking the flake surface. Second, bend and radial breaks were recorded on flakes and flake fragments from a previous biface reduction experiment conducted by Jennings et al. (2010). Finally, flakes were fractured by trampling.

Intentional flake fracture was initiated by placing an Edwards chert (from a source in central Texas, c.f. Banks, 1990; Wyckoff, 2005) flake or flake fragment (hereafter both are referred to simply as “flake”) on a thin piece of leather hide lying on a large Edwards chert nodule. The flake center was then struck with an antler billet. Because the location of opposing force has been suggested as an important factor influencing fracture initiation (Cotterell and Kamminga, 1987), two types of flakes were fractured: twenty curved and twenty flat flakes. Curved flakes did not rest on and were not in contact with the hide/nodule surface directly under the point of impact. Flat flakes were in direct contact with the hide/nodule surface at the impact point. All breaks larger than 1 cm in length were analyzed as described below.

In a previous experiment (Jennings et al., 2010), six Edwards chert nodules were reduced as bifacial flake cores. Here, flakes larger than 2.5 cm in maximum dimension produced during this reduction experiment were analyzed for the presence/absence of bend or radial fractures, and if present, each fracture larger than 1 cm in length was analyzed as described below. Striking platforms were not counted as breaks, and nor were hinge terminations. Step terminations were counted as bend breaks.
The goal of the trampling experiment in this study differs from other trampling experiments. No attempts were made to directly replicate a specific trampling scenario, such as walking on flakes at a camp site. Flakes were not scattered about in a grid, and trampling time was not measured. Rather, the singular goal of this study was to break each flake by walking on it. Twenty Edwards chert flakes were selected for trampling. Flake fracture occurred on two phases. First, each flake was placed on a dry, hardened silty-clay soil surface with no vegetation cover. Each flake was then stepped on in a single step. If the flake broke, the fragments were collected and removed from the trampling experiment. Flakes that could not be broken in a single step graduated to phase two. Phase two replicates flake-on-flake trampling which might be expected at a dense lithic workshop. One flake was placed on the silty-clay surface. A second flake was placed directly on the base flake. Finally, a third flake was placed directly on top of the second flake. As with phase one, this three flake sandwich was trampled in a single step. All breaks larger than 1 cm in length were analyzed as described below.

Flakes from these three experiments, intentional fracture, biface reduction, and trampling, were then analyzed and compared for the types of breaks produced and the characteristics of the breaks. The number of fractures produced and the number of breaks per fragment were counted. Breaks or fragments smaller than 1 cm in maximum dimension were excluded. Breaks were classified as bend, radial, or Hertzian based on the mechanics of fracture (only bend and radial breaks were recorded for the biface reduction debitage). Three measurements were recorded (Fig. 1). Maximum flake thickness was measured on each intentionally fractured and trampled flake before the flake was broken and on each piece of biface reduction debitage possessing a bend or radial break. Maximum break thickness measures the maximum thickness between dorsal and ventral flake surfaces where they intersect with the break face. Break angle measures the acute angle formed by the intersection of the break face with either the dorsal or ventral fragment surface. The highest possible value for this measurement is 90°, and measurements were taken at the midpoint of the break. Break angle can be measured on either fragment associated with a break. Presence/absence attributes related to fracture initiation were also recorded. Lipping on the break surface occurs when the fracture begins curving parallel to the striking surface and typically results in one fragment with a small lip at the fracture termination and another fragment with the mirror scar of the lip. For this study, lipping was recorded as present if a lip was present on the break surface of any fragments associated with a single break. Partial Hertzian cone formation occurs when a fracture begins with a Hertzian initiation, but this is overtaken by bending or radial fracture. In such cases, a small partial cone, resembling a bulb of percussion, forms on one break surface while the other break surface retains a negative mirror of the cone. In rare cases, a small complete Hertzian cone can be detached at the impact point, leaving negative cone scars on both major bend/radial break surfaces. Eraillure scars result from the detachment of small flakes from the break surface near the point of impact. Finally, impact spalls result from the detachment of small flakes from the impact surface (either the dorsal or ventral flake surface) at the point of impact.

For the intentional fracture and trampling experiments, all measurements were recorded once per break, not once per fragment. For the biface reduction debitage, refitting was not attempted, so this may have resulted in some duplication if the same break was measured on two fragments. Kolmogorov–Smirnov Tests show that the continuous measurements are not normally distributed for these data. Therefore, non-parametric Kruskal-Wallace and Mann-Whitney-U tests were used in comparisons of break thickness and angle. Likelihood ratio chi-square tests were used for attribute frequency comparisons.

3. Results

3.1. Intentional fracture

Of the 20 curved and 20 flat flakes intentionally struck, 39 were successfully broken by at least one fracture 1 cm or greater in length. The single unbroken flake was a flat flake that broke along multiple small fractures that did not meet the 1 cm length threshold. The 39 successfully broken flakes were fractured by bending, radial, and Hertzian fractures (Fig. 2). Nineteen flakes broke along multiple fractures, and in total, 77 fractures measured 1 cm or longer (Table 1). Bending fractures were the most common (n = 41), followed by radial (n = 34) and Hertzian (n = 2). Break type frequencies do not significantly differ between curved and flat flakes (p = 0.062).

Comparisons of fracture types reveal important differences resulting from the mechanics of fracture propagation (Table 2). Lips occur significantly more frequently on bending fractures (p < 0.001). Bending breaks are significantly thicker (p = 0.003) and have significantly more acute angles (p < 0.001) than radial breaks. Hertzian breaks have significantly more acute angles than both bending and radial breaks.

Evidence of the point of impact (Table 3) is evident on 18 (15.5%) of the 116 total fragments. This evidence includes full or partial Hertzian cones along portions of break surfaces, impact spalls that fragmented off of the top surface, and one bipolar eraillure scar along a break surface (Fig. 3). Only one flake has multiple impact indicators, a partial cone and impact spall. Impact point evidence does not significantly vary between curved and flat flakes (p = 0.750).
3.2. Biface reduction

Reduction of six bifaces produced 655 flakes and flake fragments greater than 2.5 cm in maximum dimension, and 176 of these (26.9%) have at least one bending or radial break, and 25 fragments have multiple breaks. Although the frequency of fractures varied among the reduction events, the differences are not significant ($p = 0.059$). Of breaks measuring greater than 1 cm, 102 resulted from bending fracture and 100 resulted from radial fracture, and the frequency of bend and radial breaks does not significantly differ among the six biface reduction events ($p = 0.241$).

Lips occur significantly more frequently on biface reduction fragments that broke by bending fracture than those broken by radial fracture ($p < 0.001$). Fragments with bend breaks are significantly thicker than fragments with radial breaks ($p = 0.021$), but fragment lengths do not differ ($p = 0.191$). Bend and radial break thicknesses, however, do not significantly differ ($p = 0.107$) and neither do break angles ($p = 0.380$).

Table 1

<table>
<thead>
<tr>
<th>Break type</th>
<th>Count (percent)</th>
<th>Count (percent)</th>
<th>Count (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intentional Fracture</td>
<td>20 (60.1)</td>
<td>11 (33.3)</td>
<td>2 (6.1)</td>
</tr>
<tr>
<td>Intentional Fracture Flat</td>
<td>21 (47.7)</td>
<td>23 (52.3)</td>
<td>0</td>
</tr>
<tr>
<td>Intentional Fracture Combined</td>
<td>41 (53.2)</td>
<td>34 (41.2)</td>
<td>2 (2.6)</td>
</tr>
<tr>
<td>Biface Core 1</td>
<td>22 (59.5)</td>
<td>15 (40.5)</td>
<td>0</td>
</tr>
<tr>
<td>Biface Core 2</td>
<td>14 (37.8)</td>
<td>21 (62.2)</td>
<td>0</td>
</tr>
<tr>
<td>Biface Core 3</td>
<td>17 (42.2)</td>
<td>19 (52.8)</td>
<td>0</td>
</tr>
<tr>
<td>Biface Core 4</td>
<td>12 (42.9)</td>
<td>16 (57.1)</td>
<td>0</td>
</tr>
<tr>
<td>Biface Core 5</td>
<td>12 (50.0)</td>
<td>12 (50.0)</td>
<td>0</td>
</tr>
<tr>
<td>Biface Core 6</td>
<td>25 (62.5)</td>
<td>15 (37.5)</td>
<td>0</td>
</tr>
<tr>
<td>Biface Cores Combined</td>
<td>102 (50.5)</td>
<td>100 (49.5)</td>
<td>0</td>
</tr>
<tr>
<td>Trampling Phase 1</td>
<td>8 (100.0)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Trampling Phase 2</td>
<td>13 (81.3)</td>
<td>2 (12.5)</td>
<td>1 (6.2)</td>
</tr>
<tr>
<td>Trampling Combined</td>
<td>21 (87.5)</td>
<td>2 (8.3)</td>
<td>1 (4.2)</td>
</tr>
</tbody>
</table>

Fig. 2. Bend (b, d, e, f) and radially (a, c, g, h) fractured flakes produced by intentional fracture (a, b), trampling (c, d), and bifacial reduction (e–h).

3.3. Trampling

Of the 20 flakes included in the trampling experiment, 8 were successfully broken during phase 1, a single flake placed on the ground. Eleven were successfully broken during phase 2, flake-on-flake trampling. One unbroken flake withstood both phases of trampling. The 19 successfully broken flakes were fractured by bending, radial, and Hertzian fractures. Three flakes broke along multiple fractures, and 24 fractures measured 1 cm or longer. Bending fractures were most common ($n = 21$), while radial ($n = 2$)
and Hertzian (n = 1) fractures were distant minorities. Although the results are not significant, likely due to small sample sizes, phase 2 flake-on-flake trampling produced more multi-fracture break events and produced the only radial and Hertzian fractures. Average break thicknesses and break angle do not differ between phase 1 and phase 2 flakes.

Lips occur significantly more frequently on bending fractures (p = 0.003). Bend and radial break thicknesses (p = 0.398) and angles (p = 0.120) do not significantly differ. Likewise, break thicknesses (p = 0.076) and angles (p = 0.830) do not significantly differ among phase 1 and phase 2 flakes.

Evidence of the point of impact damage is evident on 13 of the 64 total fragments (20.3%). This evidence includes full or partial Hertzian cones and impact spalls. Impact point evidence significantly differs between phase 1 and phase 2 flakes (p = 0.003) because no cones or impact spalls were produced on phase 1 fractures.

3.4. Intentional breakage vs. biface reduction

When all breaks are included, biface reduction fragments and intentionally broken flakes do not significantly differ in terms of flake thickness (p = 0.540), break thickness (p = 0.266), or break angle (p = 0.820). Comparisons by fracture type, however, reveal significant differences. Flake thickness of bending breaks does not significantly differ between biface reduction and intentional fracture (p = 0.814), and the thickness of the bend also does not significantly differ (p = 0.226). Bend break angles produced during biface reduction are significantly larger than those produced by intentional fracture (p = 0.027). For radial breaks, flake thickness does not significantly differ between biface reduction and intentional fracture (p = 0.124), but radial breaks produced during bifacial reduction are significantly thicker than intentionally produced radial breaks (p = 0.027). Radial breaks produced intentionally have significantly higher break angles than those produced during bifacial reduction (p = 0.029).

Breaks on biface reduction flakes have no evidence of full or partial Hertzian cones, impact spalls, or eraillure scars. Not surprisingly, significantly more intentionally broken flakes have impact makers than flakes fractured during bifacial reduction (p < 0.001).

3.5. Intentional breakage vs. trampling

Relative proportions of break types significantly differ between intentional flake fracture and trampling (p = 0.006). This significance is driven by the near absence of radial fractures produced by trampling. When all breaks are included, trampled fragments and intentionally broken flakes do not significantly differ in terms of flake thickness (p = 0.968), break thickness (p = 0.696), or break angle (p = 0.114). Likewise, break thicknesses and angles do not significantly differ when bend and radial breaks are compared separately.

A portion of the breaks produced by both trampling and intentional fracture have evidence of impact. The relative frequency of full or partial Hertzian cone formation along the break face (p = 0.263), impact spalls (p = 0.867), and eraillure scars (p = 0.348) do not differ between intentional and trampling breaks. The relative frequency of total impact markers also does not differ (p = 0.419).

4. Discussion

These experiments provide new insights into the characteristics of intentionally and incidentally produced bend and radial

Table 3
Counts of fragments with evidence of point of impact damage. Percentages of total fragments within each experiment are in parentheses.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Total Fragments</th>
<th>Cone/partial cone</th>
<th>Impact spall</th>
<th>Eraillure scar</th>
<th>Total fragments with point of impact damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intentional Fracture</td>
<td>116</td>
<td>10 (8.6)</td>
<td>8 (6.9)</td>
<td>1 (0.9)</td>
<td>18 (15.5)</td>
</tr>
<tr>
<td>Biface Reduction</td>
<td>176</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>Trampling</td>
<td>64</td>
<td>9 (14.1)</td>
<td>4 (6.3)</td>
<td>0 (0.0)</td>
<td>13 (20.3)</td>
</tr>
</tbody>
</table>

Fig. 3. Point of impact damage produced by intentional fracture (a, c, e) and trampling (b, d, f). Arrows point to impact spall scars (a–d) and Hertzian cone scars on the break surface (e, f).
fractures on individual flakes. Intentionally striking the center of flakes can result in bending, radial, and Hertzian fracture. Both bend and radial fractures can be produced on curved flakes with opposing forces surrounding the point of impact or flat flakes with opposing force directly beneath the point of impact. The presence of lips along the break and more acute break angles distinguish intentionally produced bend breaks from radial breaks, and Hertzian breaks have more acute angles than bend and radial breaks. Intentional flake fracture leaves evidence of the point of impact on fractured fragments (15.5% of the fragments in this study). Impact markers include Hertzian cones, impact splats, and eurilide scars, and they occur on both bend and radial breaks.

Debitage from the reduction of six bifacial flake cores provides evidence of the frequency and characteristics of breaks produced incidentally during core reduction. Flakes fragment during biface reduction, and flakes break by both bending and radial fracture. The frequency of fragments with bend or radial breaks varies with the reduction of individual cores. In this study, 26.9% of flakes larger than 2.5 cm have at least one bend or radial break. Tallavaara et al. (2010) report the presence of bend or radial breaks on 72% of flakes produced during quartz nodule reduction, demonstrating the potential for fractures in these materials. Breaks in thin sections can have on flake fracture. Bend and radial break thicknesses and angles on bifacial reduction debitage in the current study do not significantly differ.

Flake breakage from trampling can result in bending, radial, and Hertzian fracture. Single flakes placed directly on the ground broke only by bending fracture with no evidence of impact. Flake-on-flake trampling primarily produces bend breaks, but radial and Hertzian breaks also occur. Impact markers also occur on some flake-on-flake trampling breaks, and these markers are identical to those produced by intentional fracture.

Comparisons of intentionally broken flakes to incidental breaks produced during biface reduction and flake trampling reveals some potential means for identifying purposeful flake fracture. Pending additional experimentation, I offer the following as guidelines for distinguishing intentional flake fracture based on the results of this study. It should be noted that since extremely high-quality Edwards chert was used in this study, these guidelines may not all apply to assemblages of poor quality stone. Likewise the bifacial cores and intentionally fractured flakes in this experiment were produced using only soft hammer percussion. Given the relationship between indenter type and fracture rate identified by Tallavaara et al. (2010), these guidelines may not apply to assemblages dominated by hard hammer percussion flaking.

- The key factor distinguishing intentionally fractured flakes from incidental fracture during biface reduction is evidence of the point of impact damage at the break. Core reduction does not produce point of impact damage on bend or radial breaks.
- Given that the bifacial reduction debitage in this study produced radial break angles averaging 77°, radial break angles for an assemblage averaging at least 83°–90° provides strong additional evidence for intentional fracture.
- Using simple fragment counts to distinguish between core reduction and intentional break production is more problematic given the large discrepancy between the cores analyzed in this study and the cores reduced by Tallavaara et al. (2010). I estimate that assemblages of 50% or greater fragments with bend or radial breaks may provide evidence of intentional flake fracture. For assemblages of high-quality chert such as Edwards, 50% or greater may be sufficient. However, I suggest relying on flake fracture percentages only as supporting evidence to the first two guidelines.
- To distinguish intentionally fractured flakes from trampling damage, the ratio of radial to bend fractures should exceed 3/20.
- It may not be possible to identify intentionally fractured flakes in a biface reduction assemblage that has been significantly affected by flake-on-flake trampling, but again, high frequencies of radial breaks may be indicative of intentional fracture.

5. Conclusions

Bend and radial break flake tools have been identified in Paleolithic and Paleoeindian assemblages (Bergman et al., 1987; Ferring, 2001; Frison and Bradley, 1980; McAvoy and McAvoy, 2003; Waters et al., 2011), and while the intentional production of bend and radial flake fractures for tool use has been inferred, no previous experimental program has identified specific criteria for distinguishing intentionally produced flake fracture from other unintentional fracture events. This study is the first systematic comparison of bend and radial breaks produced by intentional flake percussion to those produced by incidental breakage during biface reduction and flake trampling damage. High frequencies of radial breaks with near 90° angles and impact damage markers distinguish intentional breakage from biface reduction. Likewise, high frequencies of radial breaks also distinguish intentional breakage from trampling damage, but both can produce impact markers. Although identifying intentionally broken flakes in a severely flake-on-flake trampled biface assemblage may not be possible, perhaps we should not expect to if incidentally produced bend and radial break fragments are readily available for tool blank scavenging. In such cases, evidence of invasive reshaping along breaks and use-wear analyses may be the only means for conclusively demonstrating these breaks were an important toolkit component.

Acknowledgements

Bruce Bradley and Mike Collins were very helpful in discussing bend/radial flake tool features they identified in Folsom assemblages. Mike Waters provided guidance throughout this study. Ashley Smallwood helped me refine many of these ideas and is always willing to listen to me jabber about broken flakes.

References


