Geophysical Prospection Survey of an Ancient Amphorae Workshop at Tsoukalia, Alonnisos (Greece).

Sarris, A.[1], Athanassopoulou, E.[2], Doulgeri-Intzessiloglou, A.[3], Skafida, Eu.[3], Weymouth, J.[4]

1. *Laboratory of Geophysical-Satellite Remote Sensing & Archaeo-environment, Institute for Mediterranean Studies, Foundation of Research & Technology, Hellas (F.O.R.T.H.), Rethymno, Crete, Greece,* asaris@ret.forthnet.gr
2. *Department of Anthropology and Geography, University of Nebraska-Lincoln, Lincoln, Nebraska,* efa@unl.edu
3. *13th Ephoreia of Prehistoric & Classical Antiquities, Ministry of Culture, Archaeological Museum of Volos, Volos, Greece,* protocol@igepka.culture.gr
4. *Department of Physics and Astronomy, University of Nebraska-Lincoln, Lincoln, Nebraska, U.S.A.,* weymouth@unlserve.unl.edu

---

Mailing address of the author to whom correspondence will be addressed:

Dr. Apostolos Sarris
Laboratory of Geophysical - Satellite Remote Sensing & Archaeo-environment
Institute for Mediterranean Studies - Foundation of Research and Technology,Hellas (F.O.R.T.H.)
Melissinou and Nikiforou Foka 130
P.O. Box 119, Rethymnon 74100, Crete, Greece
tel. ++30-831-25146, 56627, 56628, fax ++30-831-25810
mobile: 0944-789404
e-mail: ASARIS@RET.FORTHNET.GR

Keywords: Geophysical prospection, magnetics, EM, GPR, Amphorae workshop, Alonnisos.

Abbreviated Title: Geophysical Survey of an Amphorae Workshop, at Tsoukalia, Alonnisos (Greece).

---

short report.

Abstract

At Tsoukalia, Alonnisos, there are substantial remains of a 4th century BCE transport amphora production site, consisting of dense surface scatters of ceramics and kiln debris. Typological studies have shown that Tsoukalia, together with other major coastal amphora workshop centers in the area of Sporades islands, participated in a trade network extending up to the Black Sea. The archaeological investigations in the area of the workshop, initiated in 1999, included surface survey, ethnographical studies, topographic mapping, geomorphological studies and geophysical survey. Geophysical techniques included magnetic (both fluxgate gradiometer and caesium gradiometer) and electromagnetic techniques and the application of the ground penetrating radar. Geophysical prospection was employed to locate areas of specific archaeological interest and map the subsurface architectural remains of the site, enhancing the reconstruction of the diachronic land use of the site and the wider area of interest and contributing to the further understanding of the economic patterns of ancient Ikos.

Introduction

The archaeological site of Tsoukalia, located on the NW side of the island of Alonnisos (ancient *Ikos*), in the Aegean (Fig. 1a & 1b), has substantial remains of a pottery workshop, an amphora producing facility dating to the Classical/early Hellenistic period (mainly fourth century BC). It has to be mentioned that Tsoukalia in modern Greek means "pots". Amphorae were mainly used for the storage and transportation of wine, justifying the hypothesis of the existence of vineyards covering a large area of the island. The surface archaeological material consists of large piles of broken vessels, fragments of discarded amphorae and "wasters", defective products that were damaged at some stage of the manufacturing process and were not used for shipping. Most of this material has come to the surface in the last few decades from repeated disturbance looting of the extensive pottery dumps (Fig. 1c). The site was re-used for similar activities in the early 20th century, when a brick and tile factory operated there for a few years. The 4th century BC phase is the primary focus of our research. A small number of stamps on the amphora handles with the inscription IKION has been also discovered at the site (Doulgeri-Intzessiloglou and Garlan 1990:373, Athanassopoulou *et al* 1999). Similar stamps have been found in Athens, Pella and Alexandria (Doulgeri- Intzessiloglou and Garlan 1990:388, footnote 78).

The islands of Northern Sporades were important centers of wine exportation in antiquity. One of the numerous shipwrecks located in the region between Alonnisos and the nearby islet of Peristera, has been found loaded with amphorae of a very similar kind to those manufactured at Tsoukalia (Hadjidaki 1992; 1996). Pottery typological studies indicate that Tsoukalia participated in a trade network extending up to the Black Sea, and particularly the Ukraine (Doulgeri-Intzessiloglou and Garlan 1990). Furthermore, several ancient sources (Sophocles, Aristophanes, Demosthenes) mention extensive wine trade from the neighboring island of Peparithos (modern Skopelos) to the region of the Black Sea, stressing the importance of Sporades islands in the ancient transportation and trade network. In particular, two types of amphorae that were produced in the area have been identified in foreign markets.

The site of Tsoukalia has been the focus of a collaborative research project between the American School of Classical Studies at Athens and the 13th Ephoreia of Prehistoric and Classical Antiquities of the Greek Archaeological Service[1]. The archaeological investigations in the area of the workshop, initiated in 1999, included surface survey, topographic mapping, geomorphological studies and geophysical survey. The latter was carried out in two phases (1999 & 2000) in order to map subsurface targets of potential archaeological interest, which most likely could be correlated to the activities of the workshop.

Research Goals & Strategies

Topographic mapping, systematic surface survey and geophysical prospection techniques have been employed in order to locate areas of specific archaeological interest, map the subsurface architectural remains of the site and provide additional evidence of site usage.

A total station and data logger have been used to map and document the scatters of surface pottery, visible features, modern structures, roads, drainage areas etc. Intensive surface survey was carried out in a large portion of the site and provided valuable information regarding the size and volume of the operation of the amphorae workshop. The ceramic finds of the surface survey include a variety of

[1] We would like to thank the Greek Ministry of Culture for issuing the permit that enabled us to carry out our research. We would also like to thank the 1984 Foundation, the University of Nebraska Foundation and the Mayor of Alonnisos for providing grants and other support to our project. Finally, we would like to thank S. Topouzi, A. Giourou, V. Kevgas, Ch. Karathanasis and F. Triantafyllidis who participated in the geophysical fieldwork activities.

forms. There is a large number of amphora fragments and a few other forms of discarded vessels.

Preliminary geomorphological study by Dr. Kabouroglou (Ephoreia of Caves and Paleoanthropology, Greek Archaeological Service) is also under progress. Comparative analysis of amphora fragments and clay sources in the vicinity of the site is currently under progress by Dr. Ian Whitbread, of the Fitch Laboratory of the British School of Archaeology at Athens, aiming towards the composition characterization of pottery products and the corresponding clay sources.

A geophysical survey, conducted by the Laboratory of Geophysical-Satellite Remote Sensing & Archeo-environment of the Institute for Mediterranean Studies/Foundation of Research & Technology, Hellas, covered a large portion of the site aiming towards the mapping of the subsurface remains. The agenda of the project used a suite of shallow-depth high-resolution geophysical prospection techniques (Fig. 1) for identifying and locating features related to the workshop activities of the site (Sarris *et al* 2000). Geophysical techniques included magnetic and electromagnetic techniques and the application of ground penetrating radar. High-resolution vertical magnetic gradient techniques covered an area of more than 6,000 m^2. Caesium gradiometer readings (in both vertical and horizontal orientation) were taken above candidate targets to improve their information context. Part of the site was also explored by electromagnetic measurements with both vertical and horizontal orientation of coils. Finally, a number of experiments have been conducted with ground penetrating radar.

The above studies aim towards the reconstruction of the diachronic land use of the site. The primary goal of our research program is to understand the economic patterns of Classical/Early Hellenistic Ikos in relation to amphora production, agriculture and trade, which were co-ordinated activities and most likely formed the central part of the island economy (Athanassopoulou, *et al*, 1999).

Geophysical Prospection Survey

Since Tsoukalia has distributions of pottery wasters and presumably contains one or more pottery kilns, magnetic methods were considered ideal for the detection of such targets. Structures affected by intensive burning, such as hearths, burnt buildings, kilns and ovens are characterized by thermoremanent magnetization (TRM), as well as enhanced magnetic susceptibility, and as a result they are easily detected in a magnetic survey (Weymouth, 1986: 4; Aidona, *et al.*, 2001). A number of examples have been reported in the past regarding the detection of pottery, especially transport amphora production centers throughout the Mediterranean (Sarris & Jones, 2000), by locating the -often fragmentary- kilns e.g. Byzantine (Gunsenin 1994) and Sinopean amphorae (Drahor 1996) in Turkey and Thasian amphorae (Jones 1986) in Greece. Even small sized Minoan kilns, for example in Chamalevri, Crete (Sarris, 1998) and highly fragmentary metallurgical sites, for example in Cvinger, Slovenia (Music and Orengo 1998), have been successfully identified by magnetic techniques. Thus, it was decided that magnetic methods were the most appropriate for the particular survey due to the targets sought (kilns, pottery dumps, etc).

The site was also surveyed by electromagnetic (EM) techniques measuring both soil conductivity and soil magnetic susceptibility. The penetration depth of the EM techniques is larger than that corresponding to magnetic techniques, reaching a depth of 4-6m, below the surface. Since the topography of the site exhibited a large variation in elevation, mainly due to alluvium deposits by a nearby creek and erosion effects, it was decided that EM techniques could be used as a supplementary technique, in order to provide additional evidence on the targets sought and to investigate the existence or absence of deeper archaeological relics.

The 1999 geophysical survey was carried out in different regions of the site, mainly east of the dirt road, where there was evidence of the maximum surface concentration of pottery fragments, possible kiln remnants and a disturbed pottery dump. A total of 24 grids of various dimensions (Fig. 2) were surveyed here. Another grid was surveyed in the west section of the archaeological site, close to the sloping side of a small hill, where concentration of pottery fragments was also significant. In the 2000 field survey season, geophysical investigations expanded to the north and southwest. Another grid, located to the south, on the top of a small hill, was laid out in an area where large stone blocks have been found, suggesting the existence of architectural relics.

A Geoscan FM36 fluxgate gradiometer (0.5m distance between the sensors), a Scintrex Smartmag SM-4G caesium gradiometer (0.5m distance between the sensors) and a Geonics EM31 conductivity meter were employed for measuring the vertical magnetic gradient, the horizontal or vertical difference of the total magnetic field intensity and the soil conductivity/magnetic susceptibility correspondingly. Measurements were carried out with a sampling interval of 0.5m in magnetic surveys for both East and North directions. Some experiments with the fluxgate gradiometer were conducted with sampling interval of 0.25m to achieve a higher resolution. Electromagnetic measurements were taken every 1m, along transects 1m apart.

Increased noise levels were recorded at specific areas due to the presence of modern structures, metal fences and barrels, ceramic concentrations, old secondary soil deposits, etc. Most regions were covered by at least two techniques, fluxgate gradiometer and electromagnetic, in order to increase the confidence levels of the detected anomalies. Finally, an EKKO 1000 ground penetrating radar was employed in specific sites of interest to provide additional data with respect to previously detected targets.

Vertical Magnetic Gradient

The mosaic of the geophysical measurements was created, based on the statistical analysis of the common rows of the adjacent grids (Fig. 3). Selective despiking, compression of the dynamic range of values, kriging interpolation and the application of directional derivatives were systematically used to enhance anomalies of interest. Processing of the data was successful in removing the extreme values originated by the existence of surface features and modern constructions, recognizing linear features and pinpointing the most intensive anomalies of interest. Surface features were coded and superimposed on the maps of the geophysical data. A diagrammatic representation of the magnetic anomalies appears in relation to the magnetic gradient map (Fig. 4).

In the east section of the surveyed area, the magnetic data show a linear diagonal anomaly (A11) that represents a terrace (1m high) and a central noisy region (A1-A3) which is located at the same area where a couple of ancient building blocks have been found on the surface (possibly re-used). The terrace runs from approximately x=990E, y=25N to x=998E, y=35N. Some of the isolated anomalies (A8 & A9), which are present in the magnetic data, are most likely caused by metal fragments. Another linear anomaly (A16) runs in a south to north direction. The latter seems to turn to the east, extending in a west to east direction (anomaly A15). It is suggested that anomalies A15 and A16 are caused by the traces of an older fence, probably used together with the terrace A11 as an enclosure for animals. Shepherds have utilized the site almost continuously in the last few decades.

A prominent anomaly lies in the southern section of the site and extends in a diagonal direction from south to north. This anomaly shows evidence of a large buried structural feature, of strong magnetic signal, consisting of three compartments (A20a, A20b & A20c). The outline of the feature exhibits a negative magnetic gradient and the inner region shows a strong positive magnetic gradient signature. It is suggested that this target is related to a kiln structure of dimensions 22mx5m, the southern section of which was exposed and used as a garbage pit in the most recent years. Nevertheless, it remains uncertain if the specific kiln is dated to the classical period or if it is related to more recent activities (a small scale brick factory was operating in the region during the beginning of the 20th century).

To the west of the suspected kiln structure, anomalies A21, A22 and A23 are probably related to the activities of the workshop in connection to the kiln A20. Directional derivatives suggested the existence of a linear feature A23 running almost parallel to the outline of the kiln (A20).

A high magnetic anomaly (A29), which extends over an area of approximately 10m x 5m, is located close to a disturbed dump (anomaly A31), which was filled with pottery fragments. The application of high pass filtering and directional derivatives (Fig. 5) has indicated a number of linear features in the particular region running in a west to east and south to north directions, suggesting that anomaly A29, together with A27 and A30, may be caused by the relics of a kiln structure. It is probable that the candidate target is badly preserved as it is located at the edge of a high elevation plateau of the site and thus it may have been exposed to the erosive effects of the sea, wind and the nearby hill slopes.

Further to the north, anomalies A39 and A40 suggest the presence of two well-preserved structures. These potential targets are located on the lower slopes of the hill, close to the coast, with an orientation to the west. The distribution of ceramic sherds in the northern section of the surveyed area (x=1020-1030E, y=120-150N) was mainly responsible for the noisy magnetic signals that were registered in the specific region. Part of this area (anomaly A37), was systematically surveyed by archaeologists, who measured the density and the mass of ceramics in a 12x9 grid. The dense ceramic spread in the lower slopes of the hill has been found to continue upwards, suggesting that there are even more structures in the higher slopes of the hill. A similar ceramic debris, originating by erosion of the disturbed pottery dump (A31), may have caused the noisy signals in the surroundings of A31, as well as the higher magnetic values in the area of anomaly A34.

The variation of the magnetic data with respect to elevation indicates that the strongest signals come from the central section of the surveyed region, which is away from the sloping sides of the nearby hill and thus with the least soil deposits. Furthermore, a comparison of the magnetic signals between the northern and SE part of the surveyed area, both of which are located close to the slopes of the hill, indicates a smoother background signal in the SE section, suggesting an absence of fired debris in place or uphill.

In the SW section of the surveyed area, four grids were located next to a small creek leading to the sea. The area had been leveled due to construction works for building a residential house close to the coast. A few linear anomalies (A42, A43 & A44) have been identified in the specific region. Anomaly A42 corresponds to the location of ceramic concentrations and wall remnants (close to the surface). Close to the dirt road, magnetic measurements identified a rectangular anomaly (A41) of dimensions 15m x 5m, together with some internal characteristics (firehearth?). The candidate structure is located SW of the disturbed pottery dump (A31). The existence of the dirt road and a metal fence prevented the expansion of the survey to the north. Still, geophysical data suggest that the workshop activities were taking place within most of the surveyed area.

Caesium Magnetic Techniques

An area of 10m x 10m, above anomaly A29 (x=983-993E, y=97-107N), was investigated in detail, using both the fluxgate gradiometer (sampling interval of 0.25m in both directions in automatic mode) and the caesium gradiometer (sampling interval of 0.5m in both directions in manual mode). The vertical mode of the caesium gradiometer (lower sensor height 0.30m) resulted in similar images of the subsurface target as those produced by the high-resolution vertical magnetic gradient survey (Fig. 6) suggesting that the specific target is characterized by a more or less uniform spread of relics.

Similar work has been carried out at certain portions of grids G9 and G10 (x=962-982E, y=55-73N), which were surveyed by a caesium gradiometer in horizontal (at a 1m height) and vertical gradient mode and the FM36 fluxgate gradiometer, with various sampling intervals (0.25-1m), to test the repeatability of the magnetic results and to provide a finer detail of the candidate kiln structure. All measurements confirmed the existence of a three-compartment anomaly of dimensions approximately 22m x 5m, extending in a diagonal direction, with its long axis aligned north to south (Fig. 7).

Electromagnetic Survey

With the exception of the high conductivity values caused by the ceramic fragments content of the disturbed dump (A31) and the organic filling of the depression at A20c, electromagnetic data exhibit a general trend with decreasing values from a west to east direction (Fig. 8). This trend is mainly due to the geomorphology of the site: conductive alluvium deposits to the SW and NW section (due to a small creek to the west and the coast to the north) and resistive rocky slopes of a hill to the east section. Naturally, a better correlation with the magnetic data is achieved by the compression of the dynamic range of the in-phase mode (proportional to the soil magnetic susceptibility).

A small experiment that was carried out in grids G9 and G10 (x=965-982E, y=45-73N), measuring both the soil conductivity and the soil magnetic susceptibility in the vertical and horizontal orientation of coils, produced a strong signal between A20b and A20c (Fig. 9). Although the inner details of the target were difficult to be mapped due to the large spacing of the EM31 coils, electromagnetic survey suggested that the candidate target extends more than 1-2m below the current surface.

Ground Penetrating Radar

A portion of grids G9 and G10, right above the area where the kiln structure has been detected by the magnetic survey, was also prospected by ground penetrating radar (EKKO 1000) with antennas of 450 and 225MHz. Twelve parallel traverses, 1m apart, were scanned in a NW to SE direction using the 225MHz antenna. A smaller portion of the same region (nine traverses) was surveyed with the 450MHz antenna (Fig. 10).

All GPR traverses were processed systematically using an average envelope amplitude filter, a 3-point noise filter, a 5-trace background subtraction window and a 2-trace horizontal smoothing filter. A high pass dewow filter and an automatic gain control (max=500) were also applied for enhancing the original data. The first break point of each transect was calculated and it was used for shifting the traces of each traverse to the corresponding timezero datum. Further processing included the removal of background noise, migration and envelope filtering. After processing, all transects were combined to create vertical time (or depth) slices.

For the 225MHz antenna, ten equally spaced time slices (5.6nsec average width) were produced for traces from 0-55.6nsec. Time slices (3.3nsec width) up to the first 33.2nsec for the data collected by the 450MHz antenna were even more informative (Fig. 11). A diagonal shaped anomaly was indicated for times from 13.3-23.2nsec, corresponding to the diagonal wall of the kiln. Reflection signals are also registered from the interior and exterior (to the west) of the kiln structure, suggesting remnants of collapsed walls. The exterior reflections correspond well with the magnetic anomaly A23, which seems to run parallel to the western wall of the kiln structure. Taking in account the composition of the soil (alluvium deposits containing silts and clays) and a typical velocity of 0.06m/nsec, it has been estimated that the kiln structure extends within a depth range of 0.8-1.6m below the surface.

Time slices were overlaid horizontally and their superposition with other perpendicular and diagonal slices has been successful in showing the continuation of the reflection anomalies that correspond to the walls of the kiln structure (Fig. 12a). Slices were also combined to produce a 3 dimensional volumetric model of the reflection anomalies. A variable opacity has been used for the better visualization of the model (Fig. 12b). The 450MHz antenna produced a much better model than the 225MHz antenna, corresponding well to the results of the magnetic survey. The combination of time slices from 19-26nsec with the volumetric model shows clearly the extension of the walls of the kiln, with particular emphasis on the northern part of A20 (A20a).

Final Remarks

Archaeological survey, ethnoarchaeological studies, geophysical mapping and geomorphological studies enhanced the reconstruction of the diachronic land use of the site and the wider area of interest. The comparative use of magnetic, soil conductivity and ground penetrating techniques was crucial in the interpretation of data. The geophysical maps located a number of features related to the workshop activities, such as kilns, the extent of pottery dumps, structural remains, etc. Two possible kiln structures, one of which seems to be in a well-preserved condition, were identified among other candidate targets. Ground penetrating radar data were used for constructing a volumetric model of the kiln structure, indicating the extent of its walls. Three more architectural features were also identified in the central section of the surveyed region and in the lower slopes of the northern hill. The workshop seems to extend over most of the surveyed region, suggesting large-scale activities.

The well-preserved archaeological material of Tsoukalia is expected to yield a wealth of information on economic patterns of the specific time period, since amphora production, agriculture and trade were activities that were co-ordinated and most likely formed the central part of the island economy. The site of Tsoukalia is quite exceptional in that regard because it offers a rare opportunity to study the technology and scale of amphora production and wine export. Within this framework of research, the goal is to develop a model of how estate based agriculture would be structured on classical Ikos and how it would be related to the amphora workshop at Tsoukalia. The archaeological project at Tsoukalia will contribute towards an understanding of the economy that supported a minor classical polis, ancient Ikos. It will provide a new perspective on the role of small city-states and rural sites. Such minor polities, although spatially remote, were interconnected and interacted closely with the political and economic centers of the mainland.

References

Aidona, E., Sarris, A., Kondopoulou, D. & Sanakis, Y. (2001). Application of Magnetic and Spectrometry Methods in the Detection of Human Activity in Soils: A Case Study at the Archaeological Site of Kitros (Northern Greece), *Journal of Archaeological Prospection*, No 8, pp. 187-198.

Athanassopoulou, E. F., Doulgeri-Intzessiloglou, A. & Skafida, E. (1999). Amphora production, agriculture and trade: the Alonnisos Archaeological Project, Greece, *101st Annual Meeting of the Archaeological Institute of America*, Dallas, Texas.

Drahor, M. G. (1996). A large scale geophysical prospection on the Acemhoyuk and magnetic research on the amphorae workshop sites at the Sinop region – Turkey. *1st Congress of the Balkan Geophysical Society*, 64. Athens, Greece.

Doulgeri-Intzessiloglou, A & Garlan, Y. (1990). Vin et amphores de Peparethos et d'Ikos, *Bulletin de Correspondance Hellenique* 114:361-394.

Gunsenin, N. (1994). Ganos: resultats des campagnes de 1992 et 1993. *Anatolia Antiqua. Eski Anadolu III,* Institut Francais D'Etudes Anatoliennes D'Istanbul 166-178.

Hadjidaki, E. (1992). Anaskafi se klassiko nauagio stin Alonisso (5os ai) (Excavation of a classical shipwreck in Alonnisos (5th c.). *Enalia* IV (1/2) 16-25.

Hadjidaki, E. (1996) To nauagio tis Peristeras (The shipwreck of Peristera). *Kathimerini*, Epta Imeres, 27:175-177.

Jones, R.E. (1986). Geophysical prospection at amphora production sites on Thasos. In Empereur, J.Y. and Garlan, Y. (eds.) *Recherches sur les Amphores Grecques. Bulletin de Correspondance Hellenique Supplement XII*, Paris, 279-285.

Music, B. and L. Orengo. (1998). Magnetic investigation of the Iron Age Iron-smelting complex at Cvinger near Mineska vas. *Arheoloski vestnik* 49: 157-86.

Sarris, A. (1998). Geophysical issues in archaeological research: paradigms, uncertainties & inferences, invited talk at *the International Symposium on Remote Sensing in Archaeology*, Boston University, Boston, U.S.A.

Sarris, A., Gkiourou, A., Kevgas, V., Topouzi, S., Karathanasis, Ch., Athanassopoulou, E., Intzessiloglou, A., Skafida, L., & Weymouth, J. (2000). Geophysical Mapping of an Ancient Amphorae Workshop at Tsoukalia, Alonissos (Greece), *32nd International Symposium on Archaeometry (Archaeometry 2000),* Mexico City, Mexico.

Sarris, A. & Jones, R. (2000). Geophysical and Related Techniques Applied to Archaeological Survey in the Mediterranean: A Review, *Journal of Mediterranean Archaeology*, (Sheffield: Sheffield Academic Press, Ltd.), 13/1:3-75.

Weymouth, J. W. (1986). Geophysical methods of archaeological site surveying. In Schiffer M.B. (ed.) *Advances in Archaeological Methods and Theory* (New York: Academic Press). 5: 311- 395.

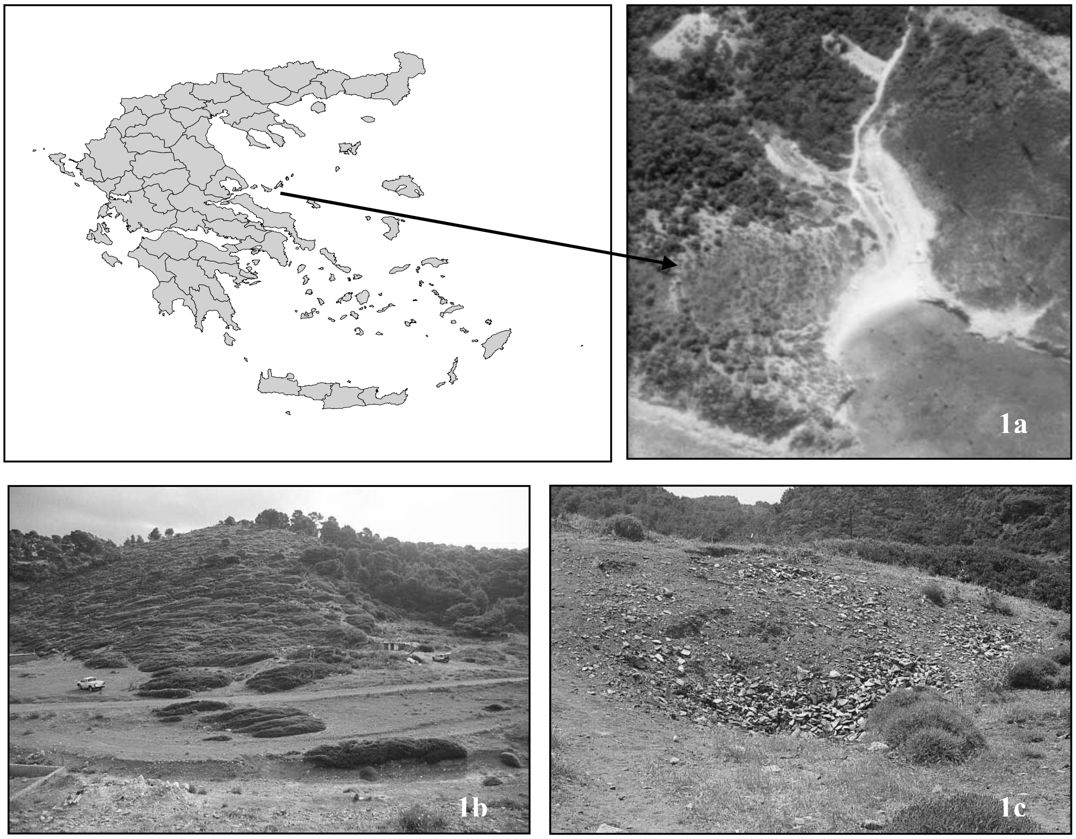


Figure 1. (a) Aerial imagery of the archaeological site of Tsoukalia, Alonnisos, (b) Photo of the extent of the site, (c) An open pit area containing numerous fragments of discarded amphorae.

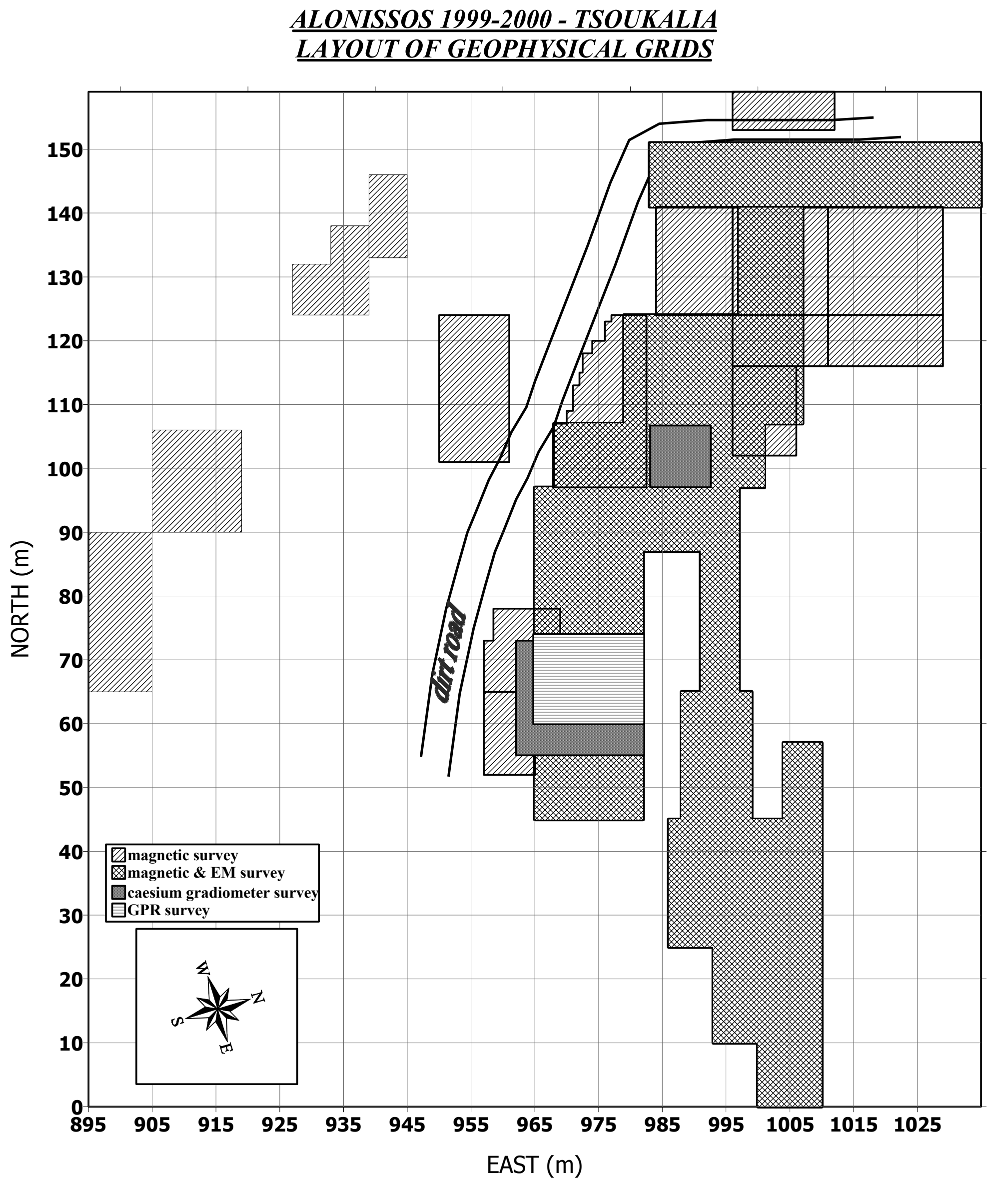


Figure 2. Topographic layout of the geophysical grids and survey method coverage.

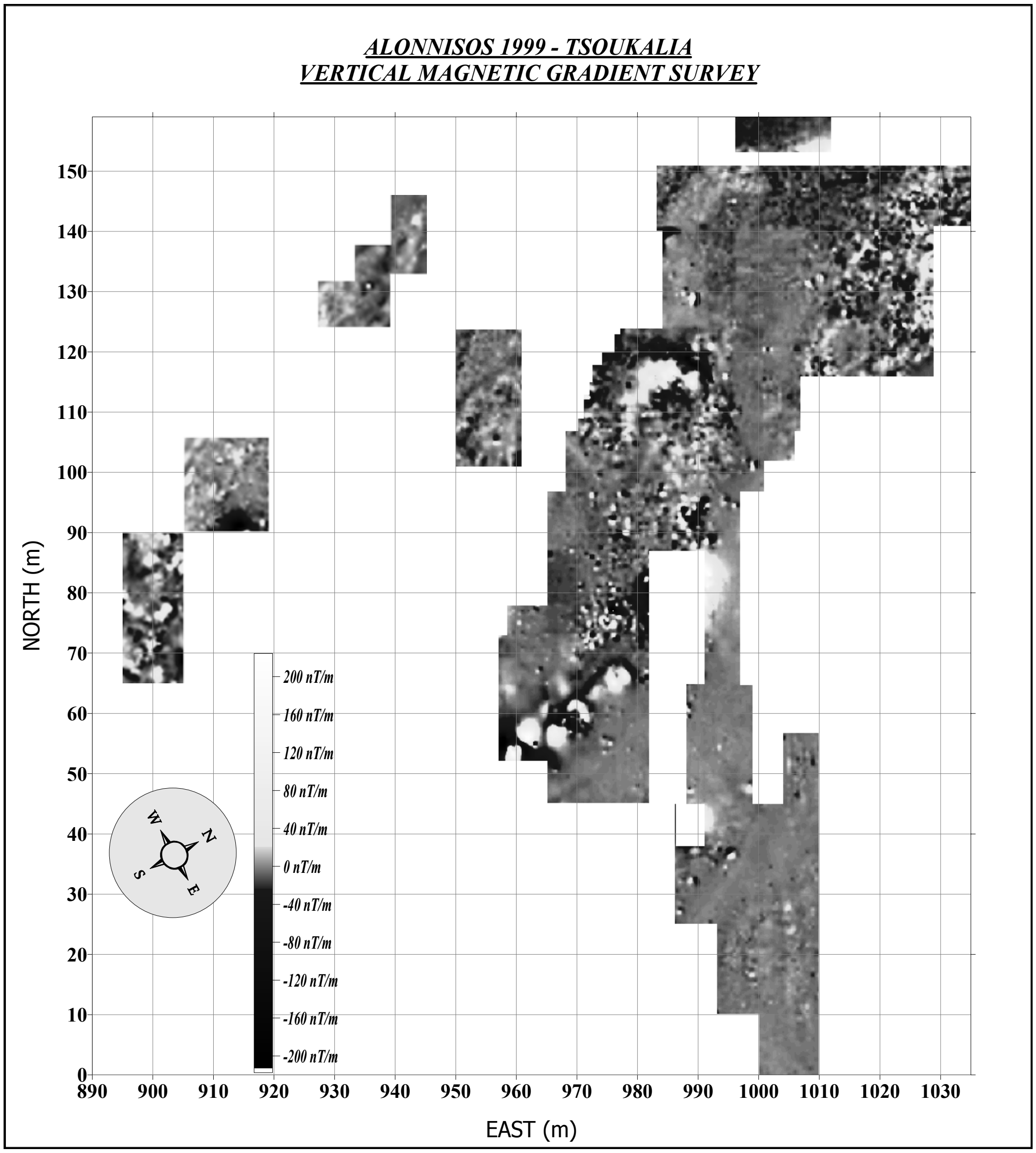


Figure 3. Results of the vertical magnetic gradient survey.

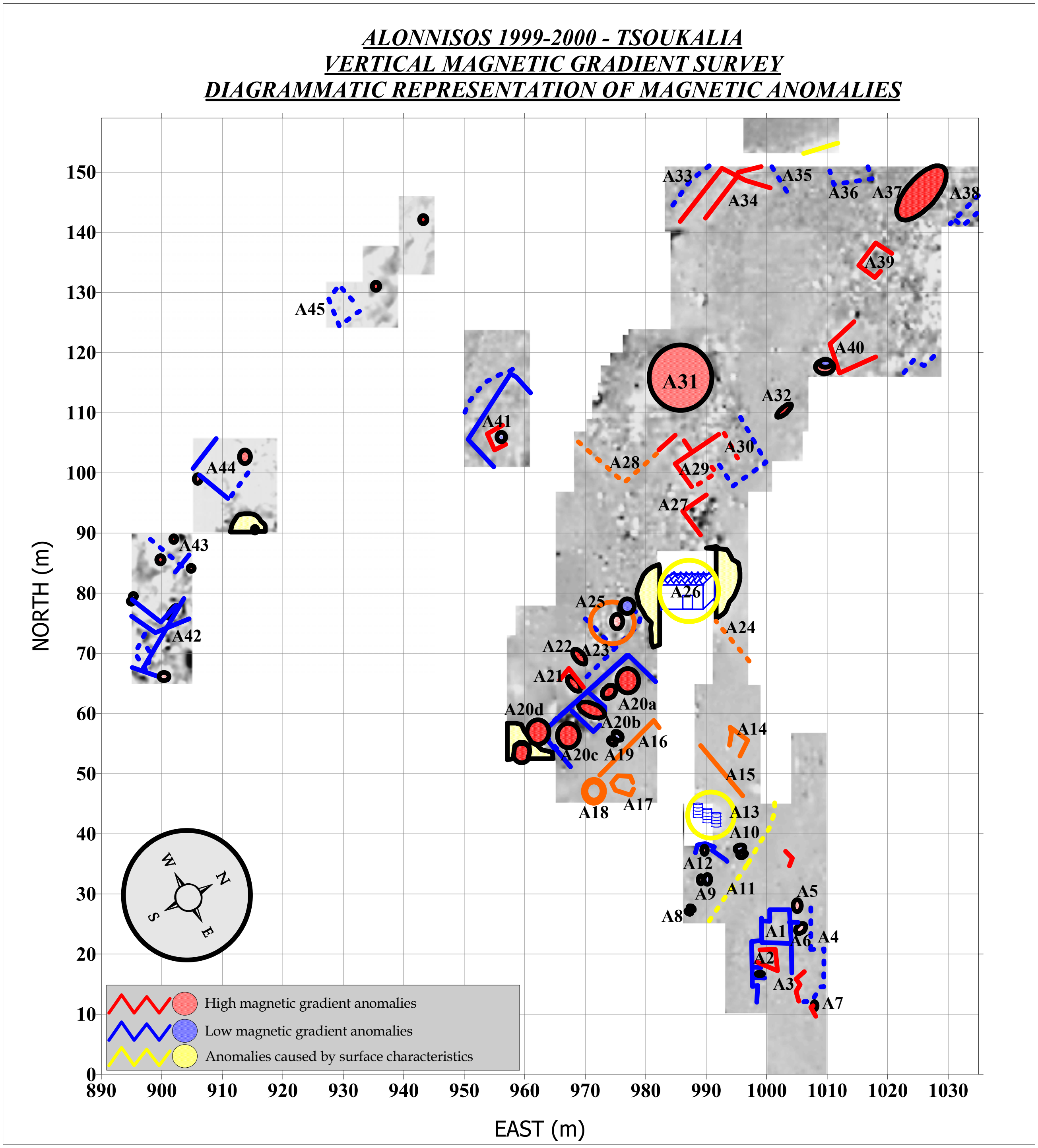


Figure 4. Diagrammatic representation and coding of the magnetic anomalies.

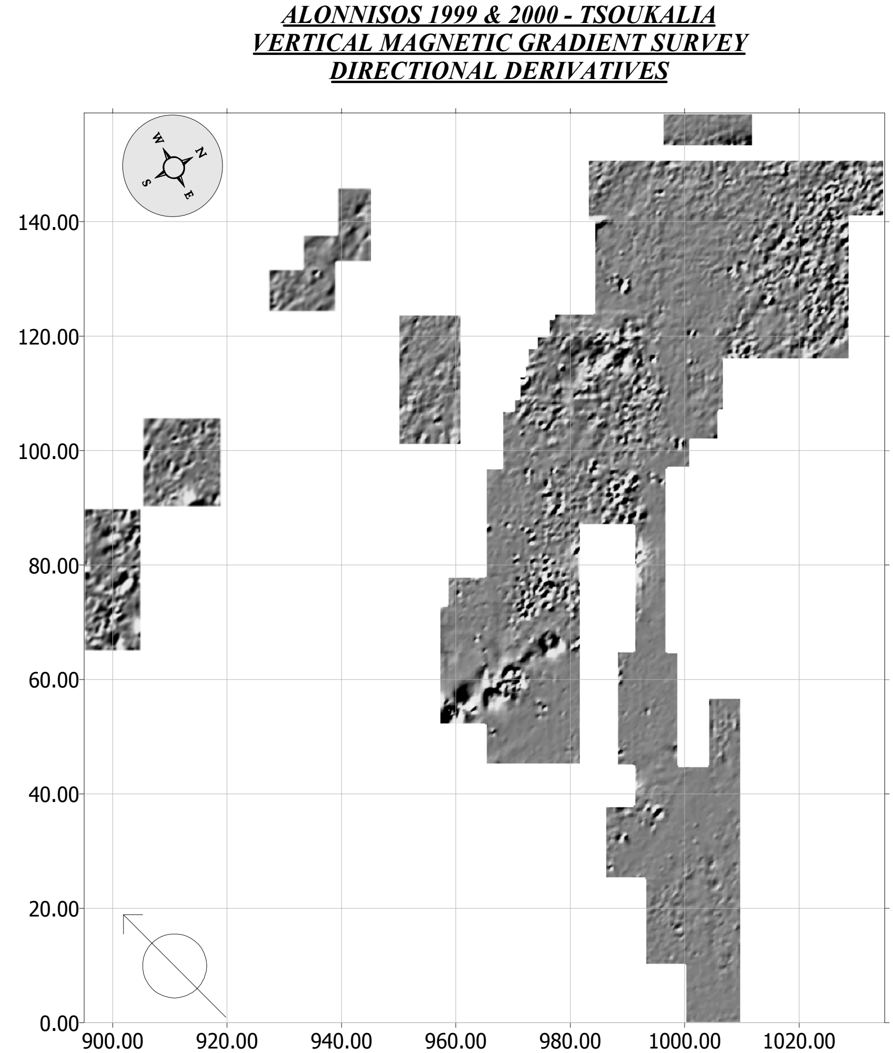
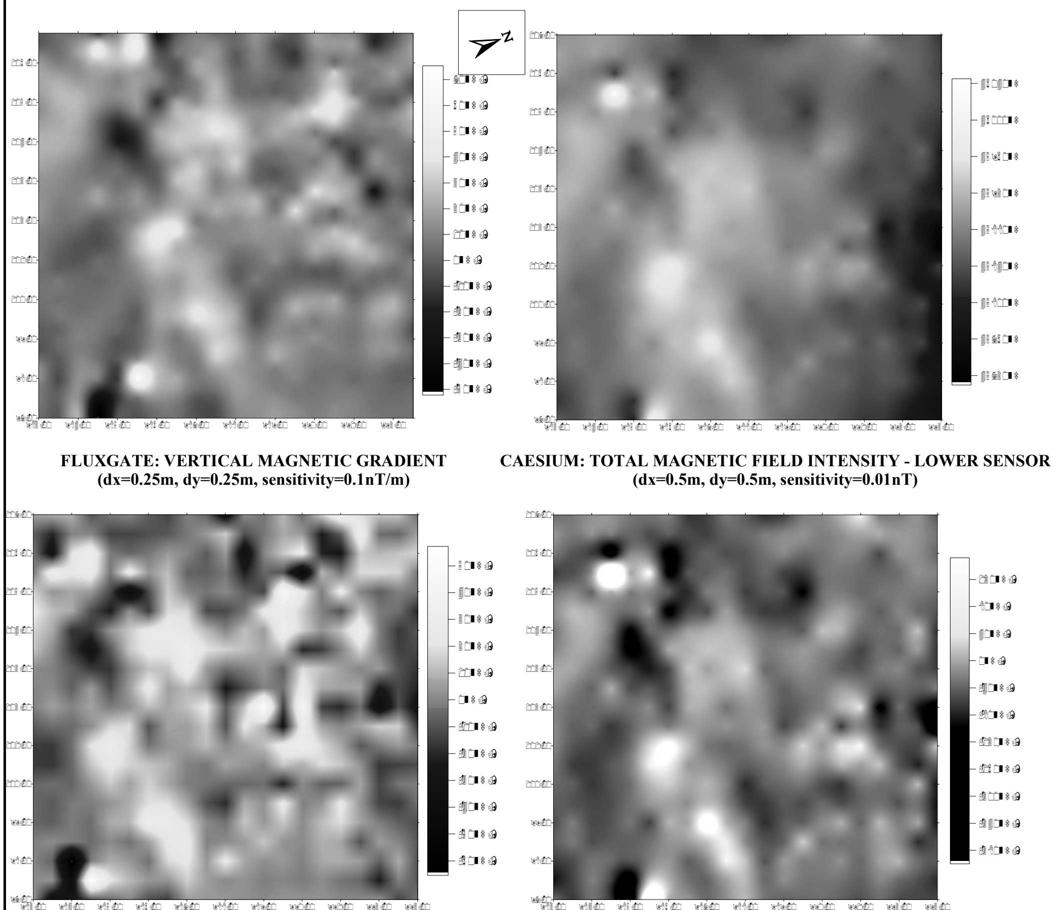


Figure 5. Effect of directional derivatives to the vertical magnetic gradient data. The computation of directional derivatives is capable of emphasizing linear anomalies extending in a direction perpendicular to the direction of the derivatives. Direction of the algorithm is shown in bottom left square.

ALONNISOS 1999-2000 - TSOUKALIA
MAGNETIC SURVEY - DETAILS OF GRID 17



FLUXGATE: VERTICAL MAGNETIC GRADIENT
(dx=0.25m, dy=0.25m, sensitivity=0.1nT/m)

CAESIUM: TOTAL MAGNETIC FIELD INTENSITY - LOWER SENSOR
(dx=0.5m, dy=0.5m, sensitivity=0.01nT)

FLUXGATE: VERTICAL MAGNETIC GRADIENT
(dx=0.5m, dy=0.5m, sensitivity=0.1nT/m)

CAESIUM: TOTAL MAGNETIC FIELD GRADIENT - VERTICAL MODE
(dx=0.5m, dy=0.5m, sensitivity=0.01nT)

Figure 6. Results of high-resolution magnetic experiments in the area of grid G17, over anomaly A29 (x=983-993E, y=97-107N).

TSOUKALIA - MAGNETIC SURVEY: DETAILS OF THE CANDIDATE KILN

FLUXGATE: VERTICAL MAGNETIC GRADIENT
(dx=0.25m, dy=0.25m, sensitivity=0.1nT/m)

CAESIUM: TOTAL MAGNETIC FIELD INTENSITY GRADIENT
(dx=0.5m, dy=0.5m, sensitivity=0.01nT/m)

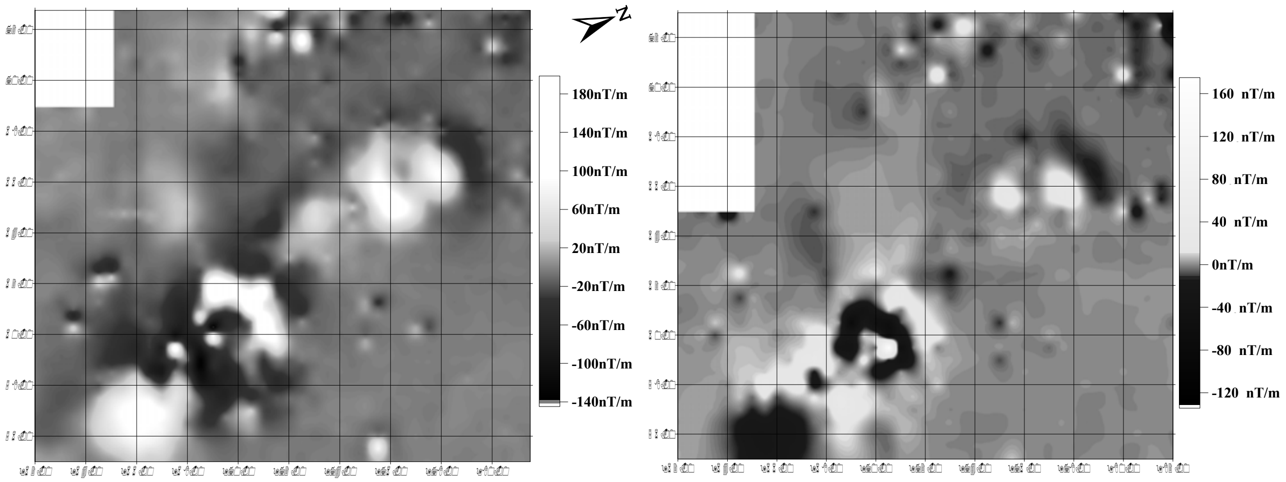
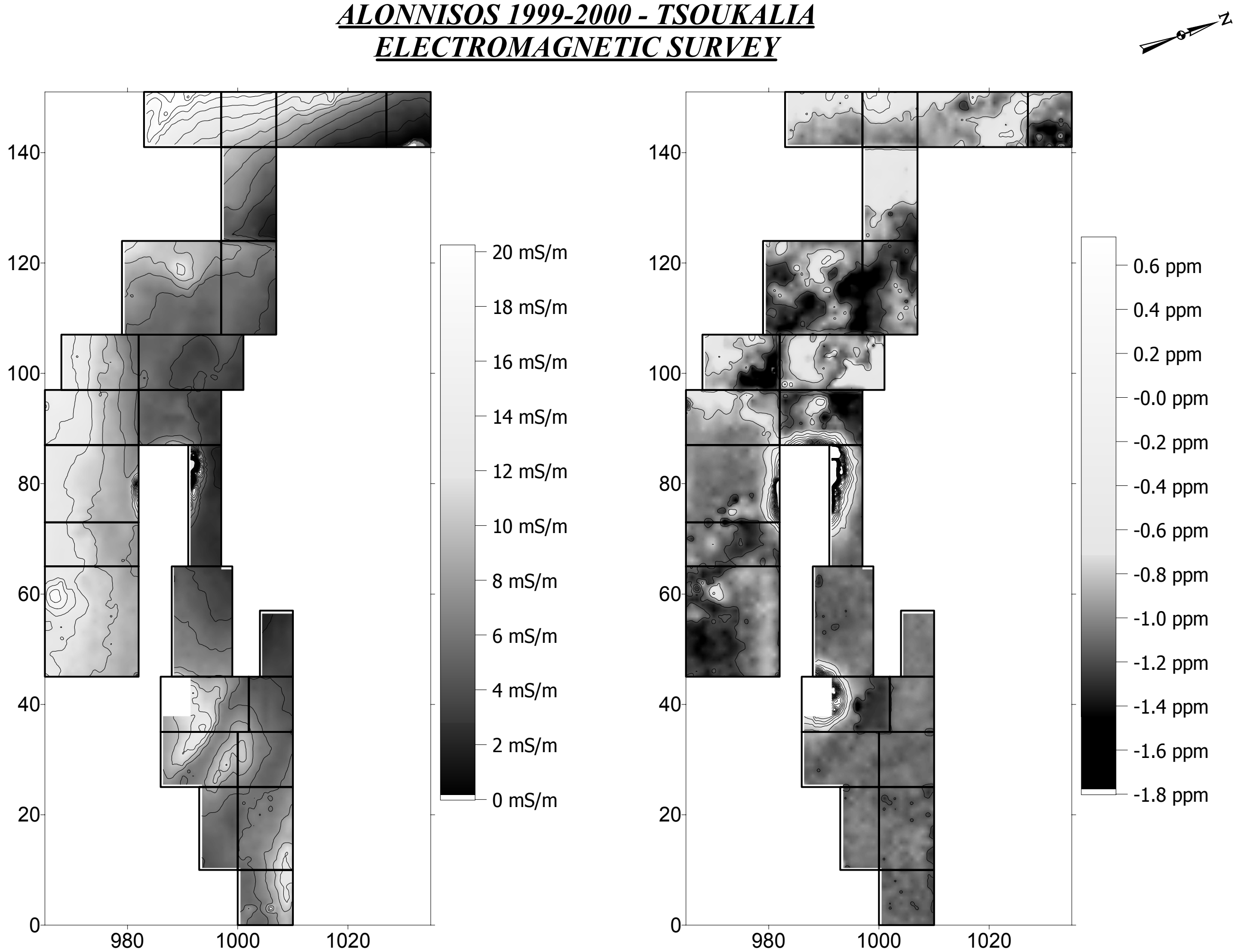


Figure 7. Comparison of the results of high-resolution magnetic (caesium & fluxgate gradiometer) experiments in the area of grid G9&G10 (x=962-982E, 55-73N). The suspected kiln structure is registered in all methods.

ALONNISOS 1999-2000 - TSOUKALIA
ELECTROMAGNETIC SURVEY



EM31: Quadrature Phase
Dynamic Range: 0, 20 mS/m
(Soil Conductivity)

EM31: In-Phase (Raw Data)
Dynamic Range: -1.8, 0.6 ppm
(Soil Magnetic Susceptibility)

Figure 8. Results of the Geonics EM31 electromagnetic survey, measuring both the quadrature (left) and in-phase (right) modes.

TSOUKALIA, ALONNISOS
VERTICAL MAGNETIC GRADIENT & ELECTROMAGNETIC SURVEYS ABOVE THE SUSPECTED KILN

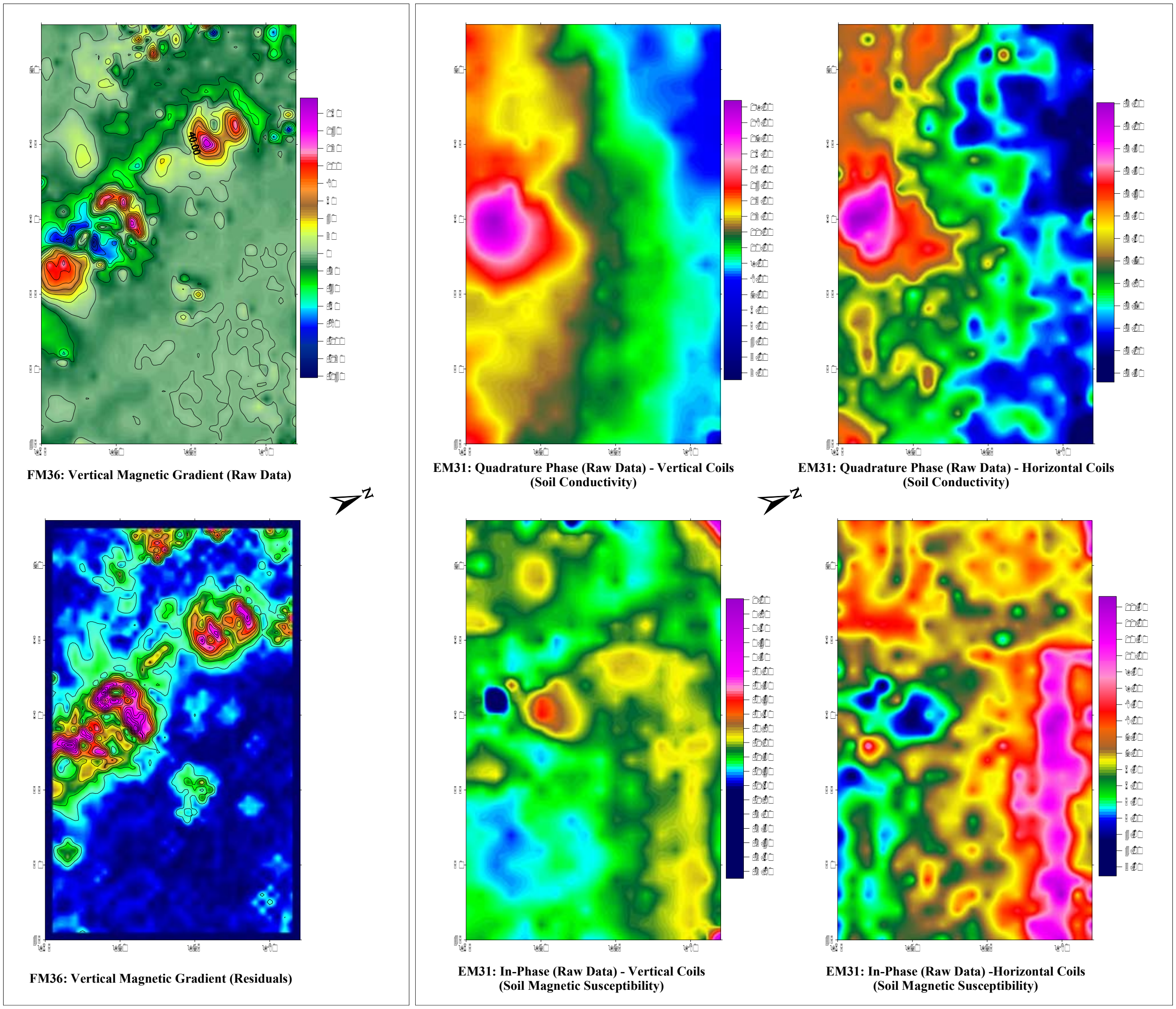


Figure 9. Comparison of magnetic data (left maps) to the corresponding electromagnetic measurements - in both vertical and horizontal components - for grids G9 and G10 (above the kiln: x=965-982E, y=45-73N).

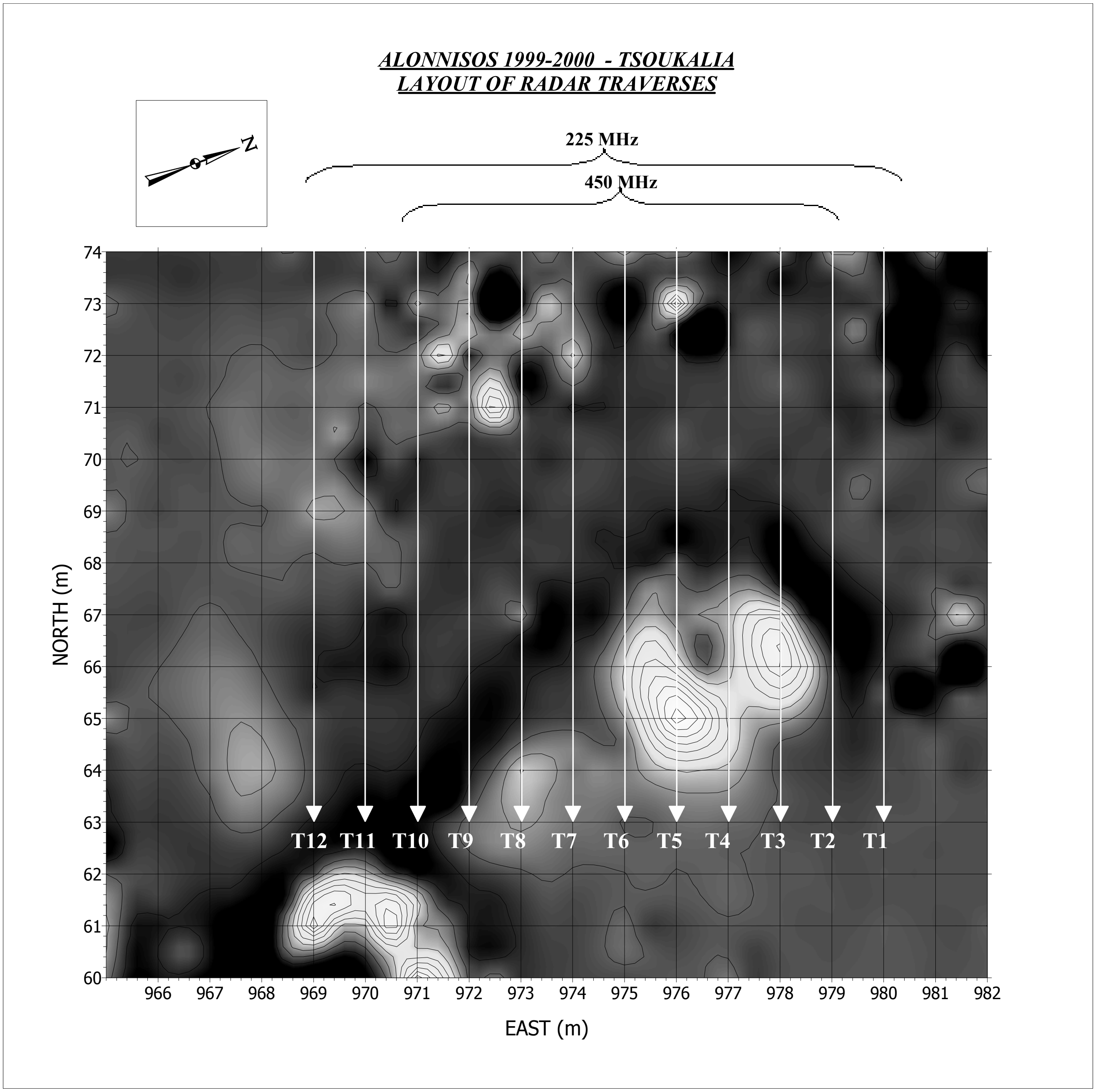


Figure 10. Layout of the ground penetrating radar traverses above the kiln structure. The traverses' layout has been superimposed on the vertical magnetic gradient map of the same region.

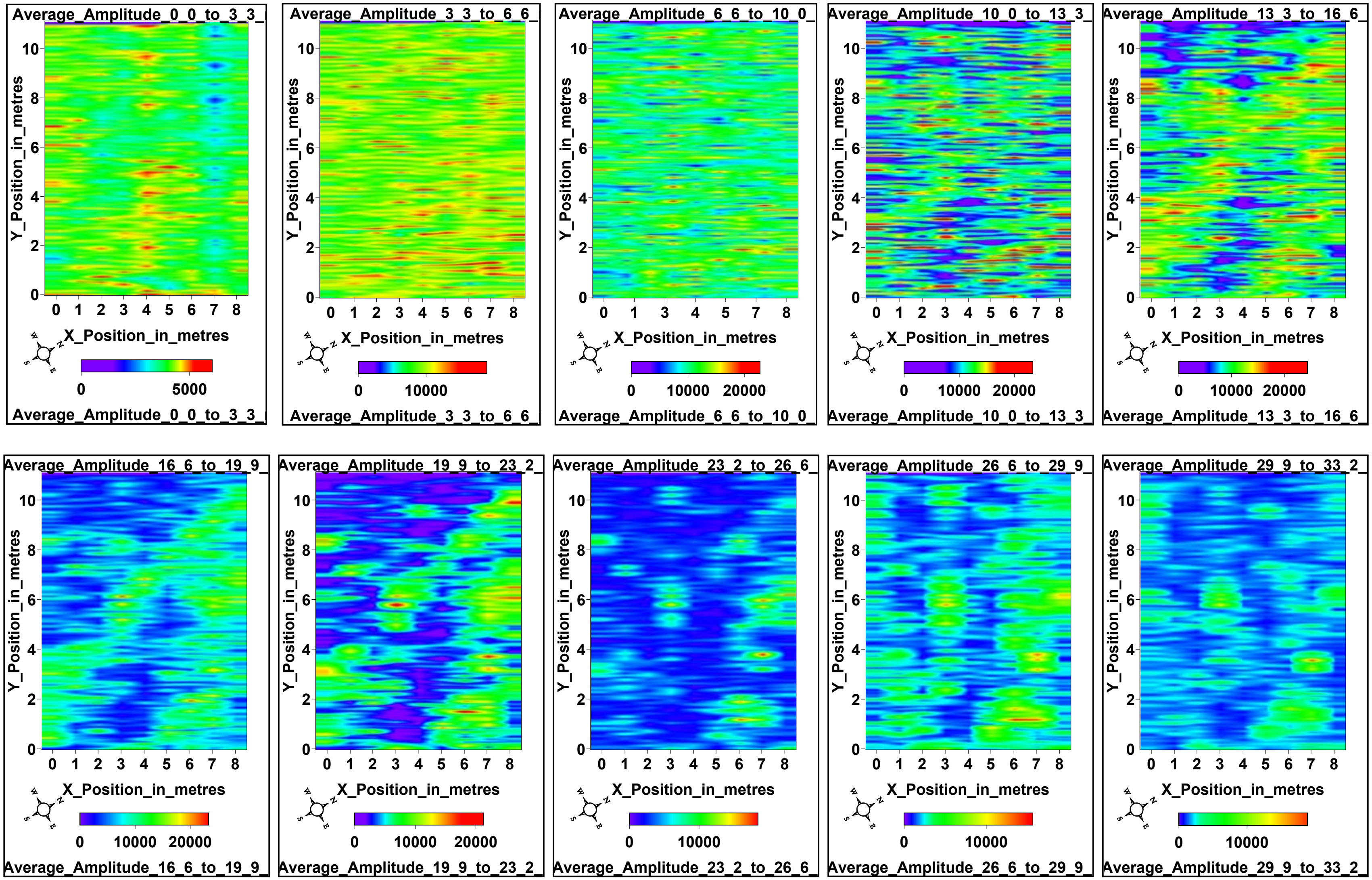


Figure 11. Time slices (3.3nsec width) up to the first 33.2nsec for the data collected by the EKKO-1000 450MHz antenna

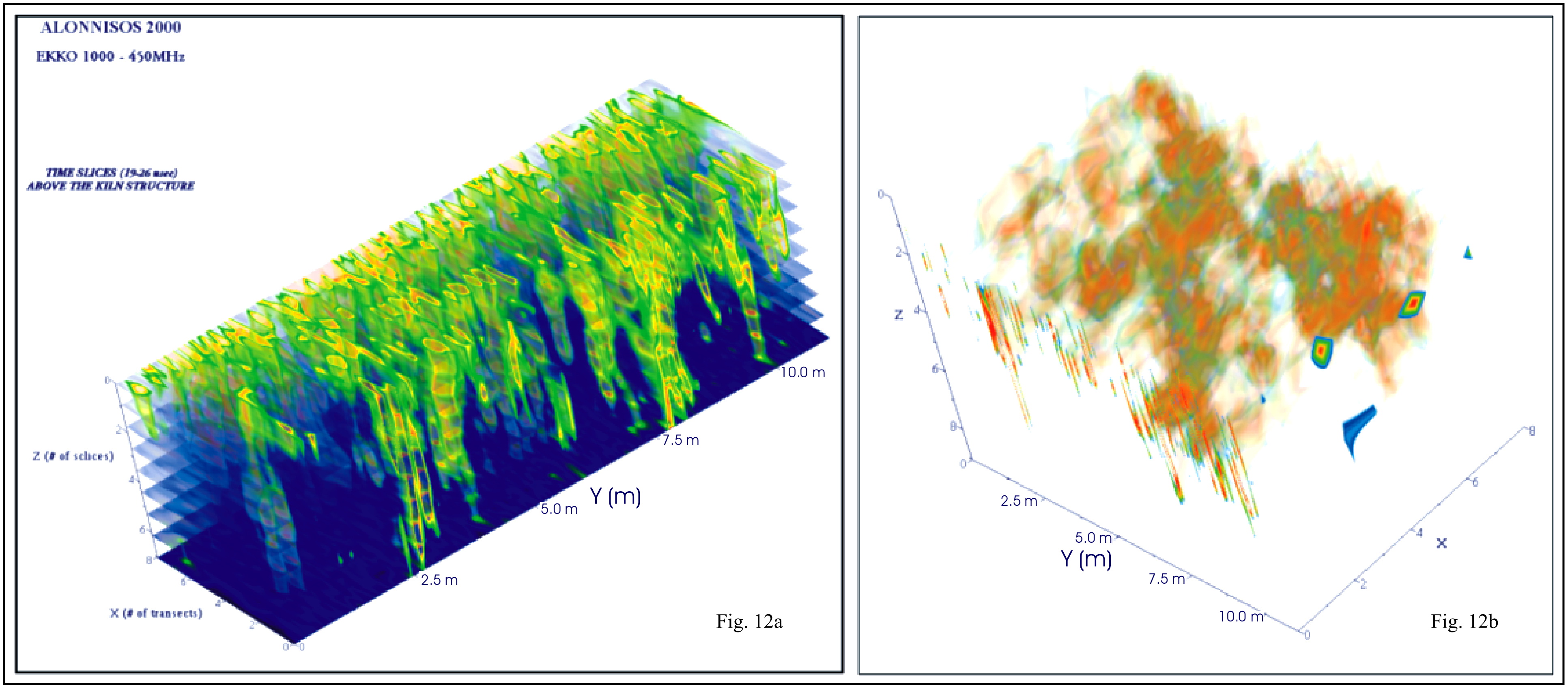


Figure 12. Three-dimensional visualization of the ground penetrating radar slices using isosurface volumetric modeling. Nine parallel time slices of 3.3nsec width (12a) were combined to produce a 3D volumetric model (12b) of the suspected kiln structure.