NEW TECHNIQUES IN ARCHAEOLOGY

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(Read November 12, 1965, in the Symposium on Archaeology: Horizons New and Old)

THIS PAPER is concerned with new, post-war, techniques being developed for archaeological dating, exploration, and interpretation. The acceleration in scientific technology, particularly since the last war, seems to me a new order of development which is without precedent. It affects not only the way we live, but the way we think because it provides new tools for basic scientific research. The application of accelerators in the study of fundamental particles, the radio telescope and space vehicles in astronomy, and the electron microscope in biology are perhaps the most familiar examples of technical apparatus which dramatically affect our knowledge and theories about the nature of our environment. They expand the horizons of thought in ways which we do not yet fully understand. Technological tools for scientific investigation may well turn out to be this generation's principal contribution to learning.

The possibilities for the application of this new order of technology in archaeology are clearly demonstrated by the results of the radiocarbon method for absolute dating. It is not simply a convenient tool for dating a specific archaeological site or period, but the means by which we can establish a firm chronology for cultural history during the past 40,000 years. And there are now other promising radioactive methods which will probably provide the chronology for all of man's history. Thus much of our past preoccupation with dating in archaeology will be redirected to other problems in historic reconstruction. Moreover, radiocarbon dating has produced some fundamental changes in historic perspective. For example, the time since the last glacial period is now known to be in the order of 10,000 years rather than 20,000 years [1] and this alters our theories about the end of the paleolithic period. With radiocarbon we have learned that the archaic culture of eastern United States existed some 5,000 years B.C. rather than, as supposed, about the time of Christ. In Jordan, at Jericho, we can date the end of the mesolithic period at 9,000 B.C. and the begininng of a pre-pottery neolithic period with developed architecture and urban living at about 8,000 B.C. I doubt that most of us would have accepted a date of 8,000 B.C., for that level at Jericho, without the radiocarbon record.

The very early dates for pre-Classic Maya civilization at Kaminalhuyu in Guatemala, human occupation of islands in Micronesia in the second millennium B.C., archaeological remains on the northern tip of Greenland dating from the third millennium, and for the very early dates for the neolithic in Japan, are all examples of startling changes in our thinking about cultural history derived from this method of absolute dating.

There is also another side to the coin. We have learned that the physical scientists do not simply present us with a magic box for archaeology. The radiocarbon method was developed over a period of years by physical scientists in constant collaboration with the archaeologists. It is still being perfected and the research, relying in many respects upon archaeological data, is now contributing to basic research in earth sciences. For example, we now know that the amount of radiocarbon (C-14) in the atmosphere is not constant and that there have been significant changes during the past. Changes may be due to fluctuations in cosmic ray intensity (the source of the neutrons which collide with N-14 to produce C-14 in the upper atmosphere), fluctuations in the earth's magnetic field which affects the numbers of cosmic rays, or to changes in the equilibrium conditions between atmosphere and oceans. The increased carbon dioxide in the atmosphere which results from increased population and the consequent increased release of CO_2 into the atmosphere from industry and combustion of all kinds, and the increase of C-14 in the atmosphere resulting from large-scale nuclear weapons testing have affected the inventory of C-14 in modern times.

The radiocarbon laboratory at the University

[1] Richard F. Flint, *Glacial and Pleistocene Geology* (John Wiley and Sons, N. Y., 1957).

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of Pennsylvania has been investigating these phenomena since 1951,[2] and like other laboratories engaged in similar research, has utilized organic materials of known age supplied by the archaeologists and the tree-ring laboratories in order to establish the amount and the periods of fluctuation in C-14. Such basic research in the radiocarbon method has not only refined the system so that more dependable and precise dates are possible, but explores the intricate problems of cosmic ray and magnetic field intensities [3] which affect our environment in ways which are not yet fully understood. Studies of remanent magnetism in Roman kilns, and other fired clay materials, indicate that the magnetic field of the earth was about 65 per cent stronger in Roman times [4] than at present and from this it has been suggested that the C-14 content of the atmosphere was so much lower 2,000 years ago that C-14 dates would be a minimum of 240 years too old. The Pennsylvania laboratory is demonstrating, with the analysis of archaeological materials of known age, that there are several periods in the past of significant change and is beginning to correct archaeological dates on the basis of these known fluctuations.

In this connection, it was noted some years ago, that there was a discrepancy of about 400 to 500 years between radiocarbon dates and archaeological dates for the early Egyptian dynasties.[5] It is probable that the discrepancy is due to a different level of radiocarbon content in the atmosphere at that time. In order to arrive at a true dating, it is indeed difficult to find organic materials from 2,500 B.C. which can be dated independently of the radiocarbon method and of the standard Egyptian archaeological methods. To arrive at this dating, and to determine the cosmic ray and radiocarbon levels during this remote period, intensive studies of tree-ring and radiocarbon analysis are now being carried out on sections of the long-lived sequoia and bristlecone pines.[6] A tree-ring sequence on living and dead bristlecone pines can be carried back 7,000 years. C-14 analysis of a sequence of rings of known age, is beginning to give us a reliable graph of the fluctuation, during the past 7,000 years. Moreover, there is a good possibility that a reliable tree-ring chronology can be worked out with the ancient cedar beams remaining in Egyptian structures, which with certainty could explain the 400–500 year discrepancy in old Kingdom Egyptian dating. The possibilities for tree-ring dating in the Near East are indicated by the study of juniper beams in the Gordias tomb and the city mound at Gordion in Turkey. With them it was possible to establish an 804-year floating chronology for the Central Anatolian plain.[7] Lebanon cedars used in Egypt should provide an even more sensitive growth record. Preliminary investigations in Egypt indicate there are sufficiently preserved logs or beams in pyramids or other structures to provide a growth record. Floating tree-ring chronologies can be correlated with historically fixed dates.

With these refinements in the C-14 method, we may expect to work out a much more accurate chronology for historic events not only in the pre-historic but in the proto-historic epochs of Bronze and Iron Age civilizations in the Mediterranean and the Near East. But the point I wish to emphasize here is that collaboration between archaeologists and physical scientists in perfecting the C-14 method of dating leads also to a better understanding of significant forces in our natural environment.

The potassium-argon, rubidium-strontium, uranium and lead isotope ratio methods of dating developed during the post-war years, are of primary interest in calculating geological time, but they are, of course, applicable in dating the earliest stages in human development (probable range of 12 to 0.36 million years). For example, late trinil basalt from the Muriah volcano in central Java has been dated by the potassium-argon method at 500,000 years and thus gives an age estimate for Pithecanthropus. Best known to

[2] Elizabeth K. Ralph, Henry N. Michael and John Gruninger, Jr., "University of Pennsylvania Dates VII," *American Journal of Science, Radiocarbon Supplement* **7** (1965): pp. 179–186.

[3] E. Thellier and O. Thellier, 'Sur l'Intensité du Champ Magnétique Terrestre dans le Passé Historique et Géologique," *Annales Géophysiques* **15** (1959): pp. 285–376.

[4] (*a*) Martin J. Aitken and G. H. Weaver, "Magnetic Dating: Some Archaeomagnetic Measurements in Britain," *Archaeometry* **5** (1962): pp. 4–22. (*b*) Martin J. Aitken, H. N. Hawley and G. H. Weaver, "Magnetic Dating: Further Archaeomagnetic Measurements in Britain," *Archaeometry* **6** (1963): pp. 76–80.

[5] Elizabeth K. Ralph, "University of Pennsylvania Radiocarbon Dates III," *American Journal of Science, Radiocarbon Supplement* **1** (1959): p. 48.

[6] Elizabeth K. Ralph, Henry N. Michael, and John Gruninger, Jr., "University of Pennsylvania Dates VII," *American Journal of Science, Radiocarbon Supplement* **7** (1965): pp. 179–186.

[7] ASCA Newsletter I, 1st February 1965 (Applied Science Center for Archaeology, University Museum, Philadelphia, Pennsylvania).

archaeologists are the attempts to date the remains of Zinjanthropus in Bed I in the Olduvai deposits of east Africa. There is still disagreement about the age of these deposits but the last opinion I have seen,[8] is that the bed is not appreciably older than 1.7 million years. Predictable improvements in the rubidium-strontium method probably will make it applicable in early Pleistocene ages [9] when applied to obsidians and acid volcanic rock.

Recent investigations (1965) promise to bridge the gap between the C-14 method covering the past 40,000 years and the potassium-argon and other methods for dating much more ancient periods. At least a series of thorium 230—uranium 238 measurements on corals from atoll borings demonstrate the possibility of obtaining dates for Pleistocene carbonates.[10] This should cover the range between 10,000 and 200,000 years ago or most of the hiatus between the earlier methods. Moreover, a search for other radioactive methods will most certainly continue.

One such method, known as the thermoluminescence technique for dating pottery, has been under investigation for more than ten years, most recently at the Research Laboratory for Archaeology and the History of Art in Oxford and at the Applied Science Center for Archaeology in the University Museum of the University of Pennsylvania. Today, I am pleased to announce here, that only within the last few months, the method has been worked out so that accurate dating of pottery is now possible.[11] Radiation from the minute traces of radiocarbon elements (primarily thorium and uranium) in pottery and clay bombards other substances in the clay and raises electrons to metastable levels. When the clay is fired in the kiln each electron falls back to its stable position and emits a photon of light. Then when a fragment of ancient pottery is reheated in the laboratory, the amount of thermoluminescence observed is representative of the accumulated radiation damage and hence of the time elapsed since the original firing of the pottery. As I understand it, the basic principle is straightforward but there were many uncertainties and difficulties facing the scientists who have explored the adaptation to a dating technique for pottery.

Without attempting an explanation of these problems I may simply report that Elizabeth Ralph and Mark Han at the University Museum have refined a technique of bombarding the sherds to be analyzed with x-rays, and of analyzing a series of samples from the same sherd, so that a significant improvement in the age correspondence is achieved. They have analyzed a series of sherd samples from Iran dated by the C-14 method by associated charcoal samples over a range of periods from 5,500 B.C. to 900 B.C., and a group of sherds from Italy, dating about the time of Christ, and have plotted the thermoluminescence measurements against the known age of the sherds. Empirical proof of the method can be seen in the accompanying graph, where thermoluminescence measurements are shown vertically and known age of the sherds horizontally. It can be seen that the average of measurements on the older sherds from Iran (samples 1, 2, 3) dating 5,500, 4,200 and 3,500 B.C., and the youngest sherds from Italy, correspond very closely with the known ages. At the present moment there is an average uncertainty of ±300 years for the four samples from Italy. We will of course proceed with the analysis of several different series of sherds of known age in order to prove further the time-scale, but it is now reasonably certain that the method is a reliable one for dating pottery. With expected improvement in precision it should be comparable to C-14.

The advantage over the C-14 method for dating sites containing pottery is, of course, obvious not only because dating materials are much more plentiful but because there will be no possibility of error in correlating datable material and the artifact or culture to be dated. Moreover, we expect the analysis to be much less expensive when finally perfected.

Still another new method of radioactive fission-track dating is now being applied to natural and man-made glasses.[12] A freshly fractured surface

[8] Richard L. Hay, "Stratigraphy of Beds I through IV, Olduvai Gorge, Tanganyika," *Science* **139** (March 1, 1963): pp. 829–833.

[9] W. Genter and H. J. Lippolt, "The Potassium-Argon Dating of Upper Tertiary and Pleistocene Deposits," *Science in Archaeology* (Basic Books, N. Y., 1963), pp. 77–84.

[10] Aaron Kaufman and Wallace Broecker, "Comparison of Th^{230} and C-14 Ages for Carbonate Materials from Kale Lahonatan and Bonneville," *Journal of Geophysical Research* **70**, 16 (August 15, 1965): pp. 4039–4050.

[11] Elizabeth K. Ralph and Mark C. Han, "Dating of Pottery by Thermoluminescence," (for the coming article to be published in *Nature*).

[12] (*a*) R. L. Fleischer and P. B. Price, "Glass Dating by Fission Fragment Tracks," *Journal of Geophysical Research* **69**, 2 (January 15, 1964): pp. 331–339. (*b*) R. L. Fleischer, P. B. Price and R. M. Walker, "Fission-Track Dating of Bed I, Olduvai Gorge," *Science* **148**

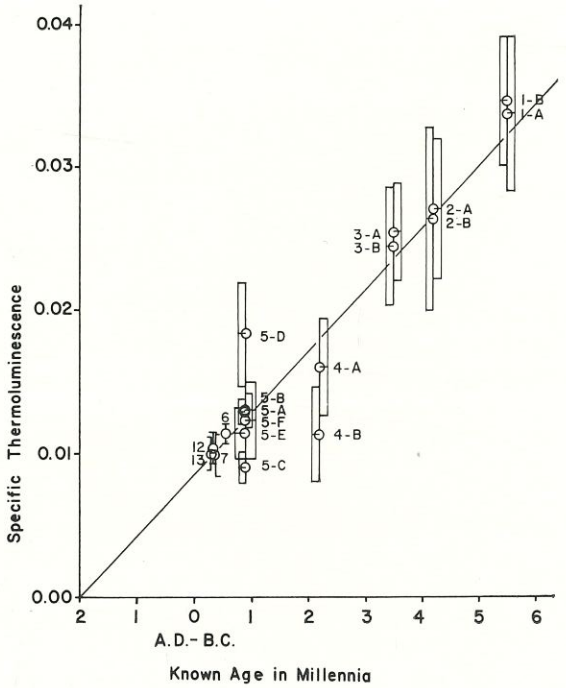

FIG. 1. Plot of specific thermoluminescence versus known age for samples from Solduz Valley, Iran, (nos. 1 to 5) and Plain of Sybaris, Italy (nos. 6, 7, 12, and 13). The postscripts *A, B,* etc. represent different sherds of the same age for each number. (Preliminary results from E. K. Ralph and M. C. Han, Applied Science Center for Archaeology, University Museum, University of Pennsylvania.)

of glass which contains uranium can be etched with hydrofluoric acid so that microscopic etch pits appear wherever a uranium atom has disintegrated near the surface. Then, if one counts the etch pits microscopically and also knows the uranium content of the glass, it is possible to use the known rate of decay of uranium to calculate the age of the glass, that is, the time since the glass was solidified. Promising experiments have been carried out with a number of tektites, a Libyan glass, and also with a pumice from Bed I at Olduvai Gorge. The result at Olduvai, 2.03 ± 0.28 million years, is comparable with the 1.75 million years determined by the potassium-argon method.

The discovery and development of new tools for the analysis and identification of archaeological materials is proceeding in many laboratories around the world. Only an indication of what such tools are doing for archaeology will be given here.

Neutron activation analysis, based upon nuclear transmutation caused by bombardment in a nuclear reactor, may be utilized for widely varying analyses of blood or soil, for surveying the mohole, analyzing the surface of the moon, or for studies of ancient pottery and metals.[13] For example, the Brookhaven Laboratory [14] has carried on an experiment with pottery from Italy and from Central America, to demonstrate that a detailed analysis of elements contained in the clays make it possible to determine the region of manufacture. The fine orange ware found at Piedras Negras in the lowlands of Guatemala is thus proved to have been fabricated in the highlands. It is a method which does not injure or destroy the material to be studied.

The Research Laboratory for Archaeology and the History of Art at Oxford, has reported [15] on a number of analytical techniques currently being investigated which, like the neutron activation method, can be used for quantitative and qualitative studies of materials directed in archaeology to tracing the origin of manufacture and various trade routes, for gaining an understanding of ancient technology, and for the detection of fakes: these methods include x-ray fluorescence, electric beam x-ray scanning microanalysis, beta-ray back-scatter meter, and optical emission spectrometry. But the essential point I should like to make here is that these are for the most part archaeological tools recently derived from post-war atomic and nuclear studies. Their number and rate of development indicate the probable future impact upon archaeological studies.

A number of electronic instruments have proved to be useful in archaeological exploration but most of them, at present, are used for locating buried

(April 2, 1965): pp. 72–74. (*c*) R. L. Fleischer and P. B. Price, "Techniques for Geological Dating of Minerals by Chemical Etching of Fission-Track," *General Electric Research Laboratory Report* **64-RL3635 M** (April, 1964). (*d*) R. L. Fleischer and P. B. Price, "Uranium Contents of Ancient Man-Made Glass," *Science* **144** (May 15, 1964): pp. 841–842. (*e*) Robert H. Brill, R. L. Fleischer, P. B. Price, R. M. Walker, "The Fission-Track Dating of Man-Made Glasses: Preliminary Results," *Journal of Glass Studies* **6** (1964): pp. 151–155.

[13] Richard E. Wainerdi and Normal P. DuBeau, "Nuclear Activation Analysis," *Science* **139** (March 15, 1963): pp. 1027–1033.

[14] Edward V. Sayre, Alexander Murrenhoff, and Charles F. Weick, *The Nondestructive Analysis of Ancient Potsherds through Neutron Activation* (Brookhaven National Laboratory, Upton, New York, 1958).

[15] *Brochure of The Research Laboratory for Archaeoiogy and the History of Art* (Oxford University, Oxford, England).

features in and about a known archaeological site. Ultimately, we hope to develop such instruments so that they can be used to search for unknown sites over large, archaeologically unknown areas. The problem now is to increase the scanning range so that large-scale exploration is possible.

Resistance apparatus, used to measure the electrical conductivity in surface soils, can be applied effectively in locating many relatively shallow archaeological features when there happens to be a contrast in humidity or some other quality which determines a difference in soil conductivity. For example, many ancient ditches, refuse pits, buried constructions, and other features have been located and accurately mapped in England by this method during the past fifteen years. Various instruments of this type also have been used in Italy and Germany and German archaeologists have developed the most practical, light-weight, inexpensive instrument, known as the "Geohm." Tests of the instrument carried out by the Applied Science Center of the University Museum at many sites in the United States, Italy, Central America, and the Near East, unquestionably prove its usefulness under certain specific geophysical conditions. But it is slow to operate and we find that it can rarely locate features which are more than one or two meters beneath the surface.

The proton magnetometer, developed for archaeological use by Hall and Aitken at Oxford, measures minute differences in the magnetic intensity in surface soils. It is highly effective in locating kilns and fire-pits, as well as other fired archaeological remains, and, under certain conditions, buried stone structures and earth works. In Italy, for example, we discovered that we could very quickly locate the rock-cut tombs at Tarquinia and Cerveteri on magnetic contour maps prepared from magnetometer surveys over known cemetery areas. Our experiments there in 1961 proved that we could locate, on the average, five or six tombs per day of survey. Moreover, on the plain of Sybaris, in South Italy, we were able to trace a buried stone wall for more than 1,300 meters in a few days, and to locate other stone and brick structures which were not more than three meters beneath the surface. Martin Aitken has explained this success with the instrument as due to a magnetic contrast between the structures and the slightly magnetic clays in which they were buried.

More recently, 1964–1965, we have been experimenting at Sybaris with rubidium and cesium magnetometers,[16] developed by Varian Associates for the University Museum of the University of Pennsylvania. These are more sensitive instruments which make it possible to locate structures up to five and six meters beneath the surface. Preliminary tests with a rubidium magnetometer (designed originally for space research) at Sybaris during the fall of 1964 demonstrated that the high sensitivity of the instrument could be utilized in archaeology, and thus it was possible to pick up archaeological remains lying at least five meters deep. But the instrument as designed was not practical for archaeological survey. Varian Associates in collaboration with the University Museum then designed and built a light-weight read-out (a mechanism which converts and displays the frequencies detected in the form of numbers), and substituted cesium for rubidium in the sensing apparatus, which made the sensors less affected by changes in orientation. Tests of the new cesium magnetometer at Sybaris in the fall of 1965 have been highly successful. Large structures lying six meters beneath the surface are easily detected. Moreover, with the new read-out it is possible to carry on continuous recording so that an operator can walk steadily across a field calling out numbers of frequencies to a recorder. In this way a magnetometer survey can be made of ten to twenty acres in one day, which is several times the area covered in any day with the proton magnetometer.

The search for the ruins of Archaic Greek Sybaris in South Italy is an experiment in large-scale exploration of an archaeologically unknown area. From the Graeco-Roman accounts we know that the ruins must lie somewhere on or about the plain of the Crati River. This is an area of eighty to one hundred square kilometers and if the ruins lie on the plain, we now know they must be at least five meters beneath the surface. With the magnetometers and with drills we have located and mapped a ruin with Archaic, Hellenistic, and Roman levels extending over an area of about three and one half square kilometers. Test excavations and drills have disclosed Archaic pottery over most of the area, but so far only modest structures of the period of Sybaris. We can be relatively certain that this area, known as the Parco del Cavallo, is the site of the Greek and Roman ports, but without the discovery of massive

[16] Sheldon Breiner, "The Rubidium Magnetometer in Archaeological Exploration," *Science* **150,** #3693 (October 8, 1965): pp. 185–193.

stone buildings, such as those at Paestum, Locri, and Metaponto, it is impossible to know certainly that this is the site of the city of Sybaris itself. However, in October, 1965, the cesium magnetometer located some sort of structures measuring up to 50 meters in length at the 6 meter (Sybaris) level, and we begin to feel confident that test excavations will disclose the massive temple constructions we would expect to find at the site of the actual city. If so, we can then be sure that the Parco del Cavallo area is both the city and the port. It is significant to note that these deep and massive structures were not found with the proton magnetometer or with the drills.

With the cesium magnetometer we now have an electronic instrument capable of searching large areas for unknown sites, given a specific type of terrain where archaeological remains are detected as magnetic anomalies. We also know that on other types of terrain, such as the highlands about the Sybaris plain, where there are individual pockets of magnetic soils, magnetometers cannot be used for survey.

Experiments with other types of electronic instruments such as seismic apparatus, metal detectors, and sonic equipment, have not as yet produced very satisfactory results. Seismic instruments do generally detect the depth and contours of bedrock, metal detectors for the most part have too little depth range for archaeological purposes, and so far, there are unsolved problems with sonic devices. Professor Edgerton at the Massachusetts Institute of Technology is experimenting with a "Boomer" system for penetrating underwater sediments, and the University Museum of the University of Pennsylvania has been experimenting with a high-frequency device for use on land. In principle, both attempt to direct an electric impulse into the soil so that its reflection from an underground feature can be recorded, and thus locate the structure. In essence it is an archaeological probe resembling sonar or radar. The major problem seems to be in producing a satisfactory coupling device which will enable a high-frequency impulse to penetrate the earth without too great a loss of energy. Sonic instruments may yet turn out to be the most useful archaeological probes for large scale exploration.

Technology in the post-war years has opened a new world beneath the sea as well as in space,[17] and only now are most of us becoming aware that the sea holds some of the most promising future discoveries in archaeology. Perhaps because scuba-diving equipment was first utilized extensively for the sport of underwater exploration, we failed to see its use in serious archaeological research. Today, thanks to the application of many new devices for underwater exploration by such trained archaeologists as George Bass, there is now a well-defined discipline of underwater archaeology. It began when archaeologists were trained to dive with scuba equipment and to apply the systematic techniques of land archaeology to the study of remains underwater. It expands with rapidly developing equipment permitting more efficient underwater surveys and more effective methods of excavating and recording.

Free-swimming scuba equipment made possible the systematic excavation and recording of a Bronze Age wreck off Cape Gelydonia which had been discovered by Turkish sponge divers, the discovery of Maya remains in lake Amatitlan in Guatemala, the study of many Roman wrecks in the Mediterranean, the exploration of the sunken city of Port Royal in Jamaica, the investigation of the sunken port at Corinth, and the excavation of a Villanovan village at the bottom of Lake Bolsena in Italy. Then the development of stereophotogrammetric mapping of wrecks off Bodrum on the Turkish coast introduced a new precision and efficiency in underwater work. At present emphasis is being placed upon new techniques for exploration.

Scuba divers cannot work with safety at depths greater than 150 feet. Moreover, at that depth they can work for only a short period each day. Free-swimming exploration, even at shallow depths on the vast land-shell of the seas where archaeological remains may be found, is painfully slow. Hence at present we have a very limited idea of the extent and kind of remains which can be found there. Most of those which have been found are accidental discoveries. It is now clear that the most important discoveries will be made when better exploration equipment is developed for the archaeologist.

To this end, the University Museum of the University of Pennsylvania commissioned the Electric Boat Division of the General Dynamics Corporation to build a small, two-man submarine specifically for undersea archaeological survey. The operators inside the submarine are at surface atmospheric pressure which eliminates many of the

[17] George F. Bass, *Underwater Archaeology*, Ancient Peoples and Places Series, **148** (Praeger, New York, 1965, in press).

physiological problems of the scuba diver. Cruising under sea at four knots and to depths of at least three hundred feet, up to eight hours a day, with viewing ports and outside pressurized lights, the range and speed of undersea search is vastly increased. Moreover, with the addition of the stereophotogrammetric equipment for mapping which has been attached to the submarine, accurate mapping of the sunken remains is now possible in a fraction of the time required by scuba divers.

Still other exploration techniques under sea were pioneered by George Bass during the summer of 1965 off the coast of Turkey. A steel capsule, shaped something like a Mercury Space Capsule and known as a "Tow-Vane," was used to plane down to 275 feet for observation of the sea bottom. The operator inside the capsule remained at atmospheric pressure, breathing recirculated air to which oxygen had been added. He maintained contact with the towing vessel on the surface by means of a telephone. A closed-circuit television camera was also towed along the sea bottom with a monitor in the cabin of the towing vessel observing the sea floor in the area scanned by the camera. It is interesting to note that the camera could often "see" better than the naked eye when the sea water was clouded, and that natural light was sufficient down to 270 feet. Still another experiment was made with a proton magnetometer designed by E. T. Hall of the Oxford Laboratory for undersea use. It also was towed over the sea bottom in search of metal and deposits of pottery.

All of these instruments functioned properly and could examine the sea bottom in search of archaeological remains as intended. Nevertheless, the specific wrecks known to be in the area searched were not found. And from this we reached the obvious conclusion that the sea is very big, remains of wrecks are very small, and the scanning range of the instruments used is still too limited to give us an easy and rapid way to explore the sea bottom. But this kind of search is in its infancy, and the development of such techniques is proceeding at an extraordinarily rapid rate.

Finally, there is one aspect to this research into the new technology of archaeology which in the long run may be the most significant. For once, in a very small way to be sure, some of us interested in the humanities are working directly with the physical scientists on specific research projects to solve technical problems of concern to us both. We archaeologists are too little aware of the revolutionary technological changes affecting our world and I think the physical scientists are too little aware of the forces of history. Here, we are at least crossing over between the two worlds of science and the humanities in a very practical day-by-day experience. There is enthusiasm and excitement on both sides and a new awareness of the attitudes in another kind of discipline.

I think most of us are concerned about a better understanding between humanists and scientists in this strange new world of rapid change. There can be no doubt that such understanding develops most readily through daily collaboration in the laboratory and in the field.

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The possibilities for the application of this new order of technology in archaeology are clearly demonstrated by the results of the radiocarbon method for absolute dating. It is not simply a convenient tool for dating a specific archaeological site or period, but the means by which we can establish a firm chronology for cultural history during the past 40,000 years. And there are now other promising radioactive methods which will probably provide the chronology for all of man's history. Thus much of our past preoccupation with dating in archaeology will be redirected to other problems in historic reconstruction. Moreover, radiocarbon dating has produced some fundamental changes in historic perspective. For example, the time since the last glacial period is now known to be in the order of 10,000 years rather than 20,000 years [1] and this alters our theories about the end of the paleolithic period. With radiocarbon we have learned that the archaic culture of eastern United States existed some 5,000 years B.C. rather than, as supposed, about the time of Christ. In Jordan, at Jericho, we can date the end of the mesolithic period at 9,000 B.C. and the beginінg of a pre-pottery neolithic period with developed architecture and urban living at about 8,000 B.C. I doubt that most of us would have accepted a date of 8,000 B.C., for that level at Jericho, without the radiocarbon record.

The very early dates for pre-Classic Maya civilization at Kaminalhuyu in Guatemala, human occupation of islands in Micronesia in the second millennium B.C., archaeological remains on the northern tip of Greenland dating from the third millennium, and for the very early dates for the neolithic in Japan, are all examples of startling changes in our thinking about cultural history derived from this method of absolute dating.

There is also another side to the coin. We have learned that the physical scientists do not simply present us with a magic box for archaeology. The radiocarbon method was developed over a period of years by physical scientists in constant collaboration with the archaeologists. It is still being perfected and the research, relying in many respects upon archaeological data, is now contributing to basic research in earth sciences. For example, we now know that the amount of radiocarbon (C-14) in the atmosphere is not constant and that there have been significant changes during the past. Changes may be due to fluctuations in cosmic ray intensity (the source of the neutrons which collide with N-14 to produce C-14 in the upper atmosphere), fluctuations in the earth's magnetic field which affects the numbers of cosmic rays, or to changes in the equilibrium conditions between atmosphere and oceans. The increased carbon dioxide in the atmosphere which results from increased population and the consequent increased release of CO_2 into the atmosphere from industry and combustion of all kinds, and the increase of C-14 in the atmosphere resulting from large-scale nuclear weapons testing have affected the inventory of C-14 in modern times.

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of Pennsylvania has been investigating these phenomena since 1951,[2] and like other laboratories engaged in similar research, has utilized organic materials of known age supplied by the archaeologists and the tree-ring laboratories in order to establish the amount and the periods of fluctuation in C-14. Such basic research in the radiocarbon method has not only refined the system so that more dependable and precise dates are possible, but explores the intricate problems of cosmic ray and magnetic field intensities [3] which affect our environment in ways which are not yet fully understood. Studies of remanent magnetism in Roman kilns, and other fired clay materials, indicate that the magnetic field of the earth was about 65 per cent stronger in Roman times [4] than at present and from this it has been suggested that the C-14 content of the atmosphere was so much lower 2,000 years ago that C-14 dates would be a minimum of 240 years too old. The Pennsylvania laboratory is demonstrating, with the analysis of archaeological materials of known age, that there are several periods in the past of significant change and is beginning to correct archaeological dates on the basis of these known fluctuations.

In this connection, it was noted some years ago, that there was a discrepancy of about 400 to 500 years between radiocarbon dates and archaeological dates for the early Egyptian dynasties.[5] It is probable that the discrepancy is due to a different level of radiocarbon content in the atmosphere at that time. In order to arrive at a true dating, it is indeed difficult to find organic materials from 2,500 B.C. which can be dated independently of the radiocarbon method and of the standard Egyptian archaeological methods. To arrive at this dating, and to determine the cosmic ray and radiocarbon levels during this remote period, intensive studies of tree-ring and radiocarbon analysis are now being carried out on sections of the long-lived sequoia and bristlecone pines.[6] A tree-ring sequence on living and dead bristlecone pines can be carried back 7,000 years. C-14 analysis of a sequence of rings of known age, is beginning to give us a reliable graph of the fluctuation, during the past 7,000 years. Moreover, there is a good possibility that a reliable tree-ring chronology can be worked out with the ancient cedar beams remaining in Egyptian structures, which with certainty could explain the 400–500 year discrepancy in old Kingdom Egyptian dating. The possibilities for tree-ring dating in the Near East are indicated by the study of juniper beams in the Gordias tomb and the city mound at Gordion in Turkey. With them it was possible to establish an 804-year floating chronology for the Central Anatolian plain.[7] Lebanon cedars used in Egypt should provide an even more sensitive growth record. Preliminary investigations in Egypt indicate there are sufficiently preserved logs or beams in pyramids or other structures to provide a growth record. Floating tree-ring chronologies can be correlated with historically fixed dates.

With these refinements in the C-14 method, we may expect to work out a much more accurate chronology for historic events not only in the pre-historic but in the proto-historic epochs of Bronze and Iron Age civilizations in the Mediterranean and the Near East. But the point I wish to emphasize here is that collaboration between archaeologists and physical scientists in perfecting the C-14 method of dating leads also to a better understanding of significant forces in our natural environment.

The potassium-argon, rubidium-strontium, uranium and lead isotope ratio methods of dating developed during the post-war years, are of primary interest in calculating geological time, but they are, of course, applicable in dating the earliest stages in human development (probable range of 12 to 0.36 million years). For example, late trinil basalt from the Muriah volcano in central Java has been dated by the potassium-argon method at 500,000 years and thus gives an age estimate for Pithecanthropus. Best known to

[2] Elizabeth K. Ralph, Henry N. Michael and John Gruninger, Jr., "University of Pennsylvania Dates VII," *American Journal of Science, Radiocarbon Supplement* 7 (1965): pp. 179–186.

[3] E. Thellier and O. Thellier, 'Sur l'Intensité du Champ Magnétique Terrestre dans le Passé Historique et Géologique," *Annales Géophysiques* 15 (1959): pp. 285–376.

[4] (*a*) Martin J. Aitken and G. H. Weaver, "Magnetic Dating: Some Archaeomagnetic Measurements in Britain," *Archaeometry* 5 (1962): pp. 4–22. (*b*) Martin J. Aitken, H. N. Hawley and G. H. Weaver, "Magnetic Dating: Further Archaeomagnetic Measurements in Britain," *Archaeometry* 6 (1963): pp. 76–80.

[5] Elizabeth K. Ralph, "University of Pennsylvania Radiocarbon Dates III," *American Journal of Science, Radiocarbon Supplement* 1 (1959): p. 48.

[6] Elizabeth K. Ralph, Henry N. Michael, and John Gruninger, Jr., "University of Pennsylvania Dates VII," *American Journal of Science, Radiocarbon Supplement* 7 (1965): pp. 179–186.

[7] ASCA Newsletter I, 1st February 1965 (Applied Science Center for Archaeology, University Museum, Philadelphia, Pennsylvania).

archaeologists are the attempts to date the remains of Zinjanthropus in Bed I in the Olduvai deposits of east Africa. There is still disagreement about the age of these deposits but the last opinion I have seen,[8] is that the bed is not appreciably older than 1.7 million years. Predictable improvements in the rubidium-strontium method probably will make it applicable in early Pleistocene ages [9] when applied to obsidians and acid volcanic rock.

Recent investigations (1965) promise to bridge the gap between the C-14 method covering the past 40,000 years and the potassium-argon and other methods for dating much more ancient periods. At least a series of thorium 230—uranium 238 measurements on corals from atoll borings demonstrate the possibility of obtaining dates for Pleistocene carbonates.[10] This should cover the range between 10,000 and 200,000 years ago or most of the hiatus between the earlier methods. Moreover, a search for other radioactive methods will most certainly continue.

One such method, known as the thermoluminescence technique for dating pottery, has been under investigation for more than ten years, most recently at the Research Laboratory for Archaeology and the History of Art in Oxford and at the Applied Science Center for Archaeology in the University Museum of the University of Pennsylvania. Today, I am pleased to announce here, that only within the last few months, the method has been worked out so that accurate dating of pottery is now possible.[11] Radiation from the minute traces of radiocarbon elements (primarily thorium and uranium) in pottery and clay bombards other substances in the clay and raises electrons to metastable levels. When the clay is fired in the kiln each electron falls back to its stable position and emits a photon of light. Then when a fragment of ancient pottery is reheated in the laboratory, the amount of thermoluminescence observed is representative of the accumulated radiation damage and hence of the time elapsed since the original firing of the pottery. As I understand it, the basic principle is straightforward but there were many uncertainties and difficulties facing the scientists who have explored the adaptation to a dating technique for pottery.

Without attempting an explanation of these problems I may simply report that Elizabeth Ralph and Mark Han at the University Museum have refined a technique of bombarding the sherds to be analyzed with x-rays, and of analyzing a series of samples from the same sherd, so that a significant improvement in the age correspondence is achieved. They have analyzed a series of sherd samples from Iran dated by the C-14 method by associated charcoal samples over a range of periods from 5,500 B.C. to 900 B.C., and a group of sherds from Italy, dating about the time of Christ, and have plotted the thermoluminescence measurements against the known age of the sherds. Empirical proof of the method can be seen in the accompanying graph, where thermoluminescence measurements are shown vertically and known age of the sherds horizontally. It can be seen that the average of measurements on the older sherds from Iran (samples 1, 2, 3) dating 5,500, 4,200 and 3,500 B.C., and the youngest sherds from Italy, correspond very closely with the known ages. At the present moment there is an average uncertainty of ± 300 years for the four samples from Italy. We will of course proceed with the analysis of several different series of sherds of known age in order to prove further the time-scale, but it is now reasonably certain that the method is a reliable one for dating pottery. With expected improvement in precision it should be comparable to C-14.

The advantage over the C-14 method for dating sites containing pottery is, of course, obvious not only because dating materials are much more plentiful but because there will be no possibility of error in correlating datable material and the artifact or culture to be dated. Moreover, we expect the analysis to be much less expensive when finally perfected.

Still another new method of radioactive fission-track dating is now being applied to natural and man-made glasses.[12] A freshly fractured surface

[8] Richard L. Hay, "Stratigraphy of Beds I through IV, Olduvai Gorge, Tanganyika," *Science* **139** (March 1, 1963): pp. 829–833.

[9] W. Genter and H. J. Lippolt, "The Potassium-Argon Dating of Upper Tertiary and Pleistocene Deposits," *Science in Archaeology* (Basic Books, N. Y., 1963), pp. 77–84.

[10] Aaron Kaufman and Wallace Broecker, "Comparison of Th^{230} and C-14 Ages for Carbonate Materials from Kale Lahonatan and Bonneville," *Journal of Geophysical Research* **70**, 16 (August 15, 1965): pp. 4039–4050.

[11] Elizabeth K. Ralph and Mark C. Han, "Dating of Pottery by Thermoluminescence," (for the coming article to be published in *Nature*).

[12] (*a*) R. L. Fleischer and P. B. Price, "Glass Dating by Fission Fragment Tracks," *Journal of Geophysical Research* **69**, 2 (January 15, 1964): pp. 331–339. (*b*) R. L. Fleischer, P. B. Price and R. M. Walker, "Fission-Track Dating of Bed I, Olduvai Gorge," *Science* **148**

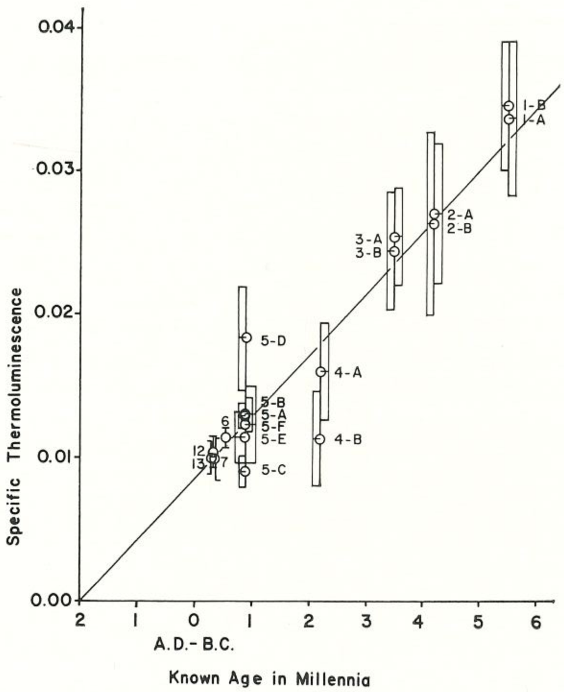

FIG. 1. Plot of specific thermoluminescence versus known age for samples from Solduz Valley, Iran, (nos. 1 to 5) and Plain of Sybaris, Italy (nos. 6, 7, 12, and 13). The postscripts *A, B,* etc. represent different sherds of the same age for each number. (Preliminary results from E. K. Ralph and M. C. Han, Applied Science Center for Archaeology, University Museum, University of Pennsylvania.)

of glass which contains uranium can be etched with hydrofluoric acid so that microscopic etch pits appear wherever a uranium atom has disintegrated near the surface. Then, if one counts the etch pits microscopically and also knows the uranium content of the glass, it is possible to use the known rate of decay of uranium to calculate the age of the glass, that is, the time since the glass was solidified. Promising experiments have been carried out with a number of tektites, a Libyan glass, and also with a pumice from Bed I at Olduvai Gorge. The result at Olduvai, 2.03 $\pm$ 0.28 million years, is comparable with the 1.75 million years determined by the potassium-argon method.

The discovery and development of new tools for the analysis and identification of archaeological materials is proceeding in many laboratories around the world. Only an indication of what such tools are doing for archaeology will be given here.

Neutron activation analysis, based upon nuclear transmutation caused by bombardment in a nuclear reactor, may be utilized for widely varying analyses of blood or soil, for surveying the mohole, analyzing the surface of the moon, or for studies of ancient pottery and metals.[13] For example, the Brookhaven Laboratory [14] has carried on an experiment with pottery from Italy and from Central America, to demonstrate that a detailed analysis of elements contained in the clays make it possible to determine the region of manufacture. The fine orange ware found at Piedras Negras in the lowlands of Guatemala is thus proved to have been fabricated in the highlands. It is a method which does not injure or destroy the material to be studied.

The Research Laboratory for Archaeology and the History of Art at Oxford, has reported [15] on a number of analytical techniques currently being investigated which, like the neutron activation method, can be used for quantitative and qualitative studies of materials directed in archaeology to tracing the origin of manufacture and various trade routes, for gaining an understanding of ancient technology, and for the detection of fakes: these methods include x-ray fluorescence, electric beam x-ray scanning microanalysis, beta-ray backscatter meter, and optical emission spectrometry. But the essential point I should like to make here is that these are for the most part archaeological tools recently derived from post-war atomic and nuclear studies. Their number and rate of development indicate the probable future impact upon archaeological studies.

A number of electronic instruments have proved to be useful in archaeological exploration but most of them, at present, are used for locating buried

(April 2, 1965): pp. 72–74. (*c*) R. L. Fleischer and P. B. Price, "Techniques for Geological Dating of Minerals by Chemical Etching of Fission-Track," *General Electric Research Laboratory Report* **64-RL3635 M** (April, 1964). (*d*) R. L. Fleischer and P. B. Price, "Uranium Contents of Ancient Man-Made Glass," *Science* **144** (May 15, 1964): pp. 841–842. (*e*) Robert H. Brill, R. L. Fleischer, P. B. Price, R. M. Walker, "The Fission-Track Dating of Man-Made Glasses: Preliminary Results," *Journal of Glass Studies* **6** (1964): pp. 151–155.

[13] Richard E. Wainerdi and Normal P. DuBeau, "Nuclear Activation Analysis," *Science* **139** (March 15, 1963): pp. 1027–1033.

[14] Edward V. Sayre, Alexander Murrenhoff, and Charles F. Weick, *The Nondestructive Analysis of Ancient Potsherds through Neutron Activation* (Brookhaven National Laboratory, Upton, New York, 1958).

[15] *Brochure of The Research Laboratory for Archaeology and the History of Art* (Oxford University, Oxford, England).

features in and about a known archaeological site. Ultimately, we hope to develop such instruments so that they can be used to search for unknown sites over large, archaeologically unknown areas. The problem now is to increase the scanning range so that large-scale exploration is possible.

Resistance apparatus, used to measure the electrical conductivity in surface soils, can be applied effectively in locating many relatively shallow archaeological features when there happens to be a contrast in humidity or some other quality which determines a difference in soil conductivity. For example, many ancient ditches, refuse pits, buried constructions, and other features have been located and accurately mapped in England by this method during the past fifteen years. Various instruments of this type also have been used in Italy and Germany and German archaeologists have developed the most practical, light-weight, inexpensive instrument, known as the "Geohm." Tests of the instrument carried out by the Applied Science Center of the University Museum at many sites in the United States, Italy, Central America, and the Near East, unquestionably prove its usefulness under certain specific geophysical conditions. But it is slow to operate and we find that it can rarely locate features which are more than one or two meters beneath the surface.

The proton magnetometer, developed for archaeological use by Hall and Aitken at Oxford, measures minute differences in the magnetic intensity in surface soils. It is highly effective in locating kilns and fire-pits, as well as other fired archaeological remains, and, under certain conditions, buried stone structures and earth works. In Italy, for example, we discovered that we could very quickly locate the rock-cut tombs at Tarquinia and Cerveteri on magnetic contour maps prepared from magnetometer surveys over known cemetery areas. Our experiments there in 1961 proved that we could locate, on the average, five or six tombs per day of survey. Moreover, on the plain of Sybaris, in South Italy, we were able to trace a buried stone wall for more than 1,300 meters in a few days, and to locate other stone and brick structures which were not more than three meters beneath the surface. Martin Aitken has explained this success with the instrument as due to a magnetic contrast between the structures and the slightly magnetic clays in which they were buried.

More recently, 1964–1965, we have been experimenting at Sybaris with rubidium and cesium magnetometers,[16] developed by Varian Associates for the University Museum of the University of Pennsylvania. These are more sensitive instruments which make it possible to locate structures up to five and six meters beneath the surface. Preliminary tests with a rubidium magnetometer (designed originally for space research) at Sybaris during the fall of 1964 demonstrated that the high sensitivity of the instrument could be utilized in archaeology, and thus it was possible to pick up archaeological remains lying at least five meters deep. But the instrument as designed was not practical for archaeological survey. Varian Associates in collaboration with the University Museum then designed and built a light-weight read-out (a mechanism which converts and displays the frequencies detected in the form of numbers), and substituted cesium for rubidium in the sensing apparatus, which made the sensors less affected by changes in orientation. Tests of the new cesium magnetometer at Sybaris in the fall of 1965 have been highly successful. Large structures lying six meters beneath the surface are easily detected. Moreover, with the new read-out it is possible to carry on continuous recording so that an operator can walk steadily across a field calling out numbers of frequencies to a recorder. In this way a magnetometer survey can be made of ten to twenty acres in one day, which is several times the area covered in any day with the proton magnetometer.

The search for the ruins of Archaic Greek Sybaris in South Italy is an experiment in large-scale exploration of an archaeologically unknown area. From the Graeco-Roman accounts we know that the ruins must lie somewhere on or about the plain of the Crati River. This is an area of eighty to one hundred square kilometers and if the ruins lie on the plain, we now know they must be at least five meters beneath the surface. With the magnetometers and with drills we have located and mapped a ruin with Archaic, Hellenistic, and Roman levels extending over an area of about three and one half square kilometers. Test excavations and drills have disclosed Archaic pottery over most of the area, but so far only modest structures of the period of Sybaris. We can be relatively certain that this area, known as the Parco del Cavallo, is the site of the Greek and Roman ports, but without the discovery of massive

[16] Sheldon Breiner, "The Rubidium Magnetometer in Archaeological Exploration," *Science* **150**, #3693 (October 8, 1965): pp. 185–193.

stone buildings, such as those at Paestum, Locri, and Metaponto, it is impossible to know certainly that this is the site of the city of Sybaris itself. However, in October, 1965, the cesium magnetometer located some sort of structures measuring up to 50 meters in length at the 6 meter (Sybaris) level, and we begin to feel confident that test excavations will disclose the massive temple constructions we would expect to find at the site of the actual city. If so, we can then be sure that the Parco del Cavallo area is both the city and the port. It is significant to note that these deep and massive structures were not found with the proton magnetometer or with the drills.

With the cesium magnetometer we now have an electronic instrument capable of searching large areas for unknown sites, given a specific type of terrain where archaeological remains are detected as magnetic anomalies. We also know that on other types of terrain, such as the highlands about the Sybaris plain, where there are individual pockets of magnetic soils, magnetometers cannot be used for survey.

Experiments with other types of electronic instruments such as seismic apparatus, metal detectors, and sonic equipment, have not as yet produced very satisfactory results. Seismic instruments do generally detect the depth and contours of bedrock, metal detectors for the most part have too little depth range for archaeological purposes, and so far, there are unsolved problems with sonic devices. Professor Edgerton at the Massachusetts Institute of Technology is experimenting with a "Boomer" system for penetrating underwater sediments, and the University Museum of the University of Pennsylvania has been experimenting with a high-frequency device for use on land. In principle, both attempt to direct an electric impulse into the soil so that its reflection from an underground feature can be recorded, and thus locate the structure. In essence it is an archaeological probe resembling sonar or radar. The major problem seems to be in producing a satisfactory coupling device which will enable a high-frequency impulse to penetrate the earth without too great a loss of energy. Sonic instruments may yet turn out to be the most useful archaeological probes for large scale exploration.

Technology in the post-war years has opened a new world beneath the sea as well as in space,[17] and only now are most of us becoming aware that the sea holds some of the most promising future discoveries in archaeology. Perhaps because scuba-diving equipment was first utilized extensively for the sport of underwater exploration, we failed to see its use in serious archaeological research. Today, thanks to the application of many new devices for underwater exploration by such trained archaeologists as George Bass, there is now a well-defined discipline of underwater archaeology. It began when archaeologists were trained to dive with scuba equipment and to apply the systematic techniques of land archaeology to the study of remains underwater. It expands with rapidly developing equipment permitting more efficient underwater surveys and more effective methods of excavating and recording.

Free-swimming scuba equipment made possible the systematic excavation and recording of a Bronze Age wreck off Cape Gelydonia which had been discovered by Turkish sponge divers, the discovery of Maya remains in lake Amatitlan in Guatemala, the study of many Roman wrecks in the Mediterranean, the exploration of the sunken city of Port Royal in Jamaica, the investigation of the sunken port at Corinth, and the excavation of a Villanovan village at the bottom of Lake Bolsena in Italy. Then the development of stereophotogrammetric mapping of wrecks off Bodrum on the Turkish coast introduced a new precision and efficiency in underwater work. At present emphasis is being placed upon new techniques for exploration.

Scuba divers cannot work with safety at depths greater than 150 feet. Moreover, at that depth they can work for only a short period each day. Free-swimming exploration, even at shallow depths on the vast land-shell of the seas where archaeological remains may be found, is painfully slow. Hence at present we have a very limited idea of the extent and kind of remains which can be found there. Most of those which have been found are accidental discoveries. It is now clear that the most important discoveries will be made when better exploration equipment is developed for the archaeologist.

To this end, the University Museum of the University of Pennsylvania commissioned the Electric Boat Division of the General Dynamics Corporation to build a small, two-man submarine specifically for undersea archaeological survey. The operators inside the submarine are at surface atmospheric pressure which eliminates many of the

[17] George F. Bass, *Underwater Archaeology*, Ancient Peoples and Places Series, **148** (Praeger, New York, 1965, in press).

physiological problems of the scuba diver. Cruising under sea at four knots and to depths of at least three hundred feet, up to eight hours a day, with viewing ports and outside pressurized lights, the range and speed of undersea search is vastly increased. Moreover, with the addition of the stereophotogrammetric equipment for mapping which has been attached to the submarine, accurate mapping of the sunken remains is now possible in a fraction of the time required by scuba divers.

Still other exploration techniques under sea were pioneered by George Bass during the summer of 1965 off the coast of Turkey. A steel capsule, shaped something like a Mercury Space Capsule and known as a "Tow-Vane," was used to plane down to 275 feet for observation of the sea bottom. The operator inside the capsule remained at atmospheric pressure, breathing recirculated air to which oxygen had been added. He maintained contact with the towing vessel on the surface by means of a telephone. A closed-circuit television camera was also towed along the sea bottom with a monitor in the cabin of the towing vessel observing the sea floor in the area scanned by the camera. It is interesting to note that the camera could often "see" better than the naked eye when the sea water was clouded, and that natural light was sufficient down to 270 feet. Still another experiment was made with a proton magnetometer designed by E. T. Hall of the Oxford Laboratory for undersea use. It also was towed over the sea bottom in search of metal and deposits of pottery.

All of these instruments functioned properly and could examine the sea bottom in search of archaeological remains as intended. Nevertheless, the specific wrecks known to be in the area searched were not found. And from this we reached the obvious conclusion that the sea is very big, remains of wrecks are very small, and the scanning range of the instruments used is still too limited to give us an easy and rapid way to explore the sea bottom. But this kind of search is in its infancy, and the development of such techniques is proceeding at an extraordinarily rapid rate.

Finally, there is one aspect to this research into the new technology of archaeology which in the long run may be the most significant. For once, in a very small way to be sure, some of us interested in the humanities are working directly with the physical scientists on specific research projects to solve technical problems of concern to us both. We archaeologists are too little aware of the revolutionary technological changes affecting our world and I think the physical scientists are too little aware of the forces of history. Here, we are at least crossing over between the two worlds of science and the humanities in a very practical day-by-day experience. There is enthusiasm and excitement on both sides and a new awareness of the attitudes in another kind of discipline.

I think most of us are concerned about a better understanding between humanists and scientists in this strange new world of rapid change. There can be no doubt that such understanding develops most readily through daily collaboration in the laboratory and in the field.

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NEW TECHNIQUES IN ARCHAEOLOGY

Froelich Rainey

This paper is concerned with new, post-war techniques being developed for archaeological dating, exploration, and interpretation. The acceleration in scientific technology, particularly since the last war, seems to me a new order of development which is without precedent. It affects not only the way we live, but the way we think because it provides new tools for basic scientific research. The application of accelerators in the study of fundamental particles, the radio telescope and space vehicles in astronomy, and the electron microscope in biology are perhaps the most familiar examples of technical apparatus which dramatically affect our knowledge and theories about the nature of our environment. They expand the horizons of thought in ways which we do not yet fully understand. Technological tools for scientific investigation may well turn out to be this generation's principal contribution to learning.

The possibilities for the application of this new order of technology in archaeology are clearly demonstrated by the results of the radiocarbon method for absolute dating. It is not simply a convenient tool for dating a specific archaeological site or period, but the means by which we can establish a firm chronology for cultural history during the past 40,000 years. And there are now other promising radioactive methods which will probably provide the chronology for all of man's history. Thus much of our past preoccupation with dating in archaeology will be redirected to other problems in historic reconstruction. Moreover, radiocarbon dating has produced some fundamental changes in historic perspective. For example, the time since the last glacial period is now known to be in the order of 10,000 years rather than 20,000 years and this alters our theories about the end of the paleolithic period. With radiocarbon we have learned that the archaie culture of eastern United States existed some 5,000 years B. C. rather than, as supposed, about the time of Christ. In Jordan, at Jericho, we can date the end of the mesolithic period at 9,000 B. C. and the beginning of a pre-pottery neolithic period with developed architecture and urban living at about 8,000 B. C. I doubt that most of us would have accepted a date of 8,000 B. C., for that level at Jericho, without the radiocarbon record.

The very early dates for pre-Classic Maya civilization at Kaminalhuyu in Guatemala, human occupation of islands in Micronesia in the second millennium B. C., archaeological remains on the northern tip of Greenland dating from the third millennium, and for the very early dates for the neolithic in Japan, are all examples of startling changes in our thinking about cultural history derived from this method of absolute dating.

There is also another side to the coin. We have learned that the physical scientists do not simply present us with a magic box for archaeology. The radiocarbon method was developed over a period of years by physical scientists in constant collaboration with the archaeologists. It is still being perfected and the research, relying in many respects upon archaeological data, is now contributing to basic research in earth sciences. For example, we now know that the amount of radiocarbon (C-14) in the atmosphere is not constant and that there have been significant changes during the past. Changes may be due to fluctuations in cosmic ray intensity (the source of the neutrons which collide with N-14 to produce C-14 in the upper atmosphere,), fluctuations in the earth's magnetic field which affects the numbers of cosmic rays, or to changes in the equilibrium conditions between atmosphere and oceans. The increased carbon dioxide in the atmosphere which results from increased population and the consequent increased release of CO_2 into the atmosphere from industry and burning of all kinds, and the increase of C-14 in the atmosphere resulting from large scale nuclear weapons testing have affected the investory of C-14 in modern times.

The radiocarbon laboratory at the University of Pennsylvania has been investigating these phenomena since 1951, and like other laboratories engaged in similar research, has utilized organic materials of known age supplied by the archaeologists and the tree-ring laboratories in order to establish the amount and the periods of fluctuation in C-14. Such basic research in the radiocarbon method has not only refined the system so that more dependable and precise dates are possible, but explores the intricate problems of cosmic ray and magnetic field intensities which affect our environment in ways which are not yet fully understood. Sutdies of remenant magnetism in Roman kilns, and other fired clay materials, indicate that the magnetic field of the earth was about 65% stronger in Roman times than at present and from this it has been suggested that the C-14 content of the atmosphere was so much lower 2,000 years ago that C-14 dates would be a minimum of 240 years too old. The Pennsylvania laboratory is demonstrating, with the analysis of archaeological materials of known age, that there are several periods in the past of significant change and is beginning to correct archaeological dates on the basis of these known fluctuations.

In this connection, it was noted some years ago, that there was a discrepancy of about 400 to 500 years between radiocarbon dates and archaeological dates for the early Egyptian dynasties. It is probable that the discrepancy is due to a different level of radiocarbon content in the atmosphere at that time. In order to arrive at a true dating, it is indeed difficult to find organic materials from 2,500 B. C. which can be dated independently of the radiocarbon method and of the standard Egyptian archaeological methods. To arrive at this dating, and to determine the cosmic ray and radiocarbon levels during this remote period, intensive

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studies of tree-ring and radiocarbon analysis are now being carried out on sections of the long-lived sequoia and bristlecone pines. A tree-ring sequence on living and dead bristlecone pines can be carried back 7,000 years. C-14 analysis of a sequence of rings of known age, is beginning to give us a reliable graph of the fluctuation, during the past 7,000 years. Moreover, there is a good possibility that a reliable tree-ring chronology can be worked out with the ancient cedar beams remaining in Egyptian structures, which withccertainty could explain the 400-500 year discrepancy in old Kingdom Egyptian dating. The possibilities for tree-ring dating in the Near East are indicated by the study of juniper beams in the Gordias tomb and the city mound at Godrion in Turkey. With them it was possible to establish an 804 year fl floating chronology for the Central Anatolian palin. Lebanon cedars used in Egypt should provide an even more sensitive growth record. Preliminary investigations in Egypt indicate there are sufficiently preserved logs or beams in pyramids or other structures to provide a growth record. Floating tree-ring chronologies can be coorelated with historically fixed dates.

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There are a number of electronic instruments which proved to be useful in archaeological exploration but most of them, at present, are used for locating buried features in and about a known archaeological site. Ultimately, we hope to develop such instruments so that they can be used to search for unknown sites over large, archaeologically unknown areas. The problem now is to increase the scanning range so that large-scale exploration is possible.

Resistance apparatus, used to measure the electrical conductivity in surface soils, can be applied effectively in locating many relatively shallow archaeological features when there happens to be a contrast in humidity or some other quality which determines a difference in soild conductivity. For example, many ancient ditches , refuse, pits, buried constructions, and other features have been located and accurately mapped in England by this method during the past fifteen years. Various instruments of this type also have been used in Italy and in Germany and German archaeologists have developed the most practical, light-weight, inexpensive instrument known as the "Geohm ". Tests of the instrument carried out by the Applied Science Center of the University Museum at many sites in the U. S. , Italy, Central America, and the Near East, unquestionably prove its usefulness under certain specific geophysical conditions. But it is slow to operate and we find that it can rarely locate features which are more than one or two meters beneath the surface.

The proton magnetometer developed for archaeological use, by Hall and Aitken at Oxford, measures minute differences in the magnetic intensity in surface soils. It is highly effective in locating kilns and fire-pits, as well as other fired archaeological remains, and under certain conditions, buried stone structures and earth works. In Italy, for example, we discovered that we could very quickly locate the rock-cut tombs at

Tarquinia and Cerveteri on magnetic contour maps prepared from magnetometer surveys over known cemetery areas. Our experiments there in 1961 proved that we could locate, on the average, five or six tombs per day of survey. Moreover, on the plain of Sybaris, in South Italy, we were able to trace a buried stone wall for more than 1,300 meters in a few days, and to locate other stone and brick structures which were not more than three meters beneath the surface. Martin Aitken has explained this success with the instrument as due to a magnetic contrast between the structures and the slightly magnetic clays in which they were buried.

More recently, 1964-1965, we have been experimenting at Sybaris with rubidium and cesium magnetometers, developed by Varian Associates for the University Museum. These are more sensitive instruments which make it possible to locate structures up to five and six meters beneath the surface. Preliminary tests with a rubidium magnetometer (designed originally for space research) at Sybaris during the fall of 1964 demonstrated that the high sensitivity of the instrument could be utilized in archaeology, and thus it was possible to pick up archaeological remains lying at least 5 meters deep. But the instrument as designed was not practical for archaeological survey. Varian Associates in collaboration with the University Museum then designed and built a light-weight read-out (a mechanism which converts and displays the frequencies detected in the form of numbers), and substituted cesium for rudibium in the sensing apparatus which made the sensors less affected by changes in orientation. Tests of the new cesium magnetometer at Sybaris in the fall of 1965 have been highly successful. Large structures lying 6 meters beneath the surface are easily detected. Moreover, with the new read- out it is po possible to carry on continuous recording so that an operator can walk steadily across a field calling out numbers of frequencies to a recorder. In this way a magnetometer survey can be made of 10 to 20 acres in one day, which is several times the area covered in one day with the proton magnetometer.

The search for the ruins of Archaic Greek Sybaris in South Italy, is an experiment in large-scale exploration of an archaeologically k unknown area. From the Graeco-Roman accounts we know that the ruins must lie somewhere on or about the plain of the Crati river. This is an area of 80 to 100 square kilometers and if the ruins lie on the plain, we now know they must be at least five meters beneath the surface. With the magnetometers and with drills we have located and mapped a ruin with Archaic, Hellenistic, and Roman levels extending over an area of about three and one half square kilometers. Test excavations and drills have disclosed Archaic pottery over most of the area, but so far only modest structures of the period of Sybaris. We can be relatively certain that this area, known as the Parco del Cavallo, is the site of the Greek and Roman ports, but without the discovery of massive stone buildings, such as those at Paestum, Locri and Metaponto, it is impossible to know certainly that this is the site of the city of Sybaris itself. However, in October 1965 the cesium magnetometer located some sort of structures measuring up to 100 meters in length at the 6 meter (Sybaris) level, and we begin to feel confident that test excavations will disclose the massive temple constructions we would expect to find at the site of the actual city. If so, we can then be sure that the Parco del Cavallo area is both the city and the port. It is significant to note that these deep and massive structures were not found with the proton-magnetometer or with the drills.

With the cesium magnetometer we now have an electronic instrument capable of searching large areas for unknown sites, given a specific type of terrain where archaeological remains are detected as magnetic anomalies. We also know that on other types of terrain, such as the highlands about the Sybaris plain, where there are individual pockets of magnetic soils, magnetometers cannot be used for survey.

Experiments with other types of electronic instruments such as seismic apparatus, metal detectors, and sonic equipment, have not as yet produced very satisfactory results. Seismic instruments do generally detect the depth and contours of bed-rock, metal detectors for the most part have too little depth range for archaeological purposes, and so far, there are unsolved problems with sonic devices. Professor Edgerton at the Massachusetts Institute of Technology is experimenting with a "Boomer" system for penetrating underwater sediments, and the

University Museum has been experimenting with a high-frequency device for use on land. In principle, both attempt to direct an electric impulse into the soil so that its reflection from an underground feature can be recorded, and thus locate the structure. In essence it is an archaeological probe resembling sonar or radar. The major problem seems to be in producing a satisfactory coupling device which will enable a high-frequency impulse to penetrate the earth without too great a loss of energy. Sonic instruments may yet turn out to be the most useful archaeological probes for large scale exploration.

Technology in the post-war years has opened a new world beneath the sea as well as in space, and only now are most of us becoming aware that the sea holds some of the most promising future discoveries in archaeology. Perhaps, because scuba diving equipment was first utilized extensively for the sport of underwater exploration, we failed to see its use in serious archaeological research. Today, thanks to the application of many new devices for underwater exploration by such trained archaeologists as George Bass, there is now a well defined discipline of underwater archaeology. It began when archaeologists were trained to dive with scuba equipment and to apply the systematic techniques of land archaeology to the study of remains underwater. It expands with rapidly developing equipment permitting more efficient underwater surveys and more effective methods of excavating and recording.

Free-swimming scuba equipment made possible the systematic excavation and recording of a Bronze Age wreck off Cape Gelydonia which had been discovered by Turkish sponge divers, the discovery of Maya remains in lake Amatetlan in Guatemala, the study of many Roman wrecks in the Mediterranean, the exploration of the sunken city of Port Royal in Jamaica, the investigation of the sunken port at Corinth, and the excavation of a Villanovan villate at the bottom of Lake Bolsena in Italy. Then the development of stereophotogrammetric mapping of wrecks off Bodrum on the Turkish Coasts introduced a new precision and efficiency in underwater work. At present emphasis is being placed upon new techniques for exploration.

Scuba divers cannot work with safety at depths greater than 150 ft. Moreover, at that depth they can work for only a short period each day. Free-swimming exploration even at shallow depths on the vast land-shelf of the seas where archaeological remains may be found, is painfully slow. Hence at present we have a very limited idea of the extent and kind of remains which can be found there. Most of those which have been found are accidental discoveries. It is now clear that the most important discoveries will be made when better exploration equipment is developed for the archaeologist.

To this end, the University Museum commissioned the Electric Boat Division of the General Dynamics Corporation to build a small, two-man submarine specifically for undersea archaeological survey.

The operators inside the submarine are at surface atmospheric pressure which eliminates many of the physiological problems of the scuba diver. Cruising under sea at 4 knots and to depths of at least 300 feet, up to 8 hours a day, with viewing ports and outside pressurized lights, the range and speed of undersea search is vastly increased. Moreover, with the addition of the stereophotogrammetric equipment for mapping which has been attached to the submarine, accurate mapping of the sunken remains is now possible in a fraction of the time required by scuba divers.

Still other exploration techniques under sea were pioneered by George Bass during the summer of 1965 off the coast of Turkey. A steel capsule, shaped something like a Mercury Space Capsule and known as a "Tow-Vane", was used to plane down to 275 feet for observation of the sea bottom. The operator inside the capsule remained at atmospheric pressure breathing recirculated air to which oxygen had been added. He maintained contact with the towing vessel on the surface by means of a telephone. A closed-circuit television camera was also towed along the sea bottom with a monitor in the cabin of the towing vessel observing the sea floor in the area scanned by the camera. It is interesting to note that the camera could often "see" better than the naked eye when the sea water was clouded, and that natural light was sufficient down to 270 feet. Still another experiment was made with a proton magnetometer designed by E. T. Hall of the Oxford Laboratory for undersea use. It also was towed over the sea bottom in search of metal and deposits of pottery.

All of these intruments functioned properly and could examine the sea bottom in search of archaeological remains as intended. Nevertheless, the specific wrecks known to be in the area searched were not found. And from this we reached the obvious conclusion that the sea is very big, remains of wrecks are very small, and the scanning range of the instruments used is still too limited to give us an easy and rapid way to explore the sea bottom. But this kind of search is in its infancy, and the development of such techniques is proceeding at an extraordinarily rapid rate.

Finally, there is one aspect to this research into the new technology of archaeology which in the long run may be the most significant. For once, in a very small way to be sure, some of us interested in the humanities are working directly with the physical scientists on spedific research projects to solve technical problems of concern to us both. We arechaeologists are too little aware of the revolutionary technological changes affecting our world and I think the physical scientists are too little aware of the forces of history. Here, for once, we are at least crossing over between the two worlds of science and the humanities in a very practical day-by-day experience. There is enthusiasm and excitement on both sides and a new awareness of the attitudes in another kind of discipline.

I think most of us are concerned about a better understanding between humanists and scientists in this strange new world of rapid change. There can be no coubt that such understanding develops most rapidly through daily collaboration in the laboratory and in the field.

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Analytical Techniques-General

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NEW TECHNIQUES IN ARCHAEOLOGY

Froelich Rainey

This paper is concerned with new, post-war techniques being developed for archaeological dating, exploration, and interpretation. The acceleration in scientific technology, particularly since the last war, seems to me a new order of development which is without precedent. It affects not only the way we live, but the way we think because it provides new tools for basic scientific research. The application of accelerators in the study of fundamental particles, the radio telescope and space vehicles in astronomy, and the electron microscope in biology are perhaps the most familiar examples of technical apparatus which dramatically affect our knowledge and theories about the nature of our environment. They expand the horizons of thought in ways which we do not yet fully understand. Technological tools for scientific investigation may well turn out to be this generation's principal contribution to learning.

The possibilities for the application of this new order of technology in archaeology are clearly demonstrated by the results of the radiocarbon method for absolute dating. It is not simply a convenient tool for dating a specific archaeological site or period, but the means by which we can establish a firm chronology for cultural history during the past 40,000 years. And there are now other promising radioactive methods which will probably provide the chronology for all of man's history. Thus much of our past preoccupation with dating in archaeology will be redirected to other problems in historic reconstruction. Moreover, radiocarbon dating has produced some fundamental changes in historic perspective. For example, the time since the last glacial period is now known to be in the order of 10,000 years rather than 20,000 years and this alters our theories about the end of the paleolithic period. With radiocarbon we have learned that the archaie culture of eastern United States existed some 5,000 years B. C. rather than, as supposed, about the time of Christ. In Jordan, at Jericho, we can date the end of the mesolithic period at 9,000 B. C. and the beginning of a pre-pottery neolithic period with developed architecture and urban living at about 8,000 B. C. I doubt that most of us would have accepted a date of 8,000 B. C., for that level at Jericho, without the radiocarbon record.

The very early dates for pre-Classic Maya civilization at Kaminalhuyu in Guatemala, human occupation of islands in Micronesia in the second millennium B. C., archaeological remains on the northern tip of Greenland dating from the third millennium, and for the very early dates for the neolithic in Japan, are all examples of startling changes in our thinking about cultural history derived from this method of absolute dating.

There is also another side to the coin. We have learned that the physical scientists do not simply present us with a magic box for archaeology. The radiocarbon method was developed over a period of years by physical scientists in constant collaboration with the archaeologists. It is still being perfected and the research, relying in many respects upon archaeological data, is now contributing to basic research in earth sciences. For example, we now know that the amount of radiocarbon (C-14) in the atmosphere is not constant and that there have been significant changes during the past. Changes may be due to fluctuations in cosmic ray intensity (the source of the neutrons which collide with N-14 to produce C-14 in the upper atmosphere.), fluctuations in the earth's magnetic field which affects the numbers of cosmic rays, or to changes in the equilibrium conditions between atmosphere and oceans. The increased carbon dioxide in the atmosphere which results from increased population and the consequent increased release of CO_2 into the atmosphere from industry and burning of all kinds, and the increase of C-14 in the atmosphere resulting from large scale nuclear weapons testing have affected the inventory of C-14 in modern times.

The radiocarbon laboratory at the University of Pennsylvania has been investigating these phenomena since 1951, and like other laboratories engaged in similar research, has utilized organic materials of known age supplied by the archaeologists and the tree-ring laboratories in order to establish the amount and the periods of fluctuation in C-14. Such basic research in the radiocarbon method has not only refined the system so that more dependable and precise dates are possible, but explores the intricate problems of cosmic ray and magnetic field intensities which affect our environment in ways which are not yet fully understood. Sutdies of remenant magnetism in Roman kilns, and other fired clay materials, indicate that the magnetic field of the earth was about 65% stronger in Roman times than at present and from this it has been suggested that the C-14 content of the atmosphere was so much lower 2,000 years ago that C-14 dates would be a minimum of 240 years too old. The Pennsylvania laboratory is demonstrating, with the analysis of archaeological materials of known age, that there are several periods in the past of significant change and is beginning to correct archaeological dates on the basis of these known fluctuations.

In this connection, it was noted some years ago, that there was a discrepancy of about 400 to 500 years between radiocarbon dates and archaeological dates for the early Egyptian dynasties. It is probable that the discrepancy is due to a different level of radiocarbon content in the atmosphere at that time. In order to arrive at a true dating, it is indeed difficult to find organic materials from 2,500 B. C. which can be dated independently of the radiocarbon method and of the standard Egyptian archaeological methods. To arrive at this dating, and to determine the cosmic ray and radiocarbon levels during this remote period, intensive

studies of

studies of tree-ring and radiocarbon analysis are now being carried out on sections of the long-lived sequoia and bristlecone pines. A tree-ring sequence on living and dead bristlecone pines can be carried back 7,000 years. C-14 analysis of a sequence of rings of known age, is beginning to give us a reliable graph of the fluctuation, during the past 7,000 years. Moreover, there is a good possibility that a reliable tree-ring chronology can be worked out with the ancient cedar beams remaining in Egyptian structures, which with certainty could explain the 400-500 year discrepancy in old Kingdom Egyptian dating. The possibilities for tree-ring dating in the Near East are indicated by the study of juniper beams in the Gordias tomb and the city mound at Godrion in Turkey. With them it was possible to establish an 804 year floating chronology for the Central Anatolian plain. Lebanon cedars used in Egypt should provide an even more sensitive growth record. Preliminary investigations in Egypt indicate there are sufficiently preserved logs or beams in pyramids or other structures to provide a growth record. Floating tree-ring chronologies can be coorelated with historically fixed dates.

With these refinements in the C-14 method, we may expect to work out a much more accurate chronology for historic events not only in the pre-historic but in the proto-historic epochs of Bronze and Iron Age civilizations in the Mediterranean and the Near East. But the point I wish to emphasize here is that collaboration between archaeologists and physical scientists in perfecting the C-14 method of dating. leads also to a better understanding of significant forces in our natural environment.

The potassium-argon, rubidium-strontium, uranium, and lead isotope ratio methods of dating developed during the post-war years, are of primary interest in calculating geological time, but they are, of course, applicable in dating the earliest stages in human development (probable range of 12 to 0.36 million years). For example, late trinil basalt from the Muriah volcano in central Java has been dated by the potassium-argon method at 500,000 years and thus gives an age estimate for Pithecantropus. Best known to archaeologists are the attempts to date the remains of Zinjanthropus in Bed I in the Olduvai deposits of east Africa. There is still disagreement about the age of these deposits but the last opinion I have seen, is that the Bed is not appreciably older than 1.7 million years. Predictable improvements in the rubidium-strontium method probably will make it applicable in early Pleistocene ages when applied to obsidians and acid volcanic rock.

Recent investigations (1965) promise to bridge the gap between the C-14 method covering the past (40,000 years) and the potassium-argon and other methods for dating much more ancient periods. At least a series of thorium-230 - uranium 238 measurements on corals from atoll borings, demonstrate the possibility of obtaining dates for Pleistocene carbonates. This should cover the range between 10,000 and

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The Research Laboratory for Archaeology and the History of Art at Oxford, has reported on a number of analytical techniques currently being investigated, which, like the neutron activation method, can be used for quantitative and qualitative studies of materials directed in archaeology to tracing the origin of manufacture, various trade routes, an understanding of ancient technology, and for the detection of fakes: these include X-ray fluorescence, electric beam X-ray scanning micro-analysis, beta-ray backscatter meter, and optical emission spectrometry. But the essential point I should like to make here is that these are for the most part archaeological tools recently derived from post-war atomic-nuclear studies. It is their number and rate of development which indicates the probable future impact upon archaeological studies.

There are a number of electronic instruments which proved to be useful in archaeological exploration but most of them, at present, are used for locating buried features in and about a known archaeological site. Ultimately, we hope to develop such instruments so that they can be used to search for unknown sites over large, archaeologically unknown areas. The problem now is to increase the scanning range so that large-scale exploration is possible.

Resistance apparatus, used to measure the electrical conductivity in surface soils, can be applied effectively in locating many relatively shallow archaeological features when there happens to be a contrast in ~~humidity~~ moisture content or some other quality which determines a difference in soil conductivity. For example, many ancient ditches, refuse, pits, buried constructions, and other features have been located and accurately mapped in England by this method during the past fifteen years. Various instruments of this type also have been used in Italy and in Germany and German archaeologists have developed the most practical, light-weight, inexpensive instrument known as the "Geohm". Tests of the instrument carried out by the Applied Science Center of the University Museum at many sites in the U. S., Italy, Central America, and the Near East, unquestionably prove its usefulness under certain specific geophysical conditions. But it is slow to operate and we find that it can rarely locate features which are more than one or two meters beneath the surface.

The proton magnetometer developed for archaeological use, by Hall and Aitken at Oxford, measures minute differences in the magnetic intensity in surface soils. It is highly effective in locating kilns and fire-pits, as well as other fired archaeological remains, and under certain conditions, buried stone structures and earth works. In Italy, for example, we discovered that we could very quickly locate the rock-cut tombs at

Tarquinia and Cerveteri on magnetic contour maps prepared from magnetometer surveys over known cemetery areas. Our experiments there in 1961 proved that we could locate, on the average, five or six tombs per day of survey. Moreover, on the plain of Sybaris, in South Italy, we were able to trace a buried stone wall for more than 1,300 meters in a few days, and to locate other stone and brick structures which were not more than three meters beneath the surface. ~~Martin Aitken has explained~~ This success with the instrument is due to a magnetic contrast between the structures and the slightly magnetic clays in which they were buried.

More recently, 1964-1965, we have been experimenting at Sybaris with rubidium and cesium magnetometers, developed by Varian Associates for the University Museum. These are more sensitive instruments which make it possible to locate structures up to five and six meters beneath the surface. Preliminary tests with a rubidium magnetometer (designed originally for space research) at Sybaris during the fall of 1964 demonstrated that the high sensitivity of the instrument could be utilized in archaeology, and thus it was possible to pick up archaeological remains lying at least 5 meters deep. But the instrument as designed was not practical for archaeological survey. Varian Associates in collaboration with the University Museum then designed and built a light-weight read-out (a mechanism which converts and displays the frequencies detected in the form of numbers), and substituted cesium for rudibium in the sensing apparatus which made the sensors less affected by changes in orientation. Tests of the new cesium magnetometer at Sybaris in the fall of 1965 have been highly successful. Large structures lying 6 meters beneath the surface are easily detected. Moreover, with the new read- out it is possible to carry on continuous recording so that an operator can walk steadily across a field calling out numbers of frequencies to a recorder. In this way a magnetometer survey can be made of ~~10 to 20~~ 5 to 10 acres in one day, which is several times the area covered in one day with the proton magnetometer.

The search for the ruins of Archaic Greek Sybaris in South Italy, is an experiment in large-scale exploration of an archaeologically unknown area. From the Graeco-Roman accounts we know that the ruins must lie somewhere on or about the plain of the Crati river. This is an area of 80 to 100 square kilometers and if the ruins lie on the plain, we now know they must be at least five meters beneath the surface. With the magnetometers and with drills we have located and mapped a ruin with Archaic, Hellenistic, and Roman levels extending over an area of about three and one half square kilometers. Test excavations and drills have disclosed Archaic pottery over most of the area, but so far only modest structures of the period of Sybaris. We can be relatively certain that this area, known as the Parco del Cavallo, is the site of the Greek and Roman ports, but without the discovery of massive stone buildings, such as those at Paestum, Locri and Metaponto, it is impossible to know certainly that this is the site of the city of Sybaris itself. However, in October 1965, the cesium magnetometer located some sort of structures measuring up to 100 meters in length at the 6 meter (Sybaris) level, and we begin to feel confident that test excavations will disclose the massive temple constructions we would expect to find at the site of the actual city. If so, we can then be sure that the Parco del Cavallo area is both the city and the port. It is significant to note that these deep and massive structures were not found with the proton-magnetometer or with the drills.

With the cesium magnetometer we now have an electronic instrument capable of searching large areas for unknown sites, given a specific type of terrain where archaeological remains are detected as magnetic anomalies. We also know that on other types of terrain, such as the highlands about the Sybaris plain, where there are individual pockets of magnetic soils, magnetometers cannot be used for survey.

Experiments with other types of electronic instruments such as seismic apparatus, metal detectors, and sonic equipment, have not as yet produced very satisfactory results. Seismic instruments do generally detect the depth and contours of bed-rock, metal detectors for the most part have too little depth range for archaeological purposes, and so far, there are unsolved problems with sonic devices. Professor Edgerton at the Massachusetts Institute of Technology is experimenting with a "Boomer" system for penetrating underwater sediments, and the

University Museum has been experimenting with a high-frequency device for use on land. In principle, both attempt to direct an electric impulse into the soil so that its reflection from an underground feature can be recorded, and thus locate the structure. In essence it is an archaeological probe resembling sonar or radar. The major problem seems to be in producing a satisfactory coupling device which will enable a high-frequency impulse to penetrate the earth without too great a loss of energy. Sonic instruments may yet turn out to be ~~the most~~ useful archaeological probes for large scale exploration.

Technology in the post-war years has opened a new world beneath the sea as well as in space, and only now are most of us becoming aware that the sea holds some of the most promising future discoveries in archaeology. Perhaps, because scuba diving equipment was first utilized extensively for the sport of underwater exploration, we failed to see its use in serious archaeological research. Today, thanks to the application of many new devices for underwater exploration by such trained archaeologists as George Bass, there is now a well defined discipline of underwater archaeology. It began when archaeologists were trained to dive with scuba equipment and to apply the systematic techniques of land archaeology to the study of remains underwater. It expands with rapidly developing equipment permitting more efficient underwater surveys and more effective methods of excavating and recording.

Free-swimming scuba equipment made possible the systematic excavation and recording of a Bronze Age wreck off Cape Gelydonia which had been discovered by Turkish sponge divers, the discovery of Maya remains in lake Amatetlan in Guatemala, the study of many Roman wrecks in the Mediterranean, the exploration of the sunken city of Port Royal in Jamaica, the investigation of the sunken port at Corinth, and the excavation of a Villanovan villate at the bottom of Lake Bolsena in Italy. then the development of stereophotogrammetric mapping of wrecks off Bodrum on the Turkish Coasts introduced a new precision and efficiency in underwater work. At present emphasis is being placed upon new techniques for exploration.

Scuba divers cannot work with safety at depths greater than 150 ft. Moreover, at that depth they can work for only a short period each day. Free-swimming exploration even at shallow depths on the vast land-shelf of the seas where archaeological remains may be found, is painfully slow. Hence at present we have a very limited idea of the extent and kinds of remains which can be found there. Most of those which have been found are accidental discoveries. It is now clear that the most important discoveries will be made when better exploration equipment is developed for the archaeologist.

To this end, the University Museum commissioned the Electric Boat Division of the General Dynamics Corporation to build a small, two-man submarine specifically for undersea archaeological survey.

The operators inside the submarine are at surface atmospheric pressure which eliminates many of the physiological problems of the scuba diver. Cruising under sea at 4 knots and to depths of at least 300 feet, up to 8 hours a day, with viewing ports and outside pressurized lights, the range and speed of undersea search is vastly increased. Moreover, with the addition of the stereophotogrammetric equipment for mapping which has been attached to the submarine, accurate mapping of the sunken remains is now possible in a fraction of the time required by scuba divers.

Still other exploration techniques under sea were pioneered by George Bass during the summer of 1965 off the coast of Turkey. A steel capsule, shaped something like a Mercury Space Capsule and known as a "Tow-Vane", was used to plane down to 275 feet for observation of the sea bottom. The operator inside the capsule remained at atmospheric pressure breathing recirculated air to which oxygen had been added. He maintained contact with the towing vessel on the surface by means of a telephone. A closed-circuit television camera was also towed along the sea bottom with a monitor in the cabin of the towing vessel observing the sea floor in the area scanned by the camera. It is interesting to note that the camera could often "see" better than the naked eye when the sea water was clouded, and that natural light was sufficient down to 270 feet. Still another experiment was made with a proton magnetometer designed by E. T. Hall of the Oxford Laboratory for undersea use. It also was towed over the sea bottom in search of metal and deposits of pottery.

All of these intruments functioned properly and could examine the sea bottom in search of archaeological remains as intended. Nevertheless, the specific wrecks known to be in the area searched were not found. And from this we reached the obvious conclusion that the sea is very big, remains of wrecks are very small, and the scanning range of the instruments used is still too limited to give us an easy and rapid way to explore the sea bottom. But this kind of search is in its infancy, and the development of such techniques is proceeding at an extraordinarily rapid rate.

Finally, there is one aspect to this research into the new technology of archaeology which in the long run may be the most significant. For once, in a very small way to be sure, some of us interested in the humanities are working directly with the physical scientists on spedific research projects to solve technical problems of concern to us both. We archaeologists are too little aware of the revolutionary technological changes affecting our world and I think the physical scientists are too little aware of the forces of history. Here, for once, we are at least crossing over between the two worlds of science and the humanities in a very practical day-by-day experience. There is enthusiasm and excitement on both sides and a new awareness of the attitudes in another kind of discipline.

I think most of us are concerned about a better understanding between humanists and scientists in this strange new world of rapid change. There can be no coubt that such understantling develops most rapidly through daily collaboration in the laboratory and in the field.

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