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Explaining the origin of fluting in North American Pleistocene weaponry

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ABSTRACT

Clovis groups, the first widely successful colonizers of North America, had a distinctive technology, whereby manufacturers removed flakes to thin the bases of their stone projectile points, creating "flutes." That process is challenging to learn and costly to implement, yet was used continent-wide. It has long been debated whether fluting conferred any adaptive benefit. We compared standardized models of fluted and unfluted points: analytically, by way of static, linear finite element modeling and discrete, deteriorating spring modeling; and experimentally, by way of displacement-controlled axial-compression tests. We found evidence that the fluted-point base acts as a "shock absorber," increasing point robustness and ability to withstand physical stress via stress redistribution and damage relocation. This structural gain in point resilience would have provided a selective advantage to foragers on a largely unfamiliar landscape, who were ranging far from known stone sources and in need of longer-lasting, reliable, and maintainable weaponry.

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1. Introduction

Although the timing varied, modern humans had dispersed around the globe (reaching all continents except Antarctica) well before historic times. As a result, the processes by which humans — hunter–gatherers for the most part — adapted to new landscapes, usually ones with diverse and unfamiliar resources and environments, and possibly undergoing geologically rapid climate changes, have never been recorded (Kelly and Todd, 1988; Meltzer, 2009). There are, of course, archaeological traces of the process, and these have shed important light on aspects of prehistoric colonization, particularly the speed and scale of movement across unknown lands, the newly arrived peoples' use of and impact on the native fauna, and the means by which colonizers learned their landscapes (Kelly and Todd, 1988; Meltzer, 2004a, 2009; O'Connell and Allen, 2012; Waters and Stafford, 2007).

Yet, less consideration has been given to the technology underpinning those processes. People new to a continent would have brought with them tools developed elsewhere that could have been used or modified, or they may have developed new tools to meet the challenges of the new landscape. Were the latter the case, it could potentially reveal elements of the technological strategies by which colonizers responded to novel challenges.

One example of a newly invented technology is the archaeologically sudden appearance of Clovis projectile points in Late Pleistocene North America (Eren and Buchanan, 2016). The oldest of these date to ~13,400 years ago and occur in the southcentral and southwestern portions of North America (Ferring, 2001; Meltzer,

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2009; Sanchez et al., 2014; Waters and Stafford, 2007). These bifacially flaked lanceolate spearpoints were often crafted on highly siliceous cryptocrystalline stone, principally chert, obsidian, or chalcedony and then carried, cached, traded, used, and eventually discarded, sometimes hundreds of kilometers from the stone's original geological source (Boulanger et al., 2015; Ellis, 2011; Eren et al., 2017; Hoard et al., 1992, 1993; Holen, 2010; Kilby, 2008; Meltzer, 2009; Speth et al., 2013). Edges of the proximal (basal) portion of the point, where it was attached (hafted) to a handle or shaft, are usually ground dull, presumably to prevent cutting of the lashings binding the point in place. Point tips often exhibit impact scars; microfracture analysis suggests this resulted from the weapons having been thrust or thrown (Hutching, 2015). Micro-wear evidence has supported the hypothesis that Clovis points were occasionally multifunctional tools, used as butchery knives in addition to hunting weaponry (Smallwood, 2013; Smallwood and Jennings, 2016).

Although Clovis points vary across space and many centuries, all share a singular technological attribute: a flake removal — the "flute" — that creates a shallow channel extending from the base of the point toward the tip (Fig. 1). Fluting is distinctive, widespread, and associated with the first widely successful colonizers of North America. Given its absence from the stone-tool repertoire of Pleistocene Northeast Asia, fluting appears to have been an American invention, likely the first (Meltzer, 2009; Waters and Stafford, 2007).

The purpose of fluting, however, is enigmatic. Early on it was hypothesized (Cook, 1928) that fluting enhanced bloodletting of a speared animal (akin to a grooved bayonet – at the time, World War 1 was still a recent memory). That hypothesis fails, as the fluting scars would have been largely filled in or covered by the shaft, mastic, and haft wrappings (Rondeau, 2015). Another early idea was that fluting enhanced hafting (Cook, 1928; Roberts, 1935). Yet, unfluted projectile points were mounted on spears for millennia without it, and it seems likely that if fluting did enhance hafting it would have presumably occurred prior to Clovis weaponry. The possibilities that fluting was done for stylistic or artistic purposes, was a form of costly signaling, or served in a pre-hunt ritual (Bradley, 1993; Frison and Bradley, 1999), are not unreasonable, but such notions are difficult to test, nor do they preclude the possibility that fluting also had a utilitarian function.

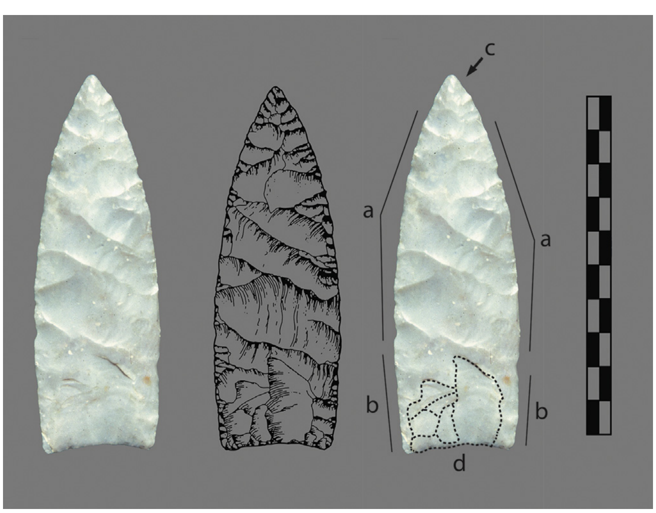

Fig. 1. Photograph (left) and line drawing (middle) of a Clovis fluted projectile point from the Clovis type site, Backwater Draw #1, New Mexico. Prominent features of a Clovis point (right) include the sharp distal lateral blade edges (a); the proximal lateral edges ground dull, presumably for hafting purposes (b); the tip (c); and the flute scars that thinned the base and basal edge of the specimen (d). (Source: modified from Meltzer 2004b, Fig. 3; originally drawn by F. Sellet and assembled by J. Cooper)

It seems reasonable to conclude that if fluting were simply a technological idiosyncrasy, it would not have been so widespread over space and time. Whether it spread by diffusion across an extant population or was carried by dispersing populations, it was associated with what appears in some instances to be the first groups to enter a region. Moreover, fluting was a challenging technology to master, occurring after a point was already thinned to ~7.5 mm. As modern stone-tool replication experiments suggest, further thinning by fluting is challenging, and examples of fluting failures in the Clovis archaeological record are common (Bradley et al., 2010; Morrow, 1995, 2015; Smallwood, 2012; Waters et al., 2011). Quantitative estimates indicate that 10.5–22.2% of points broke during fluting (Ellis and Payne, 1995). Considering that the time required for an expert knapper to produce a single point is at least 30 min, these persistent failures would have been costly to forager time and energy budgets (Schillinger et al., 2014), especially when stone supplies were scarce or sources unknown. There must have been a real or perceived functional advantage to fluting projectile points for Clovis groups to have adopted such a risky and costly technique and then maintained it for multiple generations. As such, understanding the purpose of fluting has the potential to provide insight into the challenge of colonizing a new and unknown landscape.

2. A hypothesis for Clovis fluting

One consequence of Clovis fluting on which researchers agree is that, when successful, fluting thins the proximal end of a point, especially its base (Bradley et al., 2010; Meltzer, 2009). In principle, a thinner stone-tool edge is weaker and more brittle than a relatively thicker one. Yet, given the many centuries fluting was applied to Paleoindian points, it raises the question of whether that weakness could potentially have been an asset.

Here we explore the possibility that fluting served as a "shock absorber," a feature designed to crumple (rather than fracture) on impact, thereby increasing a point's overall resilience and extending its lifespan. Put in more formal terms, material specimens under load, such as a Clovis point upon impact, experience stress. Once a specimen's stress limit is reached at a given location, that portion of the specimen will break, or experience crunching or crumpling, and the stress will be redistributed. If the redistributed stress is below the overall failure stress level, then the specimen remains intact and may continue to support load; if not, the specimen fails, sometimes catastrophically. However, depending on the geometry of the specimen under stress, damage may relocate from one position on the specimen to another, including from the tip to the base.

Here we test the hypothesis that fluted points will withstand higher energies and last longer than unfluted points because stress will relocate from the tip to the thinner, brittle basal edge that results from fluting. We conducted two sets of analyses, one analytical and the other experimental. First, we examined whether the geometry of Clovis-style fluted points increased point robustness relative to unfluted points via stress redistribution and damage relocation. Two types of analytical modeling were performed: static, linear finite element modeling and discrete, deteriorating spring modeling. Second, we used displacement-controlled axial-compression tests to experimentally assess under controlled conditions the relative mechanical responses of fluted and unfluted specimens. We discuss each analysis in turn.

3. Analytical modeling

The objective of the static, linear finite element modeling was to establish the essential features of stress distribution of fluted and unfluted points subject to axial, static loading. Three-dimensional models of four geometric point variants with three support conditions each (Fig. 2) were modeled in the drafting software SolidWorks and imported into ANSYS, a finite element analysis software suite, for stress analysis (Fig. 3) (SI). The first point geometry represents an unfluted point, and the second, third, and fourth point geometries represent points with different types of flutes (Fig. 2a and SI). The various hafting support conditions represent possible interfaces between a point's basal edge and a thrown or thrust shaft: fully engaged, partially engaged, or engaged at a single concentrated spot (Fig. 2b). Subjecting analytical point models to a force at the tip produces normal stress distributions throughout its body; areas of interest include locations of local stress maxima and minima where material failure will potentially occur.

Table 1 shows the maximum compressive normal stresses at the tip and base of each point geometry and boundary-condition combinations before any breakage or crushing. Negative values in Table 1 indicate axial compression. The average normal stress on a cross-section, σ, is given by the equation

$$\sigma = \frac{F}{A},$$

where F is internal axial force and A is the cross-sectional area (Timoshenko, 1940). Not surprising, the ANSYS models predicted that point tips experience the highest stresses. Further, the maximum stress for the relatively thinner fluted-point bases was consistently greater than the maximum stress for the relatively thicker unfluted-point bases, independent of boundary condition. This result affirms that fluted-point bases are more likely to crumple and be crushed than unfluted-point bases.

In cases where some crushing or fracture damage occurred at the tip, portions of the tip deteriorated and a remaining, larger cross-sectional area of the blade portion of the point became exposed. At some level of deterioration, the remaining size of the cross-sectional area near the tip of the fluted point ought to become larger than the basal cross-sectional area, and damage should relocate from the tip to the base.

To examine this possibility, two ANSYS models (geometries #1 and #3) were altered to remove the top 25% of the point (Table 1, last two rows). These model results showed that as the points deteriorated from crushing, the basal stresses comprised a larger percentage of the maximum stress in the point. Therefore, the chance of crushing or fracture at the basal edge increased.

In order to further investigate the effect of damage relocation, a simplified linear material, nonlinear geometry series spring model was developed to capture stress distributions throughout a point that experiences damage and subsequent material deletion. These point-damage model (PDM) results showed evidence of damage relocation from the tip to the basal edge as a static load is applied.

Preliminary physical testing was conducted to determine, qualitatively, the general behavior of a stone point under load. As the applied load was increased, tiny portions of a stone point were crushed or splintered off at both the basal edge and the tip (SI). Based on the results from preliminary point testing and the elastic

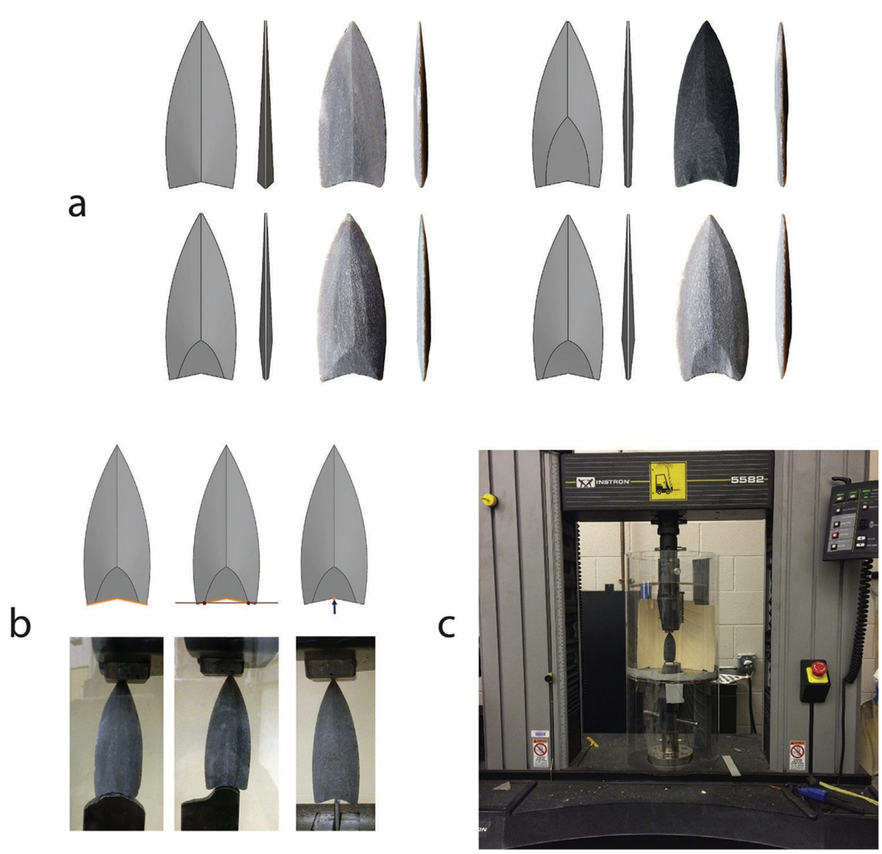

Fig. 2. Analytical and experimental stone-point specimens included four types: unfluted (a, upper left); long fluted (a, upper right); short tapered flute (a, lower left); and short flute (a, lower right) (see SI for details). Support conditions included fully engaged (b, left), partially engaged (b, middle), and point contact (b, right). The static, compressive loading setup used an Instron 5582 axial load frame (c). The flutes were ground in all instances.

Table 1
Analytical results from ANSYS (a) and the point-damage model (b).

(a) ANSYS Stress Results				
Geometry	Boundary condition	Maximum stress at top (psi)	Maximum stress at base (psi)	Percentage of maximum stress at base to top (%)
1	1	−712.33	−6.27	0.88
1	2	−712.33	−6.55	0.92
1	3	−712.33	−74.79	10.51
2	1	−712.57	−16.99	2.38
2	2	−712.57	−17.17	2.41
2	3	−712.57	−246.13	34.54
3	1	−712.86	−14.71	2.06
3	2	−712.86	−15.54	2.18
3	3	−712.86	−281.70	39.52
4	1	−714.66	−23.06	3.23
4	2	−714.66	−25.77	3.61
4	3	−714.66	−474.05	66.33
25% of specimen top deleted				
1	1	−25.09	−7.02	27.97
3	1	−26.21	−14.51	55.35

(b) PDM Damage Relocation Results		
Geometry	Boundary Condition	Length at 1st Switch (in)
1	1	1.42
1	2	1.14
1	3	0
2	1	1.70
2	2	1.42
2	3	0.85
3	1	1.70
3	2	1.56
3	3	0.99
4	1	1.85
4	2	1.70
4	3	0.99

behavior of the stone material, each specimen was assumed to be composed of tiny “springs” arranged vertically in series up the length of a point. Each spring represents, mechanically, a portion of the fluted point that is compressed; each spring experiences the same compressive force, but given the configuration of the point each spring has a different cross-sectional area. Damage in the PDM occurs as a removal of the material (represented by the deletion of a single spring) when that portion of the fluted point reaches its failure stress. Because of the brittle nature of stone, failure is defined as the stress at which crushing fracture occurs; this value was estimated from preliminary physical tests as approximately 250 megapascals (MPa). The physical phenomenon of crushing is represented, analytically, by spring elimination in the PDM model.

The process of discretizing the point into slices (to represent the springs) and assigning each slice a cross-sectional area and length is shown in Fig. 3b. Each cross-sectional area was calculated using the SolidWorks models at the center of each slice, with the entire slice model representing 20 springs (Fig. 3b, left). The dotted line in Fig. 3b (center) shows the vertical location where the cross-sectional area of the slice was calculated. The red line in Fig. 3b (right) shows the series of springs that approximate the point.

The same geometry and support conditions used in the ANSYS models were employed in the analysis of the PDM. A static load was applied to the tip (or uppermost cross-sectional area), and the stresses, strains, and deflections were calculated. The degree of freedom for each spring element is the vertical axial translation. If the stress calculated in a given spring exceeded the assumed failure stress, that spring was deleted and the analysis continued.

A specimen, after every spring deletion, was reinitialized as a new specimen with one less spring, which affected the equivalent stiffness of the remaining material. This model is geometrically nonlinear as material deletion is represented by instantaneous spring deletion. In these simulations, spring deletion, representing crushing of the point, always occurred at the tip of the point first; this result is in agreement with the ANSYS predictions. In all but one simulation, the material deletion relocated from the tip of the point to the basal edge.

In contrast, the unfluted point with a single concentrated support condition never experienced spring deletion switching from tip to base. In such a specimen, the cross-sectional area increases continuously from the tip down to the concentrated support condition. Therefore, the stress force per area is always greatest at the uppermost location of the point. Moreover, in all other simulation iterations point length at the time of damage relocation was on average greater for the fluted points than it was for the unfluted points. The same was true under equivalent boundary conditions (Table 1). In other words, the fluted points showed spring deletion switching from the top to the base of each point sooner than in unfluted points, in turn suggesting that fluted points preserve more of their upper portion under stress than do unfluted points.

4. Displacement controlled axial-compression experimental tests

Experimental tests were also performed to assess the effect of impact on the physical and mechanical behavior of the fluted and unfluted geometric variants. Similar to in the analytical study, the actual physical tests were performed on five specimen types — here using stone replicates — for each of the combinations of point geometry and support types (Fig. 2a and b). The points, made of Georgetown chert from Edwards Formation limestone (Texas), were professionally produced with lapidary equipment to be the same size and shape, though varying in flute presence and/or kind. We used geometric morphometrics to define what that composite size and shape should be (SI). We did not use replicated knapped (chipped) fluted points for the

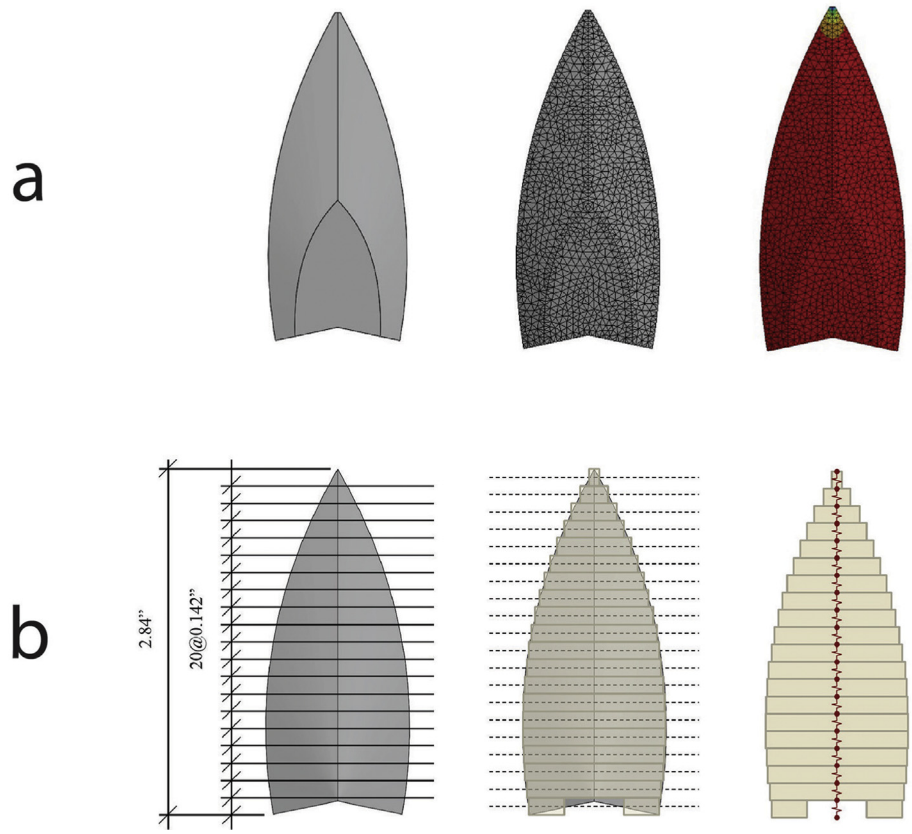

Fig. 3. Analytical stone-point discretization: geometry (a, left), finite element mesh (a, middle), and stress results (a, right); PDM discretization of linear spring elements (b).

experiment, as it would have been impossible to produce specimens that were constant in size, shape, fluting and flaking characteristics, thus making it difficult to control for key variables in the experiment. Future research may profitably examine specific Clovis-point shapes from particular sites or regions, in so far as these can be identified as coherent forms.

The points were placed on an Instron 5582 load frame (Fig. 2c). The axial compression was performed under displacement control with a constant-rate-of-displacement header moving at 0.01 mm/s. This low header velocity eliminates inertial effects so that the physical test results can be compared to the static analytical results. Compression continued until the specimen fractured catastrophically and could no longer function as a point, or in such a manner that the geometric support conditions caused the specimen to become unstable in the loading apparatus (SI).

We examined three variables in these tests to assess the resilience of fluted-versus unfluted-point geometries: energy at failure, time at failure, and point length at failure. Given the analytical modeling results, we expected that fluted points would withstand higher energies, last longer, and ultimately achieve shorter body lengths before failure than unfluted points.

We were thus surprised when experimental comparisons of fluted- versus unfluted-point geometries showed no significant differences in these variables (Fig. 4) (SI). However, we realized that the benefit to stone points arose not *necessarily* because of the presence/absence of a flute but rather because fluting provided conditions more conducive to damage relocation. During the physical testing, an occasional unfluted point would crush or fracture at its base by chance and thus incidentally receive the benefits that come with damage relocation. Similarly, on occasion a fluted point would not crush or fracture at its base and not receive those benefits. These occurrences were exceptions confounding the comparisons.

We therefore compared all points, regardless of flute presence, that experienced damage relocation versus those that did not. When examined in this manner, the comparison showed statistically significant advantages in all three variables for points (fluted and unfluted) that experienced damage relocation (Fig. 4) (SI). Thus, and consistent with our analytical modeling, our physical experiments showed that damage relocation significantly increases the resilience of points.

If damage relocation is key to increasing the resilience of a point, and can occur in both fluted and unfluted points, then that raises the question asked at the outset: "why flute?" More specifically, does fluting significantly increase the chances of damage relocation occurring over unfluted points? To answer this question we conducted two goodness-of-fit tests of the occurrence of damage relocation in fluted versus unfluted points. A chi-square test showed that significantly more points with basal crushing occurred among fluted points than unfluted points ($\chi 2 = 8.03$, $df = 1$, $p = 0.0046$, Monte Carlo $p = 0.0082$). Because one cell in the table had less than five specimens, we also conducted a Fisher's exact test; it also showed a significant association between fluted points and the occurrence of basal crushing ($p = 0.0067$). In other words, the presence of fluting significantly increases the chances of damage relocation occurring on a point, and because damage relocation increases a point's overall resilience in terms of energy absorbed, the time before catastrophic breakage, and remaining intact until that moment of breakage, fluting does convey a technological advantage.

Further statistical analyses supporting these experimental results can be found in the online supplementary materials (SI).

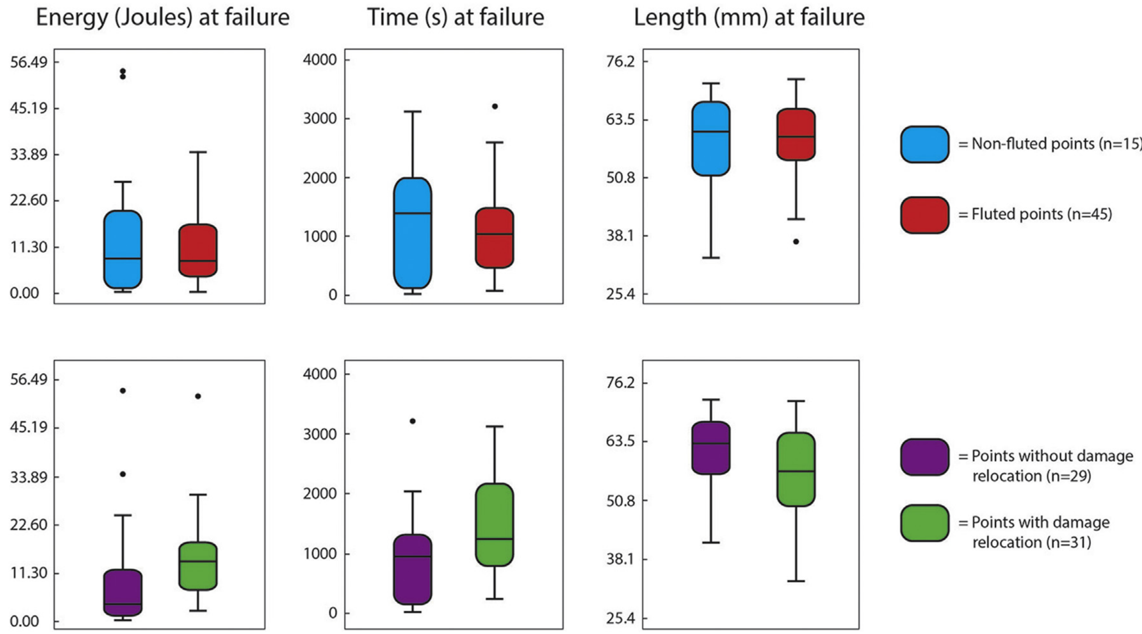

Fig. 4. There were no significant differences in energy at failure (Joules, J), time at failure (seconds, s), or length at failure (millimeters, mm) between experimental unfluted (blue, n = 15) and fluted points (red, n = 45) (top row). Significant differences were evident in these variables, however, when points without damage relocation (purple, n = 29) were assessed against points with damage relocation (green, n = 31) (bottom row). (See SI for details about the statistical analyses). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

5. Discussion

Our results have shown that, regardless of basal-support condition, fluted as opposed to unfluted Clovis-style projectile points possess structural advantages in overall resilience and the ability to absorb physical stress, such that fluted points are less subject to catastrophic failure.

Our "point first" approach to understanding Clovis fluting in no way is meant to disregard or ignore the fact that stone projectile tips were likely part of multicomponent weapon systems. The type and extent of hafting, for one, may have influenced the resilience of fluted points and frequency of breakage. For example, one hypothetical possibility (of several) is that the bases of fluted points were enveloped in the end of a slotted haft. In this scenario, there may have been increased contact between a point's two faces and the haft, in addition to contact between the haft and point's base. This facial contact would have reinforced the base at some level. Or perhaps the point was bound in place by mastic and hafting wrappings, which would have also reinforced the base, maybe even cushioning the impact in that area. In these hypothetical scenarios, the shock-absorption properties we have shown to be inherent to fluted-point geometry would have acted in concert with these other mechanisms to absorb physical stress and prevent catastrophic failure.

Whether the shock-absorbing benefits would have been sought or even consciously recognized by Clovis knappers (SI), or were merely the unintended consequence of the application of a particular technology, fluting would have had a positive functional value. Its benefits would have offset both the steep learning curve and production risks involved in the fluting process as well as provided a selective advantage to Clovis foragers ranging far from their stone sources and in need of long-lasting reliable and maintainable weaponry. As a low-density but highly-mobile forager population on the North American continent, Clovis people would have placed considerable emphasis on mitigating subsistence risk (Meltzer, 2004a; Smith and DeWitt, 2016). However, long-distance forays into unfamiliar territories would have meant that resupply of stone was not a certainty (Andrews et al., 2015; Eren, 2013; Smallwood, 2010). Indeed, even in some regions like the Southeast (Smallwood, 2012) or Southern Plains periphery (Jennings, 2015), where Clovis populations at times may have established relatively intensive collector settlements near high-quality stone sources, Clovis people may have still been unfamiliar with the broader landscape during long-distance forays for food, or seasonal migrations. Thus, the Clovis investment of time and energy in a costly technological production procedure would have increased their weaponry's reliability when it counted most: during hunting, exploring, and procuring resources in uncharted lands.

Although we do not have a clear or at least consistent picture of what *pre*-Clovis points look like, they were not fluted. It is a matter of speculation as to why fluting arose in the first instance: whether it truly was the first American invention, a new technology developed for colonizing a new world. Or perhaps it arose from a simple technological mutation: a point that was basally thinned, either accidentally or experimentally, proved more resilient or longer-lived — or at the very least did not cause any noticeable detriment — and hence the practice, regardless of its ultimate cause, evolved via positive feedback into more formal fluting and became fixed in the Clovis technological repertoire.

What is striking is that over the centuries fluting became more extensive and elaborate in the difficult, intricate, and riskier production process of full-faced fluting seen on subsequent Folsom, Barnes, and Cumberland projectile points. By late Paleoindian times, fluting was abandoned altogether. Further testing of post-Clovis projectile-point structural properties may help explain these cultural changes. However, one possibility is that unlike their Clovis ancestors, later Paleoindians using lanceolate point forms would have been much more familiar with their landscape and its stone resources for resupply (see discussions in Andrews et al., 2015 versus Jennings, 2016). Hence, they could afford to design their weaponry exclusively toward the goal of maximizing its killing potential via planned obsolescence (Frison, 2004) as opposed to balancing lethality with resilience. Thus, full-face fluted and nonfluted late Paleoindian point styles such as Folsom and Agate Basin, respectively, may very well have been invented to break upon impact in order to cause maximum damage to prey (Frison, 2004), a projectile-point design strategy documented ethnographically as well (Ellis, 1997).

One may wonder how the use of our experimental static compression tests may compare with dynamic tests in which experimental specimens are instead quickly thrust or thrown. While we will conduct such tests in the near future, and encourage others to do so as well, we implemented static (or more appropriately quasi-static) compression conditions as an initial investigation under controlled analytical and experimental conditions. In materials that exhibit linear stress-strain relationships (e.g. brittle stone), the primary difference in a quasi-statically (i.e. very slowly applied load) and a dynamically applied load is that the magnitude of stresses will increase as the rate of load increases. In fact, the theoretical increase in the axial stress resulting from a dynamically applied load to that of a slowly applied load of the same magnitude is 100% (Timoshenko, 1940). While this distinction is certainly important for characterizing the amount of impact force a Clovis point can tolerate in an impact situation, the distribution of the internal stresses is not likely to be affected significantly by load rate. For example, if one applies ½ the force to Clovis point, one expects to get lower stress, but the distribution of the stress would be similar to the distribution if the full force were added (Cook et al., 1989; Boresi et al., 2011).

Not only should dynamic models and experimental tests be conducted in the future, but experiments with higher levels of external validity should also be conducted. As recently described by several researchers (Mesoudi, 2011; see also Clarkson et al., 2015; Eren et al., 2016; Lycett and Eren, 2013; Pettigrew et al., 2015; Roe and Just, 2009), "internal validity" and "external validity" can be seen to refer to opposing strengths and weaknesses in reference to the data provided by different levels of experimental control. On one hand, experiments with high levels of internal validity can be repeated, and their parameters and variables might be controlled and manipulated in multiple ways, but specific assumptions and inferences are required to give them archaeological meaning. On the other hand, experiments with high levels of external validity have higher levels of realism, but possess little control or randomization of the variables they produce, increased bias, and are difficult to replicate. Future experiments with increased external validity may be able to consider peripheral variables not currently considered in our current models and experiments. For example, our models and experiments assumed that the mechanical direction of force on the point is directly from the tip down. An experiment with increased external validity might be able to examine "glancing blows" or the influence of fluted point breakage if the point is rotating in the air. Additionally, Clovis points that are "flaked" and possess more size and shape variability than our tightly controlled specimens, should be examined. One further avenue of inquiry would be to examine a greater range of Clovis point shapes. "Debert-style," "Vail-style," or "Lamb-style" fluted points from far Northeastern North America possess, on average, deeper basal concavities than Clovis points from other parts of the continent. A deeper concavity might result in less contact area between the shaft and the basal edge. While the exact geometry will certainly affect the breakage pattern for any point, and should be examined further in the future, the issue of varying contact area sizes has been considered in the three support conditions used here. These support conditions bound the behavioral patterns; i.e. the actual breakage pattern will be some intermediate result between that seen when the shaft is applied as a point load and partially.

Finally, it should be noted that our overall approach to the question of Clovis fluting differs from previous studies examining stone projectile points (e.g. Cheshier and Kelly, 2006; Christenson, 1997; Hunzicker, 2008; Iovita et al., 2014; Odell and Cowan, 1986; Waguespack et al., 2009). Because an actual, preserved Late Pleistocene haft, set of lashings, or bindings has never been discovered, we decided to tackle the question by focusing on the evidence we do possess: the morphology of the Clovis fluted projectile point itself. This approach allowed us to understand the physical properties of Clovis fluted versus non-fluted geometries, which are inherent to the point types regardless of how these specimens were actually hafted in the past.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2017.03.004.

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