# Spatial patterning of Middle Palaeolithic lithic assemblages at the Abri du Maras, Southeast France: combining GIS analysis and 3D palaeotopographic reconstructions

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**Title:**

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**Abstract:**

The intra-site spatial analysis of prehistoric assemblages is a topical way of assessing the use of space by ancient hominins. Such approaches can bring to light how prehistoric groups occupied their living space and organised activity areas, and thus describe their cultural and social behaviours. The Abri du Maras in Southeast France is a major Middle Palaeolithic site with huge potential for characterising the cognitive and technological behaviours of Neanderthals. In this study, we carry out a high-resolution spatial analysis focusing primarily on the lithic assemblages of levels 4.1 and 4.2, dated to MIS 3. The methodology combines two approaches: the use of GIS tools selected from free and open-source QGIS software, and palaeosurface rendering, using 3D software, in order to incorporate palaeotopographic data into the spatial analysis. Data for these palimpsests show a structured spatial patterning of occupations with some differences between the two levels. In level 4.1, a clear spatial pattern is observed with main areas where intense knapping activities were carried out and peripheral areas where specific remains were located. The spatial pattern for level 4.2 appears less clear, but also revealed patterns related to the type of remains. Our analysis provides evidence of complex spatial organisation for Neanderthals and corroborates previous results from other Middle Palaeolithic sites. We also highlight the relevance of our methodology, combining free and open-source GIS tools and palaeotopographic rendering, as well as the complementarity of 2D-3D tools, to achieve high-resolution spatial analysis of Palaeolithic sites.

**Keywords:** Spatial pattern, GIS analysis, Lithic assemblages, 3D palaeotopographic rendering, Middle Palaeolithic, Abri du Maras

## 1. Introduction

Spatial analysis is an effective tool for assessing the relationship between archaeological material and hominin behaviours and revealing small- and large-scale spatial patterns. It consists of two main approaches: inter-site analysis and intra-site analysis (Coil, 2016). Intra-site spatial analysis focuses on the material in individual sites through the study of site formation processes (taphonomy) and spatial patterning in order to assess social, economic or symbolic behaviours. In modern society, specific activities are related to particular areas (Alperson-Afil and Hovers, 2005; Anderson and Burke, 2008). Therefore, one of the assumptions underlying intra-site spatial analysis in archaeology is that similar associations can be observed in the archaeological record. Thus, spatial analysis has been an essential tool for many decades now, allowing archaeologists to better understand the behaviour of early hominins through the way they used space.

Due to their apparent lack of complexity, Middle Palaeolithic spatial structures have long been debated. Initially, some authors described Neanderthal spatial patterning as less complex than that of modern humans, comparing it to carnivores, such as hyenas (Pettitt, 1997), or as a simple and instinctive response to the environment (Mellars, 1996). However, these ideas have been criticised and some Lower and Middle Palaeolithic spatial structures have been considered as "modern" and similar to those described for *Homo sapiens* (Alperson-Afil, 2008; Alperson-Afil et al., 2009; Alperson-Afil and Hovers, 2005; Henry, 2012; Henry et al., 2004; Neruda, 2017; Oron and Goren-Inbar, 2014; Vaquero et al., 2001; Vaquero and Pastó, 2001).

The question of Neanderthal modernity was recently raised at the Abri du Maras. This rock shelter has yielded the oldest evidence of cord making known to date (Hardy et al., 2020). This fibre technology requires a complex knowledge of plants and the understanding of mathematical concepts for creating and managing pairs of numbers to create a string structure. Consequently, the authors consider Neanderthals as the cognitive equals of modern humans (Hardy et al., 2020). Therefore, the potential of the Abri du Maras for characterising the behaviour and technological capacities of Neanderthal has already been proven (Hardy et al., 2020, 2013; Moncel et al., 2021, 2014). In this context, this paper presents a high-resolution spatial analysis, focusing primarily on the comparison of the lithic assemblages of levels 4.1 and 4.2, dated to MIS3 (Richard et al., 2021, 2015), and considered as short-term occupations by the technological and subsistence strategies (Moncel et al., 2021, 2014). We combine innovative GIS (Geographic Information System) tools and palaeosurface rendering using 3D software. The main objective is to examine the occupation patterns of human groups at the Abri du Maras in relation to the topographical contexts of the site (Guillemot 2021). Through the study of two archaeological levels, we analyse and compare how occupants structured their inhabited space in a limited period of time.

## 2. The dataset

### *2.1.Chronological and archaeological context of the Abri du Maras*

The Abri du Maras is a vast rock shelter located in a small valley near the Ardèche River, downstream of the Ardèche gorges. It is currently 12 m long, and 3 m deep with a ceiling height of 2 m (Combier, 1967). The first excavations in the 1950s-1960s by R. Gilles and J. Combier unearthed a stratigraphic sequence of eight archaeological layers with Middle Palaeolithic deposits and a Levallois laminar debitage at the top of the sequence (Moncel et al., 1994). Those layers record the gradual collapse of the cave roof over time (Debard, 1988).

New excavations in front of the shelter since 2006 have focused on the middle and lower part of the stratigraphic sequence, only intermittently excavated during former fieldwork.

The new sequence records six stratigraphic units. Stratigraphic layer 6 is currently the oldest known unit bearing evidence of human presence (Moncel et al., 2018) and lies directly on the limestone substratum (Moncel et al., 2021). Layer 5 is made up of an organic brown unit with a sandy-silty matrix (Moncel et al., 2014). Three occupation phases have been identified in this layer and dated to the end of MIS 5 (Marín et al., 2020; Richard et al., 2015). The overlying upper deposit is layer 4, 0.5 to 1 m thick, consisting of blocks of various sizes in loessic lenses. This coarse infilling contains two phases of occupation (levels 4.1 and 4.2) separated by a sterile loessic layer, dated to MIS 3 (level 4.1: between 40 ± 3 ka and 46 ±3 ka ; level 4.2: between 42 ± 3 ka and 55 ± 2 ka) (Richard et al., 2015). More recent chronological data confirm these ages and the attribution of the sequence to MIS 3 (Richard et al., 2021). Layer 4 was deposited during progressively colder and drier conditions (Puaud et al., 2015) and the faunal corpus is composed in order of abundance of *Rangifer tarandus*, *Equus ferus* cf. *germanicus*, *Cervus elaphus*, *Bison priscus*, *Capra ibex*, *Equus hydruntinus* and *Megaloceros giganteus* (Daujeard et al., 2019). While the reindeer largely dominates the level 4.1 faunal assemblage, level 4.2 does not show such a mono-specific spectrum. Core technology consists of diverse, often short debitage sequences, including Levallois type debitage, made on local flint collected within 15-30 km of the site. The lithic assemblage and refits attest to short-term occupations with mostly unretouched flint flakes, blades, bladelets and points. Large ready-to-use flakes, blades and points were also brought to the shelter while additional *in situ* debitage produced small flakes (Moncel et al., 2021, 2014). The two layers have been considered as evidence of repeated short-term occupations.

The new excavations extend over a surface of around 50 m² for levels 4.1 and 4.2, which only represents part of the available surface of the shelter during human occupations. The accumulation and position of blocks from the collapse of the shelter indicate possibly the limits of the shelter ceiling during the occupation of levels 4.1 and 4.2. The ceiling border was estimated to be located in bands 8/9.

Excavations were conducted using a square metre grid. Each object, larger than 2 cm for faunal remains and 1 cm for lithic remains, was georeferenced in three dimensions using X, Y, and Z coordinates and recorded in a GIS database with (vertical and horizontal) spatial distribution data (Moncel et al., 2021).

### *2.2.Taphonomy and site formation processes*

The study of site formation processes is an essential step in deciphering the spatial analysis of Palaeolithic sites. Taphonomy has become crucial for distinguishing natural from anthropogenic accumulation processes (Dibble et al., 1997), and assessing how intact assemblages actually are (Henry et al., 2004). As Romagnoli and Vaquero (2016) point out, determining assemblage integrity is a prerequisite for assessing human behaviours through spatial pattern analysis.

At the Abri du Maras, taphonomy has been investigated in several studies. Both levels have been described as a well-preserved and almost exclusive anthropogenic accumulation, showing a near absence of animal-induced modification on remains such as digested marks or carnivore and rodent tooth marks (Daujeard et al., 2019; Moncel et al., 2015; Vettese et al., 2022). From a spatial point of view, the evidence of bones in anatomical connections, the lithic and bone refits associated with short-distance connection lines, the absence of significant orientation of material, as well as the scarcity of trampling evidence suggest no major disturbance of archaeological remains (Daujeard et al., 2019; Moncel et al., 2021, 2014;

Vignes, 2021) allowing us to conclude that the artefacts have not undergone any major spatial (horizontal or vertical) displacement (Moncel et al., 2015).

However, one particular part of the site shows post-depositional disturbances that have been identified during fieldwork. Beyond bands 8/9 in the southeast part of the shelter, the site is partially eroded due to the collapse of the shelter and the development of a small valley in front of the site. The material in this sector encountered some disturbances and will not be taken into account for this work.

### *2.3.Spatial database*

The lithic database, grouping all the coordinated lithic remains and their characteristics (length, width, type of rock, typological determination) was intensively exploited for the GIS spatial analysis of the lithic assemblages. We also used spatial information on charcoal remains and bone remains. As our research focuses on lithic assemblages, no detailed spatial analysis of bones was undertaken. We merely visualised the general scattering of bones and compared them to the more detailed spatial analysis of the lithic material. We also used data from lithic refits; namely the analysis of lithic refits from level 4.2, as the spatial analysis of lithic refits from level 4.1 has been published elsewhere (Moncel et al., 2021). Lithic assemblage composition is quite similar for both levels and mainly composed of flakes and flake fragments (including in both cases some Levallois flakes), laminar products, points and cores (Table 1).

| | Level 4.1 | Level 4.2 |
|---|---|---|
| Flakes (all sizes) | 981 | 984 |
| Flake fragments | 340 | 243 |
| Blades-bladelets | 208 | 100 |
| Points | 81 | 55 |
| Handaxes | | 1 |
| Cores | 51 | 38 |
| Entire-broken pebbles | 32 | 25 |
| Debris | 347 | 97 |
| Undetermined | | 72 |
| Total lithic artefacts:<br>*Including tools* | 2040<br>*50* | 1615<br>*81* |
| Bone remains | 2734 | 3099 |
| Ash lenses | 7 | 3 |
| Charcoal remains | 127 | 97 |

*Table 1. Technological categories of lithic assemblages and other artefacts from levels 4.1 and 4.2*

### *2.4.3D data*

For the palaeotopographic rendering of the two archaeological levels, we used the 3D point cloud of the Abri du Maras. Laser scanning was carried out during the 2019 campaign using a 360 Light Detection And Ranging (LiDAR) terrestrial laser scanner (Faro Focus). During acquisition, 42 scans were performed. These "scenes" were then assembled, using *3DReshaper* software, into a single point cloud of 70 million points, representing the whole shelter.

Since the scan was carried out several years after the excavation of levels 4.1 and 4.2 (excavations have currently reached layer 5), the 3D model does not show their respective topographies. Indeed, the 3D survey is carried out at a given moment of the excavation work and gives a 3D image of the surface in its state of progress during the excavation**.** Therefore, we used the following methodology to reconstruct them in the 3D model of the Abri du Maras.

## 3. Methods

### *3.1.3D palaeotopographic rendering*

The method of palaeotopographic rendering and analysis was carried out in three stages (Fig. 1). We began by cleaning and meshing the point cloud to obtain cleaned surface-based information (Jaillet et al., 2014), more suitable for the next steps. We also performed a rotation and three translations (in X, Y, Z coordinates) to obtain a model in the same coordinate system as the one chosen for excavations at the Abri du Maras.

The second stage consisted of surface rendering using the stratigraphic section drawings, which were drawn manually during past excavations and then computerised. Five section drawings were used, showing the stratigraphic limits of the two levels at different locations of the site. We proceeded as follows:

1. we created vertical planes georeferenced at the exact location of the section drawings,
2. we built texture on these planes by projecting the computerised section drawings (previously saved as a JPEG file),
3. we digitalised points on the stratigraphic limits of the two archaeological levels shown by the projected section drawings,
4. the obtained point clouds were then meshed to obtain surface-based information representing the base of each archaeological level.

The final step was to analyse the 3D topographies in more detail. We chose to go back to 2D by rasterising them on CloudCompare software (using the average cell height method and a cell size of 0,008 x 0,008 m). This process transforms a 3D surface into a Digital Terrain Model (DTM), which is a digital picture where each pixel contains a value representing elevation information (ESRI, 2016). Finally, we uploaded these DTM files into QGIS software and used the "profile tool" plugin to analyse the topography (Fig. 1). Several longitudinal (west-east) and transversal (north-south) profiles were made on the DTM passing through areas of high material density identified by the spatial analysis, allowing us to study the relationship between archaeological spatial structures and the floor topography during human occupation.

### *3.2. GIS spatial analysis*

The lithic database was imported into QGIS software 3.18 version (QGIS.org, 2021). Due to the high density of artefacts, scattering maps (where each item is represented by a symbol) do not show any clear distribution patterns. We thus used the following method for more in-depth spatial patterning.

#### *3.2.1 General scattering of artefacts: average nearest neighbour*

The first step is to statistically characterise the overall scattering of material. Average nearest neighbour is a method used to estimate whether the general pattern is dispersed, clustered or random (de la Torre et al., 2019; Moncel et al., 2021; Sánchez-Romero et al., 2021). If the null hypothesis is rejected, then we can apply "local methods" to identify subzones with clustering or dispersion phenomena (Sánchez-Romero et al., 2021).

#### *3.2.2. Local analysis*

Two different local methods were used to ensure the reliable identification of clusters:

**(1) Kernel density.** This is one of the most common and effective methods (Baxter et al., 1997). It converts a vectorial point layer into a raster heat map where the colour gradient depends on material density. This method calculates the density of point features around each output raster cell (the pixel size was set at 0.01 m, resulting in a low-pixel image with better resolution). A smoothly curved surface is created over each point and spreads to a specific radius around the points. Density value is highest at the point's location and decreases with increasing distance. It reaches zero at the limit of the search radius distance (set as 0.5 m which is probably the best adapted for our data). The sum of the overlapping Kernel surfaces is then calculated for each pixel (Alperson-Afil, 2008; Alperson-Afil et al., 2009; Oron and Goren-Inbar, 2014; Stavrova et al., 2019). Finally, we standardized densities using maximum values to obtain a uniform scale (from 0 to 1), to facilitate comparisons (Alperson-Afil, 2008; Alperson-Afil et al., 2009, 2007; Coil et al., 2020). Despite the popularity of this method, criticisms of its subjective aspects have emerged (the fact that the analyst has to input a search radius) and of its lack of statistical criteria to identify clusters (Sánchez-Romero et al., 2021; Stavrova et al., 2019).

**(2) Hotspot analysis.** Recently, statistical methods have become widely used tools for conferring statistical significance on the cluster identification process (de la Torre et al., 2019; Gabucio et al., 2023; Giusti et al., 2018; Mora Torcal et al., 2020; Reeves et al., 2019; Romagnoli and Vaquero, 2016; Sánchez-Romero et al., 2021, 2020, 2016; Spagnolo et al., 2020, 2019; Stavrova et al., 2019). Among the various methods, hotspot analysis, using the Getis-Ord Gi* statistic (Getis and Ord, 1992; Ord and Getis, 1995), appears to be particularly effective. We used the "Hotspot Analysis" plugin, available on QGIS since 2016 (Oxoli et al., 2018, 2017, 2016). Hotspot analysis detects statistically significant clusters based on quantitative variables and the spatial relationship between artefacts. Qualitative variables must be transformed into quantitative inputs using frequency per quadrats. We created a grid of 0.25 $m^2$ quadrats and counted items within each quadrat using the tool "count points in polygon". Hotspot analysis can then be performed. This method identifies high

concentration zones, called hotspots, and low concentration zones, called coldspots. The only prerequisite for this analysis is a sample of at least 30 elements. We systematically compared results with kernel density analysis to assess the proficiency of the QGIS hotspot analysis plugin.

Using these methods, we started by visualising the general distribution of archaeological finds considering all the lithics, bones and fire-related artefacts. Regarding the latter, it is important to note that no clearly structured hearth has been brought to light at the Abri du Maras. However, studies have shown that burnt artefacts and charcoal distribution can help to identify the locations of "phantom hearths" (Alperson-Afil, 2017, 2008; Alperson-Afil et al., 2007). Moreover, charcoal clusters may indicate dispersed hearths, as fire did not alter the surrounding sediment. Ash lenses can also point to the position of hearths or areas of ash dumping and cleaning. Consequently, we analysed the spatial pattern of fire-related artefacts to locate the position of possible hearths, or at least areas of fire-related activities.

Secondly, we carried out analyses by sub-categories of lithic artefacts in order to identify whether specific elements showed a particular pattern compared to others or to overall distribution. Our spatial analysis focuses in particular on stone knapping and the possible identification of the location of reduction sequences. For this purpose, the spatial analysis of Raw Material Units (RMUs) is an effective tool. RMUs incorporate the lithic material from a knapping event, or a series of knapping events carried out for the reduction of a specific nodule (Bargalló et al., 2020b; Chacón et al., 2015; Moncel et al., 2014; Vaquero, 2008; Vaquero et al., 2017). We can thus differentiate pieces brought to the site already knapped (tool kits) (Bargalló et al., 2020a, 2016; Moncel et al., 2021, 2014) from those resulting from *in situ* knapping events. Fifty-two RMUs have been described for level 4.1 (Moncel et al., 2021). Fifteen are composed of pieces introduced to the site already knapped, and a dozen indicate complete or almost complete on-site knapping sequences, with items from all stages of the *chaîne opératoire*. Thus, the spatial patterns of these RMUs may indicate the location of knapping activities and may differ from those of the tool kits. Cortical flakes represent the initial phase of the reduction sequence (Courbin et al., 2020; Oron and Goren-Inbar, 2014), so they may also indicate the place of knapping areas. Lithic refits of level 4.1 have already been published (Moncel et al., 2021), so we only performed the spatial analysis of the lithic refits from level 4.2. They can provide additional information about the knapping activities carried out on site. The examination of the spatial pattern of retouched artefacts is also a critical component of our spatial analysis as tools have already shown potential to characterize activities at the Abri du Maras (Hardy et al., 2013). We also conduct a spatial analysis based on quantitative criteria, such as the length of the artefacts, to determine whether the remains were organised according to their size. In particular, the comparison of these results with the palaeotopographic data may provide taphonomic information.

## 4. Results

### *4.1. General scattering of artefacts*

Nearest neighbour analysis was carried out to characterise the overall scattering of archaeological finds in levels 4.1 and 4.2. This statistical test was applied to all remains, and shows that spatial distribution is significantly clustered (all remains from level 4.1: score z = -55.9, $p$ value < 0.01; all remains from level 4.2: score z = -63.1, $p$ value < 0.01). We also applied this test to the three main categories of artefacts separately (level 4.1: lithics: score z = -32.7, $p$ value < 0.01; bones: score z = -41.7, $p$ value < 0.01; charcoal remains: score z = -

7.24, *p* value < 0.01; level 4.2: lithics: score z = -34.7, *p* value < 0.01; bones: score z = -49.9, *p* value < 0.01; charcoal remains: score z = -8.42, *p* value < 0.01;). In all cases, spatial scattering is statistically clustered.

### *4.2.General patterns of lithics, bones and fire-related artefacts in level 4.1*

The hotspot analysis of level 4.1 (Fig. 2) shows that lithic, bone and charcoal clusters overlap in the same areas, especially in the north-eastern part of the excavated zone, except for square I5, where no charcoal concentrations were found. Likewise, kernel density shows the same results (Fig. S1). Statistically significant clusters of charcoals appear to be closely spatially related to the densest accumulations of burnt artefacts (Fig. 2C). Charcoal and ash lenses are observed in areas with high concentrations of lithics and bones.

Thus, the main clusters of bones and lithics and indicators of fire activities are concentrated in the north and north-eastern part of level 4.1. Our analysis, therefore, shows that these were probably the main activity areas in level 4.1.

### *4.3.Spatial patterns associated with typo-technological aspects of level 4.1*

RMU flint-13 (n=231) and RMU quartz-5 (n=40) are the largest RMUs and include artefacts from all stages of the on-site *chaîne opératoire.* They are located in the previously identified main accumulation areas (Fig. 3), where most of the lithics, bones and charcoals are clustered. Kernel densities reveal the same spatial distributions (Fig. S2).

Eight out of the 10 RMUs with evidence of on-site *chaîne opératoires* show preferential concentrations in the same areas (square I5-I6 and the north-eastern part of band 6). These patterns may indicate that the main knapping areas were the northern and north-eastern parts of the site. For the other two RMUs, cluster distribution (Fig. S3 and S4) appears to indicate secondary knapping areas in the western and south-western parts of the site.

Fifteen RMUs, made up of 26 pieces, contain artefacts brought to the site already knapped (tool kits). Only kernel density analysis can be performed because they incorporate less than 30 pieces. Their spatial distributions indicate a more random pattern than the previous RMUs (Fig. 4). They seem to be scattered over the whole site without preferential accumulation areas. This confirms that spatial patterns differ for items from *in situ* knapping events and pieces introduced to the site already knapped.

Cortical flakes are clustered in the main accumulation areas confirming that knapping activities probably took place in this part of the site (Fig. 5). Kernel density shows the same results (Fig. S5).

Figure 6 shows that lithic tools are found in square I5 and also a little in M6, areas already identified for their cluster of lithics. However, the rest of the lithic tool spatial analysis displays a different pattern to those previously highlighted, which is confirmed by kernel density (Fig. S6). A significant cluster of tools is located in the middle of the excavated area, where no other cluster has been found. Very few retouched artefacts are found in the north-eastern part, where most lithics, bones and charcoals are located.

Several statistically significant clusters of large and small pieces were detected (Fig. 7). In the northwest, a cluster of large pieces (hotspot H1) was brought to light in an area where no particular accumulation had yet been identified. The second hotspot (H2) is mainly in square J7, where part of the lithic tools is located. The last hotspot (H3) is located in the eastern part of the site, south of the largest concentration of lithic remains. Two coldspots (clusters of small pieces) were identified. The larger one is located in the main concentration of lithic artefacts. A second coldspot (C2) to the south of H3 is composed of fewer pieces.

The composition of the aforementioned clusters confirms length differences between hotspots and coldspots (Table S1).

### *4.4.General patterns of lithics, bones, and fire-related artefacts in level 4.2*

We performed the same analyses than level 4.1 to identify the main activity areas in level 4.2. The hotspot analysis of lithics, bones and charcoals displays two main cluster areas. The most extensive one is in the north-eastern part, and the second one is in the northwest of the excavated area (Fig. 8). The largest charcoal cluster is in the western part. Kernel density shows the same results as hotspot analysis (Fig. S7).

Burnt lithic clusters overlap with charcoal and ash lenses (Fig. 8C). Fire-related artefacts are closely spatially related and are located in the main clusters of lithics and bones.

### *4.5. Spatial patterns associated with typo-technological aspects of level 4.2*

We carried out a detailed spatial analysis of the upper level 4.2. Many lithics from this level have been refitted but data from RMU analysis are still being processed.

Hotspot analysis (Fig. 9) and kernel density (Fig. S8) show that cortical flakes are clustered in the western part of the site. No dense zone, or meaningful cluster, is visible in the northeast, among the largest concentration of lithic artefacts. As mentioned above, we did not focus on the southeast of the site (from squares K9-L9-M9-N9) as it has undergone extensive post-depositional disturbances.

Out of a total of 1615 lithic remains from level 4.2, 81 are retouched artefacts. Statistically significant clusters are found in the western part of the site (Figs. 10 and S9), whereas no tool clusters are visible in the eastern part of level 4.2, where the highest concentrations of lithics and bones are found. However, lithics, bones and charcoals are also clustered in the western part of the site. Lithic tools are concentrated on the margins of those clusters, rather than in them.

The spatial analysis of cores also shows clustering in the west of the site (Figs. 11 and S10) and no statistical concentrations in the northeast, where the most significant clusters of remains are located.

We performed hotspot analysis according to artefact length to shed more light on these patterns (Fig. 12). Three clusters of large pieces can be identified, two of which are in the disturbed area. The first hotspot (H1) is located in the northwest of the site, close to where cores, tools, and clusters of lithics, bones and charcoals are found. Two other hotspots (H2 and H3) are in the disturbed area of the site. A significant cluster of small artefacts (coldspot C1) is located in the north-eastern part of the site, where the highest concentration of lithics and bones was already identified. This area is thus mainly composed of small pieces, and no large pieces are found in this zone. A second coldspot (C2) is in the disturbed part of the site. The composition of the clusters confirms length differences between hotspots and coldspots (Table S2).

Level 4.2 comprises 22 refit groups, for a total of 53 pieces, with 29 connection lines (Fig. S11, Table S3). Most of the refits are in the main accumulation areas (northeast of the site) and only two refits are in the western part of the excavated area (Fig. S11). Most of the connection lines are between 0 and 2 m and are within the normal dispersion range for on-site knapping sequences, as shown by experimental archaeology (Cziesla, 1990; Moncel et al., 2021, 2014; Vaquero et al., 2019, 2017). Four connection lines are beyond 2 m and could suggest the intentional anthropogenic displacement of some pieces during daily activities.

### *4.6.Palaeotopography of level 4.1*

The topography of the base of the surface of level 4.1 was rendered in 3D. Most of the area was successfully interpolated, bringing to light the general topography of the level. Fig. 13A shows the dip in an altitude-dependent colour scale. The 4.1 surface shows downward dips from the northwest to the southeast, probably due in part to the compression and compaction of sediment over time. The highest elevation in the northwest corner is about -2 m above level 0, and the lowest in the southeast corner is almost -3.60 m.

The DTM and the QGIS "profile tool" plugin allow us to study the topography in more detail (Fig. 13B). Several longitudinal (west-east) and transversal (north-south) profiles were made on the DTM, passing through clusters of small and large lithic artefacts previously identified. The longitudinal sections show a slight, progressively decreasing west-east dip, with a steeper slope in the western part, clearly visible on profiles BB' and CC' (at bands E, F and G). Beyond these bands, the dip is negligible or even non-existent, as shown in the eastern half of profile CC'. The difference in elevation from one end to the other is 1 m maximum. The transversal profiles (DD' and EE') show a north-south dip, steeper than the west-east dip, with a negative gradient of almost 1 m over a distance of 3 m (section DD'). However, the slope rises slightly in the middle (band 7) and falls again.

### *4.7.Palaeotopography of level 4.2*

In the upper level, 3D rendering was successful for most of the area, but part of the eastern trench could not be entirely interpolated. Nevertheless, this surface provides general information on the northwest to southeast dipping topography of level 4.2 (Fig. 14A).

In QGIS, profiles were made on the DTM (Fig. 14B) and deliberately run through clusters of small and large remains to detail the topography in these areas. The W-E profiles show a gradual decrease in dip from west to east, with an altitude differential of about 1 m from one end to the other. In the western part of the site, the DD' profile shows a very slight north-south dip in the first part, followed by significant steepening of the slope and subsequent stabilising. In the eastern part, the dip decreases progressively from north to south and then significantly, with an altitudinal difference of 90 cm over a distance of 4 metres (section CC'). However, the slope rises slightly and decreases significantly again towards the centre of the surface (visible on profile EE'). The southern ends of profiles CC' (from square M9) and EE' (from square L9) correspond to the beginning of the disturbed area.

## 5. Discussion

### *5.1. Site formation processes*

Site formation processes have to be considered when performing spatial analysis. It is a prerequisite for assessing human behaviours through spatial patterns (Romagnoli and Vaquero, 2016). As previously said, many studies have shown that both levels are well-reserved anthropogenic accumulations, with a lack of post-depositional disturbances (Daujeard et al., 2019; Moncel et al., 2021, 2015, 2014; Vettese et al., 2022; Vignes, 2021).

Our analysis completes those results. The combination of spatial analysis and topographic data is a powerful tool that can help to assess site formation processes. Indeed, disturbances, such as runoff or water flow, can alter the spatial distribution of remains, causing movement and downslope displacement (Petraglia and Potts, 1994). Spatial analysis and palaeotopographic rendering of levels 4.1 and 4.2 do not show such patterns. The areas

with the highest artefact density are located in the northern part of the site and follow a gentle slope. In contrast, the lowest areas (south and southeast of the site) contain fewer remains and no significant clusters of material. This pattern is general across the site and for both levels, the areas of highest densities are found in the highest part of the site, east and west, while towards the south, the artefact densities are much lower. Thus, the material is not located in the more depressed areas and is not organised following the slope, which would have been observed if levels had encountered spatial disturbances caused by water for example. In addition, water flows tend to sort archaeological remains by size (Dibble et al., 1997; Gabucio et al., 2023; Petraglia and Potts, 1994; Sánchez-Romero et al., 2020) with displacements of large pieces into hollows and the removal of smaller remains from the assemblage. Both archaeological levels comprise clusters of small items that are found in the northern part of the site, areas with gentle slopes. For level 4.1, section EE' has a slight depression and the majority of the cluster of large lithic artefacts is not located in the deepest part, but at the margins of this depressed zone. Thus, we can say that, for both levels, clusters of large pieces are not in the lowest or most depressed part of the site. The proximity of the large and small artefact clusters, especially for level 4.1, also indicates the absence of significant spatial disturbance, such as water flows.

Another important issue and a common feature of Palaeolithic sites is the palimpsest problem (e.g., Bailey, 2007; Galanidou, 2000; Henry, 2012; Machado et al., 2019, 2013; Malinsky-Buller et al., 2011; Mallol and Hernández, 2016; Mora Torcal et al., 2020; Picin and Cascalheira, 2020; Reeves et al., 2019; Vaquero, 2008; Vaquero et al., 2012; Vaquero and Pastó, 2001). Both levels are palimpsests of several occupations (Moncel et al., 2021, 2015), meaning that Neanderthals possibly occupied the same areas repeatedly during short-term stays in the shelter. Multiple short-term occupations of the same site during a short period of time are a common characteristic of Middle Palaeolithic sites (for this specific topic see Cascalheira and Picin, 2020). In those cases, vertical plots are commonly used to decipher palimpsests (e.g., Bargalló et al., 2020, 2016; Coil et al., 2020; Mora Torcal et al., 2020; Sañudo et al., 2012; Vaquero, 2008; Vaquero and Pastó, 2001) and although this paper focuses primarily on horizontal analysis, we also visualised vertical dispersion (Guillemot 2021). But it was not possible to untangle any palimpsests.

However, in some cases, palimpsests are not necessarily an issue. Indeed, the rapid burial of the levels at the Abri du Maras (Moncel et al., 2021), makes them "rapid-accumulation palimpsests" (Malinsky-Buller et al., 2011). According to this model, spatial patterns and anthropogenic clusters can still be observed even though these two sub-levels are palimpsests. Moreover, following the idea of Reeves et al., (2019), palimpsests should not only be viewed as a hindrance to spatial analysis but on the contrary, can be a necessary condition for identifying behaviours. Bailey and Galanidou (2009) already suggested that palimpsests, especially in caves or rock shelters, have a great potential to give information about the use of space. The fact that the same rock shelter was used many times for many short-term occasions and probably by the same groups tends to create patterns that are repeated over time. This is mainly due to the physical conditions of caves and rock shelters (walls, ceiling, interior versus exterior…) that influenced the way of using space, and the fact that palimpsests create a living space where remains of past occupations may influence subsequent occupations (Bailey and Galanidou, 2009). Thus, these characteristics probably influence the way of re-using the same space, especially if the occupations are of similar duration. Following that idea, palimpsest does not hinder patterns but creates them. However, even if palimpsest makes patterns distinguishable, we must keep in mind that the different clusters may not be contemporaneous.

### *5.2. Significance of level 4.1 spatial patterns*

The hotspot analysis of level 4.1 identified several main activity areas associated with peripheral areas (Fig. 15A). The largest clusters of lithics, bones and fire-related remains are concentrated in the north-eastern part of the site. The analysis of cortical flakes and RMUs shows that *in situ* knapping activities took place there. This is confirmed by the presence of clusters of lithic refits in this area, with connection lines within the normal dispersion range for on-site knapping sequences (Moncel et al., 2021). Metrical analysis indicates that this area includes small flakes, which are a reliable indicator of the location of knapping activities (Henry et al., 2004; Sañudo et al., 2012; Vaquero et al., 2001; Vaquero and Pastó, 2001). All the analyses point to areas dedicated to knapping activities and surrounded by some clusters of lithic tools and large lithic artefacts (Fig. 15A). Those types of remains have been described as artefacts moved from the main activity areas to the peripheries (Vaquero et al., 2001).

This pattern can be compared to the "drop-toss area" model observed among modern hunter-gatherers (Binford, 1983). According to Binford, knapping activities are concentrated in areas around hearths. These areas mainly contain small pieces ("drop zone"). The reason for this is that large pieces, which could potentially hinder the continuation of the activity or are required for use elsewhere, are moved to peripheral areas ("toss zone"). Level 4.1 of the Abri du Maras displays similar spatial patterns. No hearth has been identified but ash lenses, charcoal remains, burnt lithics and their spatial relationship indicate fire-related activities and perhaps the location of short-lived hearths that did not alter the surrounding sediments. Studies have already shown that fire-related artefacts can attest to ‘phantom hearths’ (Alperson-Afil, 2017, 2008; Alperson-Afil et al., 2007). The knapping areas in level 4.1 seem to be closely related to fire-related activities.

The particular case of square I5 should be mentioned. While showing evidence of a drop zone (cluster of cortical flakes, cluster of RMU showing knapping activities and presence of refits), this square also displays a cluster of tools. Length analysis is not helpful as the results do not show statistical evidence for clusters of small or large artefacts. This mixture of features may be due to palimpsests and illustrates that some parts of the site may be difficult to understand due to repeated short-term occupations. This could also explain the presence of few lithic tools in M6.

This paper focuses almost exclusively on lithic material and it is thus difficult to define spatial organisation in greater detail. Level 4.1 contains evidence of intense specialised reindeer butchery activities (Daujeard et al., 2019; Moncel et al., 2021), showing that all the stages of the butchery *chaîne opératoire* were carried out *in situ* (Daujeard et al., 2019; Vettese et al., 2017). A high-resolution spatial analysis of the faunal remains will be required to complete our conclusions.

### *5.3. Significance of level 4.2 spatial patterns*

The spatial organisation of level 4.2 is different to that of level 4.1 (Fig. 15B). We identified two main accumulation areas, possibly related to the aspect of the shelter. It is important to recall that the shelter may have been slightly larger during occupations of level 4.2 than level 4.1. Neanderthals could have occupied the site differently, extending activities over a larger surface. Another explanation could be the extension of level 4.2 excavations. Indeed, compared to the above level, level 4.2 was excavated over a larger area, which could generate a bias in the understanding of the site and give the impression that Neanderthals occupied the shelter over a larger surface.

Area 1 presents the most significant clusters of lithics and bones. Further investigation showed that this area contains mainly small artefacts. Moreover, most of the lithic refits are from this area, with most connection lines in the normal dispersion range for on-site knapping sequences (Cziesla, 1990; Moncel et al., 2021, 2014; Vaquero et al., 2019, 2017). As with the upper level, these two characteristics appear to reveal an area used for knapping activities. Area 2, located in the western part of the site, comprises smaller clusters of lithics and bones but also contains the largest cluster of charcoals. This area includes clusters of lithic tools, cores and large artefacts. With just two refits and no clusters of small remains, it is unlikely that the western part of level 4.2 was a central location of knapping activities. Both areas attest to fire-related items, even though more intense fire activities seem to have taken place in Area 2, as shown by the higher density of charcoals. Finally, squares I6 and J6 are intriguing. They are located at the boundary of Area 1, but clusters of cores, cortical flakes and lithic tools can be observed in this zone.

Binford's model seems less relevant here as it would predict more fire-related artefacts and cortical flakes in Area 1, where knapping activities have been identified. Without data on RMUs, it is difficult to describe the spatial patterning of this level in more detail. However, we clearly observe the distribution of different types of artefacts in distinct areas, and these two areas attest to very different typo-technological characteristics. The absence of refits connecting them confirms the organisation of level 4.2 into two different zones, and perhaps different and unrelated phases of site occupation. Moreover, an initial spatial analysis of faunal remains has identified a different pattern between ungulate types and according to anatomical elements. While the remains of large-sized ungulates (horse, bison, megaceros), as well as cranial and post-cranial axial skeletons, seem to be more densely concentrated in Area 1, the bones of medium-sized ungulates (reindeer, red deer), and the remains of the appendicular skeletons are more concentrated in Area 2 (Vignes, 2021). This may confirm the spatial organisation of level 4.2 into two distinct areas, or unrelated phases of occupation.

### *5.4. The Abri du Maras in the Middle Palaeolithic cultural context*

The spatial analysis of Middle Palaeolithic sites is an integral component of debates on the complexity of Neanderthal behaviour and social organisation (e.g., Anderson and Burke, 2008; Henry et al., 2004; Oron and Goren-Inbar, 2014; Pettitt, 1997; Vaquero et al., 2001; Vaquero and Pastó, 2001). For many years, no complex spatial organisation was found for Middle Palaeolithic sites (Alperson-Afil and Hovers, 2005), sometimes due to the inherent difficulties in understanding palimpsests. This has led some authors to consider that Neanderthal social organisation was less complex than that of Modern Humans (Oron and Goren-Inbar, 2014).

However, that idea has now come under strong criticism, and some authors view Middle Palaeolithic spatial structures as indicative of complex organisation, similar to that of *Homo sapiens*. At the Abric Romaní (Spain, levels H, I, J, K and L dated between 45 to 52 ka), the spatial layout of Neanderthal activities fits the model of hearth-related assemblages, with knapping activities systematically carried out near hearths (Vaquero et al., 2001; Vaquero and Pastó, 2001). The Jordanian Tor Faraj site (floors I and II, average age of 55.1 ± 5.6 ka) is spatially organised in a complex way, with butchery areas, final lithic and food processing areas, initial lithic processing areas and bedding areas (Henry, 2012; Henry et al., 2004). At the Amud Cave site in Israel (55 to 69 ka), sub-unit B2 comprises knapping areas and specific zones for the disposal of unusable lithic materials (Alperson-Afil and Hovers, 2005). In levels 2.2 and 3 of the Crimean site of Karabi Tamchin (MIS 3), a differential use of space was observed according to activities (discard areas, tool manufacturing, bone processing and tool use areas) (Anderson and Burke, 2008). Level VII of the Amalda I Cave

(Spain, between ca 42 600 and 44 500 uncal BP) reveals a different spatial layout in keeping with artefact type and the length of remains (Sánchez-Romero et al., 2020). The spatial organisation of the Israeli open-air site of Quneitra (53 ± 5.9 ka BP) is delimited by knapping, butchering or marrow extraction activities (Oron and Goren-Inbar, 2014).

Our analysis indicates that the Neanderthal groups of the Abri du Maras structured the spatial management of the shelter, with main activity areas used for intense knapping activities and associated with fire-related activities. Other areas with specific remains, such as the largest pieces or lithic tools, were located elsewhere. These behaviours are similar to those described above; the inhabited space is structured by the type of remains and probably by the type of activities. It is important to emphasise that the spatial pattern of level 4.2 is slightly different and more difficult to interpret than level 4.1, perhaps because the shelter was occupied over a larger area or because activities were different. It is important to remember that while the lithic industry is similar for both levels, the faunal assemblage of level 4.2 is more diverse (Daujeard et al., 2019) perhaps reflecting a different type of occupation. The palaeotopographic reconstructions for the two levels do not show significant differences (a decreasing slope from northwest to southeast for both levels), and the inter-level variation of the spatial organisation was probably dictated by the social organisation or cultural choices of Neanderthal groups, such as types of activities, and not by a change in soil topography. Inter-level variations have already been observed for Middle and Upper Palaeolithic sites (e.g., Anderson and Burke, 2008; Caron-Laviolette et al., 2018; Vaquero et al., 2001). A recent study on butchery tradition indicates that different marrow extraction methods occurred between levels 4.1 and 4.2 (Vettese et al., 2022), suggesting that the shelter was used by distinct groups with their own tradition and perhaps different group compositions or structures (more or less specialized Neanderthals). This may explain the difference in the spatial pattern between levels, both groups occupied the site differently. This variation in spatial organisation between sub-levels has yet to be confirmed by further analysis, especially spatial studies of faunal remains, level 4.2 RMU analysis and high-resolution vertical spatial analysis.

### *5.5. Methodological aspects*

We wanted to demonstrate the efficiency of a spatial analysis carried out under a free and open source GIS software. While some authors have stressed the need to use such open source software in order to ensure a healthier scientific practice (Ducke, 2012; Ince et al., 2012; Morin et al., 2012), others have shown the advantages of open source GIS software over proprietary software for archaeological research (Orengo, 2015). This is especially important in a context where GIS has become an indispensable tool for archaeologists (Brouwer Burg, 2017; Howey and Brouwer Burg, 2017; Orengo, 2015; Richards-Rissetto, 2017; Whitley, 2017). So far, hotspot analyses have only been carried out using commercial software, including ArcGIS (Mora Torcal et al., 2020; Sánchez-Romero et al., 2021, 2020; Stavrova et al., 2019). Our analysis shows the relevance of performing hotspot analysis using an open source software. We systematically compared hotspot results with kernel density analysis to test the reliability of the plugin and confidently identify clusters by combining methods (Sánchez-Romero et al., 2021). Both methods gave the same results, thus, the QGIS "Hotspot Analysis" plugin appears to be an appropriate free and open source tool for studying spatial patterns.

Palaeotopographic reconstruction is a valuable tool to help investigate the spatial distribution of archaeological remains (Bargalló et al., 2020a; Gabucio et al., 2023; Sánchez-Romero et al., 2020). Combined with high-resolution spatial analysis, it provides detailed behavioural and taphonomic information. The 3D method used in this paper is not just a

digitisation of archaeological surfaces but a reconstruction of parts of the site, which no longer existed when the laser scanning of the Abri du Maras was carried out. We have used available section drawings to reconstruct ancient topographies. While this method seems efficient, we must to emphasize that the reconstructed surfaces are imperfect, as some parts could not be interpolated correctly. This was due to the limited number of useful section drawings that have been used (some being unavailable to record or to use by the quantity of blocks due to the final collapse of the shelter). That point is essential because even if the reconstructed topographies seem coherent, we would have needed more stratigraphic section drawings, spread over the whole site area, for homogeneous, complete and more precise rendering.

Finally, we would like to highlight the complementarity between 2D and 3D analyses. Once the palaeosurfaces had been rendered in 3D, we chose to go back to 2D by analysing them with QGIS. In our view, the possibilities of 2D-3D back and forth have not been sufficiently underlined, even though the potentialities of "GIS + 3D" have already been discussed (Dell'Unto and Landeschi, 2022). 3D technologies offer access to new types of analysis and ultimately to a better understanding of archaeological sites (Campana, 2016; Westoby et al., 2012). At the same time, the development of GIS has led to significant advances in how we visualise, process and analyse archaeological data (McCoy and Ladefoged, 2009). But when used together, 2D and 3D methods offer excellent tools for the high-resolution spatial analysis of archaeological sites and the reconstruction of the daily activities of past human groups.

## 6. Conclusion

The primary goal of this research was to perform a high-resolution spatial analysis of the lithic assemblages of levels 4.1 and 4.2 (MIS 3) from the Abri du Maras. By combining 2D analyses, using a free and open-source GIS software, and 3D palaeotopographic reconstructions we were able to provide evidence about the use of space by Neanderthals. We have to keep in mind that both levels are palimpsests. However, even if Neanderthals repeatedly occupied the shelter in a short period of time, it is still possible to identify spatial patterns.

Spatial management is well-defined in level 4.1, where the main areas were used for knapping and probably associated with fire activities. Specific remains, such as large pieces or lithic tools were located on the periphery of these main areas. The spatial pattern in level 4.2 was somewhat different and not as clear, with two main distinct accumulation areas related to specific typo-technological composition. Those inter-level variations of spatial organisation do not appear to be dictated by a change in soil topography but probably by cultural choices, activities or different ways of occupying the shelter surface (perhaps because the shelter was larger and occupied over a larger area). Our analysis also furnishes new evidence on site formation processes and confirms that levels at the Abri du Maras were not subject to intense post-depositional disturbances. These observations point to a complex organisation at the Abri du Maras, with a structured division of space according to the types of remains and probably the types of activities. These behaviours are similar to those described in modern hunter-gatherer models and to those observed in other Middle Palaeolithic sites with complex social organisations.

Future analyses, currently under study, particularly of level 4.2, may provide additional information to better understand the occupational patterns of some of the last Neanderthal groups in the Rhône Valley.

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**Figure caption list**

**Figure 1.** Methodology used for palaeotopographic rendering and analysis of levels 4.1 and 4.2.

**Figure 2.** Spatial patterns of lithics, bones and fire-related artefacts from Maras level 4.1. Hotspot analysis applied to lithic artefacts (A); hotspot analysis applied to faunal remains (B); spatial analysis of fire-related artefacts: kernel density of burnt lithics, hotspot analysis of charcoal remains and ash lenses scattering (C).

**Figure 3.** Hotspot analysis of the two RMUs with the most pieces: hotspot analysis of the RMU flint-13 (A), hotspot analysis of the RMU quartz-5 (B) from Maras level 4.1.

**Figure 4.** Kernel density of tool kits from Maras level 4.1.

**Figure 5.** Hotspot analysis of cortical flakes from Maras level 4.1.

**Figure 6.** Hotspot analysis of lithic tools from Maras level 4.1.

**Figure 7**. Hotspot analysis according to the length of lithic artefacts from Maras level 4.1.

**Figure 8.** Spatial patterns of lithics, bones and fire-related artefacts from Maras level 4.2. Hotspot analysis applied to lithic artefacts (A); hotspot analysis applied to faunal remains (B); spatial analysis of fire-related artefacts: kernel density of burnt lithics, hotspot analysis of charcoal remains and ash lenses scattering (C).

**Figure 9.** Hotspot analysis of cortical flakes from Maras level 4.2.

**Figure 10**. Hotspot analysis of lithic tools from Maras level 4.2.

**Figure 11.** Hotspot analysis of cores from Maras level 4.2.

**Figure 12.** Hotspot analysis according to the length of lithic artefacts from Maras level 4.2 (dotted circles represent clusters in the disturbed areas of the site).

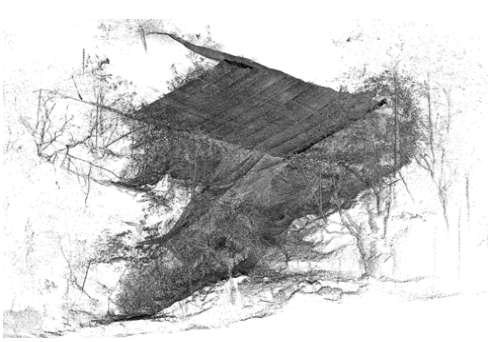
**Figure 13.** Palaeotopography of level 4.1: palaeosurface rendering of level 4.1 in the 3D mesh model of the Abri du Maras (A), DTM of the surface of level 4.1 with N-S and W-E palaeotopographic profiles.

**Figure 14.** Palaeotopography of level 4.2: palaeosurface rendering of level 4.2 within the 3D mesh model of the Abri du Maras (A), DTM of the surface of level 4.2 with N-S and W-E palaeotopographic profiles.

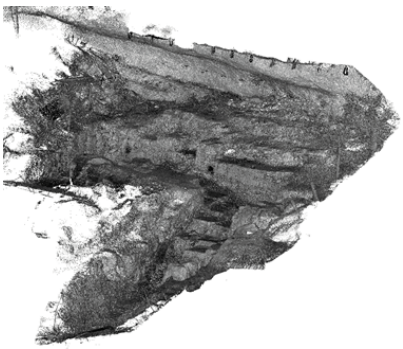
**Figure 15.** Spatial patterns identified from the spatial analysis of Maras level 4.1 (A) & level 4.2 (B).

Figure 1

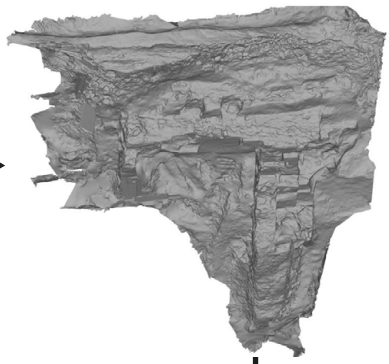
## Preliminary processing on the 3D model



*Cleaning*



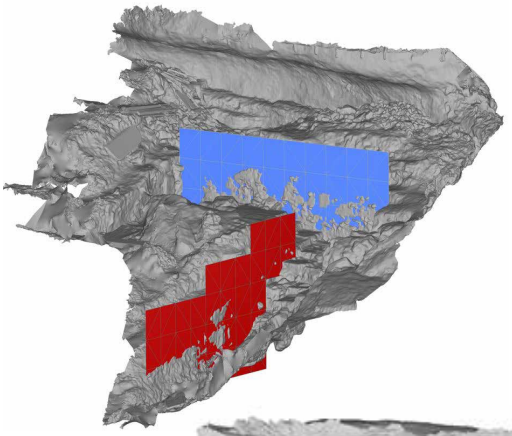
*3D meshing*



**Modification of the coordonate system**
- Rotation
- Translation in X, Y and Z coordonates

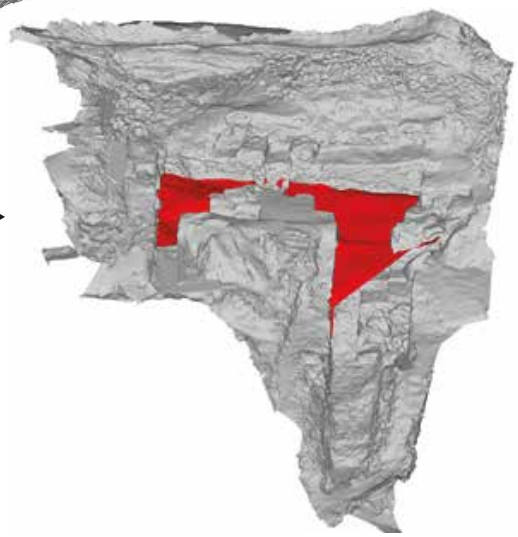
## Palaeosurface reconstruction

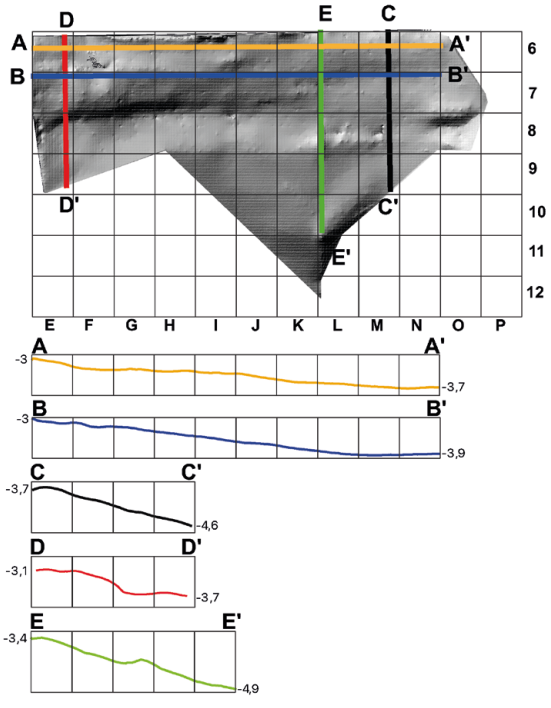
*Bulding texture using stratigraphic section drawings*



*Georeferenced vertical plans*

**Generating palaeosurface**
- Digitalizing points on the stratigraphic limits showed by the stratigraphic section drawings
- Meshing the obtained point cloud to generate 3D surface-based information






## Analysing palaeotopography in 2D

**QGIS analysis**
- Rasterising 3D surface into DTM
- Saving as TIF file
- Importing into QGIS
- Using profil tool

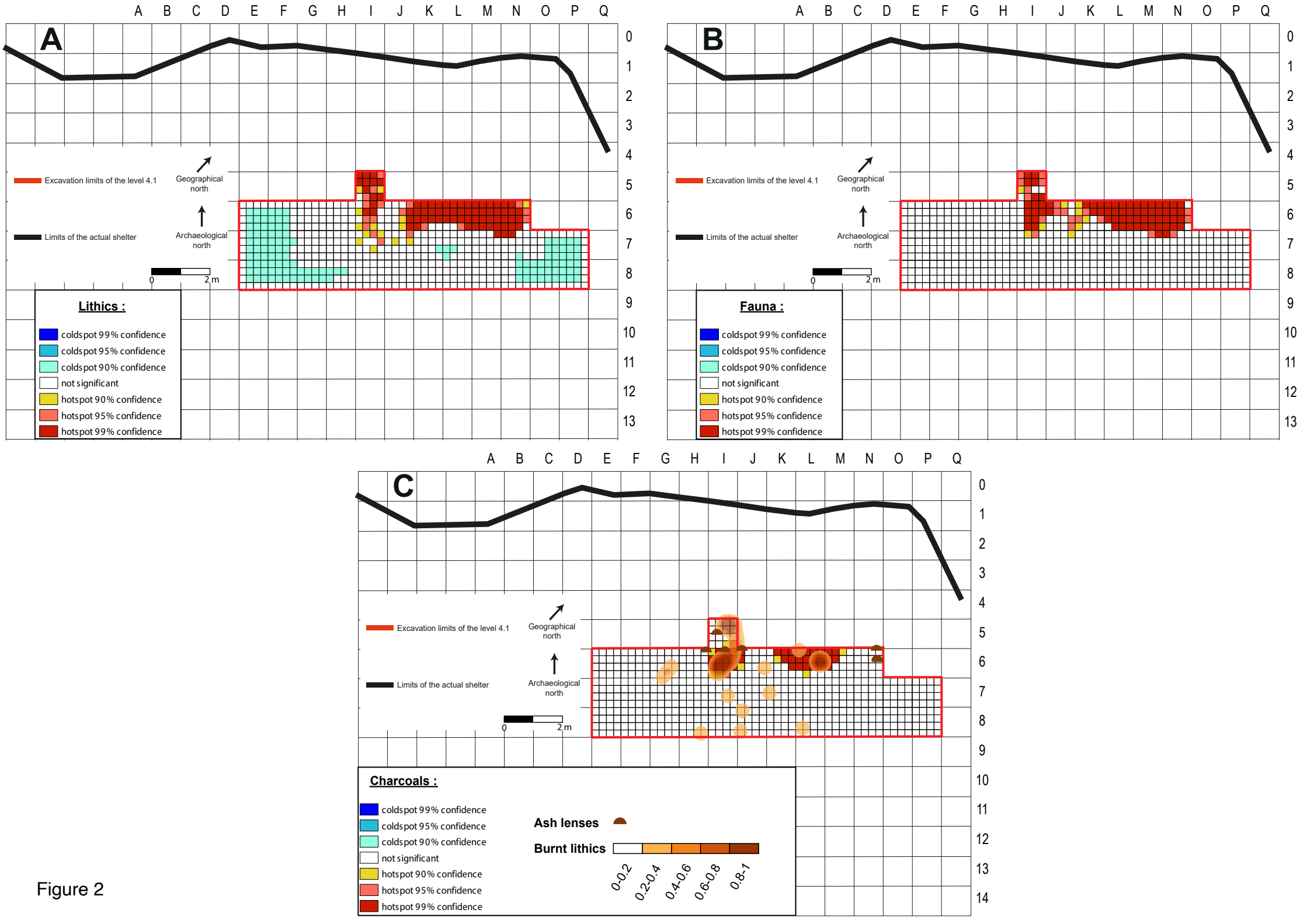
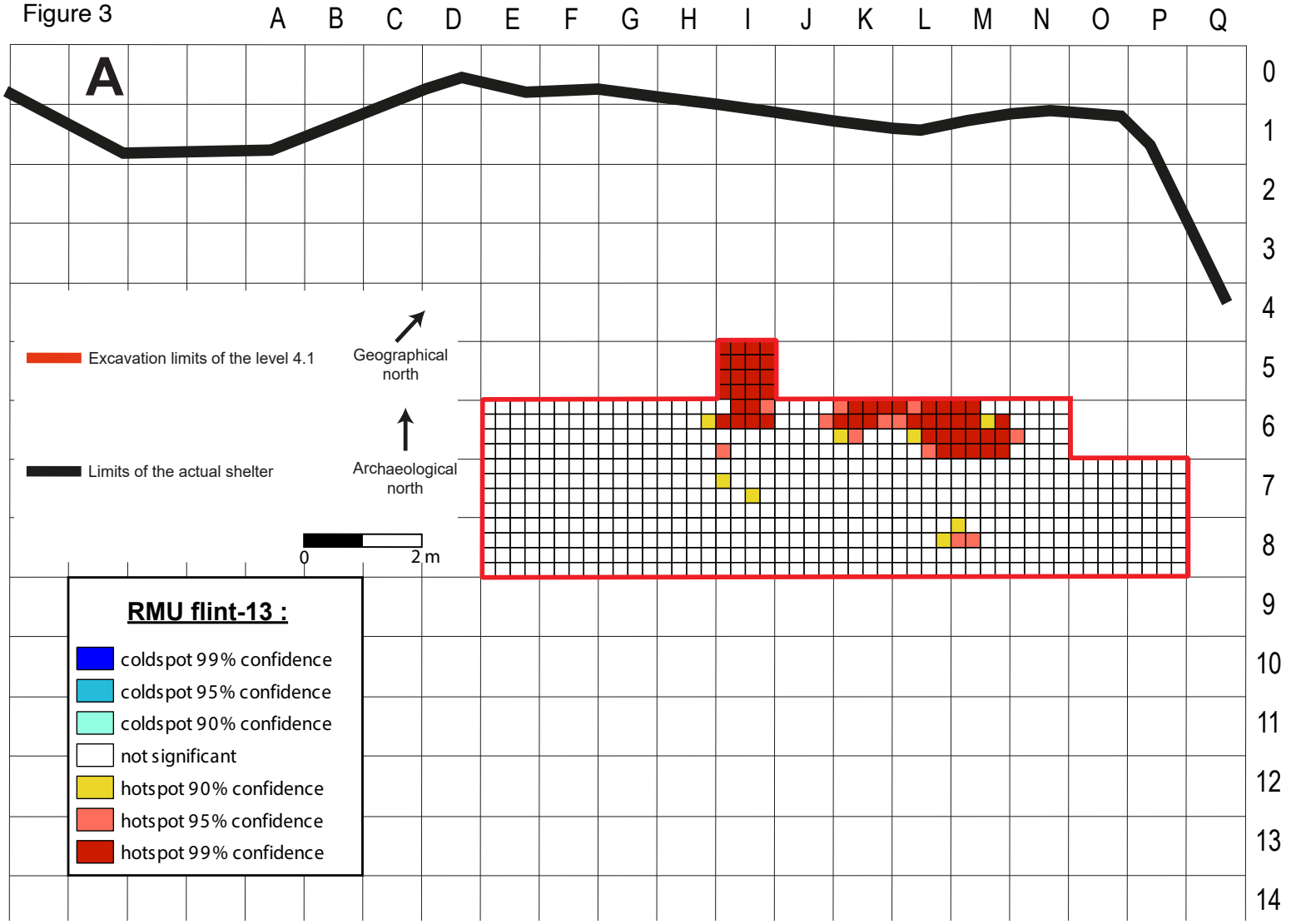

A
B
C
A B C D E F G H I J K L M N O P Q
0 1 2 3 4 5 6 7 8 9 10 11 12 13
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Excavation limits of the level 4.1
Limits of the actual shelter
Geographical north
Archaeological north
0
2 m
Lithics :
coldspot 99% confidence
coldspot 95% confidence
coldspot 90% confidence
not significant
hotspot 90% confidence
hotspot 95% confidence
hotspot 99% confidence
Fauna :
Charcoals :
Ash lenses
Burnt lithics
0-0.2
0.2-0.4
0.4-0.6
0.6-0.8
0.8-1

Figure 2

Figure 3


A
A B C D E F G H I J K L M N O P Q
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Excavation limits of the level 4.1
Limits of the actual shelter
Geographical north
Archaeological north
0
2 m
RMU flint-13 :
coldspot 99% confidence
coldspot 95% confidence
coldspot 90% confidence
not significant
hotspot 90% confidence
hotspot 95% confidence
hotspot 99% confidence

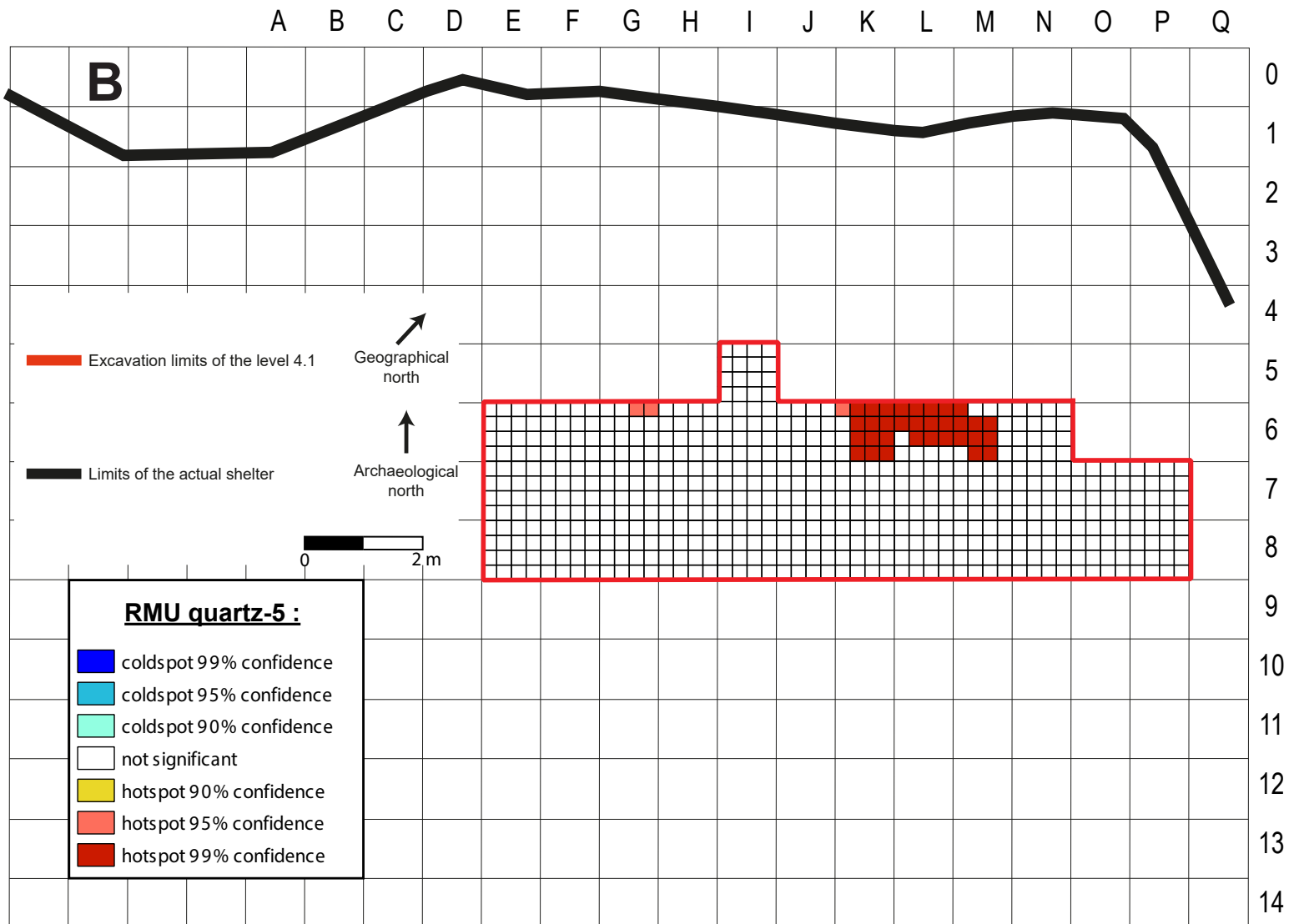

B
A B C D E F G H I J K L M N O P Q
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Excavation limits of the level 4.1
Limits of the actual shelter
Geographical north
Archaeological north
0
2 m
RMU quartz-5 :
coldspot 99% confidence
coldspot 95% confidence
coldspot 90% confidence
not significant
hotspot 90% confidence
hotspot 95% confidence
hotspot 99% confidence

Figure 4

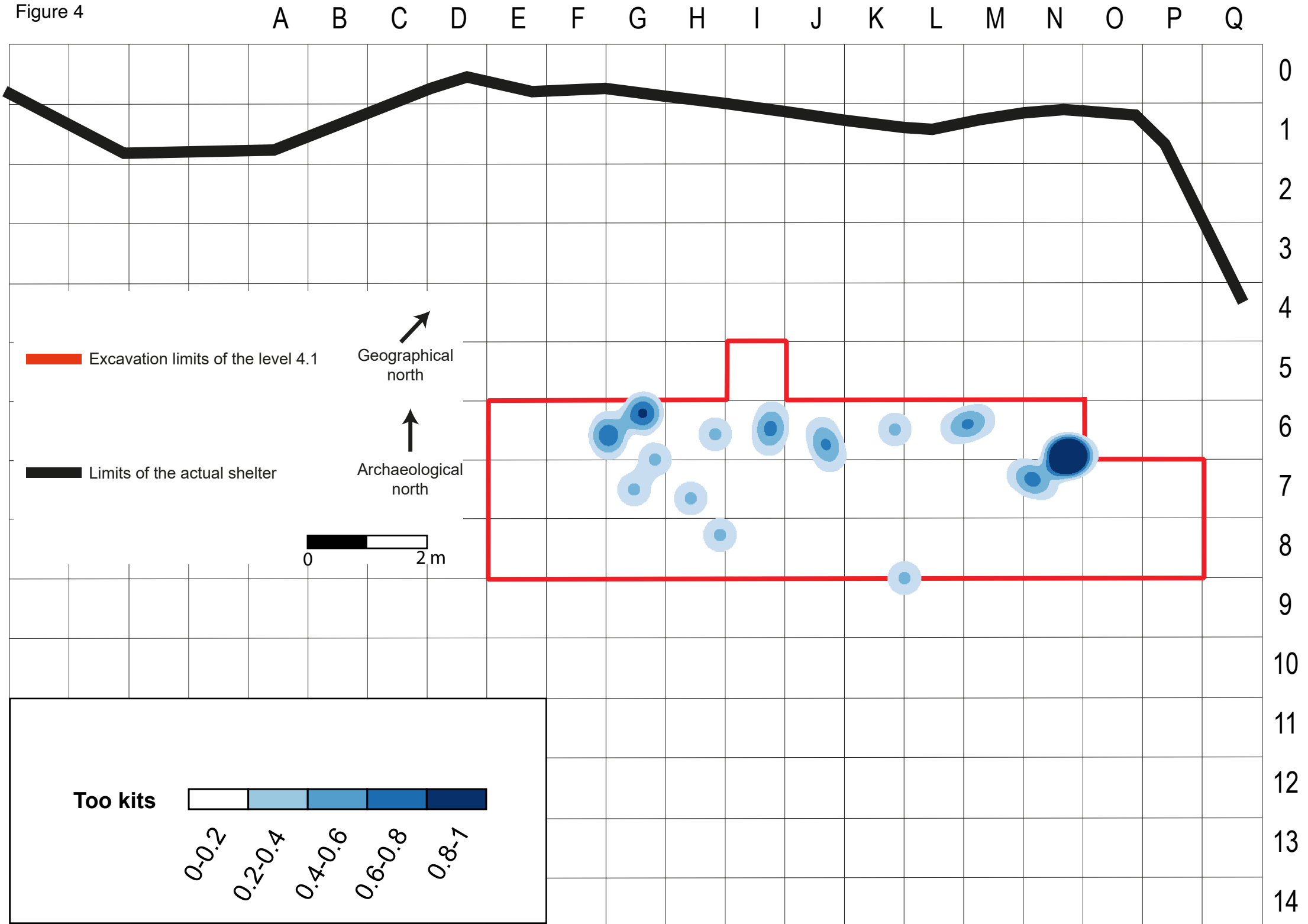

A B C D E F G H I J K L M N O P Q
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Excavation limits of the level 4.1
Limits of the actual shelter
Geographical north
Archaeological north
0
2 m
Too kits
0-0.2
0.2-0.4
0.4-0.6
0.6-0.8
0.8-1

Figure 5

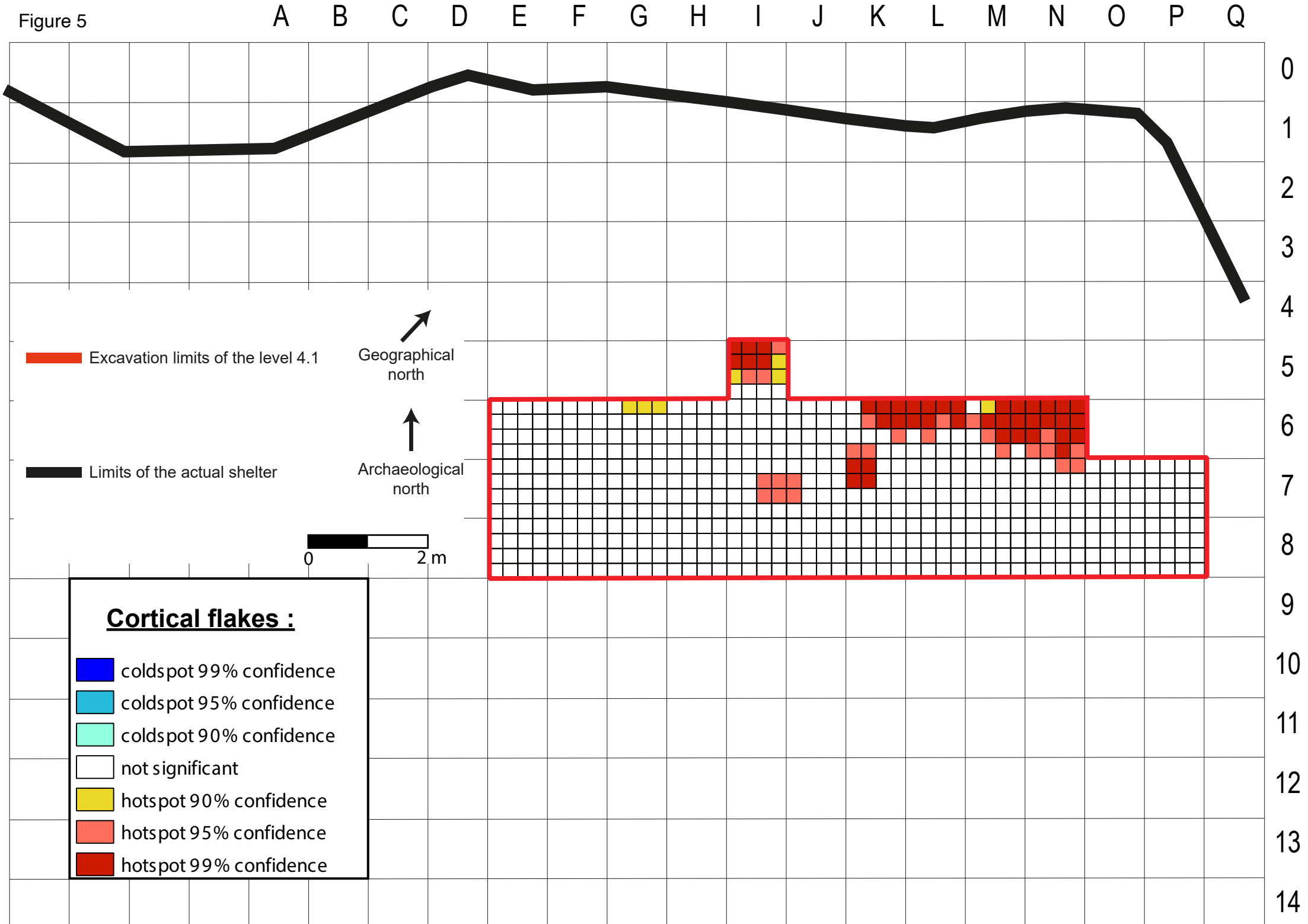

A B C D E F G H I J K L M N O P Q
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Excavation limits of the level 4.1
Limits of the actual shelter
Geographical north
Archaeological north
0
2 m
Cortical flakes :
coldspot 99% confidence
coldspot 95% confidence
coldspot 90% confidence
not significant
hotspot 90% confidence
hotspot 95% confidence
hotspot 99% confidence

Figure 6

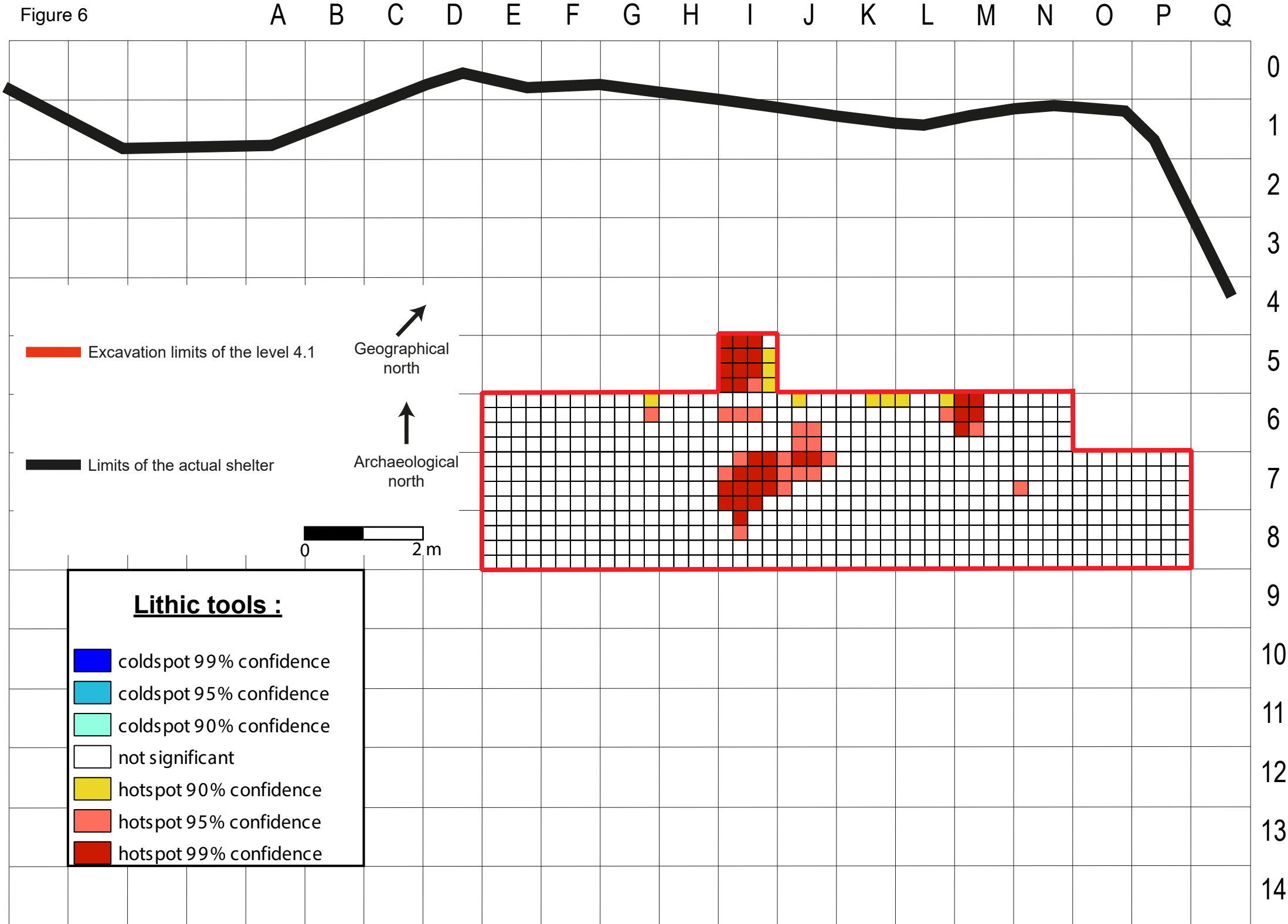
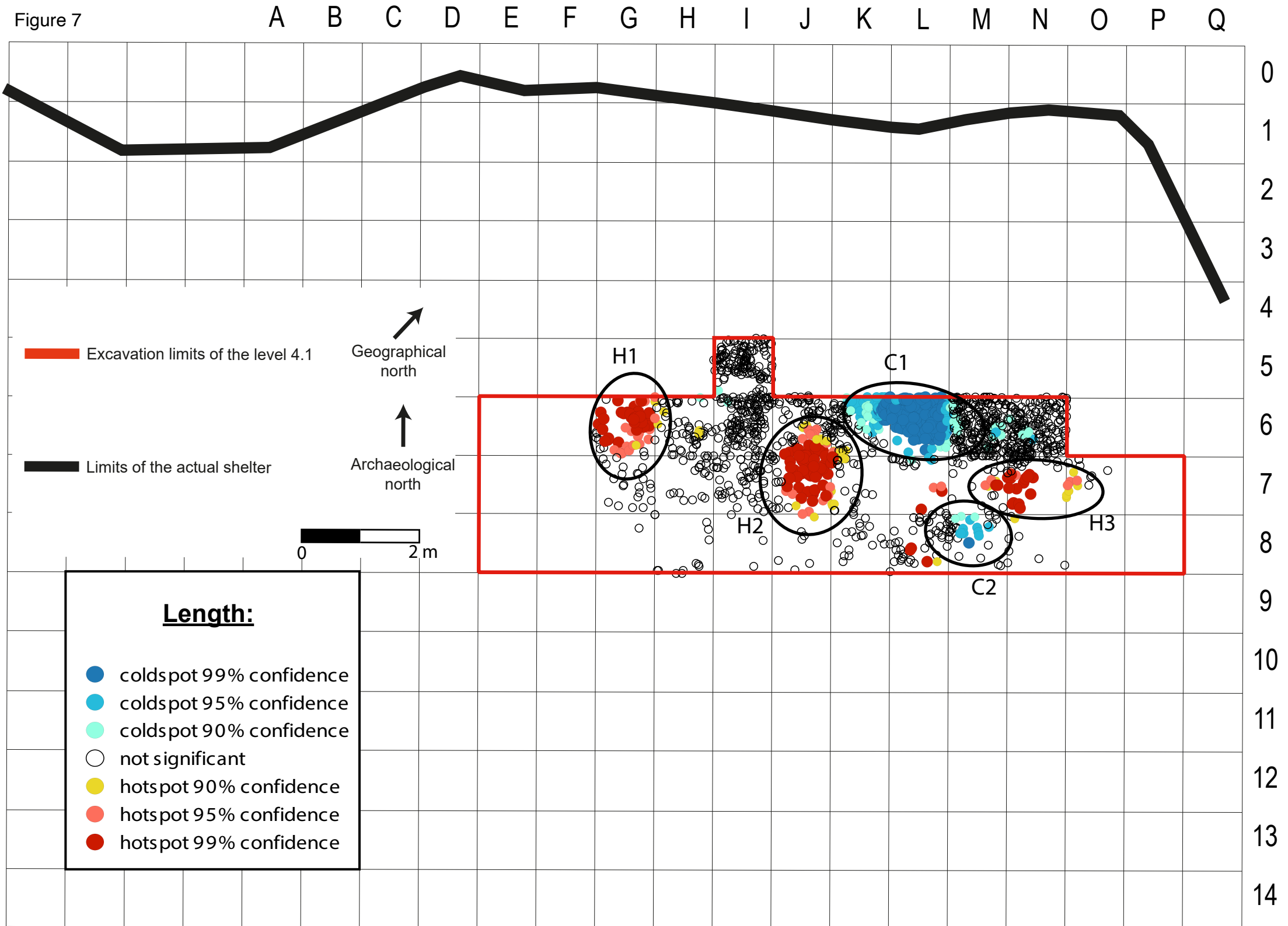
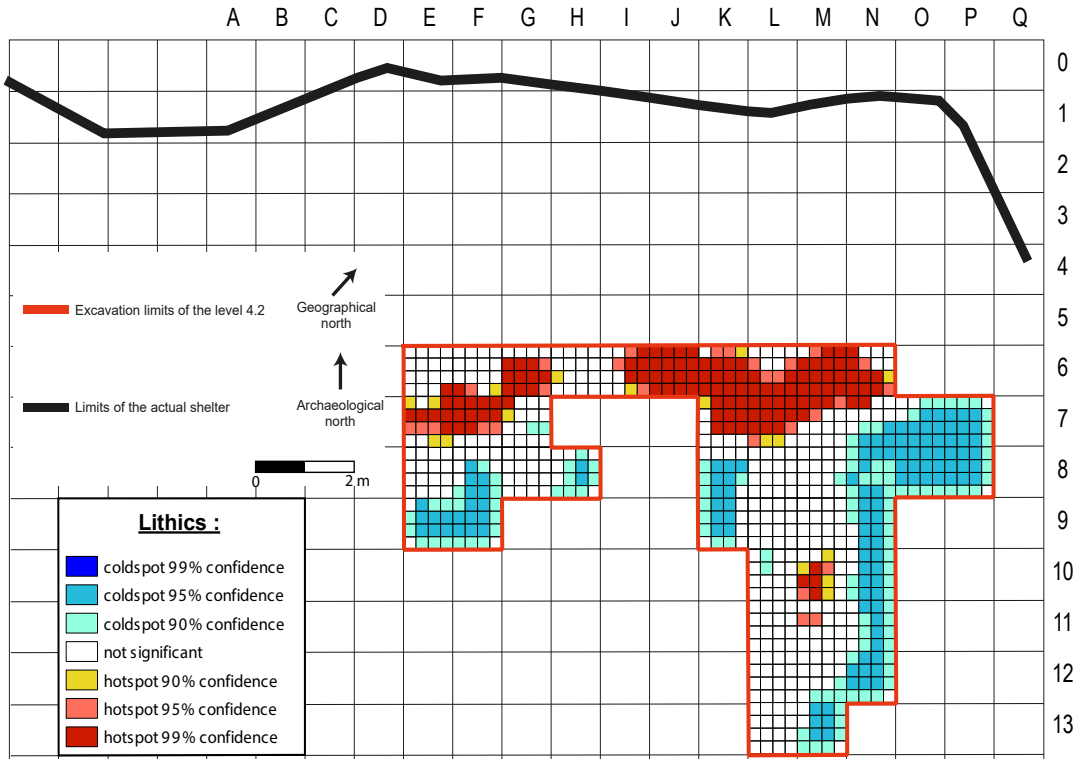
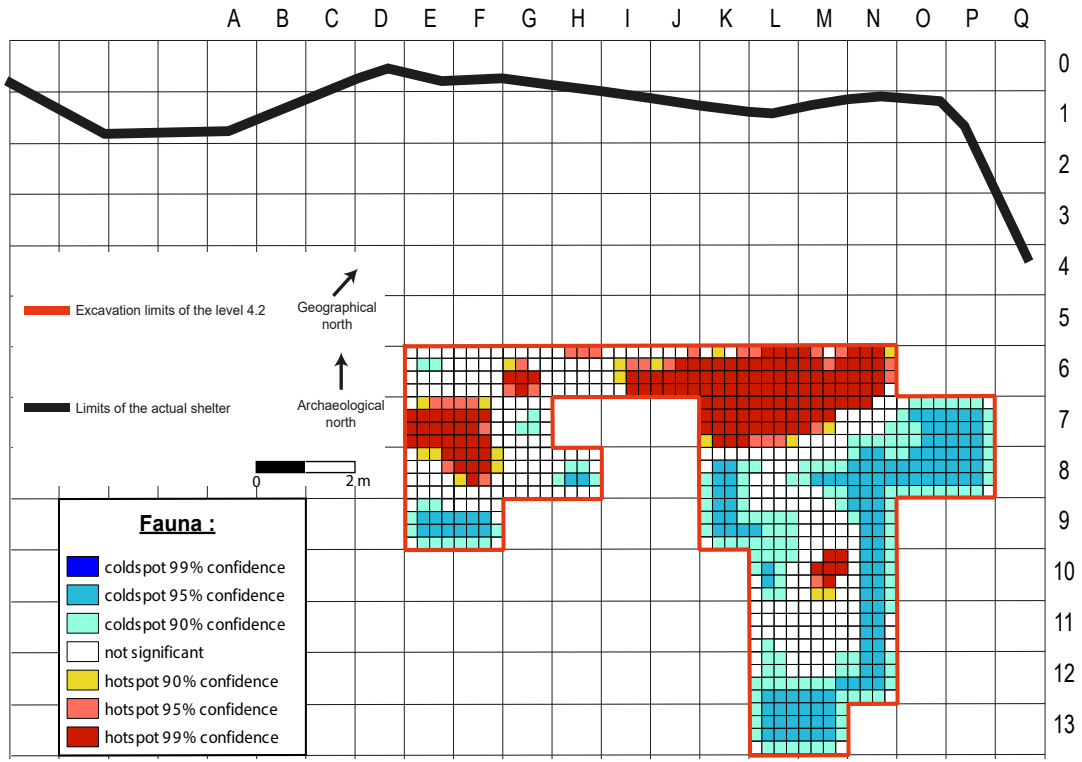

A B C D E F G H I J K L M N O P Q
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Excavation limits of the level 4.1
Limits of the actual shelter
Geographical north
Archaeological north
0
2 m
Lithic tools :
coldspot 99% confidence
coldspot 95% confidence
coldspot 90% confidence
not significant
hotspot 90% confidence
hotspot 95% confidence
hotspot 99% confidence

Figure 7


A B C D E F G H I J K L M N O P Q
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Excavation limits of the level 4.1
Limits of the actual shelter
Geographical north
Archaeological north
0
2 m
H1
H2
C1
C2
H3
Length:
coldspot 99% confidence
coldspot 95% confidence
coldspot 90% confidence
not significant
hotspot 90% confidence
hotspot 95% confidence
hotspot 99% confidence


A B C D E F G H I J K L M N O P Q
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Excavation limits of the level 4.2
Limits of the actual shelter
Geographical north
Archaeological north
0 2 m
Lithics :
coldspot 99% confidence
coldspot 95% confidence
coldspot 90% confidence
not significant
hotspot 90% confidence
hotspot 95% confidence
hotspot 99% confidence


A B C D E F G H I J K L M N O P Q
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Excavation limits of the level 4.2
Limits of the actual shelter
Geographical north
Archaeological north
0 2 m
Fauna :
coldspot 99% confidence
coldspot 95% confidence
coldspot 90% confidence
not significant
hotspot 90% confidence
hotspot 95% confidence
hotspot 99% confidence

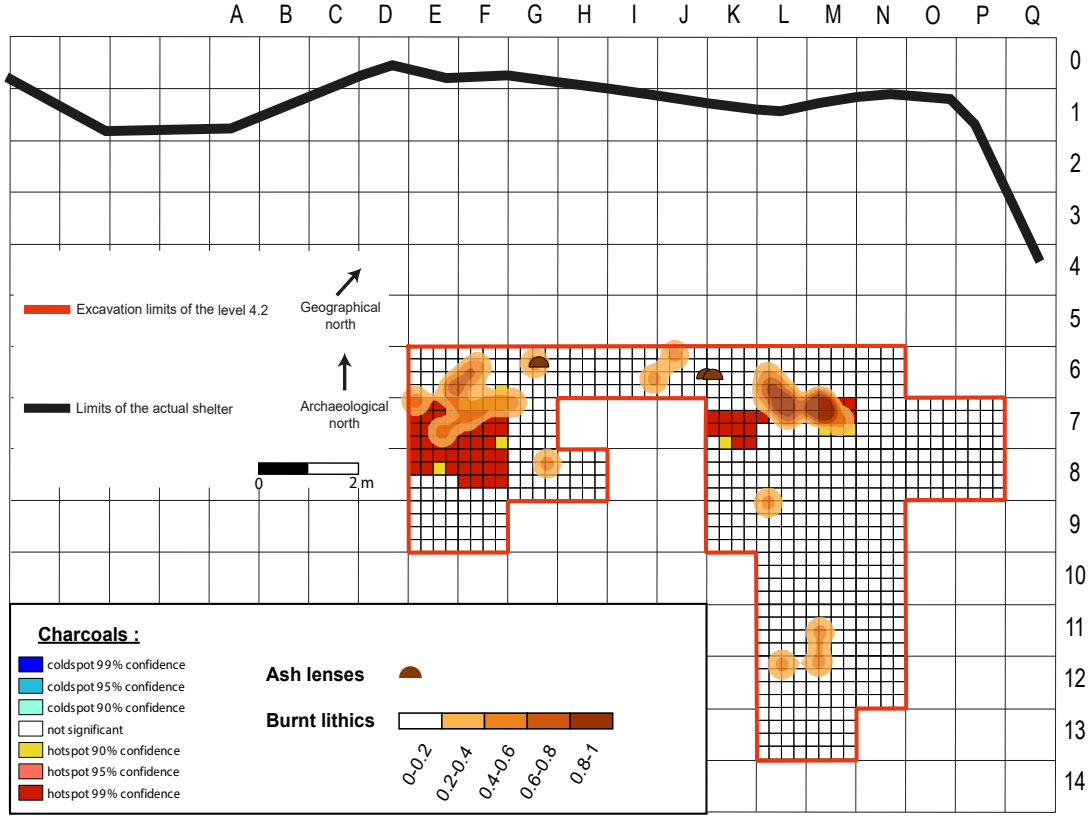

A B C D E F G H I J K L M N O P Q
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Excavation limits of the level 4.2
Limits of the actual shelter
Geographical north
Archaeological north
0 2 m
Charcoals :
coldspot 99% confidence
coldspot 95% confidence
coldspot 90% confidence
not significant
hotspot 90% confidence
hotspot 95% confidence
hotspot 99% confidence
Ash lenses
Burnt lithics
0-0.2
0.2-0.4
0.4-0.6
0.6-0.8
0.8-1

Figure 8

Figure 9

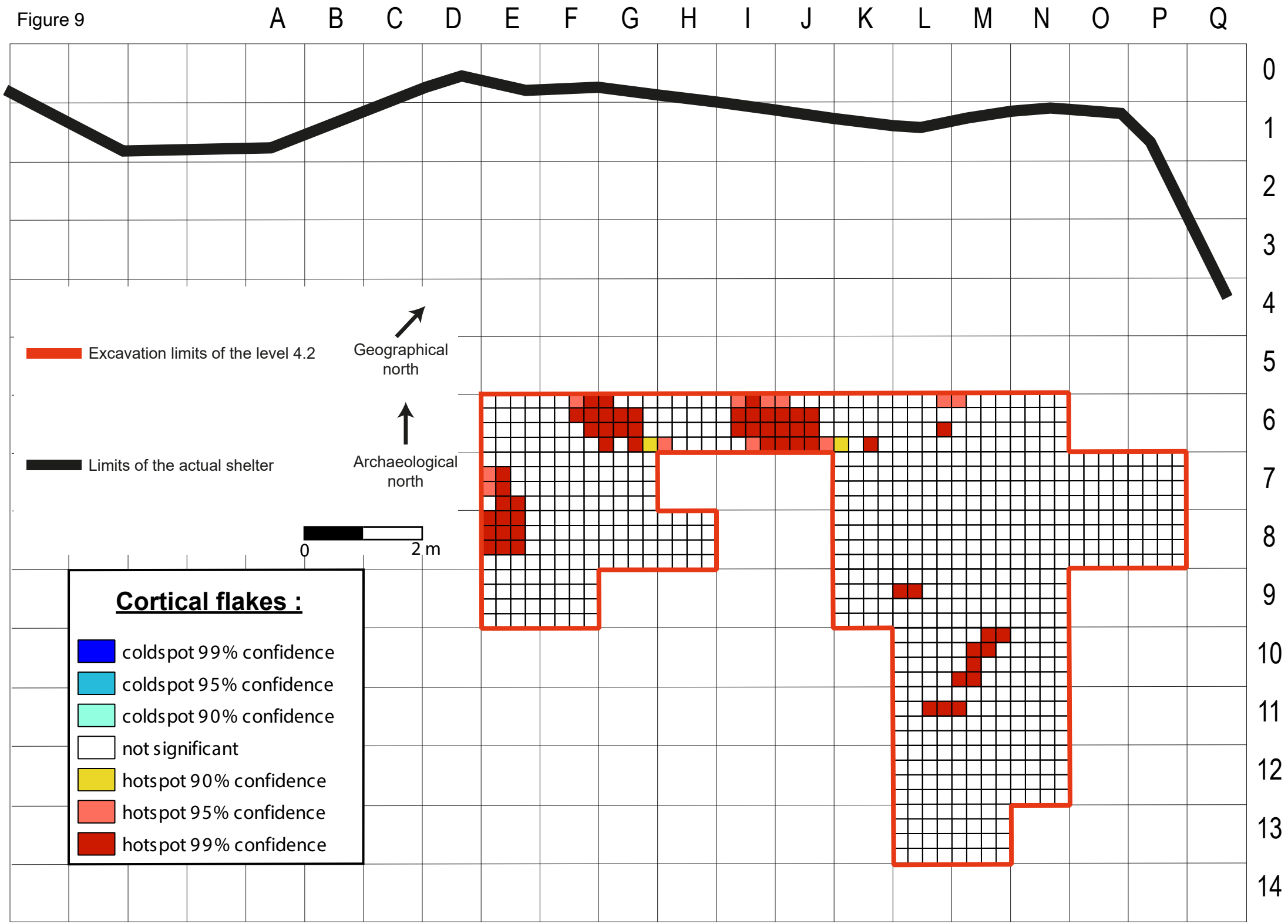

A B C D E F G H I J K L M N O P Q
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Excavation limits of the level 4.2
Limits of the actual shelter
Geographical north
Archaeological north
0
2 m
Cortical flakes :
coldspot 99% confidence
coldspot 95% confidence
coldspot 90% confidence
not significant
hotspot 90% confidence
hotspot 95% confidence
hotspot 99% confidence

Figure 10

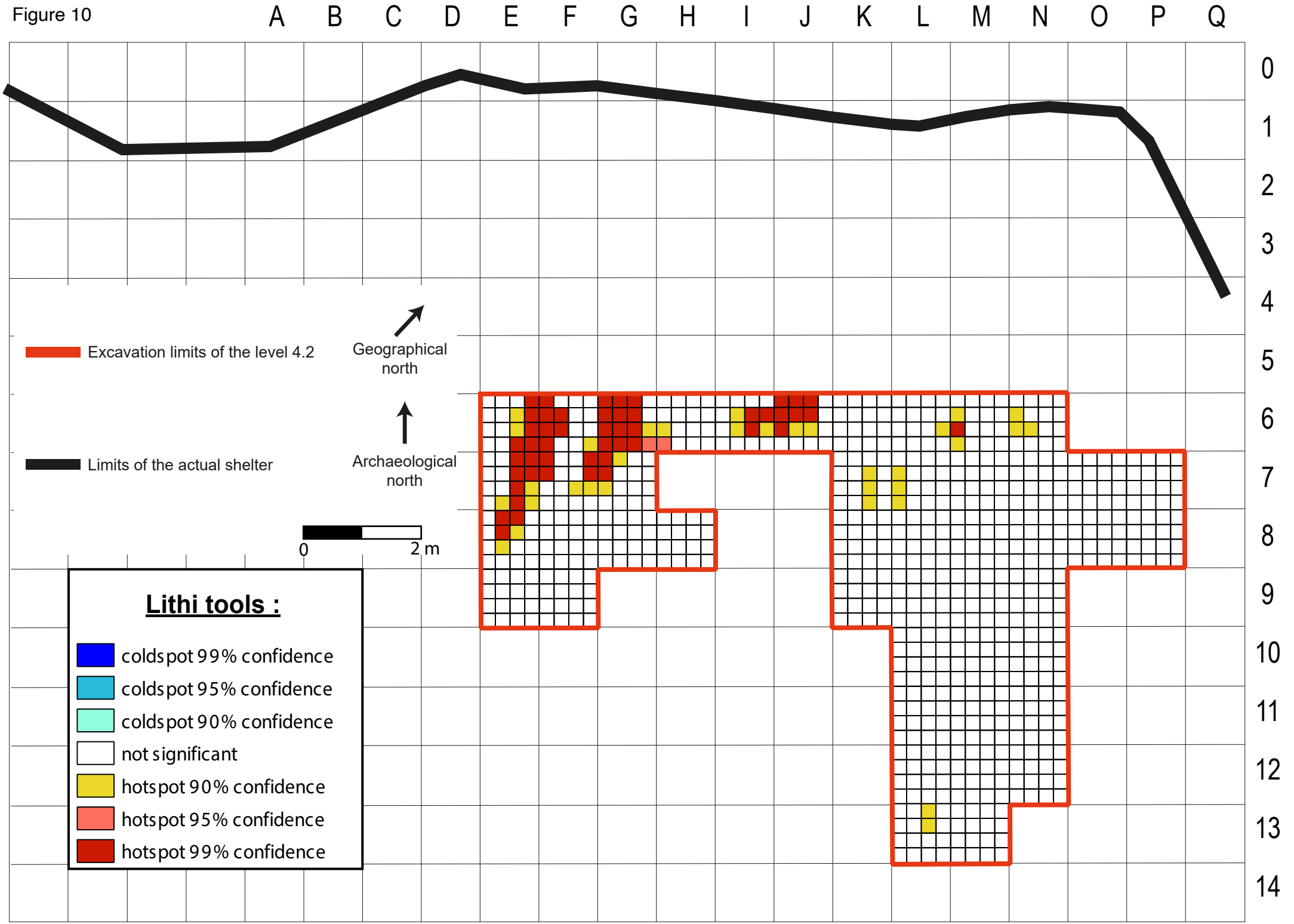

A B C D E F G H I J K L M N O P Q
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Excavation limits of the level 4.2
Limits of the actual shelter
Geographical north
Archaeological north
0
2 m
Lithi tools :
coldspot 99% confidence
coldspot 95% confidence
coldspot 90% confidence
not significant
hotspot 90% confidence
hotspot 95% confidence
hotspot 99% confidence

Figure 11

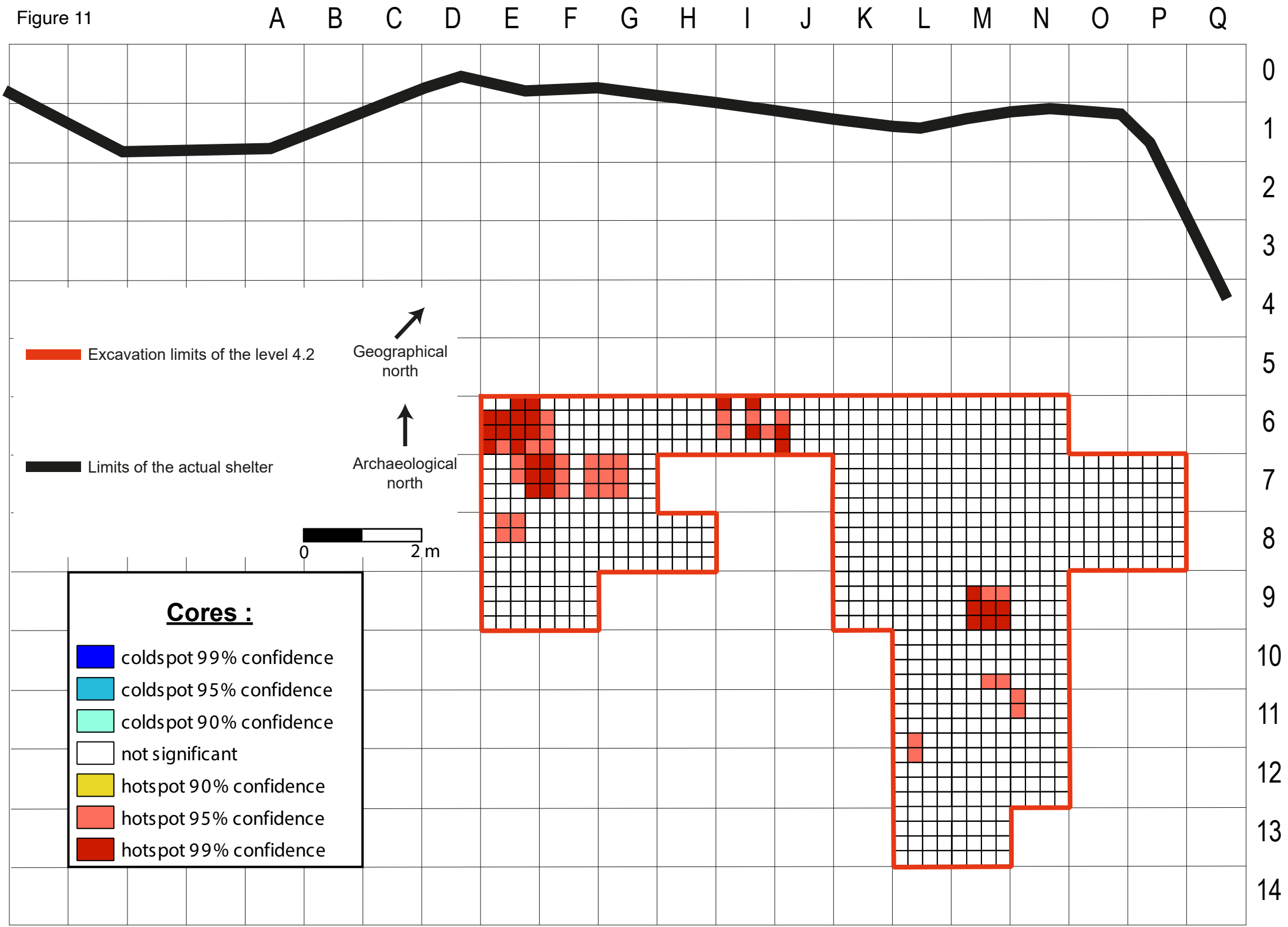
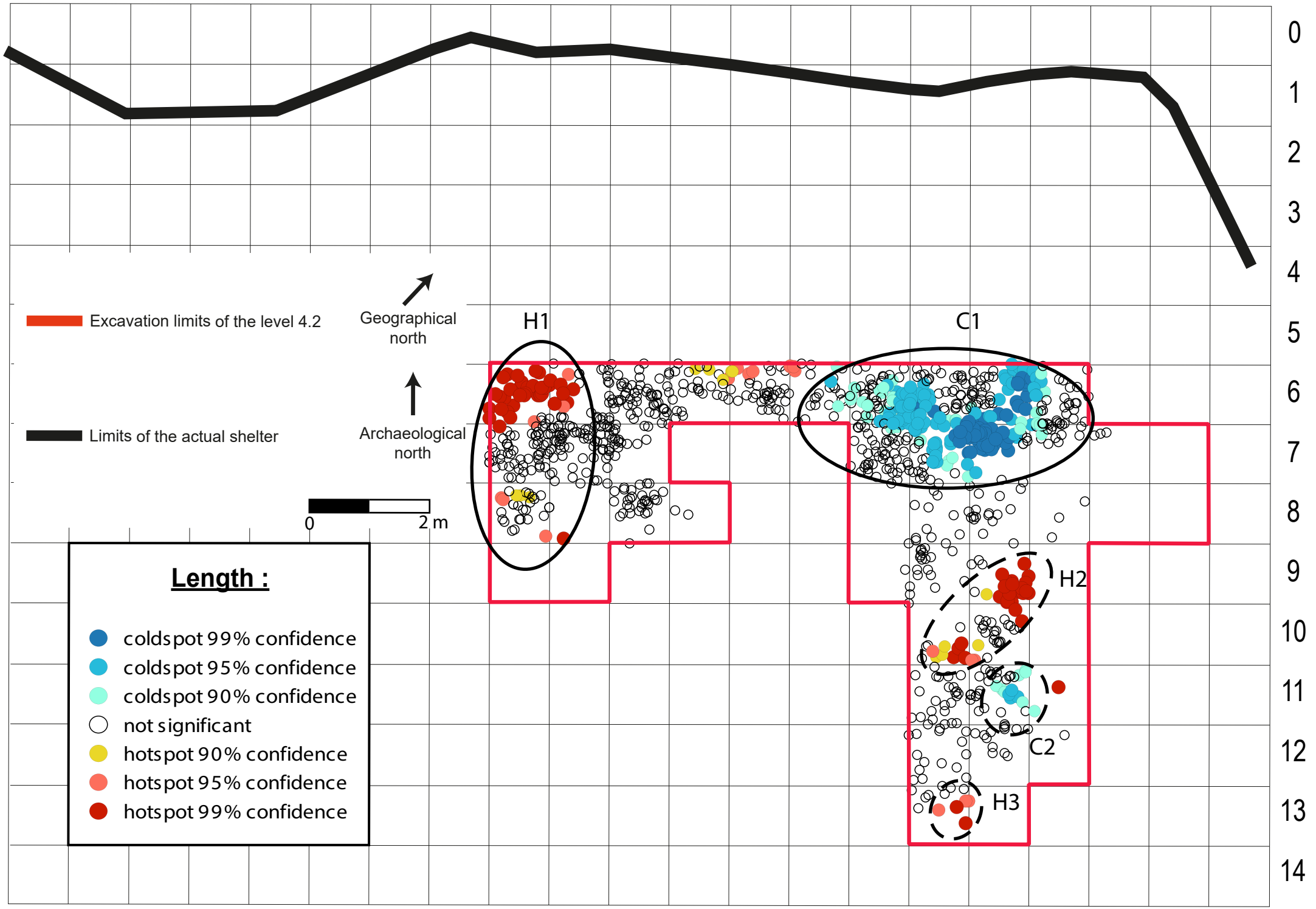
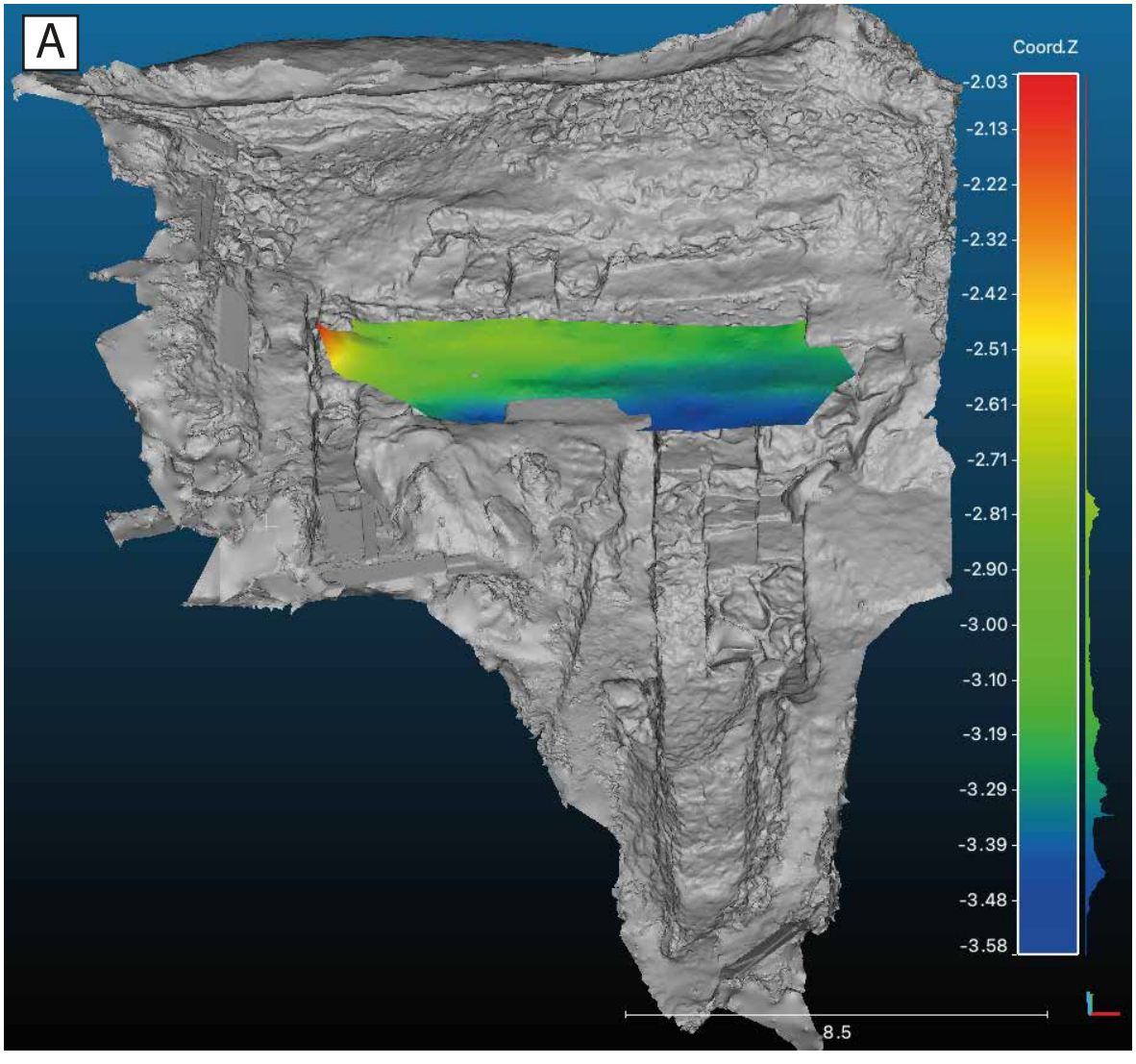

A B C D E F G H I J K L M N O P Q
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Excavation limits of the level 4.2
Limits of the actual shelter
Geographical north
Archaeological north
0
2 m
Cores :
coldspot 99% confidence
coldspot 95% confidence
coldspot 90% confidence
not significant
hotspot 90% confidence
hotspot 95% confidence
hotspot 99% confidence

Figure 12


A B C D E F G H I J K L M N O P Q
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Excavation limits of the level 4.2
Limits of the actual shelter
Geographical north
Archaeological north
0
2 m
H1
C1
H2
C2
H3
Length :
coldspot 99% confidence
coldspot 95% confidence
coldspot 90% confidence
not significant
hotspot 90% confidence
hotspot 95% confidence
hotspot 99% confidence


A
Coord.Z
-2.03
-2.13
-2.22
-2.32
-2.42
-2.51
-2.61
-2.71
-2.81
-2.90
-3.00
-3.10
-3.19
-3.29
-3.39
-3.48
-3.58
8.5

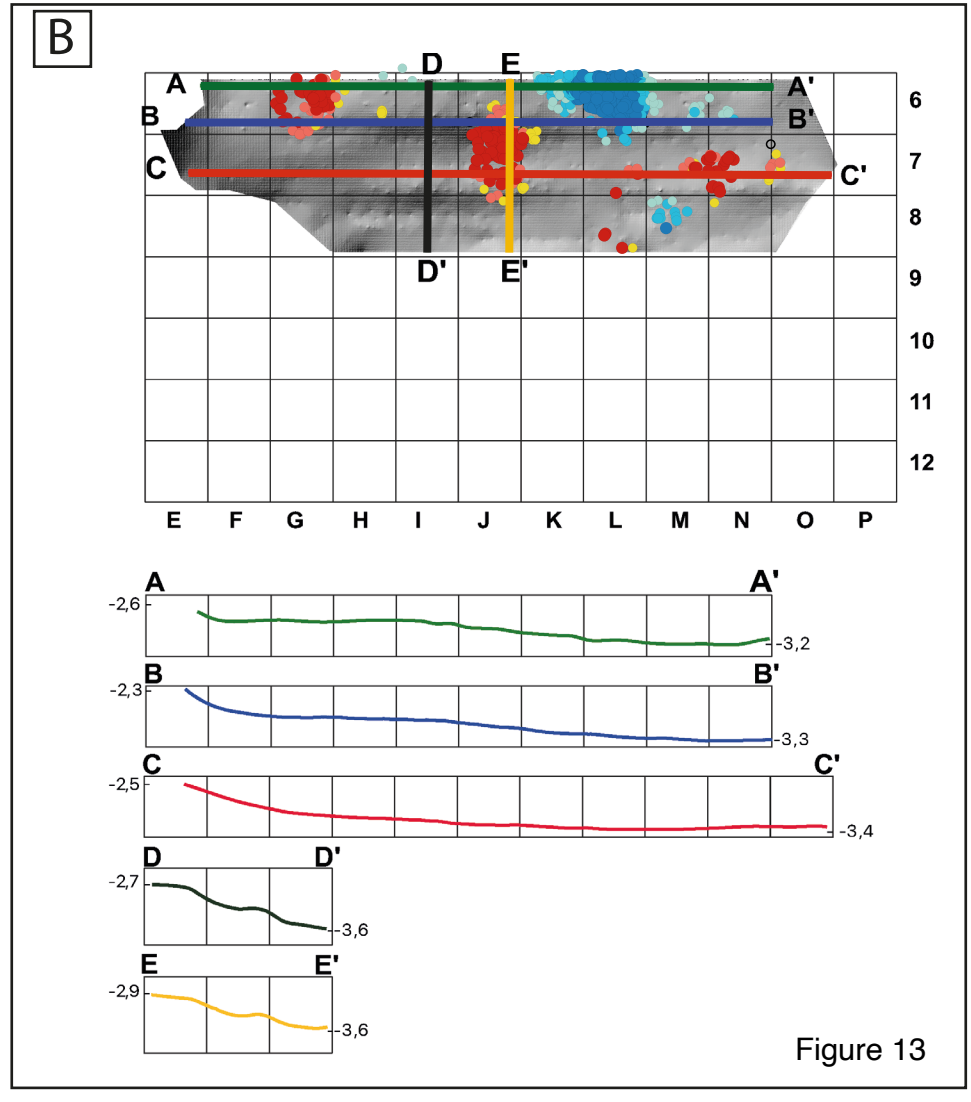
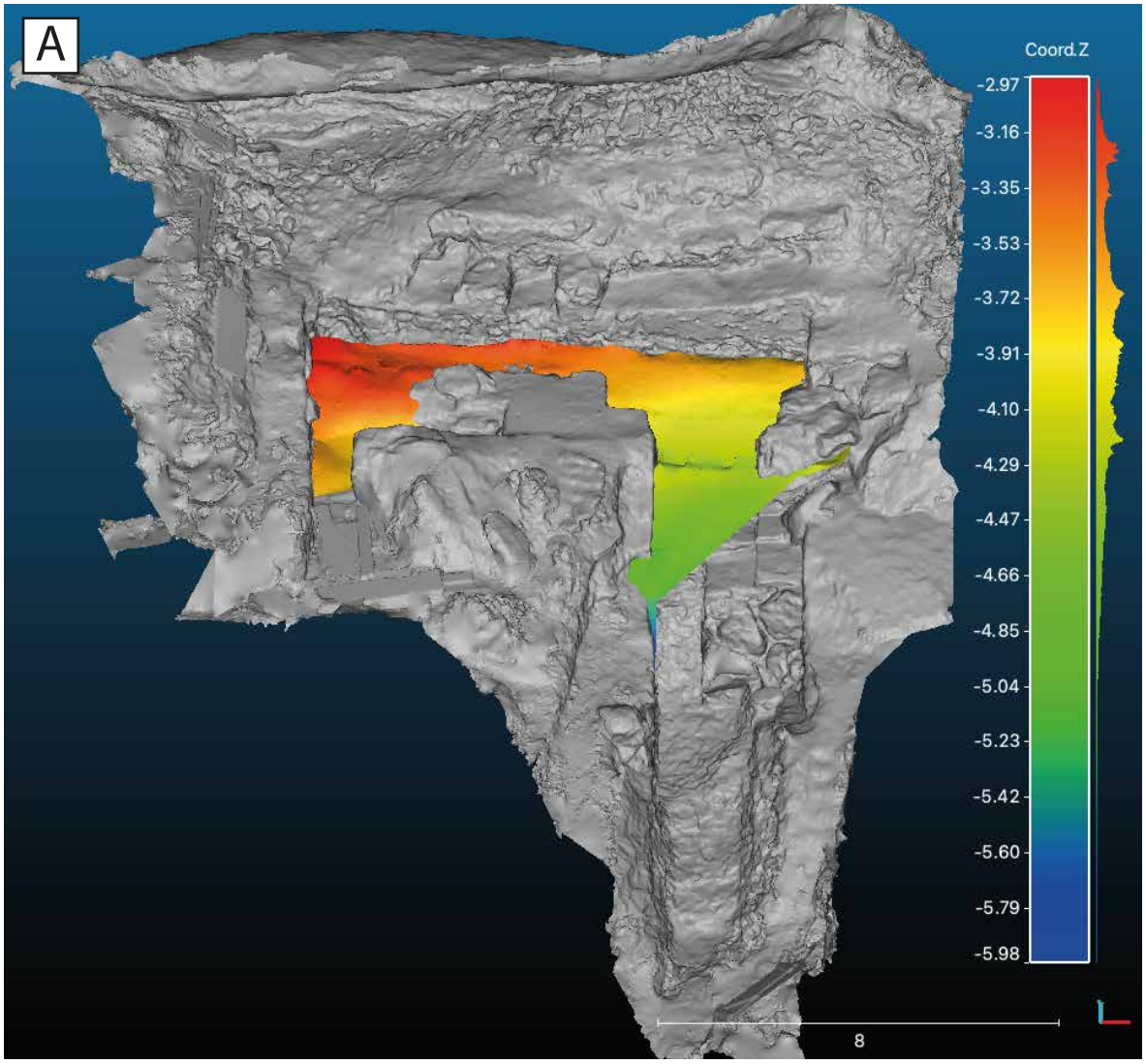

B
A
A'
B
B'
C
C'
D
D'
E
E'
6
7
8
9
10
11
12
E F G H I J K L M N O P
-2,6
-3,2
-2,3
-3,3
-2,5
-3,4
-2,7
-3,6
-2,9
-3,6

Figure 13


A
Coord.Z
-2.97
-3.16
-3.35
-3.53
-3.72
-3.91
-4.10
-4.29
-4.47
-4.66
-4.85
-5.04
-5.23
-5.42
-5.60
-5.79
-5.98
8

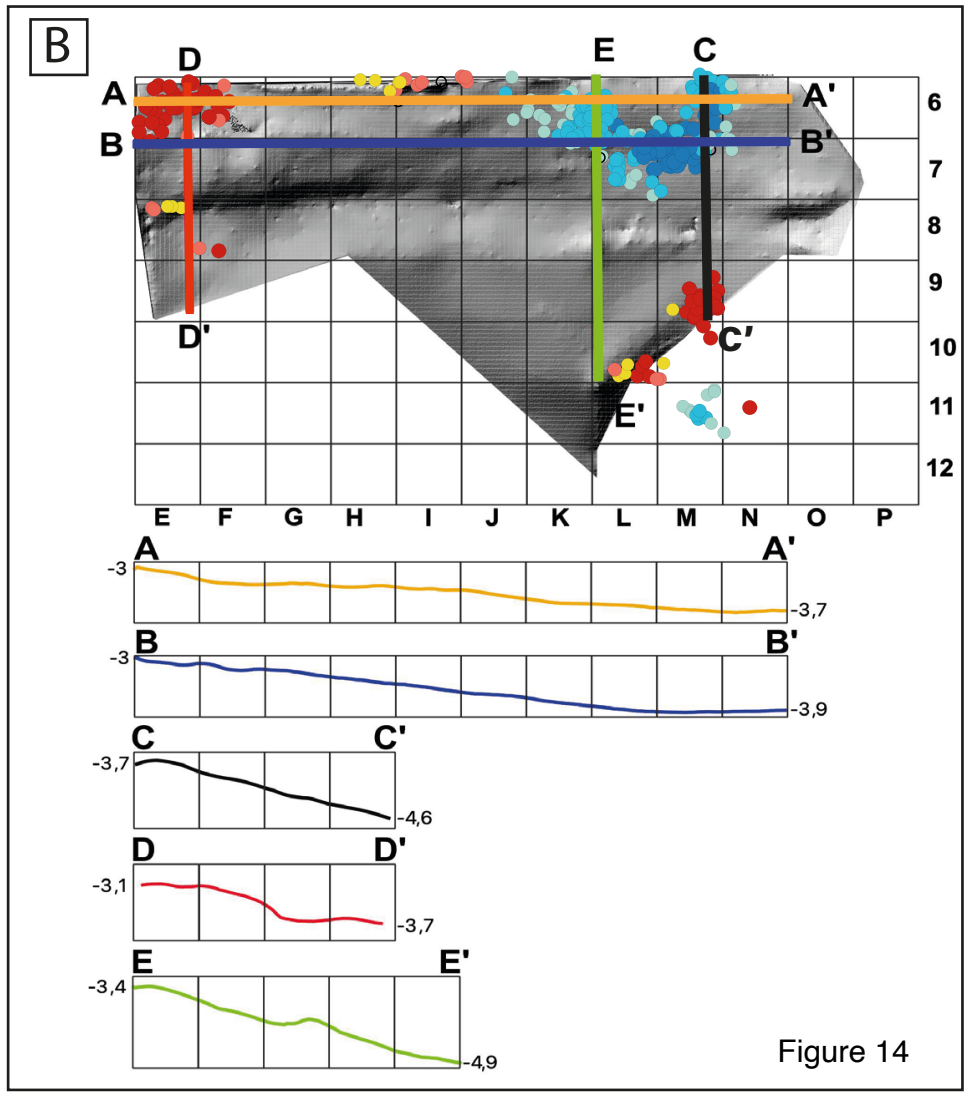
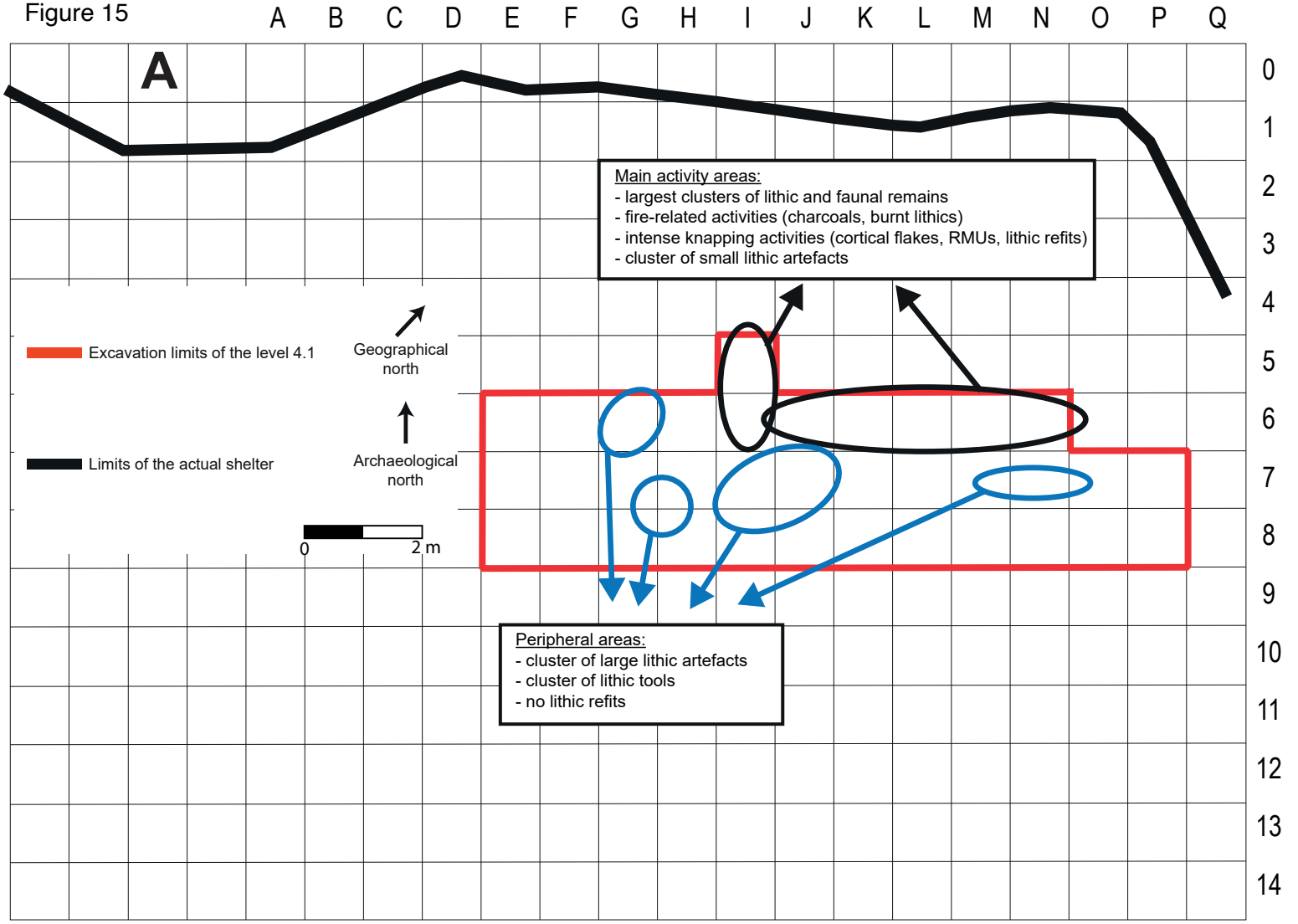
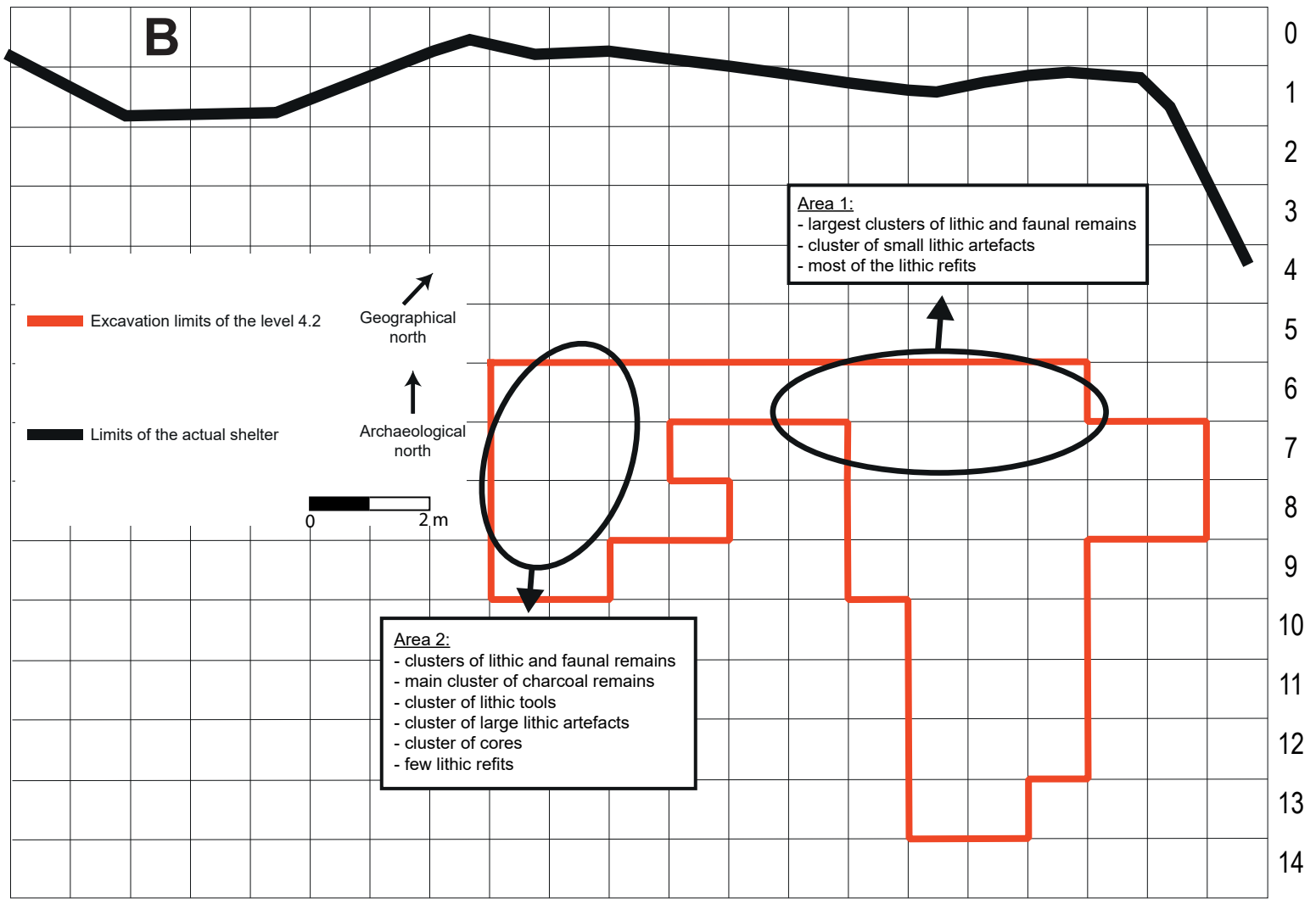

B
D
E
C
A
A'
B
B'
D'
C'
E'
6
7
8
9
10
11
12
E F G H I J K L M N O P
A
A'
-3
-3,7
B
B'
-3
-3,9
C
C'
-3,7
-4,6
D
D'
-3,1
-3,7
E
E'
-3,4
-4,9

Figure 14

Figure 15


A
A B C D E F G H I J K L M N O P Q
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Main activity areas:
- largest clusters of lithic and faunal remains
- fire-related activities (charcoals, burnt lithics)
- intense knapping activities (cortical flakes, RMUs, lithic refits)
- cluster of small lithic artefacts
Excavation limits of the level 4.1
Limits of the actual shelter
Geographical north
Archaeological north
0
2 m
Peripheral areas:
- cluster of large lithic artefacts
- cluster of lithic tools
- no lithic refits


B
A B C D E F G H I J K L M N O P Q
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Area 1:
- largest clusters of lithic and faunal remains
- cluster of small lithic artefacts
- most of the lithic refits
Excavation limits of the level 4.2
Limits of the actual shelter
Geographical north
Archaeological north
0
2 m
Area 2:
- clusters of lithic and faunal remains
- main cluster of charcoal remains
- cluster of lithic tools
- cluster of large lithic artefacts
- cluster of cores
- few lithic refits