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Abstract: Ever since their percolation from neighbour disciplines, archaeology has employed spatial statistics to unravel, at different scales, past human behaviors from scatters of material culture. However, in the interpretation of the archaeological record, particular attention must be given to disturbance factors that operate in post-depositional processes. In this paper, we answer the need for a specific taphonomic perspectives in spatial analysis by applying point pattern analysis of taphonomic alterations on faunal and lithic assemblages from the Early Pleistocene site of Pirro Nord 13, Italy. The site, biochronologically dated between 1.3 and 1.6 Ma BP, provides evidence for an early hominin presence in Europe. The archaeological and paleontological deposit occurs as filling of a karst structure that is currently exposed. We investigated the spatial association of the archaeological and paleontological remains, as well as the spatial distribution of identifiable taphonomic features, in order to test different hypotheses of site formation and post modification processes. Our results contribute to the interpretation of the diagenetic history of Pirro Nord 13 and support the undisturbed spatial association of lithic artifacts and fossil remains.

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A. Howard
Editor,
Journal of Archaeological Science: Reports

Tübingen, December 28, 2015

Dear Howard,

I would be pleased to submit for publication in *Journal of Archaeological Science: Reports* an original research article entitled *The need for a taphonomic perspective in spatial analysis: formation processess at the Early Pleistocene site of Pirro Nord (P13), Apricena, Italy*, which is co-authored with M. Arzarello (University of Ferrara).

In this manuscript we investigate the depositional and post-depositional processes involved in the formation of the Early Pleistocene site of Pirro Nord 13 (Italy). The site, biocronologically dated between 1.3 and 1.6 Ma BP, provides evidence for an early hominin presence in Western Europe. The integration of spatial point pattern analyses with taphonomic studies on the faunal and lithic assemblages allows us to test different hypotheses of site formation and modification processes. Our study offers a contribution to the field of spatial analyses and site formation studies.

We strongly believe that *Journal of Archaeological Science: Reports* is the appropriate venue for our manuscript and we hope that our contribution will be welcomed.

Thank you in advance for your consideration.

Yours sincerely,

Domenico Giusti

The need for a taphonomic perspective in spatial analysis: formation processes at the Early Pleistocene site of Pirro Nord (P13), Apricena, Italy

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Abstract

Ever since their percolation from neighbour disciplines, archaeology has employed spatial statistics to unravel, at different scales, past human behaviors from scatters of material culture. However, in the interpretation of the archaeological record, particular attention must be given to disturbance factors that operate in post-depositional processes. In this paper, we answer the need for a specific taphonomic perspectives in spatial analysis by applying point pattern analysis of taphonomic alterations on faunal and lithic assemblages from the Early Pleistocene site of Pirro Nord 13, Italy. The site, biochronologically dated between 1.3 and 1.6 Ma BP, provides evidence for an early hominin presence in Europe. The archaeological and paleontological deposit occurs as filling of a karst structure that is currently exposed. We investigated the spatial association of the archaeological and paleontological remains, as well as the spatial distribution of identifiable taphonomic features, in order to test different hypotheses of site formation and post modification processes. Our results contribute to the interpretation of the diagenetic history of Pirro Nord 13 and support the undisturbed spatial association of lithic artifacts and fossil remains.

Keywords: Spatial analysis, Point pattern analysis, Site formation processes,

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Taphonomy, Early Pleistocene, Lower Palaeolithic, Pirro Nord 13

1. Introduction

Studies of site formation processes and spatial analyses have long recognized the role of post-depositional factors in affecting the integrity of archaeological assemblages (Hodder and Orton, 1976; Petraglia and Nash, 1987; Schick, 1984, 1986; Schiffer, 1972, 1983, 1987; Wood and Johnson, 1978). More recently, a number of scholars have stressed the importance of establishing the degree of disturbance to archaeological deposits to fully comprehend its record (Dibble et al., 1997; Djindjian, 1999; Texier, 2000).

Beside geoarchaeological techniques, several archaeological and paleontological methods are widely applied to characterize the processes involved in the formation of an archaeological site and assess any post-depositional 'background noise'. Taphonomy moves from its original definition (Efremov, 1940) to a wider conceptual framework, targeting vertebrate assemblages, as well as taphonomic entities produced by human behaviour (Domínguez-Rodrigo et al., 2011). Moreover and often in joint effort, from different spatial perspectives, fabric analysis (Benito-Calvo and de la Torre, 2011; Bernatchez, 2010; Bertran et al., 1997; Bertran and Texier, 1995; Domínguez-Rodrigo et al., 2014c; Lenoble and Bertran, 2004; McPherron, 2005; de la Torre and Benito-Calvo, 2013); refitting analysis (López-Ortega et al., 2011; Sisk and Shea, 2008; Villa, 1982); vertical (Anderson and Burke, 2008) and size distribution analysis (Bertran et al., 2006, 2012; Petraglia and Potts, 1994) offer meaningful contributions in the unraveling of site formation and modification processes.

The importance of spatial point pattern analysis in the archaeological interpretation of sites has long been recognized, but distribution maps still rely mainly on visual examinations and subjective interpretations (Bevan et al., 2013). On the other hand, quantitative methods, adopted from neighbor disciplines since the early 1970s (see Hodder and Orton (1976); Orton (1982); and references therein), continue to promote new impulses to archaeological spatial analyses and allow for the characterization of spatial patterns by adopting a more formal, inductive approach. Recent studies (Bevan and Conolly, 2006, 2009, 2013; Bevan et al., 2013; Bevan and Wilson, 2013; Crema, 2015; Crema et al., 2010; Crema and Bianchi, 2013; Eve and Crema, 2014; Orton, 2004), even acknowledging post-depositional effects or research biases, have continued to adopt at different scales (from intra-site to regional scales) improvements in spatial statistics to unravel past human behaviors from scatters of material culture. Yet, only a relatively limited number of scholars have applied point pattern statistics to site formation processes analysis (Domínguez-Rodrigo et al., 2014b,a).

In this paper, we adopt a taphonomic perspective to spatial point pattern analysis of the lithic and faunal assemblages from the Early Pleistocene site of Pirro Nord 13, Italy (Arzarello et al., 2007, 2009, 2012; Arzarello and Peretto, 2010). The main aim of our study is to investigate the processes involved in the formation of the Pirro Nord (P13) deposit and to evaluate the degree of post-depositional disturbance.

The site of Pirro Nord (P13) provides important contributions to the ongoing debate about the first hominin occurrence in Europe (Carbonell et al., 2008; Crochet et al., 2009; Despriée et al., 2006, 2009, 2010; Lumley et al., 1988; Parés et al., 2006; Toro-Moyano et al., 2011, 2009, 2013). A 'Mode 1' lithic assemblage has been identified in stratigraphic association with late Villafranchian/early Biharian paleontological remains. Furthermore, the presence of the Arvicolinae species *Allophaiomys ruffoi* correlated to the *Mymomis savini* - *Mymomis pusillus* biozone, allows for a biochronologically refined age of between 1.3 and 1.6 Ma, making P13 the earliest-dated locality with human evidence currently known in Western Europe (Lopez-García et al., 2015). The paleontological and archaeological remains are preserved inside a complex karst system, exposed and partially destroyed by mining activities of a Mesozoic limestone quarry. The fissure P13 is a vertical fracture located at the stratigraphic boundary between the Mesozoic limestone and the Pleistocene calcarenite formation. The deposit of the fissure is more than 4 meters-thick and includes large

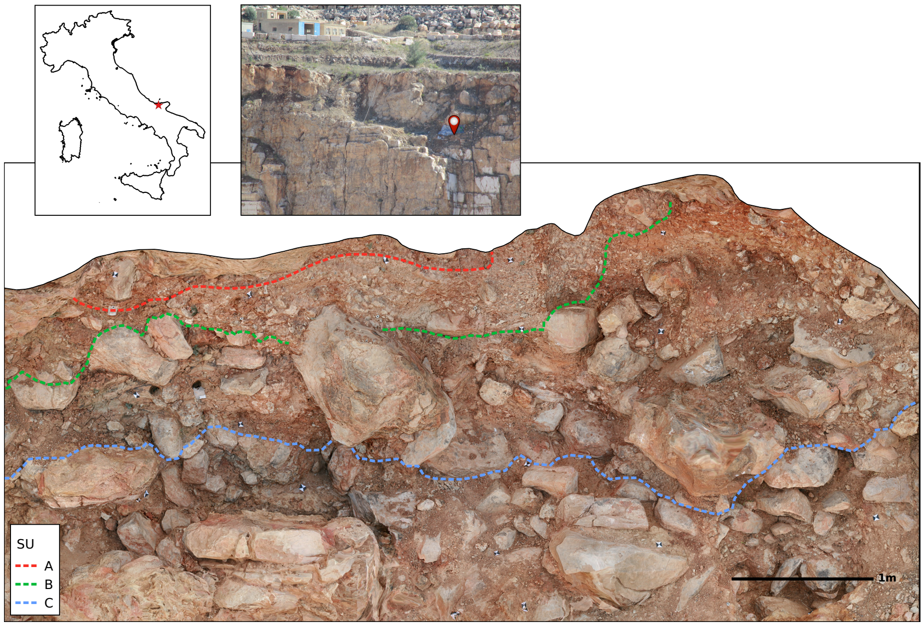

Figure 1: Location of the Pirro Nord site inside the ”Cave dell’Erba” quarry and snapshot of the photogrammetric model of the excavated area (2013), with marked sedimentary units.

blocks of Pleistocene calcarenite and clay-sandy sediments containing gravel-size clasts, numerous fossils and lithic artifacts (Fig. 1). As a residual component of a wider karst system, it is worthwhile to assess the degree of any potential post-depositional reworking of the archaeological and paleontological remains and to evaluate the stratigraphic integrity of the site.

2. Background

With the author’s permission, we integrate in our study unpublished (Bagnus, 2011) and published (Arzarello et al., 2012, 2014) data from previous taphonomic studies. A brief report is presented here.

2.1. Taphonomy of macro vertebrate fossils

Taphonomic analysis (Bagnus, 2011) on macro vertebrate fossils evaluated biostratinomic and diagenic processes and grouped faunal remains into different sub-categories: three main taphorecords (TR's, *sensu* Fernández-López, 1987) are defined according to different stages of bone surface modifications by physical and chemical agents (Tab. 1). Grouping was based mainly on weathering (Behrensmeyer, 1978; Díez et al., 1999; Kos, 2003; Torres et al., 2003), abrasion (Behrensmeyer, 1991) and oxidation (Hill, 1982; López-González et al., 2006; White, 1976; White et al., 2009), because these alterations prevail and are widespread across all the sedimentary units. Based on macroscopic observations of these main taphonomic features, fossils from TR2 and TR3 are interpreted as re-sedimented fossils: displaced bones along the sedimentary surface before burial; whereas fossils from TR1 are considered re-elaborated (*sensu* Fernández-López, 1991, 2007, 2011). The higher degree of abrasion and the presence in the latter sub-group of multiple generations of oxides, non uniformly distributed on the fossil, are explained with repeated exhumations and dislocations of previously buried elements (López-González et al., 2006).

Therefore, a hypothetical model of site formation processes has been proposed: animals died close to the karst sinkhole and the action of heavy rains transports sediments and partially articulated carcasses into the fissure. The rapid burial of fossils is confirmed by the general low degree of weathering. Karst erosional processes are responsible for the very large percentage of fractured fossils, as a result of the collapse of rock blocks from the vault. The TR1 group of fossils points to internal water-flows, reworking and transportation of already fossilized bones. Finally, manganese oxides that give the external widespread black color to all the fossils, stones and part of the lithic artifacts are products of the freatic water fluctuation. Although the taphonomic analysis definitely improved the interpretation of the P13 fossiliferous deposit, the interactions between bones and karst water flow have not been studied in relation to the spatial distribution and orientations of the skeletal elements.

2.2. Taphonomy of lithic artifacts

The degree of natural alterations (thermal, tribological and chemical) of lithic artifact surfaces, as a result of contact with the sediments, is a valuable

Table 1: Contingency table of taphorecords (reproduced from Bagnus, 2011).

SU	TR1	TR2	TR3	Total by SU
A	10	30	45	85
B	26	86	114	226
C	34	69	179	282
Total by TR	70	185	338	593

index of integrity of the depositional context and it can usefully support spatial analysis in reconstructing both the past environmental conditions and the site formation processes (Burroni et al., 2002). According to a recent review of preliminary technological analyses (Arzarello et al., 2012, 2014), the lithic assemblage shows a general good state of preservation. If we consider the degree of patination as a good indicator of the intensity, and not necessary of the duration, of chemical processes to which the deposit has been subjected (Burroni et al., 2002), artifacts undergo non-homogeneous interactions with chemical agents. Beside fresh artifacts, many of them (35%) bear Fe-Mn coatings (Fig. 2a). Iron-manganese, as well as white superficial patina (5%), seems to equally affect artifacts of different flint raw materials, more readily on those presenting a porous structure (Fig. 2b). Macroscopic observations of tribological features on the assemblage reveal mint to sharp, not rounded, artifact ridges and edges. Post-depositional fractures affect 20% of the lithic material (Fig. 2c). No refittings were found, as it is expected for materials coming from a non-primary position. As particle size distribution of lithic assemblages has great implications in interpreting site formation processes (Bertran et al., 2012), systematic screen-washing of sediments was carried out in order to guarantee recovery of lithic debris, even though a very low percentage of small-size specimens has been noted. This result can be preliminary explained either as a function of the mode of knapping, which did not produce a lot of debris, or is more likely due to natural post depositional processes (washed-out effect of low energy agents), prior to final burial possibly outside the karst fissure. Moreover, the dimen-

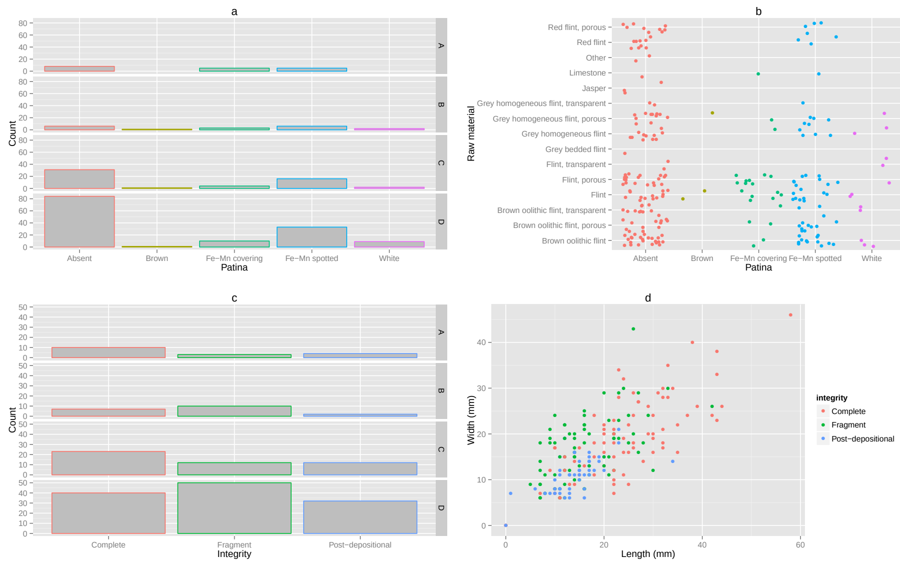

Figure 2: Frequency of patinae on the lithic assemblage (a) and their distribution on raw materials (b); frequency of fractures (c); scatterplot of artifact dimensions (d).

sional analysis of the complete lithic assemblage (Fig. 2d) does not show sorting effects.

We analyze the spatial distribution of taphonomic features on the lithic asssemblage, considering that various natural mechanisms, disturbing the spatial arrangement of artifacts and sediments, will produce distinctive combinations of wear features on the surfaces of lithic artifacts (Burroni et al., 2002).

3. Materials and Methods

Since 2007, systematic field investigations of the P13 fissure, carried out by the University of Ferrara (in collaboration with the Universities of Torino and Roma "La Sapienza", until 2010), have distinguished four Sedimentary Units (SU's) on lithological basis. From the top to the bottom of the section, units A to D are characterized by sediments of clayey-sand of increasing thickness (Fig. 1). Unit A includes few coarse gravels and a very low number of paleontological and archaeological remains. Unit B contains more gravels, while an abrupt increase in the number and dimension of clasts and big block of rocks is evident within units C and D. These last units show poor size sorting of angular and sub-rounded gravels, probably correlating to a low degree of reworking that took place during a short interval of time. We also record a significant increase in the number of fossils and artifacts (Fig. 3a). From the first excavation season, a grid of 1sq. m. units has been set. Since 2010, the three-dimensional coordinates of finds are recorded with a Total Station, which replaced the use of a water level. Orientation (dip and strike) of coordinated faunal remains (length $\geq$ 2cm), geological clasts (length $\geq$ 5cm) and all the lithic artifacts is estimated with a 45 degree of accuracy, which is not precise enough for detailed fabric analysis. During 6 years of excavation, more than 1600 macro vertebrate fossils have been recorded. However, Bagnus (2011) conducted taphonomical analysis on fossils recovered during the 2007 to 2010 field seasons and only 593 of these are classified in one of the three taphorecords (Tab. 1). From the total number of 366 lithic artifacts collected until the 2014 field season, 147 have been recorded with three-dimensional coordinates. In order to avoid possible sampling issues in spatial data analysis due to the variation in the recording methods, we selected subsets of the lithic and faunal collection, excluding SU's A and B. From the micro mammal assemblage, we included in this study only the *Allophaiomys ruffoi* species. Of the 53 arvicoline teeth collected from the screen-washed sediments, 49 have secure provenance attribution from SU B ($n = 2$), C ($n = 14$) and D ($n = 33$) (Lopez-García et al., 2015).

The observed patterns of the archaeological and paleontological remains within SU's C and D, has been treated as realizations of spatial point processes, i.e. site formation and modification processes.

Indeed, a spatial point pattern is generally defined as the location of events generated by a point process, operating simultaneously at different scales: a first-order global scale and a second-order local scale (Bailey and Gatrell, 1995). The former results from the frequency (density) of events within a bounded region; the latter results from spatial dependency between points, e.g. from a tendency for values of the process at nearby locations to interact with each

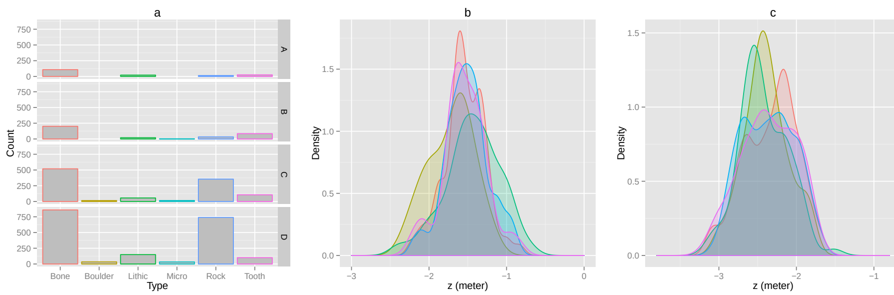

Figure 3: Frequency of finds (a) and their vertical distribution in SU's C (b) and D (c).

other. Three different types of interpoint interaction are possible: random (or Poisson); regular and clustered. Regular patterns are assumed to be the result of inhibition processes, while clustered patterns are the result of attraction processes. Therefore, two main issues of interest are explored by spatial point pattern analyses: the distribution (density) of entities in space and the existence of possible interactions between them (Ord, 1972).

First-order effect in the observed point-pattern is non-parametrically evaluated by means of kernel density estimation (Diggle, 1985). As an average density of points in the study region, intensity informs about uniform or inhomogeneous distribution of events.

Multiple scales of second-order patterning and the probability of a stochastic occurrence are explored by the Ripley's K summary function (Ripley, 1976, 1977), for both univariate and bivariate point patterns. This technique is designed to identify the relative aggregation and segregation of point data at different scales. The univariate $K(r)$ function measures the expected number of events found up to a given distance r around an arbitrary event. By comparing the estimated value $\hat{K}(r)$ to its theoretical Complete Spatial Randomness (CSR) value, it is possible to assess what kind of interaction exists between events. The bivariate function, or cross-type $K_{ij}(r)$ function seeks to evaluate, at each distance r, the spatial relation between two types ij of observed events. In this case, the definition of the null hypothesis of Complete Spatial Randomness and Independence (CSRI) use a randomization technique of either the location of one of the types (random shift hypothesis), or the type itself of the event at each point, preserving the original location (random labeling hypothesis) (Goreaud and Pélissier, 2003). The former aims to evaluate the spatial relationship between patterns of two independent processes, while the latter assumes the same process in determining the pattern for different types.

Monte Carlo simulation (Robert and Casella, 2004) has been used to generate a global critical envelope of random expected values for the null hypothesis of CSR and CSRI, providing an adequate level of statistical significance. We choose a small significance level ($\alpha = 0.01$ obtained with 99 simulations), due to the higher possibility to commit a Type 1 error by testing our hypotheses. Values of the empirical distribution (black solid line) are plotted against the theoretical Poisson distribution (red dotted line) and the simulated global envelope of significance (grey area). When the solid line of the observed distribution is above or below the shaded grey area, the pattern is significantly clustered or dispersed.

In order to investigate the processes involved in the formation of the Pirro Nord deposit, we assume the formation of the deposit to be the result of subsequent mass-wasting events filling the fissure and resulting in the chaotic distribution of fossils and artifacts independently of each other. We assume such processes responsible for the observed pattern of finds to be homogeneous and stochastic, to which we refer to as Complete Spatial Randomness (CSR) null hypothesis. We tested the relative spatial distribution of finds (lithics and fossils) comparing the empirical pattern to simulated Poisson patterns.

While on the other hand, to evaluate the degree of post-depositional disturbance of the deposit, patterns of taphonomic features are assumed to deviate from the homogeneous Poisson null hypothesis towards aggregation, e.g. where post-depositional agents locally rework the original distribution. Taking into account the inherent spatial properties of taphomomic processes, we assume that taphogenic products (*sensu* Fernández-López, 2000) in space are not mutually independent and that entities which are close to each other, are likely to have followed the same genesis. The identification of taphonomic spatial patterns allow us to model the spatial processes that produced them and thus propose a reconstruction of the forces involved in the formation and modification of the deposit. Like in applications of point pattern analysis in spatial epidemiology (Diggle, 2003; Gatrell et al., 1996), we distinguish between *cases* and *controls*. The distribution of cases of a certain taphonomic alteration can be regarded as the realization of a diagenetic point process, whereas controls points refer to non-altered remains. Spatial correlations of diagenetic alterations on the lithic and faunal assemblage are explored by the $K_{ij}(r)$ function, random labelling the pair case/control of each alteration. We assume in this case that independent processes, subsequent to the initial event that generated the location of the finds in each SU, determine their preservation status.

Finally, in order to assess the relative spatial distribution of the taphorecord sub-groups, we applied three-dimensional $K(r)$ and nearest neighbour functions. We suppose that processes determining the location of the TR1 type operated in a subsequent moment after the first deposition. We aim to establish in this case whether the sub-pattern of TR1 points are spatially segregated from the others.

All the spatial analyses were performed using the *spatstat* package (Baddeley et al., 2015; Baddeley and Turner, 2005) in R statistical software (R Core Team, 2015).

4. Results

The normal distribution of records in SU's C and D (Fig. 3b, c) allow us to exclude the covariate effect of the third coordinate and extrude it from spatial analyses. In order to reduce the impact of the Modifiable Area Unit Problem (MAUP) in point pattern analysis (Openshaw, 1996), especially insidious in this study due to the particular geological setting of the site, we shaped the windows of analysis according to the extension of excavated areas for each SU.

The intensity of lithic and faunal assemblages has been non-parametrically estimated by performing a Gaussian smoothing kernel of their distribution. Figures 4a, b show clustered distributions of fossils and evidence of a positive spatial association with the lithic assemblage. The bivariate version of the homogeneous K function allow us to statistically test the hypothesis of aggregation between the two types of remains. In figure 4c, d results of the cross-type K function indicate statistically significant clustering of the lithic artifacts and faunal remains for values of r higher that 0.15m and 0.2m in SU C and D respectively. These results statistically confirm the stratigraphic association of artifacts and fossils, previously based on field observations.

To achieve our second objective (to evaluate the degree of post-depositional disturbance of the deposit), we first analyzed spatial distribution of oxides on the lithic and faunal assemblages independently, then we moved to a comparative analysis. We are particularly interested in the spatial distribution of Fe-Mn oxides (cases) compared with the absence of them (controls). We also included in the analysis post-depositional fractures on lithic artifacts.

The observed density of lithic artifacts is proportional to the thickness of the stratigraphic units. The vertical distribution of lithics with Fe-Mn oxides follows the overall distribution of the complete assemblage. Thus, the higher occurrence of patinated artifacts at the lower part of the sequence cannot be considered the result of an oxidation process affecting this part more than the rest of the sequence (Fig. 5b). Therefore, we extruded from subsequent analyses the covariate effect of the third coordinate. Figure 5a does not suggest segregation of patinated and not-patinated lithics; instead, it shows a small area of clustered artifacts at the bottom-right corner of the map, identified by the highest peak in figure 5b. We also plotted the relative proportions of intensity to search for evidence of segregation between cases and controls. Strong aggregations of patinated and non-patinated lithics occur not uniformly in SU's C and D. If we perform random labeling of the presence/absence of Fe-Mn patina, the outputs of the cross-type function (Fig. 5c, d) show that the observed pattern of oxides is with a 0.01 level of significance the result of CSRI in SU C: oxides appear clustered, but we cannot reject the null hypothesis of a random distribution, since the black solid line falls within the grey envelope. Aggregation of patinated

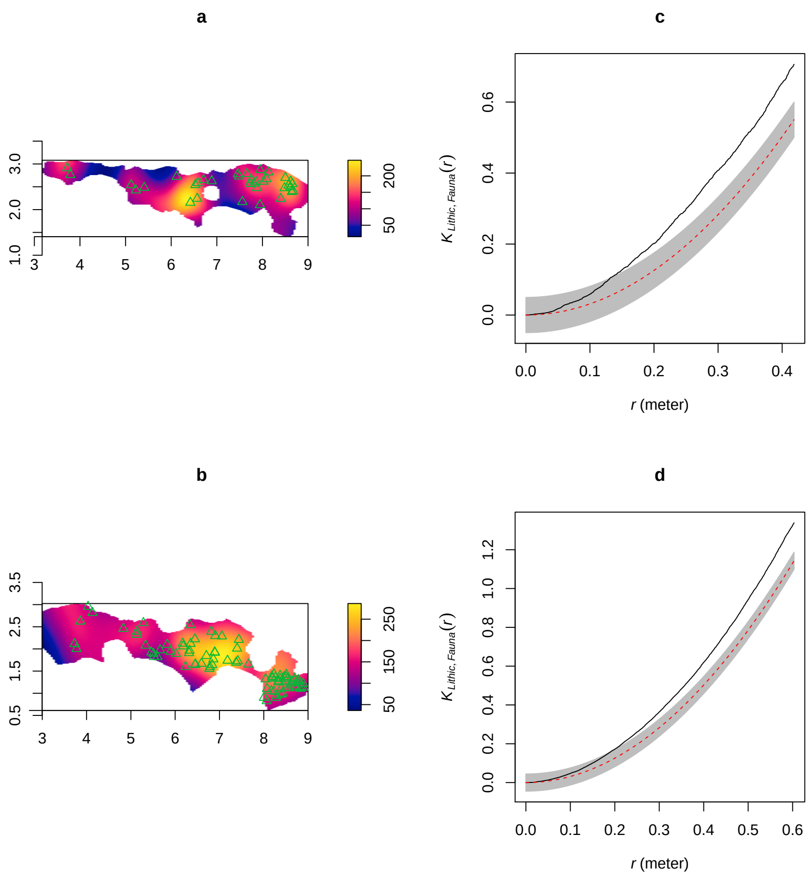

Figure 4: Smooth density estimation of the faunal assemblage and distribution of the lithic artifacts in SU's C (a) and D (b); global envelopes of the homogeneous cross-type $K_{ij}(r)$ functions for lithic/fossil in SU's C (c) and D (d).

and non-patinated lithics is reported for SU D, but in this unit the observed $K_{ij}(r)$ function over-exceeds the enveloped null hypothesis, hence it indicates statistically significant clustering. Such pattern reflects the already observed aggregation of lithic artifacts in that stratigraphic layer. Consequently, oxidized and non-oxidized artifacts most probably occur in SU D well aggregated in the space, while their aggregation is not statistically significant in the above unit, most probably due to the higher number of spatially isolated not-patinated lithics.

The spatial distribution of post-depositional fractures is evaluated by means of the cross-type $K_{ij}(r)$ function random labelling the cases/controls of broken artifacts and lithic fragments. The aim of this analysis was to asses whether the post-depositional fractures are the results of impacts and/or friction with rocks already present in the matrix. Figures 5e, f show some segregation tendencies, but the observed values remain inside the grey envelope and we cannot reject the null hypothesis of Complete Spatial Randomness and Independence. Stochastic processes are most probably accountable for the distribution of post-depositional fractures on the lithic assemblage in both of the studied stratigraphic units.

We could not compare the oxidation patterns between lithics and fossils from SU D, because the taphonomic analysis of Bagnus (2011) did not include fossils from SU D. We directed our analysis thus on SU C. Three ordinal degrees of oxidation (low, medium and high) are recognized, based on its aspect, intensity and extension. The distribution map (Fig. 6a) does not suggest any evident pattern. Vertical distribution of the low to high oxides seems to follow the overall distribution of fossils, suggesting no evident vertical covariate effect (Fig. 6b), as it was the case with the lithic assemblage. The i-to-any $K_{i\bullet}(r)$ function, as counterpart of the $K_{ij}(r)$ function, calculates the expected number of points of any type within a distance r of a typical point of type i. Strong aggregation of high oxides with any other degree occurs on fossils from SU C for higher values of r (Fig. 6c). When we apply random labelling of the extreme degrees of oxidation (high and low), the output of the bivariate $K_{ij}(r)$ function shows a segregation tendency between them, but it is not statistically significant and

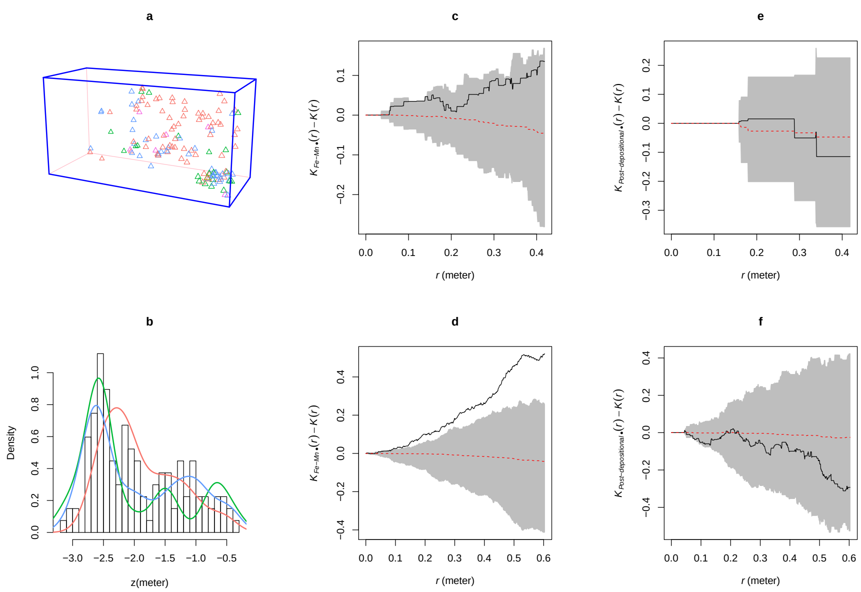

Figure 5: Distribution map of surface alterations on the lithic assemblage (a): absent of patination (red), Fe-Mn oxides covering the artifact (green), spotted Fe-Mn oxides (blu); vertical density of the lithics and their alteration status (b); global envelopes of the homogeneous bivariate $K_{ij}(r)$ function, random labeling $cases$/emphcontrols of patinated lithics in SU's C (c) and D (d); and random labeling post-depositional fractures and lithic fragments in the same units (e, f).

a Poisson distribution of oxides is more plausible (Fig. 6d).

The lack of taphonomic studies for the complete faunal assemblage definitely limits our analysis; however the discrete number of observations let us investigate the spatial distribution and interaction of the three categories of fossils (taphorecords) classified by Bagnus (2011). Most of the remains in the TR1 group come from SU's B and C (Tab 1), but the TR1 intensity is very low. Visual inspection of the 3D plot (Fig. 7a) suggests the global relative aggregation of the three types of taphorecords and that the global distribution of TR1 is random. The vertical distribution of the TR1, skewed towards lower values of z (Fig. 7b), does not allow to extrude that coordinate from the analysis. Due to the covariate effect of the third coordinate, we applied three-dimensional spatial statistics. Results of the 3D $K(r)$ function (Baddeley et al., 1993) suggest aggregation of TR1 for values of r higher than 0.6m and a statistical significant Poisson distribution for lower values. Similar clustering is also identifiable for TR2 and TR3, but at smaller distances of r, around 0.4m (Fig. 7c, d, e). The three-dimensional empty-space F function is the cumulative distribution function of the distance from a fixed point in space to the nearest point (Baddeley et al., 1993). Values of $\hat{F}(r) < F_{pois}(r)$ suggest a clustered pattern of TR1 slightly outside the envelope for $r > 1.5$m, while we cannot reject the null hypothesis of CSR for lower values (Fig. 7f). For each TR2 and TR3 point, the distance to the nearest TR1 point is computed. Results show, for both TR2 and TR3, high frequency of points to the nearest TR1 event for r around 0.4m and a definitive decline for $r > 0.5$m. These results reflect the outputs of the summary K function and offer a closest view. It validates the clustering pattern of the first taphorecord with the others. Since we are interested in patterns of interaction at lower scales, for $r < 0.6$m we cannot reject the null hypothesis of CSR and we consider the distribution of re-elaborated faunal remains (TR1) as most probably the result of a Poisson process.

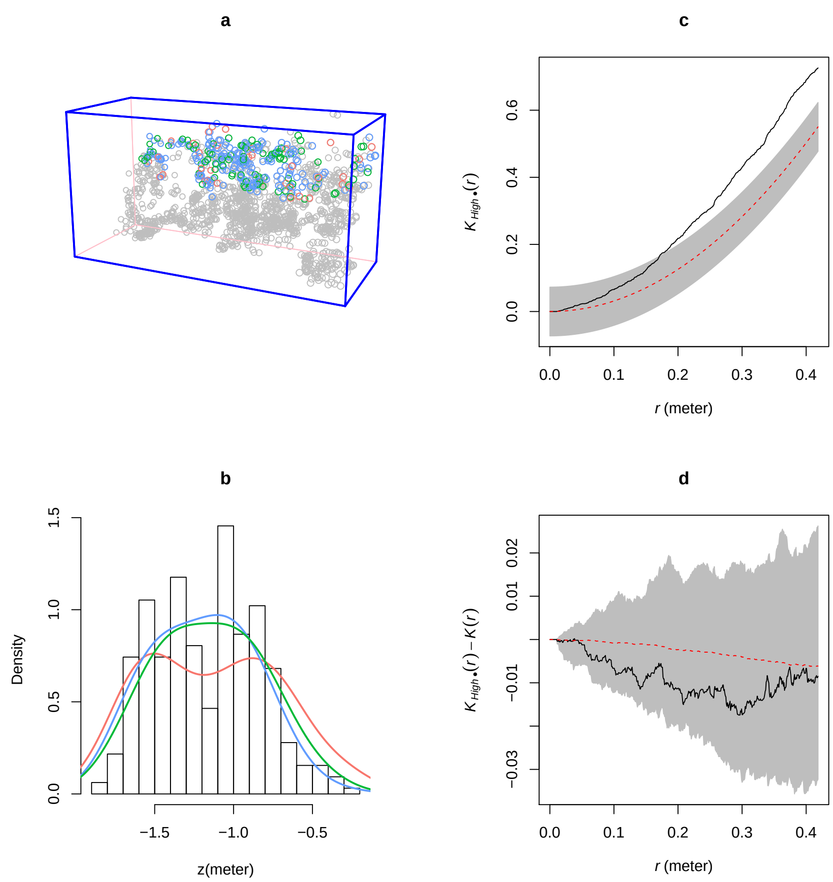

Figure 6: Distribution map of oxides on the faunal assemblage (a): absent to low (red), medium (blu) and high (green) degrees; vertical density of fossils and their alteration status (b); global envelopes of the homogeneous i-to-any type $K_{i\bullet}(r)$ function for high oxidazed fossils in SU C (c); global envelopes of homogeneous bivariate $K_{ij}(r)$ function, random labeling high/low oxidation status in SU C (d).

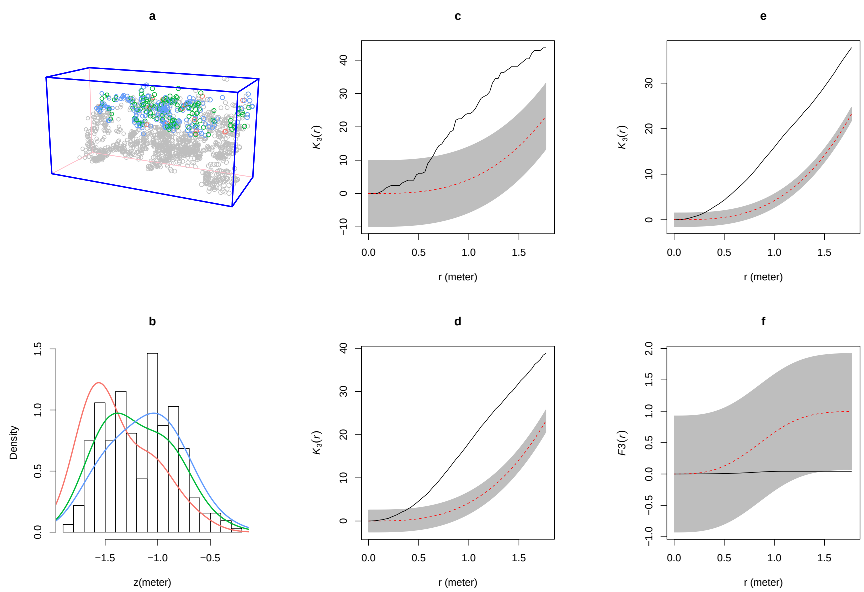

Figure 7: Distribution map of taphorecords (a): TR1 (red), TR2 (green) and TR3 (blu); vertical density of fossils and taphorecords (b); global envelopes of the homogeneous univariate 3D $K(r)$ function for taphorecord TR1 (c), TR2 (d), TR3 (e); global envelopes of the homogeneous univariate 3D $F(r)$ function for TR1 (f); 3D nearest neighbour distance of TR1 from TR2 (g) and TR3 (h).

5. Discussion

The Early Pleistocene site of Pirro Nord (fissure P13) has yielded evidence for one of the earliest occurrences of hominins in Europe. The importance of the evidence calls for a multivariate taphonomic analysis in order to establish the nature of the processes involved in the formation of the deposit and the degree of its post-depositional disturbance. We accomplish that need by investigating the spatial association of the archaeological and paleontological remains, as well as the spatial distribution of artifacts and fossils with diagenetic alterations. We focused our analysis on the lower stratigraphic units C and D, since they provide the most significant corpus of finds and they have been studied with the same research protocol.

Faunal remains and lithic artifacts show clear clustering when evaluated by means of Gaussian smoothing kernel. Positive spatial association between fossils and lithics is statistically confirmed by the cross-type K function (Fig. 4c, d) for the examinated SU's. Fossils and artifacts tend then to occur aggregated with each other, but in an uneven space. The clustered distribution of the finds is most likely the result of the limited accommodation space that was available for the sedimentation, because of the rugged topography of site. The big blocks of calcarenite, which in some places transect the stratigraphic units (Fig. 1), created a complex internal structure and might have influenced the direction of sediment accumulation. The stratigraphic and spatial association between the two types of remains should be considered as the result of the same formation process. Finds occur in the clayey-sand sediment together with a high number of angular to sub-rounded gravels and boulder-sized rock clasts. Such a stratigraphic setting suggests repeated mass-wasting processes (at least two events, represented by SU's C and D, which were included in this study) with low degree of reworking in a relatively short span of time (Arzarello et al., 2012). Rapid-moving and chaotic water-laden masses, such as mud-flows or earth-flows, of soilwash and rock rubble with fossils and artifacts (Butzer, 1982, p. 46), could have been triggered by intense rainfalls and trapped in the karst sink-hole directly opening to the outside. Sedimentary filling would have derived from the top, by gravity, directed into the empty space between the large limestone blocks that made up the internal structure of the fissure. The thickness of the layers is likely correlated to the intensity of such events. The presence of partially articulated vertebrate skeletal elements and their general low degree of weathering indicate fast burial and transport of bones from nearby locations (Bagnus, 2011). A close spatial proximity between the original location of the finds and the karst fissure, as well as a relatively fast burial, is also corroborated by the unrounded ridges and edges of the lithic artifacts and by the technological consistency of the assemblage (Arzarello et al., 2014). Our spatial statistics analyses confirm field observations about the role of topography in sediment accumulation, and the spatial association (clustering) of archaeological and paleontological remains.

After dealing with our first research question (to examine the spatial distribution of finds in the context of the site formation processes), our analyses were particularly directed to test the hypothesis of post-depositional processes reworking the deposit. We assume that the spatial aggregation of taphonomic surface alterations, and their relative segregation compared to non-altered finds, indicate the activity of diagenetic agents.

We focused more on the spatial distribution of oxides, because traditional explanation for the development of Fe-Mn patinas on the surface of flint refer to the deposition of various iron and manganese oxides and hydroxides out of soil water (Stapert, 1976). The origin of manganese coatings on fossils in karst environments may derive as well from circulating water or from the manganese present in the surrounding limestone rock, dissolved by groundwater (Hill, 1982). By applying a set of spatial statistics to the archaeological and paleontological remains, we searched for evidence of localized areas at the site, which might have been subjected to the presence of water, especially water-flows. In SU C, the spatial distribution of Fe-Mn patinas on lithics and fossils is, with a certain degree of significance, the result of homogeneous Poisson processes. In contrast, in SU D patinated and fresh artifacts occur definitely spatially aggregated to each other. Rottländer (1975) identified a possible different cause of Fe-Mn coatings in the iron that is already present in the flint. In this light, the spatial association of flint artifacts with and without patination also depends on the chemical and microstructural composition of the raw material itself. On the other hand, the same oxides affecting a good percentage of finds, have been equally found broadly scattered on the numerous clasts of calcarenite that are included in the matrix, thus supporting an external origin of the Fe-Mn coating process. The vertical distribution of oxides spans the complete stratigraphic sequence and apparently shows a gradual increase through the lower layers. Intensity of oxides is indeed more likely proportional to the density of finds and not related to the depth. The content of water and organic matter in the sedimentary body could be responsible for the randomly diffuse Fe-Mn patinations. In presence of organic matter, indeed, it is likely that the release of organic acids will accelerate patination on chert (Burroni et al., 2002). Moisture of the sedimentary body could also be accounted for the wide random spread of Fe-Mn coatings. We did not find statistically significant evidence of aggregation of oxidized records compared to non-oxidized ones; thus, we can exclude the assumption of localized concentration of water, which is included in the hypothesis advanced by Bagnus (2011) for the presence of inner flows reworking the deposit. Moreover, this previous interpretation is not supported by the spatial distribution analysis of the TR1 group. Results of the point pattern analysis applied to the three taphorecords (Fig. 7), suggest that the process responsible for the displacement at small scale (< 0.6m) of the TR1 group is completely random, i.e. it did not produce a clustered or regular pattern. Moreover, fossils from the TR1 group occur spatially aggregated with fossils from the TR2 and TR3 groups, suggesting some spatial proximity of the three types of processes represented by the three taphorecords. Consequently, the re-elaborated TR1 (*sensu* Fernández-López, 1991, 2007, 2011) cannot be associated with the reworking action of water-flows and is more likely correlated to random and limited rearrangement of parts of the sedimentary matrix. A possible cause of some localized movement of sediments could be the rock falls from the vault of the karst fissure, during the deposition of SU's C and D. As showed in figure 3a, an abrupt increase in the number of boulder-sized rocks is observed within the lower layers. Moreover, rock falls caused most of the post-depositional fractures on the faunal assemblage (Bagnus, 2011). Such intense erosional process could most likely be correlated to the seismic activity of the region (Bertok et al., 2013).

Post-depositional fractures, which affect 20% of the lithic assemblage, have been explained as possibly resulting from the fall into the fissure (Arzarello et al., 2014). We tested the hypothesis of post-depositional fractures caused by the transport and the impact of artifacts with rocks already present in the matrix. Results of our analyses suggest statistically significant random spatial distribution of post-depositional fractures. If we consider also the lack of refittings, they should occur before their secondary definitive deposition.

However, keeping a caution approach to spatial analysis, a documented point pattern can be most realistically thought of as the result of multiple processes heterogeneously working at different scales (Bevan and Wilson, 2013). Multiple or repeated post-depositional processes could obliterate contemporaneous or preceding patterns, resulting in a final Poisson distribution of the record. Moreover, karst site formation processes are highly dependent on the structure and extension of the overall karsic system, as well from the surrounding environment. The lack of information about the original characteristics of the system and the reduced area of excavation strongly limit the analysis. Furthermore, point pattern statistics, although powerful and essential, are at the moment not fully equipped to analyze three-dimensional distributions, especially when the study-area corresponds to a three-dimensional volume with a complex shape such as a karsic structure.

On the other hand, "one must look to non-spatial evidence to corroborate or disprove theories about spatial processes" (Hodder and Orton, 1976, p. 8). The integration with other taphonomic disciplines reinforces the results of spatial analyses and outline new opportunities for point pattern analyses. As recently remarked (Cobo-Sánchez et al., 2014), taphonomic research should be multivariate (Domínguez-Rodrigo and Pickering, 2010) and it should include spatial analysis as a heuristic tool in the interpretation of site integrity. This is especially demanding when the research questions deal with past human behaviour and even more so when site dating is based on the stratigraphic association of artifacts and fossils.

6. Conclusions

The Early Pleistocene site of Pirro Nord 13 provides evidence of the earliest human presence in Western Europe. Lithic artifacts have been found in a karst fissure filling, together with late Villafranchian/early Biharian paleontological remains. The main goals of our study were: 1) to investigate the depositional processes involved in the formation of the deposit; 2) to assess the degree of any potential post-depositional reworking of the archaeological and paleontological remains.

The integration of spatial point pattern analyses with previous taphonomic studies on the faunal and lithic assemblages allowed us to test different hypotheses of site formation and modification processes.

On the basis of our analyses, 1) we consider the deposit as result of subsequent events of a type of mass-wasting process, such as a mud-flow or earth-flow, carrying rock rubble with fossils and artifacts. The applied set of spatial analyses confirm, with an adequate level of statistical significance, the assumption, based on field observations, regarding the spatial association between the finds. 2) Based on our taphonomic point pattern analyses of several diagenetic features on the lithic and faunal assemblages, we reject the hypothesis of a substantial post-depositional reworking and mixture of the sedimentary deposit and we corroborate the stratigraphic integrity of the Pirro Nord 13 site.

Finally, the present study answers the need for a taphonomic perspective in spatial analysis, by applying well developed quantitative methods in spatial statistics. Point pattern analysis can be very flexible and is useful in the investigation of both cultural and taphonomic processes. Until now it has found limited application on taphonomic studies, but, as our study demonstrates, it offers new analytical opportunities to the multidisciplinary study of the complex processes that operate in the formation and modification of archaeological sites. It allows analysts to test multiscalar patterns and to model the taphonomic processes underlying archaeological distributions, which are otherwise difficult to identify from the simple visualization of maps, especially for those sites characterized by complex geo-stratigraphic settings.

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