Electrical Resistivity Mapping of Landscape Modifications at the Talgua Site, Olancho, Honduras

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Geophysical reconnaissance in 1995 provided information useful in developing a successful strategy for the 1996 field season in resistivity mapping of subsurface cultural features at Talgua Village, an archaeological site in eastern Honduras. Ground truth excavations confirmed that high-resistivity anomalies detected by modified dipole–dipole apparent resistivity pseudosections correlate with a layer of small cobbles imported to fill low spots of this prehistoric settlement. Resistivity measurements reveal that mounds on this site were erected on normal subsoil, while at least one plaza was originally a topographic low that has been filled. The volume of imported stones is at least 500 m^3, which represents a significant public improvement effort. Similar imported fill under the rest of Talgua Village could be mapped by similar means, and other prehistoric sites of the region could be geophysically tested for similar features. Resistivity profiles provide archaeologists with a quick, inexpensive, accurate, and noninvasive method of determining the extent of landscape modification at Talgua Village. © 1999 John Wiley & Sons, Inc.

INTRODUCTION

The Talgua Archaeological Project was a multiyear (1994–1996) investigation of the pre-Columbian remains found near the town of Catacamas in eastern Honduras (Figure 1). Although the project is best known for its reporting of several Early Formative (1400–800 B.C.) cave ossuaries at the Cueva del Río Talgua (Brady et al., 1995) and the Cueva de las Arañas (Brady et al., 1999), a settlement survey of the Río Talgua drainage was also carried out (Dixon et al., 1999) in 1995. Archaeological excavation was undertaken during both the 1995 and 1996 seasons at the largest surface site, the Talgua Village, located about 3 km south of the caves. This village consists of a clustering of 80–100 mounds, none more than 3 m high, which are laid out around a number of large, essentially level, plazas. Geophysical surveys were conducted in conjunction with the archaeological work at the Talgua Village during both seasons.

Although geophysical methods have been used to investigate archaeological sites for over 50 years (Wynn, 1986), numerous projects do not take advantage of relatively rapid, noninvasive techniques for subsurface imaging and mapping. Those

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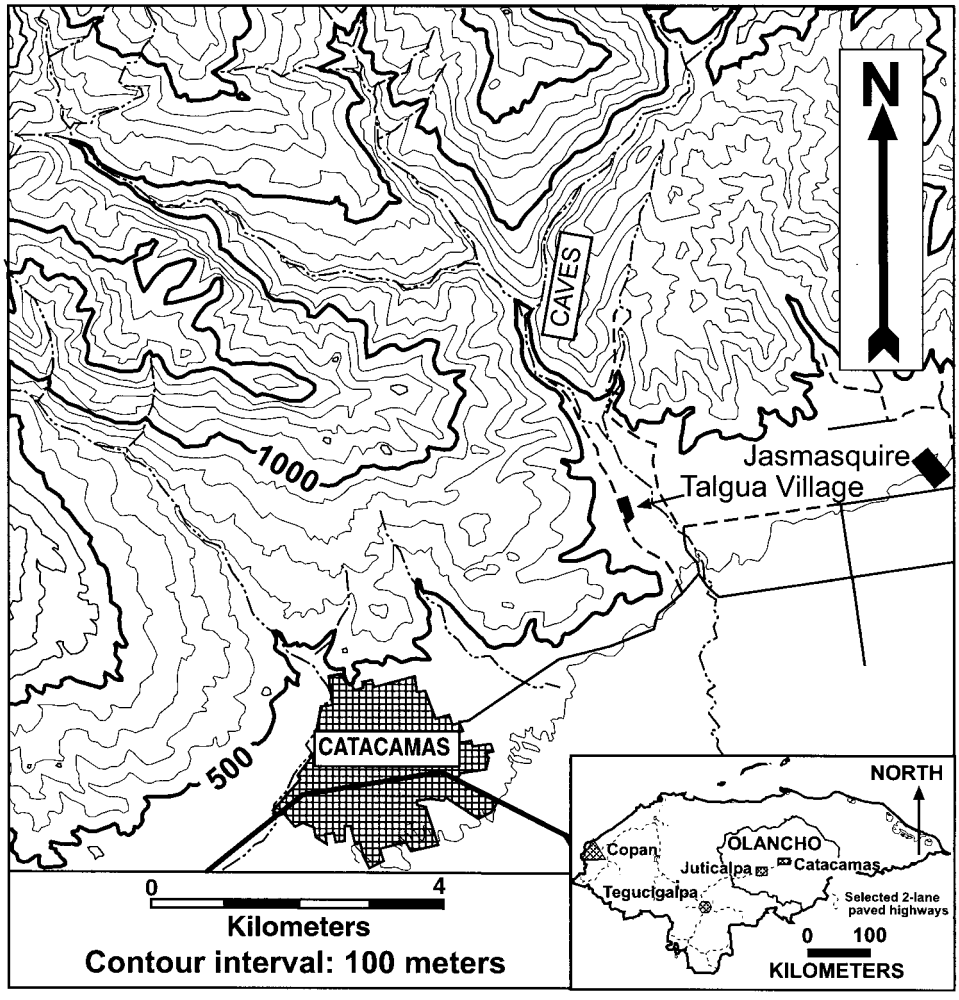

Figure 1. Map of the Catacamas, Honduras area showing locations of Talgua Village and Jasmasquire archaeological sites with respect to ossuary caves. Base map after the 1:50,000 Catacamas sheet, Instituto Geográfico Nacional, Tegucigalpa, D.C., Honduras.

methods most widely used are electrical resistivity, magnetometry, and ground-penetrating radar (Weymouth, 1986), although seismic reflection (Stright, 1986) and microgravity (Lakshmanan and Moutlucon, 1987) have also provided information of interest to archaeologists in some situations. Although the objectives of geophysical surveys are often cultural, mapping subsurface paleogeomorphology can also be useful to archaeologists (Darwin et al., 1990). Selecting an appropriate

method and field strategy is a site-specific decision that depends on the geophysical signatures of both the natural setting and cultural features.

The goal of resistivity mapping at the Talgua Village changed over the life of the project. During the first year, electrical resistivity was employed to check for possible subterranean ossuary crypts that were noted in ethnohistoric documents at the time of the conquest. According to Stone (1957:75), the Spanish doctor, Alonso Criado de Castilla, writing in 1600, stated that, ". . . the soldiers found many houses with vaulted underground compartments where they buried their dead and there the bodies stayed dried and whole with their meals. . . ." A dry void space or stone-lined crypt should produce an electrical resistivity high. Fieldwork in July 1995 provided resistivity signatures useful in planning more productive surveys conducted during June 1996. During the second season, resistivity surveys were more closely integrated into the overall plan of investigation. Surveys by Luke et al. (1997) identified promising excavation locations for archaeologists faced with limited time and resources. This article reports some electrical measurement results at Talgua Village.

METHODS

Electrical Resistivity

Electrical resistivity is based on Ohm's Law

$$R = V/I,$$

where R is electrical resistance in ohms (Ω), V is potential difference in volts, and I is electrical current in amperes. If a homogeneous, isotropic cylinder of length L and cross-sectional area A has an electrical resistance R, the material of which the cylinder is composed has an electrical resistivity ρ defined by

$$\rho = RA/L,$$

where ρ has the units ohm-meters (Ω m).

Most minerals are very resistive to electrical currents. Only clays, graphite, many sulfide or oxide minerals with metallic lusters, and very rare native metals are good electrical conductors (Parasnis, 1975:165). However, water held in pores (spaces between mineral grains) of many kinds of rocks and soils is often an excellent conductor, particularly water high in dissolved solids (Archie, 1942). Dry soils and sediments are thus more electrically resistive than water-saturated ground.

Archaeological sites may hold tombs or other large voids concealed below the surface. Sometimes these openings are lined with hard, well-cemented rock. If these voids are above the water table with void spaces filled largely with air, they are highly resistive, as are low-porosity rocks appropriate for lining tombs or tunnels. Soils surrounding such voids often hold sufficient capillary water to exhibit moderate electrical resistivities, higher than the resistivity of water-saturated soil

but less than the resistivities of solid, low-porosity rock. Large stones placed over a burial should also generate resistivity highs.

Reconnaissance—1995

A modified Soiltest R-40 resistivity system was used. This device, powered by a 6-V rechargeable battery, transmits up to 60 mA at 120 V as a 57-Hz square wave. Modifications include the use of digital multimeters, rather than the internal bridge, to measure current and voltage, and the replacement of the small internal power cell with a larger external battery. Steel grounding rods, cut to 15-cm lengths and sharpened on one end, were used as electrodes. The R-40 is compact (20 × 27 × 36 cm), weighs only a few kilograms, and can provide days of service between battery charges. Although considered obsolete, this modified R-40 proved a good choice for the field conditions encountered at Talgua Village.

The Lee configuration (Figure 2[a]) was selected for the initial measurements because of its ability to isolate lateral resistivity changes. Apparent resistivity (ρ_a) is given for the Lee array as

$$\rho_a = 4\pi aR$$

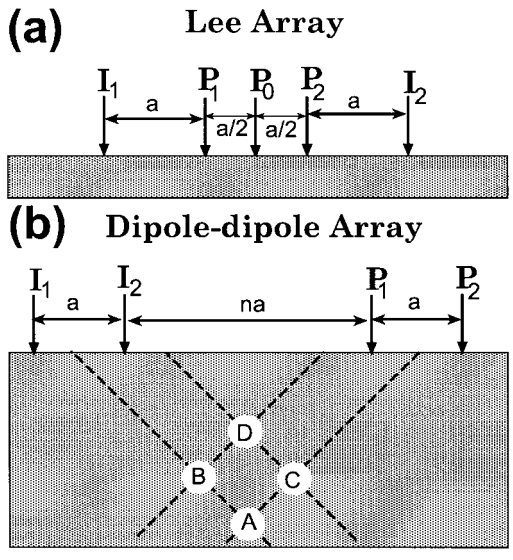

Figure 2. (a) Configuration of the Lee electrical resistivity array. Electrical current is transmitted via electrodes I_1 and I_2, and voltage changes measured between P_1 and P_0 as well as between P_0 and P_2. Indices a and a/2 are distances separating electrodes. (b) Configuration of the dipole–dipole electrical resistivity array. Current is transmitted into the earth via electrodes I and the resulting potential difference measured between electrodes P. Each dipole is of dimension a. Dipoles are collinear and separated by distance na, where n is an integer.

(Parasnis, 1975), where a is the separation of electrodes as shown in Figure 2(a), I the current flowing through electrodes I_1 and I_2, and V the potential difference between P_0 and either of the adjacent potential electrodes. ρ_a is calculated for each potential difference (V_0-V_1) and (V_0-V_2) and the ratio of adjacent apparent resistivities is calculated and plotted as a function of the P_0 location.

Although the "a"-spacing of 2 m was selected to provide maximum sensitivity at depths of 0.5–1.5 m (see Figure 15 of Edwards [1977]), profile data at a constant spacing cannot discriminate between lateral changes in material properties and changes in the relative thickness of different materials. Depth variations can be investigated by taking soundings, in which electrode ("a") spacing is increased in successive logarithmic intervals (Zohdy et al., 1974:13). The greater the separation of electrodes, the deeper the interrogation of the earth.

One advantage of the dipole-dipole array (Figure 2[b]) is that results displayed on a *pseudosection* generate a cross-sectional image of the subsurface that shows both vertical and lateral variations in apparent resistivity. In the traditional pseudosection, each data value is plotted midway between the current and potential array, at a point where lines drawn at a 45° angles from the center of each dipole intersect (point A on Figure 2[b]). If each potential electrode in Figure 2(b) were located one "a" spacing nearer the current dipole, apparent resistivity would be plotted at point B. If the current dipole were moved instead, apparent resistivity would be plotted at point C. A pseudosection showing lateral and vertical variations in apparent resistivity is generated by advancing dipoles along a profile, measuring I and V and various n-spacings for each position of the I_1, I_2 dipole. This pseudosection can be quickly interpreted in a qualitative sense, with the relative locations of resistivity highs and lows easily discerned. Apparent resistivity for this configuration is

$$\rho_a = \pi an(n + 1)(n + 2)\, V/I,$$

and Edwards (1977) concludes that effective depth of 0.96a requires n = 3. For large n and a values, large currents (I) are needed in order to induce a measurable voltage V, a disadvantage of the dipole–dipole array. The traditional dipole–dipole pseudosection (Figure 2[b]) exaggerates depths to contacts between different materials, but actual depths can be better estimated if values are plotted at "effective depths" consistent with Edwards' (1977) modified pseudosection (see Figure 9 of Stierman [1984]). Calculations based on 1995 results showed that lateral and vertical variations in electrical resistivity within the upper 2 m could be investigated using the R-40 in the dipole–dipole configuration with "a"-spacings of 1.00 m, despite the R-40's maximum output of only 60 mA.

RESULTS

Lee Array—1995

Figure 3 shows the location of the first resistivity profile attempted at the Talgua Village. The origin (0 point) was selected 2.25 m north of the site datum. This

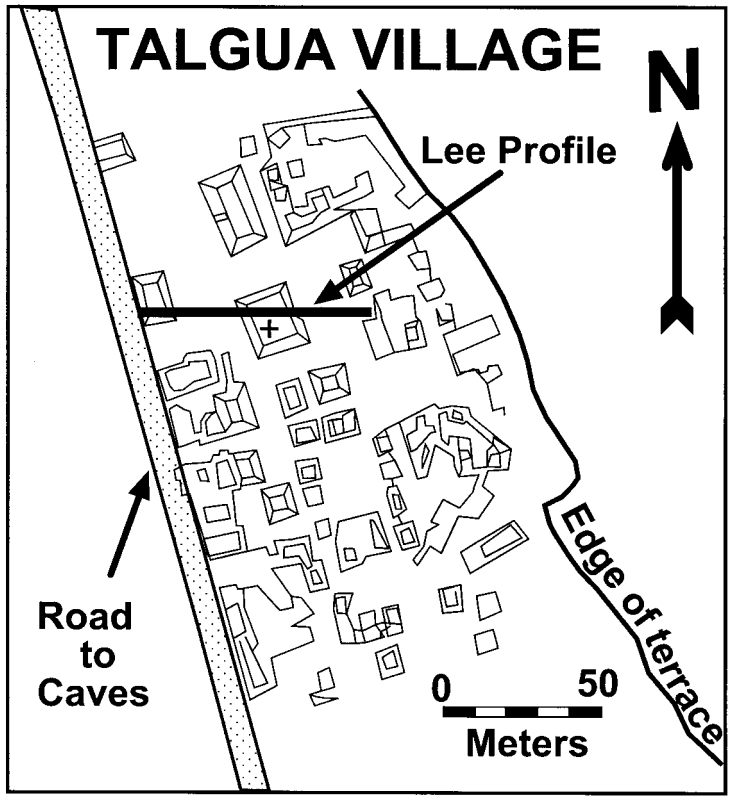

Figure 3. Location of electrical resistivity profile, Lee array, July 1995, in Talgua Village. Base map after Hasemann et al. (1994).

location was selected to investigate shallow variations over two mounds and across two plazas as part of one continuous profile, while avoiding trees and other inconvenient features. A fiberglass surveyor's tape was stretched to the west and electrodes placed at even numbered meter marks. The center (P_0) electrode was placed at odd numbered meter marks, and readings were made. The line was extended to the east from the origin, with sufficient overlap to provide continuous coverage (Figure 4). Figure 4 shows ρ_a along profile. It is clear that the plaza to the west of the central (site datum) mound is underlain by materials that differ from those under the plaza to the east.

Soundings—1995

Soundings east and west of the 22 m point, selected because of variations (Figure 4) with no visible cause, show differences that are modest but significant (Figure

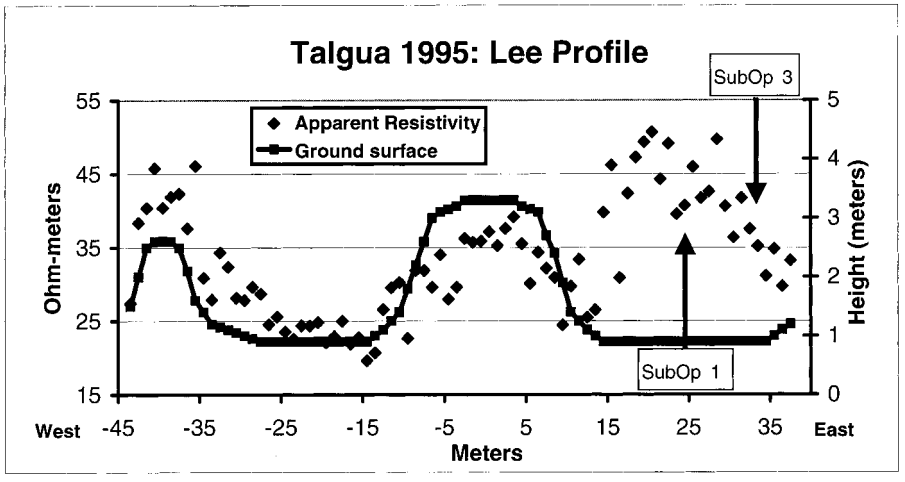

Figure 4. Apparent resistivity as a function of location along the Lee array resistivity profile. "a"-spacing = 2.00 m. Half of the signal is due to materials lying between 0.5 and 1.5 m below the surface (Edwards, 1977). Topography (ground surface) greatly exaggerated. Locations of excavations (SubOp 1 and SubOp 3; Begley, 1996) later dug directly under this profile are shown.

5). Both soundings exhibit patterns consistent with a resistive layer lying between a shallow conductor and a deeper conductor, with the "west" sounding showing more resistance than the "east," consistent with Figure 4. Sounding curves were interpreted by comparing ρ_a with hypothetical curves generated using modeling program based on Zohdy and Campbell (1981) and results displayed in Table I. Curve matching (Telford et al., 1993:539–554; Van Nostrand and Cook, 1966:86–110), in which ρ_a is calculated as a function of electrode separation for a horizontally layered earth where soil or rock resistivity (ρ_r) changes with depth, has largely replaced graphical techniques (Barnes, 1952) for interpreting resistivity soundings (Zohdy et al., 1974).

The difference in layer 1 ρ_r (30 vs. 27 Ω m) is not important. Resistivities of shallow soils frequently exhibit differences due to minor variations in compaction and water content. There exist unavoidable ambiguities in matching earth models to sounding observations. In this case, increasing the thickness of layer 2 while decreasing its ρ_r (or vice versa) generates curves that fit the data as well as those shown in Figure 5. The "east" sounding was fit with a layer thickness values set consistent with excavation SubOp 1 (Table I) at that location (Begley, 1996) and ρ_r values for each layer varied until a satisfactory fit was obtained. Neither the same thickness nor the same ρ_r for layer 2 can be used to fit "west" sounding data. This is not a case of trade-off ambiguity between ρ_r and thickness. Layer 2 west of the 22 m point is both thicker and of higher resistivity than layer 2 to the east (Table I). Layer 3 consists of identical (18 Ω m) material for both soundings. Most variations along the Lee profile (Figure 4) are probably due to lateral variations in ρ_r and thickness of layer 2 in plazas and to high-ρ_r material used to construct mounds.

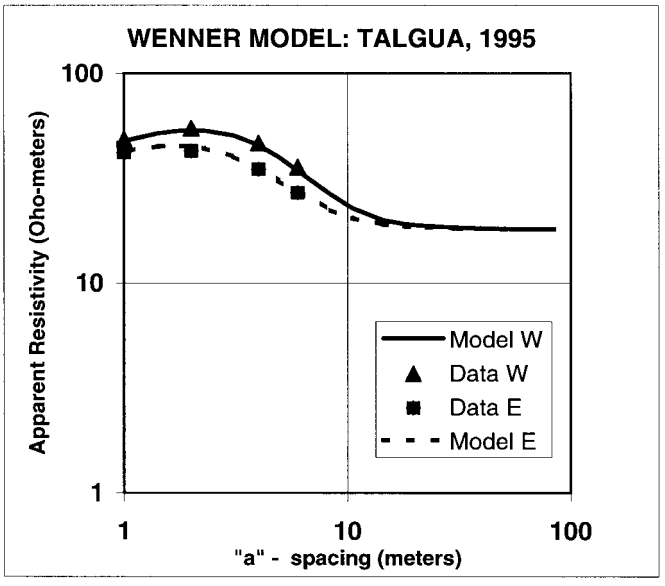

Figure 5. Wenner sounding curves (note logarithmic axes) for measurements (solid symbols) east and west of the 22 m east point (Figure 4). Lines show values calculated for horizontal layered models specified in Table I.

Dipole–Dipole Profiles—1996

Excavations at locations identified by Luke et al. (1997) were under way in 1996 before these dipole–dipole measurements could begin. Calculations based on 1995 results suggested that a-spacings of 1.00 m could be separated by n = 6 to n = 7 intervals, sufficient to probe to depths of 2 m, using the R-40 system. Fiberglass surveyor's tapes were laid out and steel electrodes set at 1.00 m intervals beginning at the "0" end until all electrodes were used. Current was transmitted by the (0,1) dipole and voltages measured first at (2,3), then at larger n values, until the voltage could no longer be read with confidence. Dipole (1,2) then became the current

Table I. Layered models used to calculate "model" resistivity sounding curves shown in Figure 5.

	Interpretation, Resisitivity Soundings				Excavation Log: SubOp 1	
	West of 22 m East		East of 22 m East		23–25 m East	
Layer	ρ_r: Ω m	Thickness (m)	ρ_r: Ω m	Thickness (m)		Thickness (m)
1	30	0.3	27	0.3	Black soil	0.3
2	65	2.5	54	2.0	Pebbles	2.0
3	18	>7	18	>7	Laterite	>0.7

W and E refer to data and model west and east of the 22 m east location respectively. Excavation log from Begley (1996).

dipole and the voltmeter moved from dipole to dipole, decreasing n values until reaching n = 1. The current dipole then advanced and the process repeated. Readings were recorded in a field book and later entered into a spreadsheet, which calculated ρ_a and appropriate coordinates for plotting values. Results were then contoured using Surfer™ desktop software. Modified pseudosections for profiles 1–4 (Figure 6) are displayed in Figures 7 and 8.

Profile 1 (Figure 7[a]) crossed a strong magnetic anomaly (Stierman, 1996) located near 30 m north. The small ρ_a high plotted 0.45 m deep at this location may be the ρ_a signature of the fire pit later excavated (Begley, 1996). This fire pit, about 1 m in diameter and filled with cracked rock, did not generate a significant ρ_a

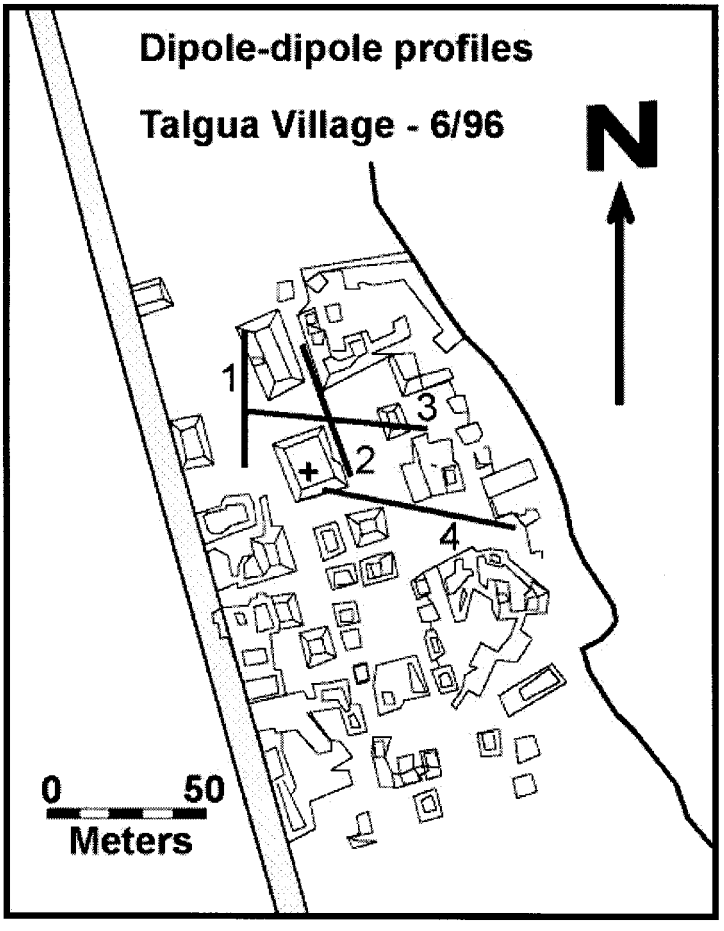

Figure 6. Map showing location of four dipole-dipole profiles, June 1996, Talgua Village. Base map after Hasemann et al. (1994).

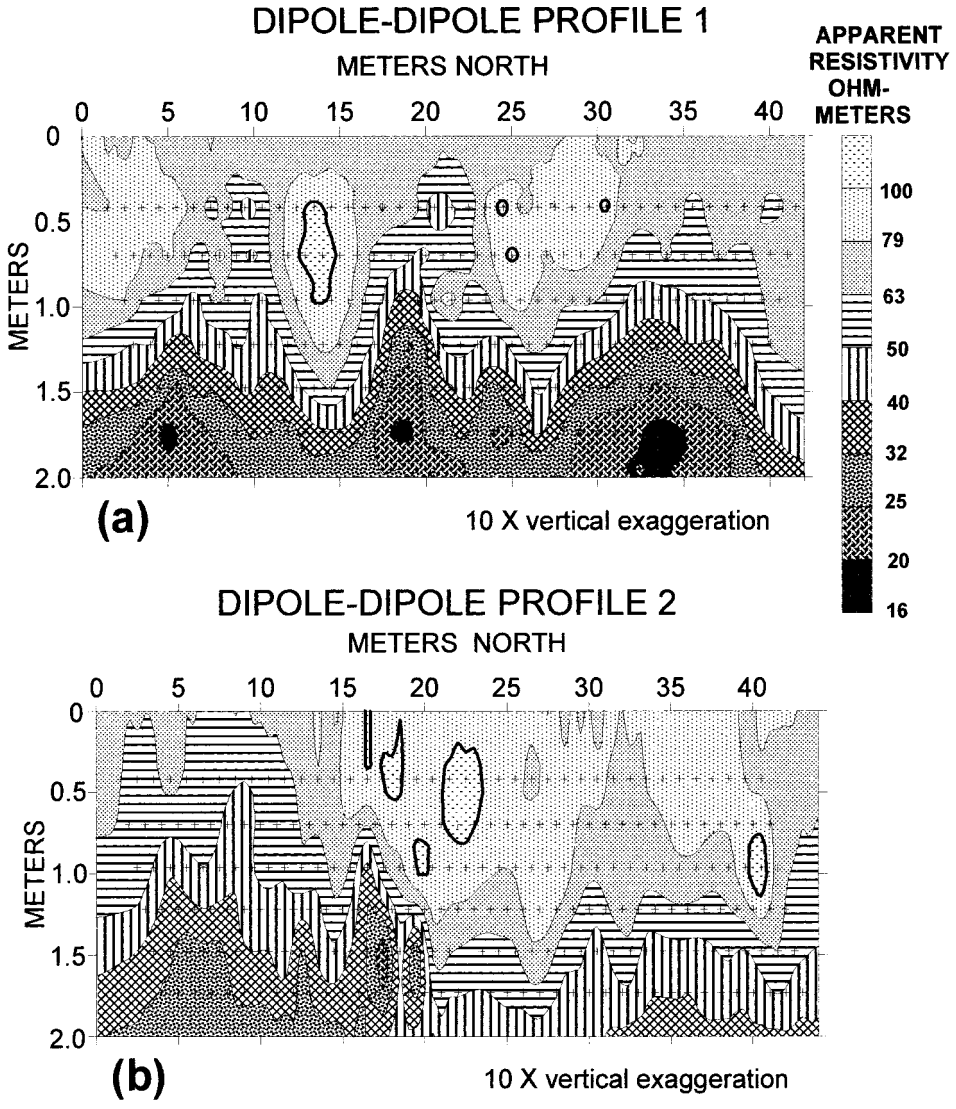

Figure 7. Modified (after Edwards, 1977) dipole–dipole pseudosections, Profiles 1 (a) and 2 (b): (+) data points used to generate contours. Note: Contour intervals are logarithmic. These profiles cross essentially level ground.

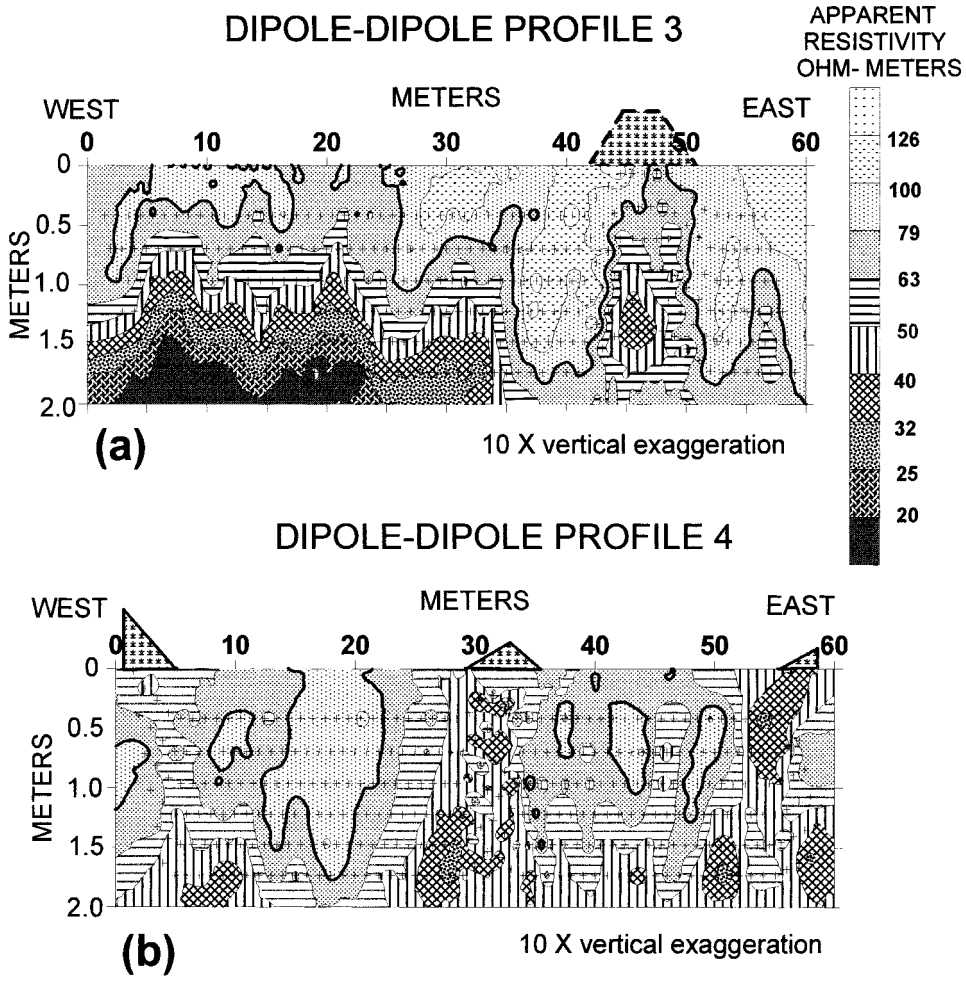

Figure 8. Modified (after Edwards, 1977) dipole–dipole pseudosections, Profiles 3 (a) and 4 (b): (+) data points used to generate contours. Contour intervals are logarithmic. Topography shown is greatly (10×) exaggerated.

anomaly. A soil boring into a ρ_a low at 20 m north encountered brown clay, and a fine sand was collected from a boring into a ρ_a high at 14 m, in contrast to dark brown-red laterite found under about 0.2 m of dark topsoil by most other soil borings along profile 1. The 18 Ω m material (layer 3) of Table I is probably this same laterite, the geological base of Talgua Village. Sand collected at 14 m looked uniform and well sorted, so that this resistivity high appears due to sandy clay-free sediment filling a drainage channel eroded into low-ρ_r laterite. The low ρ_r of the laterite is probably due to conductive clays.

Table II. Summary interpretation of apparent resistivity patterns, dipole–dipole profiles 3 and 4 (Figures 8[a] and [b]).

Distance Interval (m)	Geophysical Signature (Ω m)	Interpretation
Profile 3		
0–26	<50 below 1.2 m	Normal soil over laterite
26–36	<50 below 1.6 m	Depth to laterite increasing
36–43	>63 above 1.7 m	High resistivity material replaces normal soil and laterite
43–51	<50 below 1.2 m	Nearly normal
51–55	>63 above 1.7 m	More high resistivity material
55–59	complex	Interesting, need to extend profile
Profile 4		
0–7	<50 below 1.6 m	Nearly normal, edge effect due to slope break at base of mound
8–23	>63 above 1.7 m	High resistivity material replaces normal soil and laterite
23–36	<50 below 1.2 m	Normal soil over laterite
36–50	Complex, high over low resistivities	High resistivity material shallow, laterite present but deeper than normal
50–60	Complex, low over moderate resistivities	Laterite or clay near surface, laterite present below 1.5 m

The ρ_a high between 15 and 24 m along profile 2 (Figure 7[b]) correlates in part with a canopy previously erected to provide shade for field school lectures and shelter during brief episodes of rain. This anomaly is, however, much wider than that shelter, so that it cannot be due entirely to compaction and protection from rain. The ρ_a high between 15 and 24 m may be the same drainage channel identified in profile 1. The small ρ_a high just north of 40 m is interesting, the sort of pattern (isolated ρ_a high) expected for a stone-lined burial.

Profile 3 (Figure 8[a]) exhibits values consistent with "stream bed" ρ_a, profiles 1 and 2, for the first 25 m. Then, an abrupt change occurs. Between 35 and 43 m east along profile 3, low ρ_a characteristic of laterite are not present to an effective depth of almost 2 m. A high ρ_a zone about 10-m wide and 2-m deep lies just east of a shallower (only 1-m deep) 10-m wide zone of high ρ_a. Table II summarizes variations along profile 3 and profile 4 (Figure 8[b]).

DISCUSSION

Excavations in the plaza east of the site datum and between profiles 3 and 4 in June 1996 revealed a layer of small cobbles, 2-m thick, overlying brick-red laterite (Figure 9). This cobble layer exhibits no sorting, nor imbrication, nor any other pattern suggesting a natural depositional environment, in either unit where it was exposed. Occasional sherds were mixed with these cobbles and a probable hearth found under them (Begley, 1996). Complete lack of sedimentary structures, to-

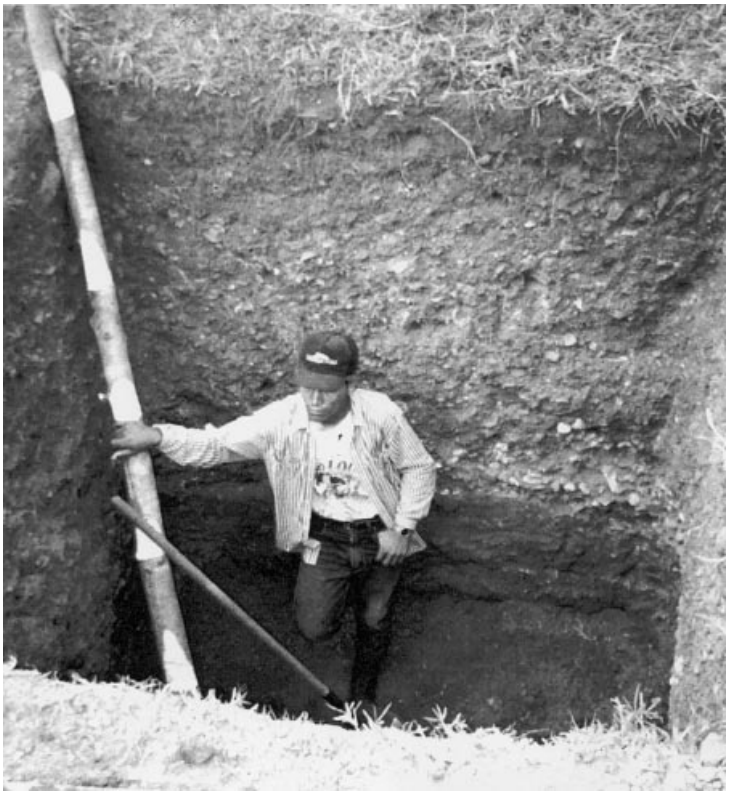

Figure 9. Photo showing cobble fill overlying laterite in Begley's (1996) SubOp 3. Contact between fill and laterite is near left elbow of worker standing in the pit.

gether with their stratigraphic position with respect to cultural material, support the interpretation that these stones were imported to the site (Brady et al., 1999). These cobbles are rounded and were no doubt once transported by a stream. Most cobbles are red indurated siltstone, identified as Valle de Angeles Formation rocks mapped by Gordon (1990) northeast of Talgua Village.

ρ_a lows between 43 and 50 m on profile 3 (Figure 8[a]), and between 25 and 35 m on profile 4 (Figure 8[b]), occur either as the profile crosses low mounds (Figure 8[a]) or just off the end of a series of mounds (Figure 8[b]). The final 8 m of profile 4, characterized by low ρ_a, correlate with another set of low mounds. It appears that most, if not all, of the mounds rest on shallow, low-ρ lateritic soils, and that the fill is restricted to some of the plazas between mounds.

The cobbles were probably imported and used by ancient inhabitants of Talgua Village to fill in the low spots of their settlement. This fill might have functioned as a "french drain," a structure used by civil engineers as fill material that permits

fluids to drain. Testing the hypothesis that the filled areas could have served as drains will require extensive subsurface mapping. These stones are small enough to form a surface easy to walk on, but are irregular in shape, leaving many passages through which water can flow.

Figure 10 summarizes the interpretation of combined excavation and resistivity observations with respect to this imported fill. Both the central (site datum) mound and large mound to its north were raised on a relatively level original lateritic surface just west of a topographic low. Mounds were also raised on the other side of this low spot, which was at some point filled in with up to 2 m of stones. If imported stone fill extends from excavations in which it was identified to dipole profiles 3 and 4 and westward to the point where it was detected under Lee profile 1, an area of at least 50 m^2 of Talgua Village is underlain by this fill (Figure 10). If the fill averages 1 m in thickness, we arrive at a volume equal to 500 m^3, the capacity of 50 large dump trucks. This conservative estimate represents a minimum amount of total fill present at Talgua Village, and evidence of an enormous community public effort (Brady et al., 1999).

The finding of large scale filling and leveling at the Talgua site was clearly one of the project's most significant discoveries. Estimates of sociocultural complexity and political centrality are generally strongly influenced by surface mound size since these represent visible public works. The small size of the Talgua Village mounds appeared to be consistent with the assumption that northeastern Honduras

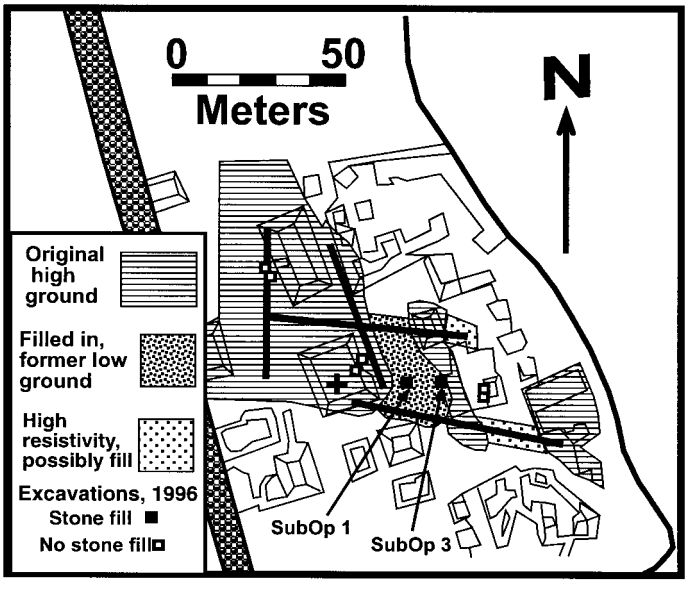

Figure 10. Map showing areas of Talgua Village underlain by artificial fill and areas where fill (other than mounds) is known to be absent. Excavation locations from Begley (1996).

was marginal to the Mesoamerican cultural developments to the west. The documentation of this large-scale landscape modification clearly calls for a thoughtful reevaluation of this assumption.

The discovery of this platform filling in a limited number of test pits raised a common archaeological dilemma of how one estimates the extent and scale, and therefore the significance, of such earthworks. Test pitting provides a very limited number of data points and trenching is prohibitively expensive, time-consuming, and destructive for the limited amount of information provided. While much of the Talgua Village subsurface remains unexplored, the fact that the stone fill can be detected by relatively rapid, noninvasive geophysical methods means that the rest of this site, as well as other archaeological sites identified nearby, can be tested for similar features with minimal effort. Geophysical exploration becomes increasingly efficient and interpretation of anomalies improved once the geophysical signatures of the various subsurface structures present are identified. At Talgua Village, geological and archaeological evidence that this fill was imported, combined with identification of a geophysical signature of this fill, allows us to confidently interpolate the distribution of imported fill into areas not excavated.

CONCLUSIONS

Electrical resistivity measurements established that lateral variations in physical properties existed at depths of 0.5–2 m under the Talgua Village site, a pre-Columbian settlement in eastern Honduras. Dipole–dipole profiles show variations in depth to low-resistivity lateritic subsoils. High ρ_a material up to 2-m thick proved to be a bed of small cobbles, imported to the site to fill in low areas between mounds raised on existing natural high ground. Now that excavations have revealed the structure responsible for high ρ_a signatures, these noninvasive techniques can be used to rapidly map these structures elsewhere in Talgua Village and to test other sites in the area for similar features.

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