

December 21, 1967

Dr. Encel H. Dodge, Director  
Project Research and Grants  
4th Floor, Franklin Building

Dear Dr. Dodge:

Twenty-two copies of a grant proposal entitled "Testing of Cesium Magnetometers and Aerial Reconnaissance Techniques" are attached.

Dr. Rainey and I shall appreciate it you will submit this proposal to Dr. Richard W. Lieban, Program Director for Anthropology, National Science Foundation.

Sincerely yours,

Elizabeth K. Ralph

EKR/abn

NATIONAL SCIENCE FOUNDATION  
WASHINGTON, D.C. 20550

Ralph  
ASCA

January 8, 1968

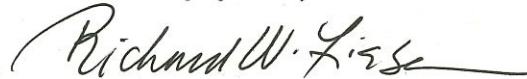
Dr. Froelich Rainey  
The University Museum  
University of Pennsylvania  
33rd & Spruce Streets  
Philadelphia, Pennsylvania 19104

Dear Dr. Rainey:

Your proposal for support of the research named below has been received by the Division of Social Sciences and assigned to the Anthropology Program for study and evaluation.

It will be reviewed by our Advisory Panel at its next meeting. Processing normally requires three to six months from the time of receipt. You will be advised as early as possible regarding the Foundation's ability to support your work.

Sincerely yours,



Richard W. Lieban  
Program Director for  
Anthropology

Testing of Cesium Magnetometers and Aerial Reconnaissance Techniques.

Please return to EKR file

NATIONAL SCIENCE FOUNDATION

WASHINGTON, D.C. 20550

April 3, 1968

Dr. Froelich Rainey  
University Museum  
University of Pennsylvania  
Philadelphia, Pennsylvania 19104

Dear Dr. Rainey:

We regret to inform you that the National Science Foundation is unable to support your research project.

In evaluating each proposal submitted to the Foundation, a number of factors are considered. They include the following: the scientific merit of the proposal and its merit in relation to other proposals received by the Foundation in the same general field of science; the relation of the proposal to contemporary research in the field; the distribution among fields of science within the program of the Foundation; the geographical distribution of research support by the Foundation; and, finally, the funds available for research support. Thus, many excellent proposals cannot be supported for reasons aside from intrinsic merit, although this is an important consideration.

Even though we are unable to support this proposal we would be pleased to consider other research proposals which you might wish to submit.

Sincerely yours,

*Howard H. Hines*

Howard H. Hines  
Division Director  
Social Sciences

Proposal No. S8-0335R  
"Testing of Cesium Magnetometers and Aerial Reconnaissance Techniques"

cc: Business Office

Called Lieban,  
These were his  
Comments  
Complementary  
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Review  
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Testing combine  
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obtained

Be M

~~10 Dr Raivey~~  
file

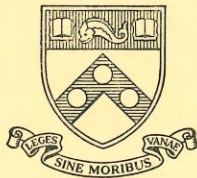
Arch.  
Buch



12/22/1967

*UNIVERSITY of PENNSYLVANIA*

DEPARTMENT OF PHYSICS



Philadelphia, Pennsylvania

Testing of Cesium Magnetometers  
and  
Aerial Reconnaissance Techniques

Submitted to:

National Science Foundation  
Washington, D.C. 20550

December 22, 1967

Principal

Investigator: Froelich Rainey

Position: Director, University  
Museum and MASCA

School: Graduate School of  
Arts and Sciences

Department: University Museum

Starting

Date: May 1, 1968

Duration: 1 Year

FUNDS REQUESTED

\$20,664

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

Contracting Office: OFFICE OF PROJECT RESEARCH AND GRANTS  
3400 Walnut Street, Philadelphia, Penna. 19104

Date:

APPROVED: \_\_\_\_\_

David R. Goddard, Provost

APPROVED: \_\_\_\_\_

Froelich Rainey, Principal Investigator  
Director, University, Museum

\_\_\_\_\_  
Otto Springer, Dean of the College

Testing of Cesium Magnetometers and  
Aerial Reconnaissance Techniques

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 seven 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 what we believe to be the optimum instrument for land-based archaeological prospecting - namely, the new portable cesium magnetometer.

During the past year 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 two projects - namely:

(1) The application of land-based surveying with cesium magnetometers to many archaeological sites and the demonstration that complete cities such as Elis in Greece may now be mapped out completely by this method.

(2) The continuance of our recent experiments with aerial reconnaissance techniques.

These two projects - one on land - and one in the air - are independent in regard to instrumentation, but are complementary for several reasons. As in the initial phases of our tests with a variety of land-based instruments when it was necessary to drill and to do test excavations for confirmation of anomalies found, the cesium magnetometer has now delineated extensive areas of known archaeological deposits, and it provides a rapid means of testing new anomalies which may be detected by aerial techniques.

#### B. Project I. Cesium 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. 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 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, 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 (in press). One of the most successful, recent experiments with <sup>the</sup> cesium magnetometer was carried out at the site of Elis in Greece (see below under Procedure).

During the past year Varian Associates has 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 the new Model V-4971 could be used to delineate the entire archaeological zone which may cover an area of more than 25 square kilometers while the precision Model 4920 is being employed to map out the "heart" of the city. Needless to say, this would help to accelerate the complete 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."

#### C. Project II. 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 content 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 Engstrom 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.

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 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 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 wave length projected from a survey plane should penetrate the jungle foliage to be reflected from the ground to the airborne profile recorded, 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.

References

1. Breiner, S., 1965, The Rubidium Magnetometer in Archaeological Exploration. Science, 150, pages 185-193.
2. Rainey, F. and Ralph, E. K., 1966, Archaeology and Its New Technology. Science, 153, pages 1481-1491.
3. Ralph, E. K., 1965, Comparison of a Proton and a Rubidium Magnetometer for Archaeological Prospecting, Archaeometry, 7, pages 20-27.
4. Ralph, E. K., 1967, Instrument Surveys, pages 53-144 in Rainey, F. and Lerici, C. M., The Search for Sybaris 1960-1965 (Lerici Editori, Rome).
5. Ralph, E. K., Morrison, F., and O'Brien, D. P., in press, A High-Sensitivity Difference Magnetometer: An Archaeological Application.

## II. Procedure

### A. Mexico

In early spring, dual experiments are planned at the San Lorenzo site (Olmec) in collaboration with Professor Michael Coe of Yale University who will continue excavations at the site in 1968.

It is planned first to photograph the site with infrared film so that anomalies recorded from the air can be tested with a cesium magnetometer on the ground and by excavation. This will be the first test also of the new Portable Search Magnetometer Model V-4971 at an archaeological site and will be made in collaboration with geophysicists from Varian Associates.

### B. Greece

#### Ancient Elis, Greece

(In collaboration with Professor Spyridon Marinatos, University of Athens and Dr. George Papathanasopoulos, Director of the Olympia Museum.)

A preliminary survey made in early September, 1967 demonstrated that this is a perfect site for cesium magnetometers. The walls of the fifth century B. C. city and in some parts of the site, overlying walls are so readily detectable that it appears to be possible to plot magnetically the complete plan of ancient Elis. The completion of this survey is urgently desired by the Greek Department of Antiquities because of the construction of a modern irrigation ditch and reservoir which are presently projected to pass through the site. When the plan

of the ancient city is revealed with the magnetometers, it is hoped that the modern ditch can be diverted away from the most important parts. Excavations have been conducted at this site since the nineteenth century, but in comparison, digging is so slow and expensive that except for the location of the theatre, nothing is known of the city plan.

Since it is anticipated that the central zone of ancient Elis can be mapped out within a month with the precision magnetometer, this site will provide also a testing ground for infrared photography and for the search magnetometer.

## (2) Other Greek Sites

At the invitation of Professor Marinatos, we plan to inspect many archaeological sites in Greece to determine which ones are suitable for magnetic and for aerial surveys. Because many of the hill regions and islands of Greece are highly magnetic and not suitable for magnetic surveying, this is an important first step before the planning of comprehensive surveys. Aridity and rainfall patterns will be studied to guide the suitability and timing of infrared photography.

## C. Ireland, Dun Ailinne

(In collaboration with Dr. Bernard Wailes, Assistant Professor of Anthropology, University Museum, University of Pennsylvania and Mr. Percy Le Clerc and Mr. Marcus O' Eochiadh, National Monuments Branch, Dublin, Ireland.)

Dun Ailinne is one of the traditional royal sites, possibly the

seat of the "High Kings." It is a rounded hill with a roughly circular bank and ditch enclosing an area of about thirty acres. Dr. Wailes, on behalf of the University Museum, has been invited to excavate this site. Since the mound is extensive and there are no clues on the surface to guide the excavation, it would be extremely helpful if significant features can be located either with cesium magnetometers and/or by infrared photography prior to excavation. Previous experience at Navan Fort, a similar mound in Northern Ireland, has demonstrated the feasibility of finding entrance passageways and other guiding features with magnetometers.

#### D. Italy, Sybaris

In the late winter (1968), the Italian Air Force is planning to take a new set of infrared photographs over the plain and surrounding hill regions of Sybaris. These will be taken at a lower altitude, 5,000 feet, and at the optimum time of year. We then plan to test new anomalies spotted from the air with magnetometers on the plain and with resistivity and other instruments in the hill regions.

#### E. Sites in Michigan, U. S. A.

(In collaboration with Dr. Charles E. Cleland, Curator of Anthropology, the Museum, Michigan State University.)

It is planned to investigate a number of historic and prehistoric sites in Michigan with all of the "toys" of the trade. It is not anticipated that all of the sites will be ideal for prospecting with instruments, but part of the purpose is a training and indoctrination program

for students in archaeology and anthropology. It is hoped that the students will gain enough instruction and practice to enable them to be aware of the potential and applicability of various types of apparatus.

### III. Facilities

#### A. Instruments and Supplies

1 Precision Portable Cesium Magnetometer, Varian Associates  
Model 4920.

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

3 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.

7 rolls Infrared Film, black and white Kodak Type 5424 (in Italy).

#### 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).

#### IV. Personnel (Curricula Vitae for Rainey, Ralph, and Ring are attached).

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

Elizabeth Ralph, Faculty Associate in Department of Physics, University of Pennsylvania, and Associate Director of MASCA, plans to direct and to participate in full-time surveys at sites in Greece, Italy, Ireland, and Michigan.

Raymond Ring, Research Assistant, Department of Physics, University of Pennsylvania, plans to assist with instrument surveys in Michigan and possibly others.

#### Other Assistants - Europe

Giacinto Loisi and Nunzio Lione (surveyor), Cassano Ionio, Cosenza, Italy. Loisi and Lione have now had five seasons of experience with the cesium magnetometer and are the most able and hard working assistants that can be found locally, that is, for work in southern Italy and Greece. Because of their experience and energy, surveys may be conducted much more rapidly than with untrained helpers.

If, for some reason, it is not possible for them to go to Greece, it is anticipated that David Zimmerman, graduate student in Physics, from the Research Laboratory of Archaeology and the History of Art, will be able to assist in Greece and possibly in Ireland.

#### Consultants - Mexico

Two geophysicists from the Quantum Electronics Division, Varian Associates, Palo Alto, California.

To make magnetometer survey and to test new search magnetometer at San Lorenzo site (Olmec) following infrared aerial survey made in late November or December 1967.

V. Budget Explanation

Salaries	N. S. F.	University of Pennsylvania Contributions	Total
Froelich Rainey, Principal Investigator, 10% of Full-Time, FTE - 1 man month		\$2,400	\$ 2,400
Elizabeth Ralph, Faculty Associate, 30% of Full-Time, FTE - 4 man months		\$3,600	\$ 3,600
Raymond Ring, Research Assistant, One Summer Month FTE - 1 man month		\$ 400	\$ 400
Total of University of Pennsylvania Salaries		\$6,400	\$ 6,400
Overhead, 30%		\$1,920	\$ 1,920
Giacinto Loisi, Three Months	\$ 900		\$ 900
Nunzio Leone, Three Months	\$ 900		\$ 900
Total Other Salaries	\$1,800		\$ 1,800
Overhead, 13%	\$ 234		\$ 234
Employee Benefits (10%)	\$ 180	\$ 640	\$ 820
Consultants -			
Two Geophysicists from Varian Associates, Two Weeks	\$2,400		\$ 2,400
Salaries Total	\$4,614	\$8,960	\$13,574

V. Budget Explanation

(Continued)

<u>Equipment</u>	<u>N. S. F.</u>	<u>University of Pennsylvania</u>	<u>Total</u>
One Portable Search Magnetometer, Varian Associates, Model V-4971	\$ 5,750		\$ 5,750
<u>Expendable Equipment and Supplies</u>			
Infrared Film	\$ 1,000		\$ 1,000
Batteries and other Minor Instrument Components	\$ 500		\$ 500
<u>Aircraft Rental, Mexico and Ireland</u>	\$ 2,400		\$ 2,400
<u>Travel,</u>			
Principal Investigator Mexico and Europe	\$ 1,500		\$ 1,500
Faculty Associate, Europe Spring and Fall and Michigan Summer	\$ 4,500		\$ 4,500
Italian Assistants, Greece	\$ 200		\$ 200
Research Assistant, Michigan	\$ 200		\$ 200
Sub-Total	\$16,050		\$16,050
Total Budget	\$20,664	\$8,960	\$29,624

RESEARCH GRANT BUDGET SUMMARY

INSTITUTION		PRINCIPAL INVESTIGATOR(S)		PROGRAM NAME			DURATION	GRANT NUMBER	
University of Pennsylvania		Froelich Rainey		Testing Cesium Magnetometers and Aerial Reconnaissance Techniques			1 year		
A. SALARIES AND WAGES		NSF Funded Men Months			Grants Man Months			NSF GRANT	GRANTEE SHARE
		Col	Acad	Sum	Col	Acad	Sum		
1. Senior Personnel									
a. 1 (Co) Principal Investigator(s) ..					1				2400
b. 1 Faculty Associates .....					4				\$ 3600
Sub-Total .....									6000
2. Other Personnel (Non-Faculty)									
a. Res. Assoc. - Postdoc. ....									
b. Non-Fac. Professionals - Doc. ....									
c. Non-Fac. Professionals - Other .....									
d. 1 Grad Students (Res. Asst.) .....							1		400
e. Professional School Students .....									
f. Pre-Baccalaureate Students .....									
g. Secretarial-Clerical .....									
h. 2 Technical .....								1800	
i. ....									
3. Special Allowances .....									
Total Salaries and Wages .....								\$ 1800	\$ 6400
B. FRINGE BENEFITS .....								\$ 180	\$ 640
Total Salaries, Wages and Fringe Benefits (A+B) .....								\$ 1980	\$ 7040
C. PERMANENT EQUIPMENT									
1. Varian Associates Model V-4971 Magnetometer .....								5750	
2. ....									
Total Permanent Equipment .....									
EXPENDABLE SUPPLIES AND EQUIPMENT IR. Film and Batteries .....								\$ 1500	\$
E. TRAVEL									
1. Domestic Michigan for Faculty Assoc. and Research Assist. ....								700	
2. International Europe for principal investigator faculty .....								5700	
Total Travel associates and assistants .....								\$ 6400	\$
F. PUBLICATION COSTS .....									
G. OTHER COSTS									
1. Aircraft Rental, Mexico and Ireland .....								2400	
2. Consultants, 2 geophysicists from Varian Associates .....								2400	
3. ....									
Total Other Costs .....								\$ 4800	\$
H. TOTAL DIRECT COSTS (A through G) .....								\$ 20,430	\$ 7040
I. INDIRECT COSTS									
1. On Campus 30 % of \$6400 .....									1920
2. Off Campus 13 % of \$1800 .....								234	
Total Indirect Costs .....								\$ 234	\$ 1920
J. TOTAL COSTS (H and I) .....								\$ 20,664	\$ 8960
K. AMOUNT OF THIS AWARD (ROUNDED) .....									