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Doorn, Peter

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Geographical Location and Interaction Models and the Reconstruction of Historical Settlement and Communication: The Example of Aetolia, Central Greece

Peter Doom*

Abstract: This paper attempts to demonstrate how geographical information and spatial models can be used for the reconstruction of settlement patterns and the communication between settlements in the past. Location models and quadrat analysis offer many opportunities for a detailed analysis of changing settlement patterns over time. The shifts in these patterns reflect the transformation of historical conditions and the changing relevance of location factors over time. Gravity and potential models and the application of intramax analysis offer tools to study patterns of communication in historical societies. Finally, the reconstruction of trade routes can be undertaken with the help of a geographic version of the model of conservation of energy-

Introduction

Although geography and history can be considered as sister disciplines, historians rarely employ spatial models for the study of past developments. The disciplines in which space and time define the central scope of research can however supplement each other very well. A historical approach can enrich a spatial analysis in the same way as a geographic point of view may enhance a historical study. This paper attempts to demonstrate how geographical information and spatial models can be used for the reconstruction of settlement patterns and the communication between settlements in the past. This approach will be applied to empirical material collected within the compass of the Aetolian Studies Project, an interdisciplinary research project which has been undertaken since the early 1980's.[1]

* Peter Doom, Department of History, University of Leiden, P.O. Box, 9515 2300 RA Leiden tel. +31 (71) 272733, e-mail: LETTPD@HLERUL2
[1] S. Bommeljé and P.K. Doom (eds.), *Aetolia and the Aetolians: towards the interdisciplinary study of a Greek region* (Utrecht, 1987).

It is a central goal of the Aetolian Studies Project to reconstruct the history of habitation in Aetolia from prehistory to recent times. The area referred to as »Aetolia« here is situated in mainland Greece, north of the Gulf of Corinth and east of the Akheloos river (Figure 1). It encompasses five modern provinces (or *eparchies):* Doris, Navpaktia, Mesolongion, Trikhonis and Evrytania. Information on human settlements, on the relation of these settlements with their natural environment, and on the interaction between the settlements has been collected from a wide variety of sources: archaeological remains, ecclesiastical sources, Ottoman tax registers, historical and modern topographical maps, censuses and statistics, travel accounts and military handbooks, village interviews, air photos, local monographs, and field observations served as sources for this research.

Most of the information collected for Aetolia has been stored in data bases and text bases. In this contribution some analytical possibilities of the material will be shown using techniques borrowed from human geography: first, location models will be used to study shifts in the pattern of habitation over time; next, gravity and potential models will be employed to analyze the possible communication between settlements; and third, analysis of topography and relief will be applied to establish the course of historical trade routes.

Over the past decade, special software has been developed to store, analyze and represent information derived from maps and to combine it with other data about the map elements: geographical information systems (GIS).[2] A typical GIS integrates properties of mapping programmes, statistical packages, and database software. A distinction can be made between raster operations, in which a map is treated in the form of a grid of regular areas such as quadrats, and vector manipulations, in which structural units such as point, line and surface information are distinguished. This contribution will show the types of manipulation that are possible and the insight that can be gained from the application of this kind of systems.

Location models and shifts in habitation

There is no general theory of settlement location. Location theory is more oriented towards locating economic activities than towards locating human habitation. On the other hand, the assumption can be made that people tend to live more or less near their place of work. This holds true especially for agricultural activities and rural societies. Three classical models for locating primary, secondary and tertiary activities can be discerned: the Von Thünen model deals

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[2] D. R. F. Taylor (ed.), *Geographic Information Systems: the minicomputer and modern cartography* (Oxford, 1991); M. F. Goodchild and D. W. Rhind (eds.), *Geographical Information Systems: principles and applications* (Harlow and New York, 1991), 2 vols.

with locating agricultural production; the Weberian model with industrial location; and central place theory by Christaller and Lösch is concerned with patterns of commercial activities and services.

The conceptual framework developed by Von Thünen is the most widely used model to describe or explain the location of agricultural activities.[3] The driving force of the model is the attempt of farmers to minimize farm-to-market distances (or rather travel times or costs of transport). This is not the place to go into the merits and weaknesses of this model[4], but it ought to be realized that the model is primarily geared towards explaining the location of agricultural activities, not of human settlement. This is why the model is usually »turned around« in studies of rural settlement, that is, a centre of habitation is not seen as the starting point for the analysis of rural land-use patterns, but as the resultant of the exploitation of a given »catchment area«.[5]

Industrial location theory is to a large extent based on elaborations of the Weberian model, in which the costs of transporting material sources to an industrial plant and the costs of transporting the finished product to the market pull at the location of an industrial plant.[6] Also this idea has been »translated« into terms of rural settlements: the location of a village is then seen as the result of the pull of various location factors, such as cultivated land, water, wood for fuel and construction, etc.

Central place theory, developed by Christaller and Lösch, deals with the location of tertiary activities (commerce and services).[7] Although central place theory assumes a modern commercial economy, it has been demonstrated that settlement patterns in traditional peasant societies can conform to central place principles[8]. However, this theory is less often used for explaining settlement location.

It has been stated by several theorists of spatial location that these three classical location models are complimentary rather than antagonistic. Michael Chisholm sees the models of Von Thünen and Weber as variants of an essentially analogous approach to the problem of optimization of location, stating

[3] J.H. Von Thünen, Der isolierte Staat in Beziehung auf Landwirtschaft und Nationalökonomie (Hamburg, 1826).

[4] See, for instance: M. Chisholm, *Rural settlement and land use: an essay in location* (New York, 1962; 1979).

[5] E.S. Higgs (ed.), *Palaeoeconomy* (Cambridge, 1975); E.S. Higgs and C. Vita-Finzi, »Prehistoric communities: a territorial approach«, in: E.S. Higgs (ed.), *Papers in economic prehistory* (Cambridge, 1972), 27-36.

[6] A. Weber, *Über den Standort der Industrien, I: Reine Theorie des Standorts* (Tübingen, 1909).

[7] W. Christaller, *Die zentrale Orte in Süddeutschland: eine ökonomisch-geografische Untersuchung über die Gesetzmässigkeit der Verbreitung der Siedlungen mit städtischen Funktionen* (Jena, 1933); A. Lösch, *Die räumliche Ordnung der Wirtschaft* (Jena, 1941).

[8] G. W. Skinner, *Marketing and social structure in Rural China,* Journal of Asian Studies, 34 (1964), pp. 3-43.

that both models merely differ externally.[9] Chisholm is primarily concerned with the description and analysis of land-use patterns, starting from a Thünian framework. Distance from the farmstead to the working areas is the main explanatory factor for intensity of land use. But if one »inverts« the analysis and sees the settlement location as the phenomenon to be explained by a given land-use pattern, the problem is similar to the Weber model where several factors pull at the location of an industry.

Walter Isard has attempted to merge the different models of the Thünen-Löschian-Weberian framework into a general theory of location.[10] Isard builds his integrated theory starting with a setting in which natural resources, physical configuration and the matrix of technological conditions are given. He imagines an isolated area with a varied topography and uneven resource content. In this area human occupation and settlement takes place. The selection of a site for initial habitation and cultivation of crops will depend on a host of location factors: on the existing vegetation, the difficulties of clearing, transport resources, climate, topography, type of soil and nature of drainage, the available tools and techniques, defense considerations, and cultural factors. In addition to these he discerns less rational factors, among which arbitrary choices based on incomplete knowledge of the terrain and indeterminate whims and fancies.[11]

Factors of settlement location

All authors on settlement location agree that the location of individual settlements and the development of settlement patterns is influenced by various factors. They see the selection of a site as a combination of factors pulling at a site location or as a compromise of different functions or requirements.[12] Most of them specify comparable factors, though they differ with respect to the stress they place on individual factors.

Chisholm studies the role of five basic elements in settlement choice of communities with low technological skills: water, arable land, grazing land, building materials, and fuel. Obtaining and transporting each commodity has a certain cost. A Weberian (or inverted Thünian) analysis is used to select the best (i.e., least cost or most profitable) location. By attaching a weight value or cost factor to each location factor, the best location can be evaluated (see Table 1 and Figure 2).

Chisholm has described the process of village location as the result of a number of factors »pulling« a village to a specific site, where each factor is

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[9] Chisholm, *Rural settlements,* p. 28.
[10] W. Isard, *Location and space economy: a general theory relating to industrial location, market area, land use, trade, and urban structure* (Cambridge, Mass. and London, 1956).
[11] Isard, *Location and space economy,* p. 2-3.
[12] C. Lienau, *Ländliche Siedlungen* (Braunschweig, 1986), 43.

described as a function of distance and cost. The difference with industrial location is, however, that all location factors for agricultural production units are distributed widely (with the possible exception of water). Chisholm gets around this problem by stating that »no great error is made if we assume that all the work and produce [of each factor] pertains to a single point located at the centre«[13]. The validity of this statement is however not proven. The highly dispersed nature of agricultural activities makes it practically unfeasible to apply Chisholm's idea empirically. Moreover, the model is applicable to find the optimal location for one settlement only and cannot be used directly to analyze a whole region.

Location factors are not simple physical or anthropogeneous constants. An example of the changing priorities is the preference of neolithic settlers for light soils, that were not the most fertile when technology improved. Under conditions of political stability and military security, the improvement of infrastructure stimulates economic integration. In such circumstances, the transport situation can become a decisive criterion for the centrality of settlements.

The multitude of location factors enumerated in the literature is summarized in Table 2. We make distinction between factors operating at the level of the village site itself and those of the relative location of the village in its environment *(situation)*. The factors are grouped into five categories: land, water, weather or micro-climate, communication, safety and cultural factors. Chance is not mentioned as a separate factor, but it should be noted that in all location choices an element of chance will be present. There will often be more than one location in a given environment that offers comparable advantages. Which site is ultimately selected will depend on the value attached to the different factors, but also to chance.

Quadrat analysis and GIS for locating settlements

GIS-techniques make it possible to extend the model presented by Chisholm for the analysis of a whole region. Before the introduction of Gl-Systems, various techniques such as quadrat analysis, trend surface analysis and grid generalisation methods had already been designed to evaluate spatial patterns.[14] Hodder and Orton describe some techniques for measuring the relationship between a discrete variable (a point-pattern such as settlements) and a variable which describes the environment of the pattern (a continuous variable).[15]

The essence of the idea is represented in Figure 3. A hypothetical landscape has been divided into quadrats. Of each quadrat a number of location factors can be measured. In the landscape of Figure 3, communication, water supply, safety and arable land have been quantified. In map A a major north-south

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[13] Chisholm, *Rural settlements,* 97.
[14] 1 . Hodder and C. Orton, *Spatial analysis in archaeology* (Cambridge, 1976), 155.
[15] Hodder and Orton, *Spatial analysis in archaeology,* 224-229.

route runs through the landscape, from which a secondary east-west route bran-
ches off. The crossroads of the two routes has the highest communication
value, then locations on the main road. The farther away from the main or
secondary road, the lower the communication value. The principle of declining
influence with distance is called »distance decay«.

In map B we discern a north-south running stream parallel to the main land
route. On the west bank two natural sources can be used for water supply, on
the east bank a less important source is situated. Again, the attraction of the
water supply decreases with distance. In map C the factor safety is represented
by height. The mountains in the west offer places of refuge, the lower hill in the
east less safe. Finally, arable land is depicted as a roughly circular area in the
river valley. The central area has the highest potential for cultivation, the mar-
gins are less suited for farming.

In this hypothetical landscape, all four location factors have been scored on a
scale from 0 to 4. Of course, other factors might have been selected and the
operationalization might have been different, but this does not detract from the
general principle. We could now, for instance, add all location factors to see
which quadrats have the highest total score, as in map E. The quadrats with the
highest scores (and darkest shades) would be the most attractive settlement
sites if all factors have the same importance. More interesting, however, is it to
formulate alternative location models reflecting differing historical conditions.
This can be done by attaching weights, comparable to Chisholm's cost factors,
to the various location factors.

In map F we simulate a situation of high insecurity and external threat. In
this case, communication will get a weight of - 1 , because of the danger of
invading armies. The safety (height) factor receives a value of +2, whereas land
and water retain their positive values, albeit at half force. Map G shows a
simulated self-sufficient economy, in which communication and safety are not
so important (weight 0.5) and land and water have a strong influence (weight
1.5). In map H the economy is integrated in a larger system. Communications
with the outside world become more important (weight 1.5), safety exerts a
relatively weak influence (weight 0.5). Map I, finally, summarizes how the
optimal site for settlement location would shift within the area with changing
historical conditions.

Many other types of analysis would be possible. We could evaluate the
locational characteristics of given settlements in a quantitative way. Also the
mutual relationships among different location factors can be analyzed (for in-
stance, land and water, safety and communication, land routes and streams,
etc.).

Several examples of the application of quadrat analysis can be given in the
context of archaeology and prehistory. Chadwick has developed models to
simulate the Mycenaean settlement pattern in Messenia. His research area co-
vered some 3800 km². Maps of the research area were covered by a 2 x 2 km

celled lattice of 1109 quadrats. In order to check for scale dependency, analyses were repeated for 4 x 4 km and 6 x 6 km grid cells.[16]

First the frequency distribution of the sites was inspected. The form of the distribution could be represented by a negative binomial function and by a compound model based on the Poisson distribution. The result was interpreted as showing that the settlement patterns in the Late and Middle Helladic periods were essentially random, but »biased by the varying utility of the underlying environment«[17]

An environment surface was constructed to take this variability into account. The attractivity of the physical environment was operationalized in terms of access to water (expressed in three distance classes to a permanent stream or spring) and geomorphological characteristics as a proxy (also in three classes) for land use. By combining the indexed water and land resources and inspecting the number of sites in each category, weights were assigned to each combination.

The first model that was tested rested on the assumption that the environment is the sole determinant of settlement location (plus a random factor). The fit of the model was tested at the level of 4 x 4 km grid cells. The aspatial fit was evaluated by comparing the simulated settlement distribution with the observed distribution using a chi-squared test. The spatial fit was evaluated by testing on spatial autocorrelation based on the distribution of the residuals. The model failed to pass the second test. Spatial autocorrelation appeared to be a serious problem, mainly because of the incorrect assumption of the mutual independency of settlement locations.

Two adaptations were made in a second model. The environment surface was modified to include the possible exploitation of surrounding cells. More important, the second model took into account the presence of earlier settlements. Each new settlement needs to have its own territory, and therefore must be at some distance from all other settlements. A »settlement field« after the idea of Hägerstrand in the field of innovation diffusion was generated to take this into account. In an iterative procedure the space could now be filled.

The results of the model are in line with the view that location in space is random, but subject to constraints. Here constraints are offered by the environment (access to land and water) and to existing settlements.

The case of Aetolia

Four areas of 15 x 20 km with distinct geographical features in Aetolia were selected to test the above ideas empirically. A grid of 30 x 40 cells of 500 x 500 m (1 cm'2 on the map) was drawn over the sheets of the topographical map.[18]

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[16] A.J. Chadwick, »A computer simulation of Mycenaean settlement, in: *Simulation studies in archaeology,* ed. by I. Hodder (Cambridge, 1978), 47-57.

[17] Chadwick, »A computer simulation«, 50.

[18] The 1:50,000 topographical map of Greece, published by the Geographic Hellenic Army Service in 1971, is based on air photos made in the Second World War.

For want of space we will present selected results for one of these regions only: the central southern area comprising the provincial capital Karpenisi in the mountain province of Evrytania. The other three regions are situated in the eparchy of Doris (the area comprising the modern capital of Lidoriki and the ancient sites of Veloukhovo and Strouza), Trikhonis (centring on ancient Thermon and including the northern and eastern shores of Lake Trikhonis), and Mesolongion/Navpaktia (northern coast of the Corinthian Gulf, mouth of Evinos river, ancient site of Kalydon).[19]

The following location factors were read from the topographical maps:

Height: estimated average height per cell on the basis of the contours, rounded to the nearest 50 m. Height is clearly related to human habitation. Only few settlements are found above the 1000 m. line. Cultivation above 1400 m. does not occur in this area, although mountain pastures are used in summer for the flocks of goats and sheep.

Slope: counting the average number of contours, which are drawn on the map at 20 m intervals, for the diagonal of a quadrat. By multiplying the number of contours with 20 and dividing the product by 700 (the approximate diagonal length of a quadrat) the slope is obtained as a fraction; multiplying the percentage by 0.45 gives the slope in degrees. It is assumed that settlements tend to prefer gentle slopes. Because of the mountainous character of the area, the scarce flat land will be devoted to agriculture, whereas steep slopes are not suitable for habitation.

Aspect: the orientation of a slope towards the sun in eight directions of the compass. Locations at the bottom of a valley or top of a mountain or hill were also registered. Saddles were not registered separately, but were counted as bottom locations. It is assumed that settlements in the mountains will prefer sunny, southern slopes to cold northern slopes.

Arable land: the percentage of the surface of each cell that was cultivated was recorded as detailed as possible: 0 - 10 - 25 - 33 - 50 - 67 - 75 - 90 - 100 % cultivated. Quality of the cultivated area was not taken into account here, because factors such as availability of water and slope were already recorded separately. Built up area was classified as cultivated (gardens). It can be argued that the arable area in Aetolia was never in history larger than during the 1930s and 1940s, when population pressure on the land was very high. As the air photos on which the topographical maps are based were taken during the Second World War, the cultivated surface registered can be regarded as maximal, reflecting the potential for agriculture. Of course, not all arable land will have been under cultivation at all times in the past.

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[19] An exhaustive account on the four regions can be found in an unpublished thesis by: R. de Bakker, *Rurale nederzettingen in Centraal-Griekenland: een kwantitatieve lokatie-analyse in historisch perspectief* (Leiden, 1992).

Water supply: rivers, perennial streams, springs or fountains and wells were recorded. A tentative weighting was attached to the different sources of water supply in the following manner: well counted for 0.5 point, a spring for 1 point, a perennial stream for 1.5 points and a river for 2 points. In this way, a differentiation in water affluence was made. Water was necessary for drinking and irrigation of the fields.

Communication: based on 19th century maps and travel literature, the main lines of communication in the second half of the 19th century were reconstructed. Historical trade routes, largely defined by the natural relief, were read from the earliest available fairly reliable map of Greece, drawn by French military topographers in 1852.[20] Distinction was made between main routes and secondary paths. The first class was valued at 2 points, the second at 1 point.

View: from the height we can calculate the »view« from each quadrat, viz. how many cells can be seen in the eight directions of the compass. Both a good view and a hidden location could play a role in the defense of settlements. In classical antiquity and during the Turkish period visual communication between villages was important to mobilize the population in times of danger.

For several of the location factors not only the value of a given quadrat is relevant, but also the values of adjacent quadrats. It is not primarily the presence of water, arable land or a trade route that counts, but the distance from a settlement to these resources. A distance decay function was used to take this into account.[21]

In Figure 4 four of the location factors are reflected in quadrat maps of Southern Evrytania. Height is represented in map A. The white areas indicate two river valleys: the Karpenisiotis river has its origin in the north-east and flows in a south-western direction. In the south-east the sources of the Krikellopotamos, flowing to the west, can be distinguished. The valley bottoms are at about 650 metres above sea level in this mountainous region. In the southwest the Kalliakouda mountain is the highest in the area, with its top at about 1900 metres. Mount Veloukhi, the highest mountain of Evrytania (ca. 2300 metres), lies just outside the map in the north-east, z

In general the terrain is very rough (map B). The valley of the Karpenisiotis is the only relatively flat area. Slopes are often precipitous in the south and west. Also the middle to south-eastern area is somewhat less steep.

It is not surprising that the arable land occupies the less steep areas (map C). The basin at the northern end of the Karpenisiotis valley offers the largest area for cultivation. Several fairly well circumscribed exploitation areas can be discerned, which are surrounded by largely uncultivated zones. In the map of the

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[20] Carte de la Grece, scale 1:200,000 (Paris, 1852).
[21] In practice distance decay works like a weighted moving average of the values of surrounding quadrats; the weights decrease proportionately to the distance from a given quadrat.

water supply (map D) we again find the influence of the rivers. But the area in general is fairly rich in water. There are numerous natural springs for irrigation and drinking water.

In addition to these location factors, information on all recorded settlements (or inhabited quadrats) that have ever existed or that still exist in the four areas, from prehistory to the present, were registered. This information has been collected during fieldwork campaigns of the Aetolian Studies Project since 1981. The duration that settlements existed at a particular location was classified in a number of broad historical periods: Prehistoric (till 5th Century BC), Classical and Hellenistic (5th-2nd Century BC), Roman (2nd Century BC-5th Century AD), Byzantine and Medieval (5th—15th Century), Ottoman (15th Century - 1821), and Early Modern (1821-1940). The distribution of the settlements in Southern Evrytania over the periods is reflected in Table 3. It is notable that the number of settlements is highest in the modern period. In the classical-hellenistic and Ottoman periods the numbers of settlements were about equal. Less than ten archaeological sites have been identified as prehistoric on the basis of ceramics. This may be partly due to the difficult finding conditions and identifiableness of prehistoric shards. In the Roman period the area was most probably largely depopulated. The number of Byzantine and medieval sites is also rather small.

Only for the post-war period the topographical map offers information on dispersed habitation. Some settlements occupy several quadrats. We took the presence of 15 houses or more in a quadrat as a criterion for a settlement (see Figure 5A). Also some archaeological sites cover more than one quadrat. For want of space, only the sites in the Classical-Hellenistic period are given as an example (Figure 5B).

Now it is possible to analyze the relationships between the settlement sites and the location factors in a variety of ways. In the first place, the connection between individual factors and settlement preferences through time can be analyzed, showing for instance how the relative weight of factors such as safety, access to land, water and communication changed over time. One example of this type of analysis is given. Figure 6 shows the height distribution of the settlements per historical period. The left-most column shows the height distribution of the whole region. It can be seen that about 50% of all land in the research area is above 1150 metres, but that there only few settlements above this height (and none above 1400 metres). Only in the Classical and Hellenistic periods we find about 20% of the inhabited sites above this contour line. This indicates a tendency of settlements to prefer defensive locations in this period. In the Ottoman period it is notable that both high and low locations are overrepresented. It is known that several villages were relocated in this period to sites that were out of view from the main routes of communication, viz. hidden in the woods.

Secondly, it is also possible to cluster the quadrats on the location variables and to inspect the resulting habitation areas.[22] On the basis of several criteria it

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[22] The variables representing aspect of slope and communication were left out of the

was decided to discern four clusters or habitation zones (Table 4), which are graphically represented in Figure 7. It is noteworthy that the clusters form fairly contiguous areas, whereas contiguity was not required in the cluster analysis.

Zone 1 is the most favourable zone for exploiting natural resources: it is relatively low-lying, flat land, most of which is arable and with a good water supply. The only factor that is relatively less advantageous is the defense factor view, which is average. In the map it appears that the valley of the Karpenisiotis river and the source-area of the Krikellopotamos belong to this zone.

Zone 4 is least attractive for habitation. Its characteristics are exactly the opposite from those of Zone 1: it is steep highland, practically without arable land and a poor availability of water. Only from a defensive point of view such locations (high, good view) might be attractive. The largest area in this category is the Kalliakouda mountain, but several lesser mountain tops also belong to Zone 4.

Zones 2 and 3 are in between these two extremes. Zone 2 definitely more attractive for human occupation than Zone 3. Zone 2 consists of the lower slopes and bottoms of steep river valleys, which are only partially arable. The valley of the Krikellopotamos constitutes this zone, together with some marginal areas of the Karpenisiotis. Zone 3 is the least pronounced area; its characteristics do not deviate much from the mean for the whole region, and generally the conditions are even a bit less favourable than on average. It is a transitional upland area between the river valleys of Zones 1 and 2 and the mountain tops of Zone 4.

As might be expected, Zone 1 is strongly favoured for human habitation in all periods, while settlements in Zones 3 and 4 are clearly under-represented. However, it is interesting to observe the shifting preference for the various zones over time. In prehistory, when the number of (identified) sites is still small, almost all settlements are found in Zone 1, and a few in Zone 2. No prehistoric site has been found in the two other zones. In the Classical-Hellenistic period the preference for Zone 1 is less outstanding: about half the sites are in this Zone. In this period we find the strongest incidence of sites in Zones 3 and 4, i.e. of sites in defensive locations. Because only one Roman site has been found in Southern Evrytania, it is impossible to say anything about the preference for locations in this period. In the Byzantine and Medieval period almost three quarters of the sites is in Zones 1 and 2, but settlements are also present in Zones 3 and 4. In the Ottoman and Early Modern period no more sites are found in Zone 4 and over 90% of the inhabited quadrats is in Zones 1 and 2. In the period since independence, there is a shift of sites from Zone 2 to the more attractive zone 1.

A third way to demonstrate how preferences of site choice may change under changing historical conditions is possible by manipulating the weights of the

analysis. Aspect is not an interval/ratio variable and the distribution of the communication variable appears to be highly skewed.

various location factors on a theoretical basis. Three models were defined to represent alternative historical conditions, in the way explained above. All location factors were normalized to the same scale and then weighted. Model 1 represents a situation of self-sufficiency, in which arable land and water supply receive an extra weight. Model 2 reflects a location strategy under conditions in which the region is integrated in a larger economic system. Because an orientation on external markets play a role in this model, trade routes receive an additional weight. The third model is representative of an unsafe situation with external threat. Communication routes, which can be used by invading armies, receive a negative weight. Either very good views (to warn and mobilize) or very bad views (hidden location) have got a positive weight.

The maps resulting from the three models, reflecting alternative location strategies, are represented in Figure 8. The differences between the results of model 1 and model 2 are rather minimal, because the main land routes through the mountains follow the river valleys, where also the arable land and the water supply are best. The third map shows a radically different pattern. For some areas the image is almost reversed. From a defensive point of view, the attractive locations for settlement are quite dissimilar from the situation under conditions of self-sufficiency or integration in a market economy.

To which model does the settlement pattern in the various historical periods conform best? If we look at the percentage of settlements in the most favoured locations according to each model, the following conclusions can be drawn (Figure 9): in the Prehistoric period, the settlement distribution complies best with the defensive model (3), then with the autarkic model (1), and least with the commercial model (2). In the Classical-Hellenistic period, there is not much difference between the three models regarding the explanation of location choice. In the Byzantine-Medieval period, the defensive model is better than the other two. In the Ottoman and Early Modern periods the situation is other way round: here both the autarchic and commercial models »explain« the pattern of settlement locations substantially better than the defensive model does.

There are many more possibilities for location analysis than can be described here. For instance, it is also possible to evaluate the location characteristics of individual sites. By analyzing the profile of all sites, it possible to rank order or group them according to the quality of their location. Questions like: which sites occupy the best locations? what is the relationship between settlement size and quality of the natural environment? could be investigated.

Gravity and potential models[23]

The central idea of the geographic gravity model is that we can observe the same kind of regularities in the interaction between social units as between physical entities.[24] According to Newton's famous law of gravity, the attractive force between two objects varies directly with the product of their masses. Meanwhile, the gravitational force is inversely proportional to the (square of the) distance between the objects. In formula:

$$I_{ij} = \frac{M_i M_j}{D_{ij}^2}$$

where:
I_{ij} = Interaction between settlements i and j
M_i = Mass of i
D_{ij} = Distance between i and j

In a geographical sense, the Newtonian law of gravity is used somewhat less strict, but the central idea remains that, other things being equal, the intensity of communication between two population centres will be directly proportional to their sizes and inversely related to the distance between them.

The potential model is derived from the gravity model by aggregating the interaction from one settlements to all other settlements in a given system. The potential accessibility is a yardstick of proximity of a settlement to all other settlements in a specific region. In formula:

$$A_i = \sum_{j=1}^{n} \frac{P_j}{D_{ij}}$$

where:
A_i = Potential interaction (Accessibility) of settlement i
n = Number of settlements

If we know the distances (either actual kilometres, calculated Euclidian distances, or travel times) and historical population numbers of all settlements in a specific region, we can calculate the hypothetical communication within the system. The effect of changes in the distribution of the population on potential

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[23] See also: P.K. Doorn, »Geographical analysis of early modern data in ancient historical research«, *Transactions of the Institute of British Geographers,* New Series 10 (1985), 275-291.
[24] G. A. P. Carrothers, *An historical overview of the gravity and potential concepts of human interaction,* Journal of the American Institute of Planners, 22 (1956), pp. 94-102; W. Isard, *Methods of regional analysis; an introduction to regional science* (Cambridge, Mass., 1960).

interaction can now be studied. A further possibility is to apply grouping methods on the basis of the intensity of communication in order to construct mutually cohesive (nodal) regions.

Gravity and potential models have been applied in geographic studies of migration, commuting, marketing, and other kinds of communication.[25] The models have also been used in various studies of »spatial archaeology«, especially to investigate relations in artefact patterns.[26] Examples of historical applications of gravity models are scarce.[27] Atkinson used the model to indicate potential contacts between ancient sites.[28] We applied the model to analyze the potential communication between settlements in the province of Doris in the 19th and early 20th century. To this aim, walking distances in hours between all villages in Doris were documented and calculated, partly on the basis of fieldwork and village interviews, partly on the basis of travel and local literature.[29] The data on population numbers were adopted from the censuses for several selected years, reflecting different spatial distributions of the population.

The settlement pattern of 1879 is representative for the period after the overthrow of the Turkish rule, when the villages in the interior highland of Doris grew rapidly. We have repeated the analysis for other years, but for want of space we will restrict the discussion to 1879 only. The accessibility potentials for that year are represented graphically in three dimensions in Figure 10. Settlements with a high potential value (i.e. with good communicative properties) are shown as peaks in the map, troughs represent settlements which are not very accessible.

The patterns of potential interaction can be further analyzed with the help of intramax analysis. This is a technique for the clustering of interaction data. The procedure, put forward by Masser and Brown, is a variation of Ward's hierarchical cluster analysis.[30] It seeks to maximize the increase in the proportion of the total interaction within aggregations of spatial units. The maximization of intrazonal interaction takes place at each stage of the grouping process. In this way, settlements with a high mutual interaction are fused, while areas with a

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[25] R. Abler, J. S. Adams and P. Gould, *Spatial organization: the geographer's view of the world* (London, 1971), pp. 350-385.

[26] Hodder and Orton, *Spatial analysis in archaeology.*

[27] One example is: J. de Vries, »Barges and capitalism: passenger transportation in the Dutch economy, 1632-1839«, *AA.G. Bijdragen 21* (1978), 275-303.

[28] R.J.C. Atkinson, »The demographic implications of fieldwork«, in: E. Fowler (ed.), *Field survey in British archaeology* (London, 1972), 60-66.

[29] W.M. Leake, *Travels in Northern Greece* (London, 1835; repr. Amsterdam, 1967); W.J. Woodhouse, *Aetolia: its geography, topography, and antiquities* (Oxford, 1897; repr. New York, 1973); F.C.H.L. Pouqueville, *Voyage de la Grèce* (Paris, 2nd ed. 1926).

[30] I. Masser and P.J.B. Brown, hierarchical aggregation procedures for interaction data«, *Environment and Planning,* A:7 (1975), 509-523; I. Masser and P.J.B. Brown (eds.), *Spatial representation and spatial interaction: studies in applied regional science* 10 (Leiden and Boston, 1978), 151-172.

low mutual interaction are kept apart. Thus, the technique can be used to analyze the degree to which a regional system is interconnected and to gain insight into the structure of the relationships within a spatial system. Applying the technique to the potential interaction data calculated with the gravity model can be an aid in interpreting the communicative structure. It offers a very useful way of presenting the interaction data graphically. A regional division based on the intramax analysis is represented in Figure 11.

An interesting result of the analysis is the high degree of coincidence of the intramax regionalization and the administrative structure of the eparchy of Doris in the 19th century. The similarity between the communicative regions of 1879 and the division in *demes* (counties, municipalities) of that time is 80 per cent and the gravitational centre of each cluster neatly coincides with a *deme* capital.

After the Second World War the old communication network and pattern of exchange in Doris were more and more disrupted by the construction of new roads, the introduction of motorized traffic and the building of a dam in the Mornos river for the water supply of Athens. Many of the ancient footpaths and mule tracks have fallen into decay as new roads were bulldozed through the mountains.

Models for reconstructing trade routes

Although the gravity and potential models give an interesting image of flows of communication and aggregate accessibility, the method is too rough for the reconstruction of actual routes. We could borrow another model from natural science, the law of the conservation of energy, to substantiate the most likely course of historical land routes, once certain communicative centres and concentrations of population are given.[31]

The basic assumption is that man tends to minimize his efforts in order to achieve his goals. With regards to communication this means that he will spend as little energy as possible to reach a certain point in space. In an isotropic plain, he would travel in a straight line if he wanted to go from point A to point B. In Greece, and particularly in Aetolia, plains are uncommon. High mountains and deep river valleys form natural barriers to communication. Routes tend to be defined by the shortest, quickest or easiest way of surmounting the distance and barriers between points A and B. Imagine a hypothetical landscape as in Figure 12. The shortest route from point A to point B would be a straight line, but this would not be the easiest course: the traveller would have to climb two ridges and cross a river at a place where there is no bridge or ford.

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[31] See also: Y. Bommeljé and P.K. Doom, »The long and winding road: land routes in Aetolia since Byzantine times« (paper prepared for the symposium: *Land routes in Greece from Prehistoric to Post-Byzantine times,* Athens, May 1991; forthcoming).

If we quantify and enter the communicative characteristics (largely defined by slope and rivers) of the landscape in a GIS, we can calculate the amount of energy needed for travelling from A to B as the product sum of difficulty times distance. By calculating the energy needed for alternative routes, we can simulate the trial and error process by which in the real world the easiest route is found. Clearly, the route costing minimum energy is the one that would most likely be chosen in reality.

We applied this principle to evaluate the difficulty of several alternative routes. One example will be presented here. The scene is again set by the eparchy of Doris. The heart of Doris is formed by a place called Stenon (lit. narrow), a place where three rivers (Megas, Kokkinos and Belesitsa) meet and together form the Mornos river. Before the artificial Mornos lake was created, the communicative value of Stenon was emphasized by a Turkish packhorse bridge that spanned the narrow ravine. From prehistoric till Turkish times, the largest and most impressive walled settlement of the area, and later a castle, overlooked the strategically important site.[32] Also the present capital of the eparchy is located at only a few kilometres distance from Stenon. Without doubt, the connection of this site to the coast of the Corinthian Gulf has been important during many phases of history. Near the present-day villages of Tolofon (Vitrinitsa till the early 20th century) and Erateini, extensive remains of coastal habitation have been found since prehistory. But what was the most likely route from the nodal point in the interior (Stenon) to the coast?

Figure 13 shows three alternative routes from the coast to Stenon. On the horizontal axis distance is displayed, on the vertical axis height in metres. Table 5 shows a breakdown of the data of route A in tabular form, and a summary of the travel data is given in Table 6. Route A has a total length of 22.5 km. But over this length, 1225 vertical metres have to be climbed. Because of the difficulty of the route, speed of travel (on foot) is considerably reduced to about 3.5 km/h. Travel time is about six and a half hours. The second alternative (route B) is 5 km longer than route A and the amount of vertical metres to mount is 1925. Average travel speed is about the same, and the journey will take about 8 hours. Route C is as long as route B, but here only 825 vertical metres have to be ascended and descended. This route therefore costs less energy. Average walking speed is 4.3 km/h and the travel time is even slightly less than taking route A. In sum, route A is shorter but route C is easier. Therefore, both alternatives are potential trade routes. In this case, alternative evidence (such as from travel literature, presence of traditional country inns, etc.) would be necessary to substantiate the argumentation.

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[32] The ancient site, near the largely submerged village of Kallion (Veloukhovo), is identified as Kallipolis; the medieval and Ottoman defense works can only be the castle of Lidoriki.

Conclusion

In this contribution the value of applying geographical models and information systems in a historical context has been demonstrated. Location models and quadrat analysis offer many opportunities for a detailed analysis of changing settlement patterns over time. The shifts in these patterns reflect the transformation of historical conditions and the changing relevance of location factors over time. Gravity and potential models and the application of intramax analysis offer tools to study patterns of communication in historical societies. Finally, the reconstruction of trade routes can be undertaken with the help of a geographic version of the model of conservation of energy.

Acknowledgements

Table I. Matrix of location factors and costs "pulling" at a village

Resource	Distance X	Distance Y	Cost unit	Distance * Cost X	Cost Y
Water	0,5	1.5	10,0	5,0	15,0
Arable land	2,0	2,0	5,0	10,0	10,0
Grazing land	3,5	1,5	3,0	10,5	4,5
Fuel	3,0	0,5	3,0	9,0	1,5
Building materials	1,0	0.5	1.0	1,0	0,5
Sum	10,0	6,0	22,0	35,5	31,5
Average	2,0	1,2	4,4	1,6	1,4

Table 2. Location factors for rural settlements

Location factor	Village site	Situation (exploitation area and outside world)
Land	Suitability of building site: 1. soil (type, use for building) 2. relief (slope, plain, valley, hill top, terrace, saddle, promontary) 3. orientation (sun, wind, view),	Resource content of exploitation area: 1. Access to arable and grazing land, soil fertility (geology), slope, vegetation, difficulty of clearing 2. Availability of building materials and fuel
Water	Access to water for drinking, cooking, and washing: 1. flowing surface water (streams) 2. springs 3. ground water (wells, cisterns)	Access to water for irrigation and animals: 1. hydrological situation (soil humidity, drainage) 2. streams, sources, wells, cisterns
Weather/ micro climate	Protection from extreme weather influences in summer and winter: height, aspect (sun, wind)	Implications for growing season and animal feeding: height, aspect (sun, wind, precipitation)
Communi- cation	-	Position in communication network: access to market centres and periodic markets; communication with surrounding settlements
Safety	1. Natural: flooding, avalanches, diseases, earthquakes, landslides 2. Defence and strategic value: potential for visual communication, accessibility, hidden location	Natural: susceptibility to flooding, avalanches, and land slides Human: openness of terrain, presence of hidings (*katafygia*: caves, woods, mountains), lookouts
Cultural	1. Incomplete knowledge of terrain (ignorance, prejudice) 2. Inertia and previously existing settlements 3. Technological conditions: the available tools and techniques for building	1. Predominant exploitation strategies: available tools and techniques for cultivation 2. Incomplete knowledge of territory 3. Already occupied territory

Table 3. Settlement numbers (inhabited quadrats) per period in Southern Evrytania

Prehistoric (Preh)	7
Classical and Hellenistic (C/Hl)	31
Roman	1
Byzantine and Medieval (Byz/Med)	11
Ottoman (Ott)	33
Early Modern (EMod)	58

Table 4. Location characteristics of four clusters or habitational zones in Southern Evrytania

Variable	Zone 1	Zone 2	Zone 3	Zone 4
Height	--	---	+	+++
Slope	---	+	+	++
View	0	-	-	+++
Arable land	+++	-	--	---
Water supply	++	+++	-	---

Note: pluses (+) and minuses (-) represent positive and negative deviation from cluster mean (0).

Table **5. Breakdown of distance and travel time of land route A (Coast to Stenon over Amygdal6a)**

Location	Horizontal distance (km)	Height (m)	Slope (pct.)	Travel speed (km/h)	Travel time (Hr)
Erateini	0.0	0			0.0
Foot of Koutsouros	1.0	20	2.0	4.7	0.2
Kokkinovrakhos (saddle of Koutsouros)	5.0	800	19.5	1.8	2.5
Amygdalea	7.0	600	10.0	3.3	3.1
Agia Trias (begin of Belesitsa valley)	9.0	475	6.3	4.0	3.6
Crossroad Vraila-Malandrino	12.0	450	0.8	4.9	4.2
Crossroad Levka-Pendapolis	16.0	425	0.6	4.9	5.0
Below Lidoriki	20.0	375	1.3	4.8	5.9
Stenon	22.5	375	0.0	5.0	6.4

Table 6. Distances and travel times of three alternative land routes

Route	Horizontal distance (km)	Vertical distance (m)	Vertical meters/km	Travel time (hr)	Av. speed (km/hr)
Route A	22.5	1225	54.4	6.4	3.5
Route B	27.5	1925	70.0	7.8	3.5
Route C	27.5	825	30.0	6.3	4.4

Figure 1. **Aetolia in Central Greece (based on French topographical map from 1852)**
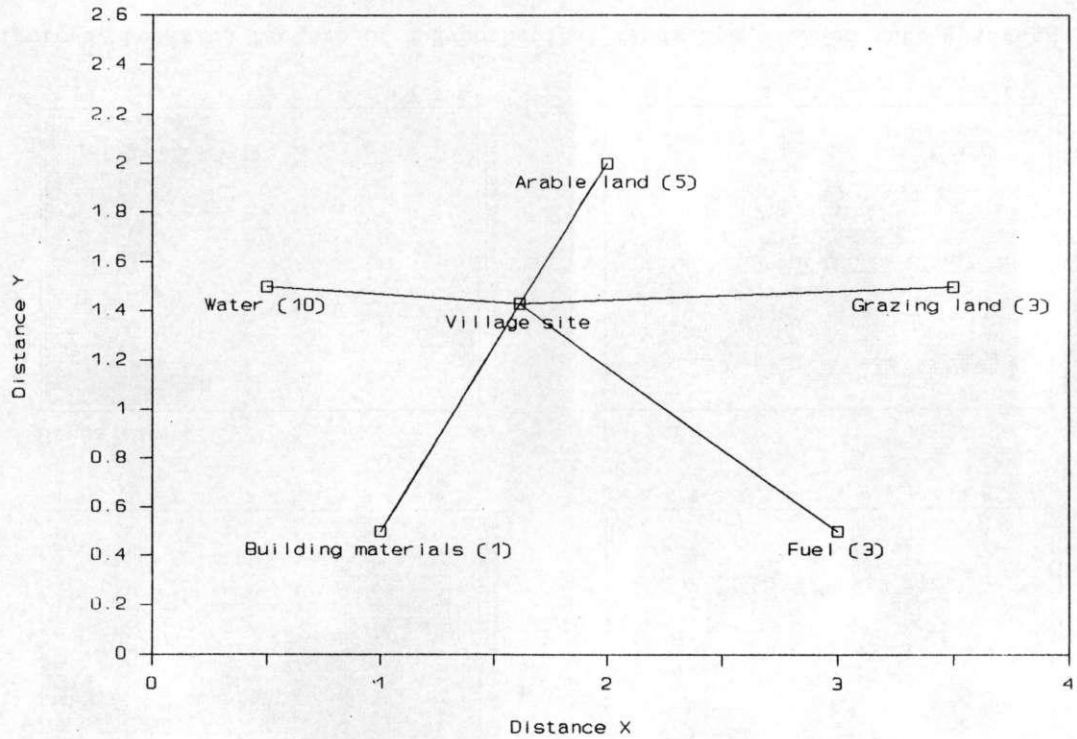
Figure 2. **Graphic representation of Table 1**

A. Communication
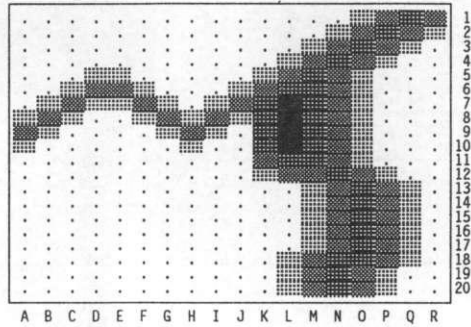
B. Water
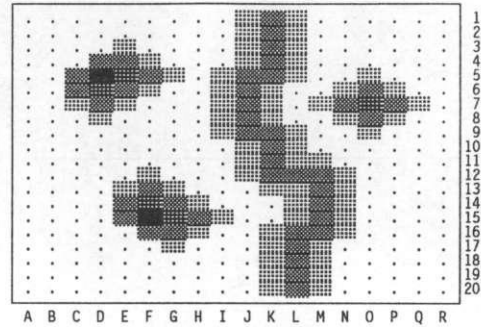
C. Safety
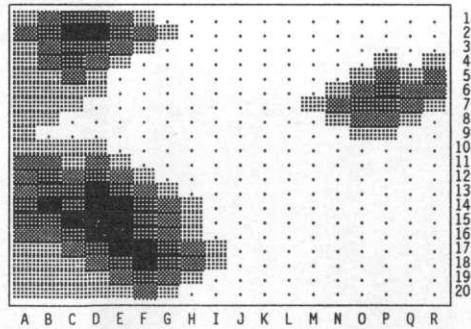
D. Land
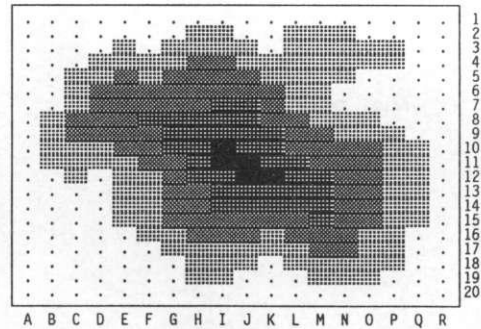
Figure 3. Location factors of a hypothetical landscape divided into quadrats

E. Combination of all location
factors (A + B + C + D)
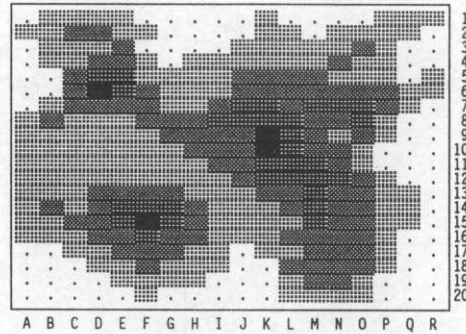
F. High insecurity, external threat
(-A + 0.5B + 2C + 0.5D)
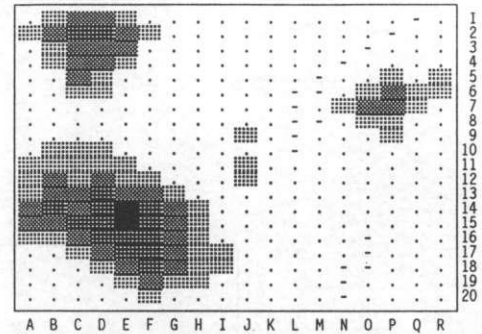
G. Self-sufficient economy
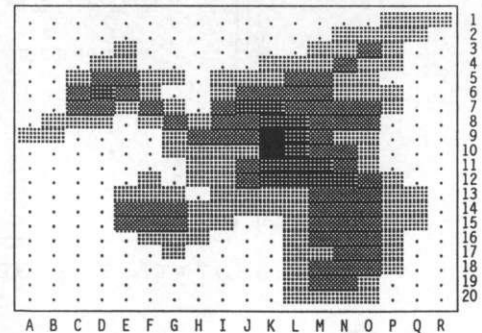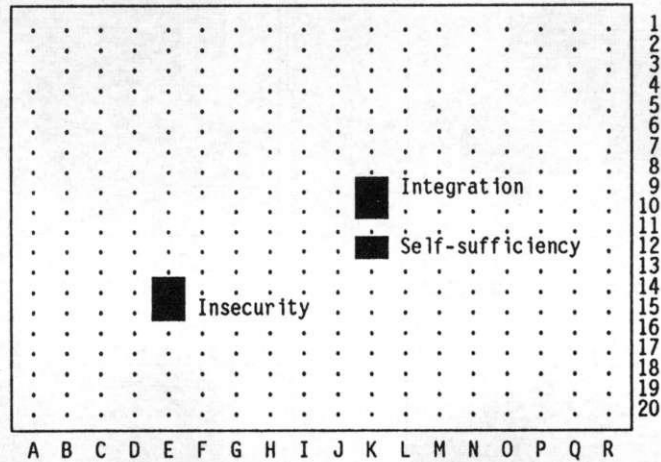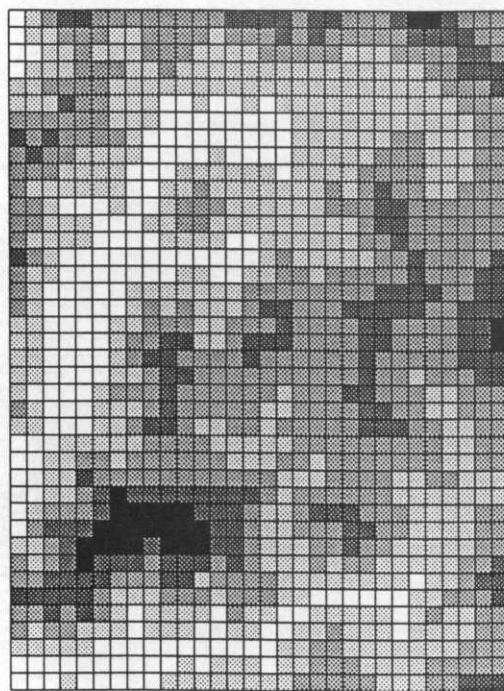(0.5A + 1.5B + 0.5C + 1.5D)
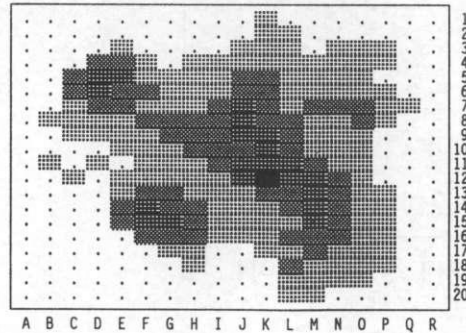
H. Integrated economy
(1.5A + B + 0.5C + D)

Figure 3. Location factors of a hypothetical landscape divided into quadrats
(continued)

H. Model of the wandering village

Figure 3. Location factors of a hypothetical landscape divided into quadrats (continued)

A. Height in metres
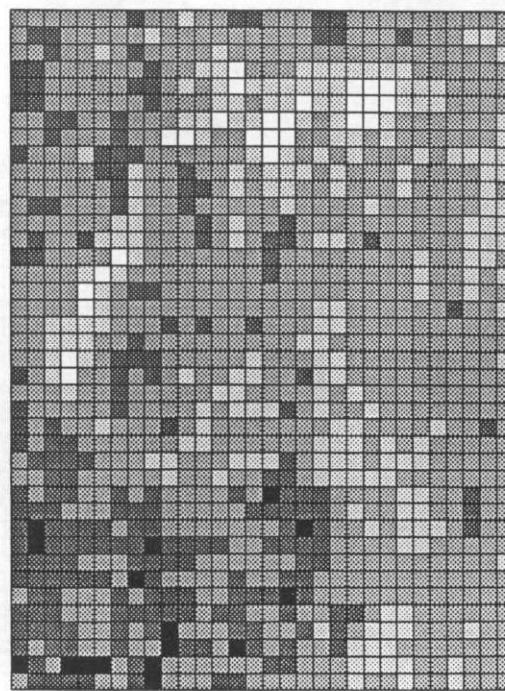
LOW-<900
1400-<1650   800-<1150
1650-HIGH   1150-<1400

B. Slope in degrees

LOW-<5
20-<30   5-<10
30-HIGH   10-<20

Figure 4. Four location factors in Southern Evrytania: (A) Height; (B) Slope;
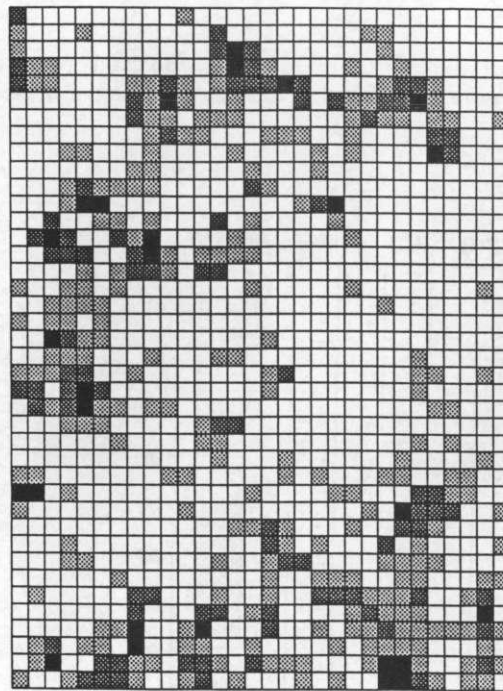(C) Arable land; (D) Water supply
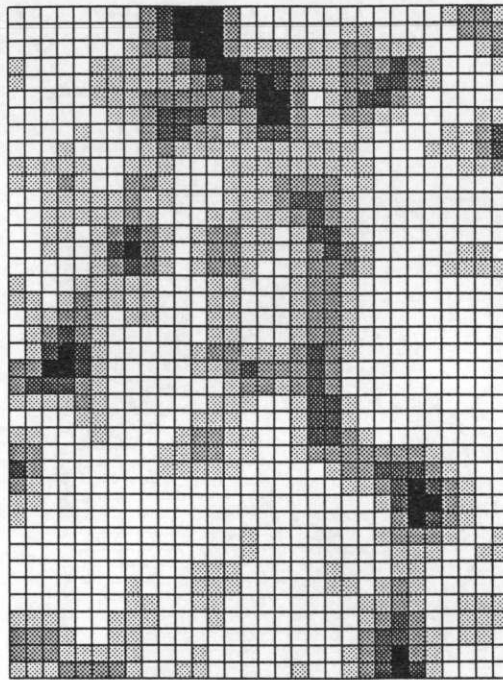
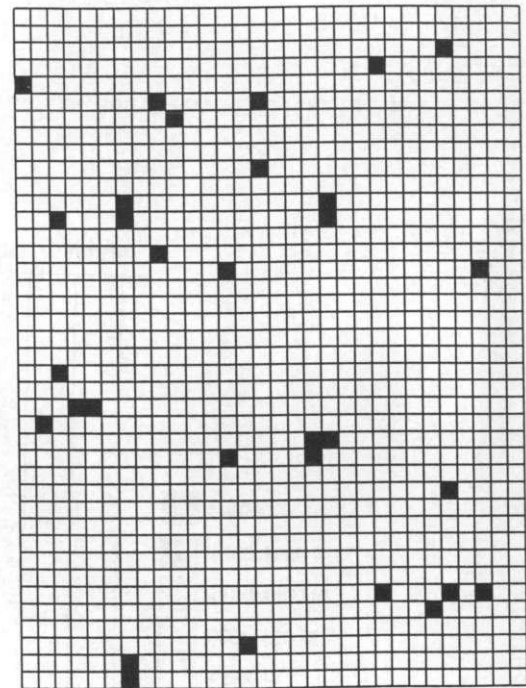C. Arables land (per cent of total surface)

LOW-:20 20-<40 40-<60
60-<80 80-HIGH
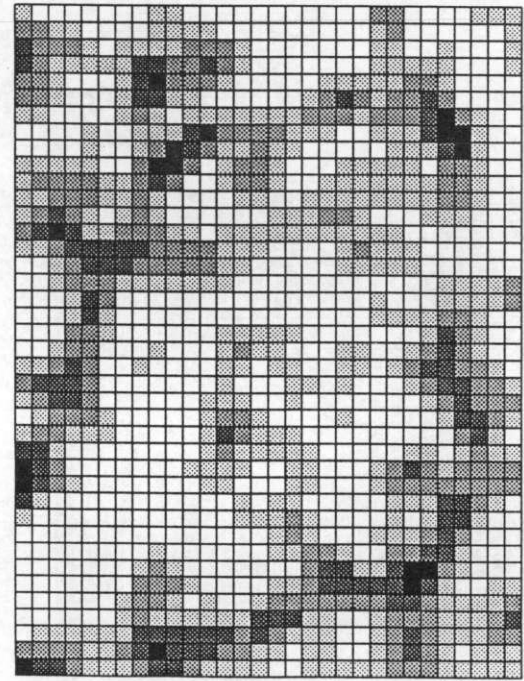
D. Water supply (0 = dry, 2 or more = wet)

LOW-:0.5 0.5-<1 1-<1.5
1.5-<2 2-HIGH

Figure 4. Four location factors in Southern Evrytania: (A) Height; (B) Slope;
(C) Arable land; (D) Water supply
(continued)

A: Houses in modern period   B: Sites in Classical/Hellenistic period

☐ 0   ▨ 1-<5   ▦ 5-<15   ■ 15-High

Figure 5. (A) Number of houses per quadrat in modern period and (B) number of inhabited sites in Classical-Hellenistic period, Southern Evrytania
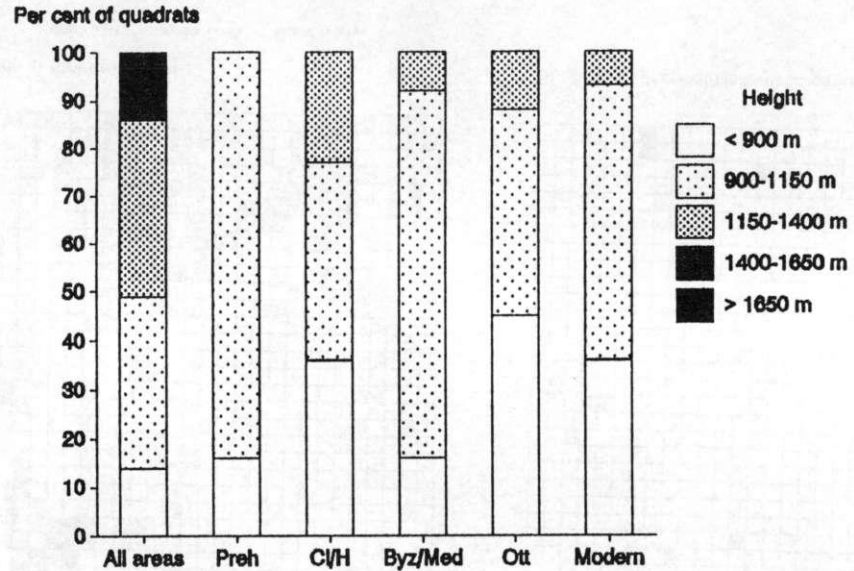
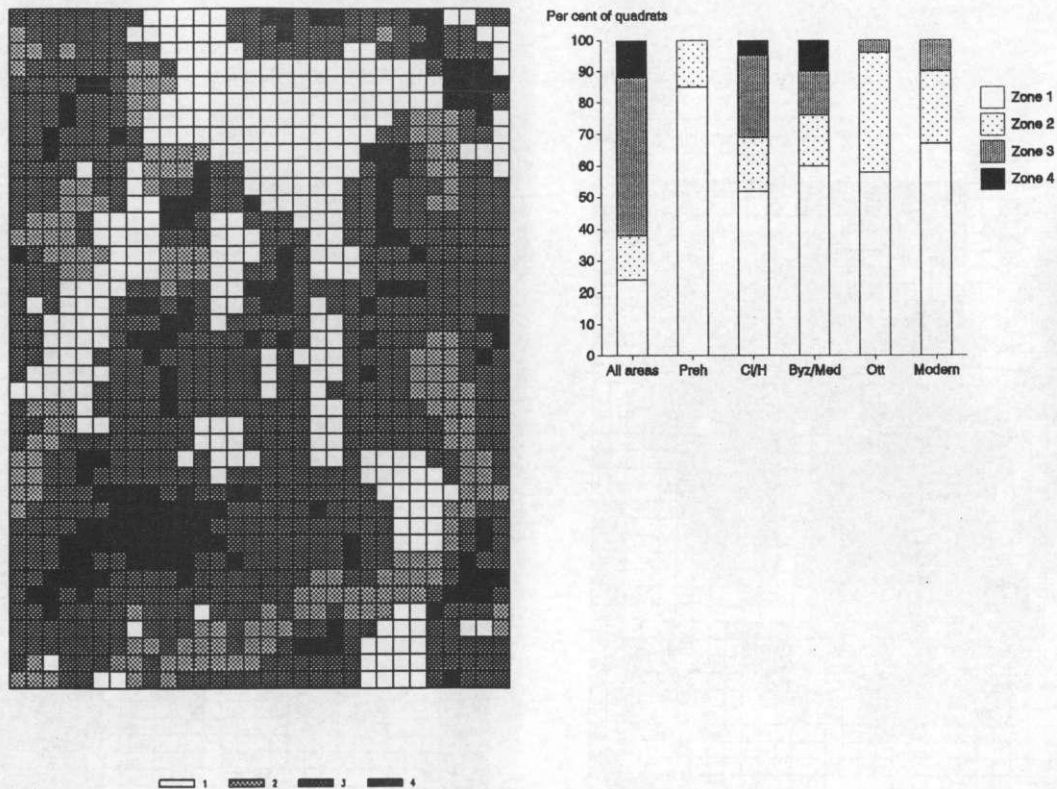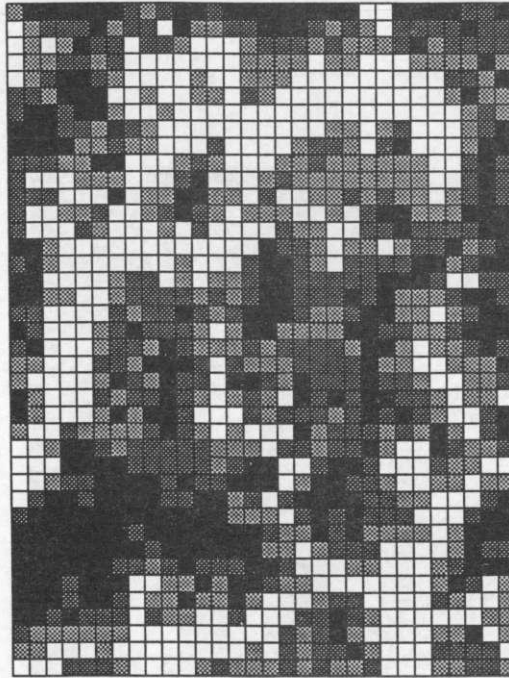*Figure 6.* Height distribution of settlements in Southern Evrytania per historical period
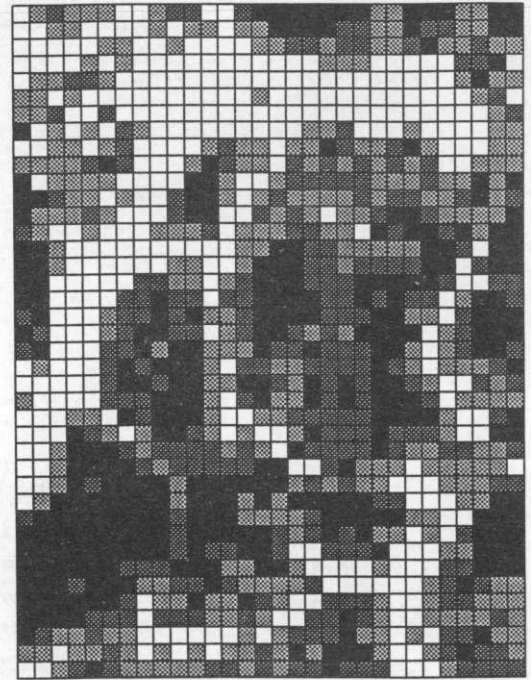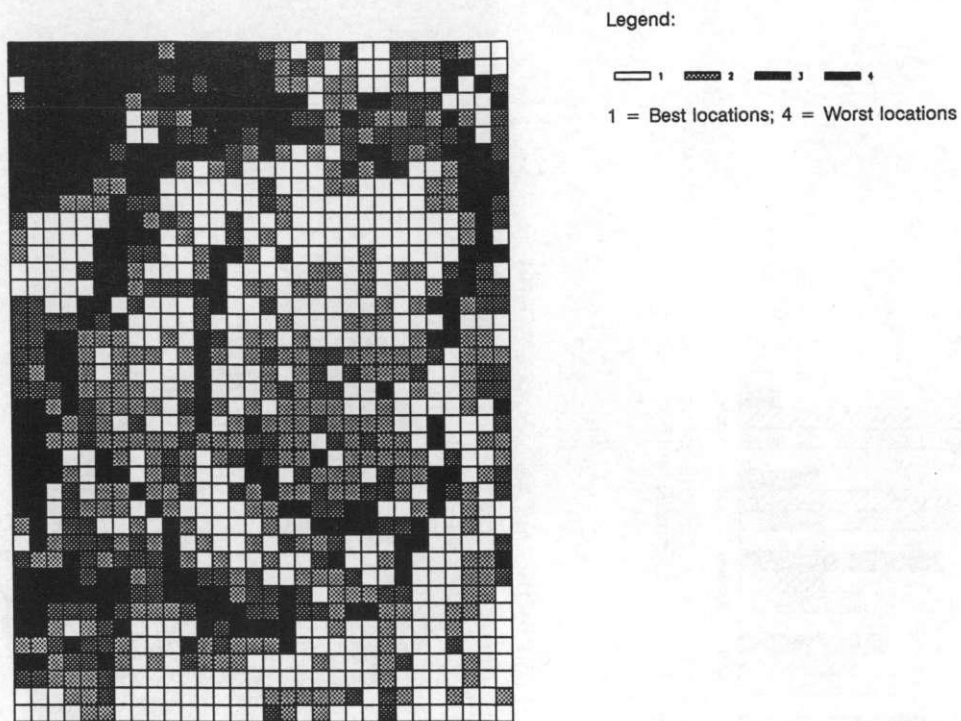
Figure 7. **Four habitation zones in Southern Evrytania**

99

Model 1: Autarky

Model 2: Commercial

Figure *8.* Location strategies in Southern Evrytania: (1) Autarky; (2) Commercial; (3) Defensive

Legend:

1 = Best locations; 4 = Worst locations

Model 3: Defensive

Figure 8. **Location strategies in Southern Evrytania: (1) Autarky; (2) Commercial; (3) Defensive**
(continued)

Per cent of settlements in best quadrats

Model 1: Autarky
Model 2: Commercial
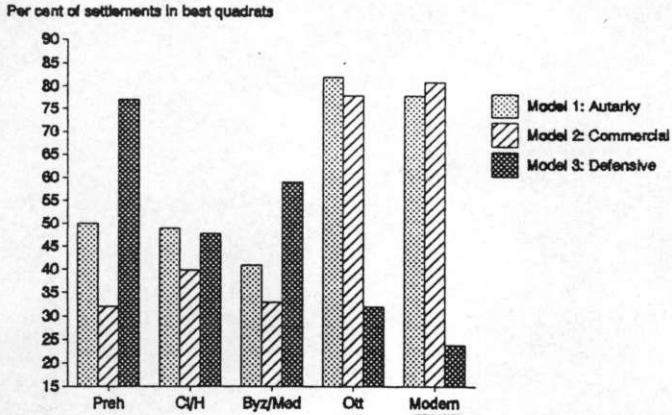Model 3: Defensive

Figure 9. Settlements in the best locations according to the three location models (per cent)

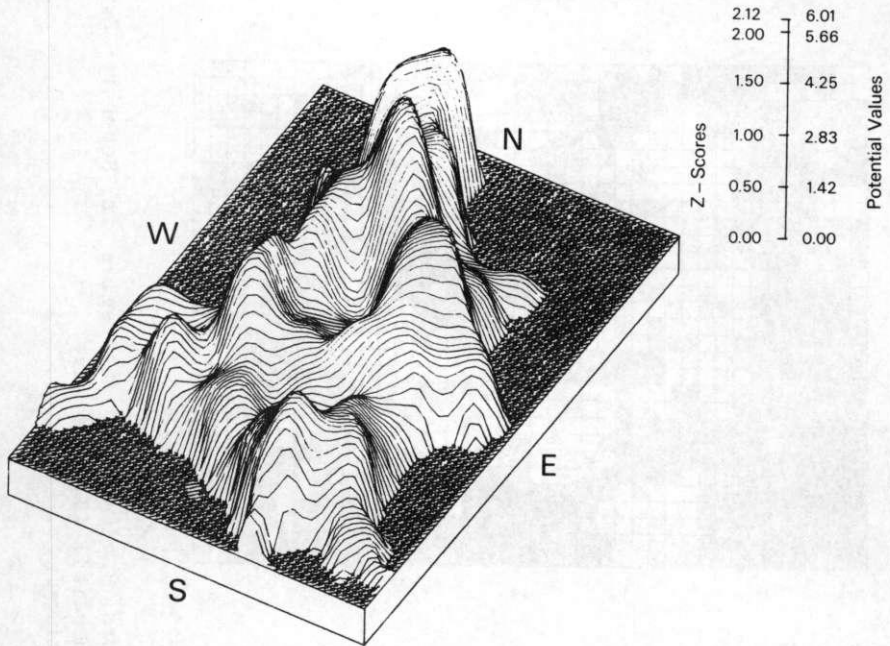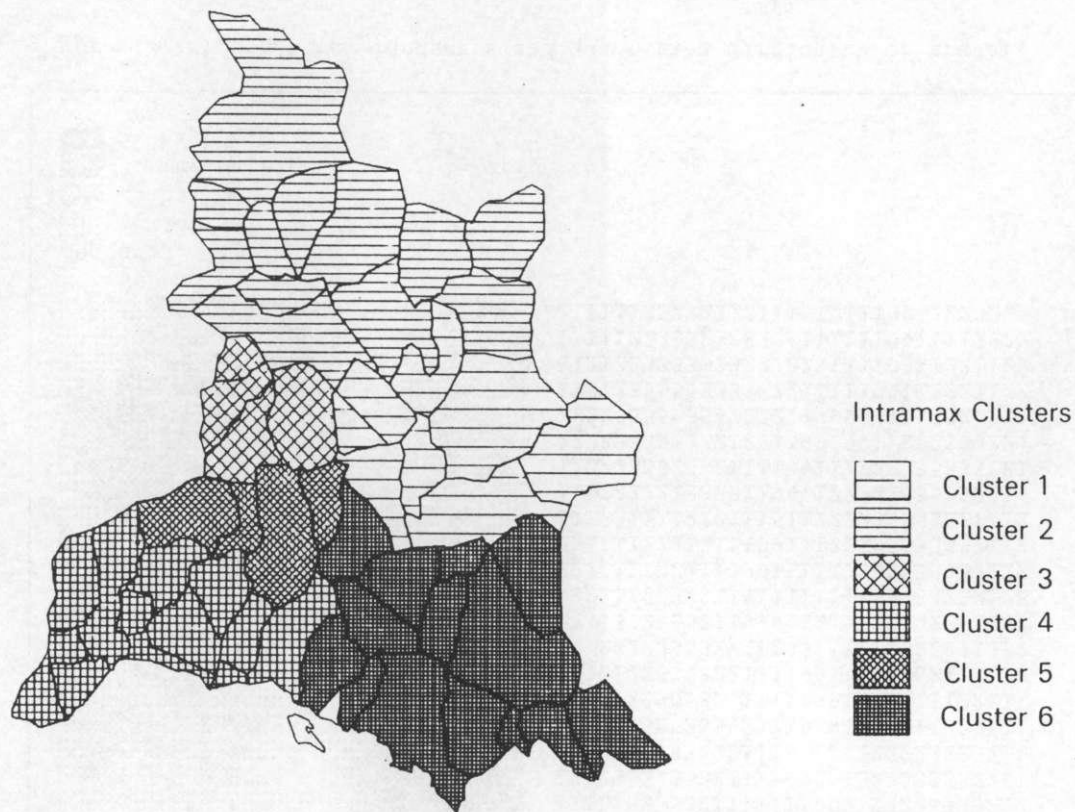Figure 10. Accessibility potentials 1879, *eparchy* of Doris

Intramax Clusters

Cluster 1
Cluster 2
Cluster 3
Cluster 4
Cluster 5
Cluster 6

Figure 11. Intramax regionalization of potential interaction 1879, *eparchy* of Doris

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1222333332221111111119999911122333
1122333333211111111199911122233333
1112233533321111111999122223333222
1222333533221111999112223333332211
1122335533332211199111122222233211
1112233553333221119191111111223111
1111223355321111119911111111122111
2111122335322111199111112222111122
2112222235322119991111112322211222
3211122233211999111111122332211222
A32211222221191111111122333322212B
2222112221111991111123335533332122
2111111221211199111223355555332112
1112211112221115112222355553321112
1122222212322119911222235553332211
1222223323321111991111222235533221
2222333533221221199199112223333221
1222335553333222211999991222222211
1121233555333322211111199111221122
1111223333333222221111119911221122
1111122233222222111111199111112222
111111122222212111J1111119911222221
```

Legend:
- 1. low
- 2. hilly
- 3. medium high
- 5. high
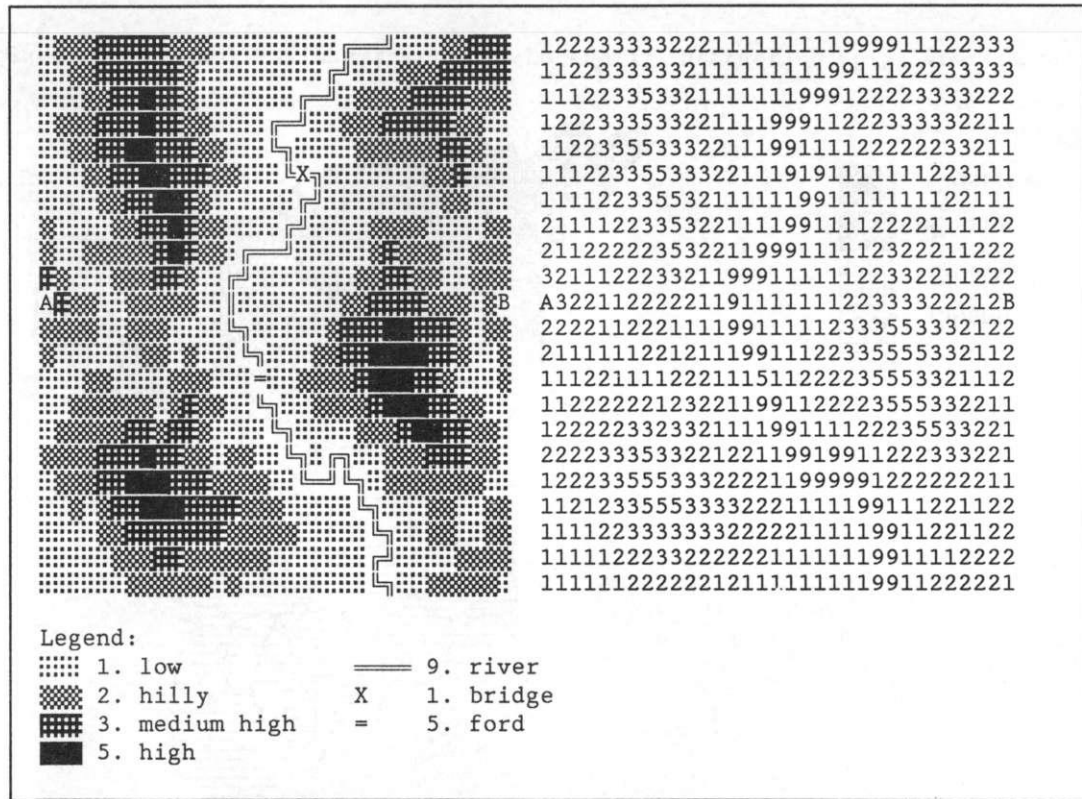
- 9. river
- X 1. bridge
- = 5. ford

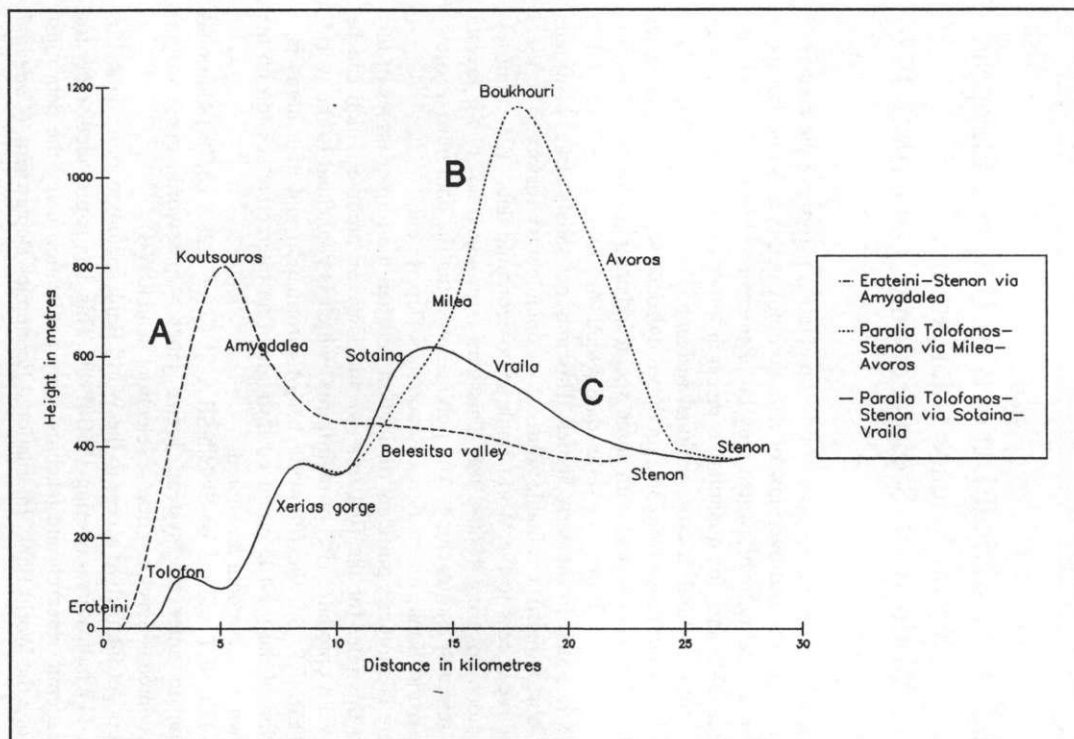*Figure 12.* Hypothetical landscape and quantified difficulty of travel

Figure 13. **Three alternative routes from the coast of the Corinthian Gulf to Stenon, Doris**