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acteristics is being explored. Apart from some studies with model genes, the main focus has been on the insertion of somatotropin genes in rainbow trout, catfish, and carps, and on the insertion of genes coding antifreeze proteins into the Atlantic salmon. While several research teams have demonstrated incorporation of the exogenous gene into genomic DNA, there is little evidence yet for gene expression. Research is expected to proceed along the following lines: (1) development of methods for screening large numbers of embryos or larvae for gene integration; (2) development of gene insertion techniques; (3) development of genes, promoters, and vectors from various fish sources; (4) demonstration of expression; (5) evaluation of heritability and expression in subsequent generations; (6) development of methods to regulate gene expression; and (7) development of safety and containment procedures for cultures.

DNA probes. The development of DNA probes offers a variety of possible applications in aquaculture, including disease diagnostics, the detection of specific production characteristics, and the identification of specific stocks. In the area of diagnostics, a DNA probe has been developed for the detection and quantification of the causative organism of bacterial kidney disease. One of the major uses of this probe is expected to be the screening of broodstock to reduce transmission through the gametes. With regard to production characteristics, there has long been a need to determine the sex of fish prior to sexual maturation. This can be achieved on an experimental basis in salmonids by radioimmunoassay of 17β-estradiol or vitellogenin in females or 11-ketotestosterone in males. These techniques, however, determine phenotypic rather than genotypic sex, and thus the development of a sex-specific DNA probe would offer significant benefits, for example, in the generation of monosex spermatozoa. The DNA techniques also offer significant possibilities for stock identification. Restriction endonuclease digests of mitochondrial DNA have been used to distinguish between related species but may not be able to resolve stocks within a species. The polymerase chain reaction can potentially be utilized to amplify a stock-specific region of the nuclear DNA and thus permit detection using a hybridization probe. Appropriate hybridization probes could also be used to detect tandem-repetitive regions of DNA, referred to as minisatellites, and thus identify individuals within a family.

Integration of techniques. In the development of aquaculture production systems, it is necessary to consider not just a particular biotechnology in isolation but how it can be incorporated along with other biotechnologies into a viable production system. It is expected in the future that biotechnology in its various forms will play a major role in the development of aquaculture in both the developed and developing nations.

For background information *SEE ENDOCRINE SYSTEM (VERTEBRATE); GENETIC ENGINEERING; HORMONE* in the McGraw-Hill Encyclopedia of Science & Technology.

Edward M. Donaldson

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Archeology

Recent advances have been made in archeology in the study of prehistoric pottery using radiography, and the study of jade artifacts using visible and near-infrared spectroscopy.

Radiography for Analysis

Radiography can be used by archeologists to investigate hidden aspects of the construction of prehistoric pottery. These include traces of the specific methods by which clay was built up to form the vessel; the amount, size, and kind of temper added to the clay to make it workable and to make the finished vessel functional; fracture patterns that indicate vessel use and failure; and the hidden internal morphology of hollow vessels. These features constitute basic data that archeologists have used or ideally can use, in conjunction with theoretical arguments, to help reconstruct the subsistence, demographic characteristics, social organization, cultural boundaries, and trade networks of past peoples. Integration of recent advances in medical radiography and established industrial radiographic methods with ceramic archeology has made documenting many of these characteristics more feasible.

Vessel formation. A ceramic vessel can be constructed by pinching, slab building, drawing, coiling, wheel throwing, molding, or beating. Surface visual evidence of these procedures is usually obliterated by later shaping and finishing steps. However, they can be detected in a radiograph by the shape and orientation of air voids and the orientation of asymmetrical temper in the clay. For example, the walls of a slab-built and beaten vessel have air voids that are flattened and circular when viewed normally, whereas a coiled vessel's walls have elongated, horizontal voids. In a cross section of the wall, asymmetrical temper particles parallel the wall for a slab-built, beaten vessel but are randomly oriented for a coiled vessel. Coiled ceramics are sometimes also characterized by elongated voids between coils or differences in the density of temper among coils, which arise from poor kneading of the clay. Each method of vessel construction has its own diagnostics.

Documenting the procedures by which vessels were formed, especially the details of how coils or slabs were joined, and mapping areas of similar and different methods over space can be used by archeologists to reconstruct cultural boundaries, the expanse of learning pools, marriage exchange networks, or trade networks. Details of manufacture are passed on from teacher to student, allowing past networks of social interaction to be traced through the investigation of prehistoric pottery. Details are also good indicators of close interaction because they are not easily copied by casual viewers outside a network. Similarly, changes in manufacturing procedures can be traced through time and used as markers in order to construct local chronologies. Finally, differences between construction methods used for vessels can indicate the kinds of stresses, for example, mechanical or thermal, which they were intended to endure. Therefore their general function, such as storage or cooking, can be determined.

Hollow vessels. Radiographs have been used to define the internal morphology of walls and other hidden aspects of hollow vessels. Hidden clay rattle balls in the legs of pots and the configuration of tubes and holes in double-chambered vessels are among the ceramic structures that have been studied. Such hidden features, like primary formation procedures, are good indicators of close social interaction.

Tempering characteristics. Radiographs can reveal the volumetric density, size distribution, shape, and material type or approximate mineralogy of temper inclusions. Material type or mineralogy can be inferred from the gray level of the particle's image, supplemented with size and shape information. Materials with elemental atomic numbers and specific gravities greater than those of clay (for example, igneous and metamorphic rocks) appear as light spots on the film relative to the background clay gray level. Minerals with different specific gravities take on a range of gray levels. Voids from weathered-out limestone or shell or burned-out plant temper appear as more exposed, dark spots. Sherd, or grog, tempering is usually not detectable directly because clays differ too little in their specific gravities. However, air pockets around grog particles may reveal them.

Tempering characteristics can be used with visible ones to identify sherds that belong to the same or different vessels in archeological deposits having a mixture of sherds from multiple broken vessels. In traditional technologies, different vessels, even those made by the same potter for the same function, can vary significantly in the quantity and of their temper inclusions (from 5 to 10%) and the size of their temper. Potters may control these characteristics only approximately, for example, by the feel of the clay-temper mixture or with unstandardized net or basket seives.

Being able to match sherds by vessel and to count the numbers of vessels rather than numbers of sherds from archeological deposits or sites is essential to accurate reconstruction of the past. For example, estimating the frequency of trade of vessels between communities requires that the numbers and proportions of exotic versus local vessels, not sherds, be known. Similarly, the length of time that a site was occupied and its population size can be estimated only when the number of vessels used and deposited and vessel use-life are known; sherd counts are irrelevant. Also, when vessels are represented by multiple sherds, more accurate estimates of their volumes and shapes can be made, which can help to identify their functions or food-serving and family sizes.

The volumetric density, size, and kind of tempering particles within vessels or sherds can also be used to infer their function. These parameters are often adjusted by potters to meet certain performance or esthetic requirements. For example, a cooking pot that is subjected to rigorous and cyclical heating and cooling can be expected to have lower volumetric densities of temper particles or smaller temper particles than a mobile storage vessel when the tempering material (for example, quartz) has a thermal expansion coefficient much greater than clay. These characteristics minimize thermal shock for the cooking vessel and mechanical breakage for the storage vessel. Serving wares may have little temper in order to enhance their surface appearance. In view of these facts, radiography has been used to document reductions in the amount of quartz temper within cooking vessels from west-central Illinois, dating between A.D. 250 and 800. The reductions correlate with and have been used to track changes in prehistoric diet and culinary practices—in particular, an increased use of starchy seeds, which required longer cooking at higher temperatures than previously used foods. These shifts in turn were tied to changes in climate, human population density, and residential mobility.

The mineralogy of rock tempers, and quantitative estimates of the proportions of different temper minerals, can be determined with a combination of radiographic and petrographic thin section work. Reliable data on mineral proportions, and even the presence or absence of rarer minerals, often cannot be gathered economically with thin sections or binocular microscopic studies of broken sherd edges, alone. Mineralogy data are useful for determining whether a vessel was made locally or imported and for tracing past trade networks. If temper minerals are not found locally, either the minerals were imported or, more likely, the vessel was.

Methodological improvements. Diagnostic features such as temper particles and coil joins are visible in a radiograph because they differ in specific gravity from their surroundings. Consequently, they allow a differing number of x-rays relative to their surroundings to pass from the x-ray source through them to the radiographic film and to expose the film differentially. Compared to anomalies in other materials, however, ceramic features are subtle and may yield little radiographic contrast. Application of several standard industrial and newer medical radiographic products and methods allows archeologists to overcome this difficulty. These products include the following: (1) high-contrast industrial films (used to detect fractures in metal products and weldings) and new medical mammography films (used to document soft tissue anomalies); (2) recently developed medical x-ray tubes with a molybdenum rather than a tungsten target and without filters, which generate softer, longer-wavelength x-rays (used to increase radiographic contrast for ceramics which are less than about 0.2 in. or 5 mm in thickness and can pass this radiation); (3) the new method of xeroradiography, which simulates high contrast with edge enhancement (useful for defining vessel joins and hidden walls but not small temper particles or their mineralogy); and (4) an x-ray machine with a beryllium window that admits soft radiation, a low kilovoltage setting (20–50 kV) that generates soft radiation, and back lead screens and a diaphragm to reduce scattered radiation (used to increase contrast). *Christopher Carr*

Spectroscopy for Analysis

Jade has been an intriguing enigma through hundreds of years of civilization. Historically and prehistorically it has been the material most prized by the Chinese and Mesoamerican cultures. Because of its importance, jade was traded extensively within and among the various Mesoamerican and Central American cultures. Therefore, jade artifacts provide a means to examine the interactions between these cultures. By making a detailed analysis of the composition of an artifact, its relationship to other artifacts and to the sources of the raw material may be determined. This information can then be used to define ancient trade routes and intercultural exchange.

The material known as jade can be composed of one of two mineral species in two different mineral groups. Nephrite, the more common variety, is an amphibole that is intermediate in composition between tremolite, $Ca_2Mg_5(OH)_2(Si_4O_{11})_2$, and actinolite, $Ca_2(Mg,Fe)_5(OH)_2(Si_4O_{11})_2$. Jadeite, $NaAl(SiO_3)_2$, is the pyroxene variety of jade. All of the archeological and geological samples of jade from Central America and Mesoamerica that have been examined to date have been composed of the mineral jadeite. There is no known source for nephrite in Mesoamerica and Central America. Many other materials, such as serpentine, chalcedony, aventurine, and other hard green rocks or minerals, have observable physical properties, such as color, hardness, and density, that are similar to those of jadeite. These jadelike materials were often utilized by pre-Columbian civilizations. The mineral jadeite rarely occurs as a pure mineral, but as a major component in a mixture with a wide range of other mineral species in a rock known as jadeitite. Thus, naturally occurring jades are found with a range of observable physical properties.

VNIR spectroscopy. Visible and near-infrared (VNIR) reflectance spectroscopy provides a means for the nondestructive identification and characterization of many of the minerals present in artifactual and geological samples. Many rocks and minerals can be reliably identified by the wavelengths at which they absorb visible and near-infrared light that has been reflected off the surface of the sample. In many cases, the VNIR reflectance spectrum for a particular mineral is unique to that mineral (**Fig. 1**).

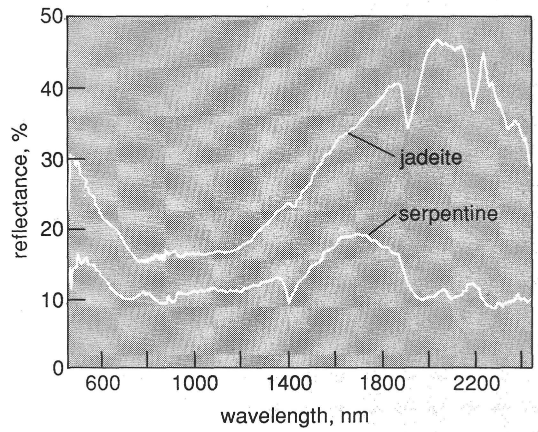

Fig. 1. Reflectance spectra of the minerals jadeite and serpentine.

The similarities in the identities and compositions of the minerals between archeological and geological samples are used to link artifacts with specific geological sources or to identify groups of artifacts that are compositionally similar. The delineation of trade networks from the relationships between artifactual and geological materials may then be used to infer cultural relationships. The existence and complexity of long-range trade networks have been used by archeologists to determine the degree of social organization and stratification in a society.

Jade artifacts. The VNIR reflectance spectra of jade artifacts from Mesoamerica and Central America vary widely. The differences between these spectra are attributable to differences in both the minor mineral assemblages and the compositions of the jadeite phase present in the sample. Because the wavelengths of the absorption features associated with jadeite are dependent on the detailed composition of the mineral, it is possible to differentiate jadeites derived from compositionally distinct source areas. While this application of these techniques requires more development, it can presently be used to differentiate jade from other materials, and to classify Mesoamerican and Central American jade artifacts into three broad groups. Maya artifacts form two of the groups, while Olmec and Costa Rican artifacts form a third group. More detailed work will help determine the validity of these groupings and may allow for a more detailed classification scheme.

While the major absorption features in the VNIR reflectance spectrum of jadeite are due to iron in the +2 oxidation state [Fe(II)], the other minor absorption features are controlled primarily by elemental substitutions in the jadeite crystal lattice and by the presence of small amounts of other pyroxene phases in solid solution with the jadeite. The mineral jadeite is rarely found in its pure stoichiometric form, $NaAlSi_2O_6$. It is the impurities, in the form of elemental substitutions or solid solutions with other compatible pyroxenes, that produce the colors seen in jade (see **table**). It is the identity and oxidation state of the transition met-

Elemental impurities in jadeite and the colors produced	
Impurity	Jade color
Manganese(II)	Pink
Chromium(III)	Emerald green
Iron(III)	Brown or red
Iron(II)	Pale green

als, such as iron, chromium, and manganese, contained in these impurities that determine the color of the jade.

Based on the analysis of Maya, Costa Rican, and Olmec artifacts which, based on their VNIR reflectance spectra, were judged to have major components of jadeite, it appears that the visible portion of the VNIR reflectance spectrum of jade may be indicative of the source of the raw materials used for the artifacts. **Figure 2** shows the visible reflectance spectrum for three of the most common jade colors. Reflectance curve A is an example of Chichen green jade, the color of which appears to have been most prized by the Mayans. The emerald green color is due to the intense absorption of blue and red light by chromium(III) contained in a small component of the pyroxene ureyite ($NaCrSi_2O_6$) in solid solution with the jadeite. Some additional absorption of blue light is due to iron(III). Reflectance curve B is an example of a reflectance spectrum of Mayan green jade. Many of the Mayan jade artifacts are this color. The pale green color is due to absorption of red light by a small amount of iron(II) contained as an impurity in the jadeite. This absorption feature is much more broad that the one produced by chromium(III); therefore, the color produced is more subdued. The absorption of blue light is due to the presence of iron(III). Reflectance spectrum C is an example of Costa Rican or Olmec blue jade. The majority of the Costa Rican and Olmec artifacts examined are of this color. The blue-green color is due to the absence of any iron(III), which would otherwise result in absorption of blue light. Iron(II) contained as an impurity in this jadeite

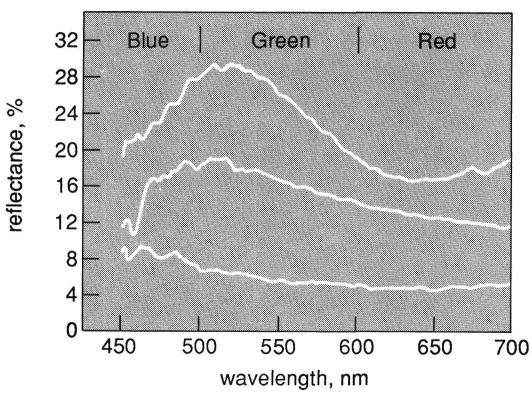

Fig. 2. Jade is found in a wide variety of colors, from brilliant emerald green to blues. The reflectance spectra plotted here represent three of the most common jade colors encountered in Central American and Mesoamerican artifacts.

results in absorption of red light.

It was found that many of the geological samples from the Motagua Valley in Guatemala have VNIR reflectance spectra that are similar to the spectra for both of the Mayan jade types, that is, the Chichen green and the "Mayan green" jades. Based on these observations, it seems likely that the Mayan's source of jade was the Motagua Valley. Many of the other geological samples from the Motagua Valley showed no similarity to any of the artifacts examined, perhaps because the jade raw materials were selected on the basis of some set of criteria. It may be that only jades having the desired color, either the pale green or the emerald green, were selected.

The primary type of jade utilized by the Costa Rican and Olmec cultures, the blue jades, is spectrally distinct from the types of jade commonly associated with the Maya culture. Despite the lack of geological evidence, the dissimilarity of the Costa Rican and Maya artifacts suggests the existence of a second jade source. Many have noted a similarity in color and style between Olmec artifacts and those from the Nicoya Peninsula in northwestern Costa Rica. This, combined with the quantity of jade artifacts from this peninsula, has led to speculation of the existence of a local Costa Rican source and a possible Olmec Pacific coast trade route. There is, however, no archeological evidence of the presence of the Olmec in Costa Rica. While there is currently no known geologic source for the blue jades, the Motagua Valley in Guatemala cannot be ruled out without more extensive geologic field work there.

For background information SEE JADE; SPECTROSCOPY in the McGraw-Hill Encyclopedia of Science & Technology.

Brian Curtiss

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Astronomy

There is intriguing but inconclusive evidence of the existence of low-mass ("substellar") companions of stars beyond the Sun. Astronomers are searching for them by several independent methods. Apparently, both extrasolar planets and brown dwarfs may have been detected, although further proof is needed.

A planet is formed by the accumulation of material within a viscous accretion disk around a newborn star.