Anthropological and Archaeological Science manuscript No.
(will be inserted by the editor)

Measuring Spatial Structure in Time-Averaged Deposits

Insights from Roc de Marsal, France

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Received: date / Accepted: date

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Abstract The use of space, both at the landscape and the site level, is considered an important aspect of hominin adaptations that changed through time. At the site level, spatial analyses are typically conducted on deposits thought to have a high degree of temporal resolution. Sites with highly time-averaged deposits are viewed as inferior for these analyses because repeated site visits obscure individual behavioral events. To the contrary, here we take the view that behaviors that repeat themselves in a spatially structured way through time are exactly the kinds of behaviors that are potentially significant at an evolutionary time scale. In this framework, time averaging is seen not as a hindrance but rather as a necessary condition for viewing meaningful behavior. To test whether such patterning is visible in time-averaged deposits, we use spatial statistics to analyze a number of indices designed to measure lithic production, use and discard behaviors in a multi-layer, late Neandertal cave site in southwest France. We find that indeed some such patterning does exist, and thus sites with highly time-averaged deposits have the potential to contribute to our understanding of how hominin use of space varied through time. This is useful because a great many archaeological sites have highly time-average deposits. Interpreting the spatial patterning will likely require modeling to cre-

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ate expectations in time-averaged and likely emergent contexts such as these.

Keywords time-averaging · spatial analysis · Paleolithic · palimpsets · Roc de Marsal · Middle Paleolithic ·

Introduction

The spatial structure of stone artifacts, fauna, and other archaeological features (e.g. hearths) provide a unique window into how past people conceptualized and organized their behaviors in space (Aldeias et al. 2012; Alperson-Afil 2008, 2017; Bamforth, Becker, and Hudson 2005; Clark 2016; Henry et al. 2004; Pettitt 1997; Vaquero and Pastó 2001; Yellen 1977). In turn, these patterns ultimately reflect the ways in which humans interacted with their physical environment. Intra-site spatial analyses thus provide the opportunity to gain important insights into the behavior of Paleolithic peoples (Kroll and Price 1991; Yvorra 2003; Henry et al. 2004; Henry 2012; Oron and Goren-Inbar 2014; Mallol and Hernández 2016; Gopher et al. 2016). Closely tied with the advent of processual archaeology in the 1960s, spatial analyses utilized the material traces of modern forager activity to interpret distributions of artifacts from archaeological sites in behavioral terms (e.g Yellen 1977; Binford 1978; Gould and Yellen 1987; Simms and Heath 1990; O'Connell, Hawkes, and Jones 1991; Audouze and Enloe 1997). This approach focuses on identifying discrete "zones" of activities whose arrangement in space provide insight into the spatial organization of past people's behavior (Clark 2017). Since the 1960s, spatial analysis has seen rapid methodological improvements in both data collection and analysis. Plumb bobs and meter-sticks have given way to devices capable of quickly and accurately mapping whole archaeological assemblages in three-dimensional space (Reed et al. 2015; Wheatley and Gillings 2013; McPherron, Dibble, and Goldberg 2005), and the increased usability and accessibility of geographic information systems in the last years provide a multitude of new tools by which spatial archaeological data can be visualized and analyzed (Abe et al. 2010; Benito-Calvo and Torre 2011; Wheatley and Gillings 2013; Machado et al. 2016). Simple distribution maps have been replaced with a variety of point pattern analyses, geospatial statistics, and multivariate analysis (Alperson-Afil et al. 2009; Merrill and Read 2010; Yvorra 2003).

Spatial analysis in Paleolithic studies has, however, slowed in recent decades (Clark 2016, 2017). Despite the fact that the sophistication and the number of both documentation and analytical tools have never been greater, archaeologists still grapple with some fundamental issues regarding the formation of the archaeological record. Although ethnographic data has been a primary analog for interpreting the archaeological record, these data typically represent a time-scale of hours to months. Thus, to match this, high temporal resolution is often considered a requirement of intra-site spatial analyses (Alperson-Afil 2017). In contrast, aside from a small minority of possible exceptions (e.g. Leroi-Gourhan 1984; Audouze and Enloe 1997; Alperson-Afil et al. 2009), the majority of Paleolithic sites are palimpsests formed from sequentially overprinted occupations spanning hundreds, or sometimes, thousands of years (Dibble et al. 1997; Bailey and Galanidou 2009; Henry 2012; Vaquero, Chacón, et al. 2012). Given the destructive nature of time-averaging on signatures of singular behaviors (Stern et al. 1993; Stern 1994; Yellen 1977), much research has been devoted to obtaining high-resolution data from aggregate assemblages (Mallol and Hernández 2016; Vaquero and Pastó 2001). Protocols involving a variety of sophisticated excavation and analytical methods including *décapage*, high-resolution 3D mapping, refitting, and microbiology have been implemented in an attempt to extract individual occupations from palimpsests (e.g. Leroi-Gourhan 1984; Bailey 2007; Goldberg and Berna 2010; Aldeias et al. 2012; Henry 2012; Bisson et al. 2014; Mallol and Hernández 2016). The application of these methods has been met with variable success. It is still unclear what constitutes a brief instance of activity or an episode of occupation (Vaquero, Alonso, et al. 2012; Mallol and Hernández 2016), and when archaeological assemblages or features can be isolated in time, determining their synchrony with the rest of the assemblage remains problematic (Aldeias et al. 2012; Mallol and Hernández 2016). Even thin assemblages from open-air sites, where the structure of the archaeological assemblage appears to reflect an isochronous event, can still represent several episodes of occupation spread across considerable time (Bailey 2007; Bargalló, Gabucio, and Rivals 2016; Roda Gilabert, Martínez-Moreno, and Torcal 2016). Rather than extract individual activities from variably time-averaged deposits, spatial methods have further exposed the underlying complexity of the formation of the archaeological record. From the perspective of the activities facies model, it seems as if palimpsests are not amenable for understanding human behavior at this level. Yet, palimpsest sites are far more abundant than the rare examples when brief moments in time are preserved and for this reason should remain the subject of archaeological investigation.

This argument is not a recent realization. In response to (1975), (1981) argued that researchers should not shoehorn the archaeological record into the questions we ask but rather tailor our questions to match the nature of the record itself. Since the 1970s, archaeologists have also suggested that there are merits to understanding behavior in time-averaged datasets (Foley 1981; Ebert 1992; Pettitt 1997; Bamforth, Becker, and Hudson 2005; Holdaway and Wandsnider 2008; Bailey and Galanidou 2009; Clark 2017). Palimpsests are the result of repeated occupations, often over multiple generations, and thus afford the opportunity to investigate processes that structure human behavior more in the long-term (Foley 1981; Bailey 2007; Wandsnider 2008). The behavioral signatures preserved in these temporally coarse assemblages likely tell us something about the behavioral repertoire of populations or even taxa (Pettitt 1997). Spatial patterning on this coarsened scale no longer reflects individual activities but instead shows how broader, more temporally stable (e.g. the layout of a cave or rock shelter), external factors structured behaviors. Patterns at this scale potentially document the interaction between past populations and their physical environment (Brooks and Yellen 1987; Bamforth, Becker, and Hudson 2005). In this regard, caves are interesting because they impose physical constraints on how space can be used. For instance, the dripline defines an interior, sheltered portion of the space versus the exterior, open portion (Riel-Salvatore et al. 2013). The movement of air and ventilation may have influenced the placement of fires so as to avoid filling the space with smoke or burning the fire too quickly. Subtle factors such as differences in lighting or temperature across a cave may have influenced the structure of behavior. At a more general level, when locations like caves are subjected to repeated occupation over long periods of time, the residues of previous occupations may structure subsequent ones (Bailey and Galanidou 2009; Malinsky-Buller, Hovers, and Marder 2011). If these factors structured behavior spatially, then it is likely that artifact discard patterns may have been structured as well. Few studies have applied intra-site spatial analyses to palimpsests as a whole, but previous research has yielded interesting results. Bamforth et al. (2005) and (2009), for instance, were able to demonstrate the repeated discard of artifacts in the same locations over extended periods of time. However, though these studies suggest that palimpsests are structured (to some degree), further assessments of this notion may require new methods that consider the behavioral inputs and site formation processes under which palimpsests form.

Spatial Analysis and Time-Averaged Assemblages

Prior studies have often focused on describing spatial structure by looking at variation in artifact density across a level or horizon (e.g Baxter, Beardah, and Wright 1997; Baales 2001; Alperson-Afil 2008; Aldeias et al. 2012; Gopher et al. 2016). Artifact density has been argued to be advantageous for analyzing time-averaged deposits because it is a function of discard. Simply put, areas where past people spent more time will have accumulated more artifacts than other areas (Foley 1981). Thus, spatially delimited densities (i.e. clusters) of archaeological materials provide insight into how past behavior structured the formation of the archaeological record (e.g Carr 1984; Baales 2001; Yvorra 2003; Gopher et al. 2016). To demonstrate spatial variation in artifact density, point and kernel density functions have been widely applied (e.g. Baxter, Beardah, and Wright 1997; Alperson-Afil et al. 2009; Aldeias et al. 2012; Alperson-Afil 2017). However, ethnographic work shows that hunter-gatherer use of space is often variable and unconstrained (O'Connell, Hawkes, and Jones 1991; Clark 2017). Circumstantial factors such as weather, where individuals are coming from, group size, kinship, and anticipated next destinations influence the organization of any single episode of occupation (Bamforth, Becker, and Hudson 2005). Moreover, differences in the use-life of stone tools will also result in the differential accumulation of artifacts (Shott 1998). Over time the relationship between where behavior occurred and the artifact density will eventually be lost. Most ethnographic examples come from open air contexts where space is largely unconstrained. If, however, the frequency that behaviors occur in a given location is influenced by the space itself, as it likely is in caves, then the material traces associated with those behaviors will appear in greater proportion to others. In a palimpsest, instead of describing behavioral patterns in terms of artifact discard intensity, they should be described in terms of artifact discard likelihood. Approaching palimpsests in this manner recognizes the frenetic conditions under which time-averaged assemblages form but also considers that external factors that may more broadly govern the spatial organization of activities.

Continuous or repeated occupation, particularly in context with low sedimentation rates, can also introduce taphonomic biases into density measures. Trampling of previously discarded and still exposed artifacts will increase breakage within an archaeological assemblage (Lin et al. 2016). While a measure of trampling may be a useful indicator of activity intensity (Reynard and Henshilwood 2018), unless breakage is controlled for it will also inflate artifact density estimates and thus must be considered when measuring spatial patterns in artifact discard. Heating of surface or near surface artifacts also causes breakage and makes artifacts more susceptible to subsequent breakage through other processes (Mentzer 2009; Sandrine et al. 2005) thereby also inflating density values. Without considering the impact of these processes, we run the risk of interpreting density measurements directly as behavior when in fact they reflect only taphonomic or geological processes or some unknown mix of behavior and these other processes.

With these perspectives in mind, this study further examines whether meaningful spatial patterning can be extracted from time-averaged deposits. Our investigation focuses on data from the recent re-excavation of the Neandertal cave site of Roc de Marsal, located in southwest France. We develop methodologies specifically designed for palimpsests using spatial statistics and behaviorally meaningful indices developed from stone tool analysis. These indices are calculated as ratios of different artifact classes and conditions. We then analyze the spatial distribution of lithic material as the relative probability of discard, while also controlling for the impact of breakage on an archaeological assemblage. A neighborhood analysis is used to estimate the spatial variability across each layer. While not all of our measures showed spatial patterning, many of them did, suggesting that human behavior at Roc de Marsal was structured over long time-scales. The scale, variation, and co-variation of time allows for a discussion of the dynamic nature of human behavior and its impact and signature in palimpsests.

Materials: The Site of Roc de Marsal

Roc de Marsal (hereafter also RDM) is a small (˜80 m^2) cave (Figure 1) situated approximately 5 km southwest of Les Eyzies, southwest France, in a small tributary valley of the Vézère River. The cave opening faces south-southwest, is about 80 m above the valley floor, and is just under the overlying plateau. The site was intensively excavated twice in the last 50 years, first by Jean Lafille from 1953 to 1971 and then more recently, from 2004 to 2010, by a large collaborative team (Bordes and Lafille 1962; Turq 1979; Turq et al. 2008; D. M. Sandgathe, Dibble, Goldberg, and McPherron 2011; Aldeias et al. 2012). We know from Lafille's notebooks that he opened a meter square in the central part of the cave and then expanded the excavation into adjacent squares before switching to a strategy of excavating a trench from approximately the entrance of the cave through to the back (Goldberg et al. 2013) (see Figure 1). In addition, Lafille excavated a connecting trench into a lateral extension of the main cave. Unfortunately, Lafille did not record the spatial coordinates for individual finds systematically enough to produce the type of dataset required for our analysis. The more recent excavations took a new sample from the site by pushing the west profile of Lafille's trench back one meter along nearly its entire length, meaning from just outside the current dripline to the back of the cave (see Figure 1). The dataset from this excavation is what is analyzed here.

Figure 1. The cave of Roc de Marsal (upper left), a map showing the extent of the cave, the previous excavations, and the most recent excavations (right), some of the stacked hearth features in Layer 9 (center left), and a panoramic (distorted) view of the west profile towards the end of the new excavations. The main area analyzed here is shown in this latter photo (primarily E18 to K16).

The new excavations recognized 13 layers; however, the main artifact bearing layers are, from bottom to top, 9 through 2. The archaeology of all of these layers is Middle Paleolithic (Turq 1985; Turq et al. 2008; D. M. Sandgathe, Dibble, Goldberg, and McPherron 2011; Aldeias et al. 2012). The base (Layers 9-5) of the sequence is characterized by Levallois technology. Layers 4-2 represent a switch to Quina techniques of blank production. Denticulates are numerous in Layers 9-7, and the proportion of scrapers increases throughout the sequence. Layers 9-7 are characterized mostly by red deer and roe deer (Hodgkins et al. 2016; Castel et al. 2017). Reindeer are present in Layers 9-8 and increase in Layer 7 and above. Bovines and horse are also present. By Layer 5 times reindeer dominate the assemblage, accounting for approximately 70% of the NISP, with the rest consisting mainly of horse and bovines. This trend continues in Layer 4 where reindeer reach over 80% of the assemblage NISP. Layer 3 shows a more diverse faunal spectrum (though sample sizes are small), and Layer 2 shows a return to the Layer 4 pattern. The sequence has been intensively dated using a variety of thermoluminescence and optically stimulated luminescence methods (Guibert, Lahaye, and Bechtel 2009; Guérin et al. 2012, 2017). The different dating techniques provide somewhat different results, but Guérin et al. (2017) use their most reliable set of ages to place the base of the sequence in MIS 4 and the top of the sequence in MIS 3. In their view, the transition between MIS 4 and 3 likely occurs sometime during the deposition of Layers 6 and 5. How to reconcile this age model with sharply contrasting paleoenvironmental proxies coming from geological observations and the faunal spectrum is as yet unresolved.

A total station was used to record the location of all artifacts larger than 25 mm (piece provenienced finds) (see also Sandgathe et al. (2018) for same methods applied to Pech de l'Azé IV). Complete teeth and complete bones of non-microfaunal remains smaller than 25 mm were also recorded with the total station. All other small artifacts ($<$ 25 mm) were included with the sediment buckets and retrieved after wet screening as bulk samples (small finds). At the time of our study, the complete lithic analysis database was available, but only a limited sample of the fauna had been studied, and so these data could not be used here. A summary of the data set we use is provided in Table 1. Note that Layers 6 and 3 were not included in the spatial analysis because their horizontal extent is quite limited. Layer 2 was not included because its sample size is small. All of the other layers could be traced over a large extent of the cave, though the spatial extent of each layer does vary somewhat, and they all have large sample sizes. However, there are differences in artifact density. Layer 9 has the highest number of lithics per liter (9.4), Layers 8 and 7 have similar densities (7.3 and 8.0 respectively), Layer 5 shows an intermediate value (4.5) and lithic densities are substantially lower in Layer 4 (1.5).

Table 1: Summary of liters excavated and lithic counts for the Roc de Marsal layers analyzed here. The counts include first all lithics and then breakdown by cores, tools, flakes and burned lithics.

Layer	Liters	Lithics	Cores	Tools	Flakes	Burned
4	1925	2932	55	465	1767	61
5	532	2411	82	279	1781	205
7	504	4025	160	244	3113	833
8	511	3709	143	199	2824	764
9	868	8132	216	276	6408	3150

Intact hearths are also present, particularly in Layers 9 and 7 (Aldeias et al. 2012; Goldberg et al. 2012). These hearths vary in size from as small as 30 x 50 cm to roughly a meter on each side and are in many cases composed of the classic sequence of reddened sediment, charcoal-rich base, and overlying ash. There are multiple instances in which stacked hearths could be observed as well (see Figure 1). As measured by the frequency of heated lithics, Layer 9 shows the most intense use of fire (D. M. Sandgathe, Dibble, Goldberg, McPherron, et al. 2011). Thereafter the frequency of burned lithics decreases in the sequence with a near absence of evidence of fire (in the form of visible hearth features or in the form of heated bones or lithics) in Layers 4-2. Roc de Marsal is interesting for our spatial study in part because it highlights issues with palimpsest dissection. In an attempt to understand spatial patterning between fires and artifact discard, previous research at Roc de Marsal used a combination of micromorphological approaches and horizontal excavation (or *décapage*) to establish potential surfaces representing brief episodes of activity associated with combustion features. However, the degree of synchrony between lithic assemblages and other archaeological features could not be confidently established. Subsequent spatial analyses failed to reveal any meaningful patterning between the density of lithics and combustion features within each *décapage* surface (Aldeias et al. 2012).

Rather than attempt to increasingly resolve temporal units of analysis, as was previously done (e.g. (2012)), this study searches for behavioral patterns in the palimpsests that comprise the archaeological horizons at Roc de Marsal. Thus, each layer was spatially analyzed as a single unit of analysis. One of the disadvantages of looking for spatial patterning at Roc de Marsal is that the horizontal extent of excavation in each layer is limited. While the excavations sampled from the front to the back of the cave, the width of the excavation was generally only about 1 m. Further, this excavation corridor went mostly through the central portion of the cave, and so we have very limited samples from near the cave wall. We note, however, that Roc de Marsal is not a large cave, and so the excavations actually sampled a large proportion of the space inside the cave. In addition, from a practical point of view, it would have been inadvisable to excavate laterally more of the cave (i.e. up to the cave wall) as it would have permanently removed a record of the stratigraphic sequence there. Thus, while we miss Lafille's excavated sample in our analysis, the sample we were able to analyze is not atypical for this kind of site. On the other hand, while the small size of the Roc de Marsal cave means that a rather limited excavation captures a large percentage of each layer, it also means that where behaviors could have taken place in the cave was also constrained, and this could, in turn, force a certain amount of spatial association.

Methods: Neighborhood Analysis

This study employs a neighbor analysis to characterize spatial variation in artifact discard patterns across each layer. Moving windows or neighborhood analyses are used in geographic information science to document local variation in a given variable (Lloyd 2006). Neighborhoods of a defined two-dimensional size and shape are drawn over the area of interest. Observations located within each neighborhood are summarized according to a given statistic (Hagen-Zanker 2016). The end result produces a map where each data point represents the calculation of that statistic for its neighborhood. Often times such techniques produce a smoothed rasterized representation of the moving window result but they can also be point based. Point density functions are a common application of this type of analysis in archaeology and have been applied at a variety of different scales (Baxter, Beardah, and Wright 1997; Abe et al. 2010; Alperson-Afil and Goren-Inbar 2010; Aldeias et al. 2012; Blasco et al. 2016).

Here we use a circular window of 30 cm in radius as our neighborhood and calculate the local variation of each artifact metric (see the calculation of metrics below) based on this sample. This window size was determined largely by the spatial scope of the study area. Too small a window risks introducing local noise into the result, and too large a window risks aggregating meaningful local variation into noise. While GIS software packages offer a variety of moving window tools (e.g. Point density, Kernel density, Optimized hotspot analyses) (McCoy and Johnston 2001), our study requires the flexibility to calculate various artifact-metrics. Thus we custom developed the moving window analysis used here in R with the rgeos package specifically for the purpose of calculating each metric (Bivand and Runnel 2018; Team 2018). We have included the raw data, source code, and the markdown document used to create this publication (cf. Clarkson et al. (2015); Marwick (2017); McPherron (2018)).

Methods: Calculation of Metrics

We use seven indices to describe discard patterns of the following artifact classes and conditions: (1) overall stone artifact density, (2) complete flake weight, (3) cortex to mass ratio, (4) proximal flake ratio, (5) burning ratio, (6) scraper to flake ratio (7) core to flake ratio. The mechanics and behavioral justification for these ratios are as follows.

Artifact density for each neighborhood was calculated as the number of stone artifacts. Though density measurements are potentially biased by breakage, this describes the general distribution of artifacts across each layer and, therefore, provides a baseline comparison for the other indices.

Complete flake weight is calculated as the median weight of complete flakes within a neighborhood. The median flake weight in each neighborhood (See moving window section) is then divided by the median flake weight of the entire layer. This allows the values to be standardized such that flake weight is comparable across layers. This is a common practice in spatial analysis, as it allows one to find local variation in a metric given its global value (Isserman 1977). Values associated with this metric center on 1. Values above 1 mean that the median flake weight in the window is greater than the median flake weight of the whole layer and values below 1 mean the opposite. Our expectation for this measure is that areas of tool production (i.e. retouch) and rejuvenation might have smaller flakes, though the sensitivity of this measure for these behaviors is tempered in this case by our 2.5 cm size cut-off.

Cortex to mass ratio can act as a proxy for reduction stage under the assumption that greater proportions of the cortex are removed at early stages of the production sequence (Oron and Goren-Inbar 2014); areas associated with early-stage reduction will have higher cortex to mass ratios where middle and later stages will have less (Toth 1985). This assumption, however, is in part impacted by the technology (e.g. Levallois versus Quina techniques for blank production) and by lithic transport patterns (see below), neither of which was constant throughout the sequence. Some caution is then required when considering differences between layers. To calculate this ratio, for each artifact, the relative proportion of cortex was previously measured using intervals and here converted to a decimal based on the interval mid-point. Surface area is estimated as a two-dimensional rectangular surface by multiplying the artifact length by width (Douglass et al. 2015). Estimates of the cortical surface area are then derived by multiplying the proportion of cortex by the surface area. Cortical surface area estimates are then divided by mass to control for the influence of size on the cortical surface. Aside from reduction intensity considerations, the movement of already worked materials into and out of the site will affect the overall amount of cortex in an assemblage. Based on the cortex ratio (Dibble et al. 2005), it has already been established (Lin, McPherron, and Dibble 2015) that in Layers 5 and 4 cortex is under-represented, whereas in Layers 9-7 the expected amount of cortex is present. Nevertheless, here we can examine how the cortex that is present is distributed spatially.

The proximal flake ratio is measured by calculating the ratio of proximal flakes to complete and proximal flakes. Proximal flakes here are defined as broken flakes preserving more than 50% of the platform. As this index increases, the representation of proximal flakes within a given neighborhood increases meaning a greater degree of breakage. Thus, high values reflect an abundance of breakage and low values the opposite. We included this breakage index to infer areas of intense trampling. Holding other factors constant, areas that are subject to more activity or trampling should have a higher frequency of flake breakage (Nielsen 1991). However, breakage rates will also depend on factors such as the substrate and the size/morphology of the flakes themselves, both of which could vary across the layer and size/morphology will vary between layers for a number of reasons including changes in blank production technology. The relationship between flake size/morphology and breakage is poorly understood, and so we are unable to control either of these factors here. We do know, however, that burning increases breakage and so heated flakes are removed from this calculation.

The burning ratio is designed to investigate the spatial structure of burned artifacts as a proxy for the placement of fires. Fire placement within the cave was likely structured and fires may have in turn structured where behaviors took place (e.g Galanidou 1997; Pettitt 1997; Gopher et al. 2016), thus understanding whether there is structure in the spatial distribution of burned artifacts may provide insight into the organization of behaviors in space. Note that we are not suggesting that artifacts were intentionally heated, rather they are incidentally heated when fires are constructed on artifact bearing deposits or tossed directly into an active fire (Aldeias et al. 2016). Thus if there is consistency in where burning events occurred, then there should also be structure in the burned artifacts. However, burning increases breakage which then over-represents burned lithics relative to other lithics within any given neighborhood. Rather than computing the relative frequency of burned lithics to all other lithics, we account for breakage by only considering complete and proximal flakes in our estimation. The ratio of burned complete flakes and burned proximal flakes to all complete and proximal flakes was calculated for each neighborhood.

The scraper to flake ratio and *core to flake ratio* are designed to characterize the discard of cores and scrapers relative to flakes across each layer. Previous studies have argued that artifact types such as scrapers and cores are also structured around combustion features (Pettitt 1997), and so we may expect that locations subject to continuous burning over long time scales may also structure the discard patterns of scrapers and cores. The distribution of scrapers is calculated as the relative frequency of scrapers to the number of proximal and complete flakes. As with scrapers, the spatial distribution of cores is calculated as the frequency of cores relative to the number of proximal and complete flakes (core to flake ratio). The inclusion of complete and proximal flakes only is, again, to account for potential distortion of values due to breakage introduced by taphonomic processes.

Local Indicators of Spatial Association

The neighbor analysis allows us to observe spatial variation in the calculated metrics. However, it provides no way to quantitatively characterize the meaningfulness of the variation we observe in each layer. To address this, a Local Moran's I test is applied to the results of the moving window analysis (Anselin 1995). Global Moran's I then characterizes the spatial structure of a given attribute as non-random clustered, non-random even, or random (Bivand, Pebesma, and Gómez-Rubio 2013). This is done using a neighborhood analysis to analyze first local relationships between values observed at a specific point and its neighbors. The global structure of a distribution of values is then calculated based on these measurements. Since Moran's I requires an understanding of spatial relationships at a local scale, it can be broken down into its individual parts. Statistical tests can then be applied to each of these parts to determine the statistical significance of clustering or dispersion at the local scale (Anselin 1995; Lloyd 2006; Bivand, Pebesma, and Gómez-Rubio 2013). The significance of clustering around each point in these analyses can be plotted in space. Using this method, the statistical meaningfulness of spatial variation in each metric is detected as statistically non-random "clusters" on the local scale. Results of the Local Moran's I test can then be used to demarcate areas of statistically significant clusters of high and low values and outliers (Lloyd 2006). Outliers are defined as statistically significant clusters of high values that are surrounded by clusters of low values or vice versa. This technique is beneficial as it provides an objective determination of when spatial variation in each calculated metric is the result of non-random processes. In doing so, this provides a way to better discern between spurious variation and systematic structuring of artifact discard patterns.

This study uses the spdep package in R to implement Local Moran's I methods as developed by Anselin (1995). Clusters of high and low values were determined with 95% confidence. Hereafter, statistically significant clusters of high values are referred to as high clusters and statistically significant clusters of low values will be referred to as low clusters. Outliers, where non-random high values are surrounded by low values or the opposite, are referred to as high-outliers and low-outliers respectively. An additional note of importance is that both Local and Global Moran's I are scale-dependent and require the definition of a neighborhood size. Since the results of this test are directly influenced by the size of the neighborhood used, additional measures must be taken to determine the most appropriate window size (this window is independent of the moving window used to calculate the above metrics at each artifact location). We used a correlogram to estimate the most appropriate window size for each metric. This approach involves calculating Global Moran's I at a series of incrementally increasing neighborhood sizes (Bivand, Pebesma, and Gómez-Rubio 2013). The results are then plotted against neighborhood size. The neighborhood size exhibiting the greatest autocorrelation (Moran's I) was then chosen as the window size for the Local Moran's I test (see SOM). Clusters of statistically significant high and low values were then used to further explore the significance of the spatial variation of each metric.

Interpretative Framework

One large risk of the approach taken here is that, given the number of indices (metrics) examined and the nature of the spatial statistics applied to them, any one layer from any site is likely to produce a pattern of some kind. While *a priori* we expect caves to produce patterns for the reasons outlined in the introduction, interpreting these patterns in the absence of any specific *a priori* predictions or expectations about what patterns, in particular, are expected risks falling into the Texas sharpshooter fallacy wherein patterns are searched for, found and only then are explanations built to account for them. To help mitigate this problem, we look for repetition in the patterning between layers. In this framework, each layer is viewed as an independently drawn sample of the accumulation of behaviors preserved at the site with the one (mostly) constant being the physical configuration of the cave. Patterning that repeats across these independent samples is then more robust and likewise are any explanations for this patterning. The extent to which layers actually represent independent samples can be challenged on the basis, for instance, that visible traces of previous activities (in the underlying layer) may continue to structure behavior in the new layer just as we suspect happens within a layer. We see no clear way of addressing this issue in a single cave sequence. Clearly, strong behavioral inferences require consistent patterning in multiple sites.

Figure 2. The spatial distribution of lithic artifact density across each layer. Deep red colors indicate areas with high densities of artifacts whereas lighter red values grading to blue indicate lower artifact densities. The coloring for each layer is scaled separately, and the values are the values are for a neighborhood with a 30 cm

radius. The dashed line represents the current dripline (see also Figure 1).

Results: Inter-level comparisons of Spatial Organization

Density

Layers 5 and 4 are less dense than the underlying Layers 9, 8 and 7 (Table 1), and the spatial distribution of artifact density is variable between layers (Figure 2). At the base of the sequence, in Layer 9, artifact density is predominately concentrated towards the front of the cave, though a smaller concentration of artifacts is also observed at the area beyond the cave terrace. Artifact densities in Layer 8 are also primarily concentrated at the front of the cave. Additionally, moderate concentrations of artifacts are present throughout the cave terrace. Layer 7 shows spatially discrete concentrations of high artifact densities occurring in the front and terrace parts of the cave. In Layer 5 areas of high density are spread throughout the cave terrace. A small concentration of artifacts also occurs in the front of the cave. Finally, in Layer 4 the highest artifact densities are again towards the front of the cave. Note that consistent with (2012), the locations of visible fire features in Layers 9, 7, and 5 do not appear to be related to artifact density.

Figure 3. Clustering in median flake weight values across each layer. Orange represents statistically significant clusters where median flake weight is high. Blue represents statistically significant clusters where median flake weight is low. Note that only complete flakes are included. Grey represents non-significance. The dashed line represents the current dripline (see also Figure 1).

Complete Flake Weight

Though median flake weight varies in magnitude between layers, there is consistency in its representation across the excavated areas of the cave in Layers 9, 8, 7, 5 (Figure 3). In each of these layers, the median flake weight is greatest in the front of the cave. However, there is a considerable degree of noise in this pattern (SOM Figure 6). Despite the noise, the Local Moran's I results reveal that statistically significant high clusters of median flake weight values are consistently found in the front part of the cave. Moreover, statistically significant clusters of low median flake weight values occur towards the cave terrace. A linear regression reveals a significant relationship showing that flakes greater than the median flake weight for each layer become increasingly over-represented as one moves from the cave terrace to the front of the cave (p-value: $< .001$, R-squared: 0.115). Layer 4 shows a different pattern with no relationship between the distance from the front of the cave and median artifact weight.

Figure 4. Spatial distribution of non-random clusters of the cortex to mass ratio. Orange represents significant clusters of the high cortex to mass ratio. These are areas where there are greater amounts of cortex. Blue represents areas with significant clusters of the low cortex to mass ratio meaning very little cortex is found in these areas. The dashed line represents the current dripline (see also Figure 1).

Cortex

Non-random clustering of the cortex to mass ratio is observed in each layer (Figure 4). However, there is little consistency in the structure of the patterning between layers (SOM Figure 7). Layer 9 demonstrates the greatest degree of clustering. Large statistically high clusters of cortex to mass ratios occur on the cave terrace. The greatest clustering occurs nearest to the dripline. However, smaller high clusters are also present on the part of the cave terrace farthest from the mouth of the cave. Low clusters are at the farthest most extreme of the cave terrace as well as at the front of the cave. High and low clusters in Layer 8 are situated throughout the cave. Layer 7 shows no coherent patterning in the locations of both high clusters and low clusters as both types of clusters occur throughout all parts of the cave. In Layer 5 clusters representing low cortex to mass ratios occur predominantly on the cave terrace, farthest away from the dripline and mouth of the cave. In Layer 4, high clusters are in the front of the cave and at the very front of the cave terrace and clusters with low cortex are in the center portion of the cave terrace.

Figure 5. Top: The spatial distribution of burned flakes in relation to all flakes. Note how Layers 7 and 9 show the greatest degree of spatial organization of burned flake proportions. Bottom: The spatial distribution of high and low clusters associated with the burning ratio. Orange indicates areas with statistically non-random high proportions of burned flakes. Blue represents statistically significant areas where there are fewer burned flakes. The dashed line represents the current dripline (see also Figure 1).

Burned Flakes

The lower Layers 9, 8, and 7 all possess significantly higher proportions of burned lithics than in upper Layers 5 and 4 (Table 1). Layer 9 exhibits the greatest amount of structure (Figure 5). High proportions of burned flakes form a single non-random high cluster that straddles the dripline. The extent of the cluster begins in the front of the cave and extends on to the cave terrace. The spatial patterning of burned lithic values encompassed by the extent of this cluster creates a focal point comprised of the highest proportion of burned flakes. The proportion of burned flakes systematically decreases from this focal point. Non-random low clusters of burned flake proportions surround the edges of this focal point and extend toward the front and central parts of the cave as well as on to the farthest most reaches of the cave terrace. Despite the absence of visible fire features, Layer 8 has a proportion of burned lithics intermediate to Layer 9 below it and Layer 7 above it. The majority of Layer 8 has low proportions of burned flakes. Low clusters of burned flake proportions are, thus, found throughout all sections of the cave in this layer. A few high concentrations of burned flake proportions form along the right side of the front portion of the cave and cave terrace. While the overall proportion of burned flakes is considerably less, Layer 7 exhibits spatial patterning similar to that of Layer 9. High proportions of burned flakes form two non-random clusters in the front and terrace sections of the cave. Burned flake proportions surrounding these loci are largely not significant or comprise statistically significant low clusters of burned flakes. In Layer 5 the overall percentage of burned flakes is relatively low; however, some clustering of burned flake proportions can be observed. The highest proportions of burned flakes form a statistically significant cluster on the terrace part of the cave. Although Layers 9, 7 and 5 all have evidence of combustion features, no single feature directly corresponds to areas of high burning. Layer 4 has the lowest number of burned lithics. Variation in the proportion burned flakes is observed, however, and 75% of the values are less than .05. Though the Local Moran's I test revealed both high and low clusters of burned lithics, there is no structure to their overall distribution.

Figure 6. The spatial distribution of high and low clusters associated with the ratio of proximal flakes to all flakes. Orange indicates statistically high clusters of proximal flake ratios, meaning there are more broken flakes relative to complete flakes. Blue indicates statistically low clusters of proximal flake ratio values. In these areas there are fewer broken flakes and more complete flakes. The dashed line represents the current dripline (see also Figure 1).

Proximal Flake Ratio

The distribution of flake breakage is variable across layers (SOM Figure 8). In Layer 9, low clusters of proximal flakes relative to all flakes are situated on the cave terrace. Clustering showing statistically significant high proportions of broken flakes are located in the front section of the cave (Figure 6). The distribution of both the high and low clusters of broken flakes also inversely corresponds with the spatial distribution of burned flakes. This high cluster corresponds with the statistically significant low cluster of burned lithics in the front of the cave but is situated on the edge of a high cluster of burned flakes, whereas low clusters representing low proportions of proximal flakes are directly within the burn zone. In Layer 8 high and low clusters of proximal flake proportions are distributed throughout the layer with no general patterning to their distribution. The relative frequency of proximal flakes in Layer 7 is structured similarly to Layer 9. Clusters representing high breakage patterns are situated toward the front of the cave whereas clusters of low breakage are found in and extending beyond the cave terrace away from the mouth of the cave. The high cluster in the back also exhibits a similar spatial association with the focal points of burned lithics. High clustering indicative of breakage, corresponds with the low clusters of burned flakes and vice-versa. For Layer 5, clusters with low proportions of proximal flakes are found on the cave terrace whereas high clusters are in the front of the cave and in the parts of the excavation farthest from the mouth of the cave. Finally, this index in Layer 4 is generally not structured in space as much of the variation is non-significant. The high and low clusters that are present show little evidence of spatial patterning.

Figure 7. The spatial distribution of high and low clusters of the relative frequency of scrapers in comparison to flakes. Orange points reflect areas where the proportions of scrapers are high. Blue reflects statistically significant areas where scraper proportions are

low. The dashed line represents the current dripline (see also Figure 1).

Scraper to flake ratio

There is little consistency in how the proportion of scrapers in comparison to flakes is distributed throughout each layer (SOM Figure 9). Overall, scrapers comprise a small proportion of each assemblage. However, non-random structure is observed in each layer (Figure 7). In Layer 9, the high scraper to flake ratio values are primarily in the front of the cave and at the outer edge of the terrace. Though noisy, statistically significant clusters of the high scraper to flake ratio values appear to form a "ring-like" shape that surrounds a statistically significant cluster with low values. This low cluster also corresponds to the area where the proportion of burned flakes is the highest. In Layer 8, the largest high cluster of the scraper to flake ratio values are in the front of the cave along the drip line. However, high and low clusters are found throughout the cave. Within Layer 7 high clusters are in the front of the cave whereas low clusters are predominantly situated on the cave terrace. A high cluster also appears to correspond with the cluster of high proportions of burned flakes, with a large degree of overlap. Additionally, a few isolated small high clusters can be observed in the middle of the cave as well. The majority of the clustering of high scraper values in Layer 5 occurs in the front whereas low-clustering occurs toward the front of the cave terrace and beyond. Scraper to flake ratios within the cave terrace of Layer 5 are predominantly non-significant. Layer 4 shows the greatest degree of spatial structure with high clusters occupying the cave terrace and beyond whereas the low clusters are in the front and central sections of the cave.

Figure 8. The spatial distribution of the core to flake ratio. Orange points reflect areas where the proportions of cores are high. Blue reflects statistically significant areas where core proportions

are low. The dashed line represents the current dripline (see also Figure 1).

Core to flake ratio

The core to flake ratio shows a fair degree of consistency across the layers (SOM Figure 10). Greater proportions of cores (low flake to core ratio) occur in the front of the cave and on the cave terrace. In addition, high clusters of the core to flake ratio occur; however, this pattern is not as systematic as the pattern observed in median weight. The organization of cores within each layer also shows similarities with the spatial distribution of scrapers. Much like the pattern observed in the scrapers, the clustering of core to flake ratios shows the greatest amount of patterning in Layer 9. Aside from a few very small high clusters of cores in the front and on the cave terrace, high clusters of the core to flake ratio are in the front of the cave (Figure 8). As with the scraper to flake ratio, high clusters of the core to flake ratio are situated on the edge of the area with high burned flake proportion values. The large low cluster of core to flake ratios on the cave terrace corresponds to the area of highest burned flake proportions. Low clusters of cores extend beyond the cave terrace away from the drip line to the very front of the excavation. High and low clusters of core to flake ratios are detected in Layer 8 but do not appear to show any apparent spatial structure. In Layer 7 statistically significant high and low clusters of cores are relatively small compared to Layer 9. The largest high clusters are on the cave terrace and front part of the cave. Few smaller clusters of high proportions of core to flake ratios are also found toward the central part of the cave and toward the very front of the excavation. In Layer 5, there is a fair amount of spatial separation between high clusters and low clusters of cores. High clusters occupy the front and cave terrace nearest to the dripline whereas low clusters are situated in the middle and front of the cave terrace. In Layer 4, clusters of high core to flake ratios are in the front of the cave and the cave terrace.

Discussion

The results yielded by this study make for several talking points regarding the spatial structure of time-averaged assemblages as well as for drawing behavioral inferences from them. The results of each index show spatial variation across each layer. None of the variations in each of these measurements tracks the overall density of artifacts, suggesting that they provide a useful, if not better, means for understanding stone artifact discard patterns preserved within palimpsests. Moreover, the Local Moran's I showed that the spatial variation of every metric also formed statistically non-random clusters. In the literature repetition is a common theme in how time-averaged patterns arise and, thus, are thought to represent the "modal behavior" (Foley 1981). At RDM, median complete flake weight is always greatest within the cave itself (as opposed to the terrace) in Layers 9-5. This result seems to suggest that at least some discard behavior was consistently carried out in specific parts of the cave. Though size sorting due to small changes in slope within the cave, particularly towards the mouth but also some towards the back, also need to be further examined. However, many of our indices showed inconsistent variation in both their spatial distribution and in relationship to one another across each layer. Despite the detection of non-random patterning, this lack of consistency in patterning makes it difficult to interpret many of these metrics in terms of long-term behavioral trends. This may imply that most of these discard behaviors were not structured by the morphology of the cave. Rather, it means that behavior was structured in relation to the other behaviors being carried out in the cave. The tendency for high core to flake ratios to cluster away from high cortex to mass ratio values in Layers 9-5 may suggest that cores were consistently discarded away from where they were initially reduced. This seems to support the notion that long terms discard patterns associated with the various activities carried out at Roc de Marsal did not occur in a vacuum. Palimpsests form as the result of the interaction of many different behavioral, environmental, and taphonomic processes through time and space. Thus, the non-random structure identified by the Local Moran's I test likely emerged from this dynamic interaction instead of from any modal or singular behavior. In this sense, it does not seem sensible to attempt to interpret these patterns in terms of the singular behaviors assumed to be reflected in them.

This is no more apparent than in patterning surrounding burning episodes at RDM. Despite the fact, that fire features span the excavated area in both Layers 9 and 7, there is a high degree of structure in each level. Counterintuitively, high proportions of burned flakes form large focal points that generally do not correspond to any single combustion feature. In the long term, aggregation localities subjected to burning would likely have been maintained with ash raked out and redeposited, an action detected micromorphologically in some cases at Roc de Marsal, see Aldeias et al. (2012) and Goldberg et al. (2012)). If this is so, then the weak correlation between visible combustion features in Layers 9 and 7 and the hotspots of heated lithics may be due to some extent to maintenance over time, thus disassociating ash with the burn location. This, in turn, may be due to a limited number of places that fires can be placed. However, this was not true in all cases and thus it is difficult to generalize whether heated artifacts are a better index of fire locations than visible traces of fire.

Nevertheless, it is interesting that the larger area reflected of continuous burning also has an effect on the discard patterns of other artifact types. Clearest are the high core to flake ratio, scraper to flake ratio and proximal flake ratio, which are all situated on the edges or just outside of these burn zones (Figure 9). The propensity to discard scrapers and cores, in combination with high levels of flake breakage, suggests that areas close to these areas of high burned flake ratios are high activity areas. Though it is not possible to know which behaviors were carried out at this location, it is clear that fire played an important enough role to structure the discard behaviors of the occupants of Roc de Marsal over long timescales. Thus when we look at the Layer 9 assemblage without reference to the spatial data, scrapers less frequently show signs of heating in comparison to unretouched flakes (Fisher Exact test, $p = 0.035$). This pattern is less clear in Layer 7 than it is in Layer 9. Though proximal flake ratios are very similar, the pattern with the core to flake and the scraper to flake ratios is less clear. Still the pattern is strong enough that at the assemblage level again scrapers are less likely to show signs of heating (Fisher Exact test, $p = 0.000$). Why the spatial structure is less clear in Layer 7 is difficult to say. Both Layers 9 and 7 have evidence of the structured use of space in the form of stacked hearths (Aldeias et al. 2012). However, Layer 7 also has more than half as many lithics as Layer 9, and the areas immediately around the burning hotspots in Layer 7 are less well sampled given the limits of the excavation and some clandestine excavations that occurred before the most recent excavations. By comparison, in Layer 8, which has a high percentage of heated lithics but no visible evidence of hearths and no clear spatial patterning in heated lithics, scrapers are just as likely as flakes to show signs of heating (Fisher Exact test, $p = 0.297$). Thus the spatial patterning observed in these Layers 9 and 7 provides insight into how archaeological signatures of structured behavioral patterns transform during palimpsest formation. Though high-resolution data can show how the discard of formalized tools is associated with individual fire features (Pettitt 1997), over time, it is not any one single feature that structures the record but rather these broader zones of continuous use and their spatial relationship with the cave.

Figure 9. Each figure has as its base map the areas of high burning in Layer 7 (top row) and Layer 9 (bottom row). Overlaid on this are the high clusters of scrapers and of cores and the low clusters of complete flakes. The dashed line represents the current dripline (see also Figure 1).

The patterns revealed at RDM demonstrate that the aggregation of episodes of behavior over-time imposes structure on the time-averaged archaeological record. This alone demonstrates the utility of palimpsests for understanding hominin behavior over long time-scales. However, interpreting these patterns and their evolutionary relevance is currently difficult. The disconnect between individual instances or relatively brief episodes of behavior and the long-term pattern present at Roc de Marsal reflects a well-known phenomenon in social science often referred to as emergence (Schelling 1978; Miller and Page 2007). Though it has been documented in primate tool use studies (Luncz et al. 2016), it has been rarely discussed in archaeology. If time-averaged behavioral patterns are better studied as a whole, instead of being reduced to the individual parts, then we must reconsider how we approach palimpsests. Rather than continue to attempt to isolate individual occupation or behavioral episodes, it may be more useful to devise research projects that attempt to better understand the complex interactions of hominin behaviors, ecology, taphonomy, and the formation of the archaeological record. Though this raises issues over how to develop analogs to understand processes that operate on time-scales beyond our lifetime, the combination of ethnoarchaeology and computational individual-based modeling is well poised to do this.

Ultimately, Roc de Marsal provides some initial insights into the behavioral structure of palimpsests. However, the notions asserted here will require further validation through future research. This will require the continued development of methods that provide robust expectations for what aggregated patterns of behavior look like in the archaeological record. With the increased use of spatial statistics and agent-based modeling, it is becoming possible to generate and test hypotheses surrounding the behavioral and taphonomic complexity that underlay palimpsests.

Conclusion

Rather than dissect palimpsests, this study argues that there are merits to analyzing palimpsests as a whole. In doing so, we develop a novel methodology that combines some of the taphonomic and behavioral inputs that influence the formation of time-average assemblages. The application of these methods to the aggregate assemblages of Roc de Marsal shows that palimpsests, at least in this case, contain structured patterns. However, in many cases, these patterns are not easily tied back to behavior. The structure revealed in the archaeological layers at Roc de Marsal provides a starting point for discussions regarding the nature of the patterns present within palimpsests and the ways in which to best draw behavioral inferences from them. Ultimately, this will require continued work and the further incorporation of sophisticated geospatial statistics and computational modeling.

Acknowledgments

The research at Roc de Marsal had the financial support of the US National Science Foundation (Grants #09177739 and #0551927), the Leakey Foundation, the University of Pennsylvania Research Foundation, the Service Régional de l'Archéologie d'Aquitaine and the Conseil Général de la Dordogne. The authors thank Jean-Jacques Hublin and the Max Planck Society for supporting this research presented here. JR thanks David Braun and the Center for the Advanced Study of Human Paleobiology at George Washington University for supporting his research. The approach taken here to time-averaged assemblages benefitted from valuable discussions with a number of people including Simon Holdaway, Sam Lin, Željko Režek, and Luke Premo. A special thanks goes to José Ramón Rabuñal Gayo who reviewed the code and code/text consistency. As always, all mistakes remain our own. We note that Harold Dibble participated fully in the research presented here and was able to comment on the nearly final manuscript. The Roc de Marsal team misses him greatly.

Supporting Information

S1. rMarkdown file used to make this document (Reeves et al. - RDM Time Averaging.rmd).

S2. Supplementary information (Reeves et al. - RDM Time Averaging SOM.pdf).

S3. rMarkdown file used to make the supplementary information (Reeves et al. - RDM Time Averaging SOM.rmd)

S4. Data files needed to compile markdown documents (Reeves et al. - RDM Time Averaging.zip)

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