Geophysical Surveys in the Jebel Hamrat Fidan, Jordan

Alan J. Witten,[1] Thomas E. Levy,[2] Russell B. Adams,[3]
I.J. Won[4]

[1]*School of Geology and Geophysics, The University of Oklahoma, 810 Energy Center, Norman, Oklahoma 73019*
[2]*Department of Anthropology, University of California at San Diego, 9500 Gilman Drive, La Jolla, California 92093-0532*
[3]*Department of Archaeology, University of Bristol, 43 Woodland Road, Bristol, BS8 1UU, United Kingdom*
[4]*Geophex, Ltd., 605 Mercury Street, Raleigh, North Carolina 27603-2343*

The Jebel (Jebel is mountain in Arabic) Hamrat Fidan marks the "gateway" to the Feinan district of southern Jordan—one of the largest sources of copper during the prehistoric and Early Bronze Ages in the eastern Mediterranean. Preliminary excavations and surveys at sites along the Wadi Fidan have revealed a long history of settled occupation extending from the Pre-Pottery Neolithic (ca. 6,500 B.C.) to early medieval times. Because of this long history of occupation, and the fact that this area was a regional center for the production of copper, the study of this area is important for understanding early metallurgy, craft specialization, and social evolution. During the summer of 1997, geophysical investigations at a series of Neolithic and Bronze Age sites identified specific areas within Wadi Fidan for future intensive excavations. Three geophysical techniques (electromagnetic induction, ground-penetrating radar, and magnetometry) were used to help locate buried architectural and industrial features remaining from early mining and metallurgical operations, including copper ore bodies or voids. Geophysics was not used at the actual mining sites because of scheduling constraints; however, geophysics did delineate buried stone walls at three distinct Wadi Fidan sites. Magnetometry and ground penetrating radar provided little useful information. Buried stone walls were apparently "masked" by numerous magnetic stones on the ground surface making magnetometry useless. Reflections from known strata demonstrated that radar penetrated the ground adequately; however, known shallowly buried walls were not recognizable. Electromagnetic induction produced maps of linear and rectilinear features that suggested spatial distribution of widespread buried stone walls suitable for future excavation. A significant and unexpected finding was that electromagnetic induction proved capable of delineating buried stone walls. © 2000 John Wiley & Sons, Inc.

INTRODUCTION

Ancient zones of natural resource development, such as the production of elemental metal from ore, are important to the understanding of cultural evolution.

Geoarchaeology: An International Journal, Vol. 15, No. 2, 135–150 (2000)

These zones provided raw materials over thousands of years to ancient civilizations and were inhabited and exploited during these periods making these unique areas windows into the processes of long-term culture change (Levy, 1998). The remains of construction activities and artifacts found in these areas reflect the social, economic, and religious dimensions of their inhabitants. More importantly, perhaps, these zones provided resources of regional significance, and, for this reason, their study provides insight into cultures that existed within a radius of hundreds of kilometers around the resource zone.

The Feinan district of southern Jordan, located in the biblical region of Edom, contains one of the largest sources of copper ore in the Middle East (Hauptmann, 1989, 1990; Hauptmann et al., 1989, 1992). Preliminary archaeological studies indicate that copper from this district was exploited from the Pre-Pottery Neolithic period (about 6,800 years B.C.) through the early Islamic period (about 1,000 years A.D.), one of the longest periods of ancient resource exploitation and development. Consequently, the Jebel Hamrat Fidan and Feinan regions are excellent areas for the study of the impact of craft specialization on social evolution. During the summer of 1997, geophysical studies were performed in one part of the Jebel Hamrat Fidan, along the main drainage system in the area known as the Wadi Fidan. Wadi Fidan is a mountainous, rugged, and desolate area. Several earlier surveys (cf. Adams, 1991; Glueck, 1935; Hauptmann, 1989; MacDonald, 1990) and small-scale archaeological excavations in the Wadi Fidan (Adams, 1991, 1997, 1998) revealed that this area supported copper exploitation and production from the Pre-Pottery Neolithic, reaching an industrial scale during the later Early Bronze Age and continuing after an interval during the Middle and Late Bronze Ages, with renewed ore exploitation during the Iron Age and later.

The use of geophysics at Wadi Fidan was part of a larger scale geophysical effort dedicated to providing archaeologists, anthropologists, and archaeometallurgists with a better understanding of the spatial distribution of both copper resources and the settlements that supported the exploitation of this resource. Specifically, features of geophysical significance included both buried copper ore bodies and underground voids left behind by the mining of these ore bodies, as well as buried stone walls that remain from the villages and production facilities that supported the copper mining and smelting operations.

Three geophysical methods were employed as part of the Wadi Fidan 1997 field study: electromagnetic induction (EMI), ground penetrating radar (GPR), and magnetometry. EMI has been used for many years in the exploration for ore bodies (ore bodies contain metal and, therefore, are good electrical conductors), and, more recently, to detect voids. It was, therefore, used in this study to attempt to locate both ore bodies and voids left behind by the mining of copper ore. Other geophysical methods were tested for use in locating buried stone walls. Scheduling conflicts prevented the application of geophysics at sites suspected of being the source copper ore; however, all geophysical methods were employed at sites where buried stone walls had recently been exposed by excavation.

THE WADI FIDAN SITES

Before the Jebel Hamrat Fidan (JHF) Regional Archaeology Project was established, no systematic archaeological survey had been carried out in the region. The goal of the 1997 JHF archaeological survey was to begin a systematic sampling of the main settlement area of the JHF, namely, the Wadi Fidan drainage system. While five major sites spanning the Neolithic through Iron Age were previously recorded and investigated, their place in local settlement hierarchies and settlement strategies was unknown. To remedy this situation, a 5 km stretch of Wadi Fidan was selected for investigation. The study area extends from the edge of the Wadi Arabah, where the Wadi Fidan debouches, upstream to Ain el-Fidan, a spring at the eastern end of the drainage. A corridor of 500 m on each bank of the wadi was set as the limits of the 1997 survey.

Figure 1 shows a number of archaeological sites in the region. Three of these sites, Wadi Fidan A, Wadi Fidan 4, and Khirbet Hamra Ifdan, were selected for the 1997 geophysical studies. Each of these is a hill-top site and, at each site, earlier small-scale excavations exposed shallowly buried stone walls.

Archaeological Survey and Sites Selected for Geophysical Survey

The Wadi Fidan A site is Pre-Pottery Neolithic (PPN) and lies at the mouth of Wadi Fidan and at the extreme western end of the Feinan drainage system, where it empties into the broad plain of the Wadi Arabah. Additional PPN sites have been discovered and excavated further up-stream along Wadi Ghwair (Simmons and al-Najjar, 1996). Wadi Fidan A sits on a plug of monzogranite that is part of the basement rock in the area (Rabba, 1994). Previous excavations at the site (Adams, 1991; Richardson, 1997) revealed extremely well preserved stone wall architecture, with many of the walls still standing to just under 2 m high (Figure 2). The stone-built architecture is typical of the late Pre-Pottery Neolithic, and excavation of the primary structure revealed a well-preserved plaster floor, evidence of red painted plaster walls, and a stone-built oven set against one wall.

Wadi Fidan 4 lies on the southern bank of Wadi Fidan on a rocky plateau situated approximately 25 m above the wadi channel. The plateau is a remnant of Precambrian monozogranite with a thin veneer of Pleistocene sediment consisting of poorly sorted sand- to boulder-size limestone, sandstone, and igneous clasts. This landform is roughly triangular and has an area of about 8,700 sq. m. Surrounded on the west, north, and east by Wadi Fidan, the plateau resembles a pennisula. A narrow ridge connects the plateau to the adjacent slopes of the Jebel Hamrat Fidan making a natural fortification. The site is covered with archaeological material dating to the beginning of the Early Bronze Age.

The last site to be sampled using geophysical survey methods was Khirbet Hamra Ifdan (KHI), also an Early Bronze Age site. KHI is located at the eastern end of the Wadi Fidan gorge, just to the west of the 'Ain el-Fidan spring (Figure 1). Much like Wadi Fidan 4, the site is associated with a Pleistocene diamicton that unconform-

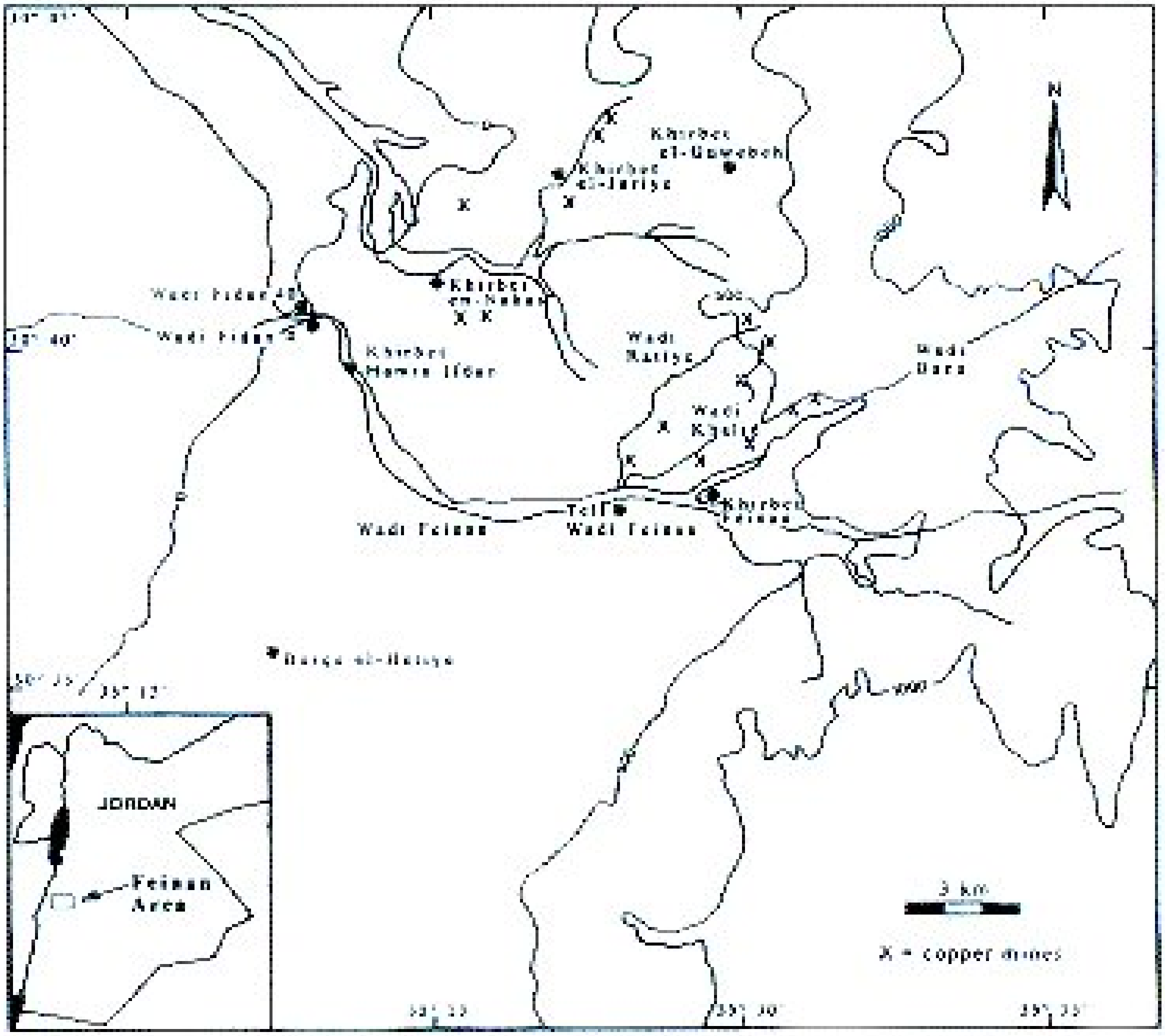

Figure 1. Map of Jebel Hamrat Fidan Regional Archaeology Project, Jordan.

ably overlies Precambrian monzogranite. At KHI, the bedrock forms a small plateau that stands about 25 m above the channel of Wadi Fidan. KHI is totally isolated in the middle of the wadi, making it a naturally defensible site, which no doubt played a role in its local dominance of metallurgy in antiquity. Large quantities of slag, ores, copper artifacts, copper working installations, and casting molds have been found at the site.

GEOPHYSICAL STUDIES

Geophysical studies were performed at each of the three Wadi Fidan sites. The objective of these studies was to delineate buried stone walls to guide archaeological excavations. At two of these sites, Wadi Fidan A and KHI, the buried stone had been identified in earlier and very limited pilot excavations; however, the extent of

Figure 2. Ground truth test at Wadi Fidan A. Electromagnetic induction detected the extension of these PPNB walls. Here, the south wall of the principal structure exposed in a 1993 excavation can be seen. The wall is preserved to a height of about 3 m.

the buried construction at either of these sites was unknown. The Wadi Fidan 4 site was under active excavation at the time of the geophysical studies, and a number of 5 sq. m units had been opened. All of the units revealed stone walls approximately 40–50 cm high, 50 cm wide, and up to 8 m long built on the underlying granite bedrock.

Three geophysical methods (magnetometry, GPR, and EMI) were employed at each site. Magnetometry responds to magnetic sources that are either permanently magnetized or, as result of ferromagnetic materials, are created by the earth's magnetic field. The magnetic data were acquired by walking with the magnetometer along straight parallel lines 1 m apart and at fixed intervals in time. If the walking rate is relatively constant, the measurements are uniformly distributed over the length of each parallel line. The Geometrics 858 cesium vapor magnetometer stores the magnetic data for subsequent downloading to a personal computer. The data can then be displayed as a two-dimensional (horizontal) map of anomalous magnetic data. For isolated magnetic inclusions, such as buried stone walls, the regions of anomalous magnetic values should appear on the map almost directly above these buried features. The pattern of magnetic anomaly should be a pattern of magnetic disturbance, possibly randomly oriented dipoles, that replicate the pattern of the walls.

Buried stone walls can be detected in magnetic data in one of two ways. Either because the walls are composed of rocks that are magnetic in origin (permanently magnetized) such as basalt or because the rocks are nonmagnetic but occur in an iron-rich soil that has been undisturbed long enough that the host soil contains some remnant magnetism induced by long-term exposure to the earth's magnetic field (Parasnis, 1986), the buried walls appear as linear or rectilinear spatial patterns in the magnetic data. Since induced magnetization is, in general, much weaker than permanent magnetization, detecting nonmagnetic walls is less likely; however, nonmagnetic walls were mapped with magnetometry at Titrus Höyük (Matney and Algaze, 1995), an Early Bronze Age city in Turkey.

Magnetometry failed, however, to detect any features appearing characteristic of buried walls, and, in fact, at all three sites the magnetic data revealed a dense but random pattern of magnetic anomalies. All three sites had many stones strewn about the ground surface. Magnetic measurements made on a number of the surface stones revealed that some were magnetic while others were nonmagnetic. Since it can be expected that the stones in the buried walls have a similar distribution of magnetic and nonmagnetic rocks, the acquired magnetic data would have a random distribution of magnetic anomalies from both surface and subsurface stones.

The GPR instrument used was the Mala RAMAC system with 400 MHz center-frequency antennas. At each of the Wadi Fidan sites, GPR data were acquired along parallel lines 2 m apart. The GPR system acquired a 154 ns time window at every 5 cm along each line. For a subsurface feature to be detected, either the dielectric constant or electrical conductivity must differ between the feature and its surroundings. The radar data revealed the presence of the underlying granite bedrock, and, because the radio waves did not penetrate this strata, it was established that this layer has a relatively high electrical conductivity. A few isolated features were detected by radar (Figure 3) but did not appear in any pattern that would suggest buried walls. This failure may be due to the very small dielectric constant or electrical conductivity differences between the buried walls and their surroundings. The surface rocks could exacerbate this problem. The GPR antennas must be extremely close to the ground surface to ensure that the wave energy penetrates the ground. Because the antennas were elevated slightly above the ground surface to clear the surface rocks, it is possible that the wave energy penetrating the ground was reduced to the point where potentially weak reflectors, such as the buried walls, could not be detected.

The EMI tool employed at Wadi Fidan is the GEM-2 developed by Geophex, Ltd. (Won et al., 1996). The GEM-2 operates much like the magnetometer described above. Data from the GEM-2 were acquired at fixed time intervals over each of a series of parallel lines spaced 1 m apart with data acquired along each line. The GEM-2 can acquire data over multiple frequencies, and the output is a volume-averaged response to changes in electrical conductivity. This response volume is frequency-dependent or, more precisely, skin-depth-dependent, where the skin depth is inversely proportional to the square root of the product of the operating

Figure 3. Radar cross-section showing isolated reflectors (the hyperbolas) and the bedrock layer at a depth of about 1 m.

frequency and the background conductivity. Consequently, as the frequency is decreased, the skin depth and response volume increase. For this reason, higher operating frequencies provide a finer horizontal resolution for shallower features. At all Wadi Fidan sites, two frequencies were used: 2,430 Hz and 9,210 Hz. With the exception of a single wall at Wadi Fidan 4, no features suggesting buried walls appeared in the low frequency EMI data. For this reason, EMI results presented here are for the higher (9,210 Hz) operating frequency.

Figure 4 is a map displaying GEM-2 data acquired at Wadi Fidan A as gray scales. In this figure, the highest measured values are rendered in white, the lowest in black, and intermediate values in shades of gray. While no features suggesting buried stone walls are evident in this figure, a closer inspection reveals a subtle pattern of linear and rectilinear features in the lowest (black and dark gray) measured values. To support this interpretation, the Wadi Fidan A survey region adjoins an earlier excavation where partially exposed walls (Figure 2) appear to extend into the undisturbed surveyed region.

To enhance the appearance of the low conductivity features in the EMI data, the data shown in Figure 4 are redisplayed in Figure 5 with a gray-scale mapping that emphasizes the lowest measured EMI values. In this figure, the lowest measured values are rendered as black and shades of gray with all other values rendered as white. With this mapping, the linear and rectilinear features become clearer. The features that are believed to be buried walls are interpreted as white lines superimposed on the data displayed in this figure. The exposed stone wall mentioned above is indicated on this figure. Figures 6 and 7 are EMI data, displayed with the same gray-scale mapping used in Figure 5, for the Wadi Fidan 4 and KHI sites, respectively. Like the Wadi Fidan A site, these other two sites show the buried stone walls to be extensive.

Figure 8 is a gray-scale plot of the EMI data acquired at the KHI site similar to that shown in Figure 4. However, in this figure, a full range plotting contrast is used to illustrate the bimodal character of the EMI measurements. As seen in Figure 8, the measured EMI values appear as either relative highs (the areas rendered in white and light gray) or relative lows (the areas rendered in black and dark gray). The displayed values are relative to the spatially averaged value, providing two possible explanations for this bimodal distribution. The first possibility is that the relative highs simply represent the background geology and appear artificially high because the spatial average is forced to be zero. A second explanation is that areas that appear as a high conductivity are, in fact, a result of a buried material with high conductivity. If this is the case, the areas with relatively high conductivity displayed in white in Figure 8 may be an indication of the presence and distribution of buried copper slag.

DISCUSSION OF EMI RESULTS

Buried walls may appear as lows in the EMI data because of contrasts in electrical conductivity attributable to conductivity differences between the stone walls

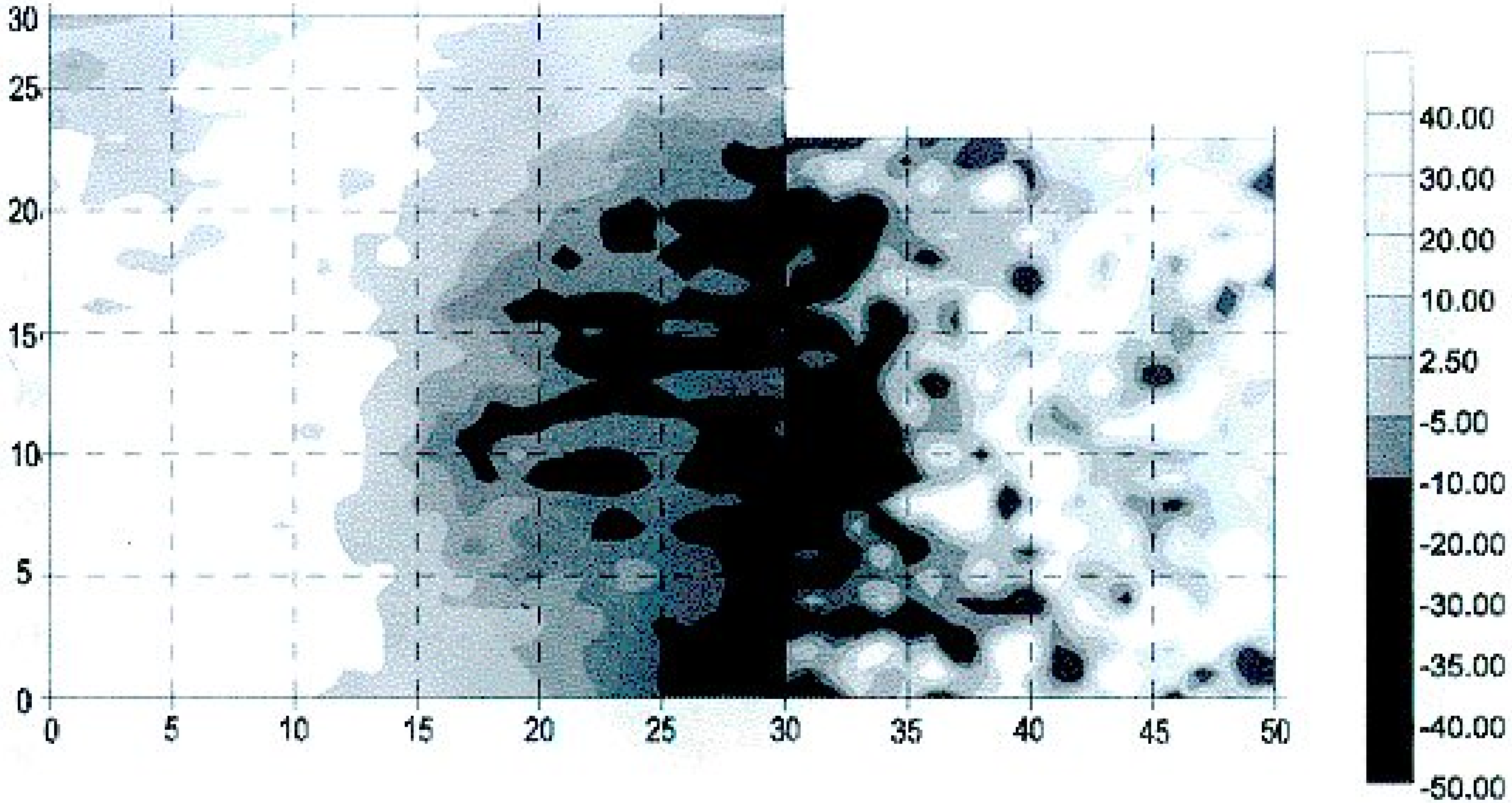

Figure 4. EMI data acquired at the Wadi Fidan A site rendered as gray scales. All dimensions are in meters.

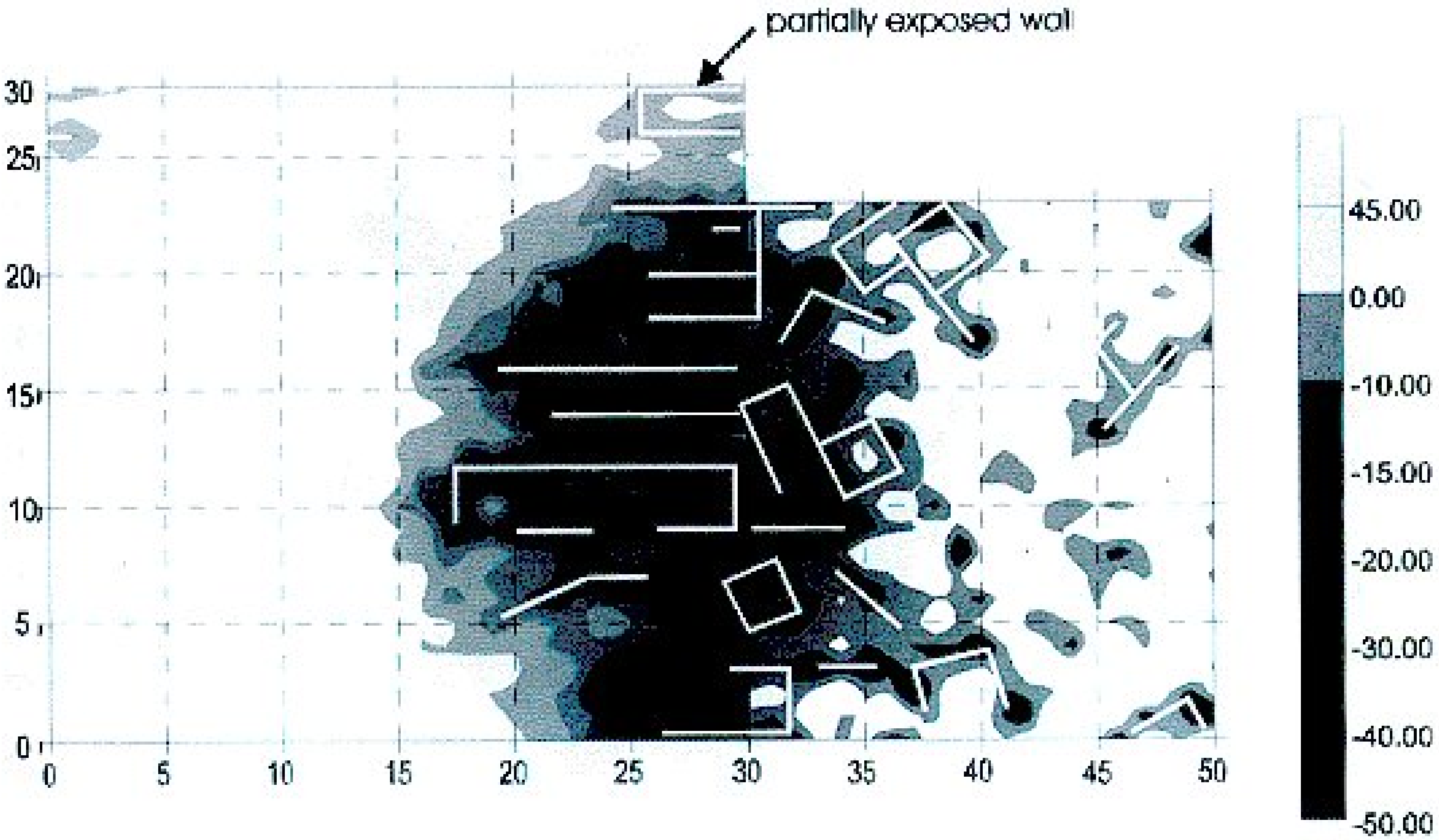

Figure 5. EMI data acquired at the Wadi Fidan A site rendered as gray scales. The lowest conductivity features are black, and interpretations are superimposed as white lines. All dimensions are in meters.

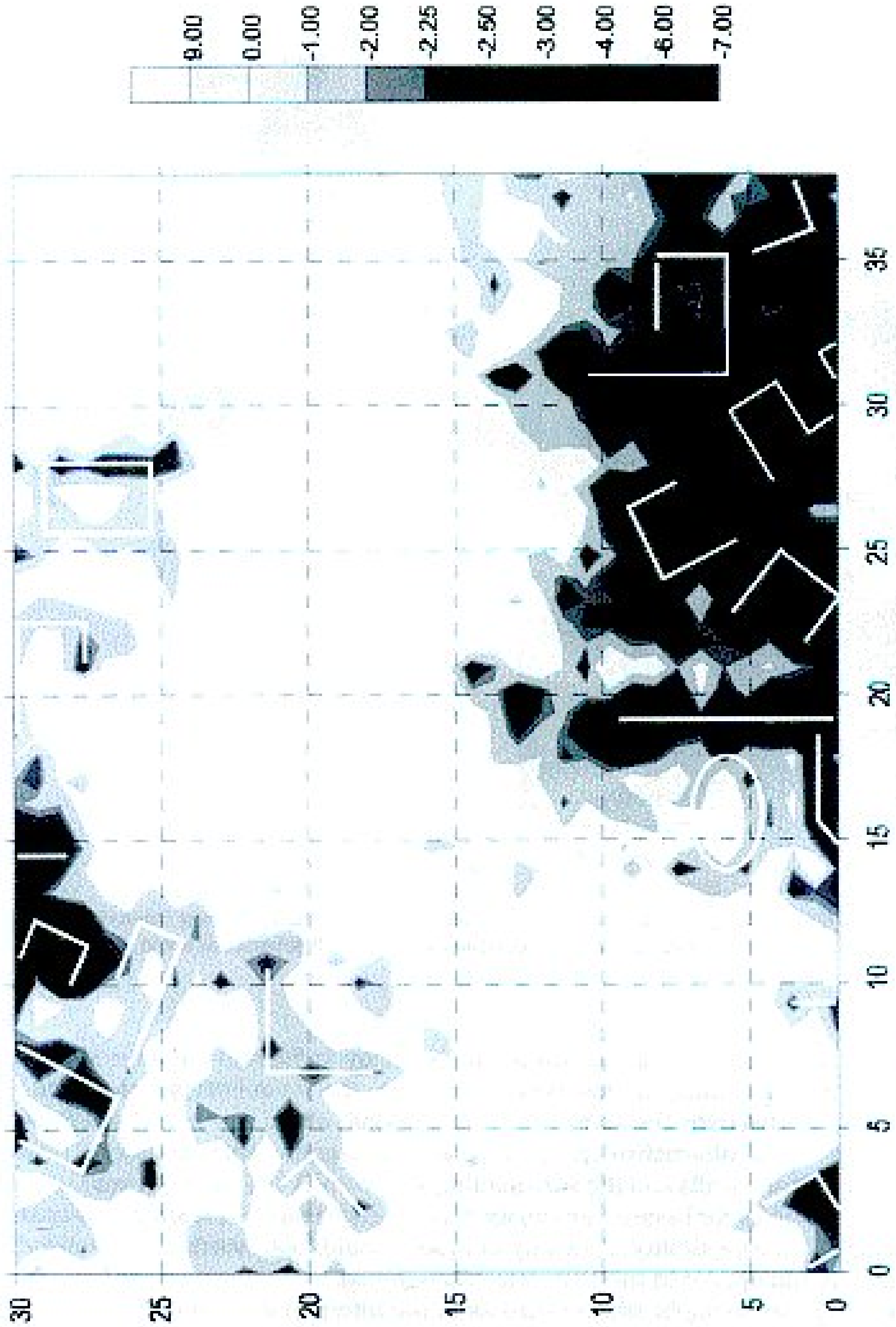

Figure 6. EMI data acquired at the Wadi Fidan 4 site rendered as gray scales. The lowest conductivity features are black and interpretations are superimposed as white lines. All dimensions are in meters.

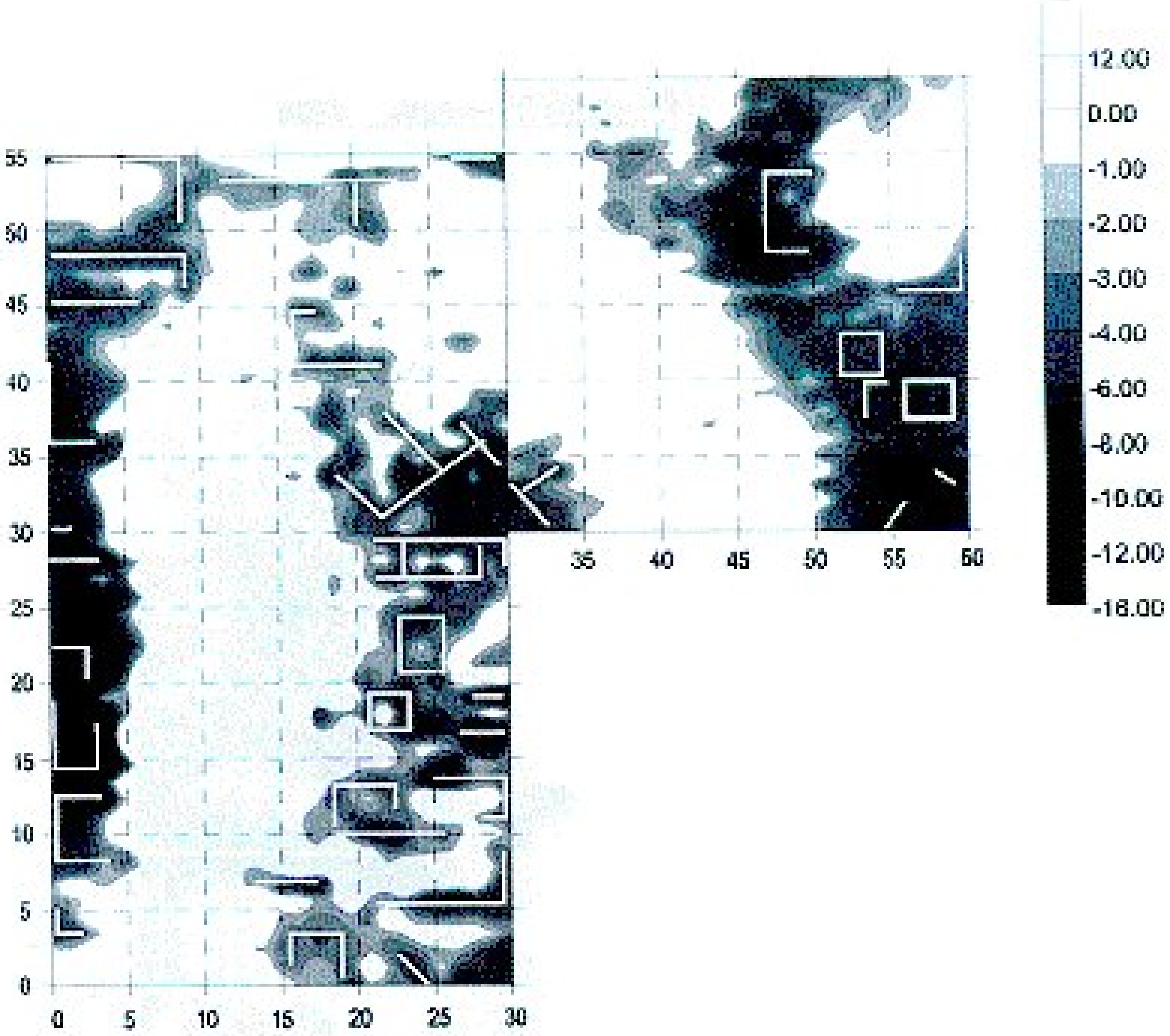

Figure 7. EMI data acquired at the KHI site rendered as gray scales. The lowest conductivity features are black, and interpretations are superimposed as white lines. All dimensions are in meters.

and the host soil. If the stones within the walls are indigenous, and the stones and the soil have the same origins, both would have the same intrinsic electrical conductivity. In this case, the contrast must be a result of the absence of soil moisture in the stone. An alternative explanation is that magnetic susceptibility differs between the stone walls and the surrounding soil. Won et al.'s (1998) results showed, however, at least for large conductivity, that spectral response is altered by changes in magnetic susceptibility. If this hypothesis is valid, both surface and subsurface stones should appear in the EMI data. They do not.

Although some doubt still remains as to the interpretation of the EMI data, fea-

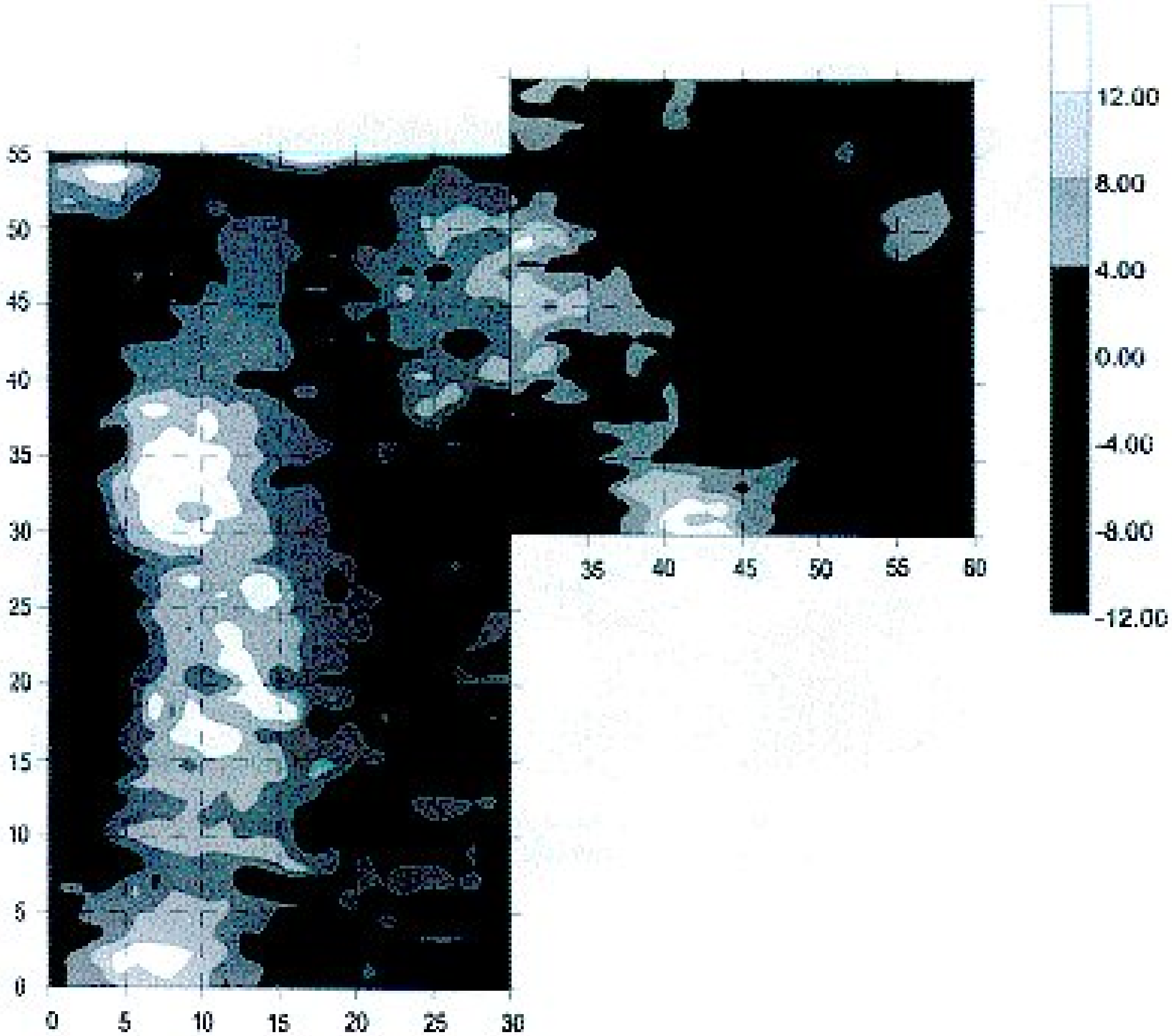

Figure 8. EMI data acquired at the KHI site rendered as gray-scales. The mapping was selected to emphasize areas of relative high conductivity (white) and low conductivity (black). All dimensions are in meters.

tures with such linear and rectilinear patterns are not, in general, typical of naturally occurring geologic structure. Furthermore, when we went to the places where these features occurred and inspected them, we found that several of them broke the ground surface and were visible. These features had not been previously identified because they were difficult to distinguish from randomly positioned surface stones. Subtle surface manifestation of a buried stone wall appears in the foreground of the photograph shown in Figure 9.

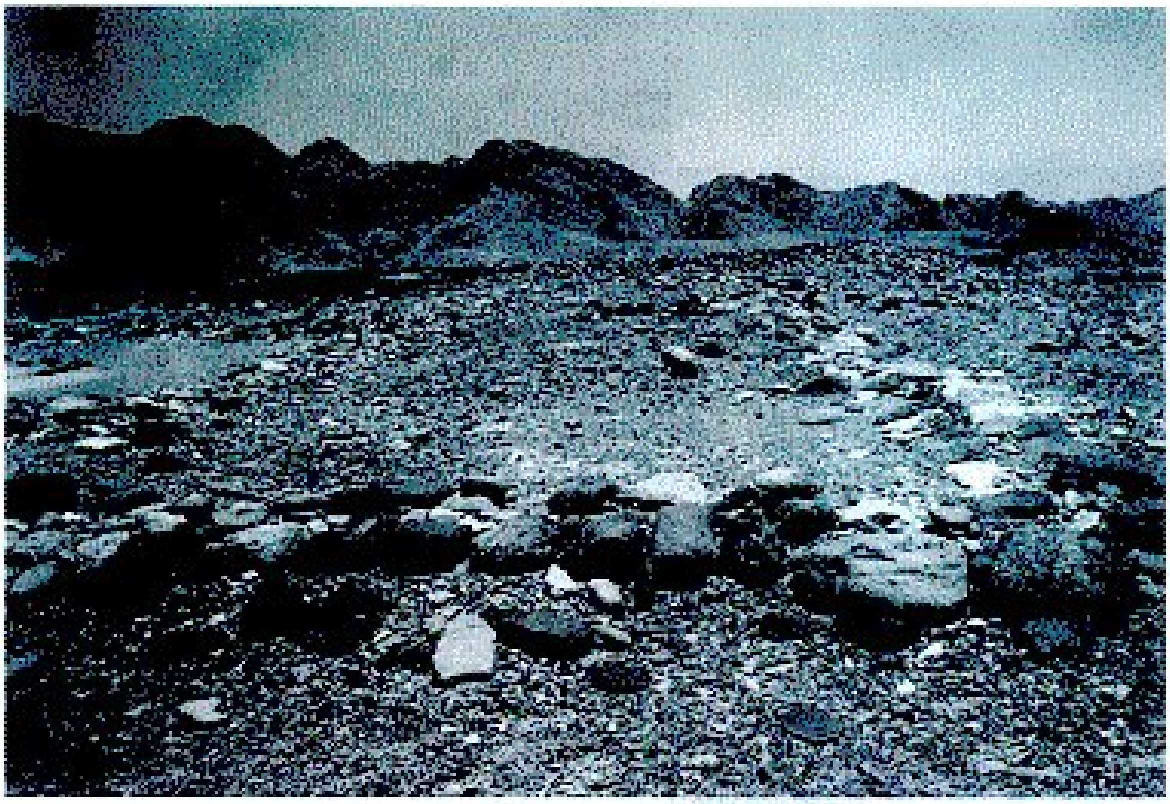

Figure 9. Photograph of an area of the Wadi Fidan 4 site showing numerous stones on the ground surface. Note the protruding stone wall in the foreground.

CONCLUSIONS

Electromagnetic induction correctly mapped the extensions of known walls at Wadi Fidan A. In addition, excavation confirmed the walls detected by EMI at Wadi Fidan 4.

Further geophysical studies are planned both at the Wadi Fidan sites as well as at other sites within the region. At the Wadi Fidan sites, the effort will focus on the use of GPR and EMI to locate and delineate copper ore deposits and voids remaining from early mining operations.

The additional regional sites remain to be identified, and, in the absence of information on the nature of the targets of interest, their depth, and local geology, specific geophysical techniques cannot be identified. The fact that magnetometry and GPR yielded little information at Wadi Fidan does not make them useless at other sites in southwestern Jordan. Since the relevant contrast between targets of interest and the local geology may be different, and because both of these methods are relatively simple and rapid to use, they should be considered at other sites within the region. As a result of the unexpected success of EMI at Wadi Fidan, its uses at other archaeological sites is quite certain.

We are grateful to Dr. Ghazi Bisheh, Director General, Jordan Department of Antiquities for his help and support in initiating the Jebel Hamrat Fidan project. Thanks also to Dr. Mohammad Najjar for many useful discussions concerning the Faynan district. We also thank Khalil Hamdan, Jordan Department of Antiquities, and Aladdin Mahdi for their logistical support in the field. We are indebted to Drs. Pierre and Patricia of the American Center of Oriental Research in Amman for their help in making this project possible. Thanks also to Alison McQuitty and the British Institute at Amman for Archaeology and History for logistical support. Much financial support for this research came from the C. Paul Johnson Family Charitable Foundation (Chicago) and the Geophex Foundation (Raleigh, North Carolina), The British Institute at Amman for Archaeology and History, The Palestine Exploration Fund, and the U.C.S.D. Judaic Studies and Summer Session Program. Additional support came from the Nelson Glueck School of Biblical Archaeology, HUC-JIR. Finally, we would like to thank the Bedouin villagers of Greig'gra for their hospitality and help in making this work possible.

REFERENCES

Adams, R.B. (1991). The Wadi Fidan Project, Jordan 1989. Levant, XXIII, 181–183.

Adams, R.B. (1997). On early copper metallurgy in the Levant: A response to claims of Neolithic metallurgy. In H.G.K. Gebel, Z. Kafafi, &G.O. Rollefson (Eds.), The prehistory of Jordan II. Perspectives from 1997. Studies in early Near Eastern production, subsistence and environment (pp. 651–656). Berlin: Ex Oriente.

Adams, R.B. (1998). The development of copper metallurgy during the Early Bronze Age of the Southern Levant: Evidence from the Feinan region, southern Jordan. Doctoral dissertation, University of Sheffield, United Kingdom (unpublished).

Glueck, N. (1935). Explorations in Eastern Palestine, II. The Annual of the American Schools of Oriental Research 15 (1934–1935), New Haven, Connecticut: American Schools of Oriental Research.

Hauptmann, A. (1989). The earliest periods of copper metallurgy in Feinan, Jordan. In A. Hauptmann, E. Pernicka, & G.A. Wagner (Eds.), Old World archaeometallurgy (pp. 119–135), Der Anschnitt Beiheft 7, Bochum: Deutsches Bergbau Museum.

Hauptmann, A. (1996). Chalcolithic copper smelting: New evidence from excavations at Feinan. In S. Demirci, A.M. Ozer, & G.D. Summers (Eds.), Archaeometry 94: The Proceedings of the 29th International Symposium on Archaeometry (pp. 3–10). Ankara: Tubitak.

Hauptmann, A., Weisgerber, G., & Bachmann, H.G. (1989). Ancient copper production in the area of Feinan, Khirbet en-Nahas, and Wadi el-Jariye, Wadi Arabah, Jordan. In S.J. Fleming & H.R. Schenck (Eds.), History of technology: The role of metals (pp. 7–16), Philadelphia: The University Museum, University of Pennsylvania.

Hauptmann, A., Begemann, F., Pernicka, E., & Schmitt-Strecker, S. (1992). Early copper produced at Feinan, Wadi Arabah, Jordan: The composition of the ores and copper. Archaeomaterials, 6, 1–33.

Levy, T.E. (1998). Cult, metallurgy and rank societies—Chalcolithic Period (ca. 4500–3500 B.C.E.). In T.E. Levy (Ed.), The archaeology of society in the Holy Land, 2nd ed. (pp. 226–244), London: Leicester University Press.

MacDonald, B. (Ed.) (1992). The Southern Ghors and Northeast Arabah archaeological survey, Sheffield Archaeological Monographs 5, Sheffield: J.R. Collis Publications.

Matney, T., & Algaze, G. (1995). Urban development at Mid-Late Early Bronze Age Titris Hoyuk in southeastern Anatolia, Bulletin of the American Schools of Oriental Research, 299–300, 33–52.

Parasnis, D.S. (1986). Principles of applied geophysics, London: Chapman and Hall.

Rabba, I. (1994). The Geology of the Al Qurayqira (Jebel Hamrat Fidan) Map Sheet No. 3051 II, Geological Mapping Division Bulletin 28, Amman: The Hashemite Kingdom of Jordan Natural Resources Authority.

Richardson, J.E. (1997). An analysis of the faunal assemblages from two Pre-Pottery Neolithic sites in the Wadi Fidan, Jordan. In H.G.K. Gebel, Z. Kafafi, & G.O. Rollefson (Eds.), The prehistory of Jordan II. Perspectives from 1997. Studies in early Near Eastern production, subsistence and environment (pp. 497–510), Berlin: Ex Oriente.

Simmons, A., & al-Najjar, M. (1996). Test excavatons at Ghwair I, a Neolithic settlement in the Wadi Feinan, ACOR Newsletter, 8.2, 7–8.
Won, I.J., Keiswetter, D.A., Fields, G.R.A., & Sutton, L.C. (1996). A new multifrequency electromagnetic sensor. Journal of Environmental and Engineering Geophysics, 1, 129–137.
Won, I.J., Keiswetter, D.A., & Novikova, E. (1998). Electromagnetic induction spectroscopy. Journal of Environmental and Engineering Geophysics, 3, 27–40.

Received January 3, 1999
Accepted for publication October 17, 1999