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EFFECTS OF RAW MATERIAL ON FLAKE BREAKAGE PATTERNS

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ABSTRACT

Differences in the mechanical properties of raw materials can exert significant influences on resulting patterns of flake breakage within a debitage assemblage. A recent technique of debitage analysis based on flake breakage categories (Sullivan and Rozen 1985) is used to demonstrate these effects in archaeological and experimental situations. These cases demonstrate significant variation in flake breakage patterns that can be attributed to raw material differences. Therefore, attempts to use these breakage patterns to infer past human behavior or technological process must control for the effects of different raw materials.

INTRODUCTION

Experimental studies demonstrate that the physical properties of various lithic materials strongly affect the manufacture, utility, and durability of stone tools. One of the earliest and still one of the best scientific investigations of the physical properties of raw materials was published by Mary Ellen Goodman over 50 years ago (Goodman 1944; see Domanski et al. 1994 for similar work involving heat treatment). More recently, Greiser and Sheets (1979) discussed the effect of raw material variation in lithic use-wear analysis. Peter Jones (1979) used experimental replications to demonstrate some of the effects of raw material on debitage production in biface manufacture. In addition, archaeological studies suggest that raw material variation plays an important role in prehistoric lithic procurement and manufacturing strategies (e.g., Lischka 1969; Callahan 1979; Straus 1980; Dibble 1985; Andrefsky 1994a) as well as in the organization of technology (e.g., Bamforth 1986; Andrefsky 1994b). These studies illustrate the general agreement among archaeologists that raw material differences can have a commanding impact on lithic assemblage variation.

In this paper we look at the effects of raw material on flake breakage patterns. This work uses the debris from 12 core and 12 biface/tool reductions using obsidian, basalt, quartzite, and several cherts and chalcedonies (Table 1). Core reductions were accomplished with a variety of hard hammer percussors, while the biface/tool reductions included use of hard and soft hammer percussors and minimal pressure flaking. These reductions were done on plastic tarps by knappers

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with intermediate to advanced skills. We passed the debris resulting from each of the 24 reductions through wire screens, which yielded 3,646 flakes greater than 1/4" mesh (average of more than 150 flakes per reduction).

These flakes were then classified using the categories defined by the key in Figure 1, which was originally proposed by Sullivan and Rozen (1985; Sullivan 1987) for discriminating core reduction from tool (biface) manufacture. The decision tree in Figure 1 is geared to flake breakage and relies on the ability of an analyst to distinguish various attributes on debris. "Complete flakes" are distinguished by the presence of a single point of applied force, a discernible interior surface, and intact margins. "Proximal," or "platform remnant bearing, flakes" have a single point of applied force but lack complete margins. "Split flakes" have a point of applied force present, but consist of a lateral shear from the platform to the distal terminus of the flake. "Medial-distal fragments" lack a point of applied force, but the interior surface is discernible. Finally, "non-orientable fragments" are those items which lack any discernible interior surface (see Kuijt et al. 1995; Sullivan 1987).

Classification of the debris resulting from these 24 reductions is shown in Table 2. Obviously, this study is limited, since many of these flakes would have been selectively removed for use as tools and blanks by prehistoric individuals. In fact, we know that actual prehistoric selection criteria varied greatly through time and across space. Therefore, the development of appropriate decision models of flake removal must be designed for specific archaeological cases, but for now, we chose to hold this factor constant for all reduction experiments.

Our investigation of variation in flake breakage patterns looks at several potential factors, including reduction type (core versus biface/tool); raw material; and skill level of the analyst. Additionally, we consider some archaeological examples in which flake breakage patterns seem to be influenced by raw material. Finally, differences in the

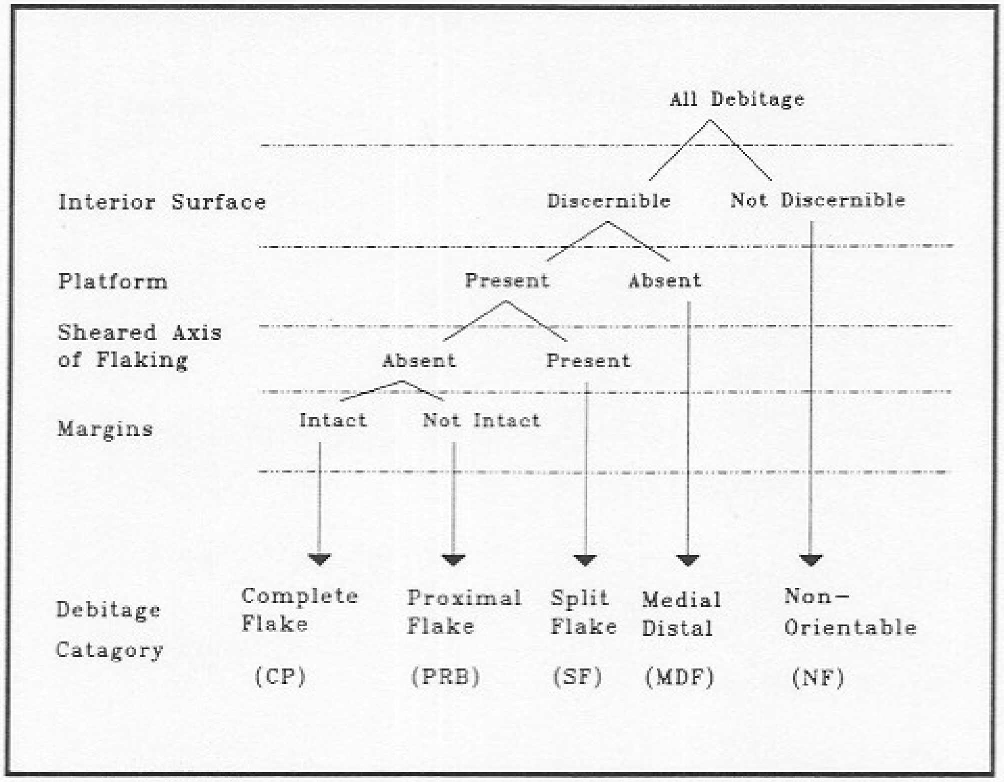

Figure 1. Decision tree for implementing the flake breakage typology (after Kuijt et al. 1995; Sullivan and Rozen 1985; Sullivan 1987).

way core reduction is accomplished are demonstrated to impact flake breakage patterns.

VARIATION WITHIN AND BETWEEN REDUCTIONS

Flake assemblages from the core and biface/tool reductions are compared in Table 3. The chi-square statistic indicates that differences in the flake assemblages from these two reduction types are statistically significant at the 99% confidence level. Standardized chi-square residuals (see Koopmans 1987) indicate where the greatest contributions to this statistical difference are found. Core reductions show significantly greater than expected numbers of split flakes and nonorientable fragments, but less than expected numbers of complete flakes and proximal flakes. Biface/tool reductions show significantly greater than expected numbers of proximal flakes and less than expected numbers of split flakes.

Sullivan and Rozen (1985) proposed that high percentages of complete flakes and nonorientable debris result from core reduction, while high percentages of medial/distal fragments should indicate tool manufacture. These propositions are not supported by the experimental data in this study. For the 12 core reductions, the percentage of medial/distal fragments is 41.5% (n=590), while the percentage of complete flakes is only 28.6% (n=407) and the percentage of nonorientable fragments is only 3.0% (n=42). For the 12 biface/tool reductions, the percentage of medial/distal fragments is 37.9% (n=842), but complete flakes account for a nearly equal percentage (34.2%, n=760). These controlled experimental results question the methodological validity of this debitage typology, since these patterns do not conform to the expectations originally proposed by Sullivan and Rozen .

Although there are statistically significant differences in the proportions of flake breakage types between core and biface/tool reduction assemblages, considerable overlap exists in these populations. An analysis of variance (ANOVA) test comparing flake frequency in the 12 core and 12 biface/tool reduction groups shows that variance within the core and biface/tool groups is as great as the variance between them (F-ratio = 1.0; $p > F = .412$). As a result, reduction type does not appear to affect the flake breakage type frequencies. In this population, it is not possible to reliably predict reduction type from the flake frequencies in any individual case.

We propose that raw material differences might be one cause for the large within-group variation. We conducted an ANOVA comparing flake frequency across three primary raw material groups (obsidian, chalcedony/chert/flint, basalt/quartzite). These categories reflect the basic patterns of raw material grain that use-wear researchers have advocated for structuring analysis (Greiser and Sheets 1979). ANOVA results demonstrate that variance in flake breakage patterns within these raw material groups is not as great as the variance between them, but these differences are not significant at the 95% confidence level (F-ratio = 1.61; $p > F = .129$). Although raw material does not have a statistically significant effect on flake breakage type frequencies, it accounts for greater variance in flake breakage frequencies than does reduction type.

Patterns of the effect of raw material on flake breakage type proportions are illustrated in Tables 4 and 5. Flake breakage type proportions in the core reductions (Table 4) exhibit statistically significant differences among the raw materials. Split flakes are the largest contributors to these differences, especially among the basalt/quartzite core reductions, observed frequency being more than twice the expected frequency. Basalt/quartzite core reductions also exhibit significantly fewer than expected numbers of complete flakes and medial/distal fragments. The chalcedony/chert/flint core reductions exhibit more than expected complete flakes, but fewer than expected split flakes. Obsidian core reductions show fewer than expected numbers of split flakes and proximal flakes, but more than expected medial/distal fragments.

Flake breakage type proportions in the biface/tool reductions (Table 5) also exhibit statistically significant differences among raw materials. Again, the basalt/quartzite split flakes are the largest source of these differences, with an observed frequency about twice the expected frequency. Biface/tool reductions of basalt/quartzite also exhibit significantly fewer than expected complete flakes, while the numbers of proximal flakes and nonorientable fragments are more than expected. Chalcedony/chert/flint debris from biface/tool reductions also exhibit more than expected complete flakes, but fewer than expected split flakes. Flake breakage type proportions from the obsidian biface/tool reductions show fewer than expected split flakes and proximal flakes, but more than expected complete flakes. In summary, the flake breakage type profiles of obsidian and chalcedony/chert/flint are similar, while the breakage pattern of basalt/quartzite is distinct. Like the core reductions, the primary difference among the tool reductions is a higher proportion of split flakes in the basalt/quartzite debitage.

The greater tendency for split flakes to occur in raw materials like basalt and quartzite may be related to unique material characteristics and flaws which influence the initiation, propagation, and termination of flakes. Review of flake formation fracture mechanics (Cotterell and Kamminga 1987:691-698) suggests that the higher breakage rates among flakes made from granular stones may reflect lowered stiffness with respect to the forces of compression and bending. Data on the mechanical properties of lithic raw materials are limited, but quartzite appears to be more resilient (Goodman 1944:433) and possesses lower compressive and tensile strength than chert and obsidian (see Domanski et al. 1994: Tables 4 and 5).

Strategy of Reduction

Another major source of variation in flake breakage rates may result from differences in the "strategy of reduction," a term we have used previously to describe patterned sequences in flintknapping related to changing tools and tactics (Mauldin and Amick 1989) . Such differences are imposed by the individual knapper but constrained by the available materials. Alternative strategies of reduction can provide more than one way to achieve an intended product. For example, we contrast two distinct strategies of core reduction using the split halves of an obsidian cobble. The strategy used for reducing one half required the removal of flakes with cortical platforms (Tables 1 and 2: Exp. #5A), while the strategy used for the other half required the removal of flakes with noncortical platforms (Tables 1 and 2: Exp. #5B).

Table 6 compares the distribution of flake breakage types for these two halves of the same cobble. The core in which all flake platforms are cortical shows greater than expected numbers of complete flakes and fewer than expected medial/distal fragments. In contrast, the core with noncortical platforms shows fewer than expected numbers of complete flakes and greater than expected medial/distal fragments. A chi-square test demonstrates these differences are statistically significant at the 99% confidence level. A higher percentage of complete flakes may result when cortical platforms are employed, because the naturally abraded surface serves to strengthen the striking platform and inhibit flake shattering.

Recognition of this alternative source of variation is vexing, because strategies and goals can change at any point in the sequence of lithic reduction. A further complication is caused by the ambiguity of inferring prehistoric strategies and goals involved in the production of an archaeological artifact. This observation points to the strength of refitting as an analytical tool for determining the actual sequence of prehistoric tool manufacture and use.

Analytical Skill

Accurate classification of flake breakage depends on an ability to identify the attributes of flake formation and to use them properly in orienting the flake. Consequently, we suspect some differences in flake breakage patterns should result from variation in the skill level of the analyst. Students enrolled in an intensive Lithic Analysis seminar served as guinea pigs in testing this proposition. These students were practicing archaeologists working for federal agencies and contract firms, yet most had little experience or training in lithic analysis. After a two hour illustrated lecture on flintknapping and the attributes of flake formation and orientation, the students were asked to classify the debitage assemblages from the experimental reductions listed in Table 1. They were provided with the classification key (Figure 1) and instruction on its implementation. Student classification results are compared with ours to assess the role of analytical skill level in the implementation of these flake breakage categories.

Table 7 compares flake breakage classifications for six biface/tool reductions analyzed by the students versus the instructor (Amick). Comparison was limited to biface/tool reductions to lessen the potential effects of different reduction types. Statistically significant differences with confidence levels greater than 99% exist between the classifications by students versus the instructor. The greatest differences are among the nonorientable fragments and the medial/distal fragments. Students' classifications show nearly twice as many nonorientable fragments as expected and fewer medial/distal fragments, complete flakes, and proximal than expected. Split flakes are slightly greater than expected among the student results. Instructor classifications show fewer than expected nonorientable fragments and split flakes, but greater than expected numbers of complete flakes, proximal flakes, and medial distal flake fragments.

Several difficulties were encountered by the students who were using the classification paradigm. The major question asked was: "How much breakage is necessary to exclude a flake from the complete category?" The high percentage of nonorientable fragments identified by the student analysts suggests two additional sources of variation in the classification of flake breakage types. First, an ability to properly orient the artifact is required; and second, an ability to identify the point of applied force is necessary. These differences suggest our ability to properly orient and identify flake formation features increases with training and experience. Disagreement between students and the instructor is lowest for the obsidian assemblages. This pattern may result from the clear development and better visibility of flaking characteristics in glassy and homogeneous materials. Thus, a certain degree of analytical bias may also be caused by the character of the raw material and the skill level of the analyst. These factors may interact to confound the source of variation in flake breakage categories.

COMPARISON WITH OTHER EXPERIMENTAL RESULTS

Chert Reductions

In a recent experimental investigation of flake attributes, Bradbury and Carr (1995:111-112) also considered the utility of breakage patterns for flake typologies. Their experimental reductions, using Fort Payne chert (Bradbury and Carr 1995: Table 13), provide a useful opportunity for comparison with our reductions. We used our five core reductions (Exp. # 2, 4, 25, 27, 32) and five biface/tool reductions (Exp. # 1, 22B, 23, 26, 33) in chalcedony/chert/flint for comparison. Bradbury and Carr (1995) used an earlier formulation of the flake breakage typology which groups split flakes and proximal flakes in the single category of broken flakes (BF). We combined our split flakes and proximal flakes to correspond with this classification. Table 8 presents a comparison with the hard hammer core reductions. Despite similarity of raw material and reduction type, there are statistically significant differences between these assemblages. Bradbury and Carr (1995) show significantly fewer than expected broken flakes and greater than expected numbers of medial/distal and nonorientable fragments. Patterns in our transposed core reduction categories show significantly greater than expected numbers of broken flakes and fewer than expected medial/distal and nonorientable fragments.

Table 9 compares our biface/tool reductions with those of Bradbury and Carr (1995). Again, a statistically significant difference is present. In this case, our reductions show greater than expected numbers of complete flakes and nonorientable fragments, but fewer than expected medial/distal fragments. The reverse pattern is present from Bradbury and Carr's data. The reasons for these deviations are not known. Variability may result from differences in raw materials, knapping skills, knapping tools, strategies of reduction, or analytical skills.

Bipolar Reductions

Presentation of bipolar core reduction data by Kuijt et al. (1995: Table 2; also see Kuijt and Russell 1993: Table 2) provides a case to compare with our bipolar core reduction (Tables 1 and 2: Exp. # 7). Table 10 shows statistically significant differences between these bipolar reduction assemblages with more than 99% confidence. Nonorientable fragments represent only 5.2% of our bipolar debitage assemblage compared to 44.3% of the experimentally produced bipolar assemblage reported by Kuijt et al. (1995). The goal of these experiments by Kuijt et al. (1995; also Kuijt and Russell 1993) is to construct a pattern of flake breakage that can be used to identify bipolar reduction. However, their method does not correctly classify our bipolar material.

Potential sources for these contradictions may be differences in raw material, strategy of reduction, knapper skills, and analyst skills. Our bipolar experiment involved the reduction of a single cobble of obsidian weighing 170 g. The reduction was done by Peter Ainsworth, an accomplished flintknapper with advanced skills, using a soft sandstone anvil and hammerstone and following the bipolar technique described by Crabtree (1967:62-3, italics added):

> the anvil is used to support the material and provide inertia for the artifact. The blow must not be directed towards the face of the stone anvil and through the lithic material, for the blow will be opposed by the anvil and the opposing forces will either cause shattering or will induce strains in the material, rendering it worthless. *The blow must be applied in such a manner that the force will be deflected away from the resistance of the anvil.* This causes a shearing effect from the opposing forces, yet they are not in direct opposition. The immobilization of the lithic material on the anvil allows the stone to be cleaved with the application of a minimum amount of force.

Cortical surfaces were preferred as striking platforms, the core was rotated frequently, and only the thumb and fingers served to support the core. This application of the bipolar technique minimized shatter while maximizing the number of usable flakes. Kuijt et al. (1995) reduced nine cobbles of trachydacite (vitreous basalt) ranging from 61 to 165 g (ave. = 99 g), using a granite anvil and quartzite hammerstone and a pliable leather support. Their flake assemblage also represents the fraction larger than 1/4" screen mesh. Use of a harder percussor/anvil in concert with a less vitreous raw material may have caused greater frequency of shatter. For example, Crabtree (1967:61) notes: "Agate hammerstones used on obsidian will cause shattering, collapse of platforms, induce unseen stresses and render the material useless. A softer percussor will not have these ill effects." Thus, variations in the raw materials and techniques used can be expected to cause differences in flake breakage patterns.

Kuijt and Russell (1993) used the flake breakage patterns from their experiments on trachydacite to imply bipolar reduction in historic Bedouin assemblages made on flints. This conclusion is weakened by large variation in flake breakage patterns shown elsewhere in this paper to be associated with differences in raw material and technique. Furthermore, Kuijt and Russell (1993; and Kuijt et al. 1995) fail to consider experimental data from alternative reduction techniques in their comparison. This failure illustrates the potential methodological danger that results when archaeological patterns are inferred from a limited range of experimental analogs. We are not questioning the use of bipolar reduction techniques by the historic Bedouin. However, the argument by which it is demonstrated through experimental analogy is unconvincing.

EXAMPLES OF ARCHAEOLOGICAL IMPLICATIONS

Next we illustrate how these experiments are relevant to archaeological situations. These cases point out the complicating effects of raw material variation in the use of flake breakage information. First, we look at the data from 13 lithic assemblages in the region around Homolovi Ruins, Arizona (Sullivan 1987). These assemblages are dominated by chert and quartzite. Figure 2 compares the number of complete flakes versus the number of chert flakes. This plot shows a strong positive relationship (Pearson's r=.9542, p<.000001) between the number of complete flakes and the use of chert. Since the large assemblage in the upper right of the scatter plot may be driving this result, we can remove this case. The Pearson's r correlation coefficientof 0.81 (p<.002) indicates a strong positive relationship still exists among the remaining 12 assemblages. Conversely, we obtained a Pearson's r value of 0.64 (p<.0005) for the correlation of quartzite and nonorientable debris.

The original analysis of these assemblages (Sullivan 1987) suggested an association of core reduction at sites with high frequencies of complete flakes and tool manufacture at sites with lots of nonorientable debris. Based on our brief reanalysis of the data, it appears that the proportion of complete flakes may be determined largely by the use of chert, while the proportion of nonorientable debris may be determined largely by the use of quartzite. Rather than inferring different technological activities among these sites, the flake breakage frequencies may be reflecting, to a significant degree, the different flaking qualities of chert versus quartzite (see also Warburton 1991:238).

Contrasting availability of raw materials across the landscape may exert considerable influence

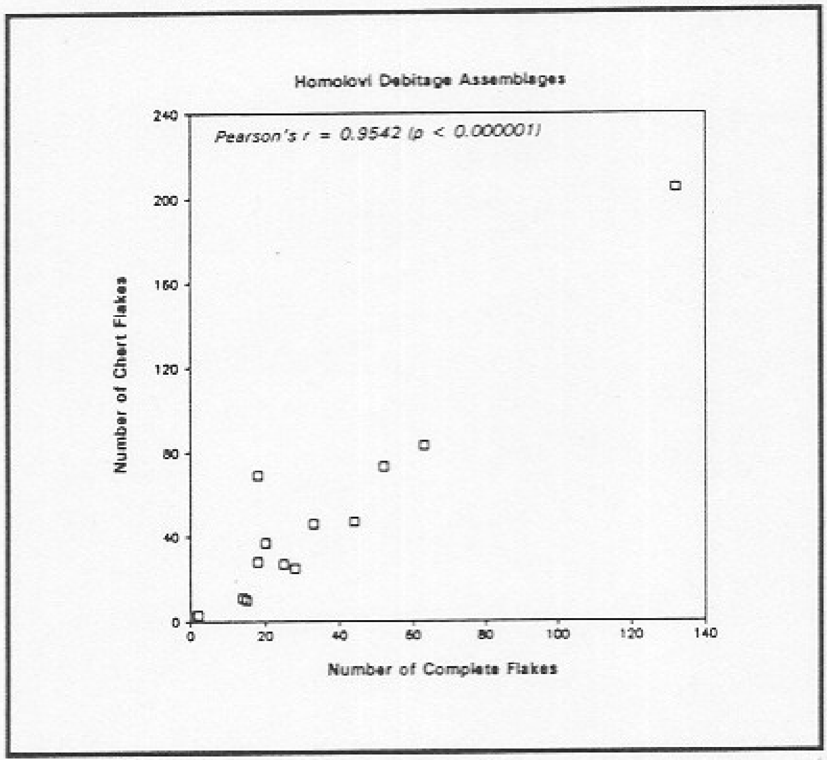

Figure 2. Scatter plot of the number of complete flakes versus number of chert flakes in the Homolovi assemblages.

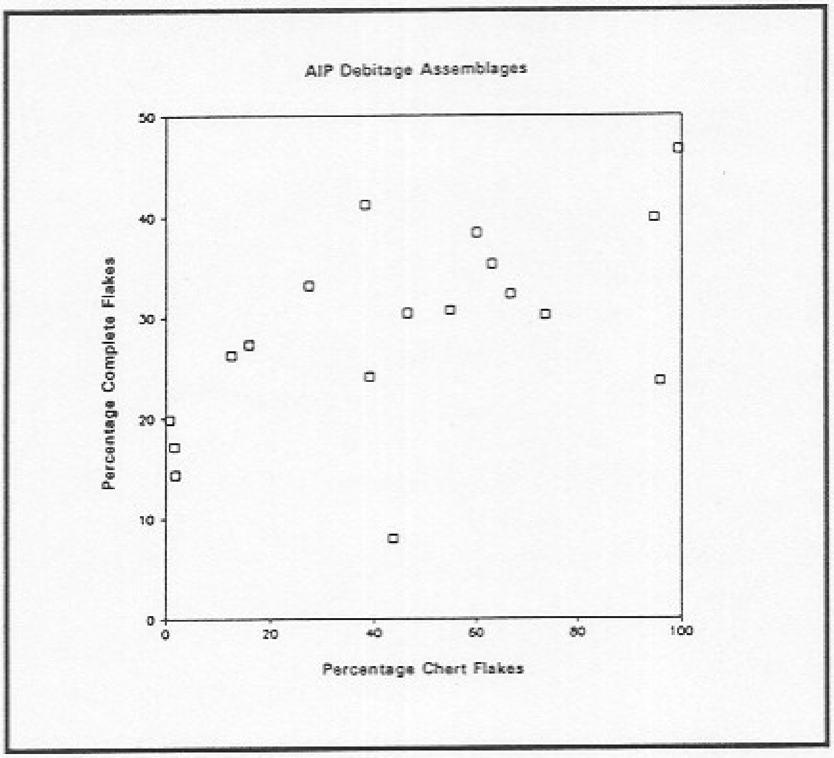

Figure 3. Scatter plot of the proportion of complete flakes versus chert flakes in the AIP assemblages.

on flake breakage rates. Data on 5,430 flakes from 18 sites found on a 340 km survey transect across southwestern New Mexico are used to illustrate this problem (Mauldin 1993). The Arizona Interconnection Project (AIP) transect crosses several different lithic sources indicated by the fluctuating frequency of various raw materials in the assemblages. Figure 3 compares the proportion of complete flakes to the proportion of chert flakes in the AIP assemblages. Complete flakes and chert frequency are correlated with a Spearman's r of .55 ($p = 0.019$), suggesting that a moderately strong positive relationship exists. This relationship between flake breakage patterns and raw materials is impressive, given the potential for variation that might also have been caused by idiosyncratic differences in the strategy of reduction as well as between individual knappers and analysts.

SUMMARY AND DISCUSSION

Our purpose in this paper is not to test the reliability or validity of the Sullivan and Rozen (1985) debitage typology. Numerous other studies have already identified the strengths and weaknesses of this debitage classification paradigm (e.g., Amick and Mauldin 1989; Prentiss and Romanski 1989; Mauldin 1993; Shott 1994:78-79; Bradbury and Carr 1995:111-112; Sullivan 1987). Our goal has been to explore several causes of variation in flake breakage patterns. We found complex but predictable interactions with raw material, reduction type, strategy of reduction, and analyst skill level. Also, Shelley (1990) has illustrated the effect of different skill levels among knappers as another source of variation in lithic assemblages. He pointed out that step fractures are common in the work of beginning flintknappers. Complete flakes with step terminations are classified as proximal flakes in the Sullivan and Rozen (1985) typology. Consequently, the debris of novice flintknappers should contain higher proportions of proximal flakes. Our experimental data are currently inadequate to explore this idea very rigorously, but the effect of idiosyncratic and skill level differences between knappers merits further attention.

Flake breakage patterns play an important role in understanding the technological variation and taphonomic history of debitage assemblages. However, experiments demonstrate that patterns of flake breakage remain poorly understood, and archaeological examples show that lithic resource distributions can have serious effects on inter-assemblage patterns of breakage. We find that breakage patterns fail to behave consistently with any variables other than raw material. As a result, it is clear that we cannot recommend flake breakage alone as the basis of an interpretive typology of debitage (cf. Sullivan and Rozen 1985), and that raw material considerations must provide the backbone of any debitage analysis.

In conclusion, the impact of differential flake breakage and variations in our ability to recognize flake attributes is significant for any debitage analysis. Post-depositional forces such as human trampling can also increase breakage (Prentiss and Romanski 1989). As flakes suffer greater breakage rates, whatever the cause, the likelihood is reduced that they will retain attributes useful for technological classification. For this reason alone, debitage analysis should consider the causes and effects of flake breakage, and the key in Figure 1 provides an effective breakage typology. However, while flake breakage can play a part in an analysis, it is poorly suited to be the foundation of any technological typology of flakes.

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REFERENCES

Amick, D., and R. Mauldin
1989 Comments on Sullivan and Rozen's "Debitage Analysis and Archaeological Interpretation." ***American Antiquity*** 54:166-168.

Andrefsky, W., Jr.
1994a The Geological Occurrence of Lithic Material and Stone Tool Production Strategies. ***Geoarchaeology*** 9:375-391.
1994b Raw-Material Availability and the Organization of Lithic Technology. ***American Antiquity*** 59:21-34.

Bamforth, D. B.
1986 Technological Efficiency and Tool Curation. ***American Antiquity*** 51:38-50.

Bradbury, A., and P. J. Carr
1995 Flake Typologies and Alternative Approaches: an Experimental Assessment. ***Lithic Technology*** 20:100-115.

Callahan, E.
1979 The Basics of Biface Knapping in the Eastern Fluted Point Tradition: A Manual for Flintknappers and Lithic Analysts. ***Archaeology of Eastern North America*** 7:1-180.

Cotterell, B. and J. Kamminga
1987 The Formation of Flakes. ***American Antiquity*** 52:675-708.

Crabtree, D. E.
1967 Notes on Experiments in Flintknapping: 4. Tools Used for Making Flaked Stone Artifacts. ***Tebiwa*** 10:60-73.

Dibble, H. L.
1985 Raw-Material Variation in Levallois Flake Manufacture. ***Current Anthropology*** 26:391-393.

Domanski, M., J. A. Webb, and J. Boland
1994 Mechanical Properties of Stone Artefact Materials and the Effect of Heat Treatment. ***Archeometry*** 36:177-208.

Goodman, M. E.
1944 The Physical Properties of Stone Tool Materials. ***American Antiquity*** 9:415-433.

Grieiser, S T., and P. D. Sheets
1979 Raw Material as a Functional Variable in Use-Wear Studies. In ***Lithic Use-wear Analysis***, edited by B. Hayden, pp. 289-296. Academic Press, New York.

Jones, P. R.
1979 Effects of Raw Material on Biface Manufacture. ***Science*** 204:835-836.

Koopmans, L. H.
1987 ***Introduction to Contemporary Statistical Methods***. 2nd ed. Duxbury Press, Boston.

Kuijt, I., W. C. Prentiss, and D. L. Pokotylo
1995 Bipolar Reduction: an Experimental Study of Debitage Variability. ***Lithic Technology*** 20: 116-127.

Kuijt, I., and K. W. Russell
1993 Tur Imdai Rockshelter, Jordan: Debitage Analysis and Historic Bedouin Lithic Technology. ***Journal of Archaeological Science*** 20:667-680.

Lischka, L.
1969 A Possible Noncultural Bias in Lithic Debris. ***American Antiquity*** 34:483-485.

Mauldin, R. P.
1993 Lithics. In ***The Chihuahua Lake Basin to the Chihuahua Desert: Archaeological Studies along the Arizona Interconnection Project Transmission Line Corridor***, edited by J. S. Bruder, pp. 5.29-5.97. Zuni Archaeology Program Report No. 347. Zuni Archaeology Program Research Series, No. 7. Zuni Archaeology Program, Pueblo of Zuni, NM.

Mauldin, R. P., and D. S. Amick
1989 Investigating Patterning from Experimental Bifacial Core Reduction. In ***Experiments in Lithic Technology***, edited by D. S. Amick and R. P. Mauldin, pp. 67-99. British Archaeological Reports, International Series 528, Oxford.

Prentiss, W.C. and E.J. Romanski
1989 Experimental Evaluation of Sullivan and Rozen's Debitage Typology. In ***Experiments in Lithic Technology***, edited by D. Amick and R. Mauldin, pp. 89-100. British Archaeological Reports, International Series 528, Oxford.

Shelley, P. H.
1990 Variation in Lithic Assemblages: an Experiment. ***Journal of Field Archaeology*** 17:187-193.

Shott, Michael J.
1994 Size and Form in the Analysis of Flake Debris: Review and Recent Approaches. ***Journal of Archaeological Method and Theory*** 1:69-110.

Straus, L. G.
1980 The Role of Raw Materials in Lithic Assemblage Variability. ***Lithic Technology*** 9:68-72.

Sullivan, A. P., III
1987 Probing the Sources of Lithic Assemblage Variability: a Regional Case Study Near the Homolovi Ruins, Arizona. ***North American Archaeology*** 8:41-71.

Sullivan, A. P., III, and K. C. Rozen
1985 Debitage Analysis and Archaeological Interpretation. ***American Antiquity*** 50:755-779.

Warburton, M.
1991 Flaked Stone from the Navajo Springs Great House, Arizona. ***Journal of California and Great Basin Anthropology*** 13:230-241.

- TABLES -

Table 1. Summary of the experimental reductions used in this study.

Exper. No. *	Reduction Goal	Raw Material	Weight	Core Strategy/ Tool Result
2	core	Morrison chalcedony	367 g	multidirectional
4	core	Morrison chalcedony	1,323 g	multidirectional
5A	core	obsidian	354 g	cortical platforms
5B	core	obsidian	518 g	noncort. platforms
7	core	obsidian	170 g	bipolar
8,9,10	core	3 obsidian nodules	432 g	maximize flk size
14A	core	Alder Hill basalt	2338 g	maximize flk size
25	core	Morrison chert	1,130 g	multidirectional
27	core	Georgetown flint	809 g	multidirectional
29	core	Hixton quartzite	3,799 g	multidirectional
31	core	Alder Hill basalt	1544 g	multidirectional
32	core	Edwards flint	3,188 g	multidirectional
1	biface/tool	Chuska chert cobble	272 g	stage 2 failure
3	biface/tool	Alder Hill basalt	2,180 g	stage 3 failure
6-1	biface/tool	obsidian	740 g	stage 3 success
6-2	biface/tool	obsidian	71 g	stage 4 failure
14B	biface/tool	Alder Hill basalt	543 g	stage 4 success
20	biface/tool	obsidian	183 g	stage 4 success
22B	biface/tool	chalcedony core nucleus	73 g	stage 4 sucesss
23	biface/tool	heated Tosawihi opalite	113 g	stage 4 success
26	biface/tool	Morrison chert	553 g	stage 3 success
28	biface/tool	Georgetown flint	894 g	stage 4 failure
30	biface/tool	Hixton quartzite	3,412 g	stage 2 success
33	biface/tool	heated Edwards flint	115 g	stage 3 success

* Exper. # 7 by Peter Ainsworth; Exper. # 27-28 by Steve Tomka: all others by Dan Amick.

Table 2. Summary of reduction experiment debris analysis results.

Exper. No.	CF	SF	PF	MDF	NF	Total
2	7	3	3	28	2	43
4	71	23	26	78	4	202
5A	34	2	7	27	3	73
5B	29	3	12	75	0	119
7	24	5	11	69	6	115
8, 9, 10	14	3	8	37	0	62
14A	8	17	9	15	1	50
25	30	4	11	28	3	76
27	77	7	42	87	1	214
29	38	55	29	40	17	179
31	29	50	34	63	0	176
32	46	3	16	43	5	113
1	83	5	28	41	3	160
3	57	61	70	106	0	294
6-1	48	6	34	91	2	181
6-2	49	4	11	24	1	89
14B	48	10	39	52	0	149
20	73	5	10	49	0	137
22B	39	2	19	9	0	69
23	28	3	17	37	2	87
26	76	6	44	67	4	197
28	147	5	53	191	0	396
30	63	50	90	137	22	362
33	49	5	11	38	0	103

Key: CF=complete flake; SF=split flake; PF=proximal flake; MDF=medial/distal flake; NF=nonorientable fragment.

Table 3. Cross-tabulation of flake breakage and reduction goal.

	Flake Breakage Category					
Reduction Goal tal	**CF**	**SF**	**PF**	**MDF**	**NF**	**To-**
Core	O=407 28.6% E=455 z=-2.3	O=175 12.3% E=131 z=3.8	O=208 14.6% E=247 z=-2.5	O=590 41.5% E=559 z=1.3	O=42 3.0% E=30 z=2.3	1422
Biface/Tool	O=760 34.2% E=712 z=1.8	O=162 7.3% E=206 z=-3.0	O=426 19.2% E=387 z=2.0	O=842 37.9% E=874 z=-1.1	O=34 1.5% E=46 z=-1.8	2224
Totals	1167	337	634	1432	76	3646

Chi-square = 53.61, df = 4, p <.000001

Key: O = observed frequency; % = row percentages; E = expected frequency; z = standardized adjusted chi-square residual

Table 4. Cross-tabulation of flake breakage and raw material group for core reduction debris

	Flake Breakage Category					
Raw Material	**CF**	**SF**	**PF**	**MD**	**FNF**	**Total**
Obsidian	O=101 27.4% E=106 z=-0.4	O=13 3.5% E=45 z=-4.8	O=38 10.3% E=54 z=-2.2	O=208 56.4% E=153 z=4.4	O=9 2.4% E=11 z=-0.6	369
Chalcedony/ Flint/Chert	O=231 35.6% E=186 z=3.3	O=40 6.2% E=80 z=-4.5	O=98 15.1% E=95 z=0.3	O=264 40.7% E=269 z=-0.3	O=15 2.3% E=19 z=-0.9	648
Basalt/ Quartzite	O=75 18.5% E=116 z=-3.8	O=122 30.1% E=50 z=10.2	O=72 17.8% E=59 z=1.7	O=118 29.1% E=168 z=-3.9	O=18 4.4% E=12 z=1.7	405
Totals	407	175	208	590	42	1422

Chi-square = 219.77, df = 8, p <.000001

Key: O = observed frequency; % = row percentages; E = expected frequency; z = standardized adjusted chi-square residual.

Table 5. Cross-tabulation of flake breakage and raw material group for biface/tool reduction debris.

	Flake Breakage Category					
Raw Material	**CF**	**SF**	**PF**	**MDF**	**NF**	**Total**
Obsidian	O=170 41.8% E=139 z=2.6	O=15 3.7% E=30 z=-2.7	O=55 13.5% E=78 z=-2.6	O=164 40.3% E=154 z=0.8	O=3 0.7% E=6 z=-1.3	407
Chalcedony/ Flint/Chert	O=422 41.7% E=346 z=4.1	O=26 2.6% E=74 z=-5.6	O=172 17.0% E=194 z=-1.6	O=383 37.8% E=383 z=-0.0	O=9 0.9% E=16 z=-1.6	1012
Basalt/ Quartzite	O=168 20.9% E=275 z=-6.5	O=121 15.0% E=59 z=8.1	O=199 24.7% E=154 z=3.6	O=295 36.6% E=305 z=-0.6	O=22 2.7% E=12 z=2.8	805
Totals	760	162	426	842	34	2224

Chi-square = 204.99, df = 8, p<.000001

Key: O = observed frequency; % = row percentages; E = expected frequency; z = standardized adjusted chi-square residual.

Table 6. Cross-tabulation of flake breakage versus strategy of reduction.

Strategy of Reduction	**Flake Breakage Category**					
	CF	**SF**	**PF**	**MDF**	**NF**	**Total**
Cortical Platforms	O=34 46.6% E=24 z=2.1	O=2 2.7% E=2 z=0.1	O=7 9.6% E=7 z=-0.1	O=27 37.0% E=39 z=-1.9	O=3 4.1% E=1 z=1.7	73
Noncortical Platforms	O=29 24.4% E=39 z=-1.6	O=3 2.5% E=3 z=-0.1	O=12 10.1% E=12 z=0.1	O=75 63.0% E=63 z=1.5	O=0 0.0% E=2 z=-1.4	119
Totals	63	5	19	102	3	192

Chi-square = 17.48, df = 4, p<.001557

Key: O = observed frequency; % = row percentages; E = expected frequency; z = standardized adjusted chi-square residual.

Table 7. Cross-tabulation of flake breakage versus skill of analyst

Skill Level	**Flake Breakage Category**					
	CF	**SF**	**PF**	**MDF**	**NF**	**Total**
Student	O=281 40.7% E=276 z=-1.1	O=46 6.7% E=34 z=1.4	O=101 14.6% E=104 z=-1.1	O=131 19.0% E=159 z=-3.1	O=132 19.1% E=61 z=7.6	691
Instructor	O=320 46.3% E=301 z=1.1	O=29 4.2% E=37 z=-1.3	O=124 17.9% E=113 z=1.0	O=212 30.7% E=173 z=3.1	O=6 0.9% E=66 z=-7.6	691
Totals	601	75	225	343	138	1382

Chi-square = 142.91, df = 4, p<.000001

Key: O = observed frequency; % = row percentages; E = expected frequency; z = standardized adjusted chi-square residual.

Table 8. Cross-tabulation of chert core reduction debitage

	Flake Breakage Category				
Source	**CF**	**BF**	**MDF**	**NF**	**Total**
Bradbury and Carr 1995	O=177 33.7% E=183 z=-0.4	O=41 7.8% E=80 z=-4.4	O=274 52.2% E=241 z=2.1	O=33 6.3% E=22 z=2.5	525
This paper	O=231 35.6% z=0.4	O=138 21.3% z=3.9	O=264 40.7% z=-1.9	O=15 2.3% z=-2.2	648
Totals	408	179	538	48	1173

Chi-square = 54.35, df = 3, p<.000001

Key: O = observed frequency; % = row percentages; E =e xpected frequency; z = standardized adjusted chi-square residual.

Table 9. Cross-tabulation of chert biface/tool reduction debitage.

	Flake Breakage Category				
Source	**CF**	**BF**	**MDF**	**NF**	**Total**
Bradbury and Carr 1995	O=213 27.9% E=270 z=-3.5	O=175 22.9% E=174 z=0.0	O=376 49.2% E=315 z=3.5	O=0 0.0% E=5 z=-2.2	764
This paper	O=275 44.6% E=218 z=3.9	O=140 22.7% E=141 z=-0.1	O=192 31.2% E=254 z=-3.9	O=9 1.5% E=4 z=2.5	616
Totals	488	315	568	9	1380

Chi-square = 65.25, df = 3, p<.000001

Key: O= observed frequency; % = row percentages; E = expected frequency; z =s tandardized adjusted chi-square residual.

Table 10. Cross-tabulation of bipolar core reduction debitage

	Flake Breakage Category					
Source	**CF**	**SF**	**PF**	**MDF**	**NF**	**Total**
Kuijt et al. 1995	O=49 11.9% E=57 z=-1.1	O=7 1.7% E=9 z=-0.8	O=1 0.2% E=9 z=-2.7	O=173 41.9% E=189 z=-1.2	O=183 44.3% E=149 z=2.9	413
This paper Exp. #7	O=24 20.9% E=16 z=2.0	O=5 4.3% E=3 z=1.5	O=11 9.6% E=3 z=5.2	O=69 60.0% E=53 z=2.2	O=6 5.2% E=41 z=-5.5	115
Totals	73	12	12	242	189	528

Chi-square = 87.31, df = 4, p<.000001

Key: O = observed frequency; % = row percentages; E = expected frequency; z = standardized adjusted chi-square residual.

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