Size Distributions of Artifact Classes: Combining Macro- and Micro-Fractions

Julie K. Stein

Department of Anthropology, University of Washington, Seattle, Washington

Patrice A. Teltser

Department of Anthropology, Southern Illinois University, Carbondale, Illinois

The size and composition of microartifacts (objects less than 2 mm) and macroartifacts (objects greater than 2 mm) are utilized to interpret the formational processes of an archaeological site. Because grain-size distributions are known to reflect mode of transport and source, the attribute of size is examined by plotting each artifact class (unmodified rock, modified rock, ceramic, concretion, bone/shell, and metal) in size frequency diagrams. The plots allow the agent and mode of transport to be reconstructed, which in turn allows the formational processes of the site to be interpreted. The example used is the Pelts Site (23-DU-29) of southeastern Missouri. The site was chosen for this pilot study because the formation processes can be reconstructed from other data. The size distributions of each artifact class support those reconstructions and allow the proposed method to be evaluated as an interpretive method for other archaeological sites.

INTRODUCTION

Grain-size distributions of individual classes of materials are used by sedimentologists to interpret depositional histories of geological deposits (Blatt et al., 1980; Stein, 1987; Visher, 1969). Although archaeologists are concerned with reconstructing the depositional history of archaeological sites, especially the artifactual materials within them (Schiffer, 1987), they have not examined artifactual material in terms of grain-size distributions. In this article we measure the grain-size distribution of individual classes of artifacts to test if the interpretations of site depositional history conform to the expectations generated by other site data. By combining both the analysis of macroartifacts and microartifacts, and measuring them over continuous grain-size intervals, the resulting curves can be compared to sedimentological principles of sediment transport. We predict that artifact classes have grain-size distributions that reflect the manner in which they entered the depositional record and the manner in which they have been altered since that deposition occurred.

Examination of size distributions of large-sized artifacts is not new in archaeology (Bullard, 1970; Butzer, 1978, 1982; Dunnell and Stein, 1989; Fladmark, 1982; Hassan, 1975, 1978; Hull, 1987; Rapp, 1975; Rosen, 1986). Perhaps the earliest reference to a specific technique for analyzing small-sized

Geoarchaeology: An International Journal, Vol. 4, No. 1, 1–30 (1989)

CCC 0883-6353/89/010001-30$04.00

artifacts was proposed by Hassan (1978). His study, referred to as microarchaeological analysis, required that a sample of at least 1/2 kg be weighed, then screened through 1 mm and 0.1 mm mesh screens. The approximate abundance of various elements caught on the two screens was estimated visually with the aid of a particle atlas. Results were used to interpret activity areas in a North African site (Hassan, 1975).

A second attempt to use grain-size distributions to interpret artifact deposition is by Fladmark (1982), where he examined lithic debitage produced from laboratory knapping experiments. He sieved material through geological screens with the diameter of each screen decreasing by one half. The dimensions were −5 phi to 4 phi (smaller than 64 mm and greater than 0.063 mm), the same units used in the study reported here. The results were extremely useful for generating the theoretical size distributions needed to interpret various kinds of lithic manufacturing activity.

The most recent effort by Rosen (1986) represents a study of compositional types also using screens whose diameters decrease by one half. Rosen did not examine the gravel fraction, but rather restricted her screen size to a range of −1 phi to 4 phi (smaller than 4 mm and greater than 0.063 mm). Compositional types were quantified using visual comparitor charts (expressed as percentages). This procedure results in a series of relative percentages for each category and each size fraction. The data were used to interpret activity areas in a tell.

Most work with small-sized artifacts and their distributional relationship to the larger-sized artifacts has been influenced by these three studies. Hassan's examination of small-sized artifacts was the beginning of controlling for the attribute of artifact size in analysis of archaeological site materials, yet not in itself enough to allow reconstruction of size distributions and activity areas. Fladmark, using the size gradations on just one compositional type, demonstrated the potential of examining size distributions. These two studies together gave Rosen the key ingredients for her reconstructions. Yet Rosen's method calls for the use of comparitor charts to quantify compositional types. These charts lower the accuracy and precision of the study, and thus make the interpretations less rigorous. In the study described here the efforts of Hassan, Fladmark, and Rosen have been considered and expanded so that macroscopic and microscopic grain-sizes are combined into one distribution.

THEORETICAL BASIS FOR INTERPRETATIONS

Size distributions of grains found together in a depositional unit are routinely used in sedimentology to interpret depositional histories. Although originally thought to be controlled by individual depositional environments (lagoon, beach, dune, etc.), the shape of the grain-size distribution relates more clearly to the mode of sediment transport (Visher, 1969; discussed in Stein, 1987). There are three main modes of sediment transport: rolling, saltation, and suspension. Rolling transport moves sediment grains along the surface.

When air or water are the transport agents this transport mode usually contributes the coarsest fraction, exhibited as a modal peak in frequency curves. Saltation transport moves grains by bouncing them along the surface. The maximum grain size transported by saltation is dependent on the energy of the transport medium, the depth of the water (for aqueous transport), the nature of the bed (bed roughness), and the sizes available in the source area. The portion of a deposit transported by saltation is identified as a modal peak usually in the sand fraction of the frequency curve.

Suspension transport moves sediment grains entirely within the medium. The maximum grain size transported in suspension is dependent on the turbulent energy of the medium (for water and air), the viscosity of the medium, and the sizes available in the source area. For aqueous and aeolian transport the maximum size of grain carried is related directly to velocity of the medium. While in viscous and solid transport mediums such as mud, ice, and biological agents (including people), the grain sizes carried in suspension can be of any size. In fact, solid transport agents usually carry grains in a suspension mode. The size of the grain is controlled not by the medium, but rather by the sizes that are available in the source area. The frequency curves produced by highly viscous or solid transport agents will commonly reflect the grain-size distributions of the source deposits and be multimodal, the number and location of which depend on the number of sources involved.

Archaeological deposits are usually the product of numerous depositional events with a significant contribution made by solid transport agents. Biological transport agents (identified above as suspension transport) bring grains to the site during one or more activities. Manufacturing activities bring lithics, ceramics, and construction materials. Subsistence activities bring plants and animals. Each activity brings to the site a unique composition and size range of materials. Each activity is a unique source of one type of compositional grain. The deposit is created by the deposition of material from all these sources into one unit. The unit, sometimes called layer, stratum, or bed (Stein, 1987) is defined by the investigator by noting that the lithological characteristics of the unit are sufficiently different from the units above, below, and adjacent to it to warrant a separate name (Stein, 1985, 1987). Units are thus named using attributes such as color, grain size, or content and usually represent deposition events (sources and transport agents) that somehow changed from what was previously or later deposited. The deposit identified in such a manner contains grains from numerous sources, each source contributing a unique type of compositional grain, with its unique type of size distribution.

The size distributions of particles resulting from manufacturing and subsistence activities have been suggested from studies using physical principles and experimentation. For example, the grain-size distributions of lithic debris reflect the mechanical aspects of lithic manufacturing (Clark, 1984; Fladmark, 1982; Stahle and Dunn, 1982, 1984). The grain-size distributions of lithics reflect modal peaks in the frequencies of cores, flakes, and shatter. Grain-size distributions of ceramics reflect the mechanical aspects of ceramic breakage (Bradley and Fulford, 1980; Chase, 1985; Schiffer, 1987; Skibo and Schiffer, 1987; Stein, 1987). Their grain-size distributions exhibit a modal peak at the size in which the ceramics entered the record, with the slope tapering off gently in the direction of the fine-sized grains. Such a curve also allows the interpretation of the post-depositional alterations that may have broken the sherds (e.g., plowing), as well as the size at which the sherd entered the record (Schiffer, 1983, 1987).

The grain-size distributions of microartifacts and macroartifacts described here use the sedimentological principle that grain-size distributions are the results of sizes of grains available in source area, mode of transport, and post-depositional disturbances. By constructing grain-size distribution curves for each compositional type of grain found in each individual deposit within a site, the size distribution of artifacts are interpreted.

THE PELTS SITE

The site chosen for this study was selected because much of its depositional history has been reconstructed from geomorphic evidence (Fisk, 1944; Saucier, 1974), archaeological evidence (Teltser, 1988), and historic records. These reconstructions suggest hypothetical size distributions for each compositional artifact type. The fit of the actual size distributions to those suggested by the other evidence will determine if size distributions are useful tools in analyzing site formational processes.

The Pelts Site is located in the southeast corner of Missouri on a late-Pleistocene/early-Holocene landform called the Malden Plain (Figure 1). This plain was created by the discharge of the Ohio River system during the end of the glacial maximum when significantly higher quantities of sand, silt, and clay were being transported to the Gulf of Mexico (Fisk, 1944; Saucier, 1974).

The Malden Plain is composed of deposits representing three depositional events. The oldest event left the channel bar deposits, transported by the Pleistocene braided stream systems that carried well-sorted sands from the glacial margins. More recent events deposited fine-grained alluvium in the backswamps of modern underfit rivers. The low-velocity regime of these alluvial backswamps are not sufficiently competent to cover or to entrain the previously deposited sandy alluvial bars. Rather, the present rivers have followed low-lying areas created by channel scars of the Pleistocene rivers, and the overbank deposits of these modern rivers have filled in the swales of the Pleistocene rivers.

The third depositional event recorded in the Malden Plain is the deposition over the last 6000 years of prehistoric and historic archaeological material on the exposed surfaces of both the Pleistocene sandy bars and the recent find-grained backswamp deposits. Prehistoric occupation began in the Archaic Period and continued through the Mississippian Period, and predominantly

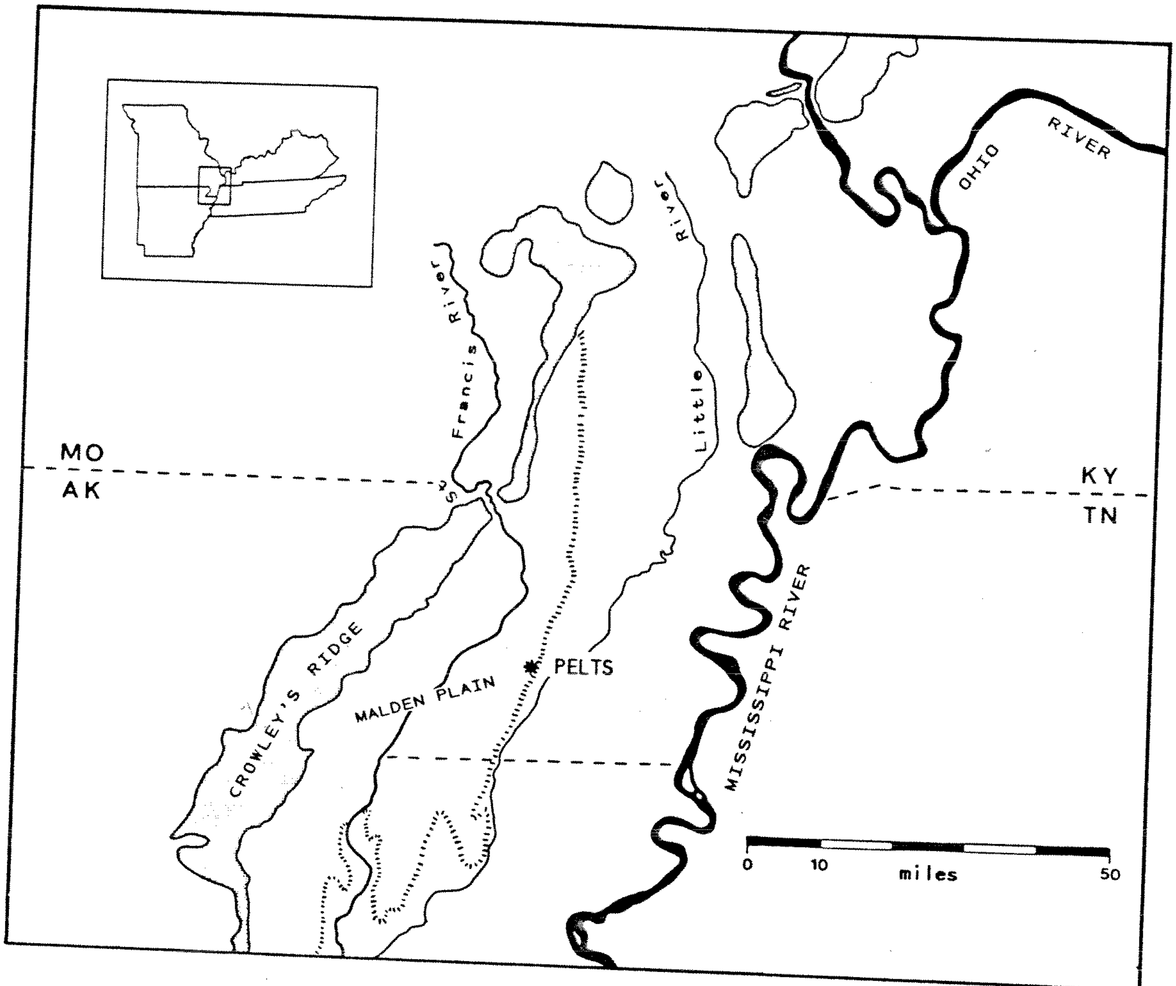

Figure 1. Location map of Malden Plain and the Pelts Site, Missouri.

occurred on the tops of the Pleistocene sandy bars, on land surfaces projecting above the water of the backswamps. Major land reclamation projects designed to drain the swamps were initiated as early as the 19th century, and have allowed intensive cultivation of soybeans, wheat, and cotton on both the sandy bars and the fine-grained backswamp deposits. Although urban areas are increasing in the recent decade, approximately 90% of this area in southeast Missouri is currently under cultivation (Gurley, 1979).

FIELD PROCEDURES

The samples used in this study were collected in southeast Missouri (Figure 1) during the summer of 1984 by one of the authors (P. Teltser). The location is one of many concentrations of artifacts found along the Malden Plain escarpment, where artifacts form a continuous distribution in varying densities. Prehistoric artifacts at this particular location are found in densities sufficiently high to consider the location an archaeological "site," assigned the name Pelts (23-DU-29). All archaeological materials at this location were originally deposited on a surface stable since the Pleistocene sands were deposited, and have been mixed with the sands by plowing.

Artifacts and bulk samples recovered from this site were collected following a two-tiered collection strategy. All large-size artifacts (greater than 2 mm) were collected from the surface using 4 × 4 m collection units. The size of the collection unit was chosen to answer questions regarding settlement structure, and thus maintain sufficient spatial control over the distribution of artifacts across the site. Bulk samples (approximately 500 g) were collected from the upper 5 cm of the plow zone at the northwest corner of each 4 × 4 m collection unit.

Because the study required large numbers of artifacts in all size categories, the units chosen for this grain-size study were located within the densest concentration of large artifacts at the site, assuming that high concentrations of large-size artifacts would correlate positively with high concentrations of microartifacts. Four of the units are spaced 24 m apart along a line (samples A, B, C, D). The fifth unit was selected from an area 24 m west of that line (sample E). This unit was included to provide better aerial coverage of the artifact concentration observed at Pelts.

LAB PROCEDURES

Size distributions of all artifacts greater than 2 mm were determined by weighing all the material (sherds, modified rock, unmodified rock, historic material, bone, shell, etc.) that passed through geological screens of gradational sizes (1 phi intervals; Folk, 1980). The most effective way of determining their sizes was to pass the individual objects through the screens manually. This insured that the edges of the lithics and ceramics were not damaged by the mesh of the screens.

Contents of the bulk samples were passed through a 2 mm sieve. All artifacts retained on the screen were disregarded for the experiment, because the area had already been surface collected and these large-size objects must have been under the surface. The material (less than 2 mm) was processed according to a modified version of grain-size analysis described in Folk (1980). The bulk sample was not pretreated for removal of organic matter or carbonate for fear that the chemical processes would damage the artifactual contents (e.g., bone and shell). The sample was saturated with a 1% solution of sodium hexametaphosphate and washed through a .0625 mm (4 phi) screen to separate the sand fraction from the silt/clay fraction. The sand fraction was dried and poured into a set of nested screens of gradational (1 phi interval) sizes. The silt/clay fraction was processed using the pipette technique (Folk, 1980).

The previously described procedure resulted in a gravel fraction (material larger than 2 mm) derived from surface collection of a 4 × 4 m unit, a sand fraction (smaller than 2 mm and larger than .0625 mm) from a bulk sample, and a silt/clay fraction (smaller than .0625 mm) from a bulk sample, all of which were divided into size classes of 1 phi intervals, from −5 phi to 12 phi.

CALCULATIONS

Calculating Grain-Size Distributions

In grain-size analysis the sand and gravel fraction, which is determined by sieving, and the silt and clay fraction, which is determined by a settling method (either pipette or hydrometer), are incorporated into a single size distribution by multiplying the silt and clay portion by a splitting factor to render it proportional to the original weight of sample passed through the sieves. Our strategy was the same, except that the gravel portion was sampled by collecting objects from a plowed surface rather than from a volumetric excavation unit. Therefore, the weight of each of the gravel-size intervals had to be corrected upwards to make them comparable to the original weight of the "surface sample."

For example, the largest artifact recovered was −5 phi (smaller than 64 mm and larger than 32 mm). In order for an object of this size to appear on the surface of a 4 × 4 m collection unit it would have to be part of a bulk sample with a volume of 4 m × 4 m × 64 mm. Smaller objects such as −4 phi objects, which are smaller than 32 mm and larger than 16 mm, would not necessarily appear on the surface of a sampling universe defined by such a volume. However, they would appear on the surface of a sampling universe defined by a volume of 4 m × 4 m × 32 mm. Thus the weight of each gravel-sized phi fraction was calculated separately, and depended on the volume of a unit necessary to allow an object to be seen on the surface. Corrected weights for −5, −4, −3, and −2 phi were easily obtained by multiplying each by 2^0, 2^1, 2^2, and 2^3 respectively, because these fractions were sampled by controlled surface collection and because of the logarithmic relationship of the phi scale.

Once the corrected weight of each phi interval in the gravel fraction was calculated, the weight was subtracted from the "super" sample total. The remaining portion was used to calculate a splitting or conversion factor for bulk samples which contained only sand, silt, and clay. In sample A, for example (Table I), after the −5, −4, −3, and −2 phi fractions were subtracted, 1,356,438.9 grams of the "super" sample remained. The −1 and 0 phi fractions, weighing 1.22 and 3.40 grams respectively, were seived from a subsample of 485.6 grams. To convert these weights from the subsample to the "super" sample, they were both multiplied by 1,356,438.9/485.6. The remainder of the sand, silt, and clay fractions were sampled from another subsample of 60.5 grams. The weight obtained for each phi fraction within the subsample was multiplied by 1,343,533.7/60.5 to obtain the corrected weight.

Calculating Compositional Types

For each size fraction the particles were sorted by macro- and microscopic examination of grains under reflected light into one of the following composi-

Table I. Calculations of grain-size distribution of each sample, derived from starting weight of hypothetical "super" sample.

Phi	Weight of split	Weight Coarser Than	Conversion Factor	Corrected Weight	Amount in Super Sample Remaining	Individual Percent
			Sample A			
−5	2713600.0	0.0	—	0.0		
−4	1356800.0	55.3	2^0	55.3	1356744.7	.004
−3	678400.0	116.6	2^1	233.0	1356671.9	.02
−2	339200.0	18.2	2^2	72.8	1356438.9	.01
−1	485.6	1.22	1356438.9/485.6	3407.9	1353031.0	.25
0		3.40		9497.3	1343533.7	.70
1	60.5	4.26	1343533.7/60.5	94727.8	1248805.9	6.98
2		21.10		469191.7	779614.3	34.58
3		24.12		536346.1	243268.1	39.53
4		5.02		111627.6	131640.5	8.23
5		2.82		62707.1	68933.4	4.62
6		1.22		27128.6	41804.8	1.99
7		.43		9561.7	32243.0	.71
8		.24		5336.8	26906.3	.39
9		.32		7115.7	19790.6	.52
10		.35		7782.8	12007.8	.57
11		.23		5114.4	6893.3	.37
12		.31		6893.3	0.0	.51

Phi	Weight of split	Weight Coarser Than	Conversion Factor	Corrected Weight	Amount in Super Sample Remaining	Individual Percent
			Sample B			
−5	2713600.0	68.9	2^0	68.9	2713531.1	.003
−4	1356800.0	302.9	2^1	605.8	2712925.3	.02
−3	678400.0	651.7	2^2	2606.0	2710319.3	.10
−2	339200.0	99.1	2^3	791.8	2709527.5	.03
−1	544.4	1.06	2709527.5/544.4	5275.4	2704252.1	.19
0	186.5	.46	2704252.1/186.5	6670.0	2697582.1	.25
1		6.52		94540.1	2603041.9	3.48
2		61.10		885950.6	1717091.3	32.65
3		81.09		1175805.9	541285.4	43.33
4		16.12		233740.2	307545.2	8.61
5		10.15		147175.1	160370.1	5.42
6		3.27		47415.0	112955.1	1.75
7		1.55		22475.0	90480.1	.83
8		.99		14355.0	76125.0	.53
9		1.30		18850.0	57275.0	.70
10		1.41		20445.0	36830.0	.75
11		1.09		15805.0	21025.0	.58
12		1.45		21025.0	0.0	.78

tional types: prehistoric ceramics, modified rock (chert), bone/shell, metal, concretions (primarily iron/manganese), and unmodified minerals and rock-fragments.

Table I. *Continued*

Sample C

Phi	Weight of split	Weight Coarser Than	Conversion Factor	Corrected Weight	Amount in Super Sample Remaining	Individual Percent
−5	2713600.0	65.6	2^0	65.6	2713534.4	.002
−4	1356800.0	156.3	2^1	312.5	2713221.9	.01
−3	678400.0	250.3	2^2	1001.1	2712220.8	.04
−2	339200.0	59.3	2^3	474.4	2711746.4	.02
−1	338.5	.35	2711746.4/338.5	2803.5	2708942.9	.10
0		.86		6888.7	2702054.1	.25
1	47.9	1.76	2702054.1/47.95	99178.6	2602875.5	3.66
2		16.90		952340.3	1650535.3	35.08
3		20.78		1170984.1	479551.2	43.16
4		3.81		214699.2	264852.0	7.91
5		2.20		123973.3	140878.7	4.57
6		.71		40009.6	100869.2	1.48
7		.32		18032.5	82836.7	.67
8		.24		13524.4	69312.3	.50
9		.26		14651.4	54660.0	.54
10		.29		16341.9	38319.0	.60
11		.27		15214.9	23104.1	.56
12		.41		23104.1	0.0	.85

Sample D

Phi	Weight of split	Weight Coarser Than	Conversion Factor	Corrected Weight	Amount in Super Sample Remaining	Individual Percent
−5	2713600.0	29.55	2^0	29.6	2713570.4	.001
−4	1356800.0	78.83	2^1	157.7	2713412.7	.01
−3	678400.0	299.99	2^2	1199.9	2712212.8	.04
−2	339200.0	75.82	2^3	606.3	2711606.5	.02
−1	169600.0	3.59	2^4	57.4	2711549.1	.002
0	338.41	1.56	2711549.1/338.41	12499.7	2699049.4	.46
1	65.45	4.83	2699049.4/65.45	199181.2	2499868.2	7.34
2		29.45		1214469.1	1285399.1	44.75
3		21.76		897346.3	388052.8	33.07
4		3.89		160417.1	227635.6	5.91
5		2.39		98559.6	129076.0	3.63
6		.98		40413.6	88662.4	1.49
7		.35		14433.4	74229.0	.53
8		.49		20206.8	54022.2	.75
9		.49		20206.8	33815.4	.75
10		.14		5773.3	28042.1	.21
11		.32		13196.3	14845.8	.49
12		.36		14845.8	0.0	.55

Table I. *Continued*

Phi	Weight of split	Weight Coarser Than	*Sample E* Conversion Factor	Corrected Weight	Amount in Super Sample Remaining	Individual Percent
−5	2713600.0	0.0	—	0.0		
−4	1356800.0	518.30	2^0	518.3	1356281.7	.04
−3	678400.0	597.36	2^1	1194.3	1355087.4	.09
−2	339200.0	133.69	2^2	534.1	1354553.3	.04
−1	594.7	.76	1354553.3/594.7	1731.1	1352822.2	.13
0	591.9	1.67	1353031.1/591.9	3816.9	1349005.4	.28
1	65.1	1.76	1349005.4/65.1	36470.8	1312534.6	2.68
2		21.37		442830.2	869704.4	32.64
3		28.46		589749.5	279954.9	43.47
4		4.61		95528.6	184426.2	7.04
5		3.15		65274.5	119151.8	4.81
6		1.51		31290.3	87861.4	2.31
7		.78		16163.2	71698.3	1.19
8		.53		10982.7	60715.6	.81
9		.59		12226.0	48489.6	.90
10		.70		14505.4	33984.2	1.07
11		.62		12847.7	21136.5	.95
12		1.02		21136.5	0.0	1.56

All objects collected on the surface of the 4 × 4 m unit were first identified as to their material composition, then passed through a geological screen to determine the size, and finally weighed. For example, the weight of all ceramics of −5 phi size were tallied for every unit, followed by the weight of all ceramics of −4 phi, −3 phi, etc. These calculations provided the size and compositional data for all the objects recovered from the surface (all objects greater than 2 mm).

Identification of the composition of objects smaller than 2 mm required magnification and a sampling strategy. In the sand fractions a binocular microscope (using reflected light) was used to determine if sand-sized grains were ceramic, flake, concretion, or other compositional type. Unlike the gravel fraction, all of the thousands of grains retained in a screen could not be identified compositionally. A sample of each size fraction had to be examined and proportions of each compositional type calculated.

The procedure for determining the proportions of compositional types in each sand-sized fraction follows a modification of sedimentological procedures (Chayes, 1956; Daniels et al., 1968; Galehouse, 1971; Weibel and Elias, 1967a,b). It begins with splitting the size fraction (see Folk, 1980 for details on sample splitting) until an approximate 5 g split is acquired. The grains contained in the 5 g split are poured onto a glass petri dish, below which is attached a piece of graph paper of no greater than 1 cm grid intervals. The grains are spread equitably across the grids. While looking through the microscope, the grains located in one grid unit are counted according to compositional types. We found that a density of 100 grains/grid was the maximum that could be accurately counted. The compositional types of grains resting on each grid are recorded until approximately 1000 grains are examined.

The actual numbers of grains that are necessary to acquire statistically valid numbers depends on the quantity of compositional types being counted and the rarity of any given type. If 20 composition types are being counted, then more grains will have to be processed. If only five types are examined, then fewer grains have to be counted. If a type that occurs with a frequency of only 1/1000 grains is being examined, then obviously a 10- or 20-fold increase must occur in the number of grains counted. The number of compositional categories and the rarity of any one type in this study dictated that at least 1000 grains had to be counted for each size interval.

After the grains were counted, the proportions of each compositional type were calculated. The counts are converted to weight percentages and used to calculate the percentage of each compositional type in each size fraction. The proportions can be calculated two ways, as percentages of each compositional type in any one size fraction, or as the percentage of a certain compositional type across all size fractions.

PROBLEMS WITH IDENTIFICATIONS

Errors in identification of all artifact classes occur in size-fractions smaller than 1 phi (0.50 mm). To check the accuracy of the identifications being made for these size intervals, a subset of exactly 1000 grains was removed from the size fractions of 1 phi and 2 phi for all the samples. Each subset was counted twice by each author. The results indicate that each of the authors was very consistent in their accuracy of identifying compositional types, but the identifications varied consistently between analysts. From these results we decided that to increase the precision of our identifications only one person should do the counting and identifications. This systematized the biases introduced by different analysts but made the percentages consistent from sample to sample.

There was also a problem in differentiating between ceramics and concretions. In sand-sized grains iron concentrations look very similar to ceramics. Both have quartz grains (of 2 phi and 3 phi-size) bound by a finer-grained (silt- and clay-sized) matrix. In the concretions, the sand is derived from the sandy parent material and bound by iron oxides precipitated in the subsurface soil environment. In ceramics, sand is used as a tempering agent and most likely derived from the sandy sediment on which the artifacts have been deposited. Therefore, both concretions and ceramics contain sand and a fine-grained matrix. Concretions are found almost exclusively in the sand fraction. Ceramics are found in both sand and gravel fractions. The calculations of the amount of ceramics or concretions found in the sand fraction may be incorrect due to misidentification of ceramics and concretions.

In an attempt to differentiate the two compositional types, two attributes were explored. Concretions were predicted to have higher iron content than ceramics and thus would respond more strongly to a magnetic field than would sherds. Secondly, the size of the spacing between quartz grains was thought to be closer in concretions than in ceramics, because ceramics are made by adding sand to a clay paste and concretions are made by adding the iron oxide to stationary sand grains.

Analysis revealed that neither of these criteria were useful for differentiating sherds from concretions. Using larger size intervals (a size at which surface treatment on sherds was visible and more confident identifications were possible), the spacing between grains in ceramics was variable, ranging from those that were touching to those that were widely spaced. For concretions in the same size fraction, the measurements in the spacing of the quartz grains had a similar variability. Also, when exposed to a magnetic field, some concretions exhibited strong magnetic properties, while others did not. Some ceramics reacted as strongly to the magnetic field as did concretions. Evidently the paste in the ceramics is as highly magnetic as the iron concretions.

Other attributes that might be useful for separating sand-sized ceramics and concretions are still being tested. But until such discriminators are discovered the authors are not confident in counting correctly the distributions of ceramic and concretion grains smaller than 1 phi. Thus, no compositional determinations were made for size fractions smaller than 1 phi.

GRAPHIC REPRESENTATION OF DATA

When separating artifact classes and displaying their grain-size distributions, two methods of graphing are used. First, compositional types are graphed by comparing the distribution of one compositional type across all size fractions. The percentage in such a distribution curve equals 100%. A second graph displays the percentages of grains that are one material type for each grain-size fraction. For this graph, each phi fraction adds to 100% when adding all the percentages of compositional types. For each compositional type examined, both types of graphs are provided.

RESULTS

Initially the grain-size distribution of all grains (including all compositional types of gravel, sand, silt, and clay sizes) are calculated and graphed (Figure 2). A modal peak occurs at the interval larger than 3 phi (0.125 mm) and smaller than 2 phi (0.25 mm) for all samples except sample D, for which the modal peak is between 2 phi (0.25 mm) and 1 phi (0.50 mm). Note that the gravel fraction for every sample (defined according to the Folk, 1980 terminology of size classes) is very small, ranging from .33% to .07%. The silt fraction is also small (9.11% to 6.39%), as is the percentage of clay (4.49% to 1.96%). Thus,

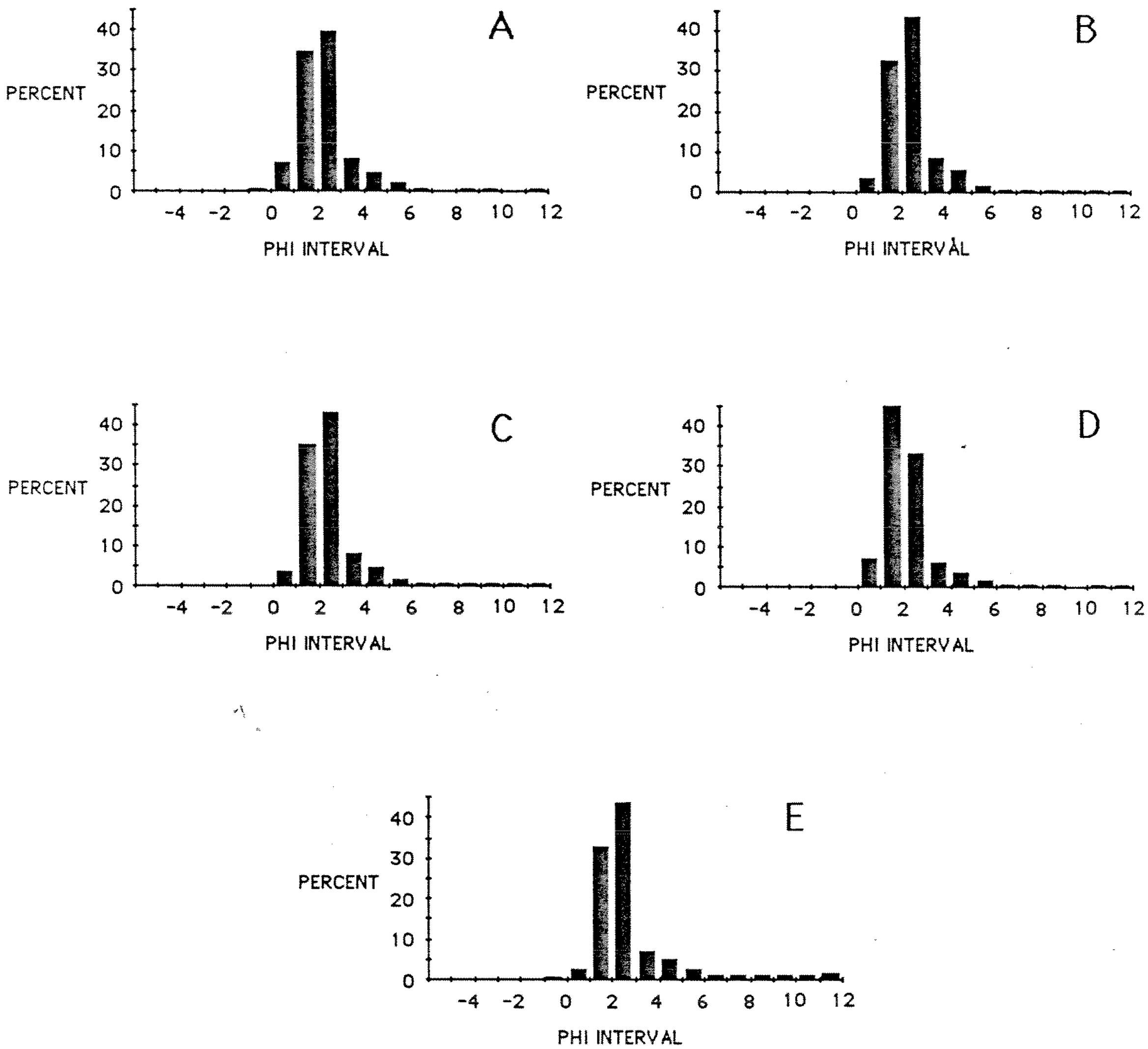

Figure 2. Histograms of samples showing distribution of all grains across all size intervals measured in grain-size analysis.

the overwhelming grain size represented in the samples is the sand fraction (91.54% to 86.13%), and most of that is in the 2 phi and 3 phi-sized interval.

The portion of the entire grain-size distribution, which was counted by the authors that is unmodified rock and minerals, is expressed in Figures 3 and 4. Unmodified rocks and minerals are defined as grains that show no attributes that would suggest that they have been modified by people and are therefore not artifactual. In the large-sized fractions few unmodified rocks and minerals are found, with most grains occurring between the 0 phi and the 1 phi interval (smaller than 2.00 mm and larger than 0.50 mm).

In Figures 5 and 6, the distribution of bone and shell is graphed. For most samples the bone and shell material makes up an extremely small amount of

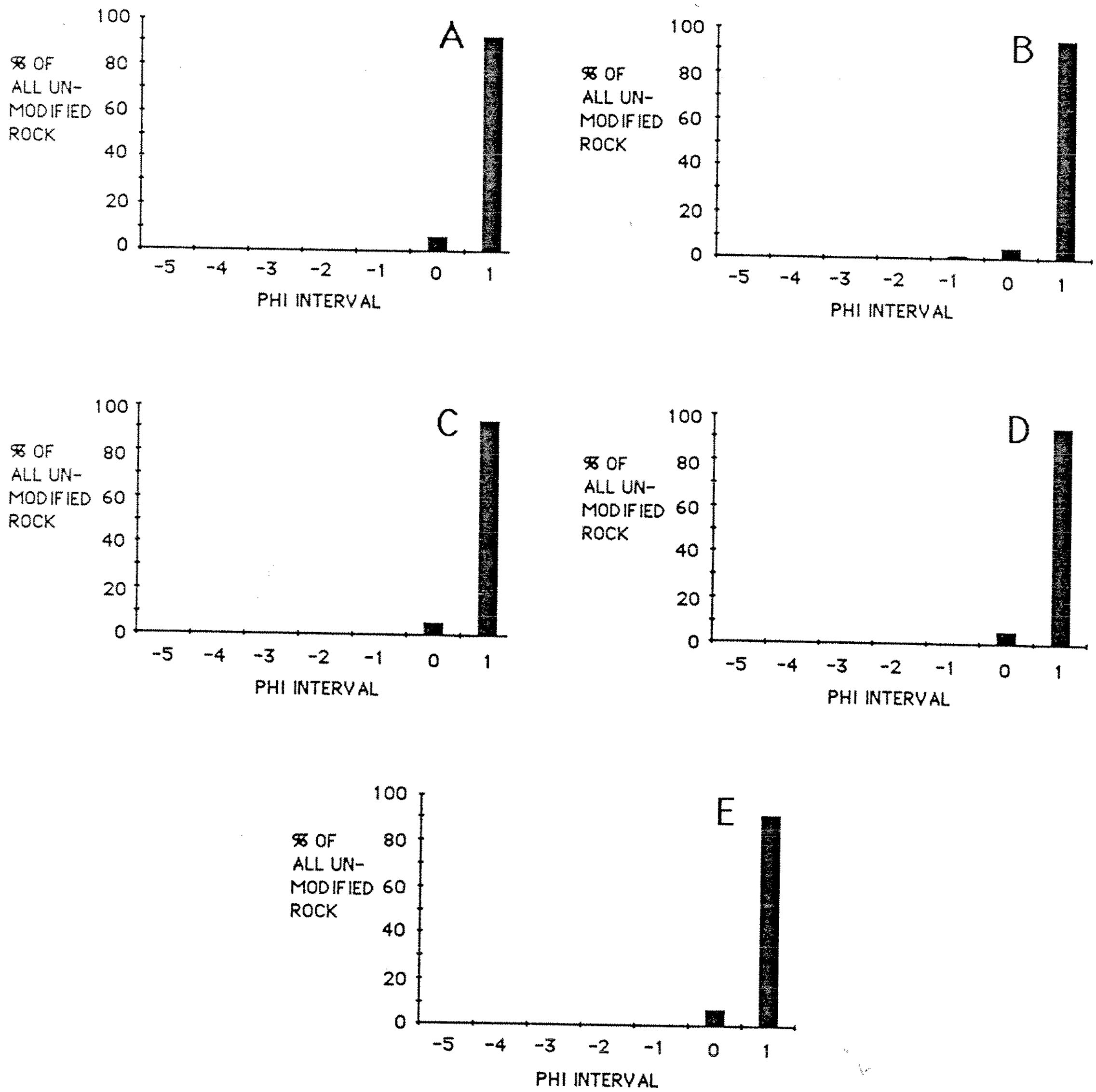

Figure 3. Percentage of unmodified rock in each phi-interval that was counted in compositional study. Values used to make graph equal 100% of unmodified rock in the counted sample. Note that the counted sample does take into account all the unmodified rock in the finer-grained fractions.

the phi size fractions (Figure 6). Such poor representation is most likely related to the acidity of the soils in this area (Gurley, 1979).

The frequency distribution of the compositional type metal is displayed in Figures 7 and 8. Figure 7 shows the distribution of metal across all size intervals, and Figure 8 displays the distribution of metal as percentages in each phi size. In all samples where metal was found, the size and amount varies widely.

The distribution of concretions is shown in Figures 9 and 10. In Figure 9, where the concretions are graphed across all the size fractions, the vast majority of concretions are found in the smallest phi fractions (−1 phi, 0 phi,

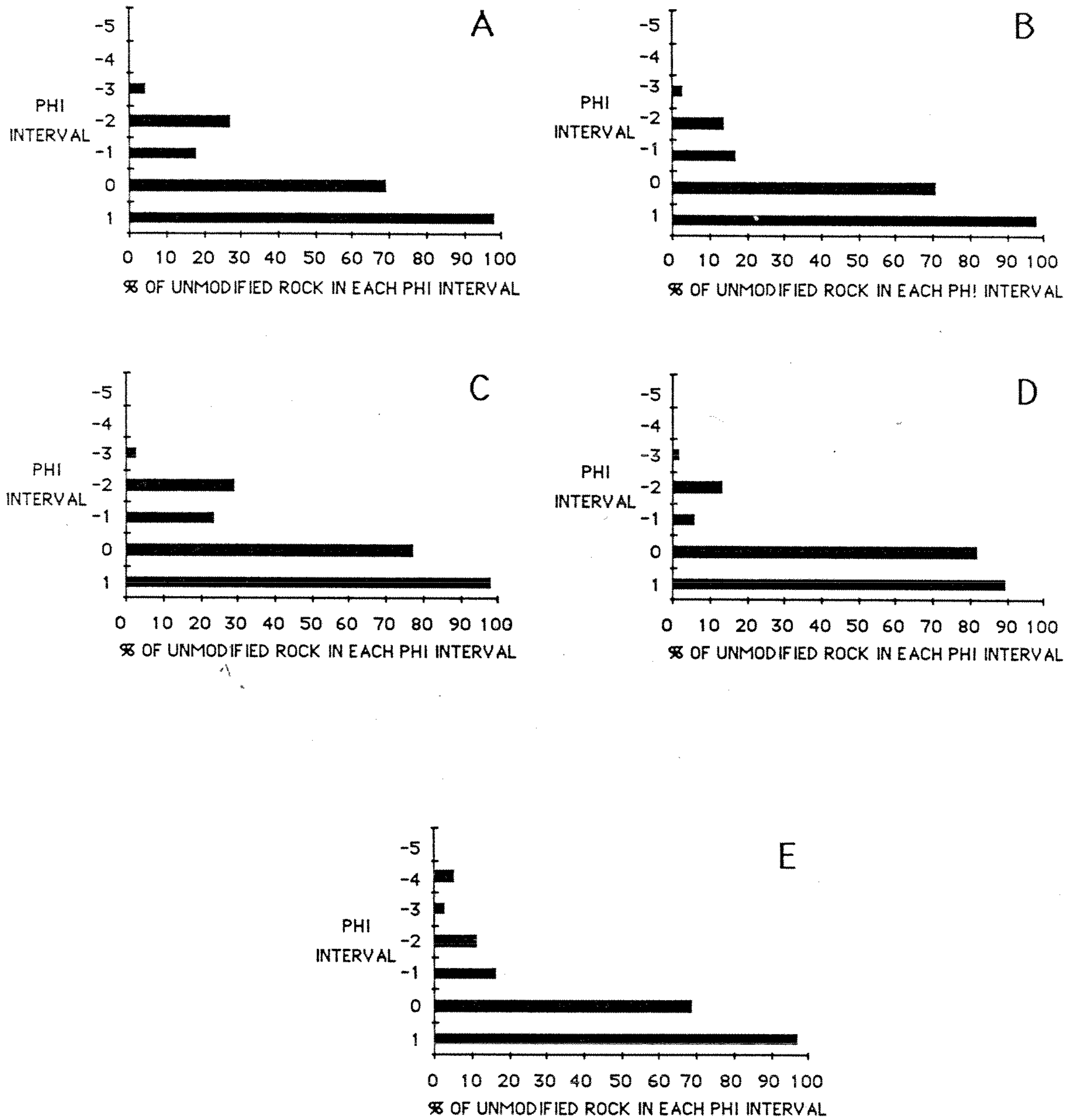

Figure 4. Unmodified rock in each of the counted intervals is expressed as a percent of the phi interval. When this percent of unmodified rock is added to the percentages of all other material types they equal 100% for each phi interval. Note that the sand-size fractions have a large amount of unmodified rocks.

and 1 phi). Concretions seem to make up only a small proportion of any phi size (Figure 10).

In the grain-size distributions of ceramics at the Pelts Site, there are a variety of modes observed (Figures 11 and 12). In Figure 11, all of the samples (A, B, C, D, and E) have a mode in the fine-gravel fraction at −3 phi (smaller than 16 mm and larger than 8 mm). They also have a second mode located in

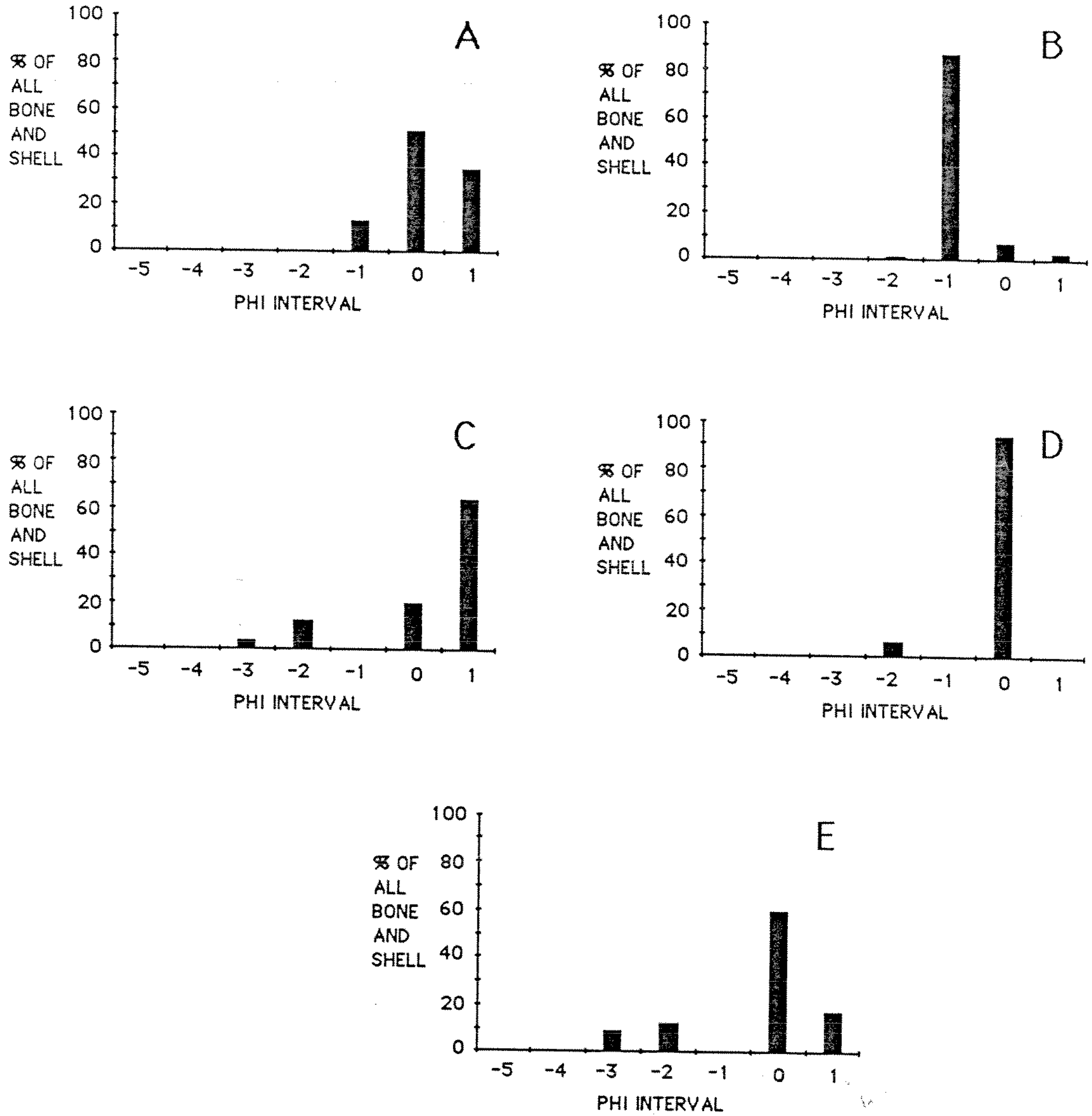

Figure 5. Percentage of bone and shell in each phi-interval that was counted in compositional study. Values used to make graph equal 100% of bone and shell in the counted sample.

the sand fraction, but for each the second mode is in a different sand-size interval and the frequency of sand changes as the sizes of the intervals get smaller. In samples A, C, and E the mode is at −1 phi and the amount of ceramics in the sand fraction decreases as the sizes get smaller. In sample B the mode is at 0 phi and the amount increases, then decreases. In sample D the mode is at 1 phi and the amount increases as the sizes get smaller. Figure 12 shows clearly that ceramics are the most abundant type of material found at the Pelts Site, especially in the gravel-size fraction.

The size distributions of modified rock (Figures 13 and 14) illustrate clearly that modified rocks are not abundant in the samples. Modified rock is defined as all chert grains that have resulted from stone tool manufacture, and identified by the presence of one or more diagnostic morphological features (Fladmark, 1982; Patterson, 1983). In most size intervals modified rock comprises less than 20% of each phi interval (Figure 14). In sample C a single chert core is unusual in that it was the only object found in the −5 phi size, and thus makes up 100% of that phi fraction. In the distribution of the modified rock across the phi intervals (Figure 13), modified rocks are found most frequently in the sand-sized intervals and rarely in the gravel-sized ones.

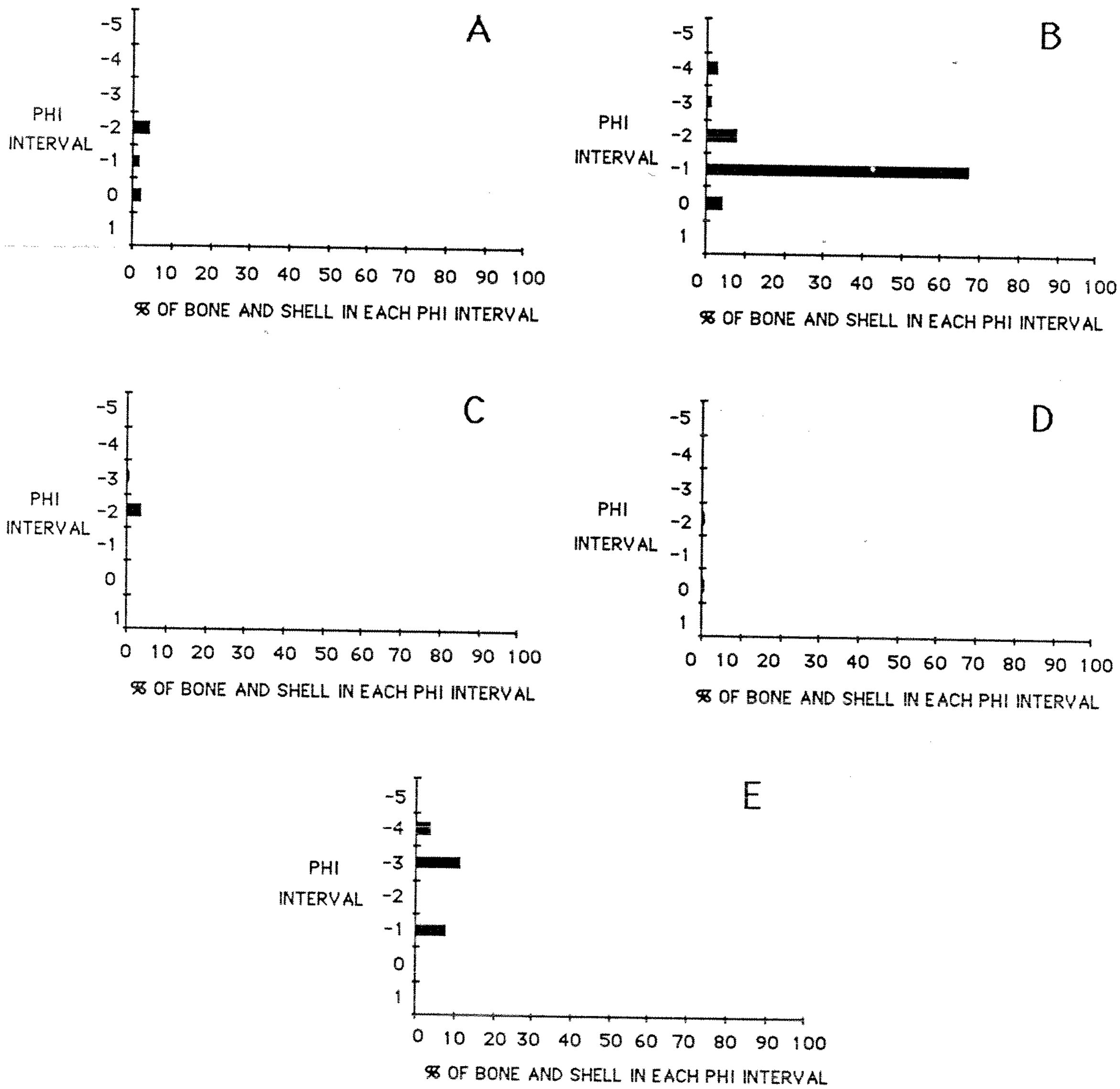

Figure 6. Bone and shell in each of the counted intervals is expressed as a percent of the phi interval. When this percent of bone and shell is added to the percentages of all other material types they equal 100% for each phi interval. Bone and shell make up only a small percentage of each size interval, probably because of the acidity of the soils.

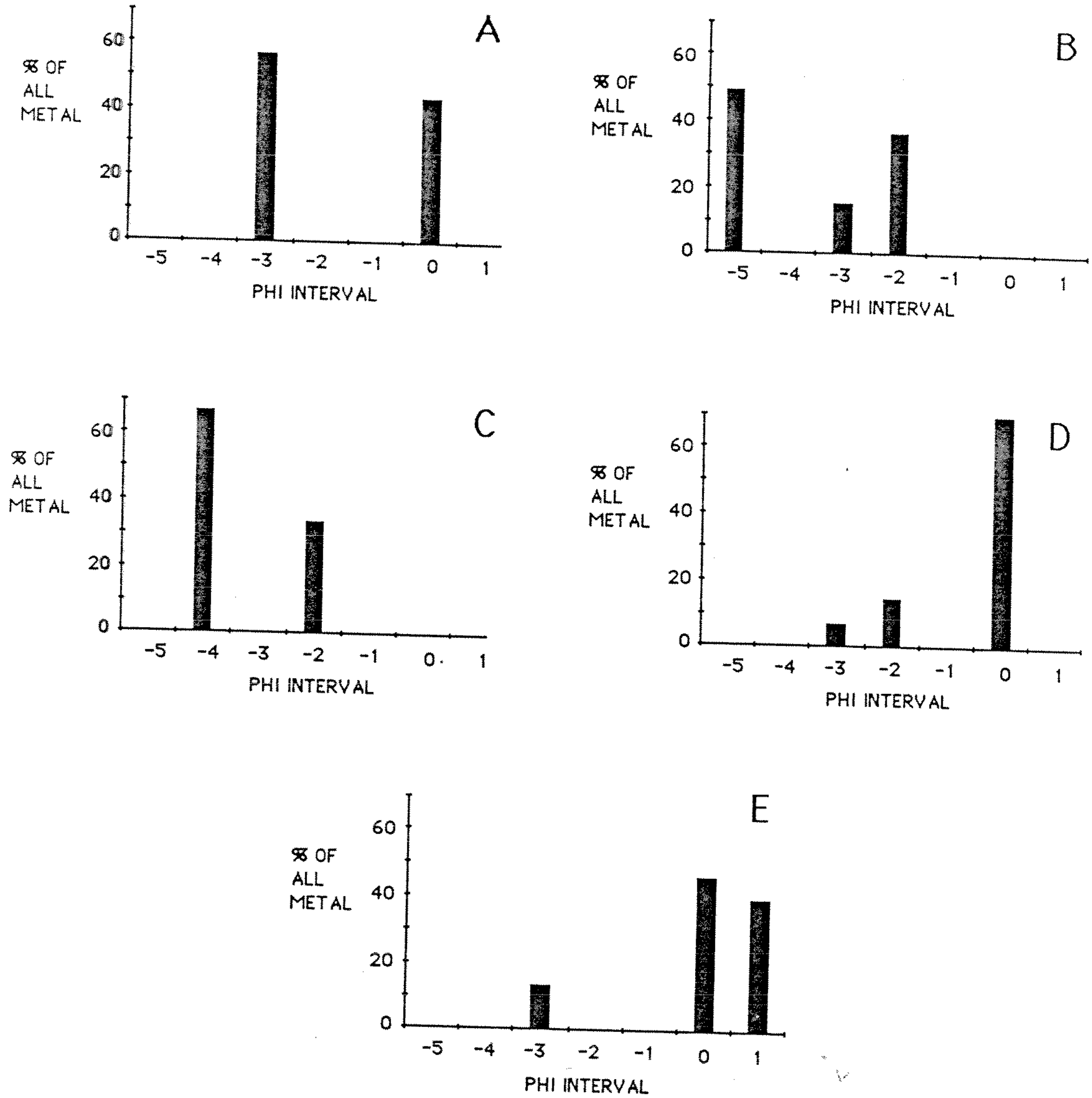

Figure 7. Percentage of metal in each phi-interval that was counted in compositional study. Values used to make graph equal 100% of metal in the counted sample.

DISCUSSION

The size distribution of each compositional type was predicted on the basis of other site data. The fit of the distributions to those predictions is discussed for each compositional type.

Unmodified Rock

The overwhelming compositional type found in the 0 phi, 1 phi, 2 phi, 3 phi, and 4 phi-size interval is unmodified quartz grains (determined by counts for 0 phi and 1 phi intervals and displayed in Figure 4, and by qualitative examination by the authors for the 2 phi, 3 phi, and 4 phi intervals). Early Paleozoic sandstones, with quartz grains of fine-sand size, are probably the source for these unmodified grains. Glaciation in the northern drainage basins of the Mississippi, Missouri, and Ohio Rivers eroded these rocks, allowing the Pleistocene rivers to transport the grains to the location of the Pelts Site. Thus, the majority of the unmodified minerals and rock fragments in the "super" sample are found in the 2 phi and 3 phi-size intervals and are not related to cultural depositional events.

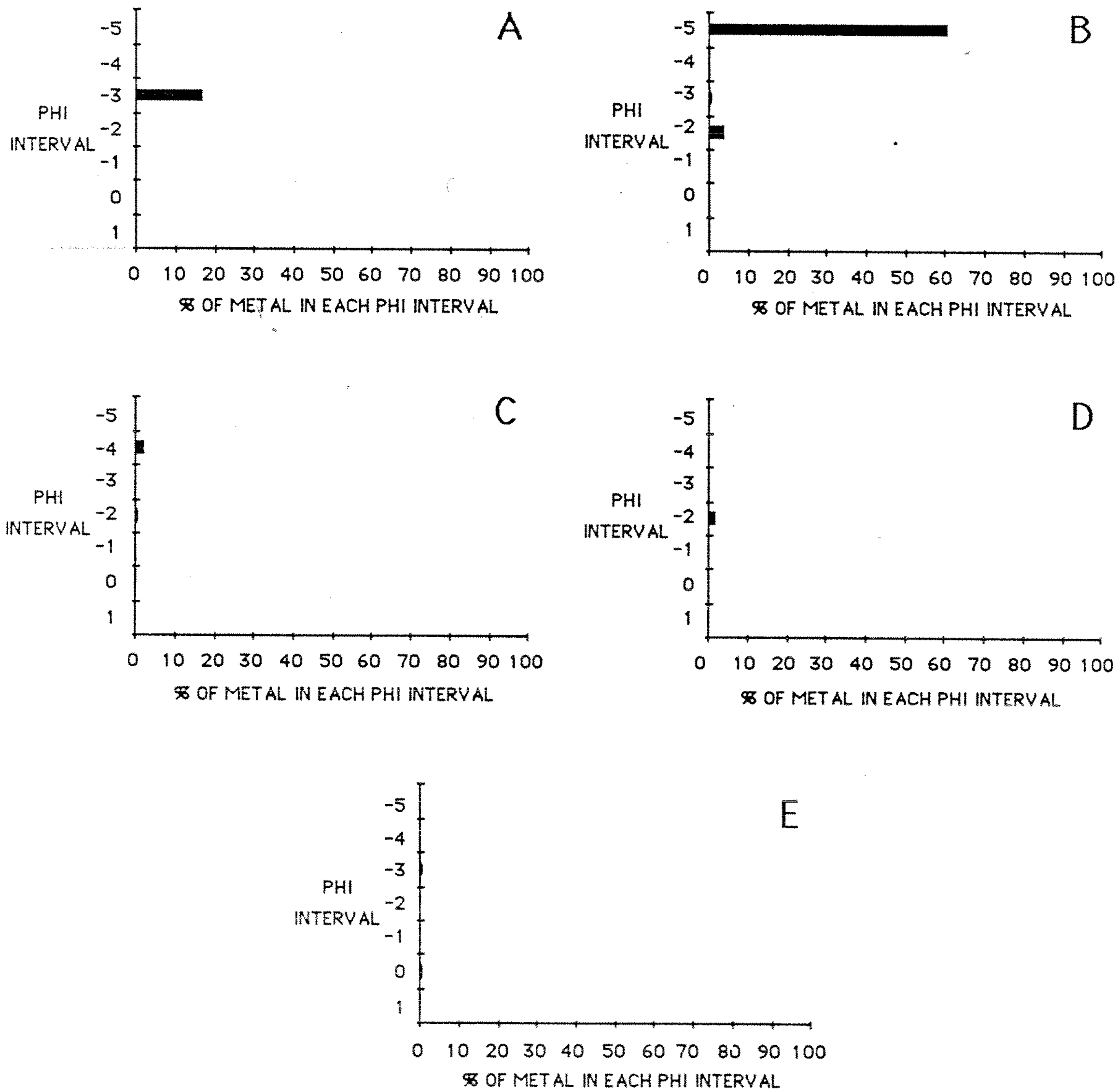

Figure 8. Metal in each of the counted intervals is expressed as a percent of the phi interval. When this percent of metal is added to the percentages of all other material types they equal 100% for each phi interval. Metal makes up a large percentage of only two size intervals in two samples, and probably represent large pieces of farm machinery.

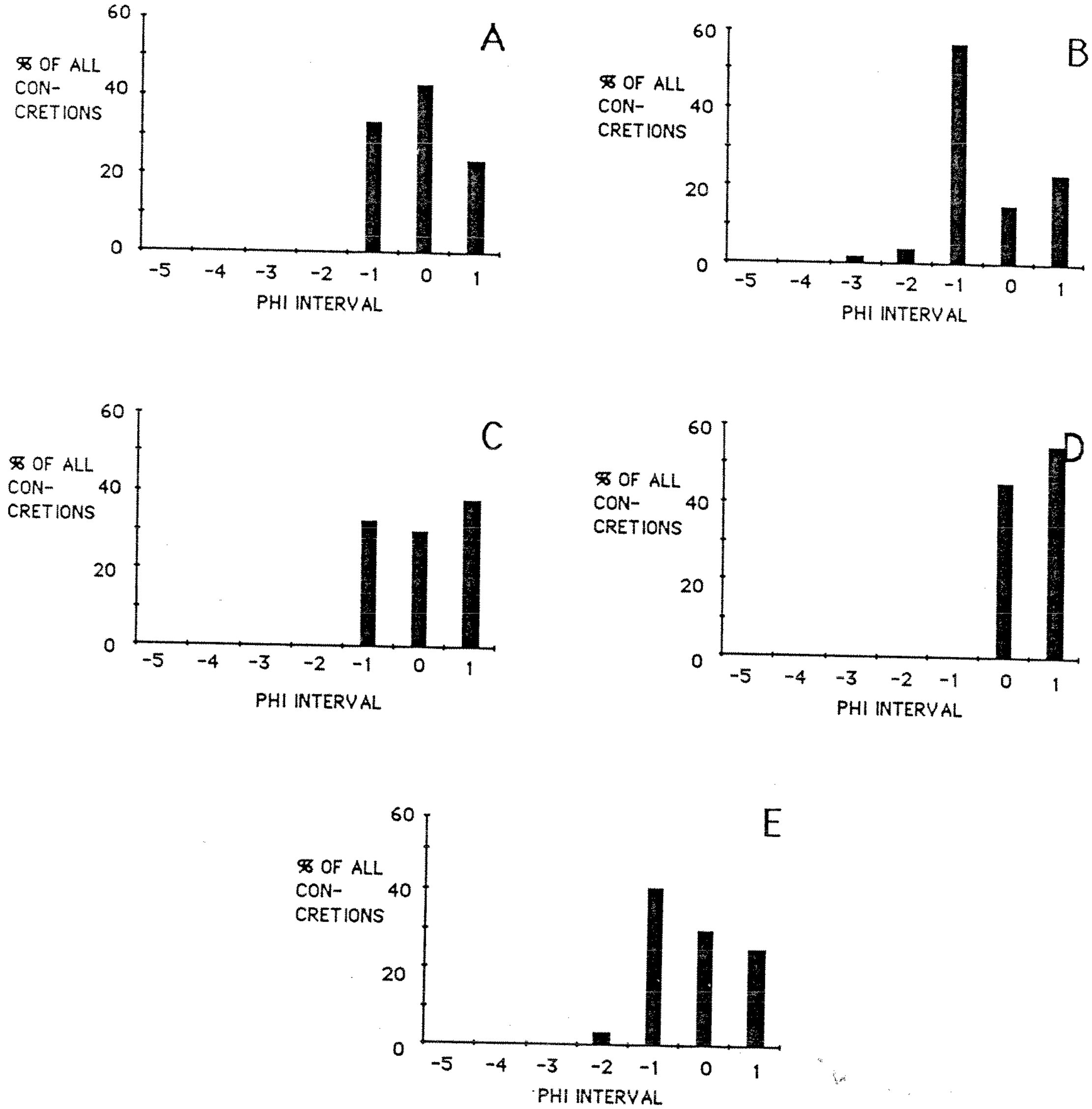

Figure 9. Percentage of concretions in each phi-interval that was counted in compositional study. Values used to make graph equal 100% of concretions in the counted sample. Variations in the shape of the curves could be a result of identification errors.

Metal

The source of the metal is historic, either derived from fragments of farm machinery, nails, or other activity associated with Anglo-American buildings located nearby. Although every sample has some metal in it, the sizes and numbers of pieces seem to be dependent not on the location of samples in reference to the historic building, but rather on random events associated with the loss of machine parts from tractors and plows as they move across the agricultural field (Lewarch and O'Brien, 1981).

The most notable characteristic, displayed in Figure 8, is that metal makes up less than 5% of the compositional types in most size intervals. The exception to this low level of abundance is the intervals larger than −5 phi size of sample B, and larger than −4 phi size of sample A. These two exceptions result from the discovery in each of these collection units of a single large machine part. As predicted from identification of macroscopic artifacts, these data indicate that metal is not a major compositional class of grains at this site.

Concretions

The interpretation of this distribution flows from principles of soil genesis. In the lower horizons of acidic sandy soils, such as those found at the Pelts Site

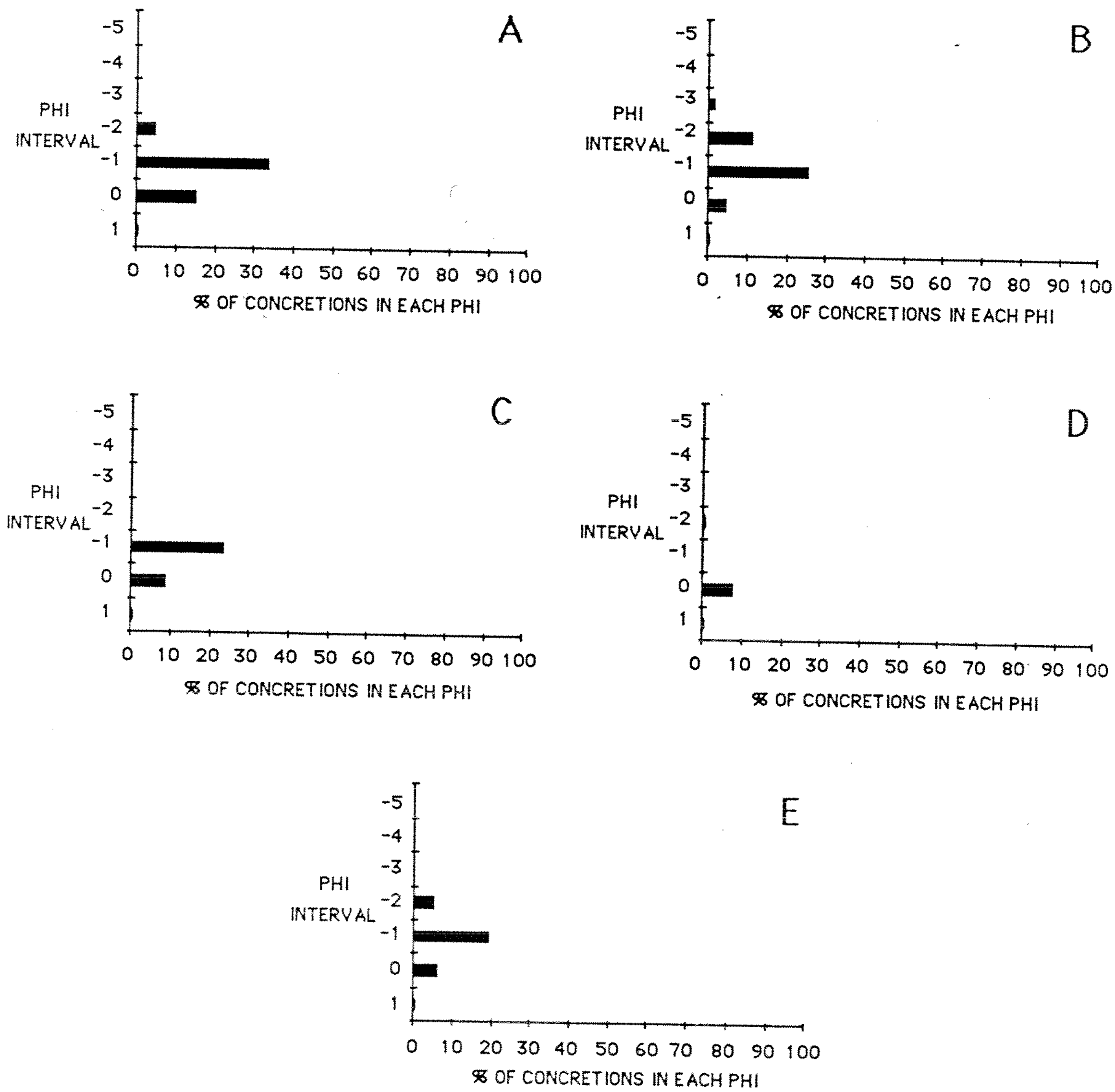

Figure 10. Concretions in each of the counted intervals are expressed as a percent of the phi interval. When this percent of concretions is added to the percentages of all other material types they equal 100% for each phi interval.

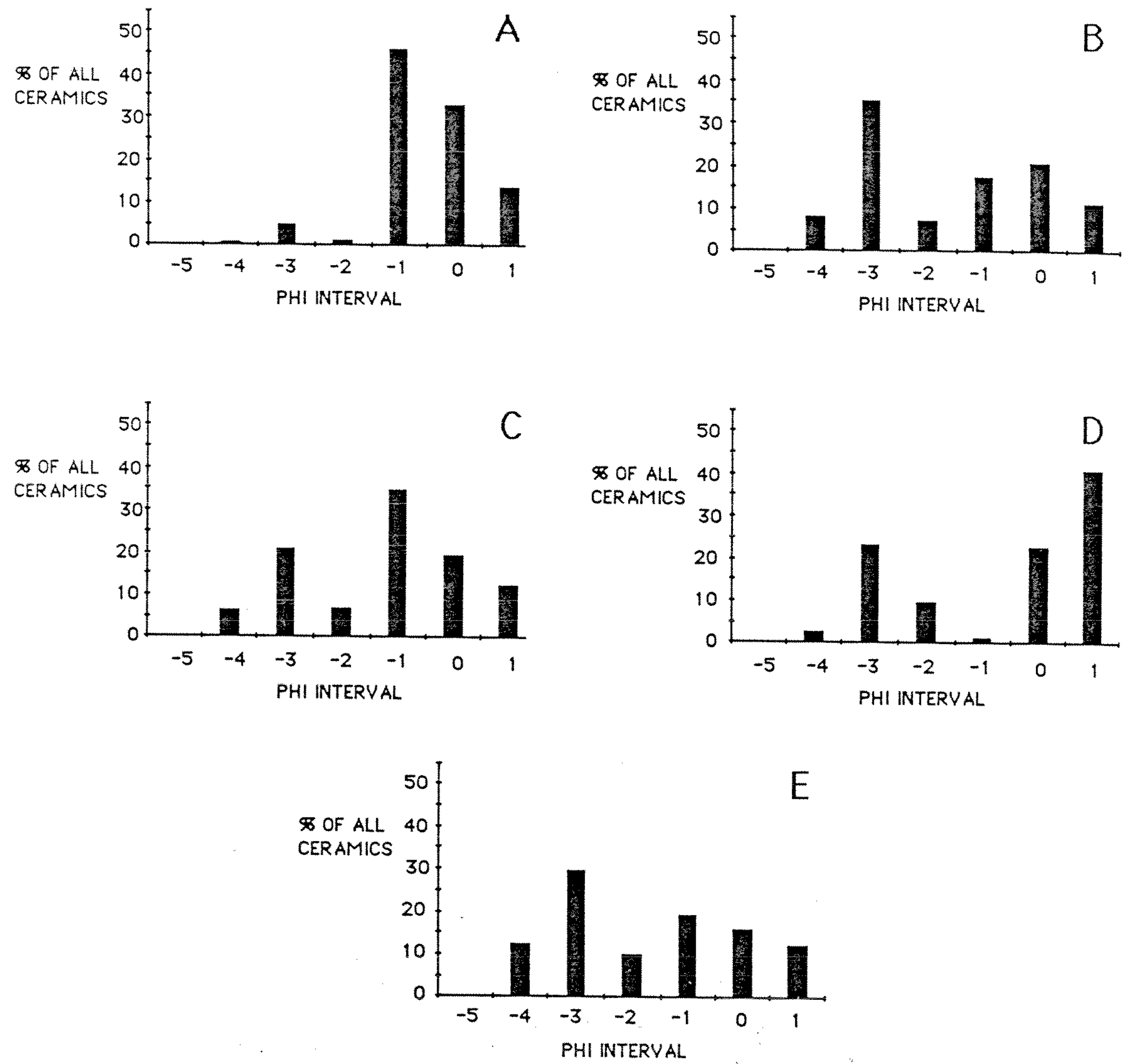

Figure 11. Percentage of ceramics in each phi-interval that was counted in compositional study. Values used to make graph equal 100% of ceramics in the counted sample. Note that although weakly defined, the mode in the −3 phi size interval is observed in every sample.

(Gurley, 1979), concretions are formed in the presence of fluctuating groundwater, oxygen-rich soil atmosphere, and abundant available iron. The concretions form in the B and C soil horizons and are brought to the surface through agriculturally induced mixing of the A and the upper portion of the B soil horizons. Because the genesis of concretions begins at the chemical level, by precipitation of iron oxides, concretions first exist in small sizes (microscopic level) and grow linearly along subtle bedding planes and around inclusions. The plow, which is responsible for bringing them to the surface, terminates the precipitation of iron and truncates the growth of the concretion. Thus, concretions at this site should be small and found in the smallest grain-size fractions.

The distributions (Figures 9 and 10) support this suggestion to some extent. Other than one large concretion in sample B, most concretions were found in the smallest intervals examined. But the shape of the distribution curve does not increase from lower percentages in the larger size intervals to a peak in the smallest size intervals. This difference, between the observed and expected, is perhaps the result of the problems in identification of small-sized ceramics and concretions.

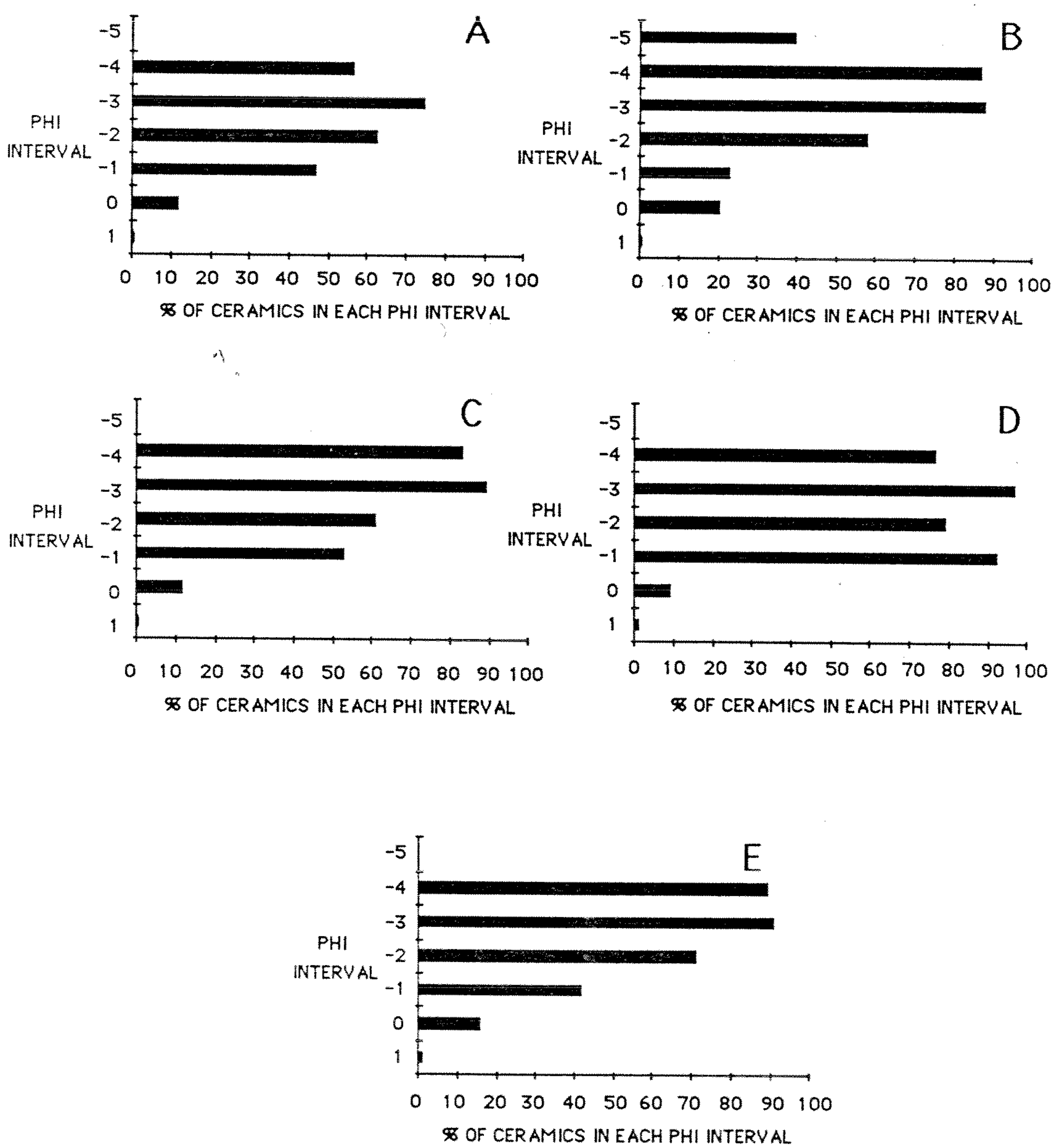

Figure 12. Ceramics in each of the counted intervals are expressed as a percent of the phi interval. When this percent of ceramics is added to the percentages of all other material types they equal 100% for each phi interval. Ceramics are the most abundant material type in the gravel fractions of the samples.

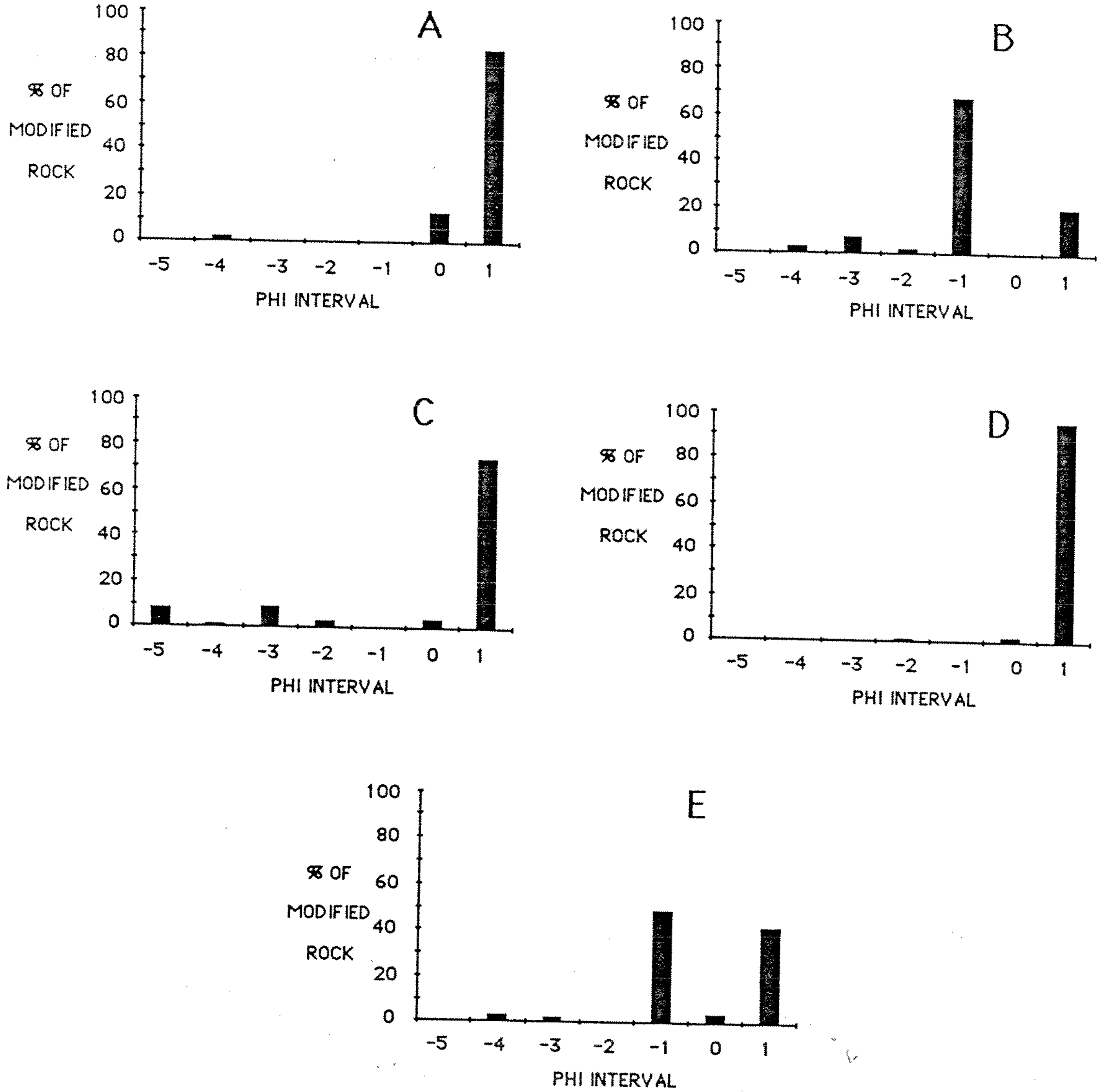

Figure 13. Percentage of modified rock in each phi-interval that was counted in compositional study. Values used to make graph equal 100% of modified rock in the counted sample. Most lithics are found in the sand-size fractions.

Ceramics

In a general sense, ceramics enter the record as vessels and sherds. They are manufactured as large objects and become smaller as they are exposed to diminution processes (mechanical and chemical weathering) through time. Depending on how much time elapses and how much destruction occurs, the grain size of the vessel will change from only one large grain (the vessel), in one size interval (large gravel), to many grains distributed over a more diverse range of grain sizes. As diminution progresses, the grain-size distribution (calculated not by grain counts but by weight) will change from a distribution with a single mode in one large-size fraction (for example the −8 phi size, smaller than 512 mm and larger than 256 mm), towards a distribution that is more poorly sorted, skewed toward the fines, and has a mode in the smaller gravel-size fractions such as −3 phi (smaller than 16 mm and larger than 8 mm). The total weight of the sample in either of the above cases is the same (the weight of the original vessel), the difference between the grain-size distributions is caused by the manner in which the weight is spread over the grain-size intervals.

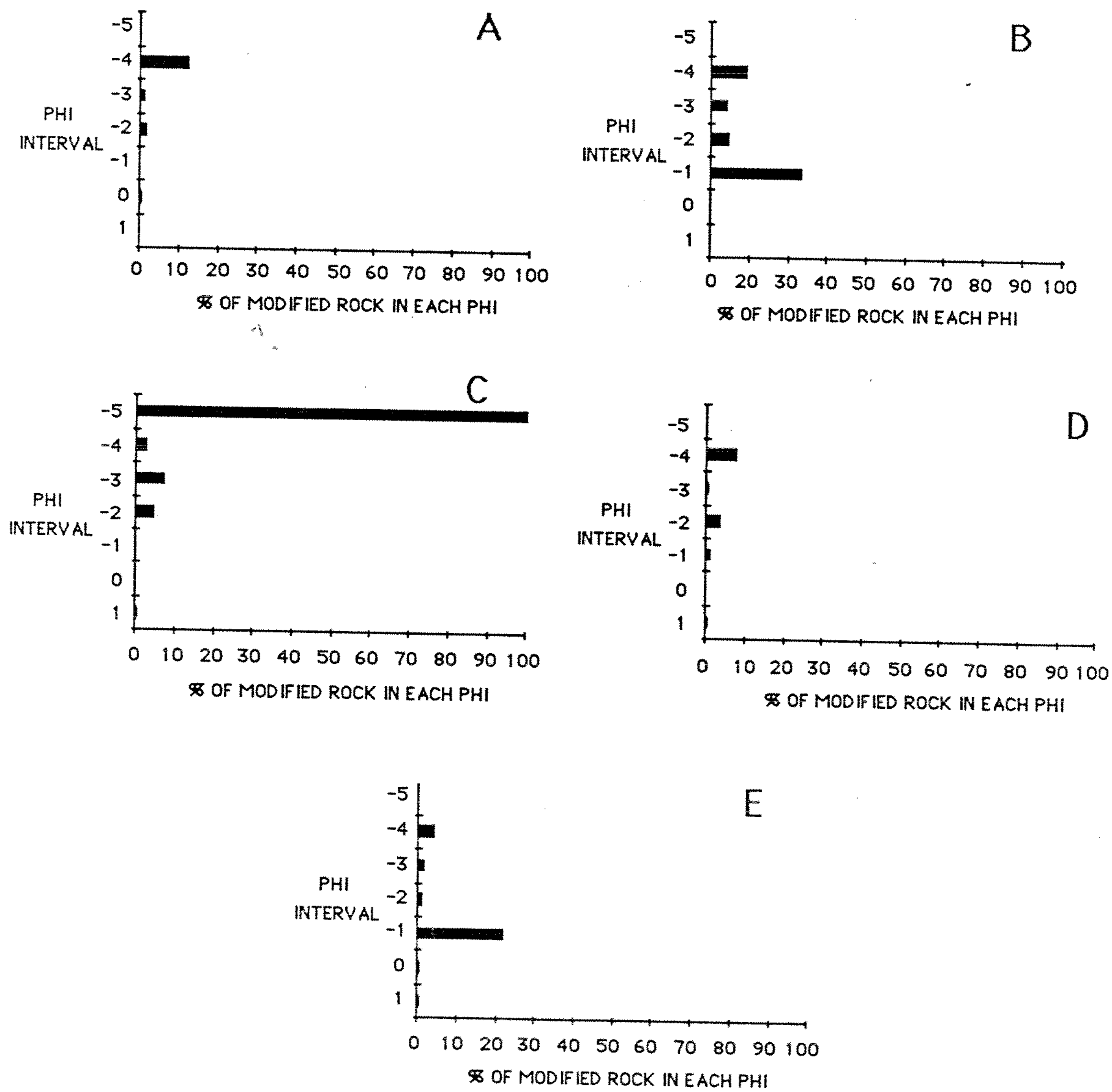

Figure 14. Modified rock in each of the counted intervals is expressed as a percent of the phi interval. When this percent of modified rock is added to the percentages of all other material types they equal 100% for each phi interval. Other than the one core in sample C, lithics make up only a small fraction of each phi interval.

At the Pelts Site the ceramics have been mechanically weathered (plowed) for over 100 years. Such exposure, to severe mechanical stresses, should break the ceramics into smaller and smaller sizes. The mechanics of plowing (and disking) are such that as the size of an object becomes smaller the probability of it being broken is lower (Lewarch and O'Brien, 1981). Rather than breaking the object, the plow or disk is more likely to push it aside and not cause further reduction. At some point the ceramics will be broken into sizes that will protect them from further breakage. In the ceramic distribution of the Pelts Site sherds (Figure 11), the small mode at −3 phi (smaller than 16.0 mm and larger than 8.0 mm) in the fine gravel-sized fraction, is interpreted as the size below which mechanical stresses no longer operate. Over 100 years of plowing has reduced sherds larger than fine gravel to a modal size of −3 phi.

The shape of the sand-size portion of the ceramic grain-size distribution (the −1 phi, 0 phi, and 1 phi intervals), may be explained by examining mechanical weathering in light of the grain-sizes produced by mechanical fracture. When a hard substance is fractured a far greater proportion of smaller grains (shatter) are produced, than are larger grains. For example, when either a glass or ceramic plate is dropped, the object breaks into a few large pieces. But with closer examination, hundreds of tiny shards can be found. When ceramics at the Pelts Site were plowed, they broke into a few large pieces, predominantly of the size −3 phi. But in the process, huge quantities of sand-sized sherds of −1 phi, 0 phi, and 1 phi sizes were produced (grains smaller than 2.0 mm and larger than 0.5 mm).

Between samples, the difference in the shapes of the sand-size distributions is not known. It is perhaps related to the proximity of sherds in the 4 × 4 m unit to the location of the bulk sample (the NW corner). In this study the bulk sample is considered to be an adequate sample of all the microartifacts associated with the macroartifacts in the 4 × 4 m unit, because plowing has homogenized the sediment. Even with the homogenization of the plow, the spatial distribution of microartifacts (sampled at one spot) may be slightly different from the spatial distribution of macroartifacts (sampled over a 4 × 4 m unit). This difference may be reflected in the shape of the sand-size curve. Proximity of the bulk sample to sherds that are being fractured would affect both the number and the size of sand grains found in the sample.

In addition to mechanical weathering, chemical weathering acts on the surfaces of the sherds to further reduce their size. In acid soils and at mid-latitude surface conditions, objects are readily oxidized, leached, and water-saturated. The edges of Pelts Site sherds are slightly rounded (although this rounding could be the result of mechanical fracture as well as chemical weathering). In some of the shell-temper sherds the shell has been leached. These observations suggest that chemical weathering has contributed to the reduction of sherd size. It has probably affected most significantly the small-sized ceramics, reflected in the sand-size portion of the distribution curve. Even though the contribution of chemical weathering is suspected to be important, the significance of chemical vs. mechanical weathering cannot be determined in this collection. Further experimental work is needed to help quantify the roles of the two types of weathering processes.

Modified Rock

The distribution of modified rock at the Pelts Site is best explained as the product of lithic reduction technology of cobble-sized raw material. The nearest source of raw material in the area of the Malden Plain is Crowley's Ridge (approximately 15 km away) and consists of cobble-sized gravels. Because the raw material was available in an already convenient transportable package, primary reduction is thought to have occurred on-site. This suggestion is supported by the presence of full reduction sequences in the assemblage, including abundant cores and flakes (Teltser, 1988). The weight percentage of gravel-sized debitage are low (Figure 13), because the original piece of raw material was small. But the weight percentages of sand-sized flakes are high because replication studies show that in the course of lithic reduction, the frequencies of flakes produced are greatest in the sand-sized fractions (Fladmark, 1982). As in the case with ceramic fracture, when chert is fractured, larger sizes are merely swamped by the fact that more tiny flakes are produced during manufacture.

Another, less plausible, explanation for the predominance of sand-size modified rocks is that they were produced by non-human agents (Patterson, 1983). The sand fraction of the Malden Plain was deposited by braided streams flowing from the edges of continental glaciers. Glaciers are capable of producing sand-size chert grains through rock-on-rock impact and grinding. This explanation is not entirely supported by the data for two reasons: because the modal size carried by the braided stream is 2 and 3 phi, while modified rock percentages begin to increase in the 0 phi, 1 phi, and 2 phi sizes, and because the morphological characteristics used to identify modified rocks (predominantly the shape being thin and flat, and the edges being angular) are probably not those produced by glacial impact and long-distance transport (Brown, 1973; Krinsley and Donahue, 1968; Stein 1987).

Another neutral agent that could produce small-size lithics is mechanical fracturing induced by the plow. If sufficiently large numbers of gravel-sized lithics were at the site, then the impact imparted on them could result in the increase in frequency of sand-sized flakes. As seen in Figure 14, the percentages of modified rock are less than 10% of the material type in each phi fraction, and especially low in the gravel-size fractions. On each of the gravel-sized objects, edge wear analysis suggests some edge fracturing, but less than would be needed to produce all the sand-size flakes discovered in this study.

CONCLUSIONS

At the Pelts Site the examination of the size distributions of microartifacts and macroartifacts has provided information to support archaeological and geological evidence concerning the deposition of the archaeological record and the post-depositional alteration of that record. Reconstruction of the formation processes of the Pelts Site, based on geological data, suggests that the site was first affected by the deposition of one stratigraphic unit during the Pleistocene, which contains unmodified predominantly-quartz sand. After the drainage characteristics changed at the end of the Pleistocene the deposition of sand stabilized. Holocene deposition of fine-grained silts and clays occurred in the low areas of the region, leaving the sand above the zone of deposition exposed (stable), with neither deposition nor erosion occurring. Soil science data suggests that at this same time iron concretions were forming in the subsurface. Also in the Holocene, based on archaeological data, these stable surfaces had deposited on them a thin veneer of lithics, ceramics, bones and shells. In the last 100 years historical data suggest that agricultural practices have significantly disturbed the surface. Plowing and disking brought concretions to the surface (truncating their growth), broke sherds mechanically, and added metal fragments from farm machinery. This final depositional and post-depositional event is responsible for the creation of the single stratigraphic unit (the plow zone) that was sampled and described in this study.

In this study the technique of examining the size distributions of grains, which were divided into various compositional types, supports the interpretations mentioned above and suggests two additional interpretations of depositional processes. Firstly, ceramics were reduced to a modal size of -3 phi (smaller than 16 mm and greater than 8 mm), a size suggested to be the product of mechanical weathering and perhaps related to the physics of forces imparted by machinery. Examinations of ceramics in other plowed fields may indicate that this size class of ceramics relates to mechanical fracture properties of ceramics or the physics of plowing (Lewarch and O'Brien, 1981), properties that might be used to interpret the site-formational processes at other sites.

A second observation suggested by the grain-size distributions is that both ceramics and lithics are found in greatest abundances in the sand-size fractions (smaller than 4.0 mm and larger than 0.5 mm). These sand-sized grains probably enter the record as products of fracture mechanics. Ceramics are really artificial rocks and when broken behave as minerals and rocks that are subjected to impact forces. Lithics are also minerals, and they too respond to impact forces in predictable manners. The presence of these sand-size ceramics and lithics suggests that mechanical impact was a significant formation process at the site. For the ceramics the impact was probably imparted by the plow. For the lithics the impact could be either imparted by the plow or the impact associated with lithic manufacturing.

The data and technique reported here demonstrates that the analysis of size frequencies of microartifacts and macroartifacts is powerful as a theoretical tool with which to expand our interpretations of site formational processes. Although it is labor intensive and possesses certain problems associated with quantification, identification, and interpretation, it follows sedimentological principles used in geology and has produced promising results.

The authors are grateful to Mr. G. Horner of Kennett, Missouri for access to the Pelts Site, and to R.C. Dunnell, F. Whittaker, and J. Feathers for advice and logistical support during the fieldwork, and for the helpful comments of two anonymous reviewers.

REFERENCES

Blatt, H.G., Middleton, G., and Murray, R. (1980). *Origin of Sedimentary Rocks (2nd edition).* Englewood Cliffs, New Jersey: Prentice-Hall, 634 pp.

Bradley, R., and Fulford, M., (1980). Sherd size in the analysis of occupation debris. *Bulletin of the Institute of Archaeology* **17,** 85–94.

Brown, J.E. (1973). Depositional histories of sand grains from surface textures. *Nature* **242,** 396–398.

Bullard, R.G. (1970). Geological studies in field archaeology. *The Biblical Archaeologist* **33,** 98–132.

Butzer, K.W. (1978). Sediment stratigraphy of the Middle Stone Age sequences at Klasies River Mouth, Tsitsikama Coast, South Africa. *South African Archaeology Bulletin* **33,** 141–151.

Butzer, K.W. (1982). *Archaeology as Human Ecology.* New York: Cambridge University Press, 364 pp.

Chase, P.G. (1985). Whole vessels and sherds: An experimental investigation of their quantitative relationships. *Journal of Field Archaeology* **12,** 213–218.

Chayes, F. (1956). *Petrographic Modal Analysis.* New York: Wiley.

Clark, J.E. (1984). Where the chips fall: Stone tool manufacture and debitage disposal among the Lacandon Maya. Annual Meeting, Society for American Archaeology. Portland, Oregon.

Daniels, R.B., Gamble, E.E., Bartelli, L.J., and Nelson, L.A. (1968). Application of the point count method to problems of soil morphology. *Soil Science* **106,** 149–152.

Dunnell, R.C., and Stein, J.K. (1989). Theoretical issues in the interpretation of microartifacts. *Geoarchaeology* **4,** 31–42.

Fisk, H.N. (1944). *Geological Investigations of the Alluvial Valley of the Lower Mississippi River.* Mississippi River Commission Publication, No. 52, Vicksburg, Mississippi.

Fladmark, K.R. (1982). Microdebitage analysis: Initial considerations. *Journal of Archaeological Science* **9,** 205–220.

Folk, R.L. (1980). *Petrology of Sedimentary Rocks.* Austin: Hemphill, 184 pp.

Galehouse, J.S. (1971). Point counting. In R. Carver, Ed., *Procedures in Sedimentary Petrology,* pp. 385–407, New York: Wiley.

Gurley, P.D. (1979). *Soil Survey of Dunklin County, Missouri.* Washington, D.C.: Soil Conservation Service, 145 pp.

Hassan, F.A. (1975). Geology and geomorphology of the Ain Misteheyia locality. In *The Prehistoric Cultural Ecology of Capsian Escargotieres,* by D. Lubell, J.-L. Ballais, A. Gautier, F.A. Hassan. *Libyca* **23,** 60–70.

Hassan, F.A. (1978). Sediments in archaeology: Methods and implications for palaeoenvironmental and cultural analysis. *Journal of Field Archaeology* **5,** 197–213.

Hull, K.L. (1987). Identification of cultural site formation processes through microdebitage analysis. *American Antiquity* **52,** 772–783.

Krinsley, D., and Donahue, J. (1968). Environmental interpretation of sand grain surface textures by electron microscopy. *Geological Society of America Bulletin* **79,** 743–748.

Lewarch, D.E., and O'Brien, M.J. (1981). The expanding role of surface assemblages in archaeological research. In M.B. Schiffer, Ed., *Advances in Archaeological Method and Theory Vol 4.,* pp. 297–342, New York: Academic Press.

Patterson, L.W. (1983). Criteria for determining the attributes of man-made lithics. *Journal of Field Archaeology* **10**, 297–307.

Rapp, G., Jr. (1975). The archaeological field staff: The geologist. *Journal of Field Archaeology* **2**, 229–237.

Rosen, A.M. (1986). *Cities of Clay: The Geoarchaeology of Tells.* Chicago: University of Chicago Press, 167 pp.

Saucier, R. (1974). *Quaternary Geology of the Lower Mississippi Valley.* Arkansas Archaeological Survey, Research Series 6.

Schiffer, M.B. (1983). Toward the identification of formation processes. *American Antiquity* **48**, 675–706.

Schiffer, M.B. (1987). *Formation Processes of the Archaeological Record.* Albuquerque: University of New Mexico Press, 428 pp.

Skibo, J.M., and Schiffer, M.B. (1987). The effects of water on processes of ceramic abrasion. *Journal of Archaeological Science* **14**, 83–96.

Stahle, D.W., and Dunn, J.E. (1982). An analysis and application of the size distribution of waste flakes from the manufacture of bifacial stone tools. *World Archaeology* **14**, 84–97.

Stahle, D.W., and Dunn, J.E. (1984). An experimental analysis of the size distribution of waste flakes from biface reduction. *Arkansas Archaeological Survey Technical Paper No. 2,* 41 pp.

Stein, J.K. (1985). Interpreting sediments in cultural setting. In J.K. Stein and W.R. Farrand, Eds., *Archaeological Sediments in Context,* pp. 5–19, Orono: Center for the Study of Early Man, University of Maine.

Stein, J.K. (1987). Deposits for Archaeologists. In M.B. Schiffer, Ed., *Advances in Archaeological Method and Theory Vol. 11,* pp. 337–392, Orlando, Florida: Academic Press.

Teltser, P.A. (1988). The Mississippian Archaeological Record on the Malden Plain, SE Missouri: Local Variability in Evolutionary Perspective. Ph.D. dissertation, University of Washington, Seattle.

Visher, G.S. (1969). Grain size distributions and depositional processes. *Journal of Sedimentary Petrology* **39,** 1077–1106.

Weibel, E.R., and Elias, H. (1967a). Introduction to stereology and morphology. In E.R. Weibel and H. Elias, Eds., *Quantitative Methods in Morphology,* pp. 1–19, New York: Springer.

Weibel, E.R., and Elias, H. (1967b). Introduction to stereology principles. In E.R. Weibel and H. Elias, Eds., *Quantitative Methods in Morphology,* pp. 89–98, New York: Springer.

Received November 10, 1987
Accepted for publication August 15, 1988