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Raw material impact strength and flaked stone projectile point performance

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ABSTRACT

Archaeologists have previously proposed several different measures of flaked stone raw material “quality”, but this variable has proven difficult to quantify, and the precise characteristics that improve performance remain unclear. This paper presents the results of controlled experiments that were designed to test projectile points made from stones with varying impact strength. By comparing an independent measure of strength with projectile point experimental data, our research suggests that this variable can be objectively measured, and it is a good predictor of some aspects of projectile tip function. Our results show that highly homogenous fine-grained materials with low impact strength (e.g., obsidian) perform well when penetrating elastic materials such as skin and muscle. These same materials, however, function poorly when penetrating more inelastic materials like rawhide, and they are substantially less durable.

1. Introduction

For a number of reasons archaeologists generally consider obsidian to be a high “quality” flaked stone raw material (Callahan, 1979; Kuzmin et al., 2002; Shackley, 2005; Smith, 2015; Tripkovic, 2003; Whittaker, 1994). First, obsidian is an isotropic stone with no preferred direction of fracture (Shackley, 2005:185). Second, obsidian requires less force to detach flakes than other material types. Because of these two characteristics, obsidian can more readily be reduced into complex shapes such as projectile tips. Third, the edges of obsidian flakes are exceptionally sharp. Fourth, obsidian was widely employed for flaked stone tool manufacture and it was transported across long distances, which suggests it was a highly valued raw material (Ellis, 1997; Eerkens et al., 2008; Frahm and Hauck, 2017; Kuzmin et al., 2002; Loendorf et al., 2013; Thomas, 2012; Tripkovic, 2003). As an example, Norton (2008) reports that obsidian from western North America has been recovered from archaeological sites located over 2500 km overland to the east.

This traditional assessment of raw material quality, however, does not reflect all aspects of the performance of tools made from these materials (Braun et al., 2009; Smith, 2015). Instead, materials that perform exceptionally well in some tasks (e.g., warfare) may not be ideal in all respects for others (e.g., hunting). Therefore, in order to understand the performance characteristics of a raw material, it is first necessary to define the relevant functional parameters of tools made from them (Knecht, 1997). This paper focuses on the performance of projectile points manufactured from materials with varying impact strength. Our investigations suggest that while projectile tips made from highly brittle materials such as obsidian excel in some ways, they perform poorly in others.

Rather than replicating prehistoric technology, this investigation instead consisted of controlled experiments in which, to the extent possible, all variables were held constant, and the only factor

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that differed among experimental armatures was the impact strength of the raw materials. Therefore, our experiments provide an objective evaluation of performance when penetrating media with varying elasticity for 58 morphologically similar flaked stone projectile points made from four categories of raw materials.

The perception of raw material quality is not merely a semantic issue. Instead, it affects how researchers interpret the archaeological record, including factors like defining the technological organization of lithic industries (Andrefsky, 1994, 2005; Brantingham et al., 2000; Braun et al., 2009; Daniel et al., 2007; Ensor, 2009; Feinman et al., 2006; Nelson, 1991; Smith, 2015; Tripkovic, 2003; Woods, 2011). Presumed quality also conditions assumptions regarding the value of materials, including the identification of high status goods (McGuire, 1992; Tripkovic, 2003; White et al., 2013). Research presented here suggests that it is impossible to rank order flaked stone point raw materials from low to high quality with respect to projectile performance. Instead, understanding "quality" in this sense necessitates the definition of specific functional traits, and optimization of one design parameter usually results in compromising others (Bousman, 1993; Braun et al., 2009; Knecht, 1997).

2. Quantifying quality

While lithic researchers commonly incorporate the concept of raw material quality in their analyses, this term frequently is not defined, and it is "assumed that certain types of stone were selected for the predictability with which they fractured" (Braun et al., 2009). In general, definitions of stone quality tend to focus on flaking characteristics, with less attention given to durability and other factors (Brantingham et al., 2000; Braun et al., 2009; Feinman et al., 2006; Woods, 2011). Although previous assessments of quality have often been subjective measures based on the observations of modern flintknappers, several approaches for the quantification of this variable have also been proposed, including recording the crystalline properties of stone and conducting mechanical fracturing or hardness tests (Andrefsky, 1994; Brantingham et al., 2000; Braun et al., 2009; Callahan, 1979; Cotterell and Kamminga, 1987; Dibble and Rezek, 2009; Feinman et al., 2006; Lerner et al., 2007; Smith, 2015; Whittaker, 1994; Woods, 2011).

Unlike much of the previous work, our study focuses exclusively on flaked stone projectile point performance. This research, in part, tests the relationship between impact strength and point function. Impact strength describes the ability of an object to resist structural failure when subjected to a rapid collision (Mabry et al., 1988). Lithic analysts generally employ the word "toughness" when referring to the ability of stone to resist breakage, but this term is usually defined as the energy required to propagate a crack in the material (Cotterell and Kamminga, 1987, 1992; Woods, 2011). Although "strength" and "toughness" are similar, the following discussion exclusively employs "strength" because cracks were not intentionally introduced to the materials prior to testing, and strength is therefore a more accurate description of the tested property.

2.1. Impact strength research methods

In order to independently assess the materials employed in the projectile point experiments, their strength was measured using a falling-weight impact tester and sample slabs (see Mabry et al., 1988). Variables affecting fracture were first tested using soda-lime window glass slabs, which were also subsequently used as controls. The glass varied in thickness and was cut into fragments of various sizes and shapes. This testing indicated that the primary variables affecting slab fracture were the distance to the edge and the thickness. Consequently, to control for differences in slab geometry impact locations were always at a constant distance from the nearest edge, and variation in thickness was standardized by dividing the energy necessary to break the slab by the thickness.

The raw material sample slabs were cut using a tile saw with a wet diamond blade. Between 3 and 10 slabs were cut from each of the available materials. Tile saws are a comparatively inexpensive method for producing uniform test slabs, but it was difficult to cut thicker nodules and the slabs varied by a maximum of 1.3 mm in thickness.

The experimental setup consisted of a stand with a height adjustable electromagnet that held a steel ball bearing (Fig. 1; Mabry et al., 1988). For each slab, the bearing was released progressively higher until the slab fractured. This incremental-height method has been shown to produce more consistent results (Mabry et al., 1988). In order to control the contact location, the ball impacted a hardened steel punch with a 4.75 mm diameter tip that was placed directly on the slab, 5 mm from the nearest edge. The punch was placed along an edge that lacked cortex, and had an approximately 90° angle to the impacted face. Slabs were placed directly on a sheet of aluminum that rested on a steel anvil. The slab was repositioned after each impact, so that no spot was hit more than once. Using these procedures we completed 287 impacts to 102 test slabs.

The raw materials employed in the projectile experiments included two obsidian varieties (Government Mountain and Mule Creek), two chert types (Whetstone and Tolchaco), a black fine grained volcanic stone, and a metamorphosed fine grained

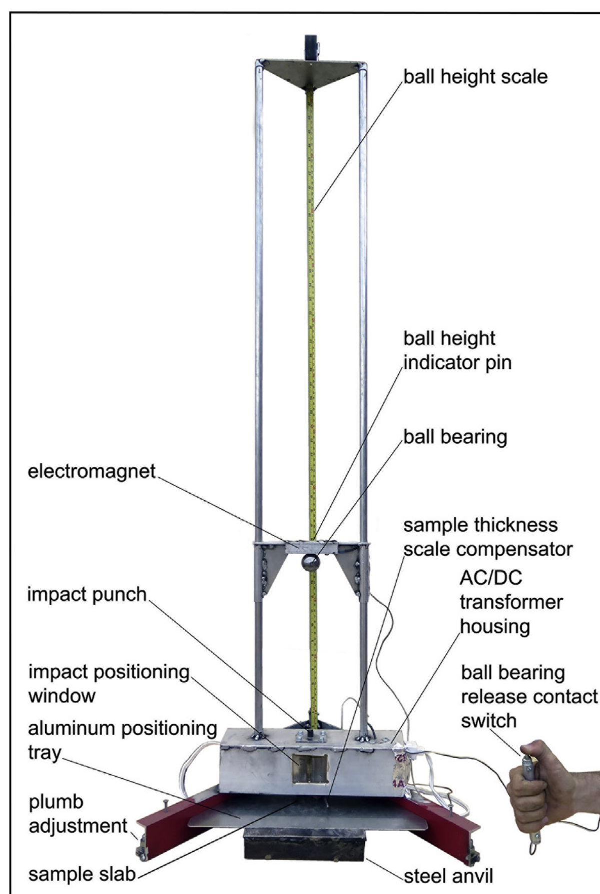

Fig. 1. Device employed to test slab impact strength (illustration by Robert Ciaccio).