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Focus on the target. The importance of a transparent fracture terminology for understanding projectile points and projecting modes

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ABSTRACT

Projectile points have always attracted a lot of attention, but the last few years, efforts have intensified to recognize them in assemblages and to understand the details of their functioning (propulsion mode, hafting method, …). Debates have increased following the recognition of older projectile points and the use of projectiles as indicators of human behavioural complexity. The most frequently used method for identifying projectiles relies on the identification of so-called "diagnostic impact fractures". Although this procedure appears clear, a careful review of the literature reveals numerous inconsistencies in their description and terminology. We discuss some of these inconsistencies that seem to cause confusion and we present some first steps toward an improved methodology for the identification of projectile points based on new experimental data.

1. Introduction

Projectiles, defined here generically as referring to all weapon types independent of their projecting mode, have always been considered important in archaeological assemblages. Their suggestive morphology has attracted the attention of many archaeologists. Thanks to their rapid and distinct morphological variation across time and space, they were quickly used to construct the first typo-chronologies and models of cultural variation (see Knecht, 1997 for an extensive review). Some points are intensely worked, due to which they often served as a basis for technological studies (see Knecht, 1997 for an extensive review). The function of these points has been much debated. Most often they have been considered as weapon tips, sometimes as knives, but it is clear that morphological attributes alone are insufficient to determine their use (Beyries and Plisson, 1998; Brindley and Clarkson, 2015; Chesnaux, 2014; Clarkson, 2016; De Bie and Caspar, 1996; Hauck et al., 2013; Hester and Heizer, 1973; Moss and Newcomer, 1982; Nance, 1971; O'Farrell, 1996; Shea, 1988).

Hunting and preparing for the hunt (manufacturing, using and repairing the equipment, etc.) must have been an important and time consuming activity in the life of Palaeolithic populations (Bleed, 1986; Ellis, 1997; Greaves, 1997; Lee, 1968). Studying hunting equipment in more detail thus has the potential to shed more light on a crucial aspect of Palaeolithic human behaviour. Since early on, researchers have realised the relevance of a closer examination of fractures to identify projectiles in assemblages (Witthoft, 1968) and their examination has nourished many earlier debates on the existence of projectiles in the Middle Palaeolithic/Middle Stone Age and the capacity of different hominids to hunt (Beyries and Plisson, 1998; Shea, 2009, 1988, 2006; Sisk and Shea, 2011; Villa and Roebroeks, 2014). More recently, these debates have shifted towards the importance of different projecting modes for understanding behavioural complexity (Brown et al., 2012; Lombard and Haidle, 2012; Shea and Sisk, 2010). Especially the development of long-range hunting weapons is considered to have significantly impacted human subsistence and it has been suggested that it may have been an important factor in the development of our species (Shea and Sisk, 2010; Shea, 2006). Up until today, projectiles thus form a crucial element in debates on human behaviour (McBrearty and Brooks, 2000; Villa and Roebroeks, 2014). In most cases, the key elements of hunting equipment have disappeared, as they were manufactured out of organic material, and the stone points are the only evidence that is left. Therefore, an improved comprehension of their operational details, for example, the appearance and development of new weapon projecting techniques needs to rely on these stone points.

While several stone point types have been assumed to have served as hunting weapons, efforts have been invested over the last decades to verify these assumptions with empirical data. In the framework of functional studies of wear traces, a combination of criteria has been

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proposed that would allow the recognition of projectiles in archaeological assemblages. The most commonly used procedure to identify projectiles, however, relies on the identification of tip (apex) or base fractures, often referred to as so-called "diagnostic impact fractures". This method is based on several archaeological and experimental studies in which particular fractures were observed on the apex of projectile points and appeared to result from forces upon contact with an animal, more in particular with bone (Barton and Bergman, 1982; Bergman and Newcomer, 1983; Frison, 1974; Moss and Newcomer, 1982; Odell, 1978; Witthoft, 1968). The recurrent observation of apex fractures on experimental projectile points and the realisation that some of these may be diagnostic for projectile use (Fischer et al., 1984), gradually developed into a more formalised procedure, even though it remained based on sparse and very diverse experiments (Beyries and Plisson, 1998; Chesnaux, 2014; Crombé and Caspar, 2001; De Bie and Caspar, 1996; Hutchings, 2011; Lazuén, 2012; Lombard et al., 2004; O'Farrell, 1996; Pargeter, 2007; Pétillon et al., 2011; Rots and Plisson, 2014; Schoville and Brown, 2010; Shea et al., 2001; Sisk and Shea, 2009; Soriano, 1998; Wilkins et al., 2012; Yaroshevich et al., 2010). Together with the shift in the debate toward the potential behavioural implications of different projecting modes, efforts have recently also been invested in trying to find empirical data that would allow a reliable identification of the propulsion mode that was used (Cattelain, 1997; Geneste and Plisson, 1990; Iovita et al., 2014; Sano and Oba, 2015, 2014; Shea, 2006).

Given the importance of projectile points for understanding broader technological evolutions and variability, their identification based on impact fractures gradually gained in popularity. While initial determinations generally remained rather cautious (Fischer et al., 1984), more ambitious determinations have been proposed more recently (e.g., Wilkins et al., 2012). It has been criticised that the latter determinations relied on a poor understanding of impact fractures and that apex fractures cannot be used as sole arguments for projectile identification (Rots and Plisson, 2014).

2. Background

Historically, attitudes have changed in terms of the value that was attributed to diagnostic impact fractures. In order to illustrate these changes, we review 16 projectile studies in which the diagnostic value of specific impact fractures considered by the authors was clearly indicated. These studies are considered to be representative of the chronological development of the discipline (Table 1). In the beginning, the terms flute-like and burin-like fracture and their diagnostic value were shared amongst authors (Barton and Bergman, 1982; Bergman and Newcomer, 1983; Witthoft, 1968). Also the lithic use-wear conference organised by Brian Hayden in Columbia (Canada) resulted in a nice synthesis about fracture mechanics in siliceous material (Hayden, 1979), on the occasion of which the Ho Ho Committee proposed an attribute-based system for fracture description (Committee, 1979). Fischer et al. (1984) are the first to apply the Ho Ho terminology to describe impact fractures. They created three specific categories that they considered diagnostic to recognize projectiles based on attribute aggregation: step-terminating bending fractures, spin-offs and bifacial spin-offs. At the same time, they stressed that these "diagnostic" fracture phenomena can also occur during blank production. Indeed, it was recognized from the start that these fracture types in themselves are only characteristic of a specific load and direction of pressure, forces that may equally occur in circumstances other than projectile use. This is exactly the reason why functional analysts have always sought to corroborate the fractures with other lines of evidence (i.e., wear traces, residues) (see Rots and Plisson, 2014 for a discussion). Odell and Cowan (1986) introduced a first mixture of descriptive systems as they continued to use the old typological system (Barton and Bergman, 1982; Bergman and Newcomer, 1983; Witthoft, 1968), but they combined it with the Fischer et al. categories and they added a hinge-terminating bending fracture as a diagnostic category. De Bie and Caspar (1996) followed the same idea, but they also added the feather-terminating bending fracture. Afterwards, most authors

Table 1
Diagnostic impact fracture categories that are taken into account in different publications and the variation through time.

Diagnostic impact fractures	Flute-like	Burin-like	Spin-offs	Bif spin-offs	Step terminating bending	Hinge terminating bending	Feather terminating bending	Crushing
Witthoft, J., 1968	🟥	🟥						
Bergman, Barton, 1982	🟥	🟥						
Bergman, Newcomer, 1983	🟥	🟥						
Fischer et al., 1984			🟥	🟥	🟥			
Odell, Cowan, 1986	🟥	🟥			🟥	🟥		
Caspar, De Bie, 1996		🟥	🟥	🟥	🟥	🟥	🟥	
O'Farrell, 2004			🟥	🟥	🟥	🟥	🟥	
Lombard, 2005		🟥	🟥	🟥	🟥			
Lombard, Pargeter, 2008		🟥	🟥	🟥	🟥			
Villa, Lenoir, 2006		🟥	🟥	🟥	🟥			
Villa, Lenoir, 2009	🟥	🟥	🟥	🟥	🟥		🟥	
Sano, 2009	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
Sano, Oba, 2014	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
Lazuén 2012	🟥	🟥			🟥	🟥	🟥	🟥
Wilkins, et al., 2012		🟥	🟥	🟥	🟥			
Chesnaux, 2014		🟥	🟥	🟥	🟥	🟥	🟥	

continued to use at least partly the old typological system (Chesnaux, 2014; Lazuén, 2012; Lombard and Pargeter, 2008; Lombard, 2005; Sano and Oba, 2015a; Sano, 2009; Villa and Lenoir, 2009, 2006; Wilkins et al., 2012), but opinions diverged with regard to the additional diagnostic categories: either only the three originally proposed by Fischer et al. (Lombard and Pargeter, 2008; Lombard, 2005; Villa and Lenoir, 2006; Wilkins et al., 2012), or also an inclusion of hinge- and/or feather-terminating bending fractures (Chesnaux, 2014; Lazuén, 2012; Sano and Oba, 2015; Sano, 2009; Villa and Lenoir, 2009). Aside from this variation in the categories considered diagnostic, the literature also reveals discrepancies in the terminology used to describe macro-fractures and in the precision of existing definitions or applications of this definition. The vagueness or inconsistency in these terminologies is unintentional; each author uses terms for which each has a specific definition in mind. Depending on the author, these definitions may slightly differ from the original (precise or less precise) version. Researchers (including the co-author) have not always explicitly shared an unequivocal and complete definition associated with a clear illustration of each of the terms they have used. Unintentionally, it has in some cases resulted in misunderstandings of what a term exactly represents with respect to the fracture characteristics. Nobody benefits from this confusion and the growing popularity of the identification of projectile points in archaeological assemblages based on fracture characteristics stresses the need for a shared framework of terms, with precise definitions and explicit illustrations.

In this paper, we highlight some of the observed inconsistencies in currently used terminologies (DIFs) and we evaluate their effects on the interpretations. We propose a more transparent attribute-based terminology that directly builds onto the work of the Ho Ho Committee (1979) and we test the potential of this terminology to explain the relationship between the impacted material, the strength of the hafting, the mode of propulsion and the fracture's characteristics. The goal of this paper is not to discuss the reliability of interpretations based on macro-fractures analysis, but rather to refine current terminologies and definitions in order to propose a first step toward an improved methodology for the identification of projectile points. After all, a more robust methodology needs to rely on a precise and shared set of definitions.

3. Methods

The observations and propositions discussed in this paper are based on a careful review of the literature and on an analysis of a set of experimental points. Even though we consider that the interpretation of archaeological material needs to rely on several lines of evidence, such as the archaeological context, residues (if available) (e.g., soft tissues, embedded bones flakes, remains of glue) and wear traces (fractures, MLIT's, use polish, striations, hafting traces) (Fullagar et al., 2009; Rots and Plisson, 2014), we only focus on macro-traces in this article. Macro-traces are most commonly used to identify projectiles and we believe that most terminological confusion is linked with these approaches. We argue that a more attribute-based approach to describe macro-fractures may provide a viable or more precise alternative to current approaches.

For each of the fracture types routinely considered in projectile studies (grouped under the DIF-approach), the existing literature is examined and we briefly review commonly used definitions. Even though the terms used to describe them may vary between authors, we try to evaluate their degree of consistency between authors. While the same or similar terms are often used, they do not necessarily have the same meaning for each author. To aid in the evaluation, also published pictures were examined even though we are aware that not all diagnostic features may be easily visible on a single photograph. Comments remain cautious and suggestive, and exclusively intended to move the discussion forward. We stress that the intention is not to identify wrong from right, but to document the variation in the use of a term. Perfect descriptions do not exist and all analysts, including the authors, have used incomplete or vague descriptions in the past. This is not the issue here, as it is largely a historic construct, but as research develops, one needs to reflect on methods and procedures to seek ways of improvement. Definitions proposed in the past may have been confusing or incomplete, or their application may not have been rigorous. While this may not be so problematic for periods where projectiles commonly occur, it may be problematic when older assemblages with very different point morphologies and sizes are examined with the same procedures. In addition, it may hinder analyses that try to move beyond the identification of a projectile only, towards projecting modes, for instance.

In order to evaluate currently used terminologies and to test the potential of a stricter revised attribute-based terminology that builds on to the propositions of the Ho Ho Committee (1979), we performed a systematic projectile experiment with Gravettian and micro-Gravettian points. We describe the fractures on the experimental points in two different ways: with the aid of the commonly used DIF-approach and with the attribute-based terminology (the latter is essentially a revision and elaboration of attribute systems used up to now). Subsequently, these different categorisations are compared in order to reveal inconsistencies and to try to identify ways of avoiding them in the future.

Each fracture identified as having been caused by impact was examined with a V12 Zeiss binocular stereoscopic microscope (magnification between ×8 to ×100) and a V16 motorized Zeiss Axio Zoom microscope (magnification between ×6.5 to ×180). All points were photographed at ×16 magnification before the experiment to avoid confusion with production-related fractures. The aim of the analyses was to evaluate whether the revised system is sufficiently flexible and precise to reduce the existing confusion.

3.1. Basic definitions

It is important to first explain a few basic definitions concerning a fracture's characteristics, in particular for the attributes that are most

Fig. 1. A. A cone initiated scar; B. A bending initiated break initiated from a surface.

Table 2
Complete list of the revised attribute system with all considered attributes and attribute states.

Entity	Attribute	Attribute state
Global	Fracture part (Fig. 2) (part of the fracture that is described)	Positive; negative
	Fracture composition	Single; multiple
	Fracture group	Scar; break
Initiation	Initiation type	Cone; bending; intermediate; absent
	Locus	Distal; mesial; proximal
	Location of initiation	Ventral surface; dorsal surface; apex; right lateral edge; left lateral edge; base; earlier fracture surface
	Profile of initiation	Concave; convex; straight
Propagation phase	General direction	Apex to base; base to apex; perpendicular to the long axis; diagonal towards the base; diagonal towards the apex
	Length	Absolute value
	Profile of propagation phase	Normal; overshot (plunging)
Termination	Termination type	Snap; feather; hinge; step; absent; complex (hinge to step; hinge and step; …..)
	Fissuration of termination	Yes; no
	Location of termination	Right lateral edge; left lateral edge; base; earlier fracture surface; ventral surface; dorsal surface
	Thickness of termination	Absolute value

frequently described. These definitions also form the basis of what we have termed a revised attribute-based terminology (see below).

Attributes that are often included in fracture descriptions are the initiation and termination. For the initiation, a distinction is commonly made between cone and bending initiated fractures (Fig. 1). While several phenomena are able to break brittle solids like flint, two fracture types are principally encountered when a flint point impacts its target: the initiation either occurs far from the contact area (bending break) or just under the contact area (hertzian break), as a result of, respectively, a bending stress and a compressive stress (Bertouille, 1989; Cotterell and Kamminga, 1987, 1979; Tsirk, 2014). This variation in stress is mostly generated by a difference in the angle of contact between the flint and the bone or skin and thus by a difference in the direction of load exerted on the piece (Cotterell and Kamminga, 1979: Figs. 4, 6; Lawrence, 1979: Figs. 1, 2 and 3). Hertzian and bending fractures are extreme categories and several parameters will contribute to guiding the fracturing more towards one or towards the other. The load, the direction of pressure and the angle of contact are the main parameters that determine the fracture phenomenon, but other attributes like the impacted material or the angle of the tip (apex) of a point will influence whether the fracture will initiate more toward a cone or more toward a bending (Bertouille, 1989; Cotterell and Kamminga, 1979; Tsirk, 2014). These phenomena generate two types of morphologically distinctive initiation types. The *cone initiation* is generated by a compressive stress and has a narrow point of initiation and a concave profile. The *bending initiation* is generated by a bending stress and has a wide point of initiation and a convex or straight profile. These two categories are on the extremes of a continuum (Lawrence, 1979) and it is not always easy to place a fracture in one or the other category (see below).

For a fracture's termination, following the definitions proposed by Crabtree (1972), a step termination is the result of an abrupt (90°) change in the direction of a propagating crack. When the crack meets a flaw inside the material, the propagation will be stopped because the energy involved is not enough for the crack to continue beyond the flaw (Cotterell and Kamminga, 1987; Crabtree, 1972). A hinge termination is also abrupt, but it has a curved profile and it meets the opposite surface in a steep or nearly right angle (Cotterell and Kamminga, 1987). A hinge termination is created when a crack generated by a force with an important bending component suffers a loss of energy. If the energy had been constant, the crack would have continued its propagation. The loss of velocity allows the outward component of the force to act which creates the hinge termination (Cotterell and Kamminga, 1987; Crabtree, 1972). A feather termination is smooth, with a minimal ridge where it cuts the opposite surface (Ho Ho Committee, 1979). The feather termination can be generated by a wide range of initiations, forces and angles (Cotterell and Kamminga, 1987). The snap termination occurs only under a bending stress without a compressive component. In this case, the fracture propagation will cross the thickness of the point more or less perpendicularly (Ho Ho Committee, 1979).

The Ho Ho Committee proposes a provisional use fracture classification constituted by these two types of initiation and these four types of termination (Fig. 1 in Ho Ho Committee, 1979). While this terminology may appear quite clear, the reality is less obvious, particularly for terminations, and most of the time we deal with combinations of different types of termination (see below).

3.2. DIF approach

Based on what is commonly used by several authors (De Bie and Caspar, 1996; Fischer et al., 1984; Lazuén, 2012; O'Farrell, 2004; Odell and Cowan, 1986; Sano and Oba, 2014; Sano, 2009; Villa and Lenoir, 2009, 2006; Wilkins et al., 2012), we decided to include the following fractures as diagnostic categories in what we define here as the "DIF approach": step-, hinge-, and feather-terminating bending fractures, burinations and spin-offs. All spin-offs were integrated independent of their size. We avoided the terms flute-like fractures and crushing given their poor level of definition (see below).

Table 3
Selection of attributes used during the analysis and their attribute states, which are sometimes grouped together for simplification of the analysis given the modest sample size.

Attribute	Grouped attribute states
Fracture group	Break; scar
Location of the initiation	Initiated from a surface (*ventral or dorsal*); initiated from an edge (*lateral right or left*); initiated from an earlier fracture surface
Location of the termination	Termination on a surface (*ventral* or *dorsal*); termination on an edge (*lateral right* or *left*)
Type of initiation	Bending; cone; intermediate; absent
Type of termination	Hinge; step; feather; snap; absent; plunging; complex (*step and hinge, …; step to hinge, …*)
Locus	Distal; mesial; proximal

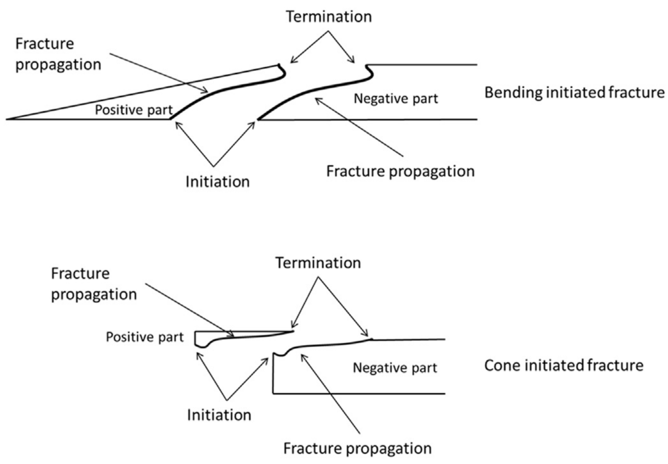

Fig. 2. Synthesis of different parts of a bending and cone initiated fracture.

3.3. Attribute-based system

An attribute-based system forces rigour upon the analyst to be complete in descriptions for all included attributes. While our goal is only to illustrate some inconsistencies in current terminologies and to demonstrate the potential of an attribute-based terminology, it is not relevant to discuss all details of the newly developed attribute system with all considered attributes states here, but it is summarized in Table 2. We focus on an aggregation of 6 different attributes: given the moderate size of the experimental sample included in this study, we decided to group certain attribute states (Table 3, Fig. 2).

3.3.1. Fracture group

A first difficulty with regard to impact fractures is their nature. We distinguish between breaks and scars (Fig. 1). A *break* is a fracture that cuts the point across its entire width and removes a part of both lateral edges (apex fractures) or of both surfaces (edge fractures). A *scar's* propagation does not reach both lateral edges and only removes a chip on the surface of the apex or edge. While this distinction is clear when the apex and edges are compared, it is far more difficult to distinguish both groups on the apex itself, in particular with regard to bending fractures where it may be essentially a matter of size; after all, these two categories are on the extremes of a continuum.

3.3.2. Location of initiation

The zone where the initiation of the fracture occurs needs to be specified. While several attribute states are available in the complete registration system, it is limited three groups of attribute states in the framework of this study: *initiated from a surface* (Fig. 1b), *initiated from an edge* (Fig. 3c), *initiated from an earlier fracture surface* (Fig. 3a, 3b).

3.3.3. Location of the termination

To locate the termination zone, we use similar groups of attribute states: *termination on a surface* (Fig. 3a), *termination on an edge* (Fig. 3b, c). Locating both the initiation and the termination is essential because the combination allows us to describe precisely the path of a fracture on a stone point. Most of the time, a fracture initiates on one surface or edge and terminates on the opposite (another) surface or edge. Exceptionally, however, a fracture may initiate and terminate on the same surface. This is typically the case for an overshot (plunging) fracture (Fig. 4c, 5), which has been described before in the context of projectiles (Geneste and Plisson, 1989). Such a fracture is impossible to describe correctly without the details on the location of the initiation and termination.

3.3.4. Type of initiation

Aside from a *cone* and *bending* (Fig. 1) initiation, we consider a third, *intermediate* attribute state given that a distinction is not always easy. In addition, fracture initiations are frequently removed or obliterated by subsequent removals, because the contact between the stone point and the animal (hide, bone) is rarely unique. This necessitates a fourth attribute state *absent* (Fig.4b). It is evident that an initiation should only be described as a *cone* or *bending* initiation when it is truly preserved.

3.3.5. Type of termination

Given that the reality of fracturing shows that terminations are not so clear-cut and that we often deal with combinations of different types of termination, it is relevant to register these combinations and to add categories to the four "standard" terminations (*snap, feather*, *step, hinge*; Fig. 6) identified by the Ho Ho Committee (cf. Committee, 1979: Fig. 1). When different types of termination occur in a combined form, they all need to be associated with the same initiation and propagation phase. We distinguish juxtaposed combinations from superposing combinations in the full attribute system, but given the moderate size of the experimental sample included in this study, all combined terminations are grouped under one attribute state "*complex termination*". Nevertheless, if terminations are laterally juxtaposed, the standard categories are combined with "**and**" (e.g., a combined step *and* hinge or a combined step *and* feather termination; Fig. 4d); if terminations superpose one another (see also Odell and Cowan, 1986), the word "**to**" is used (e.g., a combined hinge *to* step termination; Fig. 4a). Aside from these multiple terminations, a termination can also be absent because it is removed by subsequent fractures.

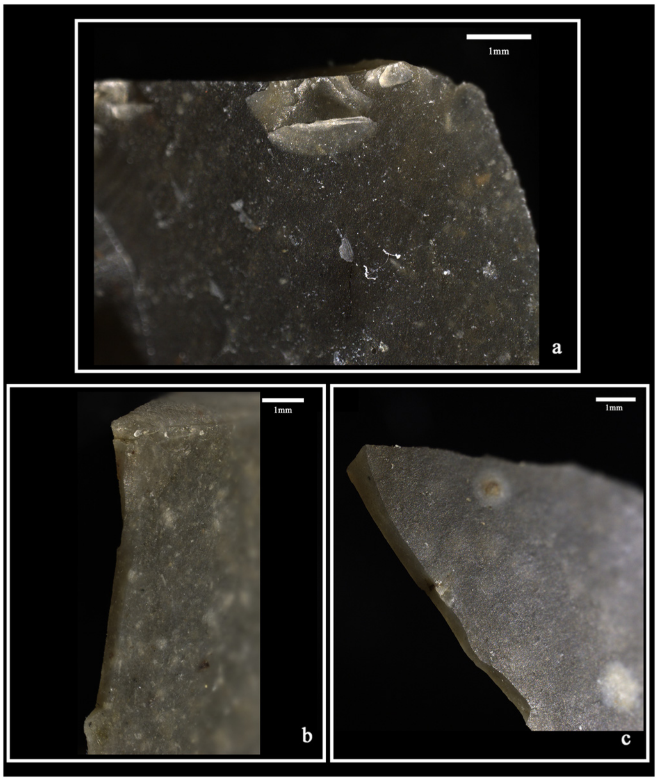

Fig. 3. A. Spin-off: scar initiated from an earlier fracture surface by a longitudinal compression load and terminated on a surface; B. Burin-like spin-off: scar initiated from an earlier fracture surface by a longitudinal compression load and terminated on an edge; C. Burination: break initiated from an edge by a bending load and terminated on an edge.

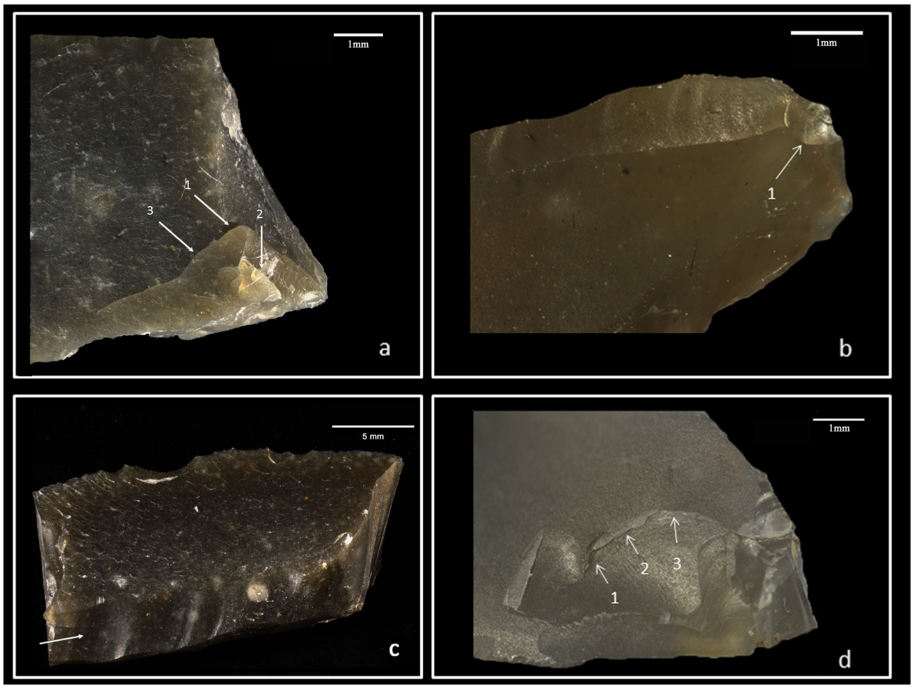

Fig. 4. A. Break with a complex termination combining a hinge (1) to step (2) and a fissured zone (3); B. A subsequent scar (1) has removed the initiation of the main fracture and the initiation of the latter is thus absent; C. Overshot fracture; D. Fracture with a complex termination combining a hinge (1), a fissured step (2) and a feather (3).

3.3.6. Locus

This attribute is used to locate the trace on the blank: *distal*, *mesial* or *proximal*.

4. Experiment

The experimental stone tools included in this study are only a sample of a larger reference collection that has been produced to examine the influence of different variables, such as point morphology, mode of projection and strength of hafting systems on macro- and microscopic wear traces formed during projectile use. The included sample is selected based on its relevance for highlighting terminological problems and demonstrating the potential of more detailed fracture descriptions, which is the goal of this paper. Within the complete experimental program, the impact of several variables is tested, but we chose to limit the number of variables for this study. We only focus on one raw material (flint), one point morphology (Gravette point) but two point size categories, one hafting mode but three fixing techniques (sinew, resin glue, sinew + resin glue), two projecting modes (bow and spear-thrower), each with their own shaft type (pinus arrow shafts and hazel dart shafts) and one target.

Thirty Gravettian and 30 Microgravettian points have been reproduced by an experienced knapper, Christian Lepers (ULg) in Belgian Harmignies flint. Fifteen points per type were mounted on pinus arrow shafts and 15 points per type were mounted on hazel dart shafts, resulting in a total sample of 60 points. The physical characteristics of the shafts and the variation amongst them are summarized in Table 4. Aside from the weight, also the spin was measured. The spin is a measure of the stiffness of the shaft. It measures the elastic deformation of the shaft between two points under the stress of a certain mass (Fig. 7). This measurement is used regularly in archery, because an optimal stiffness exists for each value of propulsion energy expended. If the shaft is too rigid, the projectile will deflect from its trajectory; if it is too flexible, there is a risk of breakage at release or the projectile will lose too much propulsion energy.

The points were mounted in a split at the extremity of the shaft; 20 were fixed with horse sinew bindings, 20 were fixed with resin glue (70% spruce resin, 30% beeswax) and 20 were fixed with a combination of both (resin + horse sinew + again resin) to reinforce and protect the sinew (Fig. 8a). The arrows were shot at a distance of 10 m into an artificial target with a reproduction of a Neolithic Holmegaard bow (Junkmanns, 2013) made from elm wood with a draw weight of 47 lb at a draw distance of 30 in. Darts were shot into the same artificial

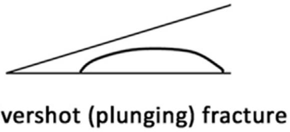

Fig. 5. Profile of an bending overshot fracture.

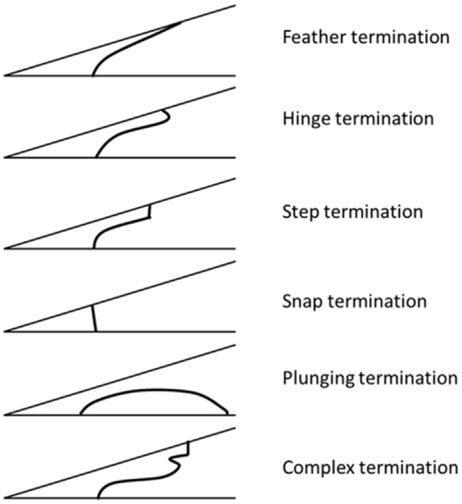

Fig. 6. Profile of the different types of termination that are considered in the revised attribute system.

Table 4
Ballistic details for the shafts used in the experiments.

	Arrow spin (cm)	Dart spin (cm)	Arrow weight (gr)	Dart weight (gr)	Arrow length (cm)	Dart length (cm)
Min	1,08	3	29	133	82	210
Q_1	1,1775	4	31	152,5		
Median	1,21	4,65	31,5	172,5		
Q_3	1,21	5,35	33,75	186,75		
Max	1,5	7,2	40	209		

target, also from a distance of 10 m, with a hazel spear-thrower of a length of 60 cm.

The artificial target was composed of a nearly complete animal skeleton encased in ballistic gelatin (Fig. 8b). Ballistic gelatin has been used since a long time as a proxy for animal bodies in prehistoric ballistic experiments, following their successful use in military experiments. It has been used to perform penetration tests in order to compare the efficiency of different point morphologies, raw materials, and propulsion modes (Carrère and Lepetz, 1988; Carrère, 1990; Waguespack et al., 2009; Wilkins et al., 2014). It has also been used to evaluate the strength of certain hafting arrangements or glue recipes (Chesnaux, 2014; Gaillard et al., 2015). Several composite targets involving ballistic gel have also been made to explore the formation of wear traces from impact on stone points. One for example consisting of an assemblage of a polyurethane bone-like plate, 20% of ballistic gelatin and cow leather (Iovita et al., 2014) or another one from an assemblage of deer skin, 60 mm of ballistic gelatin and cattle scapulae (Sano and Oba, 2015, 2014). While previous studies have used artificial gelatin targets to address precise research questions, generally in artificial settings, we wanted to create a target that is as similar as possible to a real animal and that mimics the variation in type of contact and contact material of an animal target. It is our conviction that such a target is required when examining fracture patterns in detail. For instance, the fact that a point may slide against a rib instead of only touching it head-on (cf. bone plate) is one of the crucial elements. The goal is to obtain the most reliable data attainable in an artificial context on the variation in fracture types and on fracture frequencies. The experiment included here is only the first phase of a larger-scale projectile experiment. The artificial target was made out of a bloc of ballistic gelatin containing a real pony skeleton and it was covered with a stretched pony skin that had been rehydrated in water to simulate fresh skin (Fig. 8b). The pony skeleton was refitted into anatomical position using plastic wire; no metal was used to avoid potential friction wear on the stone points during the experiment. The gelatin (Type A, 240–260 bloom) was mixed with an amount of 10% of weight in water at 45 °C and the bloc was cooled in a cold chamber at 4 °C during 48 h (see Jussila, 2004 for details). To the basic recipe, two drops of essential cinnamon oil were added per 4 l to increase the transparency of the mixture (Davis and Davis, 2002), which constitutes one of the important advantages of using gelatin for projectile experimentation as fractures within the target are perfectly visible (Fig. 8c).

Projectiles were shot with a maximum of 10 times. After each shot, the stone point was examined while still inside the target to evaluate whether it had touched bone; if bone was touched, the stone point was not used any further. If the point touched skin and gelatin only, it was removed from the target and it was checked for visible damage. If necessary, a binocular stereoscopic microscope was used for closer inspection. If no damage was visible, the projectile was re-used. A total of 131 shots were performed with the 60 stone-tipped shafts. On average, points had to be fired twice before showing visible damage. Sixteen points touched bone without suffering macroscopic damage and 44 points showed macro-traces caused by an impact against different materials.

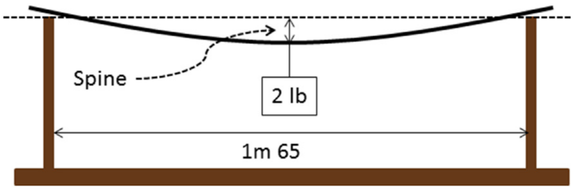

Fig. 7. Spin measurement.

5. Analysis

Based on the literature, inconsistencies in the terminology per fracture category are systematically identified and subsequently confronted with the newly produced experimental data in order to propose potential solutions.

5.1. Step/hinge/feather/snap-terminating bending fracture

5.1.1. Literature

Since its first use by Fischer et al. (1984), a step-terminating bending fracture has been most frequently referred to in the literature. A step-terminating bending fracture is believed to result from impact, as was also confirmed experimentally (Fischer et al., 1984; Lombard et al., 2004; O'Farrell, 1996; Odell and Cowan, 1986). Hinge- and feather-terminating bending fractures are less cited, but they are considered as sufficiently "diagnostic" for projectile use by some authors (Chesnaux, 2014; De Bie and Caspar, 1996; Lazuén, 2012; O'Farrell, 2004; Odell and Cowan, 1986; Sano and Oba, 2014; Sano, 2009; Villa and Lenoir, 2009).

Two attributes are described for this fracture type, its initiation and its termination. Few authors provide a precise definition of a bending initiation or of a step-, hinge-, feather-, or snap- termination, but most seem to follow the definitions proposed by the Ho Ho Committee (1979) and by Fischer et al. (1984) (cf. Section 3.1). It has been argued by Fischer et al. (1984) that, considering the orientation of the fracture propagation and the location of the initiation, a fracture with a bending initiation and a step termination is diagnostic for projectiles when the fracture occurs on the apex of the stone point and has a parallel orientation to the axis of use.

In the literature, inconsistency concerns both the initiation of this fracture and its termination. Borgia (2009), for instance, appears to mix the two types of initiation – bending and cone – to describe two parts of the same fracture event: "The scheme is based on the position of two main types of complementary fractures, cone and bending (Fig. 10, n°1 a–b), which are formed in the moment of the impact and tend to have a determined disposition: the fractures cone involve the part of the instrument turned towards the impact, those bending the part of the instrument turned towards the base", in (Borgia, 2009: 54). The major disagreement, however, concerns the description of the fracture's termination, as it is not always clear-cut. This reflects an unfortunate reality and the difference between a step and a hinge termination is not always easy. As a result, what seems to be a hinge termination is sometimes described as a step and vice versa (e.g., Naudinot, 2009: Fig. 48). In addition, terminations are often more complex than a single term can describe and it may in reality be composed of different termination types (e.g., Lombard, 2005: Fig. 7a) for which no commonly shared term currently exists.

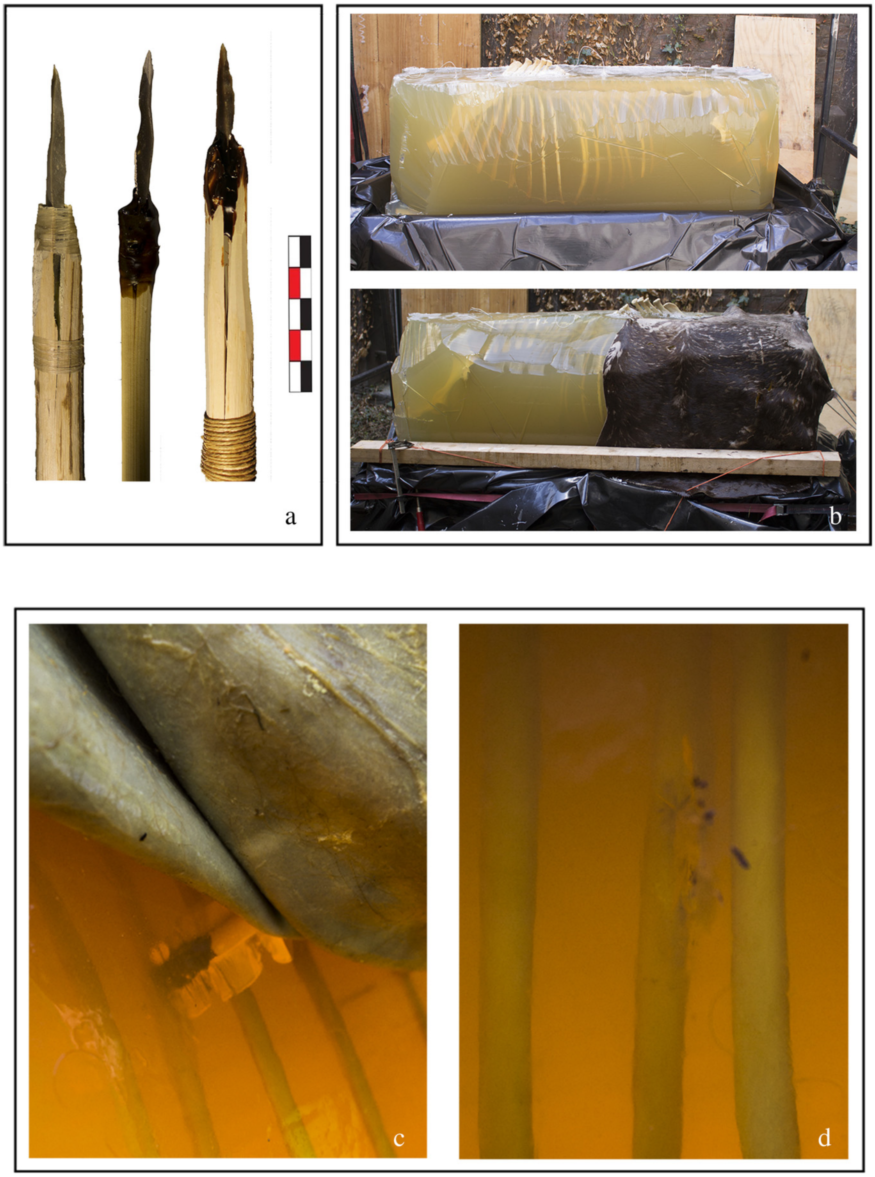

Fig. 8. A. Points hafted in split wooden shafts, from left to right: fixation with sinew bindings, fixation with glue – sinew – glue, fixation with glue; B. Artificial target consisting out of a pony skeleton incorporated in a ballistic gel; C & D. Evocation of the transparent nature of the target and the advantages on the level of the visibility of the projectiles it offers.

5.1.2. Experiments

If we try to examine the potential problem of this DIF category by comparing it with an attribute-based registration based on our experimental dataset, it seems that no confusion is present for the orientation and localization of this trace type. For the initiation, all bending fractures are distributed in a unique attribute aggregation category (i.e., break initiated from a surface and terminating on the opposite surface) (Fig. 9). By contrast, a fracture's termination could rarely be categorized under a single term and most terminations in our experimental dataset prove to be complex in nature (Table 5), which implies that different types of terminations are either juxtaposed or superposed. One could therefore wonder how complex terminations are general dealt with if one is forced to place them in one of four categories (snap, feather, hinge, step). It is likely that this problem causes a huge variation between analysts and that percentages presented as a result of an experiment may be variably affected. The representative nature of this fracture category can thus be questioned, but at the same time one may argue that we have perhaps not yet fully exploited the interpretative potential of fracture terminations.

5.2. Spin-off and bifacial spin-off

5.2.1. Literature

Fischer et al. (1984) are the first to define a spin-off: "a cone fracture which initiates from a bending fracture and which removes parts of the original surface of the specimen" (Fischer et al., 1984: 23–24, Fig. 7a). They explain the formation of a spin-off by a compression phenomenon that occurs just after the first bending fracture. The two fracture surfaces are pressed together and generate several longitudinal removals. The definition is precise about the initiation and location of the spin-off, but the termination of the spin-off is not specified.

Most researchers seem to adhere quite strictly to this definition, but inconsistency nevertheless exists for its initiation and its location. While a cone initiation is part of the definition, both Sano (2009) and Lombard (2005) do not distinguish between a cone and bending initiation; according to Sano (2009) because the initiations are generally too small to be clearly visible. This difficulty with the initiation of spin-offs also recurs when examining the published pictures on which the cone initiation is not always evident: sometimes it seems to be a bending

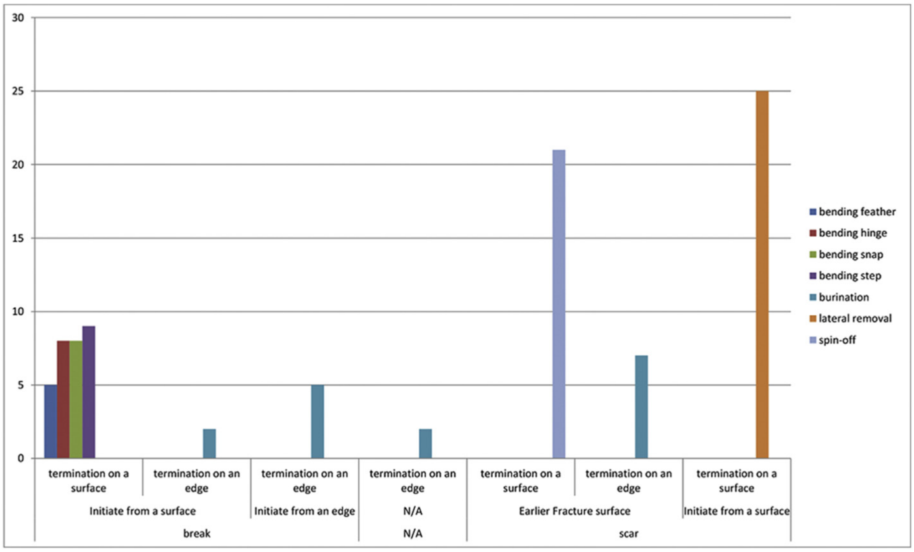

Fig. 9. Experimental projectile points: distribution of the traditional diagnostic impact fracture groups compared to the groupings based on the refined attribute system (included attributes: fracture group, location of initiation, location of termination).

initiation (e.g., Lombard and Pargeter, 2008: Fig. 5), other times the initiation seems to be removed by subsequent fractures (e.g., (Borgia, 2009): Fig. 11). While the initiation of a spin-off fracture is, according to its initial definition, connected with a bending initiated fracture and corresponds to that bending fracture in terms of its direction of propagation, this relation does not always seem to be respected. Examples presenting a perpendicular orientation with regard to the original bending fracture have been identified (e.g., Sano, 2009: Fig. 18 V2-7.2).

The diagnostic value of spin-offs depends, according to Fischer et al. (1984), on the length of the spin-offs. They argue that small spin-offs can be generated by a bending stress without an important compressive component (Fischer et al., 1984: Fig. 6) and they propose a minimal length for spin-offs before considering them diagnostic for projectile use. For Fischer et al., this minimal length is relative in nature and depends on the size of the point: "The larger the objet, the larger is the required spin-off fracture" (Fischer et al., 1984: 24). Other researchers have proposed absolute values as a minimal length, generally between 1 and 6 mm (Chesnaux, 2014; Villa and Lenoir, 2009), while many researchers do not mention a minimal size.

5.2.2. Experiments

On the condition that the original definition is strictly adhered to, all spin-off fractures are distributed in a unique attribute aggregation category (scar initiated from an earlier fracture surface and terminated on a surface) (Fig. 9). This DIF category should thus not create much confusion.

5.3. Flute-like family

The term "flute-like scar" appears for the first time in Witthoft's Eskimo arrow point study (Witthoft, 1968). "Flute-like" is a term derived from knapping terminology, more in particular the fluting of paleo-indian points. This process, also called channel-flaking, aims to reduce the thickness of the proximal part of a point by the longitudinal detachment of an elongated flake (in the axis of the point) that does not touch the edges. Fluting can be done on one or both faces using direct or indirect percussion or pressure flaking (Crabtree, 1966; Inizan et al., 1995). When the term "flute-like fracture" is used in the context of projectiles, the term usually describes shallow, large and elongated scars that are initiated from the ventral or dorsal surface and propagated with a parallel orientation to the axis of use (Bergman and Newcomer, 1983; Frison, 1974). Sano (2009) and Villa and Lenoir (2009) add to this definition that the fracture has to show a bending initiation. The termination is not specified.

In the literature, this fracture type seems to be one of the most confusing terms and its use is variable. There is no agreement on what this term actually represents as some authors consider it to be a synonym of Fischer's bending fracture (Lazuén, 2012; Villa and Lenoir, 2009), while others consider it as a synonym of a spin-off (Clarkson, 2016) even though the latter has a cone initiation according to the original definition. It seems that the morphological resemblance of some fractures with the negatives resulting from intentional fluting as part of a knapping process has stimulated certain researchers to borrow a well-known term from knapping technology. It is questionable whether this term is useful for describing projectile fractures, in particular given the confusion that proves to surround its definition and use in the literature. Given that alternative terms exist, we believe it would be best to abandon the use of terms like "flute-like fractures" in the context of projectiles. In our experimental study, this fracture type was therefore not considered.

Table 5
Proportion of the types of termination for bending initiated fractures.

Type of termination	Percentage and number
Snap	26,67% (8)
Feather	13,33% (4)
Hinge	20,00% (6)
Step	6,67% (2)
Complex termination	33,33% (10)
Total	100,00%

5.4. Burin-like family

5.4.1. Literature

The burin-like fracture family includes the largest variety in broadly similar terms: pseudo-burin, pseudo-burin spall, pseudo-burination, burin removal, burin-like fracture, burin-like scar, burin-like break, impact scar burin like fracture, impact burination. All terms evoke the resemblance between the morphology of this fracture and the one resulting from an intentional burin blow. No explicit definition was ever proposed, but all authors seem to agree that a burin-like fracture is a removal propagated along one of the lateral edges of a point. Variations exist, however, concerning its initiation type and location, its termination, its propagation direction and its exact location on the point.

Table 6
Distribution of the traditional diagnostic impact fractures compared to the refined attribute system. Considered attributes are the fracture group, the location of the initiation and the location of the termination.

	Bending snap	Bending feather	Bending hinge	Bending step	Burination	Lateral removal	Spin-off	Total
Break	8	5	8	9	7			37
Initiate from a surface	8	5	8	9	2			32
Termination on a surface	8	5	8	9				30
Termination on an edge					2			2
Initiate from an edge					5			5
Termination on an edge					5			5
N/A					2			2
N/A					2			2
Termination on an edge					2			2
Scar					7	25	21	53
Earlier Fracture surface					7		21	28
Termination on a surface							21	21
Termination on an edge					7			7
Initiate from a surface						25		25
Termination on a surface						25		25
Total	8	5	8	9	16	25	21	92

A burin-like fracture is generally initiated from a surface or an edge (Bergman and Newcomer, 1983; Lombard et al., 2004; Odell and Cowan, 1986; Sano, 2009) (Fig. 3c). For some authors, however, it may also be initiated from a scar of a preceding fracture (Chesnaux, 2014; Soriano, 1998), in which case it is more specifically referred to as a burin-like spin-off (for instance "spin-off burinant" in Chesnaux, 2014, Lombard, 2005) (Fig. 3b). The initiation is rarely characterized (Bergman and Newcomer, 1983; Chesnaux, 2014; Odell and Cowan, 1986; Soriano, 1998), but some specify that it should be in bending (Lombard et al., 2004; Sano, 2009). The termination is also rarely specified, but some authors consider that it has to be either a step or a hinge (Bergman and Newcomer, 1983; Lazuén, 2012; Odell and Cowan, 1986), while others consider the termination as irrelevant (Chesnaux, 2014; Lombard et al., 2004; Sano, 2009; Soriano, 1998). Importantly, the same term is used independent of the fracture's location, on the apex or on the base. The fracture may also have a different orientation: instead of being parallel to the edge, it may also be perpendicular to it.

5.4.2. Experiments

If we consider all "burinations" that we could document on the experimental points in the dataset, they prove to divide over 6 different attribute aggregation categories in the attribute-based system (Fig. 9). Since the original "definition" of a burination only includes that the fracture propagation follows one of the lateral edges, this DIF category of course generates a lot of confusion and proves to group very different fractures. A little less than half (7) of the burinations that we registered are initiated from an earlier fracture surface (Table 6). This type of burination shows a cone initiation and a longitudinal propagation direction parallel to the edge (Fig. 3b). Consequently, their creation is more linked to a compression phenomenon than to a bending phenomenon, which essentially qualifies them as spin-offs. This overlap in the definition of a spin-off and a burination initiated from an earlier fracture surface is problematic and can significantly modify the results of an analysis. The other half of the burinations that were registered have a bending initiation and initiate from a surface or an edge (Fig. 3c).

5.5. Tip crushing

Tip crushing is a vague term that covers a potentially wide range of fractures characterized by a small size and/or a superposing nature hampering a more accurate description. It usually concerns multiple small scars varying in orientation and initiation on the apex of the point. They have abrupt terminations (step, hinge) and they either differ in orientation (e.g., Odell and Cowan, 1986) or they have an orientation parallel to the long axis of the piece (e.g., Villa and Lenoir, 2009). It is clear that this fracture category is not very precise and therefore, inconsistencies in the use of this term are difficult to evaluate. Overall, little diagnostic value is attributed to this fracture category and few interpretative problems have generally resulted from its use. Consequently, we do not consider it for the experimental dataset in this study.

6. Future potential of an attribute-based system

The analysis of the experimental dataset based on a strict and detailed attribute-based system reveals a few new and intriguing correlations. While the experimental dataset included here is limited (but its elaboration is in progress), it nevertheless appears to hold a lot of potential. We deal with two correlations in more detail: (1) between the impacted material and the fracture morphology, and (2) between the mode of propulsion and the fracture morphology. The discussion follows the same comparative procedure between a DIF-approach and an attribute system as above. Because only one point morphology was used in the experiment, no variation in fracture types and patterns was observed, but the fracture size differed between the two point sizes. The latter difference was not yet quantified, but the fracture size appeared broadly relative to the point size. What concerns the hafting mode, no correlation was observed between the strength of the hafting system and the fracture characteristics (independent of the descriptive approach used). By contrast, the fracture frequency appeared to be linked with the strength of the hafting system. No difference was observed between a resin hafting or a hafting with horse sinew bindings, but fractures were clearly more abundant in the case of points fixed

Table 7
Proportion of traditional diagnostic impact fracture categories per impacted material.

	Bone; gelatin; skin	Gelatin; skin	Total
Bending snap-terminating fracture	11,8% (4)	12,12% (4)	11,94% (8)
Bending feather-terminating fracture	8,8% (3)	6,1% (2)	7,46% (5)
Bending hinge-terminating fracture	5,9% (2)	18,2% (6)	11,94% (8)
Bending step-terminating fracture	17,6% (6)	9,1% (3)	13,43% (9)
Burination	35,3% (12)	12,12% (4)	23,88% (16)
Spin-off fracture	20,6% (7)	42,4% (14)	31,34% (21)
Total	100% (34)	100% (33)	100% (67)

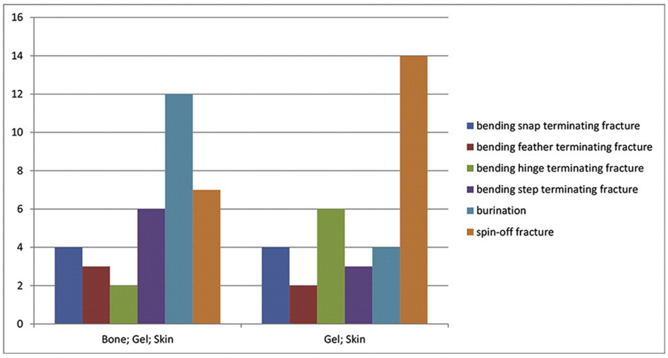

Fig. 10. Experimental projectile points: distribution of the traditional diagnostic impact fracture groups per impacted material.

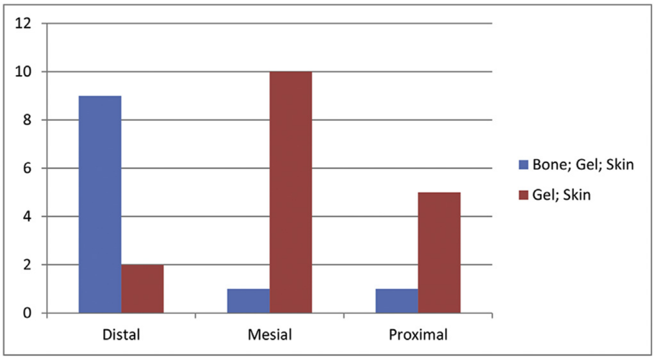

Fig. 11. Experimental projectile points: location of the damage that is caused per impacted material.

with a combination of resin and sinew bindings. The reason is that the stone point is secured more firmly in the shaft due to which the stone point absorbs more pressure upon impact with less pressure being transferred to the connection between the point and the shaft.

6.1. Relationship between impacted material and fracture morphology

In total, 114 fractures were registered on 44 of the 60 Gravettian and micro-Gravettian points, 16 points were de-hafted by the impact itself or upon touching bone and do not show macroscopic damage. On average, about three fractures were recognized per damaged point.

6.1.1. DIF- approach

Thirty-four of the registered fractures were lateral removals, which fall outside the categories generally considered in a DIF-approach. Only 80 fractures can thus be included on a total of 44 points. A few additional fractures were excluded because they were produced by an accidental contact against the wooden structure that supported the target (8) or with the soil when they missed the target (5), leaving 67 fractures formed by a contact with the target, either with bone (34) or with skin/gelatin (33) (Table 7). Following the DIF-approach, it seems that fractures caused by a contact with bone were principally burinations, secondly spin-offs, and thirdly various bending initiated fractures. By contrast, a contact with skin/gelatin mainly resulted in spin-offs, next to some bending initiated fractures and burinations.

Based on these results, one could conclude that a relation exists between the formation of burinations and a contact with bone, and another one between spin-off's and bending hinge-terminating fractures and a contact with skin/gelatin (Fig. 10).

6.1.2. Attribute-based approach

The use of an attribute system influences the above conclusion. Firstly, the lateral fractures can now also be taken into account (34 fractures), resulting in a total of 92 fractures (which again excludes fractures generated by wood and soil contact). For this sample, 59,8% of the fractures proved to be generated by bone contact, while 40,2% were created by a skin/gelatin contact.

Secondly, the correlation observed between bone contact and the formation of burinations as was identified based on the DIF-approach is no longer valid. Due to the inconsistency of the burination category (see above), seven fractures were in reality scars initiated from an earlier fracture. The seven remaining ones disperse over several attribute groups (Fig. 9).

Thirdly, based on the DIF approach, a more frequent occurrence was observed of spin-off fractures in the case of a break against skin/gelatin in comparison to bone, but insufficient detail was available to truly examine the correlation. Thanks to the higher number of descriptive attributes in the revised attribute approach, it allows to establish a relation between the fractures initiated from an earlier fracture surface and a contact with skin/gelatin. In addition, the majority of the fractures caused by a contact with bone are located on the distal part of the point, while damage generated by a contact with skin/gelatin is preferentially located on the mesial or proximal part of the point (Table 8, Fig. 11). These results are suggestive for the improved insight in the causes and characteristics of fracture formation on projectiles that an attribute system may provide.

Table 8
Distribution of the location (locus attribute) of scars initiated from an earlier fracture surface per impacted material.

Locus	Bone; gelatin; skin	Gelatin; skin	Total
Distal	9	2	11
Mesial	1	10	11
Proximal	1	5	6
Total	11	17	28

6.2. Relationship between mode of propulsion and fracture morphology

6.2.1. DIF-approach

Fifty-five percent of the fractures were created on points shot with a bow and 45% were formed on points shot with a spear-thrower. Both types of weapons resulted in the same fracture types and in similar proportions of bending fractures and spin-offs. Burinations, however, were far more frequent on points shot with a bow than on those shot with a spear-thrower (Table 9, Fig. 12). By contrast, hinge terminating bending fractures were somewhat more frequent in the case of the spear-thrower.

6.2.2. Attribute-based approach

Based on the larger sample of 92 fractures (see above), 57,3% of the fractures prove to have been created on points shot with a bow and 46,7% on points shot by a spear-thrower. Again, the observed correlation between burinations and the bow that was supposedly visible based on a DIF-approach is no longer valid. Seven of the burinations are in reality

Table 9
frequencies of the traditional diagnostic impact fracture categories per mode of propulsion.

	Bow	Spear-thrower
Bending snap-terminating fracture	13,51% (5)	10,00% (3)
Bending feather-terminating fracture	5,41% (2)	10,00% (3)
Bending hinge-terminating fracture	8,11% (3)	16,67% (5)
Bending step-terminating fracture	10,81% (4)	16,67% (5)
Burination	32,43% (12)	13,33% (4)
Spin-off fracture	29,73% (11)	33,33% (10)
Total	100,00% (37)	100,00% (30)

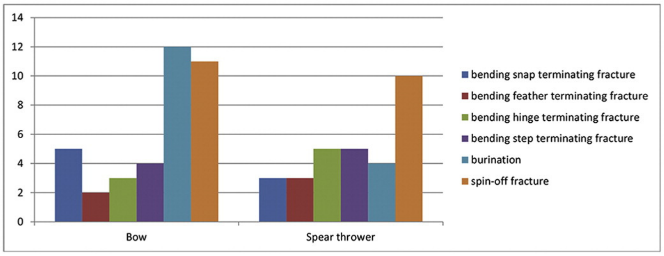

Fig. 12. Experimental projectile points: distribution of the traditional diagnostic impact fracture groups per mode of propulsion.

scars initiated from an earlier fracture surface (Fig. 13) and thus more related to the formation process of spin-offs than burinations.

With the DIF-approach, spin-offs were more or less equally represented for both weapon types and no differences were visible between spin-offs created by a bow or a spear-thrower. By contrast, based on the attribute system, distinct differences were observed in terms of the location of the fracture termination: only the bow resulted in scars with a termination located on an edge, while fractures terminating on the surface are equally divided between the bow and the spear-thrower (Fig. 14).

For scars initiated on an earlier fracture surface and terminating on the surface, the locus attribute allows to specify that most scars produced on arrow points are located in the distal part while most scars on dart points are located on the mesial part (Fig. 15).

6.3. Statistical testing of the correlation between impacted material, mode of propulsion and fracture morphology

Thanks to the use of an attribute-based approach, we can propose two assumptions concerning the category of scars initiated from an earlier fracture surface: (1) most scars produced on arrow points are located in the distal part of the points while most scars on dart points are located in the mesial part (Fig. 15); (2) the majority of the fractures caused by a contact with bone are located in the distal part of the point, while damage generated by a contact with skin/gelatin proves to be preferentially located in the mesial or proximal part of the point (Fig. 11). These correlations were examined with a multiple correspondence analysis realized on IBM SPSS Statistics release 20.0.0 (Costa et al., 2013).

The first dimension (71.29%) groups skin (type of contact responsible), mesial/proximal (location of fracture), spear thrower (propulsion mode) on the one hand and bow (propulsion mode), bone (type of contact responsible), distal (location of fracture) on the other hand. The second dimension is less significant (22.39%), isolating a mesial/proximal and skin group and a distal and bone group, but putting in opposition the two modes of propulsion with the information given by the first axis (Fig. 16).

The strength of the correlations was subsequently evaluated with a Yates's Chi^2 test,[1] which is a conservative test (Costa et al., 2013). The test was performed on 28 scars initiated from an earlier fracture surface, which allows observing that:

- a correlation exists between impacted material and the fracture's locus (χ^2 Yates = 13.629; p = 0.000), the strength of which is further confirmed by the Cramer's V test (Cramer's V = 0.774; p = 0.000). The comparison between expected and observed frequencies in the contingency data table indicates that two groups of two variables appear systematically: one groups skin and mesial/proximal and a second groups bone and distal (Table 10).
- a strong correlation exists between mode of propulsion and impacted material (χ^2 Yates = 6326; p = 0.012, Cramer's V = 0.554; p = 0.003).The comparison between expected and observed frequencies in the contingency table indicates that two groups of two variables appear systematically: One groups spear thrower and skin and a second groups bow and bone (Table 11).

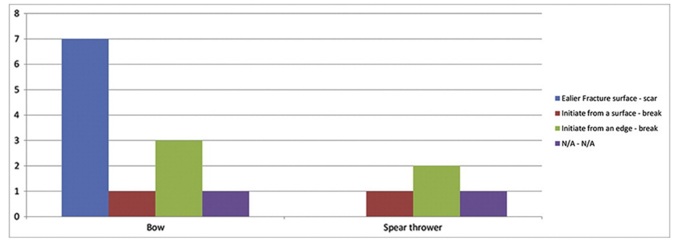

Fig. 13. Experimental projectile points: distribution of the traditional burination category over different fracture groups and location of initiations within the refined attribute system, viewed per mode of propulsion.

No correlation can be established between the mode of propulsion and the fracture locus (χ^2 Yates = 2096; p = 0.148).

The statistical analysis partially confirms our assumptions. Most of the scars initiated from an earlier fracture surface and located in the distal part are preferentially related with a bone contact. By contrast, most mesial scars initiated from an earlier fracture surface are due to a skin-gelatin contact. Furthermore, the spear thrower preferentially generates fractures after only a skin-gelatin contact while the bow generates distinctively more fractures after a bone contact. However, we are not able to demonstrate statistically that a direct correlation exists between mesial scars and the use of a spear thrower and between distal scars and the use of a bow.

We may conclude that an attribute system has more potential to reliably examine relationships between variables than was possible based on the poorly defined categories that are generally used within a DIF approach.

7. Discussion

Damage associated with a projectile impact event is highly variable (Rots and Plisson, 2014) and it is often difficult to describe in a transparent and accurate way. Aside from problems that were highlighted previously regarding the reliance on macro-fractures only to identify projectile use (Rots and Plisson, 2014), a careful review of the literature has shown that several inconsistencies exist in the descriptive framework that is currently used. Some of these inconsistencies are the result of poorly defined categories or an insufficiently strict application of existing definitions. In addition, a variety of features appears to be classified under the same term, the effect of which was demonstrated by the comparative application of two different descriptive approaches to one experimental dataset (the commonly used DIF approach versus a refined attribute-based system). Burinations proved to represent the most confusing fracture category. Burinations vary significantly

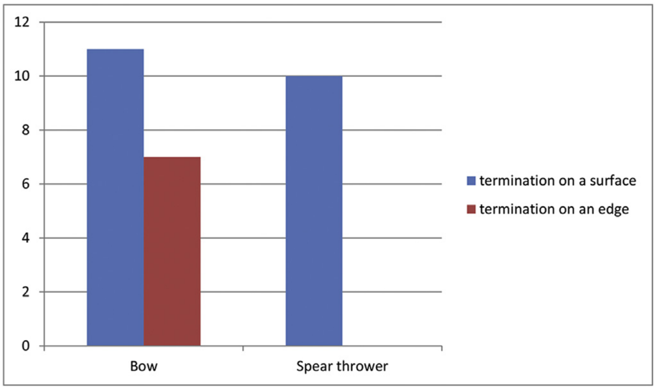

Fig. 14. Experimental projectile points: location of the termination for scars initiated on an earlier fracture surface per mode of projection.

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[1] The Yates Chi^2 test was chosen because the expected outcomes are between 3 and 5.

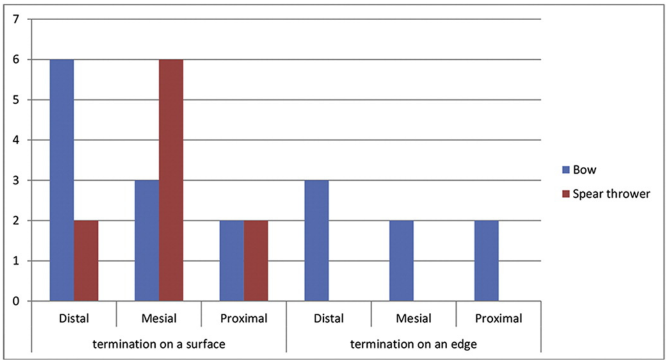

Fig. 15. Experimental projectile points: mode of propulsion compared to the location of the termination and the location of the damage for scars initiated on an earlier fracture surface.

amongst them and five attributes proved responsible for this variation: the fracture group, the location of the initiation, the location of the termination, the type of initiation and the type of termination (Fig. 9). While all burinations may superficially look the same based on morphological parameters, it is a term that masks a high degree of internal variability. It is therefore advisable either to avoid this category or to add more descriptive detail when using it.

We demonstrated that most problems arise from a mixture of terms derived from a more typological approach with terms derived from an attribute approach. These terms have varying levels of precision resulting in unnecessary confusion. A homogenization of currently used descriptions was therefore needed. In order to do so, the attribute-based approach that was initially proposed by the Ho Ho Committee to describe macro-fractures (Ho Ho Committee, 1979) was revised. An application of this revised system to a modestly-sized experimental dataset has allowed demonstrating that such an approach permits more accurate and complete fracture descriptions and more flexibility in examining the correlation between different variables. A similar degree of precision did not prove to be possible with a DIF approach. Its poorly defined and more typological categories mask much of the variability, moreover, illusionary correlations proved to appear. An attribute system by contrast, allows detailed multivariate statistical analysis (if sample sizes are sufficiently important).

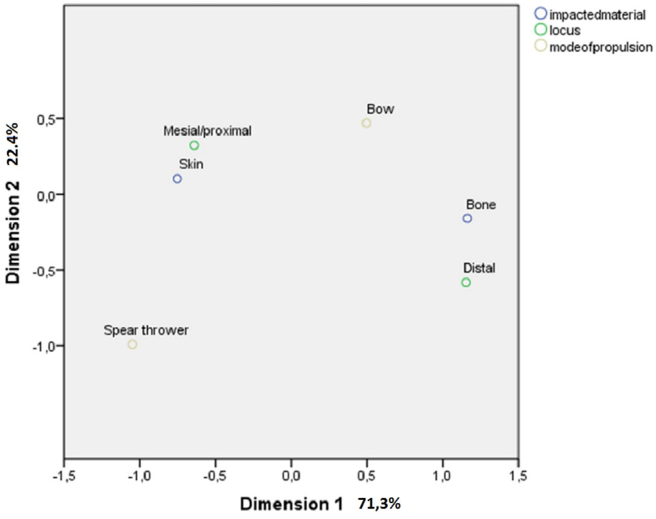

Fig. 16. Experimental projectile points: multiple correspondence analyses for mode of propulsion, impacted material and locus of the damage in the category of scars initiated on an earlier fracture surface.

Table 10
Contingency data table of impacted material/locus.

			Locus		
			Mesial/proximal	Distal	Total
Impacted material	Skin	Observed frequencies	16	1	17
		Expected frequencies	10.9	6.1	17
	Bone	Observed frequencies	2	9	11
		Expected frequencies	7.1	3.9	11
Total		Observed frequencies	18	10	28
		Expected frequencies	18	10	28

Impact fractures were often considered as predominantly resulting from a contact with bone. During our experiment, we observed that this is not necessarily the case. A lot of damage proved to be caused by a contact with skin and ballistic gelatin only. Regarding the influence of propulsion mode and impacted material on the creation of specific fracture patterns, the scars initiated from a previous fracture surface category reveal interesting elements. First, a strong correlation proved to exist between this fracture category, a skin-gelatin contact and the use of a spear thrower as well as between this fracture category, a bone contact and the use of a bow. Secondly, we have shown that this kind of fracture is either linked with a skin-gelatin contact if it occurs on the mesial-proximal part of a point or with a bone contact when formed on the distal part of points. No direct link between the mode of propulsion (spear thrower, bow) and the location of the fracture (mesial-proximal, distal) could yet be established (Fig. 16). Further analysis involving a larger dataset may perhaps resolve this problem.

We suggest that the observed patterning is the consequence of the mechanical and ballistic differences between a spear-thrower and a bow. When a bow is stretched to shoot an arrow, problems of arrow release or spin calibration may occur. This will generate a deflection of the projectile that will subsequently hit the target under an oblique angle. Such a risk is relatively limited with the bow because each shot is performed with similar energy expenditure; it is thus possible to easily calibrate the spin of the arrow. However, in the case of darts launched with a spear-thrower the situation is entirely different. This mode of propulsion involves the movement of the entire body during the shot, resulting in significant variability in energy expenditure between each shot. In addition, we know that also the spin of (experimental) darts is much more variable than of arrows, which significantly increases the risk of the projectile hitting the target under an oblique angle. We argue that this oblique contact is responsible for the formation of the mesial scars initiated from an earlier fracture surface. When a dart point hits the skin obliquely, its distal end penetrates the skin while the important inertia (linked to the weight and the length of the shaft) of the projectile increases the bending stress, causing a bending fracture on the mesial part of the point. Following this first phenomenon, the longitudinal compression between the two bending fracture surfaces creates longitudinal scars usually known as "spin-offs" (Fischer et al., 1984: Fig. 3b,c).

Table 11
Contingency data table of mode of propulsion/impacted material.

			Impacted material		
			Skin	Bone	Total
Mode of propulsion	Spear thrower	Observed frequencies	9	0	9
		Expected frequencies	5.5	3.5	9
	Bow	Observed frequencies	8	11	11
		Expected frequencies	11.5	7.5	11
Total		Observed frequencies	17	11	28
		Expected frequencies	17	11	28

This phenomenon can also occur with bow propulsion but the risk of an oblique contact is much lower than in the case of a spear-thrower and the less important size and weight of arrow an shaft strongly limit its apparition. Our results thus reveal a detectable difference between bow and spear-thrower propulsion modes. The observed variability in fracture patterns could be caused by the mechanics governing each propulsion mode. If this hypothesis finds further confirmation, it opens promising avenues of research to differentiate the effects of each projecting mode on fracture patterns.

The presented experimental data are the first results of a larger-scale experimental program focusing on the understanding of fracture patterns on projectile points. Of course, the presented results are strongly influenced by the ballistic characteristics of the projectiles and the propulsion mode and technique used in the experiments. The results are therefore not directly transferrable to the analysis of archaeological points. The sample of 60 points used in this pilot experimental study allowed promising, but preliminary results. The observed correlations require further testing based on larger experimental samples. Nevertheless, the analysis demonstrates the potential of a refined attribute-based terminology. After all, these results would have been unattainable if the poorly defined categories of the DIF-approach would have been used. A potential inconvenience of an attribute system is the loss of simple terms useful in discussions, but this could be resolved in the future if time is invested in defining each term via an aggregation of specific attributes. We consider it crucial to continue developing an attribute system, building onto earlier attempts of other researchers. It allows more accurate and more complete descriptions of macro-fractures, which is the best basis to progress in the understanding of the variability in fracture formation on stone projectile points.

8. Conclusion

Lately, Paleolithic projectile points have enjoyed renewed attention among researchers. Many experiments have been undertaken to understand fracture formation and to propose criteria based on which projectiles could be recognized in the archaeological record. A number of fracture categories were proposed as having diagnostic value for projectile identification, but we have demonstrated that these categories are not strictly defined. If we want to guarantee reliable projectile identifications in the future, we need to try to control the integrity and interpretative value of the descriptive categories we use. A higher level of precision and an overall clarity in description and interpretation is becoming increasingly more important as we move towards older assemblages, including those for which projectiles are not commonly accepted to exist. Also the number of points and the frequency of fractures are often much lower in older assemblages and interpretations may thus be more debatable if they are not based on well-founded criteria. It is thus fundamental to have an efficient, precise and shared terminology to describe each fracture and its organization. We thoroughly revised a formerly used attribute system and we added attributes to increase its precision. While the interpretative potential of some of these attributes is still unknown, we believe that their inclusion will not only help to avoid confusion in future, but also to identify potential indicative correlations between variables. One of the great advantages of an attribute-based descriptive system is its flexibility and the possibility to use multivariate statistical analysis to examine the diagnostic value of each attribute. In addition, it also facilitates sharing of experimental and analytical results, which may eventually lead to an integrated and shared large dataset. It is our conviction that a precise terminology with shared definitions is essential for continued investigations of fractures on projectile points and for evaluating the value of fractures for projectile identification as well as perhaps for distinguishing between projecting modes. A mutually shared terminology and set of definitions has all the potential for truly improving our understanding of past hunting techniques, their variability and their evolution.

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