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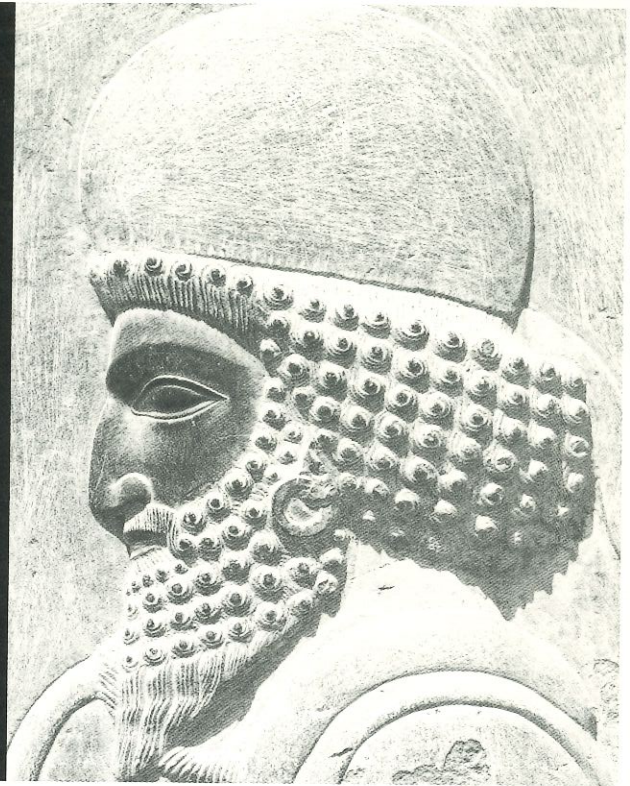
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Science and Archaeology

BY FROELICH RAINEY

In the past few years archaeologists have more and more turned to the discoveries of the natural scientists to help them gain a better understanding of the past. No one has been more active in encouraging the use and development of science for archaeology than Froelich Rainey, director of Philadelphia's University Museum. Here he presents an account of some of his own work in this field.

One of the most attractive aspects of the search for new scientific techniques in archaeology is the constant element of surprise. Recently in *Earth and Planetary Science Letters* 15 (1972) 223-231, an article by Jeffrey Bada was entitled "The Dating of Fossil Bones Using the Racemization of Isoleucine." Most archaeologists have been thinking about new dating techniques in terms of atomic or nuclear phenomena, not in terms of biochemistry. But now the study of amino acids, which has brought about a wholly new understanding of biology and genetics, suddenly suggests the possibility of quite another field in archaeological dating.

Some years ago, while some archaeologists and physicists were trying to devise a more efficient method for probing beneath the surface of the ground in the search for the remains of the ancient Greek city of Sybaris, then thought to lie about six meters deep on the plain of the Crati, a river in Italy, we found that a magnetometer designed for a satellite could be adapted to archaeology and give enough magnetic sensitivity to locate remains at that depth. The United States Defense Department heard of it, requested that we experiment with them at one of the military proving grounds, and, as a result, they utilized the new cesium magnetometer in Viet Nam for the location of buried munitions. For the first time, to my knowledge, archaeology con-

tributed to the military, rather than the other way around.

Such surprising developments in science and archaeology are, of course, similar to what is happening in most fields of research. When at a meeting of the Planning Board for the 21st Century Exhibition the members were debating the world of the future, they were all impressed with the startling impact of new technology, rather than "pure" science, upon daily life. It is not so much the gadgetry affecting man's way of living as it is the technical tools for research that open up new ways of probing into the environment and thus change man's attitudes and ideas about the world. The electron microscope and the radio telescope are the classic examples, but revolutionary chemistry, solid-state physics and a new order of electronics in general cut into the very core of the nineteenth century conceptions about the nature of man and the universe.

The following comments on the application of new scientific techniques in archaeology certainly are not intended as a summary of all the extraordinary applications now being made, but rather as reminiscences of my own involvement over the past 25 years. With the establishment of the Museum Applied Science Center for Archaeology (MASCA) at the University Museum in Philadelphia in 1961, the development of such techniques became my major professional concern.

Most archaeologists first became aware of the possibilities of applying scientific technology to archaeology with the discovery of radiocarbon dating after the Second World War. In my own case the effect was profound and somewhat upsetting. The chemist Aristide de Grosse, who had previously postulated the existence of "cosmic radio-elements," came into the Museum sometime in 1948 to ask for a large piece of Egyptian wood which could be dated with considerable accuracy through traditional methods. He explained, in terms which were then completely unintelligible to me, his isolation of carbon 13 in Baltimore sewer gas—to be used in medical research. Soon afterwards, he and Willard Libby from the University of Chicago joined forces; Libby suggested they search for natural carbon 14 (hereafter C14), a radioactive isotope which might be used in dating organic materials. Later, some archaeologists met with them at the Wenner-Gren Foundation to discuss funds and the search for organic materials of known age. Four of us spent the next several years turning up such materials for experiments in Libby's nuclear laboratories. The upsetting part came when I turned in some wooden objects from a site where I had worked in the Arctic and received a date nearly a thousand years later than expected.

We did not know then that the measured value of the half-life of C14 was incorrect, that humic acid in the soil affected samples, that there would be methods of counting more efficiently than with solid carbon counters and that the ratio of C14 and C12 in the atmosphere and the oceans had not remained constant throughout the ages. All these problems were to occupy scores of C14 laboratories through the next 20 years and still do at the present time. Moreover, the two worlds of science and the humanities have had their problems of communication. In the early days when we were rather desperately trying to find organic materials of known age to test the theory of C14 dating, some of the archaeologists coyly urged that we give the laboratory misdated objects just to see if the gadget really worked! More recently, when it was discovered that the C14 inventory in the air and the oceans had shifted over the past several millennia and it was announced that all radiocarbon dates older than at least 1000 B.C. must be corrected, there were some who interpreted this to mean that C14 was now discredited.

Actually, I suppose, archaeologists expect too much of the "hard" sciences. We have learned that radiocarbon dating is a highly complex business, based to a large extent upon probabilities (with which we are so familiar in archaeological interpretations) and not yet free of unpredictable "bugs." Let us imagine for a moment that an archaeologist a thousand years hence is attempting to date the ruins of a burned house in New England. He finds objects which clearly date the house sometime in the twentieth century. But in collecting charcoal from the ruins he inadvertently takes a sample from antique paneling made in the colonial period. His C14 dates are then two or three hundred years earlier than he would expect. If that particular piece of paneling happened to come from the inner part of a two-hundred-year-old tree, he would have a date four or five hundred years older than expected. In addition, the enrichment of atmospheric C14 from nuclear explosions and the previous depletion due to the increase in "dead" carbon dioxide as the result of burning fossil fuels since about 1850 would also figure in the C14 reading. Perhaps even the amount of C14 in the atmosphere, changed by some magnetic phenomenon, would affect his date. Actually this hypothetical example of the future happens all the time today when we are trying to establish an absolute date for an archaeological deposit. Clearly, one way to avoid a gross error is to run analyses on several samples from the same deposit and to make all the corrections now known to be necessary. If four samples correspond closely and a fifth is far out of line, it is reasonable to assume that the four give you the actual date.

The most recent upsetting discovery about the C14 method is that fluctuations of C14 have taken place in the air and oceans. This was first called to our attention by the inconsistency between Egyptian archaeological dates and C14 dates for Egyptian materials. Libby had assumed in the beginning that this factor had remained constant. Today calculation of these fluctuations can be made with considerable accuracy up to 7,000 years ago because of the detailed analysis of tree rings from the long-lived bristlecone pines. At the Laboratory of Tree-Ring Research in Tucson, Arizona, C. W. Ferguson has established a master chronology, using living trees of an age in excess of 4,000 years and preserved bristlecone pine logs from the forest floor which overlap the living

trees in age. This 7,000-year tree-growth record, marking each separate year through seven millennia, makes it possible to check the actual C14 values throughout that span of time and thus to produce a fairly precise correction factor for any C14 date. Elizabeth Ralph and Henry Michael of MASCA have recently published charts of the necessary corrections, which can be utilized in correcting all published dates within the time range of the bristlecone pines (see *MASCA Newsletter* 9:1[1973]). Most significant are the dates for the Bronze Age and Neolithic period, before 1000 B.C.; in conventional dating they range from one to seven hundred years too late. The date for the Early Bronze Age (Troy I period) at Chios, Greece, for example, should read 2560 B.C. and not 2150 B.C. as it now appears in the literature.

Unfortunately, there is as yet no tree-ring record against which to check C14 fluctuations prior to 5400 B.C. (The range, however, is being extended slowly each year.) The specific causes for these variations are still subject to argument, but it is possible that prior to 6000 B.C., the divergence between true and C14 dates will decrease until they equalize at the end of the Ice Age.

One episode in radiocarbon dating may highlight the effect of the recent correction factors and the difficult communications between archaeologists and scientists. A conference of vulcanologists, geologists and archaeologists met on the Island of Thera (Santorini) in 1969 to correlate the volcanic explosion of that island with the end of the Minoan period. Several radiocarbon dates on organic materials in cores, taken from the sea bottom, presumably dated the ash fall from the explosion. Burned beams from the Late Minoan site, buried under the debris from that last great eruption, had also been dated by the radiocarbon method. The majority of these dates, both from the sea bottom and the Minoan site, pointed to about 1500 B.C. as the time of the eruption. Professor Marinatos and several other archaeologists were satisfied with the date for the Late Minoan period represented by the buried Minoan settlement. Unfortunately a C14 conference in Sweden, only a few weeks prior to the Santorini meeting, accepted the proof of C14 fluctuations in the biosphere and the need for correction factors. This meant that the "acceptable" 1500 B.C. date should be corrected to read about 1700 B.C., a correction which played havoc with all the archaeological theories about the date of the Late Minoan period.

In attempting to explain the reality of the correction factors, I referred to the Egyptian chronology, the astronomically fixed dates in that chronology that had played such an important role in revising our ideas about radiocarbon dating, and the uncertainty of other Egyptian archaeological dates based upon king lists, inscriptions and other archaeological data. Claude Shaeffer, in a very amusing commentary, observed that we seemed to have used the Egyptian chronology to correct radiocarbon dating and then turned about and tried to correct the Egyptian chronology with C14 dating! Actually, of course, it is not the Egyptian material, but the tree-ring records which have made it possible to work out the correction factors. As for the age of the Minoan site, our C14 dates were obtained from charcoal in burned house beams; they could easily be from trees living two hundred years before the destruction. More recently we have run C14 analyses on short-lived organic materials, such as grain, that now give us dates from the transitional Minoan period of Thera between MM III and LM I of about 1600 B.C. after all corrections are made.

Since the discovery of the radiocarbon-dating technique, eight or nine other atomic or nuclear methods of dating have been, or are in the process of being, worked out. Potassium-Argon, Fission-Track, Uranium and Lead Isotopes and Thermoluminescence (abbreviated TL) methods are the best known. TL is applied most specifically to archaeology, while other methods are applied more to geology or earth history. MASCA and the Research Laboratory for Archaeology at Oxford have been perfecting the TL technique during the past ten years. Elizabeth Ralph and Mark Han of MASCA finally worked out a successful system applicable to archaeological dating, which was first described in *Nature* in 1966. But as in the case of C14, refinement and improvement still continue. It is not my intention here to enter into the technical details of all these various new techniques, but since TL is just now beginning to be accepted as a reliable method and applies to pottery, that mainstay of archaeological interpretation, a brief description may be useful.

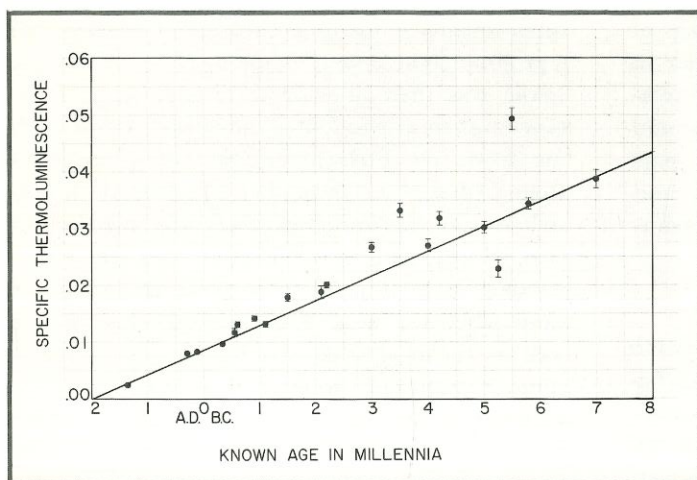
The TL method measures the amount of accumulated radioactive damage that takes place (through internal bombardment by alpha, beta and gamma rays) in clay artifacts after firing. To establish a date for the remains of pottery, bricks, tiles or any other fired clay object, one grinds

fragments of the artifact to a fine powder and then heats this rapidly so that the released photons can be detected by a photomultiplier device. The resulting glow curve indicates the accumulated radioactive damage since the original manufacture of the object. In general, the older the pottery, the greater thermoluminescence or glow that is recorded.

As with all nuclear clocks, however, there are problems. Tests must be made to determine the original radioactive content of the clay; samples must be bombarded with fixed amounts of x-rays to measure susceptibility to radiation damage, and several samples from each object must be

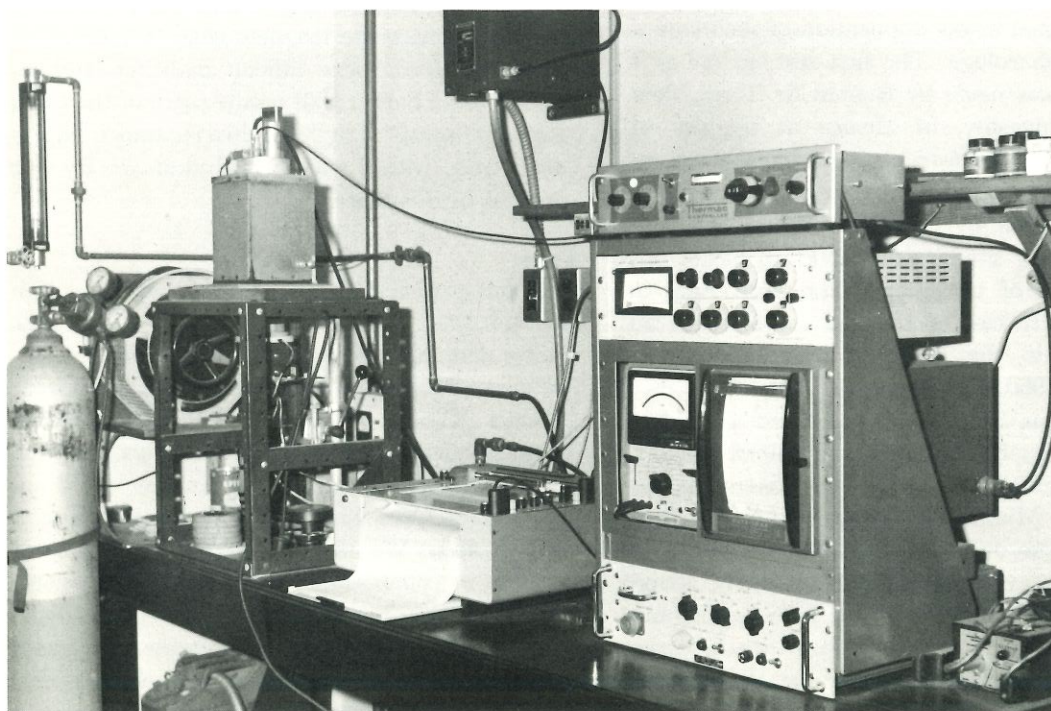
utilized to obtain a reasonably accurate date. Furthermore, thermoluminescence gives a date for only the last firing (above 400°C); if the pottery has been reheated for some reason, the TL date will be too late. Exposure of the pottery to x-rays before measurement of its natural TL will render the technique useless. Despite these difficulties, we can at present use this method to fix, with some accuracy, cultures or events back to the time of the development of ceramics.

As indicated on the accompanying graph, correlation between TL dates and known dates are good, and TL dating may eventually approach the accuracy of C14 dating. It will be apparent



Graph correlating known dates and specific dates obtained by thermoluminescence. The sloping line represents exact correspondence between the two.

Glow curve apparatus to make thermoluminescent tests.



that TL eliminates one great source of error, that is, the inevitable difficulty of being sure that the organic material dated is actually the same age as the archaeological culture or deposit for which a date is sought. Moreover, the system is not plagued by the shift in atmospheric C14 and may thus help to refine the C14 system.

In effect, all these atomic and nuclear methods of dating will potentially cover the entire period of man's life on earth as well as the age of the earth itself. Increasingly, one system checks another so that confidence and certainty increase. All of us in archaeology are now aware of the revolutionary effect upon the whole chronology of human history. One need only mention the correction in our ideas about the end of the Ice Age, the origins of agriculture, the beginnings of ceramic-making (now apparently much older in the Far East than in the Near East) and the relative ages of cultural development in the new and old worlds. Experience over the past 20 years argues in favor of much greater accuracy and more refined methods to come in the next generation.

Electrical instruments for underground search were first brought to my attention in Alaska before the Second World War, where Professor Joesting was experimenting with resistance apparatus in gold prospecting. Just after the war, Paul Fejos of the Wenner-Gren Foundation became interested in the application of such equipment to archaeology. The first test, so far as I remember, was made by Helmut de Terra, then at Yale University, in Mexico at the site of Tepectepan. Such instruments did not catch on with American archaeologists, and I next ran into their application by Professor Case, at Oxford, who was using similar equipment to locate pits and trenches of the Bronze and Iron Ages in Britain. His success encouraged me to make an experiment in the Olmec country of eastern Mexico in 1960.

The famous Precolumbian archaeologist Matthew Sterling, his son and I obtained a commercial electrical resistance instrument manufactured in Minnesota and spent two or three weeks at Cerro de las Mesas, where Sterling had excavated many years earlier. Fortunately, young Matthew was a hi-fi buff and knew something about electronics. Our first "strike" was a large, carved stone stele buried under the alluvial soils of the plain, and, of course, we were elated with

this first success. Unfortunately, after it was fully uncovered Mat suddenly realized he had excavated the same monument and published it 14 years before. We did, however, detect not only the stairway buried under the surface of one of the many earth mounds at the site, but other "anomalies" which convinced us that the instrument had promise for that kind of archaeological search.

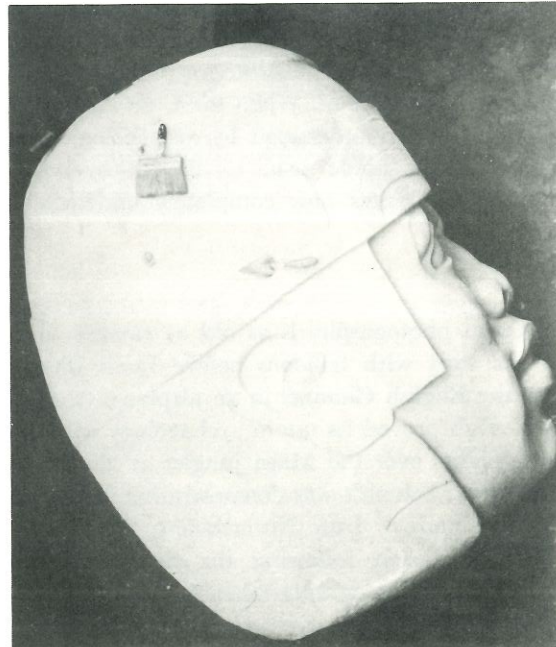
Meanwhile E. T. Hall and M. J. Aitken, at Oxford, had developed the proton magnetometer specifically for archaeology and were demonstrating its success at sites in England. In 1961, the architect Aubrey Trik, the physicist Richard Linnington and I joined the engineer Carlo Lerici and his crew at Tarquinia with a very small resistance instrument made in Germany and a proton magnetometer made by Hall and Aitken. Lerici was then utilizing an Italian-made resistance instrument to locate the buried ramps leading down into Etruscan tombs (cut in the limestone bedrock at Tarquinia) which made it possible to spot the tomb chambers. He had also developed the periscope for examining the tombs without excavation. The surprise for all of us came when we found that the tomb chambers as well as the ramps showed up on our magnetic contour maps. We were soon locating up to six Etruscan tombs each day, and for me that kind of routine survey became boring. But, at the Etruscan acropolis of Tarquinia, Franco Brancaleoni and I learned that we could spot buried stone walls with the magnetometer. We began to cast about for a more difficult challenge. He had discovered a buried wall on the plain of the Crati River in south Italy with his resistance equipment and, with Lerici, urged that we try our new apparatus there.

That search, beginning in 1961, was to result in eight years of trial and error, failures and false starts, then final success in the discovery and mapping of the buried remains of Archaic Greek Sybaris. The Archaic level lay from 4.5 to 6.5 meters beneath the present surface, and we soon learned that the proton magnetometer could not detect structures which were more than 2 to 3 meters deep. We then experimented with sonic devices in collaboration with Texas Instruments and Petty Geophysical Company but did not succeed in designing a suitable portable instrument employing sonic frequencies. We turned next to Varian Associates in Palo Alto to develop a



Cesium magnetometer with precision readout in use at San Lorenzo, Mexico.

more sensitive instrument. Shelly Breiner and Beth Ralph, working in the field, and design engineers at Varian with their capable technician Dean Smith produced the cesium magnetometer which finally solved our problem. Limestone walls with concentrations of roof tiles lying up to six meters deep could be located with this much more sensitive instrument. Moreover, magnetic contour mapping became so rapid that we could cover up to five hectares a day. Although individual buildings could, at times, be recognized in the Sybaris ruins (six kilometers in circumference), we learned from test excavations that destruction of the city in the sixth century B.C. had left little of the structures so that we could not map streets or a city plan. That was to come later at Elis in Greece where Beth Ralph with the cesium magnetometer succeeded in that kind of detailed underground mapping. A circle was closed for me in experiments with magnetometers when I returned with the archaeologist Michael Coe to the Olmec Country in Mexico in 1968 to search for buried Olmec monuments at San Lorenzo. There could be no more dramatic example of the magnetometer's effectiveness in archaeology. Extraordinary stone carvings, some weighing several tons and transported for about 70 kilometers, turned out to be magnetic. The alluvial soil in which they are buried is magnetically "quiet," and hence spotting them with the cesium magnetometer is the straightforward business of



Olmec head found with cesium magnetometer at San Lorenzo, Mexico.

charting their location on a magnetic contour map. Seventeen monuments were discovered where they were not expected, that is, not on the ridges where Coe had discovered many fragments. Moreover, one colossal head, found five meters beneath the surface, was in mint condition.

This false-color composite photograph, made from multispectral imagery, was taken by NASA's Earth Resources Technology Satellite (ERTS-1), on August 22, 1972, orbit 134, from an altitude approximately 900 km. over southern Greece. The area of 32,000 square kilometers encompassed by this image extends from the Gulf of Corinth in the northwest to the Gulf of Laconia, on the southeast coast of the Peloponnesos. Athens, the capital of Greece, with its population of 627,000 can be seen to the northeast. The great seaport of Piraeus lies southwest of Athens on the Saronic Gulf. Subtle shades of blue in the seas surrounding Greece represent varying water depths. West-southwest of Athens the Corinth Canal can be seen connecting the Saronic Gulf and the Gulf of Corinth. Greece is so mountainous and its soil has been so eroded that only about one quarter of the country is arable, a condition shown by the lack of red which, on such composites, indicates the green of vegetation. In addition, the hot, dry Greek summers are reflected in the sere aspect of the image. On the Peloponnesos vineyards along the southern shore of the Gulf of Corinth are visible. Forested areas can be perceived in only a few restricted areas at higher elevations. The paucity of surface reservoirs and streams is also striking.

Magnetometers have now been used at scores of sites all over the world, towed along the sea bottom and flown low over the sea to locate wrecks. They have been of great help in saving archaeological sites from destruction, but treasure hunters also use them to discover and loot rich concentrations of remains, such as Spanish wrecks off the coast of Florida. In volcanic areas and other rocky sites where there is either too much or too little magnetism they are not useful, but on alluvial soils where there are deeply buried remains they are indispensable for any large-scale systematic excavations. When their use and operation are better understood by archaeologists in general, they should lead to the discovery of archaeological sites now completely undetected.

Aerial photography is as old as cameras and got its start with balloons before Louis Blériot flew the English Channel in an airplane. Charles Lindbergh proved its use in archaeology with his early flights over the Maya jungles at about the time Erich Schmidt was demonstrating its use on the grasslands of Iran. Nevertheless, the technological explosion following the Second World War and the photographs taken by the spy planes of the 1960's have given archaeological search from the air a new dimension. Moreover, high-resolution photography from satellites, such as the Gemini series, has led to a new burst of interest in remote sensing which now culminates in the Earth Resources Technology Satellite recently launched by the United States Department of the Interior and NASA. My own introduction to these new aerial sensing devices came through Ambassador Frederich Rheinhardt, in Rome, who had taken a personal interest in the long search for Sybaris. A United States Air Force team

making an aerial study of volcanic areas in Italy and Libya also arranged, through the Embassy, to experiment with a multiband camera and an infrared sensing device over the plain of the Crati River where we expected the ruins of Sybaris to be. There were no positive results from that attempt, presumably because the remains lay at such depth and under the water table, but a high school student in Washington, D.C. read of the experiment and mentioned it to his father, who happened to be William Pecora, Director of the United States Geological Survey and the man responsible for the planned Earth Resources Technology Satellite. When he called to suggest I come to Washington to discuss the possibility of archaeological surveys from a satellite, I could hardly take it seriously. But two hours with remote sensing experts from the Department of the Interior and NASA were sufficient to convince me. The satellite is now circling the earth every 103 minutes, and Bruce Bevan of MASCA has proposed various tests, for example, the detection of ancient water courses, which could guide normal aerial photography as to the optimum time for archaeological survey in any given area. Certain growth conditions, times of day, seasons or general moisture content permit an ancient water course to be "seen" more clearly. The same conditions would determine the optimum time for archaeological photography in that area.

A recent report by P. S. Klass explains that early returns from the earth resources spacecraft are better than predicted. So that archaeologists may get an idea of the future possibilities in this field, here are some of the reported findings. Images transmitted from the spacecraft now make it possible to spot: a road only ten meters wide on the band five (red) scanner image; ponds only 92 meters in diameter, all from a height of nearly 965 kilometers; the types of



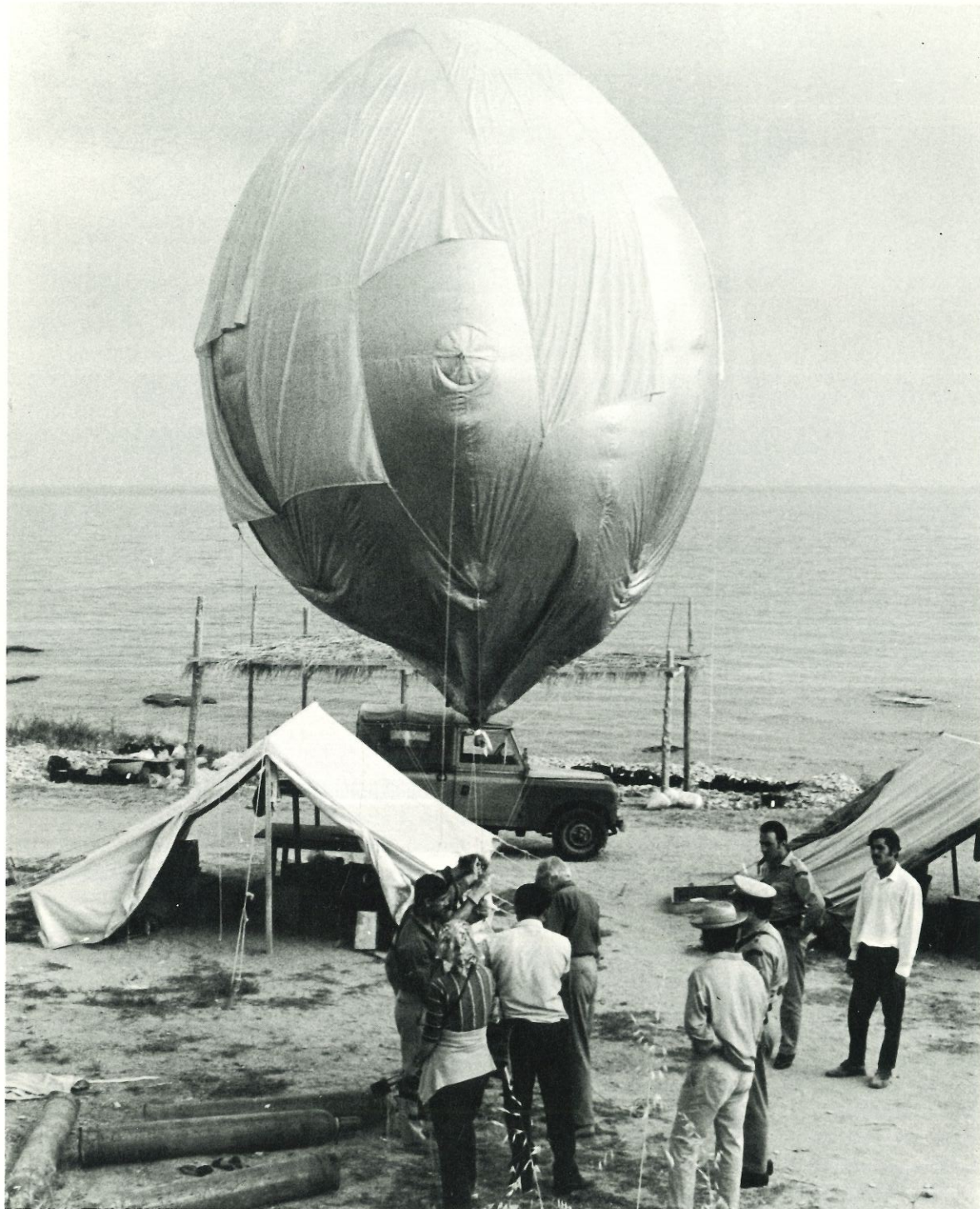
agricultural crops (barley, wheat, sugar beets, etc.); separate fields of only eight hectares; a probable invasion of the Red Tide (plankton which affect shellfish); ice conditions all over the Arctic; the total settlement pattern of Rhode Island as well as clear and turbid waters in oceans, rivers and lakes. With images of such resolution now being transmitted from outer space, surely we should eventually be able to "see" ancient settlement patterns (such as the limit of Roman cultivation in Britain), earthworks, ancient roads and, perhaps, long-abandoned canal and irrigation systems.

The advantage of combining aerial surveys with instrument surveys on the ground was demonstrated recently for us at a Roman site near Kingscote, England. John Hampton of the Royal Commission on Historical Monuments and I had organized an experiment with various types of aerial films at several well-known archaeological sites where excavations and earlier aerial photographs gave us a detailed knowledge of the correlation between images and excavated remains. This project was part of a long-range plan to test new sensing techniques on well-documented sites. At Kingscote a technique enhancing contrasts on aerial photographs accentuated a very faint linear feature, which was possibly an indication of a Roman road leading to the site. To test this we did an instrument survey on the ground with a cesium sensor and a new audio readout. One very foggy day two operators (who were, incidentally, musicians) picked up a peculiar series of pulses or beats on the audio equipment in the open field outside the area of concentrated Roman ruins. They found the same tonal pattern in a series of parallel sweeps across the field and marked out (with bamboo canes) a long, linear anomaly, which might be the road. But then, with a worried expression, Hampton pointed out that it did not correspond exactly with the dim feature on his aerial photos. We groped about in the fog trying to fix base points and sight lines. The fog was so thick that the operators fell back on the curious series of tonal pulses in order to find their way back to our base points. When the fog lifted, Hampton realized that he also had been lost. The aerial anomaly actually did corre-

late with the line of curious pulses worked out with the magnetometer. Subsequent excavation showed that our anomaly was the Roman road with ditches on each side. M. J. Aitken had joined us that day, and both of us were satisfied that one did not have to be a musician to detect the tonal pattern.

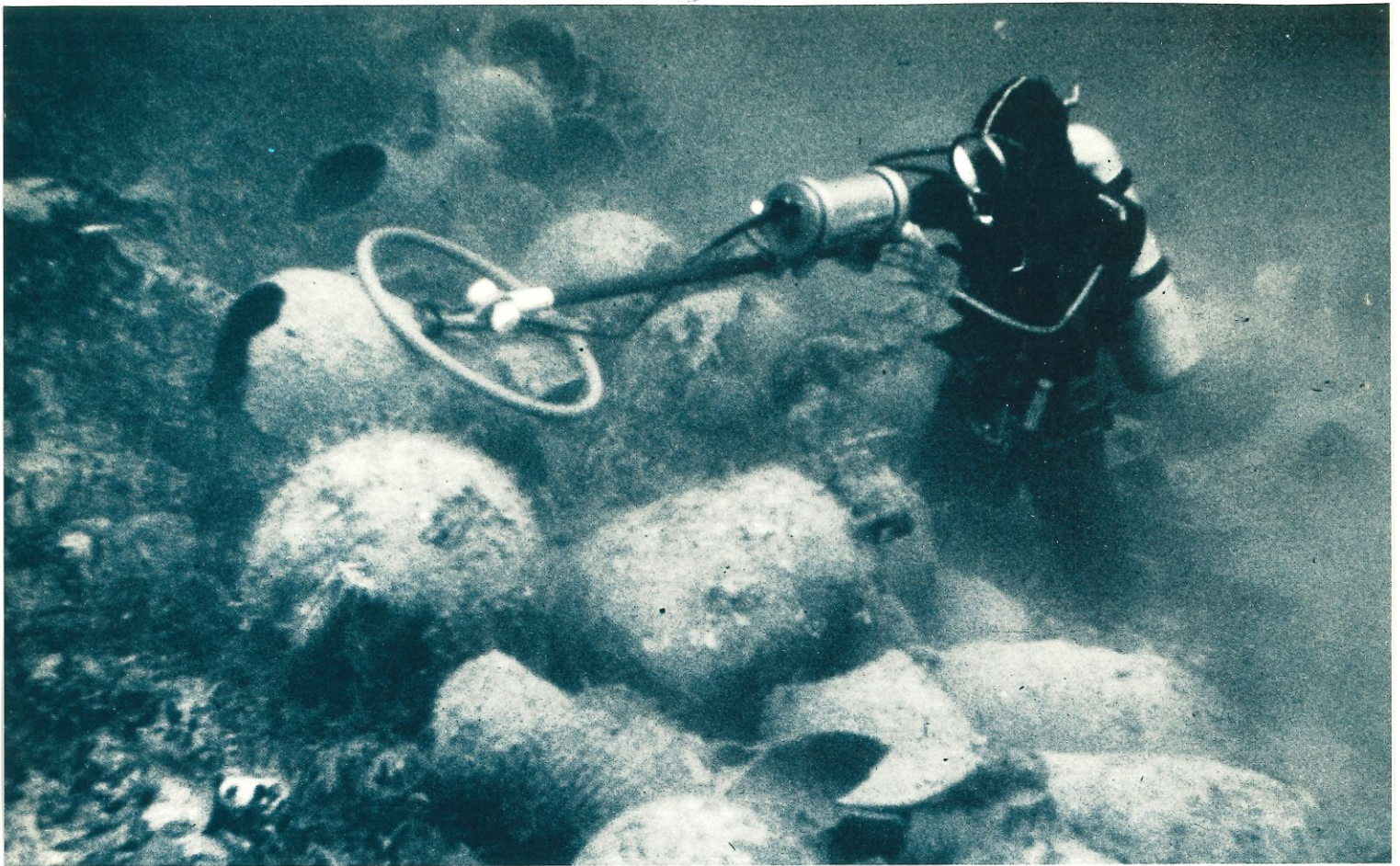
Aerial photography returns to its beginning with balloons these days as the architect Julian Whittlesey continues to demonstrate their value in the recording and mapping of archaeological sites. A hot-air balloon large enough to carry two persons and cameras, hydrogen balloons that carry radio-operated cameras and airfoils, something like wing-shaped kites, that carry ground-operated cameras are all part of Whittlesey's equipment. The balloons are normally tethered over a known archaeological site, but they also can be towed by a land rover or a boat in search of sites. For experiments with different films, such as infrared, the balloons are naturally much less expensive than aircraft. They have also been used to test cameras for aircraft. Photographs taken at 50 to 500 meters over sites, like Sarepta in Lebanon, serve as a perfect ground plan of excavated structures.

Fenimore Johnston, one of the Board of Managers of the University Museum, first called my attention to underwater archaeology in 1948. That was well before scuba equipment and Jacques Cousteau had turned weekend crowds of divers onto wrecks in many oceans, lakes and rivers. Johnston was then building underwater cameras for the Navy, following the introduction of frog men and leech explosives, primarily by the Italians during the Second World War. He came into the office one day with a Naval officer to propose that we begin undersea research in the Mediterranean. However, it was clear at once that we could do it then with only professional divers. The Navy was not prepared to finance the experiment, and the daily cost of a professional diver was far beyond the research budget of the Museum. The Navy officer laughingly suggested that the only feasible economic plan for us was to train Ph.D.'s to dive. None of us guessed at that time that George Bass would do precisely that many years later.



Rodney Young, head of our Mediterranean section, was just as interested as I in the possibilities of the new field, and by the late 1950's we had found Peter Throckmorton who launched our first attempt off the coast of Turkey. As a graduate student in Rodney's department of Classical Archaeology, George Bass learned to

use scuba equipment in Philadelphia's YMCA pool, got his baptism in actual undersea archaeology with Throckmorton and then began his systematic development of expert undersea excavation which was to turn the work into an acceptable academic profession. Between 1960 and 1970 Bass devised a grid system for map-



Metal detector in use over Late Roman shipwreck at Yassi Ada off the coast of Turkey. The wreck was found at a depth of 50 meters.

ping wrecks, using an airlift for excavation, balloons for lifting heavy materials, a tow-line for underwater exploration, a "telephone booth" (a plastic dome with an air bubble, anchored on the bottom to give the divers rest and security in a pinch), underwater television, stereoscopic cameras for mapping, the two-man submarine the *Asherah* and side-scanning sonar. The culmination of this period of technical development came in the late 1960's when the crew managed to locate a deep wreck off the Turkish coast with the new side-scanning sonar and then, for examination, to descend to it in the *Asherah* reaching the wreck precisely on target—no mean achievement in the open sea.

Unfortunately, all these techniques created for the professionals can also be used by amateurs. Today, one of our most critical problems is the systematic looting and destruction of ancient wrecks all over the world. Some countries manage to protect their unique undersea deposits of priceless historic materials, others do not, and probably in the long run, most can be saved only through great expansion of systematic excavation by trained archaeologists.

The Applied Science Center for Archaeology at the University Museum has concentrated upon dating and exploration techniques, while the other similar center at Oxford has concentrated on exploration and TL dating as well as some of the new techniques for analysis and identification of material. Many other centers in the United States and abroad are developing and using the new analytical techniques.

There is now a whole battery of new methods for measuring very small quantities of a great many elements. When the concentrations are less than 0.01 percent, they are then referred to as "trace" elements. The patterns of concentration of such elements can be utilized as a "fingerprint." One of the most dramatic uses of such fingerprinting in archaeology is to determine the source of the raw material for certain artifacts (for example, the various sources of obsidian used for tools in the Mediterranean) and thus to learn something about trade relations and communications in the prehistoric period. Already this kind of study has shown that seaborne and overland communications in the Stone Age were much more extensive than most of us had

imagined. This rapidly expanding study of trace elements in archaeological materials will probably lead away from the conventional reliance upon stylistic types (subjective at best) for the reconstruction of cultural connections to more objective conclusions about cultural diffusion in general.

A new order of chemistry, also developing over the past generation, is just beginning to have impact upon the conservation of materials both in the field and in the laboratory. My own interest in this came about as a matter of necessity when Rodney Young discovered the famous tomb in the great tumulus at Gordion and, somewhat later, when George Bass began to recover parts of ancient wrecks off the coast of Turkey. In both cases ancient water-soaked wood had to be treated in the field to preserve it. We were then alerted to the need for emergency methods in the field and also to the new methods which could be applied. The extraordinary job of preserving the *Vasa* in Sweden is now well known, but I have the impression that the problem there generated many current experiments and that improved methods are in the making. MASCA also has been involved in experiments with the preservation of mud brick in the field, particularly in Iraq and Iran, where the problem of conserving vast blocks of excavated mud-brick buildings is of particular concern. Several years ago, the archaeologists Teresa Carter and David Crownover tried to pump an inexpensive chemical into the standing walls at Tel el Rimah near Mosul. In the laboratory the chemicals were effective, but when applied in the field, penetration was so shallow that the surface flaked away. At the present moment the chemist Darrel Butterbaugh is experimenting at MASCA with new polymers with promising results, but the real test will come with large-scale experiments in the field.

Judging from the past 20 years, and even from the past two or three years, there are many unforeseeable techniques just over the horizon. I am reminded of the planning board for the 21st Century Exhibition and two of its most creative members. One predicted with assurance that within six or seven years (that was in 1961) all vehicles on our highways would be powered by electricity. Another was quite certain that biochemical knowledge of the cell and the gene would mean the end of aging in human beings within the next decade. On the other hand, another member reminded us that in 1937 a

similar group had failed to predict atomic energy, antibiotics and jet propulsion. In archaeology I am also reminded of my early years in graduate school when those who claimed men and mammoth as contemporaries in America were considered by the more conservative to be crackpots. Certainly technology and its rate of growth should convince all of us to keep an open mind.

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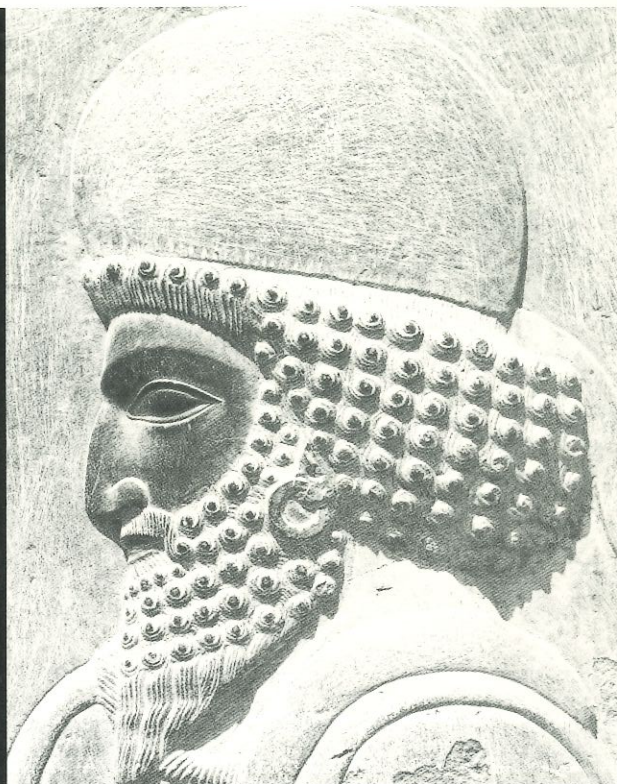
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Science and Archaeology

BY FROELICH RAINEY

In the past few years archaeologists have more and more turned to the discoveries of the natural scientists to help them gain a better understanding of the past. No one has been more active in encouraging the use and development of science for archaeology than Froelich Rainey, director of Philadelphia's University Museum. Here he presents an account of some of his own work in this field.

One of the most attractive aspects of the search for new scientific techniques in archaeology is the constant element of surprise. Recently in *Earth and Planetary Science Letters* 15 (1972) 223-231, an article by Jeffrey Bada was entitled "The Dating of Fossil Bones Using the Racemization of Isoleucine." Most archaeologists have been thinking about new dating techniques in terms of atomic or nuclear phenomena, not in terms of biochemistry. But now the study of amino acids, which has brought about a wholly new understanding of biology and genetics, suddenly suggests the possibility of quite another field in archaeological dating.

Some years ago, while some archaeologists and physicists were trying to devise a more efficient method for probing beneath the surface of the ground in the search for the remains of the ancient Greek city of Sybaris, then thought to lie about six meters deep on the plain of the Crati, a river in Italy, we found that a magnetometer designed for a satellite could be adapted to archaeology and give enough magnetic sensitivity to locate remains at that depth. The United States Defense Department heard of it, requested that we experiment with them at one of the military proving grounds, and, as a result, they utilized the new cesium magnetometer in Viet Nam for the location of buried munitions. For the first time, to my knowledge, archaeology con-

tributed to the military, rather than the other way around.

Such surprising developments in science and archaeology are, of course, similar to what is happening in most fields of research. When at a meeting of the Planning Board for the 21st Century Exhibition the members were debating the world of the future, they were all impressed with the startling impact of new technology, rather than "pure" science, upon daily life. It is not so much the gadgetry affecting man's way of living as it is the technical tools for research that open up new ways of probing into the environment and thus change man's attitudes and ideas about the world. The electron microscope and the radio telescope are the classic examples, but revolutionary chemistry, solid-state physics and a new order of electronics in general cut into the very core of the nineteenth century conceptions about the nature of man and the universe.

The following comments on the application of new scientific techniques in archaeology certainly are not intended as a summary of all the extraordinary applications now being made, but rather as reminiscences of my own involvement over the past 25 years. With the establishment of the Museum Applied Science Center for Archaeology (MASCA) at the University Museum in Philadelphia in 1961, the development of such techniques became my major professional concern.

Most archaeologists first became aware of the possibilities of applying scientific technology to archaeology with the discovery of radiocarbon dating after the Second World War. In my own case the effect was profound and somewhat upsetting. The chemist Aristide de Grosse, who had previously postulated the existence of "cosmic radio-elements," came into the Museum sometime in 1948 to ask for a large piece of Egyptian wood which could be dated with considerable accuracy through traditional methods. He explained, in terms which were then completely unintelligible to me, his isolation of carbon 13 in Baltimore sewer gas—to be used in medical research. Soon afterwards, he and Willard Libby from the University of Chicago joined forces; Libby suggested they search for natural carbon 14 (hereafter C14), a radioactive isotope which might be used in dating organic materials. Later, some archaeologists met with them at the Wenner-Gren Foundation to discuss funds and the search for organic materials of known age. Four of us spent the next several years turning up such materials for experiments in Libby's nuclear laboratories. The upsetting part came when I turned in some wooden objects from a site where I had worked in the Arctic and received a date nearly a thousand years later than expected.

We did not know then that the measured value of the half-life of C14 was incorrect, that humic acid in the soil affected samples, that there would be methods of counting more efficiently than with solid carbon counters and that the ratio of C14 and C12 in the atmosphere and the oceans had not remained constant throughout the ages. All these problems were to occupy scores of C14 laboratories through the next 20 years and still do at the present time. Moreover, the two worlds of science and the humanities have had their problems of communication. In the early days when we were rather desperately trying to find organic materials of known age to test the theory of C14 dating, some of the archaeologists coyly urged that we give the laboratory misdated objects just to see if the gadget really worked! More recently, when it was discovered that the C14 inventory in the air and the oceans had shifted over the past several millennia and it was announced that all radiocarbon dates older than at least 1000 B.C. must be corrected, there were some who interpreted this to mean that C14 was now discredited.

Actually, I suppose, archaeologists expect too much of the "hard" sciences. We have learned that radiocarbon dating is a highly complex business, based to a large extent upon probabilities (with which we are so familiar in archaeological interpretations) and not yet free of unpredictable "bugs." Let us imagine for a moment that an archaeologist a thousand years hence is attempting to date the ruins of a burned house in New England. He finds objects which clearly date the house sometime in the twentieth century. But in collecting charcoal from the ruins he inadvertently takes a sample from antique paneling made in the colonial period. His C14 dates are then two or three hundred years earlier than he would expect. If that particular piece of paneling happened to come from the inner part of a two-hundred-year-old tree, he would have a date four or five hundred years older than expected. In addition, the enrichment of atmospheric C14 from nuclear explosions and the previous depletion due to the increase in "dead" carbon dioxide as the result of burning fossil fuels since about 1850 would also figure in the C14 reading. Perhaps even the amount of C14 in the atmosphere, changed by some magnetic phenomenon, would affect his date. Actually this hypothetical example of the future happens all the time today when we are trying to establish an absolute date for an archaeological deposit. Clearly, one way to avoid a gross error is to run analyses on several samples from the same deposit and to make all the corrections now known to be necessary. If four samples correspond closely and a fifth is far out of line, it is reasonable to assume that the four give you the actual date.

The most recent upsetting discovery about the C14 method is that fluctuations of C14 have taken place in the air and oceans. This was first called to our attention by the inconsistency between Egyptian archaeological dates and C14 dates for Egyptian materials. Libby had assumed in the beginning that this factor had remained constant. Today calculation of these fluctuations can be made with considerable accuracy up to 7,000 years ago because of the detailed analysis of tree rings from the long-lived bristlecone pines. At the Laboratory of Tree-Ring Research in Tucson, Arizona, C. W. Ferguson has established a master chronology, using living trees of an age in excess of 4,000 years and preserved bristlecone pine logs from the forest floor which overlap the living

trees in age. This 7,000-year tree-growth record, marking each separate year through seven millennia, makes it possible to check the actual C14 values throughout that span of time and thus to produce a fairly precise correction factor for any C14 date. Elizabeth Ralph and Henry Michael of MASCA have recently published charts of the necessary corrections, which can be utilized in correcting all published dates within the time range of the bristlecone pines (see *MASCA Newsletter* 9:1[1973]). Most significant are the dates for the Bronze Age and Neolithic period, before 1000 B.C.; in conventional dating they range from one to seven hundred years too late. The date for the Early Bronze Age (Troy I period) at Chios, Greece, for example, should read 2560 B.C. and not 2150 B.C. as it now appears in the literature.

Unfortunately, there is as yet no tree-ring record against which to check C14 fluctuations prior to 5400 B.C. (The range, however, is being extended slowly each year.) The specific causes for these variations are still subject to argument, but it is possible that prior to 6000 B.C., the divergence between true and C14 dates will decrease until they equalize at the end of the Ice Age.

One episode in radiocarbon dating may highlight the effect of the recent correction factors and the difficult communications between archaeologists and scientists. A conference of vulcanologists, geologists and archaeologists met on the Island of Thera (Santorini) in 1969 to correlate the volcanic explosion of that island with the end of the Minoan period. Several radiocarbon dates on organic materials in cores, taken from the sea bottom, presumably dated the ash fall from the explosion. Burned beams from the Late Minoan site, buried under the debris from that last great eruption, had also been dated by the radiocarbon method. The majority of these dates, both from the sea bottom and the Minoan site, pointed to about 1500 B.C. as the time of the eruption. Professor Marinatos and several other archaeologists were satisfied with the date for the Late Minoan period represented by the buried Minoan settlement. Unfortunately a C14 conference in Sweden, only a few weeks prior to the Santorini meeting, accepted the proof of C14 fluctuations in the biosphere and the need for correction factors. This meant that the "acceptable" 1500 B.C. date should be corrected to read about 1700 B.C., a correction which played havoc with all the archaeological theories about the date of the Late Minoan period.

In attempting to explain the reality of the correction factors, I referred to the Egyptian chronology, the astronomically fixed dates in that chronology that had played such an important role in revising our ideas about radiocarbon dating, and the uncertainty of other Egyptian archaeological dates based upon king lists, inscriptions and other archaeological data. Claude Shaeffer, in a very amusing commentary, observed that we seemed to have used the Egyptian chronology to correct radiocarbon dating and then turned about and tried to correct the Egyptian chronology with C14 dating! Actually, of course, it is not the Egyptian material, but the tree-ring records which have made it possible to work out the correction factors. As for the age of the Minoan site, our C14 dates were obtained from charcoal in burned house beams; they could easily be from trees living two hundred years before the destruction. More recently we have run C14 analyses on short-lived organic materials, such as grain, that now give us dates from the transitional Minoan period of Thera between MM III and LM I of about 1600 B.C. after all corrections are made.

Since the discovery of the radiocarbon-dating technique, eight or nine other atomic or nuclear methods of dating have been, or are in the process of being, worked out. Potassium-Argon, Fission-Track, Uranium and Lead Isotopes and Thermoluminescence (abbreviated TL) methods are the best known. TL is applied most specifically to archaeology, while other methods are applied more to geology or earth history. MASCA and the Research Laboratory for Archaeology at Oxford have been perfecting the TL technique during the past ten years. Elizabeth Ralph and Mark Han of MASCA finally worked out a successful system applicable to archaeological dating, which was first described in *Nature* in 1966. But as in the case of C14, refinement and improvement still continue. It is not my intention here to enter into the technical details of all these various new techniques, but since TL is just now beginning to be accepted as a reliable method and applies to pottery, that mainstay of archaeological interpretation, a brief description may be useful.

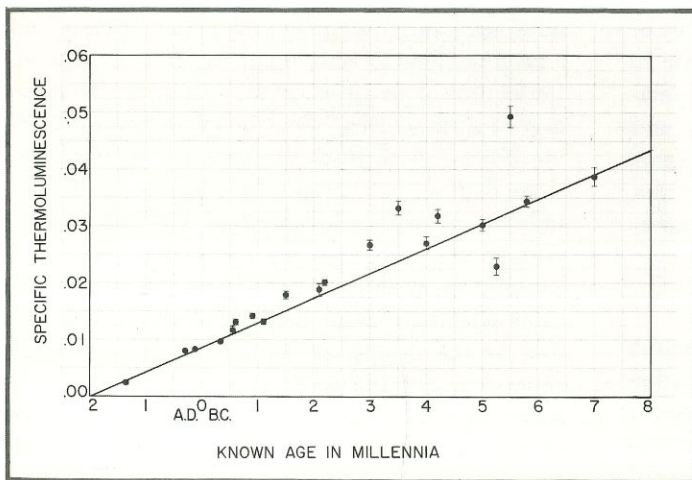
The TL method measures the amount of accumulated radioactive damage that takes place (through internal bombardment by alpha, beta and gamma rays) in clay artifacts after firing. To establish a date for the remains of pottery, bricks, tiles or any other fired clay object, one grinds

fragments of the artifact to a fine powder and then heats this rapidly so that the released photons can be detected by a photomultiplier device. The resulting glow curve indicates the accumulated radioactive damage since the original manufacture of the object. In general, the older the pottery, the greater thermoluminescence or glow that is recorded.

As with all nuclear clocks, however, there are problems. Tests must be made to determine the original radioactive content of the clay; samples must be bombarded with fixed amounts of x-rays to measure susceptibility to radiation damage, and several samples from each object must be

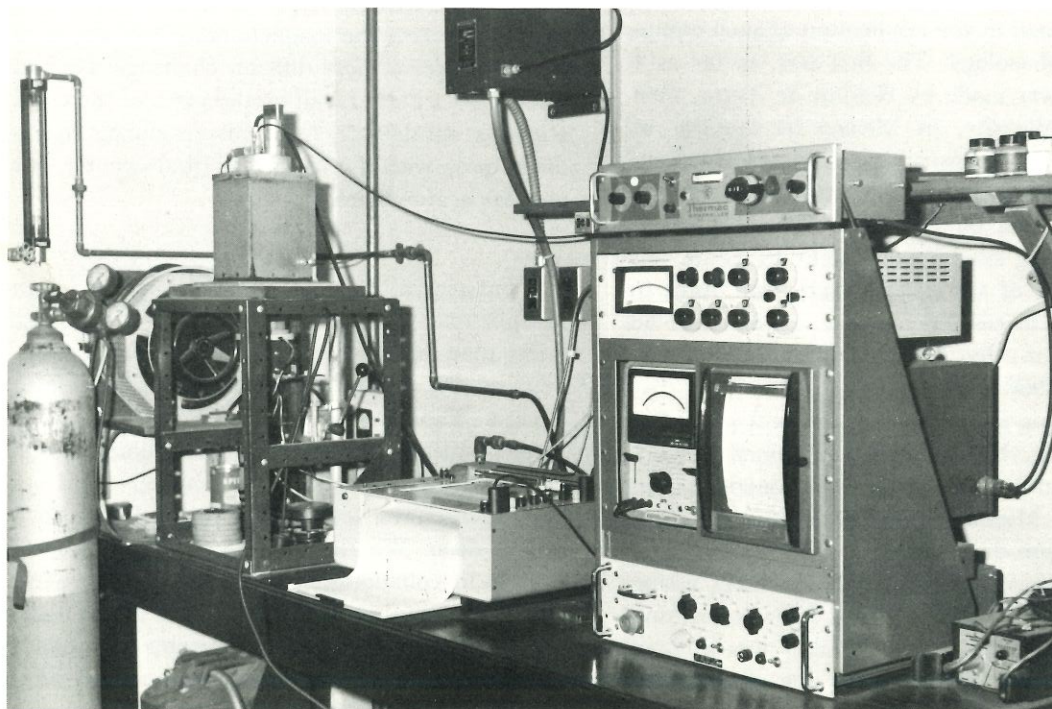
utilized to obtain a reasonably accurate date. Furthermore, thermoluminescence gives a date for only the last firing (above 400°C); if the pottery has been reheated for some reason, the TL date will be too late. Exposure of the pottery to x-rays before measurement of its natural TL will render the technique useless. Despite these difficulties, we can at present use this method to fix, with some accuracy, cultures or events back to the time of the development of ceramics.

As indicated on the accompanying graph, correlation between TL dates and known dates are good, and TL dating may eventually approach the accuracy of C14 dating. It will be apparent



Graph correlating known dates and specific dates obtained by thermoluminescence. The sloping line represents exact correspondence between the two.

Glow curve apparatus to make thermoluminescent tests.



that TL eliminates one great source of error, that is, the inevitable difficulty of being sure that the organic material dated is actually the same age as the archaeological culture or deposit for which a date is sought. Moreover, the system is not plagued by the shift in atmospheric C14 and may thus help to refine the C14 system.

In effect, all these atomic and nuclear methods of dating will potentially cover the entire period of man's life on earth as well as the age of the earth itself. Increasingly, one system checks another so that confidence and certainty increase. All of us in archaeology are now aware of the revolutionary effect upon the whole chronology of human history. One need only mention the correction in our ideas about the end of the Ice Age, the origins of agriculture, the beginnings of ceramic-making (now apparently much older in the Far East than in the Near East) and the relative ages of cultural development in the new and old worlds. Experience over the past 20 years argues in favor of much greater accuracy and more refined methods to come in the next generation.

Electrical instruments for underground search were first brought to my attention in Alaska before the Second World War, where Professor Joesting was experimenting with resistance apparatus in gold prospecting. Just after the war, Paul Fejos of the Wenner-Gren Foundation became interested in the application of such equipment to archaeology. The first test, so far as I remember, was made by Helmut de Terra, then at Yale University, in Mexico at the site of Tepectepan. Such instruments did not catch on with American archaeologists, and I next ran into their application by Professor Case, at Oxford, who was using similar equipment to locate pits and trenches of the Bronze and Iron Ages in Britain. His success encouraged me to make an experiment in the Olmec country of eastern Mexico in 1960.

The famous Precolumbian archaeologist Matthew Sterling, his son and I obtained a commercial electrical resistance instrument manufactured in Minnesota and spent two or three weeks at Cerro de las Mesas, where Sterling had excavated many years earlier. Fortunately, young Matthew was a hi-fi buff and knew something about electronics. Our first "strike" was a large, carved stone stele buried under the alluvial soils of the plain, and, of course, we were elated with

this first success. Unfortunately, after it was fully uncovered Mat suddenly realized he had excavated the same monument and published it 14 years before. We did, however, detect not only the stairway buried under the surface of one of the many earth mounds at the site, but other "anomalies" which convinced us that the instrument had promise for that kind of archaeological search.

Meanwhile E. T. Hall and M. J. Aitken, at Oxford, had developed the proton magnetometer specifically for archaeology and were demonstrating its success at sites in England. In 1961, the architect Aubrey Trik, the physicist Richard Linnington and I joined the engineer Carlo Lerici and his crew at Tarquinia with a very small resistance instrument made in Germany and a proton magnetometer made by Hall and Aitken. Lerici was then utilizing an Italian-made resistance instrument to locate the buried ramps leading down into Etruscan tombs (cut in the limestone bedrock at Tarquinia) which made it possible to spot the tomb chambers. He had also developed the periscope for examining the tombs without excavation. The surprise for all of us came when we found that the tomb chambers as well as the ramps showed up on our magnetic contour maps. We were soon locating up to six Etruscan tombs each day, and for me that kind of routine survey became boring. But, at the Etruscan acropolis of Tarquinia, Franco Brancalearoni and I learned that we could spot buried stone walls with the magnetometer. We began to cast about for a more difficult challenge. He had discovered a buried wall on the plain of the Crati River in south Italy with his resistance equipment and, with Lerici, urged that we try our new apparatus there.

That search, beginning in 1961, was to result in eight years of trial and error, failures and false starts, then final success in the discovery and mapping of the buried remains of Archaic Greek Sybaris. The Archaic level lay from 4.5 to 6.5 meters beneath the present surface, and we soon learned that the proton magnetometer could not detect structures which were more than 2 to 3 meters deep. We then experimented with sonic devices in collaboration with Texas Instruments and Petty Geophysical Company but did not succeed in designing a suitable portable instrument employing sonic frequencies. We turned next to Varian Associates in Palo Alto to develop a



Cesium magnetometer with precision readout in use at San Lorenzo, Mexico.

more sensitive instrument. Shelly Breiner and Beth Ralph, working in the field, and design engineers at Varian with their capable technician Dean Smith produced the cesium magnetometer which finally solved our problem. Limestone walls with concentrations of roof tiles lying up to six meters deep could be located with this much more sensitive instrument. Moreover, magnetic contour mapping became so rapid that we could cover up to five hectares a day. Although individual buildings could, at times, be recognized in the Sybaris ruins (six kilometers in circumference), we learned from test excavations that destruction of the city in the sixth century B.C. had left little of the structures so that we could not map streets or a city plan. That was to come later at Elis in Greece where Beth Ralph with the cesium magnetometer succeeded in that kind of detailed underground mapping. A circle was closed for me in experiments with magnetometers when I returned with the archaeologist Michael Coe to the Olmec Country in Mexico in 1968 to search for buried Olmec monuments at San Lorenzo. There could be no more dramatic example of the magnetometer's effectiveness in archaeology. Extraordinary stone carvings, some weighing several tons and transported for about 70 kilometers, turned out to be magnetic. The alluvial soil in which they are buried is magnetically "quiet," and hence spotting them with the cesium magnetometer is the straightforward business of



Olmec head found with cesium magnetometer at San Lorenzo, Mexico.

charting their location on a magnetic contour map. Seventeen monuments were discovered where they were not expected, that is, not on the ridges where Coe had discovered many fragments. Moreover, one colossal head, found five meters beneath the surface, was in mint condition.

This false-color composite photograph, made from multispectral imagery, was taken by NASA's Earth Resources Technology Satellite (ERTS-1), on August 22, 1972, orbit 134, from an altitude approximately 900 km. over southern Greece. The area of 32,000 square kilometers encompassed by this image extends from the Gulf of Corinth in the northwest to the Gulf of Laconia, on the southeast coast of the Peloponnesos. Athens, the capital of Greece, with its population of 627,000 can be seen to the northeast. The great seaport of Piraeus lies southwest of Athens on the Saronic Gulf. Subtle shades of blue in the seas surrounding Greece represent varying water depths. West-southwest of Athens the Corinth Canal can be seen connecting the Saronic Gulf and the Gulf of Corinth. Greece is so mountainous and its soil has been so eroded that only about one quarter of the country is arable, a condition shown by the lack of red which, on such composites, indicates the green of vegetation. In addition, the hot, dry Greek summers are reflected in the sere aspect of the image. On the Peloponnesos vineyards along the southern shore of the Gulf of Corinth are visible. Forested areas can be perceived in only a few restricted areas at higher elevations. The paucity of surface reservoirs and streams is also striking.

Magnetometers have now been used at scores of sites all over the world, towed along the sea bottom and flown low over the sea to locate wrecks. They have been of great help in saving archaeological sites from destruction, but treasure hunters also use them to discover and loot rich concentrations of remains, such as Spanish wrecks off the coast of Florida. In volcanic areas and other rocky sites where there is either too much or too little magnetism they are not useful, but on alluvial soils where there are deeply buried remains they are indispensable for any large-scale systematic excavations. When their use and operation are better understood by archaeologists in general, they should lead to the discovery of archaeological sites now completely undetected.

Aerial photography is as old as cameras and got its start with balloons before Louis Blériot flew the English Channel in an airplane. Charles Lindbergh proved its use in archaeology with his early flights over the Maya jungles at about the time Erich Schmidt was demonstrating its use on the grasslands of Iran. Nevertheless, the technological explosion following the Second World War and the photographs taken by the spy planes of the 1960's have given archaeological search from the air a new dimension. Moreover, high-resolution photography from satellites, such as the Gemini series, has led to a new burst of interest in remote sensing which now culminates in the Earth Resources Technology Satellite recently launched by the United States Department of the Interior and NASA. My own introduction to these new aerial sensing devices came through Ambassador Frederick Rheinhardt, in Rome, who had taken a personal interest in the long search for Sybaris. A United States Air Force team

making an aerial study of volcanic areas in Italy and Libya also arranged, through the Embassy, to experiment with a multiband camera and an infrared sensing device over the plain of the Crati River where we expected the ruins of Sybaris to be. There were no positive results from that attempt, presumably because the remains lay at such depth and under the water table, but a high school student in Washington, D.C. read of the experiment and mentioned it to his father, who happened to be William Pecora, Director of the United States Geological Survey and the man responsible for the planned Earth Resources Technology Satellite. When he called to suggest I come to Washington to discuss the possibility of archaeological surveys from a satellite, I could hardly take it seriously. But two hours with remote sensing experts from the Department of the Interior and NASA were sufficient to convince me. The satellite is now circling the earth every 103 minutes, and Bruce Bevan of MASCA has proposed various tests, for example, the detection of ancient water courses, which could guide normal aerial photography as to the optimum time for archaeological survey in any given area. Certain growth conditions, times of day, seasons or general moisture content permit an ancient water course to be "seen" more clearly. The same conditions would determine the optimum time for archaeological photography in that area.

A recent report by P. S. Klass explains that early returns from the earth resources spacecraft are better than predicted. So that archaeologists may get an idea of the future possibilities in this field, here are some of the reported findings. Images transmitted from the spacecraft now make it possible to spot: a road only ten meters wide on the band five (red) scanner image; ponds only 92 meters in diameter, all from a height of nearly 965 kilometers; the types of



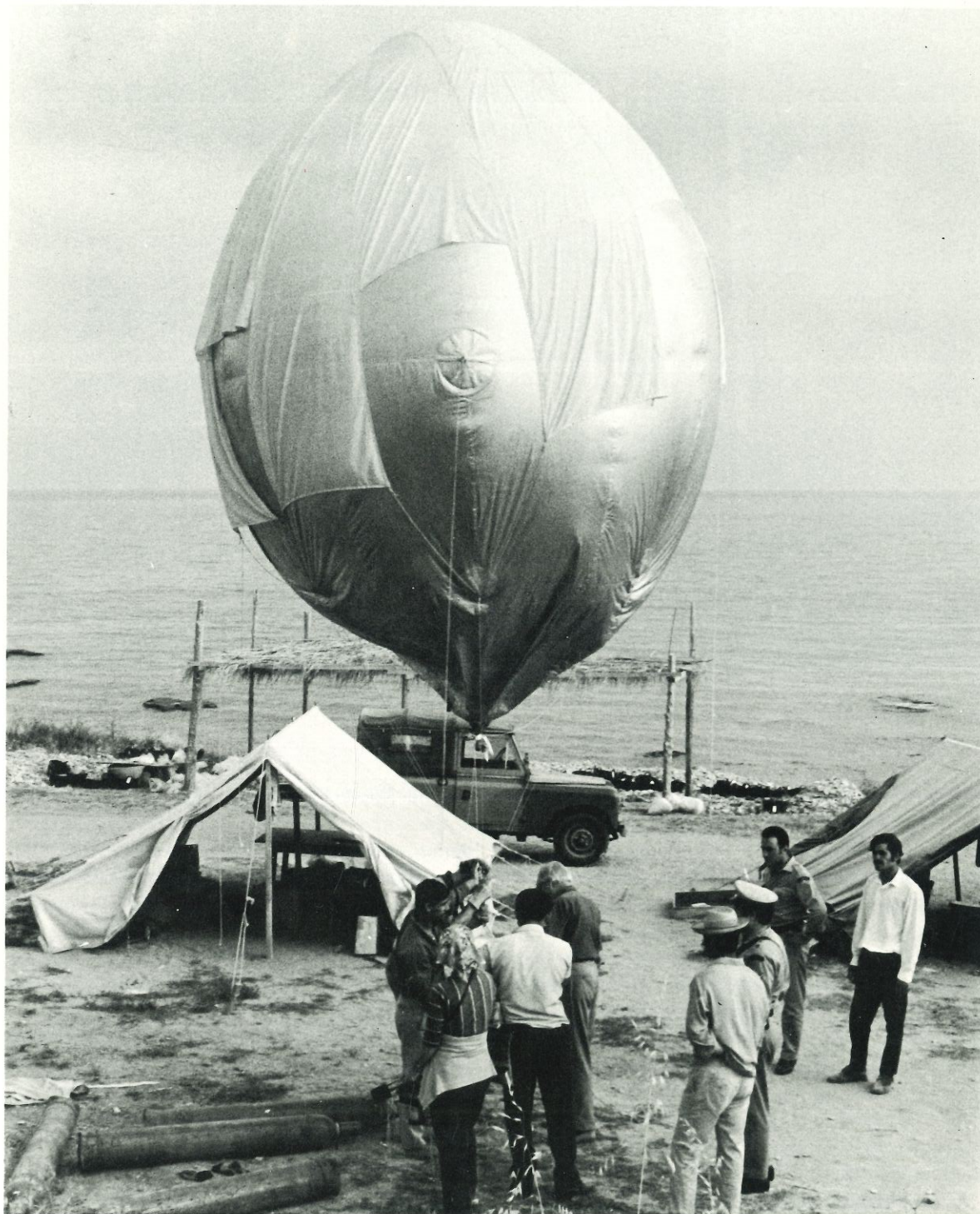
agricultural crops (barley, wheat, sugar beets, etc.); separate fields of only eight hectares; a probable invasion of the Red Tide (plankton which affect shellfish); ice conditions all over the Arctic; the total settlement pattern of Rhode Island as well as clear and turbid waters in oceans, rivers and lakes. With images of such resolution now being transmitted from outer space, surely we should eventually be able to "see" ancient settlement patterns (such as the limit of Roman cultivation in Britain), earthworks, ancient roads and, perhaps, long-abandoned canal and irrigation systems.

The advantage of combining aerial surveys with instrument surveys on the ground was demonstrated recently for us at a Roman site near Kingscote, England. John Hampton of the Royal Commission on Historical Monuments and I had organized an experiment with various types of aerial films at several well-known archaeological sites where excavations and earlier aerial photographs gave us a detailed knowledge of the correlation between images and excavated remains. This project was part of a long-range plan to test new sensing techniques on well-documented sites. At Kingscote a technique enhancing contrasts on aerial photographs accentuated a very faint linear feature, which was possibly an indication of a Roman road leading to the site. To test this we did an instrument survey on the ground with a cesium sensor and a new audio readout. One very foggy day two operators (who were, incidentally, musicians) picked up a peculiar series of pulses or beats on the audio equipment in the open field outside the area of concentrated Roman ruins. They found the same tonal pattern in a series of parallel sweeps across the field and marked out (with bamboo canes) a long, linear anomaly, which might be the road. But then, with a worried expression, Hampton pointed out that it did not correspond exactly with the dim feature on his aerial photos. We groped about in the fog trying to fix base points and sight lines. The fog was so thick that the operators fell back on the curious series of tonal pulses in order to find their way back to our base points. When the fog lifted, Hampton realized that he also had been lost. The aerial anomaly actually did corre-

late with the line of curious pulses worked out with the magnetometer. Subsequent excavation showed that our anomaly was the Roman road with ditches on each side. M. J. Aitken had joined us that day, and both of us were satisfied that one did not have to be a musician to detect the tonal pattern.

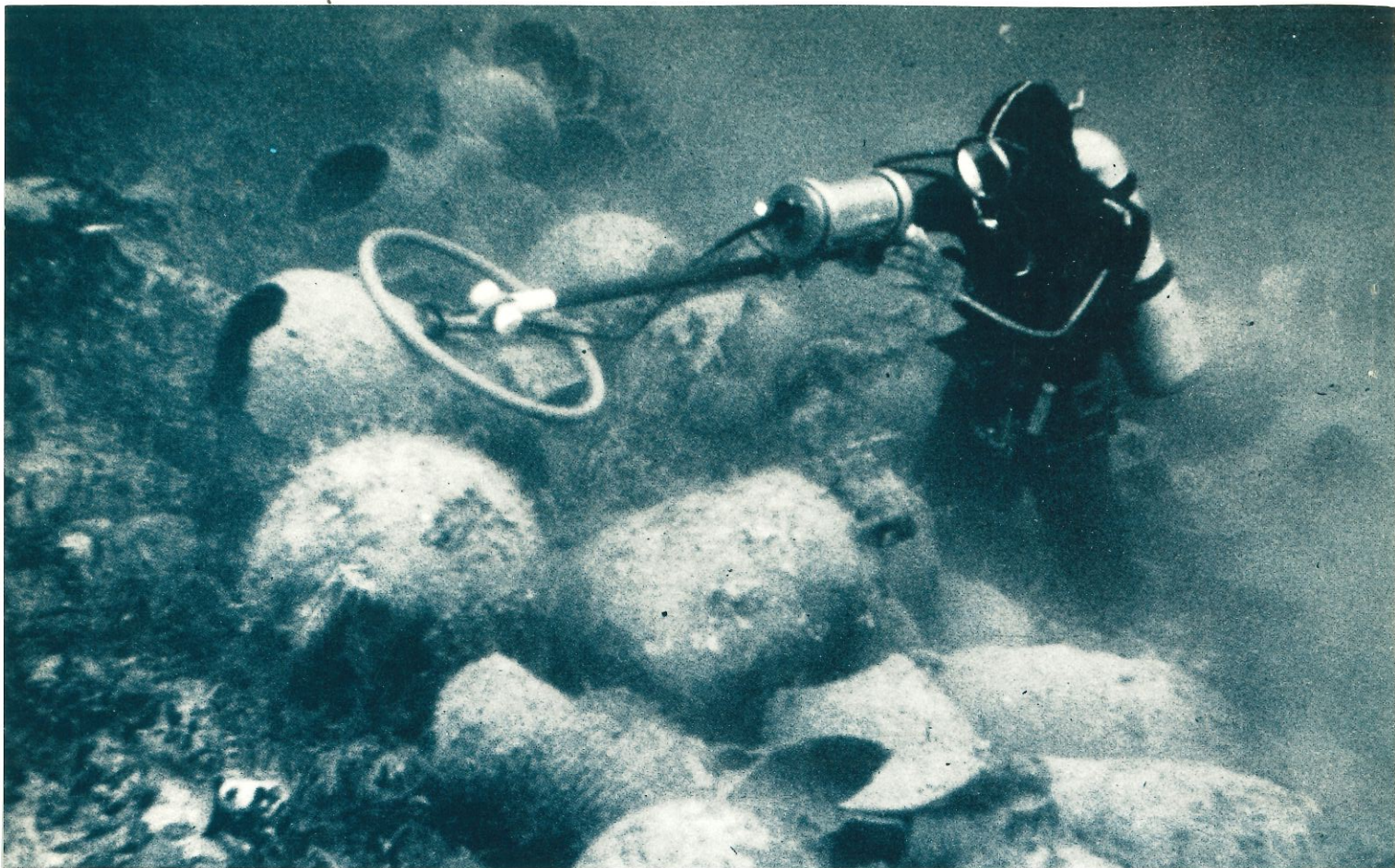
Aerial photography returns to its beginning with balloons these days as the architect Julian Whittlesey continues to demonstrate their value in the recording and mapping of archaeological sites. A hot-air balloon large enough to carry two persons and cameras, hydrogen balloons that carry radio-operated cameras and airfoils, something like wing-shaped kites, that carry ground-operated cameras are all part of Whittlesey's equipment. The balloons are normally tethered over a known archaeological site, but they also can be towed by a land rover or a boat in search of sites. For experiments with different films, such as infrared, the balloons are naturally much less expensive than aircraft. They have also been used to test cameras for aircraft. Photographs taken at 50 to 500 meters over sites, like Sarepta in Lebanon, serve as a perfect ground plan of excavated structures.

Fenimore Johnston, one of the Board of Managers of the University Museum, first called my attention to underwater archaeology in 1948. That was well before scuba equipment and Jacques Cousteau had turned weekend crowds of divers onto wrecks in many oceans, lakes and rivers. Johnston was then building underwater cameras for the Navy, following the introduction of frog men and leech explosives, primarily by the Italians during the Second World War. He came into the office one day with a Naval officer to propose that we begin undersea research in the Mediterranean. However, it was clear at once that we could do it then with only professional divers. The Navy was not prepared to finance the experiment, and the daily cost of a professional diver was far beyond the research budget of the Museum. The Navy officer laughingly suggested that the only feasible economic plan for us was to train Ph.D.'s to dive. None of us guessed at that time that George Bass would do precisely that many years later.



Rodney Young, head of our Mediterranean section, was just as interested as I in the possibilities of the new field, and by the late 1950's we had found Peter Throckmorton who launched our first attempt off the coast of Turkey. As a graduate student in Rodney's department of Classical Archaeology, George Bass learned to

use scuba equipment in Philadelphia's YMCA pool, got his baptism in actual undersea archaeology with Throckmorton and then began his systematic development of expert undersea excavation which was to turn the work into an acceptable academic profession. Between 1960 and 1970 Bass devised a grid system for map-



Metal detector in use over Late Roman shipwreck at Yassi Ada off the coast of Turkey. The wreck was found at a depth of 50 meters.

ping wrecks, using an airlift for excavation, balloons for lifting heavy materials, a tow-line for underwater exploration, a "telephone booth" (a plastic dome with an air bubble, anchored on the bottom to give the divers rest and security in a pinch), underwater television, stereoscopic cameras for mapping, the two-man submarine the *Asherah* and side-scanning sonar. The culmination of this period of technical development came in the late 1960's when the crew managed to locate a deep wreck off the Turkish coast with the new side-scanning sonar and then, for examination, to descend to it in the *Asherah* reaching the wreck precisely on target—no mean achievement in the open sea.

Unfortunately, all these techniques created for the professionals can also be used by amateurs. Today, one of our most critical problems is the systematic looting and destruction of ancient wrecks all over the world. Some countries manage to protect their unique undersea deposits of priceless historic materials, others do not, and probably in the long run, most can be saved only through great expansion of systematic excavation by trained archaeologists.

The Applied Science Center for Archaeology at the University Museum has concentrated upon dating and exploration techniques, while the other similar center at Oxford has concentrated on exploration and TL dating as well as some of the new techniques for analysis and identification of material. Many other centers in the United States and abroad are developing and using the new analytical techniques.

There is now a whole battery of new methods for measuring very small quantities of a great many elements. When the concentrations are less than 0.01 percent, they are then referred to as "trace" elements. The patterns of concentration of such elements can be utilized as a "fingerprint." One of the most dramatic uses of such fingerprinting in archaeology is to determine the source of the raw material for certain artifacts (for example, the various sources of obsidian used for tools in the Mediterranean) and thus to learn something about trade relations and communications in the prehistoric period. Already this kind of study has shown that seaborne and overland communications in the Stone Age were much more extensive than most of us had

imagined. This rapidly expanding study of trace elements in archaeological materials will probably lead away from the conventional reliance upon stylistic types (subjective at best) for the reconstruction of cultural connections to more objective conclusions about cultural diffusion in general.

A new order of chemistry, also developing over the past generation, is just beginning to have impact upon the conservation of materials both in the field and in the laboratory. My own interest in this came about as a matter of necessity when Rodney Young discovered the famous tomb in the great tumulus at Gordion and, somewhat later, when George Bass began to recover parts of ancient wrecks off the coast of Turkey. In both cases ancient water-soaked wood had to be treated in the field to preserve it. We were then alerted to the need for emergency methods in the field and also to the new methods which could be applied. The extraordinary job of preserving the *Vasa* in Sweden is now well known, but I have the impression that the problem there generated many current experiments and that improved methods are in the making. MASCA also has been involved in experiments with the preservation of mud brick in the field, particularly in Iraq and Iran, where the problem of conserving vast blocks of excavated mud-brick buildings is of particular concern. Several years ago, the archaeologists Teresa Carter and David Crownover tried to pump an inexpensive chemical into the standing walls at Tel el Rimah near Mosul. In the laboratory the chemicals were effective, but when applied in the field, penetration was so shallow that the surface flaked away. At the present moment the chemist Darrel Butterbaugh is experimenting at MASCA with new polymers with promising results, but the real test will come with large-scale experiments in the field.

Judging from the past 20 years, and even from the past two or three years, there are many unforeseeable techniques just over the horizon. I am reminded of the planning board for the 21st Century Exhibition and two of its most creative members. One predicted with assurance that within six or seven years (that was in 1961) all vehicles on our highways would be powered by electricity. Another was quite certain that biochemical knowledge of the cell and the gene would mean the end of aging in human beings within the next decade. On the other hand, another member reminded us that in 1937 a

similar group had failed to predict atomic energy, antibiotics and jet propulsion. In archaeology I am also reminded of my early years in graduate school when those who claimed men and mammoth as contemporaries in America were considered by the more conservative to be crackpots. Certainly technology and its rate of growth should convince all of us to keep an open mind.

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