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NEW FRONTIERS IN ARCHAEOLOGICAL EXPLORATION

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It is now more than fifteen years since the talents of archaeologists, physicists and engineers were combined in an effort to write a bright new chapter in the saga of man's quest for information about his past.

New knowledge and principles developed in the fields of nuclear science, electronics and sonics, and the vastly improved detection instruments constructed by engineers--often for commercial ends--seemed to offer then opportunities for a major breakthrough that would provide archaeologists literally with something akin to the mythical seven league boots.

Hopefully, guesswork--even though mostly "educated guesswork"--could be eliminated from the process of locating underground remains of which no surface indications were visible and the range and speed of archaeological surveys could be greatly expanded.

Have these hopes materialized? Have the portable new detection instruments specially designed for, or adapted to, archaeology fulfilled the expectations of their developers? Even if they haven't--remembering that the effort still is undergoing growing pains--does what we have learned from field experiments provide a basis for believing that eventually they will do so?

One of the pioneers and a leader in this somewhat lonely field since 1961 has been the Applied Science Center For Archaeology located at the University Museum of the University of Pennsylvania in Philadelphia. The Center has been headed since its inception by the authors as Director and Associate Director. They personally have supervised and participated in the field experiments in which all of the known instruments considered to have potential have been tested. The Center also has contributed to the development and improvement of a number of the instruments.

Feeling that sufficient information has been obtained for a realistic appraisal of the new techniques made possible by the instruments and of the performance--and limitations--of the instruments themselves, they have prepared this report. It is based on experiments made, in some instances with the collaboration of other institutions, governmental agencies and individuals in four areas of the world, at more than a dozen different sites, under varying conditions, and working in several types of subsoil.

The instruments tested can be classified as: magnetic, resistivity, seismic, sonic, and metal detecting.

A fair summation would be that much progress has been made, unexpected problems and difficulties have been encountered, and much remains to be done.

Some instruments have proved to be of great value in detecting archaeological features at known sites as an aid in the direction of excavation. But there is reason to believe also that this is only a natural first step and that the instruments offer promise of being indispensable in exploring areas that are now beyond the scope of conventional archaeological survey.

Descriptions of the experiments that provided the data to support this conclusion are presented in the pages that follow.

Cerro de las Mesas, Mexico

Our first experiment in the field was carried out in the winter of 1960 in collaboration with Mathew W. Sterling of the Smithsonian Institution and his son Mathew, Jr.[1], at a site where Sterling had worked many years before. Cerro de las Mesas lies on the plain inland from the Bay of Alvarado, some forty miles south of Vera Cruz. It is a ceremonial center for a rich archaeological zone, where there are many large earth mounds, some constructed as early as 600 B.C., although the building period culminated 1000 years later in what is now called the Tajin period. The site was chosen as ideal for instrument testing because the plain is composed of a deep, fairly homogeneous sedimentary deposit in which Sterling had found stone stelae and other monuments of stone, all of which had been imported by the ancient inhabitants. Our object was to determine whether a resistivity instrument, known as the Michimho, which was manufactured by Associated Research, Inc. in Chicago, for highway engineers, could detect stone monuments buried in this homogeneous sedimentary deposit where any sizeable stone was certain to be imported.

The instrument operates on the following principle. Four metal rods are placed in the ground in a line with equidistant spacing, and are attached to the instrument with flexible cables. From the Michimho (or Geohm, or similar instrument) an alternating current is sent to the outer two metal rods. The earth between and below the rods then completes the circuit for the path of current, and the difference of potential which develops between the inner two affords a measure of the conductivity, or conversely, the resistance of the earth between the central rods. For each reading the volume measured is roughly that of a cube with sides equal to the spacing between the rods.

Experimenting at first with a stelae measuring 92 cms. in height and 42 cms. in maximum diameter, which had been excavated and reburied by Sterling 19 years before, we learned that the stone could be detected by a lower than average conductance reading if the metal rods through which the electric current was passed were set no more than one meter apart. At greater spacings of the rods the deviation from normal conductance in the soil was so slight that detection was very uncertain. A large part of the central square between earth mounds where Sterling had found buried stone stelae was then explored on a grid pattern with resistivity readings made at one and two meter intervals. Only one monument was rediscovered and this was actually struck when driving in one of the metal rods. Hence the experiment was inconclusive because we do not know whether there are no other monuments in this area or whether the instrument simply failed to detect them. Also, we have learned from subsequent experience with this and other types of instruments that regions of recently disturbed soil thousands of whitish spots extending outward from the known zone of Etruscan tombs. Each of these whitish spots seen from the air was actually a buried tomb which could not be seen in a normal survey on the surface. Aware of the extraordinary number and extent of these tombs, engineer Carlo M. Lerici of Rome and Milan, developed a unique technique for locating and exploring them with a minimum of labor. He assembled an electrical resistivity apparatus with potentiometers and electronic voltmeters to locate the rock-cut ramps leading down into the tombs cut into bedrock, and then developed a periscope which could be inserted through a hole drilled into the cavity of the tomb so that the tomb could be investigated from the surface without excavation. With this technique he and his staff from the Lerici Foundation in Rome had investigated hundreds of tombs during the years from 1956 to 1960.

Rainey and Lerici met in Rome in 1960 and agreed to collaborate in the further development of such exploration techniques. Hence in 1961, a team from ASCA in Philadelphia joined the Lerici Foundation team at Tarquinia to experiment with various types of instruments at that site. Tarquinia is an ideal site for this kind of experiment. Bedrock is predominantly marine limestone. The later, and most numerous, Etruscan tombs were excavated in this relatively soft material at depths now varying between two and six meters. The tomb builders cut a long, sloping ramp down through this bedrock to the tomb entrance and later, with time, it filled in with loose soil so that entrance and tomb today are completely buried beneath the soil of the fields. It is the loose and damp soil filling the ramp which is located by electrical resistance apparatus. Once the entrance is found, it is a fairly simple matter to find the tomb itself.

Our first experiments were made with a small resistance apparatus known as the Geohm, made by the Gossen Company in Erlanden, Germany, which was designed for archaeological prospecting. It had the advantage of being much smaller and cheaper than the potentiometric apparatus previously utilized by the Lerici

Foundation although it operates on the same general principle. We soon learned that it could readily detect the entrance ramps to Etruscan tombs in the same manner as the potentiometer and more rapidly. Since the instrument costs less than $100, weighs only a few pounds, and is simple to operate, it was apparent that it was a practical instrument for use by archaeologists for this particular purpose. Nevertheless, it is slow to operate and interpretation is sometimes difficult.

At this time we also began experiments with the Elsec proton magnetometer designed specifically for archaeology by the Littlemore Scientific Engineering Co. in Oxford, England. Martin Aitken and others had repeatedly proved the usefulness of this instrument at numerous archaeological sites in England. Its operation is based on the fortuitous fundamental principle that the precession rate of protons is dependent upon the magnetic field in which they are located. The detector of the instrument, therefore, consists of a plastic bottle containing alcohol (a source of many protons) surrounded by a coil. For one second a current is sent through the coil to create an artificial magnetic field, stronger than that of the earth's. Due to minute inherent dipole moments, the protons are aligned in the direction of this artificial field. When released, however, at the cessation of the current, the protons gyrate in a manner similar to tops and the frequency of their gyration or precession is a measure of the strength of the magnetic intensity of the earth under the detector bottle. This frequency is then converted to a reading which appears on the five meters of the instrument--so-called proton magnetometer units, abbreviated P.M.U. One P.M.U. is roughly equivalent to the reciprocal of one gamma (1×10^{-5} oersteds).

The instrument, therefore, is a very sensitive detector of magnetic intensity, and has the additional advantage over more conventional magnetometers in not being sensitive to orientation nor to require leveling. These features make it suitable for rapid surveying.

Our most important discovery at this time was that the proton magnetometer could detect the precise location of the tomb itself, rather than the entrance ramp, and that a survey with this instrument was many times faster than a survey conducted with a resistance instrument. Magnetic readings were made on a grid pattern, so that a magnetic contour map could be drawn of the surveyed area and from these contours precise location of individual tombs could be made. When this system was finally worked out, we were able to locate 5 or 6 tombs in a single day. On this site we learned that about 100 magnetic readings could be made every 15 minutes, and that a grid of 50 x 25 meters, with 1250 individual magnetic readings could be completed in about 4 hours.

There are very specific circumstances at Tarquinia, and Cerveteri which make this kind of tomb discovery possible. For there, it appears that the limestone, which is normally non-magnetic, has a slight magnetism. The majority of the tombs, therefore, appeared as regions of minimum magnetic intensity due to the fact that they represented sizable hollow areas within the limestone. This reasoning may also explain why the entrances, areas of soil disturbances which are usually more magnetic than undisturbed soil, did not produce magnetic anomalies. It is possible that the magnetism of the entrances just happened to match that of the limestone.

At the acropolis of Tarquinia, the Lerici Foundation had located various foundation walls lying less than one meter below the surface of cultivated fields on that promontory. As a further test of the proton-magnetometer, we ran a series of magnetic readings in parallel lines at right engles to the known location of one of these walls. In every case the wall produced a much lower than normal magnetic reading so that it was a simple matter to chart its exact position.

Also at Tarquinia, we experimented with a simple refraction seismograph which was designed to measure the time interval elapsed between the production of a shock wave (in this case produced by a hammer against a metal plate lying in the ground) and its arrival at a detecting geophone placed at some distance from the hammer. This instrument (Model MD-1 Engineering Seismograph), made by Geophysical Specialties,Co., Hopkins, Minnesota, was designed to assist highway and other construction engineers in the location of bedrock and other layer changes, which even though shallow from the geophysicists' point of view, are deeper than the normal archaeological features. The basic difficulty for us is the fact that the long wavelengths of these seismic frequencies by-pass the relatively small structures which we are seeking. Also, at Tarquinia the tombs were cut in solid limestone so that their walls did not differ from the surrounding rock.

Tikal, Guatemala

A trial with three instruments, the proton magnetometer, the Geohm resistance instrument, and a seismograph, was also made by Richard Linnington of the ASCA staff at this Mayan ceremonial center in the heavily forested region of the Peten in Guatemala, in 1961. The proton magnetometer was not properly calibrated at that time and hence did not function. But in any case, it is doubtful whether the magnetic type of instrument can be used in such a dense, forested zone with tree roots everywhere penetrating the deposits.

The Geohm, however, did function and very elaborate resistance grids were made in three areas; on the face of the pyramidal structure supporting Temple I; in search of a tomb cavity thought to be located in this pyramid; on the north acropolis where excavation of stone structures was proceeding; and in the west plaza in search of a deep cultural deposit where trial excavations could be made. Results in the first two areas were inconclusive, but in the plaza, resistivity contours made it possible to locate an area of deep disturbances which was confirmed by excavation. Nevertheless, we concluded that this was not a type of archaeological site which would repay intensive instrument survey.

Sybaris, Italy

Herodotus, the Greek historian, lived for a time at the Greek city of Thurii, on the Ionian Sea in South Italy, during the 5th century B.C. From him and from other Greek and Roman writers, we know that Thurii replaced the famed city of Sybaris, which was founded there in the 8th century B.C. and then destroyed by the neighboring Greeks of Croton in the 6th century B.C. This original Archaic settlement was renowned for its size, wealth, luxury, and decadence. It became, in fact, such a symbol of luxury and decadence that its name survives in our word "sybaritic." Graeco-Roman writers agree in locating Sybaris somewhere on or about the present plain of Sybaris near the rivers Crati and Sybaris (now called the Coscile) but the precise location is not given in any of the numerous ancient accounts of the city. The plain is a flat swampy area of some 80 square kilometers, surrounded by low terraces which rise to high snow-covered mountains. The two rivers and numerous "torrenti" have repeatedly innundated the plain depositing enormous quantities of sediment washed down from the mountains. Also, we know that the land-sea level has fluctuated during the 2500 years since Sybaris was destroyed and much of the sediment in the plain may be sea-deposited. It is evident, at least, that the rising sea level has blocked the outwash of the rivers, causing a ponding which may account for the deep sedimentary deposits on the plain.

The search for the ruins of Sybaris began in 1878 and there have since been several systematic campaigns to locate the remains. Paestum was a colony founded from Sybaris and this gives some indication of the kinds of ruins which should be found at the site of the mother city. Ruins of an extensive Roman building were found near the mouth of the Crati river in 1932.

In 1960 Franco Brancaleoni of the Lerici Foundation explored part of the Sybaris plain with the potentiometer (resistance instrument) used at Tarquinia and Cerveteri, and located a buried wall north of the Crati river, about two kilometers above the present mouth of the Ionian Sea, and less than one kilometer from the Roman structure found in 1932. In that campaign, he traced the course of the wall for about 100 meters, confirming the instrument anomalies with a series of shallow test pits.

In the fall of 1961[3], the combined University Museum-Lerici Foundation crews moved from the Etruscan sites to Sybaris to continue our experiment with the proton magnetometer. We soon learned that the instrument could easily pick up the wall where it was know, with the top of the wall no more than one meter beneath the surface of the plain. Within ten days, we had traced it for about 750 meters. Test excavations demonstrated that we could still detect its position when the top was as much as 3.5 meters beneath the surface.

The following spring, 1962, we continued tracing the wall for a total distance of 1350 meters. At that time during a visit to the site made by Martin Aitken, of the Oxford Laboratory, he and Elizabeth Ralph made some tests of soil susceptibilities in order to analyze the geophysics involved in locating the wall. The success in the detection of large buried walls on the plain of Sybaris with the proton magnetometer is due to an unusual application of the instrument. The majority of the anomalies found were not caused by magnetic materials such as iron or kilns or increased soil susceptibility due to previous disturbances, but were anomalies of minimum magnetic intensity (high proton magnetometer units). This type of detection was possible because most of the walls were non-magnetic, whereas the thick deposits of clay, especially at the deeper levers, were slightly magnetic.

The biggest find was the long wall in the so-called port region. It was big in many ways--it was long, it was deep, and it was high. In order to interpret the anomalies that were detected with the proton magnetometer, over this wall, let us follow the reasoning of Vacquier[4 5], et al, and assume for the moment that the wall is magnetic and the surrounding earth, non-magnetic. In this case then, if we neglect the horizontal components, there would be an excess of south seeking poles (due to the minute dipole moments of the particles) at the top surface of the wall and an excess of north seeking poles at the bottom, while all those in the middle would cancel each other out as far as the magnetometer above the surface of the earth is concerned. The vertical magnetic intensity at the magnetometer then is proportional to the difference of the solid angles subtended by the top and bottom surfaces. In the case of the large non-magnetic wall at Sybaris, the situation is the reverse of this, but since the Elsec proton magnetometer readings are the reciprocals of magnetic intensity, the net effect is a curve with a peak--for us, a non-magnetic anomaly. This is illustrated in Fig. 1. On the basis of the maximum reading recorded and from the relative difference between the solid angles subtended to the top and bottom of the wall as the detector bottle position is changed, the calculated curve has been plotted (above the wall in Fig. 1). The actual curve which was obtained with the magnetometer in a line run perpendicular to the wall is shown also (dashed line). It is readily apparent that the agreement between the actual anomaly and the hypothetical one is good.

If we continue this reasoning, then for a small deep wall (see right hand side of Fig. 1), we find that the anomaly to be detected is negligible. In other words, with this relatively small magnetic contrast between walls and earth, it appears that it is not possible to detect the small deeply buried Archaic Greek walls on the plain of Sybaris with this instrument.

South of the Crati river where large magnetic anomalies were found, and the drills did not detect walls, the situation is very different. These anomalies were evidently due to very heavy concentrations of pottery such as in tombs, or to other fired materials. From the great depths at which the potsherds were found with the drills (4 to 6 meters) in this region, it is estimated that a quantity of fired materials about the size of a deep wall, that is, a cube approximately 1.5 by 1.5 meters, would have many times greater magnetism than the gray clay of the region north of the Crati for detection.

The search for Sybaris is probably the most ambitious experiment with electronic instruments in archaeological surveying so far attempted. From the ancient accounts we assume that the buried ruins must extend over several square kilometers, but they may be found anywhere in an area of 80 to 100 square kilometers, either on the flat plain or on the low terraces above the plain. Moreover, they must lie several meters deep because deep plowing in the area and the excavation of many irrigation ditches have not exposed them. The late Roman ruins found at the Parco del Cavallo, on the plain, in 1932 are also deeply buried in the silt and now lie below the water table.

During three seasons[5] in 1961, 1962 and 1963, we have explored a large part of the plain and also selected regions on the terraces above the plain with the proton magnetometer and the Geohm resistance instrument, as well as with power driven drills. The drills were utilized to test anomalies found by the instruments, but also for independent investigation. More than 1000 drill holes to depths of 6 to 25 meters have been made during this period. Several preliminary reports of this work have been published[6], and the complete report is now in preparation so that only a brief summary is necessary here.

On the plain in the vicinity of Parco del Cavallo, near the mouth of the Crati river, we have outlined an area of about four square kilometers, which is certainly the port of Sybaris, Thurii, and the Thurii-Copea, that is, the original Archaic Greek city, the following Greek city of the Hellenistic period, and the later Roman city of about the time of Christ. Hundreds of drill holes in this area disclose a stratified deposit of potsherds and other cultural refuse beginning two or three meters below the surface and extending to a depth of 6 to 7 meters. But the instruments and the drills indicate that buried constructions are limited to a zone about the Parco del Cavallo on the river which measures only about 600 meters by 1100 meters. Here many buried structures were detected by the proton magnetometer and proven by the drills. Hence onlyh the southern part of the 4 square kilometer area of cultural debris appears to be occupied with buried ruins of buildings while the northern sector is not. The significance of this is not clear and can be determined only with extensive test excavations in the northern area. The whole area, of course, may turn out to be the site of the cities themselves, and not only the port, but there are reasons to believe that we have found the port and that the remains of the cities themselves will be found inland and perhaps on the terraces above the low swampy plain.

It should be observed that the proton magnetometer was able to pick up two different types of anomalies on the plain; buried stone structures which appeared lower than normal magnetic readings, and brick constructions as well as concentrated deposits of pottery, which give a higher than normal reading. The latter type could be detected as much as 5.5 meters in depth, the former no more than 3 to 4 meters in depth.

Above the plain, on the terraces rising toward the surrounding mountains, we picked up numerous anomalies which, however, in most cases turned out to be only pockets of unusually magnetic soil. Thus on the alluvial plain, the magnetometer was successful, not on the higher ground. Resistance apparatus is not useful on the plain because the water table is no more than one to one-and-a-half meters below the surface. It can be used on the higher ground but is not practical in a survey of such magnitude because of the slowness of operation.

In an attempt to overcome the disadvantages of commercial seismographs designed for other purposes, a portable sonic prototype was constructed by MacLaughlin Electronics, Perkiomenville, Pa. This unit was tested at Sybaris, first in 1962, and with some improvements, again in 1963. Experiments were made with both magneto-strictive and crystal transducers. These were pulsed at the same rate as the sweep of an oscilloscopic detector, and it was anticipated that reflections from buried walls (detected by a geophone and fed to the horizontal plates of the oscilloscope) would appear as distortions of the normal oscilloscopic trace. This specialized and very portable detector functioned as anticipated, but the transducers were incapable of imparting a wave of sonic frequency into the ground with sufficient force to be reflected or oven to be detected as direct transmission at distances greater than one meter. We did, however, learn more about the problems of attenuation and ground coupling at sonic frequencies. This, combined with the knowledge gained from the experiments made by the Petty Geophysical Company on our behalf, have served as guides in the design of a different type of apparatus which is now under construction--work which is proceeding with the advice and assistance of the Texas Instrument Company in Dallas.

Navan Fort, Armagh, North Ireland

The University Museum is collaborating in the excavation of Navan Fort with archaeologists from Queen's University in Belfast, and the Ministry of Finance, North Ireland. The Fort is a great entrenchment encircling a hilltop about 2 miles west of Armagh. Traditionally, it is said to be the site of Eamhain Macha, where the Red Branch Knights had their headquarters for almost 700 years, and where the ancient Kings of Ulster reigned. Actually, the mound will probably turn out to be a Bronze or Iron age tomb. The excavations there are part of a training program for U.S. and Irish students in archaeology.

Michael Tite, of the archaeological laboratory in Oxford, made a proton magnetometer surveyjover the central mound before excavation began, but the results will not be known until its excavation is completed.

Elizabeth Ralph continued with a proton magnetometer survey of areas surrounding the central mound and beside a neighboring lake. Results of these surveys are still inconclusive because adequate test excavations have not yet been carried out.

Independence Square, Philadelphia

The restoration of the Independence Square area has provided a convenient testing zone and a training ground for students. The location of buried walls are known from test trenches made under the direction of John Cotter, and here the Geohm resistivity apparatus could be tested under various weather conditions. The magnetometer is useless at such a site in the center of a city, because of all kinds of magnetic interferences.

Harpers Ferry, West Virginia[7]

The U.S. Rifle works at Herpers Ferry were abandoned in 1860. Edward McM. Larrabee of the National Park Service has been making an archaeological study of the site for the past four years and with him and John Cotter we arranged for an instrument survey to be conducted by Hamilton Carson of the University Museum's ASCA. This was a good site for experimentation with instruments because excavations were in progress and thus, features detected with the instruments were immediately tested by excavation.

The most impressive result was the location of a turbine pit at a depth of 5 ft. with the resistance apparatus. Water collected within the solid walls of the pit probably was responsible for high conductance readings which outlined the pit.

Experiments with a seismic instrument were less convincing in the location of buried structures, but did result in determining the depth of bedrock.

Isle Royal, Lake Superior

Hamilton Carson of ASCA, in collaboration with John Cotter, in 1963, carried out a metal detector survey of a site where Indians had excavated pits in search of copper deposits. A map of the region was made locating anomalies recorded by the metal detector. These are probably concentrations of copper, but adequate test excavations have not been made.

Fortress of Louisbourg, Nova Scotia, Canada

This is the French stronghold on Cape Breton, which was maintained from

1713 to 1760. In an arrangement worked out with Edward McM. Larrabee, chief archaeologist, now working at Louisbourg, Elizabeth Ralph carried out an instrument survey in August and September 1963, to aid in excavation. Utilizing magnetic, seismic, resistance, and metal detecting instruments, she was successful in locating certain archaeological features in the ruins which were helpful in projecting the following excavations. For example, it was necessary to locate certain graves known to be in the chapel, before excavation could proceed. This was done accurately with the proton magnetometer (see Fig. 2). The Geohm (resistance apparatus) was also successful in locating a tunnel below the Place d'Armes. More specific information on the results of this survey will follow with the completion of excavation.

Fort Loudon near Chambersburg, Pennsylvania

A search for former trenches and embankments at this site where there were no surface indications, was undertaken with a proton magnetometer also in 1963 by Elizabeth Ralph and John Whitthoff. Magnetic disturbances in parallel lines probably represent either trenches or embankments, and test trenches are now to be made.

Caleb Pusey House, Chester, Pennsylvania

This historic house is in an urban area where the proton magnetometer could not be used. However, the Geohm resistance apparatus charted a number of anomalies in the area around the house which presumably are the foundations of walls. The work was done in collaboration with Dr. Allen Schick, and was successful as a guide to excavations.

Hagley Museum, Wilmington, Delaware

This is the site of the original DuPont powder mills. A survey of certain sections of the site was arranged in 1963 with James Ackerman of the Hagley Museum, in part to train students from the University of Pennsylvania in the use of survey instruments. In the area where there had been many explosions, there was so much buried iron that the proton magnetometer could not function; in other sections, less riddled with iron fragments, grids were made with both proton magnetometer and resistance apparatus. There were indications of buried conduits and metal fragments.

The metal detector was most useful on this site in locating buried machinery and various metal fragments at shallow depths.

Fort Lennox, Ile-aux-Noix, Quebec Province, Canada

By arrangements with John H. Rick of the National Historic Sites Division of the Canadian Department of Northern Affairs and National Resources, ASCA is now (summer, 1964) engaged in a search for buried structures in the central part of the island. The existing fortress was first constructed by the British Government in 1820 and abandoned in 1870, but there are references to earlier structures, the precise location of which is unknown. The site was selected to train Canadian archaeologists in excavation techniques and also to operate various types of survey instruments.

Very accurate location of one large rectangular stone structure has been made with the resistance apparatus--namely, the foundations of the hospital. A contour plot of the resistivity readings is shown in Fig. 3. The excellent correspondence of the area of higher than normal resistance with the outer walls and of very high resistance with the bases of the hearths is readily apparent. Additionally, recent excavations have revealed that the bulges in the central portions of the long east and west walls correspond with entrances to the building. These non-magnetic stone walls, buried in earth with negligible magnetism did not produce definite anomalies with the proton magnetometer. However, due to the fact the earth was more disturbed within the walls than without, there were variations in magnetometer readings of greater magnitudes within the area of the foundations of the hospital.

This fact has enabled us to find several general areas of previous occupation with the magnetometer. Once found, then intensive surveys of these more limited areas with the Geohm have served to pinpoint outer structures. The magnetometer, of course, was the optimum instrument in finding a large brick hearth within the cookhouse.

At this site experiments with the rubidium magnetometer produced by Varian Associates have also been conducted. As expected, the correspondence between magnetic anomalies found with both types of magnetometers was excellent. At this site, the extra sensitivity available with the rubidium magnetometer was not required due to the relatively large anomalies from such recent occupation.

Tests made with the Soiltest Terra-Scout seismograph indicated that this instrument also operates well for the function for which it was designed--namely, to find bedrock at this site, but that detection of these small, shallow walls was possible only when the geophone (the receiver) happened to be near the walls. Even then detection was uncertain.

Comparative evaluation of the usefulness of the instruments

It will be apparent from this summary of trials at various kinds of archaeological sites during the past three years that the present survey instruments are useful in detecting archaeological features at known sites and are thus helpful in guiding subsequent excavations and in saving the labor of excavating many trial trenches. For example, at the Etruscan necropoli or Tarquinia and Cerveteri, almost all tombs have been looted and only a few (approximately three or four in one hundred) are worth excavating. Rapid location with the proton magnetometer and examination with the periscope saves endless excavation and assists in preserving the most important tombs such as those relatively rare tombs at Tarquinia which contain wall paintings. Also, at the several historic sites in the U.S., preliminary surveys with instruments clearly save labor, speed up the location of ruins, and serve to map the extent of buried structures, which may never be unearthed.

The light, inexpensive, resistance instrument known as the Geohm is effective in locating relatively shallow archaeological features, such as stone structures,and clearly distinct strata, but it is slow to operate over any large area. We believe that it will be increasingly used by archaeologists in surveying known sites of limited extent as a guide and labor-saving device.

Our experiments so far, with seismic apparatus, have not been encouraging. Although archaeological features can be detected with this type of instrument, it appears to have no particular advantage over the resistance instruments and is even slower to operate. One possible advantage is in the measurement of the depth of bedrock on any site to be excavated, which can be done effectively with any good seismograph.

The present metal detectors are of limited usefulness because of their shallow depth of detection. It is possible that their penetration can be improved with further development. At present in archaeology, they are undoubtedly most useful undersea in the search for wrecks.

Of the various types of instruments, we have found the Elsec proton magnetometer the most effective in large scale surveying, simply because magnetic intensity recordings can be made rapidly. But the instrument is not effective on many archaeological sites. It can only detect variations in magnetic intensity which are caused by certain types of deposit or features underground. As we discovered in the investigations at Sybaris, where soil conditions and magnetic intensity contrasts favored the use of this instrument, only very large archaeological features could be detected at depths of more than three to four meters.

Thus, none of the instruments developed and tested so far is as yet satisfactory for the kind of large scale survey in search of unknown archaeological sites, which we expect to carry out in the future. What we need to develop is an instrument which can be operated as rapidly as a proton magnetometer and which will detect also a wider range of archaeological features at depths up to 10 meters. At the moment the best possibility appears to be the sonic principle which should make it possible to detect almost any sub-surface anomaly. Research carried out by the Petty Geophysical Company in San Antonio, Texas for ASCA during the past two years indicates that a sonic impulse in the range of 600 cycles per second can be reflected from depths as much as 30 feet. There are still serious problems of ground coupling, energy source, recording, and in reducing the size of the equipment, as well as in devising an instrument which can record over a large area in a relatively short time--but we believe the principle is proven.

If such an instrument can be developed, then electronic surveys in archaeology should do much more than aid in the charting and exploration of known sites. Archaeologists normally explore sites such as mounds and caves which are obvious on the surface. Rarely are such sites found by accident. But with the present rapid development of electronic techniques, we should be able to produce an instrument which will make it possible to search large areas where there are no indications on the surface and to discover entirely unknown sites. Such land exploration is like that just now beginning undersea, and both, thanks to the new technology, should open wholly new fields of research into the past.

Footnotes

1. Mathew W. Sterling, Froelich Rainey, Mathew W. Sterling, Jr. "Electronics and Archaeology", in EXPEDITION, the Bulletin of the University Museum, Summer 1960, Philadelphia, Pennsylvania.

2. This experiment was conducted by Froelich Rainey, Richard Linnington, Aubrey Trik, and James Delmege of the University Museum, and Carlo M. Lerici, Franco Brancaleoni, and Lucia Cavagnaro together with the technical staff of the Lerici Foundation. It has been described by Carlo M. Lerici in "New Archaeological Techniques and International Cooperation" in EXPEDITION, the Bulletin of the University Museum, Spring 1962, Philadelphia, Pennsylvania, and by Richard Linnington in "Quaderni di Geofisica Applicata" the Bulletin of the Lerici Foundation, Vol. XXII, 1961. pp. 10-27.

3. A preliminary report of this work is given by Richard Linnington in "Quaderni di Geofisica Applicata", the Bulletin of the Lerici Foundation, Vol. XXII, pp. 10-27, year 1961.

4. Vacquier, V., Steenland, N.C., Henderson, R.G., and Zietz, I., 1951: "Interpretation of Aeromagnetic Maps", in Geol. Soc. Amer. Memoir, No. 47.

5. Rainey directed all the surveys at Sybaris during three seasons in 1961, 1962, 1963. But in 1962, Elizabeth Ralph replaced Richard Linnington on the University Museum team. Thereafter, all instrument surveys were directed by Ralph.

6. See Froelich Rainey's articles in the Illustrated London News: "Electronics to the Rescue in Search for the lost city of Sybaris: Discoveries by a joint U.S.-Italian Expedition - Part 1.", Vol. 241, No. 6436, pp. 928 - 930, December 8, 1962. Also, "Engineering Devices used in the Excavation of the lost City of Sybaris: Discoveries by a joint U.S. - Italian Expedition - Part 2.", Vol. 241, No. 6437, pp. 972-[illegible], December 15, 1962.

7. Hamilton R. Carson, "A Seismic Survey at Harpers Ferry", Archaeometry, Vol. 5, 1962.

CAPTIONS

Fig. 1. Wall Anomalies, Plain of Sybaris

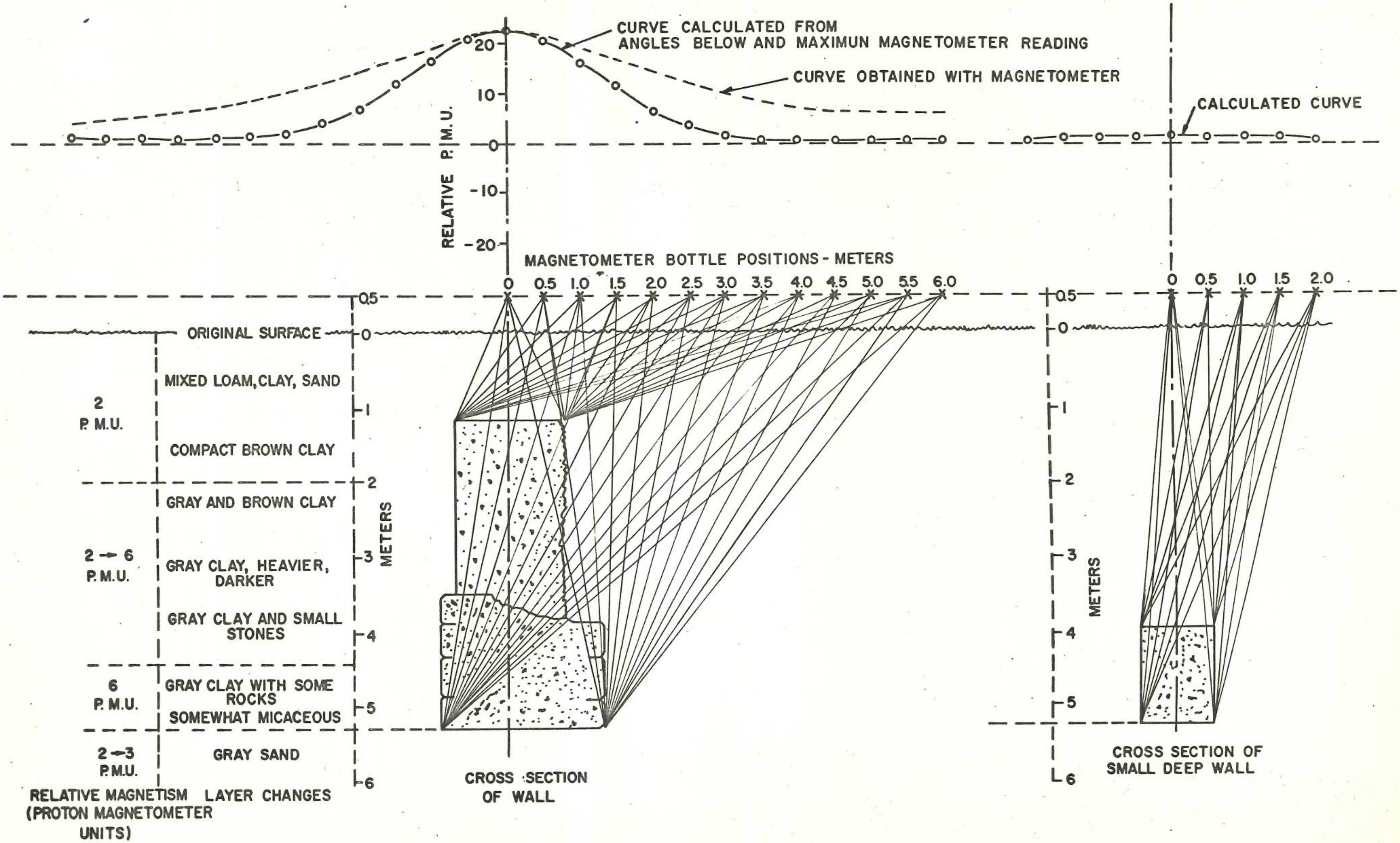
Left to right: Relative magnetism of earth layers.
Description of soil levels on N. side of the wall.
Cross section of long wall as revealed in test pit A with calculated and actual proton magnetometer anomalies shown above it.
Cross section of small deep wall with calculated anomaly shown above.

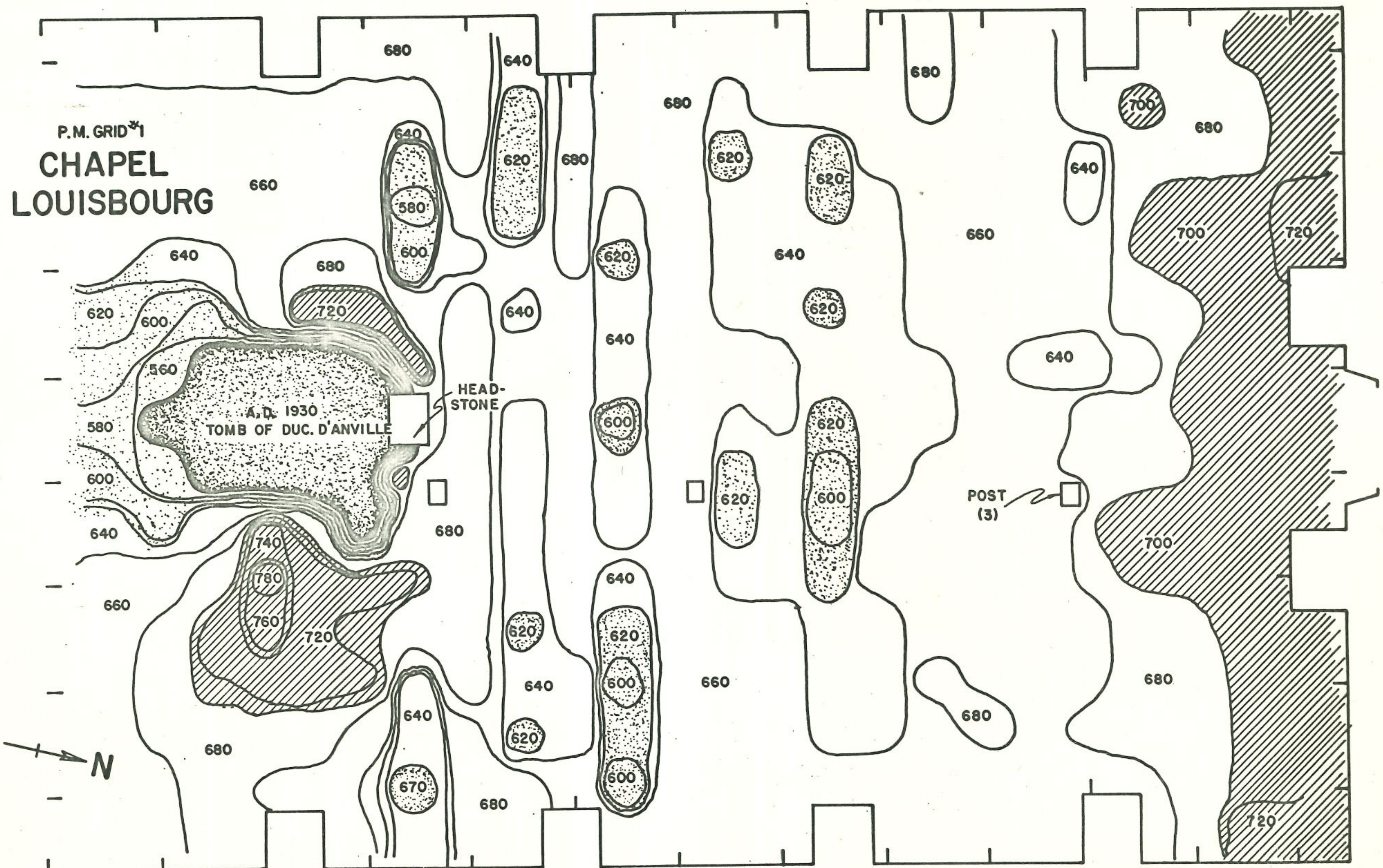
Fig. 2. Magnetic Contour Map of Louisbourg Chapel

Small magnetic regions in regular rows represent the graves which were sought. Large magnetic anomaly was caused by reinforced concrete tomb of the Duc D'Anville who was reinterred in 1930.

Fig. 3. Resistivity Contours in Grid over Hospital Foundations, Ile-aux-Noix

Region of readings above 20 ohms coincides with hospital foundations. Very high readings near both ends represent foundations of hearths.

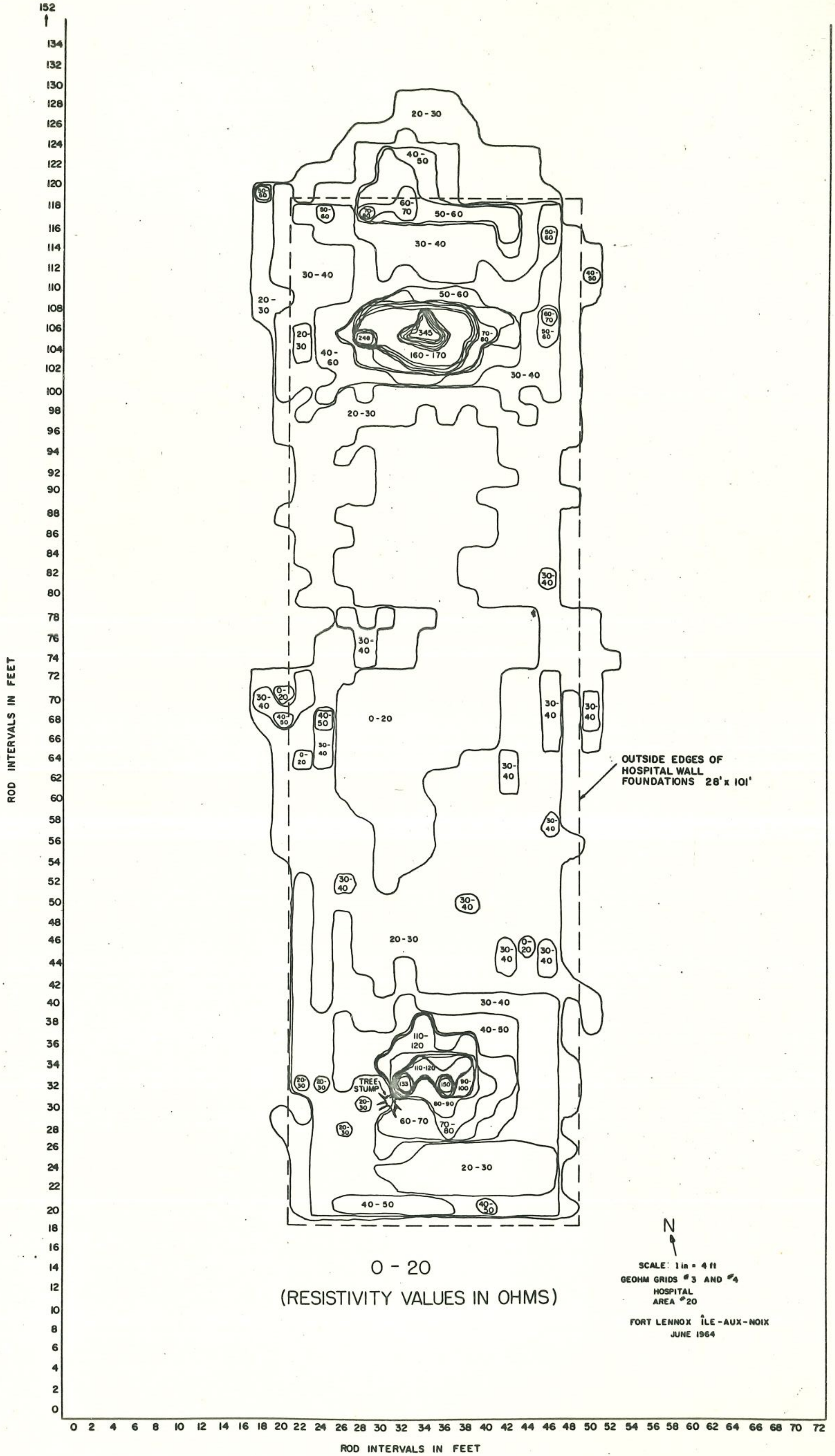

CURVE CALCULATED FROM
ANGLES BELOW AND MAXIMUN MAGNETOMETER READING
CURVE OBTAINED WITH MAGNETOMETER
CALCULATED CURVE
RELATIVE P. M. U.
20
10
0
-10
-20
MAGNETOMETER BOTTLE POSITIONS - METERS
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0
0 0.5 1.0 1.5 2.0
ORIGINAL SURFACE
MIXED LOAM, CLAY, SAND
COMPACT BROWN CLAY
GRAY AND BROWN CLAY
GRAY CLAY, HEAVIER, DARKER
GRAY CLAY AND SMALL STONES
GRAY CLAY WITH SOME ROCKS
SOMEWHAT MICACEOUS
GRAY SAND
2 P. M.U.
2 → 6 P. M.U.
6 P. M.U.
2 → 3 P. M.U.
RELATIVE MAGNETISM (PROTON MAGNETOMETER UNITS)
LAYER CHANGES
METERS
0.5
0
1
2
3
4
5
6
CROSS SECTION OF WALL
CROSS SECTION OF SMALL DEEP WALL



BASE READING = 43660 P.M.U. = 0.551 OERSTEDS.
SCALE: 1/4" = 1'.0"

CURVED LINES DEFINE REGIONS OF EQUAL MAGNETIC INTENSITY AT INTERVALS OF 20 P.M.U.

MAGNETIC REGIONS
ANTI-MAGNETIC REGIONS


ROD INTERVALS IN FEET
ROD INTERVALS IN FEET
OUTSIDE EDGES OF HOSPITAL WALL FOUNDATIONS 28' x 101'
TREE STUMP
0 - 20
(RESISTIVITY VALUES IN OHMS)
N
SCALE: 1 in = 4 ft
GEOHM GRIDS #3 AND #4
HOSPITAL
AREA #20
FORT LENNOX ÎLE-AUX-NOIX
JUNE 1964