

POLYGONS IN ARCHAEOLOGY

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The problem addressed in this paper is mainly methodological. It is about the joint exploitation of the two most fruitful methods introduced into archaeology in the last thirty years: *multivariate analysis* and *geographical information systems* (GIS). The two methods have so far been used separately, and mostly by different specialists. Their integration was discussed preliminarily (Neustupný 1995); the solution offered in this paper is presented in rather general terms, and therefore it should be applicable to many instances.

Considering the topic delimited in the foregoing paragraph it must be stressed at the outset that it cannot be dealt with other than in the framework of our present day theoretical and methodological discussion. We cannot surpass the limitations given to this generation of archaeologists by contemporary mathematics, computer hardware and software and, of course, by the current archaeological paradigm.

This is the reason why I am using a particular instance of multivariate analysis (principal component analysis from the factor analysis family) and a particular GIS software (IDRISI). The proposed method, however, can be generalised to include any known computer tool. Moreover, the principal component analysis, as a form of what I have described as vector synthesis, can be shown to be isomorphic with the best way of archaeological thinking (Neustupný 1993, 129).

A. SPACES IN ARCHAEOLOGY

Space, as a set of objects fulfilling a set of conditions, is one of the most general concepts of modern science. It is well known from mathematics where it reflects a most abstract concept based on the *three-dimensional real space* in which people and other beings live and physical bodies move. There are many methods available as to how one could grasp the real space intellectually, and this leads to several mutually interrelated concepts of space; the Euclidean space as taught at school is just one of the possibilities.

Strictly speaking, the '*mathematical space*' has been defined in such a way as to include the geographical space, an important constituent of the real world, as a particular subspace. In very abstract terms, the *geographical space* is represented by those parts of the Earth that people can potentially reach in the course of their cultural behaviour. As a consequence of this, geographical space has no sense outside the social world. On this occasion, I am also going to introduce the concept of (*social*) *formal space* to create a counterpart to the geographical space. In very broad terms the formal space is that part of our world which specifies the properties of individual objects of the social world, i.e. the entities and qualities formed and/or conditioned by *human* beings. This article, in dealing with the interrelation of vector synthesis and GIS in archaeology, is therefore about the interrelation of the formal space with the geographical space.

The formal space

Some time ago I tried to demonstrate that the concept of mathematical space can be successfully applied to archaeology (Neustupný 1973). Archaeological entities and qualities can be conceived in terms of objects mapped into n-tuples of generalized values, each of them reflecting a property of the object. In conse-

quence of this, we have a set of *objects*, a set of *properties* of the objects, and a set of *values* these properties might acquire. In the terminology of the Euclidean space (a particular instance of the mathematical space, described by classical geometry) the objects are *points*, the properties correspond to individual *dimensions* (x, y, z), and the values to the *coordinates* in those dimensions (real numbers).

If the objects are prehistoric huts, for example, their archaeological contents (e.g. the classes of pottery) can be conceived as formal dimensions of the huts, and the number of sherds belonging to the individual classes of pottery can be interpreted as values of the coordinates. The position of a 'point' called *hut 1* in the formal archaeological space can then be determined, for example, by means of a triple (15, 2, 6) in which the numbers 15, 2, and 6 can be interpreted as the number of sherds of storage jars, bowls and cups respectively. The triple, however, could also be read as (buff, brown, grey), if the values of the individual dimensions (the classes of pottery) express the prevailing colour of pottery. In another example, battle axes as objects can be studied by means of their physical dimensions (properties), and the real numbers expressing length are examples of their appropriate values. This can be expressed by *Table 1*.

objects/ /points	properties/ /dimensions	values/ /coordinates
hut	pottery classes	sherd counts
hut	pottery classes	colour shades
battle-axe	physical dimensions	length
beaker	decoration	types of decoration

Table 1. Examples of simple formal spaces.

The three concepts of geographical space

Geographical space is the real space we move in. It is a rather abstract concept with very few defining properties. The vectorised geographical space, described by means of Euclidean mathematics, is a particular, even more narrowly defined instance of the geographical space, the way how it is conceptualised by modern geography. Although many people identify the two concepts, the geographical space in general is not identical with the vectorised space, which presupposes a measure of distance and a system of coordinates. I am going to argue that *the concept of geographical space can operate on much simpler grounds*. This is obviously also valid in the case of the spaces of archaeological entities, whose location in the geographical space can be conceived as completely independent of any coordinates expressed by real numbers. The concepts of space which I am now going to mention, differ in the complexity of assumed interrelationships of the space elements.

Relational geographical space

Although modern archaeologists often fix the position of their sites and features by reference to some kind of coordinates, it was

still common in the first half of the 20th century to achieve the same results by reference to either modern objects and/or other archaeological features. An example of this approach to the location of areas of archaeological interest is '*Site 28 in between the church and the railway station of village X, grave Nr. 39B*'. There are no coordinates, no direction and no distance in this way of determining the location of a site and/or a particular grave. This kind of spatial referencing did not allow an easy solution to certain problems but, on the whole, it became the basis for a satisfactory solution of many archaeological questions. To a large extent, the so-called typological paradigm of archaeology grew out of this conception of space, as direction was only taken into account in the case of assumed diffusion or migration, and distance was mostly considered unimportant.

The type of spatial referencing mentioned in the preceding paragraph can be described as the relational approach to space, as it determines the position of individual archaeological entities in relation to modern entities and in relation to other archaeological entities. I have described the classes of relations by means of which this can be achieved in another place in more detail (*Neustupný 1993, 90*). The strength of the relational conception of the geographical space is in its simplicity, its disadvantage being the impossibility to determine the distance between entities and the direction from one entity to another. However, such specifications were often considered unnecessary within traditional archaeology.

Common geographical space

There is another concept of geographical space, used by modern people in their everyday life which, no doubt, was also applied in prehistoric times. This concept, which can solve the main problems ensuing from the relational conception of space, assumes that 'distance' is the distance *between two points* which is measured directly (there is no formula for calculating distance). The concept of direction from one point (one element of the space) to the other is replaced by the concept of a *path* (or an itinerary) that leads from one point to the other possibly passing through several other points; distance is the length of this path. Consequently, this approach does not use any system of coordinates. The individual person (who is also the observer) decides which pairs of points should be joined by a path and investigated as to their distance.

Medieval itineraries are examples of this kind of space conceptualisation. However, it is also commonly used by modern people, for example when going by car from one place to another considering exclusively road numbers, or when walking through a town (this leads to the concept of the city block metric, typical of this kind of space). No doubt, this seems to have been the common concept of geographical space in later prehistory. I am inclined to use the term common approach (and common space) for this instance.

Vector geographical space

Full spatial referencing, however, can only be achieved, if the position of an entity is determined by means of so-called coordinates. In this case, a point is chosen as the origin of coordinates (the zero point) and one direction as the selected direction; the position of each point in the entity is subsequently determined by measuring its distance from the point of origin and the angle between the selected direction and the direction of the line passing through both the origin and the particular point of the polygon. An equivalent procedure consists of choosing the point of origin and two axes (usually at the right angle to each other), and then determining the position of each point by measuring its distance from these two axes.

Because the couples of real numbers such as [distance from the origin, angle] in the first case, and [distance from axis x, distance from axis y] in the second case, are called vectors, the procedure of expressing entities in this way is often referred to as vectorisation. Before the appearance of GIS the problem of vectorisation of archaeological entities was nearly always solved graphically, i.e. by drawing them into maps of various scales. This conception of the geographical space can be described as the (geographical) vector approach.

B. POLYGONS

The polygon concept

The concept of the polygon seems to have penetrated into archaeology via the geographical information systems (GIS) quite recently. I am going to argue in this paper that it is a concept which, when properly generalised, can make it easier to express spatial relationships between archaeological entities, to analyse them, and to synthesise meaningful archaeological structures to be interpreted in terms of archaeological theory. Also, it makes it easier to comprehend the relationship between multivariate analysis and geographical information systems, the two basic tools for processing archaeological data.

As I have explained elsewhere (*Neustupný 1993, 77*), archaeology uses several levels of analytical units depending on their 'interpretive' content. In my view archaeologists necessarily start with analytical concepts that contain interpretation, but then they proceed to concepts abstracting from interpretation as much as possible. This is done in order to give other interpretations, in addition to the preliminary one, the opportunity of contributing to our knowledge by means of the iterative repetition of the archaeological method.

I have used the term point for the analytical entity that still contains preliminary interpretation, developing some theory around this concept (*Neustupný 1993, 80*). Such points are, of course, conceptually different from points of the geographical space. At the same time I have used the term 'item' for analytical entities on the level of archaeological data, i.e. on the level of analysis that abstracts from function, meaning and significance of the record. Polygons, as characterised in this paper, clearly represent a particular instance of 'items'. In other words, they are to be considered as *elements of data deprived of any interpretation*.

The *polygon* is a continuous area in the geographical space which can be *defined* by a finite number of points connected by lines. It follows from this definition that

- (1) three-dimensional real objects become *two-dimensional objects* when represented by polygons,
- (2) continuous lines delimiting real objects are approximated by *discontinuous points* defining the polygons,
- (3) the polygon area itself is *continuous*, i.e. it is always possible to join any pair of points in a polygon by means of a *path* (not necessarily a straight line) so that all points of the path belong to the polygon. It is not important whether the polygon area is even, inclined, irregular etc.

Archaeological polygons are two-dimensional representations of facts of archaeological relevance (artifacts or ecofacts) by means of polygons as defined in the preceding paragraph. A typical example of an archaeological polygon is the area occupied by an individual vessel or an animal bone discarded by prehistoric people, or the area occupied by a grave, by a site etc.

The real world as studied by geometry, including archaeological entities, is three-dimensional consisting of entities which are delimited by curved surfaces. Polygons, as introduced in this paper, clearly represent an abstraction. Not only that three-dimen-

sional bodies are reduced to two-dimensional areas, but the continuous lines that originate from the projection become discontinuous points defining the polygons. It seems to be premature to consider the question as to whether the reduction of three-dimensional entities into two dimensions is necessary. At a CAA meeting in Leiden in April 1995 there were several papers touching on the problem of more-dimensional GIS. When more-dimensional GIS becomes reality, the definition of polygons can be widened to include 'polygons' extending into the required number of dimensions.

The definition of curved continuous surfaces and lines by means of discontinuous points, however, seems to be a useful abstraction, again considering the present day digital computer technology. The space between a pair of points delimiting a polygon can be interpolated by means of a mathematical function, i.e. continuously, but this does not eliminate the necessity of using the basically discontinuous set of points as the defining delimiters of the polygons.

Vectorized polygons represent a concept which is wider than, and independent of, any particular variety of the GIS software. This can also be proved by reference to polygons on archaeological maps drawn long before the invention of computers and the GIS software. The concept of polygon, sketched above, can be easily generalised to include 'simple' points and lines. A *point* can be defined as a polygon with an infinitely small area and circumference, and a *line* as a polygon with infinitely small area. Many GIS systems make a sharp distinction between polygons on the one hand and points plus lines on the other hand; this distinction, however, is not due to considerations of principle. As archaeological entities are never points or lines in the sense of geometry, they can be easily and sensibly represented by polygons. In consequence of this I shall describe all the three above mentioned geometrical concepts, i.e. points, lines, and polygons proper as *generalised polygons*.

The classes of archaeological polygons

There are two basic types of archaeological polygons: one of them can be defined *directly* by reference to some archaeological entity (an archaeological fact), the other is defined exclusively by its *spatial relationship* to archaeological entities. Examples of the former type of polygons (the *delimiting polygons*) are well delimited underground features or any artifact in general, the latter type (the *enclosing polygons*) being represented, e.g., by arbitrarily chosen squares or a raster superimposed upon a cultural layer of a site; the squares are supposed to be of archaeological relevance because of their possibly differential artifact or ecofact content.

Both the delimiting and the enclosing polygons are operational units enabling the study of the spatial organisation of the archaeological record, they are not units of the record itself as, for example, complexes or components are (cf. Neustupný 1993, 26-28). This is obvious in the case of various rasters, which clearly do not constitute any kind of complexes. In view of this, polygons do not primarily contain any information other than that of the spatial distribution of archaeological facts. If a non-random distribution of facts in the geographical space is obtained, it is a matter of interpretation to show that it served some purpose.

The enclosing polygons need some more comment, as such polygons imply that, for example, a Corded Ware grave and a late Bronze Age storage pit can be meaningfully connected, if they have both been found in the same enclosing polygon. Traditional archaeology did not allow such seemingly meaningless connections. Yet, I would argue that a spatial tie of this sort does contain important information:

- the Corded Ware people used exactly the same area for their graves as the late Bronze Age people for their villages (this,

if repeated, has a bearing on the different way of structuring community areas in the two periods in question),

- the Corded Ware barrow did not prevent late Bronze Age people from settling at its place: they either had no idea about the sacredness of the place and its possible danger (they did not recognise the barrow as a grave), or they knew but did not care (a much earlier grave was no obstacle for them);

- the third possible explanation is that the barrow was no more recognisable some 15 centuries after its heaping.

Of course, the same is sometimes true of delimiting polygons, such as Iron Age sunken huts. If they are taken as Iron Age complexes (i.e. as formal units of the record), it has almost no sense to mention the admixture of earlier (Neolithic, Eneolithic and Bronze Age) pottery fragments in their fill. Such fragments, however, emerge as important pieces of information, if the Iron Age features are taken as polygons and used primarily for spatial studies.

Polygon variables in archaeology

Any entity or quality that can serve as an archaeological descriptor (cf. Neustupný 1993, 105) will be described as an *archaeological variable* in the context of this article. Because archaeological polygons are spatial representations of archaeological entities, their variables acquire archaeologically relevant values. Each polygon can be mapped not only into the archaeological fact that defines or delimits it spatially (into a grave, for example), but also into a number of other descriptors that characterise the grave in various formal dimensions (for example into the classes of vessels found in the grave). This is how the geographical space and the formal archaeological space combine.

Consequently, we have a set of polygons, for example prehistoric graves, and a set of archaeological variables of those polygons, for example a list of pottery classes. Each of the graves can be assigned one or more of the pottery classes from the list in accordance with the classes of vessels actually found in the grave. In this way, e.g., grave 37 from a model site can be assigned the following variables: beaker, amphora, bowl, grave 38 variables beaker and amphora, while grave 48 contained amphora, bowl and pot. This forms a descriptive system which can be expressed in a two-way table (a matrix - cf. Table 2).

Table 2 shows a set of polygons mapped into a set of polygon variables. Seen from another point of view, the individual graves can be considered as objects of a descriptive system, while the pottery classes (beaker, amphora etc.) can be interpreted as descriptors (cf. Neustupný 1973; 1993 etc.). While the former interpretation of Table 2 (in terms of polygons and polygon variables) leads to the understanding of how the problem can be translated into GIS, the latter interpretation (in terms of objects and descriptors) leads to *multivariate analysis*. I am going to describe how these two facets of the problem can be integrated.

polygon/ /object	polygon variable/ /descriptor			
	beaker	amphora	bowl	pot
grave 37	1	1	1	0
grave 38	1	1	0	0
grave 48	0	1	1	1

Table 2. An example of a simple descriptive system.

C. STRUCTURES IN THE COMBINED FORMAL AND GEOGRAPHICAL SPACE

Polygons as objects of multivariate analysis

Looking at the problem from the *multivariate point of view*, Table 2 can be interpreted as a formal archaeological space, as a matrix for which it is possible to calculate, e.g., correlations between the individual pairs of descriptors and to look for hidden structures of the matrix in the subsequent steps of vector synthesis (cf. *Neustupný 1993*). The individual polygons need not constitute a vectorised geographical space in this instance, as the relational or common space is a sufficient basis; the information required is the correlation between all possible pairs of formal descriptors, while the spatial determination of polygons becomes irrelevant.

The vector synthesis based on such an archaeological formal space (in the general sense of the word - cf. *Neustupný 1973*) results in a set of factors and a set of factor scores, the latter being obtained as a dual solution by means of regression. Such a solution is identical to the case where the objects of the descriptive system are archaeological entities in general, i.e. where the objects are not spatially referenced at all.

Polygons as objects of GIS

Using the terminology of GIS it is possible to take just one class of pottery from Table 2 (e.g. beakers), assigning values to the polygons that represent individual spatially determined instances of the pottery class chosen (in this particular case the values will be just 1 or 0 according to the presence or absence of the class). This would create a layer (coverage or image etc. according to the type of software used) containing all the polygons in their proper place (as determined by their coordinates) and described by values of the selected class of pottery. In this way it is possible to express Table 2 by means of four elementary GIS layers. In terms of traditional terminology four maps would be created: one expressing the spatial distribution of graves with amphoras, another expressing the distribution of graves with bowls etc. To achieve this, however, it is necessary to assume that the polygon space is vectorised, not relational or common, as without a system of coordinates it would not be possible to create either a GIS layer or a traditional map.

This view of pottery classes is again an abstract simplification of the archaeological reality as it does not take into account more than just very simple formal properties of the objects. A GIS solution based on such maps only fixes the position of individual pots.

The *elementary layers*, examples of which have been given in the foregoing paragraphs (cf. Table 2), consist of polygons that represent a single polygon variable which specifies the layer. However, in addition to polygons representing the specifying variable (the *specifying polygons*), most elementary layers will also contain a *background polygon* (or several background polygons) which has not been assigned any variable. In the case of a layer representing a prehistoric cemetery the specifying polygons will consist of individual graves and the background polygon will consist of the areas not covered by any grave.

The background polygons create some problems in present day GIS systems, as in the case of the specifying polygons acquiring real number values, the background polygons also necessarily acquire real values (for example 0), and thus cannot be distinguished from the specifying polygons with the same real value (for example 0). This is a difficulty similar to the problem of *false zeros* in multivariate analysis (*Neustupný 1973*), but this time it also appears in connection with cardinal variables. A possible solution to this problem might be to exclude the background from the layer, so that the layer would consist exclusively of specifying

polygons. This, however, would create other difficulties during operations on the layers.

Non-elementary layers will result from simple set theoretical and other operations on elementary layers. The non-elementary layers need not contain the same polygons as the layers on the basis of which they originated.

Multivariate methods and GIS

The two-fold interpretation of data such as that of Table 2 has important consequences for the interrelationship between multivariate methods and GIS which will be discussed in the following paragraphs. These interrelationships, of course, reflect the more general connection between the formal space and the geographical space. I am going to assume throughout the following text that the GIS layers contain polygons in the generalised sense of the term (i.e. polygons, lines and points irrespective of how they are classified in a particular GIS software).

Each elementary layer of GIS corresponds to one descriptor. Individual polygons in a layer correspond to individual objects which acquire certain values. A set of layers 'mapping' one and the same region corresponds to a descriptive system.

If the elementary GIS layer is properly designed, its role in the description of archaeological entities is comparable to the role of a vector in archaeological analysis:

- Any of the GIS layers consists of (generalised) polygons. The values of such polygons, assembled in one layer, may be either real numbers (for example the area of a grave floor) or a subset of real numbers such as the set of natural numbers plus 0 (measuring, for example, the number of vessels deposited in a grave) or simply 1 or 0 (dichotomised data such as that of Table 2). All these cases would result in sets of layers that become spatially fixed parallels to vectors of the traditional vector algebra. In fact, sets of GIS layers are models for a more general view of vectors.

- The layer may also consist of polygons acquiring a set of values which are mutually exclusive, for example those representing soil types. A set of such layers, mutually exclusive and corresponding to the same polygon variable, is analogous to generalised vectors whose elements are individual states of a *nominal variable*.

Typically, a descriptive system based on GIS will consist of

1. a set of polygons fixed in space (by means of coordinates),
2. a set of values of a polygon variable, and
3. a set of mappings between the polygons and the values, i.e. the individual elementary GIS layers.

This is a scheme similar to that in which archaeological objects are mapped into archaeological descriptors, generating matrices in which structures can be sought by methods of vector synthesis (i.e. methods from the factor 'analysis' family). The obvious question is whether archaeological and, indeed, any other sort of structures can be formally generated on the basis of GIS layers describing archaeological polygons by means of polygon variables.

Solution based on simple correlations

This solution consists of two steps:

In *step 1* simple (usual or product-moment) correlations are calculated based on the polygons interpreted as objects of a simple (usual) descriptive system, and the solution is found in the same way as in any other instance 'analysed' by means of methods from the factor analysis family. The principle of these methods consists of finding the orthogonal vector base of the correlation matrix and selecting some of the vectors as the solution.

This leads to the generation of archaeological structures objectively contained in the correlation matrix and hence possibly in the record. This step is identical with vector synthesis performed on the basis of a formal archaeological space.

In *step 2* the factor scores attributable to individual polygons are projected into a set of GIS layers. The number of such layers will correspond to the number of extracted factors, and the factor scores will structure the archaeological space in terms of the archaeological structures as found in Step 1. Step 2 projects the formal archaeological solution into the geographical space.

There are, however, no easy methods to generate spatial structures on the basis of GIS layers as described above. One of the methods which I have used successfully in the case of IDRISI images is the following. Firstly, I have represented the objects (generalised polygons) as points. Secondly, I have assigned the values of factor scores to such points. If n factors are extracted, one gets n images by means of this procedure. Thirdly, I have interpolated a digital elevation model (DEM) by means of the INTERPOL module on the basis of the factor scores assigned to the generalised polygons. In cases where the polygons situated in a particular region of the DEM image form continuous areas of similar values, there is a possibly significant degree of clustering which suggests spatial structure (cf. *Figs. 1 to 8*).

Step 1 of this procedure works fully within the relational geographical space and, consequently, the position of individual polygons within the GIS layers is not taken into account. On the one hand, this makes the solution rather simple and in some cases impressive, especially when the structures calculated by simple vector synthesis in Step 1 form clearcut spatial structures in Step 2, as the two steps are obviously logically independent. On the other hand, the information contained in the spatial arrangement of individual polygons remains unexploited for the extraction of archaeological structures in Step 1.

A solution based on weighted distances between polygons

The information contained within the fact that individual polygons are as a rule pre-arranged in two dimensions can be disclosed by several procedures. One of them is taking into account the distance between any pair of polygons while calculating the correlations or distances *between polygons*. While the preceding solution works on the basis of the correlations between variables, this one is based on correlations (or distances) between polygons. As the number of polygons is frequently much higher than the number of variables, this leads to a considerable amount of calculations and a heavy demand on both computer hardware and software.

The principle of this method is in that the polygons which are close to each other both on the basis of the similarity of their variables and their spatial nearness are given a *weight* different from the case when the polygons equally similar as to their variables but spatially distant (or vice versa). Various methods of weighing can be devised. The scale for the absolute value of the weight, however, must be chosen more or less arbitrarily. However, I have not yet tried this method.

Direct solution

Some methods of GIS (for example the IDRISI software - cf. *Eastman 1995*) provide a direct solution by performing a kind of 'factor analysis' (the principal component analysis in this particular instance) directly on GIS layers. Strictly speaking this requires that the layers should contain no background polygons. There are also other severe limitations but, when there are no obstacles, this may lead to a straightforward solution.

I have used the direct solution in the case of Loděnice which will be described later in this paper (but then preferred the solution by means of my own software), while *M. Kuna*, following the logic explained in this article, experimented with other applications (*unpublished*).

The validation of structures

As I have already pointed out, the methods of vector synthesis from the factor analysis family objectively describe structures contained in the correlation matrix (as this is ensured by the mathematical algorithms), but these structures need not necessarily be the same as those characterising past human behaviour. The obvious reason for the possibility of such a divergence is the fact that the correlation matrix (or any other matrix containing other kinds of numerical values) may not significantly reflect the true correlations (or other statistics) because of *random fluctuations* in the observed values that form the basis for any calculations. This is perhaps the problem for which statistics were invented.

As a consequence of these difficulties, one of the principal problems of multivariate methods has always been the problem of statistically testing their results. Some methods have been developed for this purpose by statisticians, but most of them depend on strict requirements on the statistical distribution of variables in several dimensions, something very difficult to control. It is for this reason that I have suggested the procedure of validating the results instead of testing them statistically.

The validation procedure works with the concept of external evidence (*Neustupný 1981*), i.e. such empirically derived evidence which is not included in the original descriptive system being logically independent. For example, if factors are derived from Corded Ware cemeteries on the basis of artifact types in graves, the sex and age of skeletons as determined by physical anthropologists represent external evidence in relation to the artifacts. Now, the logic of validating the results of multivariate methods by means of external evidence is that it is very unlikely that the factors obtained, e.g., by vector synthesis would result by chance, if they correlate (covary) with the sex/age structure of the graves, as this kind of information is independent of the information contained in the combination of artifact classes in graves (cf. *Table 2*). I would like to stress that validation, as understood in this paper, is a methodological step equivalent to statistical testing, not to interpretation.

The great attraction of GIS lies in the fact that it discloses spatial patterning of the archaeological record which almost always represents independent external evidence in relation to the evidence of formal properties of artifacts. The role of spatial studies as a validating counterpart to formal studies (and vice versa) is therefore a most powerful addition to the methodology of validation.

The problem of transformations

In general, the patterning of the archaeological record can result either from structured behaviour of past living individuals and/or social groups (type B, or *behavioural structures* discovered by archaeologists), or from transformations that followed the exit of archaeological facts from live culture (type T, or *transformation structures*). The latter reason for the record patterning into formal structures may have many particular causes such as the selective destruction or disturbance of certain parts of the record by previous human activities or natural processes, or by differing archaeological methods used during the physical analysis of the record in the field. I would add that the third reason for the patterning of the record can be the design of the descriptive system by archaeologists; we may get 'false' formal structures (type D

structures) by including logical 'ties' into our descriptive system (cf. *Neustupný - Vencel 1995*).

I am trying to draw attention to these problems mainly because the comparison of formal and spatial structures may help to discover at least some instances of type T structures, although there is no reason to believe that formal T structures and spatial T structures do not covary.

The following examples differ somewhat in size and in the kind of polygons on which they are based. The first two cases remain on the site level (investigating into intra-site structures), while the third exemplifies intersite studies. Both Hostim and Loděnice are based on enclosing polygons; in the case of Hostim they form a regular continuous net while Loděnice works with irregular and discontinuous 'patchy' polygons of unequal size. In the case of Vikletice, however, the polygons are delimiting (graves). The basic methodology is, of course, the same in all three instances.

The Hostim site was excavated by Slavomil Vencľ in the 1960s. The method applied in the field aimed at nearly fully exploiting an area of very limited size that contained dense remains of the Late Palaeolithic period. The surveying of 267 one-square-meter plots uncovered the full extent of the site (Vencľ 1995). I have interpreted the square plots as enclosing archaeological polygons. Each of the polygons was characterised by a set of values measuring the frequency of the main categories of finds such as scrapers, animal teeth, tools in general etc. Vencľ described 23 such categories of polygon variables. The site included an area considered to be a round dwelling, possibly the remains of a tent-like structure.

A non-formalised scrutiny of the images has revealed a number of spatial patterns. One of them (Pattern 1, *Fig. 1*) covered a more or less rectangular area with two subareas both displaying a dense clustering of finds: one around the 'dwelling' (in the upper part of the excavation trench), the other in the lower part. This was the pattern displayed by most chipped tools. Pattern 2, resulting from e.g. slate implements, macroliths etc., differed from Pattern 1 by its diagonal orientation (*Fig. 2*). Pattern 3, typical of bowls, engravings and bones, consisted of categories which seemed to cluster in the right part of the excavation trench where there was no concentration of Pattern 1 types (*Fig. 3*). Several categories (cores, burnt industry, colorants) showed individual distributions. Others (slate, burnt pieces, burin spalls) were conspicuously underrepresented in the refuse area situated immediately to the east of the dwelling where most other categories were met in high densities.

On the whole, it would not be possible to explain the multivariate solution if there were no spatial counterpart to the formal structures. Apparently the palaeolithic period is still not known to

a degree sufficient to explain minor differences in the formal composition of two similar assemblages such as represented by factors 1/4 and 4/4. Not even the much more distinct factor 3/4 (bowls, bones, macroliths, chisels, cf. Fig. 4) makes much sense by itself. At present it is not possible to explain all the patterning of the record as suggested by the methods used. However, taking into account the spatial distribution of the finds it is possible to attempt a partial explanation.

The area of the dwelling in the upper part of the excavation trench (feature A) formed a clearcut contrast to the oval concentration of finds in the lower part of the trench (feature B). Feature A can be explained as a dwelling frequented mainly in the cold periods of the year. The dwelling contained a specific assemblage (cores, crest blades, slate, pieces with traces of use wear, burins etc.), and there seems to be a refuse heap to the right of the dwelling which may contain some categories of refuse from the house floor. Feature B, extending before the possible entrance to the dwelling, seems to have been a warm season area (but with a profuse evidence of fire). This area also had its refuse 'heap' reaching behind the eastern corner on the right; this refuse, however, mostly contained bone, as chipped industry was apparently left as primary refuse at the spot. The assemblages of artifacts found in feature A and B differ in their quantitative composition.

The spatial studies accomplished in the case of Hostim have demonstrated that the occupation area of prehistoric people had been structured in the late palaeolithic period. Where attempts at distinguishing places within prehistoric sites (neolithic and later) that served different kinds of purposes have been made, the search for formal differences between functionally different features ended without result (Rulf 1993; Rulf - Saláč 1995). The reason for the success achieved in the study of palaeolithic sites may be due to two factors:

(1) Much of the refuse was primary refuse (Schiffer 1976) left more or less at the spot where the original artifacts or ecofacts had been discarded.

(2) The occupation period was short, may be several season at most, so that the functionally divergent features and their remains did not overlay to the degree apparently occurring in later periods.

I have suggested earlier in this paper that some of the concentrations of artefacts and ecofacts uncovered at Hostim may have reflected socially recognised refuse areas, but such areas may not yet have been very common in palaeolithic times. In later periods, possibly beginning with the neolithic, but certainly in the eneolithic and bronze age, formalised (secondary) refuse areas apparently became widespread in Central Europe, a fact obliterating the original pattern of artifact and ecofact spatial distributions as it would become manifest on the basis of primary refuse.

At the same time, sites became scenes of long-lasting shifting activities, and consequently of long-lasting and spatially somewhat shifting accumulation of refuse in most varied parts of the site. This is another reason for the unreadability of the patterns of primary refuse even if there were any in prehistoric life. As the site shifted from one place to another, usually a spatially close one, *archaeological finds from different parts of the same site began to testify to different segments of passing time rather than to the purpose of the particular place*. In consequence of this, even the unstratified sites of later prehistory in Central Europe display a chronological variation that may completely obliterate the variation resulting from the original purpose of artifacts.

2. Vikletice: a Corded Ware cemetery

Vikletice is a Corded Ware culture cemetery in NW Bohemia excavated mainly by D.Koutecký between 1962 and 1965 (Buchvaldek - Koutecký 1970). Some 300 to 400 years of the development of the Corded Ware culture is covered by more than

150 graves distributed into 9 local groups (for the groups cf. Neustupný 1983). Assuming that the main dimensions of variability are time, gender and age I have chosen 31 variables to describe the individual graves. A detailed account of the Vikletice project will be presented separately.

As the position of nearly all the graves could be determined by means of coordinates, the graves were considered to be polygons, and the 31 variables to be polygon variables. While Hostim was a case studied by means of enclosing polygons densely covering the site, Vikletice graves are clearly delimiting polygons rather sparsely distributed throughout the cemetery. From the point of view of formal variability, the graves became objects and the variables became descriptors of a descriptive system. I have used three kinds of evidence external to this descriptive system: sex of the deceased, their age at death, and spatial clustering of the formal variability.

Already some of the observed variables, not included among the 31 descriptors, disclosed obvious spatial clustering. This was obtained by assigning values, characterising the individual graves, to points representing the graves and subsequently by calculating a digital elevation model. Clear-cut spatial structuring was obtained, for example, in the case of the total count of tools and/or weapons (Fig. 5) and the length of the grave pit (Fig. 6).

The original number of variables was subsequently reduced to 28, mainly because of the low overall frequencies of some of the variables (Table 4). I have used nearly 300 graves of the Corded Ware culture in NW Bohemia to perform vector synthesis, not only the graves found at Vikletice. Additional graves have

class	n
AMP amphora	236
ANI animal bones	20
BAX battle-axe	40
BEA beaker (unspec.)	22
BON bone artifact	25
BOW bowl	15
CBE cylindrical beaker	5
COP copper ornament	20
DHC double-handled cup	7
FAX flat axe	50
FBO footed bow	8
FPC flower-pot cup	9
HAX heavy axe	14
HBE handled beaker	33
JUG jug	49
LAM little amphora	30
LBE lugged beaker	18
LBO little bowl	11
MAC mace-head	27
NIC no equipment	26
OCH lumps of ochre	5
OHC one-handled cup	44
POL polisher	26
POT (ovoid) pot	62
SBE simple beaker	89
SHB shell bead	6
SHE sherd	15
SHL shell brooch	5
SIL flint	185
TEE animal teeth (perf.)	13
UHC unhandled cup	14

Table 4. Vikletice, a Corded Ware cemetery. List of variables used for the principal component analysis.

The new set of graves from NW Bohemia were subjected to vector synthesis by means of principal component analysis followed by Varimax rotation. Some of the 9 factors extracted could be easily interpreted on the basis of their high factor loadings. Factor 3/9, e.g., was characterised by the following descriptors: flat axes, lugged beakers, heavy axes, mace-heads, battle-axes, jugs, flint tools and amphoras. This is clearly equipment of male graves of the late or final phase of the Bohemian Corded Ware. This fact found its reflection in the correspondence of graves having high factor scores in relation to this factor with the independent (external) determination of the sex and age of skeletons found in such graves: they were significantly associated with adult male skeletons according to a statistical test. At the same time, when the values of factor scores relating to factor 3/9 were assigned to the individual graves and a DEM was calculated, a remarkable degree of spatial clustering was found in group Vb with a lesser concentration in some of the other groups (Fig. 7).

	count
Neolithic and Eneolithic pottery	5
Bronze Age pottery	226
Hallstatt period pottery	10
La Tène pottery	183
Roman period pottery	72
Prehistoric pottery	515
Early Medieval pottery	12
High Medieval pottery	759
Post-medieval pottery	8092
Chipped flint	23
Slag	3358
Sapropelite, cores (SAPCO)	318
Sapropelite, worked (SAPW)	1152
Sapropelite, seen (SAPV)	8892
Sapropelite, unworked (SAPN)	1438

Table 5. Loděnice region. List of variables used for the principal component analysis.

Factor 7/11

[illegible]

Table 6. Loděnice region. Principal component factor 7/11, factor loadings rotated by means of the Varimax algorithm.

Factor 11/11

[illegible]

Table 7. Loděnice region. Principal component factor 11/11, factor loadings rotated by means of the Varimax algorithm.

Factor 1/11

[illegible]

Table 8. Loděnice region. Principal component factor 1/11, factor loadings rotated by means of the Varimax algorithm.

Factor 4/11

1. HALLSTATT	4.	.163	888888
2. BRONZE AGE	3.	.025	8
3. CHIPPED FLINT	1.	.012	8
4. EARLY MEDIEVAL	13.	.003	8
5. HIGH MEDIEVAL	14.	-.010	8
6. SAPROPELITE, SEEN	9.	-.011	8
7. SAPROPELITE, CORES	7.	-.013	8
8. ROMAN PERIOD+MIGR.P.	12.	-.019	8
9. NEOLITHIC+ENEOLITHIC	2.	-.020	8
10. SAPROPELITE, UNWORKED	10.	-.028	8
11. POSTMEDIEVAL	15.	-.033	8
12. SAPROPELITE, WORKED	8.	-.039	8
13. LA TENE	6.	-.144	88888
14. FARMING PREHISTORY	5.	-.385	88888888888888
15. SLAG	11.	-.947	88888888888888888888888888888888

Table 9. Loděnice region. Principal component factor 4/11, factor loadings rotated by means of the Varimax algorithm.

MATRIX OF ROTATED FACTORS	1	2	3	4
1. NEOLITHIC+ENEOLITHIC	.026	.858	.012	-.008
2. BRONZE AGE	.004	.856	-.019	.003
3. HALLSTATT	.768	-.023	.018	.051
4. FARMING PREHISTORY	.763	.051	.230	.001
5. LA TENE	.022	-.021	.765	.067
6. ROMAN PERIOD+MIGR.P.	.023	.013	.716	-.055
7. EARLY MEDIEVAL	-.089	.011	-.003	.757
8. HIGH MEDIEVAL	.124	-.015	.011	.710
9. POST-MEDIEVAL	.667	.013	-.133	-.005

Table 10. Loděnice region. Principal component factors 1/4 to 4/4, factor loadings rotated by means of the Varimax algorithm.

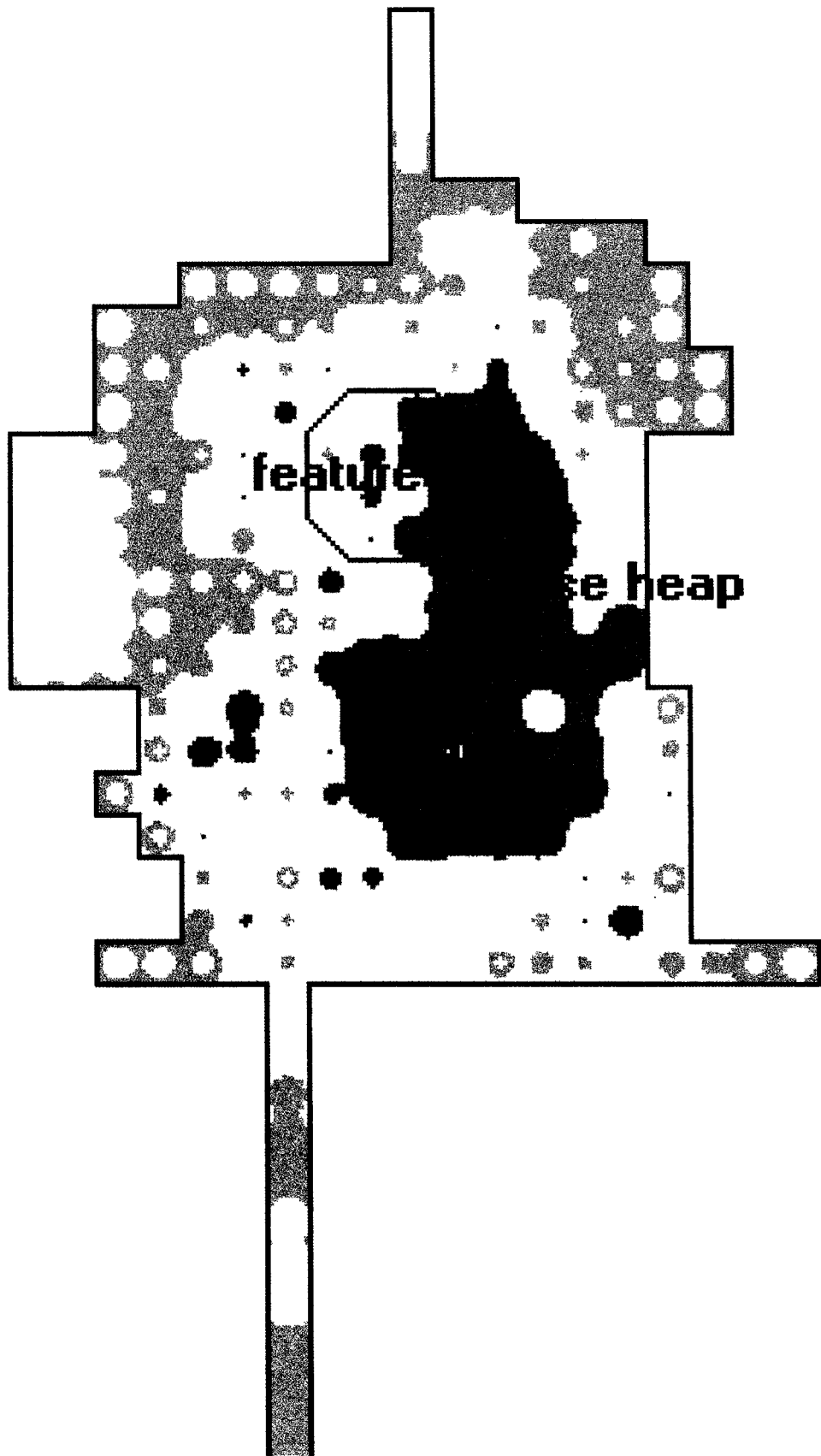


Fig. 1. Hostim, a late palaeolithic site. Digital elevation model based on the distribution of tools. Pattern 1.

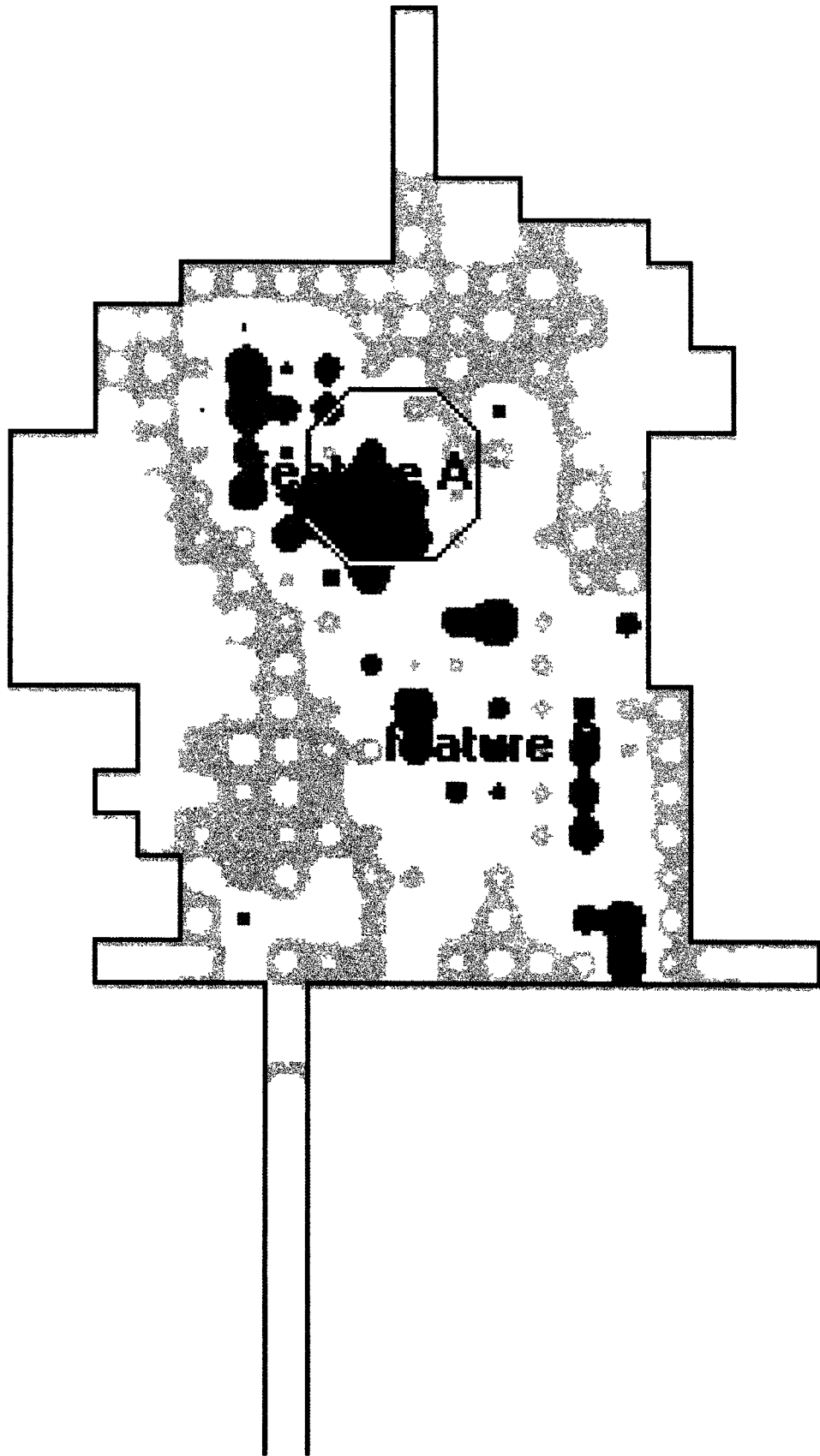


Fig. 2. Hostim, a late palaeolithic site. Digital elevation model based on the distribution of pieces of slate. Pattern 2.

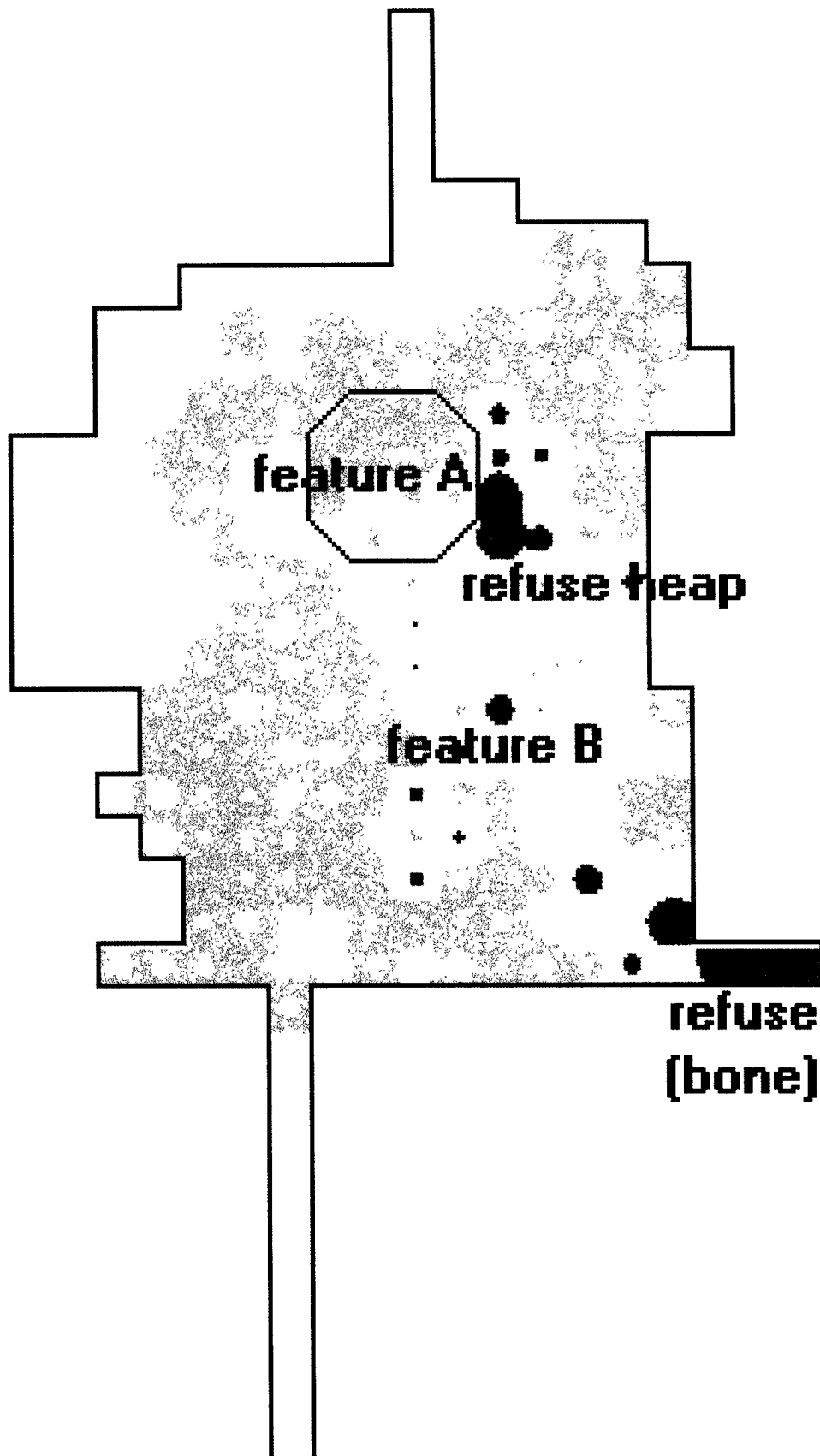


Fig. 3. Hostim, a late palaeolithic site. Digital elevation model based on the distribution of fragments of bones. Pattern 3.

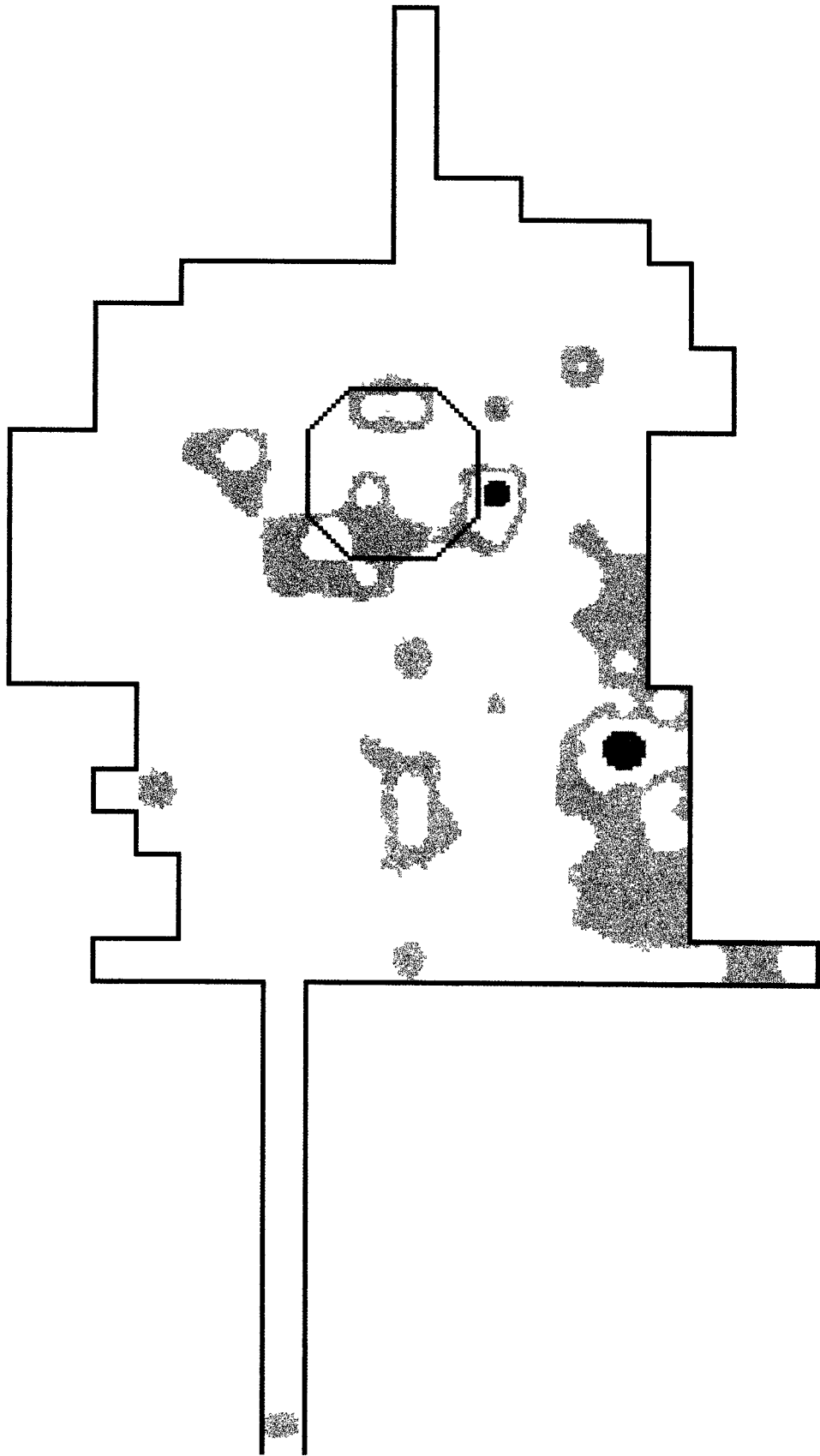


Fig. 4. Hostim, a late palaeolithic site. Digital elevation model based on factor scores of factor 3/4.

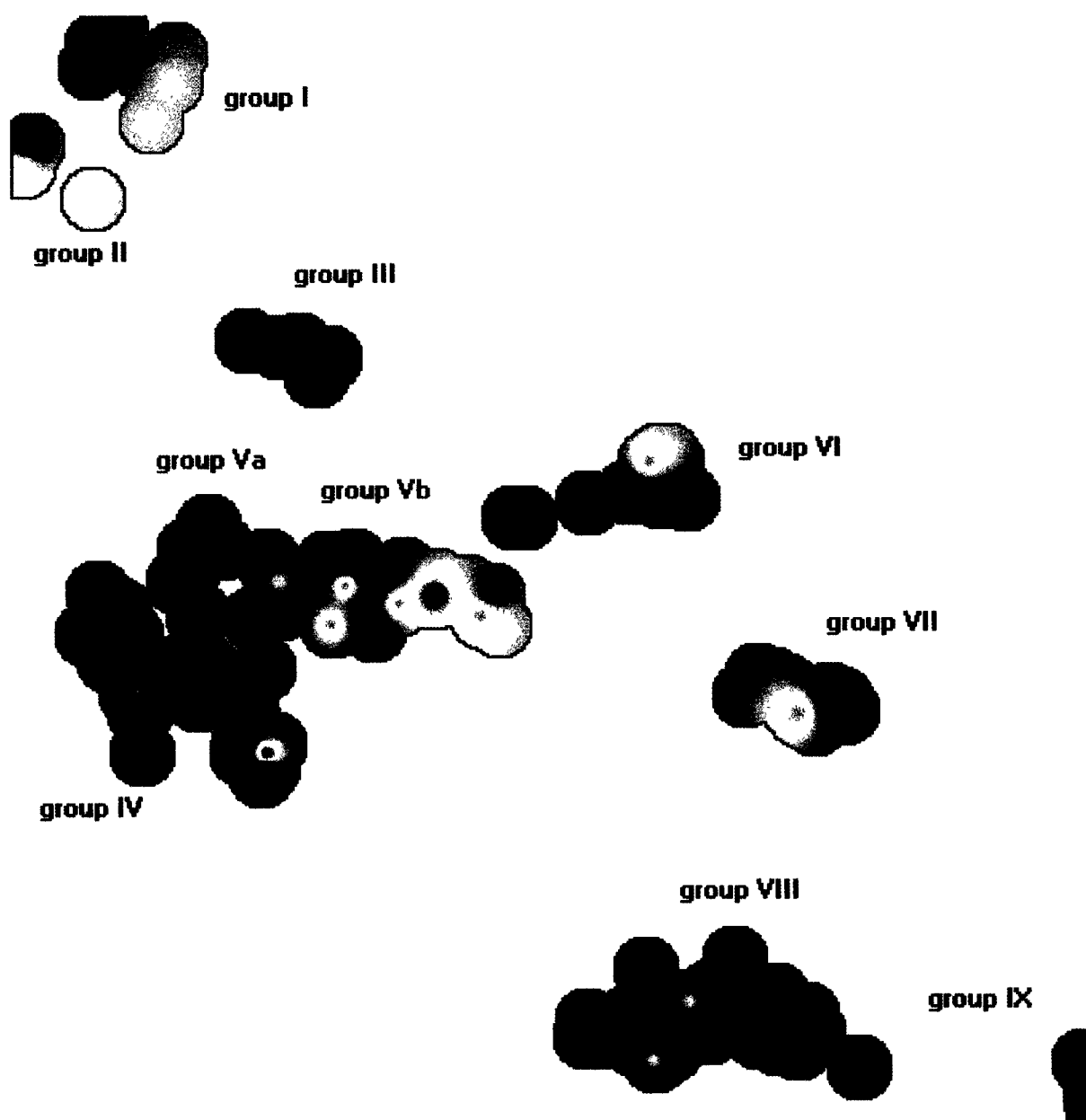


Fig. 5. Vikletice, a Corded Ware cemetery. Digital elevation model based on the total count of tools and/or weapons in individual graves. Graves of children marked by dots.

Most of the other factors of the solution could be validated either by means of a statistical test as being characteristic for the age and sex of the deceased, and/or by their spatial clustering in some of the local groups of the Vikletice cemetery. This is a good example of how formal structures also become spatial structures, but obviously it need not always be so.

The formal structures and their spatial counterparts as obtained by this research project are so rich that it has not yet been possible to explain all of them. In spite of the fact that much of the spatial variability has been previously known to respond to pass-

ing time (Neustupný 1983, Table 20), some oppositions of a non-chronological nature also seem to be involved. For example, graves belonging to factors 3/9 (Fig. 7) and 6/9 (Fig. 8) are at least partially contemporaneous, the former being statistically tied to adult men (with rich weaponry), the latter characterising adult women. Their spatial distribution, however, is different: while the 'male' factor is largely met in Group Vb, its female counterpart is dispersed in several strong clusters in various local groups of the cemetery. This, of course, may suggest that all the grave groups at Vikletice did not enjoy the same social status which, in its turn,

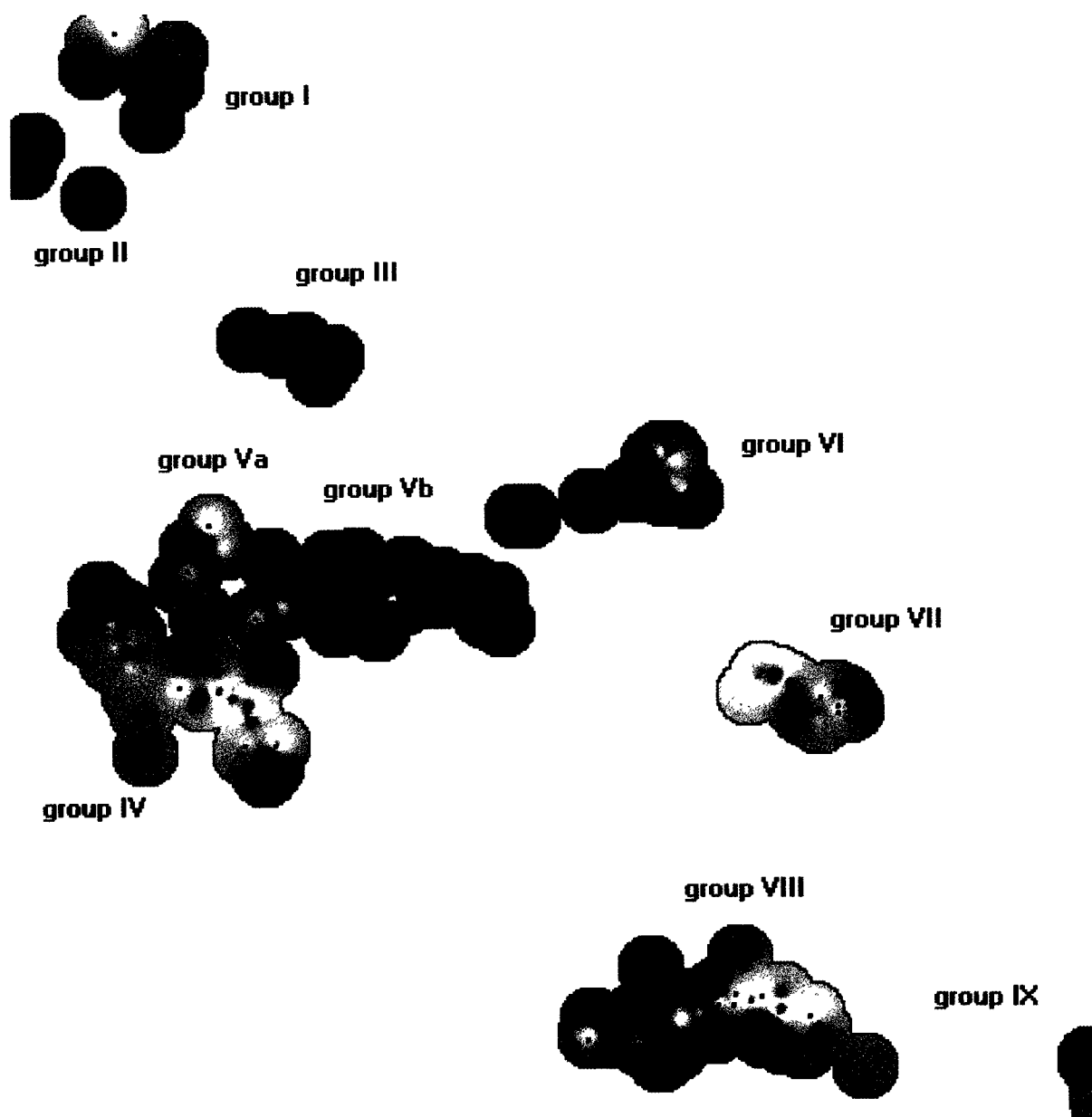


Fig. 6. Vikletice, a Corded Ware cemetery. Digital elevation model based on the lengths of graves.

might indicate a more complex family structure than usually assumed.

3. Loděnice: an Iron Age production region

What is described here as Loděnice represents a region of Central Bohemia just to the west of Prague; it became an object of intense study by means of field walking in 1993 to 1995. The project was directed by Nataša Venclová, who was also responsible for the field activities (Venclová 1994; 1995). Concurrently with the field walking Venclová compiled a detailed database of earlier finds.

The area of the region, named after the Loděnice brook which runs through its center, measured some 80 square kilometers. However, the whole area could not be walked with the same intensity, as nearly three quarters of it was covered by land which could not be accessed easily, some of it being unsuitable for archaeological research (woods, gardens, modern living quarters, industrial and agricultural plants, roads, ponds, wet and inundated places close to streams, etc.) The rest were fields where field walking polygons, usually coinciding with large fields, were laid down. Each polygon was divided into a number of squares covering something like a hectare (or less along the borders of the

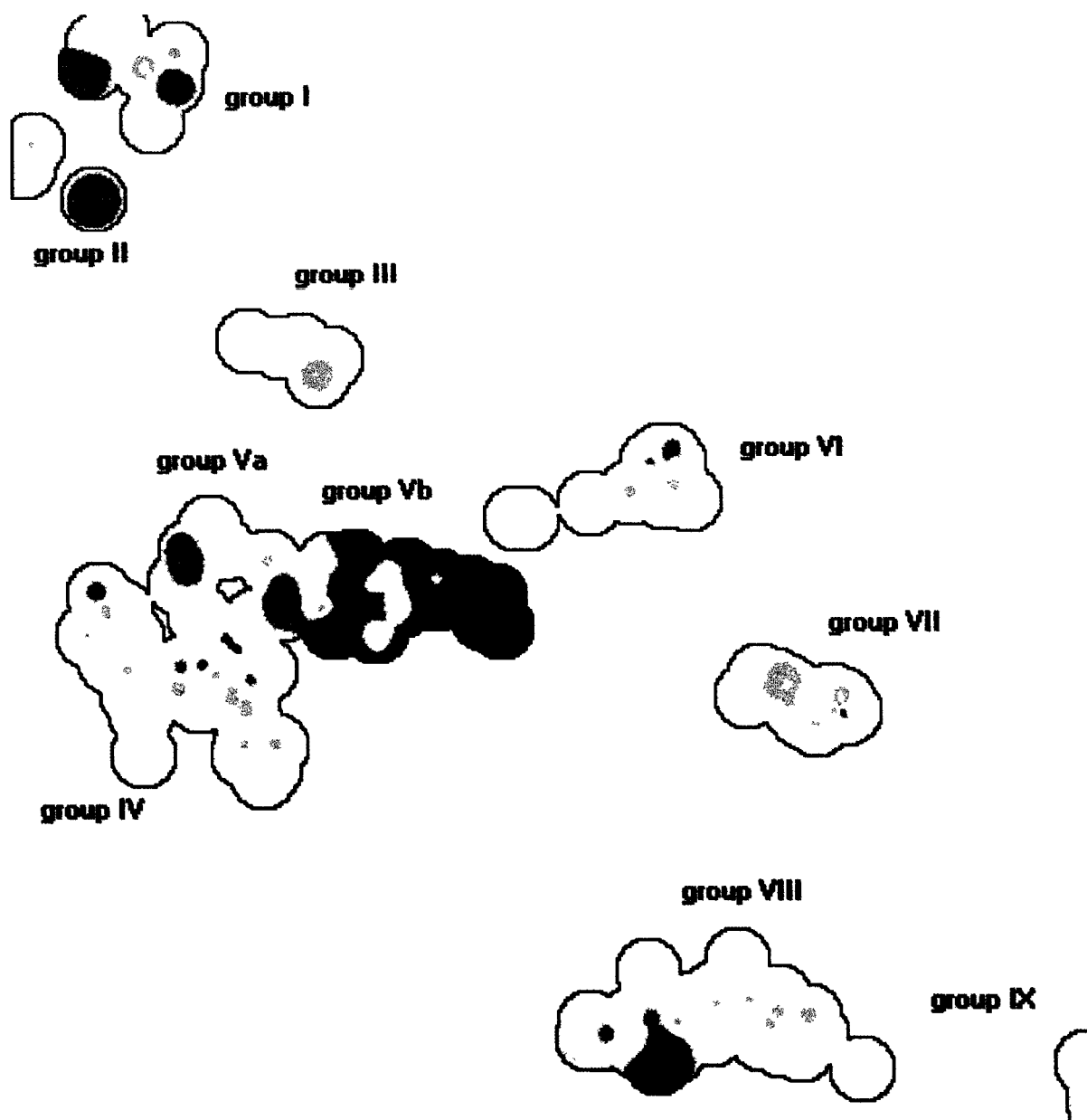


Fig. 7. Vikletice, a Corded Ware cemetery. Digital elevation model based on factor scores of factor 3/9.

polygons); there were some 1361 squares walked once, and a much smaller number of those walked twice. The methodology was taken over from the ALRNB project using Kuna's design for field walking (Kuna 1994). The polygons were mostly located randomly on the basis of an algorithm which I had previously devised for the ALRNB project. The finds were classified and described by N. Venclová, V. Moucha, J. Bubeník and T. Durdík, and detailed information from the results was stored in a database which became the basis of this preliminary report.

The region has become well known chiefly through the eminent La Tène culture remains of the early Iron age. They include

not only a 'viereckschanze' enclosure at Mšecké Žehrovice (with the famous stone head of a Celtic deity), but also traces of the production of sapropelite arm-rings widely exported from the region, as well as traces of the production of iron. The aim of Venclová's project was to put all the data together, and to investigate the spatial information supplied by the field walking project.

I have identified the individual squares with enclosing polygons and took the individual categories of finds as polygon variables. N. Venclová has distinguished 31 of them, but for the purpose of multivariate analysis I have reduced this number to 15 or 9. My next step was the calculation of a correlation matrix and

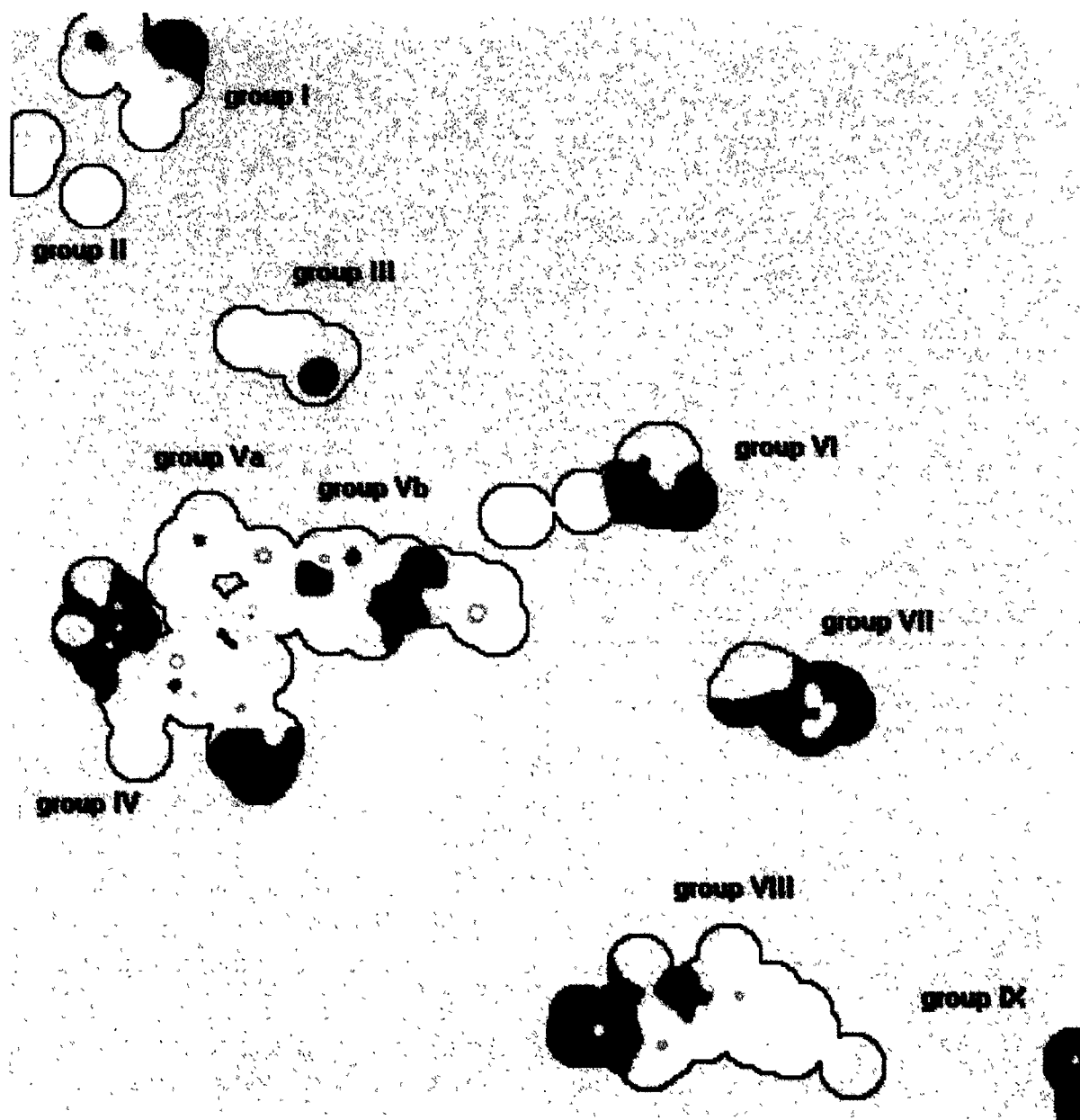


Fig. 8. Vikletice, a Corded Ware cemetery. Digital elevation model based on factor scores of factor 6/9.

the derivation of principal component factors, the calculation of factor scores and their projection into the squares.

Solution 1 has been based on 15 polygon variables (*Table 5*). I have been able to derive 11 meaningful factors. I am not going to expatiate upon the results. What may be important when considering the impact of sapropelite ring production on the Loděnice region is the fact that pieces of sapropelite were highly diagnostic of three of the factors.

Factor 7/11 had high loadings in respect of the three sapropelite varieties with which there can be doubts as to their intentional shaping (SAPN, SAPW, SAPV). In fact, La Tène pot-

tery and SAPCO, the only definite Iron age sapropelite product, are on the opposite pole of the factor (*Table 6*). Factor scores diagnostic for this factor cluster in the north-west corner of the investigated area where natural outcrops of sapropelite occurred. This, however, is not the only distribution area of high factor scores; at least three other can be distinguished (*Fig. 9*). It may be even more important to note that this factor is poorly represented in some of the La Tène pottery clusters (cf. *Fig. 15*) suggesting that some sites of this culture did not process sapropelite.

Factor 11/11 has high loadings on La Tène culture pottery, two kinds of 'worked' sapropelite (SAPW, SAPCO) and iron

Lodenice, factor 7/11

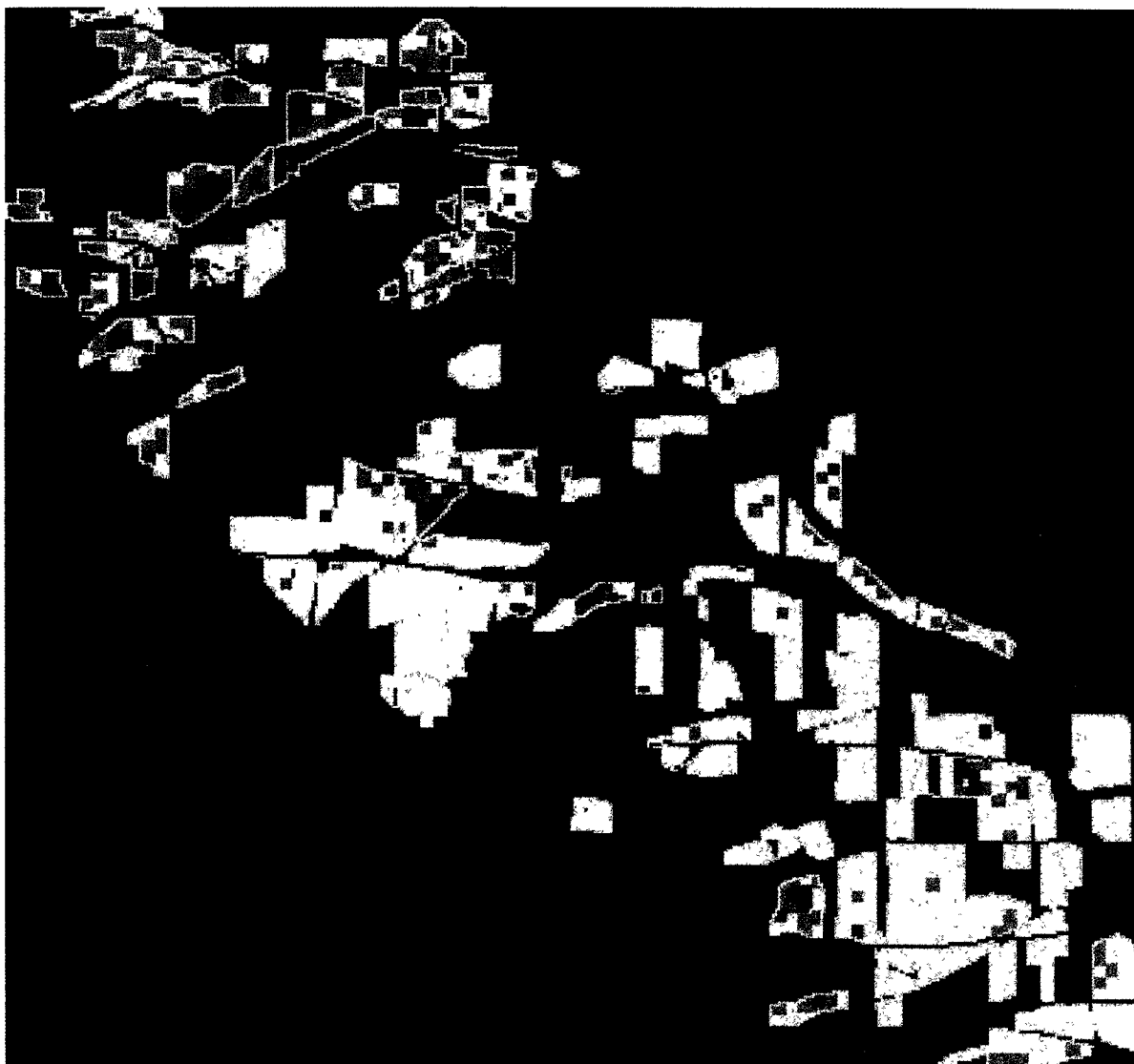


Fig. 9. Loděnice region, a field walking project. Raster representation of factor scores of factor 7/11. Dark green: scores < -2, medium green: scores between -2 and -1, light green: scores between -1 and 0, pink: scores between 0 and +1, red: scores between +1 and +2, brown: scores > 2.

bloomery slag; Roman period pottery comes next, although it may reach into the 'insignificant' region of factor loadings (Table 7). This is a clear domestic production assemblage. Its representation on the northern side of the Bakovský brook is remarkably poor, but it is common in certain clusters including those where Factor 7/11 had insignificant factor scores (Fig. 10).

Factor 1/11 displays high factor loadings in respect of all the kinds of sapropelite; it has a very weak connection with La Tène pottery fragments (Table 8). High scores of the factor concentrate in a rather limited set of polygons in the north-west corner of the region (Fig. 11).

Thus, we have got three different factors characterising finds of sapropelite. One of them (factor 7/11) clearly displays the area of its natural outcome which does not mean that the pieces found are untouched by human hands; in fact, the inclusion of some settlement sites into this factor indicates that it does not display any natural state of the raw material. Another factor (factor 11/11) reflects the usage of sapropelite in living areas apparently where the arm rings were manufactured. The same areas also served for producing iron. The third structure (factor 1/11) is difficult to explain at the moment, but it is clear enough to be taken seriously.

Lodénice, factor 11/11

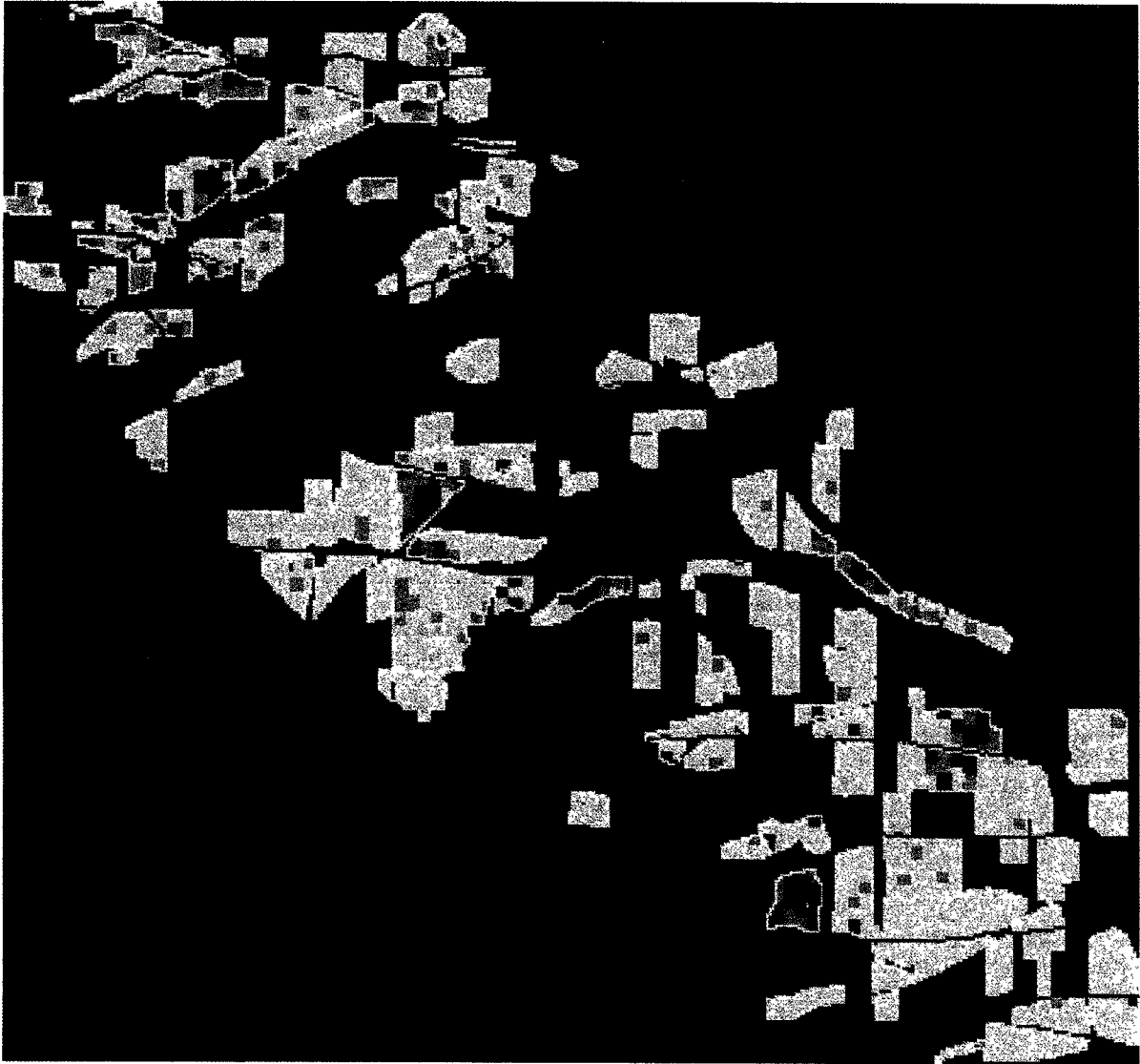


Fig. 10. Lodénice region, a field walking project. Raster representation of factor scores of factor 11/11. Colour scale the same as in Fig. 9.

It should be noted that La Tène pottery also occurs with factor 4/11 where it appears together with slag and prehistoric pottery in general, but with no sapropelite (Table 9; Fig. 9). This seems to reflect another type of Iron age production: the working of iron to the exclusion of sapropelite. Consequently, it must be investigated whether the production of iron and the production of sapropelite rings were not partly separated; the reason for the difference may be chronological. Anyway, factor analysis of the Lodénice region polygons proves without any doubt that sapropelite is to be connected with the La Tène period, and this would be an unequivocal result even without any knowledge of sapropelite

artifacts dated by means of La Tène culture pottery in underground features.

One surprising result of factor analysis of the Lodénice data is that the location of medieval sites and post-medieval sites (later than cca. AD 1500) differs. It may be interesting to note that this would be extremely difficult to discover by traditional means, as the number of pottery fragments is one order higher in the post-medieval period, and graphical plots do not help very much. This situation has already been indicated by solution 1 in 11 factors, and fully supported by solution 2.

Solution 2 was based on 9 polygon variables representing

Lodenice, factor 1/11

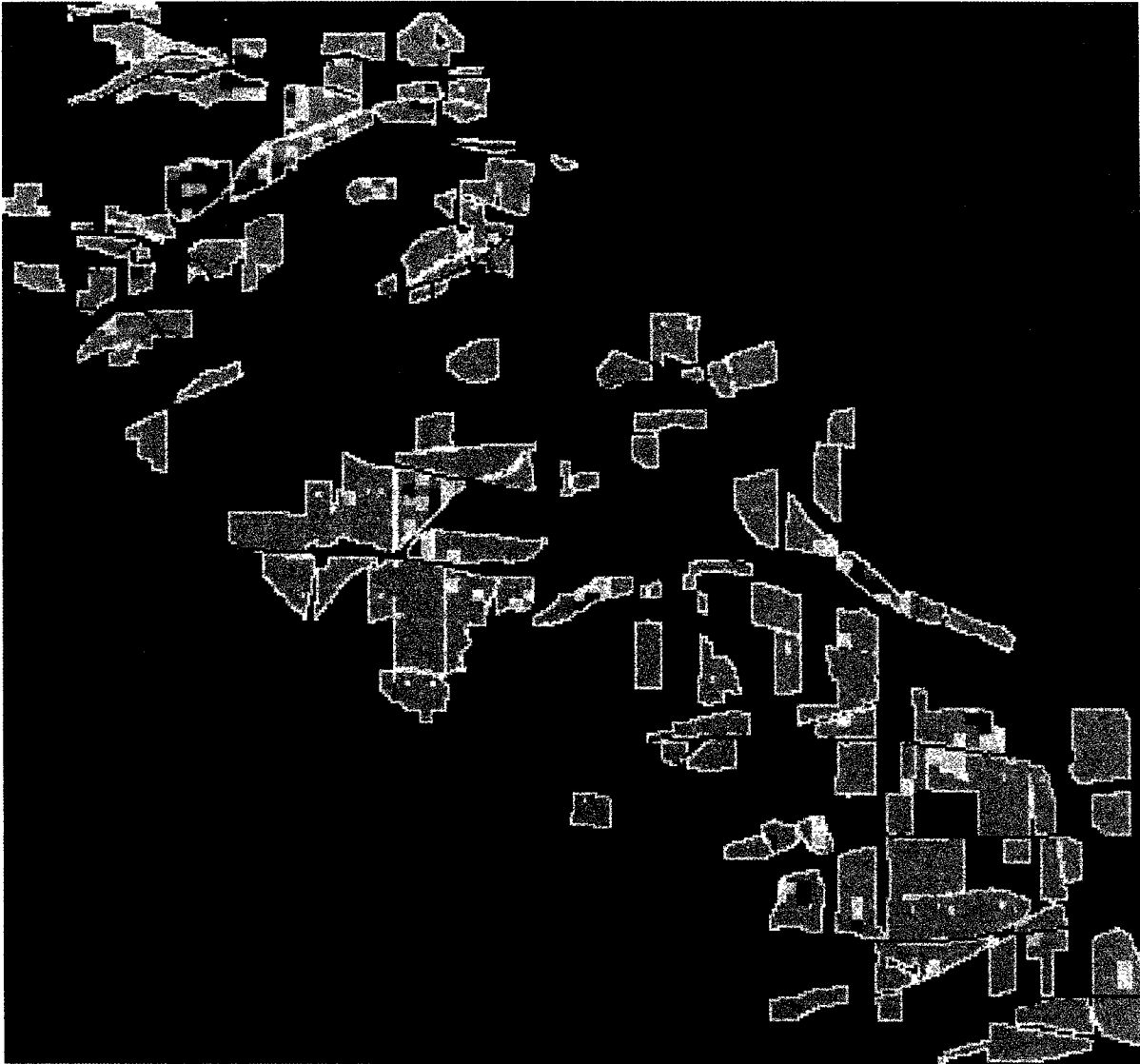


Fig. 11. Loděnice region, a field walking project. Raster representation of factor scores of factor 1/11. Colour scale the same as in Fig. 9.

exclusively pottery finds from the 1361 squares. I have chosen 4 factors. Factor 1/4 selects Hallstatt pottery, prehistoric pottery in general, and post-medieval fragments. In view of the scarcity of Hallstatt pottery fragments it seems to reflect mainly the post-medieval component. Factor 2/4 has picked out pooled neolithic and eneolithic finds and pooled Bronze age finds, while factor 3/4 is characterised by pottery of the La Tène period, Roman period, and prehistory in general. Post-medieval is in a weak opposition to this Iron age set (Table 10). Finally, factor 4/4 is composed of two types of pottery: early medieval and high medieval. By plotting the factors graphically it will be possible to delimit major

habitation components of some of the settlement areas (Fig. 13 to 16). There still remain many problems to be solved, for example how to handle 'isolated' sherds in contrast to major sherd clusters.

The overall picture of prehistoric and later settlement structure as revealed by solution 2 is very similar to that which I obtained previously on the basis of a larger sample from eastern Bohemia (Chrudim region, unpublished). The principal similarity between these solutions is in that *chronologically close cultures occupy similar places within the countryside*. More detailed chronological distinctions, however, lead to more detailed groupings of archaeological cultures. The already mentioned contrast

Lodenice, factor 4/11



Fig. 12. Loděnice region, a field walking project. Raster representation of factor scores of factor 4/11. Colour scale the same as in *Fig. 9*.

between medieval and post-medieval also seems to be widespread. The possible reason for this may be that medieval pottery clusters still reflect changing settlement patterns while later pottery fragments may have got into the ground as a consequence of something like manuring, i.e. not through changes in settling habits. I have presented here only a few partial explanations hesitating to go into more details, as the study of the Loděnice region has only just begun.

CONCLUSIONS

On the whole, multivariate analysis joined to GIS represents a most powerful formal procedure for generating archaeological structures. Exploiting the polygon concept, I have explained the principles of how such an integration of the two procedures can be realised. At the same time, I have presented several examples which, of course, do not exhaust the topic. There are other promising methods, some of them ready in commercial packages, which I have not exploited, and many other methodological procedures have not yet been developed.

Lodenice, factor 1/4

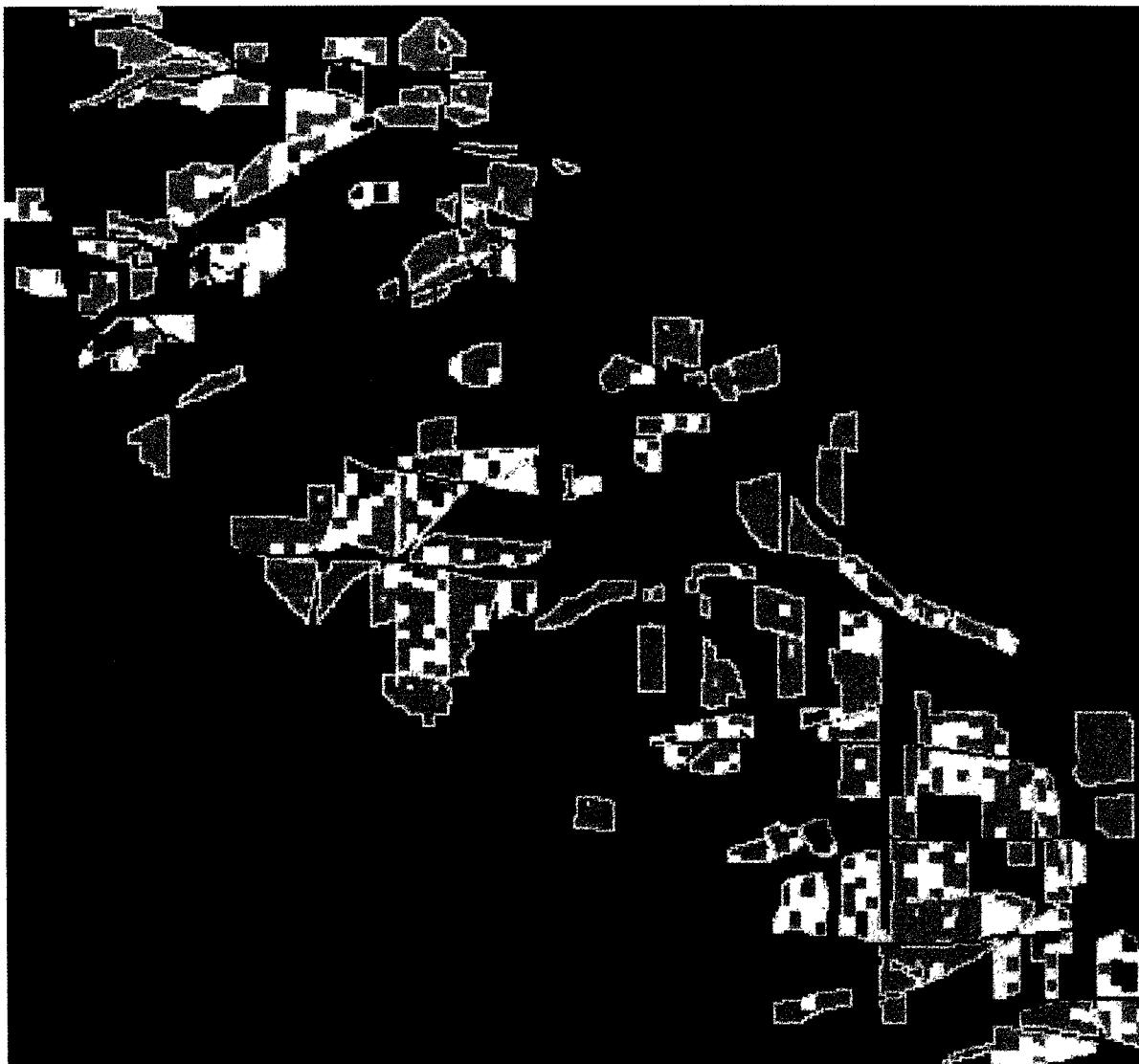


Fig. 13. Loděnice region, a field walking project. Raster representation of factor scores of factor 1/4 (mainly post-medieval). Colour scale the same as in Fig. 9.

The reason why the connection of multivariate methods and spatial studies by means of GIS works so nicely is not difficult to understand. For those who know little about mathematics the individual procedures are just technical 'tools' some of which do help and others do not. It might seem that there is a stock of mathematical tools somewhere (most likely in certain natural sciences) and, to save time, it is sufficient to select the right tool. My contention is that this is not the correct way to approach mathematics in archaeology.

Mathematics is the most abstract theory of structures of the real world and this is the reason why archaeology cannot escape

it. Success means selection of proper mathematical methods, i.e. the methods appropriate from the logical point of view, not just those whose results are easy to comprehend or those come across by chance. As I have shown elsewhere (*Neustupný 1993*) multivariate methods from the factor analysis family are isomorphic with contemporaneous archaeological requirements, and this is the reason why they work. Databases and GIS representations, too, have now been based on clear theory, in spite of the fact that their beginnings were often more pragmatic.

I am eager to point out that much of the information still unrecognised in the archaeological record concerns symbolic

Lodenice, factor 2/4

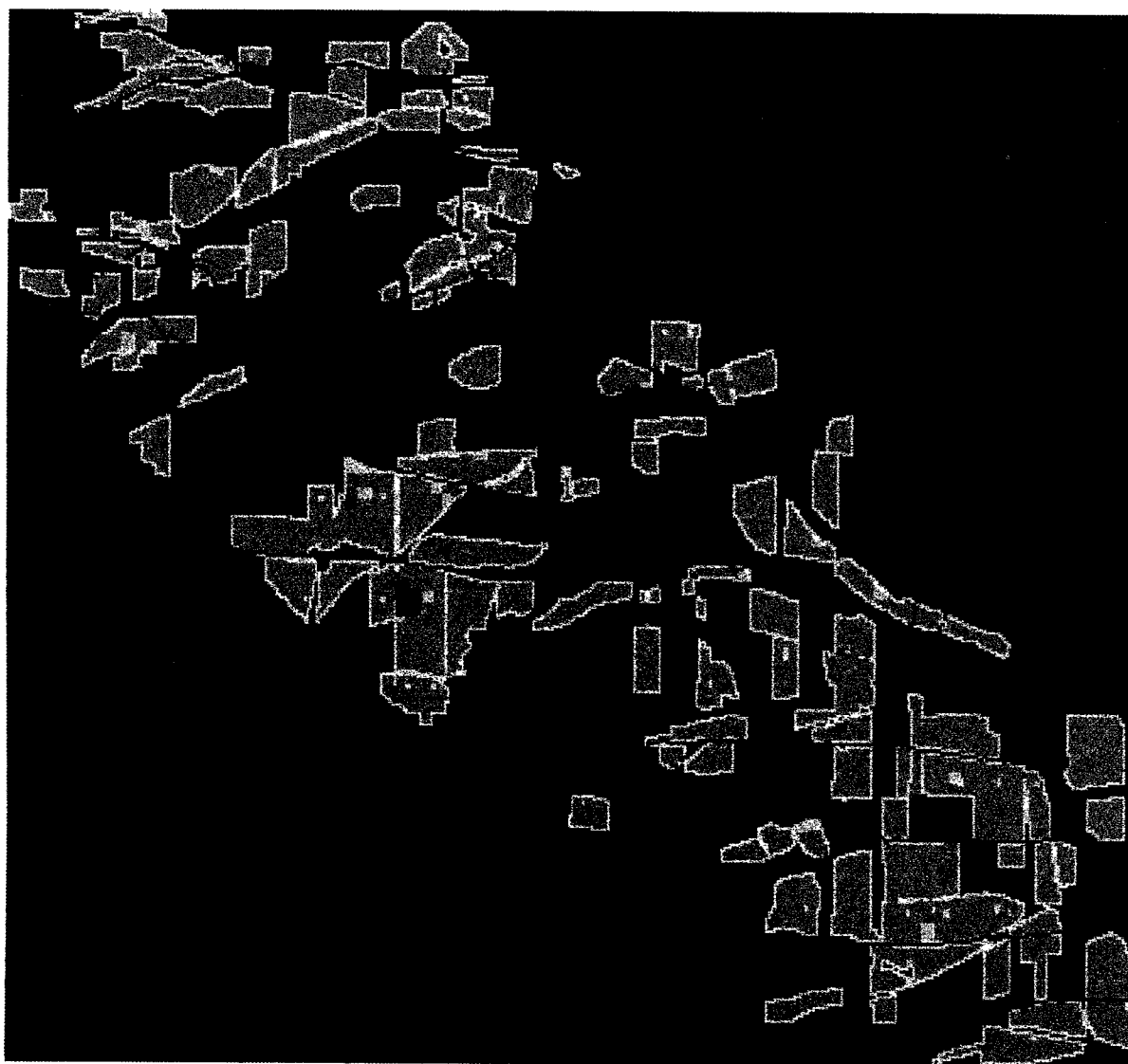


Fig. 14. Loděnice region, a field walking project. Raster representation of factor scores of factor 2/4 (Neolithic, Eneolithic, and Bronze Age). Colour scale the same as in Fig. 9.

significance. Therefore, it is difficult to understand why most colleagues, who claim to belong to the so-called postprocessual movement have completely discarded mathematical methods for the generation of archaeological structures. However, good theory can hardly be achieved without good and efficient methodology.

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Lodenice, factor 3/4

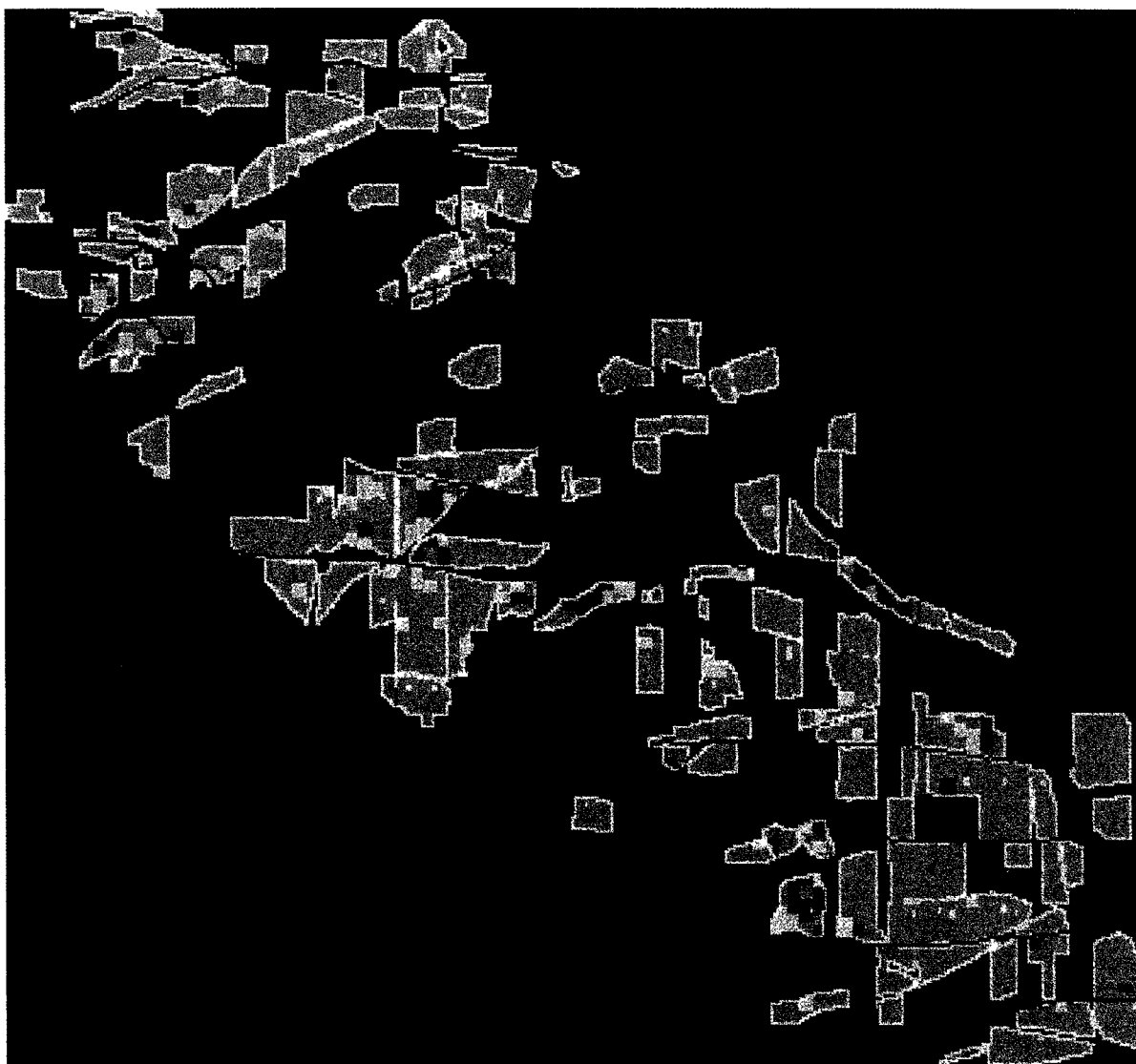


Fig. 15. Lodénice region, a field walking project. Raster representation of factor scores of factor 3/4 (La Tène and Roman Period). Colour scale the same as in Fig. 9.

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Lodenice, factor 4/4

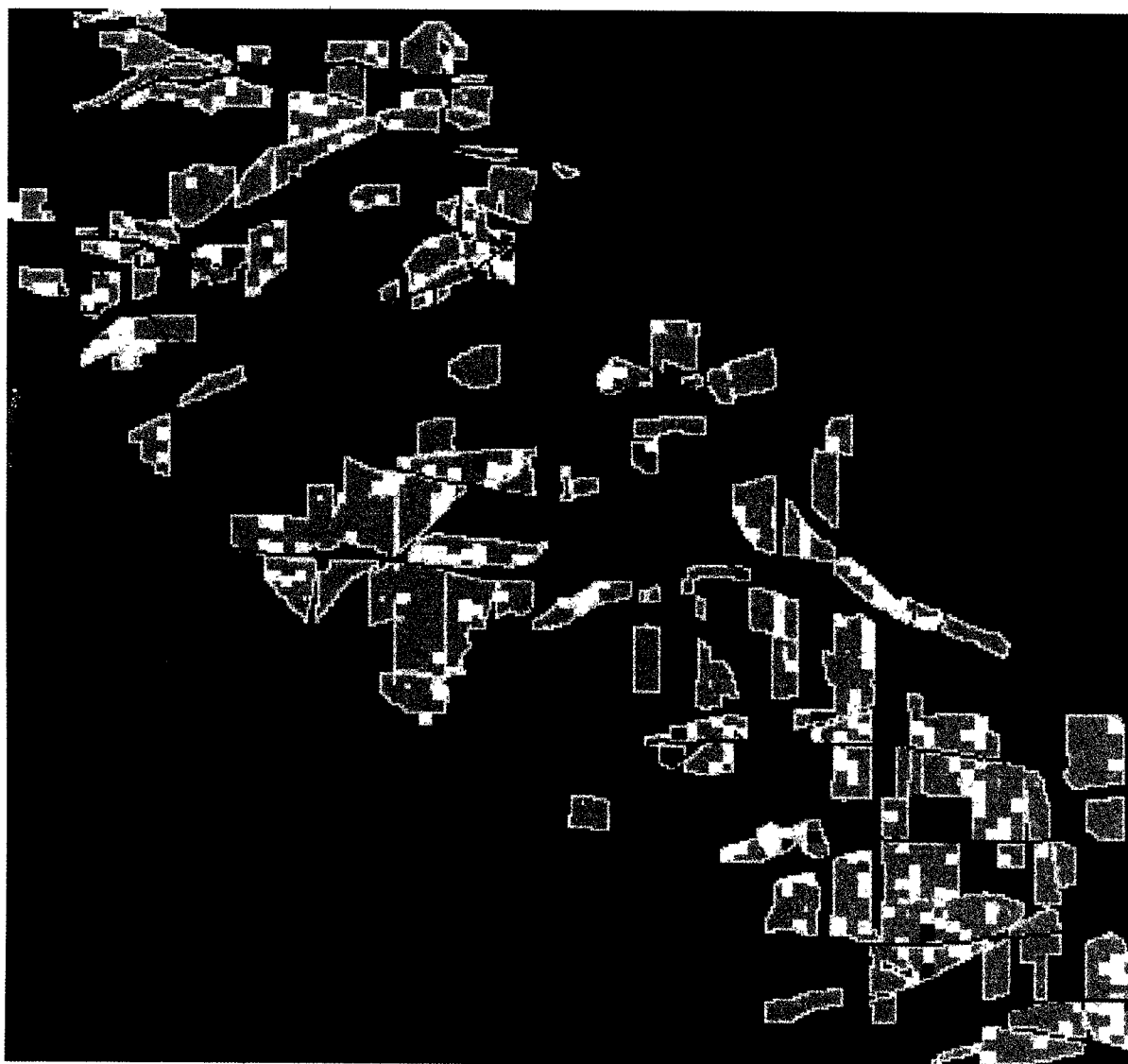


Fig. 16. Loděnice region, a field walking project. Raster representation of factor scores of factor 4/4 (Early and High Medieval). Colour scale the same as in *Fig. 9*.

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