THE PALEOINDIAN FLUTED POINT: DART OR SPEAR ARMATURE?

THE IDENTIFICATION OF PALEOINDIAN DELIVERY TECHNOLOGY THROUGH THE ANALYSIS OF LITHIC FRACTURE VELOCITY

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ABSTRACT

One of the highest-profile, yet least known peoples in New World archaeology, are the Paleoindians. Despite the absence of supportive empirical data, archaeologists have long assumed that Paleoindians employed the spearthrower along with heavy, fluted-point-tipped darts, to hunt now extinct species of late Pleistocene mammoth and bison. This assumption is critical to our understanding of Paleoindian life-ways since the identification of exploitative technology, such as weapons systems, is often the first crucial step towards the interpretation of higher order information that contributes to our knowledge of prehistoric peoples. Without an accurate assessment of the basic tools with which people interacted with their environment, we cannot fully explore more complex issues such as technological and social organization, or settlement and subsistence strategies.

Traditional analyses of weapon technologies generally rely on classification schemes to identify projectile points as spear, dart, javelin, or arrow armatures. The logical fallacy of such schemes is the assumption that the investigator knows, *a priori*, that the artifact in question served as a projectile armature. By adopting and applying a methodology based on the fracture mechanics of brittle solids, this research avoids such interpretive leaps of faith.

Employing data derived from velocity-dependant micro-fracture features, a series of controlled experiments were conducted to explore the range of lithic fracture velocities associated with various manufacturing (reduction) techniques, projectile impacts, and accidental breakage. Manufacturing and weapon delivery technologies are differentiated based on the fracture velocity exhibited by damaged artifacts; high-speed projectile impacts are reliably distinguished from other sources of lithic fracture, thus providing a quantitative means for identifying projectile armatures. Data derived from Paleoindian artifacts reveal fracture rates associated with high-velocity impacts, indicating the use of the spearthrower.

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CHAPTER I

INTRODUCTION

"Archaeology is rather like a vast, fiendish jigsaw puzzle . . . ."
- Paul Bahn -

Since the initial discovery of stone tools in association with extinct Pleistocene fauna at Folsom, New Mexico in 1926 (Figgens 1927), Paleoindian cultures have been at the forefront of American archaeology. At present, the earliest, undisputed, clearly defined cultural complex in the New World is that of the Clovis people (Haynes 1993:219), named for the type site of Blackwater Draw near Clovis, New Mexico (Hester, Lundelius, and Fryxell 1972; Sellards 1952).

By the early 1980's, Clovis assemblages had been documented throughout most of the North American continent. Although sharing broad similarities in tool kits and site types, these widespread assemblages are now known to exhibit variations in regional point morphology, environmental settings, economies, and occupation dates (Willig 1991).

Johnson (1991) states that the fluted point was the focus of the Clovis tool kit. While this may have been true prehistorically, there is no doubt that it is the focus of modern archaeological investigations. More than any other New World culture, the Clovis complex has been defined by this one artifact form, and despite apparent regional economic differentiation, the fluted Clovis point has come to signify late-Pleistocene, mammoth-hunting Paleoindians.

The concept of the Llano-Clovis big-game hunting tradition grew out of the repeated association of Clovis cultural materials with the remains of extinct megafauna at well-dated kill sites in the Southwest and on the Plains. There is no doubt that fluted points were used to dispatch late-Pleistocene megafauna. Rather, the question is: *how* were these points used to bring down such large game? Some researchers have suggested alternative hunting strategies including the use of trapping areas, dead falls, snares, mechanical traps, and pits (e.g., Frison 1991; Haynes 1980; Johnson, Kawano, and Ekker 1980). Few have devoted much attention to the weaponry *per se,* apart from empirical descriptions of the points themselves or discussions of metric and stylistic variation.

It is generally accepted that fluted points functioned primarily as spear armatures, and perhaps secondarily as knives or butchery tools. There is no concrete empirical evidence which can provide us with a complete picture of such a weapon or tool since no hafted fluted points have been recovered to date. A common reconstruction of Paleoindian weaponry suggests that the spear was propelled by use of a spearthrower (e.g., Amick 1996:414; Fagan 1987:180-181, Frison 1989:766), a device which allows spears (properly referred to as "darts" when associated with the spearthrower) to be launched with greater speed and a flatter trajectory than a hand-thrown spear.

The spearthrower is a device with considerable antiquity in the Old World, in use since at least the Magdalenian of Upper Paleolithic Europe approximately 17,000 years ago, and perhaps much earlier (cf., Caton-Thompson 1946; Knecht 1994). It is known from the circumpolar regions, western Europe, and throughout most of North America, Central and South America, Australia, Melanesia, and Micronesia. While there is no reason to assume that migrants to the New World could not have possessed the device, there currently is no empirical evidence that it was used by the earliest New World hunters.

Despite this, students of archaeology are exposed to illustrations in introductory textbooks of Paleoindians employing the spearthrower to launch fluted-point tipped darts (e.g., Fagan 1987:180-181), and even a PBS program that features a prominent Paleoindian archaeologist demonstrating the effectiveness of Clovis spearthrowers (Eder 1988).

Experiments designed to test the performance capabilities of Clovis weaponry have been conducted on elephant carcasses, and may have served to perpetuate the image among academics (Frison 1989; Huckell 1982). References to Paleoindian spearthrowers (most often referred to by the Nahua term "*atlatl*") are common in the academic literature, as illustrated in the following statements:

> The association of Clovis type projectile points and mammoth remains in archaeological sites . . . has convinced most Paleoindian investigators that the Clovis projectile point used on a thrusting spear and/or with atlatl and dart was the weaponry used to kill the mammoths [Frison 1989:766].

> Most of the [Folsom] projectile points recorded are fragments, presumably broken on impact during use as atlatl dart tips [Amick 1996:414].

Notably, these, and similar statements offer no empirical evidence for the existence of the spearthrower during the Paleoindian period, and offer no references to the origin of the spearthrower hypothesis. It is not difficult to understand why many people assume that Paleoindians possessed this type of weaponry. The range and power advantage provided by the spearthrower (Hutchings and Brüchert 1997), relative to the thrusting-spear and javelin, make it is easy to speculate that Paleoindian hunters needed as much "firepower" as possible to successfully penetrate the armoured hides of six to eight-ton mammoths.

Opponents to the Clovis spearthrower hypothesis rely on normative arguments based primarily on technological and morphological aspects of lithic point design. Wright (1995:35), for example, argues that the spearthrower is associated with notched points, and has created a model that traces the diffusion of the spearthrower from a source in the Archaic Southeast. Also relying on the interpretation of hafting technology, Gramley (1984) cites flute widths as evidence that Clovis points were employed as (thrusting-) spear armatures at the Vail site.

Evidence for the initial appearance of the spearthrower in the New World is undeniably early. Cockrell and Murphy (1978; see also Royal and Clark 1960) report a shell spearthrower hook, from Warm Mineral Springs, Florida, in association with human remains, in deposits dated between approximately 9,000 and 10,000 years ago (see also Clausen, Brooks, and Wesolowsky 1975). Other spearthrower hooks are reported from the Windust Phase at Marmes Rockshelter in Washington (Rice 1972), dated between approximately 9,000 and 10,000 years ago (Sheppard *et al.* 1987); from Fort Rock Cave, Oregon, dated approximately 8,500 years ago (Cressman 1977:105); and from the Roadcut site at Five Mile Rapids, Oregon, dated between approximately 7,600 and 7,900 years ago (Cressman 1960:24, and Figures 20 and 40).

Heite and Blume (1995:53) report a slate "bannerstone" from deposits dating to approximately 11,000 years ago at the Blueberry Hill site (Delaware). Although, bannerstones are reputed to have functioned as spearthrower weights, their association with the spearthrower has never been empirically demonstrated. The 0.9 cm diameter groove in this slate object (Heite and Blume 1995:Figure 28) suggests, however, that it is probably a grooved and shaped abrader, possibly a shaft smoother.

One is forced to conclude, therefore, that the earliest empirical evidence for the use of the spearthrower in the New World is currently represented by the spearthrower hooks from Warm Mineral Springs, and Marmes Rockshelter. The 9,000 to 10,000 year old associated dates suggest that the spearthrower was in use by at least the Early Archaic Period.

The intent of this research is to determine whether there is any empirical evidence for earlier use of the spearthrower in the New World; specifically, whether Paleoindian points were associated with the use of the spearthrower, or were restricted to hand-thrown spears, thrusting spears, or any combined use of these systems. The emphasis is on Clovis and Folsom fluted-points, but other early, pre-Archaic (as defined by Willig [1989:13-14]) point types were examined for comparison purposes. The research approach employs fracture velocity data derived from the damaged surfaces of these artifacts.

Lithic Fracture Velocity Research in Archaeology

A number of researchers have been concerned with the mechanics of brittle fracture in stone tool materials for several decades (e.g., Cotterell and Kamminga 1979, 1987; Faulkner 1972; Fonseca, Eshelby, and Atkinson 1971; Goodman 1944; Kerkhof and

Müller-Beck 1969; Speth 1972, 1974, 1975, 1981; Warren 1914; and most recently Tomenchuk 1985; Hutchings 1991). Most have been interested in the fracture process *per se* from a technical and morphological standpoint; very few have directed their attention towards the determination of fracture propagation velocity as an analytic tool with broader implications.

Referring to certain microscopic ripple marks on the fracture surfaces of flakes and blades, Faulkner (1972:162) stated a quarter-century ago that:

> Gull [i.e., fracture] wings and Wallner lines, are indicators of fracture velocity, which may prove to be a diagnostic characteristic separating flakes produced at different loading speeds.

Similarly, Cotterell and Kamminga (1987:703) state that:

> An appreciation of the mechanics of flake formation can lead directly to behavioral implications. For instance, with glassy stone like obsidian it is possible to distinguish flakes produced by pressure from those produced by percussion by calculating the crack velocity registered by Wallner lines.

Although both Faulkner, and Cotterell and Kamminga had alluded to archaeological applications, it was Tomenchuk (1985) that first employed fracture velocity determinations derived directly from archaeological materials for the investigation of prehistoric human behaviour. His landmark development of a fracture mechanics-based lithic use-wear methodology required a non-subjective, quantitative method to determine the precursory loading rate responsible for the use-damage exhibited by stone tools. His force estimating models were applicable only to use-damage resulting from quasi-static and rapid loading conditions (e.g., cutting, sawing, drilling, incising, scraping). Fracture velocity determinations were, therefore, necessary to distinguish these from use-damage resulting from dynamic loading conditions (e.g., chopping, projectile impacts, various types of high energy percussion).

While the determination of lithic fracture velocity was not Tomenchuk's (1985) central research concern, his exhaustive theoretical and methodological fracture mechanics research paved the way for subsequent investigation. Research concerning fracture velocity assessments of post-Natufian composite lithic armatures (Hutchings 1991), suggested that as the impact speeds (i.e., precursory loading rate) of projectile armatures increased, fracture propagation velocities exhibited by the damaged lithic components also increased. Since differing weapon technologies propel armatures at different speeds, lithic fracture velocity data derived from damaged armatures should be a useful indicator of the original weapon technology.

The current experimental program was designed to investigate whether weapon technologies could be differentiated based on the fracture velocity exhibited by damaged armatures. The research approach is one of replication and experimentation. Fracture velocity data collected from replicated projectile armatures damaged during controlled experimentation are compared with like data from archaeological specimens.

The archaeological sample is comprised of fluted Paleoindian, and non-fluted pre-Archaic (as defined by Willig 1989:13-14) bifacial points. The reader should keep in mind that the goal of this research is to document fracture velocities associated with these types of artifacts, and determine whether fracture velocity analysis may be used as a reliable indicator of specific delivery technologies. The goal is *not* to demonstrate that these artifacts represent the *only* lithic armatures employed by Paleoindian and pre-

Archaic peoples. In addition, while data are collected from damaged artifacts (i.e., fracture surfaces), there is no reason to assume *a priori* that a given fracture was the result of use of any type. The experimental fracture velocity research presented in Chapter IV provides the necessary framework to determine whether a given fracture could have resulted from known reduction processes or incidental damage. Therefore the selection of these artifacts, generally assumed to represent weapon armatures, in no way affirms the consequence of the analysis.

An unfortunate fact of this type of research is the surficial appearance of a lack of human focus. While the central concern is documentation of evidence which will elucidate a vital aspect of Paleoindian life-ways, the analytic universe unavoidably consists of technical items, rather than behavioral, organizational, or sociopolitical data. The reasons for this approach are discussed in Chapter III, where it is demonstrated that archaeologists currently have no theoretically reliable means of identifying rudimentary functional classifications for prehistoric weapon armatures. As a consequence, archaeological analyses of hunter-gatherer lifeways based on the interpretation of basic food-getting technology, where only the lithic armatures are represented, currently lack a solid theoretical foundation.

The practical and methodological fracture mechanics background pertinent to this research is discussed in Chapter IV. I recommend that readers interested in the history of theoretical fracture mechanics, or discussions of other aspects of brittle fracture and wave mechanics, consult Speth (1972), and Tomenchuk (1985).

Chapter V presents archaeological, ethno-historic, and experimental data concerning weapon velocities, weights, and practical hunting ranges. These data are employed in a series of controlled experiments which explore the range of lithic fracture velocities associated with various weapon technologies.

In the pages that follow, the generic term "spearthrower" is used in preference to the Nahua, or Aztec, "*atlatl*" (or "*atl-atl*"). The reason for my preference is that both "spearthrower" and "*atlatl*" are widely used by New World prehistorians, but the former seems to be the most common term employed by Old World prehistorians, thus "spearthrower" appears to be the most common usage. The term is not without its problems however, since the device propels "darts" rather than "spears", making one wonder whether the term "dart-thrower" might not be more appropriate. The term "spear" is herein reserved to denote a hand-held thrusting weapon, while "javelin" is used to describe the equivalent hand-thrown weapon.

The terms "point" and "armature" are used in preference to "projectile point", since the latter assumes use as a projectile, and thus knowledge of prior function (see Chapter III). In addition, "projectile point" is not an adequate term for the arming tip of a spear, since it is not a projectile weapon *per se*.

CHAPTER II

AN OVERVIEW OF PALEOINDIAN TECHNOLOGY

"They probably found one mammoth in a lifetime and never got over talking about it."
- Richard MacNeish -

Based on a distinctive practice of biface fluting, the term Paleoindian is defined from a technological perspective, and follows the recommendation of Griffin (1977:10), encompassing Clovis, Folsom, and their variants. The Paleoindian period represents the earliest, well-dated, and clearly defined cultural manifestation in the New World. Appearing at the end of the Pleistocene, a time of massive environmental change, Paleoindians appear to have spread rapidly throughout the North American continent, south of the ice sheets. This rapid spread has been attributed to a lack of other human competition, and an abundance of large game species uniformly distributed over broad expanses of plant and animal communities created by the lower seasonal temperature extremes of the Late Pleistocene (Haynes 1982; Kelly and Todd 1988). Alternative theories suggest that Paleoindian technology spread through diffusion among a number of diverse populations already present on the North American continent (Bonnichsen and Young 1980; Morlan and Cinq-Mars 1982:380-381). Lacking any earlier, well-defined North American culture with a developmentally antecedent tool-kit, however, Storck (1988:243) has suggested that Paleoindian technology ". . . was spread by a colonizing population that maintained a specific cultural identity" (see also Storck 1991).

Unlike modern hunter-gatherers, it has been suggested that Paleoindians were "technology oriented" rather than "place oriented" (Kelly and Todd 1988). The high faunal biomass of North America at the end of the Pleistocene offered early Paleoindians an effective solution to the risks of exploiting an unknown and rapidly changing environment. By exercising a strategy of high mobility hunting, they reduced the risks associated with a lack of environmental familiarity, and were able to respond to periodic declines in local game populations resulting from both the environmental changes of the Late Pleistocene/early Holocene, and the effects of predation, by simply shifting their range (Kelley and Todd 1988).

Clovis is the earliest cultural and technological expression of the Paleoindian period. Radiocarbon dates are available from several Plains and Southwestern sites including the Lehner, Murray Springs, and Naco sites in Arizona; Clovis (Blackwater Draw #1) in New Mexico; Dent, and Dutton in Colorado; Colby, U.P. Mammoth, and Sheaman in Wyoming; and the Domebo site in Oklahoma (Frison 1991; Frison and Stanford 1982; Frison and Todd 1986; Haynes *et al.* 1984; Leonhardy 1966). Radiocarbon dates from these sites indicate that the Clovis occupation of the Great Plains took place between 11,500 and 11,000 years ago. Haynes *et al.* (1984) restrict Clovis to a narrower span of time between 11,200 and 10,920 ^{14}C years ago based on the selection of 21 radiocarbon dates from the Lehner and Murray Springs sites; the actual range of radiocarbon dates from the Lehner site is 11,470 ± 110 B.P (SMU-308) to 10,620 ± (300). Recent efforts to recalibrate the radiocarbon calendar based on uranium-thorium and radiocarbon dates from Barbados corals suggest that, due to global carbon dioxide fluctuations during the late Pleistocene, these Paleoindian dates are a few hundred years later than they should be. The revised chronology suggests that the actual time span for Clovis, as defined by Haynes *et al.* (1984), is approximately 13,200 to 12,800 years ago (Taylor, Haynes, and Stuiver 1996)

Meltzer (1988) and others (Haynes et al. 1984) contend that eastern (Clovis) fluted point assemblages date from 10,600 to 10,200 years ago (approximately 12,500 to 11,500 years ago in the revised chronology), with a noticeable temporal gradient from the Southeast to the Northeast. Since this is the time range of Folsom and early Plano complexes rather than Clovis, Willig (1991:94) has suggested that the cultural versus temporal significance of fluting must be determined in these regions prior to their automatic temporal inclusion into the well-dated Clovis complex of the Southwest and Plains.

Clovis appears during the Pleistocene-Holocene transition. While climatic and ecological reconstructions vary with location, the overall pattern of change is generally agreed upon (Hofman *et al.* 1989). During this period the Great Plains and Southwest were cooler, moister, and experienced less extreme seasonal fluctuations in temperature than at present. Biotic provinces distinct from those presently known, contained a diversity of faunal species which today are nonsympatric, including many now restricted to boreal or tropical climates (Graham 1979; Martin, Rogers, and Neuner 1985). With the onset of the Holocene, the increased expression of seasonality restricted the natural ranges of species that were sensitive to extremes of temperature and moisture. The taxa that survived the Pleistocene-Holocene transition were those that adapted to the competitive and climatic stresses, accomplished in part by a reduction of body size (e.g., bison, beaver, armadillo), and changes in social behaviour (e.g., larger herd sizes for bison) (Graham and Lundelius 1984).

The basis of the Clovis lithic technological system was the use of large bifaces which, depending on situational requirements, served as tools, cores for biface thinning flakes to be used as tools or tool blanks, or as preforms for point manufacture (Hofman *et al.* 1989:32-33).

The Clovis point is characterized by alternating opposed biface thinning; slightly convex lateral margins with the point of maximum width near the mid-section; a concave base; one or more flutes, usually extending to the area of maximum point width, on one or both faces; and basal and lateral edge grinding (Bradley 1982:207; Haynes 1980:116; Willig 1991:93). Resharpening of these points was a common practice (Haynes 1982:385), and perhaps as a result, they are known to vary greatly in size. For example, specimens examined during the course of this research ranged in length from 3.1 to 11.8 cm. Exceptionally large specimens are known from Clovis cache sites; a 16.5 cm specimen was recovered from the Drake cache in Colorado (Stanford and Jodry 1988:21), while specimens from the Richey-Roberts cache are greater than 22 cm in length (Mehringer and Foit 1990:Figure 5).

Clovis knappers usually manufactured points from exceptionally fine-grained siliceous materials, sometimes from sources a few hundred kilometres from where they were ultimately deposited (Haynes 1980:118).

In addition to the distinctive fluted point, the Clovis lithic tool kit contains bifacial knives; burin-like tools including wedges or pièces esquillées; and large, multi-purpose bifaces, which were also used as projectile point preforms. Bifacial drills, sometimes fluted, are common. Most tools are made on large flakes and include side scrapers; concave scrapers; end scrapers, often with spurs at the intersection of the retouched distal edge and a lateral margin; denticulates; notches; unifacial knives; and gravers (Gramly 1990; Haynes 1980:116; Stanford 1991:2). Core tools include choppers, and thick, unifacial push-planes. Despite the fact that the existence of a formal, developed blade technology is disputed by some (e.g., Wright 1995:31; cf., Bradley 1993:254), examples of blade and blade core technology are reported from several localities in New York State (Funk *et al.* 1969); the Adams site (Sanders 1990) in Kentucky; Kincade Rockshelter (Collins *et al.* 1989), the Davis Blade Cache (Young and Collins 1989), and the Aubrey site (Ferring 1990) in Texas; and Blackwater Draw (Green 1963), New Mexico. Most tools on blades or blade-like flakes consist of a variety of scraper types, and combinations thereof (Haynes 1980:116). Other lithic tools found in Clovis assemblages, but as yet only rarely, include a single, large crescent from the Fenn Cache on the Wyoming-Idaho border (Frison 1991:44), and the occasional burin.

Antler, and mammoth bone and ivory flaking is also associated with Clovis, but the technology is not well known (Stanford 1991:2-3). Formal tools include awls or punches; bone, antler, and ivory points; a possible ivory flintknapping billet from Blackwater Draw (Hester, Lundelius, and Fryxell 1972; Sellards 1952); and a shaft wrench from Murray Springs (Haynes and Hemmings 1968). Other bone, antler, and ivory items bearing a resemblance to upper Paleolithic projectile points (see Knecht 1994), but often identified as "foreshafts", have been recovered from Anzick (Lahren and Bonnichsen 1974), the

Ritchie-Roberts site (Mehringer 1988), and several submerged sites in Florida (Dunbar 1991; Jenks and Simpson 1941),.

Clovis sites are almost invariably associated with ancient fresh water springs, stream and river terraces, and pond and lake shorelines. To date, most Clovis archaeological sites, particularly in the West, have been kill sites and scattered surface finds. Only a few campsites have been excavated. The data recovered from these suggests small group sizes and short term occupations. Larger campsites located adjacent to quarries probably reflect multiple reoccupation over many years (Stanford 1991:5).

Species found in Clovis sites include mammoth, bison, horse, camel, tapir, deer, antelope, peccary, bear, wolf, turtle, marmot, rodents, birds, fish, and molluscs, as well as some plants (Curran 1984; Meltzer 1988; Willig 1991). Such dietetic diversity has resulted in a recent trend to de-emphasize the big-game hunting orientation of Clovis. The undeniable presence of mammoth or bison remains (or both) at all known Clovis kill-processing sites in the Southwest and on the Plains suggests, minimally, that the hunting of these, and other large game species, was an important economic pursuit; "early Paleoindians probably were generalists in relation to large terrestrial faunal resources and opportunists in relation to all other food resources" (Kelly and Todd 1988:233).

Very little is known about Clovis hunting practices. It is widely assumed that the fluted point was the primary weapon armature of the Clovis big-game hunter, but it is not known whether this weapon took the form of a spear, javelin, or dart. Experiments on modern elephant carcasses (Frison 1989; Huckell 1982) have demonstrated the effectiveness of Clovis points used as both spear and dart armatures. While the degree of effectiveness achieved during these experiments is not great, the inability of the spears and darts to achieve a significant depth of penetration may be explained by the bulky nature of the hafting designs employed by the experimenters.

The recovery of these points from within mammoth skeletons is testimony to the fact that they were used against the largest, and most heavily armoured game; eight Clovis points were recovered from the Naco mammoth skeleton (Haynes 1982:393). Whether or not these points were directly or immediately responsible for the demise of the Naco mammoth, we may assume that the attackers considered them effective enough to engage a potentially dangerous animal.

Haynes (1980:391) has noted apparent differences in point breakage patterns between bison and mammoth kill sites. In contrast to the bison kill area at Murray Springs where several points were snapped in half and some were missing their basal ears, points associated with mammoth kills show relatively little damage. Haynes questions whether this implies differential strategies for attacking different game (Haynes 1980:391), but the data are insufficient to draw meaningful conclusions.

Frison (1991:143, 1993) has criticized the popular model that depicts Paleoindian hunters surrounding and attacking a mired mammoth or bison. He suggests that such a strategy would be hazardous to the hunters, and make butchery and retrieval tasks extremely difficult.

> Too much interpretation of prehistoric hunting is based on a lack of hunting expertise and a dependence on conjecture, artistic license, and unrealistic, staged experiments. The results are interpretations of prehistoric animal procurement that violate all the rules of intelligent hunting [Frison 1993:241].

Instead, Frison (1991:149-155) believes that the Colby site, where at least two mammoths were killed in a deep, steep-walled arroyo, offers some indication of Clovis hunting strategy; like later Plains hunter-gatherers, they may sometimes have employed a form of natural trapping area to separate and contain their prey for a direct attack. Several possible mammoth hunting strategies, including direct individual and group attacks, snares, and various pit and dead fall-type traps, have been proffered by Johnson, Kawano, and Ekker (1980).

Additional evidence from the Colby site suggests that meat and bone caching were practiced by Clovis hunters as insurance against possible future shortages (Frison 1976, 1978; Frison and Todd 1986). This practice is comparable to evidence from the Upper Paleolithic of the Central Russian Plain where mammoth bone, used for its marrow, as well as a source of raw material and as fuel, was cached in well constructed storage pits (Soffer 1985:253-258).

The transition from Clovis to the Folsom complex, which dates between approximately 10,900 and 10,200 years ago (approximately 12,900 to 11,500 years ago in the revised chronology [Taylor, Haynes, and Stuiver 1996]), appears to have been rapid, and may have taken less than 100 years (Frison 1991:50; Haynes *et al.* 1992; Taylor, Haynes, and Stuiver 1996).

The Folsom lithic technological system is highly portable and based on the production of bifaces, and large biface thinning flakes which are routed through a variety of functional and morphological use-life stages depending on situational requirements (Hofman *et al.* 1989:34).

> Folsom people were quite conservative in their use of lithic material, and . . . this is manifest in the production of a preform as a primary focal unit. By-products of this process served as blanks for other tools, which then served multipurpose rather than specialized needs. It is tempting to suggest that this efficiency in utilization of raw material and multipurpose usage of a minimum number of tool types represents an adaptation to a highly mobile way of life [Judge 1973:192].

The characteristic Folsom point is generally smaller than that of Clovis, and exhibits very fine marginal retouch. It is slightly convex in outline with the point of maximum width above the mid-section. Bases are deeply concave and have pronounced lateral ears. Folsom points are usually fluted on both faces, and flutes often extend to the distal tip.

Other flaked-stone tools of the Folsom complex include bifacial knives; backed knives; a variety of scrapers, including endscrapers, often with spurs at one or both intersections of the retouched distal end and the lateral margins; delicate gravers made on thin flakes; notches; denticulates; borers; pièces esquillées; and a variety of multipurpose, compound flake tools. Heavy duty chopping tools, and abraders also occur (Frison and Stanford 1982:107-122; Gramly 1990; Hofman *et al.* 1989:34-35). Bone and antler implements include points, needles, awls and punches, and a single bead (Frison and Craig 1982; Gramly 1990).

The Folsom environment was essentially similar to that of Clovis; indications are that seasonal variations were less extreme than at present. There was more effective moisture, and plant and animal communities were more diverse than found in the later Holocene (Hester, Lundelius, and Fryxell 1972; Holliday 1986; Walker 1982). During this period there is also evidence for an eastward expansion of coniferous forest onto the Plains, as evidenced by the recovery of pine needles and pollen in the bone beds of the 12

Mile Creek site, dated to about 10,300 years ago (Rogers and Martin 1984; Wells and Stewart 1987).

Although species such as antelope, deer, rabbits and birds, have been recovered from Folsom sites, the Folsom economy was strongly oriented toward bison hunting; bison remains are the primary fauna represented at all Folsom sites. Kills at these sites include only a small number of animals, usually less than 25, and the butchering evidence indicates that the animals were only partially butchered (cf., Jodry and Stanford 1992), suggesting a small hunting group size or high group mobility (Hofman and Ingbar 1988:343; see also Kelly and Todd 1988).

Folsom hunting practices are not well known. Like Clovis, the characteristic Folsom point is widely assumed to be the primary weapon armature of Folsom bison hunters. It is not known, however, whether this weapon took the form of a spear, javelin, or dart. Bone points may also have served as weapon armatures at Agate Basin (Frison and Zeimens 1980).

The use of steep-walled arroyos as trapping areas is a procurement strategy inferred from the Agate Basin and Carter/Kerr-McGee sites (Frison and Stanford 1982; Frison 1984). Other sites such as Stewart's Cattle Guard (Jodry and Stanford 1992), suggest that bison may have been stalked and killed while grazing. There is no strong evidence for the large-scale communal bison kills that appear on the plains during later Holocene times (Frison 1991:164).

Summary

Current knowledge of Paleoindian technology suggests that toolkits were, for the most part, relatively simple and non-specialized, being comprised of multi-purpose basic cutting, scraping, incising, and piercing tools. Widespread similarities in tool forms, with little stylistic variation suggests a restricted range of subsistence activities, and a mobile lifestyle.

Mobility patterns are poorly understood, but may be centered around logistical foraging designed to address both subsistence, and lithic procurement and re-tooling needs. High-mobility is suggested by the nature of the subsistence base, as well as the recovery of exotic materials more than 320 km distant from their point of origin.

Current evidence overwhelmingly suggests that hunting was the primary economic pursuit, and that the most sought and utilized were the largest available species such as mammoth and bison, with significantly less reliance on a wide variety of smaller game species and some plant resources. Weaponry and hunting methods are poorly understood. While the use of the spearthrower is widely assumed, there currently is no direct evidence for its existence during the Paleoindian period, despite the recovery of other organic artifacts from cache pit deposits in the Northwest and on the Northern Plains, as well as from submerged deposits in the Southeast.

CHAPTER III

PROBLEMS CONCERNING PROJECTILE CLASSIFICATION AND IDENTIFICATION

"The philosophers have only interpreted the world; the thing, however, is to change it."
- Karl Marx -

Projectile Classification

Within hunter-gatherer groups, technological and social organization, including settlement and subsistence strategies, are closely tied to exploitative pursuits and concomitant technologies. From an archaeological perspective, an important aspect in the interpretation of hunter-gatherer exploitative technologies is the correct identification of artifact function.

Due to deeply ingrained normative concepts, certain bifacial point forms are routinely associated with specific delivery technologies. Small, side-notched points, for example, are associated with the bow-and-arrow, and larger, corner-notched points are often associated with the spearthrower (Corliss 1972; Evans 1957; Forbis 1962; Thomas 1978; Wyckoff 1964). While in a great majority of instances the analyst's identifications may be correct, the basis for such routine assumptions is not necessarily supported by explicit theoretical considerations. Since the correct functional identification of a technology is essential to subsequent analyses, it is imperative that a reliable method of projectile identification be developed.

Prehistoric knives, spears, spearthrower darts, and arrows are readily recognizable items when recovered in their entirety. The length of a shaft, its overall size and weight, and the absence or presence of a notched versus a dimpled nock, for example, are often indicators of such an implement's function. Unfortunately, prehistoric spear and dart shafts, knife hafts, and many other components of weapons were constructed from organic materials. Apart from rare waterlogged deposits, dry cave deposits, frozen deposits or other instances of unusual preservation, these fragile organic components are not often preserved in archaeological contexts. The result is that archaeologists seldom recover direct evidence of the delivery technology which was employed by a site's prehistoric inhabitants.

Numerous researchers (e.g., Corliss 1972; Evans 1957; Forbis 1962; Shott 1997; Thomas 1978; Wyckoff 1964) have attempted to identify prehistoric weapon delivery technologies through examination of the one surviving component of these systems: their lithic points. Such research has commonly involved investigation of neck or stem widths of points, or various measures reflecting overall point size. The basic assumption behind these analyses is that spear-points and knives are big and heavy, arrow-points are small and light, and spearthrower dart-point sizes and weights lie somewhere in between (Figure 1).

> These [points] will be discussed in two categories: (1) small, thin, light, finely chipped specimens believed to have served on arrows; and (2) larger, thicker, heavier and more crudely chipped specimens we believe were used on darts thrown with atlatls. That such a distinction actually existed over vast areas of America is no longer denied by many archaeologists [Baker and Kidder 1937:51].

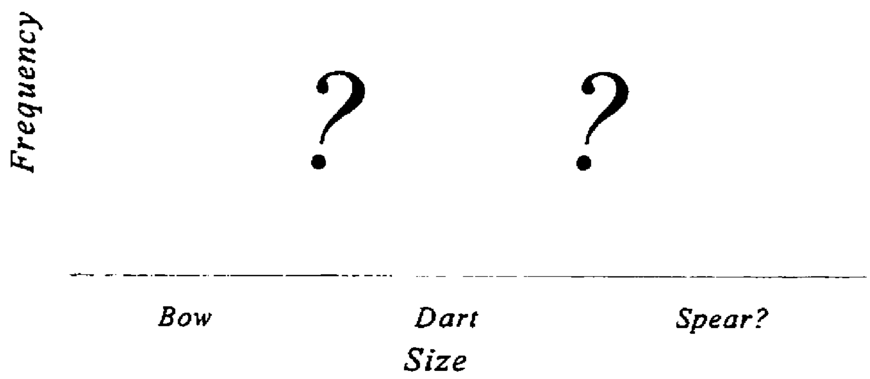


Figure 1. A stylized frequency plot of "projectile" point sizes [after Fenenga (1953)]. Even if size were directly related to function, a large number of points which fall between the nodes cannot be classified in this manner.

Despite the simplicity of such an assumption, a study by Fenenga (1953) of 884 points from the American Midwest, Southwest, and California, suggested that there may be some basis for such distinctions. Fenenga (1953) demonstrated that a frequency plot of either point neck widths, or overall weights, produced a bi-modal distribution suggesting mutually exclusive point groupings. Even though no data were presented to establish the actual sizes and weights of prehistoric projectile shafts themselves, the bi-modal distribution was interpreted as reflecting the morphological differences between spearthrower and bow projectiles. The issue was later addressed by Thomas (1978) who employed a sample of 132 hafted arrow points and 10 hafted spearthrower dart points to determine the relationship between point size and the diameter of the actual foreshaft it was attached to. His sample was drawn from ethnographic collections, and archaeological specimens recovered from Pueblo Bonito (Thomas 1978:467).

Thomas (1978) noted a correlation between arrow foreshaft diameter and arrow point neck width, but was unable to document a similar relationship between spearthrower dart foreshafts and their respective points. Despite this, the data suggested that arrow foreshafts were significantly smaller than spearthrower dart foreshafts, and arrowheads themselves were significantly smaller than dart tips. Furthermore, a discriminant analysis based on considerations of length, width, thickness, and neck width of the points, correctly classified approximately 86% of the study sample (Thomas 1978:471).

Thomas's approach provided no mechanism for dealing with unnotched projectile points. Shott's (1997) reassessment of Thomas's data utilizes a significantly enlarged sample of hafted dart points, and considers shoulder width as an alternative to neck width, since he found the latter variable to be inadequate:

> A neck width threshold of 9 mm correctly classifies 38 of 39 dart points, but misclassifies as darts 82 of 132 arrow points (62.1 percent). A threshold value of 8.5 mm produces identical results for darts but misclassifies 89 arrow points (67.4 percent). Even a threshold of 10.4 mm. One standard deviation lower than Chatters et al.'s (1995:757) mean for inferred dart points, misclassifies 57 arrows (43.2 percent) [Shott 1997:98].

In the end, however, Shott's (1997) ability to distinguish dart and arrow points is essentially equivalent to that of Thomas's (1978).

Published metric data and scale photographs are readily available for hundreds of dart foreshafts recovered from dry cave sites throughout the American Great Basin and Southwest (e.g., Berry 1976; Cosgrove 1947; Dalley 1976; Dalley and Petersen 1970; Fenenga and Heizer 1941; Guernsey 1931; Guernsey and Kidder 1921; Harrington 1933; Hattori 1982; Heizer 1938; Janetski 1980; Jennings 1957; Kidder and Guernsey 1919;

Loud and Harrington 1929; Pendleton 1985; Salls 1986; Smith 1963; Smith et al. 1963; Taylor 1966; Tuohy 1982; Woodward 1937). This literature indicates that while most dart foreshafts are approximately 0.8 cm to 1.1 cm in diameter, many are less than 0.6 cm in diameter. In comparison, the mean diameter of *arrow* foreshafts from Thomas's ethnographic sample (n = 118) is 0.7 cm, while the mean diameter of arrow foreshafts from his archaeological sample (n = 14) is 0.9 cm (Thomas 1978:Tables 1 and 2). In 1981, a 0.6 cm diameter dart foreshaft with a hafted stone point, along with five other dart foreshafts ranging from 0.4 cm to 0.6 cm, was recovered from NC Cave, Lincoln County, Nevada (Tuohy 1982). In reference to Thomas's (1978) study, these finds, as well as 56 other dart foreshafts from cave sites in the vicinity of Lake Winnemucca, Nevada, prompted Tuohy (1982:97) to comment:

> . . . I am not convinced that enough data have been marshalled [sic] to segregate arrow foreshafts from dart foreshafts on the basis of size or variability in dimensions such as length, width, weight, or shaft diameters, and the new data from "NC" Cave and the Winnemucca Lake foreshafts from a cache support this contention.

Studies such as Thomas's (1978) rely on certain normative assumptions. First, they assume that their study samples are representative of the technology throughout time; that shaft diameters associated with a projectile technology will remain essentially invariant over time. Secondly, they assume that their study samples are representative of the technology in question. In differentiating points based on metric attributes, particularly attributes of size, studies such as these tend to overlook the effects of repair and resharpening. Since the ethnographic and archaeological samples are comprised of curated and cached weapons, one should instead assume that they are not in pristine, unused condition (cf., Binford 1979). It is therefore reasonable to expect that such samples may not reflect a technological ideal. Compounding the problem, is the fact that not all bows and arrows are, or were, created equal. The type and size of the bow, the construction of the arrow; the materials used in the shaft, whether or not it was fletched, and whether it was intended for large game, small game, or warfare, may all generate variability in point size and morphology.

In choosing to study examples of hafted arrow points, Thomas's sample was unavoidably recent by way of preservation bias. This was an inevitable consequence of the research parameters, and it biased the sample by assuming *a priori* that small, late period and ethnographic arrow points and shafts are representative of bow technology throughout time. The absence of point types known to be associated with arrows does not constitute evidence for the absence of the bow. One must keep in mind that many early lithic points are of a size and weight suitable for use with the bow. In fact, Browne (1940:211) noted that even Folsom points make highly efficient arrow points. This said, I do not mean to imply that Paleoindians may have employed a bow and arrow technology, only that current means of projectile classification are unsatisfactory.

Projectile Identification

A further problem concerning the reconstruction of prehistoric weapons technologies is the actual identification of projectiles *per se*. Ahler (1971) found evidence suggesting that bifacial "projectile" points were not always used primarily as projectile armatures, but that they were often used as knives and multi-purpose tools.

Certain questions arise then: (1) what exactly constitutes a projectile, and (2) how do we know that an artifact that we might otherwise label as an arrowhead or dart-point was ever *actually used as a projectile*?

So-called "diagnostic impact-fractures" are touted by many analysts (e.g., Ahler and McMillan 1975; Barton and Bergman 1982; Bergman and Newcomer 1983; Fischer, Hansen, and Rasmussen 1984; Frison 1978; Frison, Wilson, and Wilson 1976; Holdaway 1989; Odell 1977, 1988; Roper 1979; Shea 1988; Witthoff 1968; Woods 1988) to be indicative of projectile impacts. For example, Bergman and Newcomer (1983) describe three types of "impact fracture" identified during their projectile experiments:

> *1. The burin-like fracture.* Here one or more slivers of flint resembling burin spalls are detached from the lateral edge and the resulting broken arrowhead may be indistinguishable from an intentionally made burin.
>
> 2. *The flute-like fracture*. Here a chip is removed from dorsal or ventral surface, leaving a shallow flake scar that may resemble a flat-faced burin facet or a poor attempt at fluting the arrowhead's tip.
>
> 3. *The bending-fracture*. This type of break occurs transversely some way down the arrowhead's length and as it is not percussion-induced there is no positive or negative bulb on either piece. In some cases, the bending break may result in further breaks on the corners of the snapped blade sections, presumably caused by one section pressing off burin-like spalls on the other [Bergman and Newcomer 1983:241-243].

Bergman and Newcomer (1983) employ these criteria to suggest that certain Upper Paleolithic points may constitute projectile armatures. Similar criteria have also been cited to support the hypothesis that Mousterian points represent hafted projectiles rather than simple scrapers or knives, and that Neanderthals were, therefore, capable of complex behaviour (cf., Holdaway 1989, 1990; Shea 1988, 1990; Solecki 1992).

Most archaeologists have restricted such analyses to formal points. Odell (1988), however, has labeled large numbers of modified and unmodified *flakes* from a site in the Lower Illinois Valley as projectile armatures. Relying primarily on the identification of diagnostic impact-fractures, he suggests: (1) that diagnostic projectile impact fractures may often be observed on simple retouched flakes as well as unretouched waste flakes and detritus, (2) that the practice of employing suitable waste flakes as functional projectile points may be widespread, and (3) that this phenomenon will have repercussions on studies of technology and foraging efficiency. Odell's (1988) waste flake analysis is based on previous comparative studies of impact-related breakage patterns, notably Odell and Cowan (1986), which used an extensive series of shooting experiments employing replicated bifacial points and unmodified flakes as armatures on both spears and arrows.

Odell and Cowan (1986:204) describe impact-related breakage patterns as a series of tip and base fractures classified into general types based on fracture termination as defined by the Ho Ho Committee (1976 Vancouver Use-wear Conference [Hayden 1979]). These fracture types are dominated by snap, hinge, and step terminations in varying combinations. Other types of macroscopic damage include burination of the lateral edges, and a type of fracture consisting of "... shallow scars that often carry a distance of five or more millimeters from the end and terminate in either a step or hinge" (Odell and Cowan 1986:204). The latter type of fracture occasionally resembles intentionally manufactured fluting and is referred to as a "shallow step/hinge fracture" (Odell and Cowan 1986:204). Various other types of use-wear such as edge-rounding, surface polish, and linear striations were also used to identify projectile impact-related damage.

Unfortunately, Odell's tabulated data (Tables 1 and 2; Odell 1988:344-345) are confusing and it is unclear exactly what percentage of his study sample is represented by morphological versus non-morphological (in this case waste flakes and detritus) functional projectile points. He does state that only 3% of the functional projectile points from the Smiling Dan site sample are found among ". . . modified type collection objects" (presumably, morphological projectile points) (Odell 1988:346).

There is little reason to doubt that prehistoric peoples made greater use of materials usually classified as debitage and detritus than has been popularly recognized. Yet I feel that there are several problems inherent in the study of impact breakage patterns, including the use of some forms of polish and striations, especially if these breakage patterns are to be used as definitive proof of use as a projectile. These problems arise due to both the general morphology and functional nature of points; specifically:

1) lithic projectiles generally exhibit little use-wear or haft related polish;
2) impact fractures are generally location- and orientation-specific forms of damage that can be caused as much through thrusting, or even dropping, as from projectile-related impact;
3) certain impact fractures on the presumed service tips of unmodified flakes often involve a single, point loading event and cannot always be reliably distinguished from incidental manufacturing impacts or other damage by means of traditional analyses.

It is possible to produce flakes and blades during simple core reduction which unintentionally exhibit sympathetic or repercussive fractures that often appear similar to projectile point impact fractures. For example, the thin distal and lateral margins of flakes and blades can be damaged when they strike the ground after removal from a core or are otherwise discarded or tossed into a pile for subsequent use by the flint-knapper. Such damage would constitute an impact fracture in the true sense of the term, but not an impact fracture caused by use as a projectile armature. Given a site with a relatively large population of waste flakes, blades, and other debitage, a large number of pieces can be expected to exhibit so-called impact fractures.

An investigation of flint chipping debris designed to explore the incidence of "impact fractures" on flint debitage (Hutchings 1991:Appendix F), demonstrated that 72.4% of a sample of 246 pieces of flint chipping debris were suitable for hafting as practical or useable arrowheads. Of these, 15 haftable pieces (6.1% of the original sample) were found to exhibit damage suggestive by location, distribution and morphology, of projectile use according to the macroscopic criteria of Odell and Cowan (1986) as well as those of Odell (1988) and others (e.g., Ahler 1971; Barton and Bergman 1982; Bergman and Newcomer 1983; Fischer, Hansen, and Rasmussen 1984; and Roper 1979). In fact, three of the haftable pieces which exhibited so-called "diagnostic impact fractures" also exhibited simple side-notches; one of these three exhibited simple, uniform, bilateral side-notches.

> The results obtained by this simple study demonstrate a high probability of observing projectile impact-like breakage patterns among discarded waste flakes and other debitage and detritus. Over 6% of the sample produced erroneous "use-wear". The overall morphology of these pieces, and the current definition of what constitutes a projectile point, suggests not only that they came in contact

> with some target material, but that they were shot or thrown at the target material as projectile points [Hutchings 1991:Appendix F, emphasis in original].

These results illustrate the problems inherent in employing impact breakage patterns as proof of projectile function. While projectiles do indeed frequently exhibit these breakage patterns, one cannot simply reverse the relationship between projectiles and breakage patterns so that the occurrence of these patterns indicates use as a projectile.

The essential problem then is the fact that various types of fractures which may otherwise appear identical, may result from a wide range of different events and forces, or loading rates. For example, lithic implements may exhibit seemingly identical fractures that were caused during manufacture, careless handling, or various instances of use. So-called "diagnostic impact-fractures" are little more than a series of tip fractures found on both projectile points and other pointed lithic implements and debitage. The distal tips are the most fragile component of these implements, and it is not unreasonable to expect frequent damage directed parallel to the long axis. The damage sustained by the tips of projectile armatures, however, should result from much higher loading rates and exhibit higher fracture velocities than other artifacts exhibiting morphologically similar damage, but caused by non-projectile-related use. The problem lies in the identification of the actual loading rate associated with a given tip fracture, or any other fracture thought to be associated with use. If such data can be supplied by the tool, or more specifically the fracture, in question, any and all subjective interpretive problems could be eliminated.

CHAPTER IV

THE QUANTIFICATION OF LITHIC FRACTURE VELOCITY

"Every action creates an equal and opposite reaction."
- Popular paraphrase of Newton's 3rd Law of Motion -

Archaeologists have long noted the presence of various ripple-marks on the fracture surfaces of certain isotropic, cryptocrystalline materials. In fact, the "eolith debate" at the beginning of the twentieth century (e.g., Moir 1911, 1912, 1916, 1928; Warren 1905, 1913, 1914, 1923) focused on whether the presence of certain lithic fracture surface features constituted proof of human manufacture. Today, fracture surface features are commonly used to orient incomplete blades and flake fragments, and have been successfully employed as an aid in identifying the presence of soft-hammer versus hard-hammer reduction strategies (e.g., Hayden and Hutchings 1989).

The specific processes responsible for the formation of fracture surface features are poorly understood among most archaeologists. This chapter presents the basic concepts necessary to understanding the origin and nature of the fracture surface features pertinent to this research. In order to avoid a digressive and lengthy reiteration, readers desiring more than is offered in this brief chapter will find an excellent review and evaluation of brittle fracture theory and wave mechanics in Tomenchuk (1985).

Fracture surface features are macro- and microscopic markings found on the ventral surfaces of flakes and blades, and on the flake scars of cores. These are generally formed as a result of momentary changes in modes of fracture, and interactions in stress fields, along a progressing crack front.

During the production of lithic implements, the flintknapper's primary concern is the controlled removal of flakes or blades from the core. This is achieved primarily through manipulation of the energy imparted to the core by the knapper. With respect to percussion flaking, for example, energy is controlled primarily by three methods: (1) by the selective use of percussors of different densities, (2) by the angle and speed of the impact between the percussor and core, and (3) by the selective use of percussors of different sizes. In general fracture mechanics terms, these methods are means of varying the loading rate.

The energy imparted to a core is transmitted in the form of a wave induced stress field. If this energy is sufficient to rupture atomic bonds, a fracture results. Of particular importance in the formation of certain fracture surface features, is the dynamic interaction of the crack front with two elastic waves, the longitudinal (or dilational) wave, and the transverse (or distortional) wave. These waves are generated by the initial loading event and by bond rupture episodes along the progressing crack front (Tomenchuk 1985:437-438).

Fracture Surface Features and the Determination of Fracture Velocity

Undulations are the most commonly known type of macroscopic ripple mark. While they are not velocity dependent fracture features, they are useful indicators of the orientation of the crack front and are, therefore, important to the discussion that follows.

Undulations are wave-like structures easily visible on lithic fracture surfaces. They range in size from wide, arcuate features with low topographic gradients, often expressed in exaggerated form near the fracture termination margin of hard-hammer flakes (Hayden and Hutchings 1989), to narrow, near-microscopic ripple-marks with comparatively steep topographic gradients. They are oriented perpendicular to the direction of crack propagation (i.e., parallel to the crack front), and are concentric, or arcuate, about the point of crack initiation.

Generated under all loading conditions, undulations are created by the recurrent interaction of reflected transverse (distortional) waves and the progressing crack front. This interaction causes a change in the mode of fracture where tensile loading is momentarily preempted by plane shear. "The result is a tilting of the crack plane produced by the continuous angular adjustment of the crack front in order to achieve orthogonality to the direction of local maximum tensile stress" (Tomenchuk 1985:438). It is this oscillation of the progressing fracture front, created by fluctuating stresses, that causes the fracture surface to exhibit undulations (Poncelet 1958:281T).

Microscopic fracture features on the other hand, such as Wallner lines, fracture wings, and fracture parabolas, generally receive little, if any, attention as most archaeologists are seemingly unaware of their analytical potential. They are found on only the finest-grained lithic materials such as obsidian, chalcedony, flint, and jasper. The utility of these fracture features as quantitative indicators of fracture velocity in brittle solids has been known for many years among physicists (see Smekal 1950; Poncelet 1958; Bateson 1951; Congleton and Petch 1967), and has been recognized by some archaeologists, such as Kerkhof and Muller-Beck (1969), Faulkner (1972), Tomenchuk (1985), and Cotterell and Kamminga (1979, 1990:151), for a considerable period of time. For example, a quarter century ago Faulkner (1972:162) stated that:

> Gull [i.e., fracture] wings and Wallner lines, are indicators of fracture velocity, which may prove to be a diagnostic characteristic separating flakes produced at different loading speeds.

Wallner lines (Figure 2), fracture wings (Figure 3), and fracture parabolas are microscopic fracture surface ripple marks created when a longitudinal stress wave encounters a localized disturbance, such as the fracture boundary or intrinsic flaws in the material itself. A secondarily induced, or reflected, distortional (transverse) wave front radiates from these disturbances and interacts with the progressing crack front. The result of this dynamic interaction is a slight momentary deflection at the intersection of the distortional wave pulse and the crack front, which is expressed on the fracture surface as a microscopic, ripple-like feature (Poncelet 1958:283T-284T; Tomenchuk 1985:437).

> The presence of any localized disturbance to the stress field at any location along the length of the crack front is communicated to the contiguous and progressively more remote portions of the moving crack front by means of induced or reflected transverse waves, propagating with greater celerity than the crack front itself. Since the temporary impingement of the secondarily induced or reflected elastic wave does not occur simultaneously, but rather at successive increments, along the full length of the crack front, the visual record of the protracted interactive process is an arcuate, ripple-like structure, becoming more attenuated with distance from its origin. Usually less pronounced than the previously described fracture undulation, these surface markings are rarely visible on the fracture surface of all but the most ideal chipped stone tools [sic] materials such as obsidian and homogenous, fine-grained silicates [Tomenchuk 1985:443-444].

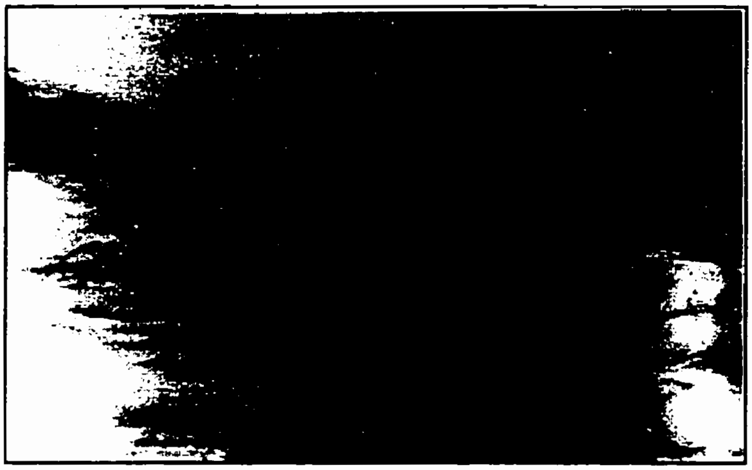


Figure 2. Photograph of an obsidian fracture surface illustrating intersecting Wallner lines and several fine undulations. 40x magnification.

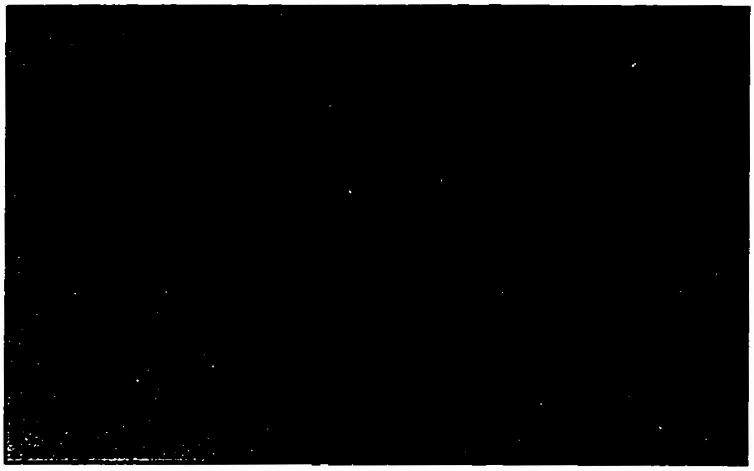


Figure 3. Photograph of an obsidian fracture surface illustrating a large fracture wing on a relatively straight fracture front. Note numerous smaller fracture wings. 40x magnification.

Wallner lines appear as ripple-like formations, attenuated along their length, which occur at an oblique angle to the crack front. They occur when:

> Sequential crack branching episodes and intrinsic or extrinsic flaws distributed at the <u>perimeter</u> of the plane of the fracture mirror . . . generate a series of crack front disturbances . . . . These structures intercept similar features emanating from the opposite mirror boundary and ultimately, the opposite mirror boundary itself [Tomenchuk 1985:444, emphasis in original].

Where the orientation of the fracture front is known, the maximum instantaneous fracture velocity at the site of a Wallner line may be determined from the effective angle of divergence of this fracture surface feature. Appropriate equations are available (Kerkhof 1975:119) for three different configurations of Wallner lines which may be generated.

Fracture velocity ($\dot{C}$) is expressed as a fraction of the transverse wave velocity (C_2). The transverse wave velocity is material dependent, and is represented by a numerical constant. It is this property that accounts for differences in the elastic properties of various stone tool materials.

Fracture Velocity Data Collection

Velocity dependent fracture surface features can be measured under low-power magnification, seldom in excess of 40x to 60x. A Wild M3 binocular microscope with magnifications of 6.3x, 15x, and 40x, was employed during this research. Both a 35 mm photographic attachment, and a tracing attachment (discussed below) were used for recording purposes. A custom-manufactured ball-and-socket stage which allows a high degree of tilt, and 360 degree rotation, was used to mount specimens for viewing.

Two sets of measurements are required in order to assess fracture velocity. The first is simply a measure of the feature's distance along the length of the fracture, and is expressed as a percentage of the terminal crack length. A high degree of precision is not necessary, and in most cases a simple millimeter ruler laid upon the fracture surface and observed under magnification is sufficient. Very small fracture surfaces may require the use of a stage micrometer. In either instance, the distance from the point of fracture initiation to the fracture feature, is divided by the overall length of the fracture surface. The use of this measure is discussed later.

A measure of the effective angle of divergence of the longitudinal and transverse waves constitutes the second set of measurements. Angles are measured at pertinent locations either directly, using a protractor reticule, or indirectly, by copying the fracture feature photographically, or by means of a microscope tracing attachment. The microscope tracing arm manufactured by WILD for their M3 and M8 binocular microscopes, was the method used for data collection throughout this research. This method is far more economical than recording each and every micro-feature photographically, and provides a relatively quick and easy means of creating an accurate, enlarged illustration, and permanent record. Angular measures may be obtained from the enlarged illustrations using a standard draftsman`s protractor.

Naturally, the fracture surface must be oriented as close to perpendicular with the viewing axis as possible, since the apparent angle of divergent features is affected by their plane of orientation. Maintaining a perpendicular orientation is not always easy since the ability to discern micro-features on highly reflective materials such as obsidian, depends a great deal on the angle of the incident light. Once a pertinent fracture feature is located, one must be careful to adjust the angle of the fracture surface, maintaining a relative lighting angle so that the feature remains visible, in order to make an accurate angular assessment.

Highly reflective surfaces such as obsidian, chalcedonies, and some flints, are often difficult to light adequately without creating excessive glare. Two 9.5 watt, diffused, flourescent lights manufactured by Bausch and Lomb (catalogue number 31-33-66) proved effective in eliminating most such lighting problems.

The clarity of various fracture features observed under magnification varies enormously, and because of this, they are not always easy to record and measure accurately. During this research, in order to reduce measurement error, each fracture feature was traced at least three times, sometimes as often as six or seven times. This produced multiple assessments of each fracture feature, and provided a check for accuracy. Multiple angular assessments were found to vary by approximately ± 1.5 degrees.

An informal test of the tracing arm recording and data collection method was conducted by comparing data collected using the tracing arm, to that obtained by photographic means. A number of different, well-defined fracture features were traced, and each recorded on 35 mm transparency film. By projecting the 35 mm transparencies, the recorded image is enlarged several hundred times and is easily, and accurately measured. Average angular measures recorded for each fracture feature using these two methods were consistently within one degree of each other.

Fracture Feature Configurations

The effective angle of divergence of the longitudinal and transverse waves is expressed in various configurations of ripple marks, each requiring specific angular measurements to be made. The first case (Figure 4a) involves a single Wallner line originating at a point S on the fracture (mirror) boundary. Two angular measurements are taken at any suitable point P where the orientation of the crack front can be determined, as, for example, at the intersection of the Wallner line and an undulation.

> The ratio of the fracture velocity to the distortional wave velocity is equal to the ratio of (1) the cosine of the angular displacement, α, between the normal to the crack front and the Wallner line to (2) the cosine of the angular distance, β, between the projected direction of the transverse wave propagation (from point S through point P) and the Wallner line [Tomenchuk 1985:447].

In mathematical notation this value is expressed as (Kerkhof 1975:Figure 14a):

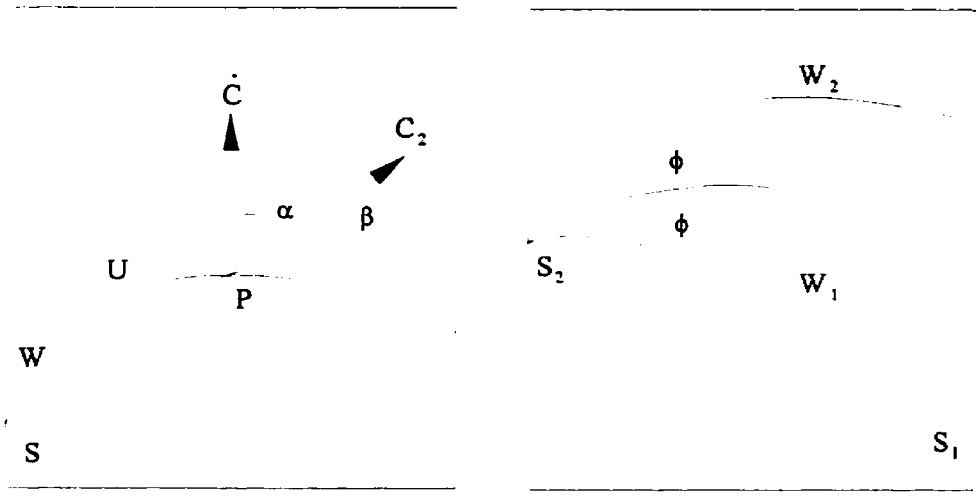
$$\dot{C}/C_2 = \cos\alpha/\cos\beta \qquad \textbf{(1)}$$

The second case (Figure 4b) involves a pair of Wallner lines, one a reflection of the other (see Field 1971:9, Figure 4c), converging on a single point at the lateral fracture boundary.

> The ratio of the fracture velocity to the distortional wave velocity is simply the sine of half the angular displacement, 2ϕ, between the two Wallner lines measured at [the convergence] point S_2 on the boundary [Tomenchuk 1985:447].

In mathematical notation this value is expressed as (Cotterell and Kamminga 1979:109):

$$\dot{C}/C_2 = \sin\phi \qquad \textbf{(2)}$$



a b

Figure 4. Variables for the determination of fracture propagation velocity ($\dot{C}$), expressed as a fraction of the distortional wave velocity (C_2), as determined from two discrete configurations of Wallner lines (W). (a) Fracture propagation direction (indicated by $\dot{C}$) is perpendicular to crack front as registered by fracture undulation (U); distortional wave propagation direction (C_2, i.e., SP). (b) Distortional wave disturbance reflected from fracture boundary resulting in convergence of two Wallner lines (W_1 and W_2) with mutual angular displacement of 2ϕ [after Cotterel and Kamminga 1979:109; Kerkhof 1975:Figure 14a; and corrected from Tomenchuk 1985:Figure 12.4].

Note that the angles (ϕ) should be derived from the tangents to the curves at the common point S_2.

The third case (Figure 5a) involves a pair of Wallner lines, originating at points S_1 and S_2 on the opposite boundaries of the fracture surface, and intersecting at point P. In this case the fracture velocity may be obtained from the following mathematical relationship:

$$\dot{C}/C_2 = \frac{\sin 2\phi}{(\cos^2\beta_1 + \cos^2\beta_2 + 2\cos\beta_1\cos\beta_2\cos\phi)^{1/2}} \qquad (3)$$

If the intersecting Wallner lines are symmetrical, such that S_1P is equal to S_2P (Figure 5b), then the equation reduces to:

$$\dot{C}/C_2 = \sin\phi / \cos\beta \tag{4}$$

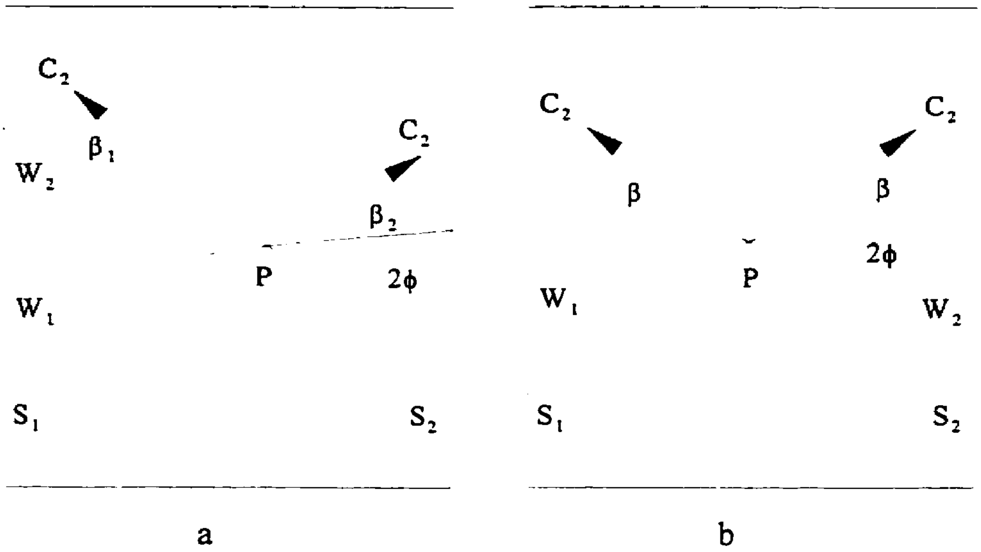


Figure 5. Variables for the determination of fracture propagation velocity ($\dot{C}$), expressed as a fraction of the distortional wave velocity (C_2), as determined from intersecting Wallner lines (W_1 and W_2). Two distortional wave disturbances (represented by C_2, i.e., S_1P and S_2P) intersect at point P. (a) Asymmetric case. (b) Symmetric case [after Kerkhof 1975:Figure 14b-c; Tomenchuk 1985:Figure 12.4].

Fracture wings are distinctive chevron, or inverted "V"-shaped, fracture features that point in the direction of the fracture origin, and are, therefore, sometimes used as indicators of fracture direction. These micro-fracture features may also be used to determine fracture velocity.

When a moving crack front encounters an internal flaw within the boundaries of the material, a secondary distortional wave may be initiated. The distortional wave interacts with the primary stress field associated with the moving crack front creating a pair of short, ripple-like marks in a distinctive "V"-shape whose apex coincides with the internal flaw. The fracture wings thus created are actually a pair of Wallner lines which diverge from a common origin. They have a tendency to rapid attenuation along their length, which contributes to the localization of this fracture feature. While Wallner lines, *per se*, are rarely visible on the fracture surface of all but the most ideal cryptocrystaline materials (e.g., obsidian), fracture wings may be observed on a variety of materials including, though not limited to, chalcedony, agate, jasper, and chert (flint). Due to their relative ubiquity, fracture wings are an excellent source of fracture velocity data (Tomenchuk 1985:455-456).

To determine the instantaneous crack velocity from a pair of fracture wings (Figure 6a):

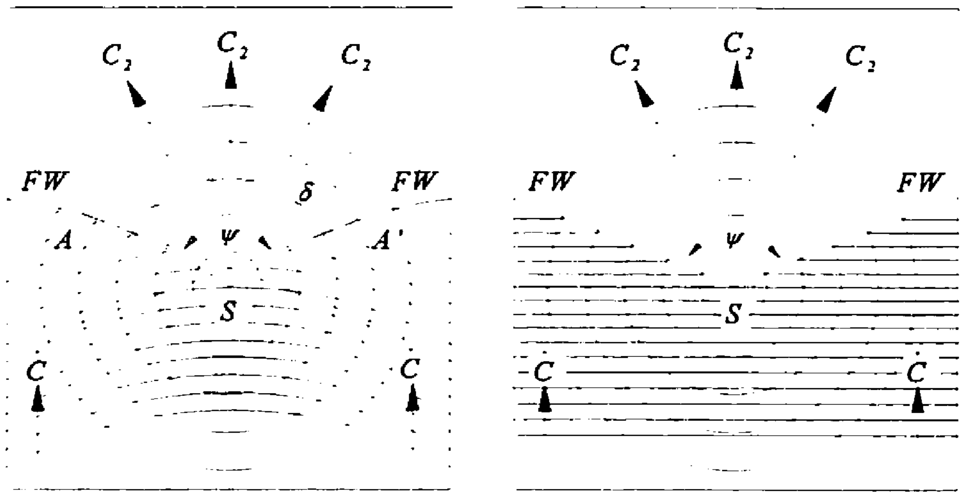
> The ratio of the fracture velocity, $\dot{C}$, to the transverse wave velocity, C_2, is simply the cosine of the quantity prepresented [sic] by the semi-angle of divergence, $\psi/2$, minus the crack front semi-angle of curvature, $\delta/2$, determined at the extremities of the fracture wings [Tomenchuk 1985:456].

In mathematical notation this value is expressed as:

$$\dot{C}/C_2 = \cos[(\psi/2)-(\delta/2)] \tag{5}$$

Any contiguous fracture undulation can be used to determine the angle of curvature of the crack front. If the angle of curvature of the crack front is zero (Figure 6b), this expression is reduced to:

$$\dot{C}/C_2 = \cos\,\psi/2 \tag{6}$$



a *b*

Figure 6. Variables for the determination of fracture propagation velocity ($\dot{C}$), expressed as a fraction of the distortional wave velocity (C_2), as determined from the effective angle of divergence (ψ) of fracture wings (FW). (a) Circular primary crack front (as indicated by fracture undulation) at point A and A'. The angle of divergence is obtained from the intersecting tangents to the fracture wings at points A and A'. (b) Plane primary crack front. The angle of divergence is measured directly from the fracture wings [after Tomenchuk 1985:Figure 12.5; see also Kerkhof 1975:Figure 9].

Fracture parabolas are extremely rare parabolic, or conic-shaped, ripple marks similar in appearance to fracture wings. Tomenchuk (1985:467) states that these features have yet to be reported in the archaeological literature. Since this author has observed but a single fracture parabola among literally thousands of artifact and experimental (i.e., replicated artifacts) fracture surfaces, a discussion of this micro-fracture feature is not warranted here. For a complete discussion of this micro-fracture feature refer to Tomenchuk (1985:461-469).

It is important to note that fracture velocity is not constant along the length of the fracture surface, and it is therefore the *maximum* measured fracture velocity which is central to this research. Instantaneous fracture velocities measured at various lengths along the fracture surface reveal that the crack front accelerates rapidly from the point of initiation, reaches a maximum velocity at approximately 20% to 50% of the terminal crack length, and then decelerates towards the termination of the fracture (Figure 7).

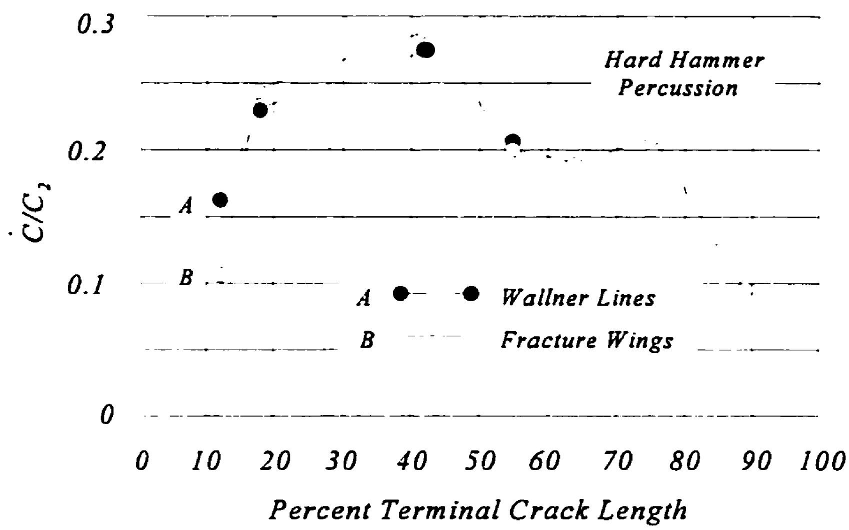


Figure 7. Fracture velocity ratios ($\dot{C}/C_2$) indicating the rate of fracture progression along the length of a single fracture surface. Note also the slight discrepancy between fracture velocity ratios determined from Wallner lines and fracture wings located at equal distances along the fracture surface [from Tomenchuk 1985:Figure 12.6a].

Thus, instantaneous crack velocities measured at fracture locations between 20% to 50% of the terminal crack length provide the most reliable indication of the precursory loading rate (Tomenchuk 1985:471-472).

Naturally, changes in fracture velocity are difficult to document since this requires the location of several fracture velocity indicators along the length of a single fracture surface, but the phenomenon was noted on the channel-flake scar of an obsidian Clovis point from Blackwater Draw (DMNH A1454.1). Fracture velocity ratios for this channel-flake scar are presented in Figure 8.

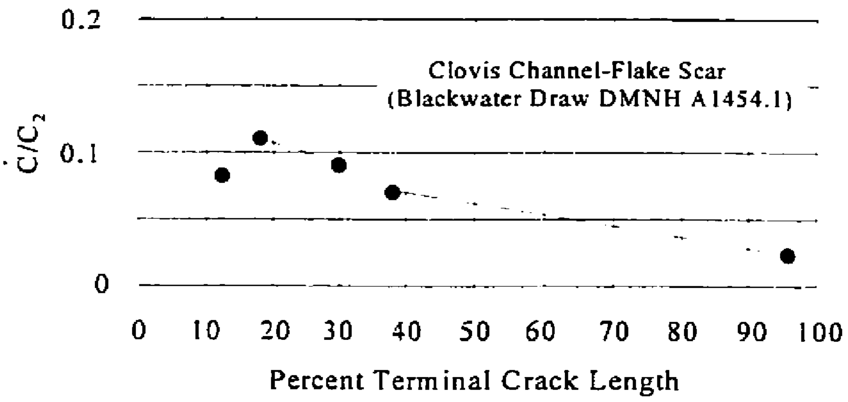


Figure 8. Fracture velocity ratios ($\dot{C}/C_2$) indicating the rate of fracture progression along the length of a single Clovis channel-flake scar from Blackwater Draw (DMNH A1454.1).

Correlation Between Lithic Fracture Velocity and Precursory Loading Rate

Attempts by archaeologists to explore the range of lithic fracture velocities associated with prehistoric technologies have been extremely limited. The sum of this research is restricted to: (1) early attempts to estimate crack velocities derived from high-speed photographs of fracturing processes (e.g., Goodman 1944; Crabtree 1968), (2) a small amount of fracture velocity data reported by Faulkner (1972), (3) a brief discussion of fracture velocity and its measurement by Cotterell and Kaminga (1979), and (4) measurement of fracture velocities derived from experimental lithic specimens by Tomenchuk (1985:449-462). Notably, all of these studies are related to stone tool *manufacture*.

Cotterell and Kaminga (1979:107) state that lithic fracture velocities measured experimentally, whether the result of percussion or pressure, are in the 200 m/s to 300 m/s range. If this were true, this investigation would not be able to proceed further since the implication is that fracture velocity determinations would be unable to distinguish prior loading rates. Fortunately, Cotterell and Kaminga are incorrect; a fact they themselves demonstrate during their discussion of Wallner lines observed on an obsidian blade flake from Lipari (1979:109). They calculate an effective angle of divergence of 21 degrees for these features, producing a $\dot{C}/C_2$ ratio of 0.18 (Cotterell and Kaminga 1979:109). Given a C_2 value of 3425 m/s for Lipari obsidian (Tomenchuk 1985:Table 11.4), an instantaneous fracture velocity of 616.5 m/s is obtained; more than double their stated maximum lithic fracture velocity for either pressure or percussion flaking.

Based on experimental research, Tomenchuk (1985:472) provides a suggested correlation between loading rate regimes and maximum instantaneous fracture velocities for stone tool manufacture. These are listed in Table 1. He further suggests that these loading rate regimes should remain essentially invariant for *use-related* fractures, but that ". . . it is not unreasonable to expect greater variability in crack velocities of the use-related fractures which might erstwhile be regarded as sharing similar service modes" (Tomenchuk 1985:473).

Table 1. Tomenchuk's tentative correlation between loading rate regimes and maximum instantaneous crack velocities ($\dot{C}$)* [1985:Table 12.7].

Loading Rate Regimes	$\dot{C}/C_2$	$\dot{C}$ (m/s)
Quasi-static	0.0 - 0.1	0 - 400
Rapid	0.1 - 0.28	400 - 1000
Dynamic	0.28 - 0.43	1000 - 1500

*Note that maximum instantaneous crack velocities ($\dot{C}$) appear to have been calculated based on a C_2 value for Rugen flint at 3622 m/s.

Referring to Table 1, quasi-static loading rates may tentatively be correlated with pressure flaking processes, while rapid loading rates may be correlated with percussion flaking processes (Tomenchuk 1985:471). For most archaeological purposes, loading rates in the dynamic range are expected to encompass the high-velocity impacts encountered by various projectile armatures. Various hafted and un-hafted tools such as adzes, celts, picks, and wedges may be subject to loading rates ranging from rapid to dynamic (cf., Tomenchuk 1985:378). Fracture velocities in the dynamic range are of particular interest to this study, and will be discussed later in this chapter.

Despite the observation of pertinent micro-fracture features on at least 34 different experimental specimens (Tomenchuk 1985:458), Tomenchuk's study reports fracture velocity data derived from only six ". . . published illustrations of experimental and archaeological flakes, blades, and cores" (Tomenchuk 1985:Table 12.4), and ten experimentally produced specimens (Tomenchuk 1985:Tables 12.2, 12.3, and 12.5). It would, therefore, be propitious to examine a larger sample of experimentally produced flakes and blades to determine the range of fracture velocities that one might reasonably (i.e., statistically) expect to be associated with known manufacturing related processes, and refine the general scheme of loading rate regimes. This should later permit the differentiation of fracture velocities that lie *outside* the range of manufacturing related processes.

<u>Quasi-static and Rapid Loading Rates</u>

Several hundred obsidian flakes and blades collected during experimental core and biface reduction by the author, were examined for velocity dependent fracture features. Pressure flaking, indirect percussion, and direct percussion flaking techniques were employed using various knapping tools. These included deer antler-, and copper-tipped pressure flaking tools; an indirect percussion punch of deer antler; an elk antler soft-hammer percussor; and sandstone and quartzite hard-hammer percussors.

All experiments were performed using Glass Butte (Oregon) obsidian (C_2 = 3865 m/s [Appendix A]). Obsidian was chosen for these experiments, not only due to its availability, but to maximize the potential for data collection. It should be noted that the use of any one particular raw material does not affect the validity or applicability of the data since the measurement of divergent stress wave angles and the calculation of fracture velocities is a non-subjective, metric operation; material-dependent elastic properties (i.e., transverse wave velocities [C_2]) are accounted for in the fracture velocity calculations. The experimental data are therefore considered representative of lithic reduction processes in general.

The data reveal $\dot{C}/C_2$ ratios ranging from 0.03 to 0.38 (Appendix B), and indicate that manufacturing related fracture velocities in Glass Butte obsidian may be expected to range from approximately 118 m/s to 1485 m/s (Table 2). Fracture velocities related to pressure flaking, soft-hammer percussion, and hard-hammer percussion are readily distinguishable (Figure 9). Interestingly, fracture velocities related to indirect percussion, while generally distinguishable from pressure flaking and hard-hammer percussion, are not distinguishable from soft-hammer percussion. The fracture velocity distributions associated with the manufacturing processes are presented in Figures 10, 11, and 12.

Table 2. Basic descriptive statistics for maximum instantaneous fracture velocities ($\dot{C}$) observed on experimental obsidian flakes and blades produced using various reduction technologies and tool materials (based on C_2 value of 3865 m/s for Glass Butte obsidian).

	Pressure		Indirect Percussion	Direct Percussion		
	Metal	Antler	Antler	Antler	Sandstone	Quartzite
Sample Size:	18	32	23	32	32	33
Minimum:	118.03	151.74	370.44	404.00	571.28	631.25
Maximum:	521.20	614.61	902.27	1178.30	1485.30	1447.85
Average:	303.11	370.79	667.66	700.48	1031.34	1037.37
Median:	286.43	345.26	654.54	646.22	1041.00	1000.34
Standard Deviation:	116.39	120.32	166.06	195.08	217.48	216.32
Standard Error:	27.43	21.27	34.63	34.49	38.44	37.66
Skewness:	0.38	0.02	-0.14	0.73	0.17	-0.01
Coefficient of Variation:	0.38	0.32	0.25	0.28	0.21	0.21

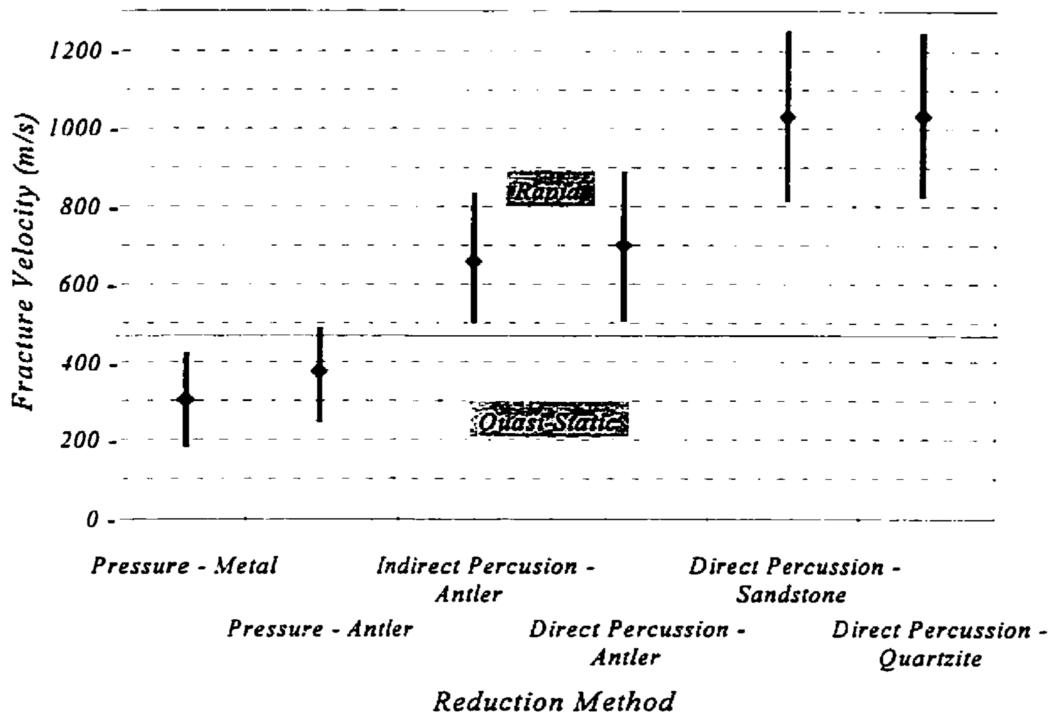
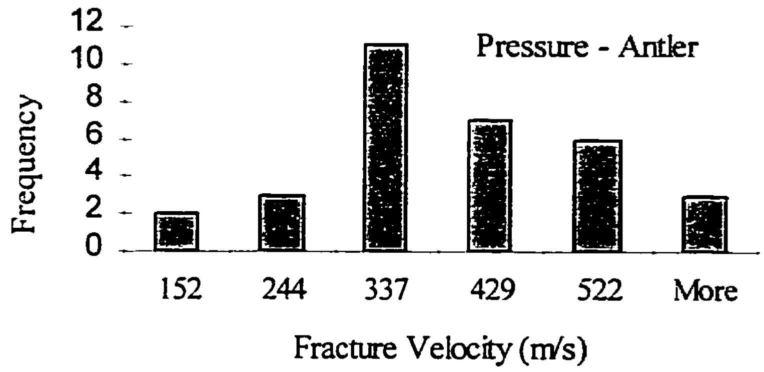


Figure 9. Average and one standard deviation for fracture velocities observed on experimental flakes and blades produced using various reduction technologies and tool materials. Fracture velocities are calculated based on a C_2 value of 3865 m/s for Glass Butte obsidian

The experimental sample does not include materials produced using the chest-, or shoulder-crutch pressure technique. Several obsidian prismatic blades produced using the chest-crutch technique were, however, examined among collections housed at the San Diego Museum of Man. Two of these blades, manufactured by Donald Crabtree in 1967, exhibit pertinent micro-fracture features, revealing instantaneous fracture velocities ranging from 46 m/s to 117 m/s.

The fact that instantaneous fracture velocities related to pressure flaking using a deer antler tine, were observed as high as 615 m/s ($\dot{C}/C_2 = 0.16$), suggests that not all pressure flaking should be considered a quasi-static process. This conclusion is



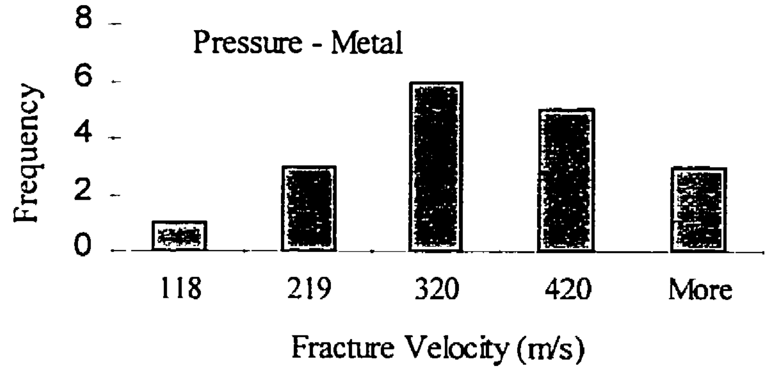


Figure 10. Frequency distribution of pressure reduction fracture velocity ($\dot{C}$) data.

preferable to suggesting that the upper boundary of the quasi-static regime be increased to encompass these experimental pressure flaking maxima, due to the general definition of quasi-static loading as ". . . the application of a *slowly* increasing force to a material" (Tomenchuk 1985:356, emphasis mine). Increasing the upper boundary of the quasi-static regime would suggest that indirect percussion flaking, which encompasses instantaneous crack velocities slightly below the 0.1 $\dot{C}/C_2$ ratio threshold (i.e., 386.5 m/s for Glass Butte obsidian), be considered a quasi-static process, which would be a flagrant contradiction to the definition. One must, therefore, conclude that pressure flaking may bridge the quasi-static/rapid threshold depending on the technique of the knapper.

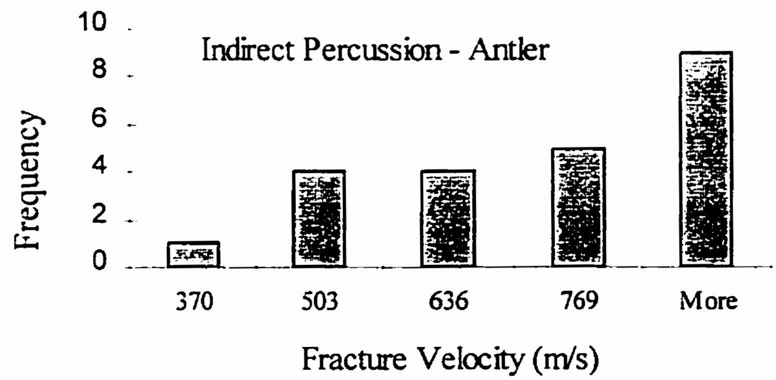


Figure 11. Frequency distribution of indirect percussion reduction fracture velocity ($\dot{C}$) data. Note truncation at the upper end of the distribution, and the considerable negative skew.

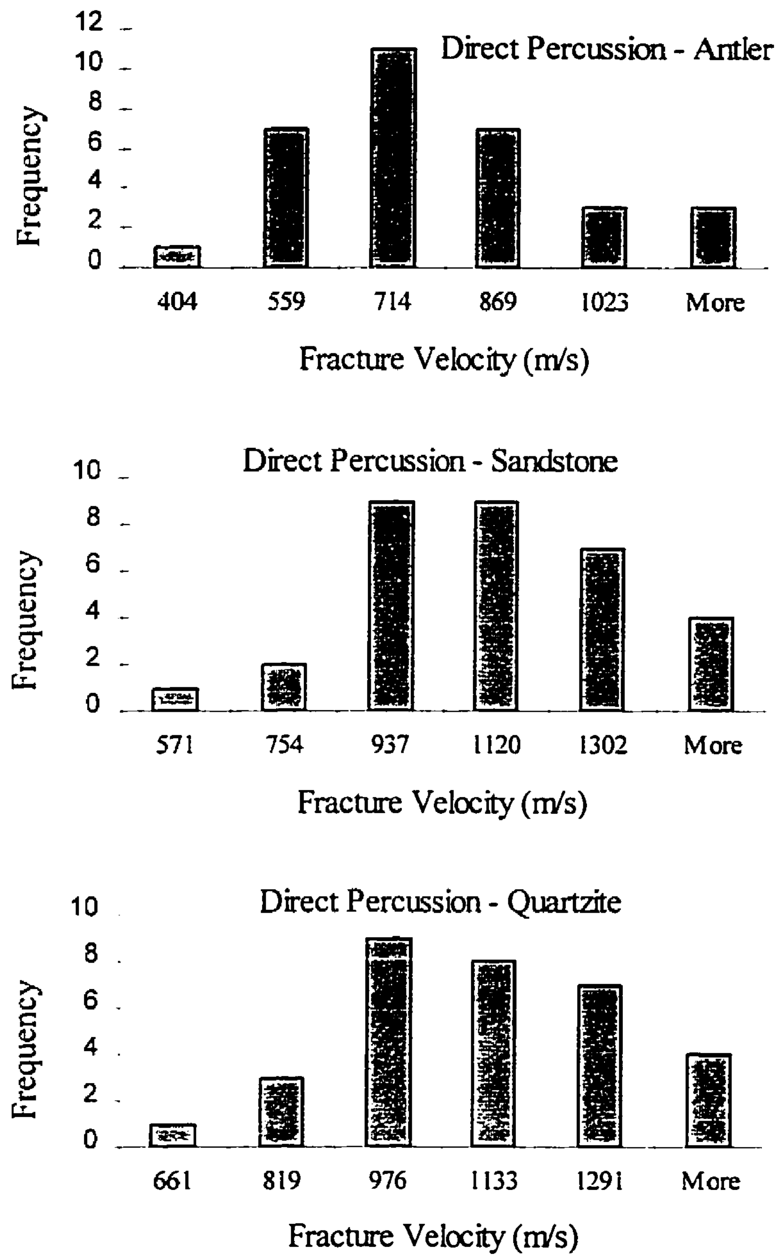


Figure 12. Frequency distribution of direct percussion manufacturing fracture velocity ($\dot{C}$) data.

At the other end of the scale, it is also apparent that direct percussion flaking can produce $\dot{C}/C_2$ ratios significantly above the 0.28 rapid/dynamic threshold outlined by Tomenchuk (1985:Table 12.7). In fact, instantaneous fracture velocities for Glass Butte obsidian as high as 1485 m/s suggest a rapid/dynamic threshold of $\dot{C}/C_2 = 0.38$. The data thus suggest a revision of Tomenchuk's (1985:Table 12.7) tentative correlation between loading rate regimes and maximum instantaneous crack velocities. In addition, it is now possible to identify specific lithic reduction processes with corresponding ranges of maximum instantaneous crack velocities (Table 3).

Table 3. Revised correlation between loading rate regimes, associated lithic reduction technologies, and maximum instantaneous crack velocities ($\dot{C}$)* based on manufacturing experiments.

Loading Rate Regimes	Reduction Technologies	$\dot{C}/C_2$	$\dot{C}$ (m/s)
Quasi-static	Pressure (chest) Pressure (hand)	0.0 - ? 0.03 - 0.10	0 - ? 115 - 385
Rapid	Pressure (hand) Indirect Percussion Soft-hammer Percussion Hard-hammer Percussion	0.10 - 0.14 0.10 - 0.23 0.10 - 0.28 0.16 - 0.38	385 - 540 385 - 890 385 - 1080 620 - 1470
Dynamic	N/A	0.38 - 0.43	1470 - 1660

*Note that maximum instantaneous crack velocities ($\dot{C}$) have been calculated based on a C_2 value for Glass Butte obsidian at 3865 m/s. $\dot{C}/C_2$ ratios have been rounded to two decimal places, hence corresponding $\dot{C}$ values may differ slightly from experimental results.

A nonparametric randomization test (Siegel 1956:152-158) was conducted to determine the significance of the difference between the sample means of the manufacturing data. Despite the overlap in instantaneous crack velocities between some of the reduction processes, the randomization test amply demonstrates the independence of the samples (Table 4).

Table 4. Combined results of two-tailed randomization test of manufacturing data for significant difference between independent samples. Values of p are presented for 10,000 partitions. Note that for most samples, significant differences are indicated at a confidence level better than 99%.

	Pressure - Antler	Pressure - Metal	Indirect Percussion - Antler	Direct Percussion - Antler	Direct Percussion - Sandstone
Pressure - Metal	0.05660	NA			
Indirect Percussion - Antler	0.00000	0.00000	NA		
Direct Percussion - Antler	0.00000	0.00000	0.45340	NA	
Direct Percussion - Sandstone	0.00000	0.00000	0.00000	0.00000	NA
Direct Percussion - Quartzite	0.00000	0.00000	0.00000	0.00000	0.91120

In application, the considerable overlap of fracture velocity ranges presented in Table 3 means that not all measured values will be assignable to specific reduction processes. Depending on context, and the specific value measured, however, fracture velocity data offer a relatively quick and simple, *non-subjective* means to assess reduction technologies.

Dynamic Loading Rates

The expectation that lithic projectile armatures, subject to high-velocity impacts, would exhibit fracture velocities in the dynamic range, was investigated during previous research (Hutchings 1991). Velocity dependent fracture surface features were observed on damaged flint microliths (truncated rectangles) suspected, through the application of design theory analysis, to have been used prehistorically as elements of composite projectile armatures. Average $\dot{C}/C_2$ ratios ranging from 0.37 to 0.52, corresponding to fracture velocities ranging from 1354 m/s to 1873 m/s (instantaneous maxima ranged from 1268 m/s to 2129 m/s) (corrected from Hutchings 1991:Table 7.15) based on a C_2 value of 3622 m/s for Rugen flint, were obtained from fracture wings exhibited by these artifacts. These fracture velocities compared favorably with those derived from limited replication experiments where flint microliths, mounted on arrow shafts as composite armatures, were shot into meat and bone targets. Average fracture velocities from the replication experiments ranged from 1387 m/s to 1498 m/s (instantaneous maxima ranged from 1181 m/s to 1811 m/s) (Hutchings 1991:Table 7.14).

The research suggested that the upper range of dynamic fracture velocities, would need to be extended beyond Tomenchuk's (1985:Table 12.7) tentative 1500 m/s limit (corresponding to a $\dot{C}/C_2$ ratio of 0.43) to include fractures resulting from use-related functions such as high-velocity impacts (Hutchings 1991:212). Most importantly, it suggested that lithic fracture velocity data could be used to identify artifacts used as projectile armatures (i.e., artifacts subject to high-velocity impacts), and that it may be possible to distinguish between loading rates attributable to specific projectile technologies in a manner similar to that demonstrated for reduction technologies.

Terminal Fracture Velocity

The terminal fracture velocity ($\dot{C}_F$) for a given material, represents the maximum transmission rate of longitudinal waves within that material. The issue of terminal fracture velocity is important since as wave propagation velocities approach this boundary, it will become increasingly difficult to distinguish variation in prior loading rates. That is to say that at some point, regardless of any further increases in loading rate, resulting fracture velocities should reflect little more than the terminal fracture velocity of the material.

Fracture mechanics researchers have attempted to determine the theoretical velocity limit for a moving crack in a brittle solid. Some (Mott 1948; Poncelet 1944;1958;1964; Roberts and Wells 1954) have attempted to demonstrate that the maximum fracture velocity is 0.5 of the transverse wave velocity. Stroh (1957:454), and Broberg (1964, cited in Tomenchuk 1985:395) equated the terminal fracture velocity with a fraction of the Rayleigh surface wave velocity. None of these theoretical attempts to estimate terminal fracture velocity are borne out by the empirical evidence (Schardin 1959; Tomenchuk 1985:395-396).

> ... the absence of published information on the terminal crack velocity of chipped tool stone exacerbates the already difficult task of determining the loading rate dependency of crack velocities. The immediate objective, therefore, is to derive representative values of $\dot{C}_F$ for a sample of chipped tool rocks [Tomenchuk 1985:380].

Tomenchuk reasons that like glass and norite, whose terminal fracture velocities have been measured empirically, chipped-stone silicates are:

> . . . hard, elastic, isotropic solids whose chemical composition is predominantly silicon dioxide. Based on the strength of the correspondence between the velocity ratios of glass and norite - especially $\dot{C}_F / C_2$ - I conclude that chipped-tool rocks will possess comparable values of velocity ratios.
>
> In principle, the manifestation of specific fracture features should exhibit the same crack propagation ranges and thresholds for both glass and the cryptocrystalline solids such as cherts and flints [Tomenchuk 1985:399].

The empirically determined terminal fracture velocity for norite is 1875 m/s (Bieniawski 1968:Table 2), while that of soda-lime glass is 1580 m/s (Field 1971:Table 1).

During this research, instantaneous fracture velocities as high as 2231 m/s were observed on experimental impact-damaged obsidian points, indicating that the terminal fracture velocity of Glass Butte obsidian is considerably higher than that of either soda-lime glass or norite. A simple experiment was therefore conducted to explore the terminal fracture velocity of Glass Butte obsidian.

Lacking access to mechanical testing equipment, a less rigorous experiment was conducted with the assistance of the Firearms Section of the R.C.M.P. Forensic Laboratory (Vancouver). Several Glass Butte obsidian cores were subjected to extremely high-velocity impacts by firing bullets into their prepared striking platforms. The obsidian targets were clamped inside a bullet trapping device at a range of approximately 3 m, and impacts ranging from 308.2 m/s to 983.0 m/s were achieved using various ammunition. Projectile velocities were measured using a photo-electric device similar to that used during replication experiments described later in Chapter V.

Four types of ammunition spanning a broad range of velocities were employed. These included standard .22 short and .22 long rifle, along with copper-jacketed 30-M1 carbine and .223 (high-velocity assault rifle) caliber. All ammunition, except for the relatively slow .22 short, shattered the obsidian cores. The ballistic and lithic fracture velocity data are presented in Table 5. Fracture velocity data were recovered from nine obsidian prepared cores and produced $\dot{C}/C_2$ ratios ranging from 0.535 to 0.648, indicating fracture velocities spanning 2068 m/s to 2505 m/s ($\bar{x}$ = 2324 m/s; s = 115 m/s). Interestingly, fracture parabolas, extremely rare on other types of fracture surfaces, were observed on fragments from most of the nine cores.

Table 5. Ballistic and lithic fracture velocity ($\dot{C}$) data for obsidian terminal fracture velocity tests.

Ballistic Test No.	Ammunition Type (caliber)	Projectile Velocity (m/s)	Projectile Weight (g)	Kinetic Energy (Joules)	$\dot{C}/C_2$	C_2 (m/s)	$\dot{C}$ (m/s)
B1	.22 short	308.2*	1.81	86.2*	0.535	3865	2068
B2	.22 short	308.2*	1.81	86.2*	0.604	3865	2334
B3	.22 short	312.4	1.81	88.5	0.604	3865	2334
B4	.223	947.9	3.53	1583.6	0.598	3865	2313
B5	.223	983.0	3.53	1703.0	0.648	3865	2505
B6	.223	947.9*	3.53	1583.6*	0.609	3865	2353
B7	30-M1 carb.	611.4	7.12	1329.8	0.619	3865	2393
B8	30-M1 carb.	602.9	7.12	1293.1	0.602	3865	2326
B9	.22 long rifle	410.6	2.57	216.3	0.593	3865	2291

Notes: The .223 and 30-M1 carbine ammunition are copper-jacketed. The photo-electric recording device occasionally failed to operate correctly - values denoted with * are based on the lowest observed velocity for that type of ammunition.

Although lacking the sophistication of proper mechanical testing equipment, the data from this simple experiment, suggest that the terminal fracture velocity ($\dot{C}_F$) for Glass Butte obsidian is approximately 2500 m/s.

Summary

The processes responsible for the formation of velocity dependent surface fracture features were discussed. Various configurations of Wallner lines and fracture wings were shown to be velocity dependent features whose effective angle of divergence is directly correlated with the precursory loading rate of a given lithic fracture.

The practical techniques for collection of lithic fracture velocity data were outlined and sources of measurement error were assessed. Average angular assessments are expected to be accurate to within one degree. Fracture velocity assessments within the range observed during manufacture-related reduction, based on a C_2 value of 3865 m/s for Glass Butte obsidian, are therefore expected to be accurate to within approximately 34 ± 1 m/s.

Common techniques of lithic reduction were found, through examination of replicated obsidian flakes and blades, to produce $\dot{C}/C_2$ ratios ranging from 0.013 to 0.384, corresponding to fracture velocities ranging from approximately 50 m/s to 1485 m/s. Tomenchuk's (1985:Table 12.7) tentative correlations between loading rate regimes and maximum instantaneous crack velocities were revised to incorporate these data. In addition, specific lithic reduction processes were identified with corresponding ranges of maximum instantaneous crack velocities. The terminal fracture velocity ($\dot{C}_F$) of Glass Butte obsidian was determined to be approximately 2500 m/s.

Experimentation, both as part of this research, and by Tomenchuk (1985), has demonstrated the applicability of lithic fracture velocity determination as an effective means of analysis of archaeological materials. Fracture velocity assessments generate non-subjective measures of empirical data which reveal the precursory loading rate of a given lithic fracture. Unlike most other types of archaeological data, they are not subject to alteration by cultural or natural processes that may affect their representability; the precursory loading rate is the result of a cultural process, but the specific morphological expression of velocity-dependent fracture features is the result of universal physical laws. In a sense, each velocity-dependent feature represents a moment frozen in time; a measurable event reflecting the action that produced it.

CHAPTER V

REPLICATION AND EXPERIMENTATION

"Perhaps how it comes to be is really more distinctive . . . than what it is."
- Alfred Kroeber -

The replication of prehistoric artifacts has come to be recognized as a valuable means of technological and systemic analysis. It is, by necessity, the primary analytical approach employed by researchers involved in any aspect of experimental archaeology, including lithic analysis. Prior to the development of hypotheses regarding any aspect of technology, a certain degree of familiarity with that technology, with respect to materials, construction, and use are required. This type of familiarity is best gained through replication, and the actual use of the replicated artifact.

A well known exponent of lithic artifact replication, Donald Crabtree (1975:106), wrote:

> . . . experimental archaeology must be related to the specific aboriginal concepts of a particular technology or cluster of techniques and then used to replicate the stages of manufacture from the raw material to completion.

Defining replication, in this case with respect to stone tools, and outlining some of the benefits of the replicative approach, Flenniken (1981:2) stated that:

> Replication, in its strictest sense, is reproducing stone tools, using the aboriginal artifacts as controls, using stoneworking fabricators similar to the ones in aboriginal use, employing the same raw materials, and following what can be demonstrated to be the same reduction technology. Therefore, the end products including the debitage, sequential stages of manufacture, and rejuvenated tools should be the same or very similar to the aboriginal controls in terms of technical category percentages, morphologies, and technologies.

Despite widespread interest in the spearthrower, there is surprisingly very little reliable data available concerning its performance. A survey of the current literature reveals considerable disparity in assessments of spearthrower effectiveness. Unlike bow and arrow technologies, which have been reasonably well researched over the past century, archaeologists have little reliable data regarding the most important variables of spearthrower performance; dart weights, effective range, and projectile velocity.

Several factors contribute to the current variability in our knowledge of spearthrower performance. The most important of these may be a general lack of familiarity and requisite skill with the device which would permit a reasonable assessment of the technology. In a pioneering experimental study, Browne (1940:211) stated "any close degree of accuracy is impossible with the atlatl and the spear." His description of throwing technique explains why: "The throw is a fast overhand sweep [that] lifts the spear to a height above the head equal to the length of both the arm and the atlatl and this uncontrolled throw is the cause of the large angle of error" (Browne 1940:211-212). This basic error in throwing technique was repeated by both Butler (1975:105) and Patterson (1977:159), and may account for a generalized perception of the spearthrower as an awkward and inaccurate weapon.

Prior to developing a program of fracture velocity experiments, it was therefore necessary to explore the nature of spearthrower dynamics. Three characteristics of spearthrower performance had to be assessed: (1) the practical range of the weapon under reasonable hunting conditions, (2) the practical range of spearthrower dart velocities associated with various dart weights, (3) and the final velocity and kinetic energy of the dart upon impact with a target at hunting-related, down-range distances. In addition, since each of these characteristics are affected by the weight of the projectile, an assessment of dart weights was necessary prior to any investigation of spearthrower performance.

Reconstruction of the Fluted-Point-Tipped Projectile

A basic, and reasonable assumption made by Paleoindian researchers is that fluted points were intended to be hafted, though no complete fluted point-tipped projectiles have yet been recovered. For the experiments that follow, it is necessary to develop a reasonable approximation of the overall weight of the hypothetical fluted point-tipped dart. Weight is an important factor limiting the speed imparted to a projectile, and contributing to the kinetic energy associated with impact. The size of the shaft and foreshaft is not as important to most experiments as the weight, but may affect or limit the performance of a projectile. It will be necessary, however, to estimate the weight based on the overall size of the shaft elements. The limitations of this approach are duly noted, but no other means of reconstruction are available

Reconstruction data based on Paleoindian-related research

Researchers have suggested, either explicitly or implicitly, that the Clovis projectile consisted minimally of the Clovis point, mounted on either a wooden, bone, antler, or ivory foreshaft with the aid of binding and mastic. This in turn was either bound to a wooden mainshaft or connected via a friction-based socket mount (Dunbar 1991; Frison 1989; Lahren and Bonnichsen 1974; Stanford 1991).

Examining Clovis point widths from the Vail site, Gramly (1984:112-113) states that specimens narrower than 24-25 mm were unfinished (i.e., lack edge grinding) and discarded, while specimens only a few millimeters wider were finished, hafted, and used. He hypothesizes that the smaller, unfinished points were discarded if their maximum widths were less than that of the existing haft for which they were intended, since they would be ineffective if their edges were enclosed by the haft. He concludes that the shafts employed at the Vail site were 24-25 mm in diameter (Gramly 1984:113). He also cites ethnographic and historic sources which indicate that thrusting spears have large shafts, approximately 25 mm in diameter, rarely greater, while javelins and spearthrower darts are much narrower. He suggests, therefore, that the Vail Clovis points were used as armatures for spears, rather than spearthrower darts.

Gramly's hypothesis does not account for the fact that the Clovis knappers chose to flute points that they supposedly knew were too small to fit the large shafts. Channel-flake removal is usually thought of as the most difficult task in shaping a fluted-point, while edge-grinding is undoubtedly the simplest. Assuming that these under-sized points were initially intended for the same use as the larger specimens, it does not seem economical or even logical to bring a point to such a near-finished state only to discard it after all the difficult stages had been completed. Gramly's conclusion also suggests that haft diameters were greater than the maximum width of channel flake scars exhibited by any of the Vail points, and ". . . also exceeds in width any group of overlapping channel flakes on any face of a Vail fluted point" (Gramly 1984:113). This contradicts a commonly accepted hypothesis that the width of the channel flake scars of fluted points is a general reflection of the haft contact area (eg., Frison 1989; Huckell 1982; Musil 1988), in much the same manner that the distance between lateral or basal notches is a general reflection of the width of the hafts for these points (Corliss 1972; Forbis 1960; Thomas 1978; Wyckoff 1964).

If one considers the maximum width of channel flake scars as a reflection of haft width, then a reasonable haft width range of 1.2 cm to 1.7 cm (see Table 6) may be considered for Clovis.

Table 6. A sample of metric data for maximum width of Clovis channel-flakes, and channel-flake scars.

Site or General Provenience	Range (cm)	Average (cm)	Sample Size	Collection Location or Literature Source
Blackwater Draw	0.8 - 1.8	1.2	6	Denver Museum of Nat. History
Lehner	1.0 - 2.1	1.5	8	Arizona State Museum
Sunshine Well	1.2 - 2.1	1.6	11	Nevada State Museum
Dietz	0.7 - 2.9	1.7	71	Oregon State Museum
Southern Idaho	0.1 - 3.2	1.7	55	Titmus and Woods (1991)

Note: Measures represent maximum width of channel-flakes, or channel-flake scars per face of each point. In some cases channel-flake widths from both sides of a single point are included in the sample.

Similar data are available for Folsom points and suggests haft widths essentially within the same range as Clovis (Table 7).

The use of a bone foreshaft in connection with Clovis points was suggested by Lahren and Bonnichsen (1974) based on materials recovered from the Anzick site. These artifacts, generally tapered at one end and beveled at the other, were identified as foreshafts due to their association with several Clovis points, even though "the contextual relations of the fluted points to the fore-shafts were destroyed, as they were exposed by a front-end loader . . ." (Lahren and Bonnichsen 1974:148). Numeric data for the Anzick foreshafts are available from two complete specimens, and eight broken or fragmentary pieces (see Table 8). It is uncertain whether fragmentary pieces represent distinct artifacts, or whether two or more fragments may represent a single foreshaft. These foreshafts range in width from 1.2 cm to 2.0 cm. Their average width is 1.79 cm.

Table 7. A sample of metric data for Folsom channel-flake widths [after Boldurian 1990:Table 13].

Site	Sample size	Mean Width (cm)
Mitchell	42	1.36
Hanson	34	1.50
Lindenmeier	93	1.641
Lindenmeier	56	1.626
Lindenmeier	25	1.526
Lindenmeier	25	1.554
Lindenmeier	85	1.469
Lindenmeier	209	1.469
Lindenmeier	105	1.537
Lindenmeier	205	1.406

Similar bone and ivory artifacts have also been recovered from the Tenana Valley, Alaska (Rainey 1940); the Grenfel site, Saskatchewan (Wilmeth 1968); Lind Coulee, Washington (Daugherty 1956); the Richie-Roberts site, Washington (Mehringer 1989);

Klamath Lake, Oregon (Cressman 1956); Goose Lake, California (Riddell 1973); Blackwater Draw, New Mexico (Hester, Lundelius, and Fryxell 1972; Sellards 1952); and several submerged deposits in Florida (see Dunbar 1991; Jenks and Simpson 1941).

Wilmeth (1968:101) reports a cross-section of 1.5 cm by 1.25 cm for the Grenfel specimen. According to Daugherty (1956:253), the three Lind Coulee specimens measure 1.4 cm, 1.1 cm, and 1.5 cm in diameter. The Blackwater Draw specimen, though usually referred to as a "bone point" (Hester, Lundelius, and Fryxell 1972; Sellards 1952), is similar in size at 1.7 cm in diameter. A second specimen from Blackwater Draw, also identified as a bone point, is incomplete, but appears to be beveled on both ends, and measures 1.5 cm in diameter (Hester, Lundelius, and Fryxell 1972:117).

Table 8. Metric data for bone foreshafts from the Anzick site [after Lahren and Bonnichsen 1974:Table 1].

Specimen No.	Weight (g)	Length (cm)	Width (cm)	Thickness (cm)
67	48.5	22.0	1.5	1.2
118/119	75.0	28.1	1.8	1.4
37	NA	NA	1.7	1.2
38	NA	NA	1.9	1.3
94	NA	NA	1.8	1.3
95	NA	NA	1.8	1.3
117	NA	NA	1.5	1.0
120	NA	NA	1.9	1.1
122	NA	NA	2.0	1.3
123	NA	NA	2.0	1.4

Note: Only numbers 67 and 118/119 are complete specimens.

Metric data, provided by the Florida Museum of Natural History, for 72 foreshafts from the Acuilla, Ichtucknee, Santa Fe, and Silver Rivers, indicates a range of foreshaft diameters from 0.32 cm to 1.23 cm, with an average diameter of 0.50 cm. Note that these specimens average less than one half the diameter of the Lind Coulee and Blackwater Draw foreshafts, and one third the diameter of those from Anzick.

Huckell employed several replicated Clovis points and tapered, wooden foreshafts during his "Denver Elephant Project" thrusting-spear experiments. The foreshafts employed average 2.2 cm in diameter, ranging from 1.8 cm to 2.4 cm (Table 9), and were fitted to a spear shaft approximately 2.5 m in length with a maximum diameter of 8 cm (Huckell 1982:219).

Table 9. Metric data for experimental Clovis points and foreshafts employed by Huckell for the "Denver Elephant Project" [after Huckell 1982:Table 1].

Specimen Number	Point Length (cm)	Point Width (cm)	Point Thickness (cm)	Foreshaft Length (cm)	Foreshaft Diameter (cm)
1	9.5	3.3	0.8	19.1	2.2
2	9.1	2.9	0.9	28.4	2.3
3	8.8	3.2	0.7	26.9	2.4
4	9.5	3.1	0.8	25.3	2.3
5	9.1	2.9	0.8	28.3	1.8

During his experiments involving the use of Clovis weaponry on elephants at Hwange National Park, Zimbabwe, Frison (1989) employed six different Clovis projectile points with chokecherry (*Prunus virginiana*) foreshafts (Table 10). Chokecherry is common on the High Plains, available in the necessary lengths and diameters, and is both light and extremely tough (Frison 1989:768). These points and foreshafts were used in connection with mainshafts of chokecherry and a dense, but unidentified African wood, employed as spearthrower darts.

Employing mainshafts with weights of 365 g, 430 g, and 950 g, Frison's (1989) Clovis weaponry produced projectiles ranging from 395.1 g to 1019.4 g, though he states that the 950 g mainshaft was "much too heavy" (Frison 1989:773). The most successful dart seems to have been foreshaft and point combination number 2 (from Table 10) and the 430 g mainshaft, for a total projectile weight of 474.7 g (cf., Frison 1993:194).

Table 10. Metric data for experimental Clovis points and foreshafts employed by Frison at Hwange National Park, Zimbabwe [after Frison 1989:Table 2].

Dart Number	Foreshaft Length (cm)	Foreshaft Diameter (cm)	Total Length (cm)	Point Length (cm)	Point Width (cm)	Total Weight (g)
1	14.9	1.75	18.8	7.30	2.95	46.0
2	16.9	1.70	20.2	7.00	2.85	44.7
3	20.3	1.79	25.3	7.75	3.08	45.4
4	15.2	2.22	20.0	7.35	2.80	69.4
5	19.3	1.80	25.2	9.10	3.30	43.4
6	22.1	1.39	24.4	5.20	2.60	30.1

Reconstruction Data Based on Non-Paleoindian Archaeological and Ethnographic Examples of Spearthrower Darts

The size and weight ranges of spearthrower darts known from both archaeological and ethnographic collections world-wide, are extremely variable. In the Arctic, for example, spearthrower darts, mostly in the form of relatively heavy harpoons, may be as short as 105 cm (Eskimo, mean = 124 cm). In contrast, Australian darts reach as much as 330-340 cm in length (Aborigine, mean = 250 cm)(Stodiek 1993:211) and may weigh in excess of 800 grams (Palter 1977:Figure 2).

A study of spearthrower dart sizes and weights, based on archaeological specimens recovered from dry cave deposits in the American Great Basin and Southwest, was recently conducted by Hutchings and Brüchert (1997):

> Some of the lightest spearthrower darts have been recovered from dry cave deposits in the American Great Basin and the Southwest; finds from more than 130 sites noted several hundred dart fragments and several complete darts, which exhibit relative consistency in size, weight, and construction. These are relatively short at approximately 116 to 160 cm in length, and many, particularly those from Basketmaker deposits, would have weighed as little as 45 to 90 grams.

Similarly, Spencer (1974:Table 2) provides data for a replicated dart shaft based on specimens recovered from dry cave sites in the Great Basin. The total weight of his dart is given as "57 cm [sic]". I interpret Spencer's typographical error to indicate a weight of 57 g. This is consistent with basketmaker dart weights, and the alternative, 57 ounces (1616 g), assuming the numeric value is correct, is much too heavy.

Spearthrower darts employed ethnographically by Australian Aborigines may be the most variable of any region. Sizes and weights range from specimens comparable to those of the Southwestern Basketmaker, to the largest known, iron-tipped specimens which average 500 grams (Cundy 1989:112). Metric data from an Australian sample of 293 ethnographic spearthrower darts was collected by Palter (1977). The average weight of these darts was found to be 246.3 g (Palter 1977:163). Unfortunately, while Palter

(1977:163) recorded an average dart length of 249.8 cm for the sample, no measures of dart diameter were reported.

Metric data for the diameters of spearthrower dart shafts and foreshafts are available from the existing literature for North American sites in the Southwest, Great Basin, California, Mexico, Texas, and Florida (eg., Berry 1976; Cosgrove 1947; Cressman 1944; Cressman and Krieger 1940; Dalley 1970, 1976; Fenenga and Heizer 1941; Gilliland 1975; Guernsey 1931; Guernsey and Kidder 1921; Harrington 1933; Hattori 1982; Heizer 1938, 1942; Janetski 1980; Jennings 1957; Loud and Harrington 1929; Pendleton 1985; Salls 1986; Taylor 1966; Tuohy 1982). This material offers several hundred examples of complete darts and dart fragments from more than 155 sites. In many instances, the metrics are provided by the author, though in some, diameters were derived from scale photographs. To summarize these data, North American spearthrower dart mainshafts recovered from archaeological contexts range from 0.8 cm to 1.9 cm in diameter. The majority though, range from 0.9 cm to 1.3 cm in diameter. Likewise, foreshafts range from 0.6 cm to 1.9 cm in diameter, but most are approximately 0.8 cm to 1.1 cm in diameter. Based on these data, it is reasonable to suggest that a typical spearthrower dart from this survey area would have a mainshaft diameter of 1.3 cm, and a foreshaft diameter of 1.1 cm.

Modern spearthrower-hunter Steve Coleman, a well known and respected individual in the use of prehistoric weaponry (e.g., Becker 1993), has researched the spearthrower extensively. Having conducted hunts frequently for several years, he has become extremely proficient in the weapon's use. Coleman prefers a dart of 221 cm length, approximately 1.1 cm in diameter, with a Clovis-style lithic point between 20 g and 30 g, for a total dart weight of 240 g (Coleman: personal communication; cf., Becker 1993:41).

Summary of Haft Diameter Data

Although the data indicate that spearthrower darts known from different parts of the world vary significantly, several important characteristics are suggested. The data most important to the experiments that follow are those concerning dart weight. Frison (1989:773) states that his experimental 950 g mainshaft was too heavy, and preferred a total dart weight of 474.7 grams for penetrating elephant hide.

A Paleoindian dart shaft modeled after Basketmaker specimens would be inadequate for all but the smallest fluted points. Such a lightweight reed shaft would not withstand the acceleration of a heavy Clovis point without flexing to the point of breakage. In addition, according to Frison's (1989) experiment, it would not carry sufficient mass to penetrate elephant hide.

The average dart weight of 246.3 g obtained by Palter (1977:163) from a large Australian ethnographic sample is surprisingly close to the 240 g preference of practicing hunter Steve Coleman. The effectiveness of Coleman's darts are aptly described by Becker:

> Penetration was about 42" through the hog . . . Never in my 30 years of bowhunting had I seen an arrow put a big game animal down for keeps as quickly as Steve's 3,000 grain [approximately 194g] dart had [Becker 1993:42].

Although this account describes a slightly lighter dart, Becker notes that in hunting wild boar, notably a large-game species, Coleman's darts often penetrate the animal completely, whether through the chest cavity, or the shoulder. This has also been observed while using lithic armatures (Coleman:personal communication). While the wild boars hunted by Coleman do not have the thick hide of an elephant, Becker's (1993) comparison between the performance of darts and arrows suggests that the dart is an extremely effective weapon against large-game animals.

It was noted above that the weight of the replicated haft is of prime importance to the experiments that follow, whereas the size is considered secondary. In most cases, the size will have little effect as long as the lithic points are presented to the targets in a reasonably realistic fashion. Gramly's (1984:113) hypothesis that hafts at the Vail site were 2.4-2.5 cm in diameter cannot be reasonably accepted as a norm for Clovis practice. The widths of many finished Clovis points are less than this, though their effectiveness can only be assumed based on the fact that they were indeed used. In such a large haft, these points could not be presented to a target in a useful fashion since their lateral margins would not be exposed for contact (see Hutchings 1991:25).

The diameters of bone and ivory "foreshafts" reported from several Paleoindian sites vary considerably. I am inclined to believe that many of these artifacts are not foreshafts at all. The hafting model proposed by Lahren and Bonnichsen (1974:Figure 3) appears clumsy and cumbersome, and the additional splint required to complete the haft has never been demonstrated to have existed. Some of these artifacts are, however, morphologically similar to Upper Paleolithic, Gravettian bevel-based bone points. The most reasonable assessment, therefore, seems to be that of Hester, Lundelius, and Fryxell (1972) and Sellards (1952) who identify the specimens from Blackwater Draw as bone points. I do not discount the possibility that more than one type of artifact is represented by this group of objects, perhaps having completely unrelated functions. For example, Gramly (1993:59) has speculated that bone rods recovered from the Richey Clovis Cache in Washington may have been components of sled runners.

Employing the hypothesis that channel-flake scars reflect the haft-contact area for Paleoindian armatures, one is again presented with a considerable range of hypothetical haft widths. Of the samples examined *average* measures of Clovis channel-flake, and channel-flake scars reflect a relatively narrow range of variation, from 1.2 cm to 1.7 cm.

The thrusting-spear experiments conducted by Huckell (1982) employed significantly larger foreshafts than the preceding Clovis data suggests. Four of Huckell's five foreshafts range from 2.2 cm to 2.4 cm., approaching the 2.4 cm to 2.5 cm diameter of thrusting-spear shafts suggested by Gramly (1984). Huckell does note certain design flaws related to the size and arrangement of his experimental mainshaft and foreshafts:

> It was found that penetration of the spear was generally stopped at one of two locations on the composite spear: the juncture of the foreshaft with the mainshaft, or the binding securing the point to the foreshaft [Huckell1982:220].

These problems suggest that while the design may be sturdy, a smaller diameter foreshaft and mainshaft would aid penetration. Logically, this suggests that dart shafts should also be smaller. The subsequent experiment by Frison (1989) employed slightly narrower foreshafts, but most were still larger than the 1.2 cm to 1.7 cm diameter suggested by the sample channel-flake data. It is not surprising then that in connection with similar experiments Frison (1991:295) later noted a tendency ". . . to underestimate the strength and flexibility of a wooden foreshaft and the binding elements to the extent that they were too bulky".

An important consideration for proper performance of a dart shaft is the ability of the shaft to flex during the throw. A thick dart shaft with little ability to flex does not transfer energy efficiently, resulting in a loss of speed. It is also much more difficult to aim since the rotation of the spearthrower is transmitted directly to the shaft, rather than offset by its flexure.

Based on this survey data, dart shafts and foreshafts of dry hemlock approximately 1.3 cm in diameter were chosen for the experiments employed in this research, except where noted. These shafts produce an average completed "Clovis" dart weighing approximately 240 g. Other dart weights varied according to the parameters of various experiments, but generally ranged from approximately 82 g to 545g.

Effective Hunting Ranges

For the most part, ethnographic data concerning the effective range and accuracy of the spearthrower is available only from Australia and the North American Arctic (Hutchings and Brüchert 1997). Most accounts reflect the fascination that ethnographers held for the device and record long distance, competition-type throws. In most of these cases it appears that distances were often estimated rather than measured. In addition, where accuracy of the device was recorded, the observer's definition is often in question. Since accuracy is a relative term, some minimal description of target size and range is required, but is generally absent from the ethnographies. While some accounts claim that the device has been used with some degree of accuracy up to approximately 64 metres, the most reliable evidence suggests that the majority of successful throws in hunting situations were at ranges between 10 m and 30 m, and that accuracy falls off dramatically beyond 27 m (Stodiek 1993:211; see also Falkenberg 1968:15-38).

Data regarding practical hunting ranges and success rates are available from field studies of spearthrower equipment used in modern hunting situations (Hutchings and Brüchert 1997). The hunts were conducted by Steve Coleman, an experienced spearthrower hunter (see Becker 1993), who runs a wild-boar hunting operation in Georgia, catering to hunters who use both the bow and the spearthrower.

Based on 109 field trials (51 hits, 58 misses) under normal hunting conditions in both wooded and open environments, the data indicate that successful throws resulting in fatal wounds or serious disablement range from 3 m to 46 m, with an average of 15 m (s = 8.5 m). Few throws beyond 23 m are successful. Misses ranged from 6 m to 54 m, with an average of 24 m (s = 14.3 m) (Hutchings and Brüchert 1997).

As target sizes increase, the effective range of the spearthrower increases only slightly. This is because more massive muscle and skeletal structures usually protect larger game, thus the need to hit vital organs becomes more critical. One would not expect a mammoth, for example, to represent an easy target due to its heavy coat, thick hide, and massive ribcage. Note also that long distance shots, or lobbing projectiles into a herd of animals, unless launched in massive volleys into a very tightly packed herd, is generally dismissed as an ineffective hunting method (e.g., Frison 1991:297).

Based on this data, a distance of 15 m was selected to represent an average practical spearthrower range.

Spearthrower Experiments

Most researchers agree that hunters generally prefer to limit the distance to their target as much as possible since this allows a flatter trajectory, improved accuracy, and greater chance of success. Despite this, a common error in spearthrower research has been the calculation of projectile velocities from maximum throwing distance (e.g., Browne 1940; Butler 1975; Dickson 1985; Fenenga and Heizer 1941; Grant 1979; Hill 1948; Howard 1974; Mau 1963; Peets 1960;Van Buren 1974), employing a basic vacuum ballistics formula where velocity (v) is equal to the square-root of the product of the distance thrown (d), and the acceleration of gravity (G):

$$v = \sqrt{dG} \tag{7}$$

Butler (1975) has employed distance data derived from the works of Browne (1940:213), Peets (1960:109), and Howard (1974:104), to compute dart velocities ranging from 20.5 to 26.9 m/s. Similarly, Cotterell & Kamminga (1990:168) calculate that a velocity greater than 31 m/s would be required to cast a dart 100 metres.

Tolley & Barnes (1979:162) found that the distance a dart could be thrown is more a function of its aerodynamics than any property of the spearthrower: consider, for example, that experienced baseball pitchers and javelin throwers routinely use lift to their advantage. This suggests that velocity estimates derived from distance data are inadequate for an accurate assessment of spearthrower performance. Simplified ballistics models based on maximum throwing distance assume ideal trajectories, ignore aerodynamic effects, and represent only an initial thrust rather than a downrange velocity representative of hunt-related target ranges.

Dart and Javelin Velocity Measurements

Limited data representing measured dart velocities can be found in the existing literature. Using both a radar gun and photographic equipment, Raymond (1986:Figure 15, Table 3) recorded average velocities of 25.3 and 21.6 m/s respectively, for a 70 g dart. Also using photographic equipment, Tolley & Barnes measured velocities "in the neighborhood of 40 meters per second (*as measured 15 meters downrange*), varying plus or minus 6 meters per second" (1979:172, emphasis added) for an unknown number of darts which ranged from 68 to 190 g. Carrère & Lepetz (1988), employing a photoelectric timing device, arrived at maximum velocities of 25.4 and 32.9 m/s for darts of 150 and 50 g respectively, at a downrange distance of 2.5 m. Likewise, Bergman *et al.* (1988) measured a velocity of 23 m/s for a 195 g dart, using an MSI photoelectric device.

The considerable range of measured and calculated velocities reported in the current literature, prompted an independent investigation of spearthrower dart velocity.

Velocity Experiments

Kinesiological studies of throwing technique indicate that more than half of a spear's final velocity can be attributed to rotational acceleration from the wrist and forearm (Cooper & Glassow 1968:122); the same is true for the spearthrower dart. In comparison, there is little velocity imparted by the straight-armed sweeping motion described by Browne (1940:211).

The contribution of wrist rotation and the importance of proper throwing technique was also evident in a series of tests conducted by Hutchings and Brüchert (1997), which employed two international competition-level javelin throwers.

> Some instruction and practice time was afforded, and although their performance improved rapidly with experience, an initial lack of familiarity limited their ability to adapt the style of wrist rotation required with the spearthrower, as opposed to the more familiar javelin. In the end, despite their proven, highly developed throwing abilities, the velocities achieved by an experienced spearthrower-user averaged 129 to 171% greater than those of the javelin throwers [Hutchings and Brüchert:1997].

This demonstrated the need to develop a reasonable degree of proficiency with the spearthrower prior to any investigation of spearthrower dart velocities. Several months, constituting well over one hundred hours of technique development and target practice were spent in preparation for the dart velocity experiments.

A photographic apparatus was designed to measure in-flight velocities both at launch, and downrange at a distance of 15 m. The 15 m target range was chosen for three reasons: (1) it represents the average successful hunting range derived from the Coleman data (Hutchings and Brüchert 1997), (2) it is within the range of successful hunting throws recorded in the ethnographic literature, and (3) it is the same range tested by Tolley and Barnes (1979) during a similar experiment, and would therefore contribute to an existing, albeit limited, body of data.

The spearthrower darts were fitted with a small light source, and thrown and photographed at night, using slow shutter-speeds. The result is a series of exposures that record an undulating streak of light indicating the flight path of the dart over a known exposure time, either one-eighth, or one-fifteenth of a second. Additional light sources, recorded on each negative, were placed at known distances along the flight line to provide a scale for measurement of the light streak (Figure 13).

The photographic apparatus employed two 35 mm still cameras, mounted 90 degrees to the flight line. The Contax RTS II camera employed in these experiments is equipped with a "Real Time System" digitally controlled, vertical travel, titanium shutter

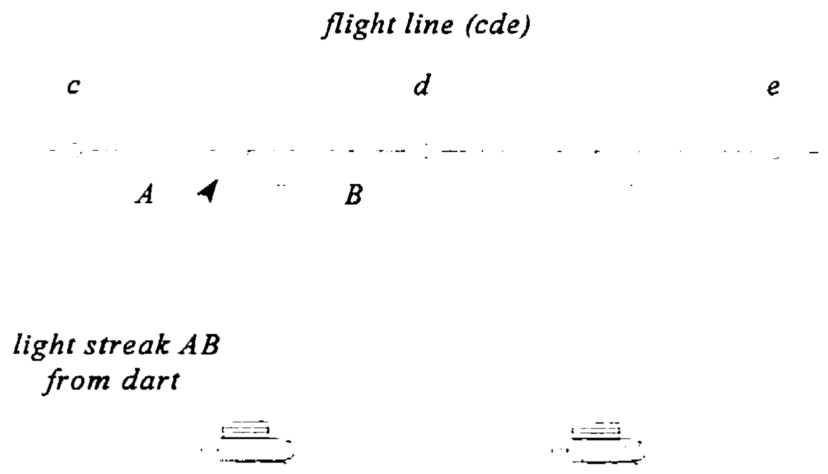


Figure 13. Schematic arrangement of apparatus employed for time-lapse photography of projectile flight. Projectiles are launched from point c and photographed at two locations along the flight line. The light-streak recorded by the first camera represents the initial launch velocity, while that recorded by the second camera represents a decelerated velocity at a theoretical, effective hunting range. Projectile flight speed is calculated, for example, as AB/cd multiplied by the reciprocal of the exposure time. Assessed in this manner, the resulting measures represent an average velocity during that portion of the flight represented by the light-streak.

mechanism governed by a high-precision quartz-crystal oscillator. A bench-test of the Contax RTS II by Goldberg and Frank (1983), determined the percentage error associated with a range of shutter speeds embracing those employed during these experiments. During pre- and post-torture tests, Goldberg and Frank (1983) measured a +1 percent (slow) error for the one-eighth second shutter speed, and a -6 percent (fast) error for the one-fifteenth second shutter speed. By comparison, the ANSI shutter-accuracy standard is +/- 25%, making most other types of 35 mm cameras unsuitable for this type of research.

The tests employed seven different dart masses ranging from 82.9 g to 545.3 g (Table 11). Darts were made from 1.3 cm diameter dry hemlock, and were of two-piece, composite construction. The 122 cm mainshafts and 61 cm foreshafts were slightly tapered on one end to accommodate a connector-sleeve made from a 7.6 cm length of PVC tubing with an inside-diameter of 1.2 cm. Dart masses could be adjusted by adding weighted metal sleeves to the shafts. The spearthrower employed in these experiments, was a rigid, unweighted male type made of spruce, with double finger-loops of leather. It is 65.4 cm in total length, 52.1 cm from the center of the finger-loops to the tip of the bone engaging-hook, and weighs 149.5 grams.

The darts were launched in level flight, at an imaginary target approximately 1.5 m to 2 m high, beyond the end of the flight-line. It is assumed that people employing the spearthrower for subsistence would have the skills necessary to combine power and accuracy. An imaginary target was therefore chosen over an actual target, to reduce any concerns about accuracy during the experiment that might limit efforts towards a powerful throw. Both stationary and running throws were made.

Table 11. Descriptive statistics for dart velocity tests measured just after launch. The 102.1 g dart was constructed of smaller pine dowel 114 cm long, and 0.9 cm in diameter. The aerodynamic effect from reduced surface area undoubtedly contributed to its higher velocity. The manually-controlled photographic apparatus made it difficult to capture both initial launch, and downrange velocities for every shot, resulting in fewer downrange data-points. The data presented are initial launch velocities; 15 m downrange velocities decrease by 9.6 +/- 1.9%.

Dart Weight (g)	Velocity Range (m/s)	Average Velocity (m/s)	Coefficient of Variation	Standard Error (m/s)	Sample Size
81.9	35.8 - 42.8	41.0	0.06	1.17	5
102.1	37.4 - 57.3	47.5	0.10	1.75	9
222.0	34.9 - 56.1	43.2	0.09	0.69	31
273.4	34.9 - 64.0	42.5	0.12	1.01	28
382.0	28.2 - 48.6	33.8	0.12	0.81	24
500.0	28.7 - 43.6	34.4	0.13	0.91	24
545.3	27.4 - 53.2	36.0	0.16	1.16	26

The results indicate that initial velocities of more than 55 m/s are readily attainable, even with darts up to 273.4 g, and that velocities 15 m downrange can often exceed 40 m/s (Table 11). The highest average velocity of 47.5 m/s (approximately 43 m/s at 15 m downrange) was achieved with a dart weighing 102.1 g. This dart was constructed of smaller pine dowel 114 cm long, and 0.9 cm in diameter. The aerodynamic effect of its reduced surface area undoubtedly contributed to its high velocity. Of the standard test darts, the highest average velocity of 43.2 m/s (approximately 39 m/s at 15 m downrange) was achieved with a dart weighing 222.0 g, and an average velocity of 36 m/s (approximately 32.5 m/s at 15 m downrange) was attained with the *heaviest* dart tested, at 545.3 g (Table 11). Downrange values at 15 m were calculated based on an average velocity decrease of 9.6% ± 1.9%.

The 222 g dart was the best *matched* projectile employed in these tests. That is to say that its length, weight, and flexibility (i.e., "spine") were better suited to the properties of the spearthrower, and the technique of the user (see Klopsteg 1943), and thus account for its superior performance. Like an arrow on a bowstring, a dart flexes due to the acceleration of the spearthrower during the throw, and continues to oscillate throughout most of its flight, producing the undulating light streak recorded by the photographic apparatus. The oscillation of an ideally matched dart allows it to spring away from the engaging hook at a critical moment, after maximum acceleration of the spearthrower, that adds to its overall efficiency (Cundy 1989:64-69; Perkins 1992).

In comparison, a similar study involving hand-thrown spears of the same materials, dimensions, and of comparable weights indicates that velocities previously attributed to spearthrower darts (cf., Butler 1975; Bergman, McEwen and Miller 1988; Carrère and Lepetz 1988; Raymond 1986) are in fact attainable without the aid of that device at all (Table 12).

The velocities derived from these experiments were employed as benchmarks for the lithic armature impact experiments which follow. A speed of 25 m/s was chosen to represent javelin impact velocity at a theoretical downrange distance of 15 m, while speeds of 35 m/s and 45 m/s were chosen to represent dart impact velocities at the same range (although tests at 45 m/s were subsequently deemed unnecessary).

Table 12. Descriptive statistics for hand-thrown spear velocity tests as measured 15 m downrange.

Spear Weight (g)	Velocity Range (m/s)	Average Velocity (m/s)	Coefficient of Variation	Standard Error (m/s)	Sample size
221.8	23.9 - 27.1	25.0	0.04	0.28	12
276.9	21.4 - 26.8	24.1	0.07	0.49	12
382.0	21.1 - 26.2	24.2	0.07	0.48	12
500.0	17.2 - 21.3	19.9	0.06	0.33	11
561.3	17.9 - 21.0	19.5	0.06	0.33	11

There is of course no way to know whether these projectile velocity data are representative of a Paleoindian hunter's abilities. Rather, they are accepted as a necessary and reasonable approximation of relevant system parameters, used as experimental controls, that allow comparison between technologies.

Fracture Velocity Experiments

A series of controlled experiments were conducted to assess the range of fracture velocities associated with lithic bifacial points used to arm spears, javelins and darts. In order to achieve repeatability during the experiments, some form of mechanism was required to maintain consistency over projectile velocity and target accuracy. A number of options were investigated including the use of a modern, commercial crossbow, and a diver's pneumatic spear gun; neither were found to be powerful enough to launch heavy spearthrower darts at velocities approaching 40 m/s. A gravity-powered, drop-testing apparatus was built and tested, but was deemed unsuitable since the nature of the impact forces were not a reasonable approximation of the desired system. Other devices suffered from similar problems, or were simply impractical.

Failing to locate and adapt any commercially available device, it was necessary to design and build a shooting machine capable of launching heavy darts at a wide range of velocities. The result was essentially a large, mounted crossbow with an adjustable draw length. The main platform, supporting legs, and trigger mechanism were constructed from heavy gauge aluminum by the Simon Fraser University Machine Shop. The fibreglass bow limbs were constructed by bowyer Larry Courchaine of Checkmate Archery, Abbottsford. The machine has a maximum draw weight of approximately 450 lbs, and employs a bowstring of 2.38 mm diameter, 920 lb test stainless steel aircraft cable. A boat trailer winch, mounted at the rear of the main platform, is used to draw the bowstring back to its locked position in the trigger mechanism. Dart velocities are adjusted by altering the position of the trigger mechanism along the main platform, and thereby altering the draw length.

In some experiments, where lower projectile velocities were required, or lighter projectiles were used, a compound bow with a draw weight of 45 lbs was substituted for the shooting machine. Relative consistency was achieved by marking the dart or arrow shafts with the desired draw length necessary to produce a specific velocity.

Dart velocity was measured with a customized archery Speedtach chronometer, manufactured by Custom Chronometer of Sumas, Washington. This photo-electric device is designed to measure projectile velocities ranging from those of arrows, to small-caliber firearms, and is accurate to one foot per second (approximately 0.3 m/s). The

Speedtach was optimized for these experiments by the manufacturer to accurately measure spear velocities as low as approximately 36 feet per second (11 m/s), which are normally below the Speedtach's accurate range.

In removing the projectiles from their normal system of operation and employing the shooting machine, or compound bow, several important benefits were realized. The most important of these was a relatively precise control over the flight path of the projectile. A major disadvantage of the spearthrower is that at close range the device is not very accurate. This is due largely to extreme flexure of the dart shaft during the initial stages of the throw. After release the dart shaft continues to oscillate throughout its flight, but at a greatly reduced amplitude after the first several metres. This created three major problems which were solved by employing the shooting machine and compound bow. First, the test range would need to be very long in order to give the dart shafts enough time to settle into relatively stable flight. This also meant that the Speedtach could be no closer than approximately 10 m since the oscillating shafts would strike the sky-screen windows of the photo-sensors. This created a second problem in that, at that distance, the Speedtach itself was at great risk of being severely damaged by an errant shot. The third problem was that longer ranges would require the use of much larger targets to prevent accidental damage to the test armatures.

The shooting machine does not seem to impart as much flexure to the dart shafts as the spearthrower does, perhaps since the dart is restricted from reflexing by the platform of the machine itself. Regardless, the accuracy of the system is sufficient to clear the sky-screens of the Speedtach, and to target an area approximately five centimeters in diameter at a range of four metres. The actual distance from the shooting machine to the target was kept to a minimum, dictated by the lengths of the projectile and the Speedtach housing. For example, the shooting machine and the target were both spaced approximately one projectile length from opposite ends of the Speedtach. This permits the velocity of the projectile to be measured after complete acceleration (i.e., after the projectile has separated from the bowstring). For practical purposes, a little extra distance was afforded between the Speedtach and target to prevent damage to the chronometer from a rebounding projectile. In most cases, therefore, the range from bowstring to target was limited to approximately three and one half meters. The stable flight, and accuracy of the device, also permitted the use of much smaller targets. Except where otherwise noted, targets for the controlled experiments consisted of several layers of fresh beef ribs supported by straw-bail backstops.

A brief series of 12 trial shots employing a 230 g dart suggests that shooting machine velocities are consistent to within a range of five feet per second at an average velocity of 119.7 feet per second (36.5 m/s). Recorded velocities ranged from 118 feet per second (36.0 m/s) to 123 feet per second (37.5 m/s) (coefficient of variation = 0.01; standard error = 0.41). Similar consistency was observed during the armature fracture velocity experiments.

The darts employed in these experiments were identical to those used in the dart and javelin velocity experiments. They were of two-piece construction consisting of a fletched, 122 cm long mainshaft and a 40 cm foreshaft, both of 1.3 cm diameter dry hemlock. A 7.6 cm length of PVC tubing with a 1.2 cm inside-diameter was used to connect the slightly tapered mainshafts and foreshafts. When required, weights were made from various lengths of 1.35 cm inside-diameter copper tubing, slipped over the foreshaft and shaft, and secured with friction tape.

During the production of dart armatures, the aim was to fashion fluted Clovis point replicas. Since a large number of points were necessary to complete these experiments, rather than discard usable points that did not conform with the Clovis template due to mistakes during manufacture, a variety of styles and sizes were ultimately employed. In addition, points were often recycled after being used and damaged, producing smaller points, sometimes fluted, sometimes not. All spear, javelin, and dart armatures were fashioned from Glass Butte obsidian.

Results of the Dart Armature Lithic Fracture Velocity Tests

Darts ranging from 166.7 g to 295.6 g ($\bar{x}$ = 243.8 g) were employed for this series of projectile armature fracture velocity experiments. Projectile velocities for the dart tests averaged 35.6 m/s (s = 1.44 m/s; coefficient of variation = 0.04). Kinetic energies ranged from 116.5 Joules to 165.1 Joules ($\bar{x}$ = 147.0 Joules). Fracture velocity data recovered from 53 dart armatures (Tables 13 and 14) produced $\dot{C}/C_2$ ratios ranging from 0.12 to 0.58, indicating fracture velocities spanning the rapid (38%) and dynamic (62%) loading rate regimes (Figure 14). Summary statistics for dart armature fracture velocities are presented in Table 15. The distribution of fracture velocities associated with dart impacts is presented in Figure 15.

The fact that high-speed projectile impacts do not always produce dynamic regime fractures indicates that the documenting of fracture velocity data for a single point may be insufficient to identify the technological cause of a fracture. Note that the $\dot{C}/C_2$ ratios derived from the dart tests which reflect rapid loading rates actually span the full range of fracture velocities associated with stone tool manufacture. This suggests that the impact fracturing of lithic projectiles is a complex process which involves more than just those fractures caused by the extreme force of sudden impact. In fact, an examination of highly fragmented points suggests that a series of subsequent fractures may occur after the initial impact. These may range from percussion fractures to actual pressure fractures as broken and shattered armature fragments are pressed into one another during the later stages of target penetration. It is, therefore, theoretically possible to document a broad range of $\dot{C}/C_2$ ratios from different fracture surfaces among the fragments of a single dart armature that might span the entire range of fracture velocities associated with dart impacts.

Table 13. Dart armature fracture velocity ($\dot{C}$) data from the controlled impact experiments. C_2 is based on Glass Butte obsidian at 3865 m/s.

Lithic Reference	Length (cm)	Width (cm)	Thickness (cm)	Weight (g)	Target Material	Projectile Velocity (m/s)	Projectile Weight (g)	Kinetic Energy (Joules)	Angular Measure	% T.C. Length	$\dot{C}/C_2$	$\dot{C}$ (m/s)
63	8.7	3.8	0.8	25.7	beef rib	36.9	231.0	157.3	166.5	70	0.12	454
106	8.2	4.3	0.8	29.9	beef rib	35.4	232.8	145.9	164.8	40	0.13	511
110	8.0	3.9	0.9	28.6	beef rib	35.7	230.9	147.1	159.8	67	0.18	678
65	8.3	2.7	0.9	21.0	beef rib	34.4	226.1	133.8	158.0	NA	0.19	737
57	8.9	3.3	1.0	29.1	beef rib	37.2	238.6	165.1	157.0	32	0.20	771
58	8.1	3.7	0.9	27.3	beef rib	37.2	230.3	159.3	155.6	38	0.21	817
69	6.8	3.9	0.9	24.5	beef rib	36.3	230.0	151.5	153.0	46	0.23	902
61	7.4	3.4	1.0	22.6	beef rib	36.6	228.4	153.0	152.8	NA	0.24	909
68	7.1	5.4	0.9	27.0	beef rib	33.6	229.6	129.6	147.0	~ 57	0.28	1098
73	7.5	5.1	0.9	34.2	beef rib	33.5	236.0	132.4	146.3	NA	0.29	1120
80	7.1	3.3	0.7	17.9	beef rib	37.8	219.4	156.7	145.7	47	0.29	1140
71	6.5	3.2	1.0	22.5	beef rib	36.0	227.6	147.5	143.3	NA	0.31	1217
100	9.6	3.8	1.1	36.2	beef rib	34.1	237.4	138.0	138.8	58	0.35	1360
67	7.5	4.3	0.8	23.8	beef rib	36.6	225.5	151.0	138.3	NA	0.36	1376
1	9.8	4.0	0.9	43.8	beef rib	34.1	205.0	119.2	137.0	10	0.37	1417
62	9.1	3.6	0.9	28.4	beef rib	36.9	229.4	156.2	130.7	67	0.42	1612
113	10.7	4.3	0.8	44.5	beef rib	35.1	247.0	152.2	130.3	47	0.42	1624
77	7.8	3.3	0.8	19.7	beef rib	37.5	224.1	157.6	129.3	91	0.43	1655
2	6.4	2.5	0.8	13.0	beef rib	37.5	166.7	117.2	129.0	44	0.43	1664
157	12.3	4.3	1.1	46.2	beef rib	35.1	248.9	153.3	124.7	32	0.46	1794
64	9.1	3.2	0.9	25.3	beef rib	36.3	231.0	152.2	122.3	<20	0.48	1865
66	7.6	4.3	0.8	28.9	beef rib	36.6	232.4	155.7	122.0	~ 80	0.48	1874
161	8.5	4.2	1.0	35.6	beef rib	36.0	238.9	154.8	121.0	NA	0.49	1903
158	9.4	3.9	0.8	42.1	beef rib	36.0	242.7	157.3	119.5	61	0.50	1947
59	9.6	3.7	0.8	28.6	beef rib	33.5	237.1	133.0	119.3	NA	0.51	1953
102	8.0	4.4	0.9	35.6	beef rib	34.7	237.7	143.1	118.7	68	0.51	1970

Table 13 (continued). Dart armature fracture velocity ($\dot{C}$) data from the controlled impact experiments. C_2 is based on Glass Butte obsidian at 3865 m/s.

Lithic Reference	Length (cm)	Width (cm)	Thickness (cm)	Weight (g)	Target Material	Projectile Velocity (m/s)	Projectile Weight (g)	Kinetic Energy (Joules)	Angular Measure	% T.C. Length	$\dot{C}/C_2$	$\dot{C}$ (m/s)
107	11.5	4.1	0.9	42.3	beef rib	35.1	245.1	151.0	115.8	45	0.53	2054
70	7.5	3.2	0.8	20.2	beef rib	37.2	223.9	154.9	115.7	39	0.53	2057
60	8.0	3.6	0.7	22.5	granite	35.7	227.4	144.9	114.4	NA	0.54	2094
74	10.7	2.9	1.0	33.6	beef rib	31.1	240.8	116.5	114.0	near term.	0.54	2105
105	10.6	4.4	1.0	49.1	beef rib	34.7	252.3	151.9	113.3	~ 44	0.55	2125
78	7.5	3.1	0.9	19.7	beef rib	36.6	224.1	150.1	112.7	29	0.55	2142
108	8.4	3.9	0.9	38.0	beef rib	35.7	240.1	153.0	110.8	63	0.57	2195
109	10.7	4.1	0.8	37.8	beef rib	35.4	241.0	151.0	110.0	45	0.57	2217
103	11.7	3.5	1.0	43.4	beef rib	35.1	245.7	151.4	109.5	45	0.58	2231

Table 14. Dart armature fracture velocity ($\dot{C}$) data from the manual impact experiments. Projectile velocity was not recorded. C_2 is based on Glass Butte obsidian at 3865 m/s.

Lithic Reference	Length (cm)	Width (cm)	Thickness (cm)	Weight (g)	Target Material	Projectile Weight (g)	Angular Measure	% T.C. Length	$\dot{C}/C_2$	$\dot{C}$ (m/s)
16	6.7	3.0	0.6	13.8	beef rib	259.7	156.2	48	0.21	797
5	12.0	4.4	1.0	48.4	beef rib	293.9	155.7	61	0.21	813
27	8.0	3.7	0.9	28.5	quartzite	274.5	148.5	24	0.27	1049
48	12.7	3.9	1.1	37.0	beef rib	239.2	146.6	52	0.29	1111
26	10.9	3.9	1.0	44.4	quartzite	290.3	135.9	42	0.38	1451
23	10.2	3.9	0.9	37.0	quartzite	283.1	134.9	37	0.38	1482
46	9.8	4.0	1.0	48.4	beef rib	260.4	134.7	48	0.39	1488
39	7.6	3.2	0.7	20.8	beef rib	231.8	129.8	61	0.42	1640
36	7.8	4.1	0.9	22.7	beef rib	232.7	128.3	47	0.44	1685
54	8.6	5.2	1.2	50.0	beef rib	260.8	126.8	54	0.45	1731
51	9.1	3.6	0.9	28.4	beef rib	239.5	125.0	41	0.46	1785
22	8.9	4.1	0.9	39.2	quartzite	285.1	120.2	45	0.50	1927

Table 14 (continued). Dart armature fracture velocity ($\dot{C}$) data from the manual impact experiments. Projectile velocity was not recorded. C_2 is based on Glass Butte obsidian at 3865 m/s.

Lithic Reference	Length (cm)	Width (cm)	Thickness (cm)	Weight (g)	Target Material	Projectile Weight (g)	Angular Measure	% T.C. Length	$\dot{C}/C_2$	$\dot{C}$ (m/s)
24	10.2	4.0	1.1	41.1	quartzite	287.4	117.3	NA	0.52	2011
18	9.9	3.8	1.0	37.7	beef rib	283.8	117.0	42	0.52	2019
19	10.6	4.3	1.1	34.5	beef rib	281.7	116.9	47	0.52	2022
17	8.6	3.4	1.0	27.8	beef rib	273.8	116.7	37	0.52	2028
28	10.6	4.2	1.0	49.2	quartzite	295.6	116.3	~ 54	0.53	2040
42	8.8	3.3	1.1	30.7	beef rib	242.0	113.8	NA	0.55	2111

During these experiments, armatures that may have penetrated several inches of flesh, but failed to contact bone were rarely damaged. The beef rib target lacks the hair and hide of a real animal target, and one can only speculate on how this might affect the experimental results.

Darts used for hunting may be expected to miss their target occasionally by mistake. As a means of exploring the effect that target density may have on dynamic fracture, a limited series of tests were made employing a stone target rather than beef ribs. Six of the darts included in these tests were shot into a quartzite target by hand, using the same spearthrower employed in the dart velocity experiments; projectile velocities were not recorded. These darts ranged from 274.5 g to 295.6 g. A seventh dart, weighing 227.4 g, was shot into a granite target at 35.7 m/s using the shooting machine. In most cases, the lithic armatures were shattered, and the foreshafts severely damaged. Interestingly, $\dot{C}/C_2$ ratios for these tests range from 0.27 to 0.54; completely within the normal range of

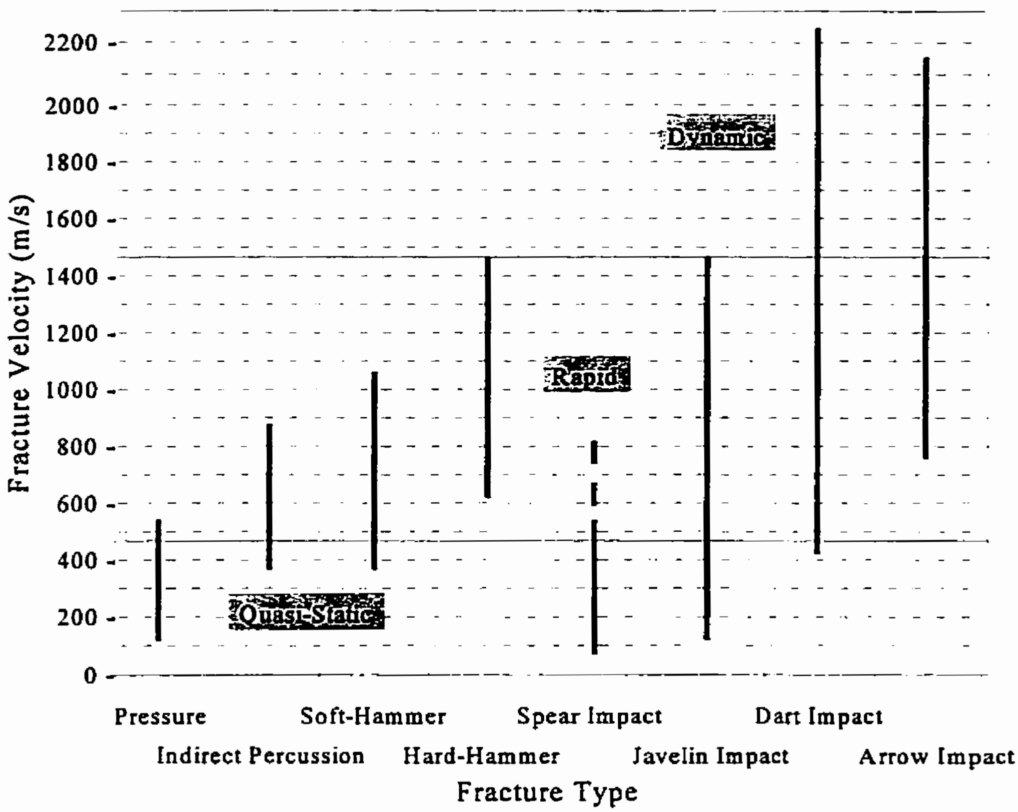


Figure 14. Comparison of experimental lithic fracture velocity ranges associated with various reduction (manufacturing) technologies and armature impacts. Fracture velocities are based on a C_2 value of 3865 m/s for Glass Butte obsidian.

fracture velocities associated with the softer beef rib targets. While the sample is very small, it suggests that target density may have a much reduced effect on fracture velocities in the dynamic regime than was observed for the quasi-static and rapid regimes during the manufacturing experiments.

Table 15. Basic descriptive statistics for armature fracture velocities ($\dot{C}$).

	Darts	Arrows	Javelins	Spears	Dropped
Sample Size:	53	15	45	32	15
Minimum:	454.28	770.56	101.17	77.57	544.58
Maximum:	2230.67	2175.24	1472.84	813.47	1385.09
Average:	1561.77	1453.54	922.27	355.16	1076.91
Median:	1663.93	1479.07	908.82	357.01	1178.30
Standard Deviation:	513.75	417.32	329.55	175.24	267.42
Standard Error:	70.57	107.75	49.13	30.98	69.05
Skewness:	-0.57	-0.31	-0.17	0.43	-0.66
Coefficient of Variation:	0.33	0.29	0.36	0.49	0.25

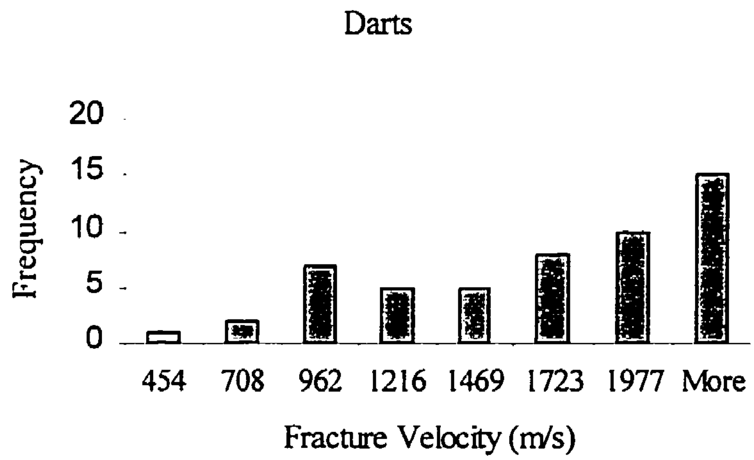


Figure 15. Frequency distribution of dart armature fracture velocity ($\dot{C}$) data. Note truncation at the upper end of the distribution, and the considerable negative skew.

Results of the Javelin Armature Lithic Fracture Velocity Tests

Javelins ranging from 137.4 g to 296.4 g ($\bar{x}$ = 192.7 g) were employed for this series of projectile armature fracture velocity experiments. Projectile velocities for the javelin tests averaged 25.1 m/s (s = 0.57 m/s; coefficient of variation = 0.02). Kinetic energies ranged from 43.3 Joules to 97.0 Joules ($\bar{x}$ = 60.8 Joules). Fracture velocity data recovered from 45 javelin armatures (Table 16) produced $\dot{C}/C_2$ ratios ranging from 0.03 to 0.38, indicating fracture velocities spanning the quasi-static (4.4%), rapid (91.2%), and dynamic (4.4%) loading rate regimes (Figure 14). Notably, only two javelin armatures produced fracture velocities in the dynamic regime, and both were borderline, with $\dot{C}/C_2$ ratios of 0.38. Summary statistics for javelin armature fracture velocities are presented in Table 15. The distribution of fracture velocities associated with javelin impacts is presented in Figure 16.

As with the dart tests, a series of 10 shots were made employing denser targets of granite and quartzite rather than beef ribs. These javelins ranged from 145.8 g to 242.2 g, and were fired under controlled conditions at velocities averaging 24.9 m/s. In most cases, the lithic armatures were shattered, and the foreshafts severely damaged. The $\dot{C}/C_2$ ratios for these tests range from 0.17 to 0.38, which is within the normal range of javelin armature fracture velocities associated with the softer beef rib targets. This again suggests that target density may have a reduced effect on fracture velocities even at the upper range of the rapid regime. More importantly, it suggests that regardless of the target, whether intentional or accidental, most lithic fracture velocities for javelin armatures will not exceed those of the rapid loading regime.

Table 16. Javelin armature fracture velocity ($\dot{C}$) data from the controlled impact experiments. C_2 is based on Glass Butte obsidian at 3865 m/s.

Lithic Reference	Length (cm)	Width (cm)	Thickness (cm)	Weight (g)	Target Material	Projectile Velocity (m/s)	Projectile Weight (g)	Kinetic Energy (Joules)	Angular Measure	% T.C. Length	$\dot{C}/C_2$	$\dot{C}$ (m/s)
188	7.5	3.0	0.9	18.6	beef rib	25.6	143.6	47.1	177.0	57	0.03	101
180	5.8	2.6	0.8	12.0	beef rib	26.2	149.2	51.2	171.8	31	0.07	276
266	7.5	3.2	0.7	18.5	beef rib	25.9	165.4	55.5	165.7	~73	0.12	481
176	5.1	2.8	0.7	10.9	beef rib	23.8	152.9	43.3	165.5	43	0.13	488
217	6.6	3.3	0.8	17.3	beef rib	25.3	156.1	50.0	163.3	15	0.15	561
84	6.4	2.7	0.9	15.6	beef rib	25.6	153.5	50.3	163.0	NA	0.15	571
164	9.5	3.6	0.8	27.4	beef rib	25.0	171.5	53.6	162.5	50	0.15	588
93	11.1	4.4	1.1	49.9	beef rib	24.7	296.4	90.4	162.0	44	0.16	605
275	6.2	2.7	0.8	15.3	beef rib	25.0	152.9	47.8	161.7	NA	0.16	615
170	8.0	3.6	0.7	21.3	beef rib	25.3	164.5	52.6	161.7	~50	0.16	615
178	4.6	2.5	0.7	8.1	granite	24.1	153.3	44.5	160.6	41	0.17	651
181	4.9	2.3	0.9	10.6	granite	25.0	152.2	47.6	159.9	NA	0.17	674
190	5.5	4.1	0.8	18.6	beef rib	25.6	143.1	46.9	159.3	50	0.18	694
168	9.7	4.3	1.0	44.5	beef rib	25.0	182.0	56.9	158.1	47	0.19	734
55	8.5	6.1	1.1	47.4	beef rib	24.4	258.3	76.9	158.0	58	0.19	737
37	7.9	5.0	0.9	28.0	beef rib	25.9	239.2	80.2	157.8	43	0.19	744
89	4.0	2.0	0.7	5.3	granite	25.0	148.1	46.3	155.7	>60	0.21	813
218	6.3	3.0	0.7	15.7	beef rib	25.9	149.5	50.1	155.0	NA	0.22	837
50	12.8	4.1	1.1	48.9	beef rib	24.7	248.9	75.9	154.3	~45	0.22	860
189	5.3	4.8	0.7	16.4	beef rib	25.9	137.4	46.1	154.2	52	0.22	863
219	6.1	3.1	0.6	12.5	beef rib	25.0	149.9	46.8	153.8	50	0.23	876
163	4.4	3.0	0.6	8.5	granite	25.3	145.8	46.7	153.8	53	0.23	876
52	9.1	3.4	1.1	39.4	beef rib	24.7	250.6	76.4	152.8	44	0.24	909
86	6.1	2.8	0.7	13.5	beef rib	25.6	151.1	49.5	151.8	NA	0.24	942
90	6.3	3.1	0.6	13.6	beef rib	25.6	153.0	50.1	151.8	NA	0.24	942
177	4.5	2.4	0.7	7.7	granite	24.7	149.8	45.7	151.7	NA	0.24	945

Table 16 (continued). Javelin armature fracture velocity ($\dot{C}$) data from the controlled impact experiments. C_2 is based on Glass Butte obsidian at 3865 m/s.

Lithic Reference	Length (cm)	Width (cm)	Thickness (cm)	Weight (g)	Target Material	Projectile Velocity (m/s)	Projectile Weight (g)	Kinetic Energy (Joules)	Angular Measure	% T.C. Length	$\dot{C}/C_2$	$\dot{C}$ (m/s)
43	7.9	3.6	0.9	27.3	beef rib	25.0	237.6	74.2	150.3	54	0.26	991
187	6.7	3.9	0.7	19.0	beef rib	25.6	146.0	47.8	149.2	25	0.27	1026
53	9.8	4.8	1.2	52.2	beef rib	25.0	264.6	82.7	148.0	NA	0.28	1065
265	8.1	2.9	0.9	22.1	beef rib	24.4	164.5	49.0	147.2	NA	0.28	1091
179	4.8	2.8	0.7	9.0	granite	25.0	146.6	45.8	146.2	NA	0.29	1124
87	4.7	2.8	0.7	10.0	granite	24.1	157.5	45.7	146.0	NA	0.29	1130
94	10.7	4.2	1.0	49.2	beef rib	25.6	296.0	97.0	146.0	39	0.29	1130
44	10.7	3.3	1.0	38.8	beef rib	25.3	243.8	78.0	145.3	~ 50	0.30	1153
85	6.7	2.7	0.7	14.1	beef rib	25.0	156.1	48.8	145.2	NA	0.30	1156
135	10.9	3.7	1.1	43.0	beef rib	24.4	289.4	86.1	143.4	39	0.31	1214
38	7.2	3.8	0.9	25.8	beef rib	25.0	235.1	73.5	142.5	33	0.32	1242
41	9.6	3.9	0.8	29.5	quartzite	25.3	239.5	76.7	140.8	36	0.34	1297
49	8.2	3.6	0.9	28.1	beef rib	25.3	241.9	77.4	139.5	NA	0.35	1338
47	9.1	3.7	0.9	29.9	quartzite	25.6	242.2	79.4	139.5	NA	0.35	1338
273	5.0	2.8	0.8	13.8	beef rib	24.4	156.4	46.6	137.8	~ 44	0.36	1391
40	10.1	3.7	1.0	36.1	beef rib	25.9	243.3	81.6	136.8	53	0.37	1423
83	6.9	2.3	0.9	14.4	granite	25.0	154.9	48.4	135.8	NA	0.38	1454
45	9.6	4.1	0.9	47.2	beef rib	24.4	257.9	76.8	135.3	64	0.38	1470
95	9.5	3.7	0.9	33.3	beef rib	25.9	279.8	93.8	135.2	47	0.38	1473

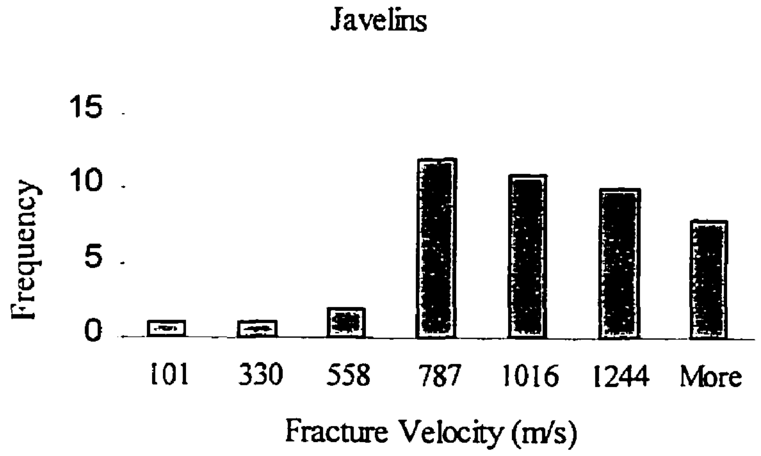


Figure 16. Frequency distribution of javelin armature fracture velocity ($\dot{C}$) data.

Results of the Spear Armature Lithic Fracture Velocity Tests

Spears ranging from 257.7 g to 335.3 g ($\bar{x}$ = 283.9 g) were employed for this series of armature fracture velocity experiments. Spears were thrust manually, with as much force as possible, into beef rib targets. Fracture velocity data recovered from 32 spear armatures (Table 17) produced $\dot{C}/C_2$ ratios ranging from 0.02 to 0.21, indicating fracture velocities spanning the quasi-static (56%) and rapid (44%) loading rate regimes (Figure 14). Again, none of the spear armatures produced fracture velocities in the dynamic regime. In fact, 84% (27 of 32) produced fracture velocities within the range of those observed for pressure flaking. Summary statistics for spear armature fracture velocities are presented in Table 15. The distribution of fracture velocities associated with spear impacts is presented in Figure 17.

Almost all impact fractures generated during this series of tests were of the large, tip-fracture type, best described as a flute-like fracture. While some of these tended to be narrow and long, most were broad and relatively indistinguishable from a true flute, if not for the location of their origin.

Table 17. Spear armature fracture velocity ($\dot{C}$) data from the manual impact experiments. Projectile velocity was not recorded. C_2 is based on Glass Butte obsidian at 3865 m/s.

Lithic Reference	Length (cm)	Width (cm)	Thickness (cm)	Weight (g)	Target Material	Projectile Weight (g)	Angular Measure	% T.C. Length	$\dot{C}/C_2$	$\dot{C}$ (m/s)
197	10.6	4.5	1.2	58.4	beef rib	303.9	177.7	58	0.02	78
182	12.1	5.5	1.4	89.4	beef rib	335.3	176.5	43	0.03	118
191	9.1	3.6	1.0	33.0	beef rib	283.5	176.3	63	0.03	125
264	9.6	3.6	0.8	29.8	beef rib	271.8	175.7	68	0.04	145
166	7.7	3.3	0.8	19.3	beef rib	263.9	175.5	50	0.04	152
183	11.5	4.6	1.3	60.0	beef rib	311.3	174.7	35	0.05	179
152	10.2	3.9	0.9	37.0	beef rib	282.9	174.5	31	0.05	185
172	5.0	3.8	0.8	12.9	beef rib	258.6	174.2	56	0.05	196
153	10.2	4.0	1.1	41.1	beef rib	286.9	173.7	64	0.05	212
173	5.8	3.5	0.8	16.1	beef rib	261.0	173.3	50	0.06	226
112	8.7	4.2	1.1	43.8	beef rib	288.2	173.0	NA	0.06	236
155	8.0	3.7	0.9	28.5	beef rib	275.1	172.5	56	0.07	253
167	10.6	4.2	1.0	49.2	beef rib	294.5	172.4	54	0.07	256
154	10.9	3.9	1.0	44.4	beef rib	290.1	170.5	64	0.08	320
175	5.6	2.7	0.7	13.8	beef rib	258.9	170.0	~40	0.09	337
202	6.9	3.4	0.8	18.7	beef rib	263.7	170.0	~59	0.09	337
165	8.6	2.9	1.0	24.1	beef rib	268.8	168.8	~42	0.10	377
169	8.3	4.3	1.1	38.0	beef rib	283.5	168.7	~41	0.10	381
204	6.3	3.1	0.6	13.4	beef rib	257.7	168.3	~50	0.10	394
151	8.9	4.1	0.9	39.2	beef rib	284.7	168.2	63	0.10	397
203	6.4	3.1	0.8	16.5	beef rib	260.9	167.2	~43	0.11	431
184	9.7	4.9	1.3	54.7	beef rib	300.8	166.8	57	0.11	444

Table 17 (continued). Spear armature fracture velocity ($\dot{C}$) data from the manual impact experiments. Projectile velocity was not recorded. C_2 is based on Glass Butte obsidian at 3865 m/s.

Lithic Reference	Length (cm)	Width (cm)	Thickness (cm)	Weight (g)	Target Material	Projectile Weight (g)	Angular Measure	% T.C. Length	$\dot{C}/C_2$	$\dot{C}$ (m/s)
111	7.7	4.3	1.0	33.3	beef rib	278.7	166.5	NA	0.12	454
195	10.7	4.6	1.3	58.5	beef rib	303.8	165.7	NA	0.12	481
196	11.7	4.0	1.1	51.1	beef rib	296.4	164.5	NA	0.13	521
185	9.8	4.8	1.2	52.2	beef rib	297.9	164.3	41	0.14	528
199	11.3	4.2	1.1	56.2	beef rib	301.0	164.3	58	0.14	528
174	5.6	3.4	0.6	13.5	beef rib	259.3	163.8	54	0.14	545
104	10.4	4.6	1.3	55.6	beef rib	300.8	163.7	~ 54	0.14	548
101	10.3	3.8	1.1	42.6	beef rib	287.8	163.5	48	0.14	555
193	8.4	3.6	1.0	31.4	beef rib	276.8	161.7	NA	0.16	615
194	11.7	4.0	1.1	51.6	beef rib	296.9	155.7	57	0.21	813

My expectations had been that there would be relatively little difference between the fracture velocities associated with spears and javelins, but in retrospect, two important factors offer probable explanations for the differing results. The first is that a javelin throw benefits from a higher velocity impact as a result of the wrist rotation associated with throwing (Cooper & Glassow 1968:122), whereas the velocity of the spear comes mainly from the relatively slow acceleration of the forearm and shoulder.

The second factor may be a direct result of the nature of the loading event itself. Unlike a projectile which relies on its own momentum to penetrate a target and is spent after impact, the thrusting action associated with the spear is continuous. The user maintains the thrust through contact with the shaft until the extent of the thrust is reached,

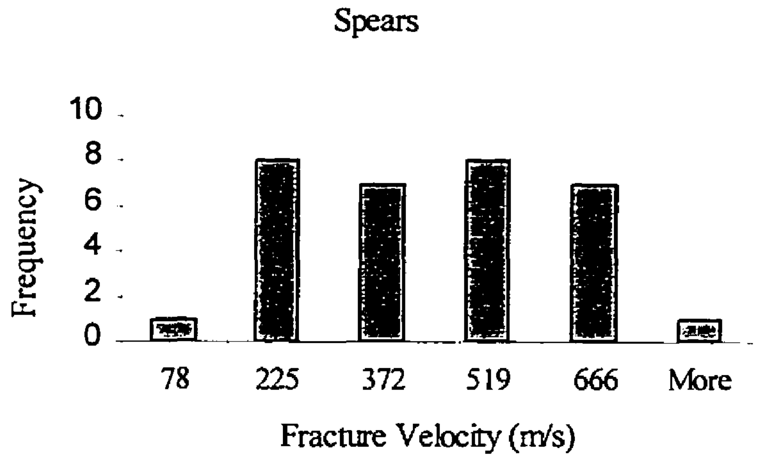


Figure 17. Frequency distribution of spear armature fracture velocity ($\dot{C}$) data.

or the tip is stopped by contact with bone. The result is that when bone is struck, the contact is followed by momentary continued pressure as the user attempts to complete the thrust. This may explain why most thrusting spear impacts reflect quasi-static loading rates (i.e., resulting in pressure-type fractures), rather than loading rates in the rapid regime.

Results of the Arrow Armature Lithic Fracture Velocity Tests

A series of tests were conducted on arrow armatures to explore the effects that projectile velocity versus kinetic energy might have on lithic fracture velocity. The intent here is to explore the nature of brittle fracture in projectile armatures, and not to imply that the bow and arrow may have been in use during the Paleoindian period.

Most of the light-weight projectiles employed in the arrow tests consisted of smaller armatures mounted on 9 mm diameter tapered hemlock foreshafts (15 cm in length), connected to 9 mm diameter socketed pine shafts (80 cm in length). Others were mounted directly to the pine shafts (80 cm in length). Completed arrows ranged from 44.5 g to 55.8 g ($\bar{x}$ = 49.8 g) and were fired into beef rib targets with a 45 lb draw weight compound bow. Projectile velocities ranged from 33.5 m/s to 46.6 m/s ($\bar{x}$ = 39.2 m/s). Kinetic energies ranged from 30.0 Joules to 48.3 Joules ($\bar{x}$ = 38.2 Joules). Fracture velocity data recovered from 15 arrow armatures (Table 18) produced $\dot{C}/C_2$ ratios ranging from 0.20 to 0.56, indicating fracture velocities spanning the rapid (46.7%) and dynamic (53.3%) loading rate regimes (Figure 14). Summary statistics for arrow armature fracture velocities are presented in Table 15. The distribution of fracture velocities associated with arrow impacts is presented in Figure 18.

Fracture velocity data recovered from the arrow armatures compare favorably with that of the darts. Considering that kinetic energies for the arrows were less than one third that of the darts, and approximately half that of the javelins, one must conclude that impact velocity is the essential variable affecting fracture velocity, rather than kinetic energy.

Table 18. Arrow armature fracture velocity ($\dot{C}$) data from the controlled impact experiments. C_2 is based on Glass Butte obsidian at 3865 m/s.

Lithic Reference	Length (cm)	Width (cm)	Thickness (cm)	Weight (g)	Target Material	Projectile Velocity (m/s)	Projectile	Kinetic Energy (Joules)	Angular Measure	% T.C. Length	$\dot{C}/C_2$	$\dot{C}$ (m/s)
35	6.5	2.9	0.7	13.2	beef rib	33.5	54.5	30.6	157.0	13	0.20	771
25	6.6	3.0	0.7	13.9	beef rib	34.1	55.8	32.4	156.0	50	0.21	804
9	4.7	2.5	0.6	6.5	beef rib	45.4	44.6	46.0	155.0	41	0.22	837
21	4.6	2.6	0.6	8.2	beef rib	40.2	50.0	40.4	144.0	30	0.31	1194
20	4.4	2.4	0.7	7.5	beef rib	42.4	50.0	44.9	141.0	60	0.33	1290
11	6.2	3.0	0.7	13.2	beef rib	41.1	54.0	45.6	137.0	18	0.37	1417
30	4.0	2.0	0.7	5.3	beef rib	38.7	47.1	35.3	136.0	15	0.37	1448
29	3.6	2.0	0.5	3.5	beef rib	37.2	45.3	31.3	135.0	55	0.38	1479
6	4.3	2.5	0.6	6.9	beef rib	46.6	44.5	48.3	133.0	33	0.40	1541
31	4.4	2.2	0.6	6.4	beef rib	37.5	48.2	33.9	130.0	60	0.42	1633
7	5.0	2.4	0.5	6.3	beef rib	46.0	44.5	47.1	128.5	NA	0.43	1679
34	5.7	2.9	0.7	11.9	quartzite	33.5	53.6	30.1	123.6	NA	0.47	1826
10	7.0	2.7	0.8	14.2	beef rib	42.4	52.3	47.0	123.0	50	0.48	1844
32	4.1	2.9	0.6	7.0	quartzite	35.4	48.6	30.5	122.3	NA	0.48	1865
33	6.4	2.7	0.8	12.2	quartzite	33.5	53.4	30.0	111.5	NA	0.56	2175

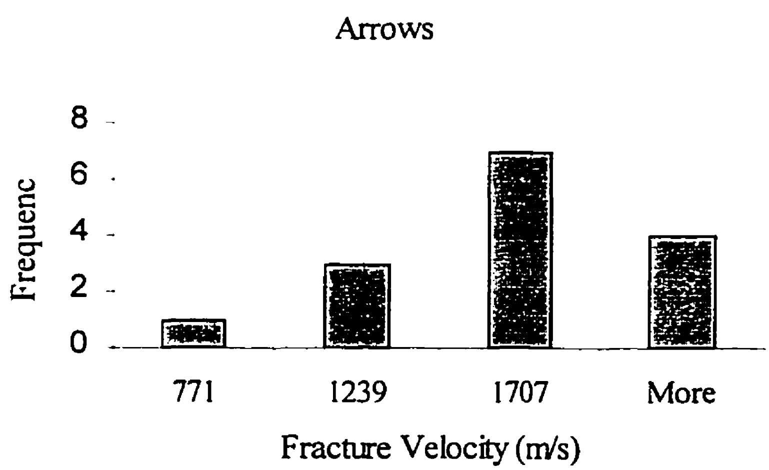


Figure 18. Frequency distribution of arrow armature fracture velocity ($\dot{C}$) data.

Results of the Dropped Armature Lithic Fracture Velocity Tests

It is reasonable to expect that projectile armatures, either hafted or un-hafted, were occasionally subjected to accidental abuse by their prehistoric owners. The most probable area of impact for a hafted armature would be the distal lateral margins and tip, and this may result in damage morphologically indistinguishable from intentional use. A series of tests were therefore conducted to explore the effects of accidental dropping of armatures onto a hard surface.

All armatures were hafted as spearthrower darts, and dropped from a height of two metres, tip first, onto an andesite boulder. Their velocity upon impact was estimated at 6.3 m/s. Total weights ranged from 225.3 g to 244.6 g ($\bar{x}$ = 232.1 g), and their kinetic energies ranged from 4.4 Joules to 4.8 Joules. Most damage was in the form of classic tip fractures; a single armature was shattered, and two suffered burinated lateral margins. Fracture velocity data recovered from 15 armatures (Table 19) produced $\dot{C}/C_2$ ratios ranging from 0.14 to 0.36, indicating fracture velocities within the rapid loading rate regime. Summary statistics for dropped armature fracture velocities are presented in Table 15. The distribution of fracture velocities associated with drop impacts is presented in Figure 19.

Table 19. Dropped armature fracture velocity ($\dot{C}$) data from the controlled impact experiments. C_2 is based on Glass Butte obsidian at 3865 m/s.

Lithic Reference	Length (cm)	Width (cm)	Thickness (cm)	Weight (g)	Target Material	Projectile	Projectile Weight (g)	Kinetic Energy (Joules)	Angular Measure	% T.C. Length	$\dot{C}/C_2$	$\dot{C}$ (m/s)
D13	8.5	3.8	0.8	25.2	andesite	6.3	232.4	4.6	163.8	59	0.14	545
D14	7.6	3.9	0.8	27.8	andesite	6.3	232.9	4.6	158.5	NA	0.19	721
D10	7.1	4.4	0.9	27.4	andesite	6.3	231.0	4.5	157.5	50	0.20	754
D7	8.2	3.6	0.8	22.7	andesite	6.3	228.8	4.5	154.8	NA	0.22	843
D1	6.8	4.0	0.9	25.1	andesite	6.3	231.4	4.5	153.5	51	0.23	886
D11	9.4	3.6	0.8	26.9	andesite	6.3	238.5	4.7	150.1	NA	0.26	997
D12	7.6	4.4	1.0	28.6	andesite	6.3	236.5	4.6	146.3	NA	0.29	1120
D5	6.5	3.2	1.0	22.5	andesite	6.3	230.3	4.5	144.5	42	0.30	1178
D9	7.4	3.4	1.0	23.0	andesite	6.3	231.1	4.5	143.0	NA	0.32	1226
D4	9.3	3.3	1.0	25.6	andesite	6.3	232.4	4.6	142.4	~65	0.32	1246
D15	7.5	3.3	0.9	23.8	andesite	6.3	225.3	4.4	142.2	~21	0.32	1252
D8	8.3	4.3	1.1	38.5	andesite	6.3	244.6	4.8	141.1	50	0.33	1287
D6	9.1	3.7	0.9	28.9	andesite	6.3	229.9	4.5	139.0	67	0.35	1354
D3	7.7	4.2	0.9	24.7	andesite	6.3	228.2	4.5	138.8	40	0.35	1360
D2	8.7	3.1	0.9	23.1	andesite	6.3	228.8	4.5	138.0	45	0.36	1385
12	5.7	2.3	0.5	8.2	concrete	4.4	46.7	0.5	131.0	80	0.41	1603

An additional experimental arrow armature (number 12) was accidently dropped, tip first, onto a concrete floor from a height of approximately one metre during an unrelated series of tests. The 46.7 g arrow struck the concrete at approximately 4.4 m/s with an estimated kinetic energy of 0.5 Joules. A $\dot{C}/C_2$ ratio of 0.41 was obtained from the fractured tip. Unlike the specimens intentionally dropped during this series of tests, the fracture velocity obtained from the arrow armature lies within the low end of the dynamic loading rate regime. While this may suggest that dynamic fractures are possible on dropped armatures, I do not readily accept this conclusion based on a single data point. It

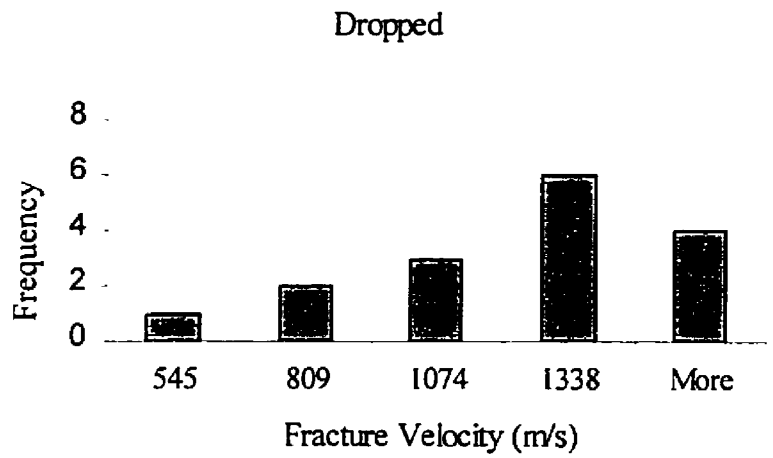


Figure 19. Frequency distribution of dropped armature fracture velocity ($\dot{C}$) data. Note considerable negative skew.

may be significant that this armature had previously been shot several times into a beef rib target without incurring any *observable* damage. In retrospect, it now seems likely that the specimen had been partially (internally) fractured by one of the previous target impacts, and that contact with the concrete floor simply finished the job. This seems a reasonable conclusion considering the data derived from this, and the other low-speed projectile experiments.

Discussion

The results of the lithic fracture velocity experiments clearly indicate that differing projectile technologies expose lithic armatures to loading rates of different magnitudes. Significantly, they demonstrate that the lithic armatures of hand-thrown or thrust weapons incur fractures at rates corresponding to the quasi-static and rapid loading rate regimes, whereas only those lithic armatures propelled at very high speeds, such as those associated with the spearthrower and bow, will incur fractures in the upper range of the dynamic regime. The revised correlation of loading rate regimes and associated lithic reduction technologies may now be modified to include use-damage resulting from armature impacts (Table 20).

Table 20. Revised correlation between loading rate regimes, associated lithic reduction technologies or use-damage type, and maximum instantaneous crack velocities ($\dot{C}$)* based on experimental results.

Loading Rate Regimes	Reduction Technology or Use-damage	$\dot{C}/C_2$	$\dot{C}$ (m/s)
Quasi-static	Pressure (chest)	0.0 - ?	0 - ?
	Spear Armature	0.02 - 0.10	77 - 385
	Pressure (hand)	0.03 - 0.10	115 - 385
	Javelin Armature	0.03 - 0.10	115 - 385
Rapid	Pressure (hand)	0.10 - 0.14	385 - 540
	Spear Armature	0.10 - 0.21	385 - 812
	Indirect Percussion	0.10 - 0.23	385 - 890
	Soft-hammer Percussion	0.10 - 0.28	385 - 1080
	Javelin Armature	0.10 - 0.38	385 - 1470
	Dart Armature	0.12 - 0.38	420 - 1470
	Hard-hammer Percussion	0.16 - 0.38	618 - 1470
	Arrow Armature	0.20 - 0.38	773 - 1470
Dynamic	Arrow Armature	0.38 - 0.56	1470 - 2164
	Dart Armature	0.38 - 0.58	1470 - 2242

*Note that maximum instantaneous crack velocities ($\dot{C}$) have been calculated based on a C_2 value for Glass Butte obsidian at 3865 m/s.

A nonparametric randomization test (Siegel 1956:152-158) was conducted to determine the significance of the difference between the sample means of the experimental data. Despite the overlap in instantaneous crack velocities apparent in

Figure 14, the randomization test amply demonstrates the independence of the samples (Table 21).

Table 21. Combined results of two-tailed randomization test for significant difference between independent samples. Values of p are presented for 10,000 partitions. In all but the darts vs. arrows, and the javelins vs. dropped samples, significant differences are indicated at a confidence level better than 99%.

	Darts	Arrows	Javelins	Spears
Arrows	0.45290	NA		
Javelins	0.00000	0.00000	NA	
Spears	0.00000	0.00000	0.00000	NA
Dropped	0.00120	0.00730	0.10440	0.00000

The fracturing processes incurred during the impact of a weapon armature are much more complex than those of a single manufacturing type of event. During manufacture, a single blow is carefully controlled and aimed by the knapper to strike the core at a specific location, usually with a very small area of contact. The result is generally a single, well-defined fracture. The intent of the hunter is much different. Weapon armatures are designed to present as much contact area to the target as possible within the limits of the technology. The result of their impact is often a combination of percussion, indirect percussion, and pressure fractures, initiated at various locations around the margins of the armature. Some of these may occur in sequence, while others may occur simultaneously.

As a consequence, the examination of a single use-damaged armature may be insufficient to identify the causal nature of the damage, since the damage observed may not be the result of an event which accurately reflects the maximum loading rate normally expected for that armature type. For example, experimental point number 69 is an obsidian Clovis replica employed as a dart armature, that incurred a large, flute-like tip fracture resulting from impact with bone at 36.3 m/s; experimental point number 163 is also an obsidian Clovis replica, though employed as a javelin armature, that incurred a tip fracture resulting from impact with bone at 25.3 m/s. The tip fractures of both armatures reveal fractures with $\dot{C}/C_2$ ratios of 0.23, indicating fracture velocities of approximately 889 m/s. Both of these fall within the range of fracture velocities observed for soft- and hard-hammer percussion, as well as dart, javelin, and arrow armature impacts, or even accidentally dropped specimens! One cannot reliably assign these fractures to any specific cause based on their known loading rates, although pressure flaking may be ruled out since their loading rates exceed that known for pressure reduction.

The cause of a specific fracture, based solely on knowledge of the precursory loading rate, can only be assigned through exclusion. That is to say, for example, that if a fracture velocity of 1700 m/s were obtained from a given armature constructed from a material with properties similar to Glass Butte obsidian, one may reasonably conclude: (1) that the fracture was not the result of any known manufacturing process; (2) that it was caused by a high-velocity impact; and therefore (3) it was the result of use as an arrow or dart armature. Due to its dynamic loading rate, the armature is excluded from consideration of any other causes of fracture. Given also, that fracture velocities are a non-subjective, metric determination, a single, reliable measure is all that is necessary for the armature in this example to be confidently assigned as an arrow or dart armature.

Summary

An examination of spearthrower dart metric data derived from both ethnographic and archaeological sources, combined with performance studies, suggests that effective spearthrower darts may vary greatly in size and weight. While there are no empirical data regarding Clovis fluted-point haft sizes, a reasonable approximation of 1.3 cm diameter, and 240 grams total projectile weight was suggested for hypothetical Clovis dart replicas.

Similarly, ethnographic and ethno-archaeological research suggested that the effective range of the spearthrower is approximately 15 m. These size and range data formed the basis of several series of experiments designed to assess the range of velocities associated with various darts and javelins. It was demonstrated that these projectiles, similar in size and weight to the hypothetical Clovis replica, could impact 15 m distant targets at average velocities of approximately 39 m/s using a spearthrower, and 25 m/s as a hand-thrown javelin. Subsequently, javelin velocities of 25 m/s, and dart velocities of 35 m/s and 45 m/s were chosen as benchmarks for the lithic projectile armature fracture velocity experiments, though tests at 45 m/s were subsequently deemed unnecessary to adequately distinguish the loading rates of these projectiles.

The lithic armature fracture experiments demonstrated that some overlap in fracture velocities could be expected between spears, javelins, arrows, and darts, but also that only the high-velocity projectiles, darts and arrows, will produce use-related fractures in the dynamic regime (i.e., in excess of 1470 m/s). In addition, spears produce unexpectedly low fracture velocities, often combined with characteristic large, flute-like tip fractures.

Flintknappers have long known that flaking implements of different densities produce flakes with differing morphological characteristics. It is little surprise, therefore, that the manufacture-related experiments in Chapter IV suggested that different density percussors and pressure implements have a direct effect on lithic fracture velocity. In contrast, the armature fracture experiments suggest that targets of different densities have little effect on lithic fracture velocities as loading rates increase beyond the upper range of the rapid regime.

CHAPTER VI

THE PALEOINDIAN DATA

"Wait a thousand years and even the garbage left behind by a vanished civilization becomes precious to us."
- Isaac Asimov -

The majority of the artifacts studied during the course of this research were recovered from sites and localities on the edge of the Southern Great Plains, the Southwest, and Far West. Represented sites and localities include Murray Springs, Naco, Dent, Lehner, Lindenmeier, Folsom, Rio Rancho, Blackwater Draw, Sunshine Well, Tonopah Lake, and the Dietz site (Boldurian 1990; Campbell and Campbell 1940; Dawson and Judge 1969; Figgens 1927, 1933; Haury, Antevs, and Lance 1953; Haury, Sayles, and Wasley 1959; Haynes 1982; Hester, Lundelius, and Freyxell 1972; Hutchinson 1988; Judge 1973; Kelly 1978; Sellards 1952; Tuohy 1968, 1988; Willig 1989; Wilmsen 1974; Wilmsen and Roberts 1978; York 1995), as well as many lesser known, and unreported sites and localities. Individual surface finds were also included since temporal priorities far outweigh spatial provenience in a study of this type.

In total, 668 Paleoindian artifacts, mostly fluted-points and fluted-point fragments, were examined. Data derived from velocity dependent fracture features observed on 55 (8.2%) of these artifacts are presented in this chapter. Appendix C provides a list of artifacts which were examined, but which lacked discernable velocity-dependent fracture features.

Impact Data

Since the primary interest of this research is the documentation of fracture velocities derived from use-damaged points, efforts focused on the distal tips and margins of these artifacts. All artifacts exhibiting any type of tip damage (e.g., flake removals and spin-offs, bending and snap fractures, burin-like breaks, crushed or shattered tips) were examined for relevant, velocity-dependent fracture features. Importantly, no assumptions as to the cause of the damage could be made at this time, since only later analysis of the fracture velocity data would reveal whether a tip was damaged from a high-velocity impact, or from some less intensive type of use or accidental contact; the concept of so-called "diagnostic impact fractures" was ignored.

Clovis Points

A total of 19 Clovis fluted-points exhibited velocity-dependent fracture features from which 21 fracture velocity assessments were made. Types of damage observed on points yielding fracture velocity data include tip fractures, bending fractures, and burinated margins. $\dot{C}/C_2$ ratios ranging from 0.13 to 0.56 were documented (an exceptional specimen exhibiting a $\dot{C}/C_2$ ratio of 0.69 will be discussed separately). Approximately 63% of these points revealed $\dot{C}/C_2$ ratios in the dynamic regime, indicating high-velocity impacts (Table 22). Summary descriptive statistics for instantaneous fracture velocity data are presented in Table 23. The distribution of Clovis fracture velocity data is presented in Figure 20.

Of particular interest are two Clovis points from Murray Springs, Arizona (see Haynes 1982:Figure 3). These artifacts both incurred tip damage, and both were refitted with fragments of their missing tips. The first (A32991) was found in the bison kill area, while its refitted tip fragment was recovered from the hunter's camp 138 meters away. The opposite situation was observed for the other specimen (A33115); it was recovered from the camp area, and its refitted tip fragment was recovered 47 meters away in the bison kill area. Fracture features observed on these two specimens reveal similar $\dot{C}/C_2$ ratios of 0.49 (A33115) and 0.51 (A32991), confirming Haynes's (1982:385) observation that the ". . . impact damage to [the] point tips clearly indicates that they were indeed propelled." A third Clovis point (A33114) from the bison kill area reveals a similar fracture velocity with a $\dot{C}/C_2$ ratio of 0.48.

The highest fracture velocity recorded was from a large obsidian Clovis point from the Dietz site (Oregon). This specimen yielded a $\dot{C}/C_2$ ratio of 0.69 from a partial fracture wing whose origin coincides with that of a fissure. Fissures are generally presumed to run perpendicular to the crack front, and should, therefore, effectively bisect the angle formed by any fracture wing with a common point of origin. Assuming this to be the case, an average angle of 46.5 degrees was obtained from the single visible fracture wing arm, suggesting a fracture velocity of 2429 m/s (based on a C_2 value of 3520 m/s for Modoc obsidian). Considering, however, that this may be greater than the terminal fracture velocity for this obsidian, it seems most reasonable to assume that fissures are not reliable indicators of the *precise* orientation of the crack front. Even so, they remain a

Table 22. Clovis fluted-point fracture velocity data. See Appendices for abbreviation key.

Institution Code	Museum Ref. No.	Material	Length (cm)	Width (cm)	Thickness (cm)	Origin (site)	Angular Measure	% T.C. Length	$\dot{C}/C_2$	C_2 (m/s)	($\dot{C}$) (m/s)
UO	553-140	obsidian	NA	4.6	0.8	Dietz site	164.5	<50	0.13	3520	475
UO	553-17	obsidian	*4.6	*2.9	*.8	Dietz site	161.2	39	0.16	3520	575
UO	553-47	obsidian	NA	2.9	0.6	Dietz site	158.5	29*	0.19	3520	657
UO	553-169	obsidian	NA	3.7	0.7	Dietz site	157.0	53*	0.20	3520	702
UO	553-193	obsidian	NA	NA	NA	Dietz site	149.8	16	0.26	3520	917
UO	553-17	obsidian	*4.6	*2.9	*0.8	Dietz site	149.6	19	0.26	3520	923
DMNH	A1454.1	obsidian	10.4	3.7	1.1	Blackwater Draw	146.0	NA	0.29	3520	1029
UO	553-140	obsidian	NA	4.6	0.8	Dietz site	142.8	27	0.32	3520	1123
BAKER	34-4-3-28	chalcedony	4.64*	2.2	0.6	Surface	139.0	85*	0.35	3092	1083
UNM	40.17.3	jasper	NA	2.0	0.6	San Jon	135.2	67	0.38	3674	1400
ASM	A12678	quartz	3.7	1.8	0.7	Lehner	133.5	67	0.39	3520	1389
NSM	CM3705.G.1879	chert	NA	NA	NA	Sunshine Well 7	132.7	44	0.40	3629	1456
BAKER	34-8-3-1	chalcedony	NA	2.6	0.7	Surface	128.3	7	0.44	3092	1347
MS	A33114	chert	NA	3.4	0.8	Murray Springs	122.5	38	0.48	3629	1693
UO	553-204	obsidian	NA	4.7	0.9	Dietz site	122.4	74*	0.48	3520	1696
MNM	24565	chert	NA	2.2	0.3	LA 78644	122.2	85**	0.48	3629	1754
MS	A33115	chert	NA	3.1	1.0	Murray Springs	121.5	63	0.49	3629	1773
MS	A32991	chert	NA	3.3	1.0	Murray Springs	118.8	59	0.51	3664	1865
UO	553-2	obsidian	NA	3.6	0.6	Dietz site	113.2	57	0.55	3520	1938
UO	553-131	obsidian	NA	NA	NA	Dietz site	112.2	45*	0.56	3520	1963
UO	553-195	obsidian	NA	3.8	0.9	Dietz site	93.0	near term.	0.69	3520	2423

Table 23. Basic descriptive statistics for maximum instantaneous fracture velocities ($\dot{C}$) observed on Paleoindian and pre-Archaic lithic armatures.

	Clovis	Folsom	Other
Sample Size:	21	11	16
Minimum:	474.68	1371.18	752.87
Maximum:	2423.01	2002.98	1963.26
Average:	1344.41	1697.62	1554.24
Median:	1389.50	1712.10	1646.63
Standard Deviation:	530.79	210.50	368.81
Standard Error:	115.83	63.47	92.20
Skewness:	-0.79	-0.74	-0.99
Coefficient of Variation:	0.39	0.12	0.24

general indicator of crack front orientation, but should be used with caution when calculating the effective angle of divergence of a solitary fracture wing arm. In this light, the very small angle of divergence of the fracture feature observed on this Dietz site specimen is still suggestive of a loading rate in the dynamic regime.

Three other obsidian Clovis specimens from the Dietz site yielded $\dot{C}/C_2$ ratios of 0.48, 0.55, and 0.56, the latter specimen exhibiting the highest reliable fracture velocity among the Clovis materials. Other known sites with points that yielded loading rates in the dynamic regime include Lehner (Arizona), and the Sunshine Well locality (Nevada).

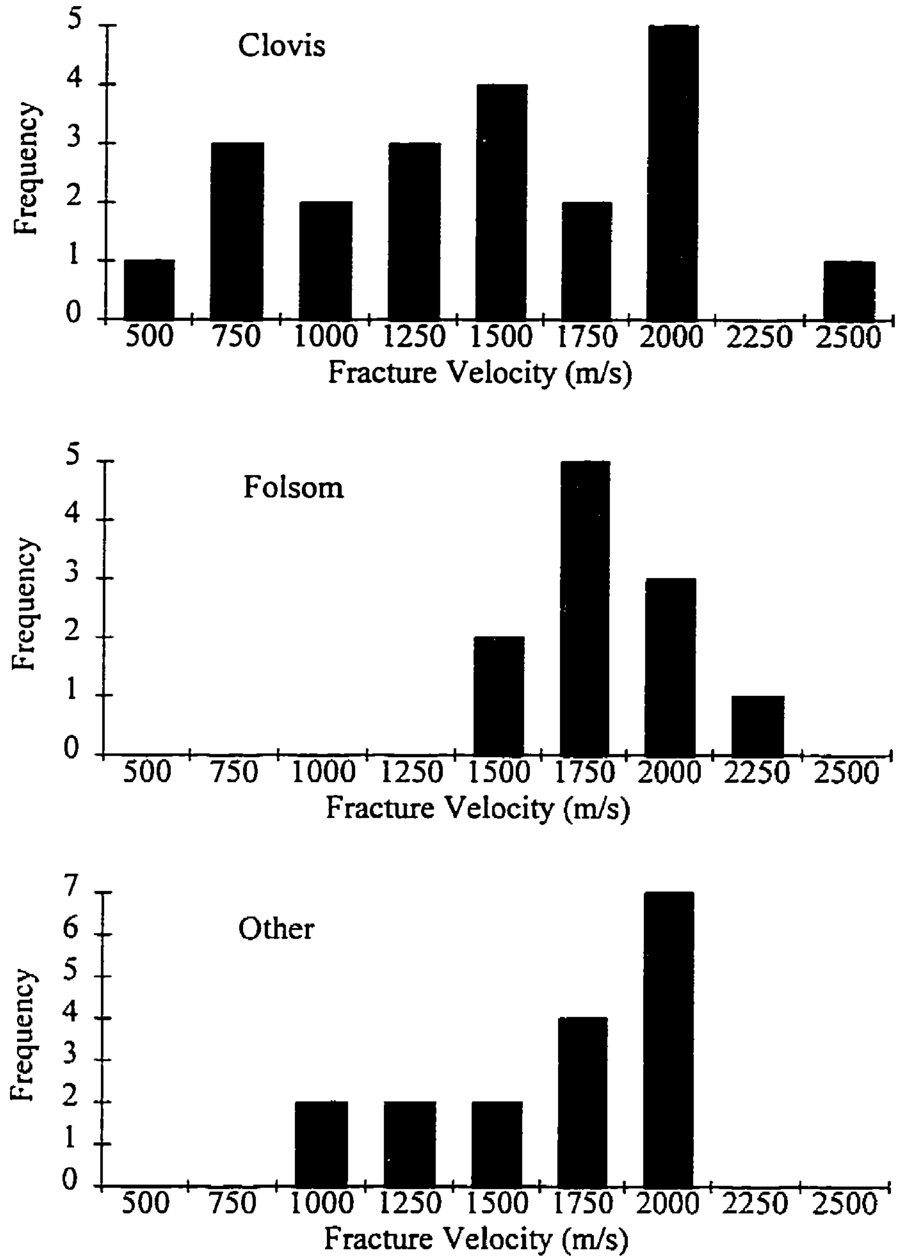


Figure 20. Frequency distribution of Paleoindian and pre-Archaic armature fracture velocity ($\dot{C}$) data. Note truncation at the upper end of the pre-Archaic (Other) sample distribution, and the considerable negative skew.

Folsom Points

Eight Folsom fluted-points exhibited a total of 11 velocity-dependent fracture features from which fracture velocity assessments were made. Types of damage observed on points yielding fracture velocity data include tip and bending fractures. $\dot{C}/C_2$ ratios ranging from 0.38 to 0.55 were documented; notably, all of these $\dot{C}/C_2$ ratios fall within the dynamic regime, indicating high-velocity impacts (Table 24). Summary descriptive statistics for instantaneous fracture velocity data are presented in Table 23. The distribution of Folsom fracture velocity data is presented in Figure 20.

Most of these points were surface collected throughout Colorado and New Mexico. One of these, collected from the Deming area of New Mexico, and exhibiting massive tip damage, yielded a $\dot{C}/C_2$ ratio of 0.55, the highest recorded for the Folsom materials. A single specimen yielding a$\dot{C}/C_2$ ratio of 0.48 was recovered from the Sunshine Well locality (Nevada).

Other Paleoindian (or pre-Archaic) Points

Other points, variously defined as Paleoindian or pre-Archaic (cf., Willig 1989:13-14), from which fracture velocity data was recovered include 16 specimens identified as Midland, Great Basin Stemmed, Western Pluvial Lakes Stemmed, Cougar Mountain Stemmed, Humbolt, Sandia, and Windust. Represented sites and localities include Manzano Cave, and Beargrass Draw in New Mexico; Hanging Rock Shelter, Massacre Lake, Pine Creek Well, Mud Lake, Lake Parman, and Sunshine Well in Nevada; and the Dietz site, and Christmas Valley in Oregon. These points yielded $\dot{C}/C_2$ ratios ranging from 0.21 to 0.56, 12 (75%) of which exhibited loading rates in the dynamic regime (Table 25). Summary descriptive statistics for instantaneous fracture velocity data are presented in Table 23. The distribution of these fracture velocity data is presented in Figure 20.

Table 24. Folsom fluted-point fracture velocity data. See Appendices for abbreviation key.

Institution Code	Museum Ref. No.	Material	Length (cm)	Width (cm)	Thickness (cm)	Origin (site)	Angular Measure	% T.C. Length	$\dot{C}/C_2$	C_2 (m/s)	($\dot{C}$) (m/s)
UNM	76.62.345	chert	NA	NA	0.3	Unknown	135.6	75	0.38	3629	1371
MNM ICC	42605.11	chert	NA	2.1	0.5	Deming	135.2	50	0.38	3629	1383
BAKER	34-4-3-91	jasper	NA	NA	0.4	Surface	129.4	NA	0.43	3674	1570
BAKER	34-2-13-26	chert	NA	NA	NA	Surface	124.3	90*	0.47	3664	1711
MNM ICC	42605.11	chert	NA	2.1	0.5	Deming	123.7	58	0.47	3629	1712
NSM	CM3705.G.1885	chert	3.08*	1.9	0.5	Sunshine Well 3B	122.7	40	0.48	3629	1740
MNM ICC	48644.11	jasper	NA	2.1	0.4	Rio Puerco	123.0	40*	0.48	3674	1753
BAKER	34-4-4-3	chalcedony	NA	NA	0.5	Surface	118.7	50*	0.51	3092	1576
BAKER	33-20-1-4	obsidian	NA	NA	0.5	Surface	115.0	73	0.54	3520	1891
MNM ICC	42605.11	chert	NA	2.1	0.5	Deming	114.5	43*	0.54	3629	1963
MNM ICC	42605.11	chert	NA	2.1	0.5	Deming	113.0	60	0.55	3629	2003

Table 25. Other Paleoindian (or pre-Archaic) point fracture velocity data. See Appendices for abbreviation key.

Institution Code	Museum Ref. No.	Material	Lithic Type	Length (cm)	Width (cm)	Thickness (cm)	Origin (site)	Angular Measure	% T.C. Length	C/C2	C_2 (m/s)	(C) (m/s)
NSM	120-40	obsidian	GBS (Parman?)	NA	NA	NA	Lake Parman	155.3	40	0.21	3520	753
UO	553-50	obsidian	Cougar Mt. stemmed	NA	2.0	0.8	Dietz site	149.2	62	0.27	3520	935
NSM	NA	obsidian	GBS (Parman?)	NA	NA	NA	Massacre Lake	143.3	NA	0.31	3520	1108
NSM	103-3586	obsidian	Humbolt	5.7*	2.0	0.7	Hanging Rock Shelter	139.1	44	0.35	3520	1230
UO	553-29	obsidian	Windust	NA	2.5	0.6	Dietz site	130.8	46*	0.42	3520	1465
MNM	24603	chert	Paleoindian (unspecified)	NA	2.3	0.7	Beargrass Draw	130.0	60*	0.42	3629	1534
AINW	59/1968	obsidian	Square stemmed	NA	3.0	0.9	Christmas Valley	128.8	46	0.43	3520	1521
NSM	CM3705.G.1837	chert	Concave, contracting basal margin	NA	NA	NA	Sunshine Well 3B	124.6	10	0.46	3629	1687
UNM	41.6.9	flint	Sandia	NA	2.5	0.9	Manzano Cave	121.0	NA	0.49	3629	1787
MNM	16217	chert	Midland*	NA	1.8	0.4	LA 71339	119.5	55	0.50	3629	1828
NSM	NA	chert	Plano	NA	3.0	0.5	Pine Creek Well	119.0	near term.	0.51	3629	1787
UO	553-1	obsidian	Fluted biface	NA	4.9	1.0	Dietz site	117.4	26	0.52	3520	1829
NSM	CM3705.G.1584	chalcedony	GBS	NA	NA	NA	Sunshine Well P2	117.4	near term.	0.52	3092	1606
NSM	NA	obsidian	GBS (long stemmed)	NA	NA	NA	Mud Lake	115.6	27	0.53	3520	1876
NSM	HCB-Shutler	obsidian	Concave Base	NA	2.5	0.4	unknown	114.5	31	0.54	3520	1904
UO	553-79	obsidian	WPL stemmed	NA	3.4	0.8	Dietz site	112.2	47	0.56	3520	1963

Fluting Data

In addition to damaged distal tips, some channel-flake scars, and channel-flakes themselves, were also examined in an effort to document the reduction technology associated with Paleoindian fluting. The fluting of bifacial points is an unusual technique practiced for a relatively short period of time, and, seemingly, restricted in geographical distribution to the New World. The recent report by King and Slobodin (1996) of a "fluted-point", approximately 4.6 cm in length, from the Uptar site in Magadan Oblast, northeastern Siberia, does not offer convincing evidence of a fluted-point-bearing, Paleoindian presence in Northeast Asia. While amazingly symmetrical, the single longitudinal flake scar exhibited by this point appears instead to be a large tip fracture. The jagged "base" does not resemble the initiation point of a channel-flake scar, nor does it appear to have been retouched or finished in any way. In addition, the high-relief undulations, while not completely unknown on channel-flake scars, are not characteristic. Please note that this assessment is based solely on published photographs (King and Slobodin 1996; Menon 1997) of the specimen, and that any conclusions should be based on examination of the point itself.

Lacking any obvious Old World predecessors, it has been suggested (e.g., Haynes 1980) that fluting was a New World development originating somewhere between Beringia and the southern limits of the ice-sheets, spreading south into the Plains and Great Basin. Alternatively, if fluted points in Alaska are post-Clovis in age, then they represent an influx from the south, and perhaps an origin south of the ice-sheets (Dixon 1975).

Carlson (1991) has hypothesized that logical ancestors of the Clovis fluted-point are the bone or antler points with multiple side-hafted blade segments found in Upper Paleolithic and Neolithic sites in Siberia, and that fluting itself is a logical development of blade technology. Some Clovis assemblages do exhibit blade technology, and while Carlson may be correct, I do not agree that blade and channel-flake removal are *necessarily* conceptually similar (Carlson 1991:84). The overall flaking technology exhibited by classic Clovis demonstrates a high degree of platform preparation and control in the production of broad, thin, invasive flakes, and is itself sufficient to supply the necessary concepts and skills for channel-flake removal.

The most easily damaged component of a slotted haft and lithic armature arrangement is usually the slot component itself. I believe fluting to be an attempt to compensate for the relative fragility of the organic haft component by reducing the thickness of the point base in favor of more substantial haft material on each side of the hafting slot. There may be three reasons why this became a problem: (1) a lack of plant materials from which to quickly and easily fashion replacement hafts, and a reliance instead on more expensive bone and antler hafting material (i.e., it was less expensive to replace the lithic component than the haft component). This could be due to a shift to a tundra type of environment where plant materials for haft construction were scarce; (2) it may have been an effort to increase the maintainability (Bleed 1986) of the weapon by designing the lithic component to fail before the haft component. For mobile hunters, it would be easier to carry replacement points than replacement hafts; or (3) a recent technological shift from a hafting arrangement in which the extant point design was sufficiently thin (relatively speaking) at the base, to one in which it was suddenly inadequate. Such a shift may have been from thick-shafted spears, to much smaller diameter spearthrower darts. Stemming may have been an alternative solution to the same problem.

Most of the research concerning fluting technology itself has centered around the more aesthetically-appealing Folsom points, and is related to the techniques of channel-flake removal (e.g., Akerman and Fagan 1986; Boldurian, Fitzgibbons, and Shelley 1985; Boldurian et al. 1986, 1987; Callahan 1979a, 1979b; Crabtree 1966; Flenniken 1978; Frison and Bradley 1980, 1981; Gryba 1988; Ibarra and Wellman 1988; Imel 1988; Neill 1952; Patten 1979a, 1979b, 1980; Sollberger 1977, 1985; Sollberger and Patterson 1980, 1986). Crabtree (1966:22), having experimented with several different fluting techniques, concluded that indirect percussion with a rest, or pressure with clamps and anvil were the two techniques most likely employed in fluting the Lindenmeier Folsom. Researchers have also proposed that leverage machines may have been used to pressure-flute Paleoindian points (e.g., Frison and Bradley 1981; Ibarra and Wellman 1988; Sollberger and Patterson 1980). In fact, practically every known reduction technology (i.e., pressure flaking, indirect- and direct-percussion flaking) can be demonstrated to produce adequate channel-flakes. In replicating points for this, and other research, I have found both indirect and direct percussion to be simple and effective techniques for fluting. Due to the fact that different reduction techniques work, and often produce morphologically similar results, no one method has ever been demonstrated to be the sole technique used by Paleoindian knappers.

The utility of fracture velocity data to impart information about manufacturing or reduction techniques was noted in Chapter IV. An example of the practical application of this type of data collection involves the recording and interpretation of fracture velocity relevant micro-features observed on the channel-flake scars of Paleoindian fluted points. During this research, fracture velocity data were collected from the channel-flake scars of 12 obsidian Clovis points (Table 26). $\dot{C}/C_2$ ratios recorded for these specimens range from 0.02 to 0.18.

Of particular interest are the very low fracture velocities obtained from the channel-flake scars of certain points, notably those recovered from the Dietz site (Oregon), Lake Tonopah (Nevada), and Blackwater Draw (New Mexico). The $\dot{C}/C_2$ ratios for these specimens range from 0.02 to 0.18, but fully 75% (nine of twelve) lie between 0.02 and 0.09, indicating quasi-static loading rates which correspond to pressure flaking.

One such specimen is an incomplete obsidian Clovis point from the Lake Tonopah Locality, that was broken during fluting of the second face. The $\dot{C}/C_2$ ratio for a single fracture wing observed on the channel-flake scar which broke the point is 0.04. Based on a C_2 value of 3520 m/s for Modoc obsidian, the fracture velocity of 144 m/s indicates that pressure flaking, using either hand or chest-crutch methods, was employed for fluting (refer to Table 3).

Table 26. Clovis flute fracture velocity data. Fracture velocity ($\dot{C}$) is calculated based on a C_2 value of 3520 m/s for Modoc obsidian. See Appendices for abbreviation key.

Institution Code	Museum Ref. No.	Material	Length (cm)	Width (cm)	Thickness (cm)	Origin (site)	Angular Measure	% T.C. Length	$\dot{C}/C_2$	$\dot{C}$ (m/s)
UO	553-204	obsidian	NA	4.7	0.9	Dietz site	178.2	NA	0.02	55
DMNH	A1454.1	obsidian	10.4	3.7	1.1	Blackwater Draw	177.3	96	0.02	82
NSM	47 ?	obsidian	NA	NA	1.0*	Lake Tonopah	175.3	33	0.04	144
UO	553-3	obsidian	NA	NA	0.8	Dietz site	174.5	<40	0.05	169
UO	553-47	obsidian	NA	2.9	0.6	Dietz site	173.0	<33	0.06	215
UO	553-140	obsidian	NA	4.6	0.8	Dietz site	172.8	NA	0.06	221
NSM	ES2	obsidian	NA	4.9	0.9	Lake Tonopah	172.0	38	0.07	246
DMNH	A1454.1	obsidian	10.4	3.7	1.1	Blackwater Draw	171.7	38	0.07	255
DMNH	A1454.1	obsidian	10.4	3.7	1.1	Blackwater Draw	171.2	12	0.08	271
UO	553-169	obsidian	NA	3.7	0.7	Dietz site	171.0	86	0.08	276
UO	553-232	obsidian	3.1	2.0	0.4	Dietz site	169.8	40	0.09	313
DMNH	A1454.1	obsidian	10.4	3.7	1.1	Blackwater Draw	169.7	30	0.09	316
DMNH	A1454.1	obsidian	10.4	3.7	1.1	Blackwater Draw	166.7	18	0.12	408
UO	553-195	obsidian	NA	3.8	0.9	Dietz site	162.7	10*	0.15	529
UO	553-166	obsidian	NA	2.6	0.6	Dietz site	159.5	<14	0.18	626
UO	553-80	obsidian	NA	2.4	0.6	Dietz site	159.0	NA	0.18	641

The same technology is in evidence on other points from the Dietz Site and Blackwater Draw. The Blackwater Draw specimen (Denver Museum of Natural History reference number A1454.1), is a relatively large obsidian Clovis point. Although fluted on both faces, pertinent micro-fracture features were observed only on the larger channel-flake scar. Approximately 50 mm in length, this channel-flake scar exhibits at least five fracture wing sites which indicate an average fracture velocity for the fluting process of 266 m/s (see also Figure 8). Instantaneous fracture velocities for this specimen range from 82 m/s to 408 m/s, based on a C_2 value of 3520 m/s for Modoc obsidian. As stated in Chapter IV, however, only those instantaneous velocities lying between 20% and 50% of the terminal crack length offer an accurate reflection of the fracture velocity. The channel-flute fracture velocity is therefore reflected by two fracture wing sites lying at 30% and 38% of the terminal crack length. The $\dot{C}/C_2$ ratios derived from these features are 0.09 and 0.07 respectively, and again suggest that a pressure flaking method was employed to remove this large channel-flake.

One point which deserves particular attention is a very large Clovis mid-section fragment from the Dietz site (Oregon State Museum of Anthropology reference number 553-204). The $\dot{C}/C_2$ ratio for the single fracture wing observed on one of its channel-flake scars is 0.02. Based on a C_2 value of 3520 m/s for Modoc obsidian, this very low value indicates a fracture velocity of 55 m/s (the actual $\dot{C}/C_2$ value is 0.0157 if considered to four decimal places). Considering the size of the channel-flake indicated by this point fragment, along with the experimental evidence from Chapter IV, and the data collected from chest-punched blades produced by Donald Crabtree (see page 51), it appears that this point was fluted using a chest-punch, or other similar pressure flaking device, which permitted a very slow application of a large amount of pressure. To my knowledge, this is the first empirical confirmation of a specific Paleoindian fluting technology.

Summary

Loading rates in the dynamic regime were documented on 27 Paleoindian fluted-points, and 16 other points variously defined as Paleoindian or pre-Archaic (cf., Willig 1989:13-14). Previous experimentation failed to generate dynamic fractures during any known lithic reduction process, or from accidental abuse. Loading rates in the dynamic regime were only generated through high-velocity impacts, of the type associated with mechanical propulsion devices such as the spearthrower and bow. Assuming that Paleoindian peoples did not possess bow and arrow technology, the data therefore indicate that they employed the spearthrower, and thus constitutes the earliest direct evidence for this weapon's use in the New World. While the presence of the spearthrower is indicated, this does not imply that Paleoindians did not employ other types of weapons. Experiments indicate that the lower range of loading rates documented for Paleoindian points overlaps the upper range of loading rates associated with both javelins and spears. Even though the Paleoindian data fall within the range of variation documented for the experimental darts, and higher, one cannot rule out the possibility that all three types of weapons may have been in use.

In addition to data from use-related fractures, a small body of data was generated through the examination of channel-flake scars from several obsidian Clovis points, revealing that these artifacts were often pressure fluted, probably through the use of a chest- or crutch-type pressure tool (a secondary function for organic points?).

My own experience, and probably that of many other flintknappers as well, suggests that large, effective channel-flakes can be removed using a variety of reduction techniques. Large channel-flake scars exhibiting very low fracture velocities, like those observed during this study, suggest that at least some obsidian points were fluted as a co-operative effort, since it probably required at least two individuals to simultaneously hold a preform and operate a chest-punch unless some kind of clamp or jig was employed to secure the preform. A possible alternative might be a mechanical pressure-flaking device like that proposed by Frison and Bradley (1981).

CHAPTER VII

CONCLUSIONS

"Science is nothing but developed perception, integrated intent, common sense rounded out and minutely articulated."
- George Santayana -

"People who like this sort of thing will find this the sort of thing they like."
- Book review by Abraham Lincoln -

The interpretation of archaeological data relies to a great extent on the use of analogy. The ability of these data to accurately reflect prehistoric events depends essentially on the integrity of the analogue employed. Traditional analyses of weapon armature technologies (e.g., Corliss 1972; Evans 1957; Forbis 1962; Thomas 1978; Shott 1997; Wyckoff 1964) employ classification schemes to identify projectile points as either spear, dart, javelin, or arrow armatures. For example, the identification of an arrow armature is traditionally a two-step process: (1) the investigator recognizes an artifact as a "projectile point", and (2), classifies it as an arrow point based on certain pre-defined criteria that distinguish it from other classes of projectile points. The basic logical fallacy of such schemes is the assumption that the investigator knows, *a priori,* that the artifact in question served as a projectile armature (cf., Ahler 1971).

In this case, the inadequacy of the traditional classification method for identification of projectile armatures lies at the very heart of its theoretical foundation within the direct historic approach. Our knowledge of what constitutes a "projectile point" is derived from data gathered through the use of ethnographic analogues. In effect, an arrow point, for example, is defined as an artifact which has been observed attached to an arrow shaft. Similarly, classification schemes like that proposed by Thomas (1978) and Shott (1997) define criteria for classes based on data derived from artifacts assumed to be representative of those classes. Consequently, such models are untestable because relevant data have already been used in their construction.

From a theoretical (i.e., scientific or logical) standpoint, as long as our models are derived from data, we have no objective criteria with which to evaluate them. As Kosso (1989:246) has stated, objective evidence is ". . . evidence that is verified independently of what it is evidence for." Therefore, instead of deriving our models from our data, models should be constructed from relations among phenomena that are predicted from theory and tested against data (Rigaud and Simek 1987:48). The methodology employed in this research to determine precursory loading rates is free of data-based interpretive analogy (while it is true that bifacial points were selected for study, based on general, normative, morphological variables that suggest *suitability* as armatures, no assumptions were made with regard to artifact function. Instead, function was identified through analysis of fracture velocity. Had this study failed to document dynamic lithic fracture velocities among Clovis fluted points it would merely have suggested that these artifacts were not used as high-speed projectile armatures, and would not necessarily indicate that Clovis did not employ the spearthrower in connection with some, as yet unknown, type of armature). Instead, it is a non-subjective, quantitative method firmly rooted in the physical sciences. The physical processes that created the velocity-dependent fracture features during the late-Pleistocene are the same physical processes that we observe today. The effects of 13,000 year-old actions were, in a very real way, set in stone, providing a Pompeii-like opportunity to measure the loading rates generated by an ancient weapon system.

The dynamic loading rates associated with the Paleoindian points examined during the course of this investigation, offer conclusive evidence for the use of the spearthrower during the earliest, well documented, period of human prehistory in the New World. The significance of this discovery addresses our basic understanding of Paleoindian peoples and life-ways. The unprecedented appearance of "technology oriented" hunter-gatherers (Kelly and Todd 1988) at the close of the Pleistocene, marks one of the more dramatic periods in hunter-gatherer prehistory. Their fully-developed biface technology, coupled with a logistic pattern of extreme mobility, offered a highly effective solution to the risks of exploiting unknown and rapidly changing environments. It is tempting to hypothesize that Paleoindian cultural and technological advances may be the result of the right technology combined with the right place and time.

The Upper Paleolithic cultures of the Central Russian Plain are known from sites such as Mezhirich, Mezin, and Yudinovo, for their use of enormous quantities of mammoth bone to construct elaborate and complex dwellings. According to Soffer (1985), current evidence suggests that the majority of the bone used in these structures was collected from the treeless tundra, rather than through active hunting, but that mammoth hunting was indeed practiced.

The distribution of Kostenki knives and points suggests a general west to east movement of Upper Paleolithic technology which parallels the megafauna extinction trajectory posited by Martin (1982). While this trend appears to begin prior to the Valdai maximum, which occurred between approximately 20,000 and 18,000 B.P. and saw the absence of human occupation on the Central Russian Plain (Ivanova 1977, cited in Soffer 1985; Levkovskaya 1977 cited in Soffer 1985; Soffer 1985:173-176; Klein 1969), Soffer (1985, 1987) has suggested that localized environmental deterioration may have been felt earlier by groups living in Eastern Europe between the Scandinavian ice sheet and Alpine glaciers. It is tempting to hypothesize that these already highly-mobile hunters and gatherers may have been prompted to move eastward into areas of lower population density, eventually spreading into Beringia sometime after 18,000 B.P. (see also Haynes 1982).

In Upper Paleolithic Western Europe, the spearthrower had been in use since at least the Magdalenian approximately 17,000 years ago, and perhaps much earlier (cf., Caton-Thompson 1946; Cressman and Krieger 1940:36; Knecht 1994; Krause 1905:124; Massey 1961:81). Indeed, Dickson (1985:6) has speculated that it may have been in use as early as 80,000 years ago during the Mousterian. There is currently no empirical evidence for its use among the Upper Paleolithic peoples of the Central Russian Plain, but if future research reveals they had possessed the weapon, they may be considered as possible progenitors of New World Paleoindians.

> Many of the Late Paleolithic mammoth-hunter sites of Eurasia show similarities in artifacts and features such as dwellings, fireplaces, and ocher burials. While game takes were not exclusively mammoths, the socioeconomic orientation of the cultures toward the hunting and utilization of mammoth meat, hide, bones, and ivory is clearly manifest. The mammoth was to the Paleolithic hunter as the reindeer is to the Laplander or the inland Eskimo. On the basis of the similarities among Clovis stone and bone artifact assemblages and such Late Paleolithic

> hunting camps as Pavlov, Dolni Vestonice, level 5 of Kostienki I [sic], and many others, I assume that the earliest root for Clovis stems from Europe during the early Late Paleolithic (Gravettian-Aurignacian), about 28,000 years ago. Mammoth hunters moving eastward gave rise to such sites as Afontova Gora II, Mal'ta and Buret I sometime between 25,000 and 15,000 BP. During this time cultural diversity had already developed in eastern Siberia, where Dyuktai people had acquired a core-and-blade technology. Bifacial points or knives at Dyuktai Cave and bone points slotted for microblades at Afontova Gora may be evidence of cultural mixing, but some people apparently did not adopt microblades. It may be these Mal'ta-Afontova Gora descendants that entered Beringia with artifacts characterized by bifaces, blades, and cylindrical bone and ivory points between 20,000 and 15,000 years ago [Haynes 1982:396-397].

Far-reaching hypotheses aside, early Paleoindians faced unknown and rapidly changing, high-risk environments with a very reliable (Bleed 1986) form of weaponry. The spearthrower provided a method of delivering relatively heavy projectiles at very high velocities, up to 50 and 60 meters per second. These velocities compare favorably with the bow, but due to the mass of the dart, result in much greater impact force.

> . . . we have computed kinetic energies from average throws in excess of 350 Joules. This is four times the kinetic energy carried by a modern arrow fired from an efficient, modern compound bow; the AMO standard is a 540 grain (35 g) arrow fired from a 30-inch draw, 60 pound peak-weight bow. Modern equipment meeting these standards will produce projectile velocities up to 70 m/s, resulting in kinetic energies less than 86 Joules. Traditional bows would be considerably less efficient. Raymond (1986:Table 5) calculates a kinetic energy of 12.6 Joules for Ishi's bow based on a velocity of 30 m/s using a 28 g arrow [Hutchings and Brüchert 1997].

When combined to create a projectile with effective penetration, this combination of large mass and high velocity results in an extremely efficient weapon. For example, in his account of the De Soto expedition to the southeastern United States in the 16th century, Garcilaso de la Vega noted that the spearthrower propelled darts "with extreme force, so that it has been known to pass through a man armed with a coat of mail" (Swanton 1938:358). Comparing the spearthrower to the javelin, data from the experiments discussed in Chapter V indicate that the spearthrower can propel a dart with as much as 185% of the velocity of its hand-thrown equivalent.

An additional advantage of the spearthrower is that it permits hunters to maintain a safer distance from aggressive prey than does the spear or javelin, thereby increasing hunting success by reducing risk of personal injury. In essence, the spearthrower, equipped with a relatively heavy dart, is the prehistoric equivalent of the modern elephant gun.

Dynamic loading rates, indicating high-velocity fractures, were indicated not only on Clovis and Folsom fluted points, but on other early point types including Plano, Midland, Western Pluvial Lakes Stemmed, Great Basin Stemmed, and Windust. Importantly, this indicates that no one hafting technique was uniquely associated with spearthrower technology during this period, and may indicate that early peoples were experimenting with hafting methods rather than delivery technologies. This in turn implies a recent switch from an earlier technology.

Logical precursors to these lithic armatures are of course the bone, antler, and ivory bevel-based points common to the Upper Paleolithic, and found at several New World Paleoindian sites and localities, including the Tenana Valley, Alaska (Rainey 1940), the Grenfel site, Saskatchewan (Wilmeth 1968), Lind Coulee, Washington (Daugherty 1956), the Richie-Roberts site, Washington (Mehringer 1989), Sheaman (Anzick) site, Wyoming (Lahren and Bonnichsen 1974), Klamath Lake, Oregon (Cressman 1956), Goose Lake, California (Riddell 1973), Blackwater Draw, New Mexico (Hester, Lundelius, and Fryxell 1972; Sellards 1952), and several submerged deposits in Florida (see Dunbar

1991; Jenks and Simpson 1941). Similar points were obviously considered effective during the European Upper Paleolithic (e.g., Knecht 1994), but an experimental study by Stodiek (1993:200-202) determined that they do not penetrate very well since they pierce a small hole and push it open rather than slicing a suitably-sized hole like a stone point. So while the organic points may have been sufficient for hunting smaller or younger animals, large mammoth and bison, with their thicker hides, probably demanded a more efficient, albeit costlier, lithic armature.

Organic points may have survived as economic alternatives, used as backups after an initial attack using lithic armatures, or may have been maintained as killing lances to dispatch incapacitated prey. Their beveled bases would create a relatively smooth joint with a shaft or foreshaft, allowing them to be repeatedly withdrawn and thrust without fear of snagging on bone or tendon. Alternatively, they may have survived simply as economic alternatives intended for smaller, or younger game. In any case, maintenance of bone, antler, and ivory technologies would have provided insurance against inopportune depletion of curated lithic armatures until the group returned to a known tool-stone quarry or located a new source.

I believe the contributions made by this research to be twofold. Most simply, it has confirmed what many Paleoindian archaeologists have believed all along; that Paleoindians employed spearthrower weaponry. The difference now being that we can support this position with theory-based, objective empirical evidence, giving us a firm foundation for higher-order analyses of Paleoindian life-ways. This research has also outlined a relatively simple analytical methodology that should prove to have many useful applications in archaeology, in both use-related and manufacture-related studies.

Although fracture velocity data may not be able to positively identify the precursory loading rates of all artifacts suspected of being weapon armatures, the data may also be incorporated in traditional discriminant function analyses (e.g., Thomas 1978; Shott 1997) to refine the discrimination of functional types.

The loading rate parameters employed here were generated through manufacture-related experiments using Glass Butte obsidian. This was done for reasons of expediency; due to the relative rarity of velocity dependent fracture features, it was simply not advantageous to use any but the finest-grained material available for the experimental research. Considering its high C_2 value of 3865 m/s, compared to approximately 3600 to 3700 m/s for most fine-grained flint toolstones, the loading rate boundaries outlined here may be considered high, but again, it was simply not expedient to identify all Paleoindian artifact material sources, and perform the same range of experiments on each. By using a material with a relatively high C_2 value, and thus raising the rapid/dynamic loading rate boundary, it is possible that fewer Paleoindian artifacts have been documented with dynamic loading rates than may have been the case had Edwards flint (C_2 = 3629 m/s), for example, been used. Had the loading rate scheme outlined by Tomenchuk (1985:Table 12.7) been used, this research would have documented approximately 21% more Paleoindian artifacts exhibiting dynamic loading rates. Similarly, the C_2 value of 3520 m/s for Modoc obsidian was used for all fracture velocity calculations involving Paleoindian obsidian artifacts, rather than the value for

Glass Butte obsidian, resulting in fewer dynamic loading rates being documented than might otherwise have been the case.

While the approach followed here has adequately demonstrated that dynamic loading rates associated with spearthrower use are often exhibited by Paleoindian armatures, future research should compare the manufacture- and use-related loading rate ranges associated with other tool-stone materials. I do not expect significant variation from the results presented here, but I feel that the potential of the methodology warrants all possible refinement.

An additional area where refinements are possible, is that of data collection. Velocity dependent fracture surface features are often so small that they are difficult to locate. The definition of these features is often improved by varying the angle of incident lighting to highlight the microscopic ripples against their own shadows. Unfortunately, many of the finest-grained lithic materials are also extremely reflective, so that when a feature is located, it is sometimes difficult to orient the plane of the fracture perpendicular to the viewing axis of the microscope . Large deviations from the perpendicular will adversely affect angular measurements. It is possible that the use of a scanning electron microscope might alleviate some aspects of this potential problem, while the application of digitizing and CAD systems may improve the accuracy of data recovery.

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APPENDICES

Key to abbreviations

AINW:	Archaeological Investigations Northwest - Portland
ASM:	Arizona State Museum - Tucson
DMNH:	Denver Museum of Natural History - Denver
UNM:	Maxwell Museum, University of New Mexico - Albuquerque
MNM:	Museum of New Mexico - Santa Fe
NSM:	Nevada State Museum - Carson City
PMA:	Provincial Museum of Alberta - Edmonton
SDMM:	San Diego Museum of Man - San Diego
TBC:	Tony Baker Collection - Denver
UA:	University of Arizona - Tucson
OSMA:	Oregon State Museum of Anthropology - Eugene
GBS:	Great Basin Stemmed
WPL:	Western Pluvial Lakes (stemmed)
?:	Questionable attribute or identification
Fluted 1x (2x):	Fluted on 1 face (both faces)
$\dot{C}$:	Longitudinal (dilational) wave velocity.
C_2:	Transverse (distortional) wave velocity.
%T.C. Length:	Distance from fracture initiation is expressed as a percentage of terminal crack length (i.e., distance from initiation divided by total crack length).
Near Term.:	Near terminal crack length (estimated).

APPENDIX A

Mechanical testing of experimental and Paleoindian tool-stone samples.

As elucidated by the fracture velocity equations from Chapter IV, fracture velocity ($\dot{C}$) is a function of the effective angle of divergence of dilational (longitudinal) and distortional (transverse) wave propagation. Distortional wave velocity (C_2) is expressed as a constant for a given material, and is dependant upon the inherent elastic properties of that material.

Mathematically, the velocity of the distortional wave (C_2) is expressed as (Jaeger and Cook 1976:350; Blitz 1967:13):

$$C_2 = (G/p)^{1/2} \tag{A1}$$

where G is the modulus of rigidity, and p is the material density. The modulus of rigidity (G) is expressed as:

$$G = E/2(1+\nu) \tag{A2}$$

where E is Young's modulus, and ν is Poisson's ratio. Young's modulus (E) is expressed as:

$$E = p\nu_s^2 \tag{A3}$$

where ν_s is the sonic velocity of the material.

With the assistance of Professor Tom Troczynski, and Florin Esanu of the University of British Columbia Department of Metals and Materials Engineering, dynamic tests of stiffness, employing the ultrasonic method to determine the sonic velocity of the material, were conducted on Glass Butte obsidian, Edwards (Georgetown) flint, and Alibates flint (Alibates agatized dolomite) (Table A1).

Table A1. Estimation of distortional (transverse) wave velocities for experimental and Paleoindian tool-stone samples. Poisson's ratio (ν) is assumed, based on similar materials discussed by Tomenchuk (1985:Table 11.4).

Tool-stone Sample	v_s (m/s)	ν	pv_s^2 (Pa)	$E/2(1+\nu)$ (GPa)	$(G/p)^{1/2}$ (m/s)
Glass Butte obsidian	5912	0.17	8.9E+10	37.94	3865
Edwards flint	5333	0.08	7.5E+10	34.63	3629
Alibates flint	5385	0.08	7.6E+10	35.03	3664

The Poisson ratio of 0.08, assumed for the Paleoindian materials, is based on that of Rugen flint (Tomenchuk 1985:Table 11.4). The Poisson ratio of 0.17, assumed for the Glass Butte obsidian, is based on that of Lapari obsidian (Tomenchuk 1985:Table 11.4).

The estimated distortional wave velocity values for Edwards and Alibates flints are comparable to that of Rugen flint at 3622 m/s. The estimated distortional wave velocity value for Glass Butte obsidian is notably higher than those of either Modoc (3520 m/s), Lipari (3425 m/s), or Arnafels (3576 m/s) obsidian presented by Tomenchuk (1985:Table 11.4). These results should be considered tentative, since only a single sample of each material was subjected to dynamic testing. Plans for future research include testing of additional samples of these and other Paleoindian tool-stone materials, including Florence-A (Kay County) chert, petrified palm (Ogallala gravels), Ogallala quartzite, Dakota quartzite, Flat Top flint, Spanish Diggings flint, Day Creek chert, Knife River flint, and Smoky Hill Jasper (Niobrara).

APPENDIX B

Lithic reduction (manufacturing) experiment fracture velocity data.

This section presents the raw data that were summarized in Table 2. The experiments were conducted using Glass Butte obsidian (C_2 = 3865 m/s, Appendix A).

Since it was important to document the full range of fracture velocities associated with each reduction technology, attempts were made during each experiment to vary the loading rate as much as possible within the given technology. For example, during direct percussion, in addition to a normal (i.e., task-oriented) approach to reduction, each tool was used with the minimum amount of force necessary to detach a flake or blade, as well as the maximum amount of force possible.

	Pressure - Metal				Pressure - Antler				Indirect Percussion - Antler			
Reference Number	Angular Measure	$\dot{C}/C_2$	$\dot{C}$ (m/s)	% T.C. Length	Angular Measure	$\dot{C}/C_2$	$\dot{C}$ (m/s)	% T.C. Length	Angular Measure	$\dot{C}/C_2$	$\dot{C}$ (m/s)	% T.C. Length
1	169.5	0.092	322	33	174.5	0.048	169	40	165.5	0.126	444	55
2	170	0.087	307	44	170.5	0.083	291	70	166	0.122	429	51
3	169	0.096	337	45	164.5	0.135	475	28	154.5	0.221	777	49
4	171.5	0.074	261	40	164	0.139	490	75	163	0.148	520	40
5	171.5	0.074	261	39	170	0.087	307	39	169	0.096	337	58
6	173	0.061	215	50	170	0.087	307	64	163	0.148	520	41
7	164.5	0.135	475	33	166	0.122	429	22	157	0.199	702	56
8	172	0.070	246	48	168	0.105	368	52	163	0.148	520	47
9	173.5	0.057	200	29	168	0.105	368	43	156	0.208	732	55
10	176	0.035	123	73	170	0.087	307	46	155	0.216	762	29
11	174	0.052	184	27	165.5	0.126	444	38	162	0.156	551	47
12	168	0.105	368	40	173.5	0.057	200	50	168.5	0.100	353	48
13	173	0.061	215	63	169.5	0.092	322	NA	166	0.122	429	72
14	165	0.131	459	33	168	0.105	368	38	161	0.165	581	45
15	170.5	0.083	291	50	165	0.131	459	25	153	0.233	822	40
16	174	0.052	184	60	170	0.087	307	63	160	0.174	611	29
17	176.5	0.031	107	50	166.5	0.118	414	54	157	0.199	702	43
18	166.5	0.118	414	47	164.5	0.135	475	71	153	0.233	822	32
19					170	0.087	307	54	160	0.174	611	50
20					170	0.087	307	24	161	0.165	581	46
21					168	0.105	368	23	160.5	0.169	596	59
22					172	0.070	246	31	155	0.216	762	54
23					172	0.070	246	38	153	0.233	822	39
24					174.3	0.050	175	44				
25					161.7	0.159	560	50				
26					175.5	0.039	138	50				
27					175.5	0.039	138	67				
28					170.2	0.085	301	43				
29					168.7	0.098	347	75				
30					170.7	0.081	285	40				
31					162.9	0.149	523	40				
32					168	0.105	368	40				
Average:			276				338				608	
Minimum:			107				138				337	
Maximum:			475				560				822	
Standard Error:			25				19				32	

	Direct Percussion - Antler				Direct Percussion - Sandstone				Direct Percussion - Quartzite			
Reference Number	Angular Measure	$\dot{C}/C_2$	$\dot{C}$ (m/s)	% T.C. Length	Angular Measure	$\dot{C}/C_2$	$\dot{C}$ (m/s)	% T.C. Length	Angular Measure	$\dot{C}/C_2$	$\dot{C}$ (m/s)	% T.C. Length
1	153.5	0.229	807	27	156	0.208	732	55	155	0.216	762	50
2	162	0.156	551	27	153.5	0.229	807	37	136.5	0.371	1304	46
3	166.5	0.118	414	66	158	0.191	672	58	151	0.250	881	49
4	163	0.148	520	64	156	0.208	732	58	136	0.375	1319	53
5	149	0.267	941	36	163	0.148	520	42	150	0.259	911	41
6	161.5	0.161	566	45	146.7	0.287	1009	33	146.5	0.288	1014	47
7	160.5	0.169	596	42	142.7	0.320	1126	49	151	0.250	881	43
8	155.5	0.212	747	25	151.7	0.244	861	69	150.7	0.253	890	48
9	152.5	0.238	837	63	145.3	0.298	1050	44	141.8	0.327	1152	52
10	161	0.165	581	51	148.8	0.269	947	48	146.8	0.286	1006	45
11	163.5	0.143	505	44	159.7	0.176	620	48	138.1	0.358	1259	49
12	157.5	0.195	687	45	153.2	0.232	816	54	151.7	0.244	861	32
13	151	0.250	881	39	141.8	0.327	1152	47	160.3	0.171	602	56
14	166	0.122	429	47	134.8	0.384	1353	39	150.8	0.252	887	53
15	164.5	0.135	475	28	148.3	0.273	961	43	145.3	0.298	1050	49
16	147	0.284	1000	40	135.3	0.380	1339	51	152.7	0.236	831	46
17	161	0.165	581	64	144.3	0.307	1079	47	144.2	0.307	1082	47
18	144.5	0.305	1073	31	148.7	0.270	950	42	146.2	0.291	1023	38
19	157.5	0.195	687	37	154.7	0.219	771	64	153	0.233	822	42
20	156	0.208	732	45	150.5	0.255	896	54	150	0.259	911	58
21	167	0.113	398	62	153	0.233	822	55	160	0.174	611	29
22	168	0.105	368	35	153	0.233	822	61	142.5	0.321	1131	42
23	160	0.174	611	51	148.5	0.271	955	58	158.7	0.185	651	62
24	163.5	0.143	505	45	152.5	0.238	837	62	157	0.199	702	49
25	162.2	0.155	545	45	139.7	0.344	1213	54	152	0.242	852	57
26	162.2	0.155	545	47	155	0.216	762	54	143.7	0.312	1097	52
27	158.5	0.187	657	59	149.8	0.261	917	57	142.8	0.319	1123	54
28	160.3	0.171	602	56	145	0.301	1058	54	161.2	0.163	575	37
29	161.8	0.158	557	48	145.8	0.294	1035	61	145.7	0.295	1038	51
30	154.8	0.218	768	63	139.5	0.346	1218	48	150.3	0.256	902	56
31	154.3	0.222	783	51	148.5	0.271	955	35	152	0.242	852	56
32	164.7	0.133	469	49	144.5	0.305	1073	56	139.7	0.344	1213	48
33									147.5	0.280	985	37
Average:			638				939				945	
Minimum:			368				520				575	
Maximum:			1073				1353				1319	
Standard Error:			31				35				34	

APPENDIX C

Artifacts lacking velocity dependent fracture features.

This appendix constitutes a listing of 522 artifacts which were examined for velocity dependent fracture features, but from which no data were recovered.

Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
553-235	AINW	Clovis blank	Christmas Valley, OR	Fragment, fluted, obsidian	20/2/96
59/1/140	AINW	Windust	Christmas Valley, OR	Base frag., chert	20/2/96
59/1/160	AINW	GBS (round base)	Christmas Valley, OR	Complete	20/2/96
59/1/31	AINW	Windust	Christmas Valley, OR	Complete, obsidian	20/2/96
59/1/52	AINW	Windust	Christmas Valley, OR	Near complete, slight tip damage, obsidian	20/2/96
59/1/54	AINW	Windust	Christmas Valley, OR	Base frag., obsidian	20/2/96
59/1/87	AINW	Windust	Christmas Valley, OR	Complete (slight base damage), obsidian	20/2/96
59/1124	AINW	Windust	Christmas Valley, OR	Complete (slight tip damage), chert	20/2/96
59/1128	AINW	Windust	Christmas Valley, OR	Complete, obsidian	20/2/96
59/1130	AINW	Windust	Christmas Valley, OR	Proximal sec., obsidian	20/2/96
59/1366	AINW	Windust?	Christmas Valley, OR	Base frag., no edge grinding, basalt	20/2/96
59/1372	AINW	Windust	Christmas Valley, OR	Base frag., basalt	20/2/96
59/139	AINW	Windust	Christmas Valley, OR	Base frag., obsidian	20/2/96
59/140	AINW	Windust	Christmas Valley, OR	Base frag., obsidian	20/2/96
59/141	AINW	Square stemmed	Christmas Valley, OR	Proximal sec., edge ground, chert	20/2/96
59/142	AINW	Windust	Christmas Valley, OR	Base frag., obsidian	20/2/96
59/143	AINW	Windust	Christmas Valley, OR	Base frag., obsidian	20/2/96
59/144	AINW	Windust	Christmas Valley, OR	Proximal sec., obsidian	20/2/96
59/145	AINW	Windust	Christmas Valley, OR	Proximal sec. (tip missing), obsidian	20/2/96

Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
59/146	AINW	Windust	Christmas Valley, OR	Proximal sec. (tip missing), obsidian	20/2/96
59/147	AINW	Windust	Christmas Valley, OR	Proximal sec., obsidian	20/2/96
59/148	AINW	Windust	Christmas Valley, OR	Complete, obsidian	20/2/96
59/148	AINW	Windust	Christmas Valley, OR	Proximal sec., massive impact (?) scar, obsidian	20/2/96
59/1496	AINW	GBS (round base)	Christmas Valley, OR	Base frag., no edge grinding, obsidian	20/2/96
59/150	AINW	Windust	Christmas Valley, OR	Midsection (base and tip missing), obsidian	20/2/96
59/1514	AINW	Windust	Christmas Valley, OR	Near complete (tip and base damage), obsidian	20/2/96
59/152	AINW	Windust	Christmas Valley, OR	Proximal frag., chert	20/2/96
59/1625	AINW	Windust	Christmas Valley, OR	Base frag., no edge grinding, obsidian	20/2/96
59/163	AINW	Windust	Christmas Valley, OR	Complete, grey chert	20/2/96
59/1640	AINW	Square stemmed	Christmas Valley, OR	Base frag., obsidian	20/2/96
59/1684	AINW	Windust	Christmas Valley, OR	Proximal sec., fire carinated, tan chert	20/2/96
59/1763	AINW	Windust?	Christmas Valley, OR	Base frag., no edge grinding, obsidian	20/2/96
59/178	AINW	Windust	Christmas Valley, OR	Base frag., obsidian	20/2/96
59/186	AINW	GBS	Christmas Valley, OR	Proximal sec., impact (?) damaged	20/2/96
59/187	AINW	Square stemmed	Christmas Valley, OR	Complete, edge ground, obsidian	20/2/96
59/1909	AINW	Square stemmed	Christmas Valley, OR	Base frag., obsidian	20/2/96
59/1956	AINW	Square stemmed	Christmas Valley, OR	Base frag., no edge grinding, obsidian	20/2/96
59/20	AINW	GBS (long stemmed)	Christmas Valley, OR	Complete, obsidian	20/2/96
59/205	AINW	Square stemmed	Christmas Valley, OR	Base frag., edge ground, tan chert	20/2/96
59/218	AINW	Square stemmed	Christmas Valley, OR	Base frag., obsidian	20/2/96
59/2251	AINW	Square stemmed	Christmas Valley, OR	Base frag., obsidian	20/2/96
59/2355	AINW	Windust?	Christmas Valley, OR	Base frag., obsidian	20/2/96
59/237	AINW	Square stemmed	Christmas Valley, OR	Base frag., obsidian	20/2/96

Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
59/2407	AINW	Square stemmed	Christmas Valley, OR	Proximal sec., chert	20/2/96
59/2429	AINW	Windust	Christmas Valley, OR	Base frag., no edge grinding, obsidian	20/2/96
59/2471	AINW	Square stemmed	Christmas Valley, OR	Base frag., no edge grinding, obsidian	20/2/96
59/2898	AINW	Concave base	Christmas Valley, OR	Complete (missing 1 ear), no edge grinding, obsidian	20/2/96
59/2929	AINW	Windust	Christmas Valley, OR	Base frag., obsidian	20/2/96
59/2997	AINW	Windust	Christmas Valley, OR	Base frag., obsidian	20/2/96
59/304	AINW	Windust	Christmas Valley, OR	Proximal sec., no edge grinding, mottled red- tan chert	20/2/96
59/3053	AINW	Windust	Christmas Valley, OR	Complete (damaged ear), obsidian	20/2/96
59/3054	AINW	Windust	Christmas Valley, OR	Base frag., obsidian	20/2/96
59/3057	AINW	Windust	Christmas Valley, OR	Base frag., obsidian	20/2/96
59/35	AINW	Windust	Christmas Valley, OR	Near complete, obsidian	20/2/96
59/41	AINW	Windust	Christmas Valley, OR	Complete, obsidian	20/2/96
59/57	AINW	Windust	Christmas Valley, OR	Near complete, obsidian	20/2/96
59/59	AINW	Windust	Christmas Valley, OR	Complete, obsidian	20/2/96
59/59	AINW	Windust	Christmas Valley, OR	Near complete (base missing), chert	20/2/96
59/64	AINW	Windust	Christmas Valley, OR	Complete, very large, obsidian	20/2/96
59/72	AINW	GBS? (round base)	Christmas Valley, OR	Complete	20/2/96
85-35-47	ASM	Clovis	AZ BB:13:15 (road surface)	Complete	14/8/95
94-100-1	ASM	Clovis	AZ T:4:107 (ASM)	Complete	14/8/95
A31232	ASM	Clovis	Escapule Site, San Pedro River, AZ	Complete (tip damaged)	14/8/95
A12676	ASM	Clovis	Lehner, AZ	Complete	14/8/95
A12677	ASM	Clovis	Lehner, AZ	Complete	14/8/95
A12679	ASM	Clovis	Lehner, AZ	Complete	14/8/95
A12680	ASM	Clovis	Lehner, AZ	Complete	14/8/95
A12681	ASM	Clovis	Lehner, AZ	Complete, quartz crystal	14/8/95
A12683	ASM	Clovis	Lehner, AZ	Complete, quartz crystal	14/8/95
A12684	ASM	Clovis	Lehner, AZ	Complete (tip damaged)	14/8/95
A12685	ASM	Clovis	Lehner, AZ	Complete	14/8/95
A12686	ASM	Clovis	Lehner, AZ	Complete	14/8/95
A4157	ASM	Folsom	Lindenmeier, CO	Base frag.	14/8/95

Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
A9961	ASM	Channel flake	Lindenmeier, CO	Frag.	14/8/95
A9967	ASM	Channel flake/graver	Lindenmeier, CO	Frag.	14/8/95
A10900	ASM	Clovis	Naco, AZ	Complete	14/8/95
A10901	ASM	Clovis	Naco, AZ	Complete (tip damaged)	14/8/95
A10902	ASM	Clovis	Naco, AZ	Complete	14/8/95
A30064	ASM	Midland	Wheeler Ranch, Texas (?)	Complete	14/8/95
1454/6	DMNH	Unspecified Paleoindian	Blackwater Draw (?)	Midsection frag.	28/8/95
1454/5	DMNH	Folsom	Blackwater Draw, NM	Base frag.	28/8/95
NA	DMNH	Clovis	Blackwater Draw, NM	Base frag.	28/8/95
NA	DMNH	Clovis	Dent Site, CO.	Cast of missing Dent point	28/8/95
NA	DMNH	Clovis	"Eastern Paleoindian"	Complete, small	28/8/95
1758.2A	DMNH	Folsom	Folsom, NM	Cast of 1391/3 in DMNH collection, Distal section	28/8/95
1758.3	DMNH	Folsom	Folsom, NM	Cast of 1261/1A in DMNH collection, Distal section	28/8/95
900 00/178	DMNH	Folsom preform	Lindenmeier, CO	Complete, missing ear	28/8/95
900/124	DMNH	Folsom preform	Lindenmeier, CO	Complete	28/8/95
900/148	DMNH	Channel flake	Lindenmeier, CO	Complete	28/8/95
900/172	DMNH	Folsom	Lindenmeier, CO	Proximal section, tip and 1 ear missing	28/8/95
1055/1	DMNH	Plainview	Lone Wolf Creek, TX	Base frag., w/spinoff	28/8/95
1496/42	DMNH	Fluted point (barely)	NA	Complete, very slight edge grinding	28/8/95
A1797.1	DMNH	Clovis	Pike Co, IL	Complete	28/8/95
68.94.5	UNM	Clovis	Belen, NM	Complete	21/8/95
67.86.2	UNM	Clovis	Clovis, NM	Base frag.	21/8/95
72.45.219	UNM	Folsom (?) (thin, fluted)	Estancia Basin, NM	Base frag.	21/8/95
72.45.367	UNM	Folsom	Estancia Basin, NM	Proximal section	21/8/95
76.62.10	UNM	Clovis	Lucy Site, NM	Base frag.	21/8/95
76.62.11b	UNM	Sandia (?) (fluted w/ concave base, 1 shoulder)	Lucy Site, NM		21/8/95
76.62.334	UNM	Midland	Lucy Site, NM	Proximal frag.	21/8/95

Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
76.62.335	UNM	Folsom	Lucy Site, NM	Midsection frag.	21/8/95
76.62.336	UNM	Folsom	Lucy Site, NM	Proximal frag.	21/8/95
76.62.342	UNM	Folsom (?) (thin, fluted)	Lucy Site, NM	Proximal sec.	21/8/95
76.62.344	UNM	Folsom	Lucy Site, NM	Complete	21/8/95
76.62.348	UNM	Folsom	Lucy Site, NM	Midsection frag.	21/8/95
76.62.9	UNM	Sandia (?) (fluted w/ concave base, 1 shoulder)	Lucy Site, NM	Proximal sec.	21/8/95
48.4.2	UNM	Folsom(?)	Mountainair, NW	Base frag.	21/8/95
41.1.238	UNM	Folsom	NA	2 fragments	21/8/95
65.31.?	UNM	Clovis	NA	Complete	21/8/95
36.42.158	UNM	Cumberland	Portsmouth, Ohio	Complete	21/8/95
69.20.127	UNM	Folsom	Rio Rancho Site, NM	Proximal frag.	22/8/95
69.20.129	UNM	Folsom	Rio Rancho Site, NM	Base frag.	22/8/95
69.20.134	UNM	Folsom	Rio Rancho Site, NM	Base frag.	22/8/95
69.20.148	UNM	Folsom	Rio Rancho Site, NM	Base frag.	22/8/95
69.20.149	UNM	Folsom	Rio Rancho Site, NM	Base frag.	22/8/95
69.20.150	UNM	Folsom	Rio Rancho Site, NM	Base frag.	22/8/95
69.20.152	UNM	Folsom	Rio Rancho Site, NM	Base frag.	22/8/95
69.20.153	UNM	Folsom	Rio Rancho Site, NM	Base frag.	22/8/95
69.20.154	UNM	Folsom	Rio Rancho Site, NM	Base frag.	22/8/95
69.20.155	UNM	Folsom	Rio Rancho Site, NM	Base frag.	22/8/95
69.20.160	UNM	Fluted	Rio Rancho Site, NM	Midsection frag.	21/8/95
69.20.163	UNM	Channel flake	Rio Rancho Site, NM	Frag.	21/8/95
69.20.167	UNM	Folsom	Rio Rancho Site, NM	Midsection frag.	22/8/95
69.20.172	UNM	Folsom	Rio Rancho Site, NM	Base frag.	22/8/95
69.20.180	UNM	Folsom	Rio Rancho Site, NM	Proximal section	22/8/95
69.20.188	UNM	Folsom	Rio Rancho Site, NM	Base frag.	22/8/95
69.20.196	UNM	Folsom	Rio Rancho Site, NM	Base frag.	22/8/95
69.20.201	UNM	Folsom	Rio Rancho Site, NM	Base frag.	22/8/95
69.20.235	UNM	Folsom	Rio Rancho Site, NM	Midsection frag.	21/8/95
69.20.239	UNM	Folsom	Rio Rancho Site, NM	Midsection frag.	22/8/95
69.20.245	UNM	Folsom	Rio Rancho Site, NM	Distal frag.	22/8/95
69.20.246	UNM	Folsom	Rio Rancho Site, NM	Base frag.	22/8/95
69.20.264	UNM	Folsom	Rio Rancho Site, NM	Base frag.	22/8/95
69.20.266	UNM	Folsom	Rio Rancho Site, NM	Base frag., obsidian	22/8/95
69.20.274	UNM	Folsom	Rio Rancho Site, NM	Proximal section	22/8/95

Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
69.20.278	UNM	Folsom	Rio Rancho Site, NM	Midsection frag.	22/8/95
69.20.33	UNM	Fluted point	Rio Rancho Site, NM	Midsection frag.	22/8/95
69.20.371b /a	UNM	Fluted preform, double	Rio Rancho Site, NM	2 frags.	22/8/95
48.1.1	UNM	Folsom	Roswell, NM	Base frag.	21/8/95
39.18.16	UNM	Folsom	Sandia Cave, NM	Complete	21/8/95
41.4.12	UNM	Clovis	Sandia Cave, NM	Base frag.	21/8/95
41.4.14	UNM	Sandia	Sandia Cave, NM	Tip damaged	21/8/95
67.91.1	UNM	Clovis (non-fluted)	Texas (?)	Tip damaged (very slight)	21/8/95
27480.11	MNM	Folsom	Deming area, NM	Complete	23/8/95
42599.11	MNM	Folsom	Deming area, NM	Base frag.	23/8/95
42600.11	MNM	Folsom	Deming area, NM	Base frag.	23/8/95
13830.11a	MNM	Folsom	Hereford, TX	Base frag.	23/8/95
13830.11b	MNM	Folsom	Hereford, TX	Base frag.	23/8/95
13830.11E	MNM	Folsom	Hereford, TX	Proximal section	23/8/95
13830.11H	MNM	Folsom	Hereford, TX	Base frag.	23/8/95
17068 LA 46583	MNM	Folsom	NA	Base frag., pos. impact fracture	23/8/95
26701 LA 48750	MNM	Concave base	NA	Base frag.	23/8/95
14981 LA 5529	MNM	Clovis	NA	Proximal frag., no edge grinding	23/8/95
24608 LA 59284	MNM	Clovis (?)	NA	Base frag.	23/8/95
17121 LA ARC	MNM	Folsom	NA	Base frag., bend frac. w/ spinoff	23/8/95
24641 LA ARC	MNM	Folsom	NA	Base frag.	23/8/95
26133 LA ARC	MNM	Folsom	NA	Proximal section	23/8/95
26220 LA102391	MNM	Fishtail point	NA	Proximal section (tip missing)	23/8/95
24565 LA78644	MNM	Fluted point	NA	Midsection frag.	23/8/95
3748	MNM	Folsom	Midland Site, TX	Base frag.	23/8/95
27473.11	MNM	Midland	Midland, TX	Complete (tip damaged)	23/8/95
51855.11	MNM	Clovis	NA	Base frag., massive impact-like frac.	23/8/95
626.11C	MNM	Folsom	Ojitos Frijos, NM	Base frag.	23/8/95
626.11F	MNM	Folsom	Ojitos Frijos, NM	Base frag.	23/8/95

Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
626.11L	MNM	Folsom	Ojitos Frijos, NM	Midsection frag.	23/8/95
626.11N	MNM	Folsom	Ojitos Frijos, NM	Base frag.	23/8/95
626.11O	MNM	Folsom	Ojitos Frijos, NM	Proximal frag.	23/8/95
640.11	MNM	Folsom	Ojitos Frijos, NM	Complete	23/8/95
24466	MNM	Clovis	Seelegson Site, NM	Complete, no edge grinding	23/8/95
13971.11	MNM	Fluted point	Tularosa Basin, NM	Complete	23/8/95
13674.11a	MNM	Yuma	Ute Creek, NM	Complete (tip damaged)	23/8/95
26 NY 257-1	NSM	GBS (long stemmed)	26 NY 257	Base frag. (stem), round-based stem, obsidian	10/1/96
26 NY 257-10	NSM	Concave, contracting basal margin	26 NY 257	Base frag., no edge grinding	10/1/96
26 NY 257-14	NSM	GBS (long stemmed)	26 NY 257	Base frag. (stem), round-based stem	10/1/96
26 NY 257-177	NSM	GBS (long stemmed)	26 NY 257	Base frag. (mid-stem), obsidian	10/1/96
26 NY 257-20	NSM	GBS (long stemmed)	26 NY 257	Base frag. (stem), round-based stem	10/1/96
26 NY 257-21	NSM	Clovis (?)	26 NY 257	Complete, impact (?) damaged tip, lite fluting, no edge grinding	10/1/96
26 NY 257-256	NSM	Clovis (?)	26 NY 257	Base frag., large, fluted(?), obsidian	10/1/96
26 NY 257-261	NSM	GBS (long stemmed)	26 NY 257	Base frag. (stem), round-based stem, obsidian	10/1/96
26 NY 257-279	NSM	Clovis	26 NY 257	Complete (tip damaged), small, obsidian	10/1/96
26 NY 257-6	NSM	GBS (long stemmed)	26 NY 257	Base frag. (mid-stem)	10/1/96
26 NY 257-7	NSM	Clovis	26 NY 257	Base frag.	10/1/96
26 NY 257-73	NSM	Midland (?)	26 NY 257	Base frag., unfluted Folsom similar to Lindemeier stlye	10/1/96
2053.G.4	NSM	Clovis	Black Rock Desert, NV	Complete, obsidian	10/1/96
NA	NSM	Clovis	Black Rock Desert, NV	Complete*, *major impact damage, Steve Wallmann donation	10/1/96
819.G134b	NSM	Clovis	Borax Lake, CA	Base frag., obsidian	10/1/96
NA	NSM	Clovis	Carlin, NV	Complete	10/1/96
819.G.134 C	NSM	GBS (square base)	Carson River, Ormsby Co., NV	Complete, obsidian	9/1/96
Cr.04.1844 /10	NSM	GBS (long stemmed)	Cr.04.1844	Complete, large, no edge grinding	10/1/96

Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
Cr.04.1844 /11	NSM	GBS (Silver Lake)	Cr.04.1844	Complete, no edge grinding	10/1/96
Cr.04.1844 /12	NSM	GBS (long stemmed)	Cr.04.1844	Base frag. (stem), lightly edge ground	10/1/96
NA	NSM	Clovis	Ebbits Pass, NV(?)	Midsection frag.	10/1/96
103-2431	NSM	Humbolt	Hanging Rock Shelter, Northern Washoe Co., NV	Complete, obsidian	10/1/96
103-2542	NSM	Humbolt	Hanging Rock Shelter, Northern Washoe Co., NV	Complete, obsidian	10/1/96
26 Wp 1605	NSM	GBS	Jake's Valley, NV	Complete, no edge grinding	10/1/96
NA	NSM	Clovis	Lahonton Res., Churchill Co., NV	Complete, tip damaged	10/1/96
NA	NSM	Clovis	Lake Tonopah, NV	Complete	10/1/96
NA	NSM	Clovis	Lake Tonopah, NV	Base frag.	10/1/96
NA	NSM	Clovis	Lake Tonopah, NV	Base frag.	10/1/96
NA	NSM	Clovis	Lake Tonopah, NV	Proximal section	10/1/96
CM 3536.G.69	NSM	GBS (long stemmed)	Monitor Valley or Railroad Valley, central NV	Complete (tip damaged), large, edge ground	10/1/96
130.L.114	NSM	GBS (Silver Lake)	NA	Complete	10/1/96
26 Chl 163-50	NSM	GBS (long stemmed)	NA	Complete	9/1/96
38G	NSM	Clovis	NA	Complete	10/1/96
NA	NSM	GBS (square stemmed)	NA	Complete	10/1/96
333	NSM	GBS (Parman?)	NA	Complete, obsidian	10/1/96
77	NSM	GBS (square stemmed)	Northern Washoe Co.,NV	Complete, obsidian, edge ground	10/1/96
NA	NSM	Clovis	Pine Creek Well, NV	Base frag., no edge grinding, Noyes coll.	10/1/96
NA	NSM	Plainview (?)	Pine Creek Well, NV	Proximal section, slight concave base, no edge grinding, Noyes coll.	10/1/96
120-25	NSM	Clovis (?)	Pluvial Lake Parman, NV	Complete, Layton i.d. as Humbolt, impact (?) damaged, fluted 1x	10/1/96
SAC-2	NSM	Clovis (?)	Sarcobatus Flat, NV	Complete, small, fluted	10/1/96

Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
1514.G.2	NSM	GBS (Parman)	Soldier Meadows Ranch, Black Rock Desert, NV	Proximal section, large PRESSURE flake/flute from distal end - might be reworked paleo-fluted type, see notebook, obsidian	9/1/96
1514.G.3	NSM	GBS (Parman)	Soldier Meadows Ranch, Black Rock Desert, NV	Complete, obsidian	9/1/96
NA	NSM	Folsom	Star Peak, Pershing Co., NV	Complete	10/1/96
NA	NSM	Clovis	Summit Lake, NV(?)	Complete, obsidian	10/1/96
NA	NSM	Clovis	Summit Lake, NV(?)	Complete	10/1/96
CM3705.G .1894	NSM	Folsom	Sunshine Well ,3C Long Valley, NV	Base frag.	8/1/96
CM3705.G .1705	NSM	Clovis	Sunshine Well 1, Long Valley, NV	Complete (tip missing), no edge grinding	8/1/96
CM3705.G .1827	NSM	Concave, contracting basal margin	Sunshine Well 1, Long Valley, NV	Base frag., labeled Humbolt, but not a basal "notch"	8/1/96
CM3705.G .1832	NSM	Concave, contracting basal margin	Sunshine Well 1, Long Valley, NV	Base frag., no edge grinding, poss. impact frac.	8/1/96
CM3705.G .1836	NSM	Leaf	Sunshine Well 1, Long Valley, NV	Complete	8/1/96
CM3705.G .1838	NSM	Concave, contracting basal margin	Sunshine Well 1, Long Valley, NV	Base frag., labeled Humbolt, but not a basal "notch", large, no edge grinding	8/1/96
CM3705.G .1840	NSM	Concave, contracting basal margin	Sunshine Well 1, Long Valley, NV	Base frag., no edge grinding	8/1/96
CM3705.G .1875	NSM	GBS	Sunshine Well 1, Long Valley, NV	Complete, slight tip damage	8/1/96
CM3705.G .1897	NSM	Clovis	Sunshine Well 1, Long Valley, NV	Base frag., no edge grinding	8/1/96
CM3705.G .1904	NSM	Clovis	Sunshine Well 1, Long Valley, NV	Proximal section, impact (?) fractured tip	8/1/96
CM3705.G .1909	NSM	Concave, contracting basal margin	Sunshine Well 1, Long Valley, NV	Complete (tip missing), labeled Humbolt, but not a basal "notch"	8/1/96
CM3705.G .1913	NSM	Concave, contracting basal margin	Sunshine Well 1, Long Valley, NV	Base frag., large	8/1/96
CM3705.G .1914	NSM	Plainview (?)	Sunshine Well 1, Long Valley, NV	Complete, Clovis-like but no flutes or edge grinding	8/1/96

Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
SW1-1	NSM	Plainview (?)	Sunshine Well 1, Long Valley, NV	Base frag., large, heavy edge grinding, no fluting	9/1/96
SW1-13	NSM	Concave, contracting basal margin*	Sunshine Well 1, Long Valley, NV	Base frag., small, *possibly a Pinto point base, edge ground	9/1/96
SW1-5	NSM	Concave, contracting basal margin*	Sunshine Well 1, Long Valley, NV	Base frag., small, *possibly a Pinto point base, no edge grinding	9/1/96
CM3705.G .1828	NSM	Concave, contracting basal margin	Sunshine Well 2, Long Valley, NV	Base frag., labeled Humbolt, but not a basal "notch"	8/1/96
CM3705.G .1900	NSM	Concave, contracting basal margin	Sunshine Well 2, Long Valley, NV	Proximal section, labeled Humbolt, but not a basal "notch", large, no edge grinding	8/1/96
CM3705.G .1902	NSM	Concave, contracting basal margin	Sunshine Well 2, Long Valley, NV	Base frag.	8/1/96
CM3705.G .1906	NSM	Concave Base	Sunshine Well 2, Long Valley, NV	Proximal section	8/1/96
CM3705.G .1907	NSM	Concave Base	Sunshine Well 2, Long Valley, NV	Base frag., large, no edge grinding	8/1/96
CM3705.G .1912	NSM	Concave, contracting basal margin	Sunshine Well 2, Long Valley, NV	Base frag.	8/1/96
SW2-48	NSM	Pinto (?)	Sunshine Well 2, Long Valley, NV	Base frag. (stem), small, see notebook, poss. lite edge grinding	9/1/96
SW2-57	NSM	Concave, contracting basal margin*	Sunshine Well 2, Long Valley, NV	Base frag., small, *possibly a Pinto point base, no edge grinding	9/1/96
SW2-77	NSM	Concave, contracting basal margin	Sunshine Well 2, Long Valley, NV	Base frag., large, edge ground, no fluting	9/1/96
SW2A-16	NSM	Concave Base	Sunshine Well 2A, Long Valley, NV	Base frag., large, unfinished, broken in manufacture	9/1/96
SW2A-7	NSM	Clovis (?)*	Sunshine Well 2A, Long Valley, NV	Base frag., small, *possibly a Pinto point base, edge ground, short lite flute 1x	9/1/96
SW2A-8	NSM	Clovis (?)*	Sunshine Well 2A, Long Valley, NV	Base frag., small, *possibly a Pinto point base, edge ground, short multi. flute 1x	9/1/96

Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
CM3705.G .1884	NSM	GBS	Sunshine Well 2B, Long Valley, NV	Complete, slight tip damage	8/1/96
CM3705.G .1893	NSM	Clovis	Sunshine Well 2B, Long Valley, NV	Base frag., small, obsidian	8/1/96
CM3705.G .1910	NSM	Concave, contracting basal margin	Sunshine Well 2B, Long Valley, NV	Base frag., thin in section	8/1/96
SW2B-19	NSM	Concave Base*	Sunshine Well 2B, Long Valley, NV	Base frag., small, *possibly a Pinto point base, no edge grinding	9/1/96
SW2B-2	NSM	Clovis (?)*	Sunshine Well 2B, Long Valley, NV	Base frag., small, *possibly a Pinto point base, no edge grinding, lite fluted 2x	9/1/96
CM3705.G .1835	NSM	Concave, contracting basal margin	Sunshine Well 3, Long Valley, NV	Base frag., labeled Humbolt, but not a basal "notch"	8/1/96
CM3705.G .1873	NSM	Concave, contracting basal margin	Sunshine Well 3, Long Valley, NV	Base frag., large	8/1/96
CM3705.G .1881	NSM	Clovis	Sunshine Well 3, Long Valley, NV	Complete, Slight tip damage	8/1/96
CM3705.G .1882	NSM	Concave Base	Sunshine Well 3, Long Valley, NV	Complete, Clovis? No flutes or edge grinding	8/1/96
SW3-13	NSM	Concave, contracting basal margin	Sunshine Well 3, Long Valley, NV	Base frag., large, no edge grinding or fluting	9/1/96
SW3-4	NSM	Clovis (?)	Sunshine Well 3, Long Valley, NV	Base frag., large, no edge grinding, multi flute 1x	9/1/96
SW3-5	NSM	Concave Base*	Sunshine Well 3, Long Valley, NV	Base frag., large, *probably a stem, no edge grinding or fluting	9/1/96
SW3-9	NSM	Clovis (?)*	Sunshine Well 3, Long Valley, NV	Base frag., small, *possibly a Pinto point base, edge ground, lite fluted 2x	9/1/96
CM3705.G .1896	NSM	Concave, contracting basal margin	Sunshine Well 3A, Long Valley, NV	Base frag., small	8/1/96
CM3705.G .1903	NSM	Concave, contracting basal margin	Sunshine Well 3A, Long Valley, NV	Base frag.	8/1/96
CM3705.G .1905	NSM	Concave, contracting basal margin	Sunshine Well 3A, Long Valley, NV	Base frag.	8/1/96

Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
CM3705.G .1829	NSM	Concave, contracting basal margin	Sunshine Well 3B, Long Valley, NV	Base frag., labeled Humbolt, but not a basal "notch", Large, no edge grinding	8/1/96
CM3705.G .1883	NSM	Concave, contracting basal margin	Sunshine Well 3B, Long Valley, NV	Base frag., large	8/1/96
CM3705.G .1891	NSM	Clovis	Sunshine Well 3B, Long Valley, NV	Base frag., obsidian	8/1/96
SW3B-165	NSM	Clovis (?)	Sunshine Well 3B, Long Valley, NV	Base frag., large, edge ground, lite multi flute 1x	9/1/96
SW3B-166	NSM	Concave Base*	Sunshine Well 3B, Long Valley, NV	Base frag., small, *possibly a Pinto point base, edge ground, impact (?) damaged	9/1/96
SW3B-79	NSM	Concave, contracting basal margin*	Sunshine Well 3B, Long Valley, NV	Base frag., small, *possibly a Pinto point base, no edge grinding	9/1/96
SW3C-64	NSM	Concave Base	Sunshine Well 3C, Long Valley, NV	Base frag., edge ground, small	9/1/96
SW3C-85	NSM	Clovis (?)	Sunshine Well 3C, Long Valley, NV	Base frag., large, no edge grinding, fluted 2x	9/1/96
SW3C-89	NSM	Clovis (?)	Sunshine Well 3C, Long Valley, NV	Base frag., large, no edge grinding, multi flute 1x	9/1/96
CM3705.G .1908	NSM	Concave, contracting basal margin	Sunshine Well 3D, Long Valley, NV	Base frag.	8/1/96
CM3705.G .1892	NSM	Clovis (?)	Sunshine Well 4, Long Valley, NV	Base frag.	8/1/96
SW4-2	NSM	Concave Base*	Sunshine Well 4, Long Valley, NV	Base frag., small, *possibly a Pinto point base, no edge grinding	9/1/96
SW4-4	NSM	Plainview (?)	Sunshine Well 4, Long Valley, NV	Base frag., large, edge ground, no fluting	9/1/96
SW4-49	NSM	Clovis (?)	Sunshine Well 4, Long Valley, NV	Base frag., large, no edge grinding, fluted 2x, reworked - burin on margin	9/1/96
SW4-54	NSM	Clovis (?)	Sunshine Well 4, Long Valley, NV	Base frag., large, edge ground, poss. lite multi flute 1x	9/1/96
SW4-56	NSM	Concave Base*	Sunshine Well 4, Long Valley, NV	Base frag., small, *possibly a Pinto point base, no edge grinding	9/1/96
CM3705.G .1880	NSM	Clovis	Sunshine Well 5, Long Valley, NV	Base frag.	8/1/96

Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
CM3705.G .1833	NSM	Clovis (?)	Sunshine Well 6, Long Valley, NV	Base frag., basal thinned?, edge ground	8/1/96
CM3705.G .1895	NSM	Clovis	Sunshine Well 6, Long Valley, NV	Base frag.	8/1/96
SW6-37	NSM	Concave Base	Sunshine Well 6, Long Valley, NV	Base frag., large, no edge grinding or fluting	9/1/96
CM3705.G .1708	NSM	Midland (?)	Sunshine Well 7, Long Valley, NV	Complete, "unfluted Folsom", no edge grinding	8/1/96
CM3705.G .1877	NSM	Humbolt	Sunshine Well 7, Long Valley, NV	Complete	8/1/96
SW8-3	NSM	Concave Base*	Sunshine Well 8, Long Valley, NV	Base frag., small, *possibly a Pinto point base, no edge grinding	9/1/96
CM3705.G .1581	NSM	Clovis*	Sunshine Well P2, Long Valley, NV	Complete, barely fluted - basally thinned? Some edge grinding	8/1/96
CM3705.G .1586	NSM	Concave, contracting basal margin	Sunshine Well P2, Long Valley, NV	Base frag., bend frac., no edge grinding	8/1/96
CM 3705.G.889	NSM	GBS	Sunshine Well, Long Valley, NV	Base frag. (stem), edge ground	10/1/96
CM 3705.G.897	NSM	GBS	Sunshine Well, Long Valley, NV	Base frag. (stem), no edge grinding	10/1/96
CM 3705.G.900	NSM	GBS	Sunshine Well, Long Valley, NV	Base frag. (stem), no edge grinding	10/1/96
CM 3705.G.995	NSM	GBS	Sunshine Well, Long Valley, NV	Base frag. (stem), no edge grinding	10/1/96
CM3705.G .1911	NSM	Concave, contracting basal margin	Sunshine Well, Long Valley, NV	Base frag., large, no edge grinding	8/1/96
2053.G.3	NSM	Clovis	Washoe Lake, NV	Distal section, obsidian	10/1/96
2392.G.118 3	NSM	Clovis	Washoe Lake, NV	Base frag., obsidian	10/1/96
26 Wa 00-500	NSM	Clovis	Washoe Lake, NV	Complete, slight tip damage, no edge grinding	9/1/96
NA	NSM	Clovis	Washoe Lake, NV	Base frag., obsidian, highly weathered	10/1/96
NA	NSM	Clovis	Washoe Lake, NV	Complete, small, obsidian	10/1/96
NA	NSM	Clovis	Washoe Lake, NV	Proximal section, tip missing	10/1/96
103-1049	NSM	GBS (long stemmed)	NA	Base frag. (mid-stem), heavy edge grinding, poss. impact damaged, obsidian	10/1/96
103-2643	NSM	GBS (long stemmed)	NA	Base frag. (stem), edge ground, obsidian	10/1/96

Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
103-2789	NSM	GBS (long stemmed)	NA	Base frag. (stem), edge ground, obsidian	10/1/96
103-2853	NSM	GBS (Parman)	NA	Complete, lite edge grinding, obsidian	10/1/96
103-3201	NSM	Humbolt	NA	Complete, no edge grinding, obsidian	10/1/96
103-3240	NSM	GBS (Parman)	NA	Complete, impact (?) damaged, obsidian	10/1/96
103-3251	NSM	GBS (square stemmed)	NA	Base frag. (stem), lite edge grinding, obsidian	10/1/96
103-3544	NSM	Humbolt	NA	Base frag., no edge grinding, obsidian	10/1/96
103-443	NSM	Humbolt	NA	Base frag., no edge grinding, obsidian	10/1/96
103-488	NSM	GBS (Parman)	NA	Base frag. (stem), lite edge grinding, obsidian	10/1/96
103-862	NSM	Humbolt	NA	Base frag., no edge grinding, obsidian	10/1/96
103-974	NSM	GBS (long stemmed)	NA	Base frag. (stem), edge ground, obsidian	10/1/96
DjOw1 27590	PMA	Scottsbluff	DjOw1, AB	Base frag.	25/9/95
DjOw1 27591	PMA	Scottsbluff	DjOw1, AB	Midsection frag.	25/9/95
DjOw1 604	PMA	Scottsbluff	DjOw1, AB	Complete, large	25/9/95
DjOw1 606	PMA	Scottsbluff	DjOw1, AB	Distal frag., tip	25/9/95
60-1-1094	PMA	Clovis	FhPr area, Cameron Collection	Base sec.	25/9/95
H67-354-111	PMA	Clovis	FhPr area, Cameron Collection	Base sec.	25/9/95
H67-354-189	PMA	Clovis	FhPr area, Cameron Collection	Complete	25/9/95
H67-354-4	PMA	Clovis	FhPr area, Cameron Collection	Complete	25/9/95
H70-9-148	PMA	Clovis	FhPr area, Cameron Collection	Base sec.	25/9/95
H70-9-165	PMA	Clovis	FhPr area, Cameron Collection	Base frag., unfinished, snapped, no edge grinding	25/9/95
H70-9-266	PMA	Fluted, concave base	FhPr area, Cameron Collection	Complete	25/9/95
H71-132-5	PMA	Clovis	FhPr area, Cameron Collection	Base frag.	25/9/95

Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
H73-174-2	PMA	Clovis (?)	FhPr area, Cameron Collection	Base sec., no edge grinding	25/9/95
H73-174-53	PMA	Fluted, triangular, concave base	FhPr area, Cameron Collection	Complete	25/9/95
H73-174-54	PMA	Clovis	FhPr area, Cameron Collection	Base frag.	25/9/95
H73-93-29	PMA	Clovis	FhPr area, Cameron Collection	Complete, tip damaged	25/9/95
H75-3-1	PMA	Clovis	FhPr area, Cameron Collection	Re-sharpened nubbin	25/9/95
H75-3-2	PMA	Fluted, concave base	FhPr area, Cameron Collection	Complete, 1 side fluted, no edge grinding	25/9/95
H75-3-3	PMA	Fluted, triangular, concave base	FhPr area, Cameron Collection	Poss. Clovis, small	25/9/95
H78-24-1	PMA	Fluted, concave base	FhPr area, Cameron Collection	Unfinished Clovis?	25/9/95
H87-406-681	PMA	Clovis	FhPr area, Cameron Collection	Complete, "H81"?	25/9/95
H65-63-5	PMA	Clovis	NA	Complete	25/9/95
H65-63-6	PMA	Clovis	NA	Complete	25/9/95
H65-63-7	PMA	Clovis	NA	Complete	25/9/95
H85-1193-135	PMA	McKean	NA	Complete, tip damaged	25/9/95
H85-1193-139	PMA	Fluted, concave base	NA	Complete, no edge grinding	25/9/95
H85-1193-20	PMA	Agate Basin	NA	Complete, tip damaged	25/9/95
H85-1193-62	PMA	Plainview	NA	Complete, tip damaged	25/9/95
H95-63-1	PMA	Scottsbluff	NA	Complete, tip damaged	25/9/95
H95-63-4	PMA	Clovis (?)	NA	Complete, re-sharpened	25/9/95
NA	PMA	Clovis (?)	NA	Complete, no edge grinding	25/9/95
NA	PMA	Clovis (?)	NA	Complete, no edge grinding	25/9/95
NA	PMA	Clovis (?)	NA	Complete, no edge grinding	25/9/95
NA	PMA	Clovis (?)	NA	Complete, no edge grinding	25/9/95
NA	PMA	Clovis (?)	NA	Complete, no edge grinding	25/9/95
NA	PMA	Clovis (?)	NA	Complete, no edge grinding	25/9/95
NA	PMA	Clovis (?)	NA	Complete, no edge grinding	25/9/95
NA	PMA	Clovis (?)	NA	Complete, no edge grinding	25/9/95
NA	PMA	Clovis (?)	NA	Complete, no edge grinding	25/9/95

Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
NA	PMA	Clovis (?)	NA	Complete, no edge grinding	25/9/95
NA	PMA	Clovis (?)	NA	Complete, no edge grinding	25/9/95
NA	PMA	Clovis (?)	NA	Complete, no edge grinding	25/9/95
NA	PMA	Clovis (?)	NA	Complete, no edge grinding	25/9/95
NA	PMA	Clovis (?)	NA	Complete, no edge grinding	25/9/95
NA	PMA	Clovis (?)	NA	Complete, no edge grinding	25/9/95
NA	PMA	Clovis (?)	NA	Complete, no edge grinding	25/9/95
NA	PMA	Clovis (?)	NA	Complete, no edge grinding	25/9/95
NA	PMA	Clovis (?)	NA	Complete, no edge grinding	25/9/95
NA	PMA	Clovis (?)	NA	Complete, no edge grinding	25/9/95
NA	PMA	Clovis (?)	NA	Complete, no edge grinding	25/9/95
NA	PMA	Clovis (?)	NA	Complete, no edge grinding	25/9/95
H90-142-1	PMA	Clovis	NA, Barager Collection	Complete	25/9/95
H90-142-2	PMA	Clovis	NA, Barager Collection	Midsection frag.	25/9/95
H90-142-4B	PMA	Scottsbluff	NA, Barager Collection	Complete	25/9/95
H63-5-8	PMA	McKean	NA, Grace Collection	Complete	25/9/95
61-4-672	PMA	Dalton	NA, Howard Collection	Complete	25/9/95
EgPr2 3731	PMA	Stemmed	Sibbald Creek, AB	Complete, Cody (?), edge ground	25/9/95
EgPr2 6886	PMA	Clovis	Sibbald Creek, AB	Base frag.	25/9/95
EgPr2 8885	PMA	Clovis	Sibbald Creek, AB	Base frag., black trac./dac.	25/9/95
EgPr2 NA	PMA	Clovis	Sibbald Creek, AB	Complete, nubbin, no edge grinding	25/9/95
1963.1.590 #18586	SDMM	Clovis	Fossil Spring Site, Northcentral San Bernadino Co., CA	Complete (tip missing), edge ground	15/1/96
NA	SDMM	Concave Base	Leach Dry Lake, NW San Bernadino Co., CA	Complete, obsidian	15/1/96
NA	SDMM	Concave Base	Leach Dry Lake, NW San Bernadino Co., CA	Complete, tip missing	15/1/96
1968.104.17	SDMM	Humbolt (?)	NS-25	Proximal section, massive impact(?) fracture	15/1/96
1934.2.1 #4904	SDMM	Clovis	Pine Hills, San Diego Co., CA	Complete (2 pieces), large, quartz crystal	15/1/96
1963.1.571	SDMM	GBS (Silver Lake)	South Granite Lake, NW San Bernadino Co., CA	Complete	15/1/96
1963.1.699	SDMM	GBS (Silver Lake)	South Granite Lake, NW San Bernadino Co., CA	Complete	15/1/96
1961.12.1	SDMM	Folsom	St. Thomas Pueblo, NV	Complete, thick, no edge grinding	15/1/96

Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
1963.1.576	SDMM	Clovis	Tietfort Basin, NW San Bernadino Co., CA	Proximal section, massive impact (/) damage, obsidian	15/1/96
1963.1.578 #18974	SDMM	Clovis	White River Sink, Lincoln Co., NV	Proximal section, obsidian	15/1/96
20-167-8-4	TBC	Clovis	Surface	Midsection frag., split	29/8/95
33-17-2-2	TBC	Folsom	Surface	Midsection frag., split,	31/8/95
33-2-13-39	TBC	Folsom	Surface	Distal frag., tip	31/8/95
33-20-1-5	TBC	Folsom	Surface	Midsection frag., split, obsidian	31/8/95
33-21-1-1	TBC	Folsom	Surface	Midsection frag., radial break, split, obsidian	31/8/95
33-21-1-3	TBC	Folsom	Surface	Proximal sec., split	31/8/95
33-21-1-6	TBC	Folsom	Surface	Distal sec., large tip frag.	31/8/95
33-23-1-4	TBC	Folsom	Surface	Midsection frag., split,	31/8/95
33-23-1-60	TBC	Folsom	Surface	Distal frag., tip, impact (?) damaged	31/8/95
34-11-1-60	TBC	Clovis (?)	Surface	Base frag., identified as Folsom	31/8/95
34-11-4-22	TBC	Folsom	Surface	Midsection frag., near tip	31/8/95
34-11-4-65	TBC	Folsom	Surface	Distal frag., tip	31/8/95
34-2-12-10	TBC	Folsom	Surface	Proximal sec. (tip missing)	31/8/95
34-2-13-152	TBC	Channel flake	Surface	Proximal sec.	31/8/95
34-2-13-232	TBC	Channel flake	Surface	Proximal sec., obsidian	31/8/95
34-2-13-276	TBC	Channel flake	Surface	Midsection frag.	31/8/95
34-2-13-301	TBC	Channel flake	Surface	Midsection frag.	31/8/95
34-2-13-302	TBC	Channel flake	Surface	Proximal sec.	31/8/95
34-2-13-303	TBC	Channel flake	Surface	Midsection frag.	31/8/95
34-2-13-31	TBC	Folsom	Surface	Proximal sec. (tip missing), obsidian	31/8/95
34-2-13-4	TBC	Folsom	Surface	Midsection frag., split, poss. impact damaged, obsidian	31/8/95
34-2-13-41	TBC	Folsom	Surface	Base sec., split	31/8/95
34-2-13-81	TBC	Channel flake	Surface	Proximal sec.	31/8/95
34-2-14-3	TBC	Folsom	Surface	Base frag.	29/8/95
34-2-14-5	TBC	Folsom	Surface	Midsection frag.	29/8/95

Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
34-2-23-3	TBC	Folsom	Surface	Midsection frag.	31/8/95
34-2-31-1	TBC	Clovis	Surface	Proximal frag., missing basal ears	29/8/95
34-2-5-1	TBC	Folsom	Surface	Midsection frag., obsidian	31/8/95
34-3-3-2	TBC	Folsom (prob.)	Surface	Midsection frag.	31/8/95
34-3-3-6	TBC	Clovis	Surface	Base frag., reworked	29/8/95
34-4-2-20	TBC	Folsom	Surface	Midsection frag.	31/8/95
34-4-3-10	TBC	Folsom (prob.)	Surface	Distal frag., tip, poss. tip damage, obsidian	31/8/95
34-4-3-103	TBC	Folsom	Surface	Proximal sec. (tip missing)	29/8/95
34-4-3-110	TBC	Clovis	Surface	Base frag., obsidian	29/8/95
34-4-3-114	TBC	Folsom preform	Surface	Midsection frag.	29/8/95
34-4-3-115	TBC	Folsom	Surface	Base frag.	29/8/95
34-4-3-12	TBC	Clovis	Surface	Distal frag., pitchstone	29/8/95
34-4-3-135	TBC	Clovis	Surface	Base frag.	29/8/95
34-4-3-136	TBC	Folsom	Surface	Midsection frag., poss. impact damage	29/8/95
34-4-3-157	TBC	Folsom	Surface	Midsection frag.	29/8/95
34-4-3-164	TBC	Folsom preform	Surface	Base frag., split	29/8/95
34-4-3-175	TBC	Folsom	Surface	Proximal sec. (tip missing), 1 ear missing	29/8/95
34-4-3-20	TBC	Folsom	Surface	Distal frag.	29/8/95
34-4-3-22	TBC	Folsom	Surface	Base frag.	29/8/95
34-4-3-23	TBC	Clovis	Surface	Base frag.	29/8/95
34-4-3-24	TBC	Clovis	Surface	Base frag.	29/8/95
34-4-3-25	TBC	Clovis	Surface	Base frag., obsidian	29/8/95
34-4-3-26	TBC	Clovis	Surface	Base frag.	29/8/95
34-4-3-27	TBC	Folsom	Surface	Base frag.	31/8/95
34-4-3-51	TBC	Folsom preform	Surface	Midsection frag., pitchstone	29/8/95
34-4-3-72	TBC	Folsom	Surface	Base frag.	29/8/95
34-4-3-74	TBC	Clovis	Surface	Base frag., pitchstone	29/8/95
34-4-3-75	TBC	Folsom	Surface	Base frag., split	29/8/95
34-4-3-79	TBC	Clovis	Surface	Midsection frag., split	29/8/95
34-4-3-8	TBC	Clovis	Surface	Midsection frag., impact damaged?, pitchstone	29/8/95
34-4-3-82	TBC	Clovis	Surface	Base frag.	29/8/95
34-4-3-86	TBC	Clovis (?)	Surface	Distal frag., obsidian	29/8/95

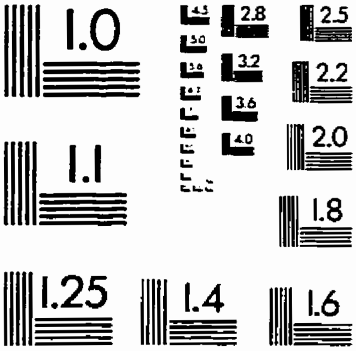
Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
34-4-3160	TBC	Clovis	Surface	Base frag., pitchstone	29/8/95
34-4-7-56	TBC	Folsom	Surface	Midsection frag.	31/8/95
34-4-9-89	TBC	Folsom	Surface	Midsection frag., split,	31/8/95
34-4c-3-66	TBC	Folsom	Surface	Base frag.	31/8/95
34-4c-3-67	TBC	Clovis	Surface	Base frag.	29/8/95
34-5-2-4	TBC	Clovis	Surface	Proximal frag. (tip missing), unfinished	29/8/95
34-8-2-26	TBC	Folsom	Surface	Distal sec.	31/8/95
34-8-2-3	TBC	Folsom	Surface	Base sec.	31/8/95
34-8-2-48	TBC	Folsom	Surface	Midsection frag.	31/8/95
A32716	UA	Unknown (prob. Clovis)	Murray Springs, AZ	Distal frag.	15/8/95
A32718	UA	Clovis	Murray Springs, AZ	Preform?	15/8/95
A32992	UA	Clovis	Murray Springs, AZ	Complete (very slight tip damage)	15/8/95
A33111	UA	Clovis	Murray Springs, AZ	Complete	15/8/95
A33116	UA	Clovis	Murray Springs, AZ	Complete, obsidian	15/8/95
A33324	UA	Clovis	Murray Springs, AZ	Distal section, tip damaged	15/8/95
A33917	UA	Clovis	Murray Springs, AZ	Base frag.	15/8/95
A42932	UA	Channel flake (or impact flake)	Murray Springs, AZ	Complete	15/8/95
A47139	UA	Clovis	Murray Springs, AZ	Base frag., obsidian	15/8/95
A47140	UA	Clovis	Murray Springs, AZ	Base frag.	15/8/95
A47162	UA	Clovis	Murray Springs, AZ	Proximal section	15/8/95
553-100	OSMA	Clovis	Dietz site, OR	Base frag., no edge grinding, obsidian	19/2/96
553-107	OSMA	Channel flake	Dietz site, OR	Frag., obsidian	19/2/96
553-109	OSMA	Square stemmed	Dietz site, OR	Base frag., impact(?) fracture, obsidian	19/2/96
553-111	OSMA	Channel flake	Dietz site, OR	Frag., obsidian	19/2/96
553-113	OSMA	Clovis	Dietz site, OR	Distal sec., obsidian	19/2/96
553-115	OSMA	Clovis	Dietz site, OR	Midsection, obsidian	19/2/96
553-116	OSMA	Clovis	Dietz site, OR	Near complete, small, obsidian	19/2/96
553-117	OSMA	Channel flake	Dietz site, OR	Frag., obsidian (mahog)	20/2/96
553-118	OSMA	Clovis?	Dietz site, OR	Complete, "reworked Clovis", obsidian	20/2/96

Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
553-12	OSMA	Clovis	Dietz site, OR	Midsection, obsidian	20/2/96
553-133	OSMA	Clovis	Dietz site, OR	Midsection, obsidian	19/2/96
553-14	OSMA	Clovis	Dietz site, OR	Distal sec., obsidian	19/2/96
553-142	OSMA	Fluted?	Dietz site, OR	Midsection, biface, obsidian	19/2/96
553-143	OSMA	Channel flake	Dietz site, OR	Frag., obsidian	19/2/96
553-153	OSMA	WPL stemmed	Dietz site, OR	Proximal sec., no edge grinding, impact (?) fracture, obsidian	20/2/96
553-159	OSMA	Clovis	Dietz site, OR	Distal sec., obsidian	19/2/96
553-16	OSMA	Clovis	Dietz site, OR	Midsection, obsidian	19/2/96
553-160	OSMA	Channel flake	Dietz site, OR	Frag., obsidian	19/2/96
553-168	OSMA	WPL stemmed	Dietz site, OR	Base frag.	19/2/96
553-174	OSMA	Clovis	Dietz site, OR	Distal sec., reworked, obsidian	19/2/96
553-176	OSMA	Cougar Mt. stemmed	Dietz site, OR	Base frag.	19/2/96
553-18	OSMA	Clovis	Dietz site, OR	Base frag., large, edge ground, bend w/ "spinoffs same as #553-2, obsidian	20/2/96
553-180	OSMA	Channel flake	Dietz site, OR	Frag., obsidian	19/2/96
553-187	OSMA	Clovis?	Dietz site, OR	Complete, unfluted, no edge grinding, obsidian	20/2/96
553-188	OSMA	Clovis	Dietz site, OR	Base frag., no edge grinding, obsidian	19/2/96
553-19	OSMA	Clovis	Dietz site, OR	Proximal sec., no edge grinding, obsidian	19/2/96
553-196	OSMA	Clovis	Dietz site, OR	Base frag., heavy edge grinding, obsidian	19/2/96
553-199	OSMA	Clovis?	Dietz site, OR	Complete, "Clovis", fluted, straight base, no edge grinding, obsidian	20/2/96
553-201	OSMA	Clovis	Dietz site, OR	Base frag., large, edge ground, obsidian	19/2/96
553-233	OSMA	Channel flake	Dietz site, OR	Frag., obsidian	19/2/96
553-234	OSMA	Clovis	Dietz site, OR	Base frag., no edge grinding, obsidian	20/2/96
553-238	OSMA	Clovis	Dietz site, OR	Base frag., small, brown chal.	19/2/96

Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
553-239	OSMA	Clovis	Dietz site, OR	Base frag., large, edge ground, obsidian	19/2/96
553-241	OSMA	Clovis	Dietz site, OR	Complete, small (on channel flake?), no edge grinding, obsidian	19/2/96
553-243	OSMA	Channel flake	Dietz site, OR	Frag., reworked, obsidian	19/2/96
553-244	OSMA	Clovis blank	Dietz site, OR	Midsection frag., "Clovis blank", obsidian	20/2/96
553-245	OSMA	Clovis	Dietz site, OR	Midsection, edge ground, obsidian	20/2/96
553-258	OSMA	Clovis	Dietz site, OR	Near complete (1 ear and tip missing), no edge grinding, obsidian	20/2/96
553-259	OSMA	Square stemmed	Dietz site, OR	Base frag., edge ground, obsidian	19/2/96
553-260	OSMA	Clovis	Dietz site, OR	Complete, nubbin, edge ground, obsidian	19/2/96
553-262	OSMA	Clovis	Dietz site, OR	Near complete, edge ground, obsidian	19/2/96
553-263	OSMA	Clovis blank	Dietz site, OR	Near complete, fluted, obsidian	20/2/96
553-268	OSMA	Clovis	Dietz site, OR	Base sec., no edge grinding, obsidian (mahog)	20/2/96
553-27	OSMA	Unspecified paleoindian biface	Dietz site, OR	Complete, "grey dorite"	19/2/96
553-271	OSMA	Clovis	Dietz site, OR	Complete, small, no edge grinding, obsidian	20/2/96
553-272	OSMA	Channel flake	Dietz site, OR	Frag., obsidian	20/2/96
553-273	OSMA	Channel flake	Dietz site, OR	Frag., obsidian (mahog)	20/2/96
553-288	OSMA	WPL stemmed	Dietz site, OR	Complete, obsidian	20/2/96
553-30	OSMA	Clovis	Dietz site, OR	Ear frag., obsidian	19/2/96
553-300	OSMA	Square stemmed	Dietz site, OR	Base frag., edge ground	19/2/96
553-309	OSMA	Channel flake?	Dietz site, OR	Frag., obsidian (mahog)	20/2/96
553-316	OSMA	Channel flake?	Dietz site, OR	Frag., "channel flake frag.", obsidian	20/2/96
553-33	OSMA	Clovis	Dietz site, OR	Complete, small, reworked, no edge grinding, obsidian	20/2/96

Museum Reference Number	Institution	Lithic Type	Provenience	Condition	Date Examined
553-39	OSMA	Clovis	Dietz site, OR	Base frag., no edge grinding, obsidian	19/2/96
553-4	OSMA	Clovis	Dietz site, OR	Base frag., no edge grinding, obsidian	19/2/96
553-43	OSMA	Cascade	Dietz site, OR	Near complete, obsidian	20/2/96
553-45	OSMA	Lanceolate	Dietz site, OR	Proximal sec., large, "Cougar Mt."?, edge ground	20/2/96
553-5	OSMA	Clovis	Dietz site, OR	Base frag., no edge grinding, obsidian	19/2/96
553-51	OSMA	Lanceolate	Dietz site, OR	Proximal sec., large, "Cougar Mt."?, no edge grinding, serrated margins	20/2/96
553-6	OSMA	Clovis	Dietz site, OR	Base frag., edge ground, obsidian, massive impact(?) fracture	19/2/96
553-60	OSMA	Cougar Mt. stemmed	Dietz site, OR	Near complete, obsidian	19/2/96
553-67	OSMA	Windust	Dietz site, OR	Base frag., obsidian	19/2/96
553-68	OSMA	Cougar Mt. stemmed	Dietz site, OR	Complete , obsidian	19/2/96
553-7	OSMA	Clovis	Dietz site, OR	Base frag., edge ground, obsidian	19/2/96
553-72	OSMA	Square stemmed	Dietz site, OR	Proximal sec., no edge grinding, obsidian	20/2/96
553-96	OSMA	Clovis?	Dietz site, OR	Base frag., small, obsidian	19/2/96
553-99	OSMA	Clovis	Dietz site, OR	Base frag., edge ground, impact(?) fracture, obsidian	20/2/96

TEST TARGET (QA-3)



150mm

6″

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