

Computer-assisted Morphometry of Digital Images: Beyond Typology in the Morphological Analysis of the Broad Spectrum of Archaeomaterials

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Abstract

Morphometry is the science of measuring two-dimensional and three-dimensional aspects and parameters of object morphology, including size, shape, and tomography. Compared to conventional measurement, computer-assisted morphometry is exponentially faster, more accurate, precise, and efficient while providing a substantially broader spectrum of measurements of morphological parameters. Objective quantification replaces subjective, perception-based typology in the analysis of variation. Morphometric data from seed reference populations are used to study patterns of morphological variation and to assess related analytical assumptions and basic protocols. Many assumptions about the nature of seed and phytolith typology were found suspect, and examples of serious misuse of mean values in archaeobotanical analysis are brought to light. Examples of applications of morphometric analysis on other archaeological materials, such as lithic debitage and projectile points, and cement sands are also discussed.

1 Introduction

In 1690, the culmination of the life's work of the most respected British scientist and scholar of his century, the Rev. Johannus Rayus, was published. Born John Ray in 1621, the son of a blacksmith, Ray had single-handedly completed a comprehensive encyclopedia of science entitled:

The Wisdom of God manifested in the works of creation, in two parts, viz. the Heavenly Bodies, Elements, Meteors, Fossils, Vegetables, Animals, (Beasts, Birds, Fishes, and Insects) more particularly in the Body of the Earth, its Figure, Motion and Consistency, and in the admirable Structure of the Bodies of Man, and other Animals, as also in their Generation, etc. With answers to some objections. (John Ray, quoted by illustration in Greene, 1959: 18.)

Along with the title itself, Ray's concept of the nature of Nature is clearly reflected:

The Works created by God at first, and by Him conserved to this Day *in the same State and Condition in which they were first made...*(John Ray, quoted in Greene, 1959:15)

.....nature is *fixed and limited* and, as we may reasonably believe, *constant and unchangeable* from the first creation to the present day. (John Ray, quoted in Greene, 1959:134) (emphasis added)

Ray was a "Natural Philosopher," a theologian-scientist whose studies were intended to confirm theological tenets. In today's terms, Ray is a Scientific Creationist and proponent of Intelligent Design—two concepts that dominated Western Science for some 250 of the last 400 years.

The foundation of natural science at that time was anti-evolution in spite of the evolutionary theories of

scholars like Lamarck and Erasmus Darwin, the grandfather of Charles Darwin. Anti-evolution theory was the foundation of the monumental work of taxonomic classification by the Swedish naturalist, Carl von Linné, known to us by his Latin name, Carolus Linnaeus. Not all scientists of that era who espoused an anti-evolutionary, fixed-design concept were theologians or were directly influenced by religious tenets. An anti-evolution, perfect-design concept was the foundation of the successful systematic classification of vertebrate fossils by the French scholar Georges Cuvier, a rationalist and avowed atheist, known as "the Pope of Bones." More famous perhaps for his geological theories of Catastrophism, Cuvier was convinced of the constant and unchanging perfect design of each species of plant and animal.

The smallest fragment of bone, even the most apparently insignificant apophysis possesses a fixed and determinate character, relative to the class, order, genus, and species of the animal to which it belonged; insomuch that when we find merely the extremity of a well-preserved bone, we are able by careful examination, assisted by analogy and exact comparison, to determine the species to which it once belonged, as certainly as if we had the entire animal before us. (Georges Cuvier, quoted in Eiseley, 1961:86)

Cuvier...perceived...that all parts and organs of any animate being stood in a mutual relationship to one another..... The [Law of Correlation] stated that if an animal develops one or its organs in an unmistakable manner, a particular development of its other organs can be counted on. Animals with horns and hoofs, for example, invariably possess teeth adapted to vegetarianism...this correlation applied even to the smallest details. (Wendt,

Law of Correlation logic demanded “perfect design” in every member of a given species. Variation was “illogical” and could not exist in nature. Logical correlation and the absence of variation were therefore fundamental in defining a “type” to represent a species. Thus: “The type is immutable” (George Cuvier, quoted in Wendt, 1956:164).

The evolutionary theory of Charles Darwin opposed John Ray’s central concept of fixity and immutability of species. For Darwin, it is variation, not constancy, that best describes nature. Scientists today overwhelmingly favor the evolutionary paradigm, yet in those areas where morphological analysis is prominent, such as in archaeology, Ideal Design–Creationist logic continues to dominate. Only the names have changed. Intelligent Design has become “Typology,” and we, rather than a divine power, supply the designing intelligence. Typology creates generalized, subjective and simplified types to represent a natural population. The process of creating a type implicitly strips away the reality of Darwinian variation in the population which the type is supposed to represent. To disagree with the types or the typology is no longer considered blasphemy; rather, now it is a threat to our egos, to our intelligence as type designers and is often taken very personally. Nevertheless, typology is still fundamentally mired in the classification and analytical logic of anti-evolutionary creationism. A type is a virtual reduction of variation to a “fixed and determinate character.” Analysis is then focused on the arbitrary unreality rather than the real variation inherent in a population. Typology, today, is obsolete science in spite of its continued wide use as an analytical tool. By contrast, computer-assisted digital image analysis includes robust and powerful measurements of size, shape, texture, and tomography. Most importantly, it provides a quantitative method, i.e., morphometry, that permits characterization and analysis of morphological variation in the direct Darwinian sense. Morphometry characterizes objective reality.

Study of morphology is a pervasive pursuit in archaeological analysis. It can be an art based on perception as in typology, or it can be a science of measurement as in morphometry. Both are essential contributors to archaeological scholarship, but as Lord Kelvin stated, in effect, “all science is measurement.” Perception may indeed, be the beginning of knowledge since seeing what to measure is an essential first step to reach the goals of science. As John Russ has informally claimed, “If you can see it, I can measure it.” It follows from this that the more we see, the more we can measure. Computer image processing and enhancement have developed tremendously in recent years and are readily available for use in standard personal computers. It is a potent aide to increasing what we see and, as a result, what we can measure.

Virtually any category of morphological analysis in archaeology can be addressed using computer-assisted morphometry, better and faster compared to conventional methods. Targets to date vary from the mundane to the spectacular, from projectile points to microscopic phytoliths, from seeds and sand to shipwrecks. What follows is a serendipitous sampling of applications of morphometry to address specific archaeological questions and/or to explore

the nature of morphology in order to “see” aspects and characteristics of archaeological materials we might otherwise miss without rigorous quantitative measurement.

2 Morphometric Analysis in Archaeobotany

My first systematic application of morphometrics in archaeobotany was conducted in cooperation with Dr. Ferenc Gyulai, Hungary’s leading expert in seed identification. Our first test involved an assemblage of 14 seeds recovered in a funerary vessel belonging to the German Iron Age (Table 1). Previously identified only to genus, *Triticum* (wheat), the seeds were measured and compared against four reference cereal grain taxa common in the European Iron Age. Only *T. aestivum* (Roman bread wheat), was a viable match, somewhat unexpected given the marginal location of the find to the boundaries of the Roman Empire.

Table 1. Comparison of “species unknown” wheat seeds ($n = 14$) recovered from an Iron Age mortuary vessel compared to 3 reference *Triticum* sp. and one *Hordeum* sp. using ANOVA (f) Probability of Significant Difference values on selected size and shape parameters. Unknown appears to be *T. aestivum*, Roman bread wheat.

Species	Area	Length	Aspect Ratio	Roundedness
<i>T. monococcum</i>	99.96%	91.77%	100.0%	100.0%
<i>T. dicoccon</i>	99.41%	100.0%	99.99%	99.99%
<i>T. aestivum</i>	80.39%	5.3%	19.32%	78.87%
<i>H. vulgare</i>	100.0%	100.0%	99.91%	99.96%

As an aid to identification of archaeological seeds, we processed and measured Dr. Gyulai’s entire herbarium collection, constituting nearly 1400 taxa, an estimated 150,000 individual seeds and some three million measurements of size and shape—in less than eight weeks. From this we developed an initial automated computer smart system which achieves about 80% accuracy at the species level and 90% at the genus level using only 2-dimensional binary or shadow images. We are looking for an efficient method for obtaining computer-based three-dimensional (3D) measurements which, we are convinced, will prove superior to unassisted expert identification of seeds.

Meanwhile, we have used computer morphometry to address basic issues of conventional seed analysis, such as adequate sample size. Montgomery (1977) recommended using “averages of three separate measurements of 10 seeds each.” Our results proved otherwise. Histogram distribution plots for area measurements for the 10-seed standard in pine seed populations (*Pinus attenuata* and *P. echinata*) did not approach normal, bell-shaped, distributions and were poor representatives of natural populations. Populations of 50 and of more than 100 likewise did not approach normality, appearing rather more non-gaussian and typically multimodal. The problem was our assumption that seed morphology should correspond to a normal distribution

of variation. In fact, nature is not normal; rather, plots of morphological variation in natural seed populations are typically multimodal across the spectrum of botanical taxa. In addition, unlike a bell-shaped curve, locations of modes were unpredictable and mean values are not necessarily modal, in fact often were not. Reliance on mean values and bell curves misrepresent the true nature of seed populations. A fundamental question needed to be addressed: Is the mean value of a population really significant for analytical comparisons?

A population of 412 seeds obtained from a single squash gourd (*Cucurbita pepo*) was tested in increments of approximately 20 to determine an optimum, representative sample size (Figure 1). The standard of 10 was again woefully inadequate, its distribution curve and its mean value substantially different from the values of the total population it might be used to represent. Incremental increases show that statistical values and distribution curve configuration stabilize at different values (e.g., area mean at $n = 150$) but other factors at no predictable levels (Table 2).

To test significance of the mean, 50 replicate pairs from a broad spectrum of unrelated taxa were used. Collection of these seeds in different years from different locations was assumed to include environmental differences that could effect changes in seed morphology. As suggested by Montgomery (1977), size parameters should be unstable, but shape parameters should reflect close genetic control in spite of environmental differences. Again, results proved

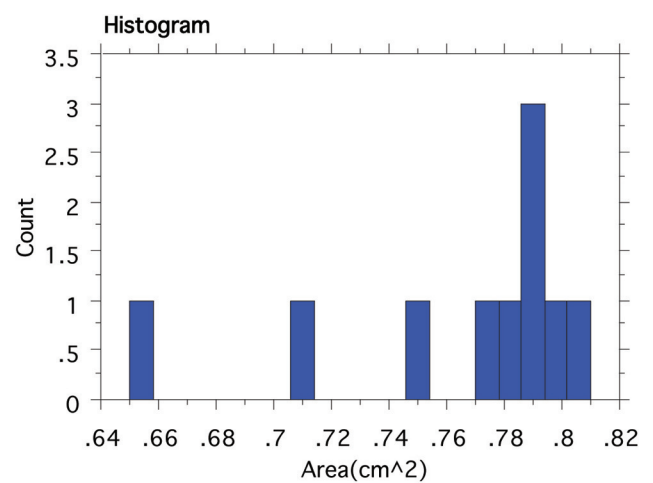
Table 2. Descriptive statistics for incremental sized populations of *Cucurbita pepo* (squash) seeds from a single gourd. Statistical values fail to stabilize at any given population increment.

N =	Mean	Std Dev	Min	Max	Var	Skew	Kurtosis
10	0.764	0.049	0.65	0.81	0.002	-1.412	0.879
20	0.77	0.064	0.65	0.92	0.004	0.03	0.312
42	0.683	0.102	0.46	0.92	0.010	0.101	-0.619
61	0.664	0.095	0.46	0.92	0.009	0.355	-0.175
87	0.641	0.094	0.44	0.92	0.009	0.378	0.229
112	0.637	0.09	0.44	0.92	0.008	0.328	0.371
137	0.63	0.085	0.44	0.92	0.007	0.417	0.736
162	0.625	0.082	0.44	0.92	0.007	0.466	1.055
188	0.624	0.079	0.44	0.92	0.006	0.435	1.104
213	0.625	0.076	0.44	0.92	0.006	0.398	1.266
238	0.625	0.074	0.44	0.92	0.006	0.385	1.326
264	0.624	0.074	0.44	0.92	0.006	0.321	1.163
288	0.623	0.074	0.42	0.92	0.006	0.215	1.126
314	0.624	0.073	0.42	0.92	0.006	0.189	1.128
338	0.625	0.072	0.42	0.92	0.005	0.12	1.132
362	0.625	0.072	0.42	0.92	0.005	0.121	1.049
389	0.624	0.071	0.42	0.92	0.005	0.133	0.989
412	0.624	0.071	0.42	0.92	0.005	0.129	0.999

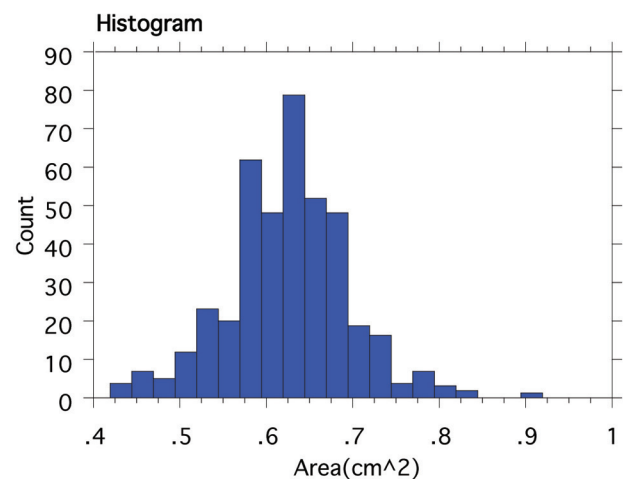
otherwise.

Eight measures of size and ten measures of shape for each case were tested by Unpaired t and verified using non-parametric Mann-Whitney tests. Of the 400 size cases tested by Unpaired t, only 7, less than 2%, provided P values of similarity above the 90% confidence level. Surprisingly, of the 500 cases of shape parameter, only 15 (3%) provided P values above 90%. Mann-Whitney results were slightly better by a trivial degree and clearly confirmed the first battery of test results. Mean shape is virtually no more stable than is mean size and both are suspect values.

Results of pair-wise comparisons of replicate populations from cucumber (*Cucumis sativus*) serve to illustrate the general condition (Table 3). Similarity of the mean was less than 1 chance in 10,000 for all eight size parameters and for five of 10 shape parameters—the best of the remaining five was a mere 24% probability. Histograms of area



n = 10
mean = .764 cm²



n = 412
mean = .624 cm²

Figure 1. Area distribution of standard population of 10 seeds compared to a population of 412 seeds from a single gourd of *Cucurbita pepo* var. Butternut (squash).

Table 3. Unpaired t-test results for similarity of the mean of eight size and ten shape parameters for replicate populations of *Cucumis sativus* (cucumber) seeds. Mean values are not similar (pop2, n = 94 ; pop 3, n = 71).

Parameter	Mean Diff.	DF	t-Value	P-Value
Area(mm ²)	2.323	163	5.256	<.0001
ConvexArea(mm ²)	2.863	163	6.43	<.0001
Perimeter(mm)	3.685	163	10.28	<.0001
ConvexPerim(mm)	12.501	163	69.164	<.0001
Length(mm)	5.856	163	66.099	<.0001
Breadth(mm)	-5.32	163	-73.744	<.0001
FiberLength(mm)	6.823	163	38.847	<.0001
Width(mm)	-2.054	163	-50.152	<.0001
FormFactor	-0.053	163	-5.506	<.0001
Roundness	0.007	163	1.486	0.1391
Convexity	-0.045	163	-6.323	<.0001
Solidity	-0.019	163	-12.359	<.0001
Extent	0.007	163	2.077	0.0393
Compactness	0.006	163	1.431	0.1545
AspectRatio	-0.035	163	-1.185	0.2377
Elongation	0.087	163	1.557	0.1214
Curl	-0.039	163	-4.164	<.0001
Fractal Dim	0.037	163	7.646	<.0001

for three cucumber seed populations exposed an anomaly (Figure 2). They did not exhibit the typical diffused, multimodal pattern. The plots, while not strictly bell-shaped, showed reduced tails at both ends and hypermodal, column-like centers that rose above the normal curve. These are more typical of populations subject to selective bias. The reason is simple: these populations are subjected to selective bias. They are agricultural domesticates subject to human, not natural, selection.

To test this observation, nine taxa of wheat (*Triticum* sp.), five domesticates and four wilds, were selected. Simple observation readily distinguishes the diffused, multimodal distribution of wild taxa from the hypermodal configuration of domestic taxa (Figure 3). However, “simple observation,” like typology, is based on perception, not quantifiable accuracy. The fact remains that domestic and wild seed populations respectively produce histograms with distinctive shapes and computer morphometry measures shapes. So, each histogram was exported to the morphometrics program for processing in the manner of any other irregularly shaped object. Three shape factors, Formfactor, Convexity, and Curl, provided measurement results that characterized shape patterns of wild versus domestic histograms. It is no accident that each of these shape factors is very sensitive to the shape of the perimeter of an object. Since a hypermodal domestic distribution is highly centered and compact, its shape is closer to that of a circle (i.e., small perimeter relative to area) and produces relatively higher measurement values. A wild multimodal distribution is more diffused with a more irregular perimeter yielding relatively lower measurement values. To simplify the results, the three

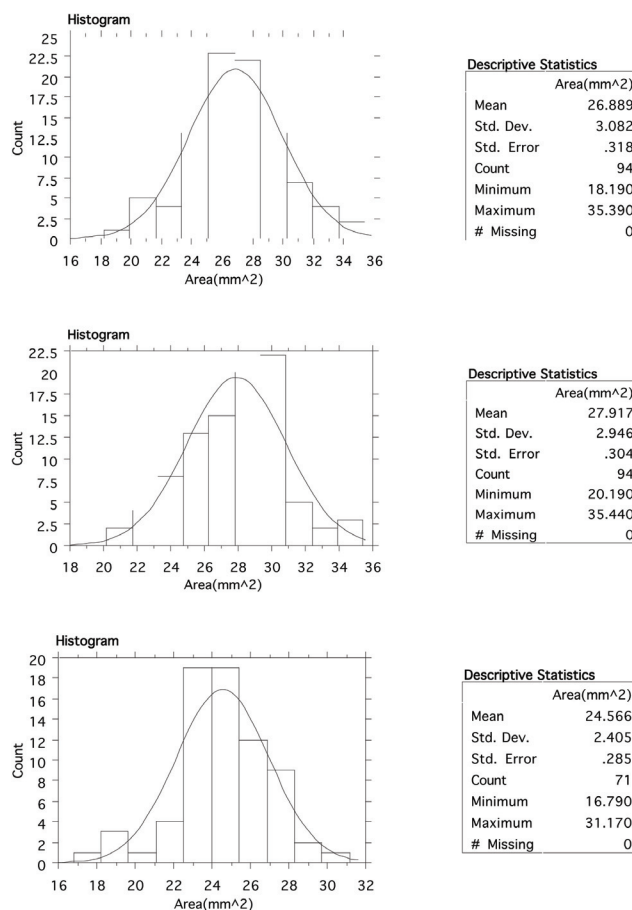


Figure 2. Area distribution for replicate seed populations of *Cucumis sativus* (cucumber). All are near normal differing from configuration of wild seed populations.

values were added together to create a single index value, herein named “RGiD”—the Rovner-Gyulai Index of (seed) Domestication. It is gratifying to note that all five domestic wheat taxa have tightly clustered RGiD values between 142 and 147, whereas the four wild populations have much lower, distinct values. It is interesting also to note the difference between tight clustering of domestics and the more varied results evident in the wild populations. This may again directly reflect the nature of Darwinian variation.

Morphometric measurement of the configuration of morphological variation was sensitive to the area size differences of the distributions between wild and domestic wheat seed populations. However, conventional descriptive statistics proved to be insensitive to the difference (Table 4). Mean values, variance, and standard deviations all overlapped, failing to distinguish wild from domestic populations. No statistical test seemed to be appropriate to measure the differences. Indeed, mean values and statistical tests are not universally appropriate in describing the configuration of archaeological populations, as in the case of fractal geometry.

Fractal geometry is the study of the form and structure of complex, rough, and irregular phenomena. In the past, many fractal patterns were mistakenly treated as if they were non-fractal. In such cases, the patterns have typically been analyzed using conventional statistics, which often assume that the variation in the pattern is caused

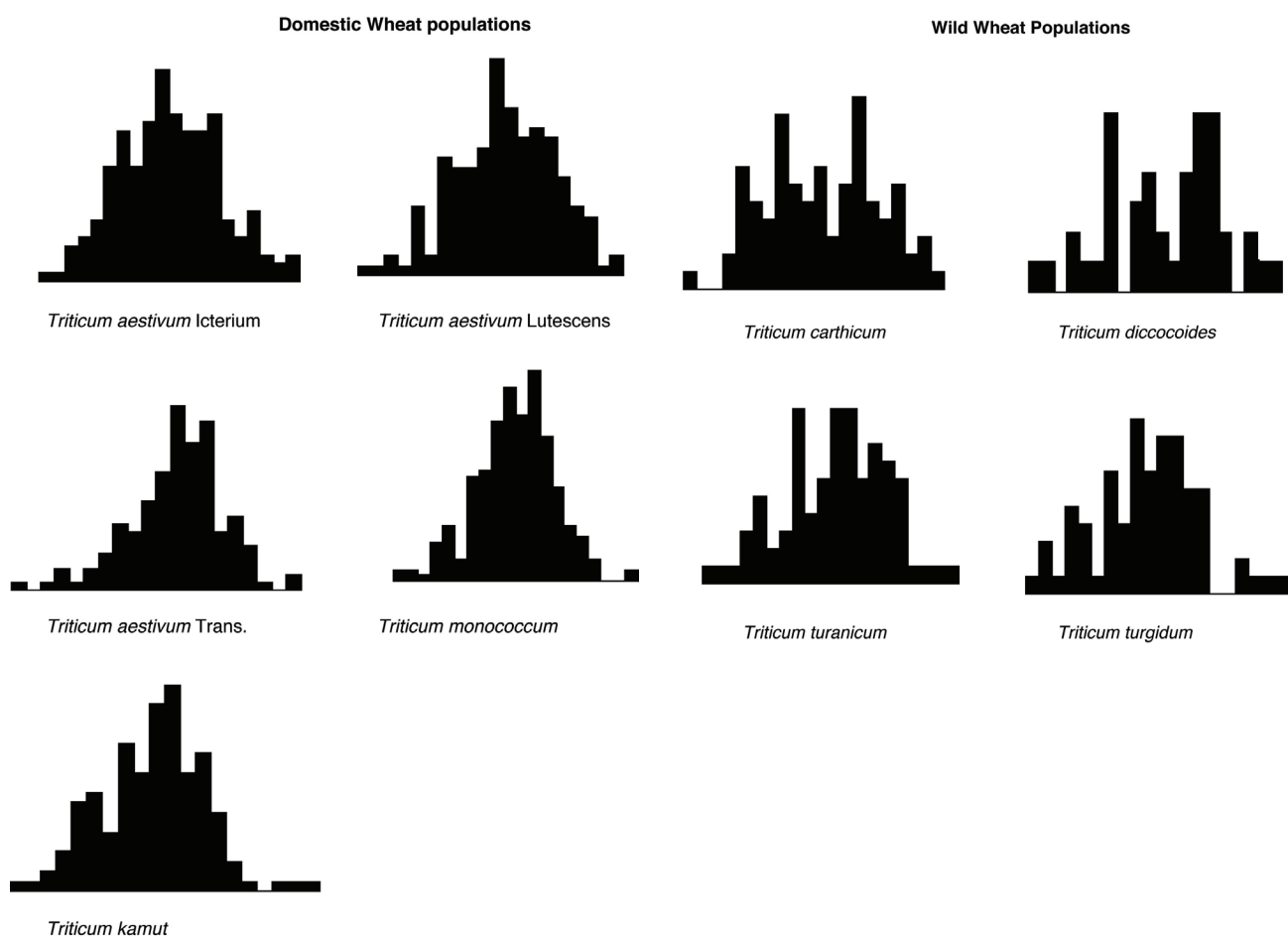


Figure 3. Configuration of area histograms of 9 seed populations of *Triticum* (wheat), 5 domestic and 4 wild. Note near normal configuration of domesticates compared to multimodal configuration of wild taxa.

by normally distributed (Gaussian) effects. When the patterns are really fractal, classical statistical modeling yields faulty results that do not properly characterize the data. Not only are the estimates or predictions made using conventional parametric statistics relatively inaccurate, but worse, they are wrong more often than the errors associated with their parameter estimates would indicate. (Brown et al. 2005:40)

This is not to suggest that seed size distribution is (or is not) fractal. However, it appears that morphometry and conventional statistics were not measuring the same morphological configurations and reliance on conventional statistics alone obscures significant observations that can be made from the data.

We are anxious to conduct systematic testing and application of RGiD, especially with archaeological assemblages. If it proves valid, it will be more than a measure of domestic versus wild seed populations. Assuming the transition to domesticated form occurred over a substantial period of time, archaeological seed assemblages, carefully collected and dated, could be used to trace the transition from multimodal to hypermodal configuration, tracking the process of domestication itself. Thus, RGiD values might be used to determine the rate and duration of the domestication process through time. Moreover, there is every reason to expect that morphometric analysis can be productively applied to

a broad spectrum of organic proxies, plant and animal, in archaeology and related sciences. This is a morphometric application. There is little likelihood that typology could reveal it, much less track it. As with the uncritical use of conventional parametric statistics, analytical comparisons using mean values can likewise obscure reality and lead to inaccurate results and conclusions.

Perhaps the best—or worst—example of misuse of mean values in archaeobotanical analysis occurs in the analysis of microscopic plant silica particles, i.e., opal phytoliths. In the late 1980s, success in using phytoliths to differentiate domestic maize from all other wild grasses was prominently reported (Piperno 1988; Pearsall 1989; Pearsall and Piperno 1990). The protocol for maize phytolith identification was fundamentally typological, based on two arbitrary types in the “lobate” morphological group: the “bilobate” (a.k.a “dumbbell”) and the “cross,” the latter subdivided into a number of subtypes or “variants.” Variants of the cross type were selected to create a multivariate discriminant function using mean values of width measurements at 400X magnification: D.F. value = 0.8082 (mean size Var. 1) + 0.1025 (mean size Var. 6) + 0.0215 (% Var. 1) (Piperno 1988:170). Accordingly, maize provides dF values of 13.0 or greater while all wild grasses ostensibly provide dF values of less than 13.

This was applied to seven phytolith samples taken from the site of Real Alto, Ecuador, dating some 7,000 years ago

Table 4. Conventional descriptive statistics for nine populations of Triticum (wheat) seeds. Note lack of differentiation between wild and domestic taxa.

Domestic	Mean	Std. Dev.	Std. Error	Count	Minimum	Maximum	Variance	Coef. Var.	Range
<i>T. aestivum icter.</i>									
Area(mm^2)	1.52010000e+1	2.73000000e+0	1.92000000e-1	203	8.09000000e+0	2.22200000e+1	7.45200000e+0	1.80000000e-1	1.41300000e+1
<i>T. aestivum lutes.</i>									
Area(mm^2)	1.85910000e+1	2.41700000e+0	1.86000000e-1	169	1.14900000e+1	2.42800000e+1	5.84100000e+0	1.30000000e-1	1.27900000e+1
<i>T. aestivum Trans.</i>									
Area(mm^2)	1.94470000e+1	2.86200000e+0	2.31000000e-1	154	9.50000000e+0	2.69400000e+1	8.19300000e+0	1.47000000e-1	1.74400000e+1
<i>T. kamut</i>									
Area(mm^2)	2.51050000e+1	3.10700000e+0	2.62000000e-1	141	1.64600000e+1	3.51400000e+1	9.65200000e+0	1.24000000e-1	1.86800000e+1
<i>T. monococcum</i>									
Area(mm^2)	1.41020000e+1	1.92100000e+0	1.18000000e-1	264	8.20000000e+0	2.00300000e+1	3.69100000e+0	1.36000000e-1	1.18300000e+1
Wild									
<i>T. carthl.</i>									
Area(mm^2)	1.28570000e+1	2.52900000e+0	2.70000000e-1	88	6.64000000e+0	1.82600000e+1	6.39700000e+0	1.97000000e-1	1.16200000e+1
<i>T. dicoccoides</i>									
Area(mm^2)	1.57770000e+1	2.22300000e+0	3.35000000e-1	44	1.05700000e+1	2.02200000e+1	4.94100000e+0	1.41000000e-1	9.65000000e+0
<i>T. turan.</i>									
Area(mm^2)	1.71460000e+1	2.94100000e+0	3.15000000e-1	87	9.48000000e+0	2.41900000e+1	8.64700000e+0	1.72000000e-1	1.47100000e+1
<i>T. turg.</i>									
Area(mm^2)	1.22640000e+1	2.01600000e+0	2.28000000e-1	78	7.65000000e+0	1.76400000e+1	4.06600000e+0	1.64000000e-1	9.99000000e+0

to the Early Formative Period (comparable to the Early Neolithic of the Old World) (Pearsall and Piperno 1990). Three phytolith samples with values of 13.4, 13.5, and 13.7 are identified as maize, two samples with values of 13.0 are possibly maize, and two below 13.0 are assessed as wild. At the time of the study, this was presented as evidence of the earliest presence of domestic maize in the subsistence economy of South America. Today, that early date for evidence of maize in South America is an anomaly inasmuch as the earliest date for maize in central Mexico, where maize originated, is fully a thousand years younger according to direct dating of preserved remains of an ancestral variety of genetically incomplete *Zea mays* (Piperno and Flannery 2001; Benz 2001). This anomaly is resolved through scrutiny of the phytolith evidence, specifically the mean value data used to identify phytolith assemblages of domestic maize versus local wild grasses of Ecuador.

The two ambiguous overlap cases falling at the 13.0 threshold were attributed to the presence of a specific local wild grass, *Cenchrus echinatus*, commonly used as roof thatch.

Many dumbbells (sic: bilobates) observed during scanning of these samples were Variant 5/6 in three-dimensional structure, a type found only in the genus *Cenchrus*. *C. echinatus* is native to this area of Ecuador. It is one of four wild species tested having discriminant-function values that fall between the 95 percent confidence intervals for wild grasses and maize. It appears that *Cenchrus* contributed to the archaeological phytolith assemblage at Real Alto, perhaps via decay of roof thatch. Substantial contribution in this manner by *Cenchrus* easily could mask light maize occurrence resulting from decay of husks or cob residue. This may be the explanation for some soil samples falling between the confidence intervals. (Pearsall and Piperno 1990:330-331)

However, critical analysis of the data indicates questionable reliance on mean values in creating and calculating the discriminant function.

According to Piperno's own data (1988, Table 3.2), mean size data for *C. echinatus* used in this maize identifier function is readily capable of providing a high frequency of false maize results if mean values are used consistently. The *C. echinatus* phytolith assemblage value falls below 13.0 only if the mean values of the four reference populations used are conflated to a single mean value, i.e., reduction of variation to an arbitrary single value, which yields a dF value of 12.9. If the range of variation of mean values for the four Panamanian *Cenchrus* populations is used in the calculations, results vary from a minimum of 12.1, a wild identification, to a high of 13.4, well into the range of false maize identification. As incontrovertible evidence of the failure of mean values to provide accurate results, a single Belize *Cenchrus* replicate (Piperno 1988, Table 3.2) gives a false maize value of 13.9, larger than all of the three values of the Real Alto phytolith populations identified confidently as maize. The fossil populations from Real Alto are individual populations compared to an arbitrary "mean of the means" reference standard. As a result, virtually all "above

average" individual fossil populations will yield false maize values. In fact, calculating the "mean of the means" of the dF values for the seven Real Alto fossil populations yields, coincidentally, a value of 12.9, identical to the mean of the mean values for the four reference populations. The phytolith evidence for the presence of maize at early Real Alto, Ecuador, based on misused mean values is wrong. This isn't maize, it is the early history of roof thatch in ancient America which readily resolves the anomalous dating problem for maize origins and distribution.

The procedures used in the 1990 phytolith study were rendered suspect even prior to its publication in the first and only morphometric study of maize phytoliths published the year before (Russ and Rovner 1989). Morphometric clustering demonstrated a high probability distinction between the two categories of bilobates and crosses. A blind test was created consisting of five unnamed phytolith assemblages, three from primitive domestic maize varieties and two from wild Teosinte varieties including Balsas Teosinte, genetically determined to be the direct wild ancestor of domestic maize. In a matter of a few hours of processing and measurement, Russ correctly grouped the two teosintes together and clearly differentiated them from the grouping of three domestic maizes. To this day, no other method has achieved such success and prior reports of success using conventional typology have been recanted by the authors (Pearsall and Piperno 1990:338).

Close examination of the morphometric data exposed some unanticipated results (Table 5). The chosen typological emphasis on cross types is perhaps easiest for the human eye to see, but proved to be the most inferior method morphometrically. Reliance on cross types alone yielded inferior

Table 5. Morphometric comparison and taxonomic identification of shot cell phytoliths from domestic maize and wild teosinte. Typological pairwise comparisons of length using ANOVA Probability of Significant Difference.

CROSSBODIES				
	T2	M1	M2	M3
T1. Mexicana	32.67%	93.37%	98.61%	95.68%
T2. Balsas		73.44%	74.91%	48.76%
M1. Harinoso			41.66%	35.50%
M2. Arrocillo				70.59%
M3. Palomero				
BILOBATES				
T1. Mexicana	32.25%		87.07%	96.90%
T2. Balsas			96.06%	96.17%
M1. Harinoso				
M2. Arrocillo				31.36%
M3. Palomero				
ALL SHORT CELLS				
T1. Mexicana	17.93%	95.92%	99.00%	96.64%
T2. Balsas		87.32%	96.18%	96.80%
M1. Harinoso			36.37%	27.87%
M2. Arrocillo				20.65%
M3. Palomero				

results compared to reliance on bilobate types alone, which was, in turn, inferior to reliance on total merged categories. In spite of Russ's obvious success using morphometry, failed typological methods remain inexplicably preferred and widely accepted throughout the phytolith and archaeological research communities while the successful morphometric procedure has been virtually ignored.

The most recent attempt to rescue the credibility of maize phytolith typology protocols using mean size values involves a new identification algorithm published in 2000 by Deborah Pearsall. It is comprised of two discriminant function formulas, derived again from maize phytolith reference mean size data which are applied to fossil phytolith populations:

Maize prediction: 3.96459 (mean Variant 1) + 0.63790 (mean Variant 6) + 21.06987 (percent of Variant 1) - 38.88593 ; and,
Wild prediction: 3.39275 (mean Variant 1) + 0.35512 (mean Variant 6) + 15.09343 (percent of Variant 1) - 25.47899 .

If the maize predictor value is higher, ostensibly it is maize; or, if the wild predictor value is higher, it is wild.

In reality, this algorithm is not new. It is a reworking of Piperno's 1988 discriminant function which Pearsall and Piperno applied in 1990 using the same three variables, the same mean values, and the same maize reference data. The reference data used to create the new predictor function which Pearsall presents in 2002 (table 5.23) seemingly as her own, i.e., without citation, is not Pearsall's data. It first appeared 12 years earlier in table 3.2 of Piperno's (1988) volume, which is often cited by Pearsall in other publications—but not cited in this instance. Comparison reveals that five maize taxa; Puya, Cateto, St. Croix, Pororo, and Canario de Ocho, with statistically superior sample sizes ranging from 115 to 200 particles, were selectively omitted by Pearsall. The lack of citation, the absence of criteria or explanation for the selective exclusion of statistically superior reference data, and the unknown effect of excluding that data raises serious doubts as to the fundamental legitimacy and validity of Pearsall's discriminant function maize phytolith predictor based on mean size values. In the absence of full disclosure, this should be sufficient to disqualify use of these formulae to assess the presence of maize in any archaeological site of any age at any location as well as in any related report of archaeological maize.

Pearsall's failure to cite the original source of this maize reference data inhibits the reader from observing that the borrowed data is improperly manipulated even further. The variable "mean of Variant 6" in Piperno (1988) is re-titled "mean of Variant 5/6" by Pearsall. Pearsall (2000:388) states simply that "Variants 5 and 6 are now combined." There is no discussion of the rationale or any explanatory criteria for combining Variants 5 and 6 which were originally separated in Piperno (1988, Table 3.2). Moreover, the combining of these two variants is applied only to the subsequent analysis of fossil phytolith populations, but not to the reference data used in deriving the identification formulae. Only the title was changed because the copied verbatim reference data for cross Variant 6 remains unchanged. In other words, Pearsall

merged the reference *titles* but neglected to merge the reference *data* for Variant 5 and Variant 6, before applying that data to fossil populations in which Variants 5 and 6 were combined. *Res ipsa loquitur*—the thing speaks for itself.

There is no need to pursue the subsequently published reports continuing to argue for the presence of early maize phytoliths based on these seriously flawed protocols, except to point out that calculations using *Cenchrus echinatus* again provide false maize identifications with this algorithm as well, along with other readily apparent mathematical manipulations supporting false results.

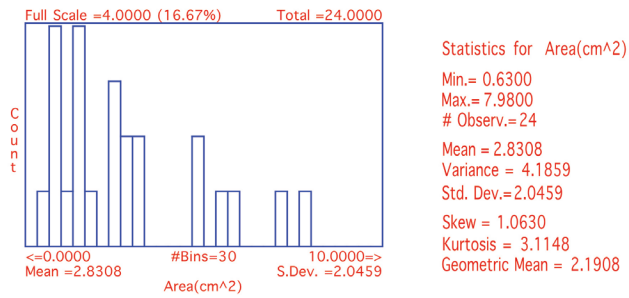
To be clear, typology is not an inherently evil system. It is a widely used method of classification sincerely employed by scholars. It remains useful to achieve efficient journalistic communication, but is it not the only method of classification and it's a poor one to use in rigorous analytical comparisons. The arbitrary and subjective nature of typology makes it vulnerable to misuse. The transparent and quantitative nature of morphometric data renders such misuse far more difficult to achieve and much more readily revealed.

3 Morphometric Study of Lithic Artifacts

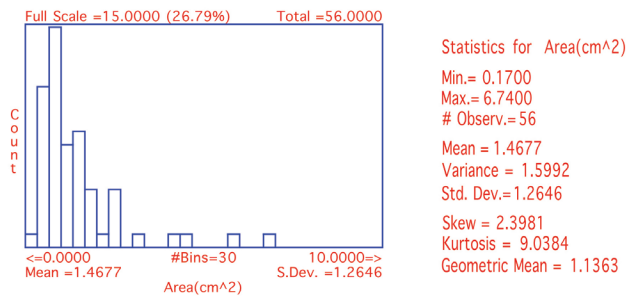
The speed, efficiency, and cost effectiveness of computer-assisted morphometry now makes it possible to do detailed morphological analysis of populations of artifacts simply too large to be addressed with conventional or manual methods. Lithic debitage is one such area. It is now possible for one person with a computer to process and measure literally thousands of objects in a day, producing literally tens of thousands of measurements of size and shape simply not otherwise feasible or even possible. The data can be enormously powerful. A straightforward example from a test excavation at a rather ordinary preceramic site (MA435) in North Carolina consists of three populations of small, end-stage, bifacial thinning flakes (Figure 4). These flakes were considered too small to measure and initially were simply counted. Computer measurement allowed detailed morphological comparison of the populations suggesting the nature and extent of behavioral information that might otherwise be lost. Significant differences are readily observed in the data. Larger flakes are well represented in Unit 2, level 2, compared to those in Feature 5. Feature 5 debitage indicated that flintknapping involved a greater emphasis on end stage production. With respect to a different stone material, i.e., quartzite versus quartz, only end-stage production flakes are present in quartzite suggesting possible differences in manufacturing, intended products, and/or local availability of these different raw materials. Such questions can be cogently addressed warranting further exploration of the site that might otherwise not be done.

Morphometric analysis of results of a replicative flintknapping experiment exposed unexpected qualifications on conventional analysis of lithic debitage. For example, in the previous case, the assumption was made that the smallest flakes were end-stage production and that larger flakes generally represent an earlier production stage in the flintknapping sequence. This is not necessarily always the case. At a

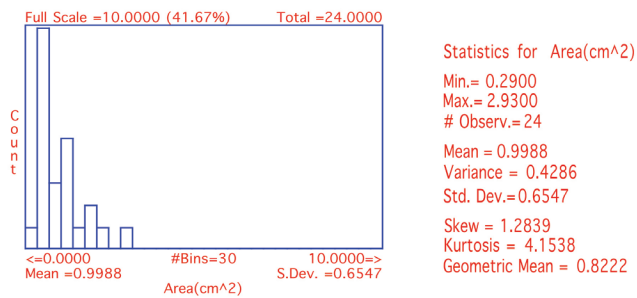
SITE 31MA435: Bifacial Thinning Flakes



Quartz flakes - Unit 2, Level 2



Quartz flakes - Feature 5



Quartzite flakes - Unit 1, Level 2

Figure 4. Morphometric area distribution of lithic debitage by context and material.

regional lithics conference, two flintknappers were giving simultaneous demonstrations in an exhibit hall where I had set up a computer system to demonstrate image processing and morphometric analysis. An impromptu test was devised to see if computer morphometry could detect differences between the sets of debitage created by the two knappers using the same material and the same stage of bifacial reduction to produce similar end products. Actually, there were two variables in the test—1) the two individual flintknappers, and 2) their respective preference for different material used as hammers: an antler billet and a hardwood billet. Each was asked to continue removing bifacial flakes that were collected. A clear difference, previously ignored, was noticed immediately. Antler billet flakes were essentially whole, similar in size and shape to the flake scar left on the objective piece. However, every wood billet flake shattered into a platform-retention flake along with several fragments and considerable “dust.”

Sets of 34 and 30 flakes respectively were imaged, processed, and measured. Only one complete shatter flake assemblage was collected (Figure 5), an error in retrospect, along with the platform-retention flakes only in all other cases. Antler billet flakes were obviously larger in area by a factor of about three times compared to wood billet

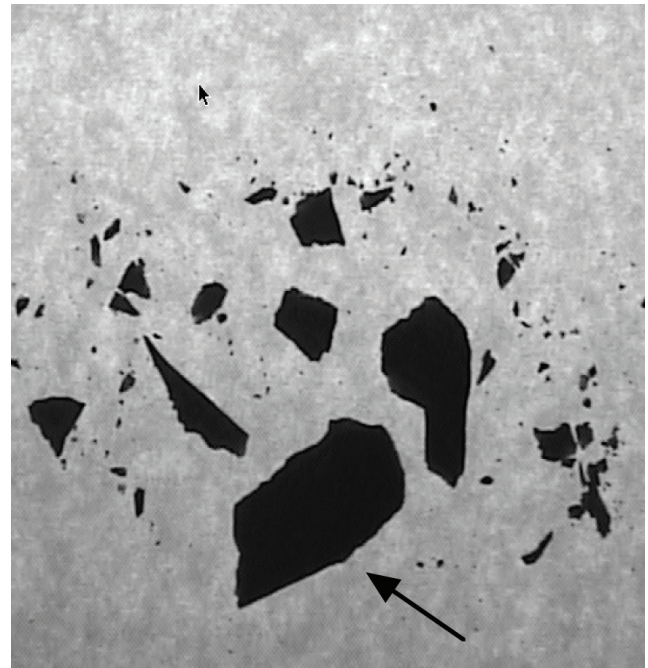
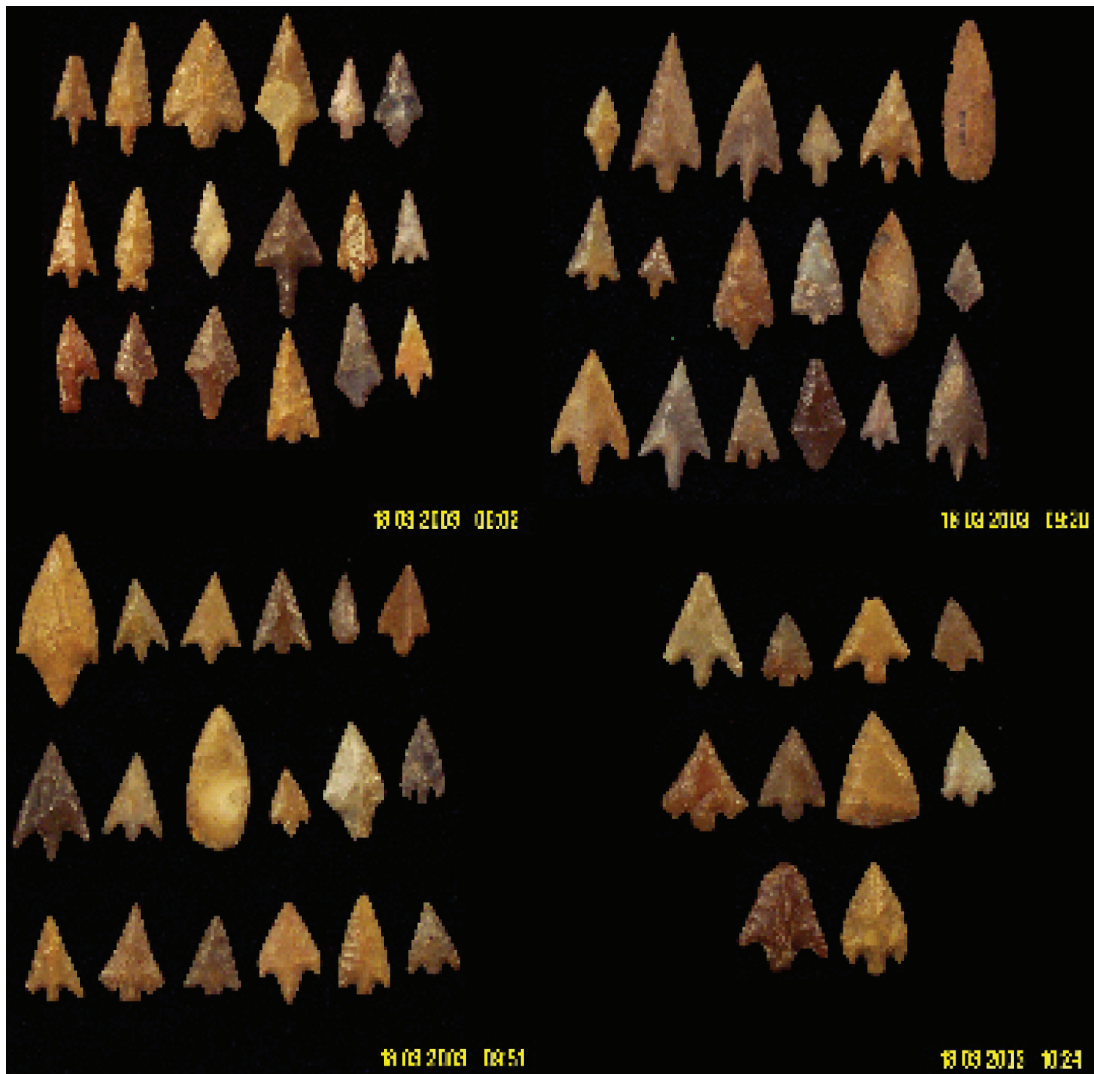


Figure 5. Shattered bifacial thinning flake struck by a hardwood billet. Arrow indicates platform retention fragment. Remainder are shattered fragments and “dust.”

Table 6. Morphometric summary of two populations of bifacial thinning flakes retaining striking platforms produced in a replication study by different flintknappers employing billet percussors of different materials. Similar lithic material and bifacial blanks of similar size and shape were used.

Descriptive Statistics -ANTLER BILLET					
	Mean	Std. Dev.	Count	Minimum	Maximum
Area (mm ²)	1809.707	1630.12	34	198.79	6557.66
Formfactor	0.666	0.06	34	0.53	0.77
Roundness	0.592	0.108	34	0.34	0.77
Convexity	0.905	0.037	34	0.81	0.94
Solidity	0.95	0.029	34	0.89	1
Extent	0.741	0.104	34	0.59	1
Compactness	0.766	0.072	34	0.58	0.88
Aspect Ratio	1.49	0.312	34	1.13	2.74
Elongation	2.012	0.3	34	1.55	2.96
Fractal Dim	1.027	0.02	34	1	1.1
Descriptive Statistics -WOOD BILLET					
	Mean	Std. Dev.	Count	Minimum	Maximum
Area (mm ²)	631.76	544.032	30	63.51	2524.88
Formfactor	0.656	0.109	30	0.24	0.78
Roundness	0.554	0.11	30	0.25	0.78
Convexity	0.911	0.065	30	0.59	0.96
Solidity	0.944	0.039	30	0.81	1
Extent	0.728	0.085	30	0.59	0.91
Compactness	0.74	0.077	30	0.5	0.88
Aspect Ratio	1.591	0.372	30	1.12	3.01
Elongation	2.172	0.669	30	1.59	4.57
Fractal Dim	1.035	0.042	30	1.01	1.25

flakes, but differences in shape were difficult to discern and subtle at best (Table 6). Formfactor, Convexity, Solidity, Extent, and Fractal Dimension were close to the same in both populations. The smaller flakes subjected to shattering tended to be slightly less round (Roundness), less compact



Figures 6. Vitry-en-C. French Neolithic Projectile Point Assemblage.

(Compactness), and slightly longer in Aspect Ratio. It seems that more attrition occurred at the lateral margins of these flakes than on the ends—an observation that may or may not have technical significance. The fact is that initial study of these two assemblages provides very little to distinguish these populations except for the obvious difference in size. The problem is that such size differences found together archaeologically would confidently be interpreted as representing a single sequence of bifacial reduction stages—clearly not the case.

Physical evidence does exist to assess the situation accurately—only hardwood billet flakes include a substantial presence of shatter fragments and dust. The computer counted more than 140 of such “items” in the one case collected, the great majority being dust particles which would never be captured in an excavation. However, shatter fragments could be captured depending on the recovery standard used. Size values readily indicated that a quarter inch mesh screen would capture 4 to 6 shatter fragments while a window screen mesh would capture 12 to 15 fragments. Ratios of shatter fragments to platform flakes might provide worthwhile insight into flintknapping techniques. This will require far more experimental work than that of our impromptu test. But, if such information is desired, there’s a

possible method to obtain it—computer-assisted morphometry. While detailed studies of debitage are rare in their own right, the irony here is that the critical information, the frequency of shatter fragments needed for an accurate assessment, is far less likely to be studied, if even collected in the first place. Study only of the platform flakes is more likely to lead to erroneous interpretation.

One of the more obvious uses of morphometry is in the classification of projectile points. Here typology is so embedded that it seems that typology itself must be tested and proven inadequate before it will be abandoned and replaced by a non-typological method such as morphometry. This contributed to the selection of an assemblage of 104 French Neolithic projectile points curated at The Field Museum in Chicago. They are from a single component of one site, yet the stylistic variation is a typological nightmare—as though styles were deliberately varied so that each hunter’s projectile was readily identified as his own unique form. Points are variously stemmed, tanged, shouldered, corner-notched, basal-notched, ovate, lanceolate, diamond shaped, and triangular, to name a few (Figure 6). Rather than attempt to create subjective and arbitrary types, it was decided to plot actual shape variation. Two shape factors, FormFactor and Roundness, were arbitrarily

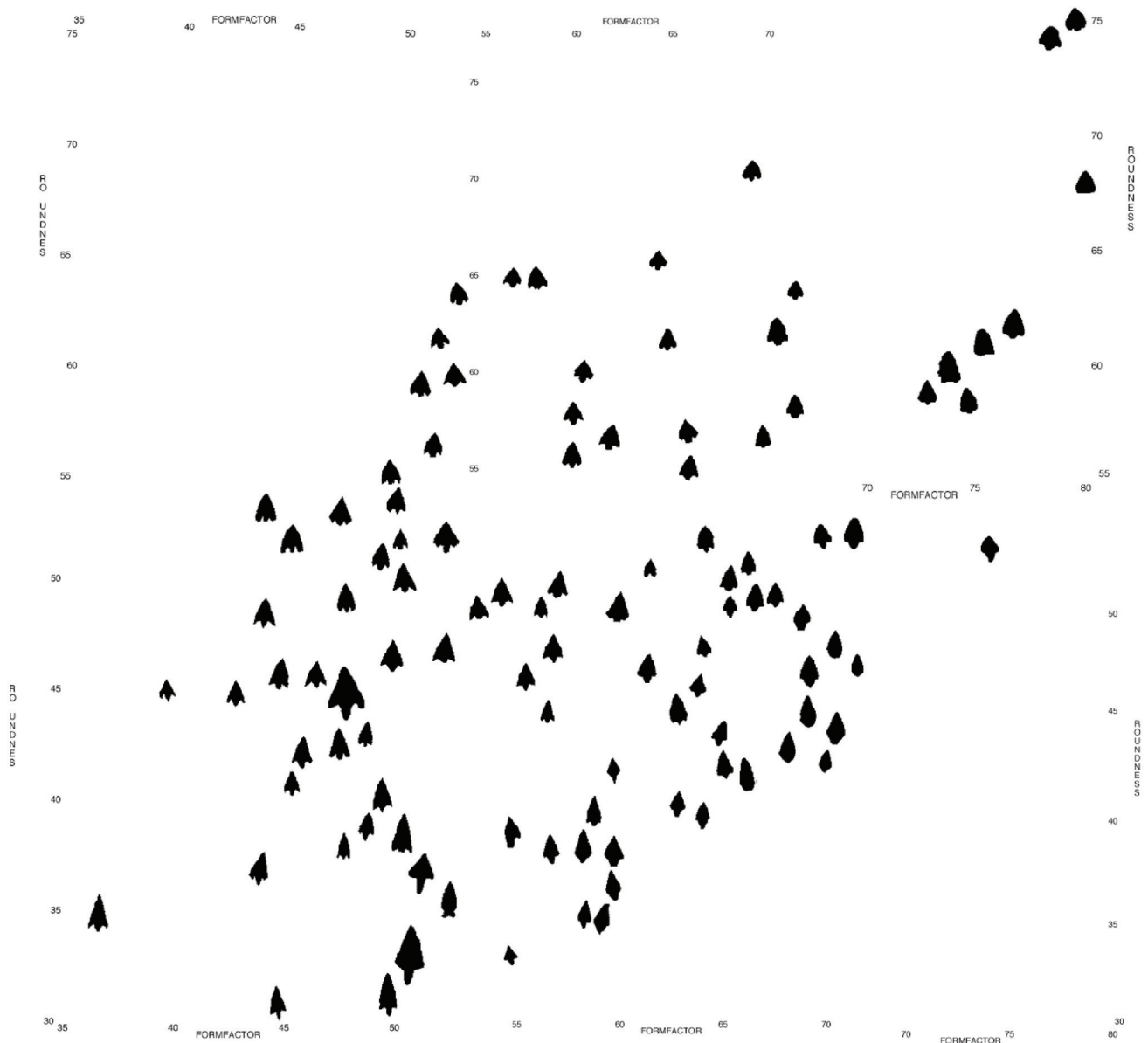
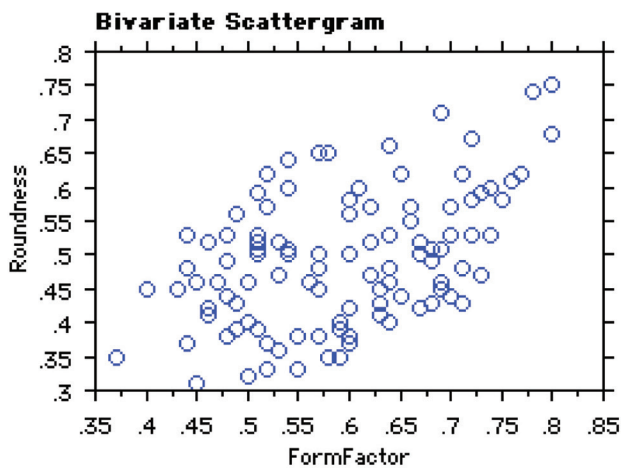


Figure 7. Bivariate plot of French Neolithic projectile point assemblage ($n=106$) based on Formfactor value (X-axis) by Roundness values (Y-axis). Plot varies coherently from “long and pointed” at lower left to “short and round” at the upper right.

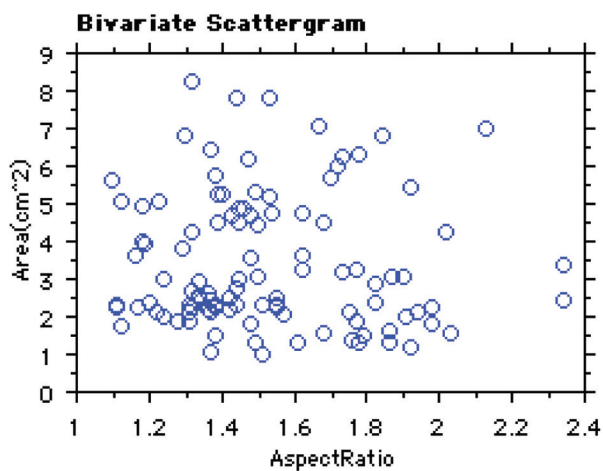
chosen, based in part on previous experience with shape variation plots. These appear to be quite effective in this case (Figure 7). Note that points with low FormFactor values have pointed, indented, and angular perimeters which plots to the left, while points with more entire perimeters and high FormFactor values plot to the right. Points with low roundness, i.e., long and narrow, plot toward the bottom, while the rounder, squat points plot toward the top. The result is a coherent plot of variation that is easily compared to any other assemblage of projectile points similarly plotted. Moreover, it is possible to measure the extent of overall clustering in the variation plot using mean nearest-neighbor distance. In this case, the value indicates moderate clustering (Figure 8). Given the constraints of projectile point form and function, random clustering is unlikely, but adherence to a narrow range of stylistic variation should provide distinctive, highly clustered values. Moderate clustering is probably the appropriate measurement even for such a high degree of variation in projectile point morphology. Similar

results, moderate clustering, were achieved using other arbitrarily chosen parameters, an Area by Aspect Ratio plot, and an Area by Roundness plot (Figure 9).

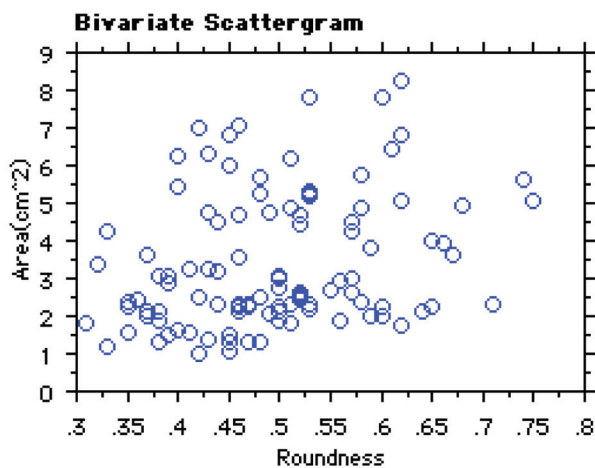
The FormFactor by Roundness plot was also tested against an existing and well established typology, William Ritchie’s typology of Brewerton projectile points from New York State (Figure 9). If the four types are morphologically and consistently distinct, a coherent plot of shapes should produce distinct clusters for each of the four types respectively. In fact, the plot indicated a far better case for continuous variation than for distinctive clustering (Figure 10). Considerable inter-fingering and overlap occurred throughout the plot. At best, there was a tendency for corner- and side-notched points to plot high and to the right, while the two “eared” types tended to plot low and to the left. Perhaps the four types should be collapsed into two types, a notched type and an eared type—for the benefit of any unrepentant typologists.



Mean nearest neighbor distance of FormFactor by Roundness = 14.81 pixels, i.e., moderately clustered.



Mean nearest neighbor distance of Aspect Ratio by Area = 15.30 pixels, i.e., moderately clustered.



Mean nearest neighbor distance of Roundness by Area = 14.10 pixels, i.e., moderately clustered.

Figure 8. Cluster plots for bivariate plots of selected morphometric parameters for French Neolithic projectile point assemblage ($n=106$), all showing moderate clustering values. Mean nearest neighbor distance value for randomness (non-clustered) = 17.58 pixels.

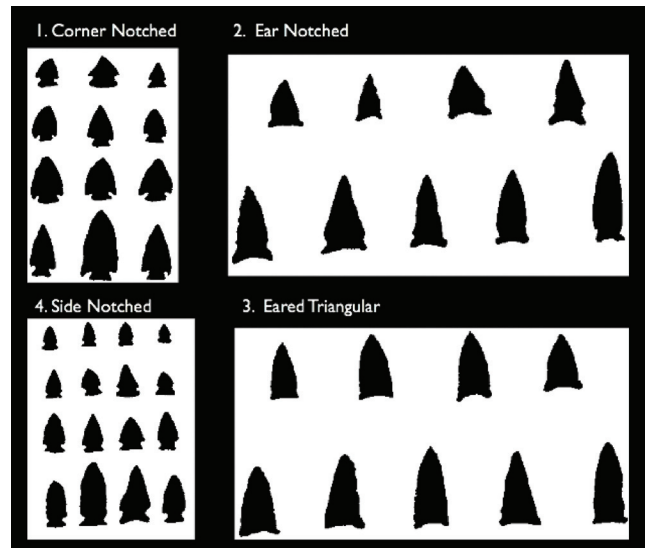


Figure 9. William Ritchie's (New York State, USA) Brewerton Projectile Point typology.

4 Morphometric Analysis of Miscellaneous Archaeological Materials

Morphometric analysis of sand aided in planning for the reconstruction of historic architecture where original materials are preferred whenever possible. In the case of tabby cement—a “home-made” mixture of sand, slacked lime, and crushed mollusc shells—to be used in the reconstruction of a Cumberland Island, Georgia (USA) cotton plantation, the source of the sand was in question (Sickles-Taves et al. 1997). Use of beach sand and/or dune sand collected along with shell from the shore was generally assumed to be the materials used. Pit sand, as recommended by the Roman builders, who used a form of tabby, was an alternate candidate. Since the plantation structures were located on the inland side of the island, levees of river-deposited sand, the source closest to the structures, were also included in the test. Samples of tabby were digested in hydrochloric acid to eliminate the lime and the shell, releasing the construction sand. Straightforward morphometric analysis provided a conclusive answer in less than a few hours of analysis (Table 7). The tabby sand was a virtual match with the river levee sand.

Table 7. Morphometric data comparing sand extracted from architectural “tabby” cement compared to sand from possible regional sources. River levee sand is the obvious match.

Mean Size Values (mm/mm ²) of Sand Grains (n = 250)			
Sample	Area	Length	Width
Beach	0.0061	0.349	0.218
Dune	0.0082	0.382	0.239
Pit	0.0103	1.313	0.850
River Levee	0.0052	0.321	0.198
TABBY	0.0052	0.319	0.197

Deterioration is a standard problem with curation, museum preservation, and historic preservation. Measuring deteriora-

1. BREWERTON CORNER NOTCHED
 2. BREWERTON EARED TRIANGLE

3. BREWERTON EARED NOTCHED
 4. BREWERTON SIDE NOTCHED

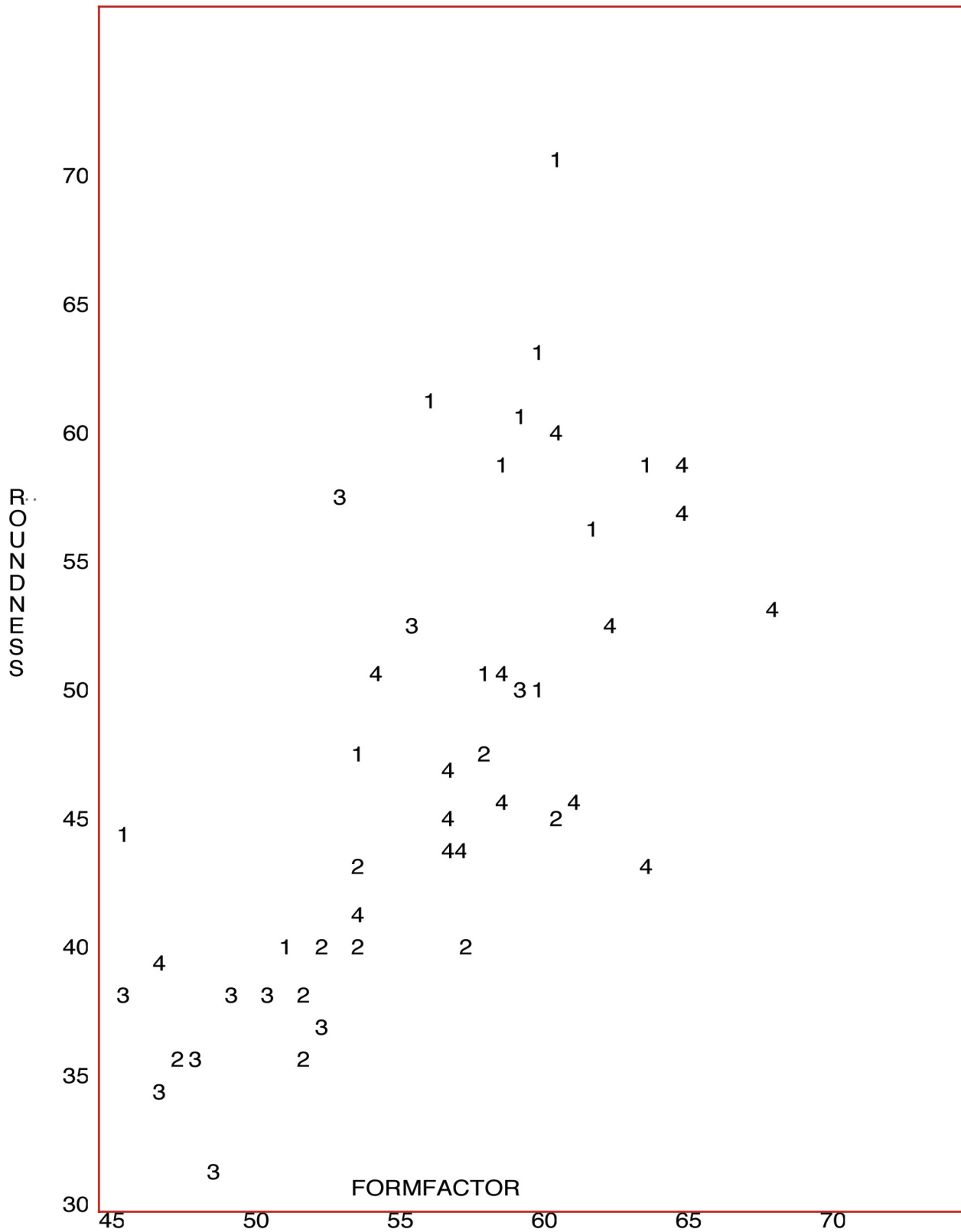


Figure 10. Bivariate plot of Brewerton projectile points based on Formfactor by Roundness. Note absence of distinct clustering according to type. Variation appears virtually continuous.

ration with morphometric tracking provides insight in the severity and rapidity of such action to enhance improved management and maintenance of many material categories, not merely to the architecture cases presented here. In the case of a tabby cement wall, comparison of measurements of a crack from photos taken ten years apart accurately and precisely calculates the extent of continued deterioration as an aid to maintenance planning (Sickles-Taves et al. 2003).

In another case of tracking preservation of vernacular architecture by Sickles-Taves et al, (2003), the “sod-dies,” houses constructed of grass sods in the tree-scarce American Great Plains are notorious for lack of long-term preservation. Using old photos, cracks again are easily measured (Figures 11 and 12)—and any preserved remnants can likewise be monitored through time.

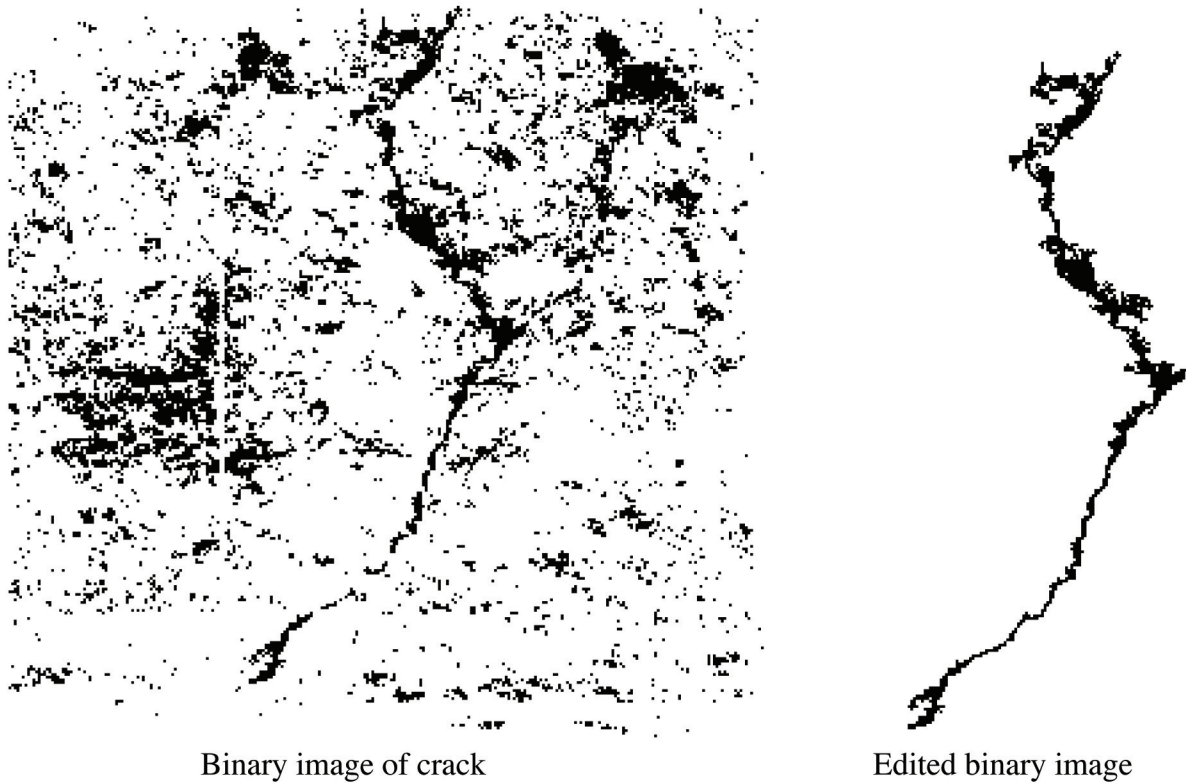


Figure 11. Morphometric measurement of increase of a crack in a tabby cement wall, Fort Dorchester, South Carolina (USA).

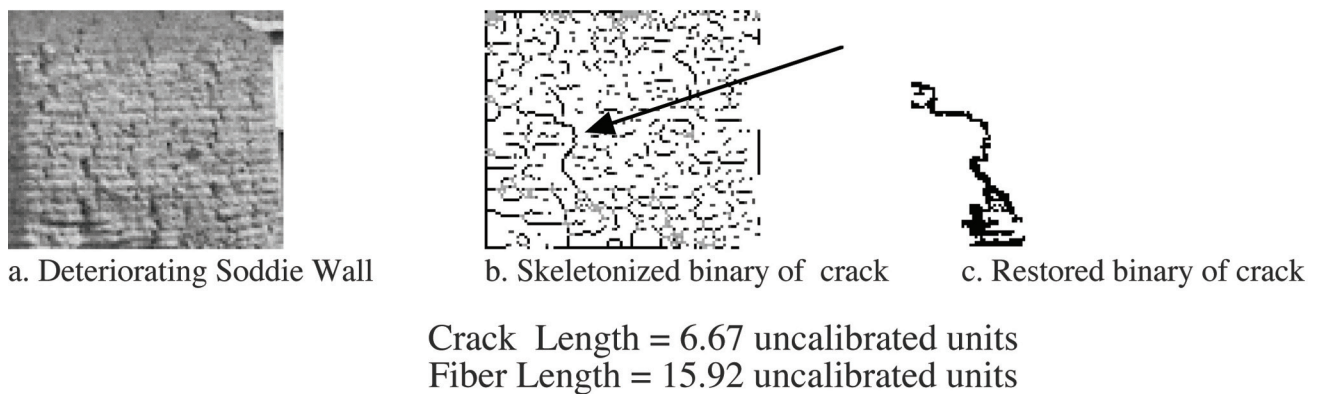


Figure 12. Morphometric analysis of architectural deterioration - measurement of wall cracks of a sod house of the American Great Plains.

5 Conclusions

Clearly, morphometric analysis is robust, precise, accurate, efficient, and effective across the spectrum of morphological analyses of archaeomaterials and contexts. Methodologically, if you can see it, it can be measured. Analytically, you may have to measure it before you can see the potential significance of it. The conclusion offered thirteen years ago at the 1993 Computers in Archaeology conference held at Stoke-on-Trent, England, remains even more relevant and germane today.

Computer image analysis and stereological morphometry should substantially replace the simpler paradigms of quantitative methods in critical areas of archaeological research. The normative type is itself typically an unreal and arbitrary stereotype, an unrepresentative fraud which should be relegated to the dustbin without regret. Likewise, it is time to stop worshipping the normative mean value and the Gaussian bell-shaped distribution curve. These icons are no longer worthy of *unquestioned* adoration in the morphological analysis of archaeological assemblages and fossil populations. (Rovner 1993)

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