

594-8168 or
Ev 6-7400

January 27, 1969

Mr. Reagan A. Scurlock
Office of Research Administration
4th Floor Franklin Building

Dear Mr. Scurlock:

I have prepared a grant proposal entitled "Near and Remote Sensing of Buried Archaeological Features" for submission to the Air Force.

Since I plan to leave for Mexico on February 1st, I have enclosed an unsigned copy, and shall appreciate it if you will check it to see if it is all right. Dr. Rainey is scheduled to return from Africa on February 1st, so we shall plan to send you the signed and other copies next week if this one is O.K. It is possible too that Dr. Rainey may want to make a few changes.

Sincerely yours,

Elizabeth K. Ralph

February 6, 1969

Mr. Lee Langan
Environmental Measurements
550 Battery Street
San Francisco, Calif. 94111

Dear Lee,

Many thanks for the helpful information which you sent.

I have enclosed a copy of our grant proposal and hope that it is all right. Now, we'll wait 3 - 4 months to see what happens to it.

Best regards,

Elizabeth K. Ralph

EKR:zb

Techburgies
file

UNIVERSITY of PENNSYLVANIA

PHILADELPHIA 19104

OFFICE OF PROJECT RESEARCH AND GRANTS

Franklin Building
3451 Walnut Street
(Area 215) 594-7293

February 17, 1969

Department of the Air Force
Air Force Office of Scientific
Research (OAR)
Washington, D. C. 20333

Gentlemen:

Submitted herewith are twenty (20) copies of a proposal for support of research entitled "Near and Remote Sensing of Buried Archaeological Features" to be conducted under the direction of Dr. Froelich Rainey, Director, University Museum.

The proposal has been approved by appropriate University officials and signed on behalf of the University by Dr. John N. Hobstetter, Vice Provost for Research.

Should you require any additional information, please do not hesitate to communicate with us.

Sincerely yours,

Anthony Merritt
Contracts Administrator

AM:jn
encls.
cc: Dr. Rainey

LSSAF

file MASCA

DEPARTMENT OF THE AIR FORCE
AIR FORCE OFFICE OF SCIENTIFIC RESEARCH (OAR)
ARLINGTON, VIRGINIA 22209



REPLY TO
ATTN OF: SREE/Lt Col Kalisch/A.C. 202, OXford 4-5518 26 February 1969

SUBJECT: Research Proposal: "Near and Remote Sensation of Buried Archaeological Features"

TO: Mr. Anthony Merritt
Contracts Administrator
University of Pennsylvania
Philadelphia, Pennsylvania 19104

Dear Sir

This letter will acknowledge our receipt of the subject research proposal. We shall be pleased to give it consideration for funding within our Fiscal Year 1970 budget. Normally we reach a technical decision on sponsorship within six (6) months of receipt. You may, therefore, expect to receive our decision before the end of this period.

It would be helpful to us if you would refer to the following code number in any future correspondence pertaining to this proposal: EM-9-10-N.

With cordial respect, I remain

Sincerely yours

A handwritten signature in cursive script, reading "Robert B. Kalisch".

ROBERT B. KALISCH, Lt Col, USAF
Chief, Electronics Division
Directorate of Engineering Sciences

Cy to: Dr. Rainey ←

DEPARTMENT OF THE AIR FORCE
AIR FORCE OFFICE OF SCIENTIFIC RESEARCH (OASR)
1400 WILSON BLVD
ARLINGTON, VIRGINIA 22209

Rainey

SREE

28 APR 1969

Proposed Research: "Near and Remote Sensing of Buried Archaeological Features", EE-9-10-N

Mr. Anthony Merritt
Contracts Administrator
University of Pennsylvania
Philadelphia, Pennsylvania 19104

Dear Mr. Merritt

We have completed our evaluation of your proposal "Near and Remote Sensing of Buried Archaeological Features" forwarded by your letter of 17 February 1969. It is with regret that we must inform you that we will be unable to include your proposal in our present research program.

We appreciate your interest in the research activities of the Air Force Office of Scientific Research.

Sincerely

ORIGINAL SIGNED

MILTON M. SLAWSKY
Director, Engineering Sciences

Cy to: Dr. Rainey 

May 7, 1969

Mr. Lee Langan
Environmental Measurements
550 Battery Street
San Francisco, California 94111

Dear Lee,

Bad news from the Air Force. They have turned down our grant application. Therefore, we have no funds for gas sensing at the moment.

Excuse the haste. Planning to leave for Italy and Yugoslavia on Friday, but will be back in early July.

With best regards,

Elizabeth K. Ralph

EKR/mrb

Experiments in Near and Remote Sensing of Archaeological Deposits.

Description of Proposed Research Abstract

Ralph
ASCA

One of the primary purposes of the University Museum's Applied Science Center for Archaeology (MASCA) since its beginning in 1960, has been the development of instruments and techniques to search out archaeological remains which are not observable on the surface. During the past seven years, MASCA has explored the use of resistance apparatus, magnetometers, seismic and sonic devices, various types of mine detectors, drilling procedures, and new types of aerial search equipment, such as infrared aerial film, infrared scanners, colour-camouflage film and others.

By Mella

- Electrical resistivity instruments have been used in Mexico, the U. S., Italy, Greece, Ireland, Turkey and Iran. At present the most useful instrument is made by the Gossen Co., Erlangen, Germany. Known as the Geohm, it has been designed for archaeology at small cost, and proves to be successful in limited areas for detecting archaeological features at shallow depths. It is most useful at a known archaeological site for the discovery of features like pits, walls, buried ditches, etc.

- Standard geophysical seismographs have a limited use in archaeology for locating bedrock and changes in strata, but it is rarely possible to locate specific archaeological features. *with these instruments.*

- The most successful type of instrument for this kind of sensing, so far developed, is clearly a magnetometer. The Oxford Research Laboratory developed a proton magnetometer for archaeology in about 1960, which proved


highly useful in England for the location of ancient kilns, fire-pits, trenches and other earth works. But MASCA demonstrated its further application in the search for tombs and other stone constructions during 1961 in Italy. We found that Etruscan tombs at Tarquinia and Cerveteri could be located on magnetic contour maps based upon proton magnetometer surveys of extensive areas. Later, we proved on the plains of the Crati in southern Italy, that it could readily locate buried stone walls up to 3 meters in depth. Additional experiments at Snaketown in Arizona, proved its capability for rapid location of fire pits and other burned areas.


But MASCA decided that more sensitive magnetometers were needed for locating much deeper archaeological deposits. With engineers from Varian Associates, we then experimented with a rubidium magnetometer ^{Canada and in} ~~for~~ in Italy. That research resulted in the development of the precision portable Cesium Magnetometer built by Varian Associates with ~~financial~~ financial assistance from the N. S. F. and the University Museum. The new magnetometer has as much sensitivity (maximum 0.05 gammas) as can be utilized in land-based archaeological prospecting, ~~surveying,~~ ^{and} but it has a built-in differential feature. With the latter, a second sensor may be used, either in a fixed position in the center of a grid being traversed, or in a gradiometer arrangement. The second sensor served to cancel out all diurnal and other extraneous magnetic disturbances. In other words, only the buried archaeological deposits under the ground are detected, if not disturbed by modern iron on or near the surface. This feature, plus the rapidity with which large areas can be explored (at least 5 times as fast as with standard proton magnetometers), make

it possible to plot complete cities by means of magnetic contrasts.

The ^uutility of this instruments is described in greater detail by Rainey + Ralph⁽¹⁹⁶⁶⁾ and by Ralph, Morrison + O'Brien (in press).

One of the most successful, recent experiments with the cesium magnetometer was carried out at the site of Elis in Greece (see below).

 With certain soil conditions, volcanic soils for example, magnetometers cannot be used for archaeological search^{ing}. To achieve an all-purpose instrument, we have been experimenting with the sonic principle. In collaboration with Texas Instruments, Inc., Petty Laboratories, Inc., and others. Tests were made with various sonic devices. These indicated that an impulse frequency of approximately 600 cps would be a good compromise for our purpose. However, due to ~~our~~ problems of the production of impulses of sufficient magnitude with portable equipment and due to much more severe attenuation in the ground of these higher frequencies, a satisfactory device has not yet been developed for archaeological prospecting. *A few tests of models designed originally for other purposes by the Bodine Soundrive Company are now planned.*

 Remote sensing from high-flying aircraft has been rapidly developed during the past few years for military purposes. Recently some of these techniques have been de-classified and are now being used for mineral and oil prospecting, crop disease spotting, studies of soil and water contamination, etc., Normal aerial photography has long been utilized by the archaeologist for the study of ancient settlement patterns, and for the location of specific sites and archaeological features which have forms or contours that can be seen only from the air. Infrared aerial film has been utilized to spot

vairations in heat and moisture content in surface soils, chemical and color changes in vegetation which reflect underground features, difference in the compaction of surface soils reflecting underground phenomena, etc. Infrared scanning devices are now being used for similar purposes. There are still other devices in the developmental stage.

In collaboration with the Cambridge ~~Air~~ Research Lab of the U. S. Air Force at Hanscomb Field, the Museum's Applied Science Center, made its first experiments in this method in southern Italy. Utilizing the Multi-band aerial camera produced by ITEK Corp. the Air Force crew recorded simultaneously nine images in the 2, 000 to 9, 000 Engstrom bands of the electromagnetic spectrum on films taken at 12, 500 feet over an area of about 80 square kms. Also, at the same time the whole area was recorded with the infrared scanning device. The several hundred aerial photographs resulting from this experiment are still under study and results are not clear. At the moment MASCA is carrying on a drilling program to test anomalies observed on the films which may or may not turn out to be distinct archaeological features, remains which we know must lie several meters in depth below the surface of the Crati river plain.

H Another MASCA experiment with the U. S. Air Force is being made over the Snaketown and Casa Grande ~~area~~ sites in Arizona where most of the different types of archaeological remains are known. Again, with the nine lens camera, images have been made in infrared black and white film, color infrared, false color or camouflage detection film, ultra-violet, and thermal infrared that is in the 10, 000 Engstrom band where a scanning

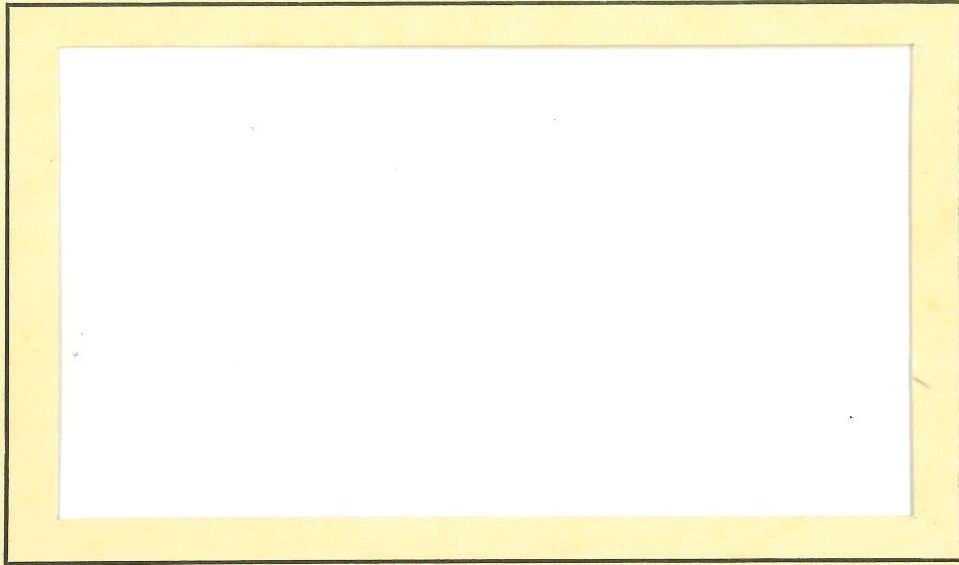
device is necessary. All of these photographs and recorded images are now being developed by NASA and when completed will be studied by the Air Force photographers in collaboration with us and Prof. Emil Haury who has recently completed new excavations at Snaketown.

Following discussions with representatives of the U. S. Geological Survey and of NASA we have agreed to carry on experiments with various remote sensing equipment to explore the possibilities of recording ancient settlement patterns and other archaeological features from high-flying aircraft.

MASCA is making still another experiment of this kind at the San Lorenzo site (Olmec) in Mexico during Dec. 1967. This is in collaboration with Prof. Michael Coe of Yale University who will continue excavations at that site in 1968, so that anomalies recorded from the air can be tested with the cesium magnetometer on the ground and by excavation.

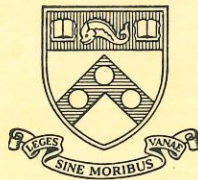
The recent development of a radar altimeter and an air borne profile recorder suggests that it will be possible to map low mounds and other ruins lying under heavy tropical growth, from an aircraft. Radar energy of the proper wave length projected from a survey plane should penetrate the jungle foliage to be reflected from the ground to the airborne profile recorder and thus provide the data for an accurate contour map of a site such as that at Tikal, Guatemala. At the moment this technique is highly experimental, but it is theoretically possible and if perfected would make it possible to survey jungle covered areas in a relatively short time. This technique may also be possible with sonic as well as radar frequencies.

Techniques



UNIVERSITY of PENNSYLVANIA

UNIVERSITY MUSEUM



Philadelphia, Pennsylvania

Request for Research Grant

Near and Remote Sensing of
Buried Archaeological Features

Submitted to:

Air Force Office of Scientific Research

January, 1969

Principal

Investigator: Froelich Rainey

Position: Director, University
Museum and MASCA

School: Graduate School of
Arts and Sciences

Department: University Museum

Starting Date: May 1, 1969

Duration: 1 Year

FUNDS REQUESTED

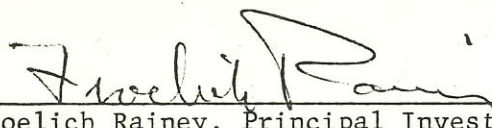
\$58,282

Corporate Name of University: THE TRUSTEES OF THE UNIVERSITY OF PENNSYLVANIA
(a Pennsylvania non-profit corporation)

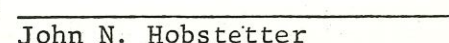
Contracting Office: OFFICE OF RESEARCH ADMINISTRATION
Franklin Building, 3451 Walnut Street
Philadelphia, Pennsylvania 19104

Date:

APPROVED:


Froelich Rainey, Principal Investigator
Director, University Museum

APPROVED:


John N. Hobstetter
Vice-Provost for Research

Near and Remote Sensing of
Buried Archaeological Features

I. Description of Proposed Research

A. Introduction

One of the primary purposes of the University Museum's Applied Science Center for Archaeology (MASCA) since its beginning in 1960 has been the development of instruments and techniques to search out archaeological remains which are not observable on the surface. During the past eight years, MASCA has explored the use of resistance apparatus, magnetometers, seismic and sonic devices, various types of metal detectors, and drilling procedures. As a result of these experiments and field tests, we now have greatly improved magnetometers for land-based archaeological prospecting--namely, the new portable cesium units.

During the past two years we have experimented also with some of the recently developed techniques of remote sensing. These include new types of aerial search equipment such as the use of infrared films, infrared scanners, and color-camouflage films.

We now propose to pursue these projects in both near and remote sensing.

B. Review of Accomplishments

1. Magnetometers

The Oxford Research Laboratory developed a proton magnetometer for archaeology in about 1960, which proved highly useful in England for the location of ancient kilns, fire-pits, trenches and other earth works. MASCA demonstrated its further application in the search for tombs and other stone constructions during 1961 - 1964 in Italy. We found that Etruscan tombs at Tarquinia and Cerveteri could be located on magnetic contour maps based upon proton magnetometer surveys of extensive areas. Later, we proved on the plain of Sybaris in

southern Italy that it could readily locate buried stone walls up to three meters in depth (Ralph, 1967). Additional experiments at Snaketown in Arizona proved its capability for rapid location of fire pits and other burned areas. But MASCA decided that more sensitive magnetometers were needed for locating much deeper archaeological deposits. With geophysicists and engineers from Varian Associates, we then experimented with a rubidium magnetometer in Canada and in Italy (Breiner, 1965; Ralph, 1965). That research resulted in the development of the Precision Portable Cesium Magnetometer (Model 4920) built by Varian Associates with financial assistance from the National Science Foundation and the University Museum (see Fig. 1). The new magnetometer has as much sensitivity (maximum 0.05 gammas) as can be utilized in land-based archaeological prospecting, and it has a built-in differential feature. With the latter, a second sensor may be used, either in a fixed position in the center of a grid being traversed or in a gradiometer arrangement. The second sensor serves to cancel out all diurnal and other extraneous magnetic disturbances. In other words, only the buried archaeological deposits under the ground are detected, if not disturbed by modern iron on or near the surface. This feature, plus the rapidity with which large areas can be explored (at least 5 times as fast as with standard proton magnetometers), make it possible to plot complete cities by means of magnetic contrasts. The utility of this instrument is described in greater detail by Rainey and Ralph (1966) and by Ralph, Morrison, and O'Brien (1968).

Last year Varian Associates developed a simplified type of cesium magnetometer called a Portable Search Magnetometer Model V-4971. This lighter and less expensive instrument does not have the differential feature nor has it quite as great sensitivity (maximum 0.5 gammas) as the portable precision unit

(Model 4920), but is even more rapid to use. It is designed as an excellent complementary device for rapid exploratory work either previous to or in conjunction with a detailed grid survey. For example, at Elis in Greece the new Model V-4971 (rented for 2 months) was used to delineate the entire archaeological zone which covered an area of more than 2 square kilometers while the precision Model 4920 was being employed to map out the "heart" of the city. Needless to say, this helped to accelerate the survey.

Another advantage of having the two instruments at the same site is in case of breakdowns. With these magnetometers, serious instrument failures have been rare, but if they do occur in far away countries, they are serious. Not only will the new unit provide a substitute if the precision model fails, but it will furnish a source of spare parts which are invaluable for trouble-shooting. The sensors, batteries, battery chargers, and cables are all interchangeable as well as some of the components of the two different types of "readouts."

Very recently the Schonstedt Instrument Company (Reston, Virginia) has developed a portable and miniaturized fluxgate magnetometer--the GMB-1 Magnetic Locator. The whole instrument, with the exception of the indicating meter, is contained in a rod about one meter long and 6 cm in diameter. It weighs only 2-1/2 kilograms including batteries. It contains two fluxgate detecting elements mounted 20 cm apart. When the difference between these is read, changes in readings due to orientation, to which fluxgate elements are subject, are overcome. Because these elements must necessarily be mounted fairly close together and its maximum sensitivity is 10 gammas, it is not anticipated that it will detect features at depths comparable to those detected with the cesium magnetometers. It is, however, much more portable--it can be carried easily by one person--and it is more rapid to use. To estimate its

utility for archaeological prospecting, trials will be made with an instrument on loan this winter at San Lorenzo, Mexico.

2. Instrument Surveys at Archaeological Sites

During the past eight years, we have used a variety of instruments 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, resistivity (or conductivity) detectors, such as the Geohm (made by the Gossen Co., Erlangen, Germany), are the optimum instruments.

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. We have chosen only a few to describe in greater detail than that given in Table I.

A full summer season was spent on the [^]Ile-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 resistivity instrument, the Geohm, that pinpointed the foundations

precisely. An example of the precise delineation of the hospital foundations is shown in Fig. 2. 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 completely, 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. The story of Sybaris and our work there have been told recently in the newspapers and are described in the references listed.

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.

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 E. K. Ralph returned in May, 1968, she found out that not only had the route of the ditch been changed, but that it was already under construction. However, 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 $1/2$ sq. km. roughly $1/4$ 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. Possible rows of houses are illustrated in Grid. No. 18B (Fig. 3). One sees two rows of closely spaced contours running roughly 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 demonstrated 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.

As a result of the development of these portable cesium magnetometers for archaeological purposes, the new units (Model V-4971) are now being used by the U. S. Army for tunnel and weapon detection, by mining companies for mineral exploration, and for the location of vehicles lost in the snow in Canada.

C. Proposed New Projects

1. Land-based Instrument Surveys

It is planned to continue work at sites appropriate for magnetometers with both cesium instruments and to try out the new fluxgate unit. At a new site in Italy, a search for copper ores, the sources for ancient bronzes, is planned. Some of the sites are as follows:

a. San Lorenzo, Mexico

Preliminary trials at this site in the spring of 1968 indicated that it is an ideal one for magnetic prospecting. The features sought are Olmec monuments which are massive and happen to be made of magnetic basaltic rock which was imported from 80 km away. If time permits, the survey may be extended to La Venta where it is anticipated that similar monuments will be found. The work at San Lorenzo will be in collaboration with Prof. Michael Coe of Yale University, and with Dr. Ignacio Bernal of the Instituto Nacional de Antropologia, Mexico City.

b. Elis, Greece

One to two months are required to complete the magnetic survey of the "heart" of Elis in order to complete the plan of the ancient city. This work is in collaboration with Prof. Spyridon Marinatos, University of Athens, and Dr. George Papathanasopoulos, Director of the Olympia Museum.

c. Turkey

Requests have been received to work at Sardis--to delineate the urban plan of the Romano-Byzantine city there in collaboration with Prof. G. M. A. Hanfmann, Field Director of the Archaeological Exploration of Sardis; and at the Keban Salvage Project near Elazig in collaboration with Dr. Halet Cambel, Univeristy of Istanbul.

d. Italy

1) Cosa

Preliminary tests are planned at Cosa, where tufa-mortar docks buried under 1.5 meters of mud and sand are sought. It is hoped that the docks will be slightly less magnetic than the mud. This work will be in collaboration with Prof. A. M. McCann, University of Missouri, and the Italian Department of Antiquities.

2) Region of Francavilla

On a hillside near Francavilla above the plain of Sybaris, Paola Zancani (Italian archaeologist) has found many graves containing unique objects of bronze, ranging from the 9th to the 4th century B.C. She has recently found indications of where the copper ores, from which these were made, may be sought. This information and the extent of these deposits are important for the history of metallurgy and for the study of ancient trading. It is hoped that these ores can be located with metal detectors.

e. Divostin, Yugoslavia

Divostin is a neolithic site being excavated by Dragan Srejovic of the Department of Archaeology, Belgrade University and Alan McPherron, University

of Pittsburgh. In preliminary excavations last year, Vinca house floors, burned in situ were exposed. A short test with a very old (and slow) proton magnetometer by members of the Geomagnetic Institute (Belgrade) indicated that these floors are readily detectable with magnetometers. With faster and more sensitive cesium magnetometers it is anticipated that the plan of the whole site could be mapped out in the next field season.

2. Aerial Reconnaissance Techniques

Under certain conditions, magnetometers cannot be used for archaeological searching. Examples are volcanic soils which are too highly magnetic and areas which are too heavily forested. Also, even though sites can be covered very quickly with cesium magnetometers as compared with other instruments, land-based prospecting is necessarily slow.

Remote sensing from high-flying aircraft has been developed rapidly during the past few years for military purposes. Recently some of these techniques have been de-classified and are now being used for mineral and oil prospecting, crop disease spotting, studies of soil and water contamination, etc. Normal aerial photography has long been utilized by the archaeologist for the study of ancient settlement patterns, and for the location of specific sites and archaeological features which have forms or contours that can be seen only from the air. Infrared aerial film has been utilized to spot variations in heat and moisture contents in surface soils, chemical and color changes in vegetation which reflect underground features, differences in the compaction of surface soils reflecting underground phenomena, etc. Infrared scanning devices are now being used for similar purposes. There are still other devices in the developmental stage.

In collaboration with the Cambridge Research Laboratory of the United States

Air Force at Hanscomb Field, the Museum's Applied Science Center, made its first experiments with this method in southern Italy. Utilizing the Multi-band aerial camera produced by ITEK Corporation, the Air Force crew recorded simultaneously nine images in the 2,000 to 9,000 angstrom bands of the electromagnetic spectrum on films taken at 12,500 feet over an area of about 80 square kilometers. Also, at the same time the whole area was recorded with the infrared scanning device. The several hundred aerial photographs resulting from this experiment are still under study and results are not clear. At the moment MASCA is complementing its cesium magnetometer surveys with a drilling program to test anomalies observed on the films which may or may not turn out to be distinct archaeological features, remains which we know must lie several meters in depth below the surface of the Crati river plain. Also, photographs were taken recently by the Italian Air Force from a lower altitude (5,000 feet), but they have not yet been interpreted.

Another MASCA experiment with the United States Air Force is being made over the Snaketown and Casa Grande sites in Arizona where most of the different types of archaeological remains are known. Again, with the nine lens camera, images have been made in infrared black and white film, color infrared, false color or camouflage detection film, ultraviolet, and thermal infrared, that is, in the 10,000 angstrom band where a scanning device is necessary. All of these photographs and recorded images are now being developed by NASA and when completed will be studied by the Air Force photographers in collaboration with us and with Professor Emil Haury, University of Arizona, who has recently completed new excavations at Snaketown.

Following discussions with representatives of the United States Geological Survey and of NASA we have agreed to carry on experiments with various types

of remote sensing equipment to explore the possibilities of recording ancient settlement patterns and other archaeological features from high-flying aircraft.

The recent development of a radar altimeter and an airborne profile recorder suggests that it will be possible to map low mounds and other ruins lying under heavy tropical growth from an aircraft. Radar energy of proper wavelength projected from a survey plane should penetrate the jungle foliage to be reflected from the ground to the airborne profile recorder, and thus provide the data for an accurate contour map of a site such as that at Tikal, Guatemala. At the moment this technique is highly experimental, but it is theoretically possible and if perfected would make it possible to survey jungle-covered areas in a relatively short time. This technique may also be possible with sonic as well as radar frequencies.

3. Correlation Spectroscopy of Volatile Compounds

Correlation spectroscopy of volatile compounds may provide an entirely new technique for archaeological prospecting. This is a sensitive method for the detection of minute amounts of gases given off from deposits under the ground. It has been developed by Barringer Research (Ontario, Canada) for the detection of air pollutants such as sulphur dioxide, nitrogen dioxide, and iodine from airborne altitudes. Under optimum conditions, the instrument can detect concentrations of gases as low as two parts per billion. It has been used also in the search for copper ores by the detection of associated mercury vapor.

The principle of operation is based upon the detection of the characteristic optical absorption or emission spectra exhibited by virtually all gases. Barringer's work to date has been on gases which absorb in the ultraviolet and visible spectra and that can be sensed remotely using natural daylight as a

source of illumination. The use of infrared wavelengths is, however, perfectly feasible and work with these is currently commencing at Barringer Research.

The success in the use of correlation spectroscopy for any type of exploration depends, of course, on the availability of some volatile compound which is indicative of the remains being sought. It is necessary also, if we are to use the sun as a source of energy, that the spectra be available within an energy "window." We plan to investigate various compounds to determine this. We do know that there is an increase in soil phosphates at ancient sites of occupation and there have been (unconfirmed) claims that traces of the gaseous phosphine are found near decaying organic matter (Dubuisay, 1956). We note that the microbiological reduction of phosphate to phosphine has been observed (Rudakov, 1927). There is also the chance of detecting methane or ammonia. It is known also that there is an increase in the concentration of fluorides in bones during the passage of time, and it is feasible that some hydrogen fluoride might be given off. Another possibility is the detection of mercury vapor at sites where mercury was used to purify gold and for other purposes in ancient times. This would require no modification in the equipment.

We plan to conduct these experiments in collaboration with Lee Langan of Environmental Measurements (San Francisco, California) which is associated with Barringer Research. Environmental Measurements is willing to study the problems involved, to supply field personnel and whatever correlation spectroscopy equipment is at its disposal. They are willing to do the early experimental phases for the support of their costs only. It is anticipated that Barringer Research will contribute its "know-how" and facilities to study the geochemical situation on the same basis. Should an appropriate gas be found which requires modification of the available equipment (a change in the "mask"), it is anticipated that Barringer Research would produce the mask on a shared basis with the

University Museum, the degree of the share depending upon other potential uses of the mask. Needless to say, there are possible applications of correlation spectroscopy for military and intelligence purposes.

II. Facilities

A. Instruments and Supplies

2 Precision Portable Cesium Magnetometers, Varian Associates Model 4920.

1 Elsec Proton Magnetometer, Littlemore Scientific Engineering Company,
Type 592/7.

4 Geohms, Gossen Company Type 323.

1 Engineering Seismograph, Geophysical Specialties Company Model MD-1.

2 Metal Detectors, M-Scope and Type T-10-X, Fisher Research Laboratory.

1 Mighty Midget Earth Drill, Model BAV 100, Houston Tool Company.

1 Power Earth Augur, Model DR-450, Soiltest, Incorporated (in Italy).

Miscellaneous rods, probes, and hand augurs.

1 Tektronix Portable Oscilloscope, Type 321 and other test and trouble
shooting equipment.

Miscellaneous batteries and battery chargers.

B. Collaboration

As described previously, we have the active collaboration of U. S. Air Force Cambridge Research Laboratories, Italian Air Force and Aerofototeca, Rome.

The University Museum currently supports 15 to 20 expeditions in many parts of the world. When instrument surveys are conducted in conjunction with these, living costs are usually supported by funds from the expedition. Also, there are the obvious advantages that permissions and contacts with local authorities have already been made and that the surveys may proceed without delay.

C. Funds Spent Previously for Instrument Development, Purchase, and Testing

National Science Foundation: \$30,495

University Museum Funds: \$25,000

Industrial Contributions: \$62,981

Private Contributions: \$74,000 (Part of this was spent for test excavations of anomalies found with magnetometers in the region of Sybaris, Italy.)

III. Personnel (Curricula Vitarum for F. Rainey and E. K. Ralph are attached.)

A. Froelich Rainey, Principal Investigator, Director of University Museum and of MASCA. In overall charge of planning and supervising all instrument and aerial surveys.

B. Elizabeth Ralph, Faculty Associate in Department of Physics, University of Pennsylvania, and Associate Director of MASCA, plans to direct and to participate full-time in surveys at sites in Mexico, Turkey, Italy, and Yugoslavia.

C. Chemists

On the MASCA staff, there are also three chemists--John Winter, Ph.D., Mark Han, and Eric Parkinson, who are available for consultation and experimentation.

D. Consultants

1. Mexico

One geophysicist from the Analytical Instruments Division, Varian Associates, Palo Alto, California, to assist with the magnetometer survey and to test new search magnetometer at San Lorenzo site (Olmec) following

infrared aerial survey.

2. Mexico, Italy, etc.

Specialist for the interpretation of aerial photographs.

3. Correlation Spectroscopy

Scientists and engineers from Barringer Research and Environmental
Measurement.

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3. Rainey, F. and Ralph, E. K., 1966, Archaeology and Its New Technology. Science, 153, pp. 1481-1491.
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5. Ralph, E. K., 1967, Instrument Surveys, pp. 53-144 in Rainey, F. and Lerici, C. M., The Search for Sybaris 1960-1965 (Lerici Editori, Rome).
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Varian Associates Precision Portable Cesium Magnetometer in use on the plain of Sybaris

Fig. 1

TABLE I

Summary of MASCA Instrument Surveys

Site	Buried Features Sought	Magnetometers	Resistivity Instruments	Supplementary Instruments
<u>THE NEW WORLD</u> <u>U. S. A.</u>				
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.	
<u>CANADA</u>				
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, Ile-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
<u>CENTRAL AMERICA</u>				
Tikal, Guatemala	buried structure in N. Acropolis, W.Plaza, and Temple I	unable to tune proton magneto- meter for mag- netic field in this region	anomalies con- fused by struc- tures too complex; could not distin- guish structures from pits	
San Lorenzo, Veracruz, Mexico	Olmec monuments 1200-900 B.C.	excellent de- tection of monu- ments due to the fact that they were made of mag- netic basaltic rock	not needed	
<u>THE OLD WORLD</u> <u>IRELAND</u>				
Novan 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 repre- sentative of cen- ter of Iron Age occupation	anomalies confused by proximity of bedrock and boul- ders	
<u>TURKEY</u>				
Gordion	location of tombs under tumuli; structures on city mound; Persian road	variable magne- tic 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
<u>ITALY</u>				
Sybaris	the 7th - 6th century B.C. city	See Rainey, F. and Lerici, C. <u>The Search for Sybaris</u> , 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	

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
<u>GREECE</u>				
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	

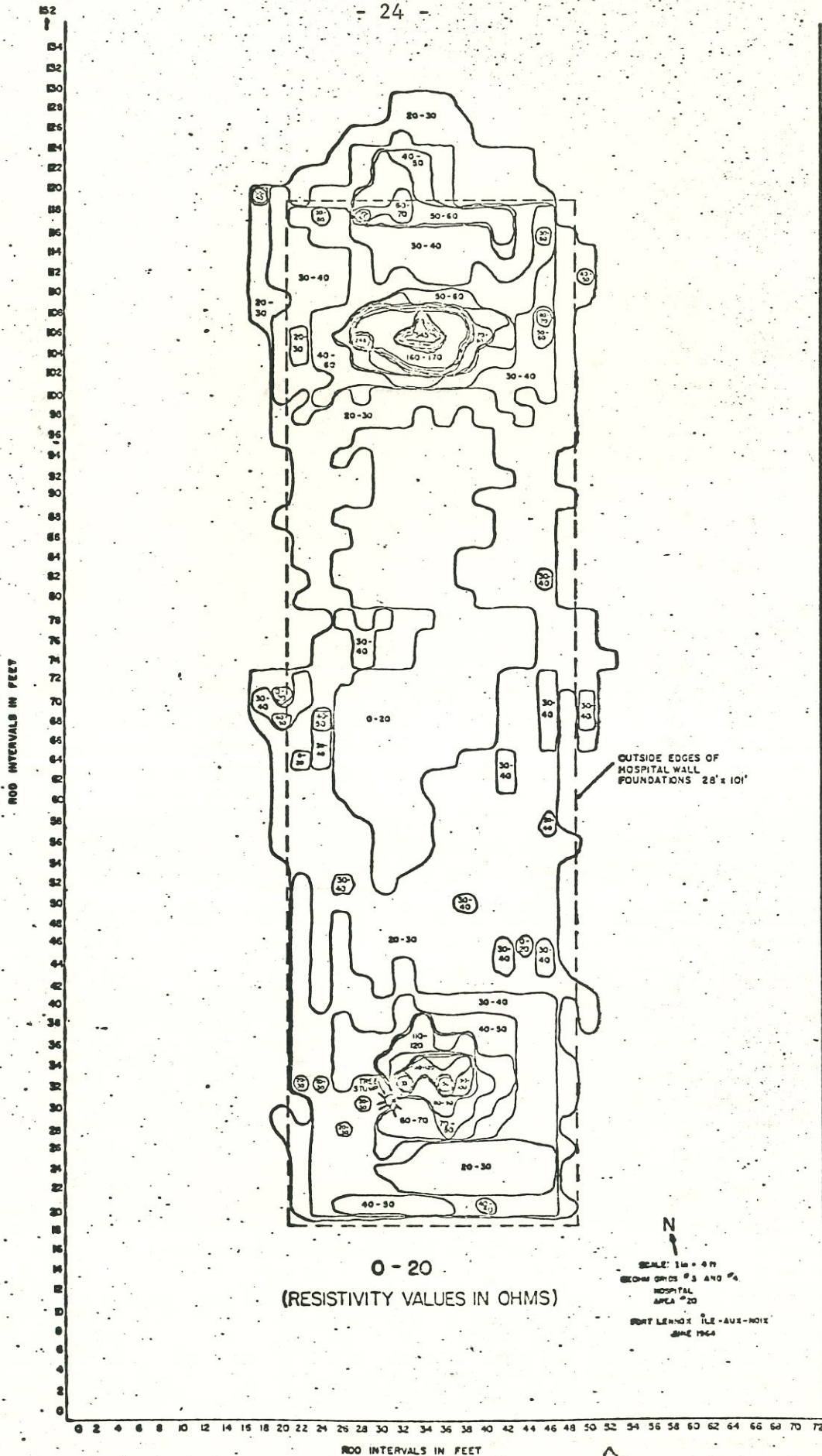


Fig. 2

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

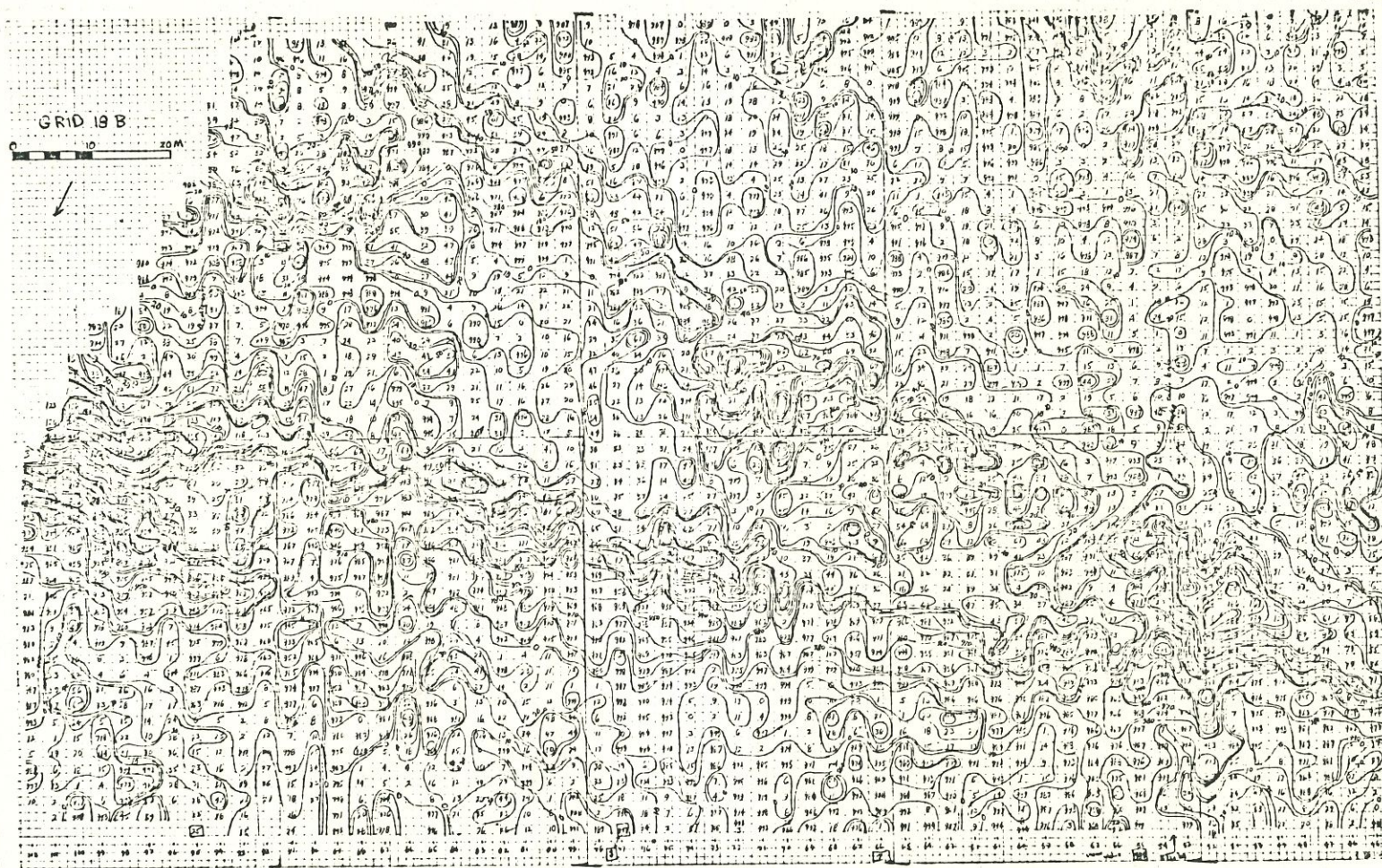


Fig. 3.

Cesium magnetometer Grid No. 18B. Closely spaced contours in upper part probably represent rows of houses, Elis, Greece.

IV. Budget Proposal

	Proposed Air Force Funds	University Contribution	Total Project Funds
<u>A. Salaries</u>			
1) Froelich Rainey Principal Investigator 10% of full-time--12 months FTE--1 man month	- -	\$ 2,500	\$ 2,500
2) Elizabeth K. Ralph Faculty Associate 33% of full-time--12 months FTE--4 man months	- -	4,240	4,240
3) Research Associate--unnamed This salary is not necessarily for one person but would support the various consultants from Varian Associates, Environmental Research, etc. while actively engaged in field tests of new equipment.	\$12,000	- -	12,000
Total Salaries	\$12,000	\$ 6,740	\$18,740
B. <u>Employee Benefits</u> (11.1%)	1,332	748	2,080
C. <u>Overhead</u> (30% of all salaries)	<u>3,600</u>	<u>2,022</u>	<u>5,622</u>
Section A Sub-Total	\$16,932	\$ 9,510	\$26,442
<u>D. Equipment</u>			
1 Model V-4971 Portable Search Magnetometer (Varian Associates)	\$ 5,750	- -	\$ 5,750
1 GMB-1 Magnetic Locator (Schonstedt Instrument Co.)	2,400	- -	2,400
1 Specialized Mask for Correlation Spectroscopy	5,000	- -	5,000
Section D Sub-Total	\$13,150	- -	\$13,150

	Proposed Air Force Funds	University Contribution	Total Project Funds
<u>E. Equipment Rental and Engineering Expenses</u>			
Lease of new cesium magnetometer equipment for tests in Mexico	\$ 4,500	- -	\$ 4,500
Engineering, servicing, and testing of telemetering system (Both supplied by Varian Associates)	1,200	- -	1,200
Section E Sub-Total	\$ 5,700	- -	\$ 5,700
<u>F. Expendable Equipment and Supplies</u>			
Batteries and other minor instrument components	\$ 1,000	- -	\$ 1,000
Infrared and other films	1,000	- -	1,000
Section F Sub-Total	\$ 2,000	- -	\$ 2,000
<u>G. Services</u>			
Geochemical studies by Environmental Measurements and Barringer Research	\$ 7,500	- -	\$ 7,500
Machine Shop, U. of Pa.	500	- -	500
Electronics Shop, U. of Pa.	500	- -	500
Section G Sub-Total	\$ 8,500	- -	\$ 8,500
<u>H. Aircraft Rental</u>			
	\$ 3,000	- -	\$ 3,000

	Proposed Air Force Funds	University Contribution	Total Project Funds
I. <u>Travel</u> (Foreign)			
Principal Investigator, Mexico and Europe	\$ 1,500	- -	\$ 1,500
Faculty Associate, Mexico, Europe, spring and fall	4,500	- -	4,500
Specialists (unnamed)	<u>3,000</u>	<u>- -</u>	<u>3,000</u>
Section I Sub-Total	\$ 9,000	- -	\$ 9,000
 TOTAL BUDGET	 \$58,282	 \$ 9,510	 \$67,792