Tools for Archeology: Aids to Studying the Past

The archeological dig or excavation is still the primary method for exploring man's prehistoric past. Increasingly, however, archeologists have been borrowing techniques from physics, chemistry, and space technology to help recover artifacts and information from early civilizations. Prospecting techniques, such as aerial photography and magnetometer surveys, aid in locating potential sites and in selecting where to dig. Excavation technology itself has been improved by the development of flotation techniques and the application of power machinery for earth moving and screening. More accurate age determinations of artifacts are now possible because of improvements in radiocarbon methods and the development of new techniques such as thermoluminescence. Many of the new tools are still being developed, many are not universally applicable, and there are some archeologists who dismiss "gadgetry" as subsidiary to the main concerns in the field. But taken all together, physical instrumentation seems likely to have a major impact on the practice of archeology and the precision of its analysis of the past.

Many of the new instruments and improvements in analytic techniques are being developed at the Museum Applied Science Center for Archeology (MASCA) of the University Museum in Philadelphia, and at the Research Laboratory for Archeology (RLA) in Oxford, England—the two largest centers for this work. But archeologists and applied scientists in many fields, and at many different universities, have also been active in improving archeological tools. The familiarity with physics and chemistry required to use these new tools properly is indicative of the greater degree of technical sophistication that is increasingly common among archeologists today.

Prospecting

Aerial photography has been used to help locate archeological formations for many years. Often, geometrical shapes that are visible only from the air are marked by variations in the growth of a crop—wheat, for example—indicating the presence of an ancient wall or ditch. In other types of terrain, photographs can indicate patterns in plant cover, rock types, and terracing, which an observer on the ground would miss. But finding traces of archeological formations with standard photography is often a hit or miss affair. Crop marks, for example, are usually visible only for short periods of the growing season, or during a drought; different crops and soils have different peak times. Recently, archeologists have been attempting to improve remote sensing techniques, by using multispectral methods, in the hope of finding better contrasts with infrared film, and by recording the natural, as opposed to the cultural, landscape. In this latter technique, archeologists use photographs to help identify former springs, shorelines of ancient lakes, and other preferred areas for habitation or hunting which may be potential excavation sites.

Experiments with black-and-white, color, and infrared films have shown that each has certain advantages and that simultaneous recording with two or more often gives the best results (*1*). Archeologists at MASCA, headed by Froelich Rainey, have been experimenting with special cameras that are capable of recording, in spectral bands, from the near ultraviolet to the medium infrared by means of nine lenses and three films. George Gumerman of Prescott College in Arizona has used a combination of infrared and black-and-white film to map the types of soil and groundcover in a Mexican valley; the photographs were used to determine how several known archeological sites fitted into the various microenvironments of the valley. Infrared scanning equipment, although too expensive for normal archeological applications, has been used to discover buried cultural features—in one instance, prehistoric garden plots in Arizona—by recording patterns in the far infrared spectrum, where film is no longer practical.

It is usually impossible to excavate all of a site, but preliminary surveys with resistivity or magnetic intensity measurements can sometimes locate buried structures or artifacts before excavation. Resistivity instruments, which measure the electrical conductivity of surface soils, can usually locate features only in the upper 2 meters of soil. Proton magnetometers, developed for archeological use by scientists at RLA, can sense features somewhat deeper and have been used to locate buried kilns and firepits. The graphs of magnetic contours prepared with the instrument show anomalies when the contrast between the magnetic susceptibility or the remanent magnetism of the buried objects and the surrounding clay is large enough.

More recently, rubidium and cesium magnetometers that are more sensitive and that can detect anomalies 6 or 7 meters into the ground have been developed by Varian Associates and used by Elizabeth Ralph of MASCA to help find the ancient Greek city of Sybaris in southern Italy. The exact location of the city had not been known, because the plain on which it was built had been covered by up to 6 meters of silt. The properties of the area—slightly magnetic, extremely uniform soil—exemplify the conditions under which magnetometer surveys seem to be most useful (*2*). Where there is a high level of background magnetic noise, magnetometers do not provide much useful information.

Two sensors are often used in magnetometer surveys, one as a fixed reference, so that diurnal and other temporal variations in the magnetic field are canceled out; any buried anomaly shows up as a difference in the readings. The maps of the magnetic field strength, prepared from magnetometer surveys, may show linear shapes that can be interpreted as walls or other large structures. In Greece, for example, the entire street plan of the ancient town of Elis was mapped out in this manner.

Underwater exploration for archeological remains has until recently been limited to the small area that a man with scuba equipment could cover. Two-man submarines that have been constructed especially for archeological exploration extend the range somewhat. George Bass of the University Museum in Philadelphia has been applying side-scanning sonar techniques that make possible the exploration of much larger underwater areas.

Because of practical limitations on the size of the screens that can be used to sift dirt at an archeological site, as much as 20 to 50 percent of the small artifacts are missed in most digs. These include such things as fossilized remains of plants, small animal bones, and other food items. A novel flotation method of recovering these remains in quantity has been developed by Stewart Struever of Northwestern University. In the first stage, running water and a fine mesh screen are used to process large quantities of soil, separating out leaves, roots, nut shells, animal vertebra, and similar items. Then, in a chemical flotation stage, the plant remains are separated from bones and pottery chips with a solution of zinc chloride in which the lighter remains float. The system, although crude (Struever built the first model out of old wash tubs), allows the processing of large quantities of soil in a short period of time and works well enough to recover thousands of samples that would otherwise be lost.

Analysis of recovered material is increasingly being done in the field as part of the excavation procedure. Kent Schneider at the University of Georgia, for example, has assembled a flotation system basically similar to that described above, a carbon-14 dating laboratory, and other instruments and fitted them in a mobile van that can be driven into the field.

Age Determination

One of the recurring needs in archeological research is accurate determination of the age of artifactual material. The most widely used radiochemical method of dating, the carbon-14 method, is based on the radioactive decay of the trace amounts of the ^{14}C isotope present in all organic substances. The accuracy of the method depends on the assumption that the amount of ^{14}C in atmospheric CO_2 has been constant in the past, but this assumption has been shown to be incorrect; discrepancies between ^{14}C dates and those based on archeological evidence for the ages of the Egyptian dynasties, and more recently, the comparison of the ages of wood samples dated both by reference to a tree-ring chronology and by the ^{14}C method have confirmed that there are large systematic errors in the older ^{14}C dates.

Tree-ring dating for the earlier periods is based on the slow rate of growth and the extremely long lifetime of the bristlecone pine trees that are found in parts of the southwestern United States; specimens as old as 4900 years have been found, making them the oldest of living trees. The growth of these trees varies perceptably with climatic changes, so that characteristic patterns often occur in the tree rings, especially in trees subjected to extremes of drought and temperature. When the tree rings are counted microscopically and the annual growth patterns are analyzed with a computer, it is possible to link up the record preserved in dead trees with that of still living trees. In this way Wesley Ferguson, of the University of Arizona at Tuscon, has been able to build up a chronology that extends back some 8200 years.

Only the outer growth ring of a mature tree is actively growing and taking in ^{14}C from the atmosphere; within a small margin of error, therefore, the ^{14}C content of a given piece of wood should be that which was present at the time its growth rings were formed. If the ^{14}C content of the atmosphere had been constant throughout the past, the ^{14}C and tree ring ages should agree. But comparison of these dates has shown that the ^{14}C dates are consistently more recent than the true age for periods earlier than 800 B.C. According to a table of correction factors established by Ralph and Henry Michael of MASCA, the discrepancy increases steadily with the age of the sample, reaching 750 years for the period between 4000 and 4500 B.C. (*3*). Thus the accuracy and reliability of the ^{14}C method has been improved.

The cause of the past fluctuations in the ^{14}C content of the biosphere is not known. One explanation is based on the assumption that climatic changes are responsible. The melting of glaciers after the last ice age may have altered the equilibrium balance between the oceans and the atmosphere sufficiently to temporarily increase the amount of ^{14}C in the air. If this explanation is correct, then the discrepancy between tree ring ages and ^{14}C dates should decrease for periods earlier than about 7000 B.C.—a possibility that can be tested if the tree ring chronology can be extended back to that time. A more probable explanation, according to many geophysicists, is that changes in the earth's magnetic field has altered the intensity of the cosmic rays reaching the earth's atmosphere and thus the ^{14}C concentration—^{14}C is produced in the atmosphere by irradiation of nitrogen with neutrons from cosmic rays.

Carbon-14 techniques are also being improved by more elaborate chemical refinement of samples before they are dated. Bones, for example, are often unreliable items for ^{14}C dating because they may have exchanged calcium carbonate with groundwater, thus contaminating the sample with carbon of more recent origin. But William Berger of the University of California at Los Angeles has developed a method of dating the organic collagen fraction within bones, after first purifying the material chemically.

Despite its usefulness to archeology, ^{14}C dating is limited to organic materials and a few inorganic carbon compounds. Other artifacts, such as pottery and bricks, are often dated by their association with ^{14}C dated material, although this is often unsatisfactory. But the thermoluminescence method of dating, which is still being developed, will allow the age of those artifacts that are made from fired clays to be directly determined as well. Crystal imperfections in the clay can trap electrons that have been raised to higher energy levels by bombardment during the radioactive decay of the trace amounts of uranium, thorium, and potassium that are found in most clays. When the clay is fired, these trapped electrons are released, giving off their energy in the form of light. The amount of light given off is proportional to the amount of radioactive material in the sample, the susceptibility of the material to radiation damage, and the length of time since the clay was last fired; by determining all except the last in the laboratory, the age of manufacture of a piece of pottery or a tile can be determined.

In applying the method, small pieces of an artifact are ground up, their radioactive content is measured, and then the sample is heated rapidly by a furnace equipped with a photomultiplier tube to measure the emitted light. The procedure is repeated, after the material has been irradiated with a known dosage of x-rays, to determine the susceptibility. By dating samples of known age, Mark Han of MASCA has been able to calibrate the method and then to show that it gives reasonable accuracy for ages back to about 1000 B.C. The improvement of the method, he believes, will eventually allow acceptable accuracy for older artifacts as well.—ALLEN L. HAMMOND

References

1. G. Gumerman and T. Lyons, *Science* **172**, 126 (1971).
2. E. Ralph, F. Morrison, D. O'Brien, *Geoexploration* **6**, 109 (1967).
3. H. N. Michael and E. Ralph, *Nobel Symp.* **12**, 109 (1970).