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Using a Geographic Information System to Create Probability Models for Sites with Tombs from the al-'Umayrī Regional Survey

Archaeologists have long been interested in the interplay between ancient humans and their environment. In an attempt to better understand this relationship, the Mādabā Plains Project has included a geographic information system (GIS) in its research design since 1992, using it to create, among other things, environmental probability models for various sites from the al-'Umayrī regional survey. These models focus on groups of sites selected from the survey database which share either temporal or functional similarities. For example, models have been constructed for sites with Iron II pottery and for sites identified as farmsteads. For this paper, environmental probability models will be created for Classical period sites from the al-'Umayrī regional survey, focusing on those sites with tombs. Tombs were selected because research into funerary customs is becoming an increasingly important component of the Mādabā Plains Project and because they are one of the few archaeological features from the survey that can be characterized as fundamentally non-agricultural, providing an opportunity to test the effectiveness of environmental probability models for non-agricultural sites.

During the course of this study, two questions will be answered. First, is it possible to identify an environmental signature for sites with tombs? In archaeological terms, an environmental signature is an identification of the environmental variables which were factors in the selection of a particular location for a particular type of archaeological site. For example, a farmstead should be located in an environmental setting best suited for agriculture, while a city might be situated in an environment best suited for its military and economic survival. The second question is dependent on a positive response to the first. If it is possible to identify an environmental signature for sites with tombs, can we be sure that this signature actually reflects the tombs? In other words, is it the tomb which determined the environmental signature, or was it the other components of the site? In order to answer these questions, this paper will begin with brief discussions of the archaeological material and of GIS, and then move to the creation of probability models.

The Archaeological Material

The al-'Umayrī regional survey has been examining the area contained within a five kilometer radius of Tall al-'Umayrī since 1984. A large project, run in conjunction with the excavation at Tall al-'Umayrī, this survey has fielded several teams, each concentrating on different aspects of the region. These teams have included hydrologists, ethnographers, artists, geologists, architects, linguists, GIS programmers, and archaeologists. During five field seasons, survey teams have located and recorded 133 sites. Of this number, 42 sites had funerary features, that is cemeteries, isolated tombs, and occupational sites with one or more tombs (Boling 1989; Christopherson 1996; Geraty *et al.* 1989; LaBianca 1991; Younker 1991).

The most intensive involvement with funerary remains in the region has concentrated principally on the excavation of Bronze Age tombs. In 1992, excavation took place at a relatively small cemetery at Umm al-Kundom (Site 73) 3 km south of Tall al-'Umayrī (Waterhouse and Krug 1993). A larger cemetery, half a kilometer south-east of Tall al-'Umayrī (Site 135), was excavated by the Department of Antiquities of Jordan in 1992-1993 by Waheeb and Palumbo (Waheeb 1994; Waheeb and Palumbo 1993). It produced one of the richest EB IV tomb repertoires in the southern Levant. During the 1994 field season, survey and excavation of this cemetery were continued by the Mādabā Plains Project with another 10 shaft tombs and 20 cistern-shaped installations either identified or excavated. Additionally, an isolated Early Bronze I megalithic tomb was discovered in 1994 and partially excavated on the southeastern slope of Tall al-'Umayrī. It contained an impacted bone heap of some 20 individuals along with 20 vessels dating to EBIB (Dabrowski *et al.* 1994). Finally, a hewn cave/tomb with a stepped entrance dated to MB IIC was also found on the southeastern slope of Tall al-'Umayrī and partially excavated in 1994. It contained at least 15 articulated skeletons.

In addition to these excavations, the al-'Umayrī regional survey has also located and recorded numerous Classical period tombs during the course of its work. Of the 42 sites with funerary components, 30 had Roman/Byzantine tombs. Given the low numbers of sites boasting tombs from other periods, these 30 sites provide the only sample of sufficient size to provide a statistically valid model.

For this reason, models constructed for this paper concentrated on sites with tombs from the Classical period.

Geographic Information Systems

Of great importance in government agencies and in the private sector, geographic information systems are quickly infiltrating academic circles, including anthropology and archaeology departments. A GIS can be defined as a system of computer hardware and software components arranged around digital databases which store, manipulate, capture, analyze, create, and display spatially referenced data. Because they reference data spatially, GIS are easily adaptable to many different disciplines, including archaeology where location information for everything from individual artifacts in an excavation to sites in a regional survey are recorded. Unlike paper maps which store multiple data themes on a single sheet (e.g. roads, cities, hypsography, etc.), GIS store data themes in individual layers. A layer for roads, a layer for elevation, a layer for Iron Age sites. Because these map layers are referenced to a common coordinate system, they can be electronically overlaid to create user specific maps which can include any combination of data themes.

Geographic information systems come in two basic types, vector and raster. Because of the differences in how they manage spatial data each has its own particular strengths and weaknesses, and for this project a raster GIS was used. In a raster GIS, data are stored in a grid of columns and rows, much like a spreadsheet, which correspond to X and Y coordinates. The intersection of each row and column forms a cell which represents a specific area in the real world and contains a Z value, or number which can represent anything from elevation, to sites, to soil types. In essence, in a raster GIS, maps can be seen as a large sheet of numbers. Because these numbers can change continuously across the surface of the map a raster-based GIS is good at modeling the environment, which also changes continuously across the surface of the earth.

Modeling the Environment

As the name suggests, environmental probability models require the capture and manipulation of environmental data. This generally means using GIS or CAD software to digitally encode the data contained in paper maps. Data for natural and cultural features in the al-'Umayrī region were digitized using Auto CAD 10.0 (Autodesk Inc. 1989) and PC ARC/INFO 3.4D (Environmental Systems Research Institute 1990), the basic map being the Jordan 1:25,000 series. Data for hypsography, hydrography, and roads were taken from the following map sheets:

- 'Ammān: 1:25,000 Topographical Map 225-145 (D. Survey 1958a)
- Nā'ūr: 1:25,000 Topographical Map 225:135 (D. Survey 1958b)

Additionally, surficial geology and soil maps were created by the Project's geologist, Douglas W. Schnurrenberger, based on 1:10,000 aerial photographs and field samples.

All coordinate information for this project was based on the Palestine Grid System. The digitized area was contained within the following coordinates:

Minimum X = 228000 m East
Maximum X = 240000 m East
Minimum Y = 136000 m North
Maximum Y = 148000 m North

GIS software imposed a grid with cells of 50 x 50 meters onto the 144 square kilometers contained within these coordinates. This raster contained 240 rows and 240 columns, creating 57,600 cells. Of the cells in the grid, 31,253 are contained within the five kilometer radius of the al-'Umayrī regional survey. All statistical analyses were carried out based on values found inside this radius.

The creation of environmental probability models necessitates the building of a number of environmental map layers in a GIS. In all, fourteen such layers were constructed for the al-'Umayrī region in ARC/INFO 7.0.2 (Environmental Systems Research Institute 1995) running on a UNIX platform. Brief descriptions of each variable follow.

Elevation: this map layer contained a digital elevation model (DEM) of the 144 square kilometers digitized for the project. Using the elevation contours contained in the 1:25000 maps, ARC/INFO interpolated elevation values for those cells lying between contours to create the DEM. The importance of this map layer cannot be overstated since many of the environmental variables used in this study model some aspect of the region's topography and were derived from this DEM.

Aspect: interpolated from the DEM, the grid cells in this map layer contained numbers which reflect the direction each cell faces. Aspect measurements are typically made on a 0-360 degree scale, but using these numbers in a quantitative analysis creates a problem since both 1° and 359° indicate a north facing slope, but quantitatively 359 is much greater than 1. Following Kvamme (Kvamme 1988), this problem was overcome by creating two aspect maps, one measuring north-south aspect and one measuring east-west aspect. For example, in the north-south aspect map, a score of '0' indicates north, '180' south, and scores between could be either east or west.

Relief: also derived from the DEM, three measures of relief, detailing differences in elevation, were calculated within a 200 m radius of each grid cell. Relief above subtracts the elevation in the target cell from the highest elevation in the search radius. Relief below locates the cell within the 200 m radius with the lowest elevation and subtracts it from the target cell. Maximum relief subtracts the lowest elevation from the highest elevation within the neighborhood.

Texture: texture is the standard deviation of all cells within a 200 m radius of the target cell in the DEM. Increasing variation amongst elevation values in this neighborhood delivers a larger standard deviation, while uniform terrain leads to a smaller standard deviation. Thus, smooth surfaces will yield low texture scores and rough terrain high texture scores.

Ridge Index: this index describes the position in relation to ridges and drainages by interpolating the viewing angle possible for each cell in the DEM. Scores close to 360 indicate hilltop and ridge locations with their wide view angles, low scores correspond to drainages and their narrow view angles, and scores around 180 are indicative of sites located mid-slope or in plains settings.

Shelter: this measure indicates the relative exposure of a particular cell within a 200 meter radius of the target cell. Higher scores indicate exposed areas, rims or hilltops, lower scores indicate sheltered areas, valleys.

Slope: also based on the DEM, this variable is a measurement of the slope of each cell in the raster.

In addition to these topographical themes, four maps based on distance were created. SOIL 1, SOIL 2, SOIL 3: these variables are distance measures to each of the three soil types in the al-'Umayrī region. The GIS calculated the Euclidean distance from each cell in the grid to the soil type in question.

Wādī: this variable is another distance measurement. In this case, the distance measured was to the nearest wadi channel.[1]

Three additional maps were necessary for the construction of the models. The first was sites with Classical period tombs. This layer was created by extracting coordinates for these sites from the al-'Umayrī survey database and exporting them to the GIS. These sites could then be queried against the environmental map layers to discover the environment at sites with tombs. The second layer was sites with Roman or Byzantine pottery. The probability model based on these sites could serve as a control, demonstrating whether or not the environmental signature for the tomb sites was based on the presence of tombs or on some other aspect of Classical period culture. The final map was a random sample of 250 non-site locations within the survey region. This layer was created in Idrisi (Eastman 1992), a PC based GIS developed and distributed by the Clark University Graduate School of Geography. These non-site locations could also be queried against the environmental layers to discover the environment at a random sample of non-site locations.

The Probability Model for Tombs

Archaeological probability models are based on the assumption that ancient humans did not choose the locations for their sites randomly. Although there are a number of ways to approach this question, a proven method is the construction of probability models based on logistic regression (Kvamme 1988 and 1992; Warren 1990). In an archaeological context, this would involve comparing the environment at a sample of archaeological sites to the environment at a sample of randomly located non-sites. For this study, a stepwise logistic regression was used to create the probability model for Roman/ Byzantine period tombs. Stepwise logistic regression compares a site sample to a non-site sample for all available environmental variables and, based on predetermined significance levels, the stepwise process begins adding and subtracting variables in order to create a maximum-likelihood model. Using aggressive significance levels, 0.15 for adding a variable and 0.20 for removing a variable, the fourteen environmental variables in the al-'Umayrī GIS were subjected to the stepwise procedure using STATA, a PC based statistical software package (Computing Resource Center 1992). Within these parameters, four variables, ridge index, distance to type 1 soils, slope, and distance to wadi channels, were found to be significant. (TABLE 1) lists these variables, along with the Y-intercept constant, in the order of their importance to the model.

Table 1. Stepwise logistic regression coefficients for Tomb Model.

Variable	Coef.	t-score	P >|t|
Slope	0.2913825	3.501	0.001
Ridge Index	0.0114524	2.823	0.005
Distance to Wadis	0.0025553	2.150	0.032
Distance to Type 1 Soil	0.0013228	1.988	0.048
Intercept Constant	-7.0896240	-5.481	0.000

The coefficients and t-scores seen in TABLE 1 are products of the logistic regression, and are indicative of the environmental signature of the site sample. Positive coefficients indicate a preference for high values of the corresponding variable, while negative coefficients indicate a preference for low values. Based on the coefficients returned by this regression, it is clear that Roman/Byzantine tombs tended to be located on steeper slopes, near ridges, and away from both type 1 soils and wadi channels. The t-scores indicate the importance of a particular variable within the model. The farther this score is from zero, the more important it is to the model. In this example, slope is more important to the model than is distance to type 1 soils. This importance is reflected in the final column of TABLE 1, which lists the probability of this t-score occurring by chance.

The coefficients in (TABLE 1) also allow the creation of probability models in the GIS. Creation of these models involves rather straightforward math. As noted above raster maps are like big sheets of numbers, and multiplying these numbers by their corresponding regression coefficients creates new maps which are weighted in

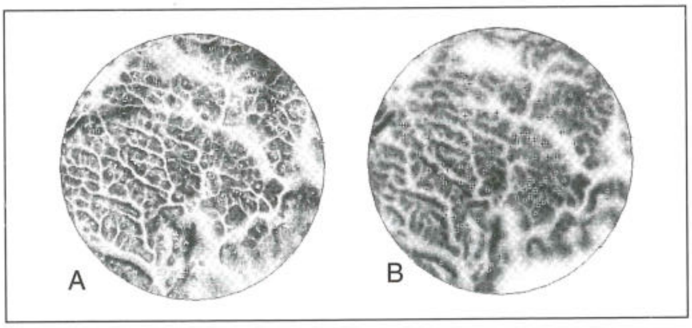
[1] The creation of most of these environmental data themes was accomplished using standard raster GIS manipulations of the digital elevation model (DEM). Additional information concerning the specific algorithms used to create them is available from the authors. Also, since many of these variables have been thoroughly discussed by Kenneth L. Kvamme, additional information about their characteristics and function is available in his publications (Kvamme 1983, 1985, 1989, 1990 and 1992).

favor of the areas most like the site sample. These weighted variables can then be summed on a cell-by-cell basis across the raster. In addition to the weighted variables, the Y-intercept constant of the regression was corrected, to eliminate bias inherent in a differently sized sample, and added to the sum of the weighted variables. Following Warren (Warren 1990), the corrected intercept constant for our model was -4.9693606. Thus the equation for creating the tomb model, was:
D = -4.9693606 + 0.2913825 * (Slope) + 0.0114524 * (Ridge Index) + 0.0025553 * (Distance to Wadi) + 0.0013228 * (Distance to Soil 1) where D represents the model.

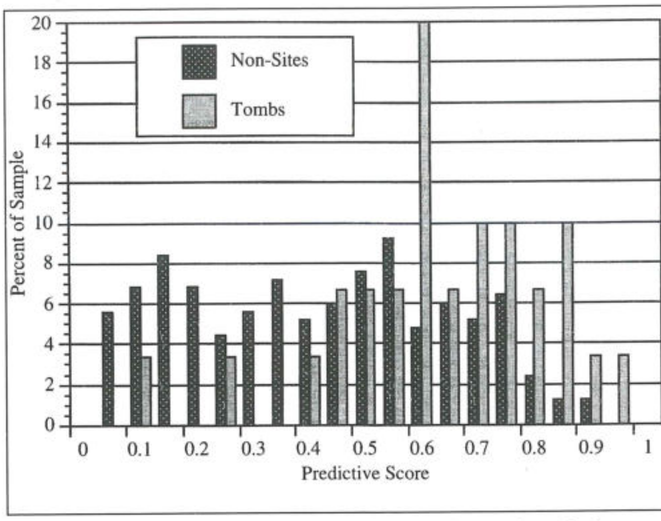
Finally, to clarify the results and facilitate comparisons with other models, it was logistically transformed to rescale the values of the model to a probability score between zero and one for each cell in the raster.[2] These scores indicate trends over the entire surface of the project area, with scores close to zero representing areas dissimilar to the environmental signature of tomb sites and those close to one representing areas similar to the signature of sites with tombs. The resulting GIS map can be seen in (FIG. 1A), with darker areas representing higher probability scores and lighter areas lower scores.

To test the ability of the model to predict the most favorable areas for Classical period tombs, it was queried by both the tomb and the non-site samples. These queries produced the distribution of scores seen in (FIG. 2). If the site selection process for tombs had been random, the scores for both samples would approach a normal distribution. Instead, the tomb sample lies primarily on the right side of the distribution, while the non-site sample is found mainly on the left. This indicates that the site selection process for the tombs in our sample was not random, but tied to the environmental variables discovered in the stepwise logistic regression.

The mid-point in this distribution can be used as a cut-point for predicting site or non-site dividing the probability scores into two groups. Looking at samples to the right of 0.5, those predicted to be sites, we find that the model



1. Probability maps for sites with Classical period tombs (A) and sites with Byzantine pottery (B) . In these maps, dark colors indicate areas with high probability and light colors areas with low probability.



2. Distribution of probability scores for non-sites and tomb sites.

correctly predicted 76.67% of the site sample. The price it paid for this level of prediction was that it incorrectly predicted 36.4% of the non-site sample to be sites. Again, if they were selecting locations for tombs at random, you would expect these percentages to be similar. The fact that 76.67% of the sites are correctly predicted while just 36.4% of the non-site sample was incorrectly predicted indicates that this model represents a 40.27% improvement over chance. In practical terms, if you were interested in finding more sites with Classical period tombs, this model would allow you to concentrate your search in the relatively small portion of the region with high probability scores, just 36%, with the promise that you will find about 76% of the sites you were interested in. The strength of this model answers our first question. Environmental probability models can be used to discern the environmental signature for sites with Classical period tombs.

A Probability Model for Roman/Byzantine Sites in General

Having answered the first question, attention can now be focused on the second, that is, does the model for Roman/Byzantine tombs reflect an environmental selection process specific to these tombs, or merely the selection process for Roman/Byzantine period sites in general? This is an important question since most sites with Classical period tombs also have non-funerary features from the same period. In order to pursue this question, an environmental probability model was constructed for the 112 sites with either Roman or Byzantine pottery. Using the same non-site sample, a stepwise logistic regression was carried out for these sites, yielding the results in (TABLE 2). The regression coefficients indicate that these sites were located atop east facing slopes, at relatively low elevations, near type 3 soils, and away from type 1 soils.

Following the methodology outlined above, the map in

2 A discussion of the procedures used to create logistic regression models, along with further explanation of the various equations used in this paper can be found in works by Warren and Kvamme (Kvamme 1988 and 1992; Warren 1990)

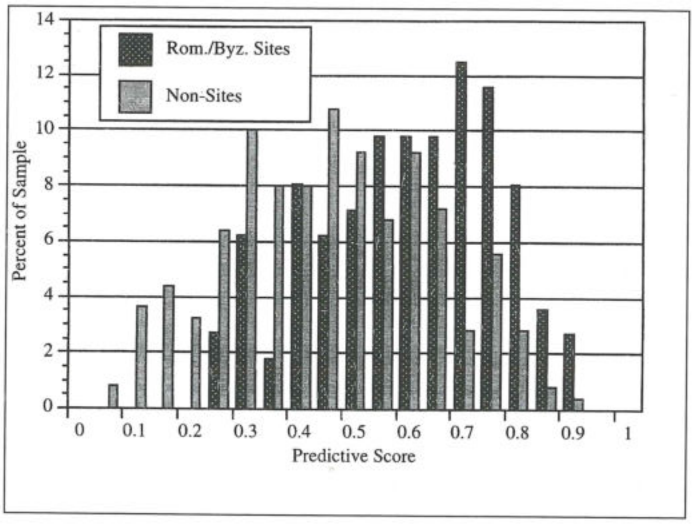
(FIG. 1B) and the histogram in (FIG. 3)were constructed and clear differences between the two models emerged. Most obvious of these differences was that the model for

Table 2. Stepwise logistic regression coefficients for all sites with Rom/Byz Pottery.

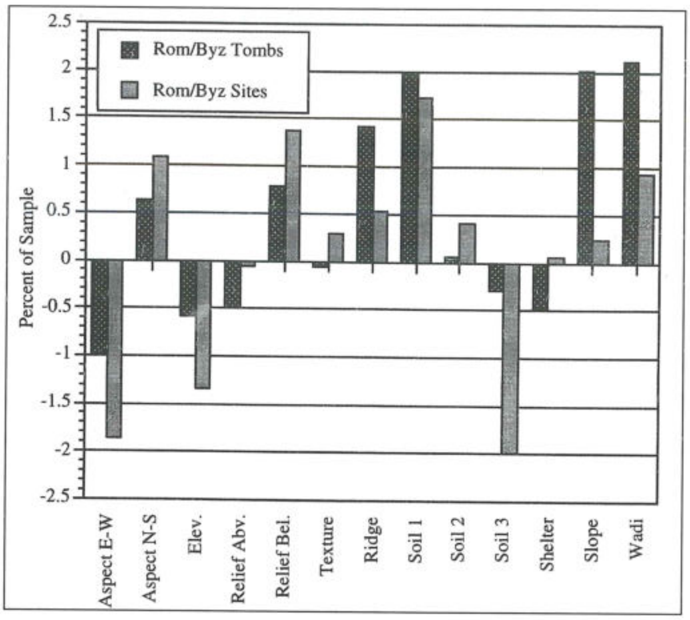
Variable	Coef.	t	P >|t|
Relief Below	0.0718237	4.424	0.000
Distance to Type 3 Soil	-0.0039869	-2.104	0.036
Aspect E-W	-0.0025341	-1.804	0.072
Distance to Type 1 Soil	0.0007943	1.794	0.074
Elevation	-0.0069786	-1.613	0.108
Intercept Constant	5.7457558	X	X

sites with Roman/Byzantine pottery was less efficient. This model correctly predicted only 67.9% of the site sample, while incorrectly predicting 35.6% of the non-sites to be sites, giving it an improvement over chance of 32.3%.

This difference in the efficiency of the two models is indicative of separate agendas used in selecting site locations. In order to highlight these different agendas, an additional logistic regression was performed on both site groupings in which all variables were included. This regression provided a ranking of all variables from most important to least important for both groups. (FIG. 4) is a histogram of the t-scores produced by the regressions. In essence, this graph details the environmental signatures for these two site types, signatures which are characterized more by their differences then their similarities. In all but one instance, variable pairs match in their negative or positive direction, and both models have very similar scores for distance to type 1 soils, but there are striking differences between the two samples for elevation, relief below, distance to soil type 3, distance to wadis, and to a lesser degree for aspect E-W and ridge index. Clearly the



3. Distribution of probability scores for non-sites and Roman/ Byzantine sites.



4. Histogram of environmental signatures for tomb sites and Roman/Byzantine sites. Signature based on t-scores returned by logistic regression.

selection process for sites with Classical period tombs was following a different agenda than that for sites with Classical period pottery.

What these agendas were has proven illusive, but some general conclusions can be drawn based on the relative strengths of the models, and on the variables most important to the two site types. The greater strength of the tomb model indicates that the environmental signature for these sites was more focused. That is, there was a clear idea about where tombs should and should not be located during the Roman/Byzantine period. Sites with Roman/Byzantine pottery, on the other hand, had a less restrictive signature, finding suitable locations in a greater variety of environments. This is not unexpected because the sites with tombs are actually a subset of the larger group of sites with Classical period pottery. Since the larger group includes many different site types, indicative of a full-blown, complex society, its environmental signature will naturally reflect this diversity.

More difficult to understand is why particular environments were preferred over others. There are, however, some inferences that can be drawn from the variables most important to the site samples. The signature for tomb sites makes sense given the funerary function of the sites. Based on the variables most important, it seems that they were locating their tombs in areas which avoided both drainages and the best agricultural land. Type 1 soils are located in the wadi bottoms where problems with water run-off and thick alluvial soils are found. Given these conditions, it is not surprising that tomb locations indicate a preference for areas away from both type one soils and wadi channels. This preference is supported by the ridge index and distance to wadi channels for these sites which also suggests an attempt to keep the tombs out of drainages. Also, by locating tombs on steep slopes they were placing them in the least desirable land agriculturally. Steep slopes require extra effort to farm, since both the construction and maintenance of terraces are labor intensive tasks. Placing tombs on the steeper slopes would not involve this kind of labor intensive work, and, at the same time, would preserve the more gentle terrain for agriculture. Finally, by locating tombs in these areas with this environmental signature, they were placing them in areas of ready-made tomb building material, that is, areas of exposed bedrock. Although it is not certain, it is probable that by the time these tombs were being built, much of the natural vegetation in the region was gone, leaving bedrock exposed as the soil eroded (Christopherson *et al*. 1996). Since the tombs used to create this model were all rock-cut, this ready availability of raw material would surely have been an important consideration to their location.

Sites with Roman/Byzantine pottery are more difficult to characterize. As noted above, this period was one of great economic diversity, a diversity reflected in the lack of a focused environmental signature for these sites. Still, there are a few things that can be said about them. Perhaps most important is their preference for type 3 soils. These soils have the best water and nutrient retention qualities (Christopherson *et al*. 1996) and comprise the best agricultural land in the region. Their preference for locating near these soils, indicates the importance of agriculture in their economy. Their preference for lower elevation and east facing slopes is more problematic. These preferences may reflect a desire to moderate local weather conditions, such as westerly winds or afternoon temperatures, but this is far from certain and it may simply be a social preference for eastern orientation and a desire to avoid climbing the hill every day. Beyond this, it is difficult to say very much about the site selection process for these sites, but what is clear is that the environmental signature for these sites is markedly different from that for sites with Classical period tombs.

Conclusion

This exercise has demonstrated several things concerning archaeology in general and funerary customs specifically, three of which we want to briefly highlight. First, even though tombs are not typically thought of as environmentally dependent, the models discussed here demonstrate that the environment played a significant role in shaping funerary customs in the region of Tall al-'Umayrī. Decisions about tomb location were clearly dependent on environmental factors specific to tombs. Second, geographic information systems provide archaeologists with a new tool for understanding the environment. They provide a level of access to the complexities of environmental interactions that previously were physically impossible. Finally, if even in death the long term structures of the environment were important, as archaeologists we cannot afford to ignore the natural world as we attempt to write archaeological history.

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