Breaking Down an Early Neolithic Palimpsest Site – Some Notes on the Concept of Percolation Theory and the Understanding of Spatial Pattern Formation

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Abstract. This paper presents the results of the spatial analysis of a large Mesolithic and early Neolithic site (Hoge Vaart-A27, Almere, The Netherlands) through the application of an approach based upon aspects of percolation theory. An extensive distribution of knapped flint was analysed, which clearly resulted from multiple occupation episodes spanning a period of approximately 300 years. It was revealed that clusters of finds (defined by attribute query) within the distribution displayed a strong correlation between cluster size and content (number or weight of items). Various quantitative features of cluster expansion have been investigated, as have the patterns related to specific behavioural settings. Even though it is impossible to spatially isolate distinct activity areas, it can be argued that in the case of Hoge Vaart-A27, basic structuring principles can be identified. Further analysis with variable grid size settings is required to investigate its effects on cluster properties. Invariance of cluster properties to window size may provide meaningful information about site formation mechanisms.

1. Introduction

Palimpsest sites form a major part of the Stone Age archaeological record, yet these locales remain difficult to decipher and interpret. Many archaeologists consider their formation processes to be impossible to understand in any detail and subsequently regard them as having a limited use in the reconstruction of past human behaviour. Although this may be true in relation to the possibility of actually isolating distinct activity areas at a site level, the existence of such multi-episode locales must be considered highly significant for the understanding of long-term use of landscapes (cf. Wandsnider 1996). Moreover, if one accepts that human behaviour was inherently structured, archaeological distribution patterns should bear traces of this structured behaviour, despite post-depositional transformation of 'initial' patterns. If we can successfully recognise underlying structuring principles, the informative value of palimpsest locales for the understanding of long-term landscape use can be significantly increased.

In this paper I will present several results of the spatial analysis of the large Mesolithic and early Neolithic site of Hoge Vaart-A27 (municip. of Almere, The Netherlands). Here, approximately 8600 m2 were excavated producing many occupation remains on a sand ridge stretching along a gully (Hogestijn and Peeters 2001). At least two Mesolithic and two early Neolithic occupation phases were distinguished as the result of close to 100 radiocarbon dates and stratigraphic considerations. Even though calibrated dates from the last Mesolithic and first early Neolithic phase slightly overlap, the distinction is realistic in view of structural differences in associated phenomena, their radiocarbon dates and the fact that Mesolithic features appear to have been truncated as the result of natural erosion. This event in fact cleared much of the Mesolithic surface.

Subsequent Neolithic activity occurred in the context of a gradually inundating landscape (Peeters forthcoming), and involved the firing of surface hearths, flint knapping, tool maintenance, occasional pottery production and food consumption. In the course of approximately 300 radiocarbon years (6000–5700 BP), at least 120 surface hearths were fired and large amounts of flint, quartz, granite, pottery and bone accumulated on the surface. Activity on the sand ridge came to an end between 5700 and 5600 BP when it was permanently inundated and was covered by reed vegetations. The second Neolithic phase involved fishing activities in the tidal gully, but no activity which left significant occupation debris (other than wood spalts originating from the construction and maintenance of fish weirs in the gully) on the by then hardly visible ridge.

2. Problem Definition

The first Neolithic phase resulted in the formation of a large high density distribution on top of the ridge, and more dispersed, lower density concentrations of material in the peripheral zones (Fig. 1). In the peripheral zone a small concentration (covering a surface of ca. 100 m2) was excavated and appears to have consisted of a number of flint knapping spots, a tool maintenance and a game processing area organized around a surface hearth. Flint refitting gave strong evidence for the contemporaneity of the hearth and activity areas and as such this concentration is considered to represent a behaviourally integer spatial configuration.

When further analysis of the qualitative and quantitative characteristics of the flint material was carried out, close similarities were found between the small peripheral concentration and the large concentration on top of the ridge. The spatial distribution of artefact types or artefact attributes within the large concentration appears to displays no differential patterning. All types and attributes reacted in the

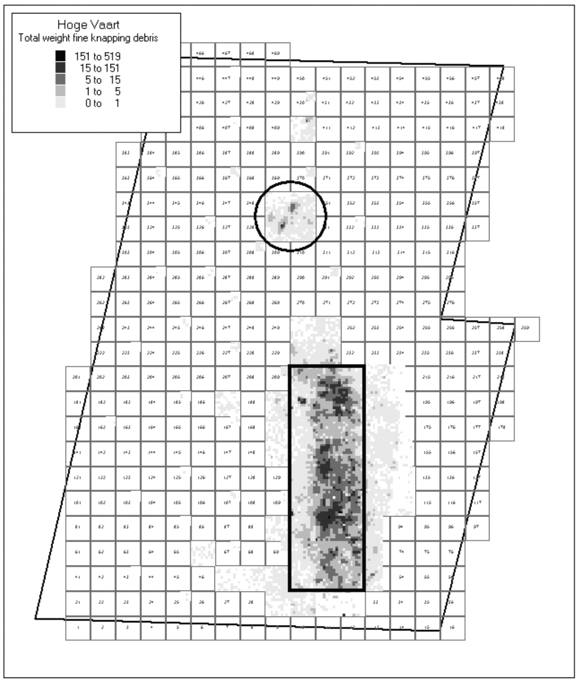

Fig. 1. Density distribution of the total weight of small flint knapping debitage per 50 x 50 cm grid-cell (larger squares represent 5 x 5 m units). The small concentration is encircled. The heavy black rectangle in the large concentration delimits the section analysed for cluster attributes.

same way: the higher the total density of remains and features (e.g. surface hearths) the higher the density of any artifact type or attribute in roughly the same proportions. As such, the large concentration can be characterized as a qualitatively and quantitatively homogeneous distribution. The fact that the Neolithic surface became gradually covered with sediment under low energetic conditions during or shortly after the activity episodes suggests that post-depositional horizontal displacement of materials was of minor importance.

This set of features led to the postulation of a working hypothesis regarding the formation of this particular palimpsest: in essence, the distribution pattern resulted from the repeated use of a gradually decreasing land surface in a structurally comparable behavioural context. Consequently, material waste is expected to have accumulated on the surface in roughly comparable qualitative and quantitative ranges, whilst spatial distributions are expected to have merged as the number of activity episodes increased in time. Thus, a strong relationship was expected between the extent of spatial clusters and the amount of material of any specific type or attribute found within the clusters. I therefore consider the archaeological distribution of material as a growth system, where spatial expansion occurred dependent of the time-depth of human activities involved, the amount of material deposited on a surface, variation in depositional conditions and the time-depth and nature of post-depositional processes.

3. Some Words on Percolation Theory

Departing from this perspective I chose to explore the properties of spatial distributions using an approach based on ideas drawn from percolation theory. Percolation theory essentially deals with the diffusion of phenomena through a system (e.g. a lattice) and cluster properties in growth systems. It has found applications in, among others the modelling of forest fire propagation and oil field assessment (Peitgen, Jürgens and Saupe 1992; Stauffer and Aharony 1994). The way in which occupied and empty 'sites' or cells of a given form (e.g. triangular, square) are distributed over a lattice to form clusters is central to this approach. In percolation theory, groups are considered clusters when at least two neighbouring cells are occupied. Isolated cells are not treated as such. Alternative definitions are possible, for instance when next-nearest neighbour cells are also considered.

Clusters which extend across the whole lattice are called 'percolating clusters'. Studies in various fields of application have shown such percolating clusters to form for the first time near the concentration p = 0.6, corresponding to a 60% probability that cells would be occupied when applying the nearest neighbour rule. From this threshold (the 'percolation threshold', pc) onwards, phenomena tend to percolate through the entire system. The diffusion of a particular phenomenon due to random percolation will take more time below this percolation threshold than above it. At the percolation threshold (p = pc) an abrupt change in the properties of the system occurs, somewhat similar to the physics of phase transitions.

It is necessary to emphasise that the analysis of percolation properties in dynamic systems is extremely difficult and involves complex mathematics. Furthermore, percolation theory focuses on the diffusion of phenomena in infinite systems (e.g. lattices). This poses serious problems with regards to its application in archaeological spatial site analysis, as excavation lattices are always finite and (generally) of extremely limited extent. The adoption of principles of percolation to finite systems still requires the solution of many problems (personal communication Uzy Smilansky).

Therefore I do not consider the present study as an application of percolation theory, but see it as a means by which to address some aspects of archaeological pattern formation from an alternative perspective. Archaeological pattern formation should not only be explained in relation to and as a function of human behaviour and post-depositional processes, but should also be studied and understood in terms of physical dynamics. If we want to distinguish between behaviourally significant patterns and those resulting from spontaneous or self-organising processes, we have to understand what characterises the different mechanisms and how they are related in time and space. This is where the concept of percolation theory may have a use.

4. Analysing Hoge Vaart Distribution Patterns

The small and large concentrations were excavated using a square lattice consisting of 50 x 50 cm grid-cells. The small concentration showed distinct spatial patterns with regards to a number of different materials and attributes. In several cases (e.g. burned and unburned microdebitage, flakes and blade fragments) clear clustering was observed. In other cases (e.g. cores and tools) the degree of clustering was low and more diffuse patterns could be distinguished. If the large concentration represented a more or less random accumulation of similar patterns, cluster merging can be expected to have occurred in differing degrees depending on the specific and 'initial' spatial distribution of attributes.

Since the small concentration was taken as the analytical reference for the large concentration, the basic unit of analysis ('scanning window') was set at the small concentration's size and covers a square lattice of 20 x 20 (n = 400) grid-cells. The large concentration covered a significantly larger lattice which, was not rectangular in shape, as several excavated 'protrusions' existed towards the periphery. In order to facilitate computing, a rectangular section of 30 x 90 (n = 2700) grid-cells was selected. This section comprised the majority of the large concentration and included both high and low-density zones.

Starting in the lower left corner of the large concentration, the 'scanning window' selected a 20 x 20 section of the large concentration,. This section was scanned for the presence of clusters. A number of attributes were recorded for each identified cluster. Once done, the window shifted by two grid-cells and a new section was selected. The whole scanning procedure was then repeated. The entire process required 221 runs to scan the large concentration. The small concentration consisted of a single window. It is important to realize that the size of the scanning window (400 grid-cells) determined the maximum size of a cluster.

Clusters were defined in a narrow sense, where a cluster consisted of at least two nearest neighbour grid-cells. Occupied but isolated grid-cells were not treated as clusters. Grid-cell values (attribute weight) were recalculated as a function of the attribute's average quantity in the small concentration (total weight or total number of items in the small concentration divided by 400 grid-cells). Cluster size (C_s = number of grid-cells for each cluster) and weight (C_w = total attribute weight or frequency for each cluster) were registered for each window scan and for each selected set of attributes (burned/unburned, complete/broken, artifact type). The next step in the analysis was to plot the relationship between cluster size C_s and cluster weight C_w in log/log (base 10) scatter graphs. The results of this exercise will be discussed below for a series of attributes which were shown to have distinct distributional characteristics within the small concentration.

5. Results

The log/log plots of C_s against C_w for all flint micro-debitage and larger flints shows two distinct point scatters (Fig. 2). Some of the clusters in the lower reaches contain relatively high amounts of small debitage and probably represent primary knapping locations at the fringes of the large concentration. The clusters from the small concentration also belong to this group. In the second scatter, $\log(C_w)$ grows as a function of $\log(C_s)$ pointing to a linear relationship between cluster size and the amount of debris present. The largest cluster of the small concentration falls on this line, but has an intermediate position between the two point scatters. Interestingly, a sudden increase of $\log(C_w)$ in relation to $\log(C_s)$ occurs near $\log(C_s) = 2.4$. The lower limit continues to fit the general trend line and corresponds to lateral merging of clusters (horizontal expansion). The sudden transition appears to correspond to excessive accumulation of small debitage (vertical expansion).

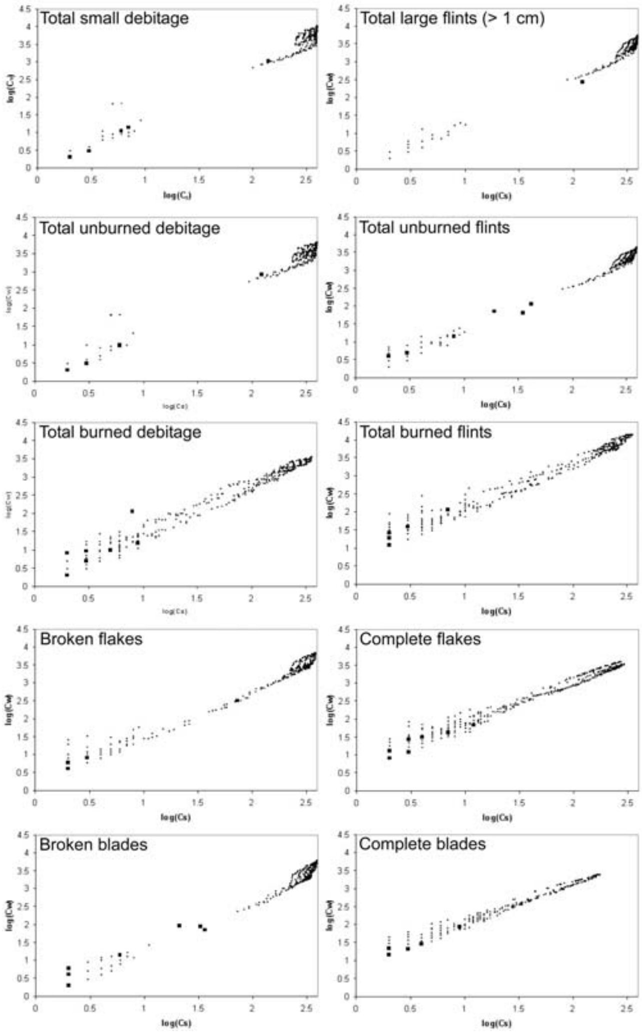

Fig. 2. Log/log scatter diagrams for different flint attributes. Small crosses represent clusters of the large concentration, rectangles represent clusters of the small concentration.

The picture can be further broken down on the basis of attribute selection. The log/log plots for unburned flints (both small debitage and individual flints) show a comparable picture to the one for the total of flints. The cluster attributes for the large concentration separate again into two point scatters. The C_w/C_s relationship remains the same, as does the sudden increase of $\log(C_w)$ near $\log(C_s) = 2.4$. The behaviour for the burned flints is manifestly different, in the sense that one long point scatter with a relatively stable C_w/C_s relation can be observed. No sudden increase of $\log(C_w)$ occurs, even though a certain expansion of the point cloud is visible. Clusters of burned flints from the small concentration only occur below $\log(C_s) < 1$ indicating less accumulation than in the case of unburned flint. This picture fits with the pattern which was observed within the small concentration (e.g. small distinct clusters near the surface hearth). In order to merge, small clusters require more occupation episodes than large clusters.

A largely comparable picture can be observed when looking at C_w/C_s relationships for broken and complete flakes. For broken flakes, the abrupt increase of $\log(C_w)$ still persists. However, both point scatters of the large concentration have merged. Most clusters of the small concentration are found in the lower reaches. Only one large cluster is present and perfectly fits the trend found in the large concentration. The C_w/C_s relationship for complete flakes appears to represent a continuous cloud. In the small concentration, cluster sizes hardly surpass $\log(C_s) = 1$. Just as was the case for unburned flints, clusters of complete flakes show no abrupt increase of $\log(C_w)$. This feature probably corresponds to relatively dispersed clusters of materials, where horizontal cluster merging occurs but has not led to extreme vertical expansion. The log/log plot for broken blades is almost identical to that of unburned flints. Clusters from the large concentration separate again in two point scatters. Complete blades show a log/log plot comparable to that of complete flakes, where the point scatter represents an elongated, narrow band indicating a strong C_w/C_s relationship. Here, also, we appear to be dealing with relatively dispersed clusters of materials and horizontal cluster merging.

The picture for blocks/chunks and cores (Fig. 3) differs significantly from the previous plots. Here, we see only small clusters of sizes well below $\log(C_s) = 1$. There seems to be no manifest cluster merging. Apparently, we are dealing with highly diffuse distributions of small clusters. The log/log plots for the main tool categories (trapeze points, scrapers, cutting tools) show a comparable picture with strong C_w/C_s relations. None of the tool categories have cluster sizes near or above $\log(C_s) = 2.4$, even though trapeze points and scrapers come close. Clusters of the small concentration only occur in the lower reaches of the point scatters. Clusters of cutting tools only occur in the large concentration. Most cutting tools consist of utilized blades. When compared to the log/log plot for complete blades, the restricted distribution of cutting tools is remarkable. Tools clearly have other distributional properties, and can be distinguished from knapping debris.

6. Discussion and Conclusion

Some descriptive statistics of the cluster properties of both the small and large concentration are presented in Table 1. Within the large concentration the maximum $\log(C_s)$ and $\log(C_w)$ values of the different input variables were higher than those of the small concentration. The smallest differences were found for those attributes where abrupt vertical growth was observed near $\log(C_s) = 2.4$. An interesting picture emerges from the difference between the large and small concentration's average $\log(C_s)$ and $\log(C_w)$ values (Fig. 4). With a regression coefficient of R2 ˜ 0.98, there is a strong relationship between the large and small concentrations in terms of cluster size and cluster weight independent of attribute. This shows that the overal mechanism of cluster expansion is more or less similar for all attributes.

However, burned micro-debitage and burned larger flints appear to plot far-off the regression line, suggesting burned flint clusters to have been subject to different merging mechanisms than the unburned counterparts. Thus, clusters of burned bone fragments were expected to expose a similar pattern, and indeed were found to plot off the regression line. It seems reasonable, therefore, to consider the possibility of differential cluster merging mechanisms, which were related to the specific use of surface hearths and the activities organised around them. These involved flint knapping, food consumption, charring of bone remains and flint, but also clearing of fire places.

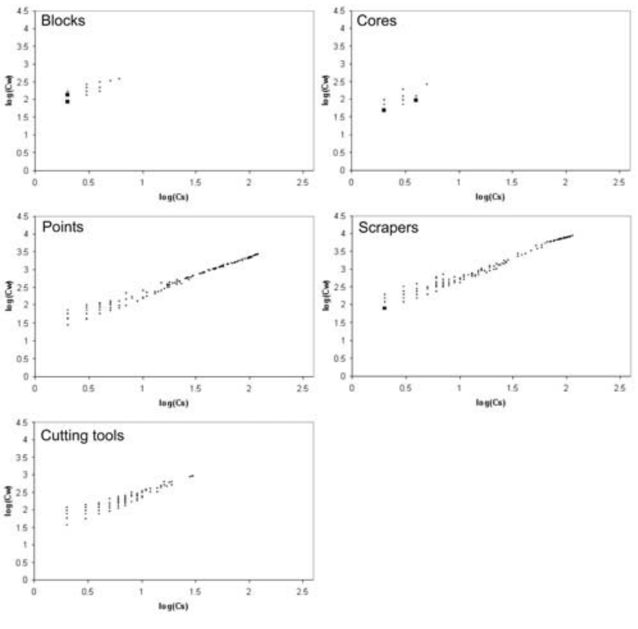

Fig. 3. Log/log scatter diagrams for some waste and tool categories. Small crosses represent clusters of the large concentration, rectangles represent clusters of the small concentration.

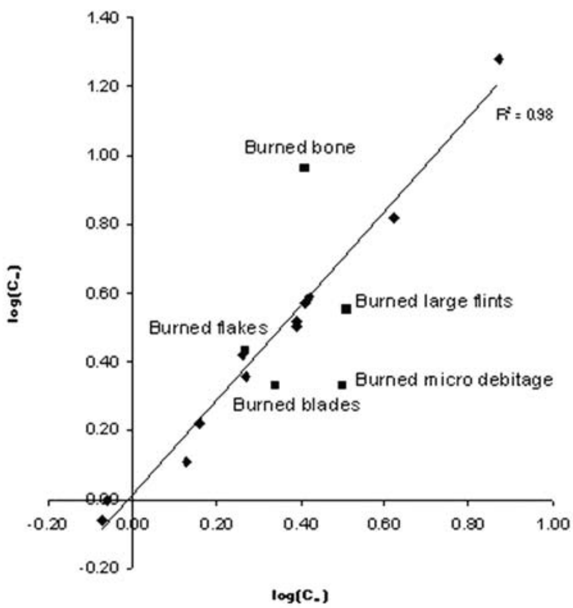

Fig. 4. Scatter diagram expressing the relationship between the difference between the large and small concentration's average log(Cs) and log(Cw) values.

	Small concentration					Large concentration				
	log C_s	log C_s	log C_w	log C_w		log C_s	log C_s	log C_w	log C_w	
Attribute	range	average	range	average	N clusters	range	average	range	average	N clusters
All small fraction	0.30-1.45	0.79	0.30-2.17	1.11	7	0.30-2.60	1.66	0.30-4.02	2.39	434
Small fraction unburned	0.90-1.46	1.21	1.08-2.11	1.69	4	0.30-2.60	1.63	0.30-3.83	2.28	427
Small fraction burned	0.30-1.04	0.64	0.48-2.31	1.25	8	0.30-2.55	1.14	0.30-3.57	1.58	1035
All individual flints	2.09	-	2.43	-	1	0.30-2.60	1.63	0.30-3.74	2.16	426
All unburned flints	0.30-1.62	1.02	0.60-2.06	1.36	6	0.30-2.59	1.41	0.30-3.66	1.88	528
All burned flints	0.30-0.85	0.41	1.08-2.06	1.44	8	0.30-2.55	0.92	1.08-4.16	1.99	1296
Broken flakes	0.30-1.86	0.59	0.60-2.50	1.00	6	0.30-2.58	1.00	0.60-3.85	1.57	959
Complete flakes	0.30-1.08	0.52	0.90-1.83	1.23	10	0.30-2.46	0.91	0.90-3.60	1.74	1539
Broken blades	0.30-1.56	0.70	0.30-1.96	0.95	10	0.30-2.59	1.32	0.30-3.78	1.77	592
Complete blades	0.30-0.95	0.49	1.15-1.94	1.39	6	0.30-2.24	0.65	1.15-3.39	1.61	3154
Blocks/chunks	0.30	0.30	1.94-2.12	2.03	2	0.30-0.78	0.43	1.95-2.60	2.14	801
Cores	0.30-0.60	0.45	1.68-1.98	1.83	2	0.30-0.70	0.39	1.68-2.43	1.83	1847
Core rejuvenations	-	-	-	-	0	0.30-1.11	0.48	2.06-2,93	2.29	1963
Trapeze points	0.48-0.77	0.62	1.76-2.00	1.87	3	0.30-2.07	0.55	1.45-3.42	1.81	3223
Micro-burins	-	-	-	-	0	0.30-0.78	0.41	2.12-2.78	2.28	922
Retouch splinters	0.30-0.69	0.40	1.56-1.95	1.66	4	0.30-2.18	0.66	1.56-3.83	2.08	3107
Scrapers	0.30	0.31	1.89	1.90	1	0.30-2.05	0.57	1.89-3.94	2.25	3242
Cutting tools	-	-	-	-	0	0.30-1.48	0.54	1.58-2.98	1.92	4149
Burned flakes	0.30-0.60	0.40	1.38-2.18	1.71	3	0.30-2.45	0.74	1.38-4.17	2.04	2420
Burned blades	0.30-0.61	0.42	1.58-1.98	1.77	4	0.30-2.35	0.69	1.58-4.14	2.19	2231
Burned bone	0.30-1.91	0.70	0.30-2.27	0.79	6	0.30-2.59	1.11	0.30-4.66	1.75	856

Table 1. Some basic statistics of cluster attributes.

Based on the initial results of my analysis, it would appear that repeated use of the Hoge Vaart locality structurally led to cluster growth. Horizontal cluster merging is primarily indicated by the linear relationship between cluster size and weight. In several cases, continued accumulation lead to increased weight values relative to cluster size from a certain threshold onwards. This threshold corresponded with cluster sizes covering ca. 60% of the 'scanning window' (240 grid-cells, $\log(C_s) = 2.38$). At this stage of analysis, it is too early to draw any inferences from this observation in relation to, for instance, the percolation threshold pc. One fundamental factor to consider is the effect of window size on cluster properties.

The degree to which cluster growth occurred, has been demonstrated to be clearly linked to initial distribution characteristics of attributes, such as dispersed low density distributions of cores and clustered high density distributions of flakes. Especially the plots which show continuous point scatters can be fitted with straight lines with slopes ranging between 1.1 and 1.3, meaning

$$C_w = \text{const}\ C_s^{\,k}$$

where k is between 1.1 and 1.3 significantly larger than 1. Some first observations seem to indicate this feature to be independent of window size, which might hint at meaningful information on structural aspects of pattern formation.

In view of these results, it seems likely that the large concentration at Hoge Vaart was essentially the result of repeated occupation in a behavioural setting comparable to the small concentration. Despite the fact that the patterns of the large concentration result from repeated occupation over some 300 years, the specific character of distributions suggests systemic continuity. The fact that attributes related to firing of surface hearths 'behave' somewhat differently from other attributes furthermore hints at structural integrity of spatial patterns related to different aspects of behaviour.

In conclusion it can be said that, even though spatial analysis of palimpsest sites may bear little fruit with regards to the identification of integer activity zones, crucial information regarding the understanding of site-formation mechanisms in relation to structured behaviour can be gained. It is possible that the systematic analysis of cluster characteristics as presented here, may reveal some basic structures of archaeological compounds which can add to a better understanding of formation mechanisms and ultimately of past human behaviour.

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