

UNIVERSITY OF ILLINOIS

DEPARTMENT OF ANTHROPOLOGY
109 Davenport Hall, Urbana, Illinois 61803

Jan. 21 - 1966

Dr. Elizabeth K. Ralph
The University Museum
University of Penna.
33rd., and Spruce Sts.,
Philadelphia 4, Penna.

Dear Dr. Ralph;

I am sorry to have been so long in answering your letter of December 7th., but as so often happens many things have intervened, including winding up a semester. We are anxious to have you write this chapter for our proposed book, and hope you will be able to do it. Your problem, of finding the time, is that of all of us. We are very hopeful we will be able to get it together by sometime in May.

We had planned on having only your article on the proton magnetometer, and that you would be able to make it as general in application as possible. What we are primarily interested in is general applications of new methods, particularly as they apply, or potentially apply, to problems in America. There has been a good deal written, (Science in Archaeology, etc.), which applies to such work in the Old World.

The thing we are most concerned about in this book is making clear the necessity for the archaeologist to rely more and more on the specialist if he is to do a competent job today. This means that budgets and planning must be much more comprehensive than they had to be in the past. Manpower costs have risen to such an extent that the use of special equipment as shortcuts in every phase of the work is justified. It is this sort of thing we had hoped you could stress in your discussion of resistivity surveying.

We sincerely hope you will be able to write this chapter, and get it to us as soon as you can. This does not mean we expect you to drop everything else and write it, for I am sure none of the contributors can do that. On the other hand we hope to get it out while it is still timely and so that other possible applications can be tested.

Sincerely;


John C. McGregor

February 8, 1966

Dr. John C. McGregor
Department of Anthropology
University of Illinois
109 Davenport Hall
Urbana, Illinois 61803

Dear Dr. McGregor:

The time has come for me to start thinking about this chapter on the application of geophysical surveying methods for your guide book for archaeologists. The "thinking" will have to be fairly fast because I am scheduled to leave for Italy around the middle of March.

I am wondering now about how long you would like it to be, and if I may illustrate it liberally with pictures and diagrams. Both will save a lot of words if these do not have to be limited because of cost, etc. Also, how many copies of text, pictures, and diagrams would you like to have, and what system should be used for the references? May I use metric units?

Sincerely yours,

Elizabeth K. Ralph

EKR:mhr

UNIVERSITY OF ILLINOIS

DEPARTMENT OF ANTHROPOLOGY

109 Davenport Hall, Urbana, Illinois 61803

Feb. 14 - 1966

Dr. Elizabeth K. Ralph
The University Museum
University of Penna.,
Philadelphia 4, Penna.

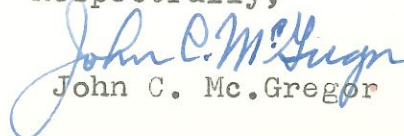
Dear Dr. Ralph;

In answer to your letter of the 8th., just received, we have set ~~no~~ length on these various chapters. It is our hope that they will be kept as brief as it is possible to adequately cover the necessary material, but not cut to the point where desirable items are omitted. We are also hoping to limit illustration as much as possible, with the use of line drawings where they are applicable instead of halftones. Purpose; to keep cost down for the publisher. One man wants to use color plates, but I fear they will not be acceptable although they would add much to his discussion.

We will need only one copy of the paper and illustrations. Typed double spaced. As to the system of referencing we have not discussed this as yet. I would therefore suggest you use whatever system you prefer, and if we have to do so this could be altered to conform to the final system at the time it goes to the publisher. I feel you will use something which would require relatively little revision in any event.

Actually these will be a series of independent papers so we are less concerned about complete conformity than we would otherwise be.

Respectfully;


John C. McGregor

March 18, 1966

Dr. John C. McGregor
Department of Anthropology
109 Davenport Hall
Urbana, Illinois 61803

Dear Dr. McGregor:

My chapter for your guidebook entitled "Geophysical Surveying Techniques in Archaeology" is enclosed. Please feel free to revise or delete any part that you want to.

A few items of information that are needed from Europe are missing. When these arrive, corrected copies of the pages which now have blank spaces will be forwarded to you.

In a few days, I shall be leaving for Italy, so I won't be able to rewrite any of it, if needed, until July when I return.

Sincerely yours,

Elizabeth K. Ralph
Associate Director

UNIVERSITY OF ILLINOIS

DEPARTMENT OF ANTHROPOLOGY

109 Davenport Hall, Urbana, Illinois 61803

April 5 - 1966

Dr. Elizabeth K. Ralph
University Museum
University of Pennsylvania
Philadelphia, Penna.

Dear Dr. Ralph;

I apologize for having been so late in acknowledging your manuscript, received some time ago, but we wanted to go over it carefully before writing you. Also we have all been very busy with other duties.

It is excellent, just as it stands, and quite what we had hoped to get from you. As you mention there are a few places where you will want to add bits of more specific information, but if you send it to us I believe we can do it here for you.

The illustrations are excellent, and I hope we will be able to use all of them just as they are. Your suggestion of reduction of one would I feel be a matter for the publisher to decide. It looks like a good idea to me.

I hope this reaches you before you leave for Italy as you wrote you were going to do, but I expect it will not.

Respectfully;


John C. Mc.Gregor

Dr. John C. McGregor

Department of Anthropology
109 Davenport Hall
Urbana, Illinois 61803

May 27, 1966

Dear Dr. McGregor,

Miss Ralph has asked me to send you the corrected pages from her chapter, "Geophysical Surveying Techniques in Archaeology". They are enclosed.

May I also add the following corrections:

page 15: the heading "2. Scollar Differential Proton Magnetometer" is to be deleted

page 17: "2." is to precede Fluxgate Gradiometer rather than "3."

If there are any further questions, please contact me.

Thank you,

Sincerely yours,

Jeannette M. Flamm

UNIVERSITY OF ILLINOIS

DEPARTMENT OF ANTHROPOLOGY

109 Davenport Hall, Urbana, Illinois 61801

May 31 - 1966.

Jeanette M. Flamm
The University Museum
University of Pennsylvania
Philadelphia, Pennsylvania
19104

Dear Miss Flamm;

This is to acknowledge receipt of corrections and additions for a paper by Miss Ralph on Geophysical Surveying Techniques in Archaeology. Thank you for sending this on so promptly.

Sincerely;


John C. McGregor

p.2

2. Martin-Clark Resistivity Meter

Manufactured by Martin-Clark Instruments Ltd., 19 The Crossways,
Onslow Village, Guildford, Surrey, England

Cost--about \$135 including 5 rods, leads, and built-in rotary switch.

Ranges--0-5/50/500/5000 ohms

Frequency of alternating current--500cps.

Power Requirements-- $4\frac{1}{2}$ volt lantern-type or torch battery (Burgess
#532 or equivalent)

Dimensions-- $4-3/4 \times 3-3/4 \times 3-1/4$ in.

Weight-- $2\frac{1}{2}$ lbs.

p.3

Jeannette -

Many thanks for this
information.

It has been raining here for 3
days - I should have stayed in Greece

Best regards to all,
Beth

October 14, 1966

Dr. John C. McGregor
University of Illinois
Dept. of Anthropology
109 Davenport Hall
Urbana, Illinois 61803

Dear Dr. McGregor:

Thank you for your kind letter of April 5, 1966. I returned from Italy a few weeks ago, and am now catching up with "home" affairs.

In our MASCA laboratories we are receiving more and more inquiries about instruments and their use. Most of the answers to these are contained in my chapter (Geophysical Surveying Techniques in Archaeology). To save the trouble of replying to each one specifically, I am wondering if you would mind if we mimeograph some "preprints" to send out in reply to these questions. If not, could you tell me the exact title of your guidebook so that it can be labelled correctly.

On the other hand, if your guidebook is going to be published in the very near future, this mimeographing will not be necessary.

Sincerely yours,

Elizabeth K. Ralph

EKR:amg

~~Applications of~~ Geophysical Surveying Techniques in Archaeology

by

Elizabeth K. Ralph

Introduction

The main technique of archaeology is excavation. But, as labor costs become higher all over the world and as modern civilization encroaches upon ancient sites, there is a need to accelerate and facilitate the finding of structures at known sites and to locate unsuspected or lost cities and sites. In this respect, the physical scientist may help with a variety of instruments for the detection of buried archaeological features.

Types of Instruments

There are now a number of geophysical prospecting instruments that have been adapted specifically for archaeological surveying. Those which have been used most extensively detect changes in either ground conductivity (or, conversely, resistivity) or local variations in magnetic intensity. Descriptions of the designs, principles, and uses of most of these instruments are reported in many chapters and articles. (See Bibliography).

Those, known to me, which I consider to be most suitable for archaeological prospecting are the following:

Conductivity--Resistivity

1. Geohm Earth Tester

Manufactured by the Gossen Co., Erlangen, Western Germany and sold in the U.S.A. by National Electronics, Box 1237, Sheridan, Wyoming.

Cost--about \$100 (Rods and leads not supplied)

Ranges--0-5/50/500/5000 ohms

Maximum Sensitivity--approx. 0.02 ohms

Frequency of alternating current--103 cps.

Power Requirements--One 4-1/2 volt lantern-type battery (Burgess #532 or equivalent). (Battery lasts from 1 day to 1 week, depending upon ground moisture.)

Dimensions--7-3/4 x 4-3/4 x 4 in.

Weight--5 lbs.

Recommended Rods and Leads (to be assembled by purchaser).

5 Rods: 1/2" dia. stainless steel, 3 ft. long, pointed at one end, with adjustable perpendicular foot "pushers" if desired. (If ground is hard, these are not needed since rods must be hammered in.)

5. Cables: made of retractile coiled shielded single conductor microphone cable (Birnbach #895 or equivalent), extended length, 25ft. (Shielding is not necessary, but this type of cable is stronger than unshielded.)

Attach banana plug at one end and battery clip at the other end of each cable.

2. Martin-Clark Resistivity Meter

Manufactured by Martin-Clark Instruments Ltd., 19, The Crossways, Onslow Village, Guildford, Surrey, England

Cost--about \$168, including 5 rods, leads, and built-in rotary switch.

Ranges--0-5/50/500/5000 ohms

Frequency of alternating current-- 500 cps.

Power Requirements--4-1/2 volt lantern-type or torch battery (Burgess #532 or equivalent)

Dimensions--4-3/4 x 3-3/4 x 3-1/4 in.

Weight-- $2\frac{1}{2}$ lbs.

Note: The built-in rotary switch of the Martin-Clark instrument enables the leads to be leap-frogged in lines without changing connections. We have found, however, that when the leads are connected to the Geohm with banana plugs, their positions can be moved as rapidly as the other operator is able to change the rods correspondingly.

Magnetometers

1. "Elsec" Proton Magnetometer Type 592.

Manufactured by the Littlemore Scientific Engineering Co., Railway Lane, Littlemore, Oxford, England.

Cost--about \$3000 in the U.S.A. without accessories

Range--24,800 to 70,600 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

Information Rate--1 per 6 secs. (standard), meter readout

Power Requirements--Two 6 volt, 8 AH batteries. (Lead-acid wet cells, or at extra cost, \$200, sealed nickel-cadmium cells).

Weights and Dimensions:	<u>Weight</u>	<u>Length</u>	<u>Width</u>	<u>Height</u>
Detector Bottle	5-1/2 lbs.	5-1/2"	3-1/2" (cylinder)	
Instrument without battery pack	12 lb.	13"	4-3/4"	8-3/4"
Instrument with battery pack and in case	21 lbs.	13-1/2"	5-1/2"	14"
Coaxial Cable	4 lbs.	100'		

2. Proton Gradiometer or "Bleeper"

Manufactured by the Littlemore Scientific Engineering Co., Railway Lane, Littlemore, Oxford, England

Cost-- about \$450.

Only a dozen were manufactured.

Sensitivity--about 5 gammas

This instrument is simpler and lighter than the Elsec proton magnetometer, but two detector bottles must be carried vertically. Precision is much less, only an audio signal is heard, and it is difficult to differentiate between positive and negative anomalies.

It is useful in making rapid traverses for the location of features such as kilns or large fire pits which cause strong anomalies.

3. Digital Differential Proton Magnetometer

Several models of this magnetometer have been designed and most of them, assembled in the Geophysical Laboratory of the Rheinisches Landesmuseum, Bachstrasse 11, 53 Bonn, West Germany. Models II, IIA, and III have the advantage that simultaneous difference readings (from two detector bottles) may be taken, and therefore, greater usable sensitivity is available (than with one detector or without simultaneous readings from two). They offer, therefore, one of the big advantages of the cesium magnetometer (item 5), but with less sensitivity, longer time required for each reading, and less portability. These instruments are not available commercially.

4. Fluxgate Gradiometer

Designed by the Research Laboratory for Archaeology and the History
of Art, 6 Keble Road, Oxford, England

Cost-- The instrument is not available commercially, If
it were, it would be about \$1400.

Sensitivity--2 gammas

Information Rate--continuous, direct reading in gammas, including sign.

Power Requirements--9 volt dry cell (for 1 day's use)

Detectors--two fluxgate elements, mounted vertically 4 ft. apart,
weight-12 lbs.

Instrument--13 x 5 x 8 in., weight-8 lbs.

Note: This instrument is more rapid to use than both proton magnetometers
and gradiometers. However, due to the fact that the fluxgate
elements are directional and that they must be matched, more
time for setting-up is required.

5. Precision Portable [Cesium] Magnetometer Model 4920

Manufactured by Varian Associates, Quantum Electronics Division,
611 Hansen Way, Palo Alto, California, U.S.A.

Cost--to be determined when available (only two prototypes have
been built as of February, 1966).

Range--20,000 to 80,000 gamma

Sensitivity--0.1 gamma with one sensor (about 0.05 gamma with two
sensors)

Information Rate--1.5 secs. maximum with digital readout in gammas
(with one sensor)

Power Requirements--24-30 volts, 16 AH (2 sets of silver-cadmium
sealed cells or equivalent lead-acid)

Weights:

Sensor--2-1/2 lbs.

Sensor Electronics--3-1/2 lbs.

Readout--9 lbs. 14 oz.

One set silver-cadmium batteries--18 lbs. 11 oz..

Dimensions--see Pl. 1

6. Suggested Supplemental Equipment

Two non-magnetic and non-conductive tape measures 100 feet long.

Daily supply of 10 to 20 wooden stakes, length dependent upon height of ground cover

Knapsack

Light-weight camp stool

Volt-ohmmeter--Triplett Model 310 or equivalent

Small long-nose pliers, wire cutters, screw drivers, and soldering iron

Spare fuses

Grid (see Pl. 2)

Field notebooks, two types, one with squared paper and the other with graph paper

Lines and Grids

All methods depend upon the detection of "anomalies"--deviations of values or instrument readings from the normal "background," or from those obtained where no buried archaeological features exist. Therefore, it is necessary to operate the instruments along traverses or lines and often in complete grids in order to interpret the results.

A "line" is as simple as its name implies. It should be started outside of the area where the buried feature is expected to be, and preferably perpendicular to it, and continue beyond it. The first exploratory lines can usually be run quickly with a minimum of measuring or surveying. Except for conductivity surveying, the distances between readings may be determined simply as paces. Usually, at the start, only the marking of the approximate location of each anomaly with a wooden stake is sufficient. To avoid confusion later, the stake should be labelled with the line and anomaly number and indicated also in the notebook. An anomaly in a line may be observed more readily if the readings are plotted directly on graph paper as shown in Figs. 8 and 9. (With the use of a "bleeper" type gradiometer no recording is necessary since only an audio change is detected.)

After the approximate location of an anomaly is determined, it may be pin-pointed more precisely by running short lines perpendicular and parallel to it and noting where the maximum deviation in readings occurs. Then the stake may be moved to the center of the anomaly. Or, if a comprehensive map of the buried features is desired and, especially, if the anomalies are small and hard to detect, a complete grid may be made over the region of interest. To make a grid, series of parallel lines are marked out which form a rectangle.

It may be marked out with four corner stakes (with locations determined either by surveying, tape measure, or paces). If plenty of

stakes are available, then the ends of each line within the grid may also be designated with stakes. If not, two additional movable stakes will serve to designate the direction of the line (see Fig. 1). These are easily advanced from line to line if two non-magnetic and non-conductive tape measures are available.

If many small grids, such as 20 by 20 yards, are being made over smooth terrain without high grass or brush, a grid can be constructed of plastic or rope clothesline with squares at intervals of two yards as shown in Pl. 2. This can be moved quickly to adjacent areas and rolled up when not in use. If one-yard or smaller intervals are desired, these can be marked on the rope with colored plastic tape.

When making a grid, it is desirable to record the actual numbers in the field notebook rather than plot them as a graph. If the numbers are recorded to scale and in the same orientation that the grid is traversed, then the contours of equal magnitude may be drawn directly from these (unless a diurnal or other extraneous change has occurred while making the grid). This system is illustrated in Figs. 2 and 3. The drawing of the contours follows the same procedure as in a survey of land elevations. On the basis of the total range of the units recorded, an appropriate contour interval is chosen. For example, in Fig. 2 this interval was 5 units. First of all, all values greater than 30 were encircled; then 25, 20, and so on. The main thing to keep in mind when drawing contours is that each adjacent one must maintain the same interval. One may not skip from 20 to 10; there must be the intervening 15 unit contour between all 10's and 20's. The final plot of contours then provides a means of interpretation. If the corner stakes of the grid have been left in the ground, then the anomalies revealed in the plot may easily be located and marked at a later time.

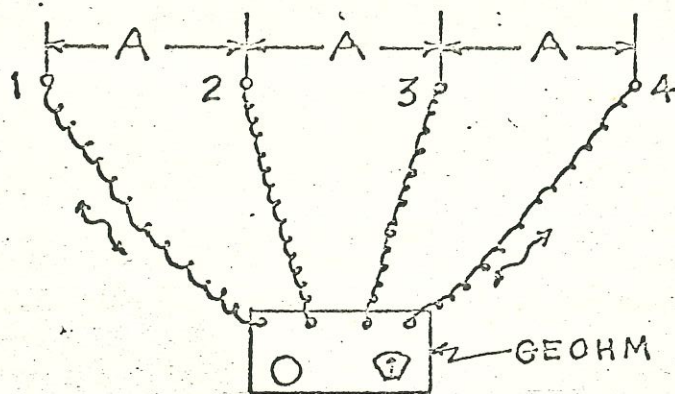
The intervals for readings within lines and between lines are determined by the depth and area of the structures sought. If they are

near the surface and not massive, both should be small, but if deep whether massive or not, they may be larger. This will be explained more fully for specific instruments.

Conductivity or Resistivity Surveying

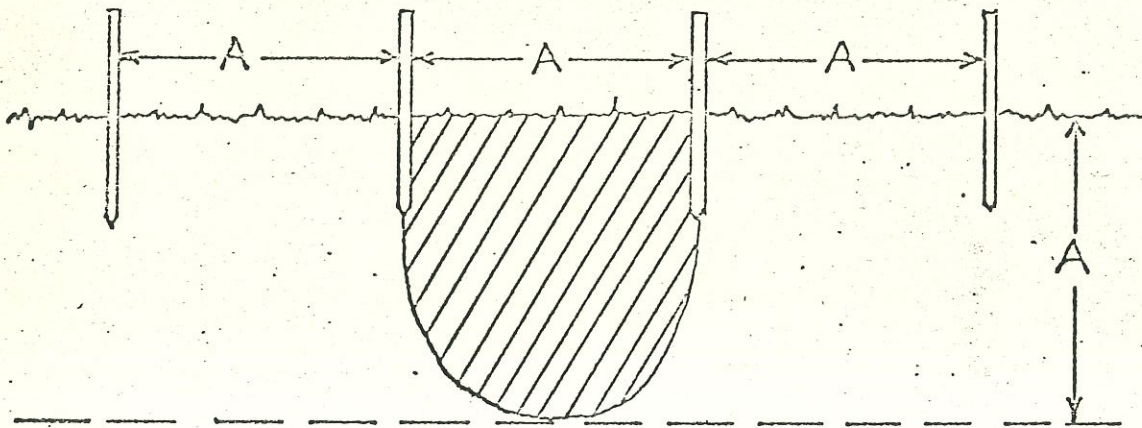
This involves portable instruments which enable one to measure the conductivity of the ground in a designated area. The conductivity or, conversely, the resistivity of the ground varies primarily with changes in water content. Therefore, stone walls and other building materials which are less permeable to water than the surrounding earth may be expected to appear as regions of high resistance whereas filled ditches, pits, etc. may retain more moisture and hence have lower resistance than adjacent regions.

Measurements are made by taking successive readings along a line or series of lines in a grid, and one looks for comparative variations. For each measurement, metal rods are driven into the ground at equal spacings and attached to the Geohm or similar instrument, with cables as shown in plan below:



As indicated by the arrows, an alternating current flows from the Geohm to the outer two rods (1 and 4). The ground between these rods completes the connection for the current flow. Due to this current and the resistance of the ground, a difference of potential results between rods 2 and 3. (This is called the Wenner configuration of electrodes; other systems are described in the bibliography.) The

Geohm detects this difference of potential and by means of an internal bridge circuit and variable precision resistors, the operator obtains a balance which determines the ground resistance being measured. This resistance is an inverse measure of the conductivity of the earth between rods 2 and 3. The region measured is roughly as shown below by the shaded area with the depth of penetration equal to the spacing (A) between the rods.



If the location of an anomaly has been determined, its depth can be judged by varying the spacing of the rods centered over one spot. To do this, readings are taken using increasing values of spacing A but from a fixed center. (This is most easily done with two tape measures laid out in a line with their zeros together.) These will be, in effect, differential readings when those for the second interval are subtracted from those for the first, etc. Before subtracting, however, each value must be corrected for the change in spacing between the rods. A plot of differential values taken from various fixed centers for a tumulus at Gordion, Turkey, is shown in Fig. 4. Hopefully, the tomb sought is at a depth of 6 to 7 meters in the region of centers C and D.

The main limitation of resistivity surveying is that the ground must not be too wet or too dry. If there is excessive moisture, walls and similar features will be by-passed by conductive paths in the wet ground which are easy for the current to follow. If too dry, the moisture in the ground may not differ from that of the walls or trench, and it is also more difficult to make good contact with the ground by means of the rods. (To check rod contact, put 4 rods at equal depths into the ground, take a reading, then put all rods somewhat deeper. If the reading does not change appreciably, one may assume that the rod contact is good.) Areas with sandy soils should be avoided, if possible, because of their low conductivity.

In comparison with nuclear magnetometers, the resistivity method is time-consuming due to the fact that for each measurement one or more rods must be spaced carefully and driven firmly into the ground and then removed for the next reading. It has been especially satisfactory at historical sites in eastern U.S.A. and Canada where walls are buried at shallow depths and the refuse, power lines, etc. of modern civilization preclude the use of magnetic methods. But we find that it can rarely locate features which are more than one or two yards beneath the surface.

Magnetic Surveying

1. Proton Magnetometers

There are a number of ways of detecting changes in magnetic intensity. However, the instrument which was first designed specifically for archaeological prospecting was the Elsec proton magnetometer. This was developed by Drs. E. T. Hall and M. J. Aitken at the Research Laboratory for Archaeology and the History of Art, Oxford University. Its operation is based on the detection of proton precession since the frequency of precession of protons is proportional to the magnetic field in which they are located. The instrument consists, therefore, of a detector "bottle" which contains methyl alcohol, a source of many protons (i.e. nuclei of hydrogen atoms) surrounded by a coil of wire. In operation a "polarizing" current is sent through the coil to create an artificial magnetic field stronger than that of the earth's. This magnetic field forces the magnetic moments of the protons to be aligned. When the current is stopped, the main field vanishes, and the protons then continue to gyrate or precess in the earth's field. During the seconds immediately after the polarizing current is cut off, the coil serves as a detector of the small alternating voltage induced in it from the precession of the protons. The frequency of this voltage represents the frequency of precession, which, in turn, is proportional to the ambient magnetic field. In the main part of the instrument this small voltage is then amplified and its frequency (the information desired) appears on the five dials of the instrument. The circuits are transistorized and the instrument is, therefore, light, readily portable and sensitive. Its maximum sensitivity is one part in 50,000, or roughly one gamma (10^{-5} oersteds) in normal earth fields. Successive readings may be taken every 3 or 4 seconds and the detector bottle may be moved to the next position during the polarizing period of one second so that no time is lost. The instrument has the great

advantage over other older types of magnetic apparatus in that the detector bottle does not have to be leveled or oriented carefully for the measurements. The readings which appear on the dials are inversely proportional to the magnetic intensity. Therefore, when regions of high magnetic intensity are measured they have low proton magnetometer readings (abbreviated P.M.U.).

As with conductivity surveying, the magnetic readings are comparative, that is, information in regard to underground features is obtained when the readings differ from those of the surrounding undisturbed ground. The limits of detection in depth vary according to the amount of contrast in magnetism of the features sought with that of the surrounding earth. And, in a given region with fairly homogeneous soil, the width of the "anomaly" (the region where readings differ from the average) affords a measure of the depth or width of the magnetically contrasting object. If the anomaly is observed to be wide, the depth is inferred to be greater than if it is narrow (assuming the object is small). Depth information may be obtained also by taking readings with the detector bottle at different heights above the ground. It might be mentioned here that when maximum sensitivity and freedom from diurnal changes are required, a second (or reference) detector bottle can be attached with a switch. If the reference bottle is in a fixed position and a reading is recorded for every 10 (for example) readings of the movable bottle, then at the completion of a grid, all readings may be corrected for diurnal change. This difficulty is avoided with the Scollar differential proton magnetometer.

The proton gradiometer or "Bleeper" may be thought of as a simplified magnetometer. Two detector bottles are carried vertically and only the difference between them is heard as an audio frequency or is observed

on an indicating meter. The upper bottle is further away from the anomalies sought and therefore less affected by changes due to buried features. The upper bottle serves also to cancel out diurnal and other extraneous changes in magnetic intensity, but since the sensitivity of this instrument is not better than about 5 gammas, this feature is less essential than with more sensitive instruments. Also, since no readings are recorded, it is not a suitable instrument for making grids and seeking small anomalies. It is however, more rapid to use. Therefore, its best application is in exploratory work in looking for large anomalies such as those from kilns, sizeable firepits, or fired brick structures. Kilns, brick walls, etc. have more magnetism than normal earth due to the fact that the firing of the clays, especially if heated above the highest Curie point (670° C.), has allowed an alignment of the minute dipole moments of the tiny magnets, inherent in the materials, in a uniform direction (that of the field of the earth at the time of firing). Even though the bricks, for example, may have been piled in diverse directions in the wall, the resultant magnetic field is usually greater than that of undisturbed soil. Regions of increased magnetism may also be caused by buried iron artifacts and by disturbance of the soil. The latter effect is due to the fact that soil, more recently disturbed than the surrounding earth, has a greater magnetic susceptibility. This then facilitates the detection of trenches, graves, pits, wells, etc.

2. Fluxgate Gradiometer

Another magnetic-type gradiometer with sensitivity comparable to that of proton magnetometers has been developed recently at Oxford. This is the fluxgate gradiometer (Allred, 1964). The detectors consist of fluxgate elements, pieces of high permeability saturable magnetic alloy which when suitably energized by an alternating current fed through primary coils induce in a secondary coil a signal of twice the frequency of the energizing current and whose magnitude is proportional to the component of the ambient magnetic field parallel to the axis of the secondary coil. In the gradiometer, two such elements are mounted with their axes separated by a vertical distance of 4 feet. With the outputs of the two elements subtracted from each other, the resultant voltage is then proportional to the difference in magnetic field between the two elements.

The upper element, being farther away from the ground, serves to cancel out diurnal and other extraneous magnetic disturbances. This instrument is more rapid to use than proton magnetometers since readings may be taken continuously. Also, direct readings in gammas, including sign, are obtained. It is slightly more difficult to set up due to the fact that fluxgate elements are directional and must therefore be maintained strictly parallel and they must be matched carefully.

Examples of Anomalies

In the U.S.A. an extensive survey with an Elsec proton magnetometer at Angel Site was reported by Richard B. Johnston (1961 and 1964). This was an extremely careful survey, but the site was a difficult one for a proton magnetometer due to the small magnetic contrast (less than 10 gammas) offered by the trenches and most of the other features sought. It was complicated further by the presence of much scrap iron.

In the course of a survey by MASCA* at Snaketown, Arizona in 1965**, small firepits in house floors about 1 yard below the surface produced disappointingly small magnetic anomalies (5 gammas or less). However, at this site there were also extremely large and deep firepits. These produced excellent magnetic anomalies, the largest of which is shown in Fig. 5. We see both the magnetic anomaly and its reaction-- the so-called reverse or anti-magnetic anomaly which almost always occurs with strongly magnetic anomalies. As is seen in the diagram, the location of the firepit corresponded with the magnetic anomaly. (Magnetic anomalies are generally displaced slightly to the south of the feature which produces them in the northern hemisphere.)

A comparison of resistivity and magnetometer lines made over the region of a canal at Snaketown is shown in Fig. 6. It is seen that pronounced anomalies were detected with both instruments over a grey silt layer north of the main canal, but that the canal itself was not detected as specifically. Probably, the grey silt appeared as a denser and less moisture-retaining area to the Geohm; and as a region of soil disturbance to the magnetometer.

With the Elsec proton magnetometer and/or the "Bleepar" many Roman kilns and other features have been detected in England. Also, the proton magnetometer has been used extensively in Italy since 1961 by MASCA and by the Lerici Foundation. Notable among the first finds were the entrances to rock-cut tombs at Tarquinia and Cerveteri (Linington, 1961). An example of a small Roman kiln found in Italy by MASCA is

*The Applied Science Center for Archaeology, University Museum, University of Pennsylvania

**The archaeological program at the site was under the direction of Professor Emil Haury, Dept. of Anthropology, University of Arizona, Tucson.

shown in Fig. 7. Here also one sees a pronounced magnetic anomaly (53380 P.M.U.) and the anti-magnetic reaction (54060 P.M.U.).

The plain of Sybaris in southern Italy affords an excellent testing ground for magnetic instruments (the water table is too high for resistivity surveying). It is an alluvial plain with homogeneous deposits of very slightly magnetic clay to depths of 5 to 6 meters underlain by sand. From information obtained by drilling and a few test excavations (Rainey, 1962; Brown, 1962), we now know that the archaic 6-7th century B.C. level is at depths of 4.5 to 6 meters. This is possibly overlain by remnants of the 4-5th century B.C. city of Thurii, and on top of this are scattered Roman ruins, some starting at 1 to 3 meters below the surface and extending downward. It is these last that are readily detectable with proton and fluxgate magnetometers.

The magnetic "quietness" of this region is shown in the plot of lines 42 and 91, Fig. 8. Anomalies produced by both stone and possible brick structures are shown in Fig. 9. One of the biggest finds was a long wall (see Map C, Fig. 10), detected by means of short perpendicular lines run over it, for a length of 1300 meters. This wall, built of non-magnetic stones and mortar and extending down 4 meters from its top into the slightly magnetic clay, produced a sizeable anti-magnetic anomaly as shown in Fig. 11.

As a result of the surveys conducted in 1961, 1962, and 1963, it became 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. 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. One reason for this is demonstrated in Fig. 11. In the top part of this figure are shown curves calculated

by the method of Vacquier et al. (1951), 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. As shown in Fig. 11, 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 other 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. This is the type of structure sought in the search for Sybaris.

The magnetizations of the clays, which are given in Fig. 11 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. These measurements indicated that our sample of 2 to 3 arbitrary units had a susceptibility of 0.7×10^4 emu/cc and one of 6 units, a value 1.0×10^4 emu/cc. A brick from a Roman wall, in Test Pit D (~~to be mentioned later~~), had a susceptibility of 10.4×10^4 emu/cc (as well as a remanent magnetization of 130×10^4 emu/gm). These susceptibilities were measured at 2000 c.p.s. As suggested by M. J. 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.

Optical Absorption Magnetometers

In October 1964 experiments were conducted with a more sensitive

magnetometer--namely, the Varian V-4938 rubidium assembly (Ralph, 1964, and 1965; Breiner, 1965). These and a preliminary trial in Canada in May were the first attempts directed toward the adaptation of a more sensitive magnetometer for archaeological prospecting. The tests were two-fold--namely, to determine the applicability of a more sensitive optical absorption type of magnetometer and to find out what revisions in the apparatus should be made for this purpose. This instrument consisted of an assembly of parts and was not portable by hand nor battery-powered.

The basic principle of the rubidium and of other optical absorption magnetometers is that, due to the Zeeman effect, the energy levels of an atom 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. (For a comparison of the two types of magnetometers see Ralph, 1964).

As a result of the tests with the rubidium magnetometer, two prototypes of an entirely new instrument--namely, a precision portable cesium magnetometer--were designed and built by Varian Associates in 1965.

These instruments were produced specifically for the University Museum for use in the search for Sybaris.

Cesium was substituted for rubidium in the sensors (the detecting elements) because with cesium, the sensors are less subject to orientation disturbance. As long as a sensor is carried vertically (cable end down) within $\pm 10^\circ$, there is no change in readings with complete 360° rotation in the horizontal plane. The principle of operation is the same as that described for the rubidium magnetometer.

Other components of the cesium magnetometer are the readout and battery pack (see Pl. 1). The readout is a small light-weight transistorized unit and the battery pack is also compact. In use the readout is carried in front suspended on a strap and the batteries, in a knapsack in back. The readings appear directly in gammas (maximum range, 0.1 gamma) when one sensor is used.

In order to make effective use of this sensitivity, an additional sensor is required to cancel out diurnal and other extraneous changes in magnetic intensity. (This is the same mode of operation as that of the differential proton magnetometer.) One may read the difference between two sensors rather than the absolute field with one. (Alternately, if one desires, two readouts may be carried and they can be synchronized for simultaneous readings.) One possibility is to carry two sensors, one above the other, at a fixed distance apart. This was not practical on the plain of Sybaris where possible structures of the 6-7th century B.C. city are buried at depths of 5 to 6 meters (see Fig. 12). To obtain maximum sensitivity at this depth, the sensors would have to be carried about 5 meters apart. Since each one with its associated electronics weighs about 6 lbs., it was not physically possible to carry one aloft with stable motion at a height of 5 meters. Therefore, on the plain of Sybaris, one sensor was placed in a fixed position with a

long cable (100 meters) leading from it to the instrument. With this "difference" mode of operation, the fixed sensor then becomes the reference oscillator and the base reading becomes 80,000 units. (If desired, these readings may be converted to gammas by the formula;
$$\gamma = \frac{80,000 - \text{sensor reading}}{80,000} \times H$$
 where H is the intensity in gammas obtained with one sensor. On the plain of Sybaris, H is approximately 44,600 γ . Therefore, it turns out that the sensitivity in the "difference" mode may be as low as 0.05 γ (on the most sensitive 0.1 γ range of the instrument).

The great advantage of the "difference" mode of operation is that all readings are affected only by the underground anomalies sought as the position of the movable sensor is changed and not influenced by diurnal or transient fluctuations in the magnetic field. Also, by putting a small magnetic anomaly (a compass) near the fixed sensor, it was possible to relate each succeeding station to the previous one so that, for example, if the reading of 10 units was recorded in one field, the same reading in the next represented the same conditions of magnetic contrast. Because of the "absolute" feature, readings could be recorded directly in a notebook oriented in the same way that the grid was traversed. It was found convenient to make large grids, usually within the boundaries of fences or hedge rows, with lines taken at intervals of 5 meters and readings taken every 2 meters in the lines. The readings were then recorded in a notebook at a scale of 1:400. With this mode of operation, approximately 5000 square meters could be covered per hour (after the distances between the lines were measured and marked out on the fence posts). The 2 meter intervals were determined only as paces. The readings appear at the maximum rate of one every 1.5 seconds, a comfortable pacing rate. At the completion of a grid, the

pages of the notebook were then pasted together in the proper orientation and the lines of equal magnetic intensity were drawn. Examples of grids number 1 and 22 (Figs. 2 and 3) are included and their locations are indicated on Map C (Fig. 10).

Interpretation of Anomalies

In all instrument surveys, there is the problem of interpretation of the anomalies detected with the instruments. Very few are as easy as the plot shown in Fig. 13 of a Geohm survey made over the hospital foundations, Fort Lennox, Île-aux-Noix, Quebec Province, Canada.*** These walls were buried at depths of 50 cm. or less and were mostly 50 cm. or more wide. As is seen in Fig. 13, the foundations are outlined perfectly and even the two hearths are indicated clearly by areas of more closely spaced contours. In addition, excavation revealed that the bulge at the northern end represented a doorway.

In many areas, it is impractical to excavate on a large scale even though it may be reasonably certain that anomalies representative of archaeological features have been detected. This is particularly true on the plain of Sybaris where the water table is high (approximately 1 meter down) and the archaic structures sought are deeply buried. In these cases, drills and rods are of great assistance. A simple rod, made in one-meter sections, and with a detachable handle may be used on alluvial plains which are free of natural rocks. For depths of a meter or less, the M-Pact-O heavy duty probing bar is a good tool (sold by Fisher Research Laboratory, 1975 University Ave., Palo Alto, Calif.). With the rod, confirmation of whether or not there is a buried structure may be obtained and its depth from the surface determined. Although slower, more complete information is determined by drilling because potsherds and chips of construction materials are brought up. If their stratigraphy is noted carefully, some light is shed in regard to the age and fabrication of the structure. Also, a vehicle-mounted drill with forced water circulation is much more powerful, so that solid unpenetrable stone foundations may be distinguished from thin deposits of roof tiles or other friable materials.

***Surveys at this site were conducted under the sponsorship of the Canadian Department of Northern Affairs and Natural Resources as part of a training program for students in archaeology.

The interpretation of the deep anomalies detected with the cesium magnetometer as shown in Map C (Fig. 10) is based upon drilling and a test excavation. It may seem curious, at first, that the anomalies detected assumed representative of structures (see Figs. 2 and 3 for examples) were predominantly magnetic whereas the foundations of archaic Greek structures are expected to consist of non-magnetic stones or blocks. Also, those buried much less deeply, such as the long Wall (sensed with the proton magnetometer in previous seasons) were almost entirely anti-magnetic. Excavation 1 (1964-1965) helped to illuminate this situation. In this excavation, massive deposits of roof tiles were found (at a depth of 4 to 5 meters) overlying small crude stone walls. From previous measurements of similar materials (see p. 20) we may estimate the following values of magnetic susceptibilities:

Stones	$\chi_s \sim 2.8 \times 10^{-4}$ emu/cc
Deep Clay	$\chi_c \sim 4.0 \times 10^{-4}$ emu/cc
Roof Tiles	$\chi_{rt} \sim 41.6 \times 10^{-4}$ emu/cc

If we consider the large anomaly northeast of Excavation 1 in Fig. 3, and assume that it is caused by deposits of roof tiles with dimensions of 10 by 80 meters and 0.4 meters thick at an average depth of 4.5 meters, then we may think of a model of these deposits of roof tiles as a long magnetized sheet of permeability μ_2 buried a medium of permeability μ_1 in a field H_1 which had previously been uniform (see Fig. 14).

Using the boundary conditions

$$B_1 = B_2 \quad (\text{normal component of } B \text{ continuous})$$

$$\mu_1 H_1 = \mu_2 H_2$$

$$H_2 = \mu_1 / \mu_2 H_1$$

Then replacing the magnetic sheet by the equivalent "surface" current i surrounding it

$$H_1 - H_2 = i/d, \quad i = d \left(\frac{\mu_2 - \mu_1}{\mu_2} \right) H_1$$

Then at the surface, the currents i give additional fields

$$H = \frac{i}{2\pi r} = \frac{d(\mu_2 - \mu_1) H_1}{2\pi \mu_2 \sqrt{r_0^2 + (t/2)^2}}$$

These add to give an anomaly in the vertical direction

$$H_v = \frac{2}{\sqrt{2}} \frac{d(\mu_2 - \mu_1) H_1}{2\pi \mu_2 \sqrt{r_0^2 + (t/2)^2}}$$

At a large distance, H_1 is unaffected

Therefore,

$$\frac{H_v}{H_1} \sim \frac{d(\mu_2 - \mu_1)}{\sqrt{2} \pi \mu_2 \sqrt{r_0^2 + (t/2)^2}}$$

To evaluate this,

$\mu_2 = 1 + 4\pi \chi_{rt}$ where χ_{rt} is the magnetic susceptibility for roof tiles.

$\mu_1 = 1 + 4\pi \chi_c$ where χ_c is the magnetic susceptibility for deep clay.

$d = 0.4$ meters

$t = 10$ meters

$r_0 = 4.5$ meters

We find, for this deposit of roof tiles,

$$\frac{H_v}{H_1} \sim 5 \times 10^{-5}$$

Since the vertical component of the earth's field in this region is about 0.37 oersted, the anomaly would be 1.9 γ .

The magnetic field produced by this sheet has a negative value at nearby regions outside of the immediate area, giving a contrast of approximately 3/2 times this value or about 2.9 γ . This is comparable with the observed effect. However, a similar mass of stones with $\chi_g = 2.8 \times 10^{-4}$ emu/cc would give a much smaller anti-magnetic anomaly ($H_v/H_1 \sim 0.2 \times 10^{-5}$) or a contrast of 0.1 γ . This would not be seen in the presence of the larger magnetic anomaly.

This simplified analysis then helps to explain why, on the plain of Sybaris, anomalies representative of remains of archaic Greek structures at depths of 4-6 meters appear as magnetic areas. It illustrates also the difficulty of interpretation, and of finding stone structures at these depths unless they are extremely massive.

In some cases, buried features may be interpreted by various other geometrical models. For example, if the structure sought is very long and narrow, it may be thought of as an infinitely long cylinder and the following formula used:

$$H_r = \left[1 + \frac{\mu_2 - \mu_1}{\mu_2 + \mu_1} \frac{a^2}{r^2} \right] H_v \cos \theta$$

Or, if it is a concentrated mass, it may be idealized as a sphere, and

$$H_r = \left[1 + \left(\frac{\mu_2 - \mu_1}{\mu_2 + 2\mu_1} \right) \frac{a^3}{r^3} \right] H_v \cos \theta$$

where

H_r = magnetic intensity at a distance r from the object

r = distance from the detector to the axis (or center) of the cylinder (or sphere).

a = radius of the cylinder or sphere

$\cos \theta$ = angle between the detector and axis (or center) of
the cylinder (or sphere).

(Directly above, $\cos \theta = 1$).

Other mathematical and simplified model approaches for the interpretation of anomalies are reported by Linington (1964), Dobrin (1960), and others.

A laboratory simulator-trainer has been constructed at Oxford for this purpose (Aitken and Alldred, 1964). With this device, a small-scale model of the particular archaeological feature under consideration is made in magnetically equivalent materials. The size and position coordinates of the detector are scaled down by the same factor as the dimensions of the feature. A short fluxgate detector is used with a sensitivity of one gamma, and artificial anomalies are located below it on a movable platform. With the simulator it is possible to determine the magnetic anomaly to be expected from a given configuration. Alternatively, the simulator can be used in the training of magnetometer operators to give them concentrated experience in the interpretation of results.

Other Types of Instruments

Experiments with other types of electronic instruments such as seismic apparatus, metal detectors, and sonic equipment, have not as yet produced very satisfactory results. Seismic instruments do generally detect the depth and contours of bed-rock, but the wavelengths are too long for detection of the smaller archaeological features. Metal detectors for the most part have too little depth range for archaeological purposes, and so far, there are unsolved problems with sonic devices. Harold E. Edgerton at the Massachusetts Institute of Technology is experimenting with a "Boomer" system for penetrating underwater sediments, and the University Museum has been experimenting with a high-frequency device for use on land. In principle, both attempt to couple a sonic impulse or wave into the soil so that its reflection or refraction from an underground feature can be recorded, and thus locate the structure. In essence it is an archaeological probe resembling sonar or radar. The major problem seems to be in producing a satisfactory coupling device which will enable a high-frequency impulse to enter the earth without too great a loss of energy and to penetrate a reasonable depth. Sonic instruments may yet turn out to be useful archaeological probes for large scale exploration.

Organization and Cost of Surveys

The instruments themselves may seem complicated, but their operation is very simple. In the field, breakdowns and difficulties are normally confined to broken cables and connectors. Anyone who can use an ohmmeter and simple hand tools could locate the trouble and make the necessary repairs. Batteries are always troublesome, but will not be a cause of instrument failure if kept properly charged (or replaced in the case of dry cells).

The interpretation of anomalies requires some experience, but this can be acquired without a formal knowledge of geophysics. Therefore, there is no obvious reason why instrument surveys cannot be conducted by archaeologists or anthropologists without assistance from physical scientists. It has been our experience, however, that surveys are rarely carried to completion unless the daily instrument work and the plotting and interpretation of results is supervised by a geophysicist, physicist, or engineer. The main reason for this is probably the fact that prospecting instruments are not of prime interest to the archaeologist and that he is usually too busy with archaeological matters.

The ideal arrangement is for the physical scientists to work concurrently with the archaeologists, possibly a few jumps ahead, especially when a program of excavation or drilling is in process. The testing of the first anomalies found at any site is almost always essential for their interpretation.

If we assume that land surveying, mapping, and the permanent location of anomalies found are the province of the archaeologist, then the instrument crew may be composed as follows:

Resistivity

1 geophysicist

1 assistant (If the ground is very hard, work will go faster with 2 assistants.)

Proton and Fluxgate Magnetometers and Gradiometers

1 geophysicist

1 assistant

Precision Portable Cesium Magnetometer

1 geophysicist

2 assistants (3 if terrain is very rough and fixed sensor is required--extra man needed to move long cable).

Note: If the geophysicist does not perform the actual instrument work, another assistant should be added in each case. The assistants may be intelligent laborers or students, but they should be definitely assigned to the geophysical crew unless the survey is conducted as a training program for students and a system of rotation is in effect.

Unless a group is considering the purchase of one or more instruments and using them themselves, the costs of instrument surveys depend upon the institution requested to do the survey and the types of instruments required. During the formative years of archaeological prospecting, the services of a physical scientist and the use of one or more instruments have frequently been offered at minimum cost with financial support needed only for travel, living costs, and student salaries.

For use of the precision portable cesium magnetometer, costs are higher. During 1966 or until these instruments are produced in quantity, the University Museum, University of Pennsylvania, is acting as agent for Varian Associates. Due to the high cost of the development of this instrument and the fact that a trained geophysicist is required to operate it, the charge for its use is \$3000 per month. This fee includes the rental of the instrument and the services, travel, and other costs of the geophysicist.

Some of the institutions which are equipped to do surveys are as follows (the list of instruments at each may not be complete):

1. MASCA--Applied Science Center for Archaeology, University Museum,
33rd and Spruce Streets, Philadelphia, Pa. 19104.
Director: Froelich Rainey
Associate Director: Elizabeth K. Ralph
Instruments:- Geohms
Elsec Proton Magnetometer
Agent for Varian Associates Portable Precision Cesium
Magnetometer
2. Research Laboratory for Archaeology and the History of Art, 6 Keble
Road, Oxford, England
Director: E. T. Hall
Associate Director: M. J. Aitken
Instruments: Various British resistivity instruments
Elsec Proton Magnetometers
Proton Gradiometers
Fluxgate Gradiometer
3. Lerici Foundation, Via Veneto 108, Rome, Italy
Director: Carlo M. Lerici
Instruments: Geohm
D.C. Voltmeter-Potentiometer Resistivity Apparatus
Proton Magnetometers
4. Rheinisches Landesmuseum, Bachstrasse 11, 53 Bonn, West Germany
Director of Geophysical Laboratory: Irwin Scollar
Instruments: Resistivity Instruments
Digital Differential Proton Magnetometers
5. Glenn A. Black Laboratory
of Archaeology, Indiana University, Bloomington, Indiana
Director: James H. Kellar
Instruments: Elsec Proton Magnetometer

Scollar Digital Differential Proton Magnetometer

(The Glenn A. Black Laboratory of Archaeology does not plan at the present time to offer services or the use of instruments to other organizations).

Plate Captions

Plate 1. Precision portable cesium magnetometer made by Varian Associates. Sensor and readout are shown.

Plate 2. Grid made of plastic clothesline.

Figure Captions

Fig. 1. Lay out of a grid.

Fig. 2. Grid (or Q) 1 made with the cesium magnetometer. Contours of equal magnetic intensity are shown in "differential" units (1 unit $\sim 0.5 \gamma$) and are drawn at intervals of 5 units. The grid has been photographed from the original data and shows also the numbers as recorded in the field notebook. The anomaly (A) representative of "structure" A is approximately in the center of this grid.

Fig. 3. Grid (or Q) 22 made with the cesium magnetometer. Contours of equal magnetic intensity are shown in "differential" units (1 unit $\sim 0.5 \gamma$) and are drawn at intervals of 5 units. The grid has been photographed from the original data and shows also the numbers as recorded in the field notebook. The location of Excavation ("Scavo") #1 is also shown. The most prominent magnetic anomaly is approximately 30 meters northeast of the excavation.

Fig. 4. Differential resistivity readings taken from fixed centers (as shown in plan) for a tumulus at Gordion, Turkey. The area of higher resistance as shown by the contours of equal resistivity may represent the location of the tomb.

Fig. 5. Proton magnetometer anomaly from large firepit at Snaketown, Arizona. Hatched areas represent magnetic regions; stippled, anti-magnetic.

Fig. 6. Geohm and proton magnetometer lines made over canals at Snaketown, Arizona.

Fig. 7. Proton magnetometer anomaly from Roman kiln on plateau of Fonte del Fico, west of plain of Sybaris, Italy. Hatched areas represent magnetic regions; stippled, anti-magnetic.

Fig. 8. Magnetically quiet lines recorded with proton magnetometer, plain of Sybaris, Italy.

Fig. 9. Anti-magnetic and magnetic anomalies detected with proton magnetometer, plain of Sybaris, Italy.

Fig. 10.. Map C, area of concentration of archaeological features and deposits on the plain of Sybaris, Italy. Locations of the long Wall, test excavations (hatched areas), and grids made with the cesium magnetometer are shown. Within the grids probable features are designated as follows:

_____ possible structures--confirmed by drilling

..... possible structures--friable resistance to drills

----- possible structures--not confirmed by drilling

~~~~~ anti-magnetic regions--representative of sand at less depth

xxxxxxx magnetic anomalies--representative of clay at greater depth

\_\_\_ \_\_\_ boundary lines of magnetometer grids

Fig. 11. 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. 12. Cesium magnetometer sensor experiment over long Wall, plain of Sybaris, Italy.

Fig. 13. Resistivity grid made with the Geohm over hospital foundations at Fort Lennox, Île-aux-Noix, Canada.

Fig. 14. Diagram for the calculation of the anomaly from the archaeological deposit in Q22, plain of Sybaris, Italy.

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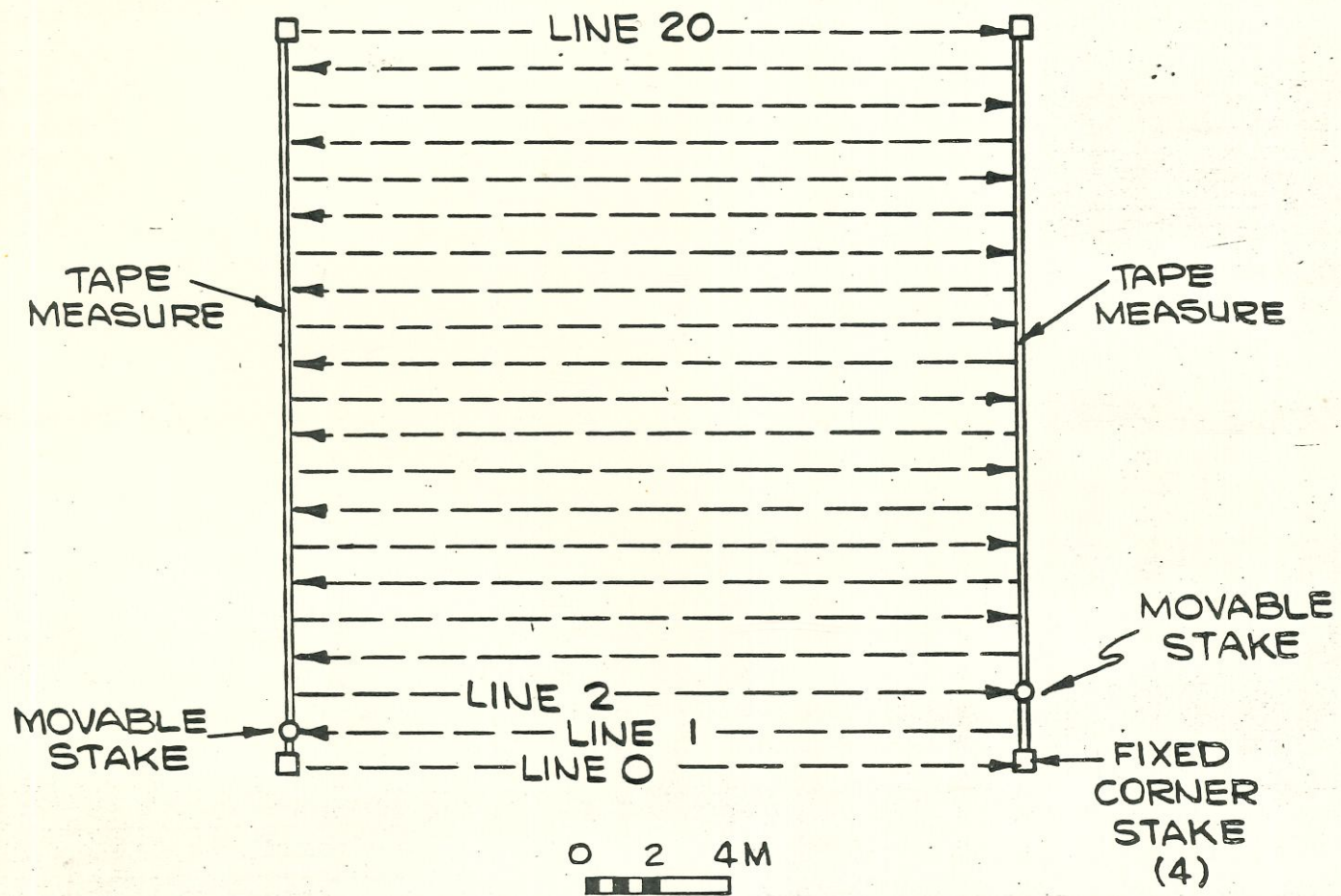
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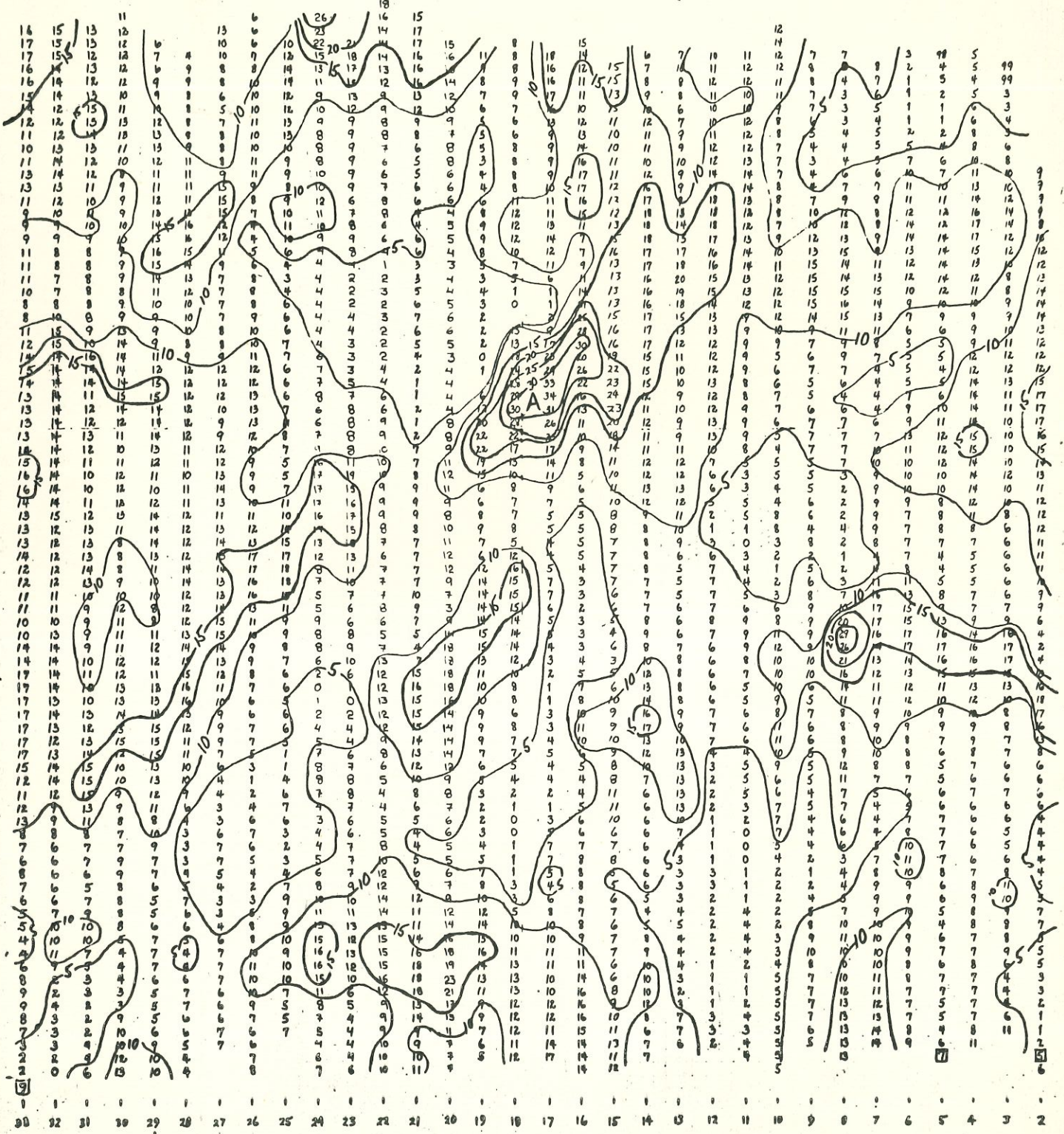
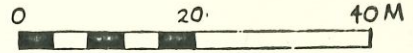
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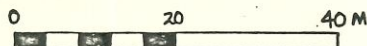
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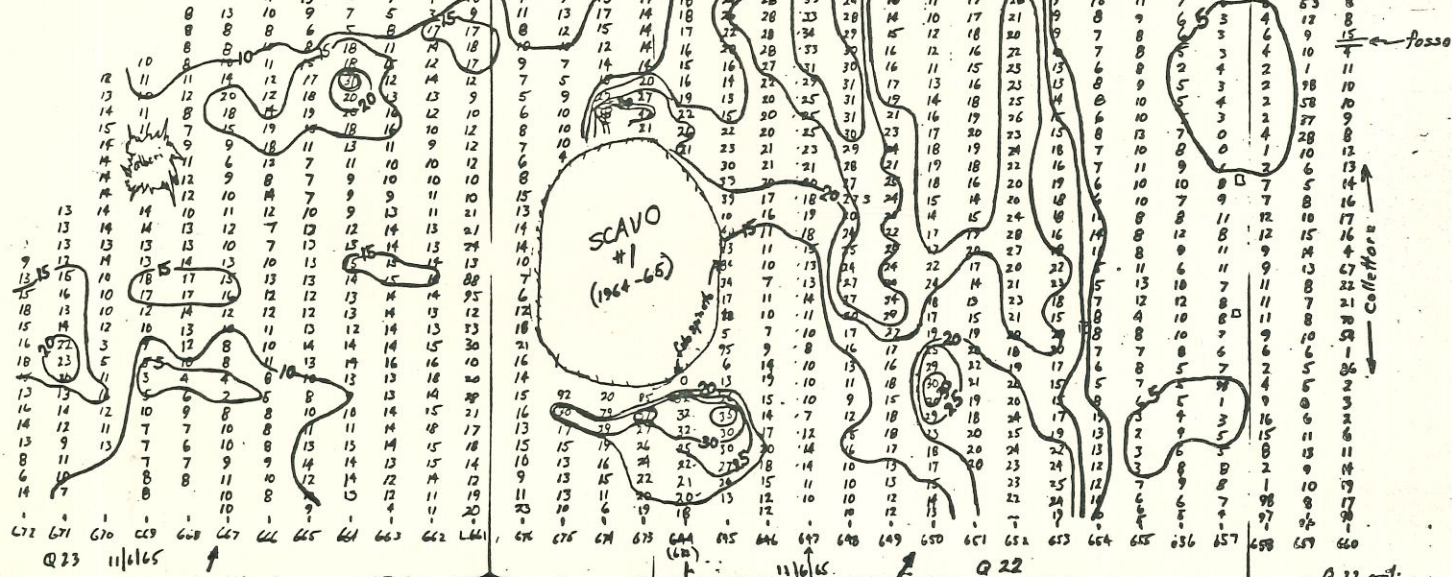
Q1





Q 22

LATTUGHELLA



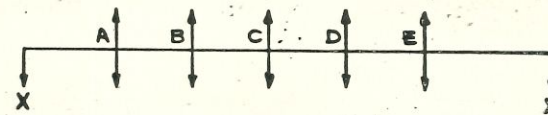
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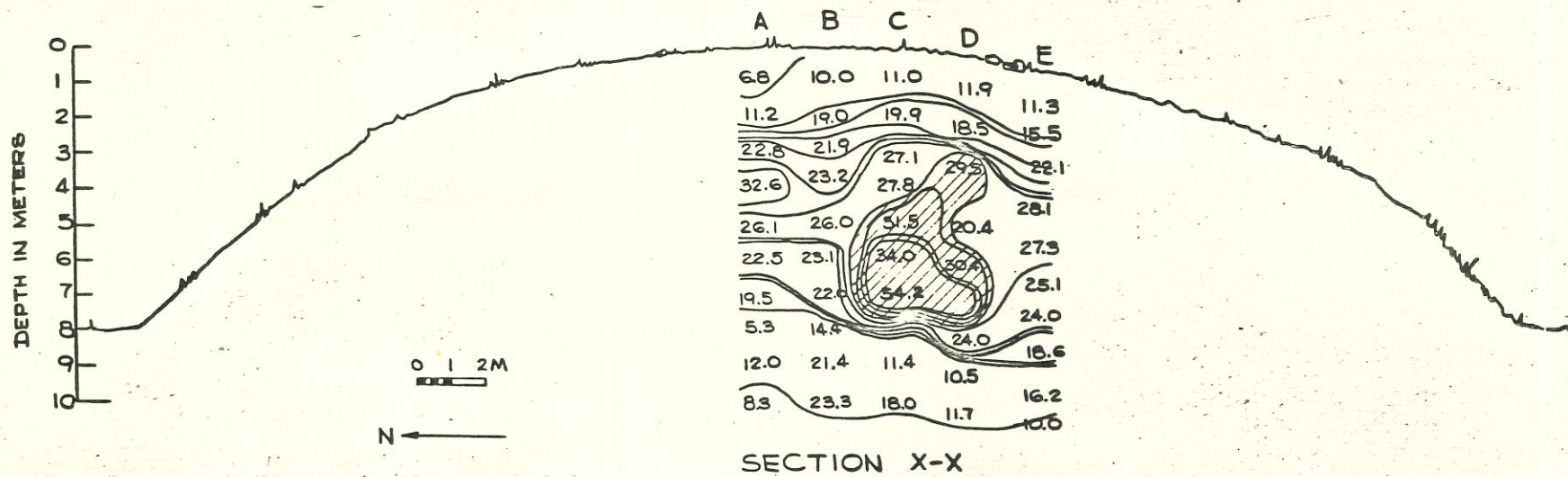
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Q 22

Q 22 cont.

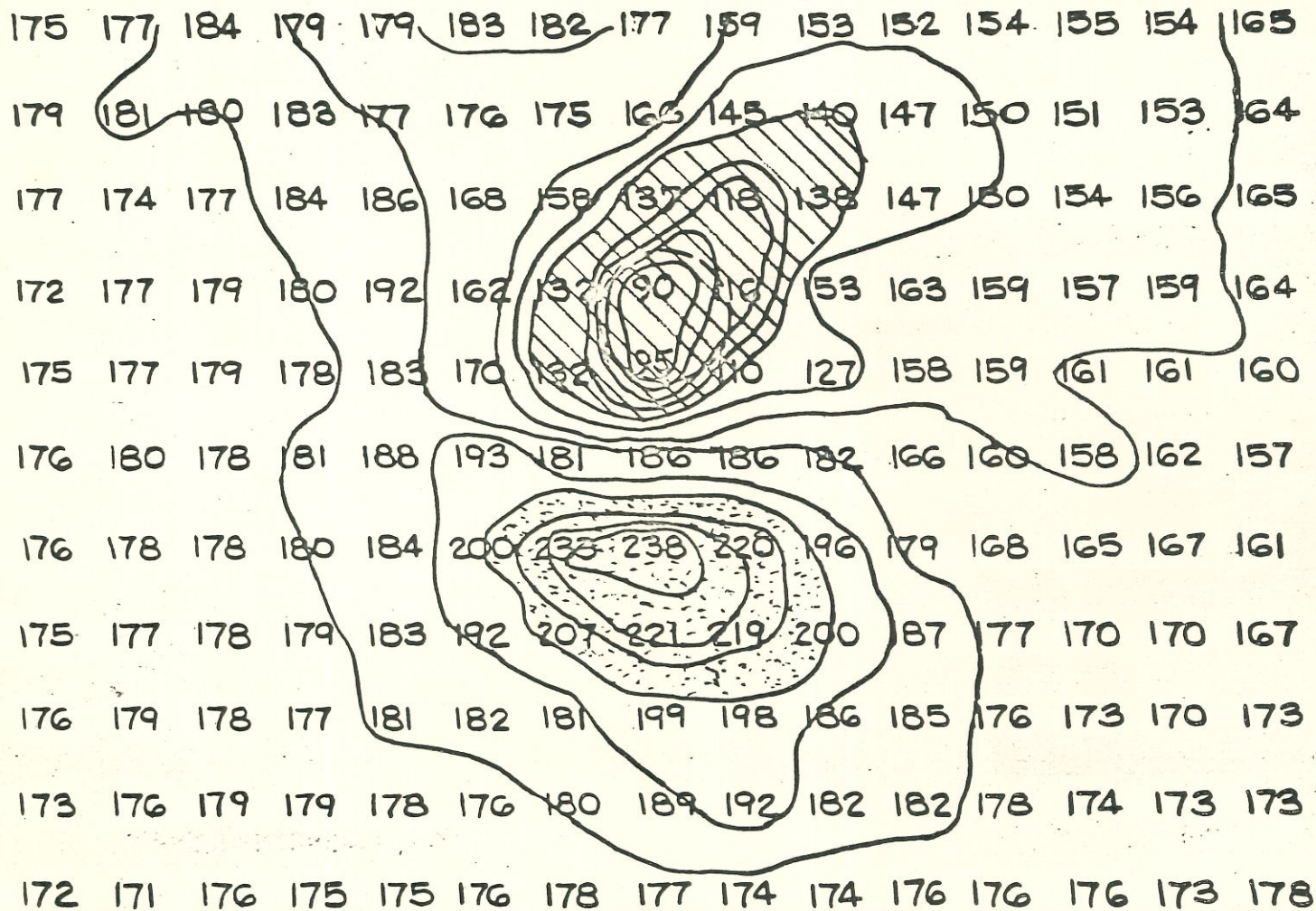


PLAN OF SECTION LOCATION

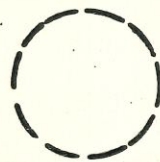


CONTOURS AT INTERVALS  
OF 10 P.M.U.

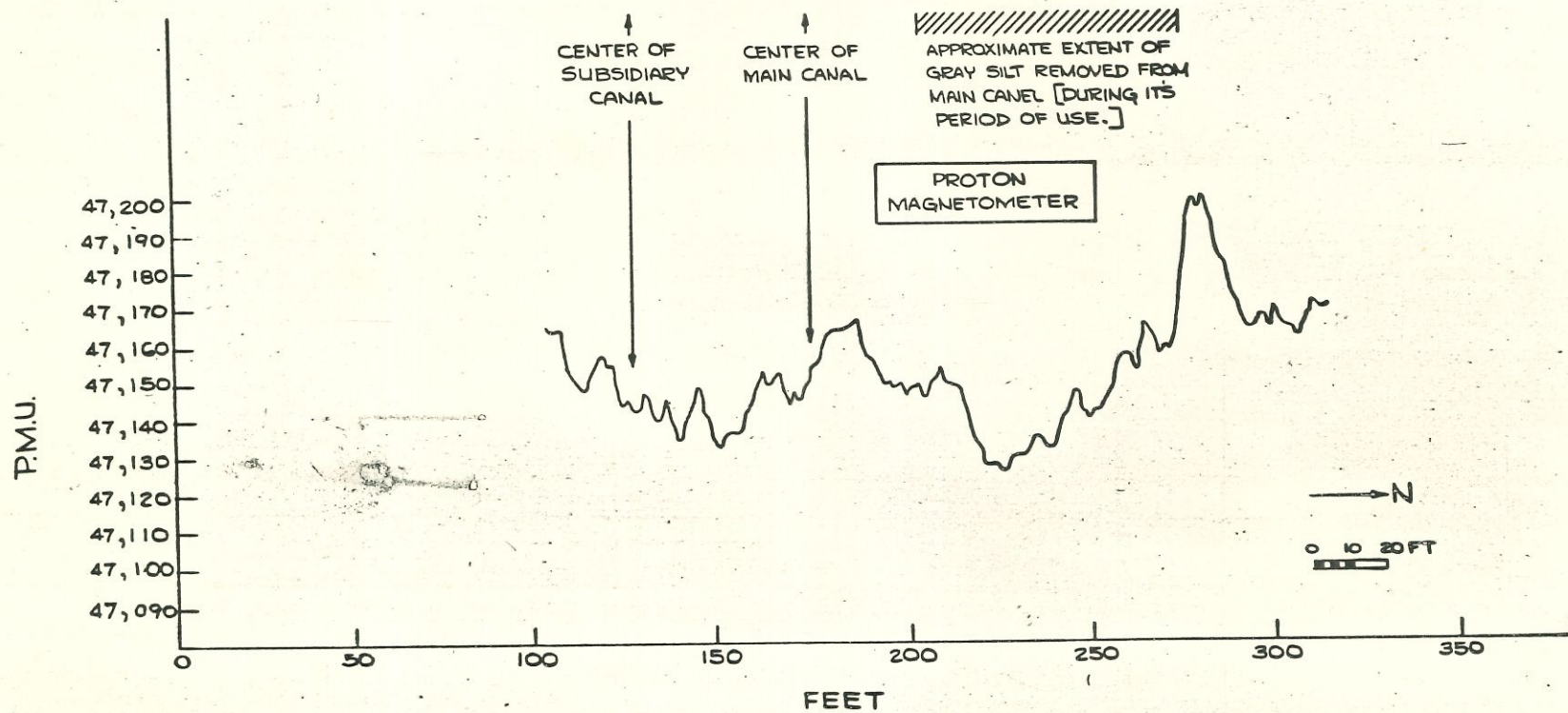
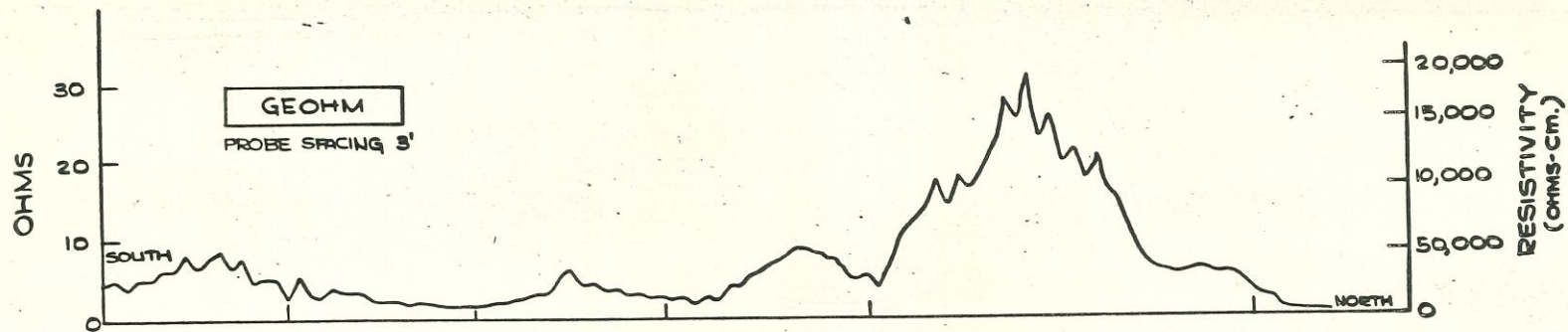
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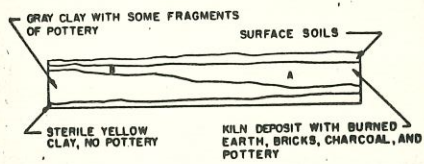
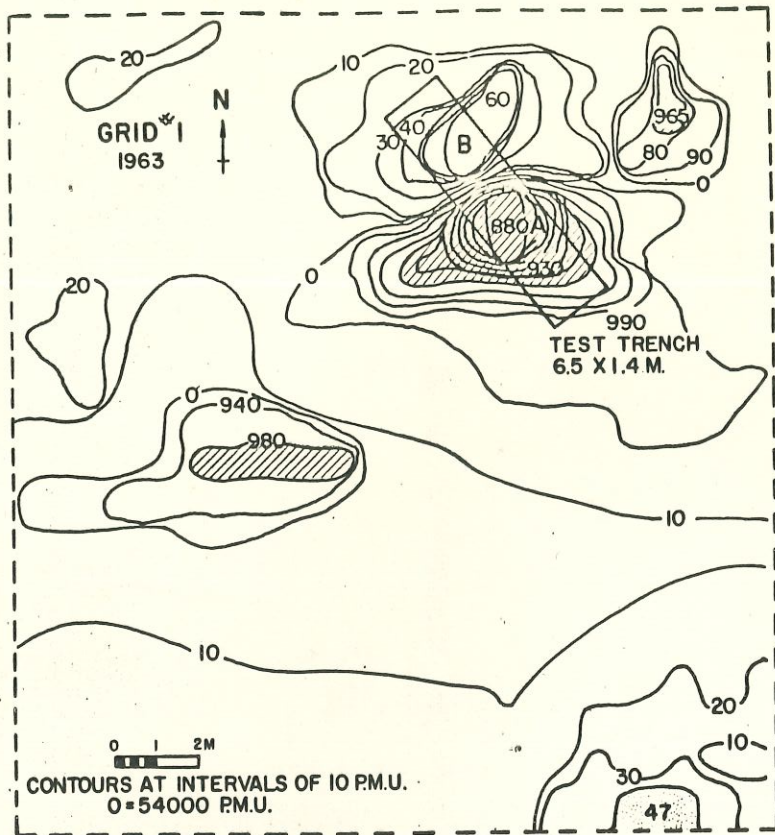


0 1 2M



APPROX. POSITION  
OF FIREPIT.

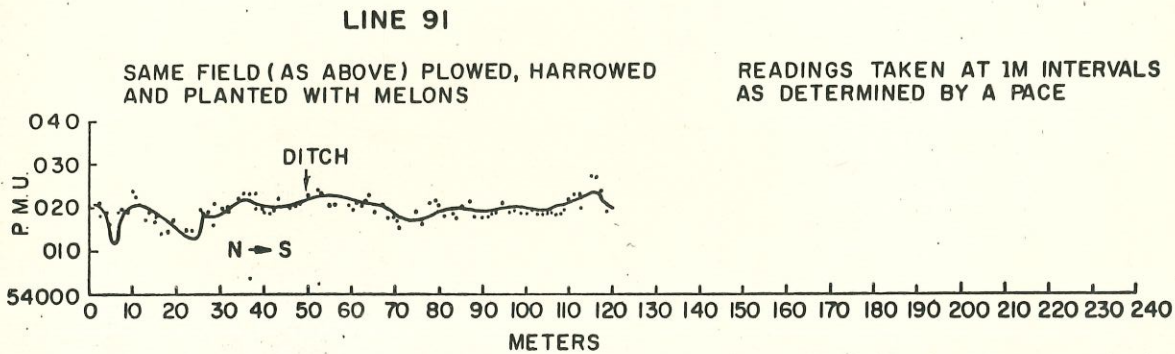
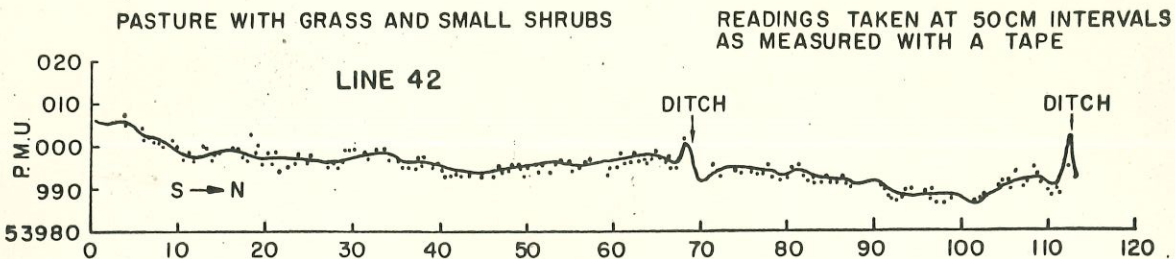




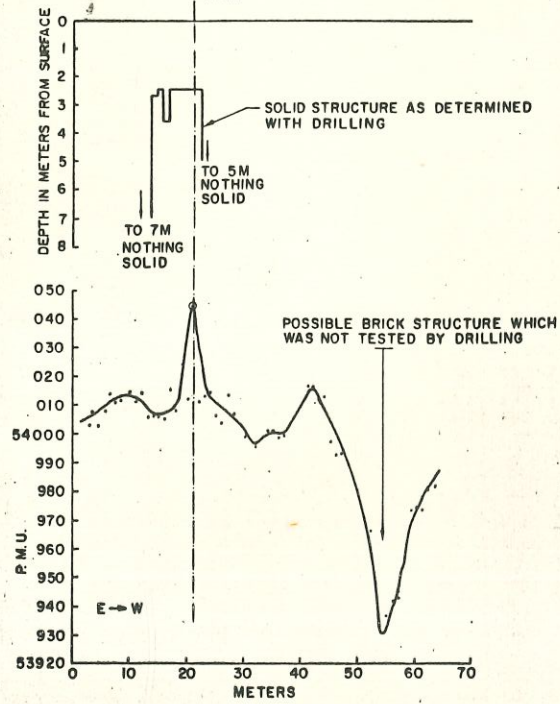
SOIL PROFILE OF TEST EXCAVATION OF KILN  
IN GRID #1 1963

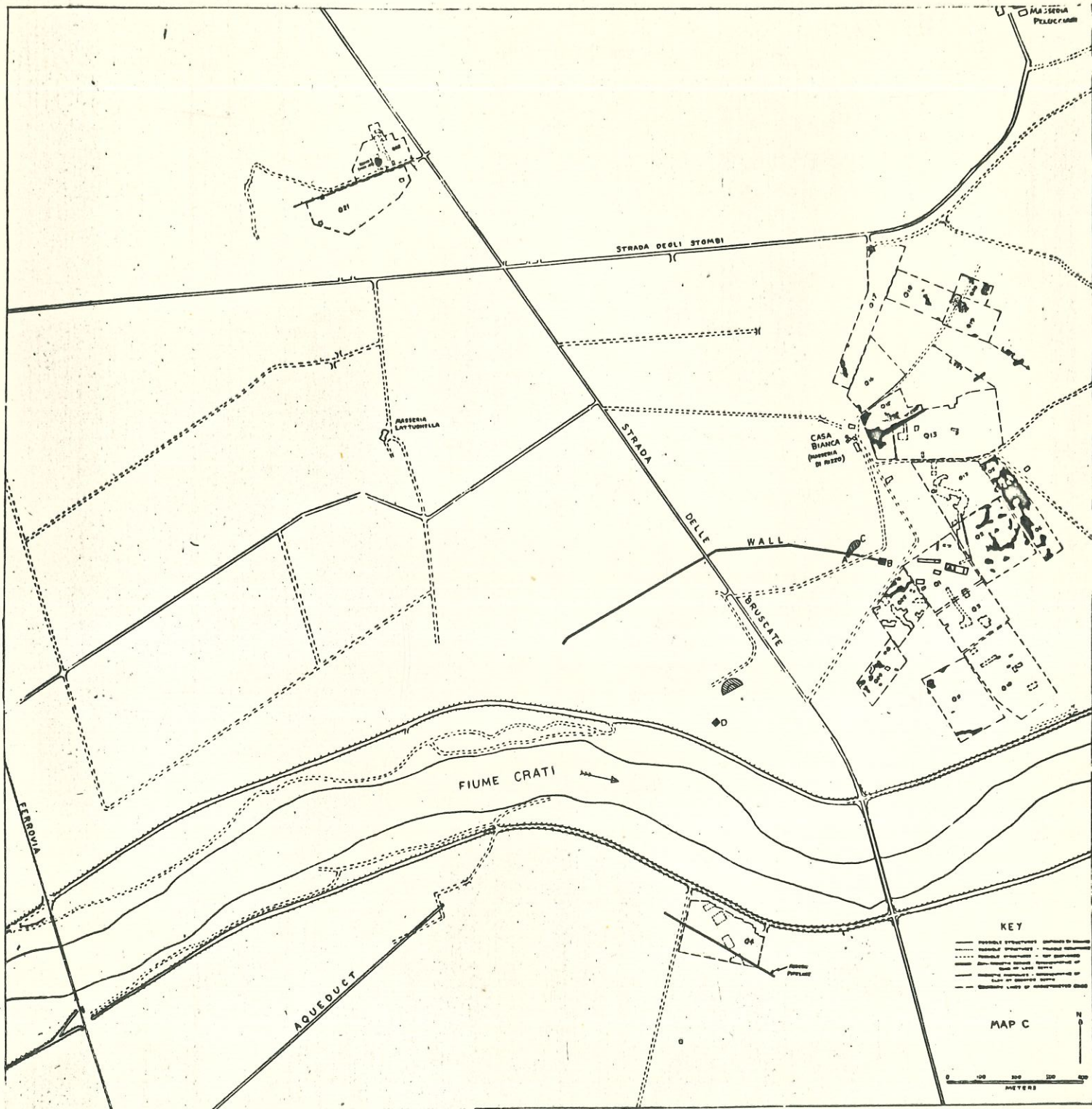


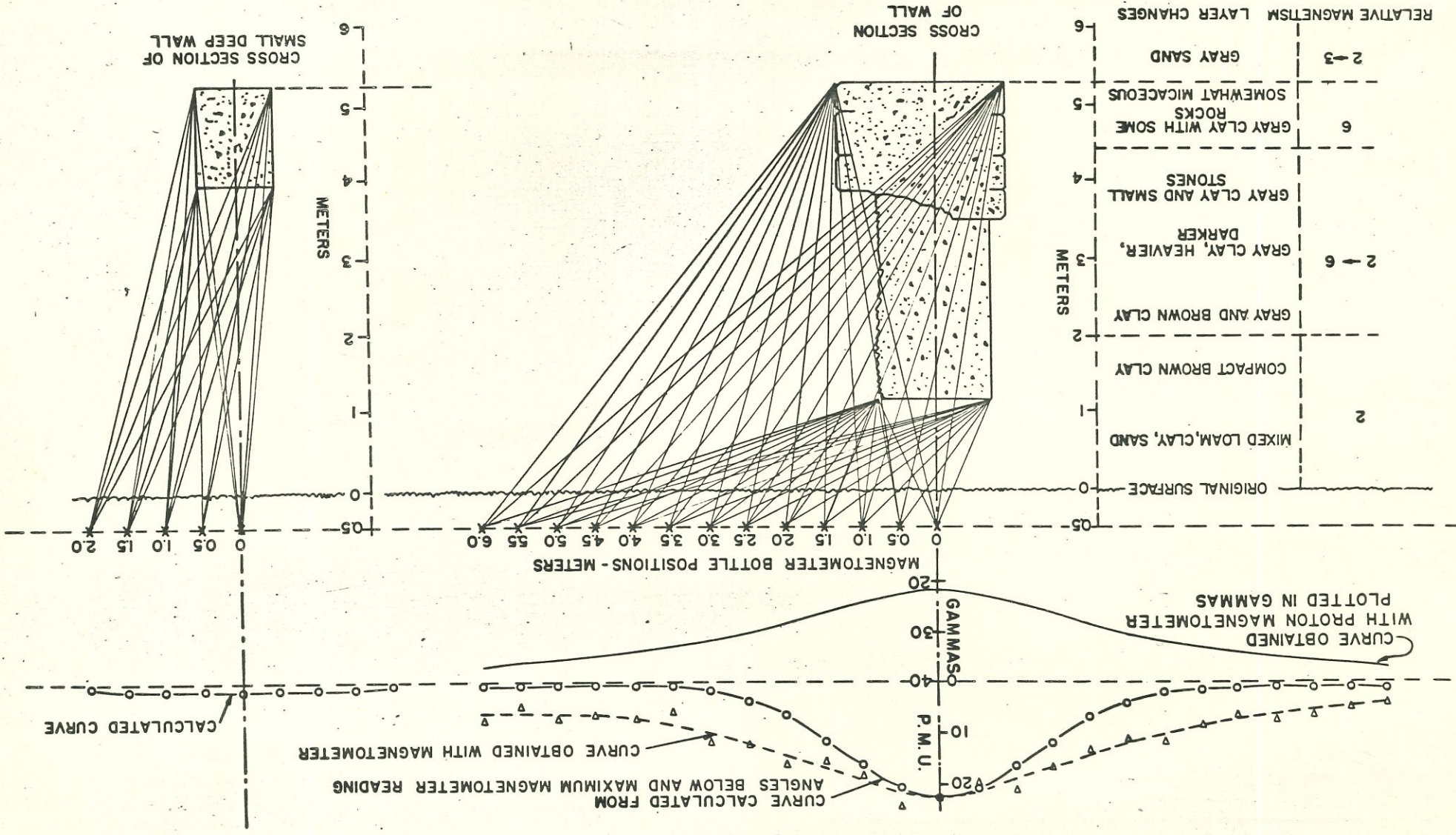
LINES WITHOUT ANOMALIES  
1962

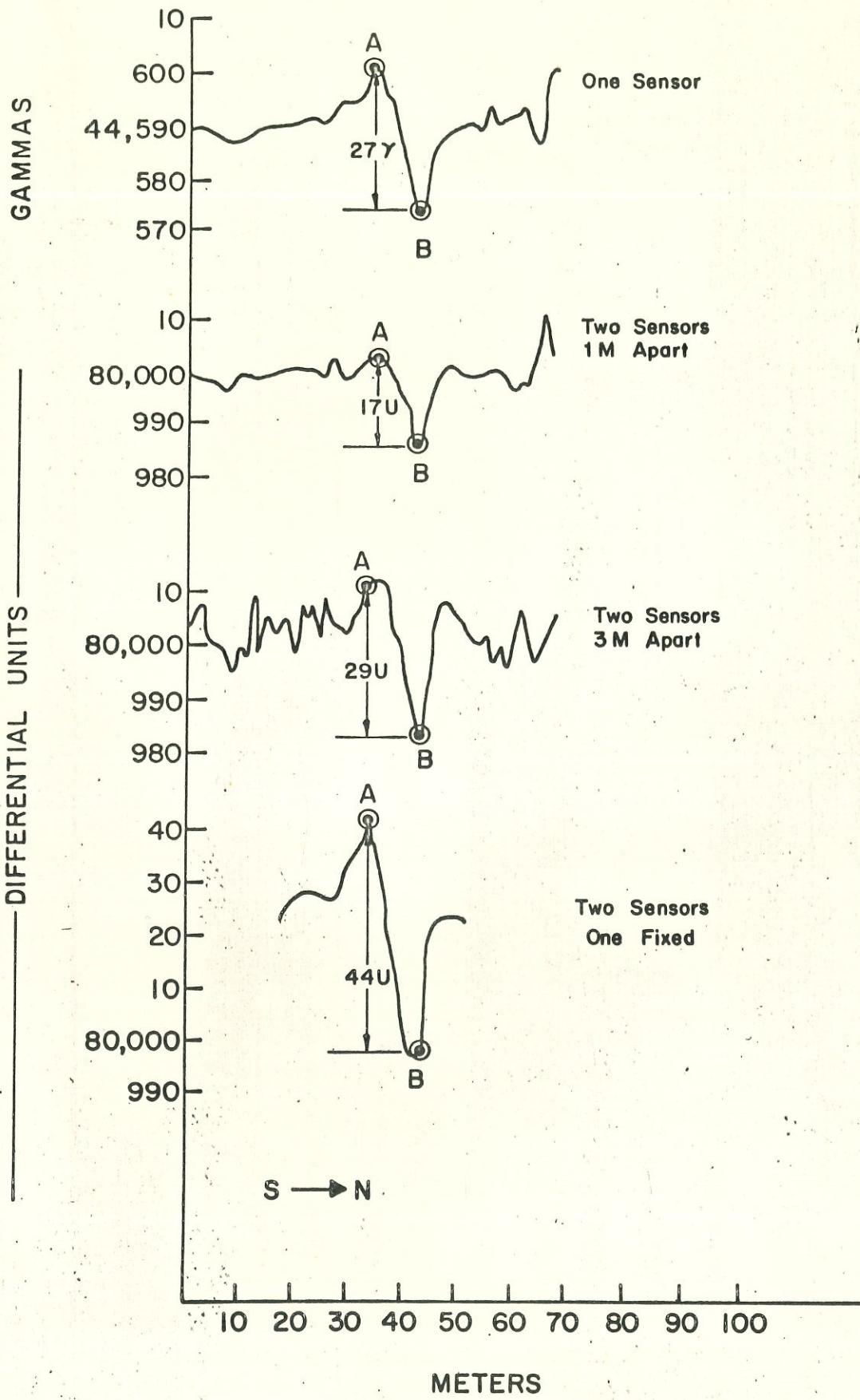


ANOMALY OF LINE 78  
1962



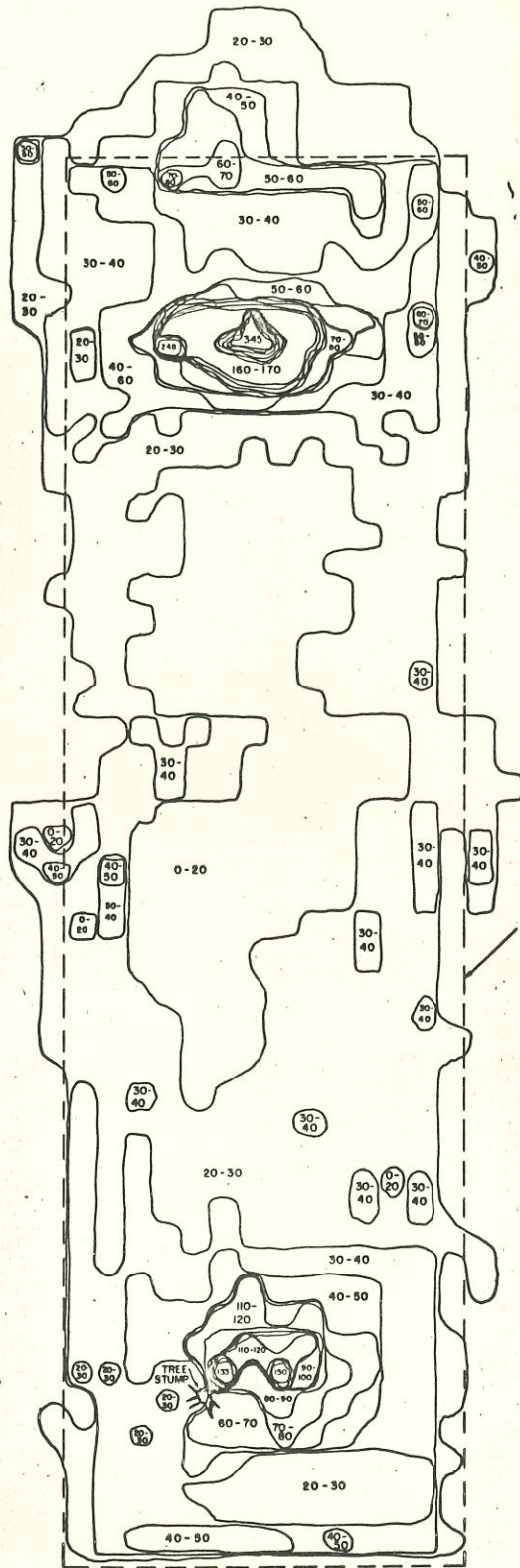






ROD INTERVALS IN FEET

134  
132  
130  
128  
126  
124  
122  
120  
118  
116  
114  
112  
110  
108  
106  
104  
102  
100  
98  
96  
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24  
22  
20  
18  
16  
14  
12  
10  
8  
6  
4  
2  
0



OUTSIDE EDGES OF HOSPITAL WALL FOUNDATIONS 28' x 101'

0 - 20  
(RESISTIVITY VALUES IN OHMS)

N  
SCALE: 1 in = 4 ft  
GEOM. GRIDS # 3 AND # 4  
HOSPITAL AREA # 20  
FORT LENOX ÎLE-AUX-NOIX  
JUNE 1964

0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72  
ROD INTERVALS IN FEET

