I. A STATISTICAL APPROACH TO DETERMINING WHICH MEMBERS OF A GROUP OF BURIAL SITES ARE DISTINCT

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One of the major problems in archaeological analysis is the identification and interpretation of nonrandom (statistically significant) variation among archaeological assemblages from the same general cultural horizon. The Windmiller Culture sites of Central California show strong similarities in their overall cultural assemblages, but the frequency of particular types vary. If the variations within the assemblage are statistically significant, one might presumably determine their cause or causes: regional variations in the cultural tradition; cultural change through time; and/or changes in tool kit for the performance of different kinds of activity. An attempt to determine the cultural significance of the variation among the Windmiller Culture assemblages is outlined below.

Samples of projectile points are used as a basis for deciding which of the six archaeological components, all representative of the earliest cultural horizon in the Central Valley Delta region, could be members of a single statistical population. If certain assumptions are made (see below), the results allow the archaeologist to determine which sites are contemporaneous and which are separated in time. The discussion is divided into five sections: (1) description of the sites, (2) the model, (3) the method of analysis, (4) underlying assumptions, and (5) results.

Description of Sites

Five sites in the Sacramento-San Joaquin River Valley, Central California, are associated with the Windmiller Culture (Lillard, Heizer and Fenenga, 1939; Heizer, 1949; Ragir, ms.). Previous descriptions lacked clear evidence for artifact development through time or consistent trait clustering by region. Unique artifacts in each site suggest that at least some of them are not contemporary (Heizer, 1949). Different phases of the Windmiller Culture are found stratigraphically superimposed in only one site, CA-SJo-68 (Ragir, ms.). Assuming that similarity among artifact assemblages indicated a proportionately close cultural relationship between sites, we devised a computer program to compare artifact assemblages. Projectile points were used because they are the only type of artifact abundant in all Windmiller components. Furthermore, point assemblages have demonstrated temporal significance in adjacent parts of the western United States (Cressman, 1960; Butler, 1962; Lanning, 1963; Clewlow, 1967; O'Connell, 1967; Fenenga, 1953; Baumhoff and Burne, 1959). Projectile points from the five sites were typed into 18 categories according to blade, stem and base shape (Fig. 1).

The five Windmiller Culture sites are (1) CA-SJo-142, (2) CA-Sac-107C, (3) CA-SJo-68, (4) CA-SJo-56, and (5) CA-Sac-168.

1. SJo-142, the McGillivray settlement mound, stands about 1000 yards south of the Mokelumne River (SE quarter of Sec. 29, T.5N, R.5E, MDB and M, New Hope Quadrangle sheet). About six inches of fairly loose topsoil overlies an indurated gray-colored stratum about 10 inches thick. Below this stratum lie 30 inches of brownish-red mixed soil containing human burials and occupation debris. Burials are found to a maximum depth of 38 inches from the surface. The majority occur at a depth less than 30 inches and lie in shallow pits dug into the light yellow sandy clay which forms the natural base of the site. A total of 44 burials was excavated from SJo-142. Five of these were identified as intrusive Cosumnes (middle culture horizon) flexed burials lying in the gray soil horizon. In addition five cremations were probably intruded into the deposit. The projectile point sample from this site includes all specimens except those from the flexed and cremated later burials.

2. Sac-107C, Windmiller Mound, from which this culture takes its name, lies in the overflow bottom of the narrow Cosumnes River Valley (NW quarter of the NW quarter of Sec. 15, T.6N, R.6E, MDB and M, Elk Grove Quadrangle Sheet), some 12 miles north of SJo-142. The Cosumnes River originally flowed about 400 yards east of the site before man diverted it in the historic period.

   A highly compacted sandy reddish-brown clay, containing extended Windmiller culture burials, formed the natural elevation and was overlaid by a dark kitchen midden containing flexed burials and cremations from the two later culture horizons. The lowest, or C, component of the mound yielded a total of 59 Windmiller burials. Only points from known Windmiller extended burials were used in the analysis.

3. SJo-68, Blossom site, is a pure Windmiller culture site less than two miles from SJo-142. It lies 1.2 miles south of the Mokelumne River (NE quarter of the SE quarter of Sec. 32, T.5N, R6E, MDB and M, New Hope Quadrangle sheet). A loose topsoil is underlain by an extremely compacted, cemented layer about one to 1.5 feet thick. Below this "hardpan" deposit lay several feet of dark brown sandy midden. Extended burials lay throughout the deposit even in the calcareous upper level.

   A complete analysis (Ragir, ms.) of the approximately 194 burials excavated from the site led to its division into two Windmiller culture components; SJo-68A (the upper component found largely in calcareous hardpan) and SJo-68B (the lower component in the brown sandy clay midden). These components were felt to be culturally distinct and the following analysis substantiates this division. The points from each component are treated separately in the following analysis.

4. SJo-56, Phelps settlement, a pure Windmiller Culture site, is located about 1.75 miles southeast of SJo-68 and two and a quarter miles southeast of SJo-142 (NW quarter of the NE quarter of Sec. 32, T.4N, R.5E, MDB and M, New Hope Quadrangle sheet). It is situated about 900 yards west of the Mokelumne River in the overflow plain.

    The upper site deposit consisted of 12 inches of loose topsoil. Under the topsoil a calcareous "hardpan" stratum, 14 inches thick, contained a few burials. Below the hardpan a somewhat hardened or compacted refuse deposit, 28 inches thick, contained many extended burials and other evidence of occupation. Seventy-three burials were excavated from 18 to 54 inches below the surface. All but two burials were prone, fully extended, with their heads to the west in the typical Windmiller burial position. The present analysis does not include the grave goods of the flexed burials which are probably later and intrusive into the deposit.

5. Sac-168 is located on a slough near the western bank of the Cosumnes River (NE quarter of the SE quarter of Sec. 1, T5N, R5E, MDB and M on the Bruceville Quadrangle sheet) about 6 miles south of Sac-107C and the same distance north of the cluster of Windmiller sites SJo-142, SJo-56 and SJo-68) in the "big bend" of the Mokelumne River. A dark kitchen midden (Sac-168A), containing Hotchkiss burials and cultural material between 300 and 500 years old, overlay a cemented "hardpan" capping a compacted brown midden containing Windmiller burials. This Windmiller component (Sac-168B) yielded 25 burials and five features. Many of the Sac-168B burials appeared disturbed, probably a result of poor preservation, aboriginal digging in the deposit and a recent flood. Mortuary goods included only four projectile points. In order to obtain an adequate sample for the statistical analysis, we used all points found in the Windmiller component of the site (i.e., points from burials as well as dissociated ones found in the midden).[1]

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[1] Subsequent analysis isolated five phases of Windmiller Cultural development (Ragir, ms.). SJo-68, Sac-107, Sac-168 and SJo-56 each contained more than one phase. The following analysis was, however, largely substantiated, the general temporal positioning of sites being the same.

The Model

Every statistical analysis employs a formal, precisely-stated model of the real-life problem to be analyzed. In this case the model is essentially a multinomial probability law, a mathematical formula which associates a proability with every possible outcome of a particular "experiment".[2] The following is an example of the use of such a probability law.

> A number of differently colored balls are selected one at a time, at random, from an urn, and then replaced. That is, a ball is selected, its color recorded, and then it is returned to the urn before the next selection. If we know the relative proportions of different colored balls in the urn, the multinomial probability law appropriate to this experiment will answer such questions as, what is the probability of drawing five black balls? three white? two green?

The list of proportions of differently colored balls in the urn (in statistical terminology, the parameter vector) is also an important part of the description of the experiment. For statistical purposes, the parameter vector completely characterizes the urn; that is, it contains all relevant information concerning the urn. Thus, for the purpose of statistical analysis, two urns are the same if their respective parameter vectors are the same and they are different if their parameter vectors are different. Urns with the same parameter vectors tend to yield samples of similar color proportions. And, concomitantly, samples which are identical in color proportions are likely to have come from urns with similar parameter vectors.

A multinomial probability law is quite general, and can be used to describe the process by which an anthropologist comes into the possession of a collection of projectile points produced by a group of Indians and left in their burial site. The "experiment" in this case is not so easily described as that of sampling from an urn, and in fact a number of possible alternate ways of characterizing the experiment depend on such variables as personal experience, technical vocabulary, or the context in which it is being discussed. Nevertheless, the situation is analogous to sampling from an urn because the burial site, or the culture represented by the site, is like the urn in that it is completely described by its parameter vector, and the process by which an archaeologist obtains a sample of flint points is analogous to the process of sampling from the urn. This sampling process is discussed at further length below. In fact, both situations (that of the urn and that of the burial site) may be described as multinomial experiments. Point samples which are identical in the proportions of various types are likely to have come from sites with similar parameter vectors, and the sites are therefore culturally identical with respect to points.

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[2] Experiment is enclosed in quotation marks because, as we shall see, it may be used in a much wider sense that that to which one is ordinarily accustomed.

We are now in a position to apply the above terminology to the Windmiller culture sites. Assuming that the point samples from each of the six components are the results of six multinomial experiments and that each site (or living group responsible for it) is characterized by its parameter vector, we realize that the specific question becomes one of determining which of these parameter vectors are the same and which are different.

The Method of Analysis

A natural approach would be to consider each pair of parameter vectors (i.e. burial sites) separately and to perform a statistical test of the hypothesis that the two vectors in question are the same. There are, however, two serious drawbacks to this approach: (1) It is possible, for instance, to reject the hypothesis that sites one and three are the same while not rejecting the hypothesis that one and two are the same and that two and three are the same, and (2) the results of the statistical tests for the various pairs of sites are not independent of each other -- which raises the very complex question of what level of confidence is appropriate for the results of all the tests taken as a group.

A second approach would be to use some measure of the degree of association between two sites and to incorporate this measure into the statistical model. Thus, we might test the hypothesis that a particular pair of sites shows a high degree of association. This approach is subject to the second objection mentioned in the preceding paragraph; but, more importantly, one must realize that measures of degree of association tend to be very arbitrary, for many equally valid (or invalid) measures may be defined and each measure leads to a potentially different set of results.

The consideration just mentioned, plus others of a more purely statistical nature (see page 6), led us to set the problem in what is known as a decision theoretic framework. What this involves is, in effect, "listing" all the possible decisions we could make regarding the similarities and dissimilarities among all six sites taken as a group. For example, if the experiment dealt with only three burial sites, we would consider the following possibilities: Vectors 1, 2 and 3 are the same; 1 and 2 are the same and 3 is different; 1 and 3 are the same and 2 is different; 2 and 3 are the same and 1 is different; 1, 2, and 3 are all different. The five possibilities are referred to as "states of nature."

The states of nature have two particularly desirable properties: (1) They are mutually exclusive; that is, only one can hold true at a time, and (2) they are exhaustive; that is, they cover all possibilities, so one must always be true. These properties enable us to avoid the logical difficulties inherent in the pairwise comparison method previously discussed. Also, they provide a convenient framework in which to express the results of the analysis. In other words, our knowledge concerning the similarities and dissimilarities among the burial sites will be completely contained in a set of probabilities that the various states of nature are true. Perhaps one state of nature will have a very high probability (say, above .90), in which case there will be an essentially clear-cut or unequivocal "solution" to the problem. On the other hand, several states of nature may be almost equally probable, reflecting the fact that our sample data do not permit us to completely "solve" the problem, i.e., to completely distinguish the true state of nature from all of those we are considering. The latter may result from the fact that the sites overlap in time, or that they are only relatively rather than completely alike or different from each other.

The statistical device used to determine the probabilities of the various states of nature is an extent of a statistical result known as Bayes' formula. This formula enables us to use the sample data (our information on projectile points) to move from one set of probabilities for the states of nature to a second set of probabilities for the states of nature. The first set of probabilities, referred to as the prior distribution, reflects our knowledge about the states of nature prior to utilizing the information contained in the sample data. The second set of probabilities, referred to as the posterior distribution, reflects the knowledge expressed in the prior distribution modified by the additional information contained in the sample data. The information contained in the sample data is expressed in terms of probabilities determined by various multinomial probability laws.

In general, the prior distribution can be determined in virtually any way whatsoever; even purely subjective assessments of the probabilities of the states of nature may be used. Since the posterior distribution depends on the prior distribution, any reservations (doubts as to validity of criteria) that apply to the prior distribution will also apply to the posterior. In the case treated in this paper, we have made the decision to keep the results of the analysis independent of other information (for instance, carbon-14 dating) and of subjective assessments of the probabilities of the states of nature. This is reflected in our use of a so-called "uniform" prior distribution. The uniform prior distribution assigns equal probability to each state of nature. Relying solely on the sample data, the uniform prior distribution eliminates the bias which might occur if we determined on subjective criteria, which states were more probable and which were less probable.[3]

This completes the discussion of the method of analysis, except that

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[3] To be perfectly correct, we should add that within each state of nature the uniform prior is also uniformally distributed over all possible "values" of the parameter vectors. This added complication stems from the fact that each state of nature specifies only relationships among parameter vectors and not the "values" the vectors so constrained can take on (see Stromberg, 1967).

we should mention one related detail at this point. Recall that our first inclination was to approach the problem by comparing each pair of parameter vectors. This approach had considerable intuitive appeal, and one might consider whether or not there is some connection between this approach and the more general one we actually used. In fact, there is some connection; we can transform a set of probabilities for the various states of nature into a set of probabilities regarding whether both members of each of the possible pairs of vectors are the same. Consider the following example of three burial sites already discussed above. (We shall introduce here a simple and convenient notation for the states of nature, using slashes to separate distinct groups of vectors; thus 12/3 means vectors one and two are the same, three is different). Let the probabilities of the five possible states of nature be

$$\underline{P}\ (123) = .10,\ \underline{P}\ (12/3) = .50,\ \underline{P}\ (13/2) = .05,$$
$$\underline{P}\ (23/1) = .15,\ \underline{P}\ (1/2/3) = .20.$$

Then the probability that vectors 1 and 2 are the same is equal to $\underline{P}(123)$ + $\underline{P}$ (12/3) = .10 + .50 = .60. Similarly, the probability that one and three are the same is equal to $\underline{P}$ (123) + $\underline{P}$ (13/2) = .10 + .05 = .15, and the probability that 2 and 3 are the same is equal to $\underline{P}$ (123) + $\underline{P}$ (23/1) = .10 + .15 = .25. This device allows us to transform our results (in the form of a posterior distribution) into a set of probabilities that each possible pair of vectors is equal. (See section on Results.)[4]

Underlying Assumptions

The statistical analysis described above is expressed within the framework of a model, and thus the results it produces are applicable to the real-life problem under consideration only to the extent that the model is a close approximation of reality. Several major assumptions underly the model.

In order to use the results of this analysis to determine which burial sites were contemporaneous and which were separated in time, one must assume that the more two sites are separated in time, the more their respective parameter vectors will differ. In particular, this assumption implies that there is no significant cyclic behavior regarding types of projectile points. Such cyclic behavior would severely restrict the usefulness of our results for dating, although it would not affect their value for determining which sites are similar with respect to points. For instance, the length of women's skirts would not be a useful variable to use for dating samples from different periods in the twentieth century. (Richardson and Kroeber, 1940).

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[4] Note that we have avoided the problem of inconsistency discussed earlier by using a decision theoretic framework instead of testing hypotheses.

A second important assumption is that it is appropriate to describe the process by which the anthropologist acquired his sample of points by means of multinomial probability laws. While such considerations as replacement of early point types by later groups (Section 2, the Model), or regional variation in point use within the delta are probably not of major importance (Heizer, 1949; Ragir, ms.), there are certain situations that may have occurred which could seriously invalidate the results. In particular, if the persons collecting points at one of the sites had biased the sample toward certain types of points, this might render the results meaningless. In effect, this would violate the assumption of random sampling which is necessary for the application of the multinomial probability laws. It is unlikely that such a bias operates with regard to such distinctive items as points.

A third facet of the analysis, although not properly an assumption, warrants discussion here. We assume that two burial sites are different if their parameter vectors differ. However, the concept of the difference between two parameter vectors is ambiguously defined in statistics, and in fact there are a number of ways of measuring this difference, all of which have considerable validity. (This is the statistician's version of the problem of measures of degree of association mentioned earlier.) Consequently, the anthropologist should keep the fact in mind that statistical methods using various measures of the difference between two parameter vectors may yield disparate results from the same data, especially when fine distinctions are being made. Moreover, statistical results involving this ambiguity should not be reported without mentioning the statistical method used (in this case a Bayesian technique with the uniform prior distribution described on pages 6 and 7).

Finally, the statistical analysis used here distinguishes among those parameter vectors which are exactly the same and those which differ even slightly. It would probably have been more realistic to distinguish among those parameter vectors which are almost identical and those which are quite different. However, this method is not as serious a departure from reality as it might appear, because (1) in the problem treated in this paper the geographical location of the sites is such that if two sites were contemporaneous, their respective living groups probably shared a common culture with respect to points, and (2) although the analysis attempts to distinguish among those vectors that are exactly the same and those that differ at all due to the limitations of the data, it is unable to determine that two parameter vectors differ if they are sufficiently similar to one another yet not identical.

Results

Recall that the method consists, in very broad outline, of determining the states of nature (in this case there are 203), which are assigned equal probability a priori, and then applying Bayes' formula and a set of multinomial probability laws to transform the prior probabilities for the states of nature into a set of posterior probabilities which reflect the added information contained in the sample.

Point type	Site					
	SJo-142	Sac-107C	SJo-68B	Sac-168B	SJo-68A	SJo-56
1	2		3	2	35	6
2	3	8	3	2	22	3
3a	1	8	1	3	42	3
3b		6	27	1	7	
5a	8	11	8	6	5	19
5b				1	3	
5c			3			
5d			1	2		
5e	1			1	1	2
6a	1	1				
6b	1					
6c	1		3		7	7
7a	4	12	6	1	9	10
7b	2	1		1		4
7c		1		1	5	9
7d					1	
9a			1		1	1
9b			1			
Totals	24	48	57	21	138	64

Table 1. Number of identifiable points (total 352) with definite provenience from six Windmiller Culture sites.

Posterior probabilities of the various states of nature are shown in Table 2.

States of Nature[5]	Probability
SJo-142, SJo-56/Sac-107, Sac-168 SJo-68A/SJo-68B	.3022
SJo-142, Sac-107, Sac-168, SJo-56/ SJo-68A/SJo-68B	.2891
SJo-142, Sac-168, SJo-56/Sac-107/ SJo-68A/SJo-68B	.2482
SJo-142, Sac-107, Sac-168/SJo-68A SJo-68B/SJo-56	.0610
SJo-142, Sac-168, SJo-56/Sac-107, SJo-68A/SJo-68B	.0445
SJo-142, SJo-56/Sac-107/SJo-68B Sac-168/SJo-68A	.0180
SJo-142, Sac-107/Sac-168, SJo-56/ SJo-68B/SJo-68A	.0167
SJo-142, Sac-107, SJo-56, SJo-68B Sac-168/SJo-68A	.0054
SJo-142, SJo-56/Sac-107, SJo-68B Sac-168/SJo-68A	.0032
SJo-142, SJo-56/Sac-168, SJo-68A/ Sac-107/SJo-68B	.0030
Sac-107, SJo-68B, Sac-168/SJo-142, SJo-56/SJo-68A	.0029

Table 2. Posterior probabilities of the various states of nature.

The probabilities of all the other states were individually less than .003 and collectively less than .0058, statistically insignificant. These results are rather striking when one considers that a priori we assumed all 203 states of nature to be equally probable, and then when

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[5] The order in which the sites are listed is not significant. Only the grouping and separation of sites are significant.

we modified these probabilities on the basis of the information contained in the sample we found that over 99 percent of the probability had shifted to only eleven of the 203 states of nature and more than 80 percent had shifted to just three.

The posterior probabilities of the states of nature transformed into probabilities that the two vectors for particular pairs of sites were the same are shown in Table 3.

Pair	Probability	Pair	Probability
SJo-142, SJo-56	.92	SJo-142, Sac-107C	.37
Sac-107C, Sac-168B	.65	Sac-107C, CJo-56	.29
SJo-142, Sac-168B	.64	Sac-107C, SJo-68A	.05
Sac-168B, SJo-56	.60	SJo-68B, Sac-168B Sac-168B, SJo-68A	.009
		SJo-142, SJo-68B; SJo-142, SJo-68A; Sac-107C, SJo-68A; SJo-68B, SJo-68A; SJo-68A, SJo-56	.006

Table 3. The probability that point assemblages from particular pairs of sites are identical.

Given the probabilities stated above, we are able to reach a tentative ordering of sites. Interpretation of these results, however, involves the same problem of determining direction of change encountered in all seriation techniques. Assuming that SJo-56 and SJo-142 are the youngest of the Windmiller components (Ragir, ms.) one gathers that occupations at SJo-56 and SJo-142 probably overlapped. Sac-107C and SJo-168B may have overlapped in time. Sac-168B is, however, as close to SJo-142 as it is to Sac-107C, and thus is probably younger than Sac-107C. The position of the two SJo-68 components in the temporal sequence must be based on considerations other than point analysis because both components are different from all other Windmiller communities analyzed. However, the point analysis does support the hypothesis that the two SJo-68 components, SJo-68A and SJo-68B, are culturally distinct. SJo-68B is probably the oldest of the Windmiller Components (Ragir, n.d.). The SJo-68B component appears to contain fewer artifact types which continue into the later Cosumnes components. The lack of late forms of artifacts and its stratigraphic position below a younger and distinct Windmiller component support its early position in the sequence.

There is no evidence in the point analysis alone which suggests the position of SJo-68A in a chronological sequence of the known Windmiller components. Its stratigraphic position puts it younger than SJo-68B, while certain bone and shell artifacts indicate that it is at least as late as and perhaps later than Sac-107C. Ragir (n.d.) places it between Sac-107C and Sac-168B in time. Regional differences and the fact that the site is so much more completely excavated than other Windmiller sites (Ragir, n.d.) with almost four times as many Windmiller burials may account for some of the differences in the projectile point parameter vectors.

Obviously this method of point analysis cannot solve all the problems involved in the chronological ordering of sites. However, it does build a framework within which an archaeologist can define problems which may be solved with additional information.

In the light of all the evidence, the suggested ordering of the Windmiller sites should be from youngest to oldest as follows:

(1) SJo-56 and SJo-142 contemporaneous (SJo-142 may have been occupied somewhat earlier than SJo-56), (2) Sac-168B perhaps partially contemporaneous with the early part of SJo-142 and the later part of Sac-107C, (3) SJo-68A may be as young as Sac-168B, but regional differences and a major difference in sample size seem to have caused great differences in point parameter vectors, (4) The point population of SJo-68B is distinct from all other Windmiller sites. Its stratigraphic position and total assemblage suggest it is the oldest of the sites under consideration.

In writing this paper the authors experienced considerable difficulty in deciding what level of statistical knowledge could be assumed on the part of the reader. In fact, this question was never resolved. The technique presented here is one of the first attempts to approach problems of this type on a firm statistical footing and as such it should be of interest to a fairly large number of anthropologists.

The method described above has the advantage of being superior to Chi square techniques in that it is not an asymptotic result (and we are in fact dealing with small samples in this paper), and it avoids the problem of testing multiple hypotheses, which causes serious difficulties if Chi square techniques are used. For further excursions into the statistical theory behind this method of analysis and for a detailed description of how to actually calculate results, the reader is referred to John L. Stromberg's Master's thesis[6] in the Department of Statistics, University of California, Berkeley, 1967. There are presently probably only a few anthropologists with sufficient statistical background to be able to apply the method themselves.

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[6] Copies are on file in the University of California Library, Berkeley.

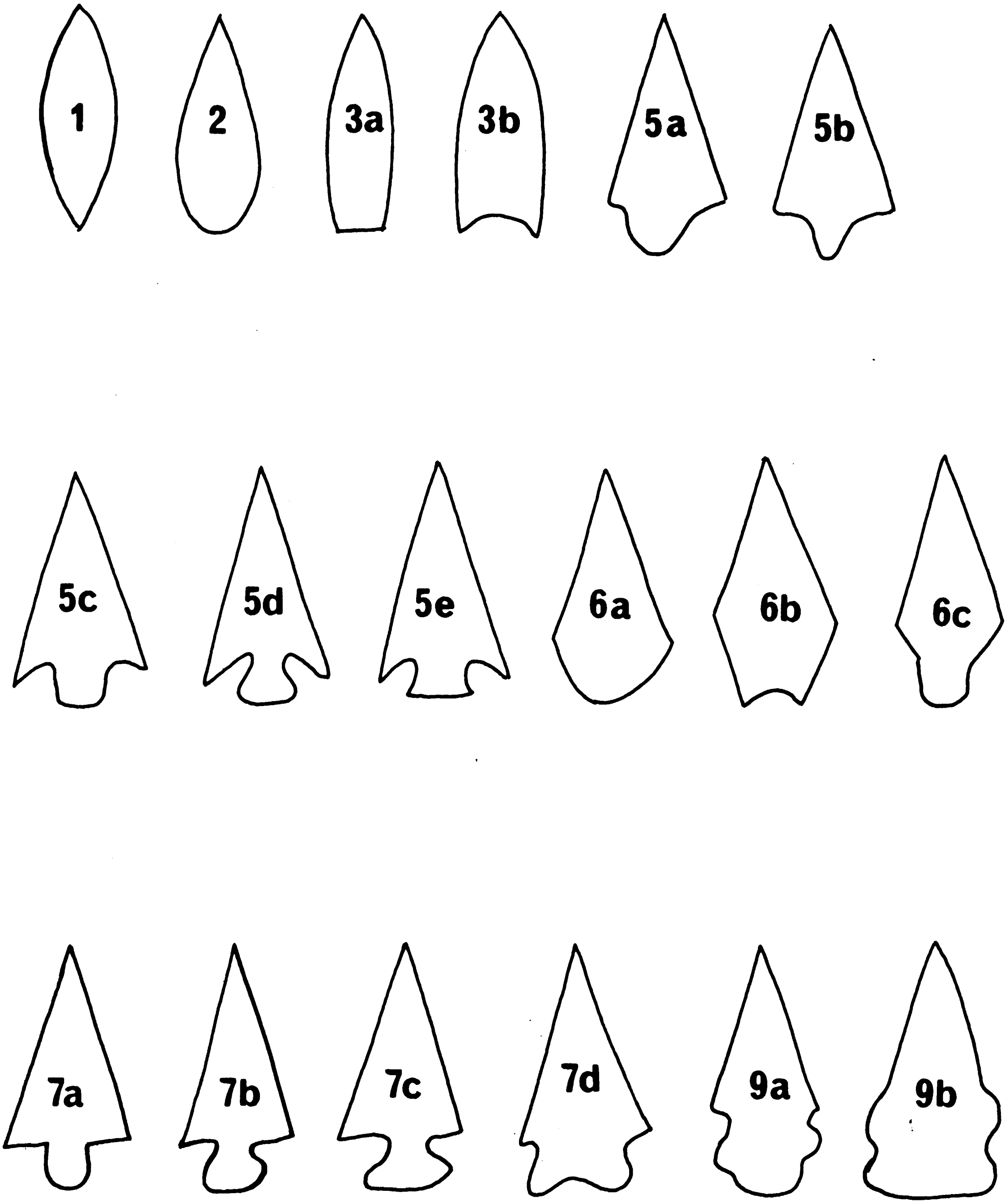

Fig. 1. Projectile Point Typology, Windmiller Culture.

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