ARCHAEOLOGICAL RECONNAISSANCE OF UNINVESTIGATED REMAINS OF AGRICULTURE (AROURA): THIRD AND FINAL SUMMARY REPORT, 2012

Michael F. Lane, University of Maryland Baltimore County (*UMBC*), *Timothy J. Horsley* (*Brandeis / Yale University*), *and Alexandra Charami, 9th Ephorate of Prehistoric and Classical Antiquities* (*IX EPCA*), *with contributions from Allison E. Cuneo, Boston University, and Weston S. Bittner, UMBC*

Introduction

Between 1 October 2012 and 11 November 2012, Archaeological Reconnaissance of Uninvestigated Remains of Agriculture (AROURA) carried out its final six-week archaeological field campaign in the ancient polder around the Late Helladic IIIB fortress of Glas (Γλας) in the northeastern Kopaic Basin, Viotía Prefecture, mainland Greece. AROURA involved extensive geophysical prospection and surface survey within the polder and at the adjacent site of Aghía Marína Pýrghos (Αγία Μαρίνα Πύργος) on three campaigns between October 2010 and November 2012 (see http://www.umbc.edu/aroura). It was directed, in official collaboration (συνεργασία), by Dr. M.F. Lane on the part of participating American institutions and, in succession, by Prof. V.L. Aravantinos and Dr. A. Charami on the part of the IX EPCA of the Hellenic Ministry of Culture and Tourism, with Dr. A. Papadaki designated the project Collaborator (Συνεργάτιδα). Dr. T.J. Horsley of Brandeis University and Yale University was the Principal Geophysical Investigator, assisted by Ms. A.E. Cuneo of Boston University. Mr. W.S. Bittner of UMBC and KCI Technologies was the Geographic Information Systems (GIS) Specialist and project photographer.

The field staff was joined in 2012 by Ms. Evangelia Valentina ("Evelyn") Ilioupoulou, graduate of the Aristotle University of Thessaloniki, Ms. Jacquelyn Helene Clements, Student Associate Member of the American School of Classical Studies at Athens (ASCSA) and postgraduate researcher at Johns Hopkins University, and Mr. Fivos Michos-Ramos, undergraduate student at the National and Kapodistrian University of Athens (NKUA), all of whom assisted with the collection of finds during surface survey and subsequent cleaning, labeling, and cataloguing. The team was also visited on 11 November 2012 by Dr. Giorgos Vavouranakis of the NKUA and five undergraduate students in his Landscape Archaeology class[1], who helped with the surface collection too. With the special permission of the IX EPCA, Dr. Nikolaos Zacharias of the University of the Peloponnese visited on 28 September to install dosimeters for optically stimulated luminescence (OSL) dating of two lenses of sediment uncovered in 2011 that correspond in plan to magnetic anomalies of archaeological interest.

The objectives of the 2012 campaign were, as explained the last work program presented to the Central Archaeological Council of the Ministry of Culture and Tourism through the ASCSA,

- further examination of the nature of magnetic anomalies around Glas, especially the boundary zone between the reticulate patterns by the polder dike and the apparently empty quarter right around the fortress (**Areas G, N**, and **P**, below)
- magnetometric prospection of the empty quarter itself, particularly to the immediate southwest of Glas, where traffic to and from its southern gate may have passed (**Area E**)
- further investigating the area where the Late Helladic canalized combined Kephissos and Melas rivers meet the polder dike northwest of Glas, and the area around the Late Helladic peripheral

[1] Σταυρούλα Βασουράκου, Κωστής Γιαννίρης, Μαρία Ρόζα Μπεσάρα, Γιώργος Σοφιανός, and Μαριάννα Ψύρρη.

canal to the east of the fortress, two locales where water-regulation mechanisms might be evident **(Areas K, L**, and **O**)

- magnetometry of the area between Glas and the contemporary settlement site of Aghía Marína Pýrghos (AMP), where routes of communication are hypothesized (**Area L**, again)
- further efforts toward independent confirmation ("ground-truthing") of magnetometry results and satellite remote sensing data by means of soil coring or modern ditch section profiling, as well as direct measurement of magnetic susceptibility of relevant sediments, and
- continuing intensive collection of finds from the surface of AMP and extensive field walking of selected areas of the plain for similar purpose.

Methods and Techniques

Spatial Control. The corner points of 60-by-90-meter blocs, consisting of six 30-meter grid squares, the basic components of sampling transects, were staked out to within five centimeters of their plotted position with the Javad Triumph-1 multiple global navigation satellite system (GNSS), the base station having been established on the Hellenic Military Geographical Service's (HMGS) triangulation station on the summit of Glas, whose exact position is given to within a millimeter in the Hellenic Geodetic Reference System (HGRS-87) projection–coordinate system. Likewise, 60-by-90-meter blocs were staked out at AMP. Corner points for magnetometry transects in the plain were marked temporarily with non-magnetic bamboo poles, whereas those at AMP were staked out as permanently as present means allowed with half-meter lengths of steel concrete-reinforcement bar bearing a plastic cap marked "AROURA ArchSurv."

Geophysics. As in 2010 and 2011, the Bartington 601-2 dual fluxgate gradiometer was employed for magnetic prospection (magnetometry) on the plain within the ancient polder. Areas of investigation (see Figure 1) were divided into one or more numbered transects 90 meters wide and between 60 and 300 meters long (i.e. one bloc to five blocs of contiguous grid squares). Within these transects magnetometric measurements (samples) were taken every 0.125 of a meter on walked traverses 1.0 meter wide.

The Terraplus KT-10 handheld magnetic susceptibility meter was used in the field to take spot measurements both of the topsoil on the surface but also, crucially, at intervals from the top to the bottom of modern ditch sections where topsoil, features corresponding to anomalies, and subsoil had been exposed.

Soil Coring. Soil cores were removed from above anomalies of interest and adjacent magnetic background areas with an extensible hand-driven auger fitted with a Dutch mud bit. Soil profiles were described for each of the cores, including such pedological fundamentals as base color and mottling (Munsell value), texture, consistence, structure, rock fragments and other inclusions, and appropriate horizon designation (A*x*, AB, E, B*x*, C, R, etc.; see Schoeneberger et al. 2002; USDA 1993). Augering was taken to a minimum depth of two meters below grade, deep enough to reach subsoil horizons and reveal any horizon that may correspond to a magnetic anomaly. Soils data, including the HGRS-87 coordinate position, measured by a stand-alone GNSS receiver, have been shared with the Hellenic Institute of Geology and Mineral Exploration (IGME), from which AROURA received its coring permit.

Supervised Reclassification of Satellite Data. Mr. Wes Bittner traced the edges in plan of magnetic anomalies detected in 2010 and 2011, creating polygon files in ArcGIS, so as to discover the ranges in each of eight bands of spectral data from the Worldview-2 earth observation satellite that corresponded to them (taking into account variation in surface cover too). The bands included two blue (B), one green (G), one yellow (Y), two red (R), and two near-infrared (NIR), each with a range of 2,047 possible values. He used the ERDAS Imagine computer application to create five permutations of three bands each (R-G-B, R_2-Y-B_2, NIR_1-R-G, NIR_2-Y-B, and NIR_1-NIR_2-Y), permutations which represent standards for assessing soil and vegetation moisture or general vegetation health, the variables that most determine crop and soil marks (field marks) corresponding to subsurface features. This form of analysis, known as "supervised reclassification" of spectral data, allowed signatures corresponding to the different kinds of anomalies (and by proxy, related features) to be traced throughout imagery of the Project Area.

Optically Stimulated Luminescence (*OSL*) *Dating.* Dr. N. Zacharias installed dosimeters for the measurement of the "annual dose" of radiation (background + inherent) in features 2011I2-P01 ②, 2011I2-P02 ②, and 2011J1-P01 ②, uncovered in ditch sections in 2011. He also took samples of the sediment making up each of these features, so that he could assess their mineral and moisture content, and their inherent radioactivity. Any time a material is sufficiently protected from background radiation such that its inherent radiation results electron energy being trapped in the crystalline component, as opposed being released (particularly by the solar spectrum), the event is known as a "zeroing" event. The energy released from a sample of this material in luminescence by lasers of known wavelength that is in excess of that released from a non-zeroed sample of the same (the "residual") is a direct measure of its age. Dr. Zacharias will retrieve the dosimeters from their locations on or around 28 December 2012 and proceed with luminescence and analysis in the OSL laboratory of the University of the Peloponnese in Kalamata, extrapolating the annual rate from the three months of collected data (see Aitken 1998 on method). The results should be available on or around 4 January 2013.

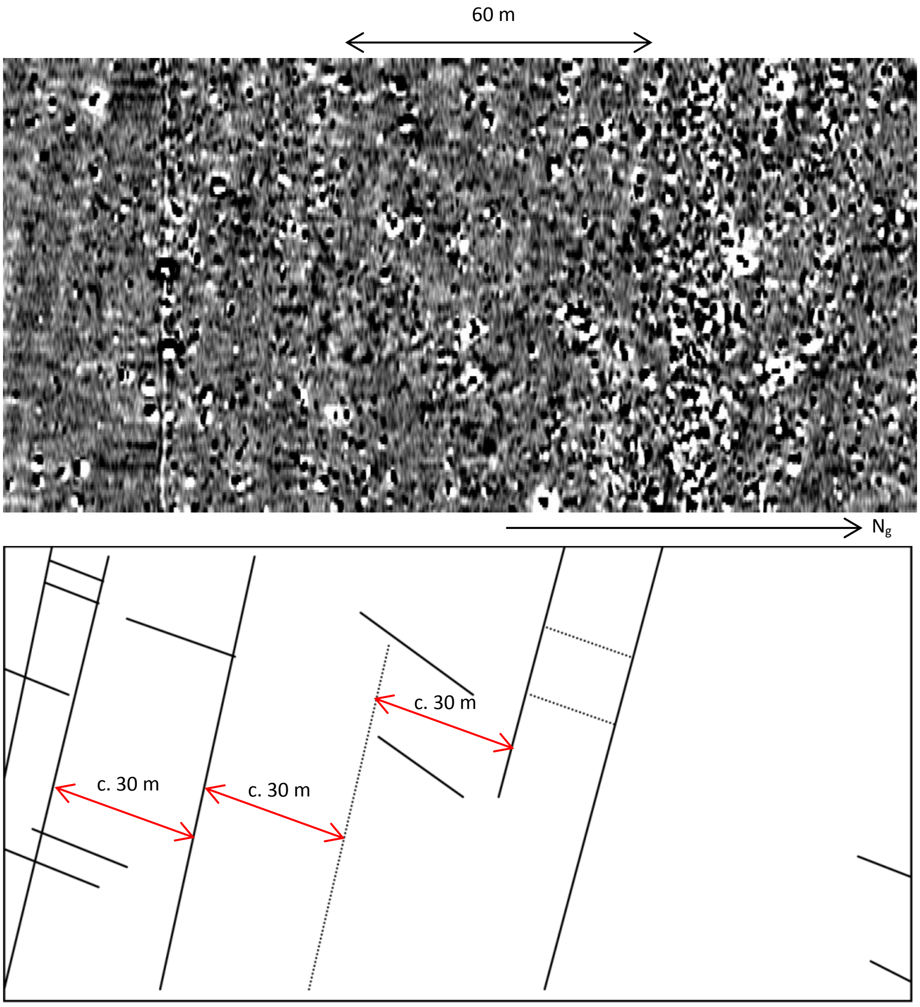
Surface Collection. Collection of finds from the ground surface in the Project Area was conducted in two ways, extensive on the plain and intensive at AMP. In both approaches, all remains of artifacts and environmental remains of archaeological importance that were thought to date up to the completion of the modern drainage of the Kopaïs (c. 1930; Christou 2002; Dean 1937) and could fit in a 15-by-30-centimeter water-resistant paper bag were collected. Larger finds were simply described and recorded, along with those collected, on standardized forms for each area sampled and in a few cases they were photographed in situ.

Extensive surface collection was done on two-meter wide traverses within grid squares that had been subject to magnetometry, one bag number assigned per traverse (which in practice could involve more than one collection bag). An average surface visibility percentage was assigned per grid square, taking into account the overburden, soil color on the surface, and nature and color of background scatter, so that an inversely proportional finds density coefficient could be calculated during subsequent analysis.

Intensive collection was carried out only at AMP. It sampled from two-meter square units within 30-meter grid squares (225 sampling units per square). Each of these units was assigned a coordinate value of the form *xxyy,* where *xx* was the "easting" from the grid southwest (true south) corner of the corresponding grid square, while *yy* was the perpendicular "northing" (values 0101–1515) Thus finds could be topographically correlated with extant architectural features and other archaeologically interesting remains, and can be correlated with finds from future excavations. Indeed, the results of intensive surface collection at AMP are meant to help guide the location of future excavations. Each two-meter sampling unit was assigned a percentage visibility estimate for calculation of a finds density coefficient in later analysis.

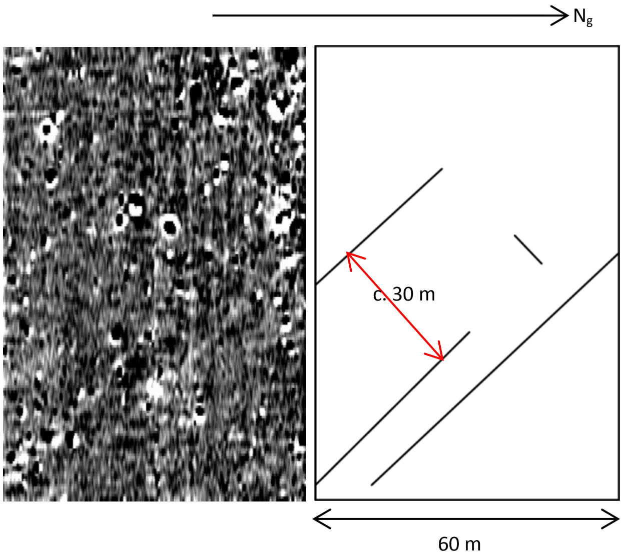
Results

Magnetometry. In the **Polder Dike Sector** (see Figure 1), two transects were subject to magnetometric sampling. One, Transect G3, appeared in the work program of 2010 and 2011, but had been unavailable for sampling until 2012, due to the presence of a high crop of maize in both years. The other, Transect N3, was aimed at sampling the part of N2 that had been impossible to accomplish in 2011, because of deep furrowing, with the addition of four adjoining grid squares.



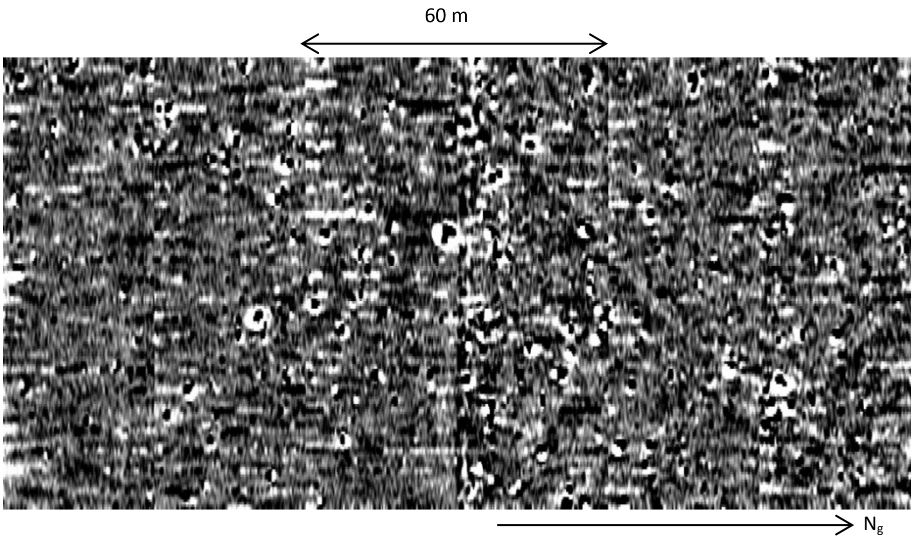
The data from Transect G3 are displayed above in the range of –0.3 nT (white) to 0.2. nT (black), the anomalies themselves contrasting with the background by less than –0.1 nT, being at least as subtle as those discovered in prior years (see also Figure 2).[2] G3 clearly presents a continuation to the south of the reticulate pattern of magnetically negative linear anomalies that are spaced between about 27 and 33 meters apart, which was previously detected in Areas G, I, and N. It may even present fractions of these intervals, such as were detected in Transect I1 in 2010. However, there is no unambiguous evidence of parallel positive anomalies, which would be displayed as black above, like those detected in previous campaigns. It is important to note, however, that while the intervals are similar, the alignment is different from that in Transect G1 and Transects I1 and I2 (see below).

[2] Dr. Horsley has processed all the data displays in essentially the same way using the ArcheoSurveyor 2.5.19 application: clipping of responses to ± 3.0 nano-Teslas (nT), zero mean traverse, minimal destagger (if required), and interpolation from 1.0 × 0.125 m to 0.5 × 0.125 m (to smooth the appearance of the data and aid anomaly recognition).

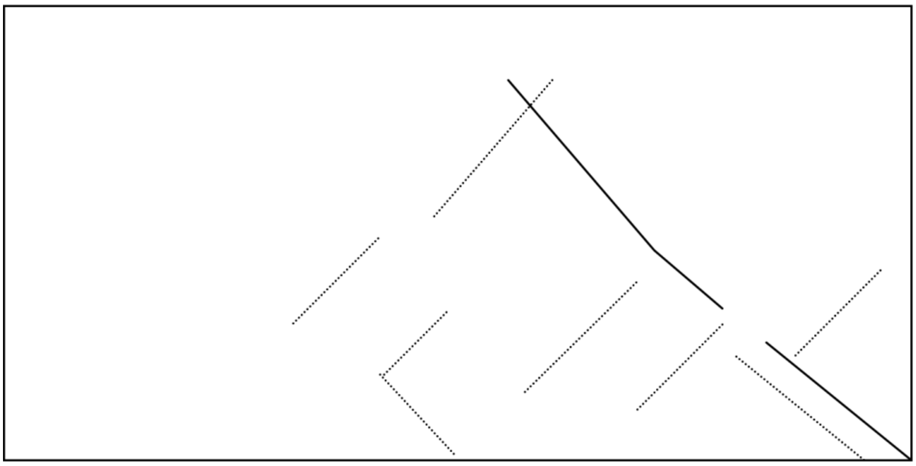


Likewise, the results from Transect N3 confirmed the observation made in 2011 that the reticulate pattern continues north beyond Area I into Transect N2, if not also N1 (see above and Figure 3). The data are displayed above in the range of –0.2 nT to 0.1 nT. Again, one of the intervals between the linear anomalies is approximately 30 meters, as observed in Transects G1, I1, and I2 in 2010 and 2011. There may be traces of parallel positive anomalies (dark), particularly toward the grid east edge of the transect, but they remain equivocal. Particularly noteworthy is how the alignment of these anomalies, although spaced similarly, is different from that evident in G3, having changed somewhere between Transect G1 and Transect I1 (as noticed in 2011).

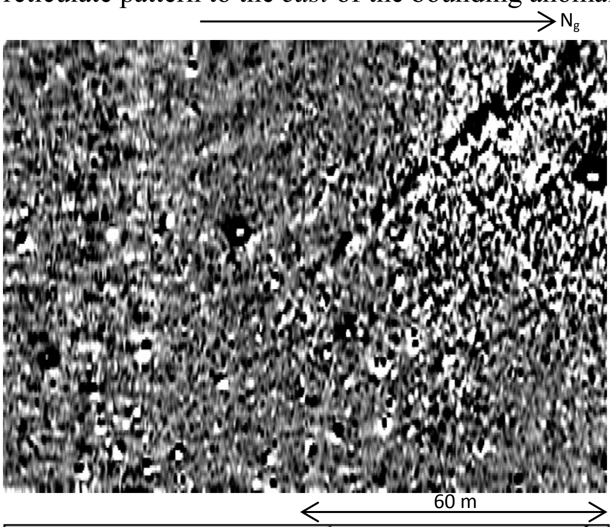
In the **West Sector**, magnetic prospection took place in Transect K2 and Transect P1 in 2012.

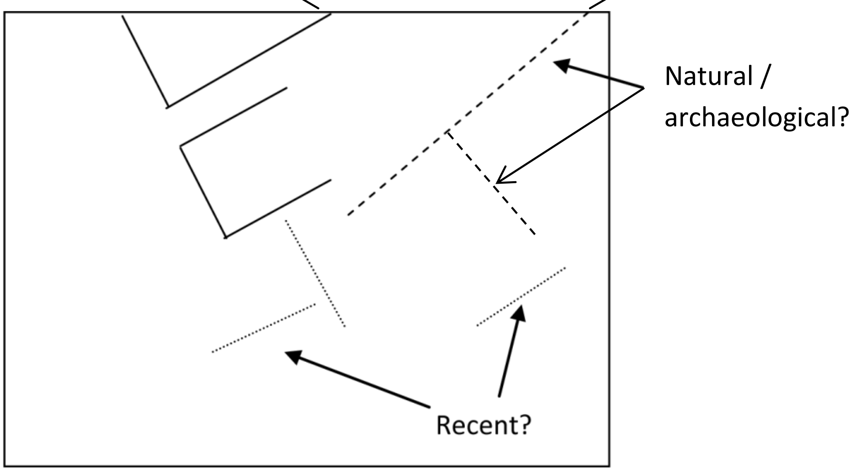


✠ ← approximate location of OSL dosimeter



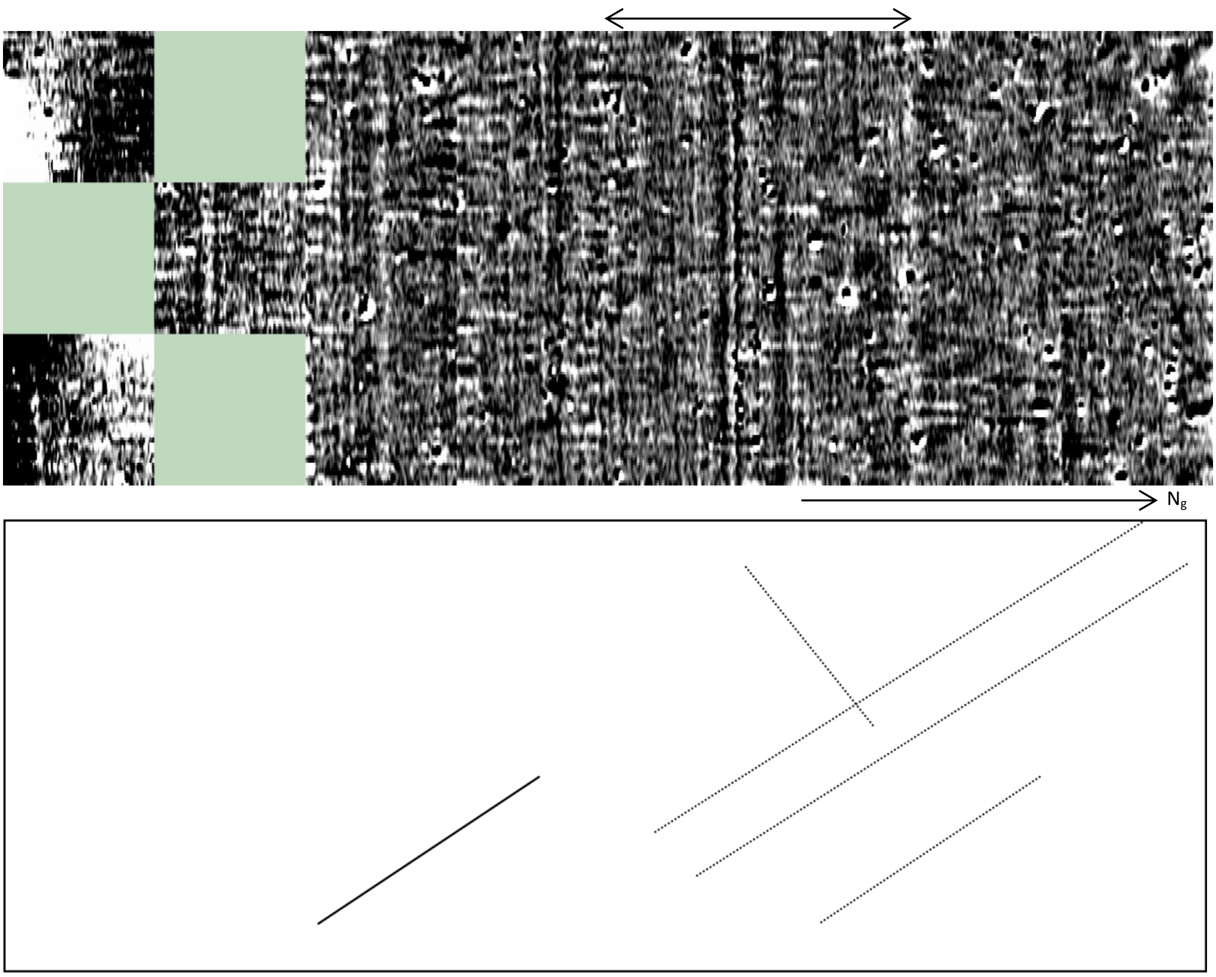
The data from Transect K2 above are displayed in the range of –0.2 nT to 0.1 nT, once again indicating very subtle anomalies (see also Figure 4). What is certain among the faint anomalies in K2 is that the strongest of them (solid line above) aligns with the "linear bounding anomaly" observed in 2010 and 2011 to cut across Transect J1 to the south and southwest. Hence it quite probably marks the continuation of the corresponding feature seen in section in the ditch between Area J and Area K, into which a dosimeter was inserted in 2012 for OSL dating. The dashed lines in the diagram above are little more than suggestions of further linear magnetically negative anomalies. If they do represent features of archaeological significance, the majority may represent an unexpected continuation of the reticulate pattern to the *east* of the bounding anomaly, in the direction of the "empty quarter" (below).



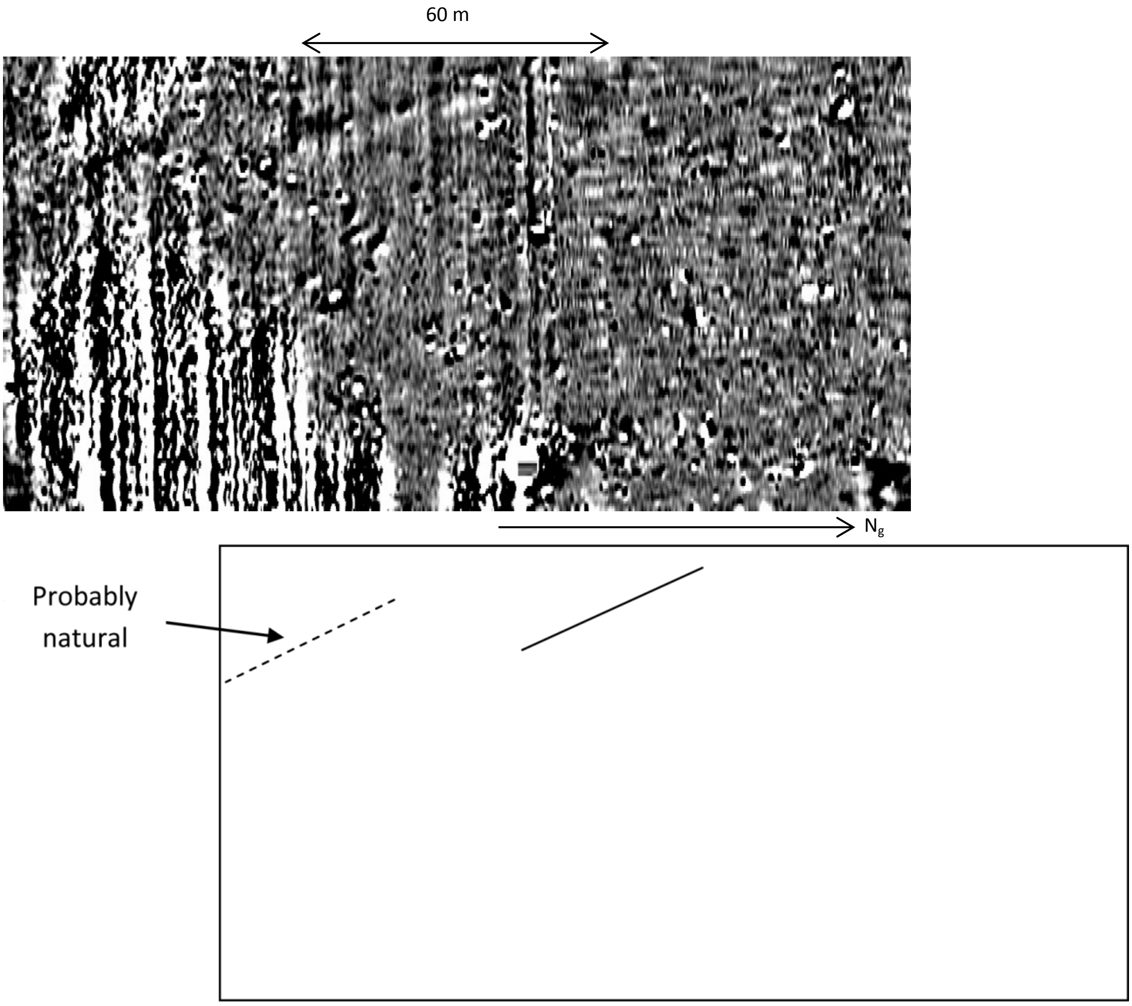


The data display above ranges between –0.3 nT and 0.2 nT (see also Figure 5). Transect P1 is within 200 meters of the polder dike (see Figure 1), toward its southern end, i.e. closer to Mt. Mýtikas than to the modern village of Kástro (lately Topólia, anciently Kopai). It is an especially interesting transect both because it contains linear negative anomalies that are oriented like the reticulate pattern parallel and perpendicular to the dike observed in Areas G, I, and N to the north, and because it contains a large quantity of surface finds, almost without exception ceramic, in striking contrast with Area F just to its north (see "Field walking" below). The negative anomalies, perhaps related to the reticulate pattern spread out along the east side of the polder dike, are very subtle but nonetheless convincing. It should be noted, however, that they do not exhibit the characteristics c. 30-meter interval of the reticulate pattern to the north. Moreover, they appear to be wider, up to three or four meters across. The stronger positive anomalies, displayed in black above and in Figure 5, are probably due to infilled natural clefts in the limestone substrate or, especially where they appear in sharp contrast, close to the surface and due to recent infilled excavation, furrowing, or rutting.

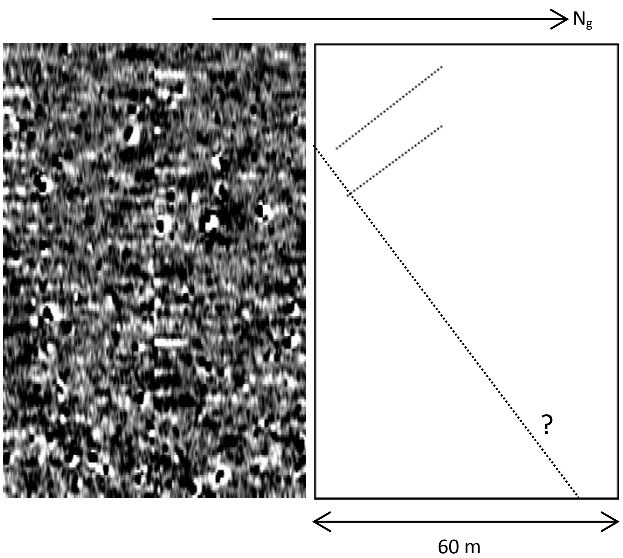
Prospection in the **North Sector** had various purposes. That in Area L was twofold, to search for water regulatory mechanisms near the north end of the peripheral canal running to the east of Glas, as it approaches the canalized Kephissos–Melas near AMP, and to detect any approach to AMP from Glas' northern gate. Investigation in Area O was meant to detect the northern end of a linear anomaly detected in Transect A1 in 2011, whose corresponding satellite image signal continues through Transect O1 to the Late Helladic canalized rivers (see Figure 6). It was thought there might be traces of water regulatory mechanisms near this juncture.



The data from Transect L2 above are very noisy and displayed over the very narrow range of –0.2 nT to 0.1 nT (above and Figure 7). Anomalies of interest are very subtle by implication. The ground was furrowed perpendicular to the length of the transect in its grid-southern two thirds, so deeply in the last 60-by-90-meter bloc that it was decided only to sample half the grid squares therein in a checkerboard pattern. There appear to be two or three fairly relatively closely spaced magnetically negative linear anomalies in the grid north half of the transect, perhaps with parallel positive anomalies between them. When oriented on the sampling grid (Figure 7), they appear to run almost due east–west (HGRS-87 orientation). Previous anomalies on such an orientation, albeit considerably sharper and more contrasting, have been attributed to modern features, such as the traces of the abandoned irrigation channels installed by the Greek state in the middle of the 1950s (as in Transects C1 and C2 in 2010, and L1 and M1 in 2011). However, nothing precludes the linear anomalies in L2 representing something older, and the scatter of sherds of various periods between them and L3 to the north, not seen in association with anomalies in L1, suggests that they are unrelated to the modern east–west features observed elsewhere. Their interval and pattern do not otherwise resemble any other discovered in the polder, so interpretation remains difficult.

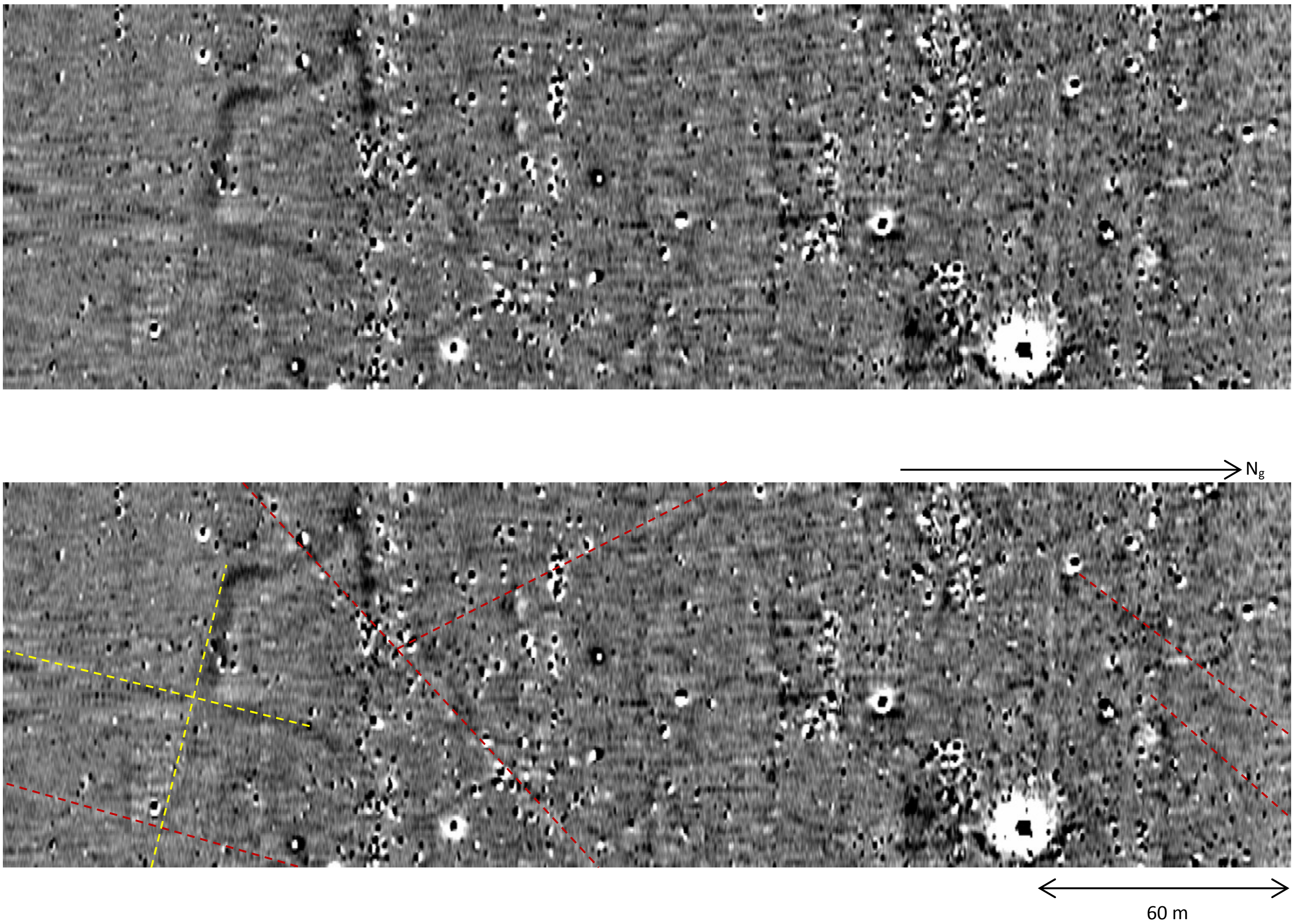


The data from Transect L3 are displayed over the rather broad range, by AROURA standard, of –0.3 nT to 0.2 nT (see also Figure 8). There is clearly something in the substrate causing a large, amorphous anomaly taking up nearly all the grid-southern half of the transect, whose magnetic response has been complicated by overlying plow furrows perpendicular to the transect's length. The limestone substrate rises in an escarpment within 60 meters of the south end of the transect, and so it seems plausible that the anomaly here, like those of similar character detected in A2 in 2010 and B2 in 2011, is due to uneven bedrock close to the surface, overlain to a greater or lesser degree with iron oxide-rich soil. It is uncertain whether the linear magnetically negative anomaly with a clear parallel positive response adjoining it to the grid west is likely to be natural or cultural. There is a parallel and fairly clear parallel magnetically positive anomaly farther to the south, but given that it appears to lie amid the responses making up the large amorphous anomaly mentioned above, it is possible that it too represents a natural feature. Thus both anomalies could have essentially the same underlying physical cause. It is worth noting, in comparison with the anomalies observed in L2 (above), that their orientation is east–west.



The data from Transect O1 are displayed at a range of –0.2 nT to 0.1 nT (above and Figure 9). The suggested alignments are very uncertain. The strongest of them are two parallel magnetically negative anomalies, spaced about 10 meters apart in the grid southwest corner. They may run perpendicular to another generally magnetically negative trend, although such an alignment may be an illusion created by subtle magnetic variation in the soil and contrast with modern ferrous noise near the surface. It could, however, correspond to the satellite spectral signal appearing to cut across O1, continuing that which corresponds to the north–south mainly negative anomaly detected in Transect A1 in 2011 (see Figure 6).

Finally, in the **South Sector**, Transect E4 was sampled with the principal aim of determining whether the presumably “empty quarter” observed immediately around Glas is indeed empty to the south and southwest of Glas’ south gate.



The range the data display above (cf. Figure 10) is relatively broad: –0.4 nT (white) and 0.3 nT (black). Hence there are a few rather convincing anomalies of archaeological interest in the data. Chief among them is the magnetically negative one running diagonally across the transect in its grid-southern half. It may be intersected some 20 meters to the grid east of the transect by another linear negative anomaly that clips the transect's grid southeast corner. It is also curious how two portions of the wide, magnetically positive (desiccation?) cracks are nearly parallel and perpendicular to this anomaly (yellow above). Less convincing, but probable, are the negative anomaly roughly perpendicular to the diagonal described above and two further linear, negative anomalies intersecting the grid north end of the transect which are almost parallel to said diagonal. What is most interesting is how the diagonal anomaly intersects a point near the base of Glas' escarpment that could be at the bottom of a ramp leading directly to the fortress's conveniently angled south gate (see Figure 14).

Soil Coring. Only two soil cores were removed in 2012, 2012N3-01 from above a linear magnetically negative anomaly in Transect N3 and 2012N3-02 from above a magnetic background area about a two meters away (Figure 11). They differed subtly but certainly, much as the prior year's 2011I2-03 differed from 2011I2-05. The former consisted of a dark grayish brown (10YR4/2), silt loam plow zone (Ap) some 44 centimeters deep, followed by a horizon designated A2 (10YR5/3 brown, mottled, silt loam, 44–76 cm below grade), an eluviated E horizon (10YR6/2 light brownish gray, mottled, silt loam, 76–150 cm), and finally a horizon, designated Bw in the field (10YR7/2 light gray, mottled, loam, 150–197+ cm). The latter consisted of a dark grayish brown (10YR4/2) silt loam plow zone (Ap) some 36 centimeters deep, followed by an A2 horizon (10YR6/2 light brownish gray, mottled, silt loam, 36–80 cm below grade) and Bw horizon (2.5Y6/3 light yellowish brown, mottled, loam, 80–200+ cm). It is possible, then, that 2012N3-01's E horizon represents a feature corresponding to the negative anomaly.

Magnetic Susceptibility Testing. Use of the KT-10 magnetic susceptibility (MS) meter confirmed not only that contrast between the volume-specific MS (or simply "volume MS") was indeed slight between topsoil and subsoil, but also that features corresponding in plan to magnetic anomalies exhibited the expected difference (negative or positive) with their surroundings. For instance, in ditch section profile 2011I2-P01, the topsoil's MS was 0.092–0.093 × 10^{-3} SI (stratum ①), that of the feature corresponding to the negative anomaly (②) 0.007–0.008 × 10^{-3} SI, that of the subsoil immediately below (④) 0.063–0.5 × 10^{-3} SI, and that of the basal subsoil layer (⑤) 0.072–0.077 × 10^{-3} SI. These results are not only important as confirmation of the nature and character of the causes of certain magnetic anomalies, but they also permit the proper application and adjustment of techniques in the Project Area and elsewhere where similar geological and hydrological conditions prevail.

Field Walking. Two magnetometry transects were also subject to systematic field walking for the collection of all visible finds from the ground surface, L3 to the northeast of Glas, in the direction of AMP, and P1 to the south of Glas, in the direction of the polder dike (see Figure 1). Both were selected because of the obvious presence of finds, particularly ceramic sherds, in *sharp contrast* with the great majority of other transects in the Project Area, with the notable exception of H2, adjoining the polder dike on its west, lake-ward side (investigated in 2010).

The day before field walking was to take place in Transect L3, all the temporary bamboo stakes except those at the grid north end were plowed in by the proprietor or lessor. Therefore, the entire land tract between the hedgerows and roads, not just the demarcated transect therein, was subject to collection, up to a line passing between the northernmost two stakes. Since most of the tract has just been plowed, surface visibility was in the 91–100 percent range. Only a strip of land in the grid northeast corner, approximately 75 meters long (following the length of the land tract) and 30 meters wide suffered a fairly low degree of visibility on the surface, about 50 percent. All together 58 ceramic sherds were collected from about 2.7 hectares of land, mostly coarse, red-fabric wares, including a few bases, handles, and incised pieces. These are certainly of diverse periods, including modern, but as of the writing of the present report, none had been determined to be chronologically diagnostic.

The density of finds in Transect P1 precluded complete collection in the time available. Only the grid northwest 30-meter square P1a1 was walked, producing 812 finds, 331 of which were identified as pottery sherds, 481 of which as other ceramic fragments (mainly building tile). The remains were clearly of various periods, including the modern, but at least two pieces have been tentatively identified as Boiotian black-figure ware of the Classical Period. As noted, P1 is close to the polder dike, beside which, in Transect H2, probable Classical pottery was found in 2010. P1 is also a couple of hundred meters from a rise ("Hügel") observed by German investigators in the 1970s and 1980s on which they identified Archaic / Classical sherds (unpublished typescript report of S. Lauffer and own field notes provided by J. Knauss, pers. comm. 2012; see also Knauss, Heinrich, and Kalcyk 1984: 205–32; Lauffer 1986: 210–50).

Intensive Surface Collection, AMP. Two further grid squares at AMP were subjected to intensive surface collection, AMP 2a1 and 2b1, as explained under "Methods and techniques" above, in addition to 2c2, which underwent collection in 2011. Both grid squares were also mapped (see Figure 12).

AMP 2a1, which included the summit to the west of the medieval tower and part of the north slope beyond the cyclopean retaining wall, produced 436 finds, the great majority of them ceramic, though there were 16 pieces of chipped stone (dark brown or reddish brown chert), and one piece of what has been tentatively identified as burnt steatite (figurine fragment?). Several sherds have been identified as belonging to Middle Helladic matt-painted wares and Protogeometric or Early Geometric wares. Several architectural features were identified, including an east–west wall on the summit, between two and three meters thick, paralleling the retaining wall, and a perpendicular cross wall (continuing southward into 2b1), only partly exposed here.

AMP 2b1 was immediately to the grid south of 2a1, sloping from the summit gradually toward the southern cyclopean retaining wall. Despite little of its surface being eroded or disturbed by human or animal excavation, it yielded 1,135 finds, again the largest part of which consisted of pottery sherds. They also included 203 fragments of building tile and 6 pieces of chipped stone, including one cortical flake of chert. Pottery periods represented included Late Helladic (tentatively LH IIIA2; e.g. Figure 13), Protogeometric or Early Geometric, and medieval (some lead-glazed). The north–south cross wall observed in 2a1 continued into 2b1, where two or more courses are exposed (up to two meters thick), and where it exhibits a dog-leg bend toward the south (grid southwest) corner of the square. There are also traces of at least one wall continuing from AMP 2c2 to the southeast, and an apparently crude subround stone structure, built of fallen courses of the medieval tower walls, on the grid east side of the square.

Other Results

Satellite Data Analysis. The supervised reclassification of satellite spectral data produced signatures that could be correlated with magnetic anomalies continuing into areas left unsampled by magnetometry and indeed into areas where field marks in the visible spectrum have not been observed (see e.g. Figure 6). In fact, combinations of reclassified values guided the precise placement of Transect K2 and resulted in the definition in 2012 of Transect O1 and Transect P1.

Radiocarbon Dating. AROURA received two accelerator mass spectrometry (AMS) radiocarbon dating results in October 2012, having received written permission in the previous summer to export the relevant samples to Beta Analytic, Inc. The first sample, 2011I2-01, derives from the soil horizon corresponding to a negative anomaly in the reticulate pattern running between Transect G1 and Transect I2 (an OSL dosimeter being installed in the equivalent feature in 2012). The second, 2011VK-01, was taken from a depth of about 240 centimeters below grade in the entrance of the Vrystiká Sinkhole, within a few centimeters of the bottom of the core removed by hand-driven soil auger in 2011 (the B horizon).

2011I2-01 yielded a calibrated date (Beta 331307) of BC 1880–1660 and BC 1650–1640 (accuracy of two standard deviations), there being several peaks and valleys in the calibration curve around the measured (conventional) radiocarbon age of 3440 ± 40 BP. Since the horizon (and corresponding lens of sediment in section 2011I2-P01) was apparently built up of lakebed sediment deposited on a surface drained in prehistory, this precise AMS date of the organic fraction of the sediment may be taken as a near terminus post quem (within a century of two, given expected formation processes) for the construction of the feature. OSL dating carried out in 2012 may confirm this result and perhaps lend it some precision (OSL generally being accurate to within five percent of calendar age).

2011VK-01 yielded a similarly accurate calibrated radiocarbon date (Beta 331308) of BC 1720 and BC 1690–1530 (the reason for the bimodal distribution explained above). This date, also derived from the organic fraction of the sediment, provides a terminus post quem for the overlying deposits in the mouth of the sinkhole, particularly laminae and facies that may be correlated with episodes of flooding and desiccation.

Assessment of Risks to Cultural Resources in Project Area

As in 2011, the American partners of AROURA reported evidence of recent illicit excavation at AMP, some perhaps happening in the weeks leading up to fieldwork, to the local antiquities warden (αρχαιοφύλακας), Mrs. E. Kandhrí, and the project Collaborator at the IX EPCA, Dr. A. Papadaki. Records of evidence included photographs and exact locations of looter's trenches. It is recommended that local antiquities wardens make patrols by the site on different days of the week at different times of day, varying their schedule as much as possible, and that they take note of the particulars of vehicles that are unfamiliar and cannot readily be traced to land owners and tenants in the immediate vicinity. They should also take note that the site is frequented by shepherds and goatherds, residing mainly in the vicinity of Kókkino, and it is on major animal-driving routes to and from the hills to the south. Locals have informed the field team that antiquities looters in the region often store their finds in sheep-sheds.

As for other parts of the Project Area, there appears to be no particular threat to archaeological remains other than the usual attrition through farming practices—indeed, mainly because they lie beneath cultivated fields that no one has any interest in digging up. It should be noted in this context that recently erected corrugated metal sheds, which lack excavated foundations, whether they contravene Greek antiquities regulations or not, have no impact on the discoveries of AROURA from 2010 through 2012.

Summary and Discussion

Magnetometry results from 2012 most of all confirmed the existence of a reticulate pattern of linear, magnetically negative anomalies, sometimes paralleled by positive anomalies (usually narrower), extending for several hundred meters along the east side (inside) of the Late Helladic polder dike. This pattern is consistent with a network of pathways, where iron oxide-rich topsoil has been removed, or, alternatively, levees built of subsoil or mixed sediment, hardly wider than two meters, being accompanied in places by channels filled with iron oxide-enhanced sediment. In any case, the pattern resembles in plan a system of cultivated fields partitioned by raised trackways and occasionally irrigated. Profiling modern ditch sections in 2011, in addition to soil coring from 2010 through 2012, revealed lenses of sediment in positions corresponding to magnetically negative anomalies, as well as traces of what may be adjoining channel fill, consistent with this interpretation.

There may, it seems, be a few separate though similar such field systems, insofar as they conform to different parallel–perpendicular alignments; that is to say, they are not all aligned with the polder dike, parts of which have remained standing until the modern era, but rather with features internal to the polder (see further below). The linkage of the reticulate pattern (or patterns) to Glas and the polder dike by way of previously observed joining and bounding anomalies and corresponding features suggests construction in the Late Helladic Period (if not the LH IIIB in particular, to which the fortress of Glas is dated). Such circumstantial evidence of construction contemporary with the wider drainage system appears to be supported by the radiocarbon date from sample 2011I2-01 (Beta 331307), although it may indicate that the field system was initiated several generations before the construction of Glas (c. 1300 BCE; Iakovidis 1998). Forthcoming OSL dates should clarify the chronology of constructions within the polder.

Investigations in 2012 also added weight to the interpretation that the "empty quarter" around Glas is indeed empty, to the degree that it lacks the intricate reticulate patterns seen around the dike to the west, an observation that is magnified by the clear crisscrossing of this quarter by known canals with thick retaining walls and newly observed, apparent major levees or causeways, possibly again paralleled by smaller channels. There may now be confirmation of a long linear, magnetically negative anomaly extending all the way from the Late Helladic artificial channel of the Kephissos–Melas to the north scarp of Glas, and there are two negative anomalies to the southwest of Glas' south gate that can plausibly be interpreted as causeways serving this gate.

It has been observed since 2010 that the magnetic anomalies believe to be associated with the network of fields around Glas are subtle by any archaeological standard. Measurements of magnetic susceptibility in the field in 2012 provided a specific explanation of this effect: the difference between topsoil and anomalies is low (in the example given above, 0.085×10^{-3} SI), lower still in some cases between anomalies and their substrate (e.g. 0.064×10^{-3} SI). The latter is particularly noticeable in the case of negative anomalies whose corresponding feature appears to be made of subsoil, sorted subsoil, or subsoil mixed with other sediment. The fact that corresponding features are substantial (some 20 to 30 cm thick) should serve as a warning against assuming that weak magnetic response or low contrast indicates attenuated archaeological remains under geomorphic conditions similar to those in the Project Area. The measured values unsurprisingly low, given that the soils are formed on relatively iron-deficient Quaternary alluvium from calcareous formations (Higgins and Higgins 1996: 76–8; Jacobshagen et al. 1986: 81–94), and there has been little time in the century or so since modern drainage, just as there was probably little time in the second millennium BCE, for soil horizons to have formed. Fortunately a very weak susceptibility contrast between feature material and the surrounding soil matrix exists, and it is apparently just sufficient to produce the extremely weak negative magnetic anomalies that AROURA has detected. It is interesting that while the archaeological features are themselves composed of natural materials (subsoil, sorted subsoil, or subsoil mixed with other sediment), they exhibit the lowest magnetic susceptibility values. This is likely simply due to contrast in compaction, with the features being looser and therefore less dense than the natural soils. Unfortunately, AROURA was never able to allocate sufficient funds to applying complementary techniques on an extensive scale, such as electromagnetic / conductivity testing, which might have enhanced the contrast or drawn out details.

Field walking indicated persistent inhabitation or, at least, traffic in Area P toward the south end of the polder dike, where it approaches Mt. Fteliá, where previous investigators had observed a rise in relief. Some of the scatter of artifacts, like that seen farther north in Area H, may be due to travel along the abandoned polder dike in later eras, and early modern maps indicate a trackway, possibly seasonal, along this contour, between Fteliá and the settlement of Kástro. The scatter is very concentrated, in marked contrast with the few dozen surface finds from transects to the north and northeast, in the direction of Glas. The concentration in Transect L3, about two thirds of the way between Glas and AMP and beside the Late Helladic peripheral canal, is much less dense that that in Transect P1, but it is more than twice as dense as the densest found in fields within the polder closer to Glas (e.g. Area D). It may therefore represent traffic along the revetment of the peripheral canal, which may have served as a causeway too, as it hugs the scarp of Nisí to its east.

Intensive surface collection at AMP again in 2012 further confirmed the long, multiphase inhabitation of this settlement and detailed its many architectural additions, renovations, and alterations. As previously noted, pottery datable to the Middle Helladic, Late Helladic, and Protogeometric or Early Geometric, as well as other periods, was discovered, as was some evidence of both the use and manufacture of chert tools on the site. The cyclopean inner circuit and retaining wall was certainly repaired or rebuilt in later times, in some cases with smaller boulders and cobbles. The north–south wall passing through grid squares AMP 2a1 and2b1 may have had a section removed near the summit, perhaps to make room for a later structure, as is evident in the pile of stone at its northernmost extant end in 2b1 and in the accumulation of roof tile and likely medieval pottery in the gap between the extant portions of the wall in both grid squares. There is also at least one relatively impermanent structure built of stone from wall courses of the medieval watchtower that have collapsed, perhaps of early modern date.

Conclusions in the Context of Previous Years' Results

One can now begin to assemble the pieces of evidence for a comprehensive picture of the landscape around Glas based on the results of all three years of the AROURA campaign (see Figure 14). All together there appear to be two kinds of field system around the Late Helladic polder dike to the west of Glas, one outside of the polder (Area H) consisting of a web of what are likely infilled canals on two intersecting alignments, with an interval between (positive) anomalies of multiples of about eight meters, and another inside the polder, evidently consisting of a rectilinear lattice of raised levees and perhaps parallel channels, whose major interval is about 30 meters (c. 27–30 m), forming near-squares. The latter system may consist of the same essential pattern on two or three different alignments (Field systems 2a, 2b, and 2c in Figure 14). That these appear to be constructed at least as much with respect to bounding and joining anomalies / features within the polder, all centripetal to Glas, as with the dike that protects it to the west, bolsters the circumstantial case that they are contemporary with the fortress or, at least, with the Late Helladic drainage system. It is useful to compare this interpretation with J. Knauss's plan, based on close examination of a vertical aerial photograph taken in 1974 (Figure 15), in which he also observed several different alignments of field marks, including evident boundaries to the east. The fact that the lake-ward "canal" system in part runs parallel to the polder dike but not under it, yet exhibits a different land measurement system, suggests that it may be considerably later than the "levee" system inside the polder. However, nothing was discovered in the soil cores of the former to indicate its exact date and so it could be contemporary.

There now appear to be three or more joining anomalies and features, in addition to the long-known revetted canal (in two parts, from Nisí to Glas and from Glas to Fteliá; see Figure 14). One extends from the polder dike eastward to a point about 80 meters to the north of Glas' west gate. Another likely extends from the canalized Kephissos–Melas to a point at the base of the cliff below Glas' highest point, about 400 hundred meters west of Glas' north gate. A third and possibly fourth converge at a point about 250 meters southwest of Glas' south gate, near the bottom of the curve of the outcropping's "rump." Presuming that all these anomalies prove to be built features, such as have been discovered in Area I and Area J (an east–west joining anomaly), then, together with the revetted canal, they suggest a deliberate plan of indirect approaches to Glas' gates. While Glas' gates do not possess a complex pattern of dog-legs or blind corners for defense, the hypothesized causeways could have served the same purpose. Anybody approaching one of the gates along them would be at first exposed from the side and then forced to take a path along the edge of the outcropping, immediately below the circuit wall, to reach one of the gates. One might therefore wonder whether the evidently empty space between these approaches was effectively impassable, for instance, flooded with water. With particular respect to the south gate, an indirect approach would presumably also serve the long ramp necessary to move huge harvests into the storehouses of Glas, which are closest to this gate.

Water regulatory mechanisms within the polder remain elusive. However, a plausible scenario can be constructed involving the features discovered to date. As earlier investigators conjectured, the eastern peripheral canal and the revetted canal would have served as overflow channels for the Kephissos–Melas when in spate, both eventually emptying into the Vrystiká Sinkhole. Neither of them appears to have irrigated any surrounding area, though, as J. Knauss suggested, the revetted canal, which connects with the eastern tip of Glas, may have served the double purpose of a causeway toward Glas' north and southeast gates and of flooding the area immediately around the fortress, whether in a distinct moat or not. One may plausibly imagine flood control gates at the point where these two canals meet the canalized Kephissos–Melas.

An irrigation system, which would have been necessary to sustain cultivated fields in season, would have been gravity-fed. It would have been necessary to introduce water into the polder before it arrived at the overflow canals. Thus the long spectral signature (field mark) and possibly corresponding magnetic anomaly running from the ancient course of the Kephissos–Melas through Transects O1 and A1 to the north side of Glas could correspond to a feature that allowed water to flow from what is slightly higher ground (and possibly also artificially raised by the canal's retaining walls) to the lower ground around Glas and thence westward and southward around Glas, following the joining and bounding features, to the "levee" system by the dike. There presumably would have been a gate system at the Kephissos–Melas end, and the wet seasons (early winter and early spring) would have necessitated flood control. It is conceivable that the one (or more?) east–west joining features may also have joined water-release mechanisms passing through the dike to the west, or that sections of the "empty quarter" served as seasonal sumps (ideal in dry seasons for pasture). There may even be field systems yet to be discovered to the north and northwest of Glas, perhaps evident in faint linear anomalies detected in Area A and Area K.

The place of AMP in this Bronze Age landscape remains an enigma. When the polder and Glas were fully functional, the site must certainly have served to protect the juncture of the Kephissos–Melas to the north of Glas with the revetted and peripheral canals to its east, and to keep an eye on the Bínia and Megháli Katavóthres (Sinkholes) and the pass to the port of Larymna to the east, none of which is visible from Glas. However, the robust presence of Middle Helladic remains, also observed by previous investigators (see Fossey 1988: 284; Hope Simpson and Hagel 2006: 79), suggests a permanent settlement well before the existence of the fortress of Glas and presumably, by implication, the existence of the polder and attendant hydraulic works. One may productively wonder what kind of agro-pastoral landscapes this settlement used in the absence of a drained polje and whether, perched above a marsh, it was a particularly salubrious place to dwell (see Morgan-Foster 2010; Sallares, Bouwman, and Anderung 2004). Furthermore, there is ceramic evidence of an LH IIIB–C phase (c. 1190 BCE), probably succeeding the final destruction of Glas just before the end of the LH IIIB (Iakovidis 1998), as well as a phase of inhabitation in the succeeding centuries of the Geometric Period (after c. 1050 BCE). The question arises of the degree to which the drainage system and polder could have been exploited after the collapse of the palace-based administrative system. These questions about the changing nature of the settlement of AMP and its relationship with natural and artificial landscapes are subjects of planned future fieldwork.

Publication Plans

Dr. Tim Horsley is currently drafting the first article on the AROURA geophysical program, results, and interpretations for the journal *Archaeological Prospection.* Dr. Lane and Dr. Charami will be contributors and co-authors, and submission of a first draft is targeted for mid-March 2013. Dr. Lane is taking the lead on an article for the *Journal of Field Archaeology,* explaining the overall aims, objectives, and methodology of AROURA, including a critical discussion of the utility of its techniques both in the Project Area and for other projects. The target date for submission of this study is the end of July 2013, after AROURA has finished its study of the finds from field walking and intensive surface collection and analysis of their spatial distributions. A comprehensive article on all three years of AROURA fieldwork, interpretation of the agricultural landscape, and implications for future research will be prepared for the *American Journal of Archaeology* between 2013 and 2014.

In the meantime, Mr. Bittner is revamping the AROURA website so as to include a GIS portal (via http://www.arcgis.com) allowing access to georeferenced databases on a subscription basis. A demonstration version of it will be presented to AROURA colleagues at the IX EPCA for approval in the spring or summer of 2013.

BIBLIOGRAPHY

Aitken, M.J. 1998. *An Introduction to Optical Dating: The Dating of Quaternary Sediments by the Use of Photo-stimulated Luminescence.* New York: Oxford University Press.

Christou, Th.D. 2002. *Το Κωπαϊδικό Ζήτημα και οι κοινωνικοί αγώνες για την επίλυσή του* (*1865–1953*). Athens: Center for the Development and Reshaping of the Western and Southern Region of Thebes.

Dean, A.J. 1937. The Lake Copais, Boeotia, Greece: Its Drainage and Development. *Journal of the Institution of Civil Engineers* 5 (1936–37): 287–316.

Fossey, J.M. 1988. *Topography and Population of Ancient Boiotia, Volume I.* Chicago: Ares Publishers.

Higgins, M.D. and R. Higgins. 1996. *A Geological Companion to Greece and the Aegean.* London: Duckworth.

Hope Simpson, R. and D.K. Hagel. 2006. *Mycenaean Fortifications, Highways, Dams and Canals.* Studies in Mediterranean Archaeology 133. Sävedalen: P. Åströms Förlag.

Iakovidis, S.E. 1998. *Γλας II: η ανασκαφή 1981–1991.* Athens: Archaeological Society in Athens.

Jacobshagen, V. et al. 1986. *Geologie von Griechenland. Beiträge zur regionalen Geologie der Erde.* Berlin / Stuttgart: Gebrüder Borntraeger.

Knauss, J., B. Heinrich, and H. Kalcyk. 1984. *Die Wasserbauten der Minyer in der Kopais: die älteste Flußregulierung Europas.* Institut für Wasserbau und Wassermengenwirstschaft und Versuchsanstalt für Wasserbau Oskar v. Miller-Institut in Obernach, Bericht Nr. 90. Munich / Obernach: Technische Universität München.

Lauffer, S. 1986. *Kopais: Untersuchungen zur historischen Landeskunde Mittelgriechenlands I.* Frankfurt am Main: Verlag Peter Lang.

Morgan-Foster, A.H. 2010. *Climate, Environment and Malaria during the Prehistory of Mainland Greece.* Ph.D. dissertation, University of Birmingham, Dept. for the History of Medicine.

Sallares, R., A Bouwman, and C. Anderung. 2004. The spread of malaria in southern Europe in antiquity: new approaches to old problems. *Medical History* 48: 311–28.

Schoeneberger, P.J., D.A. Wysocki, E.C. Benham, and W.D. Broderson, ed. 2002. *Field Book for Describing and Sampling Soils,* version 2.0. Lincoln, NE: Natural Resources Conservation Service, National Soil Survey Center.

United States Department of Agriculture (USDA), Soil Survey Division Staff. 1993. *Soil Survey Manual.* Washington, D.C.; U.S. Government Printing Office.