Application of the Physical Sciences to Archeology

Recent developments in locating sites by high-sensitivity magnetometers, in the study of provenience by elemental analysis and petrographic methods, in dating and authentication, and in recreating ancient techniques of making artifacts were reported at a symposium on the application of the physical sciences to archeology (*1*).

F. Morrison (Department of Engineering Geoscience, University of California, Berkeley) reviewed the latest applications of the recently developed cesium and other alkali vapor magnetometers in locating archeological features (such as ancient brick walls, kilns, and stone monuments) and in locating and mapping buried cities.

The action of the magnetometers is based on their ability to sensitively detect anomalies in the static magnetic field of the earth. With a sensitivity of 1 gamma (10^{-5} oersted), the magnetometer can detect an anomaly caused by 1 kg of iron at a distance of 10 m. But remanent magnetism (such as that associated with fired clay, building block material, and basalt in surrounding clay) requires a sensitivity of 0.1 to 0.01 gamma. Alkali vapor magnetometers now available are sensitive to as little as 0.001 gamma. To make use of such sensitivity, the background must be homogeneous. Time variations of the order of 0.1 to 10 gammas are also superimposed on the magnetic field of the earth, but these can be canceled out by using two detectors differentially.

When the magnetometer is operating, the cesium in the cell is heated and light is fed into the vapor. The excitation of the electrons of the cesium atoms causes the cell to become opaque. The radio frequency that is applied to return the electrons to the ground state depends critically on the magnetic field at the cell; the output from an alkali magnetometer is a frequency proportional to the magnetic field in which the sensor is placed. The proportionality constant for cesium and rubidium magnetometers is typically 3 to 5 cycles per second per gamma. With a counting interval of 20 seconds, conventional counters can yield sensitivities as high as 0.01 gamma.

In the magnetic survey of the buried town of Sybaris, roof tiles and walls were accurately located at 4-m depth to within a few tenths of a meter. Out of the eight holes that were drilled, six were on the anomaly, within a meter from where its position had been predicted.

The largest structure at the Olmec ceremonial center of La Venta is an earth pyramid, which is the oldest pyramid in the Western Hemisphere. This pyramid was assumed to have a rectangular base until 1967, when it was found, instead, to be a fluted cone with ten alternating valleys and ridges running up its sloping surfaces. This finding revived interest in the function of the 33-m mound and in the possibility that it might contain buried structures. Samples of the soil were tested and found to be effectively nonmagnetic. The known Olmec monuments, including the famous giant heads, are made of a basalt that is of a particularly magnetic type; it was therefore felt that any stone monuments or basalt structures buried or built within the pyramid would be detected by a magnetometer of the type described.

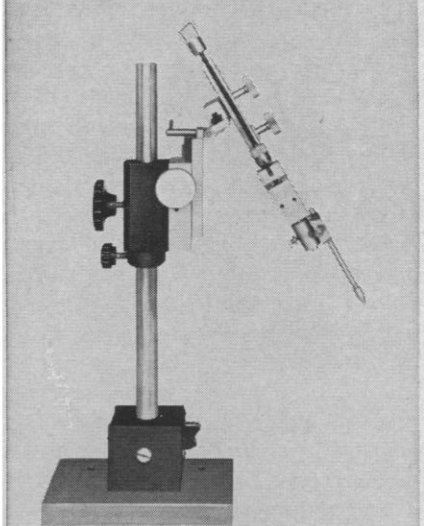
In 1969, a team sponsored by the National Geographic Society surveyed the La Venta pyramid. Surprisingly, 3- to 5-gamma anomalies were found along radial lines; they were identified as soil layers of unexpectedly high magnetic susceptibility. However, 20-gamma anomalies were also found, and a computerized interpretation of the complex data indicates a strong probability that a thin (approximately ½ m) horizontal slab forms a base for two walls; the slab would come within 1 m of the surface, and the walls to within 1 to 1½ m of the surface. Although the anomaly may derive simply from suitably arranged rubble, it is probable that basalt is producing the anomaly. Future excavation will show how well the survey has outlined the structures in the pyramid.

I. Perlman (Department of Chemistry and Lawrence Radiation Laboratory, University of California, Berkeley) spoke about neutron activation of pottery. The significant progress in this technique results from a combination of factors: a powerful reactor; the novel lithium-drifted (silicon and germanium) detectors, which combine high resolving power with high sensitivity; high-quality computation facilities; and the accumulation of considerable experience and of a background of data. It is now possible to determine over 40 different elements in the pottery samples, although such a complete analysis is usually not made. Many of these elements can be determined to 1 percent, even if present only in concentrations of one part per million. In other elements, precision is only a few percent, and some can be estimated with even less precision. Because of the nature of the activation process, neutron activation analysis actually tends to be most sensitive for the elements normally present in low concentration.

The fundamental composition of the clays is very similar, but the minor and trace elements provide a characteristic fingerprint; thus, if enough elements are determined, it should be possible to characterize clays of a particular area uniquely.

The analysis of pottery is valuable because clay is one of the most ancient materials and is universally associated with man. People settling in a new area seem to have brought their pottery with them, but they soon started to use the clay that was available locally, while continuing to make ceramic ware in the style of their country of provenience. Therefore, analysis together with comparison of style provides good evidence of migration and transplanting of groups of people.

Neutron activation analysis yields a wealth of data, which, by their very quantity, present difficulties and bring out intrinsic complexities. The first steps in handling this information are to collect local pottery from one spot, establish a standard for the local production, and group the data. The dispersion of the individual groups is then established by statistical analysis. Any particular sample can be fitted into a particular group with a probability dependent on the dispersion of this group. An interesting example of the acuity of the procedure was found in the analysis of the clay plugs used for sealing certain predynastic Egyptian jars. The clay plugs were found to agree very well in their composition with that of "Nile mud" pottery found in the vicinity, and the body of the jars was quite similar to clay that was also found locally but which represented a material apparently used for different purposes.



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An important question is how many (and which) elements are sufficient to characterize a shard adequately. Sometimes, but not usually, one or two elements are sufficient. The clay found in a place in southern Israel, for instance, is characterized by a high hafnium content (12 parts per million), whereas most other clays contain only 2 to 3 parts per million. In an analysis of a group of Cypriot pottery, one piece was found to contain this high concentration of hafnium, and the rest of the composition was subsequently found to match the clay from Israel.

Thus far, 1400 pieces of Cypriot pottery have been analyzed to obtain a background on this type of ceramic ware. To provide a reliable analysis for an unknown Cypriot sample, an estimated 10,000 pieces will be needed. Similarly, an adequate study of the Mediterranean pottery would require about 100,000 pieces. The present rate of analysis is about 2000 pieces per year. The rate of analysis may be increased, but the difficulty of handling and, particularly, of recalling the information needed for interpretation of results increases with the rate of acquisition of data.

To achieve high accuracy, it is necessary to irradiate a calibrated sample, as well as the unknown, for comparison. About 2 years was required to develop a reliable, homogeneous sample of suitable quantity, one which had a representative composition and filled all requirements for such a standard. Analysis can be made on a very small sample, but usually a 100-mg sample is taken by use of a sapphire drill. Even this quantity is small enough so that it can usually be removed in an inconspicuous place, thus causing no visible damage to valuable pieces.

S. Fleming (Research Laboratory for Archaeology and the History of Art, Oxford University, England) described the thermoluminescence method of dating ceramics. This method, which measures the faint luminescence that is produced when ceramic objects are heated to a point where normal incandescence would interfere with the measurement (500°C), is intrinsically absolute. The luminescence is caused by the release of electrons trapped in crystal lattice defects in the clay. The electrons are trapped as a result of radiation occurring in the ceramic object. Alpha and beta radiation of relatively low penetrating power comes from radioactive material always present in clays; the gamma radiation, which has a substantially higher penetrating power, arises largely from the soil in which the object is buried. Average contributions of alpha and beta radiation are 0.22 and 0.19 rad per year, respectively, while the contribution from external sources (gamma and cosmic radiation) is on the average approximately 0.08 rad per year. Thus, about 16 percent of the total radiation to which the ware is subjected is caused by the environment. Because of the low penetration of the alpha radiation, it affects only the surface of the larger grains in the clay, and measurements are now made with samples from which the coarse grains have been eliminated by careful crushing and sieving and which, therefore, consist of grains with a diameter of about 1 to 2 μm. Alternatively, tests are made by using only coarse grains (about 100 μm in diameter) on the assumption that, of the intrinsic radiation, only the beta radiation has been effective. The calibration is performed by irradiating the material with a known dose and measuring the additional light produced on heating. The larger the ratio of light output on irradiation to that produced by the original sample, the less time has elapsed since the last firing of the ware, given an approximately equal background radiation contributed by the soil in which the object was buried.

In assessing the probability of authenticity, it is necessary to establish a minimum and a maximum age for the specimen. The criteria for authentication are (i) the minimum possible age may not overlap the documented era of forgery, and (ii) the maximum age must not exclude the archeological date of manufacture. The minimum age is given by the radiation experienced by ware that was buried at depths greater than 1 m in nonradioactive soil and that was therefore only affected by cosmic radiation. It amounts to 0.014 rad per year. The maximum external radiation is much more difficult to estimate; a figure of 0.17 rad per year is used. Usually great accuracy is not so important for questions of authentication, however, because the older specimens are normally the most interesting and the distinction between old and new is not difficult to make.

The size requirement for samples is about 25 mg, although measurements have been made on as little as 5 mg. A tungsten carbide drill is used for taking samples.

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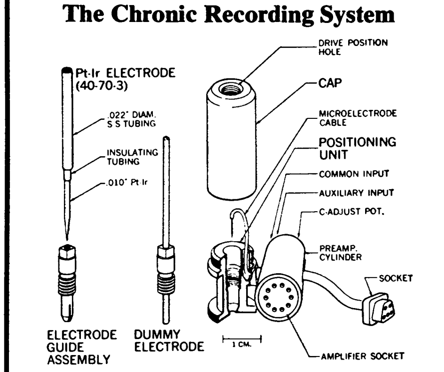

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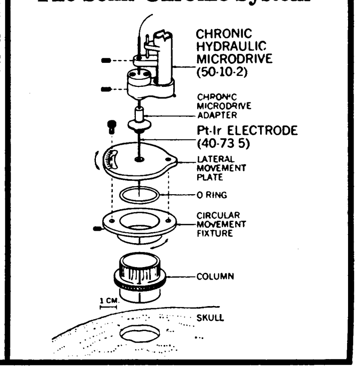

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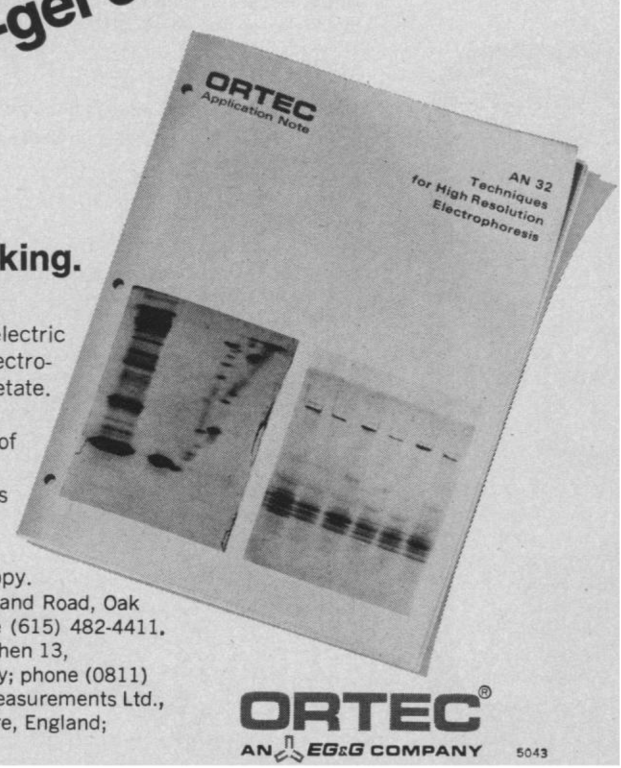

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F. J. Turner (Department of Geology and Geophysics, University of California, Berkeley) discussed the petrographic character of classic marbles. His emphasis was on the potential value of petrographic studies in determining the provenience of marbles and, particularly, on some notable pitfalls in this connection.

Since there are only two, and in some cases three or four, additional minor components in most marbles, examination of thin sections under polarized light gives information on the mineralogical identity of the component grains and on their mutual geometric relations, which define the rock texture.

Marbles are formed by metamorphic recrystallization of limestones; statuary marbles usually contain 90 to 99 percent calcite, whereas some marbles have dolomite as their principal component. Different recrystallization temperatures, pressures, and periods cause different reactions with clay and silica impurities and result in minor minerals with characteristics that are readily identifiable with the polarizing microscope. Conventional chemical analysis, x-ray diffraction, and superficial microscopy are not diagnostic since they determine only the features that these materials have in common, not those that distinguish them.

Two problems that concern the archeologist are the possible geographic source of a particular piece of stone and the matching of fragments of marble objects. Texture, fabric, and mineralogy are the characteristics that are most useful for distinguishing marbles according to their origin. Differentiation according to grain size is not a good criterion since grain size is highly variable in individual localities and, sometimes, even in single thin sections. Twinning of crystals, however, is a function of recrystallization conditions, and it varies substantially from quarry to quarry. The shape and outline of the grains also provide a textural characteristic useful for differentiating marbles.

Probably the best characteristic for matching fragments of statuary or inscribed slabs is the "fabric"—that is, the alignment of elongated grains, or crystallographic parallelism even of nonelongated grains. Fabric represents a pervasive pattern of orientation of the principal symmetry axis of the individual calcite grains. Special and laborious techniques of microscopy and x-ray analysis must be used for such studies.

Mineralogical criteria do not give such positive information; therefore, differentiation by mineralogy depends heavily on the experience and background information possessed by the petrographer. However, where characterizing minerals are present, the experienced petrographer can usually identify them easily with a polarizing microscope.

Probably the most important contribution of petrography to identification of marbles is to rule out certain hypotheses. Occasionally a marble from a particular locality may have an unusual, and therefore diagnostic, mineral constituent, such as the red manganiferous silicate Piedmontite in a pink variety of marble from Mount Pentelicon. Since petrographic information is obtained with relatively low investment of time and special equipment, petrographic techniques should be considered important and useful adjuncts to other technological methods in the support of archeology.

Radiocarbon investigations of the La Brea Tar Pits were discussed by R. Berger (Institute of Geophysics and Planetary Physics, University of California, Los Angeles). Many Pleistocene animal fossils and the only human skeleton found in the La Brea Tar Pits in Hancock Park, Los Angeles, have been subjected to radiocarbon dating experiments. Because these bones were impregnated with an "infinitely" old asphalt, a special technique that makes use of the collagen of the bones was used to obtain a valid analysis. In the collagen method, the bone is washed thoroughly in petroleum ether, ground to powder, and dried in air. The calcium carbonate is removed by acidification, since the carbonate ion in groundwater can be exchanged with it and produce spurious results. The bone is then hydrolyzed in strong hydrochloric acid and refluxed overnight to obtain the amino acids in concentrated solution. The solution is passed through a chromatographic column packed with Dowex resin, which retains the amino acids. The column is washed to remove impurities, and the amino acids are then displaced with ammonia. The amino acids are burned to carbon dioxide, which is purified to eliminate impurities that might interfere with the counting. The carbon dioxide derived from the amino acids is then placed in the counter and measured. Gas chro-

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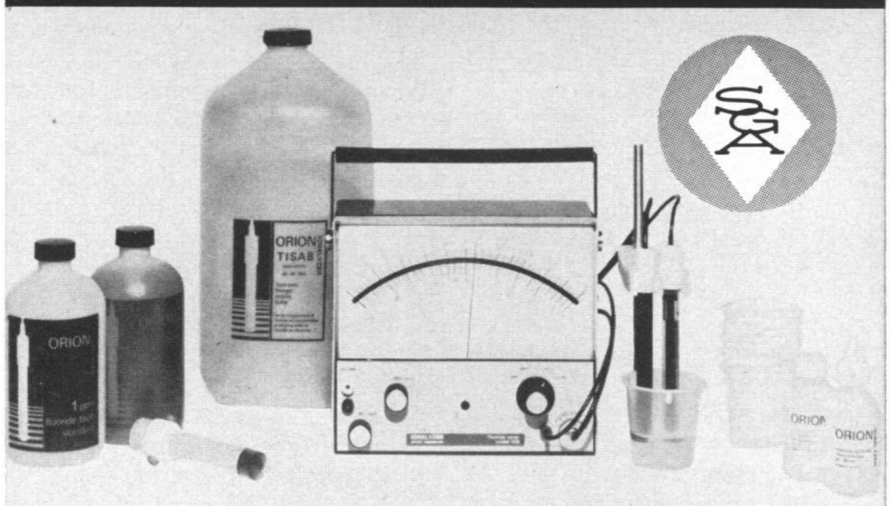

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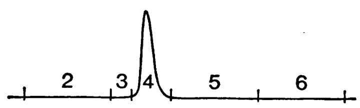

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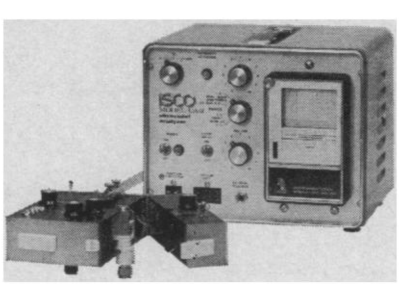

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matography is used to detect any hydrocarbons that might have slipped through. For greater precision, where sufficient sample is available, certain amino acids that occur only in bone, such as hydroxyproline, can be isolated chromatographically and used for analysis.

The collagen analysis was checked out on a quasi-mummified skeleton found in association with a bark mat in Nevada. The mat, the bone, the skin, and the hair were dated by conventional radiocarbon methods and were compared with the collagen procedure; the results were the same. The validity of dating of the La Brea fossils was further established by obtaining a radiocarbon date on wood fragments found in the tar pits; a comparison of fossil and wood gave very similar results.

The collagen method described gave an age of 9000 ± 100 years for the La Brea skeleton.

Further research along these lines has the following objectives: (i) find and date bones of little-known animal species; (ii) find how individual animal species change in their evolution over a span of 40,000 years; and (iii) look for other human bones or carbonaceous artifacts for additional dating studies.

G. H. Curtis (Department of Geology, University of California, Berkeley) reported that specimens of volcanic rock collected in 1969 at the principal hominid sites in Java (namely, Sangiran, Trinil, Ngandong, Ngawi, Jodjokerto, and Boetak) are now being dated at Berkeley. Owing to contaminants, mainly carbonate and zeolite which contribute large quantities of air, it has been difficult to obtain meaningful dates from most samples up to this time, but a fair date of 1.9 ± 0.4 million years for a tuff underlying the site of a mandibular fragment of Meganthropus can be reported. The Meganthropus fragments was found by P. Marks in 1952 in Djetis beds of continental origin near Modjokerto. Although the pumice tuff lies several meters below the hominid site, the site itself lies at least 400 m below late Pleistocene beds, all of which have been folded into an anticline and truncated by erosion, and it is believed that the pumice and hominid remains are penecontemporaneous.

The date of 1.9 million years makes this hominid, thought by many anthropologists to be an Australopithecine, contemporaneous with African hominids of similar evolutionary development. It seems reasonable to suspect that hominids were in Southeast Asia long before Meganthropus was entombed at this spot in Java.

In a discussion of lithomechanics and archeology, E. G. Thomsen (Department of Mechanical Engineering, University of California, Berkeley) showed that engineering analysis could be applied to archeological problems, and specifically to the reconstruction of methods for making tools and artifacts. The processes analyzed were the fracture of glassy materials in toolmaking, the use of stone flywheels in drilling, and the production of obsidian ear spools. In glassy materials, fracture surfaces show a consistency in character—demonstrated, for instance, by the prismatic obsidian cores found in many sites. Flint, obsidian, and other noncrystalline materials have no preferred orientation, however. Engineering analysis is able to show that, with knowledge of the fracture patterns of brittle materials (empirical in the case of early cultures), even primitive toolmakers could achieve the astonishing consistency of fracture patterns that has been observed.

Centrally perforated stone disks found in the southwestern United States may have been used as flywheels for drills. If so, the string drill, the twist drill, or the pump drill could have been known in early California.

Obsidian ear spools or plugs are among the most remarkable Central American pre-Columbian artifacts, because of their beauty, fragility, their paper-thin uniform walls, and their high axial symmetry. A relatively simple scheme was suggested for their manufacture: a rough, previously prepared and drilled core could be lapped by means of a self-centering mechanism, the principle of which may have been borrowed from weaving techniques that were well established in early antiquity.

Thomsen closed with a plea that appears applicable to the sense of the symposium: for continued and increasing exchange of the special knowledge developed in all disciplines.

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Note

1. This symposium, held 23 June 1970, was part of the 51st annual meeting of the Pacific Division of the American Association for the Advancement of Science, which met on the campus of the University of California, Berkeley. It was cosponsored and supported by the California Section of the American Chemical Society and the San Francisco Society of the Archaeological Institute of America.