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INTERIM REPORT
SEISMIC ARCHEOLOGICAL AID

Several methods that would be applicable to a seismic short range high resolution equipment were considered. The reflection system appears to be the most direct method, requiring least analysis of results and presenting a straightforward pattern. Previous experience with radar and sonar equipment indicated that an echo ranging type system would provide the greatest amount of information. The reflected signals to be displayed on a radar type screen. The simplest display is the so called "A" type scan, which is a single line calibrated in distance and the signals presented as deflections along the line. The strength of the echos is indicated by the size of the deflections. This display is simple to generate and to interpret.

The next problem was the investigation of the mechanism of transmission of sound by the earth. Fortunately, excellent work has been done in the field of seismology and a considerable fund of information is available. A summary of the wave types of interest follows.

Waves can travel in an elastic medium by several modes. Two of the basic waves in the science of seismology are well known from both theory and observation. They are body waves, that is, they travel through the interior of an elastic body, as distinct from types that travel only on the surface.

The compression or "P" waves: This wave advances by alternating compressions and rarefactions. It is the type that carries sound in air and water. In seismology, the symbol P, is used for this type of wave because it arrives first from an earthquake, and in the old days, these first waves were called Undae Primae.

Transverse or "S" waves: The second type of body wave advances by transverse displacement. These waves, as the second prominent group from an earthquake, were called Undae Secundae and given the symbol S. A prominent seismologist called the waves the PUSH and SHAKE waves.

Several other types have been detected and are included just for
They are
the record; surface waves and exist only on the surface of an elastic medium.

"R" waves or Raleigh waves, involving a vertical motion of the
particles at right angles to the direction of wave advance.

"O" waves, a horizontal motion of the particles at right angles to
the direction of wave advance.

Two additional types were detected for the first time and identified
from records obtained during the A bomb test in New Mexico, July 16, 1945.
They are "H" and "C" types. The "H" wave involves a circular motion of the
particles at right angles to the wave advance. The "C" or coupled wave also
involves a circular motion but it is tilted from right angles to the wave
advance.

The two types of waves of interest in the seismic reflection are
the P and S body waves, with the P wave at present seeming the most suitable.
A preliminary investigation of available literature indicated very little
information to date on the use of high frequency sound for the detection and
location of anomalies in the earth. This fact is very surprising, as the
applications including military uses seem very numerous. Some experiments have
been made using sound of a few thousand cycles with good penetration.

The loss of energy in earth is due to several complex effects and
it would be useless to try to extract more than approximations from the theories.
Most of the data from Sonar and N.D.T. (non-destructive testing) has been
obtained experimentally but certain conclusions can be drawn.

Only a small portion of the energy starting out from a given source

will reach a given distant point. It will continuously diminish in intensity along any path which it may follow. The decrease in intensity is due to two quite different effects. One is the divergence of the sound rays as they radiate from the source, which distributes the energy over a surface of ever increasing area. The other is absorption of energy by the medium and the scattering of the energy by reflectors contained in the medium. The first of these introduces what is known as the spreading loss and the second, the attenuation loss. The two together constitute the propagation loss which is characteristic of the medium at a given location. There are important differences between the two losses. The spreading loss, associated with a given path length depends upon the distance to the source, but it is independent of frequency of the acoustic wave being transmitted. The attenuation loss, on the other hand, is a function of the frequency of the wave. The resultant effect of these two losses, considered in conjunction with the magnitude of the transmitted signal and the stray noise, both internal and external, of the receiving system, determines the range of the equipment.

As the loss due to the spreading is independent of frequency, the attenuation loss will determine the maximum frequency usable for any given range (assuming constant power output from the acoustic source).

Theoretically, the attenuation varies approximately as the square root of the frequency until the wavelength approaches the size of particles imbedded in the transmitting medium. At this point, the attenuation will increase as the square (approximately) of the frequency. An analogous effect is the interference with visibility when fog particles are present, as when scattering reduces visibility. However, for the ranges of interest, a considerable choice is available as regards frequency. The maximum range required

should permit wide choice in the selection of frequency and power output from the energy source. The frequency required for location of small anomalies will be determined by the size of the reflecting objects. Small energy will be reflected when the wave length is longer than the objects and good reflection when the wavelength is less than the diameter of the object. High frequency sound results in greater attenuation but better accuracy in depth determination as well as probably better discrimination between layers of different transmission characteristics.

Assuming a velocity of 5,000 feet per second, the wavelength of 5,000 cy energy would be one foot and objects of this size or larger will reflect and scatter energy. Assuming the same velocity a frequency of 50,000 cycles would be scattered by particles of 0.1 ft or a little over one inch. The nature of the earth being examined will therefor determine the frequency chosen (assuming adequate range).

Equipment available for use at these frequencies is rather limited. Available high frequency .0 to 40,000 cy. vibration pickups designed for aircraft vibration studies are very insensitive and not suited for a detector. A more promising approach is the field of sonar and ultrasonic transducers.

The design of seismic detectors is based upon the principle that the case of the seismic detector (geophone) becomes part of the earth and any wave motion is transferred to the case. In the geophone is a seismic mass, a small weight suspended independently from the case, therefor any motion of the case causes relative motion between the case and seismic mass. The various geophone designs use different methods to develop a signal voltage from this relative motion. The most common geophone design uses a coil of wire suspended between the poles of a magnet so that the coil moves relative to the magnetic field, thereby inducing a signal voltage in the coil.

These geophones are sensitive to very low frequencies but are useless at high frequencies as their response to frequencies above a few hundred cycles a second is very poor.

Several materials may be used for the construction of high frequency pickups. They include materials that are piezoelectric, or electrostrictive. Several materials are used that are magnetostrictive. These are used in the sonar field especially at the lower ultrasonic frequencies.

Several experimental geophones were made using piezoelectric materials. Two were made using rochelle salt elements and two were made using barium titanate bender elements. The response of the b.t. element was adequate to above 20 kc. The rochelle salt elements were more sensitive. All responded to above 20 kc. As only relative measurements were being made, the rather crude devices were adequate. More sophisticated geophones will permit resonating the element with consequently much greater sensitivity and noise discrimination. No attempt at this time was made to use the magnetostrictive type pickup.

Several checks were made using these detectors. The signal source for very short range was an electromagnetic transducer from a high powered horn. This was coupled to the earth by several methods and pointed up the difficulty of coupling energy efficiently to the earth at high frequencies. One method that permitted pickup at several feet employed a hole carefully dug to avoid loose dirt, the transducer attached to a metal plate placed over the hole and covered with dirt. Checks were made at several distances to obtain the attenuation characteristics at different frequencies. A strong background signal was present and was determined to come from a vibrating power pole that mounts a large power transformer. Several harmonics were also

Present from the vibrating pole. The attenuation did not increase with frequency as rapidly as expected but the response of the horn transducer under poor loading conditions limited frequency tests to below 5 kc.

An impact source was then used with the frequencies below 1000 cy eliminated by a filter. The signal from the geophone was displayed on a modified A/R radar range scope type 256 B. This type scope uses a triggered sweep and has only moderate amplifier gain. Excellent reflections were obtained from a rock layer 12 ft. below the surface; in fact, several multiple reflections were visible due to the signal bouncing between the surface and the rock layer. The transducers for short range work should be damped, as they ring and the resulting train of pulses obscure closely spaced echoes. Damping can be accomplished by the use of oil. Silicone oils of different centipoise ratings are available and of course the reliable castor oil may be used. Rochelle salt is hygroscopic and the oil should be free from excess moisture when used. If electrostrictive materials or magnetostrictive materials are used, the Q should be reduced by loading, to provide adequate damping.

To couple efficiently to earth, a very small motion with great pressure ¹⁵ ~~are~~ necessary. Pressures of the order of several hundred pounds per square inch are required to couple considerable energy into the earth. An impact source will operate efficiently at low frequencies but is deficient in high frequency energy content. However, a small high velocity type impact source shows some promise. Also the various transducer materials designed for operation in cleaning devices may be modified for use in transducers.

The electrostrictive materials suitable for transducers, include ammonium tartrate, lithium sulphate, rochelle salt, sodium ammonium tartrate,

quartz, tourmaline, potassium phosphate, ammonium dihydrogen phosphate, barium titanate (polarized), hexamethyltetramine and zinc sulphide. The most practical are the barium titanates and A.D.P.

Transducer designs using these materials, have been worked out, in the field of ultrasonic cleaning, and these materials may be used for both power generation and detection.

Using barium titanate, an element resonant at 100 kc, is about 1 inch long ~~1~~ or - about 25%. The frequency may be lowered by using a sandwich construction with steel pieces above and below the barium crystal.

Among the magnetostrictive materials are nickle, permalloy and alfer. The alfer is a combination of aluminum and iron. The most available of these materials is nickle. The commercial grades are satisfactory for transducers. If the nickle type is used for both transmitting and receiving, a magnetic bias external to the nickle should be provided, as the transmitted pulse will demagnetize the nickle. The design of transducers is adequately covered in existing publications.

The most practical approach at the present time is to design the display and measuring equipment as universal as possible. It should work with one shot impact sources as well as pulsed transducers. The frequency response should be better than 20,000 cy. and should be limited in gain only by internal noise of the amplifiers. I am sure that more information can be obtained when used in the field than ever obtained by artificial tests.

The preliminary tests were encouraging and work is now under way on a transistorized light weight unit with a 3 inch cathode ray tube indicator. The screen of the c.r.t. will show a trace for about half a minute with even a single shot. Also the type screen used (P7) will permit build up of signal with recurrent pulses and provide better signal to noise ratio under ^{un}favorable conditions.

NOTE: Amplifiers ARE EXCELLENT + Respond to over 100,000 cycles.

APPLIED SCIENCE CENTER FOR

Archaeology (MASCA)

The Applied Science Center for Archaeology was initiated in 1961 by Dr. Froelich Rainey. Its aim is to apply new principles and technologies developed in the physical sciences which are appropriate to archaeological and anthropological research.

Upon the successful application of carbon - 14 dating in the laboratory here (established in 1951) and in others, it was felt that many more of the technological advances should be investigated for possible applications. As a beginning in this direction, work was started in the following fields:

- 1) Thermoluminescence dating of pottery
- 2) Development and use of instruments for archaeological prospecting.
- 3) Information Center and Newsletter.

Since then, the existing chemistry laboratory has been expanded to include a much more active program of conservation and restoration. Also, work in dendrochronology is being pursued to provide samples of known age for C-14 dating.

In the following pages a brief description of the various endeavors of MASCA is presented.

Thermoluminescence

Research in the possibility of using thermoluminescence for dating pottery was started here in 1959 and has been pursued actively since 1962. Significant progress made during the past two years indicates that the method will be a reliable one, possibly comparable/ⁱⁿaccuracy to C-14 dating or better. It has the big advantage over C-14 dating in that the artifact itself (a few milligrams of pottery) is dated rather than charcoal or other carbon sample that is merely and sometimes erroneously associated with the occupation level to be dated.

The method is based on the fact that particles from traces of radioactive elements in clays bombard the other constituents and raise electrons to metastable levels. When the clay is heated, enough extra energy is supplied to enable the electrons to return to normal states. In this transition each one emits a photon of light. The final heating of a ceramic is, therefore, the starting point of the metastable electron accumulation. In the laboratory, a few milligrams are ground, mounted, and heated very rapidly so that as much of the light output as possible is detected before the onset of heat radiation. This is detected by a photomultiplier tube, amplified, and recorded on an X-Y recorder versus temperature. For age determination, the rate of radioactive bombardment is also measured. In addition, the variations among clays in susceptibility to radiation damage is corrected for by artificial bombardment with X-rays and subsequent remeasurement of the glow curve.

Space is needed for the continuance of the development of this dating technique and for the dating of samples of unknown age.

Instruments for Archaeological Prospecting

With the destruction of many archaeological sites imminent due to the rapid encroachment of modern civilization, there is a great need for the acceleration of the finding of sites and for the delineation of structures within sites already found. Also, with the cost of labor increasing all over the world, it is becoming impractical to excavate unless there is a certainty that structures or levels of habitation will be found.

With this in mind, MASCA has tested and used instruments developed previously that are suitable for archaeological exploration. These include the Elsec proton magnetometer, the Gossen Geohm, and various metal detectors and seismographs. In the course of the search for the ancient Greek city of Sybaris, buried at depths of 4 to 6 meters, it was found that proton magnetometers were not sufficiently sensitive for the detection of structures or archaeological deposits at these depths. Therefore, the collaboration of Varian Associates was sought, and as a result, a more sensitive portable cesium magnetometer (with digital readout and differential mode of operation) was designed and developed by them. This has now been tested in two field seasons and has proved to be the ideal instrument for archaeological prospecting in regions that are normally magnetically quiet and where the features sought present some contrast in magnetism.

It was found that standard seismographs were of little use in finding the relatively small archaeological features, usually located above much more massive geological changes - the wavelengths are too long. Therefore, experiments

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Instruments (con't)

directed toward the development of a sonic instrument were conducted. Much information about the problems involved has been obtained, but a successful portable design has not yet been achieved.

In the MASCA laboratories some space is needed for storage of instruments while not in use and for experimentation, tests, and repairs.

Information Center

An extensive part of the work at the MASCA Information Center is the compilation of author and subject indices which form a catalogue of scientific techniques of value to Archaeology and Anthropology and include reports of analyses dating methods, field studies, and conservation methods. The abstracts of articles and references, and information on new developments which are the basic components of the files, are culled from many publications of diverse fields. The files are a source for the most recent information concerning archaeological techniques and include, in addition to published material, unpublished information, gathered from correspondence and experimental notes.

The Information Center, itself, now that a considerable volume of data have been collected, is becoming more useful to members of the staff, students and visiting scholars. More space is needed for the use of the files.

In addition to library and abstracting work/^aNewsletter is published three times a year, in which current developments in the field of techniques are reported. Copies are made available, free of charge, to all interested persons. The mailing list is world-wide, and the center receives notes and articles from many foreign sources.

Conservation

The valuable treasures in the Museum are by all means worthy of expert care and treatment. Contrary to many people's belief, so-called "cleaning" or "restoring" an object is not just making it look pretty. It should be primarily a question of stabilization--in a bronze or iron object, removing the chlorides so that there can be no further disintegration. Precisely how one does this depends upon the state of the metal. Metal objects particularly bronze and iron, always need attention. The longer they have to wait the less there is that can be done to save them.

Specimens in the Museum have suffered from excessive damp, excessive dryness, the industrial atmosphere, or all three. Much totally unnecessary loss or deterioration has taken place in the last ten years, to things which are by no means old or frail.

In setting up a Conservation-Restoration Laboratory some 1400 square feet is needed. This space would be used proportionately for the following processes:

- Wet cleaning area

- Area for mechanical cleaning by means of vibration tools

- Soaking of objects

- Storage of chemicals

- Electrolysis tank and work area

- Microscope area

- Oven area

- Infrared area

- Temporary storage of objects in process.

Chemistry Laboratory

When a specimen is sent ⁱⁿ to the Museum from the field its identification often is only superficial. A chemical analysis, qualitative to establish the constituents of the specimen or quantitative to determine the relative amounts of these constituents, can help in more precise identification. If a specimen has been modified or drastically changed in appearance over a long period of time an analysis may be useful in deciding its original form or use. A chemical analysis may also be useful in helping to decide on the authenticity of an object, and sometimes an analysis is required merely to add to the sum of knowledge about a specimen. Specimens may be metals, ores, corrosion products, earthy materials, organic products, etc., and either archaeological or more recent in origin.

Space is required for adequate working bench surface, for wall cases and cabinets for storage of chemicals and apparatus, and for such equipment as sinks, fume hood, oven, furnace, and balance; also for a desk and bookcase for each worker. A large table or other flat work space for laying out drawings or maps is also recommended. The area presently in use is about 366 square feet, some of which is used alternatively for conservation procedures.

Dendrochronology

The tree-ring dating program is being conducted in conjunction with the radiocarbon laboratory. By means of dendrochronology, sections of Sequoia gigantea and of Pinus aristata are providing samples of known age for C-14 dating (back to 4400 B.C.). By means of these, small fluctuations in the atmospheric C-14 inventory in past times are being assessed. When the magnitude and duration of these are known, it may be possible to correlate these with one or more of the basic causes - namely, changes in the cosmic ray intensity, in the intensity of the magnetic field of the earth, and/or in the equilibrium conditions (the balance between the atmosphere and oceans). C-14 dates for these long series of samples of known age will also provide correction factors for the dating of archaeological specimens and others of unknown age.

The tree-ring dating is being done in collaboration with the University of Arizona. In the Museum space is needed for study, sectioning, and cross-dating of ring sections.

Carbon-14 Dating

The radiocarbon laboratory at the University of Pennsylvania was established in 1951. It is one of the few laboratories in the world that has devoted itself almost exclusively to the dating of archaeological and anthropological samples. During the past 15 years 562 C-14 dates representative of 113 archaeological sites have been published. Emphasis has been in the establishment of chronologies for four main regions of the world - namely, the Near East and Mediterranean regions, Central America, South America and the Arctic. Among intensive studies have been the correlation of the Mayan calendar with the Christian, dating of some of the earliest sites and elucidation of human migrations in the western Arctic, the dating of occupations and climatic sequences for what is apparently the earliest site in eastern North America, comprehensive dating programs permitting archaeological interpretation of Mesolithic-Neolithic-Chalcolithic transitions in the Near East and the Anatolian Plateau.

The radiocarbon laboratory is the keystone of MASCA. Because the laboratory and its main staff are supported by the University and partly because of their record of achievement, it has been possible to obtain grants from the National Science Foundation, industries, and private contributors to carry out new programs. One of the NSF grants supported the addition of a second C-14 counter and associated components for methodological studies as described under Dendrochronology.

The radiocarbon laboratory is considered to be among the most reliable dating laboratories in the world, and possibly the most careful. Partly because of this, requests for dating each year now exceed our yearly capacity even with some of

Carbon-14 Dating (con't)

the counting time of the 2nd NSF counter devoted to samples of unknown age.

There is, therefore, an urgent need for more space. This is not available in the Department of Physics where the laboratory is located at present. Also, because of the pressure for space, the laboratory may be forced to move from Physics to Geology where both space and facilities are inadequate.

With more space, a third counter could be installed. The electronic components presently in service have been in continuous use for eleven years - a long life-time for vacuum tube circuits. Therefore, in addition to more space, there is an urgent need for funds for their replacement and for the third counter and components. Cost of this is estimated to be \$50,000 plus the cost of this portion of the building.

List of MASCA Requirements

Name of Laboratory	Space Required (square feet)
Thermoluminescence Dating	1000
Prospecting Instruments	300
Information Center	300
Conservation and Chemistry	1400
Dendrochronology	300
Carbon-14 Dating	<u>1200</u>
Total	4500 + hallways

Utilities Required in Each Room:

24 Electric Outlets, 115v, 15A

2 " " , 230v, 25A

2 Dual Gas Outlets

2 Dual Compressed Air Outlets

Sinks Required:

2 Carbon-14 Laboratory

2 Thermoluminescence Laboratory

2 Conservation and Chemistry

Fume Hoods Required (with small sinks and all utilities)

1 Carbon-14 Laboratory

1 Conservation and Chemistry

B. Thermoluminescence

Although thermoluminescent dating is a very promising technique and further research is very important, the work proposed here has a number of serious deficiencies.

The main thrust of the proposed research concerns the variations of TL sensitivity with annealing temperature, and the conjecture that deviant high TL ages of some older test samples may be a result of their low TL sensitivities from lower firing temperatures. First of all, their discovery of the dependence of TL sensitivity on heating temperature is not new; it has been widely published and is even the basis of a TL dating technique (Fleming, Archaeometry 15, 13-30, 1973). Second, I fail to see why the lower TL sensitivity of the low-fired pot should give a deviant age. They measure the sensitivity, it is low, but it is the appropriate one for the accumulation of the natural TL, and for calculating the TL age. If the pot had been fired at a higher temperature it would have a higher sensitivity, but that seems to be irrelevant to me. Third, even if this effect is relevant, I believe the proposer is naive in suggesting that it alone will substantially improve their TL ages. As I understand their TL method from their publications, it ignores a large number of factors conclusively shown by TL dating researchers at several other laboratories to be necessary to take into account in order to

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Exclusive

Conclusion

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a) b) c) d)
obtain reliable ages. These include variations in dose rate with grain size, variations from sherd to sherd in potassium to uranium plus thorium ratio, variations in alpha efficiency, the effects of ground water, supralinearity, and anomalous fading. These effects must be important for MASCA's relative dating technique. However, the proposed studies on the variations of TL sensitivity with firing temperature and related measurements would be of value as additional information for understanding the complex TL phenomenon.

3. The development of a method for determination of pottery firing temperatures (pp.25-26) would be valuable in its own right. As discussed above, it is unclear to me how this would directly aid TL dating although it might ultimately prove to be of value. The methods proposed, TGA and DTA, have both been reported extensively in many books and articles. Although some information can be obtained from both methods, there are several serious limitations. No references are made to this work either in the proposal or in the accompanying papers and the proposer seems unaware of the limitations and problems involved.

In the third part of the TL proposal on flints (p.27), while there is probably valuable research that could be done, what is actually being proposed is very vague. The only specific statement is "to work on a method for flint sample preparation" (p.27). However a simple, reliable sample preparation method was devised by Göksu and co-workers (Science 183, p. 651, 1974), which has been reported to be satisfactory in several publications on flint TL by various groups. I don't understand what the proposer is trying to say in the rest of the sentence about "providing experimental evidence that the TL clock is re-set at about 350°C". Since the TL is normally measured at ~350°C in the glow curve, it must by definition of the TL process be re-set at 350°C.

The apparent lack of appreciation of the substantial research by other laboratories in this field over the past ten years, the serious omissions in their TL dating method, and the paucity of publications of original research in the open literature, subject to review (the last one in 1966, Han and Ralph), leads me to question the competence of the proposer and his colleagues in this particular area.

The proposed work on mud-structures, marble, and limestone deals with an extremely important area of conservation. However it is also an extremely difficult area, which many groups in the world are working on. The proposer appears to be completely unaware of the extensive work and publications of others, and of the serious difficulties involved.

The work described and proposed consists of haphazard application and observation, lacking critical fundamental measurements, such as the depth of penetration of the consolidants. The short term improvements reported are unimpressive--being common to many attempts which are followed by catastrophic failure at longer times. Great harm can be done in this area by anything but the most cautious and thorough work.

THERMOLUMINESCENCE

In response to the question of our awareness of TL developments going on elsewhere, as well as our apparent failure to incorporate these "advances" into our TL methodology, we would like to point out the following:

- (1) The Information Center here at MASCA provides a ready source of current research developments and applications in all of our fields of research including TL.
- (2) We are in constant communication with other laboratories working in the field of TL dating.
- (3) We assist other institutions who are desirous of setting up their own TL laboratories, despite the acknowledged difficulties and uncertainties of the method as a dating technique.

The approach of the TL laboratory at MASCA is different from that of some institutions, notably Oxford. At Oxford, work has proceeded as thesis projects of graduate students under the direction of Dr. M.J. Aitken. For a thesis in physics, it is essential to investigate a fundamental aspect of a physical process. At MASCA, work is directed toward continued development of a single technique, in an effort to improve its reliability and usefulness. As a result, the character of the research is different. It is not always desirable to immediately adopt new techniques with their unsolved problems in preference to refining existing ones which have benefited from constant development. Through the years, since our initial report in 1966, we have carried out our dating by the same general procedure, in order to accumulate sufficient data to show the workability of TL for archaeological purposes. At the same time we have continued research into the associated problems in an effort to improve reliability of TL as a means of dating.

In response to the specific criticisms of the reviewer, we would like to make the following comments:

- (1) Although we would agree with the reviewer that the currently employed measurement of induced TL susceptibility should provide an adequate correction for the variations in natural TL sensitivity, we have reason to suspect that this correction may not be adequate in all cases. In 1974, when we first presented our findings on quartz susceptibility as a function of annealing temperature, we

thought there was a direct relationship implying increasing sensitivity with increasing annealing temperature. Subsequently our work with clays has added to our appreciation of the complexities of the relationship (see p. 11). No one has yet shown that the sensitivity/temperature relationship is the same for all types of radiation, and it is this which we feel must be investigated in order to eliminate any doubt concerning sensitivity assessments made by measuring X-ray induced TL. The work published by Fleming (Archaeometry 15(1973)3-30) is not relevant to this question, since it is concerned with the pre-dose methods of annealing samples at 500° C to change the 320° C peak.

- (2) Most of the factors found by other laboratories which affect TL determined ages have in fact been discovered by Oxford, and are influential to the extent that TL is considered an absolute and not a relative dating technique. In particular, though grain size is undoubtedly important to dating methods using the inclusion method (S.J. Fleming, Archaeometry 12,2(1970)133-146), in tests conducted here at MASCA using the relative dating technique, whole sherds are used. Similarly, variations in alpha efficiency, effects of ground water, supralinearity and anomalous fading (A.G. Wintle, Archaeometry Conference, Philadelphia 1977) are factors affecting the TL-determinations using the fine grain method (D.W. Zimmerman, Archaeometry 13,1(1971)29-52) and do not seem to be of great importance to TL dating as done at MASCA. The general applicability of these three recent methods has not been demonstrated; most of the pioneering work was done on carefully selected sherds. Furthermore, the principal investigators have expressed doubts (M. Aitken to E.K. Ralph at the 1977 Archaeometry Conference). The only factor mentioned which we have found to be important is the assumption of equilibrium in the thorium decay series. In cooperation with the nuclear physics department, we are currently using a solid state (lithium drifted germanium crystal) γ -detector and a multi-channel analyzer to test this equilibrium. The results of these experiments indicate that

the ratio of thorium to uranium is not a constant, but ranges from 0.5 to 4.0. Additionally, using the γ -detector, we are able to test for radon leakage and can calculate the total energy deposited as a result of the internal radioactivity. In preliminary results obtained thus far, it appears that the total energies deposited as calculated from the γ -detector are in good agreement with estimates from α -counting.

- (3) As already mentioned, we do feel that it is important to examine the temperature dependence of the TL-phenomenon. Matrix and firing temperature have been shown to be two of the more important factors affecting TL. TGA and DTA are subject to serious limitations imposed by reabsorption of water and other factors, but may well be effective techniques, when coupled with TL measurements, for determining firing temperatures, as detailed on pages 25-26 of the proposal.
- (4) The method of sample preparation developed by Mr. J.R. Watson (former graduate student assistant of MASCA) was different from that reported by Goken and co-workers (thin-section method). For further clarification on this point, see MASCA Newsletter 12,2 (December 1976).
- (5) Eight articles were published between 1966 and 1976 dealing with TL development and specific problems associated with work at MASCA. These are listed in the Curricula Vitae of the staff, p. 51.

PRESERVATION OF MUD-BRICK AND STONE STRUCTURES

We did not mean to imply that preservation research was unique to MASCA. On the contrary, we are very well aware of work that is being done at other institutions, especially work done in Italy, Iraq, and in our own National Park Service. Dr. Butterbaugh, our volunteer research chemist, is a member of the Association for Preservation Technology and attends meetings concerning preservation problems. Mr. Vincent Pigott, Dr. Butterbaugh's volunteer associate, attended the Second International Symposium on the Conservation of Buildings in Mud Brick at Yazd in March 1976 giving him an opportunity to discuss common problems with experts from all over the world. As a result of our own bibliographic research at MASCA, contact with other researchers in this field, and personal observations of eroding mud and stone structures in many parts of the world, we feel that we do indeed recognize the "serious difficulties" involved.

Dr. Butterbaugh has worked for many years with materials which are used as cement additives and improvers and with other polymers and resins. He is able to draw on the large background knowledge acquired from his former business association with a large chemical company. E-330, for instance, has been thoroughly tested and is used as a cement additive and improver. This is the first significant testing of E-330 as a soil stabilizer. The material has been tested in the Southwest U.S. for three years. Best results have been achieved by applying a water/mud/E-330 plaster over existing walls so the problem here is to get good adhesion rather than deep penetration of the material into the wall. With A-21 the penetration is 2-4 cm. Others have used these same or similar solutions at much higher concentrations and penetration has been poor. We are using very dilute solutions and so we are achieving deeper penetration. If and when failure occurs, whether due to greatly accelerated lab weathering by simulated rain, and freezing and thawing, or by natural erosion due to outdoor exposure, only the top surface grains or particles of soil erode, not the entire depth of treatment. Therefore less damage occurs than would occur from normal weathering of untreated surfaces. To the best of our knowledge no effective method of solidifying mud brick walls has been developed which will withstand hundreds of wet/freeze/thaw cycles. These treatments do.

We measured the samples not by fundamental measurements but by subjecting them to wet/freeze/thaw tests in the lab. We as well as others have made physical measurements for hardness, stiffness, water repellancy, abrasion, etc. but the real test is for durability in the field. This is precisely the purpose of our tests in Iran, Florida, Chaco Canyon and Guatamala. We know that it will be many years before we can expect conclusive results. It is also essential that more than one test be established in various parts of the world. Climatic conditions, modes of construction, types of clay, etc. vary widely between different parts of the world where mud structures are constructed. In the case of stone weathering, conditions vary even more widely. We therefore must make allowance for special problems in different areas. To avoid damage to archaeological structures only very limited surfaces have been treated. In most cases we have constructed our own mud brick walls in the test areas.

One of our experiments in Guatamala which was geared towards the problem of constructing safer structures in an area likely to be damaged by earthquakes was in collaboration with a team from CARE and was only one of many experiments which included experimental constructions of quake proof structures using various materials - from treated adobe, to wood, to ferro cement. It was suggested that the lower courses of houses might be constructed of treated adobe to prevent the serious problem of the adobe buildings collapsing due to the seepage of rain or groundwater.

[c. Oct. 12, 1960]

file
Archaeol. Techn.

Report on ultra-sonic cleaning device.

The laboratory of the National Parks Service, Independence Hall Project, was visited, and the ultra-sonic cleaning device used, by E. Parkinson and R.E. Linington on 12th Oct. 1960. The following results were obtained :-

1. Three sample bronze objects, supplied by Dr. R.S. Young, were tested in the ultra-sonic cleaning device. All were immersed in a weak detergent solution.
 - i. Bronze dagger of Bronze Age date from Cyprus. After 20 minutes of treatment the corrosion was found to be loosened, ^{hence} the metal surface could be exposed by scraping. The general appearance was only slightly improved.
 - ii. Bronze pin. After 10 minutes of treatment the corrosion on the portion treated was much looser than on the untreated portion.
 - iii. Etruscan bronze buckle, only slightly corroded. After 10 minutes of treatment no appreciable effect could be observed.
2. As far as bronze objects are concerned it thus appears that the method could be of use in removing corrosion, however supplementary mechanical cleaning would still be necessary. There does appear to be a considerable increase in the speed of cleaning. It is possible that by use of different cleaning solutions, or by a combination of cleaning methods, the general rate of treatment of bronze objects could be considerably increased.
3. From discussion with the laboratory staff it appears that they have had considerable success in the cleaning of many classes of archaeological objects, in particular well fired pottery and glass. In particular they consider it very useful for bulk cleaning of excavated objects.
4. It is possible that the method would be of use in cases where normal cleaning methods would tend to destroy surface features on the objects concerned, for example on certain types of decorated pottery.
5. It was reported that the method had been used for the cleaning of textiles.
6. Tests on ^{bronze} ~~iron~~ fragments already cleaned electrolytically showed no noticeable improvement.

Ultra-sonic cleaning device - recommendations.

1. In view of the favourable financial aspect the purchase of an ultra-sonic device is recommended.
2. In view of the possible museum uses a medium size instrument, that is with a capacity of 2 gallons, should be considered.
3. Such a device would be mainly of use in increasing the speed of normal cleaning processes. It is unlikely that the extent of cleaning produced will be much increased over normal methods. However it is possible that further development in the use of the instrument could be made with experience of its use.
3. By purchasing a medium size instrument the possibilities of using it in the field would not be adversely affected. Indeed the instrument might prove to be most useful in connection with field work, especially where time is an important factor.

R.E.L.

A.E.P.

Dr. Rainey.

[Nov. 8 / 96]

W. E. technique

THE FISHER DUO-SPECTRANAL:

A RESUME OF ITS USE FROM MAY TO NOVEMBER, 1961

First, solutions of all the common elements which can be detected spectroscopically were made up and analyzed, partly in order to gain familiarity with the instrument and partly to obtain the spectra of these elements for reference purposes. The analyses listed below were obtained using these reference spectra. The chemicals used at that time were those currently available in the laboratory, but since some were of dubious purity (though believed to be reasonably pure) and others were not the best compounds to use for the purpose, new standard solutions are now being made up using chemicals bought especially for this purpose. In addition to the elements already available, solutions of all the less common elements which are obtainable are being made up, so that a reference catalogue of the spectra of all available elements can be compiled. This is important for the interpretation of spectra of samples of unknown composition, for although each element has two or more spectral lines of maximum intensity many elements have many additional secondary lines, and the brightness of all lines depends on the concentration of the element, hence all should be identifiable so that there can be no question as to whether they come from an element present in small quantity or from an uncommon element. The present series of standards is being made accurately, using a multiple of the minimum detectable amount of each element so that the spectra obtained should be of comparable brightness.

The following specimens of unknown composition have been analyzed:

1. Yellow Backing for Armorial Button Jacket, Hasanlu. Copper, iron, calcium and magnesium were identified. Aluminum was identified by chemical methods (it has not been possible so far to obtain the aluminum spectrum).
2. Purple Residue from Backing of Button Jacket, Hasanlu. Identified: Copper, iron, calcium and magnesium; aluminum chemically.

- 3 and 4. Wire from Large Chinese Cloisonné Lions. Two samples. Identified: Copper, zinc and silver, The wire was therefore argentiferous brass.
5. Bead, believed to be silver, Hasanlu. The main constituent was found to be antimony, with calcium, magnesium and strontium.
6. "Silver" Bead, Hasanlu. Identified: Antimony, with copper, calcium, magnesium and possibly strontium.
7. "Silver" Ball, Hasanlu. Identified: Antimony, with copper and a trace of calcium.
8. "Silver" Bead, Hasanlu. Identified: Antimony, with copper, calcium and magnesium.
9. Dark Incrustation on Surface of Bowl from Beth Shemesh, Palestine. Found were a large amount of phosphorus, with iron, calcium and probably magnesium. Aluminum identified chemically. Color probably due to an iron phosphate. The phosphorus may have come from bones.
- 10, 11, 12 and 13. Four Bronze Mace Heads, Hasanlu. Comparison of the spectra one against another showed no significant differences except for the possible presence of zinc in one sample, hence it was concluded that the same alloy or type of alloy was used for all four specimens. Constituents identified were copper and tin, which were predominant, silicon and possible traces of calcium and magnesium.
- 14, 15 and 16. Glazes from three Hasanlu Ceramic Pieces. Spectra have been obtained, but interpretation awaits the possession of more and better reference spectra.

Note: In some cases the minor constituents found in the above analyses would probably have been missed in an ordinary chemical analysis.

A. E. Parkinson

A.E.P.
11/9/61.

*If any points need
elucidation please
ask me. - A.E.P.*

ASCA Projects
(Applied Science Center for Archaeology)

1/15/62
EKR

Nile

Dating Methods

C-14

The C^{14} (written C-14 for convenience) isotope of carbon affords a means of dating because all living things contain an equilibrium amount of it while alive, but no longer take it in when dead. The "living" maximum amount then decreases with time (at a constant rate which is dependent upon the half-life of C-14). This decrease serves as a measure of age.

The C-14 laboratory at the University of Pennsylvania, which is now located in the Physical Sciences Building, rooms BW4 and BW6, has been in existence for 10 years. C-14 dates are now being determined by the carbon dioxide gas method. Two main projects are in progress - 1) the dating of archaeological sites and organic objects for members of the staff of the University Museum and their collaborators, and 2) the dating of samples of known age for the elucidation of methodological problems. The latter is supported by NSF grants.

The tentative schedule of dating for the next year is as follows:

C-14 Lab Schedule -- Tentative
December 14, 1961

<u>Series</u>	<u>Nos.</u>	<u>ToBe Completed</u>
Near East		
Hasanlu (10 completed)	6	Jan. 1, 1962
Ras Shamra	8	Jan. 16
Yarim Tepe (Caspian)	5	Jan. 25
Sites Excav. by Cuyler Young	5	Feb. 3
Matson's samples	7	Feb. 17
India	10	Mar. 7
Pakistan	4	Mar. 15
Known		
Bristlecones	10	April 2
South America		
Bolivia - Ponce	5	April 10
Central America		
Tikal - charcoals	20	May 15
Knowns		
Sequoias	50	August 10
Arctic		
Giddings	30	October 1
Harp	16	October 29
Laughlin, Wisconsin	10	November 16
Mediterranean		
Gordion	8	Jan. 1, 1963
Catalhüyük	6	
Canhasan, Turkey	10	
Sunken Ships	10	

Approximate counting rate = 4 per week (2 counts for each sample using both counters)

Thermoluminescence

This possible dating technique has not yet been developed beyond experimental stages, but may be feasible. It is also based upon radioactive disintegration. The radiations (mostly alpha particles) from traces of uranian^{um} and thorium in clays bombard the other constituents and cause electrons to be excited. These electrons remain excited until the day is fired. When heated, though, the electrons return to their normal positions with the emission of light particles (photons). The baking of a pot or brick is, therefore, the starting time of this excited electron condition and the elapsed time may be determined by reheating a small bit of the object and measuring the light intensity emitted. One ^{must} also to measure the rate of bombardment (alpha intensity), make corrections for different clay materials, and so forth. By determining the last with potsherds of known age, it may be possible to create a time scale for dating.

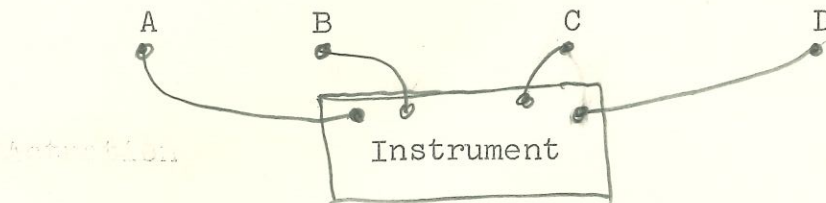
Preliminary experiments with this technique have been performed here, and it is hoped that this work will be pursued in ASCA.

Instruments for Underground Exploration

Resistivity Instrument

This instrument enables one to measure the conductivity of the ground which, under conditions ^{neither} not too wet nor ^{too} dry, will vary with inhomogeneities such as buried stone blocks, cavities, etc. Field exploration with this instrument is slower than with

others because of the necessity of putting 4 equally-spaced rods into the ground for each measurement.



Actuation of the instrument causes an alternating current to flow from A, to B, to C, to D and vice versa. The difference of potential between B and C then affords a measure of soil conductivity. The depth of penetration is roughly equivalent to the spacing of the rods. Three instruments called "Geohms" have been purchased from the Gossen Co. in Germany. *and are in use.*

Proton Magnetometer

This instrument measures the total magnetic intensity of the region under a single probe. The probe consists of a bottle of water surrounded by a coil. The protons in the water precess (after initial alignment by means of the coil) at frequencies which vary with changes in magnetic intensity. The instrument is, therefore, a sensitive detector of "magnetic" objects. Iron is an obvious subject, but buried kilns, deposits of potsherds, etc. exhibit much stronger "magnetizism" than the surrounding earth because of the uniform alignment of their minute dipoles at the time of firing. In some circumstances, soil

disturbances may also be detected because of their differing magnetic susceptibilities. The principle may^{also} be used in reverse in regions of high soil magnetic intensity where structures such as stone walls may^{through?} be located because of a decrease in magnetization.

The instrument is so sensitive that the readings are affected also by the diurnal change in magnetic intensity. A correction for this may be made by taking periodical readings of a stationary reference probe.

One "Elsec" proton magnetometer has been purchased from the Littlemore Scientific Engineering Co., Oxford, England. *and is in use*
Gradiometer

This is a differential proton magnetometer. It measures the difference between the total magnetic intensity recorded by a probe close to the ground and one (both mounted on the same rod) approximately 5 feet above it. It overcomes the need for a reference probe and corrections for diurnal variations. Because it is a differential-type unit rather than one capable of taking absolute measurements, the circuitry is also simplified.

Surveys may be made more quickly than with the standard proton magnetometer because changes in magnetic intensity which are due only to varying underground conditions are indicated. This obviates the necessity of laying out grids and recording all readings for subsequent correction with the reference readings.

One instrument is being constructed by McLaughlin Electronics (Perkiomenville, Pa.) and is scheduled for completion on April 1, 1962.

Seismic Instrument

One standard seismic-type instrument has been purchased from Geophysical Specialties Co., (Hopkins, Minnesota). It, and other similar ones, were designed for use in construction surveys, oil exploration, etc., and are capable of locating changes in ~~soil~~^{earth} layers. The frequency of operation is too low for the detection of most archaeological features. It has the additional disadvantage that a strong sound-wave of large initial amplitude must be sent into the ground. This is accomplished by banging on a metal plate with a heavy sledge hammer or by setting off a charge of dynamite, both of which are crude, cumbersome, and difficult to repeat with the same intensity.

Sonic Instrument

Instruments based on the sonic (or ultrasonic) principle are being developed by McLaughlin Electronics (Perkiomenville, Pa.). The design and construction of one unit of the basic instrument, a portable transistorized assemblage of circuits with a cathode ray indicator has been completed. Experiments with transducers (the units which transform electric pulses into sonic ^{pulses} for transmission into the ground and pick-up upon their return) and with the ground-coupling problem are in process.

Ideally, when completed, this instrument will send a pulse into the ground, one of appropriate frequency and intensity, which when reflected by an archaeological feature within its range, will

be displayed on the screen (with calibrations for depth) of the cathode ray tube indicator. The position of the feature ^{then} may be ~~then~~ determined by location of the region of minimum depth of reflection. With experience and/or refinements, it should be possible to ascertain the nature and approximate size of the buried feature.

The anticipated range of the instrument is approximately 25 feet. Reflections occur when the dimensions of an anomaly are as large or larger than a wavelength. Therefore, for example, frequencies up to 5000 cycles per second are suitable for objects of 5 inches in size or larger. The construction of several transducers, sets of filters, etc., for experimentation at different frequencies is planned.

Drill

This is a mobile ^{drill} with self-contained gasoline motor which can be moved from place to place by 3 people and can penetrate to a depth of 100 ft. In the process of drilling, pulverized cores may be collected for examination. One of these, called

has been purchased from

Information Center

Card files of references to "scientific aids for archaeology" are being compiled. These include reports of analyses (chemical and otherwise) of ancient objects, lists of laboratories where various facilities are available, facilities for and results of dating and other techniques which are pertinent to archaeology, etc. Appropriate books, periodicals and other publications are also being obtained. The purpose of this center is to facilitate

the research work of members of the staff and students -- to assemble information that is often difficult and time-consuming to find --elusive information that is widely scattered or absent in convenient libraries or that is occasionally obtained fortuitously by personal communication.

Chemical Laboratory

Expansion of the facilities and staff of this laboratory is planned. It is hoped that the laboratory will be able to handle all requests for chemical analyses and studies, either here or ^{through?} (by use of) the facilities of other organizations.

Electron Microscope

Collaboration with Mrs. Althea Revere (Vineyard Haven, Martha's Vineyard, Mass.), a specialist in electron microscopy, has been initiated. In her laboratory at present, she is studying the structure of gold to determine whether or not significant changes occur with the passage of time. Her preliminary observations indicate that octahedral crystals do "come out" slowly after the time of original casting and working. This fact may provide a means of differentiation between ancient and modern gold objects.

Metal Detectors (Instruments for Underground Exploration, cont.)

An instrument for the detection of small metal objects - coins, jewelry, etc. at depths of one meter or more would be helpful for the excavation of graves such as the ones in the

Hittite cemetery at Gordion. The development of such an instrument is being studied by Grey MacLaughlin (MacLaughlin Electronics, Perkiomenville, Pa.), and possible collaboration with the U.S. Army Engineer Research Development Laboratories (Fort Belvoir, Va.) is being pursued.

For a start in this direction, a surplus "vacuum cleaner" type mine detector (AN-PRS-3) has been purchased. This instrument has a 9 x 12 in. search head and is capable of detecting a metal coin to a depth of one foot underground.

METAL DETECTOR

Tests made with Detecting Set AN/PRS-3 2/20/62 In Fairmount Park, Phila.

Test lugs of metal were lowered into a 1" dia. hole in the ground -- ground was only slightly frozen at the surface and was wet.

RODS -- $\frac{1}{2}$ " dia. x $2 \frac{5}{8}$ " = $\frac{1}{2}$ cu. in. in volume

Metal	Depth at which sound dropped to background level (in ear phones)	
Brass	14.5 cm.	
	12.0	= 4.7 in.
	12.5	= 4.9
Copper	10.0	= 3.9
	10.5	= 4.1
Steel	22.0	= 8.3
	22.0	= 8.3
Aluminum	10.5	= 4.1
	10.5	= 4.1

SLAB -- 5" x 1" x $\frac{1}{4}$ " = 1.25 cu. in.

Copper 24 cm. = 9.4"

Technique

MEMORANDUM

TO: Dr. Rainey

FROM: ASCA

DATE: January 12, 1965

SUBJECT: Background material for points to be taken up with Drs. Bannister and/or Ferguson during January 1965 visit in Tucson.

Background. The University Museum and later ASCA have entered into a cooperative relationship with the Laboratory of Tree-Ring Research about 6 years ago. During this period the principal contributions of the TRL consisted of helping ASCA locate appropriate wood samples, dating some of the samples, and in one case (Gordion), collecting the wood for ASCA. The contributions of ASCA were both financial (\$1000.00 for the dating, and \$1000.00 for Bannister's visit to the Near East), and in the way of services (recommendation to Iskander, introduction to Gordion, et al).

(1) At the present, our principal interest is to obtain from the TRL precisely dated wood for C-14 analysis. Thus far, we have obtained through our own efforts precisely dated woods (both sequoias and bristlecones) some 3000 years old. Therefore, we are interested in woods older than 1000 B. C. Recent correspondence with Ferguson indicates that the TRL has precisely dated bristlecones to at least 1600 B. C. and possibly 1950 B. C. Also, the likelihood is that within the next few months there will be a breakthrough to approximately 3000 B. C. (Parenthetically, the TRL has in its possession undated wood about 6000 years old.)

(2) In connection with obtaining dated wood samples from the TRL, it would be desirable to learn if these woods could be released by Ferguson (who is the NSF grantee) or if Bannister's permission is necessary.

(3) It may be presumed that a number of other C-14 laboratories (including Libby's) is interested in these very old woods, and therefore, it would be desirable to establish our priority in obtaining them on the basis of our past collaboration and in view of our future projects in the Near East.

MEMORANDUM

TO: ASCA Files

FROM: Froelich Rainey

DATE: January 15, 1970

NOTE: From Perlman, David manuscript
for 1971 Science Yearbook

Can identify water from underground aquifers (not from surface)
by tritium (absence of). No effect from fall-out.

Also refers to fossil water - 20,000 to 30,000 years old in Nubian
sandstones (from Ice Age - slowly moving sheets of water).

FR:gb

4:00
Call 1st

MEMORANDUM

TO: Dr. Rainey

FROM: Gloria

DATE: January 13, 1971

Beth
Ralph
Please!
find
the

Last week a man named Richard Sherman (Ext. 7006) called to say that College Hall has lost its corner stone! College Hall was built 100 years ago this spring and they want to open the corner stone, take out the contents and put new stuff in but they can't find the stone. He has a vague idea where it is within a ten foot area and he wonders if our "magic Machines" as he called them could be put to use to find it. I said you and Beth were both away but when you got back one of you would get in touch with him. It sounds amusing and might give us a little nice publicity - Archaeologists use magnetometer to locate corner stone etc.

NE corner
may be buried - 5-6' below
Fe or Pb

Tell Glen Bernard