Natural Science and Archaeology

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Introduction

The study of archaeological science builds on the foundations of such fields as archaeology, historical science, gardening history, and architectural history, collaborating with natural science disciplines in deepening the study of archaeology, history, and the like, and enabling the development and multidisciplinary expansion of new fields of study. Therefore, it is a discipline that cannot exist without the interaction and information exchange with a wide range of natural and human sciences fields, including physics, chemistry, biology, physical science, engineering, agriculture, and medicine.

1. The Beginning of Archaeological Science

When did the field of archaeological science begin? Since European scientists were conducting chemical analysis on coins as early as the 18th century, it can be argued that the field has a history of 200 years; however, the individual who first engaged in the study of full-fledged archaeological science was most likely Martin J. Aitken. In 1958, he set up the "Research Laboratory for Archaeology and the History of Art" at Oxford University, and published a periodical research journal titled "Archaeometry." We have decided to take the liberty of translating the term "Archaeometry" as Kouko Kagaku, which means Archaeological Science. Although it appears "Archaeometry" is usually translated more accurately as Kouko Keisokugaku, which means Archaeological Measurement, we chose the former because it seemed to present the first point of full-fledged archaeological scientific research. And since 1975, the international convention "Archaeometry" is convened every other year.

We shall now take a look at Asia. The Shanghai Museum in China publishes "Archeological Science for the Conservation of Writings and Objects." First issued in 1989, it is published twice yearly and carries articles on a large range of topics, from the analysis of archaeological artifacts to their conservation. In Japan, research in archaeological science began at the end of the 19th century, 100 years later than in Europe. Research in Japan mainly consisted of the analytical chemistry of archaeological materials. H.S. Munro, an American who assumed the professorship of geology and epigraphy at Kaisei Gakko, the predecessor of the University of Tokyo, conducted an analysis of a *doutaku*, a bell-shaped vessel of the Yayoi period, for the first time in Japan. He presented the results of his analysis at the academic convention in New York in February 1877. The individual who conducted the actual chemical analysis was a Japanese student. Another scientist, E. S. Morse, the zoologist who discovered the Omori Shell Mounds in Tokyo, gave a report in 1881 of his analysis of a large *doutaku*. It was only in 1900 that the Japanese researcher Kennosuke Tsujimoto presented his analysis, "*Seido Seihin no Seibun Bunseki* (The Component Analysis of Bronze Products)."

One of the studies in archaeological science that created a furor in the Japanese archaeological community was radioactive carbon dating, a dating method established by the American chemist Willard Frank Libby (1908 – 1980). The method became the focus of attention in Japan through measurements taken in 1958 of the Natsushima Shell Mound, located offshore of Yokosuka City in Kanagawa Prefecture. The Jomon era shell mound had been excavated and estimated as being 6,000 years old using conventional archaeological research methods; however, the announcement, based on carbon dating of shells and charcoal, that the mound was in fact about 9,500 years old sent shock waves throughout the archaeological community. The application of scientific methods to archaeological research tends to result in this kind of unexpected measurement outcome, helping to deepen debate over the issue.

Another important field of research in the discipline of archaeological science is conservation and restoration science. In 1972, the discovery of the Takamatsuzuka Burial Mound in Nara Prefecture served as the catalyst for raising awareness of the importance of the application of scientific methods to the field of conservation, and helped to focus attention on the field of archaeological science.

2. Themes in Archaeological Science

Archaeological science refers to the study of archaeological materials using scientific methods. The information gained in this discipline can be used in historical or archaeological surveys and studies, or utilized for the preservation or restoration of archaeological materials. The use of scientific techniques for the study, conservation and restoration of cultural properties is a natural outcome of events; the following two purposes can be identified. They are: the study of archaeological sites and artifacts themselves; and using archaeological sites and artifacts as the medium through which to elucidate the science and technology of ancient times on a global level, that is, expanding the study into the history of science and technology. While themes in archaeological science cover a wide range, we will focus on five research topics and introduce their purposes and methodologies on the basis of results produced and cases handled to date.

(1) Scientific dating: In archaeology, relative dating techniques are used, where the age of a site or object is estimated based on the morphological comparison, whereas in studies involving the use of scientific methods, an absolute date can be given to objects. While a variety of scientific methods have been studied, physicochemical methods are effective in identifying relatively recent dates, and other measurement methods are suited to making broad measurements of ancient times.

(2) Studies on the material properties, production technique, and estimated place of production: While the basic methods are mostly to do with material analysis of the artifacts, they are heavily reliant on non-destructive techniques given the difficulties inherent in creating specimens out of the objects. The most frequently used method is x-ray fluorescence analysis. However, archaeological artifacts are often found in a state of deterioration after having been buried for prolonged periods of time. Therefore, the surface of a given specimen does not necessarily reflect the material properties of the artifact, and there is a need for skills and technique to achieve reliable analysis results.

(3) Explorations into the living environment and eating habits of ancient peoples, and reconstructing the paleo-environment: This field of study is referred to as environmental archaeology. It is a wide-ranging discipline that relates to every aspect of human activity, such as estimating the diet of ancient peoples through the analysis of animal and plant remains, studying the ecology of organisms, analyzing pollen and toilet soil to identify parasite eggs and explore the ancient diet, conducting plant opal analysis and volcanic ash analysis to explore the state of agriculture and conduct comparative studies of stratigraphical dates, surveying the traces of earthquakes to determine changes in archaeological sites and their relationship with chronological periods, and attempting to reconstruct the paleo-environment on the basis of diatom analysis and phosphorus analysis. Meanwhile,

scientific analysis of human bones, DNA analysis, and other studies of state-of-the-art technology relating to recent applications of biochemistry are also being vigorously pursued.

(4) Archaeometrical research: Morphological surveys of architectural structures and burial mounds utilizing computer graphics; research and development of underground radar and other surveying methods for ancient ruins; etc. When a person goes to a hospital, they are first given x-rays and blood tests to find a diagnosis, and treatment starts from there. In much the same way, the excavation of an archaeological site would proceed more accurately and efficiently if the site were surveyed and knowledge of the site obtained before excavation is begun.

(5) In order to conduct archaeometrical research projects with more accuracy, the safe preservation of the information contained within the archaeological artifact is of the first order of importance. In addition, it is necessary to preserve and utilize the priceless archaeological site and artifacts. Research is needed into the development of technologies and materials that lengthen the lifespan of these objects, as well as that allow their permanent preservation. In that sense, this discipline is one of the most important fields in archaeological science.

3. Age Determination

1）Radioactive carbon dating

The carbon dioxide within the atmosphere is fixed into plants through photosynthesis. Because animals consume those plants, the carbon in the air is consumed as long as organisms are alive. Carbon has three radioactive isotopes, each with a different mass number. The isotope with a mass number of 14 (C^{14}) has a uniform rate of formation when exposed to cosmic rays of a certain intensity, but once an organism dies, the concentration of C^{14} decreases with time due to radioactive decay. The time required for the amount to be decreased by half, that is, the half-life, is approximately 5,730 years. It is possible to estimate the date of creation of an archaeological specimen, for instance, a wooden artifact, by determining the degree of decrease of the C^{14} contained within that specimen.

2）Tree ring dating

This method, devised by the astronomer A.E. Douglas, takes advantage of the fact that the width of tree rings fluctuate in response to changes in climate. Douglass investigated the fluctuations in climate using tree rings, in order to study the sunspot cycle. In his methodology, the first step was to take advantage of the fact that the width of tree rings changed in response to meteorological conditions, and create a fluctuation pattern of tree ring widths that went as far back in time as possible from the presently living tree. The next step was to use that fluctuation pattern, or master chronology, for cross-referencing of the tree rings of a specimen of unknown age. In this way, the year of felling of that specimen could be determined. In Japanese archaeology, it is now possible to determine the age of a given archaeological site using hinoki cypress, sugi cedar, and kouyamaki pine, all of which are unearthed in abundance. At present, master chronologies have been completed up to 912 B.C. for hinoki cypress, 1313 B.C. for sugi cedar, and 22 A.D. for kouyamaki pine. However, while it is possible to obtain an accurate felling year with specimens that have a portion of the bark, or the outermost tree ring, remaining, this is not true of specimens which have had the sapwood portion trimmed off. For the latter, only the upper limit of the estimated year of felling can be obtained.

3）Heat luminescence

When radiation strikes the inorganic substances fluorspar (CaF_2, isometric system) and quartz (SiO_2, the main component of igneous rock), these substances drive out electrons from the atoms that compose them. These electrons move around inside the substance, are captured within holes in the crystal, and become imbedded. These remain fixed for many years, and as radiation continues to strike the substance, the number of electrons captured in this manner continues to rise. Moreover, the captured electrons are proportionate to the total radiation dose. When such crystals are exposed to excitation energy, the atoms begin to vibrate and the captured electrons are released. These electrons re-bind with the hole center via the conductor, and give off "luminescence." For instance, when a piece of earthenware is heated, the intensity of heat luminescence, which corresponds with the total radiation dose that specimen received after it was fired, can be measured. By exposing that same piece of earthenware to a known dose of radiation, and measuring the amount of heat luminescence obtained, it is possible to measure the unique luminous efficiency of that specimen. At the same time, when the amount of natural radiation can be determined, it then becomes possible to calculate how many years the specimen had been exposed to radiation, that is, the year in which that piece of earthenware had been created.

４) Other

(1) Paleomagnetism and archaeomagnetism

The magnetic ores within soils that are exposed to heat, that is, the magnetic iron ore and red iron ore, are magnetized parallel to the earth's magnetic field at the location where the highly heated soil is cooled. This magnetic orientation is called thermal remnant magnetization, and matches the orientation of the earth's magnetic field at the time the soil was exposed to heat. Because the earth's magnetic field changes gradually with time, the age of residual magnetization can be estimated by cross-referencing with the direction of the earth's magnetic field under the effect of the magnetic north. In archaeology, it is possible to determine the age at which a firing kiln was last used, since the earthen walls of kilns used for the manufacture of earthenware articles is unchanged at that location.

(2) Electron spin resonance (ESR)

A method whereby the age of such articles as fossilized bone, paper, lacquer, and leather is determined through the measurement of the state of electrons. This method takes advantage of the fact that when objects are exposed to radiation, or when they undergo such responses as oxidization and degradation, the electron configuration of that substance becomes abnormal, giving the substance magnetic properties. This method can also be used to investigate the state of deterioration of such organic substances as silk and synthetic resins.

(3) Potassium-argon dating

Natural potassium contains radioactive potassium, which undergoes radioactive decay to become argon. By measuring the amounts of potassium and argon contained in rock and minerals, it is possible to determine the age in which they were created. In archaeology, this method is used to determine the age of formation of volcanic ash and mineral deposits associated with archaeological sites. In this way, useful information can be extracted and utilized for research purposes.

(4) Fission-track dating

A method of chronological dating that takes advantage of the properties of uranium. The uranium within minerals with a high uranium content undergoes nuclear fission, becoming a heavy fragmented nucleus with about half the atomic weight, that flies out at a high speed and damages the crystal structure along its track. The damage disappears when heated, and increases anew thereafter. By measuring the number of such tracks, and the uranium content, it is possible to obtain the time lapsed since an object was heated. From this, it is possible to determine the date of creation of earthenware and glass articles as well as the period in which volcanic ash was accumulated.

(5) Obsidian hydration dating

A method of chronological dating that is based on the measurement of the thickness of the hydration layer of obsidian. Obsidian that has been recently formed presents a black, glassy sheen. However, with the passage of long periods of time, obsidian formed in ancient times has undergone the hydration of its crystal lattice by permeating water molecules. With the passage of time, the hydration layer infiltrates deeper within the rock. By measuring the thickness of the hydration layer of obsidian unearthed from archaeological sites whose dates are known, it is possible to estimate the age of creation of obsidian articles by measuring the thickness of the specimen’s hydration layer.

4. Materials, techniques, and place of production

1) Materials

In addition to such archaeological techniques as comparing the types and forms of archaeological artifacts, scientific methods such as the comparison of materials can be used in the research of the trading zones of archaeological artifacts. For instance, it is possible to identify the place of production of a given earthenware article, or the place of production of the clay used in its manufacture, by comparing the results of chemical analysis of that article against the results obtained from earthenware unearthed from a kiln site or articles known to have been created in a specific location.

2) Techniques

Archaeological artifacts come in every conceivable shape, size, and composition. The general procedure is to examine the production technique of a given specimen on the basis of structural analysis using optical equipment. In the scientific analysis of an earthenware article, methods such as petrological observation, x-ray transmission photography, and physical investigation through thermal analysis can be used. X-ray transmission is also effective in the research of casting techniques for bronze articles. There is also a method that takes advantage of the composition of bronze articles. Bronze is an alloy of copper and tin, with the admixture of lead. Lead and copper segregate instead of forming an alloy. In addition, due to their heavy specific gravity, these elements tend to sink to the bottom of the crucible. Therefore, when the molten mix is poured into a cast, the portion of the mix with higher concentrations of lead tends to be poured last, resulting in an uneven distribution of lead concentration within the same article. This can be used as the basis for determining the direction of the cast, which can lead to the elucidation of casting technique. The manufacturing technique for glass beads and lacquer products can be explored by the analysis of materials and structure.

3) Place of production

In addition to such archaeological techniques as comparing the types and forms of archaeological artifacts, scientific methods such as the comparison of materials can be used in the research of the trading zones of archaeological artifacts. In studies which attempt to identify the place of production of metal articles, earthenware crafts, roof tiles, and stone tools, the non-destructive and speedy technique of fluorescent x-ray analysis is often used. In order to investigate the exchange zone of earthenware articles, it is necessary to identify where the article was made, and where it was used. Another method uses the isotopic ratio of lead, which is determined by the date of creation of the lead deposit, and which is known to present a unique value for each geographical area. This method makes it possible to estimate the place of production of articles that contain lead. That is, by calculating the unique isotopic ratios of each mine, it is possible to estimate the place of production of bronze articles, lead glass, and glazes that contain lead.

5. Reconstruction of the paleo-environment

1) Reconstruction of the living environment and eating habits

A variety of analytical methods can be used to explore the living environment and eating habits of ancient peoples. These methods include the analysis and identification of plant and animal remains, DNA analysis, and fatty acid analysis. Deoxyribonucleic acid (DNA), which is the substance of the gene and controls the shape and properties of living things, can be extracted from dead creatures for analysis. DNA analysis of human bone can provide clues into the origins of humanity and its propagation, while DNA analysis of organisms can aid in the identification of species, seeds, or individuals. In this way, DNA analysis can be used effectively in the study of biological evolution and in estimating ancient growth and development conditions.

2) Study of environmental and climatic changes

The palo-environment can be reconstructed through such means as the observation of volcanic ash, traces of earthquakes, diatom analysis, phosphorus analysis, pollen analysis, and plant opal analysis. Pollen reflects the realities of flora, and flora is intimately associated with climatic conditions, soil conditions, and human lifestyles. By extracting and analyzing the fossilized pollen buried in the layers of sediment covering an archaeological site, it is possible to calculate the relative quantity of that particular plant in relation to the total quantity of all plants during that period. The changes over time of the relative quantities of different plant species can illuminate the historical changes in the ancient flora, and provide clues into the living conditions and living environment of ancient peoples through estimating the changes in the ancient climate and environment.

3) Pollen analysis

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6. Prospecting and metrology

These methods refer to techniques whereby buried ruins and artifacts are explored without digging them up. By sending radio waves into the ground, and by collecting such information as the intensity by which the reflection comes back to the surface, the refraction and attenuation of the waves, the differences in the electric resistance of different types of soil, and subtle magnetic anomalies, it is possible to determine where the soil is different, or distinguish foreign objects other than soil. This information can be combined with archaeological information in a comprehensive examination to survey archaeological sites and artifacts, and to shed light on their nature. In recent years, the term "prospecting of cultural properties" is sometimes used to refer to scientific prospecting methods not only for archaeological sites but also for various cultural properties including buildings made of stone or wood.

Because it deals with archaeological sites and artifacts, the most important factor in the prospecting of an archaeological site is to reference existing survey results of that site and surrounding areas when attempting to understand the prospecting results, and to fully consult with the persons in charge of archaeological investigation. When anomalies are found as a result of the prospecting, it should be possible to gain a deeper understanding of the cause of said anomalies by referencing conventional prospecting results of that site as well as the situation of sites in surrounding areas.

1) Radar surveys; electrical prospecting; magnetic prospecting

The techniques whereby buried ruins and artifacts are explored without digging them up are referred to as archaeological prospecting. By sending radio waves into the ground, and by collecting such information as the intensity by which the reflection comes back to the surface (radar), the refraction and attenuation of the waves, the differences in the electric resistance of different types of soil (electrical prospecting), and subtle magnetic anomalies (magnetic prospecting), it is possible to determine where the soil is different, or distinguish foreign objects other than soil. This information can be combined with archaeological information in a comprehensive examination to survey archaeological sites and artifacts, and to shed light on their nature.

2) General metrological science

The recent advances in computer technology have been occurring in every conceivable field, and the realm of cultural properties is no exception. These advances are being actively utilized in solving metrological challenges posed by cultural properties, correction and reconstructing of images, and in the analytic and metrological instruments themselves. The term refers to all fields of metrological science that are applicable to the study of cultural properties. Computer graphics are a typical example.

7. Conservation science

This term refers to the multidisciplinary field of study where scientific techniques are applied for the purposes of investigation or conservation and restoration of cultural properties. Methods include material analysis, structural analysis, environmental analysis, and development of restoration techniques. In material analysis, it is preferable to use non-destructive methods. For the investigation of inner structures, which cannot be seen by the naked eye, such means as x-rays, infrared rays, and ultraviolet rays can be applied. CT scanners are an effective means of x-ray transmission. In studies of the preservation environment, research into such matters as air, temperature, humidity, and lighting is conducted with the purpose of environmental conservation, while efforts are made to construct an appropriate environment. In the conservation and restoration of artifacts, traditional techniques are respected while research and development, as well as improvements and modifications, are made to restoration techniques and materials that maximize the latest scientific technologies.

1) Archaeological sites (Residential ruins, kiln ruins, burial mounds, stone buildings, maintenance of archaeological site)

(1) The purposes of archaeological site maintenance

① To give the general public a proper awareness of the nature of the archaeological site. Exposing the remnants of ancient structures for display, or reconstructing facilities such as buildings, can make a site easier to understand and appreciate properly.

② To lengthen the life of the archaeological site. The process of maintenance and continued management are what achieve the preservation of the site. The process also helps to deepen understanding of the site. Also aids in the advancement of conservation and restoration techniques.

③ To make possible the construction of an environment that allows the archaeological site to be preserved as is, without losing the information inherent in the site. To preserve and manage a site without making light of valuable information that cannot be measured with current science and technology. Archaeological sites have the potential for extracting more information with advances in science.

(2) The significance of site maintenance

① Handing down the legacy of the site as a cultural heritage: Academic evaluation of a cultural property; historical positioning of a cultural property; creating a hub for cultural exchange;

② Urban planning: Development of the area around the archaeological site;

③ Community-building: Harmonization with the local community; community service function; planning events with participation by the general public; utilization of volunteers; archaeological site as a place of relaxation;

(3) Ancient buildings and burial mounds

An example of the comprehensive conservation of a burial mound is the Takamatsuzuka Burial Mound in Nara Prefecture. In order to safely protect the facility, the environmental conditions within stone burial chamber are maintained in a state close to what they were prior to the excavation. That is, the conservation system is designed to maintain the temperature and humidity (at least 96%) at the time of excavation. Other important challenges include dealing with mechanical problems stemming from the structural makeup of the stone chamber, and measures to address bacterial and fungal growth. Generally speaking, each burial mound has its own environmental and geographical conditions, and must be addressed individually.

(4) Stone monumental architecture

Examples of stone monumental architecture include stone carvings of Buddha (*magaibutsu* (stone cliff Buddha)), stone towers, stone towers dedicated to Buddha and Prabhutaratna, stone monuments, stone architecture, decorative rocks used in gardens, cornerstones in residential ruins, stone burial chambers in burial mounds, and caves. Because there are a large number of volcanoes in Japan, it is said to be rich in tuff. The poor consolidation of tuff makes it extremely vulnerable to degradation, not only on the surface but structurally as well. Therefore, stone cliff Buddhas and stone caves carved into bedrock require more than cosmetic conservation and restoration on the surface. They need preservation work to be done from the standpoint of structural mechanics. In addition, portions where there are joints running through the bedrock are prone to start cracking and/or degrading. On the other hand, the components of tombstones and stone monuments are usually made of granite, andesite, basalt, greenschist, and other materials that are partly uniform and dense. Even so, one finds that many of them still degrade and disintegrate.

There are usually multiple factors leading to degradation, and these factors are intertwined organically. In particular, a major factor is the damage due to the weathering of salts, and due to repeated freezing and thawing. When water with salt content evaporates from the surface of rock, the salts precipitate onto the surface. Or water may infiltrate the rock and cause salts to precipitate when it dries. When this action is repeated, the crystals damage the surface layers of the rock, and excessive salts form a hard, crust-like coating on the rock surface. While at first glance this may appear to increase the strength of the rock, it is actually brittle and crumbles easily. It is typical for the inside of the hard coating to have turned into clay, causing many of the structures to crumble with increasing speed. Stone cliff Buddhas are vulnerable to damage caused by tree roots, and continuous vibration from automobiles, as well as the effects of earthquakes, are serious problems. Another major issue requiring appropriate preservation measures is biological degradation caused by lichen and microorganisms. While epoxy and acrylic synthetic resins are used to strengthen rock, silane synthetic resins have also come into frequent use in recent years. It would be ideal if, in addition to strengthening with synthetic resins, a monument can also be protected by means of a covering roof or other such structure.

(5) Transcription of soil layers; relocation of remains of archaeological structures; reconstruction models

There is a technique whereby the soil layer or cross section of an archaeological site is shaved off thinly, transcribed to a cloth or panel etc., and taken indoors. In this soil layer transcription technique, the first step is to shave off the surface of the object for transcription so that it is as smooth as possible. Even when an archaeological artifact is included in this potion, it is allowed to remain as is as a general rule, and is transcribed together with the soil layer cross section. Adhesive is applied to the surface of the soil layer cross section, and a cloth is pasted on to strengthen the film. Epoxy and urethane adhesives can be used. After hardening, the soil layer cross section is shaved off thinly. Generally speaking, the stratigraphy of a soil layer cross section is more distinct when wet. Therefore, isocyanate synthetic resins may be applied to the surface of the soil layer cross section that was shaved off, thereby artificially inducing the wet coloring.

When dealing with archaeological remains that cannot be preserved at its original location, or when handling artifacts that have become too brittle to pick up with the bare hand, or when transporting cut-off sections of large remains into an indoor environment, techniques are sometimes used whereby the objects are packaged in rigid urethane resin for relocation. At other times, they may be packaged in concrete or plaster for transport. Reconstruction models are usually displayed in museums and art galleries, and for this reason their texture and coloring have been considered important technical challenges. However, models that convey a sense of mass and that have a texture that is similar to the original lend themselves to utilization as displays that people can touch and feel. In recent years, there is an increasing trend toward outdoor display, which has necessitated the development of materials and manufacturing techniques that make the models resistant to ultraviolet rays and rain.

2) Artifacts

When preserving and restoring specimens that are cultural artifacts, records of the chemicals and restoration techniques that were used should be kept together with the priceless cultural artifact. Meanwhile, consideration should be given to making the repairs in a manner that allows the repair to be done over when a better preservation material or technique has been newly developed.

(1) Organic artifacts

Organic artifacts include wooden articles, lacquered goods, bamboo products, and goods made from fibers (ropes and knit articles made of vegetable fiber, textiles such as silk and linen, etc.). Usually, archaeological artifacts are unearthed from sites that are moist. They are supersaturated with water, and when inadvertently allowed to dry, may crack, shrink severely, or become so deformed it is impossible to tell what it looked like originally.

Wooden articles are the most numerously unearthed of organic artifacts. A variety of chemical treatment methods have been developed for their preservation. The “PEG impregnation method” consists of replacing the supersaturating water with polyethylene glycol (PEG) to stabilize the form. PEG is an ethylene oxide polymer that is categorized into liquid or solid form according to the difference in degree of polymerization. It is a stable chemical substance that is water soluble. Another effective method is “vacuum freeze drying,” wherein the water content is prefrozen and allowed to sublime under high vacuum. By replacing the water content beforehand with organic solvents, and shortening the drying time, it is possible to avoid cracking or shrinking of the wood material. Compared to PEG, the “higher alcohol method” is an efficient method that requires a shorter processing time. Higher alcohol refers to those types of alcohol with a high carbon content, such as cetyl alcohol $[CH_3(CH_2)_{14}CH_2OH]$ and stearyl alcohol $[CH_3(CH_2)_{16}CH_2OH]$. This method is suited for the preservation of textiles and other goods made from vegetable fibers, seeds and other plant remains, and artifacts that are composed of a combination of materials, such as metal and wood. Silicone resins, which are flexible, can do reasonable justice to flexible artifacts. Silicone is a general term that refers to organic silicon compound polymers, and depending on the size of polymerization (molecular weight between 300,000 and 600,000), presents in different states, such as lipid, grease, or rubber. For the preservation of organic artifacts, resins with relatively large polymerization are used. Silicone resins are highly water repellant and have excellent resistance to moisture and climatic conditions.

(2) Inorganic artifacts

Inorganic artifacts include metal products, stone tools, and earthenware articles. In particular, metal products are unstable and corrode notably quickly. Out of articles made of such metals as gold, silver, lead, tin, iron, and their alloys, iron articles are the least stable and require research into methods for their conservation and restoration. Copper and bronze products also involve complex degradation factors, and methods for their preservation are being researched. On the other hand, stone and earthenware articles are relatively stable, and do not present very serious problems in terms of preservation technique. When the surface portions have degraded, synthetic resins can be used to coat them.

The process of preserving metal products starts with cleaning to remove surface rust and adherents. X-ray transmission photography may be used as necessary to verify the original form that was obscured by surface rust. In order to rustproof the material, the rust-causing chloride ions are removed, and the material strengthened by allowing synthetic resins to infiltrate well. Distilled water or alkaline solutions are used for chloride ion removal. Some methods involve the use of an alcoholic solution of lithium hydroxide to desalt an article, or steeping the article in distilled water and boiling in a decompression chamber. Iron articles that were unearthed from sites at the ocean bottom are allowed to steep for long periods of time in sodium hydroxide solutions to extract and remove chloride ions. After desalting, the article is strengthened by impregnating with acrylic synthetic resins under vacuum.

3) Challenges in conservation science

(1) Ethics and philosophy of conservation and restoration

As international exchanges have become deeper and more frequent, national differences in preservation philosophy have come into bold relief. Since the structures and materials of cultural artifacts differ with each country, it is only natural that the philosophy and techniques for their preservation should likewise be different. Even within the same country, each restoration technician has his or her own philosophy, and these must be respected. That said, however, mistaken approaches must be rectified. For that purpose, dialogue between interested parties is essential, and forums such as academic conferences should be taken advantage of, since they offer a constant means for debate.

In several progressive nations, notably in Europe, ethics policies and practical criteria have been formulated for conservation and restoration, with projects proceeding in observation of these policies and criteria. What was once a world of oral tradition, apprenticeships, and secret techniques is now becoming one where there is an increasing call for well-organized educational curriculums and effective teaching materials that allow anyone to train and study equally. The policies and criteria enacted by the four groups ICOM-CC, the European Confederation of Conservator-Restorers' Organisations (ECCO), the American Institute of Conservation (AIC), and IIC-Canada served as the foundation. They consist of the following six items: Consideration for preservation and utilization; respect for cultural properties; self-improvement; respect for fellow professionals; contribution to the prosperity of the entire industry; and integrity.

(2) Problems with conservation science techniques

Conventionally, the challenge was to preserve the morphology of already degraded artifacts and prevent them from further deterioration. However, there are new challenges in conservation science now, relating to endeavors to reproduce the original properties and functions of artifacts. For instance, efforts are being made toward the development of methods that impart strength to wooden building materials after chemical treatment, so that they may be used for building again; or attempts are made to reproduce the original flexible state of a cloth article that has become fragile and brittle. In that sense, there is no point of arrival for conservation science. No point is good enough; the vital thing is to constantly pursue better and more effective methods.

(3) International exchange

The World Heritage Convention was adopted at the 1972 General Conference of UNESCO. Japan assented to this Convention in 1992. This Convention recognizes that parts of the cultural and natural heritage are of outstanding international value and are therefore a part of the world heritage of mankind as a whole, and aims to have countries work together for the conservation of these parts of the heritage when they are in danger of damage or destruction. Criteria for a heritage to be registered as a World Heritage were established from expert perspectives. However, there are national differences to the approach to the conservation of cultural heritages, as well as differences in standards and regulations governing conservation and restoration.

(4) Facilities and organizations

There are a number of national bodies with the function of conducting scientific research on the conservation of cultural properties: they are the National Research Institutes for Cultural Properties (Tokyo and Nara) controlled by the Cultural Agency; the Tokyo National Museum; the National Museum of Ethnology; the National Museum of Japanese History; and the National Museum of Western Art, which all have organizations for the research of conservation science. However, the number of experts who belong to those bodies come to a grand total of slightly over 30.

By comparison, in Europe, there are a large number of renowned museums and art galleries just in the city of London alone, almost all of which have laboratories for conservation science. The British Museum and National Gallery each have 80 or so experts on conservation and restoration. Their ranks include natural scientists, conservation and repair technicians, carpenters, turners, and painters. For that reason, they are capable not only of analysis and conservation of artifacts but can even build display cases and artifact stands with their own hands.

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Glossary of Terms

Fluorescent x-ray analysis

When x-rays are applied to a cultural property of unknown composition, the elements composing the specimen are excited, and generate secondary x-rays that are unique to the element. Those secondary x-rays are also called fluorescent x-rays. Their wavelength and intensity can be used to identify the elements contained as well as to measure their content. It is a non-destructive method of analysis consisting solely of x-ray irradiation, and is suited to the investigation of valuable cultural properties.

Measurement of carbon and nitrogen isotopes

This is one of the metrological methods utilized in archaeology. A mass spectrometer is used to measure the carbon and nitrogen isotopes (13C/12C, 15N/14N) contained in human bone, and on the other hand, to measure the carbon and nitrogen isotopes in the food resources that ancient peoples must have eaten. By cross referencing both groups of data, it is possible to identify whether a given group of humans subsisted mainly on marine products, meat, or fish, and estimate the eating ecology of ancient peoples.

Radioactivity analysis

In this method, an archaeological specimen is activated by being made to absorb neutrons, and its radioactivity (usually gamma rays) is measured to identify and quantify the elements contained in the specimen. This method is particularly effective for the quantification of component elements that are contained in trace amounts, and for the identification of the place of production (→ method for identification of place of production) of ceramics on the basis of analyzing the trace components contained in the clay matrix.

Photogrammetry

This method involves taking measurements of, or deciphering, the shape and size of objects recorded in photographs. Depending on the position from which the photograph is taken, photogrammetry can be categorized into three groups: Aerial, terrestrial, and underwater. This method was first applied to the field of cultural properties in the latter half of the 1950s. Some early examples include the creation of a topographical map of the Heijo Palace Site, and the drawing of a three-dimensional drawing of the Great Buddha of Kamakura.

Isotopic ratio of lead

The isotopic ratio of lead is determined by the date of creation of the lead deposit, and is known to present a unique value for each geographical area. That is, each mine presents a unique isotopic ratio. By calculating the unique isotopic ratios of bronze articles, lead glass, and glazes that contain lead, and comparing the results against those of each mine, it is possible to estimate the specimens' place of production.

Underwater archaeology

This term refers to archaeology that deals with sites and artifacts that are underwater. The methods used for research and excavation are greatly different from those used for terrestrial studies. Underwater archaeology is intimately associated with diving technology, and is also linked to the evolution of the equipment needed for investigations. This discipline only began to flourish in earnest around 1960, when researchers from such countries as the US and France investigated archaeological sites on the ocean floor and surveyed sunken ships. In Japan, the Tsuzuraosaki underwater ruins at the bottom of Lake Biwa were discovered by accident and led to full-scale excavation. An example of full-fledged underwater archaeology, involving the creation of bathymetric charts and measured drawings, and photography and recording by underwater camera, is the excavation of the wooden battleship at the bottom of the harbor in Esachi City, Hokkaido that was embarked upon in 1972.

Radiography

Because x-rays are transmitted through objects and can sensitize film like visible rays, they can be used to observe the internal structure of archaeological artifacts much in the same way as x-ray diagnosis in the medical setting. By applying the photography of cross-sections (x-ray CT) and image analysis, it is possible to obtain x-ray images of even higher precision. In 1935, 40 years after their discovery, x-rays were used to look through the dry lacquer coffin that was unearthed from the Abuyama Burial Mound in Osaka Prefecture. On the other hand, radiography uses neutron beams. Since neutron beams are more easily transmitted through elements such as iron and copper than through elements such as hydrogen, oxygen, and nitrogen that compose organic matter, this method can be applied to look through metal containers and observe the paper and cloth articles inside.

DNA analysis

Deoxyribonucleic acid (DNA), which is the substance of the gene and controls the shape and properties of living things, can be extracted from dead creatures for analysis. DNA analysis of human bone can provide clues into the origins of humanity and its propagation, while DNA analysis of organisms can aid in the identification of species, seeds, or individuals. In this way, DNA analysis can be used effectively in the study of biological evolution and in estimating ancient growth and development conditions.

Plant opal analysis

Plant opals refer to microfossils of the glass-like cells found in the leaves of the rice plant and other plants of the family Gramineae. By measuring the plant opal content of soil, it is possible to obtain the total volume of rice hulls produced during the period in which a given volume of soil was deposited. However, it is difficult to identify the variety of rice from the shape of the plant opal. The establishment of this method of analysis allowed a new phase to be opened up in the research of the origins of rice farming. As a result, dramatic advances were made in the area of research relating to the origins and propagation of rice paddy farming.