Time as a Hidden Dimension in Archaeological Information Systems: Spatial Analysis Within and Without the Geographic Framework

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Abstract

Time is an indispensable element in most archaeological studies. However, GIS models cannot easily accommodate various issues raising from the specifics of archaeological dating. The formation processes and post-depositional transformations that have affected the present nature of the archaeological record must be assessed prior to designing any GIS project in archaeology. This paper highlights some issues emanating from this matter for a GIS user and introduces an approach that may enrich the current spectrum of spatial techniques in archaeology. The traditional intra-site spatial analysis based on the concept of geographical space is complemented with new experiments, where the spatial investigation is understood more broadly. An attempt is made to map a multidimensional formal space in GIS, which has its coordinate system defined by the proncipal component factor analysis conducted on mortuary data. The exposition demonstrates that GIS can successfully model many archaeological phenomena, be they primarily geographic or not. The key idea here is that GIS tools are able to analyze general problems including those not related to geography, on the condition that they can be translated into models of spatial nature (e.g. some formal topological model).

Key words: spatial models, chronology, GIS, factor analysis, graph theory

1 Time in archaeology

The most essential property of time is perhaps the impossibility of its universal definition. In human cultures, however, there is almost always a noteworthy relation of time to space and geometry. We may speak about linear or cyclic time, in other instances about the spacetime and so forth.[1,2] An appropriate reference framework must be set for time to allow the perception of its pace and even to distinguish between two separate states in its progression. In archaeology, the significance of such thoughts is obvious enough. Time cannot be observed on finds and their contexts directly; it is accessible only through an analysis of their spatial and formal attributes.[3] This is usually performed through the stratigraphical, morphological and stylistic analyses, sometimes using statistical tools like seriation or methodologies of cooperating sciences.[4] With the exception of high-precision

[1] Peter Skoglund, "The archaeology of time-space: hoarding and burial in Late Neolithic Scandinavia," in *Spatial Analysis of Funerary Areas*, ed. Ladislav Šmejda and Jan Turek (Plzeň: University of West Bohemia, Department of Archaeology, 2006), 81-87.

[2] Chris Gosden and Karola Kirsanow, "Timescales," in *Confronting Scale in Archaeology: Issues of Theory and Practice*, ed. Gary Lock and Brian L. Molyneaux (Springer, 2006), 27-37.

[3] Albert C. Spaulding, "The Dimensions in Archaeology," in *Essays in the Science of Culture*, ed. G. E. Dole and R. L. Carneiro (New York: Thomas Y. Crowell Company, 1960), 437-56.

[4] Martin Jim Aitken, *Science-Based Dating in Archaeology* (London - New York: Longman, 1990).

dendrochronological dating which is not always applicable, time in archaeology is typically conceptualized as a discrete phenomenon. The past is divided into stages of variable length and quality of definition. Chronological phases recognized in empirical material can be intuitively percieved as horizons of roughly contemporary events, although in fact such horizons may have a substantial temporal 'thickness'. In other words, finds belonging to one archaeological stratum or phase need not to have been used simultaneously (except for the special case of closed find context). This statement is of course trite, but its proper application to spatial analysis is not an easy task.

2 Troubled times of GIS

Reasons for the difficulty of incorporation of time into GIS models are manifold and almost any GIS project can provide its own unique combination of problems. Instead of looking for any kind of all-purpose remedy we have to develop strategies taking into account particular contexts.[5]

One issue however seems to be of principal importance everywhere: it is the initial assessment of the formation processes and post-depositional transformations that may have affected the archaeological record.[6] The recognition of the ratio of human intentions and natural forces in the taphonomic history of archaeological deposits, as well as the timespan during which these factors were effective would ideally set the scene for any sound data analysis. This is not merely a matter of simple site dating; perhaps more importantly this relates to the question of quantitative structural distortions of excavated data in comparison with the situation in the original living culture.[7] On these grounds it is possible to critique traditional distribution maps that remain so popular in archaeology.

Because they grasp time as a discrete variable, they frequently include elements that were not *sensu stricto* contemporary. Thus, what might initially seem as relatively strong and spatially dense dataset is actually diluted in the time perspective that is not explicitly communicated by that type of map. Second, distribution maps typically do not contain features that were physically present in the human world at a period of their interest, but their occupation or other intensive usage had ceased some time earlier. Such abandoned sites and ruins quite possibly might have continued to live in later life strategies, narratives, myths, and rituals. In other words — seen from the social perspective, they continued to exist as relevant landscape features.[8]

Sadly, site plans are not void of the same problem. If a site shows the lack of vertical stratigraphy, this of course does not mean that all features present on a plan were strictly contemporary. An assumption that they have accumulated over time is valid in most instances. It is a type of situation that Geoff Bailey has recently called a "spatial palimpsest".[9] The same ultimately applies, though perhaps to a lesser scale, to individual horizontal planes on stratified sites. Therefore, an attempt to assign individual features to chronological phases is always an inevitable step in the site processing.

3 A case study

Cemeteries are generally no exceptions to the above mentioned considerations. In the remaining part of my paper I will present a case-study based on one of the largest prehistoric burial grounds in the Czech Republic. The site lies on a cadastre of the town Holešov and provided 430 graves that were excavated from the 1950s to 1970s.[10]

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[5] Gail Langran, *Time in geographic information systems*, (London: Taylor & Francis,1993).

[6] P. Jeffrey Brantingham, Todd A. Surovell and Nicole M. Waguespack, "Modeling post-depositional mixing of archaeological deposits," *Journal of Anthropological Archaeology* 26 (2007): 517-40.

[7] Evžen Neustupný, *Archaeological Method* (Cambridge: Cambridge University Press, 1993).

[8] John C. Barrett, "The Mythical Landscapes of the British Iron Age," in *Archaeologies of Landscape: Contemporary Perspectives*, ed. Wendy Ashmore and A. Bernard Knapp (Blackwell, 1999), 253-65.

[9] Geoff Bailey, "Time perspectives, palimpsests and the archaeology of time," *Journal of Anthropological Archaeology* 26 (2007): 205-7.

[10] Jaromír Ondráček and Lubomír Šebela, *Pohřebiště nitranské skupiny v Holešově (Katalog nálezů)*, *Studie Muzea Kroměřížska* (Kroměříž, 1985).

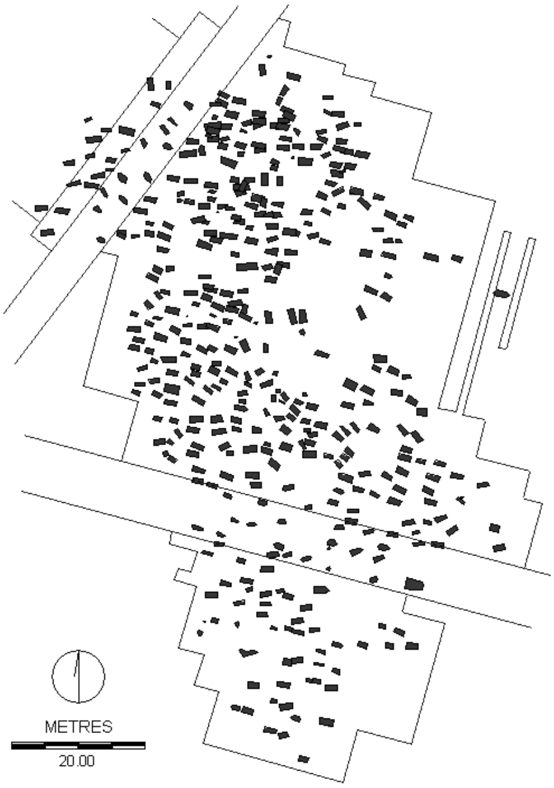

Figure 1. Site plan of the prehistoric cemetery located near Holešov, Czech Republic. Digitized from Ondráček and Šebela 1985.

As regards its formation history, there can be no doubt that the whole site is the product of a long-term burial tradition, which spanned over several centuries. The cemetery, while actively used, never looked as it does now in a site plan (fig. 1). New graves were sequentially added and surface markers of old ones may have been progressively vanishing through the time. Only some graves from their total number were observable at any given moment. Remarkably few superpositions however suggest that graves remained visible for a substantial period of time and some sort of spatial organization was in action.

It can be argued that the first graves appeared here in the times of Bell-Beaker culture that is easily recognizable in the empirical record. These burials lay in the north section of the cemetery, as do also some other graves with similar traits but obviously of slightly later date.[11] The rest of burials belong to the immediately following early Bronze Age.

The inventory of most graves is very modest. Approximately one third of all burials had no grave goods. Stone artifacts and ornaments made of copper wire, frequently accompanied by bone or faience beads represent the most common finds in the burial assemblages. There is almost no pottery in the graves, which is unfortunate, as the central European prehistoric chronology is predominantly based on the stylistic analysis of ceramic vessels.

In this case study I want to demonstrate that a rough chronological model of this site can be constructed by means of spatial analysis even if the dating evidence is relatively weak. I will use two complementary approaches to accomplish this goal: 1) a conventional spatial analysis in the geographical space, and 2) spatial analysis of a multi-dimensional analytical space.

4 Methodology

Although it is quite clear that a considerable timespan must be represented in such a large site, the traditional typological analysis of artifacts cannot really contribute much to reveal the chronological subtleties. No radiocarbon dates have been published since the excavation ended, which will hopefully change in the near future.

In the meantime, I have been trying to develop strategies for the identification of at least some of the processes that had left their mark in the archaeological record. This had to be done on the basis of published field notes and the catalogue of finds, which were converted into an information system consisting of a digital plan (fig. 1) connected to attribute tables. The spatial analysis of this data proved to be quite fruitful and helped to formulate more specific statements on the structuring of the Holešov cemetery, its chronological dynamics and social implications.[12,13]

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[11] Ladislav Šmejda, "Tradice kultury zvoncovitých pohárů na pohřebišti v Holešově," *Pravěk (Nová řada)* 11 (2001): 195-219.

[12] Ladislav Šmejda, "Cemetery structure and settlement dynamics on the verge of the Bronze Age in East Moravia," in *Landschaftsarchäologie und Geographische Informationssysteme: Prognosekarten, Besiedlungsdynamik*

We will remain focused mainly on the issue of chronology in this paper. As only a small selection of examples can be published in this limited space, the conventional spatial analysis will be represented by a single visualisation of the data. A module from the Idrisi 32 software called TREND ANALYSIS was used for that purpose.

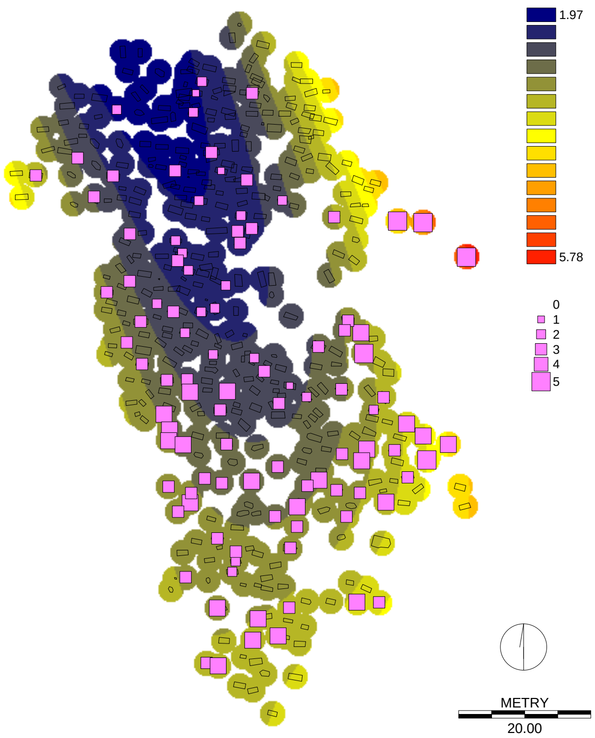

Figure 2. Cubic polynomial regression of tin ratio in artifacts made from copper alloys across the cemetery (after Šmejda 2004). Outlines of graves are shown. Squares scaled 0 – 5 represent average amounts of tin content per grave (ordinal scale).

More space will be allocated to the description of experiments conducted in the framework of multi-dimensional analytical space. Some formal graphs will be utilized there, which were prepared with the aid of yEd Graph Editor, version 3.3.0.2. Multivariate statistics was computed in the Statistica 6, using the factor analysis module. Mapping of burials in an analytical space derived from the factor analysis was then performed in the ArcGIS 9.3.

5 Trend surface analysis in the geographical space

By means of GIS, it is possible to test an assumption of the chronological development of the whole funerary area from north to south by looking into a kind of evidence independent from the few observed stylistic traits and cultural affinities of the artifacts. As the site in question is chronologically positioned at the turn of final Stone (Copper) and early Bronze Ages, we may attempt to detect the shift from copper to bronze metallurgy that is supposed to take place about this time. Spectrographic measurements of tin content in the metal artifacts plotted on the site plan show a statistically significant trend rising from the north to southern and eastern boundary of the cemetery (see fig. 2, the goodnes of fit test R^2 = 46 %, p < 0,0005).

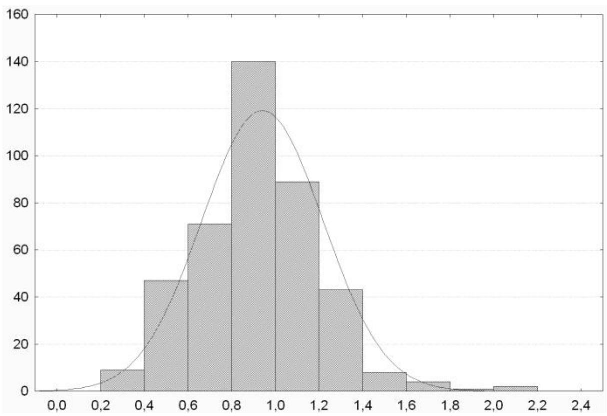

Figure 3. A histogram of grave depth values. The scale of horizontal axis is in metres.

While studying other properties of the graves, for instance their depths, we can notice similar differences in their spatial distribution. The whole set of depth measurements gives an almost normal distribution in a histogram (see fig. 3). The values

und prähistorische Raumordnungen, ed. Jürgen Kunow and Johannes Müller (Wünsdorf: Brandenburgisches Landesamt für Denkmalpflege und Archäologisches Landesmuseum, 2003), 297-307.

[13] Ladislav Šmejda, "Potential of GIS for analysis of funerary areas: prehistoric cemetery at Holešov, distr. Kroměříž, Czech Republic," in *Spatial analysis of funerary areas*, ed. Ladislav Šmejda and Jan Turek (Plzeň: University of West Bohemia, Department of Archaeology, 2004), 57-68.

from its left tail (that means very shallow graves) concentrate mostly in the southern part of the site and the majority of deepest graves are located in the north zone.[14] So it is the inverse situation to the trend identified in the case of tin-bronze spatial allocation. These two patterns seem to be closely connected to the expansion of the site through time.

6 Spatial analysis without the geographical framework

Spatial analysis conducted in the geographical framework is undoubtedly helpful, yet the geographic approach alone cannot effectively reveal other temporal patterns of a considerable interest. That is because they may only marginally be related to the geographical space. But still, their detection can be assisted by construction of spatial models, but this time we will utilise a different concept of space. I call it a 'fact space' or 'space of archaeological facts'.[15] What does it mean? We can regard descriptive databases of certain parameters as sets of records that are located in the vector space by means of values of their attributes. In archaeology we usually deal with such multidimensional descriptions that call for specific analytical procedures.

Even a basic correlation matrix of key properties, in this case the lengths and depths of graves, as well as the presence or absence of nine most common grave goods, produces interesting structure, which can easily be translated into a graph (see fig. 4). This graph representation does not utilize any coordinate system; instead it is based purely on the relationships of investigated variables. Nevertheless, we may call this output also a map, the principle of which is very close to the concept of mental maps. In this scheme, the interplay of positive and negative correlations between the classes of ornaments and grave depths is of particular interest, as well as strong positive relationships between all three types of chipped stone industry: arrowheads, blades and simple chips. This is one example of what I mean by the spatial (topological) analysis without the geographic framework.

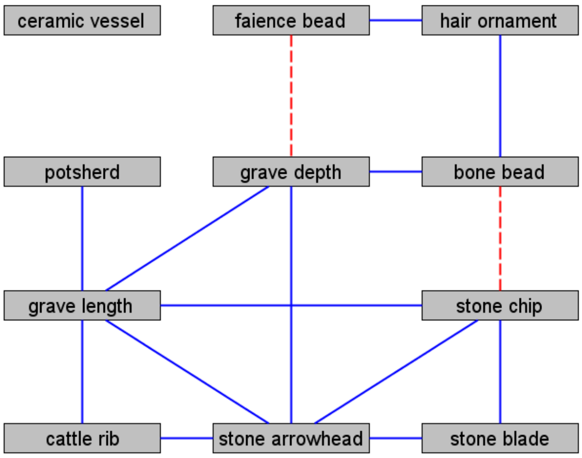

Figure 4. A correlation matrix of 11 variables transformed into a graph. Only the statistically significant correlations (p=0,05) between pairs of variables are shown by means of lines connecting respective variable names. Solid line indicates the positive, and dashed line the negative correlation. No connection means no significant correlation.

To detect all formal axes of variability in the studied dataset, I have conducted a Principal Component Analysis (PCA), including the extraction of factor loadings and factor scores for six principal components (factors).[16] Again, the results can be displayed as spatial models and further explored. The next image (fig. 5) is technically a scatterplot of factor scores; factor 1 being on the horizontal and factor 2 on vertical axis. Such a graphic representation of numerical results can also be read as a map. Especially so as it was actually created in ArcGIS 9.3, taking the factor scores as coordinates that locate individual

[14] *Idem*, Fig. 4.

[15] Ladislav Šmejda, "Expanding scales in GIS analysis," in *Layers of Perception: Proceedings of the 35th International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA) Berlin, Germany, April 2–6, 2007*, ed. Axel Posluschny, Karsten Lambers and Irmela Herzog (Bonn: Rudolf Habelt, 2008), 283, full text on CD.

[16] Ladislav Šmejda, "Hlavní osy variability pohřebního ritu na lokalitě z mladšího eneolitu a starší doby bronzové u Holešova, okr. Kroměříž," in *Sedmdesát neustupných let. Sborník k životnímu jubileu prof. Evžena Neustupného*, ed. Ladislav Šmejda and Pavel Vařeka (Plzeň: Západočeská univerzita v Plzni, Katedra archeologie 2003), 179-98.

burials on one specific projection of currenly investigated analytical space.

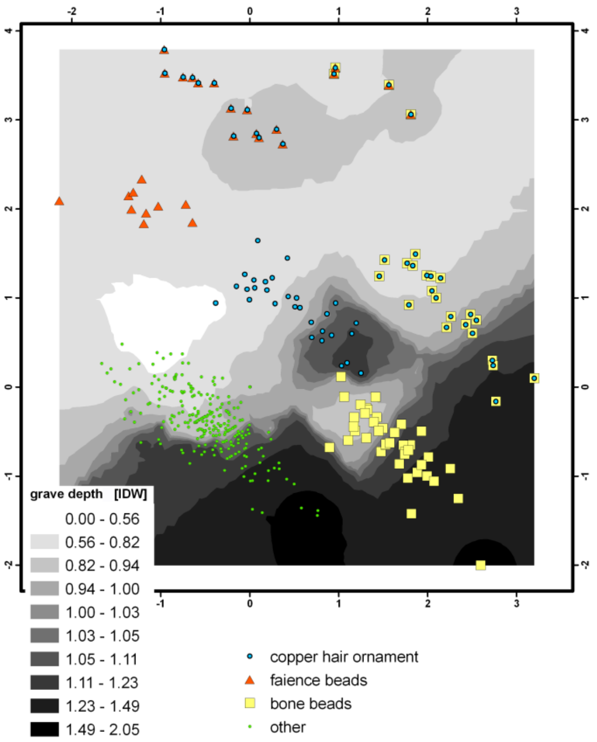

Figure 5. Two dimensional scatterplot (or a map) of the fact space. Factor scores of factors 1 and 2 used as coordinates. Symbols represent burial assemblages containing ornaments, showing all their existing combinations. Grave depths were interpolated to produce a continuous surface (grey scale, units: metres) by means of Inverse Distance Weighting (IDW).

The burials are ordered in this map in accordance to the degree of their similarity in all 11 parameters (see fig. 4), but the main stress is being put on ornaments in this result (factors 1 and 2 obviously represent structures related to jewellery). The grave depths were also added to this map as an interpolated raster surface coded in grayscale. A correlation between depths and certain combinations of grave goods is clearly shown. We could already see this kind of relationship in fig. 4.

The pattern unveiled in fig. 5 calls for further analysis. It can be transformed into another graph in order to understand the structuring of the burials discussed in the preceding paragraphs. The new graph (see fig. 6) is actually just another representation of the structure from fig. 5, being only more formalized and condensed into a simpler scheme.

Groups of graves (labelled A to F) containing identical sets of grave goods were aggregated into nodes and their relations to other groups sharing a common attribute are displayed by oriented edges.[17] Arrows indicate the direction of difference in their respective median grave depths. In terminology of the graph theory, an acyclic directed graph was created in this way. In result, it can be demonstrated that if a grave contains faience beads it tends to be shallower than grave containing bone beads. The group A, containing bone beads only, consists of deepest graves. This group differs significantly from all the other groups (Kruskall-Wallis test, $p < 0,05$). Since we have learned earlier that grave depths inversely correlate with time, we have time represented in this network too.

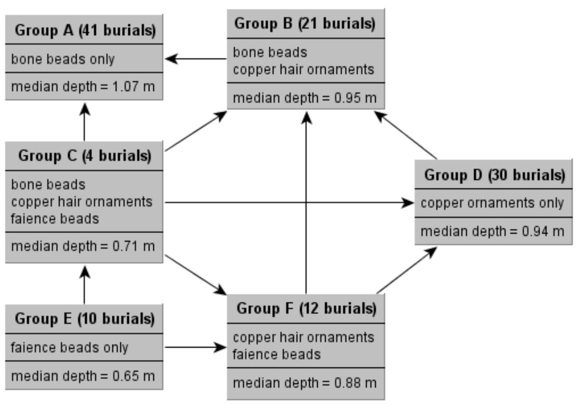

Figure 6. A graph showing relations between clusters of burials defined in fig. 5. The graves clustered in each box share the same combination of ornaments. When two groups have at least one type of ornament in common, they are connected by an arrow indicating which group tends to have deeper grave pits. Following other evidence, deep graves containing bone beeds seem to be earlier then shallow graves accompanied with faience beads. Copper hair ornaments can be found with both types of beads.

[17] Per Hage and Frank Harary, *Structural Models in Anthropology*, *Cambridge Studies in Social Anthropology*: (Cambridge University Press, 1983).

This was the second demonstration of a spatial model that is not based on the geographic but on the formal analytical space. The numerical model produced by the Factor Analysis was transformed into the qualitative graphical representation, on which the complexity of one aspect of the mortuary behavior can be explained. Of course, similar procedures can be carried out with the remaining four extracted factors; they will be extensively discussed elsewhere.

7 Summary

In conclusion, I have tried to expose some disturbing issues related to the fact that datasets commonly used in archaeology normally do not represent thin time slices. They are rather collections of data of relatively coarse and sometimes quite variable temporal resolution and they should be therefore approached with the acknowledgement of this fact. It has profound consequences especially for the spatial analysis of archaeological datasets that has been the main concern of the present paper.

I also argued that GIS and network analytical tools can successfully model relationships of many archaeological phenomena, be they primarily geographic, temporal or other, including also a combination of these. Traditional maps and plans — quite understandably — cannot explain entire chronological variability in our data. To move beyond their limits, other (non-geographical) spatial models may be developed and analyzed in an appropriate software, taking advantage of the mathematical branches known as linear algebra, graph theory, and topology.

A small case study of the early Bronze Age cemetery excavated near Holešov was presented, where both approaches (geographical and formal) were applied. The accumulation of several hundred graves must be understood in terms of prolonged evolution of the site. Therefore it would be misleading to neglect the temporal dimension of its development. In a site plan it was possible to reveal a spatial pattern corresponding with the early Bronze Age metalurgical shift from the copper to tin bronze technology. This can be interpreted in chronological terms (spatial expansion of the site).

Further, a multivariate analysis of eleven most frequent grave attributes resulted in mapping of the selected formal structure (the relationship between three classes of ornaments and grave depths) by means of several graphic representations. These were approached as spatial models of another kind, successfully describing an aspect of the socio-temporal variability of the data. Chronological discrimination between presumably earlier graves containing bone beads and later graves with finds of faience beads could be made. The statistically significant correlation of grave depths with the two types of beads is also notable, although difficult to explain at the present.

A variety of tools and approaches have been used in this contribution to demonstrate the current possibilities of studying the chronological dimension of archaeological data through spatial models. Such models can be built in the traditional geographical framework as well as in abstract analytical spaces defined by multivariate statistical techniques. By exploring these possibilities we can increase our chances to reveal the chronological depth of our data, which is the important factor determining any attempt to restore the original dynamics of the past human culture.

Acknowledgements

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