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A Mechanical and Functional Study of Bone Rods from the Richey–Roberts Clovis Cache, Washington, U.S.A.

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Bone and ivory (osseous) rods of Paleoindian age have been found over much of North America, several from the same contexts that produced Clovis points. Previous researchers have suggested that these artefacts were projectile points, foreshafts, pressure-flaker handles or sled shoes. Published morphometric data indicate that the rods display varied attribute combinations, but these data are not consistently reported, and no set of typologically definitive attributes has been established. It also is unclear which attributes of the rods are related mechanically to rod function. Experimental replication and mechanical testing of the functional interrelations of numerous attributes of the 14 fluted Clovis points and 14 bone rods recovered from the Richey–Roberts Clovis cache in eastern Washington led to the conclusion that the rods from this site served a primary function as levered hafting wedges used to tighten sinew binding on saw-like implements.

Keywords: BUTCHERING TOOLS, CLOVIS BONE RODS, HAFTING WEDGE, TOOL FUNCTION.

Introduction

In 1937, Cotter (1937: 14) reported the discovery of a ''cylindrical shaft of bone'' in direct association with mammoth remains in the gravel-pit excavations at what later became known as Blackwater Draw Locality No. 1, just outside Clovis, New Mexico (Figure 1) (Hester, 1972; Saunders & Daeschler, 1994). In the years that followed, what were said to be similar items were found in Saskatchewan, Canada (Wilmeth, 1968), and the states of Alaska (Rainey, 1939, 1940; Yesner, 1994), Washington (Daugherty, 1956; Irwin & Moody, 1978), Oregon (Cressman, 1942, 1956), California (Riddell, 1973), Montana (Lahren & Bonnichsen, 1974) and Florida (Jenks & Simpson, 1941; Dunbar, 1991). Many of the early discoveries prompted suggestions of typological similarity among the specimens and thus that the age of the newly discovered specimens was similar to that of the Blackwater Draw specimens. For example, specimens from Alaska were said to ''appear to be similar [to] long bone points in direct association with mammoth bones found [at Clovis,] New Mexico'' (Rainey, 1939: 394), and the specimens from Clovis were said to be ''very much like the [Saskatchewan] specimen [which] has almost the same width and thickness'' (Wilmeth, 1968: 101).

Cressman consulted Cotter on the typological identity of some specimens recovered from southern Oregon: ''Cotter, when examining some of our material, thought [one of the specimens] was exactly the same type as that from Clovis'' (Cressman, 1942: 100). Similarly, Jenks & Simpson (1941: 318) stated that their specimens from Florida were ''typologically the same'' as those from Clovis. Thus by the early 1940s, numerous bone rods from varied contexts across the U.S.A. were being assessed as ''belong[ing] to a long extinct culture, probably of closely approximating age, namely, of late glacial or early post-glacial time'' (Jenks & Simpson, 1941: 318). Rods then became a hallmark artefact of the Clovis culture (e.g. Sellards, 1952) and remain so today (e.g. Bonnichsen, Stanford & Fastook, 1987). Although such status may be accurate, it has not been demonstrated that all known rods are part of a single cultural manifestation known as Clovis. We suspect that once sufficient data are available, it will be found that this is decidedly not the case, but here we focus solely on the possible functions of these rods.

One noticeable characteristic of many of the rods is bevelling on one or both ends: a characteristic that, it has long been assumed, had something to do with how the tools were used. Cotter (1954: 65), for example, referred to the bone rods as ''bevelled bone foreshaft

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Figure 1. Location of sites in western North America that have produced osseous rods.

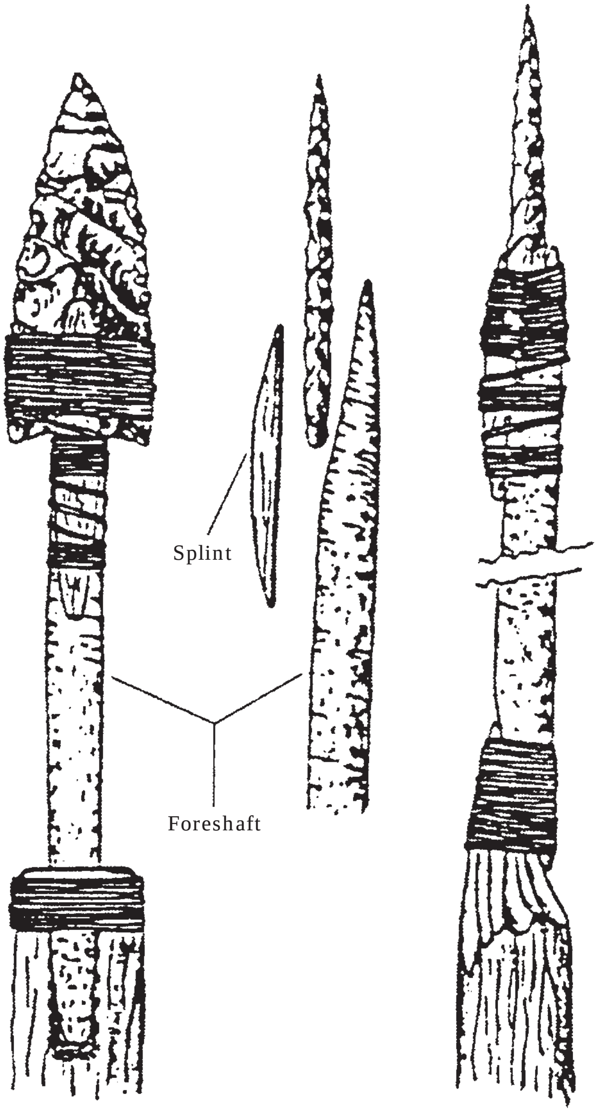


Figure 2. Lahren & Bonnichsen's (1974) model of bibevelled bone rods functioning as foreshafts (after Lahren & Bonnichsen, 1974, p. 149, fig. 3).

portions or spear tips'' and indicated that ever since he had ''participated in the original Clovis find, [he] considered these bevelled shaft portions of bone to be derivative from the familiar *sagaie* or javelin points of bone or reindeer horn from the traditional lower Magdalenian of Europe.'' Similarly, Jenks & Simpson (1941: 317) referred to the bone rods as ''bevelled artifacts'' and thought that at least one of the three specimens they described represented a ''hunting point''. Cressman (1942: 99–100) referred to his specimens as bone ''points'' or ''foreshafts''. One specimen Cressman (1956: 431) found is described as a ''long bevelled end projectile point'' because it was ''found in the lower left abdominal part of [a human] skeleton''; the bevelled end was said to be ''for hafting to a shaft,'' and the specimen was said to be ''exactly like those described [in Cressman, 1942].''

The emerging designation of these artefacts as foreshafts received some formality in the report by Lahren & Bonnichsen (1974) on the Anzick materials from Montana (Figure 1). They provided a description of the specimens (two complete and nine fragmented) and a model of how they thought the specimens served as foreshafts to which Clovis points were hafted (Figure 2). Frison (1982: 156) later stated that the ''true function of [these] objects . . . remains an open question; they are postulated as having been both foreshafts and actual projectile points.'' Still later, Wilke, Flenniken & Ozbun (1991) argued on the basis of experimental work that the Anzick specimens were handles to which an antler bit was hafted, thereby producing a composite tool for pressure flaking. Mehringer (1988*a*: 503, 1988*b*: 271, 1989: 7) indicated that it was speculative whether the rods from the Richey–Roberts Clovis cache (also known as the East Wenatchee Clovis site) in eastern Washington (Figure 1) were foreshafts, pressure flakers, or ''wedges for splitting wood.'' Most recently, Gramly (1993: 8) noted that ''the rods [from Richey–Roberts] are paired by size'' and expressed a preference for the hypothesis that these specimens once served as sled shoes.

In this paper, we summarize the morphometric attributes of various osseous rods that have been published and the functional interpretations of these implements offered by others. Except where discussing specific specimens, we avoid referring to them as ‘‘bone’’ rods because some were manufactured from ivory. The purpose of our discussion, which focuses on specimens recovered from contexts in the western United States, is to illustrate the uneven character of published descriptive data and to show the resulting breadth of interpretation that is possible as a result. We then summarize experimental work we performed to help determine the possible function of the rods from the Richey–Roberts cache. This summary is presented within a discussion of the mechanical and functional characteristics of various attributes of large fluted points and rods. Our experimental work suggests that the particular combination of attributes on the items from Richey–Roberts comprises a tool that would have efficiently performed one major function, as a levered hafting wedge, and two lesser (but not necessarily unrelated) functions, as a butchering wedge and pressure flaker.

Form and Typology

Part of the continuing puzzlement over what functions the bevelled rods might have served originates in the fact that the two original Blackwater Draw specimens appeared similar to each other and thus were thought to comprise a single type of artefact (Cotter, 1937). But when we read statements that specimens from other sites found subsequent to those from Blackwater are ‘‘similar’’ or ‘‘typologically identical’’ to the latter, skepticism seems warranted. We say this because although later publications usually provide morphometric details regarding newly discovered specimens, no one, so far as we know, has ever compiled data on the size, shape and morphological attributes of all of the implements. Some analysts have argued that all the specimens are of the same ‘‘type’’ (Cressman, 1942, 1956; Cotter, 1954; Lahren & Bonnichsen, 1974), and others (e.g. Riddell, 1973) have distinguished two ‘‘types’’ on the basis of whether bevelling occurs only on one end or on both ends. On the one hand, insofar as discussions indicate that a particular type of artefact is generally believed to have served a particular function, it is not surprising that the various specimens have been assigned to different functional categories. On the other hand, given the apparent variation in size, number of bevelled ends, and whether a specimen is deemed to be straight or curved, it perhaps is predictable that different specimens or sets thereof would have been interpreted differently in terms of their suspected function. The question that is begged by these observations concerns the relevance of the attributes considered for determining artefact function.

To begin to assess if the specimens are in fact similar in some morphological sense, we compiled such information as contained in the published record (Table 1). Inspection of Table 1 indicates that the quality of the published morphometric data is uneven. For example, although it has been reported that many specimens made from ivory have been found in Florida (Webb, Dunbar & Walker, 1990; Wilke, Flenniken & Ozbun, 1991), these remain largely unpublished. Only recently has the complete collection from Anzick been listed (Jones & Bonnichsen, 1994), and many but not all specimens have been described in detail (Lahren & Bonnichsen, 1974; Wilke, Flenniken & Ozbun, 1991). There is minimal consistency in the specific attributes chosen to describe particular rod specimens, with the exception that it is typically but not always noted that a particular specimen is bevelled on one or both ends, made of bone or ivory, and is long relative to width and thickness. As a result of the quality of the published record, it is unclear if, for example, the variation in length and width (maximum cross-section diameter) displayed by a sample of these specimens (Figure 3) represent morphological variation that is somehow significant. Further, inferring typological identity of the specimens listed in Table 1 cannot be accomplished with any reliability because there is no agreed-upon set of necessary and sufficient conditions for type membership. Finally, it is not clear that all of the typically described attributes of the rods are related to artefact function.

Form and Function

Granting that artefact form is to some degree related to artefact function, possibly all specimens listed in Table 1 served the same function, but it is equally possible that some performed one function, others performed another function, and/or that some of them were even multifunctional. Thus, some might have been used as points, others as foreshafts or pressure-flaker handles, still others as sled shoes or any or all of them as something else. We examine the suggestions of others concerning these possible functions below and focus on the mechanical efficiency of the particular attribute combinations displayed by the tools when serving a particular function. Our discussion ranges fairly widely because we assumed that only by finding a tool structure that both worked efficiently and also accounts for many apparently functional and mechanical attributes will we approximate the actual uses of the items.

Foreshafts

Based on the frequency of occurrence of the term ‘‘foreshaft’’ in the literature (e.g. Bonnichsen, Stanford & Fastook, 1987; Stanford, 1991) in reference to the rods, it appears that the general, though not universal (e.g. Wilke, Flenniken & Ozbun, 1991), consensus is that many of them served that function. Foreshafts should be rod-like, given the intended purpose of making retooling and game killing more efficient (e.g. Frison, 1974: 87–88, 1978: 333), but what about the bevelled ends? Are the bevels related to hafting, and if so, how? The length of the bevels is seldom reported,

Table 1. Descriptive data for osseous rods

Specimen*	Material	Length	Width	Thickness	Cross section	Bevel	Bevel incised?	Bevel length†
ANZick-37	Bone		17	12	Oval	1		49
ANZick-38	Bone		19	13	Oval	1		
ANZick-39	Bone					1		48
ANZick-67	Bone	228	15	12	Oval	2?		58
ANZick-94	Bone		18	13	Oval	1		44
ANZick-95	Bone		18	13	Oval	1		44
ANZick-117	Bone		15	10	Oval			
ANZick-118/119	Bone	281	18	14	Oval	2	Yes	46/51
ANZick-120	Bone		19	11				
ANZick-122	Bone		20	13				
ANZick-123	Bone		20	14				
FLorida-A	Bone	182+	12·3	12	Cylinder	1	Yes	58
FLorida-B	Ivory	91+	8·5			1	Yes	25
FLorida-C	Ivory	150·5+	10·1				Yes	
BlckWtr-9-9	Bone	252	15		Cylinder	2	On 2	
BlckWtr-9-10	Bone	234	17		Cylinder	2	On 1	
LindCoulee-178	Bone	134	13·4		Oval	1		61·6
LindCoulee-140	Bone	251+	16·4	10·4	Rectangular?			
Richey-A	Bone	263	24	18		2	On 2	59/35
Richey-B	Bone	209	24	17		2	On 2	
Richey-C	Bone	252	24	18		2	On 2	70/50
Richey-D	Bone	242	29	19				
Richey-E	Bone	231	28	20				
Richey-F	Bone	190	26	18		2?	On 1	50/83(?)
Richey-G	Bone	232	30	22		1	Yes	
Richey-H	Bone	177	26	18		1	Yes	46
Richey-I	Bone	215	30	21				
Richey-J	Bone	171	27	19		1	Yes	42
Richey-K	Bone	193	28	20		1	Yes	50
Richey-L	Bone	115	13	12				
Sheaman	Ivory	203	12·1	10	(Broken)	1	Yes	74·7
Alaska-1	Bone	285	15 ±			No	Yes‡	
Alaska-2	Bone	175	15 ±			No	Yes‡	
Alasaka-3	Ivory?§	205	23					
LowerKlamathLK	Bone	250 ±	13 ±			1		
KlamathLK	Bone	190	15	12		1	No(?)	70
Saskat-1	Bone	207	15	12·5	(Broken)		Yes‡	
GooseL-1d•	Bone	133	10			1		
GooseL-1e	Bone	168	11		(Broken)	1		
GooseL-1f	Bone	197	13		Ovoid	1		
GooseL-2a	Bone	112	8		Ovoid	1		
GooseL-2b	Bone	198	12		Flat	2		
GooseL-2c	Bone	180	9		Ovoid	2		

All measurements are in mm.

*References: Anzick-Lahren & Bonnichsen (1974); Florida—Jenks & Simpson (1941); BlckWtr—Cotter (1937); Hester (1972); Saunders & Daeschler (1994)); Lind- Coulee—Daugherty (1956); Irwin & Moody (1978); Richey—Gramly (1993); Sheaman—Frison (1982); Frison & Zeimans (1980); Alaska-1 and 2—Rainey (1939, 1940); Alaska-3—Yesner (1994); Lower KlamathLK—Cressman (1942); KlamathLK—Cressman (1956); Saskatchewan—Wilmeth (1968); Goose- L(ake)—Riddell (1973).

†If two bevels are present, two measurements are listed, separated by "/".

‡These three specimens have cut grooves encircling an end, but there is no bevel.

§Yesner (1994: 155) refers to this specimen as a "bone point" and as a "mammoth ivory point".

•Riddell (1973) provided a scale but did not indicate if inches or centimetres were shown. We have assumed it was the latter.

and we are unaware of any discussions of the angle of bevelling. Bevel length is unrelated to the maximum cross-sectional diameter of the specimens (Figure 4); a larger rod diameter would demand a longer bevel to obtain a uniform shape at the end of all rods. If the bevel was a mechanically critical attribute, then we must wonder why some rods are bevelled on both ends, others on only one end, and others on neither end. We doubt that this variation is the result of some rods not yet being completely manufactured or finished products. This assessment is based on the fact that there are other attributes of the bevelled ends that have not been discussed in the literature but which we believe are critical to correctly determining the function of the rods. We elaborate on these below.

Lahren & Bonnichsen (1974), following earlier workers (e.g. Cotter, 1937; Hester, 1972), presented a model of how the bevels might have served the hafting function (Figure 2). Part of this model probably derived from Cotter's (1954) remark that the North American rods resembled "*sagaie* or javelin points" from the European Upper Palaeolithic. It is true that there are some resemblances: the European specimens are bevelled, and some but not all bevels of the *sagaie*

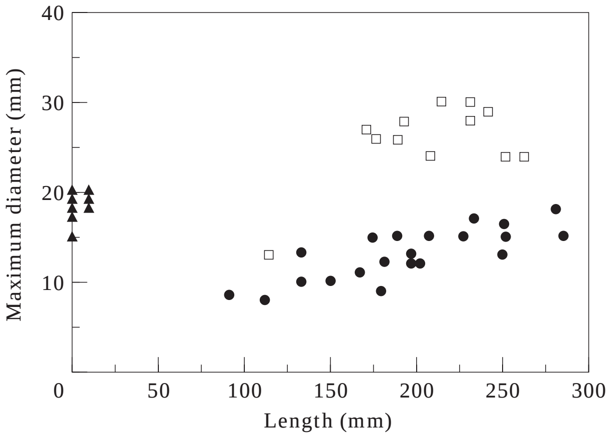


Figure 3. Bivariate scatterplot of length versus width of reported osseous rods (derived from Table 1). Plotted points labelled ‘‘no length’’ are incomplete specimens for which length is unknown; note that these tend to be smaller in diameter than the rods from the Richey–Roberts Clovis cache. □, Richey–Roberts; ●, other; ▲, no length.

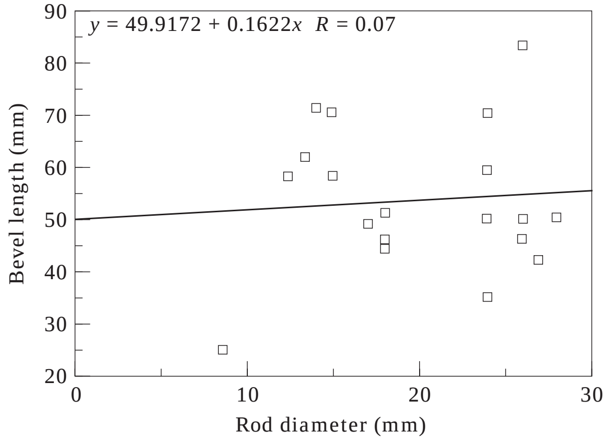


Figure 4. Bivariate scatterplot of osseous rod diameter versus length of bevel (derived from Table 1).

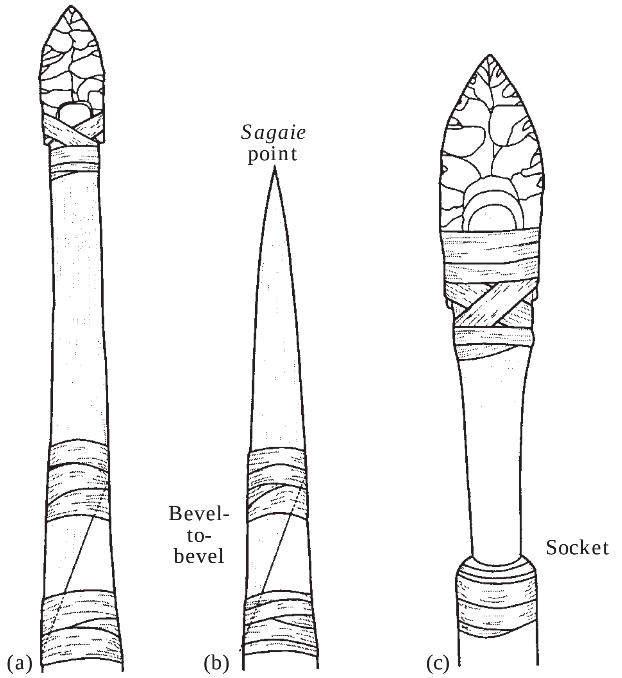
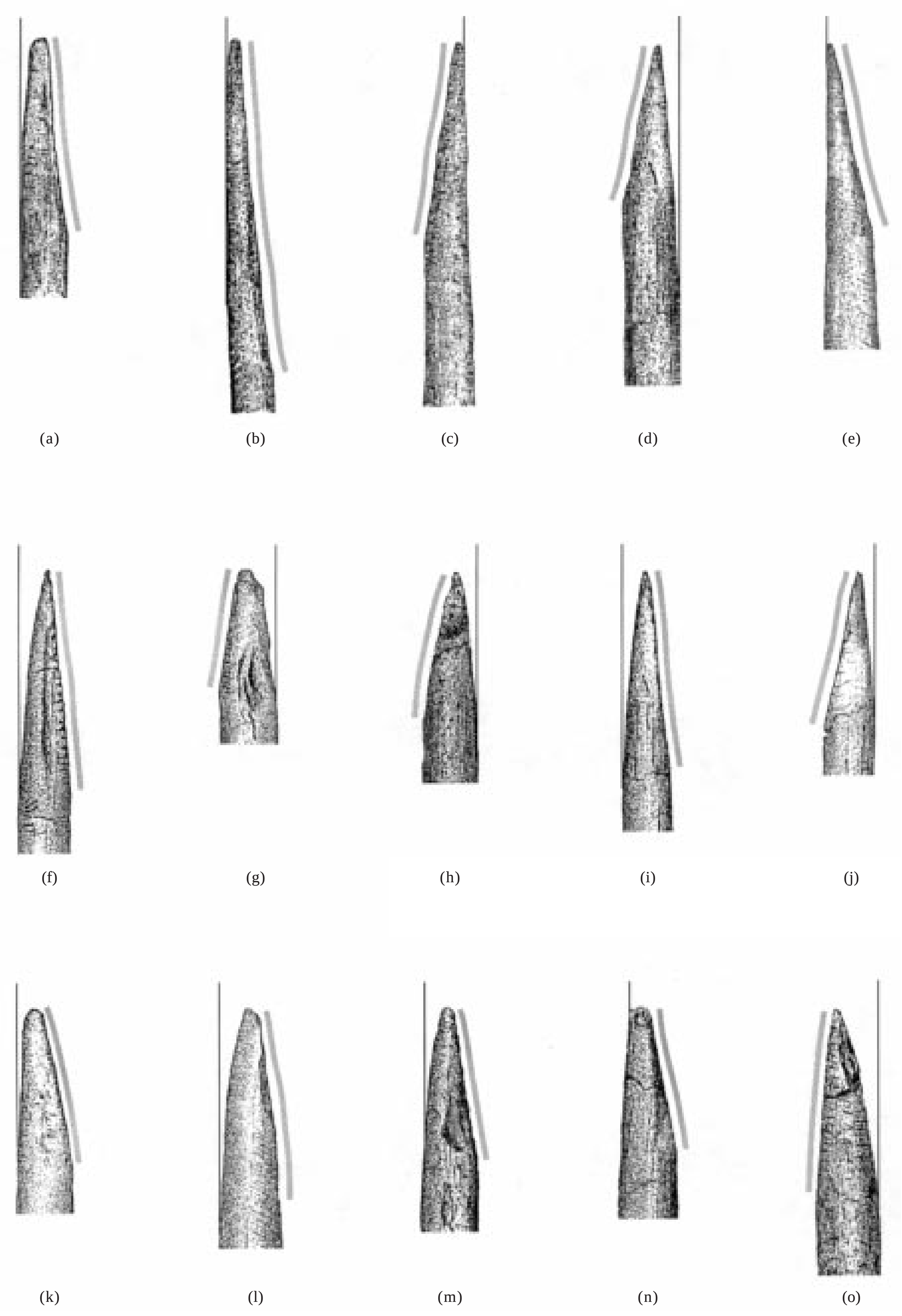


Figure 5. Techniques for hafting foreshafts (a) and (c) to a shaft and for hafting a *sagaie* point to a shaft (b). Note how the bevel-to-bevel haft (a) and (b) does not create a change in overall diameter, whereas the socket haft would hinder penetration.

points have a pattern of grooves, but that pattern is unlike the one on North American specimens (e.g. Bordes, 1968: 162, fig. 58 No. 1). Further, unlike various North American specimens, examples of *sagaie* points such as those to which Cotter referred (1) all display single bevels, (2) taper from the distal end of the bevel more or less consistently to a point, and (3) have a straight rather than a convex face opposite the bevel (e.g. de Sonneville-Bordes, 1963: 349, fig. 3 No 8; 1963: 351, fig. 7 No. 2; Bordes, 1968: 153, fig. 55 No. 4; 1968: 156, fig. 56 No. 11; 1968: 162, fig. 58 No. 2).

Our experiments produced results similar to those of Callahan (1994: 134) and indicate the bevel-to-bevel haft shown in Figure 5(a) and 5(b) works well and avoids the problem of limited penetration found with a socket haft such as that shown in Figure 5(c). We note that the bevel-to-bevel haft avoids problems of penetration only if the face of the *sagaie* point opposite the bevel is straight and if there is a smooth transition in diameter from the point (or foreshaft (Figure 5(a)) to the shaft. The rod specimens from Anzick have this attribute, as does one rod from Blackwater Draw and the ivory specimen from the Sheaman site in eastern Wyoming (Figure 6(a–e)). The faces opposite the bevels on the rods from Richey–Roberts tend to curve much more noticeably to form a convex surface than is found on specimens from other sites (Figure 6(f–o)); we explain later why we think they exhibit this curvature.

Lahren & Bonnichsen’s model (1974, Figure 2) may be reasonable if the manner of hafting foreshafts to shafts is modified to that in Figure 5(a) and 5(b). But there are three other attributes of their model that warrant comment. First, why have no ‘‘splints’’ (Figure 2) been found? If they were made of wood, perhaps they did not preserve, but if they *were* made of wood, we wonder why the main foreshaft was made of bone. We made a half-dozen wooden rods from osage orange (*Maclura pomifera*). When green these rods were too flexible and when dry too brittle to serve well as foreshafts or hafting levers (see below). Second, and more importantly, bases of Clovis points almost always were ground (e.g. Woods & Titmus, 1985: 4–5). Such grinding is unnecessary given the hafting model in Figure 2 because the base of the point is not in contact with (it is not resting on) anything. Such basal grinding would perhaps be necessary, however, if a point were hafted in and seated on the base of a wooden nock. If


(a)
(b)
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the base were sharp, or if there were not a strip of, say, hide between the point base and the nock base, the point would serve as an efficient wedge and split the shaft when the point met resistance during penetration. Third, our experiments indicate a point hafted between a splint and a foreshaft as in Figure 2 would result in poor alignment of the point, foreshaft and shaft. One reviewer of this paper agrees with us. Another reviewer notes that Callahan (1994) used this hafting system successfully, but we note that Callahan's (1994, fig. 4f) version is rather different than that shown in Figure 2.

Some experimenters (e.g. Frison, 1974: 89, 1986, 1989; Huckell, 1982) have used wooden foreshafts (with points attached) recovered from late prehistoric contexts (Frison, 1962, 1965) as analogues. Frison (1989), Huckell (1982) and Callahan (1994) replicated such wooden foreshafts, hafted lithic points in a nock in the distal ends of the foreshafts, and seated the proximal ends of the foreshafts in sockets (of various shapes) on the ends of the main shafts. The eleven replicate wooden foreshafts described by Frison (1989) and Huckell (1982) averaged 19·7 mm in diameter and ranged from 13·9 to 24 mm in diameter. The smallest one appeared to be too small (Frison, 1989: 769) to function properly, as it ‘‘broke in two places when used with a thrusting spear''. Thus, Frison concluded that the optimum diameter of wooden foreshafts was 17–18 mm.

The average width (maximum diameter) of the osseous rods under examination here (17·82 ± 6·38 mm) is not significantly different from the average diameter of the replicate wooden foreshafts (Student's $t=0{\cdot}93$, $P=0{\cdot}36$), but if the Richey–Roberts cache specimens (they represent the largest of the lot (Figure 3)) are omitted (average width of remaining rods = 14·54 ± 3·45 mm), then the replicate wooden specimens have significantly larger diameters than the osseous rods ($t=4{\cdot}27$, $P<0{\cdot}001$). That might be expected, as a wooden foreshaft is probably more susceptible to breakage as a result of bending forces than a bone rod, particularly if the former is allowed to dry out. Further, the diameter of a foreshaft may be important; Huckell (1982: 220), for example, found that penetration ‘‘stopped at one of two locations on the [foreshaft-armed] spear: the juncture of the foreshaft with the mainshaft, or the binding securing the point to the foreshaft''. Frison (1978: 337) and Callahan (1994) had similar penetration results. An osseous foreshaft might allow for a smaller diameter than a wooden foreshaft would.

Most recently, Stanford (1996) proposed a different foreshaft model that consists of two unique aspects. First, the ‘‘bi-bevelled rods are viewed as composite pieces which fit together to create a lengthened foreshaft capable of lethal penetration into a mammoth'' (Stanford, 1996: 45). If correct, we (a) wonder why some of the rod faces opposite the bevel are straight and others convex relative to the long axis of the rod (Figure 6) and (b) note that the angles of the bevels facing one another would have to be identical to ensure a straight shaft. As well, we note that any three bone rods from Richey–Roberts weigh 150 g or more; this weight would be nearly doubled with an average-sized fluted biface from the site. We wonder if such a tool would be too heavy to throw efficiently. The second aspect of Stanford's (1996) model consists of an antler ‘‘foreshaft socket.'' The blunt end of an osseous rod serving as a foreshaft would seat in one end of the antler socket, which has a nock-like slot at both ends, and a Clovis point would be seated in the other end. Although possible, we note two things about this aspect of the model. First, we suspect penetration might be hindered by such a socket. Second, we note that antler items similar to the ‘‘socket'' illustrated by Stanford can be produced by natural processes (e.g. Gordon, 1976; see also Lyman, 1994: 395). This is not to say that we think Stanford has committed an error by identifying a naturally formed item as an artefact; we simply raise this possibility.

Projectile points

Experiments using antler, bone and wooden projectiles indicate that antler (caribou (*Rangifer tarandus*), in particular) penetrates better than bone, and both of them perform better than wood (Butler, 1980; Guthrie, 1983). Some of the reported osseous rods from North America are made of bone, some of (proboscidian) ivory (Table 1). Some analysts (e.g. Cressman, 1956; Frison & Zeimens, 1980; Guthrie, 1983; Stanford, 1991) think some of the rods might have served as projectile points, and one of Cressman's (1956) specimens apparently was used in such a manner. We can attest to the killing power of an osseous point; Hayes has killed hogs (*Sus scrofa*) with darts thrown with an atlatl and tipped with bone *sagaie* points. Average penetration was 40 cm over six trials, and we note that a vital organ must be struck with such a weapon because minimal bleeding is caused. What are assumed to be true osseous points recovered from archaeological contexts appear, however generally to be shorter than the specimens listed in Table 1 (e.g. Tyzzer, 1935; Newcomer, 1977; Arndt & Newcomer, 1977). Two European *sagaie* points illustrated by de Sonneville-Bordes (1963), for example, are 85 and 105 mm long,

Figure 6. Side views of bevels on selected rods. The shaded lines indicate the location and extent of bevelling; the straight line projected from the nonbevelled side indicates the degree of convexity of that side. Not to scale. (a) Blackwater Draw specimen 9–10 (after Hester, 1972); (b) Sheaman specimen (after Frison, 1991*b*); (c) Anzick specimen 67 (after Frison, 1991*b*); (d) & (e) Anzick specimen 118/119 (after Frison, 1991*b*); (f)–(o) Richey–Roberts specimens (after Gramly, 1993).

though apparently longer specimens are known (e.g. Bordes, 1968).

Finally, as noted in the preceding discussion on foreshafts, *sagaie* points have a single bevel and taper more or less continuously to a sharp point. The bi-bevelled rods from Anzick and Richey–Roberts do not have these attributes. The specimen Cressman (1956: 431, fig. 19 No. 3) found associated with a human skeleton is too poorly preserved to evaluate these attributes, though one of the other ones he found (Cressman, 1942; Fig. 97e No. 6) appears to have them. Cotter's (1937: plate 2; see also Hester, 1972: 117, fig. 105b and c) specimens do not taper continuously. Specimens from Lind Coulee (Daugherty, 1956; Irwin & Moody, 1978) are too incomplete to evaluate, though one of them is said to be ''tapered'' (Daugherty, 1956: 254, fig 26 No. 3). Some of Riddell's (1973) specimens are bi-bevelled, and none of them tapers continuously, though several are pointed. Other specimens listed in Table 1 are also variable. Determining the function of these morphometrically varied items is difficult because of their uneven and incomplete published descriptions. That some of them may have been points is certainly possible, but until we understand better the use-wear of such implements (e.g. Tyzzer, 1935; Arndt & Newcomer, 1986), positing their function based on selected morphometric attributes is tenuous.

Pressure-flaker handles

Wilke, Flenniken & Ozbun (1991: 258) suggest, on the basis of ethnographic documentation, that the rods from Anzick ''represent a type of hand-held tool that once had an additional part attached to the bevelled end with pitch and sinew. Such an implement would be a pressure flaker, with an antler bit bound to the bevelled end or ends of a bone or ivory handle''. Experiments performed by Wilke, Flenniken & Ozbun (1991: 259) indicated that ''pitch was necessary to keep the bit from slipping on the bevel, and incisions on the lateral and dorsal surfaces of the bevelled ends of the handles were necessary to keep the sinew from slipping toward the end''. Damage on one end of one of the Anzick rods is thought to have been produced when the bit wore down and was not reset (rehafted) to extend beyond the end of the handle. Wilke, Flenniken & Ozbun (1991: 226) stated that all rod specimens from Anzick are broken and note that the reason(s) for this ''cannot be determined''. They illustrate one broken specimen from Anzick that ''gives the appearance of having seen little or no use'' (Wilke, Flenniken & Ozbun, 1991: 261, fig. 17). One fracture they illustrate appears identical to the fracture we generated when using one of our experimental rods as a wedge to tighten the binding of a haft.

Wilke, Flenniken & Ozbun's hypothesis that the Anzick rods served as pressure-flaker handles provides a functional explanation for the co-occurrence of the rods and the stone bifaces and fluted points at that site. It is unclear, however, if that explanation is equally applicable to all osseous rods. We think it is not applicable to the Richey–Roberts specimens because they differ from the Anzick specimens in what we believe are several mechanically important attributes. Particularly, we have in mind the fact that the rod face opposite the bevel is markedly convex relative to the long axis of the Richey–Roberts rods but is much straighter in the illustrated Anzick rods (Figure 6). We return to this point later.

Sled shoes

Gramly (1993) believes that the bevelled bone rods from the Richey–Roberts cache were used as ''sled shoes''. These specimens, however, are nothing like archaeological specimens of what have been called bone and ivory sled shoes associated with the Western Thule culture (*c.* 1000 BP) of Alaska (Giddings & Anderson, 1986: plates 2, 28, 50) or with the Dorset culture (*c.* 2500–1000 BP) of the eastern Arctic (Maxwell, 1985: 152). This is not to say that Paleoindian sled shoes had to resemble shoes made nine or ten millennia later; the point is that those later archaeological specimens are not morphologically similar to the Richey–Roberts bone rods. The Arctic specimens have wide, thin cross sections, relatively flat surfaces, and are perforated, apparently for lashing them to the sled runners. Further, we doubt that the binding required to hold the Richey–Roberts rods in place would have withstood much wear and tear over anything but the smoothest ice. If they had been so used, one would expect use-wear in the form of striae parallel to the long axis of the rods and distributed on only one face of each rod, but Gramly (1993) does not report evidence of this sort of wear. No evidence of such wear is apparent on the precise replicas of the Richey–Roberts rods made by Pete Bostrum of Troy, Illinois.

A Different Starting Point

Many of the functions posited for osseous rods, foreshafts, points, sled shoes, and so forth, have been based on suspected analogous specimens, especially those in the ethnographic and late prehistoric records. The treachery of such an approach to explaining the archaeological record is well documented (e.g. Freeman, 1968; Wobst, 1978). In our view, the greatest weakness with such an approach is the requisite assumption that the past is no different from the present; the uniquely historical evolutionary development of technology is denied as we force our archaeological observations into some ethnographically documented category of phenomena. Thus, we began our research without reference to ethnographically documented uses of osseous rods and merely attempted

Table 2. Major contents of five Clovis caches

Cache	Number of fluted points	Number of bifaces	Number of rods	Reference
Drake	13	0	Possible ivory rod	Stanford & Jodry, 1988
Fenn	11	29	0	Frison, 1991*b*
Anzick	8	85 fragments	5 to 7	Jones & Bonnichsen, 1994
Simon	5	22	0	Woods & Titmus, 1985
Richey–Roberts	14	15	14	Gramly, 1993

to build a tool that functioned efficiently and simultaneously accounted for numerous features evident in the archaeological record. In short, we employed mechanical inference based on experimental evidence.

We turned first to items contained in five so-called Clovis ‘‘cache’’ sites (e.g. Frison, 1991*a*, *b*; Wilke, Flenniken & Ozbun, 1991), a term signifying agglomerations of tools that appear to have been stashed in one spot for later retrieval and use.* We know little about the precise spatial relations of osseous rods, fluted stone points, and other artefacts in these sites. The Anzick materials were recovered from disturbed contexts (Lahren & Bonnichsen, 1974; Wilke, Flenniken & Ozbun, 1991; Jones & Bonnichsen, 1994), as were materials from the Simon site in Montana (Figure 1) (Butler, 1963; Butler & Fitzwater, 1965; Woods & Titmus, 1985). Items in the Fenn (Frison, 1991*a*, *b*) and Drake (Stanford & Jodry, 1988) caches were studied and described by professional archaeologists after those materials had been removed from their original archaeological contexts by others. The Richey–Roberts cache was in primary context, and though particular specimens may not have been in their precise primary depositional locations, all artefacts are believed to have originated ‘‘in a single shallow [cache] pit with dimensions 1·1 m by 1·15 m’’ (Gramly, 1993: 6; see also Gramly, 1996: 19; Mehringer, 1988*a*, *b*, 1989; Mehringer & Foit, 1990).

As indicated in Table 2, the kinds of artefacts recovered from the Clovis caches include fluted points (5 of 5 sites), bifaces (4 of 5 sites) and bone or ivory rods (2 or 3 of 5 sites).† Lithic debitage and other materials are represented in all but the Fenn cache, but this may be the result of how the latter materials were collected (Frison, 1991*b*). The bifaces are sometimes quite large and may represent preforms or blanks intended to be made into points or knives. The large fluted bifaces, typically termed ‘‘Clovis points’’, in caches appear to be finished and ready to use, as fluting is one of the last, if not *the* last, step in manufacture. Further, the edges of specimens appear sharp and ready for use, and the hafting areas on some pieces were ground in preparation for hafting (Fagan, 1988: 391; Mehringer, 1988*a*; Stanford & Jodry, 1988). Some Clovis points found in caches were reworked (e.g. Stanford & Jodry, 1988; Frison, 1991*b*), including some from Richey–Roberts (Gramly, 1993), but overall they tend to be much larger than those found associated with remains of large mammals such as mammoths or bison (Table 3 and Figure 7).

Two possible explanations for the overall large size of Clovis points in caches have been proposed. One is that the practice of ‘‘exaggerating scale on burial goods was employed’’ during Paleoindian times (Woods & Titmus, 1985: 6–7). Evidence for this alternative consists of only the materials from Anzick, which may be associated with a human burial (Jones & Bonnichsen, 1994). The largest known Clovis points, however, come from the Richey–Roberts cache, which contains no evidence of a human burial (Gramly, 1993, 1996). The other possibility is that smaller points were used for smaller game; available evidence, such as the association of some of the smallest Clovis points with the largest game, mammoths, contradicts this alternative (Gorman, 1972). From a technological perspective,

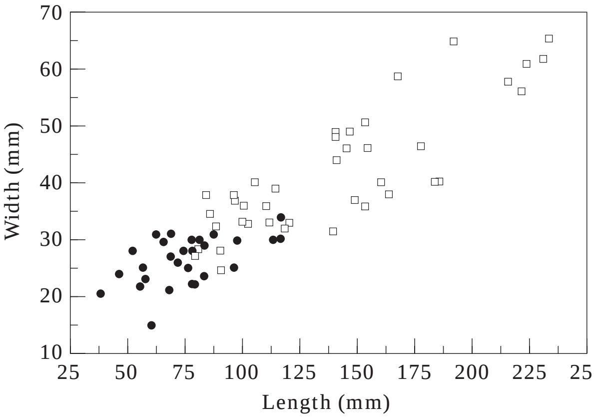

Figure 7. Bivariate scatterplot of fluted Clovis point length versus width (from Table 3). Specimens labelled ‘‘cache’’ are from Richey–Roberts, Simon, Drake, Fenn and Anzick. Specimens labelled ‘‘noncache’’ are from Blackwater Draw Locality No. 1, Domebo, Lange/Ferguson, Lehner, Lubbock Lake, Miami, McLean, Naco and Sheaman. For the ‘‘noncache’’ category, only specimens for which length ≥50 mm and/or width ≥20 mm are plotted. □, cache; ●, noncache.

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*Jones & Bonnichsen (1994: 43) have recently argued that Anzick ‘‘clearly’’ represents a Clovis-era burial. They may be correct, but until all relevant data are published and evaluated, we believe it is premature to accept this conclusion.

†The frequencies listed in Table 2 for the Fenn and Simon caches are approximate, a result of how those collections have been described in the literature. We agree with Wilke, Flenniken & Ozbun (1991: 268) that ‘‘lack of publication . . . has profoundly hindered Paleoindian studies in the United States.’’

Table 3. Measurements (mm) of fluted Clovis points plotted in Figure 7

Site	Specimen*	Length	Width	Reference
Cache:				
Anzick	88.07.30	96	37	Wilke, Flenniken & Ozbun, 1991
	88.08.18	110	36	
	88.08.12	79	27	
	88.68.20	153	36	
Drake	58	139	31·5	Bostrum, 1992
	64	114	39	
	80	163	38	
	108	90	28	
	114	88	32·5	
	179	149	37	
Fenn	CP1-53	102	32·6	Reher & Frison, 1991
	CP2-54	99·7	33·2	
	CP3-55	85·8	34·6	
	19.3b	84	38	Frison, 1991*b*
	19.5	154	46	
	19.6	111	33	
	19.11a	120	33	
	19.11b	118	32	
	2.11	177	46·5	Frison, 1991*a*
	9.2a	90·5	24·6	
	9.2b	81	28·5	
Richey Clovis cache	1	232·5	65·5	Gramley, 1993
	2	230	62	
	3	220	56	
	4	223	61	
	5	215	58	
	6	191	65	
	7	153	50·6	
	8	167	59	
	9	140	48	
	10	140	49	
	11	105	40	
	12	147	49	
	13	141	44	
	14	145	46	
Simon	a	185	40	Butler, 1963
	b	185	40	
	c	160	40	
	d	100	36	
	e	96	38	
Noncache, associated with remains of large mammals:				
Blackwater Draw No. 1	ENMU-221	60	15	Johnson, 1991
	TMM976-2	78	22	
Domebo	64.8.2	78	28	Leonhardy & Anderson, 1966
	64.8.3	68	21	
Lange/Ferguson	L-81-1	38·4	20·7	Hannus, 1989
	L-84-1	55·2	21·8	
Lehner	12674	87	31	Haury, Safes & Wasley, 1959
	12675	79	22	
	12676	83	29	
	12677	74	28	
	12769	62	31	
	12680	81	29	
	12682	56	25	
	12684	78	30	
	12685	97	30	
	12686	52	28	
Lubbock Lake	TMM892-74	46·5	24·1	Johnson, 1991
McLean	TTU47.73.3	82·7	23·5	
Miami	13	113	30	Sellards, 1938
	45	116	30	
	46	76	25	
Naco	11912	96	25	Haury, Antevs & Lance, 1953
	11913	97	30	
	10899	72	26	
	10900	68	27	
	10901	81	30	
	10902	68	31	
	10903	116	34	
	10904	58	23	
Sheaman	2.91c	67·4	29·3	Frison, 1982

*In some cases the specimen numbers refers to a collection or museum accession number; where this is unknown, the number refers to a figure number in the reference indicated.

large points would have had longer potential use lives (they could have been resharpened more times) than those in kill sites. Storing such items also means they would not have to be transported and could be recovered when needed. These observations lend credence to the notion that the collections from caches were stored in anticipation of future use.

Typically, all fluted bifaces in the Clovis-era caches (Table 2) are referred to as ‘‘points’’. This term denotes, intentionally or not, that these specimens performed a particular function. The force necessary to hurl large points such as those from caches through a hide would, however, seem to be commensurately excessive. Omitting the two obviously broken points, the remaining twelve fluted points from Richey–Roberts range in weight from 68·6 to 209·8 g, with an average and standard deviation of 138·4 ± 55 g. These points seem, then, to be larger than an optimal size for tipping a projectile (see review and references in Christenson, 1986). If the large points were used as butchering tools, they would eventually be resharpened to an extent that made them efficient projectile points. The exceedingly large size of the Clovis points at Richey–Roberts (Table 3) suggests they were intended to be used as butchering tools, specifically, saws, rather than as weapons designed to pierce hide. Gramly (1991, 1993), in fact, refers to them as ‘‘knives.’’ Other attributes of these particular specimens appear to validate such a categorization.

The Richey–Roberts cache producing the fluted points and rods was nearly completely excavated. The fact that fourteen fluted projectile points and evidence of fourteen bone rods were found in this cache (Table 2), the only one excavated virtually from start to finish by professional archaeologists, suggests that a ratio of 1:1 of these two kinds of implements might be significant.‡ The collection of bone rods from the site comprises specimens that vary in length. Our experiments indicate that the shorter rods work just as well as the longer rods when fulfilling the function we propose for them. Therefore, given that bone technology is subtractive, shorter rods might represent reworked specimens that were worn down or broken during use and then reworked. Wilke, Flenniken & Ozbun (1991) indicate that one of the rods from Anzick had been worn down slightly, and Saunders & Daeschler (1994: 16–17) report that the bevelled end of one of the rods originally recovered by Cotter from Blackwater Draw ‘‘is broken transversely through a lazy V-shaped (<) bevelled fracture suggesting snap-breakage in use’’. What might cause such wear and breakage?

Experimental butchery of elephants (Park, 1978; Stanford, 1979; Toth, 1987) provides some possible clues. While butchering an elephant known as Ginsberg, an ‘‘antler wedge’’ was used to pry tendons off the bones (Park, 1978: 94). Such use could have been made of the bevelled end of an osseous rod and produced wear to the tip during insertion and/or breakage while prying. That rods of one sort or another were used prehistorically to butcher carcasses is indicted by some of the butchering marks on remains of late-Pleistocene proboscidians in North American sites (e.g. Fisher, 1984*a*, *b*; Shipman, Fisher & Rose, 1984; Fisher, Lepper & Hooge, 1994; Saunders & Daeschler, 1994). Ginsberg was butchered with what appear to be large stone bifaces ‘‘cemented into (nocked/slotted) wooden holders’’ (Park, 1978: 92; see also Stanford, 1979: 121). During his experiments, Frison (1978: 337) found a point with a bulky haft on a nocked wooden foreshaft to be sufficiently strong ‘‘to make a functional cutting tool that would withstand heavy butchering, although attrition of the projectile point blade edges was high’’. Butchering of Ginsberg prompted one participant in the experiment to conclude that hafting a Clovis point to a ‘‘not-too-long foreshaft . . . made the [butchering] job perhaps 10 times easier’’ than when using a hand-held, unhafted point (Callahan, 1994: 38–39). Two questions thus present themselves: (1) what kind of edge morphology might make a good butchering knife or saw? and (2) how might prehistoric butchers have hafted these tools?

Blood residue of humans, bovines, cervids and lagomorphs (Gramly, 1991, 1993) was found on various tools at Richey–Roberts, the latter three suggesting these tools may have been used to butcher mammalian prey. While the presence of blood residue is not conclusive as to the use of the stone points as butchering tools, it does not contradict such a possibility. We believe the association of rods with Clovis points in settings where animals were butchered, such as Blackwater Draw, and in caches, such as Richey–Roberts, is not simply fortuitous. Given all considerations to this point, then, our experimental goal was to build a butchering tool, not a projectile, that employed both the large stone points and the rods. Using the specimens from Richey–Roberts as a model, we focused on two things: building an efficient butchering tool, one that required minimal maintenance effort during use, and determining the function of the rods. Detailed consideration of the functional and mechanical properties of various formal attributes of both the stone points and the rods was therefore critical. We next describe these properties, beginning with the stone points.

Butchering tools

In his experimental work, Toth (1987) found that although sharp (unretouched) basalt flakes served as satisfactory butchering tools, bifacially flaked Acheulean implements were ‘‘excellent tools for the heavy-duty butchering of larger mammalian species’’ (Toth, 1987: 121). He argued that the latter technology ‘‘was associated with more systematic butchering of

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‡Only 12 rods are described in Table 1 and plotted in Figure 3 because one rod was too fragmented to measure and another was left in the site (Gramly, 1993).

large carcasses'' (Toth, 1987: 121). Jones (1980), too, found that although simple unretouched flakes worked well for butchering small game, larger animals with thicker hides were butchered more easily with bifaces. He indicated that the heavier and generally larger bifaces are more easily held and used during butchering. It is clear that Paleoindians butchered proboscidians, but too few data concerning butchering marks on prehistoric proboscidian bones have been published to allow inference as to all of the exact kinds of tools that were used. Thus we again turned to the tools themselves.

Three attributes of the large fluted points from Richey–Roberts appear especially relevant to their use as butchering tools. They all have either parallel or slightly convex blade edges, rather sinuous edges, and nearly straight to noticeably concave bases, the latter forming either a shallow V or a (sometimes deep) U. We suspect all these features are functionally and mechanically related. The specimens with convex edges could have been resharpened more times than a parallel-sided or distally converging-sided specimen. Further, specimens with convex edges, if used as weapons, would have cut holes through hide that would have been larger than holes made by points with parallel or distally converging blade edges, the former allowing penetration of a foreshaft or shaft. Experimental work by Hayes suggests that only the end of the specimen distal to the widest point needs to be extremely sharp; from the widest point of the implement proximally, sharpness is less critical to efficient penetration. Once the maximum width of a point is reduced to the extent that edges are parallel or begin to converge distally, the efficiency of the tool as a penetrating weapon is decreased, though the tool can still be used as a cutting implement. Note that we are not suggesting that all Clovis cache points began their use-lives as penetrating weapons; some, especially the large ones from Richey–Roberts, began, we believe, as cutting tools.

Callahan (1994: 31) found that when points have ''straight'' or nonsinuous edges, they penetrate deeper when thrown at a carcass. Our experiments lead us to agree but also to conclude that a sinuous edge makes for a saw-like implement that is useful for cutting. A sinuous edge has alternating ''teeth'' much like a modern steel carpenter's saw except that the stone implement cuts on both the push and the pull strokes, unlike the modern saw, which cuts only during the push stroke (Bleed & Bleed, 1987). Our experimental work indicates that such sinuous-edge tools work better at cutting hide and frozen flesh than simple unretouched flake tools do, an observation corroborated by Jones's (1980) experimental butchering of large mammals and Toth's (1987) and Stanford's (1979; see also Park, 1978) experimental butchering of proboscidians. We found that sinuous-edged tools can be used to cut down small trees and saplings several cm in diameter by first girdling the wood with a groove 1 cm deep and then breaking the trunk. Such tools can also be used with some efficiency to first girdle and then break bone or antler. The reason the sinuous edge works better on harder substances than an unretouched edge is that the scalloped edge of the former pushes the tissue aside during each stroke and allows the tool edge to sink deeper with each stroke. In short, large flake scars make for a more sinuous edge that will cut deeper more efficiently than a straight edge.

The largest point from Richey–Roberts has a relatively straight edge. The edges of the next three longest points are straight for the distal third of their lengths but are rather sinuous over the middle third of their lengths, where the points are widest. This portion of the point edge is the one that tended to receive the most use in our butchering experiments. The ten remaining fluted points vary in sinuousness of their edges, but those edges tend to either be most sinuous over a large proportion of their length or along the middle third of their length. All but the largest, then, would, we suspect, have made excellent knives.

All 14 fluted points from the Richey–Roberts cache have concave bases, as do all those from Simon, Lehner, Naco and Domebo, but several from Anzick do not. The concave base of Clovis point may be a by-product of the fluting process (Crabtree, 1996; Bradley, 1982), but such a base shape has functional advantages over a straight base. A concave base results in more basal area being in contact with the shaft, foreshaft or handle, thereby reducing the amount of force transmitted from the point to some unit area of the shaft when the tool is used for penetration (Figure 8(a)). This reduces the probability of breaking the point base, especially when the point impacts a surface at an angle rather than perfectly perpendicular to the surface (Figure 8(b) and (c)). Similarly, if the point is used as a cutting tool, force applied to the edge used for cutting will be transmitted to the point base (Figure 8(d)). Force transmitted through the point causes it to pivot during such use, and the concave base helps prevent the point base from (1) slipping down and out of the nock during the pull stroke and (2) slipping up and out of the nock during the push stroke. The concave base creates a more perpendicular angle of force transmission from the point base to the shaft or handle during cutting. Fluting also helps hold the point steady during the application of such forces if the edges of the tangs of the nock are within the flute (Figure 9). On the basis of his experiments, Callahan (1994: 28) concluded that ''the purpose of the flute scar on the base of the fluted points is to provide contact surface for the hafting mechanism''. We agree. This brings us to how the points were hafted and the role of the osseous rods.

The hafting of butchering tools

Keeley (1982: 799) indicates that there are three ''basic types'' of hafts: ''(1) 'jam' or wedged hafts where the

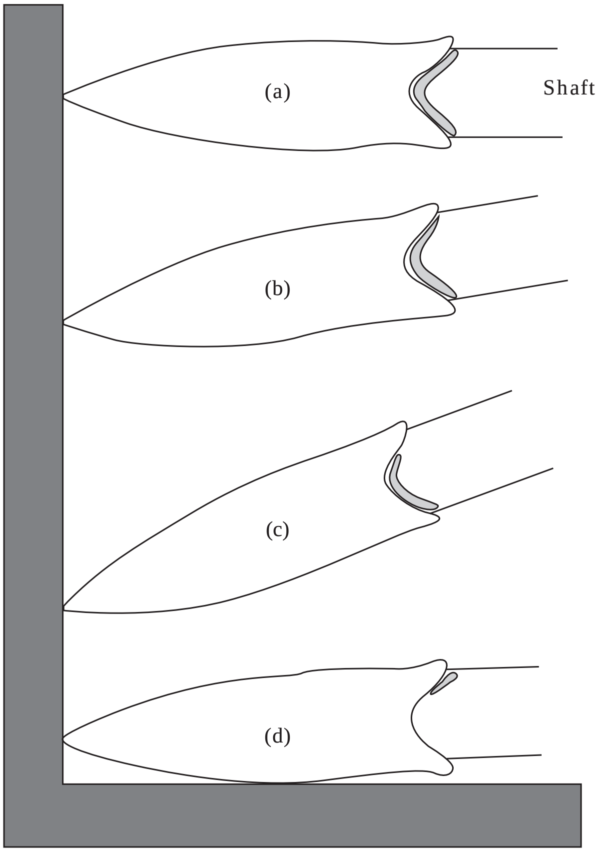

Figure 8. Schematic illustration of force application to concave base of a hafted point. Nock tangs are not shown. Shaded area on shaft indicates where force is applied to shaft/foreshaft and point base during use. (a), (b) and (c) illustrate different angles of penetration; (d) illustrates use as a cutting tool during the pull stroke; force would be on the opposite side of the shaft and point base during the push stroke.

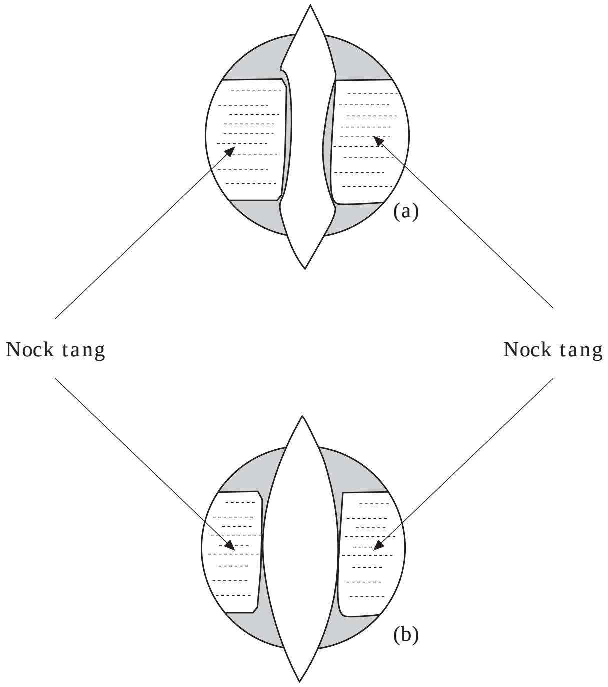

Figure 9. Distal view of the cross section of a fluted (a) and non-fluted biface (b) seated in a nocked shaft. Note that the nock tangs are thicker in the former than in the latter and that the nock tangs are within the flute. Pressure to a point edge would cause the unfluted biface to slip within the nock; the fluted point will slip much less, if at all, because the stone tool is wider at the edge of the flute scar than the nock.

tool is simply inserted into a hole or slot in the handle or shaft and is held by mechanical forces unassisted by wrapping or mastic; (2) 'wrapped' or tied hafts where the implement is simply lashed to the handle or shaft; and (3) mastic hafts where the tool is attached by means of a glue, resin, or tar. Most tools were hafted by combinations of these basic methods, not uncommonly by all three''. We believe we have discovered a way to haft large fluted Clovis bifaces that incorporates not only all three elements of hafting described by Keeley but also bone rods. The result is a mechanically efficient tool that we have used to butcher large game (deer, *Odocoileus virginianus*) and frozen meat. Importantly, this tool can be adjusted and fine-tuned during the butchering process with a minimum of time and effort. Because many of the various attributes of rods and large Clovis points found in caches are functionally interrelated within the final product, we need to detail the production process we followed to manufacture the final tool. The only step we do not describe is that associated with production of the stone point, as this has been described by others (see Crabtree, 1966; Bradley, 1982; Wilke, Flenniken & Ozbun, 1991). Using the Richey–Roberts rods as a model, we produced five bone rods from the tibia of an Indian elephant raised in the St. Louis Zoo using the groove-and-splinter technique of blank extraction (e.g. Clark & Thompson, 1953) and abrasion to produce the final rod shape. We produced bevels by abrasion and the cross-hatched grooves on the bevels by scoring with the same sharp-edged stone tool used to groove and splinter the tibia. On average, our rods are 230 mm long, 20·5 mm wide and 13·8 mm thick. Bevels average 60 mm in length.

Once a fluted biface is available, it may be hand held and used, or it may be hafted to a handle. Because (a) the large fluted points are too large to tip projectiles efficiently, (b) the largest fluted point from Richey–Roberts ''had been hafted'' (Mehringer, 1988*a*: 502), and (c) Callahan (1994: 38) found that a Clovis point hafted to a handle was ''most useful'' and ''unhafted Clovis points were infinitely less efficient at butchering than hafted points'' when butchering Ginsberg, the next mechanical problem was to produce a haft that held the point securely during butchering activities. The first step was to produce a nock. Callahan (1994: 28) found that ''sawing'' a 2-cm-deep slot or nock with a biface ''takes about one hour'' and suggests that this technique of notch production creates a more ''satisfactory'' nock than the technique we use because

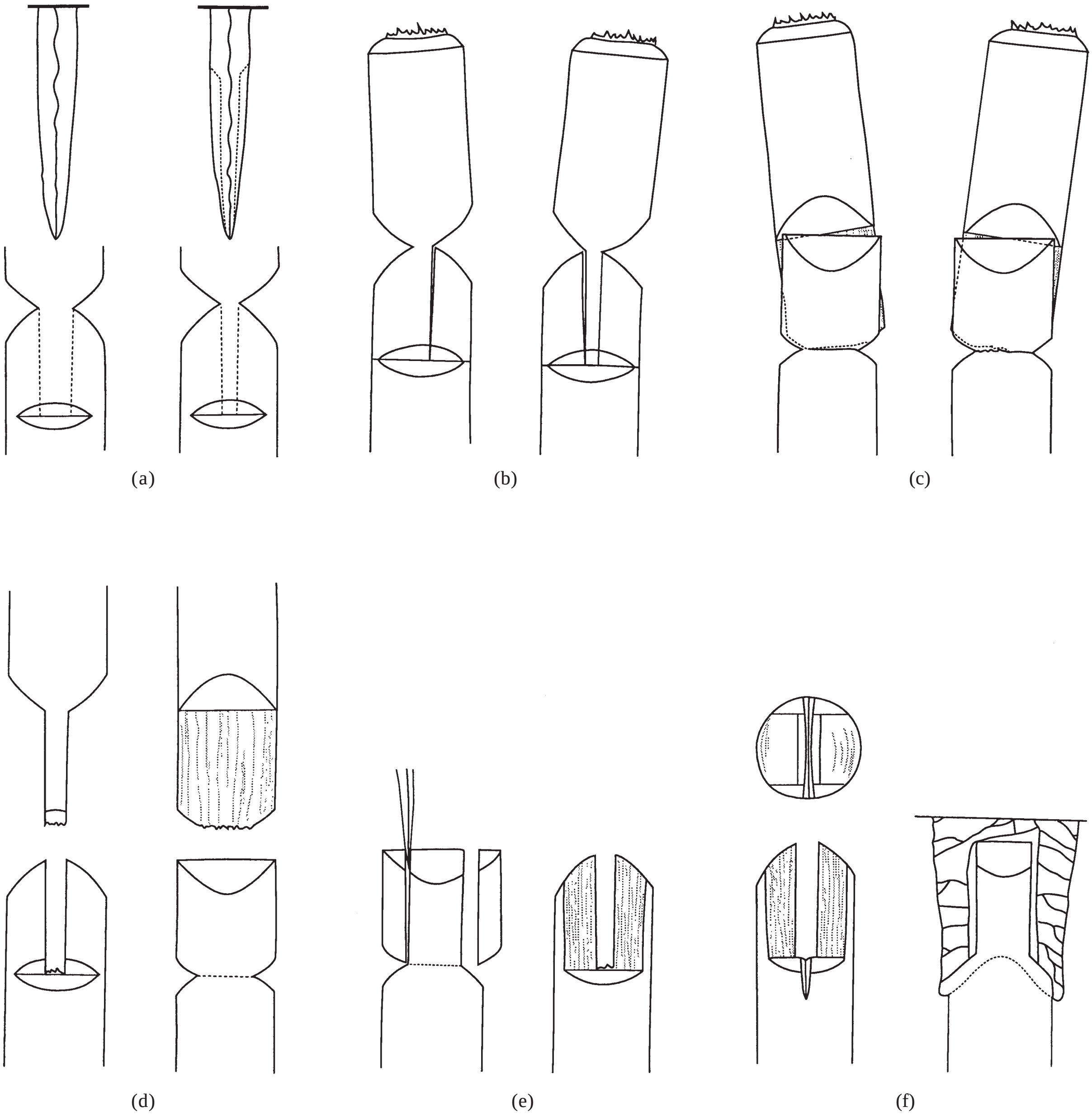

Figure 10. Producing a nock in a wooden shaft. (a) Cut two pairs of opposing notches, 90° offset, depth of distal notches determines width of nock; (b) bend distal end back and forth until wood splits down to proximal notch pair; (c) bend distal end back and forth to break-out nock-creating piece; (d) remove distal end; (e) complete nock tangs by splitting off outside pieces; (f) cut a small groove to seat concave base of point. Distal end is toward the top, proximal end toward the bottom in all.

the tangs created by the latter ‘‘are weaker’’. Hayes, after constructing hundreds of nocks and hafting hundreds of points, has found this to be untrue.

Our experiments have resulted in our being able to easily produce nocks in wooden shafts, foreshafts and handles. The technique we use is briefly described and illustrated by Olsen (1973: 132–133). Once an appropriate stick has been chosen (it should be relatively straight and of sufficient diameter and length for either a spear or arrow shaft, foreshaft or handle), four notches are cut near one end. Two notches should be 8–10 cm from one (distal) end of the stick and directly opposite each other. They are cut to a depth that leaves a width of wood between them that approximates the thickness of the point to the hafted (Figure 10(a)). The second two notches are also placed opposite each other, 90° offset from the first pair of notches and more proximally on the shaft than the first pair. The distance between the two pairs of notches establishes the depth of the nock (Figure 10(a)). After the two pairs of notches are cut, the distal end of the wood is bent back and forth over the distal-most pair of notches until the

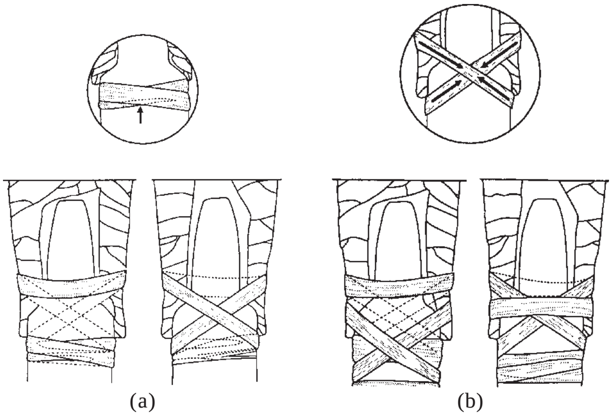

Figure 11. Cross-hatched sinew binding patterns. (a) Upper, tuck loose end under wrap; (b) upper, directions of force application to binding when pressure is placed on edge of point.

wood splits down to the proximal-most pair of notches (Figure 10(b)); the latter notch pair halts the fracture front. Then, the distal end is bent back and forth 90° offset from the first bending activity (Figure 10(c)). This second bending completes the separation of the distal end from the piece to be used as a shaft or foreshaft (Figure 10(d)). Production of the nock is completed by splitting off the outer portions of wood between the distal and proximal notch pairs (Figure 10(e)). The nock may then be fine-tuned by cutting a small groove to serve as a seat for the concave-base point (Figure 10(f)). Nock tangs can be distally tapered by abrasion, a manufacturing step that enhanced the penetration depth of some experimental implements (see also Callahan, 1994).

We have found that a replicate of the Clovis bone shaft wrench (Haynes & Hemmings, 1968) recovered from Murray Springs, Arizona, works well during both stages of bending the distal portion of the shaft that is to be removed and discarded while producing a nock. It is, in fact, virtually required to produce the correct bending force, both in terms of amount of force and direction of force application, when producing nocks in pieces of wood about 2 cm in diameter, such as may have been used as spear or lance shafts; Frison's (1989) replicated main shafts were of this size.

After a satisfactory nock is produced, the stone tool is seated in it. Deer sinew from the lower (posterior) back can be removed in strips 2–4 cm wide and as much as 45 cm long. After cleaning and splitting into strips about 0·5 cm wide, they can be used immediately or dried and used at a later date, though they must be moist and pliable when used (Park, 1978; Whittaker, 1994: 255). We have found that tying the end is not necessary, as both ends can be tucked under one or several wraps and the shrinkage during drying will anchor them (Figure 11(a)). Our experiments also indicate that cross-hatched binding (Figure 11(b)) works better than merely wrapping the sinew around and around the seated point and nock (e.g. Frison, 1978: 335, fig. 9.4; 1989: 772, fig. 3a (fig. 3.2b in the latter shows cross-hatched binding)) because the downward pressure of the cross-hatched sinew helps (a) hold the point down in the nock and (b) distributes tension forces on the sinew more directly to the main body of the shaft, foreshaft, or handle rather than to only the tangs of the nock.

The amount of sinew required to haft a biface depends on both the size of shaft to which the biface is hafted and the size of the biface. A 6–8-cm-long Clovis point that is to be used as a projectile point can be hafted with a single strip of sinew 0·5 cm wide and 30–40 cm long. Seating the point, wrapping the sinew, and allowing the sinew to dry sufficiently to tighten takes about 30 min if the air is dry and warm, plus additional time to apply mastic. Hafting larger bifaces, such as those from Richey–Roberts, that are to be used as saws requires as many as 20 strips of sinew 0·5 cm wide and 40 cm long. The greater amount of binding is required because the handle has a larger diameter than a dart shaft (3·5–4 cm (ours) versus 1·4–2·3 cm (Frison, 1989)), and the force applied to the biface during use as a butchering saw is different from that applied to one used as a projectile point. Because more sinew is required, and the haft comprises multiple layers of sinew, the entire process of seating the biface, wrapping, drying and applying mastic to the haft has, in our experiments, taken almost 2 h.

If the sinew binding absorbs moisture (which it does quickly if it is completely dry prior to use of the tool), such as from body fluids of an animal being butchered, the binding expands and becomes loose. Coating the sinew with mastic (e.g. tree resin) tends to waterproof it and extend the use-life of the haft, but a haft will none the less loosen through use and moisture absorption, even if coated with resin, which will wear off or flake off it is becomes hard and dry. Because it takes a rather long time to rehaft (particularly) large bifaces, the resin must be removed, the sinew unwound, the point reseated, the sinew rewrapped and allowed to dry, resin applied; the mechanical problem is to prolong the use life of the initial hafting. This can be accomplished by tightening the sinew via a wedge inserted between the sinew and the shaft to which the biface is hafted. We hypothesize that the bevelled rods from Richey–Roberts served this binding-tightening wedge function.

During manufacture of the cutting tool, a groove is cut in the wooden shaft or handle and extended onto the (tapered) nock tang (Figure 12). This groove, used for seating the rod, should be at least as long and wide as the rod and about half to two thirds as deep as the rod is thick (Figure 13). Sinew is bound onto the shaft or handle as tightly as possible prior to inserting the rod. Before the sinew completely dries, the rod is set in the groove cut for it and is pushed up under the binding. After the sinew has dried, the rod is levered down into the groove and the proximal end held in place with leather or sinew binding. The fulcrum should be distal to the centre point of the rod length.

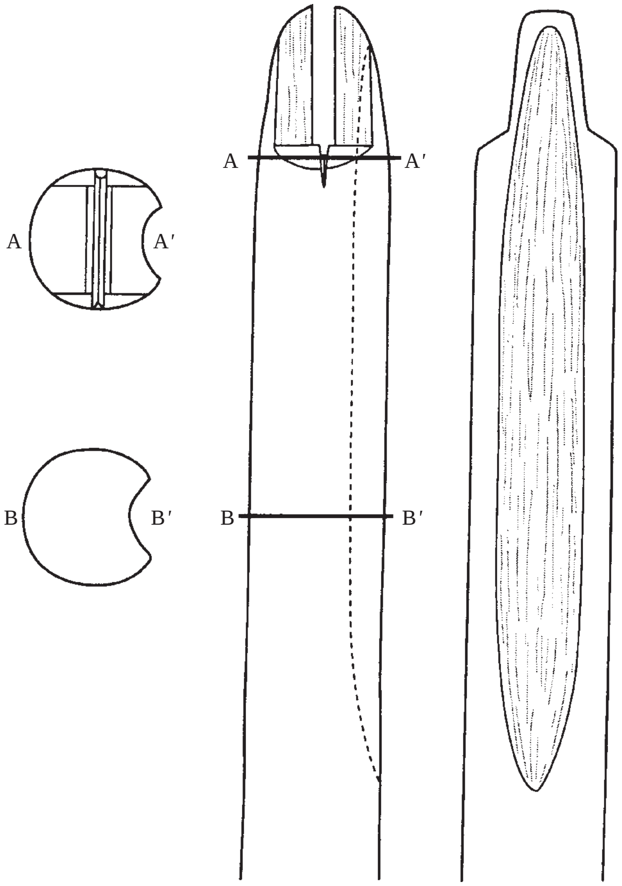

Figure 12. The groove for seating the osseous rod. Note that the nock tangs have been tapered, the groove extends distally onto a nock tang, and that the groove needs to be at least as long as the osseous rod (see Figure 13).

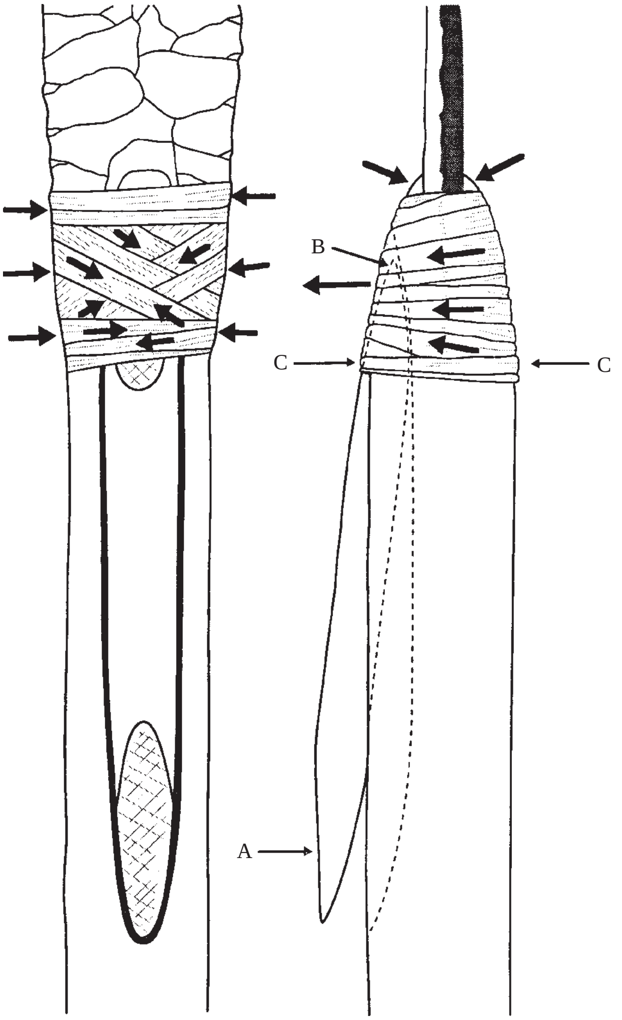

Figure 13. A shaft/handle with a lithic point, sinew binding and osseous rod in place. Arrows indicate where force is applied when the implement is used as a butchering saw. Note how the osseous rod serves as a wedge and lever (a) to tighten the sinew binding (b). The fulcrum is located at c.

The levering down serves as the final tightening of the sinew (Figure 13). It is this final levering down into the groove that mechanically explains why the face opposite the bevel must be convex rather than straight; were it not, as with *sagaie* points (Figure 5(b)) and the rods from Blackwater Draw, Sheaman, and Anzick (Figure 6), the rod would lie flat in the groove and no lever-enhanced tightening of the sinew would be possible. If the groove for the rod is cut too deeply in the fulcrum area, a small square of leather or a bit of other material of appropriate thickness can be placed at the appropriate point in the groove to serve as a fulcrum.

The grooves cut into the ends of the rod help keep the sinew and rod from slipping during use. As the sinew binding dries, it shrinks and sets down into the grooves cut in the bevel of the rod, making a mechanically sound haft (Figure 13). Without hatching on the bevel, we have found that the rod has a tendency to slip out from under the sinew binding when it is levered down. The fewer, generally less deep grooves sometimes evident on the convex face opposite the bevel help secure the rod to the fulcrum area of the groove in the handle when a bit of hide is used to raise the fulcrum. Green bone is more flexible than dry bone. This mechanical property suggests that because the grooves are cut perpendicular to the long axis of the bevel of the Richey–Roberts rods, those grooves were cut when the bone was green and flexible. Our experiments indicate such perpendicular grooves too readily result in a perpendicular fracture though one of the grooves if the bone is dry. We note that 16 of 20 of the bevelled ends of the Richey–Roberts rods have transverse cracks or breaks through the bevel or within about 1 cm of the bevel. These could represent either postdepositional cracks and breaks or the culmination of a fragmentation process begun during their use as binding wedges or butchering levers. In the latter case, microcracks initiated by levering the rod down under the haft binding would enlarge as the rods dried out while in the cache pit.

The hafting-wedge function of the rods readily accounts for why they were bevelled on both ends.

Should the bevelled end being used as a binding wedge fracture, one has but to merely turn the rod around 180°, insert the unfractured edge under the haft binding, and lever the rod down to maintain a tight binding. Bevelling of the proximal end, towards the handle, also allows the binding holding it down to be more easily slipped on and off the levered-down end of the rod. The basically cylindrical cross section of the rods can be accounted for by noting that we have found it to be relatively easy to carve a groove for the rod that is curved in cross section using a scraper with a convex bit. Finally, the thick cross section of the Richey–Roberts rods (Figure 3) would have made for a larger cross section under the bevel, where the most force was concentrated when the rod was being used to tighten the haft binding.

A relatively long bevel on a thick rod would extend the usefulness of such a hafting wedge during use of the tool. As the sinew binding absorbs moisture and stretches during use, thereby loosening the haft, the proximal end of the rod can be freed and readily pushed farther up under the sinew wrapping, and perhaps a thicker fulcrum added, thereby retightening the binding without the user having to dismantle the entire haft structure. However, if too much pressure is placed on the rod when it is levered down, the rod may fracture at the fulcrum or just distally to it. Excessive leverage pressure produced a fracture in one of our experimentally replicated bone rods (Figure 14), a fracture that appears identical to the broken specimens from Blackwater Draw (Saunders & Daeschler, 1994) and Anzick (Wilke, Flenniken & Ozbun, 1991). We note that when the rod is removed, it can be used to retouch and sharpen the stone point's edge prior to resetting it in the groove. It could also at this time be used as a wedge to pry tendons off of bones, or it could be wedged between the bones of a tight joint to help stretch tendons one wishes to cut during butchering. Such secondary uses of the rods would require minimal dismantling of the butchering tool and could occur when the sinew of the haft became loose and required resetting of the rod.

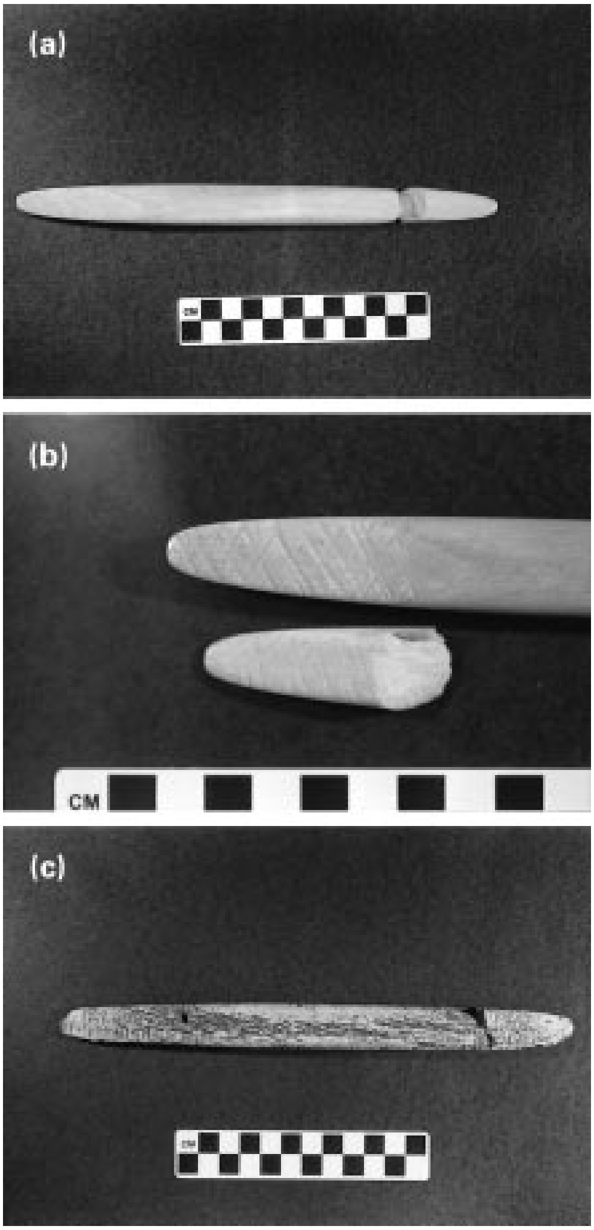

Figure 14. Comparison of (a) a replicate osseous rod (made from elephant bone) broken by excessive pressure on the end when levered down to tighten sinew binding; (b) close-up view of the ends of the replicate rod showing the break; and (c) a bone rod from Richey–Roberts showing an identical break.

Discussion

We produced a very functional cutting tool following the procedures described above (Figure 15). It is much like those used in the Ginsberg butchering experiment (Park, 1978; Stanford, 1979; Callahan, 1994), with the important exceptions that (a) it was made using purely primitive materials and technology and (b) it provides a functional/mechanical explanation for (i) the co-occurrence of extremely large fluted Clovis points and osseous rods and (ii) various of the morphological attributes found on each, at least as represented among the Richey–Roberts specimens. Experimental replicates of specimens such as that shown in Figure 5(c) have taken Hayes about 8 h to produce if the manufacture of all component parts except sinew strips is included. Omission of production of the foreshaft or rod reduces the time required by half. Production of the butchering saw shown in Figure 15 took about 6 h. This saw worked well when used to cut frozen flesh and to saw down small trees about 6–8 cm in diameter. It would be a very efficient tool to use if faced with a proboscidian carcass. Rather than carry this butchering saw around, it would perhaps have been more efficient to cache it in places where it could be obtained on an as-needed basis.

Figure 15. A replicate Clovis butchering saw/knife.

Finding archaeological examples of points and rods in spatial associations such as that in our replicate saw would confirm that our inferred butchering saw is an accurate portrayal of how the points and rods were used. However, we do not expect such associations to be found because this presumes that the saws were cached in a fully constructed condition. We doubt this would occur because the sinew binding would soften and loosen when the encasing sediment was wet, requiring dismantling and rehafting when the items were recovered for use. One might examine specimens for traces of use wear commensurate with our model, though such may not appear on the points if they were (re)sharpened prior to placement in the cache. Casts of the points from Richey–Roberts that we have examined do, however, have evidence of use wear (see also Mehringer, 1989).

The rods, too, may have been touched up prior to placement in the cache, thus removing traces of use-wear. But we note that striae parallel to the long axis of the rod are evident on the convex surface opposite the bevel of at least one rod, and they extend beyond the transverse break through the bevel, indicating they were created prior to the break. Such striae could have been created when this end of the rod was pushed up under the sinew binding or when it was pushed between tissues while serving as a butchering pry bar.

Conclusion

The archaeological record of Clovis-era rods is not what one might hope for. Of the 43 specimens listed in Table 1, fewer than half (those from Lind Coulee (*c.* 8700 RCYBP), Blackwater Draw, Richey–Roberts, Sheaman, and one from Oregon) were in well-reported primary contexts. The specimens from Blackwater Draw, Sheaman, Lind Coulee and apparently Broken Mammoth in Alaska are the only ones ($n = 6$) in contexts that might be construed as indicative of butchering, that is, in association with the remains of proboscidians and/or bison.§ The majority of the rods listed in Table 1 came from caches, but only two such sites containing rods are known (Richey–Roberts and Anzick (though ivory fragments that may represent a rod are reported for Drake (Stanford & Jodry, 1988)) and at only one of them (Richey–Roberts) were the items in primary context. What do we know, then, about Clovis caches? Frison (1991*b*) and Wilke, Flenniken & Ozbun, (1991) are, we believe, appropriately cautious in their assessments. They focus primarily on the lithic technology evidenced by the large unfluted bifaces and the fluted bifaces, though Wilke, Flenniken & Ozbun (1991) also offer a hypothesis seeking to account for the co-occurrence of the Anzick stone and osseous items. Given the apparent differences in the Richey–Roberts and Anzick rods (convex surface opposite the bevel and greater diameter of the former) perhaps the model of Wilke, Flenniken & Ozbun is correct for those specimens.

Bone may have been used more often than ivory or antler to produce hafting levers because (a) ivory is less capable than bone of withstanding bending forces (Albrecht, 1977; Currey, 1990); (b) although antler is more flexible than bone, it becomes more brittle when dry and very flexible when wet (Newcomer, 1977; Guthrie, 1983); and (c) procuring a piece of antler of sufficient size and straightness might have been difficult. We are not suggesting that all known bevelled osseous rods served as hafting wedges or levers. The examples made of ivory might have served as points (ivory withstands compression forces better than bone (Albrecht, 1977)), but this does not address why some ivory rods from Florida are apparently bi-bevelled (Wilke, Flenniken & Ozbun, 1991). To test the projectile-point hypothesis, additional use-wear studies involving breakage patterns produced when osseous rods are used as projectile points should be undertaken. Experimental work along these lines carried out thus far (Tyzzer, 1935; Arndt & Newcomer, 1986) has produced breaks and wear patterns that are not apparent on North American archaeological specimens we have examined.

Our experimental work has been directed from a mechanical perspective. That is, we have attempted to discern the function of osseous rods found associated with Clovis points on the basis of the attributes displayed by items associated in the archaeological record. Our explanation thus takes into consideration a suite of attributes of both the fluted stone points (sinuous convex edges, flutes, large size, concave base) and the bone rods (bevels, scoring of bevels, convex face opposite the bevel) in the Richey–Roberts cache. These sets of attributes are functionally and mechanically interrelated in the final tool, which we believe account for (1) the co-occurrence of the large points and the rods in caches and in butchering contexts, (2)

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§Neither the site nor the specimen from Broken Mammoth has been thoroughly described, though it appears the osseous rod from this site was recovered with good contextual information (Yesner, 1994).

the breakage and wear evident on some rods, and (3) the varied sizes of both points and rods.

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