

## COMPARISON OF A PROTON AND A RUBIDIUM MAGNETOMETER FOR ARCHAEOLOGICAL PROSPECTING

BY E. K. RALPH

*University Museum, University of Pennsylvania*

During the past four years, surveys with the Elsec portable proton magnetometer<sup>1</sup> have been conducted by members of the ASCA (Applied Science Center for Archaeology) staff of the University Museum, University of Pennsylvania, Philadelphia. These have been carried out at both archaeological and historical sites, 15 in all, in 6 different countries<sup>2</sup>. Among these the most comprehensive program has been the search for the ancient Greek city of Sybaris in southern Italy<sup>3, 4</sup>. In addition to the challenge of finding this site of former luxury and fame, the plain of Sybaris affords an ideal testing ground for instruments based on the principle of magnetic detection. Remnants of the classical periods—that of the 6th century B.C. Sybaris, the later Greek Thurii, and the subsequent Roman Copia Thurii—have been buried by meters of homogeneous alluvial clay that is very slightly magnetic.

As a result of the surveys conducted in 1961, 1962, and 1963, it was apparent that buried structures of sufficient mass which extended upward to within one to three meters of the surface could readily be detected with the proton magnetometer.

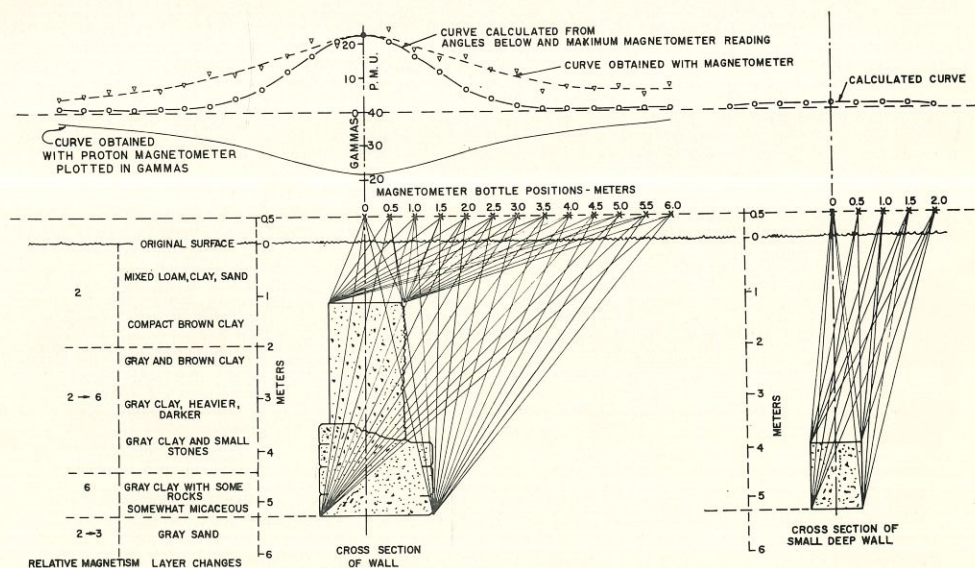


FIG. 1. Wall Anomalies, Plain of Sybaris. Left to Right:

- 1) Relative magnetism of soil layers in arbitrary units.
- 2) Description of soil layers on the north side of the Long Wall.
- 3) Cross section of the Long Wall as revealed in Test Pit A (1962) with construction lines for the calculated anomaly shown above it. Actual magnetometer anomaly in P.M.U. (proton magnetometer units) and in gammas is shown also above the wall.
- 4) Cross section of a small deep wall with construction lines for the calculated anomaly, shown above it.

Drilling and test excavations have revealed, however, that these are Roman, or, in some cases, Roman on top of Greek structures. In the course of six and one-half months of work and an additional three months in the autumn of 1964, very few definite finds of less massive, deep, and presumably, Greek walls were made with the proton magnetometer. The reason for this is demonstrated in Fig. 1. In the top part of this figure are shown curves calculated by the method of Vacquier *et al.*,<sup>5</sup> in which the horizontal components of magnetic intensity are neglected and the magnetic anomalies in the vertical direction are assumed proportional to the difference in solid angles subtended to the tops and bottoms of the walls as the detector of the instrument is moved over them. For the case of the massive wall on the plain of Sybaris where the clay is magnetic and the wall has negligible magnetism, the observed anomaly will be a decrease from the normal magnetic intensity. As shown in Fig. 1, after matching for peak height (with the measured one), the calculated curve has roughly the same shape as the measured one. The latter curve is shown also in gammas for comparison later with the rubidium data. It is apparent, however, that with this small magnetic contrast between walls and clay, the anomaly produced by the small deep wall is only 2 P.M.U.\* (approximately 2 gammas)—too small to be differentiated from natural, instrument, and other variations with a single sensor proton magnetometer.

The magnetizations of the clays, which are given in Fig. 1 in arbitrary units of relative magnetism, were confirmed by later measurements with the spinning magnetometer in the Research Laboratory for Archaeology and the History of Art, Oxford University<sup>6</sup>. These measurements indicated that our sample of 2 to 3 arbitrary units had a susceptibility of  $0.7 \times 10^{-4}$  emu/cc and one of 6 units, a value  $1.0 \times 10^{-4}$  emu/cc. A brick from a Roman wall, in Test Pit D (to be mentioned later) had a susceptibility of  $10.4 \times 10^{-4}$  emu/cc (as well as a remanent magnetization of  $130 \times 10^{-4}$  emu/gm). These susceptibilities were measured at 2000 c.p.s. As suggested by Aitken, an estimate of the actual magnetization existing in the ground is best obtained by multiplying the above susceptibility values by a factor of 4.

The anomaly caused by the massive wall of Fig. 1 is typical of those found with the proton magnetometer on the plain of Sybaris. The majority were negative anomalies, that is, anti-magnetic and were caused by massive non-magnetic structures buried in slightly magnetic clay. One exception was a large Roman villa (Test Pit D, 1962) which was built mostly of bricks, materials which are more strongly magnetic than the clays. One of the few anomalies, representative of a deep structure, that was detected with the proton magnetometer is shown in Fig. 2. This is the pronounced magnetic anomaly in the upper left hand section of Grid #16. Since this is a strong positive anomaly, and as indicated by the drill records<sup>7</sup>, is apparently more than 3.8 meters deep, it is presumed that it may have been caused by concentrations of roof tiles or other fired materials. (At this depth our guess is roof tiles rather than Roman bricks.) Even though other deeply and several less deeply buried structures were encountered by the drills, the plot of magnetic contours throughout the rest of this grid does not indicate their presence with certainty. The need for an apparatus capable of detecting the deeply buried structures and shallower ones of less magnetic contrast with greater sensitivity was indicated. Therefore, our attention was directed toward the more sensitive optical absorption magnetometers.

\* P.M.U. is the abbreviation used for proton magnetometer units.

With the kind co-operation of Lee Langan and Sheldon Breiner of Varian Associates, experiments were conducted by Breiner and Ralph with various configurations of the Varian V-4938 rubidium magnetometer<sup>8</sup> (see Plate I). Preliminary tests were made at Fort Lennox, Ile-aux-Noix, Canada<sup>2</sup> in May 1964 before the more extensive ones on the plain of Sybaris in October.

The basic principle of the rubidium and of other optical absorption magnetometers is that, due to the Zeeman effect, the energy levels become split into various sublevels whose separations are dependent upon the total intensity of the ambient magnetic field. To detect this proportional splitting, optical pumping is required. The operation of optical pumping involves the excitation of electrons into metastable states by the absorption of appropriate electromagnetic radiation. When

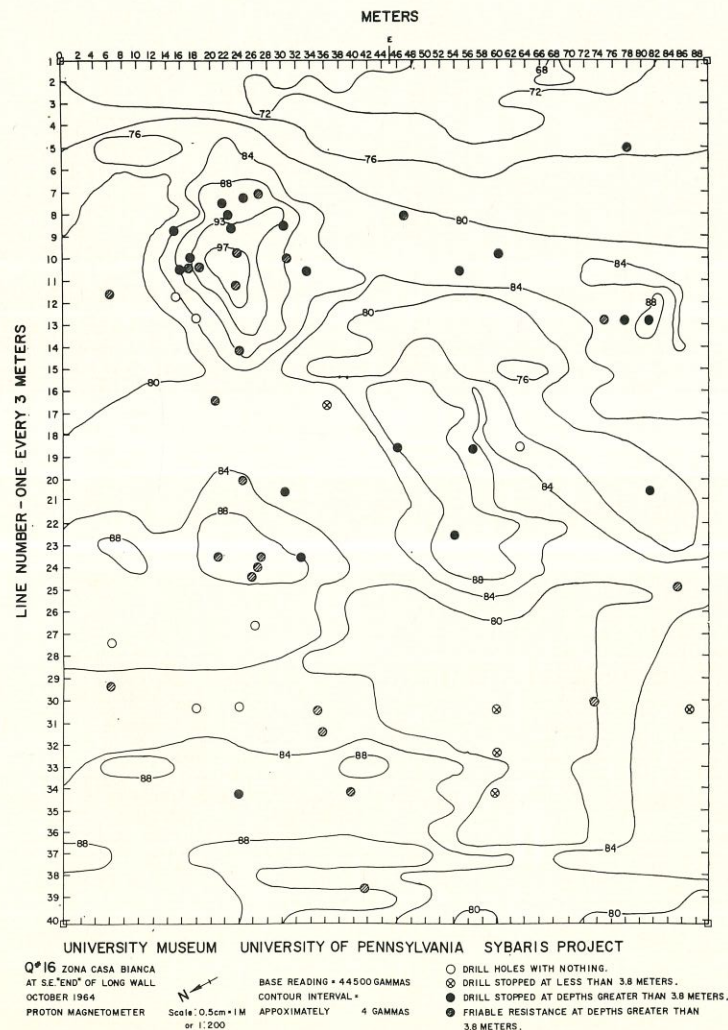


FIG. 2. Plot of magnetic contours from data obtained with the proton magnetometer for Grid No. 16, Plain of Sybaris. The round circles indicate the locations of drill holes. The notations "drill stopped" in the lower right-hand corner signify that structures were encountered at the depths indicated.

"pumping" is completed, redistribution of the pumped electrons to lower levels is accomplished by stimulation from a radio frequency corresponding to the difference in energy between the split levels. For the isotope  $Rb^{85}$  the separation between sublevels is approximately 4.667 cycles per second per gamma. In comparison, the change in precession frequency of the proton magnetometer is approximately 0.04 cycles per second per gamma. This is the basic reason why the  $Rb^{85}$  and similar optical absorption magnetometers are capable of detecting changes in magnetic intensity with approximately one-hundred-fold greater sensitivity. The specifications of the two types of magnetometers are shown in Table 1.

Experiments were conducted with both single and dual rubidium sensors. For the single sensor arrangement, the circuitry was reduced to a minimum, in a way somewhat similar to that adapted for detection of persons buried in snow avalanches.<sup>9</sup> It was battery-powered and the signal indicating a change in magnetic field was heard directly. With a single sensor and consequently no means of cancelling out background variations, sensitivity greater than that of the proton magnetometer could not be used effectively. With only an audio signal it was not readily apparent whether an anomaly was "positive" or "negative" and it was very difficult to assess its magnitude. In order to obtain *greater* sensitivity for the anomalies *only*, a dual differential sensor arrangement and recorder were tried.



PLATE 1. Complete assembly of rubidium magnetometer and sensors (one held by E. K. Ralph) at Fort Lennox, Ile-aux-Noix, Quebec P., Canada, May 1964. (Power cable leading to the fort is not shown.)

TABLE I

COMPARISON OF SPECIFICATIONS OF ELSEC PROTON AND VARIAN RUBIDIUM MAGNETOMETERS

<i>Characteristic</i>	<i>Elsec Proton Magnetometer</i>	<i>Varian Rubidium Magnetometer</i>						
Range	24,800 to 70,600 gamma	Any 6100 gamma interval from 15,000 to 80,000 gamma						
Sensitivity	± 1 gamma for H = 50,000 gamma Varies between ± 0.25 gamma for H = 25,000 gamma to ± 2.0 gamma for H = 70,000 gamma	± 0.01 gamma						
Information Rate	1 per 6 secs. (standard)	Continuous and essentially instantaneous						
Power Requirements	Two 6 volt, 8 AH batteries	Magnetometer: 105-125 volts or 210-230 volts ac, 50 to 1000 cps or 24-30 volts dc, 40 watts maximum with one self- oscillator. (Recorder is not included) Self oscillator: 24-30 volts dc, 12 watts						
<i>Weights and Dimensions</i>	<i>Weight</i>	<i>Length</i>	<i>Width</i>	<i>Height</i>	<i>Weight</i>	<i>Length</i>	<i>Width</i>	<i>Height</i>
Detector Bottle	5½ lbs.	5½"	3½" cylinder					
Instrument without battery pack	12 lbs.	13"	4¾"	8¾"				
Instrument with battery pack and in case	21 lbs. 8 lbs.	13½"	5½"	14"				
Coaxial Cable, 200 ft. long					2½ lbs.	7"	3" cylinder	3¼"
Sensor					3½ lbs.	7½"	3¼"	7"
Sensor Electronics					38 lbs.	15½"	17"	7"
Readout					14 lbs.	13½"	9½"	7¼"
Recorder					8 lbs.			
Coaxial cable, 200 ft. long					66 lbs.			
Total Weight	29 lbs.							

With this complete assembly of Varian V-4938 components, only the differences between a fixed and the moving sensor were recorded. (This assembly may be considered somewhat similar to a proton gradiometer or "bleeper", but with the differences that the sensitivity may be 100 times greater, one sensor is in a fixed position, the results are recorded, and readings are continuous. With this arrangement, external variations are nullified; and due to the fact that readings are continuous and that the moving sensor may be carried at a regular rate over the terrain, the speed of operation was approximately four times faster than that of the proton magnetometer (from one particular station). For these preliminary experiments a battery-powered recorder was not available and consequently, portability was reduced by the need of an A.C. generator. With the instruments mounted on the back shelf of a Volkswagen Microbus, the generator just outside; and 400 feet of cable leading to the movable sensor, a considerable area was covered from one station, and not much time was lost in moving to the next.

It is tempting to write that success in the location of many deep walls on the plain of Sybaris was achieved. In these initial experiments, beset by breakdowns, an unstable generator and other "growing pains", this was not fully accomplished. However, certain deep walls gave an anomaly of the order of three gammas. The first tests were made over the Long Wall (see cross Section in Fig. 1) which was known to produce a sizeable anomaly. With a fraction of the available gain of the rubidium magnetometer in use, the expected 20 gamma anomaly was strongly observed. This was a satisfactory beginning.

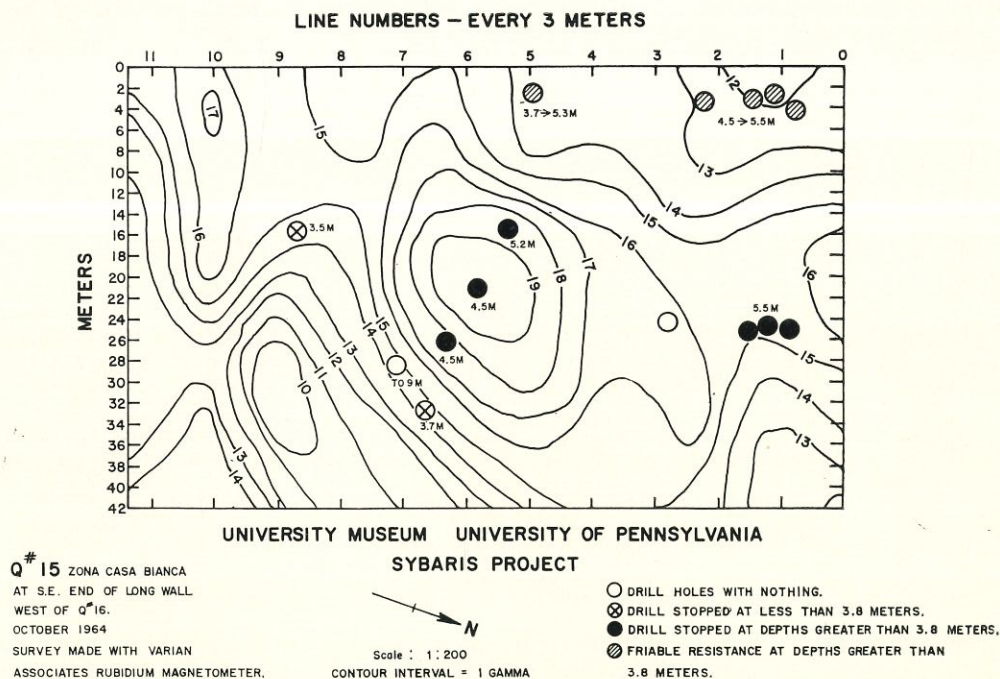


FIG. 3. Plot of magnetic contours from data obtained with the rubidium magnetometer for Grid No. 15, Plain of Sybaris. The round circles indicate the locations of drill holes. The notations "drill stopped" in the lower right-hand corner signify that structures were encountered at the depths indicated.

Tests were conducted next in the region of the southeastern "end" of the Long Wall. Preliminary sweeps indicated that anomalies could be found in this region, and two small grids were made. As is seen in the plot of one of these, Q #15 (Fig. 3), the results were encouraging. Magnetic contours could be plotted at intervals of only one gamma with sureness, and a magnetic anomaly of only three gammas in magnitude (central part of figure) and of such shape as to be representative of a buried structure was detected. This observation was confirmed by the drill results. Since this anomaly is positive, that is, it represents an increase over the normal magnetic intensity, it may also have been caused by a concentration of roof tiles. It is not clear why a structure was found also in the north central part of the grid not coincident with the center of an anomaly nor with a gradient of magnetic contours. One possible explanation is that this structure was found at a depth of 5.5 meters, possibly below the magnetic clay, whereas the wall in the center of the central anomaly was struck at 4.5 meters. There are also other possibilities such as undulations in the underlying clay which would complicate the magnetic pattern and cause the cancellation of positive and negative effects. It is unfortunate that the central portion of the larger non-magnetic anomaly represented by a lowering of the magnetic intensity to 10 gammas (southeast corner of Fig. 3) was not tested by drilling. From previous experience with the proton magnetometer and also from the drill results at the base of the anomaly, one might guess that this anti-magnetic disturbance represents a structure buried less deeply.

The larger grid, Q #16, was surveyed also with the rubidium magnetometer, but, unfortunately, a shift in sensitivity occurred within the instrument at some unknown time, and the data could not be plotted with much greater detail than those of the proton magnetometer. The resultant magnetic map is, therefore, very similar to that of Fig. 2.

These experiments with the rubidium magnetometer were conducted for two weeks only, and needless to say, much of that time was spent in making repairs and mistakes. Even though the large grid was inconclusive, it was found that areas could be covered with the rubidium magnetometer, at least four times as fast, and that it may be possible to detect more deeply buried structures. Considerable information was obtained in regard to changes and improvements to be made with the rubidium apparatus for archaeological prospecting.

#### REFERENCES

- 1 The Elsec proton magnetometer is made by the Littlemore Scientific Engineering Co., Littlemore, Oxford, England.
- 2 Rainey, F. and Ralph, E., in press: *New Frontiers in Archaeological Exploration*.
- 3 Rainey, F., 1962: *Electronics to the Rescue in Search for the Lost City of Sybaris: Discoveries by a joint U.S.-Italian Expedition—Part 1. Illustrated London News*, 241, no. 6436, 928-930; and *Engineering Devices used in the Excavation of the Lost City of Sybaris: Discoveries by a joint U.S.-Italian Expedition—Part 2. Illustrated London News*, 241, no. 6437, 972-974.
- 4 The expeditions in search of Sybaris, directed by Prof. F. Rainey (University Museum) have been conducted in collaboration with Dr. G. Foti (Superintendent of the Antiquities Department of Calabria), Eng. C. M. Leric (Director of the Leric Foundation of Rome), and Eng. and Mrs. E. Mueller (of Cassano Ionio). From these and other organizations, the following persons participated actively in the 1964 program:
  - From the Superintendency: O. Miggiano and G. Pellegrino.
  - From the Leric Foundation: F. Brancoleoni, F. Serra, B. Pastore, U. Cesarini, and D. Achilli.
  - From Cassano Ionio: G. Loisi, D. Falcone, and workmen.
  - From Varian Associates, Palo Alto, California: S. Breiner.
  - From the University Museum: F. Rainey, E. Mueller, D. Ridgway and E. Ralph.

To these persons and organizations we should like to express our gratitude, and also to Mr. O. Bullitt of Philadelphia for his generous financial support.

- 5 Vacquier, V., Steenland, N. C., Henderson, R. G., and Zietz, I., 1951: Interpretation of aeromagnetic maps. *Geol. Soc. Amer. Memoir*, No. 47.
- 6 We wish to express our gratitude to Dr. M. J. Aitken for these measurements and for his helpful advice during his visit to the plain of Sybaris in May, 1962.
- 7 The drilling program on the plain of Sybaris is described by Brown, D. F., 1963: In Search of Sybaris: 1962. *Expedition 5*, No. 2, 40-47.
- 8 Address inquiries to: Instrument Special Products, Varian Associates, 611 Hansen Way, Palo Alto, Calif., U.S.A. for V-4938 Rubidium Magnetometer data sheet and other literature.
- 9 Avalanche victim detection with rubidium gradiometer, Geophysics Technical Memorandum no. 16. Instrument Special Products, Varian Associates, 611 Hansen Way, Palo Alto, Calif., U.S.A.

Note: In this memorandum the instrument described consists of two sensors. Its operation, however, is more similar to the battery-powered single sensor arrangement with which we experimented briefly than to that of the complete dual differential assembly of V-4938 components which we have described.

Submitted to Archaeometry 1/10/65

Vol 7(1) June 1964

COMPARISON OF A PROTON AND A RUBIDIUM MAGNETOMETER  
FOR ARCHAEOLOGICAL PROSPECTING

by

E. K. Ralph  
University Museum  
University of Pennsylvania

During the past four years, surveys with the Elsec portable proton magnetometer<sup>(1)</sup> have been conducted by members of the ASCA (Applied Science Center for Archaeology) staff of the University Museum, University of Pennsylvania, Philadelphia. These have been carried out at both archaeological and historical sites, 15 in all, in 6 different countries<sup>(2)</sup>. Among these the most comprehensive program has been the search for the ancient Greek city of Sybaris in southern Italy<sup>(3,4)</sup>. In addition to the challenge of finding this site of former luxury and fame, the plain of Sybaris affords an ideal testing ground for instruments based on the principle of magnetic detection. Remnants of the classical periods -- that of the 6th century B.C. Sybaris, the later Greek Thurii, and the subsequent Roman Copia Thurii -- have been buried by meters of homogeneous alluvial clay that is very slightly magnetic.

As a result of the surveys conducted in 1961, 1962, and 1963, it was apparent that buried structures of sufficient mass which extended upward to within one to three meters of the surface could readily be detected with the proton magnetometer. Drilling and test excavations have revealed, however, that these are Roman, or, in some cases, Roman on top of Greek structures. In the course of six and one-half months of work and an additional three months

in the autumn of 1964, very few definite finds of less massive, deep, and presumably, Greek walls were made with the proton magnetometer. The reason for this is demonstrated in Fig. 1. In the top part of this figure are shown curves calculated by the method of Vacquier et al.,<sup>(5)</sup> in which the horizontal components of magnetic intensity are neglected and the magnetic anomalies in the vertical direction are assumed proportional to the difference in solid angles subtended to the tops and bottoms of the walls as the detector of the instrument is moved over them. For the case of the massive wall on the plain of Sybaris where the clay is magnetic and the wall has negligible magnetism, the observed anomaly will be a decrease from the normal magnetic intensity. As shown in Fig. 1, after matching for peak height (with the measured one), the calculated curve has roughly the same shape as the measured one. The latter curve is shown also in gammas for comparison later with the rubidium data. It is apparent, however, that with this small magnetic contrast between walls and clay, the anomaly produced by the small deep wall is only 2 P.M.U.\* (approximately 2 gammas) -- too small to be differentiated from natural, instrument, and other variations with a single sensor proton magnetometer.

The magnetizations of the clays, which are given in Fig. 1 in arbitrary units of relative magnetism, were confirmed by later measurements with the spinning magnetometer in the Research Laboratory for Archaeology and the History of Art, Oxford University<sup>(6)</sup>. These measurements indicated that our sample of 2 to 3 arbitrary units had a susceptibility of  $0.7 \times 10^{-4}$  emu/cc and one of 6 units, a value  $1.0 \times 10^{-4}$  emu/cc. A brick from a

---

\*P.M.U. is the abbreviation used for proton magnetometer units.

Roman wall, in Test Pit D (to be mentioned later) had a susceptibility of  $10.4 \times 10^{-4}$  emu/cc or  $130 \times 10^{-4}$  emu/gm. These susceptibilities were measured at 2000 c.p.s. As suggested by Aitken, an estimate of the actual magnetization existing in the ground is best obtained by multiplying the above susceptibility values by a factor of 4.

The anomaly caused by the massive wall of Fig. 1 is typical of those found with the proton magnetometer on the plain of Sybaris. The majority were negative anomalies, that is, anti-magnetic and were caused by massive non-magnetic structures buried in slightly magnetic clay. One exception was a large Roman villa (Test Pit D, 1962) which was built mostly of bricks, materials which are more strongly magnetic than the clays. One of the few anomalies, representative of a deep structure, that was detected with the proton magnetometer is shown in Fig. 2. This is the pronounced magnetic anomaly in the upper left hand section of Grid #16. Since this is a strong positive anomaly, and as indicated by the drill records (7), is apparently more than 3.8 meters deep, it is presumed that it may have been caused by concentrations of roof tiles or other fired materials. (At this depth our guess is roof tiles rather than Roman bricks.) Even though other deeply and several less deeply buried structures were encountered by the drills, the plot of magnetic contours throughout the rest of this grid does not indicate their presence with certainty. The need for an apparatus capable of detecting the deeply buried structures and shallower ones of less magnetic contrast with greater sensitivity was indicated. Therefore, our attention was directed toward the more sensitive optical absorption magnetometers.

With the kind cooperation of Lee Langan and Sheldon Breiner of Varian Associates, experiments were conducted by Breiner and Ralph with various configurations of the Varian V-4938 rubidium magnetometer<sup>(8)</sup>. Preliminary tests were made at Fort Lennox, Ile-aux-Noix, Canada<sup>(2)</sup> in May 1964 before the more extensive ones on the plain of Sybaris in October.

The basic principle of the rubidium and of other optical absorption magnetometers is that, due to the Zeeman effect, the energy levels become split into various sublevels whose separations are dependent upon the total intensity of the ambient magnetic field. To detect this proportional splitting, optical pumping is required. The operation of optical pumping involves the excitation of electrons into metastable states by the absorption of appropriate electromagnetic radiation. When "pumping" is completed, redistribution of the pumped electrons to lower levels is accomplished by stimulation from a radio frequency corresponding to the difference in energy between the split levels. For the isotope  $Rb^{85}$  the separation between sublevels is approximately 4.667 cycles per second per gamma. In comparison, the change in precession frequency of the proton magnetometer is approximately 0.04 cycles per second per gamma. This is the basic reason why the  $Rb^{85}$  and similar optical absorption magnetometers are capable of detecting changes in magnetic intensity with approximately one-hundred-fold greater sensitivity. The specifications of the two types of magnetometers are shown in Table 1.

Experiments were conducted with both single and dual rubidium sensors. For the single sensor arrangement, the circuitry

was reduced to a minimum, in a way somewhat similar to that adapted for detection of persons buried in snow avalanches. (9)

It was battery-powered and the signal indicating a change in magnetic field was heard directly. With a single sensor and consequently no means of cancelling out background variations, sensitivity greater than that of the proton magnetometer could not be used effectively. With only an audio signal it was not readily apparent whether an anomaly was "positive" or "negative" and it was very difficult to assess its magnitude. In order to obtain greater sensitivity for the anomalies only, a dual differential sensor arrangement and recorder were tried. With this complete assembly of Varian V-4938 components, only the differences between a fixed and the moving sensor were recorded. (This assembly may be considered somewhat similar to a proton gradiometer or "bleeper", but with the differences that the sensitivity may be 100 times greater, one sensor is in a fixed position, the results are recorded, and readings are continuous. With this arrangement, external variations are nullified; and due to the fact that readings are continuous and that the moving sensor may be carried at a regular rate over the terrain, the speed of operation was approximately four times faster than that of the proton magnetometer (from one particular station). For these preliminary experiments a battery-powered recorder was not available and consequently, portability was reduced by the need of an A.C. generator. With the instruments mounted on the back shelf of a Volkswagen Microbus, the generator just outside; and 400 feet of cable leading to the movable sensor, a considerable area was covered

from one station, and not much time was lost in moving to the next.

It is tempting to write that success in the location of many deep walls on the plain of Sybaris was achieved. In these initial experiments, beset by breakdowns, an unstable generator and other "growing pains", this was not fully accomplished. However, certain deep walls gave an anomaly of the order of three gammas. The first tests were made over the Long Wall (see cross section in Fig. 1) which was known to produce a sizeable anomaly. With a fraction of the available gain of the rubidium magnetometer in use, the expected 20 gamma anomaly was strongly observed. This was a satisfactory beginning.

Tests were conducted next in the region of the southeastern "end" of the Long Wall. Preliminary sweeps indicated that anomalies could be found in this region, and two small grids were made. As is seen in the plot of one of these Q #15 (Fig. 3), the results were encouraging. Magnetic contours could be plotted at intervals of only one gamma with sureness, and a magnetic anomaly of only three gammas in magnitude (central part of figure) and of such shape as to be representative of a buried structure was detected. This observation was confirmed by the drill results. Since this anomaly is positive, that is, it represents an increase over the normal magnetic intensity, it may also have been caused by a concentration of roof tiles. A structure found in the south central part of the grid was also coincident with a gradient of magnetic contours.

This structure was found at a depth of 5.5 meters, possibly below the magnetic clay, whereas the wall in the center of the central anomaly was struck at 4.5 meters. It is unfortunate that the central portion of the larger non-magnetic anomaly represented by a lowering of the magnetic intensity to 10 gammas (southeast corner of Fig. 3) was not tested by drilling. From previous experience with the proton magnetometer and also from the drill results at the base of the anomaly, one might guess that this anti-magnetic disturbance represents a structure buried less deeply.

The larger grid, Q #16, was surveyed also with the rubidium magnetometer, but, unfortunately, a shift in sensitivity occurred within the instrument at some unknown time, and the data could not be plotted with much greater detail than those of the proton magnetometer. The resultant magnetic map is, therefore, very similar to that of Fig. 2.

These experiments with the rubidium magnetometer were conducted for two weeks only, and needless to say, much of that time was spent in making repairs and mistakes. Even though the large grid was inconclusive, it was found that areas could be covered with the rubidium magnetometer, at least four times as fast, and that it may be possible to detect more deeply buried structures. Considerable information was obtained in regard to changes and improvements to be made with the rubidium apparatus for archaeological prospecting.

References

1. The Elsec proton magnetometer is made by the Littlemore Scientific Engineering Co., Littlemore, Oxford, England.
2. Rainey, F. and Ralph, E., in press: New Frontiers in Archaeological Exploration.
3. Rainey, F., 1962: Electronics to the Rescue in Search for the Lost City of Sybaris: Discoveries by a joint U.S. - Italian Expedition - Part I. Illustrated London News, 241, no. 6436, 928-930; and Engineering Devices used in the Excavation of the Lost City of Sybaris: Discoveries by a joint U.S. - Italian Expedition - Part 2. Illustrated London News, 241, no. 6437, 972-974.
4. The expeditions in search of Sybaris, directed by Prof. F. Rainey (University Museum) have been conducted in collaboration with Dr. G. Foti (Superintendent of the Antiquities Department of Calabria), Eng. C. M. Lerici (Director of the Lerici Foundation of Rome), and Eng. and Mrs. E. Mueller (of Cassano Ionio). From these and other organizations, the following persons participated actively in the 1964 program:

From the Superintendency: O. Miggiano and S. Pellegrino.

From the Lerici Foundation: F. Brancoleoni, F. Serra, B. Pastore, U. Cesarini, and D. Achilli.

From Cassano Ionio: G. Loisi, D. Falcone, and workmen.

From Varian Associates, Palo Alto, California: S. Breiner.

From the University Museum: F. Rainey, E. Mueller, D. Ridgway and E. Ralph.

To these persons and organizations we should like to express our gratitude, and also to Mr. O. Bullitt of Philadelphia for his generous financial support.

5. Vacquier, V., Steenland, N.C., Henderson, R.G., and Zietz, I., 1951: Interpretation of aeromagnetic maps. Geol. Soc. Amer. Memoir, No. 47.
6. We wish to express our gratitude to Dr. M. J. Aitken for these measurements and for his helpful advice during his visit to the plain of Sybaris in May, 1962.
7. The drilling program on the plain of Sybaris is described by Brown, D.F., 1963: In Search of Sybaris: 1962. Expedition 5, No. 2, 40-47.
8. Address inquiries to: Instrument Special Products, Varian Associates, 611 Hansen Way, Palo Alto, Calif., U.S.A. for V-4938 Rubidium Magnetometer data sheet and other literature.
9. Avalanche victim detection with rubidium gradiometer, Geophysics Technical Memorandum No. 16. Instrument Special Products, Varian Associates, 611 Hansen Way, Palo Alto, Calif., U.S.A.  
Note: In this memorandum the instrument described consists of two sensors. Its operation, however, is more similar to the battery-powered single sensor arrangement with which we experimented briefly than to that of the complete dual differential assembly of V-4938 components which we have described.

Figure Captions

- Fig. 1. Wall Anomalies, Plain of Sybaris. Left to Right:
- 1) Relative magnetism of soil layers in arbitrary units.
  - 2) Description of soil layers on the north side of the Long Wall.
  - 3) Cross section of the Long Wall as revealed in Test Pit A (1962) with construction lines for the calculated anomaly shown above it. Actual magnetometer anomaly in P.M.U. (proton magnetometer units) and in gammas is shown also above the wall.
  - 4) Cross section of a small deep wall with construction lines for the calculated anomaly, shown above it.
- Fig. 2. Plot of magnetic contours from data obtained with the proton magnetometer for Grid No. 16, Plain of Sybaris. The round circles indicate the locations of drill holes. The notations "drill stopped" in the lower right-hand corner signify that structures were encountered at the depths indicated.
- Fig. 3. Plot of magnetic contours from data obtained with the rubidium magnetometer for Grid No. 15, Plain of Sybaris. The round circles indicate the locations of drill holes. The notations "drill stopped" in the lower right-hand corner signify that structures were encountered at the depths indicated.

Table 1. Comparison of Specifications of Elsec Proton and Varian Rubidium Magnetometers

Characteristic	Elsec Proton Magnetometer				Varian Rubidium Magnetometer			
Range	24,800 to 70,600 gamma				Any 6100 gamma interval from 15,000 to 80,000 gamma			
Sensitivity	± 1 gamma for H = 50,000 gamma Varies between ± 0.25 gamma for H = 25,000 gamma to ± 2.0 gamma for H = 70,000 gamma				± 0.01 gamma			
Information Rate	1 per 6 secs (standard)				Continuous and essentially instantaneous			
Power Requirements	Two 6 volt, 8 AH batteries				Magnetometer: 105-125 volts or 210-230 volts ac, 50 to 1000 cps or 24-30 volts dc, 40 watts maximum with one self-oscillator. (Recorder is not included) Self oscillator: 24-30 volts dc, 12 watts			
Weights and Dimensions	<u>Weight</u>	<u>Length</u>	<u>Width</u>	<u>Height</u>	<u>Weight</u>	<u>Length</u>	<u>Width</u>	<u>Height</u>
Detector Bottle	5½ lbs.	5½"	3½" cylinder					
Instrument without battery pack	12 lbs.	13"	4-3/4"	8-3/4"				
Instrument with battery pack and in case	21 lbs.	13½"	5½"	14"				
Coaxial Cable, 200' long	8 lbs.							
Sensor					2½ lbs.	7"	3" cylinder	
Sensor Electronics					3½ lbs.	7½"	3½"	3½"
Readout					38 lbs.	15½"	17"	7"
Recorder					14 lbs.	13½"	9½"	7½"
Coaxial cable, 200' long					8 lbs.			
Total Weight	29 lbs.				66 lbs.			

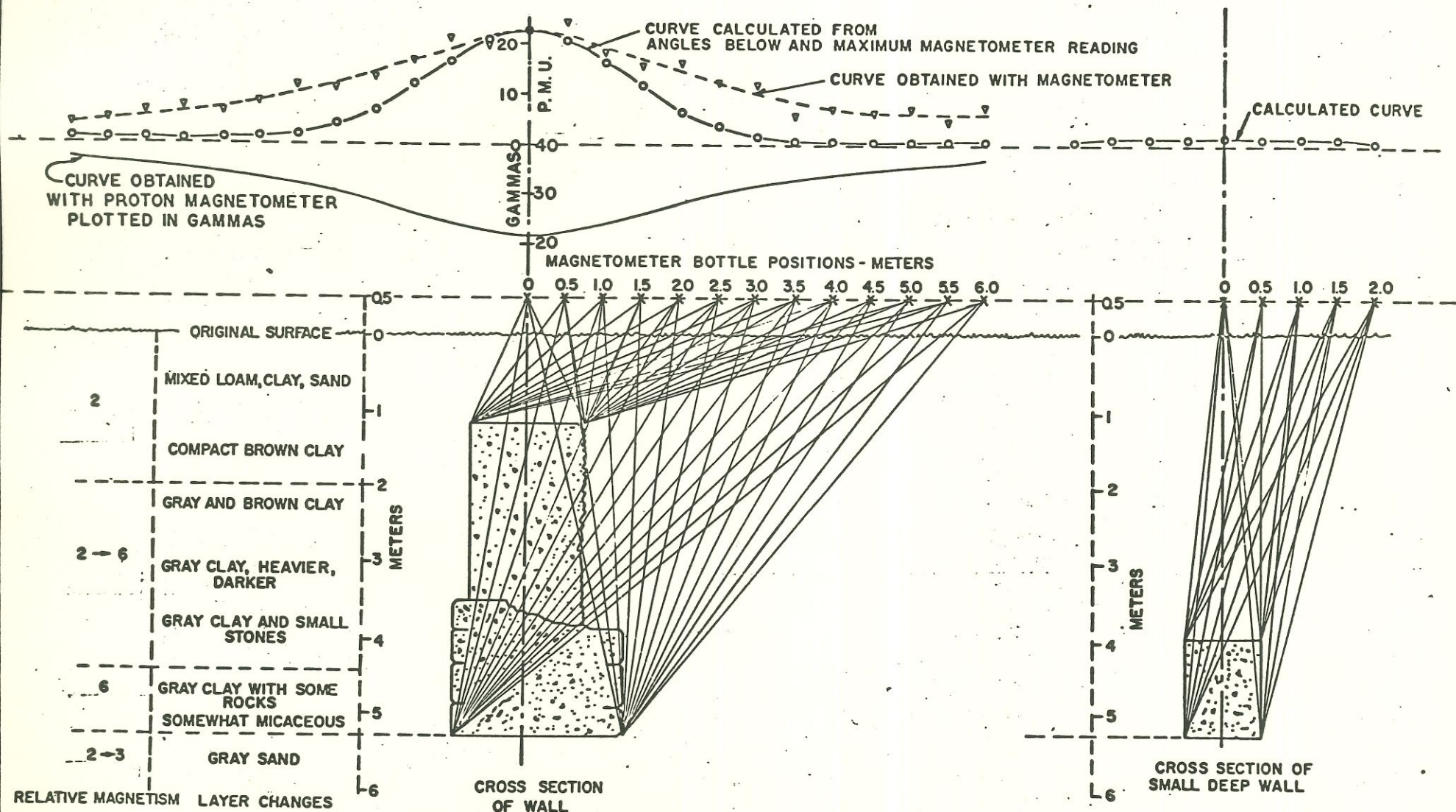
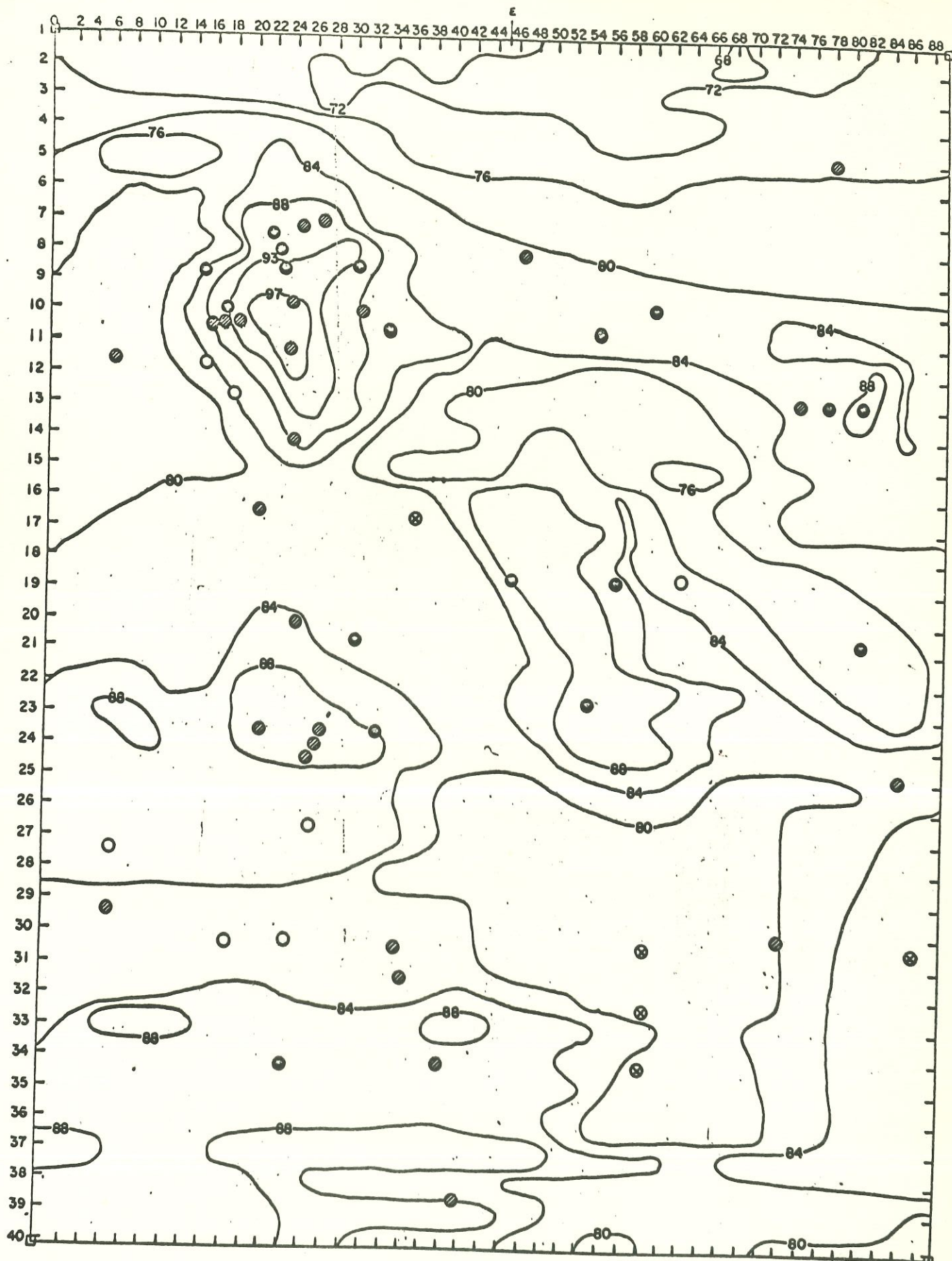


FIGURE 1.

LINE NUMBER - ONE EVERY 3 METERS



UNIVERSITY MUSEUM UNIVERSITY OF PENNSYLVANIA SYBARIS PROJECT

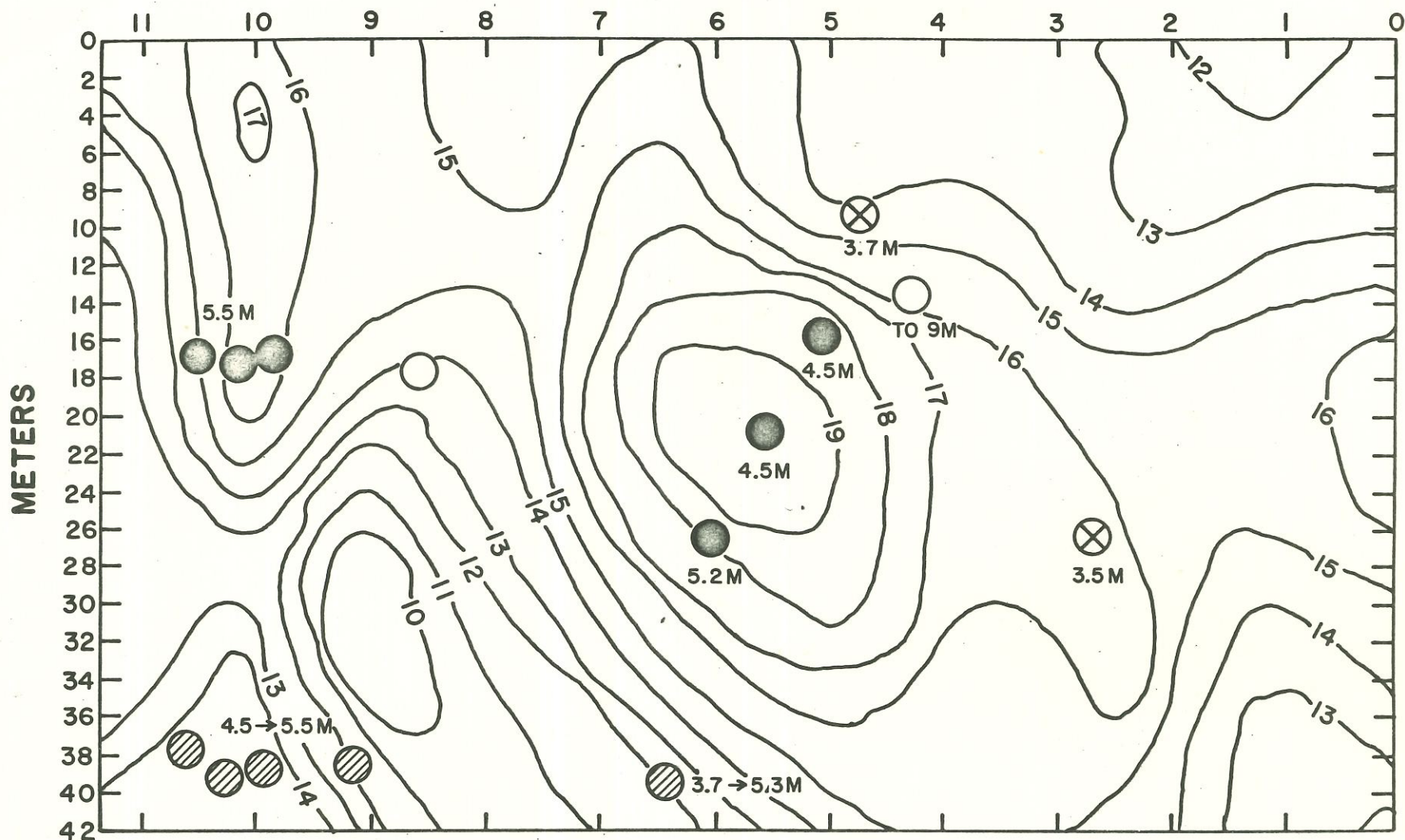
Q<sup>o</sup> 16 ZONA CASA BIANCA  
 AT S.E. END OF LONG WALL  
 OCTOBER 1964  
 PROTON MAGNETOMETER

Scale: 0.5cm = 1M  
 or 1:200

BASE READING = 44800 GAMMAS  
 CONTOUR INTERVAL =  
 APPROXIMATELY 4 GAMMAS

- DRILL HOLES WITH NOTHING.
- ⊗ DRILL STOPPED AT LESS THAN 3.8 METERS.
- ⊙ DRILL STOPPED AT DEPTHS GREATER THAN 3.8 METERS.
- ⊚ FRIABLE RESISTANCE AT DEPTHS GREATER THAN 3.8 METERS.

# LINE NUMBERS — EVERY 3 METERS



Q 15

1964

- DRILL HOLES WITH NOTHING.
- ⊗ DRILL STOPPED AT LESS THAN 3.8 METERS
- DRILL STOPPED AT DEPTHS GREATER THAN 3.8 METERS.
- ▨ FRIABLE RESISTANCE AT DEPTHS GREATER THAN 3.8 METERS.

Scale : 1 : 200