For *Expedition*, in press 9/27/68

ARCHAEOLOGICAL PROSPECTING

by Elizabeth K. Ralph

As all readers of Expedition know, the basic 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 facilitate the finding of structures at known sites and to locate unsuspected or lost cities and sites before they are lost to us forever. For this purpose, Dr. Rainey asked the help of the physical scientists in developing and experimenting with a variety of instruments for the detection of buried archaeological features. Since physicists and geophysicists are in short supply in our MASCA group, I have been fortunate in having had the opportunity to carry out most of the field trials and surveys.

The first requirement of an instrument for archaeological prospecting is that it be portable. The obvious initial step was to adapt or to use the basic principles of operation of a number of devices that had already been developed for geophysical prospecting. Those which have been found most suitable for archaeology detect changes in either ground conductivity (conversely, resistivity) or variations in magnetic intensity. A variety of instruments have now been tried and some are being used by a number of groups. The one that we have found most satisfactory for resistivity surveying is the Gossen Geohm (see Fig. 1). For magnetic detection, we started with the Elsec proton magnetometer designed by the Oxford laboratories. For reasons explained previously (Expedition, vol. 7, no. 2, pp. 4 - 8), we are now using the more sensitive cesium magnetometers. The first type (Fig. 2) was developed specifically for the University Museum by Varian Associates after initial trials with the Varian rubidium magnetometer. More recently Varian has designed an even lighter and more portable cesium magnetometer for other purposes, but this unit is also suitable for our archaeological prospecting although not quite so sensitive.

During the past eight years, we have used these gadgets at 34 different sites in eight different countries. This includes 10 field seasons abroad of average duration of three months each. We have learned that magnetic prospecting is much the fastest of all methods tried and that where sufficient magnetic contrast exists, some types walls and roof tiles can be detected at depths of 5 meters or more. However, at historical sites in the USA and Canada where walls are less massive and not buried deeply and where there is often magnetic clutter from modern civilization, the Geohm is the optimum instrument.

A summary of the 34 different sites is given in Table I. Surveys at many of the local sites were conducted over weekends only, and not all were selected as being ideal for prospecting. Some were chosen as convenient spots for testing particular instruments and others, as training grounds for students. I have chosen only a few to describe in greater detail than that given in Table I.

A full summer season was spent on the Île-aux-Noix in 1964, both to expose students in archaeology to all of the new "tools" which were then available, and to provide an extensive test of the different types of equipment; and also, of course, to find the most likely regions for excavation. The entire island, about a mile long, was covered with the proton magnetometer and experiments were conducted with the rubidium one which was then in the developmental stage. The magnetometers indicated where regions of disturbance were to be found, but it was the Geohm that pinpointed the foundations precisely. An example of the precise delineation of the hospital foundations is shown in Fig. 3. The outline of the resistivity contours corresponded exactly with the outer walls, the high density contours near each end represented hearths, and the bulge at the northern end reflected an unsuspected doorway.

At extensive sites with structures buried in alluvial plains, however, magnetometers are the most suitable. Eight seasons of work on the plain of Sybaris, Italy may not have delimited the archaic city, but the site has been an excellent testing ground for the development of better magnetometers. Also, the extensive drilling programs and a few test excavations have assisted in the interpretation of the anomalies found.

As one may note in Table I, many trials, short in duration, have been made at sites that were not suitable for magnetic prospecting for one reason or another. This was particularly true in Greece until Prof. Marinatos, Director of Antiquities, asked our help in surveying ancient Elis (about 70 km north of Olympia). This proved to be a perfect site for magnetic detection. Many of the walls of the 5th and 4th century B.C. were massive and made of reused roof tiles. (Roof tiles and bricks are much more magnetic than unfired clay and normal stone). They were found at depths of approximately one meter, but extended downward to depths of 4 to 5 meters. In some places there were Roman structures overlying the earlier ones, but on the basis of fairly extensive excavations at this site, it seems likely that the Roman walls followed the pattern of the ones below (see Fig. 4).

Elis, leading city of the second largest province (Elis) of the Peloponnese, lies along the banks of the River Peneus, between a hilly eastern region and a fertile, western, coastal plain. Originally settled in dispersed villages, the city was founded in 471 B.C. by bringing together many of these smaller populations into a large and open town. It played a minor role in ancient politics, generally amenable to Spartan policies, and preferring quiet country life. It was, however, noted for its horses and high-quality flax and achieved its greatest fame as administrator of the important sanctuary of Olympia and president of the Olympic games. These quadrennial competitions, one of the greatest of Panhellenic festivals, were traditionally reputed to have begun in 776 B.C. Elean control was definitely established by about 572 B.C. and was maintained into the Roman era.

The site of the ancient city has long been known, observable in much (Roman) brick and stone fragments scattered over an area three to five kilometers in circumference. Excavation was begun by the Austrians in 1910-14, resumed in 1931-2 and again, in a joint Greek and Austrian campaign, in 1960.

As well as offering readily detectable magnetic anomalies, most of the surface now consists of farmland uncluttered by modern civilization, except for a small village at the southern edge of the area of interest. The survey here was not only successful, but urgently needed because of the construction of extensive irrigation ditches by the Greek Government. The first tests with our cesium magnetometer were made in September 1967, supposedly in the proposed path of the large irrigation ditch. When I returned in May 1968, I found out that not only had the route of the ditch been changed, but that it was already under construction. The Greek archaeologists had been excavating extensively during the winter and early spring in the new path of the ditch. Since many of the structures were still exposed, it was possible to correlate visible lines of walls with anomalies in adjacent magnetometer grids.

Complete grids were made over $\frac{1}{2}$ sq. km. roughly $\frac{1}{4}$ of ancient Elis and its approximate limits were determined by running long radial lines out from the regions of known anomalies. It extends over approximately 2 sq. km. Within the grids, the walls and rows of houses showed up so clearly that it appears to be possible to recreate part of the ancient city plan. A possible row of houses is illustrated in Grid No. 19 (Fig. 5). In the upper part of the grid, one sees closely spaced contours running east to west which continue in adjacent grids. It is presumed that these represent rows of walls made of bricks or a combination of stones and roof tiles.

At this writing, the final plan of the city is not complete. However, this will probably be the first example of the reconstruction of the plan of a Greek city by means of magnetic contouring. Here, it has been demenstrated also that it is now possible to map a good part of a large ancient city and to find its limits, all within a period of 8 weeks. Certainly, much more was detected in these few weeks than had been uncovered or suspected during 60 years of intermittent excavations.

CAPTIONS

Table I. Summary of MASCA instrument surveys

Fig. 1. Geohm operated by Necmettin Bektöre at Gordion, Turkey. Four equally spaced rods are attached to Geohm with cables. Current is sent through outer two electrodes and the difference of potential (converted to resistivity units) is detected between the inner two.

Fig. 2. Varian Associates Precision Portable Cesium Magnetometer. Giacinto Loisi (foreground) carries cesium sensor and approacheds end of grid line marked with flag. Franco Brancaleoni carries readout, batteries, and records readings in notebook.

Fig. 3. Geohm grid over hospital foundations, Île-aux-Noix, Canada. Resistivity contours correspond precisely with foundations.

Fig. 4. Excavation at Elis, Greece. Roman walls on top of 4th century B.C. walls.

Fig. 5. Cesium magnetometer Grid No. 19. Closely spaced contours in upper part propably represent rows of houses, Elis Greece.

TABLE I

Summary of MASCA Instrument Surveys

Site	Buried Features Sought	Magnetometers	Resistivity Instruments	Supplementary Instruments
THE NEW WORLD U. S. A.				
Independence Square Philadelphia, Pa.	house foundations	excessive magnetic disturbances due to city location	good detection	
Rifle Works, Harpers Ferry, W. Virginia	structure of Rifle Works	excessive disturbances from modern iron	located turbine pit	seismograph provided some indication of turbine pit
Isle Royal, Lake Superior, Michigan	copper ore deposits	not suitable	not suitable	some hot spots were found with metal detectors
Fort Loudon, near Chambersburg, Pa.	trenches and embankments of fort	indications of location of trenches and embankments	not suitable	
Caleb Pusey House, Chester, Pa.	house and other building foundations	excessive magnetic disturbances due to location near town	excellent detection of eastern extension of house - later confirmed by excavation	
Hagley Mills, Wilmington, Del.	structures of powder works	located large conduit and many large iron fragments	some indication of location of conduit	metal detector confirmed presence of many large iron fragments and metal pipes

Site	Buried Features Sought	Magnetometers	Resistivity Instruments	Supplementary Instruments
Eleutherian Mills, near Wilmington, Del.	features of the garden of former residence of E. I. duPont	pieces of modern iron caused confusion	good detection of well, drain, and other features	
Hope Lodge, Whitemarsh, Pa.	foundations of mansion and out-buildings	not tested	good detection of foundations	
Snaketown, near Chandler, Arizona	features from period of A.D. 1 to 1400	excellent detection of large firepits - confirmed by excavation	not suitable	
Salvage site, near San Xavier, Arizona	small features representative of Indian occupation	test site for new cesium magnetometer; site was not especially suitable for magnetometers	not suitable	
Buttes Dam Site, no. of Tucson, Arizona	Indian occupation site	presence of magnetic volcanic rocks negated usefulness of magnetometer	not suitable	
Camden, South Carolina	wooden structures of Revolutionary Fort Camden	remains of structures sought did not offer magnetic contrast; located unsuspected gas pipeline	sandy soil and hence poor coupling to ground provided false anomalies	standard aerial photograph showed small variations in vegetation which may correlate with structures sought
Harvard Forest, Petersham, Mass.	collaboration with soil scientists to find out if different types of soil in this region differed in magnetism	magnetic bedrock at variable depths negated usefulness of magnetometer	not suitable	

Site	Buried Features Sought	Magnetometers	Resistivity Instruments	Supplementary Instruments
St. Croix Island, near Calais, Maine	former structures of early French settlement, A.D. 1604	detected a number of anomalies, probably representative of structures and graves	numerous ant hills and looseness of the soil due to the activity of ants or other causes, such as excess sand, caused false anomalies.	
CANADA				
Fort Louisbourg, Nova Scotia	graves and tunnels under embankments	excellent detection of graves; vague indications of tunnels	grave detection confused by proximity of bedrock; some indication of tunnel locations	seismograph confirmed that bedrock was only 4 ft. deep; many iron objects detected with metal detector
Fort Lennox, Île-aux-Noix, Quebec	many structures and graves	good indication of region of structures, but not so precise as resistivity; good detection of graves	excellent pinpointing of structures-confirmed by excavation	metal detector located various metal objects at shallow depths; seismograph gave vague indication of bedrock
Campbellton, New Brunswick	Sunken ships	trial survey made on ice; good anomalies over known locations of two ships; to be continued this winter over unknown ships	not suitable	

Site	Buried Features Sought	Magnetometers	Resistivity Instruments	Supplementary Instruments
CENTRAL AMERICA				
Tikal, Guatemala	buried structure in N. Acropolis, W.Plaza, and Temple I	unable to tune proton magnetometer for magnetic field in this region	anomalies confused by structures too complex; could not distinguish structures from pits	
San Lorenzo, Veracruz, Mexico	Olmec monuments 1200-900 B.C.	excellent detection of monuments due to the fact that they were made of magnetic basaltic rock	not needed	
THE OLD WORLD IRELAND				
Navan Fort, near Armagh, N. Ireland	mound site	indecisive results	not suitable	
Dun Ailinne, near Kilcullen, County, Kildare.	traditional royal site; possible seat of the "High Kings"	detected large anomaly representative of center of Iron Age occupation	anomalies confused by proximity of bedrock and boulders	
TURKEY				
Gordion	location of tombs under tumuli; structures on city mound; Persian road	variable magnetic earth caused anomalies much larger than ones anticipated from archaeological features	located Persian road where it existed; and structures on city mound to depth of 2-3 meters	

site	Buried Features Sought	Magnetometers	Resistivity Instruments	Supplementary Instruments
Veii	city site	erroneous anomalies, due to magnetic earth	ground was too dry in summer	
Siris	6th century B.C. Greek city	no true anomalies found; confirmed by drilling	not suitable	anomalies seen in infrared aerial photographs proved to be erroneous
GREECE				
Helice	7th - 6th century B.C. city	whole area covered with modern iron	not suitable	
Porto Cheli	4th century B.C. harbor walls	structures not detected due to lack of contrast in magnetism	ground was too dry in August; should be tried in wetter season	
Thera	Bronze Age structures	presence of magnetic volcanic gravel negated usefulness of magnetometer	not suitable due to loose pumice and great depth of structures	seismograph provided some indication of depth of bedrock and, hence, thickness of pumice layer
Elis	5th and 4th century B.C. city	excellent detection of walls which will enable reconstruction of part of the city plan	not suitable	

Site	Buried Features Sought	Magnetometers	Resistivity Instruments	Supplementary Instruments
ITALY				
Sybaris	the 7th - 6th century B.C. city	See Rainey, F. and Lerici, C. The Search for Sybaris, 1967		
Tarquinia and Cervetri	Etruscan tombs	reasonably good detection of tombs	approximately 50% detection of tombs, but very slow	seismograph not useful
Artena	city walls and structures	magnetic earth negated usefulness of magnetometer	good detection of foundation walls of structures	
Foce del Sele, near Paestum	6th century, B.C. Greek sanctuary	no archaeological features were detected although most of the zone of interest was surveyed	not suitable on alluvial plain	
Metapontum	6th century, B.C. and later Greek city	excellent detection of walls and structures	not suitable	magnetometer anomalies helped to confirm and to clarify anomalies detected in aerial photographs
Gravina	structures from many periods	many anomalies, but correspondence was confused because of presence of structures almost everywhere	not tested	

Fig. 1

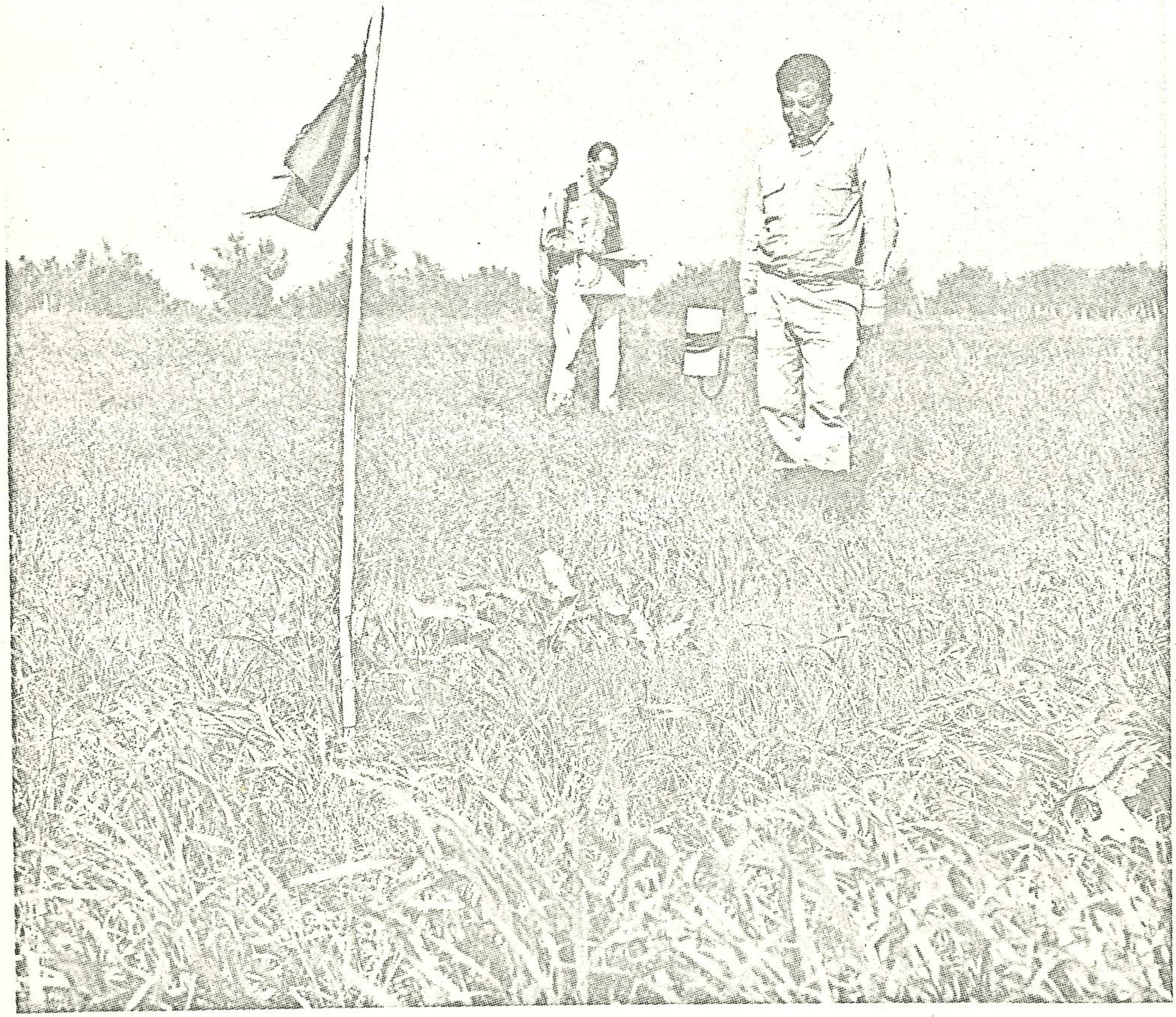

Fig. 2

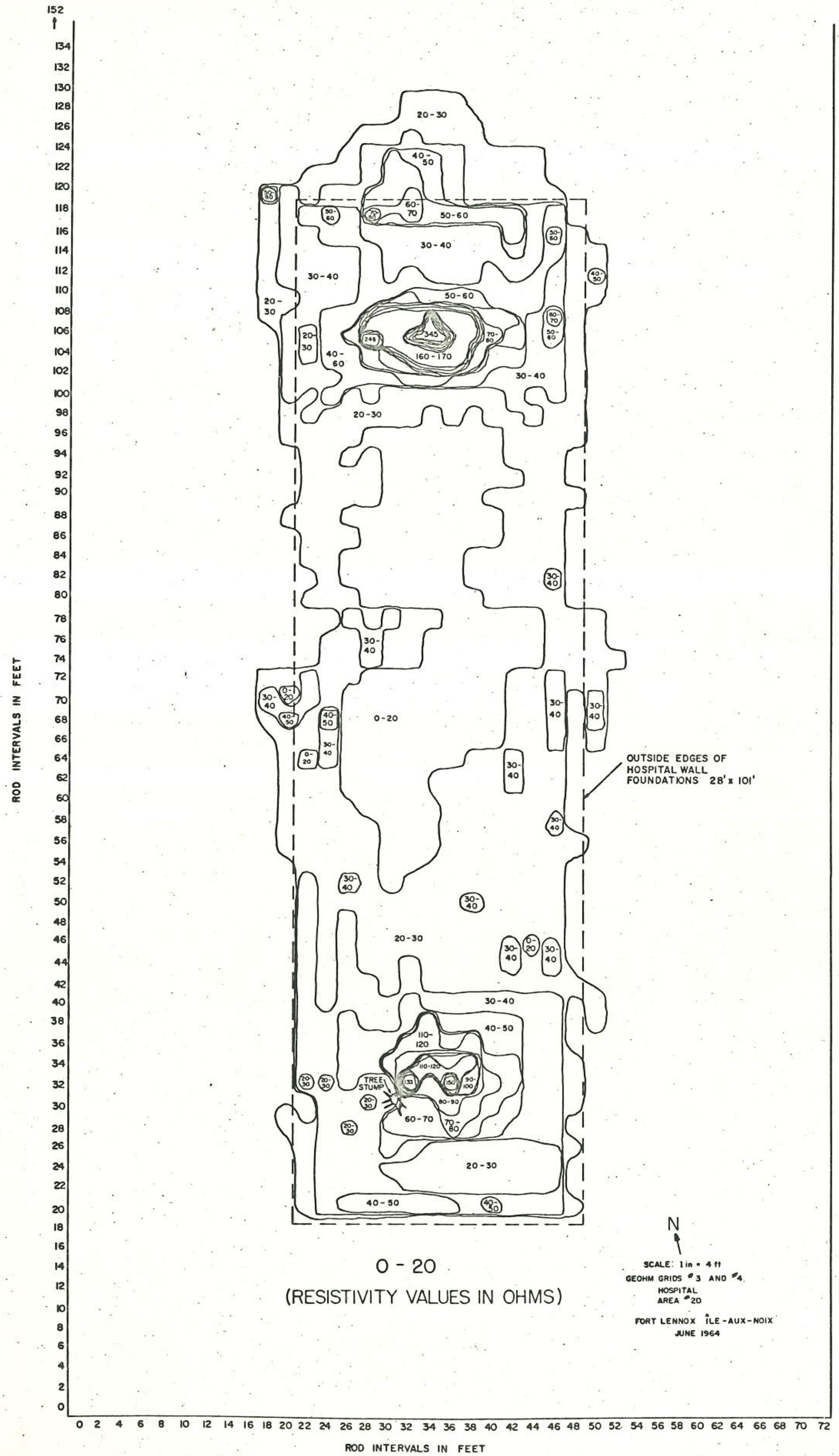
ROD INTERVALS IN FEET
ROD INTERVALS IN FEET
OUTSIDE EDGES OF HOSPITAL WALL FOUNDATIONS 28' x 101'
TREE STUMP
N
SCALE: 1 in = 4 ft
GEOHM GRIDS #3 AND #4
HOSPITAL AREA #20
FORT LENNOX ÎLE-AUX-NOIX
JUNE 1964
0 - 20
(RESISTIVITY VALUES IN OHMS)

Fig. 3

Fig. 4

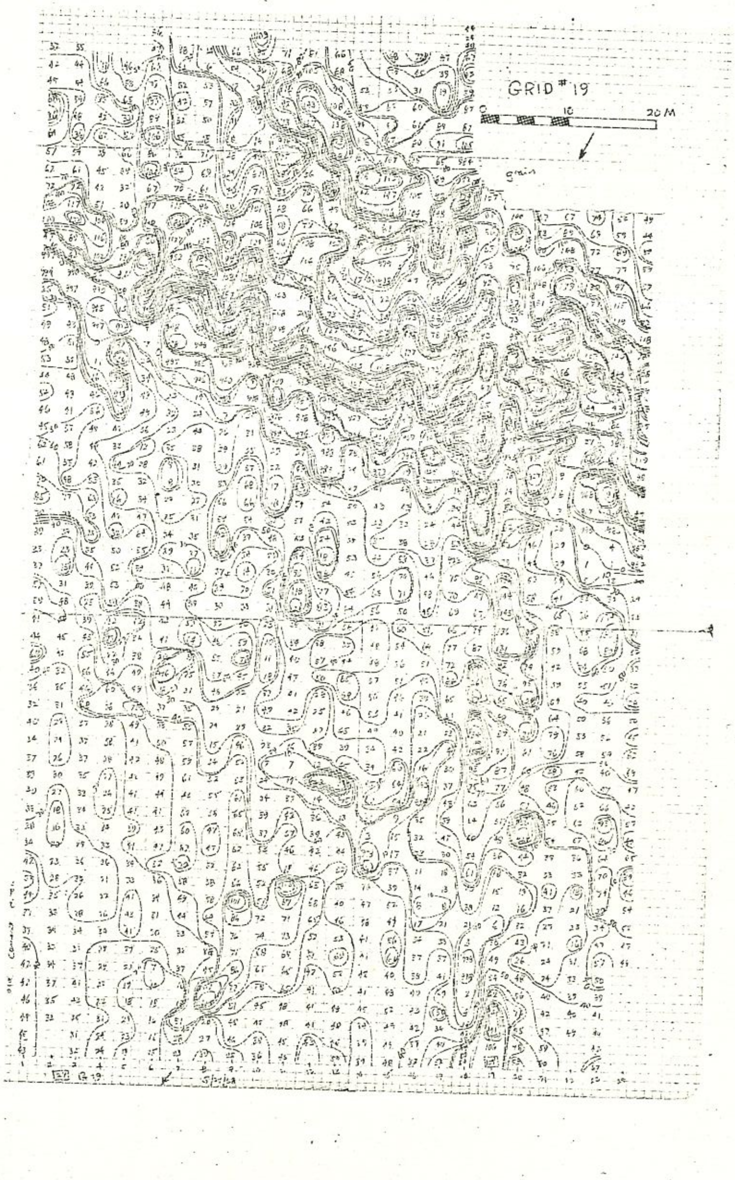

Fig. 5