

Artifact orientations and site formation processes from total station proveniences

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Abstract

It is well understood that the orientation of clasts within a deposit can yield information on site formation processes. Although the term clast usually refers to the natural component of a deposit, the artifactual and faunal components are also known to be sensitive to site formation processes. There are a number of ways in which orientations can be recorded and analyzed, and this paper describes how orientations can be recorded as part of piece proveniencing artifacts with a total station. After the method is described, the calculation, statistical analysis and presentation of artifact orientations are considered. The final part of the paper presents orientation data from Pech de l'Azé IV recorded and analyzed in this way. The example demonstrates the effectiveness of the total station method of recording orientations, their sensitivity to site formation processes, and the importance of using multiple methods of data analysis and presentation to assess and interpret patterning.

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1. Introduction

One aspect of fabric analysis is the study of the orientations of the clasts within it. This includes not only the natural, non-artifactual components of the deposit but also the artifacts and fauna. It is well understood that an assessment of the orientations of clasts within a deposit can be useful in assessing formation processes (e.g. refs. [2,3,5–7,11,13,16–18,20,25–29,32] etc.). In general, this notion is based on the assumption that patterning in orientations tends to indicate that the deposits have been subject to some sort of post-depositional alteration, while randomly distributed orientations are more likely to represent in situ or minimally disturbed deposits. There is, however, considerable complexity behind this simple statement,

particularly in the way in which orientations are recorded and the techniques used to present, detect and analyze the significance of their patterning. This paper describes a method to record, automatically in effect, artifact orientations while piece proveniencing them with a total station. The paper then steps through the techniques for calculating orientations from the three-dimensional coordinates produced by the total station and methods for presenting and analyzing them. Simulated data with known orientations are used to illustrate how the statistics and graphs respond to different kinds of patterns. Finally, data from the site of Pech de l'Azé IV are presented and analyzed to illustrate the method in the context of an actual site.

2. Recording artifact orientations

Artifact orientations are relatively easy to conceptualize but more difficult to define and measure. This is

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because artifacts are complex and typically irregularly shaped three-dimensional objects resting in three-dimensional space. One solution is to simplify the problem by focusing only on the orientation of the major or long (a-) axis of artifacts, which is known to be sensitive to some site formation processes (see references above). The most serious drawback to this approach is that it reduces three-dimensional objects to one dimension – a line. What this means is that a flake resting on its edge cannot be distinguished from one that is perfectly flat. On the other hand, the measurement of a long axis orientation is far simpler to operationalize in the field.

In many excavation contexts, it is standard practice to piece provenience – to record the three-dimensional coordinates for every artifact larger than a certain size. The size threshold varies among excavations as does the method for recording proveniences, though one very effective method is to record artifact proveniences with a total station [8]. While experimenting with this method at La Quina (France) and then Combe-Capelle Bas (France), it quickly became apparent that the total station's inherently high level of precision allowed additional data, aside from a single point location, to be captured. At first, Dibble and McPherron [9:433] experimented with tracing the outline of artifacts with multiple points to better replicate hand-drawn maps. While this was successful from a documentation point of view, the analytical value was limited. Later, the system was modified to emphasize the collection of orientation data with fewer recorded points (see also ref. [22:112–114]).

In order to facilitate the recording of orientations as part of the normal piece-proveniencing procedure (rather than as a separate, specialized study), a strict protocol is required to minimize errors. Our protocol is as follows. Once an artifact is exposed during excavation, the excavator must immediately make a decision about whether to also record the artifact's orientation by taking a total station measurement at both ends of its long axis vs. a single measurement in the middle. Several elements enter into this decision. First, if an artifact's position is disturbed during excavation, it cannot be used for artifact orientations. Second, the shape of an object is considered; orientations are only measured on artifacts with an obvious long axis (one dimension is substantially greater than the other two). Strict numerical limits are not employed for determining whether an artifact has a long axis (though this kind of filtering can be done with the GIS once the artifact's length, width and thickness are measured during analysis and see discussion section). Flat objects, like flakes, are better than voluminous ones like cores, and similarly, flakes that are as wide as they are long do not make good candidates whereas blades and medial long bone fragments obviously do. Third, one of the factors that affects

the accuracy of a total station measurement is how vertical the prism is held over the point to be measured. The greater the prism height, the greater is the potential error. Thus only artifacts which can be recorded in place with the shortest and, therefore, most accurate prism can be used for orientations. The shortest prism we use is 4.5 cm from the tip of the nail to the center of the prism (Fig. 1). Taller prisms are more difficult to level and can have larger errors. Even smaller and shorter prisms, often called peanut prisms, are available, and there exists reflector-less total stations that are able, under many circumstances, to record proveniences. These instruments have the potential to further increase the accuracy of total station measurements of artifact proveniences by completely eliminating error associated with prisms. Lastly, both end points must be measured directly by the total station with no hand-measured adjustments. Occasionally an artifact is too close to the walls of the excavation unit or one end is somehow obscured from view (scaffolding pipes, large rocks yet to be removed, etc.). In these instances a ruler is used to adjust or offset the total station measurement to an unobscured location. While this provides a reasonably accurate measurement of the location of an object, such measurements are not sufficiently accurate for orientation analysis.

If the artifact is judged suitable, then a total station measurement is made at each end of the artifact's long



Fig. 1. The location and orientation of an artifact is measured when a total station is pointed at a prism, mounted on a short nail, held over one end of the object.

axis. If it is not suitable, then either only one point is recorded at the center of the object or more than two points are recorded to trace its outline. In this way, all two point artifacts in the spatial database can be automatically selected by the GIS for orientation analysis. In other words, the number of points associated with an artifact provenience indicates the type of analysis that can be performed on it. This technique eliminates the need for an additional field in the excavation database to indicate whether the points are intended for orientation analysis and, therefore, eliminates a potential source of error (e.g. the excavator forgets to note that this artifact is suitable for orientations).

There are several advantages to using a total station to collect orientation data. Foremost among these are the accuracy and precision of the coordinate measurements and the speed with which it can be done. A comparison with alternative methods has not been attempted, but based on experience it is estimated that the inaccuracy of total station measurements is less than 5 mm in the combined X, Y and Z coordinates. What this means for orientation angles calculated from two end-points obviously depends on the length of the object, but as the archaeological example that follows will show, the error in the method does not appear to be great enough to obscure overall patterning. It is also likely that the large sample size that can be collected with this method helps overcome such errors. By building the collection of orientation data into the normal excavation process, as opposed to collecting a special sample of orientation data, the sample size can become quite large and other potential error factors, such as inter-excavator experience, are minimized. All of this is made possible by the speed of the total station. Recording a second total station measurement and saving the data requires approximately between 10 and 30 seconds depending on the equipment. Additionally, since the total station data are transferred directly into field computers, there is no possibility of data entry errors as there would be with most other methods of recording artifact orientations.

3. Calculating orientations

The orientation of an artifact's long axis line can be described by the geological terms bearing or trend and plunge [14:144,30:634]. Bearing is the angle, measured horizontally, of the long axis line relative to some geographic or arbitrary north, and the plunge is the angle, measured vertically, of the line relative to the horizontal plane. A plunge angle of 0 represents a line that is parallel to the horizontal plane, and a plunge angle of 90 is a line perpendicular to it. Bearings can range from 0 to 360 degrees. Note that this approach

and terminology differ somewhat from how artifact orientations are often discussed. Most often the term "orientation" is used to describe only the horizontal aspect (e.g. refs. [17:23,27:1093,29]). Often times too this measure is calculated without reference to the plunge by simply projecting the artifact's long axis on to a horizontal plane. Once the artifact is flattened in this way, an artifact with a bearing of 90 degrees will look like another with a bearing of 270 degrees (see below). These data will have a periodicity of 180 degrees, and when they are shown as 360 degree Rose diagrams, one half of the diagram is a mirror image of the other half. In what follows, the term "orientation" refers instead to the general alignment of an object in three dimensional space and the terms "bearing" and "plunge", as just defined, will be used to describe its horizontal and vertical components.

To calculate bearing and plunge from XYZ coordinates requires some geometry. Consider the artifact represented in the Fig. 2 by two points: P1 (X1, Y1, Z1) and P2 (X2, Y2, Z2). The bearing is represented by angle B and the plunge by angle P. The trigonometric function tangent can be used to calculate these angles from the two points. A tangent of an angle in a right triangle is equal to the proportion of the length of the side opposite that angle to the length of the side adjacent:

$$\tan B = \Delta X / \Delta Y$$

where $\Delta X = X1 - X2$ and $\Delta Y = Y2 - Y1$.

Once the tangent is known, the calculation of angle B itself is based on the arctangent (or inverse tangent) function. Thus, the angle is computed on the basis of two points as

$$B = \text{ArcTangent} (\Delta X / \Delta Y)$$

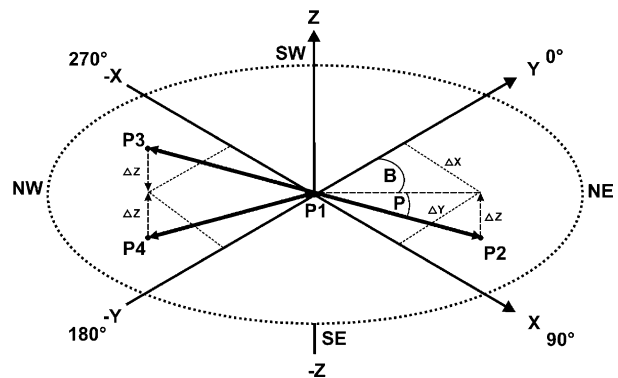


Fig. 2. Points recording the orientations of three artifacts are represented in three dimensional space. These artifacts are represented by the point pairs P1–P2, P1–P3, and P1–P4. Artifacts P1–P2 and P1–P3 have identical orientations.

There are, however, some complications in how the data are prepared for this calculation. In particular, the order in which the points are recorded will affect the artifact's bearing. In Fig. 2, the artifact P1–P3 represents an artifact with an identical bearing to P1–P2 but in this case the lowest point (P1) was measured first and the highest point second (P3). This will have the effect of reversing the signs of ΔX and ΔY and will give artifact P1–P3 a bearing 180 degrees opposite of P1–P2. Consider too the artifact P1–P4. It has identical XY coordinates to P1–P3. Only the Z differs in this case. Thus, if the Z values are ignored, P1–P4 has the same orientation as P1–P2 and P1–P3, and yet P1–P4 has a very different orientation in three-dimensional space than the other two artifacts. To capture this information and to fix the above mentioned issues, Z needs to be accounted for in the calculation. The way to do this is to always calculate bearing using the highest (or lowest) point first, in which case P3–P1 points in the same direction as P1–P2 and P1–P4 points in the opposite direction. Trying to standardize this in the field by including it in the measurement protocol is one possibility, but there will inevitably be errors that have to be corrected. Thus, the better solution is to factor this into the calculations done after the data are collected.

An example of how this can be done using a spreadsheet is provided in Fig. 3. The points in the figure are listed by row as they might come from a spatial database. Thus, two artifacts are represented with two points each, and the formulas to calculate bearing and plunge (see below) are provided. These formulas make use of several functions: ATAN2 which returns the angle in radians from the origin (0,0) to a point, DEGREES which converts the radian angle returned by ATAN2 to degrees, MOD which returns the remainder after a division by 360 in this case, and IF which provides a conditional that allows first a test of which point is higher and then the execution of one of two functions depending on the result. Note that that the functions are

shown in Microsoft Excel format, and they are described in more detail in the documentation of that program.

A few comments are merited here. First, since the ATAN2 function computes the angle from the origin to a point, the points are offset to the origin by subtracting the first point from the second (or vice versa depending on the relative elevations). Second, if this function is not available, the alternative is to use an ArcTangent function and provide the ΔX and ΔY values instead (e.g. $ATAN(\Delta X/\Delta Y)$). Third, the MOD statement is not absolutely required. However, if it is omitted, bearing angles in the range 270 to 360 will come out as negative angles from -90 to 0 . While these are mathematical equivalents, it is preferable to have angles in a range from 0 to 360 . Dividing each angle by 360 and keeping the remainder will accomplish this.

The plunge angle, P , is similarly calculated using the tangent function, though in this case the side adjacent must be calculated first. The side adjacent is the hypotenuse of the triangle (D in Fig. 2) formed by ΔX and ΔY :

$$\Delta D = \text{Square root } (\Delta X^2 + \Delta Y^2)$$

Thus the angle is

$$P = \text{ArcTangent}(\Delta D/\Delta Z)$$

Here the problem of what order the points are recorded in is easier to address because plunge angles can only vary between 0 and 90 degrees. In Fig. 2, for instance, artifact P1–P2 has the same plunge as P1–P3 even though one has a negative ΔZ and the other a positive value. In this case, taking the absolute value easily solves the problem of which point is recorded first. This has the effect of making artifact P1–P4 look identical to P1–P3, but this is in fact the case. Both of these artifacts have the same plunge but different bearings. One plunges to the southwest and the other to the northeast. To understand their orientations, the

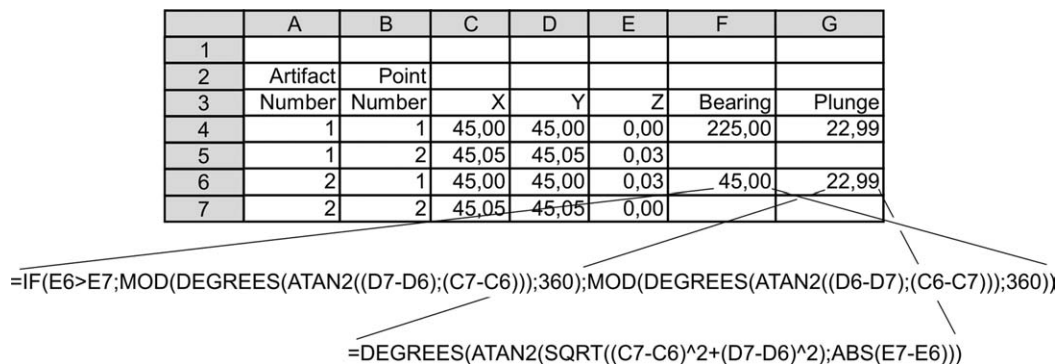


Fig. 3. An example of how to compute bearing and plunge of an artifact from a pair of XYZ coordinates using an Excel spreadsheet. The functions used in the formulas are explained in the text.

bearing and plunge of these artifacts have to be considered together in three-dimensional space. Thus, the formula for plunge becomes:

$$P = \text{ArcTangent}(\Delta D / \text{Absolute Value}(\Delta Z))$$

An example of how this can be implemented in Excel is also given in Fig. 3. Here again, the documentation explains these functions, but SQRT returns the square-root of a value and ABS returns the absolute value.

4. Presenting and assessing orientations

The two primary methods for visualizing orientation data are spherical plotting and circular histograms (Rose Diagrams). In spherical plotting, all orientation lines are positioned such that they pass through the center of a sphere and the point at which they exit the upper or lower sphere is noted on the sphere's surface (Fig. 4). The surface points from either the lower or upper hemisphere are then projected onto a two-dimensional circular diagram using one of two methods: stereographic (Wulff) or equal-area (Schmidt) [31:636]. Rose diagrams or radial histograms can then be used to visually summarize these data.

Because the resulting data are circular, standard statistical methods for summarizing patterning in these data are not applicable. There are circular statistics designed to account for the either 180 (bidirectional) or 360 (unidirectional) degree periodicity in the data. In the results that follow, a Rayleigh test of uniformity is

applied in addition to calculating the mean and standard deviation of the data. This statistic assesses whether the data are uniformly distributed or whether they have a tendency to cluster. Statistically significant results ($P \leq 0.05$) indicate that the angles are non-uniformly distributed. This statistic alone, however, does not indicate whether the data form a single mode or multiple modes. Rose diagrams are, therefore, critical to the interpretation of significant results. For data sets that show a preferential or modal orientation, a three dimensional mean vector length (L) is calculated. This value expresses the strength of the clustering in the data. Values approaching 0 are weakly clustered and values approaching 1 are strongly clustered.

Finally, Benn [1] has shown that shape indices calculated from computed eigenvalues [33–35] and plotted on a ternary diagram are useful in distinguishing fabric orientations. Bertran et al. [2] and Lenoble and Bertran [18] have followed this method and present data from experimentally derived data and from archaeological contexts. Eigenvalues represent the degree of clustering around three mutually orthogonal eigenvectors. The first eigenvector “parallels the axis of maximum clustering in the data” [1:910]. If the eigenvalue for this vector is high and the loading on the next two orthogonal vectors is low, then the data are linear, if the first two eigenvalues are roughly equal, then the data are planar (randomly oriented on a plane), and if all three eigenvalues are roughly equal then there is no preferred orientation and that data are considered to be isotropic (randomly oriented in three dimensions). This approach to orientations has the advantage of simultaneously considering the bearing and the plunge to describe artifact orientations and it is perfectly suited to the kind of a-axis orientation data that the total station method provides [1:910]. For this paper, eigenvalues and mean vector length were calculated using StereoNett Version 2.46 by Johannes Duyster. Rayleigh tests were performed with Oriana 2.00 by Kovach Computing Services. Artifact orientation calculations and Schmidt and Rose diagrams were performed with a three-dimensional GIS program authored by McPherron and Dibble.

5. Simulated data

To see how these presentation and statistical methods work and to see what kinds of patterns archaeological remains might exhibit, some simulated data sets are presented in Figs. 5 and 6 and Tables 1 and 2. In general, the assumption is that undisturbed artifacts will not be patterned and that post-depositional disturbances will act to introduce patterning into the artifact orientations (e.g. ref. [30:270–271]). Artifacts that are dropped on the ground are usually not completely

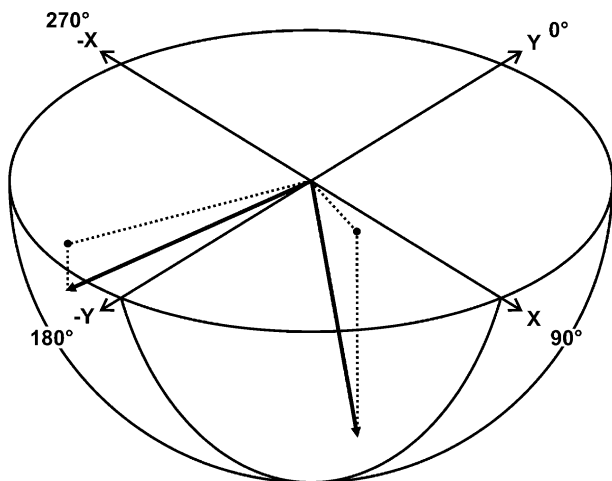


Fig. 4. The lower hemisphere of a Schmidt diagram is represented in three dimensions. To create this diagram, artifacts are positioned such that their highest point is at the center of the sphere. Where the opposite end of the artifact would then intersect the edge of the sphere is noted and then projected onto the circular top of the hemisphere. This two dimensional circular surface is a Schmidt diagram. Artifacts that are lying almost flat will plot near the edges and nearly vertical artifacts will plot towards the center.

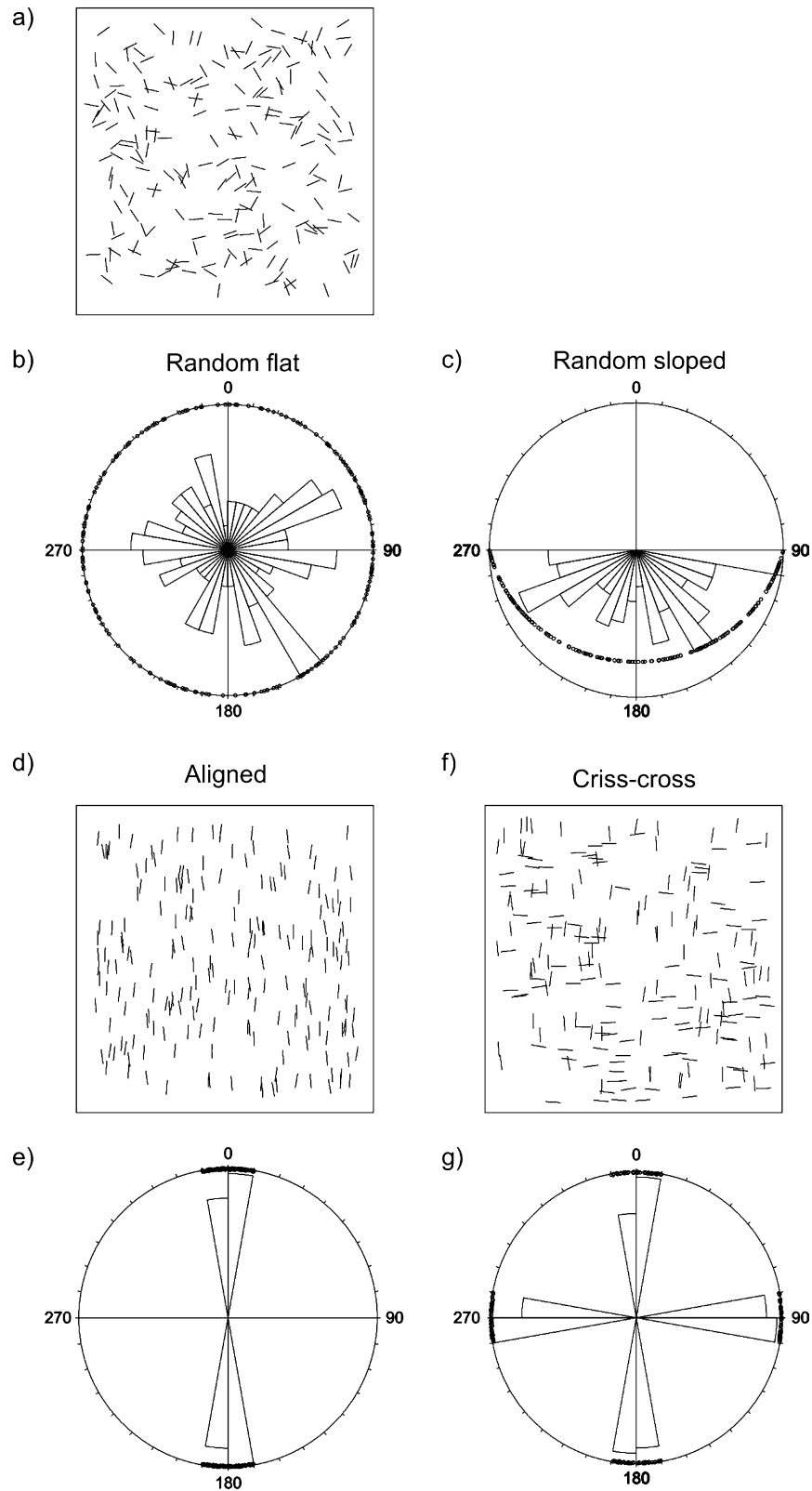


Fig. 5. Several sets of simulated data (200 artifacts each): a) Plan view of artifacts randomly oriented on a flat surface, b) Schmidt diagram of these same data, c) Schmidt diagram of randomly oriented data lying on a flat, sloping surface, d) plan view of aligned artifacts lying on a nearly flat surface, e) Schmidt diagram of these artifacts, f) plan view of artifacts aligned on perpendicular axes, and g) Schmidt diagram of these artifacts. (all Schmidt diagrams in this paper are lower half and all Rose diagrams show 10 degree intervals of bearing values).

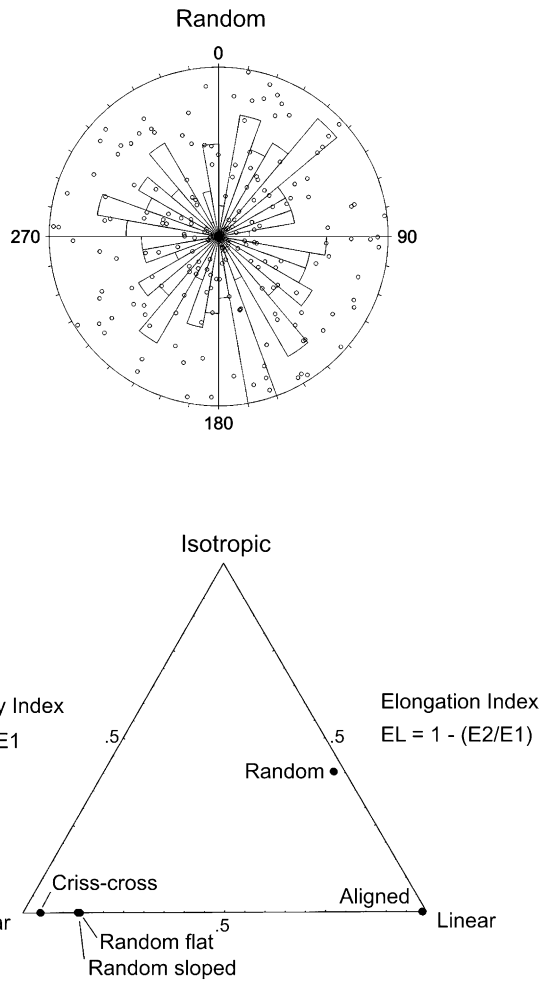


Fig. 6. Schmidt diagram of simulated data with random bearings and plunges (above) and Benn diagram for this data set and the others presented in Fig. 5 (below).

random in three-dimensional space, however. Rather, the shape of the surface on which they are dropped will structure their orientation. On a perfectly flat, perfectly horizontal surface, it is expected that artifacts will have randomly distributed bearings and their plunge will equal 0. Thus Fig. 5a simulates 200 artifacts randomly dropped onto a flat, horizontal surface. The Schmidt diagram shows the artifacts exiting the sphere at its equator and the Rose diagram within it shows the artifacts to be roughly, evenly distributed (Fig. 5b). The

Table 1
Orientation data for simulated data sets presented in Figs. 2 and 3

Data set	N	Bearing			L
		Mean	SD	Rayleigh	
Random flat	200	101.29	138.42	0.56	0.05
Random sloped	200	176.39	59.08	0.00	0.61
Random	200	246.29	154.57	0.87	0.67
Aligned	200	175.08	151.77	0.84	0.03
Criss-Cross	200	153.99	152.09	0.84	0.03

Table 2
Eigenvalues and related indices for simulated data sets

Data set	N	E1	E2	E3	IS	EL
Random flat	200.00	0.54	0.46	0.00	0.00	0.14
Random sloped	200.00	0.54	0.46	0.00	0.00	0.14
Random	200.00	0.55	0.23	0.22	0.40	0.57
Aligned	200.00	0.99	0.01	0.00	0.00	0.99
Criss-Cross	200.00	0.51	0.49	0.00	0.00	0.04

circular statistics (Table 1) support this. The Rayleigh test for bearing shows no significant patterning. On the Benn diagram, as expected, this data set plots towards the planar pole (Table 2 and Fig. 6b). Fig. 5c shows what happens when the surface on which these same artifacts are resting plunges 25 degrees at a bearing of 180 degrees. On the Schmidt diagram the artifact orientations now follow a line that represents the intersection of this 25 degree surface with the lower half of a sphere. Artifacts that are parallel to the slope have greater plunge values and plot closer to the center of the Schmidt diagram. In this case, despite the fact that the artifacts are still randomly oriented on this sloping surface, the Rayleigh test shows the data to be significantly clustered (Table 1). The Benn diagram, however, remains unaffected (Table 2 and Fig. 6b) and the data are still planar.

Figs. 5d,f show data sets wherein the artifacts are aligned. Both of these data sets simulate the extremes of the kinds of patterning that result when water flows over artifacts. In slow moving streams artifacts tend to align perpendicular to the flow with a smaller proportion aligning parallel to the flow [28]. In fast moving streams the results are reversed. The Schmidt diagrams (Figs. 5e,g) follow predictably from these data. The Benn diagram (Fig. 6b) and circular statistics (Tables 1 and 2) are less predictable. In neither case are the data statistically significantly patterned. It is clear from this example that while circular statistics, especially the Rayleigh test of uniformity, can demonstrate patterning, non-significant results do not mean an absence of patterning. Likewise, in the Benn diagram, the linear data set plots predictably at the linear pole, but the crisscross data set plots near the planar pole. The multimodality in these data are enough to give the statistical impression of randomly distributed data on a plane.

These four data sets all plot away from the isotropic pole because they vary in only two dimensions (they are on a surface). To the extent that artifacts vary from a surface they will be pulled towards the isotropic pole. Thus, the last simulated data set was created by giving 200 artifacts random bearings (0–360 degrees) and random plunges (0–90). From the Schmidt diagram (Fig. 6a) it is clear that there is no patterning in these data. Points are as likely to plot near the edges as near the center of the diagram and the Rose diagram shows an approximately uniform distribution of bearings.

Table 3
Artifact orientations from Pech de l'Azé IV

Level	N	Bearing			Plunge			L
		Mean	SD	Rayleigh	Mean	SD	Rayleigh	
1b	127	150.71	90.40	0.00	22.30	18.56	0.00	0.44
1c	26	149.54	86.04	0.06	23.74	25.29	0.00	0.42
1d	21	203.22	112.06	0.64	31.21	21.30	0.00	0.48
2	40	48.23	107.46	0.31	26.55	20.14	0.00	0.42
3a	324	166.78	107.46	0.00	24.50	23.44	0.00	0.39
3b	591	199.82	119.42	0.00	13.61	17.19	0.00	0.24
4a	312	174.21	108.63	0.00	11.43	15.32	0.00	0.23
4b	118	171.72	115.57	0.13	13.99	15.26	0.00	0.24
4c	1147	155.18	107.79	0.00	8.70	9.30	0.00	0.22
5a	772	173.97	138.72	0.11	9.21	10.57	0.00	0.15
5b	219	89.58	136.97	0.49	15.11	17.57	0.00	0.22
6a	1228	151.49	111.23	0.00	11.82	13.09	0.00	0.24
6b	1110	196.85	105.90	0.00	8.35	9.33	0.00	0.22
7	52	115.38	81.46	0.00	12.63	15.69	0.00	0.40
8	493	154.18	97.33	0.00	7.59	9.48	0.00	0.26

Interestingly, on the Benn diagram (Fig. 6b), this data set does not plot at the isotropic pole. Rather, even in these random data, these statistics show some patterning.

6. Archaeological data

The utility of this method for recording, analyzing and interpreting orientation data can be illustrated with total station data recorded during recent excavations at Pech de l'Azé IV, a Middle Paleolithic site in southwest France. Pech IV is today an open-air site at the base of an approximately 15 meter cliff face. Bordes, who excavated it in the 1970s [4], demonstrated that the site rests on a gently sloping bedrock terrace and was at the time of occupation a rockshelter. The orientation data presented here (Tables 3 and 4, Figs. 7–9) come from more recent excavations conducted by Dibble and McPherron [21,24] following the methods outlined here. These data are derived, for the most part, from an approximately 1×5 meter excavation that sampled the entire sequence. For the lower levels (Levels 6A–8) this sample covers a larger horizontal exposure (an additional 5–6 square meters). The results show a number of significant patterns.

The Rayleigh test of uniformity (Table 3) indicates that that most of the levels show preferred artifact bearings and all of them show a preferred plunge. The Rose and Schmidt diagrams presented in Fig. 7 show that in these instances, the artifacts tend to cluster in one portion of the graph (i.e. they are unimodal). The mean bearings for the significant levels are plotted in Fig. 9. They show an average bearing of approximately 164 degrees. The excavation grid at Pech IV is oriented such that 0 degrees points into the limestone cliff. If Pech IV is a collapsed rockshelter, 180 degrees would roughly correspond to the opening of the shelter. There are,

however, a number of other lines of evidence that suggest that Pech IV is actually part of a karstic system that ran at a 120 degree angle to the cliff face and that it should be classified, therefore, as a collapsed cave entrance rather than a rockshelter (Goldberg personal communication). The orientation of the mouth of this cave would have been structured by a number of factors including the angle at which the valley sliced through the karstic system and the morphology of the collapsing and retreating cliff face. Thus the fact that the artifact bearings have a tendency to fall on the 120 degree side of 180 degrees might reflect this. What is particularly interesting about these patterned bearings is that the slope of these deposits is very difficult to see or measure in the extant profiles. This is in large part due to the fact that the grid, and therefore the profiles, are not aligned with the major axis of this slope and thus capture only a minor component that is difficult to observe. The plunge data indicate that in some of the lower layers

Table 4
Eigenvalues and related indices for orientation data from Pech IV

Level	N	E1	E2	E3	IS	EL
1B	127	0.47	0.37	0.16	0.33	0.21
1C	26	0.52	0.29	0.20	0.39	0.45
1D	21	0.42	0.33	0.25	0.60	0.22
2	40	0.46	0.35	0.19	0.42	0.23
3A	324	0.40	0.39	0.21	0.53	0.03
3B	588	0.48	0.42	0.10	0.22	0.13
4A	301	0.49	0.45	0.06	0.11	0.08
4B	114	0.55	0.38	0.07	0.13	0.29
4C	1144	0.50	0.46	0.04	0.07	0.07
5A	765	0.49	0.47	0.04	0.09	0.03
5B	212	0.46	0.44	0.10	0.21	0.04
6A	1225	0.48	0.45	0.07	0.15	0.08
6B	1104	0.51	0.46	0.03	0.07	0.10
7	51	0.57	0.35	0.08	0.14	0.39
8	493	0.49	0.47	0.03	0.07	0.04

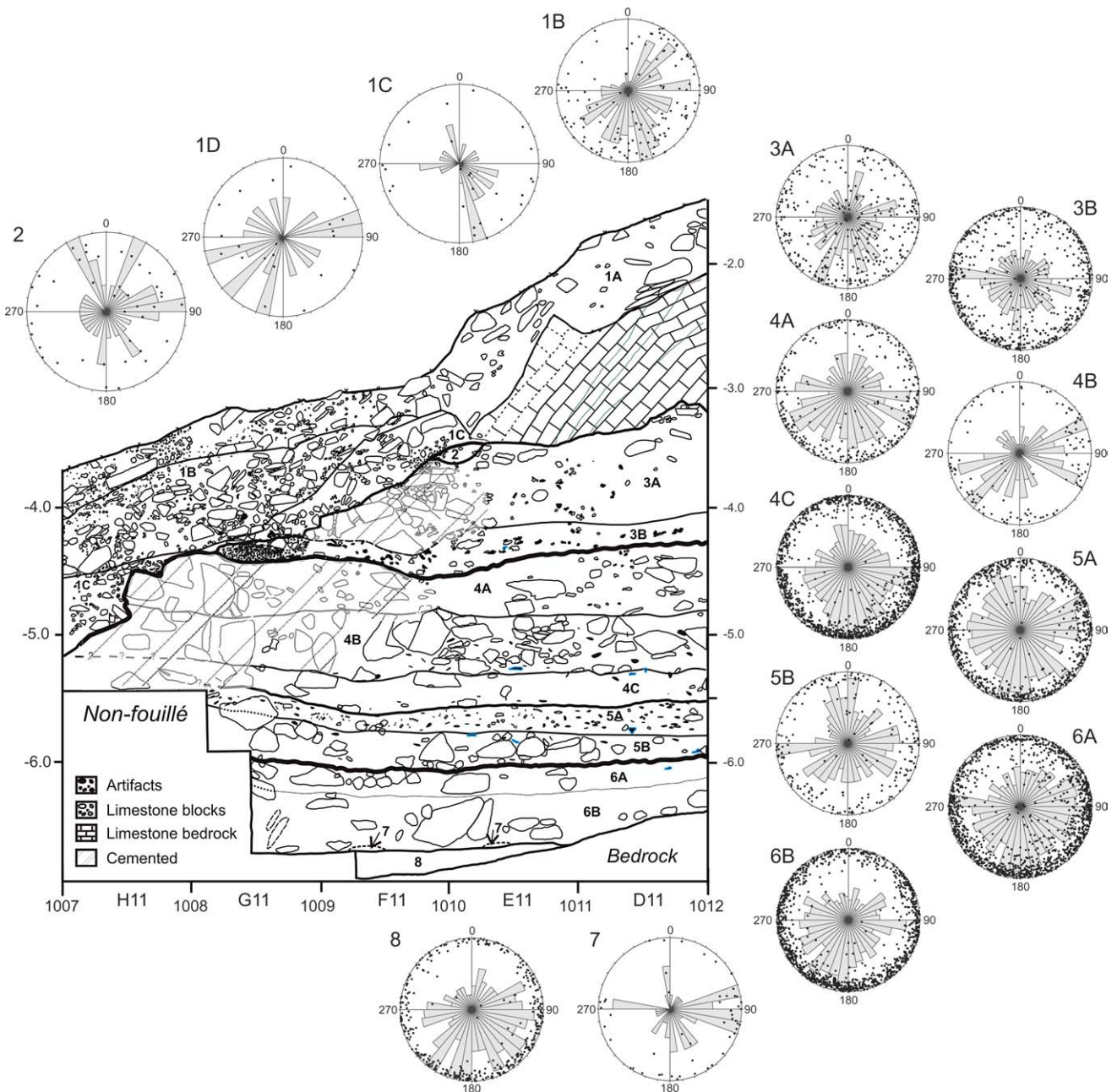


Fig. 7. Schmidt diagrams for Pech de L'Azé IV.

the slope is less than 10 degrees. What this means is that the total station is detecting patterned differences in Z that amount to less than 9 mm from front to back on a 5 cm long artifact.

The Benn diagram shows the variability in the sample and fits well with what was already known about these levels based primarily on the geology and secondarily on measures such as artifact edge damage. First, most of the levels plot towards the planar pole suggesting low levels of post depositional alteration. Second, several levels plot towards the center of the diagram and show elevated levels of isotropy. Levels 1B, 1C and 1D are

Holocene deposits which overlay the primary archaeological deposits and which are clearly slope deposits. Their eigenvalues compare favorably with published data for debris flow [1,18]. Level 2, which plots near the center of the graph, is a small pocket of material of undetermined origin that geologically looks reworked. Levels 3A and 3B are interesting because sedimentologically they are very similar but they plot in very different locations. The distinction between these two levels was based primarily on the increased density of gravels and of lithic artifacts in an approximately 15 cm thick layer at the base of the deposit (Level 3B) (Goldberg personal

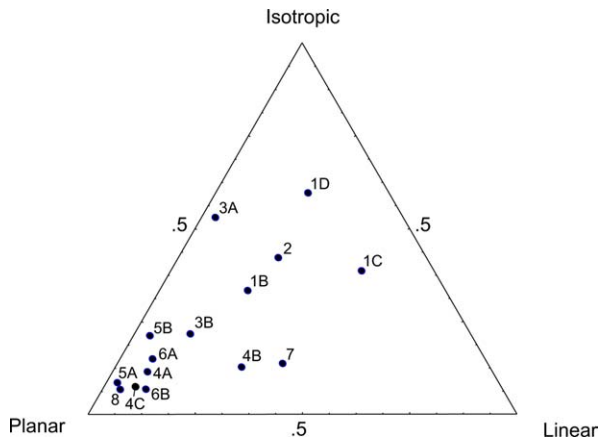


Fig. 8. Benn diagram for Pech de L'Azé IV.

communication). The transition from this deposit to the overlying 75 cm Level 3A deposit is gradual, but the orientation data clearly support this twofold division (see also ref. [23]). Level 3A is much more isotropic than Level 3B. This point is clear from the average plunge values that are nearly twice those of Level 3B and the highest for the Pleistocene archaeological levels. Level 3B too would likely plot closer to the planar pole if only Squares D11 and part of E11 were included in the analysis. There is a dip in the Level 3B deposits in Squares F11/E11 which inflates the isotropy. Thus when doing this kind of analysis, one has to be aware of horizontal changes in the depositional units, or alternatively, this type of analysis can be used to detect changes within a unit.

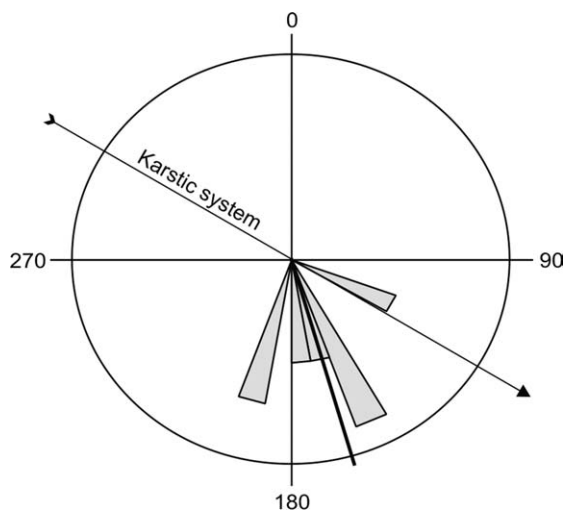


Fig. 9. Rose diagram of statistically significant bearings from Pech de L'Azé IV. Intervals are 10 degrees. The short, heavy line represents the mean bearing. The arrow across the diagram represents an approximation of the reconstructed orientation of the karstic system that formed Pech IV and would have influenced the formation and orientation of its deposits.

The remaining two distinct levels are 4B and 7. These levels have the smallest sample sizes of the non-Holocene levels, and this may be affecting their patterns. The reason the Level 7 sample is small has to do with its sedimentary context rather than the density of artifacts. It is, in fact, one of the richest layers in the site with artifacts laying often one on top the other in a very loose matrix. This loose matrix made it very difficult to excavate artifacts without altering their orientation. In addition, most of the artifacts were heavily edge damaged and broken into rectangular chunks without clear orientations. This pattern fits with the geological observations that argue for a substantial level of post-depositional alteration with cryoturbation as the mostly likely factor (Goldberg personal communication). The artifact orientations in this case are compatible with solifluction and debris flow [1,18]. Based on the geological evidence, Level 5B also has evidence of solifluction, however, in this case the artifact orientations do not reflect it. Subsequently, a closer look at the vertical distribution of damaged artifacts within this level has shown that the lower part of the level has been more affected than the upper part. Work is currently underway to divide this unit into two so that their attributes, including orientations, can be analyzed separately. Finally, Level 4B is distinguished from the levels above and below it by the large amount of roof-fall that it contains. It could be that this difference explains why 4B plots separate from 4A and 4C, though why roof-fall should make these artifacts more linear in orientation is not clear. Perhaps the linearity follows the orientation or bedding of the roof-fall.

In summary, the Pech IV orientation data show inter-level patterning that, with the exception of one level (5B), agree quite well with other lines of evidence for the site formation processes. Holocene deposits are distinct from the Pleistocene deposits within the cave and geological based subdivisions of the layers find support in the orientation data. These archaeologically derived data fit quite well with the primarily geologically derived data already published by Lenoble and Bertran [18], and they indicate that most of the levels at Pech IV show minimal post-depositional alteration. The sensitivity of the total station method to even relatively subtle changes in slope is evident in the orientation of the artifacts towards the likely entrance to the site in prehistoric times.

7. Discussion

While the data presented here show that artifact orientations derived from total station measurements are sensitive to site formation processes, the results can be difficult to interpret mainly because of issues of equifinality. As Lenoble and Bertran [18] have shown,

multiple agencies can produce very similar patterning in the data. This is primarily a problem only when assemblages plot away from the planar pole in the Benn diagrams indicating that some natural agency has introduced patterning in the data. With the exception of one solifluction data point, none of the natural processes identified by Lenoble and Bertran structure the data in a way that places it near the planar pole.

It is also clear that there is not one single approach that is always best suited to present and analyze the data. Benn diagrams appear to be generally quite effective at describing structure in three dimensions, but Schmidt and Rose diagrams are still important tools for understanding orientations. In particular, the combination of Schmidt and Rose are very effective for showing overall directionality, Schmidt diagrams show the degree of plunge by bearing, and Rose diagrams are particularly effective for identifying the modal and bimodal patterning indicative of, for instance, fluvial processes. As for the latter, it is known that the eigenvalue method on which Benn diagrams are based is not well suited to data with multiple modalities [35:1235].

The Pech IV data presented here are based on artifact (bone and stone) orientations. Bertran and Texier [2] and Lenoble and Bertran [18] present data on artifacts and on natural stones, though it is not always clear which they are using in each instance. In a study similar to the one presented here, Dibble et al. [11] collected orientations on the natural fabric of the deposit as well as on the artifacts and were able to show that both kinds of clasts were subject to the same formation processes. One area of future research would be to investigate this more systematically and to see whether these different kinds of data are equally sensitive to formation processes and to investigate under what conditions artifactual and non-artifactual data might be expected to show different depositional histories. Along similar lines, data suggest that fabric shape and size influence orientation [12,15]. As for size, 2 cm is deemed sufficient and all of the data presented here used a 2.5 cm minimum size. As for shape, Bertran and Texier [2:523] use only objects which have an elongation ratio of 1.7 or greater and Lenoble and Bertran [18:2] use a cut-off of 1.6. In the examples presented here, all data were used regardless of their elongation. For most of the stone tools, an elongation index could have been calculated from the stone tool analysis data, but in a separate study, conducted by the author, repeated efforts to correlate artifact orientations with various measures of size and shape (not limited to elongation) in the Combe-Capelle Bas total station data set [10] failed. In other words, within the set of artifacts already filtered by the excavators as having an orientation, no patterns could be found that affected orientation.

Thus, orientation data collected with a total station appear to be sufficiently precise to measure artifact orientations and produce results that fit well similar

experimentally and archaeological derived data recorded by other means [18]. On a related note, however, Bertran and Texier are correct to question the reliability of orientation recording methods. They recount, for example, an effort to derive orientation data from published drawings of artifact distributions at the Upper Paleolithic site of Pincevent, France. The resulting orientations show primary and secondary modes that align with the site grid. Given that Pincevent is considered to be an example of an exceptionally well preserved occupation surface, they [2:527] suggest that this pattern is a result of a bias on the part of the drawer to align artifacts with the grid of the paper rather than natural processes. This example is particularly instructive because of the methods used to create the site maps. Each square was photographed and then the artifacts were traced from the photographs [19:13]. It is, therefore, difficult to see how biases could be introduced into these data. On the other hand, Dibble and Chase (personal communication) found a similar problem in their attempt to collect orientation data from hand-drawn plans at the Middle Paleolithic site of La Quina, France. Despite first hand knowledge of the excavation and the acknowledged skill and experience of the excavators in this instance, Dibble and Chase found a trimodal distribution with peaks on the axes of the grid and a third peak between the two (at 45 degree intervals). In both of these examples there is the added difficulty that natural processes can create these patterns. The Pincevent pattern is what one would expect under fluvial conditions and this fits since the site was indeed buried by fluvial deposits [19:9]. At La Quina, though three modes is not the typical pattern, the levels they were investigating were at the base of the deposit where evidence of stream alteration of the deposits is present and the stream would have roughly paralleled the grid.

There is also anecdotal evidence that emulating the total station method described here by hand recording elevations at the extremities of artifacts is not sufficiently accurate. As already noted, the change in elevation is less than a centimeter over the length of a typical artifact on a slope of 10 degrees. An error of 5 mm at each end would dramatically change the plunge. Thus, for hand recording techniques, it seems that the analytical value of recording more than one point per artifact is questionable, and when using a total station, given the speed and ease with which an extra point can be recorded, the analytical value outweighs the costs.

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