Geomagnetic Mapping at Tell es-Sweyhat

The premise of the archaeological use of geomagnetics is that archaeological deposits can be recognized as disruptions of the otherwise uniform magnetic character of most soils. To recognize these disruptions one measures the earth's magnetic field across a given area and creates a map of it.

One can map the magnetic field of a given area just as one would map its physical topography. A topographic map is basically a map of how the ground surface deviates from some standard (often sea level). The topographic map of Tell es-Sweyhat (Zettler Fig. 4), for example, is constructed from a set of measurements of the earth's elevation at a variety of points across the site. The absolute elevation of the bench mark on the top of the mound is used as the standard, in essence making the elevational readings deviations below that standard point. In the same way, the geomagnetic maps of Tell es-Sweyhat are constructed from a set of measurements of the earth's magnetic field intensity, using the magnetic field intensity of a randomly selected base point on the site as a standard.

HOW IT WORKS

The intensity of the earth's magnetic field is relatively uniform, but subtle variations do exist. To use an example from topography, a local playground might appear to be flat, but closer inspection would probably reveal slight variations, for example, a circular depression where a tree once stood, linear depressions from a drainage system, or mounds and slumps caused by moles. The ground varies in ways that betray subsurface activities. The same is true for the earth's magnetic field.

Since all atoms are dipoles having both positively and negatively charged ends, all materials are potentially magnetic. Because the dipoles are randomly oriented in most materials their charges cancel one another out. However, materials that have an atomic structure in which these dipoles can be aligned can become intensely magnetic. Exposure to another magnetic field, called induced magnetism, is the most common way for this to occur. Since the earth itself has a rather strong magnetic field, some materials always have an induced magnetic character. Induced magnetism can become fixed, so that the material will remain magnetic even if the exposure to the external magnetic field is stopped. This is called remnant magnetism and it is present in a variety of metals, such as iron, and can even occur in some organic soils.

Another common way for a material to become magnetic is for the random orientation of its dipoles to be broken down by heat, allowing the dipoles to align themselves parallel to the earth's magnetic field. If the heat stops, the dipoles are "frozen" in position and the material takes on what is called thermoremanent magnetism. Hearth, kiln, and other features exposed to intense heat often have a marked magnetic character because of this effect.

MAPPING TELL ES-SWEYHAT

Tell es-Sweyhat's outer town presented a nearly ideal field situation for geomagnetic mapping. The late 3rd millennium building level is the only occupation level there, so the mapping results would not be confused by the presence of multiple, superimposed building levels. Structures were built on virgin soil, are relatively well-preserved, and are readily accessible below a shallow plow zone.

We anticipated three primary types of archaeological deposits that could be identified and mapped using geomagnetics. We expected limestone footings of walls to be visible since the stone would likely not have the same magnetic character as the soil surrounding it. In addition, we expected hearths and ovens to be clearly visible due to their thermoremanent magnetism. We also hoped that the debris of organic debris in refuse pits, wells, or other subsurface features would create a slightly higher magnetic character than surrounding soils.

In both 1993 and 1995 we used an FM-18 Fluxgate gradiometer to collect the data. (This equipment was loaned by the Department of Archaeological Sciences, University of Bradford, England, an arrangement initiated by Stuart Fleming, Scientific Director of the University of Pennsylvania's Museum Applied Science Center for Archaeology.) A gradiometer consists of two magnetic sensors on a vertical pole separated by approximately a meter. Both sensors measure the earth's magnetic field, and a computer attached to the instrument takes the difference between the two sensor's readings and records it. The logic of this technique is that any magnetic feature in the ground will tend to affect more strongly the sensor closer to the ground than the sensor farther from it. The difference is directly related to the intensity of the magnetic field at that point.

A regular pattern of data collection must be employed in order to produce a useful map. We chose to use square units or "grids." The magnetic character of each grid is represented by 400 evenly spaced readings of the earth's magnetic field. Data were collected for 20-by-20-meter grids with lines and data points at 1-meter intervals; 10-by-10-meter grids with lines and data points at half-meter intervals. Corner points for each grid were established with a theodolite and electronic distance measurer (EDM) to locate them accurately on the site. The grid lines themselves were physically laid out on the ground surface using nylon ropes with one-half-meter markings. To date we have col-
lected over 80,000 data points in nine main blocks (Zetter Fig. 4).

To create images of the subsurface features we had to turn the geomagnetic data into maps. The magnetic intensity was mapped onto the site's coordinates just as elevation would be on a standard topographic map. The final product was a set of contour maps of the earth's magnetic field over particular areas of the site. We used a variety of standard image processing techniques to enhance and highlight subtle variations in the magnetic fields, and to produce the images.

THE 1993 AND 1995 GEOMAGNETIC SURVEYS

Our 1993 pilot program was designed to address three specific issues: (1) the validity of the geomagnetic data for generating maps of archaeological features at Tell es-Sweyhat; (2) the reliability of the instrument and collection method used; and (3) the feasibility of actually mapping the outer town using geomagnetics. We defined validity as whether the geomagnetic data accurately reflected the actual archaeological deposits. To test the accuracy of our maps we excavated two of our mapped grids. Figure 1 shows the archaeological features uncovered in Operation 16 overlaid on the corresponding grid in Block 1. (Figure 2 is a photograph of the area, Figure 3 is the full map of Block 1.) It is clear that the geomagnetic data do accurately reflect the gross features of the archaeological deposits. Specifically, the large magnetic high near the center of the geomagnetic map relates directly to the klin found in the southwest corner of Operation 16, even suggesting its horseshoe shape. The two smaller kilns in Operation 16 are also apparent. More significantly, the walls forming an angle in the northwest section of Operation 16 can be seen as sligher lows on the geomagnetic map, as can the walls branching off from them. The walls alongside and behind the large klin are masked by the klin's strong magnetic signature.

We defined reliability as whether geomagnetic data collected at different times or using different collection strategies presented the same patterns of subsurface deposits. We tested reliability in two ways. First, we collected geomagnetic data at both 1-meter and half-meter intervals in seven separate grids and at different times (we always collected the half-meter interval data first). While there was an increase in resolution with half-meter collection intervals, the major magnetic features in the half-meter interval maps were still obvious in the meter-interval maps.

Second, we repeatedly gathered data over the same area on subsequent days. Figure 4 is a map of geomagnetic data in Block 3 collected over a two-day period, while Figure 5 shows the same area collected on a single day a day later, and by a different crew. The maps are obviously quite similar. Both show the major archaeological feature of interest, the casemate town wall, which appears on the maps as a pair of parallel linear magnetic lows. It is also interesting to us that smaller linear lows branch off from the south of the town wall. We hypothesize that these are the remains of structures built against the wall.

We concluded that geomagnetic mapping of Tell es-Sweyhat was feasible. In only sixteen days of fieldwork (much of it devoted to designing and evaluating different data collection strategies), we were able to map 4 hectares, which because of remapping certain grids to test reliability represents 2.4 hectares (or 7 percent) of the lower town's surface. More importantly, we were able to create useful and informative archaeological maps with the data we collected.

We continued collecting geomagnetic data in our 1995 field season. Our main objective was to map two large areas of the site; we chose this strategy because our pilot program demonstrated that it was much easier to interpret larger areas. In eighteen days of mapping we covered 4.5 hectares and are currently analyzing the data.

SUMMARY

We have now collected magnetic data over a fairly broad area of the site and have enough information to make at least some preliminary judgments about the nature and extent of archaeological resources in the outer town. However, caution is appropriate. Our interpretations have to be taken as tentative until further excavations provide a firmer basis for interpreting the magnetic data.

We hope to complete the geomagnetic mapping in our 1997 field season. Not only will the maps provide important insights in and of themselves, but, equally important, should help us select a representative sample of outer town contexts for excavation in future field seasons.

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32 EXPEDITION Volume 38, No. 1 (1996)