

Starting Guide Book for
Scientific Analysis of Archeological Artifacts
: From Sampling to Interpretation

Grant-in-Aid for Transformative Research Areas (A)
“Deduction of Production Sites
through Analysis of Archaeological Remains”
(Area No. 20H05817)

Yoshimi Kamiya

Contents

Preface	3
Analysis of organic and inorganic materials	5
Starch granule.....	5
Lacquer.....	6
Vermilion.....	7
Pottery clay.....	8
Stone and jade artifacts.....	9
From Sampling to Interpretation	10
Starch granule.....	10
Lacquer.....	14
Vermilion.....	18
Pottery clay.....	22
Stone and jade artifacts.....	26
Analysis key points	30
Bibliography	31

Preface

Archeology is the study of human activities in the past. We can learn about lifestyles and cultures of that time from unearthed materials such as artifacts including earthenware, tools and ornaments, remains of animals and plants, and others. Furthermore, scientific analysis is able to provide various information to consider human activities and the environment in the past as well as the age determination. To obtain as much information as possible, or to preserve and restore cultural properties for future generations, the unearthed materials must be handled with the utmost care. And, it is important to understand proper procedures while handling artifacts for analysis.

The development of equipment and analysis technology is always progressing, and methods to interpret data are also reviewed each time. In the early time of scientific approach to the cultural properties, a number of precious materials were damaged by destructive analysis. However, advances in equipment and technology have made it possible to analyze fewer samples. Currently, various methods of non-destructive and non-invasive analyses have been established, and are being applied to archaeology.

This booklet, entitled “Starting Guide Book for Scientific Analysis of Archeological Artifacts: From Sampling to Interpretation”, provides an introduction for scientific analysis to people involved in excavations, those engaged in preservation and restoration of cultural properties, and students in archaeology. We provide an overview of the analysis of both organic “starch granules and lacquer”, and inorganic “red pigments, pottery clay, and, stone and jade artifacts” from among the many artifacts that are analyzed scientifically. In the first half of this volume, we note the purpose of analysis for each type of artifact. And, in the second half, we describe how to handle and store samples prior to analysis, how to actually process samples, the instruments and

equipment used in the analysis, and the type of information (data) that is extracted. The analysis methods introduced here may have already been updated when you become interested. Therefore, if you need to apply the analysis for your study, we strongly recommend you to consult specialists or experienced researchers.

This booklet is written as part of the research project “Deduction of production sites through analysis of archaeological remains” in the part of Grant-in-Aid for Transformative Research Areas (A), entitled “A New Archaeology Initiative to Elucidate the Formation Process of Chinese Civilization”. Although this project launched in December 2020, it was difficult to travel to the relevant site because of the COVID-19 pandemic. The analysis cannot be performed without the artifacts to be studied. However, developing analytical methods in laboratory use and creating databases are also important in research. Thus, we thought this period, which difficult the necessary sampling, as an opportunity for reviewing current analytical procedures and improving analytical methods. And, we wish to publish this booklet aiming to share basic knowledge about scientific approaches with people in archaeology. Some technical terms and analytical methods may not be familiar to the readers. We hope; however, this booklet will assist in understanding the scientific analysis of cultural properties.

Ayako Shibutani (Starch granule)

Yoshimi Kamiya (Lacquer)

Takeshi Minami (Vermilion)

Tomoko Ishida (Pottery clay)

Yoshiyuki Iizuka (Stone and jade artifacts)

(in order of appearance)

Analysis of organic and inorganic materials

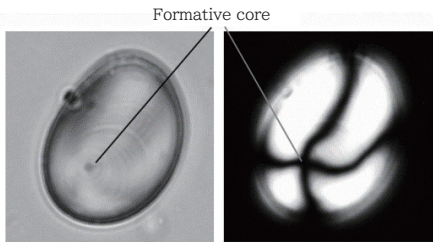
Starch granule

Ayako Shibutani

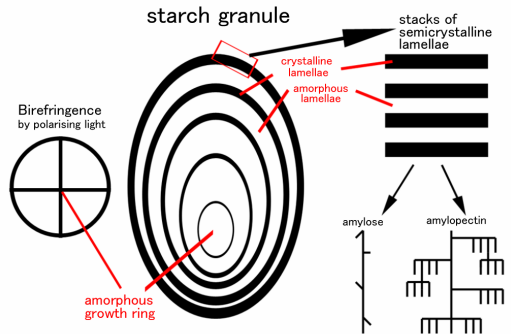
Starch granule

Starch is a substance produced by plants from carbon dioxide and water in the air and solar energy, and it is stored in the seeds, fruits, stems (trunks), leaves, and roots of higher plants, functioning as an energy source for these plants. As starch has a stable chemical structure, it is resistant to acids and alkalis as long as it is not exposed to heat, remaining in any environment for thousands of years, even if it is buried in the soil. Although there are differences in size and shape of starch granules, shape of cross polarization (black cross), and position of the core (the place where the polarizing cross intersects at the granule's center) depending on the type of plant, plants of the same species will exhibit the same morphology regardless of which part of the plant is studied. Archaeology uses this feature to study such granules as microscopic evidence of changes in people's food and environment in the past, with starch granules being discovered at archaeological sites worldwide.

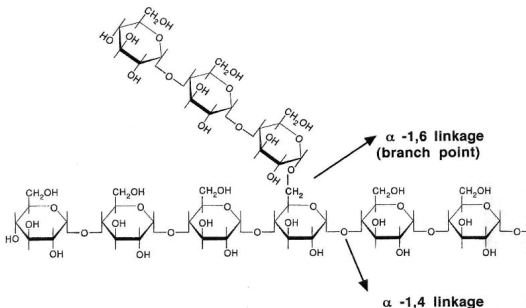
Images and schematic figures of starch



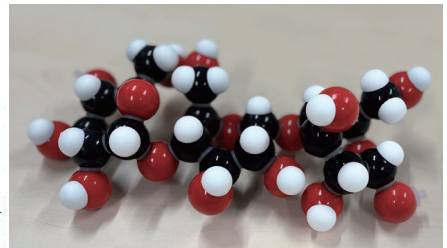
*Microscope imaging technique



Starch chemical formula



(Reprinted from Sivak & Preiss 1998)



Starch molecular model

Lacquerware refers to the diverse “materials and technologies” using lacquer. Factors such as which lacquer tree sap was used and how many times the processed lacquer was applied are relevant to “lacquered” items. In addition, there are only three species of trees whose sap can be used as lacquer, and by studying the major components, we can deduce the trade routes and place of production of the raw materials. As these three species grow only in East Asia, lacquer culture is called “Asian culture”.

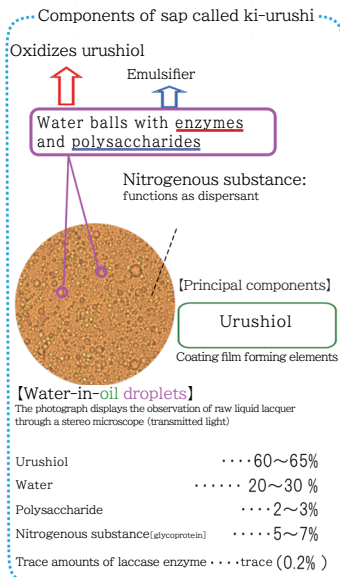
However, its components are not constant, as it is a natural product; and how much of each component is contained depends on the environment in which the tree grew, the time of harvesting, the method of harvesting and storage, the method of processing it into paint, and so forth.

There are two methods for turning liquid lacquer into film, one of which is the commonly used method. It involves a curing reaction that slowly forms a film over half a day in a high-humidity environment where laccase enzymes incorporate oxygen from moisture in the air. The other method is used for coloring gold products, such as arms and armor, and uses a curing reaction where heat is applied after painting to quickly form a coating film.

Sap cannot be collected throughout the year. Therefore, time management is essential to produce abundant lacquerware. Analyzing lacquerware provides us with sources to explore the artifacts’ manufacturing techniques and the real social structure of that time.

Three types raw lacquer sap

	Urushi	Japan wax tree	Black tree
Scientific name	<i>Toxicodendron vernicifluum</i>	<i>Toxicodendron succedaneum</i>	<i>Gluta usitata</i>
Old name	<i>Rhus verniciflua</i>	<i>Rhus succedanea</i>	<i>Melanorrhoea ushitata</i>
Primary locations	Japan, China, South Korea	Vietnam, Taiwan	Thailand, Myanmar
Main components	Urushiol	Laccol	Thitsiol
Lipid structure			
Raw lacquer film color			



[Note] Sap collected from which bark fragments and dust have been removed is referred to as “raw lacquer”.

The red pigment vermilion (mercuric sulfide) used to be sprinkled in tombs and applied to earthenware and stone tools.

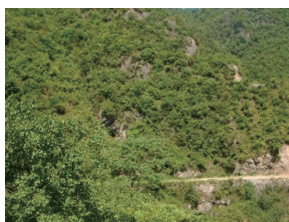
Cinnabar ore collected from cinnabar mines is crushed, after which red-colored bits are collected and pulverized to produce what is known as vermilion, and there is no chemical treatment during the refining process, it is believed it does not undergo any isotope fractionation until use at the archaeological site. Moreover, the ultra-trace sulfur isotope analysis system (described later) measures the sulfur isotope ratio directly from the vermilion in the analysis sample, which means that no isotope fractionation effect is caused during analysis.

By examining the sulfur isotope ratio of vermilion excavated from an archaeological site and comparing it with the sulfur isotope ratio of cinnabar ores, it is possible to deduce the mine from which the vermilion was collected. However, there are more than 100 cinnabar mines in Japan and China. As such, we considered the following conditions when determining the mine from which a particular vermilion was likely collected, in ancient times:

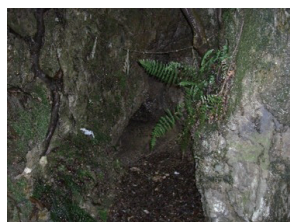
1. Ancient documents and the features of surrounding remains
2. Mines with an abundance of cinnabar ore near the outcrop



Entrance of Wanshan Mine in Guizhou Province, China



Old mining remains near Qingtonggou Mine in Shaanxi Province, China



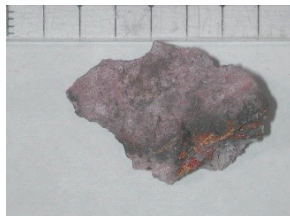
Old mining site at Niu Mine in Mie Prefecture, Japan



Cinnabar ore extracted from Wanshan Mine



Cinnabar ore in mine pit of Qingtonggou Mine

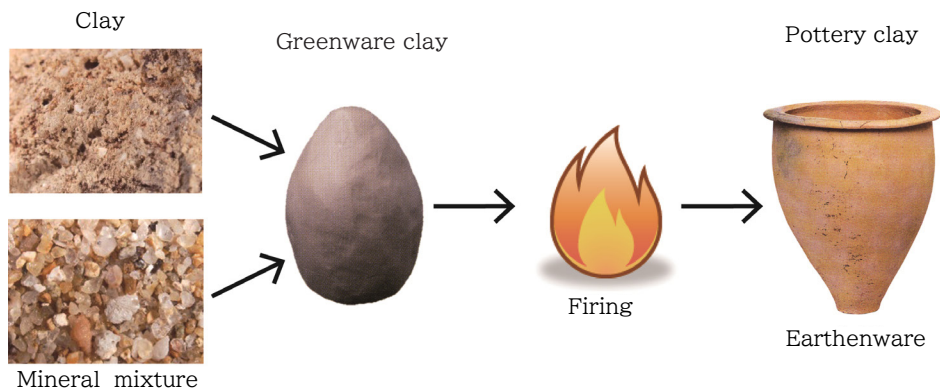


Cinnabar ore with realgar (tetra-arsenic tetra-sulfide) collected from Niu Mine in Mie Prefecture

Earthenware refers to containers made by baking clay in fire and were the first tools used by humans with an awareness of chemical changes. Earthenware and other forms of pottery have remained tools intimately connected to daily life from prehistoric times to the present day.

Earthenware are “additive tools” that retain the processes they undergo from the collection of raw materials to their manufacture, use, and disposal, until they become excavated archaeological materials; and this accumulation of processes leave traces in them. By studying various earthenware attributes such as form, pattern, paints, and traces of production and use that can be observed with the naked eye, we may discern the time period and location, set detailed measures in time and space, and discuss past earthenware-related human activities, group dynamics, relationships with the natural environment, and social backgrounds.

Pottery clay analysis is a method of approaching the materials that constitute the earthenware. Earthenware are composites made by adding and adjusting mineral admixtures and multiple clay types according to the state of the clay, completed by firing. Having undergone firing, the material is called pottery clay. All the raw materials that constitute the physical existence of the earthenware are reduced to earth-derived materials. By applying analytical methods from earth science to archaeological materials, we can clarify past human activities that have left traces invisible to the naked eye.



Stone and jade artifacts

Yoshiyuki Iizuka

Stones are a material that humankind has used since ancient times. It is resistant to weathering and alteration, and does not corrode even if exposed to the elements or buried in the ground for many years. As such, it is believed that most excavated stone artifacts retain their appearances and shapes from when they were made or used. Thus, investigating the usages and shapes of stone tools allows us to identify clues to the lifestyles and cultures of the people at that time.

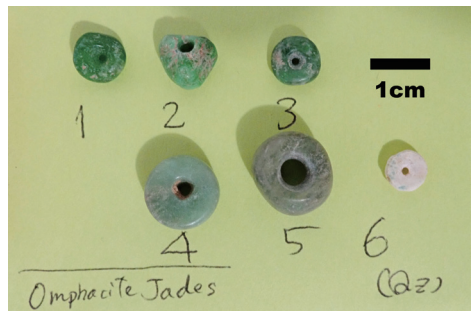
Stones were not only used as tools, but also as symbols of power, objects of worship, and to create pendants, bangles, earrings, and other accessories. Different types of stones have different colors, hardness, and toughness (brittleness), hence, they are used for different purposes according to their characteristics. Stone artifacts also differ depending on location and time period. It is possible to identify origin of characteristic stone artifacts, in turn allowing stone tools made of the identical stone may reveal information about the culture, its geographical spread, and even the stone transportation routes. In particular, “jadeite” and “nephrite”, both of which are so-called “jade” materials, and volcanic glass “obsidian” used to make stone blades, can be regarded as representative examples of raw materials.

It is essential to correctly understand and describe (record) the stone material (rocks and minerals). However, it is difficult for even researchers specializing in geology to identify stone artifacts that have been neatly shaped and surface polished when observing them by the naked eye. Nevertheless, destructive analysis of stone artifacts that are cultural properties is not appropriate from a conservation point of view. Therefore, it is not uncommon for “unknown” or incorrect rock names to be reported. While chemical analysis is a laboratory work in general, advances in analytical technology, have made it become possible to operate non-invasive chemical analysis of stone tools by portable-XRF in the field. Although interpreting the data requires knowledge of both geology and chemical analysis. Considering these circumstances, the next chapter explains how to identify among stone materials, particularly those used for stone artifacts.

Representative stone ornaments



Stone ornaments from the Jomon Period in Japan.
1: talc-rock, 2: nephrite, 3: jadeite
(collection of the Department of Archaeology,
Tohoku University, Japan)

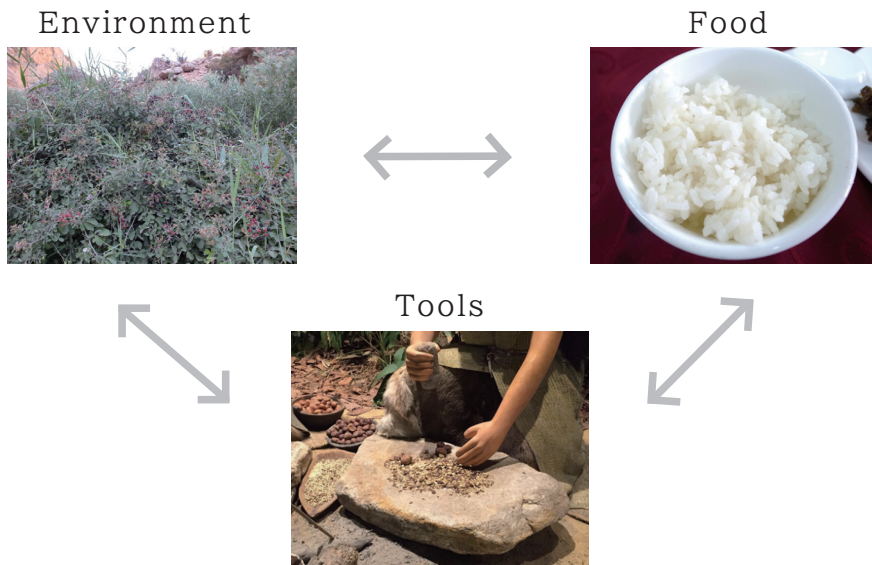


Stone beads excavated from the La Corona site in the
Late Classic Period of Maya.
1-5: jadeite, 6: quartz schist.
(collection in the Universidad del Valle de Guatemala)

From Sampling to Interpretation

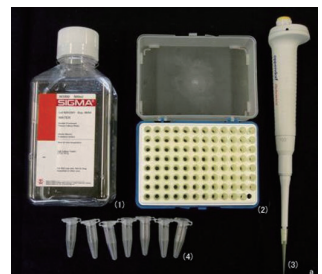
Starch granule

“Starch residue analysis” reconstructs past vegetation and human use of plants. The analysis is used on soil from archaeological sites, stone tools, pottery, substances attached to the surface of shell and wooden tools, and calculus and plaque from human and animal bones. Analyzing such substances reveals the type of climate and plants that existed at that time, and their relation to human beings. We are able to answer questions such as: What plants were processed and how? What were they used for? How were they eaten?



Sampling from pottery

When dealing with pottery, samples of burns, spills, and other attachments to the inner and outer surfaces of pottery are collected. Starch granules are easily deformed when subjected to heat while retaining moisture, which may result in observations of expanded particles and lack of polarizing crosses, however, it is possible to confirm the presence or absence of the starch granules.

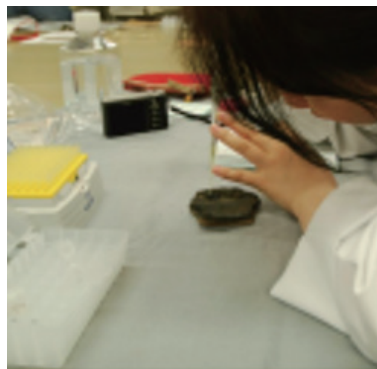


Purified water, pipette tip, micropipette, tube

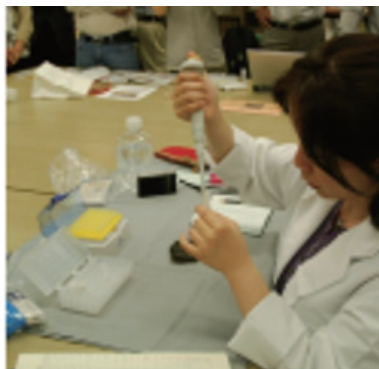


Observing materials and
deciding where to sample from

Immersed in water and collected
by micropipette (liquid sample)
Collected as flakes (flake samples)



Water with attachments
into a tube (liquid sample)
Purified water added to the
flakes (flake sample)



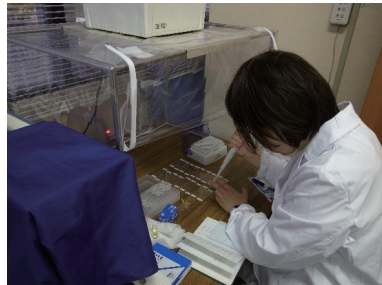
In general, pottery collected from residues during excavations are oftentimes washed with tap water during photographic recording and organization, however, it is extremely rare for starch granules contained in attachments to be lost due to the cleaning. As pottery with verified attachments are often carefully preserved immediately after excavation, it is not necessary for analysis, to collect residue samples immediately after the excavation. However, we do not yet know the effects of chemicals on the starch granules contained in the attachments. As such, it is necessary to select pottery that has not been treated with chemicals when performing the analysis.

When analyzing starch residue, samples are collected both as water absorbed from attachments infused with purified water and fine flakes of about 5 mg, specimens are prepared, and they are observed with an optical microscope equipped with a polarizing device. If starch granules are identified, the plant species from which the starch granules originate is investigated and identified through a comparison with reference specimens prepared using living plants.

Making permanent slides



1 minute of 13000 rpm in centrifuge



Encapsulated with glycerol gelatin
(refractive index 1.46-1.48)

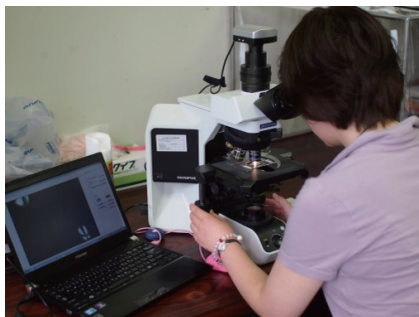


(Sample $8 \mu\text{l}$ + encapsulant $8 \mu\text{l}$) x 2



Blank slides with no sample and only encapsulant prepared
(check for contamination) No coloring with reagent (check for aging)

Microscopic observation

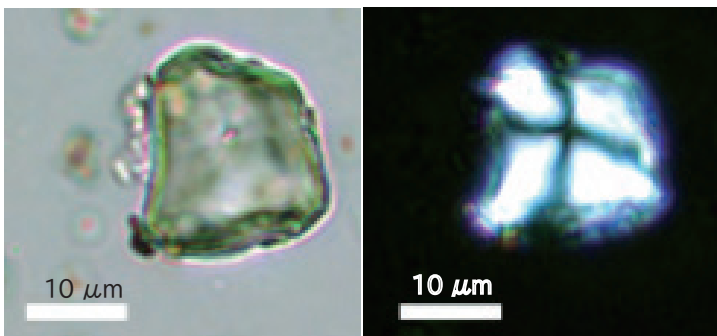


Microscope: Olympus BX53-33Z
(Olympus with polarization and phase detection device, 100-1000 times magnification)
Camera: WRAYCAM-NF500 (Wraymer)

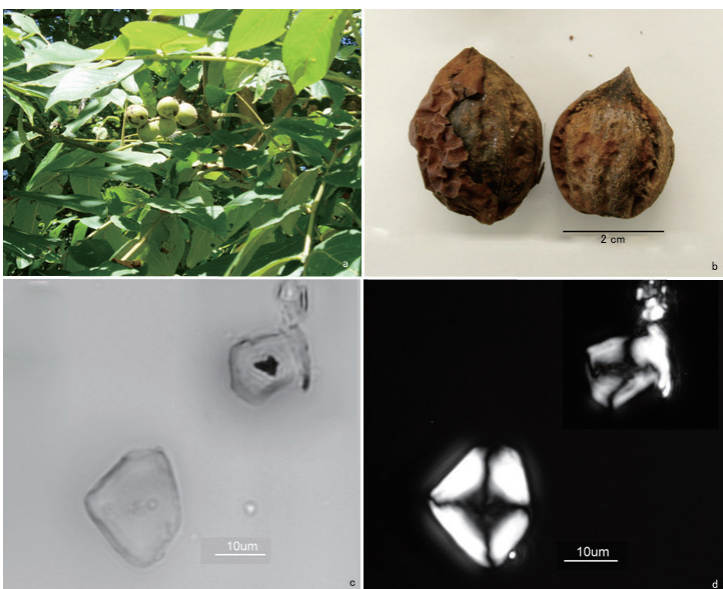


Polarization and
phase detection
equipment

Identifying the plant for the detected starch granules involves a comparison with the characteristics of the living-plant reference specimen, including granule shape, size, polarizing cross shape, and core position. However, samples with expanded granules or damaged outer edge caused by being heated or such that lack polarizing crosses often have not retained their original form, making it difficult to identify such starch granules. That is, it is important not to draw any conclusions based on starch residue analysis alone, but to investigate the plants used in combination with other scientific analyses.



Starch granules found in carbides attached to the pottery



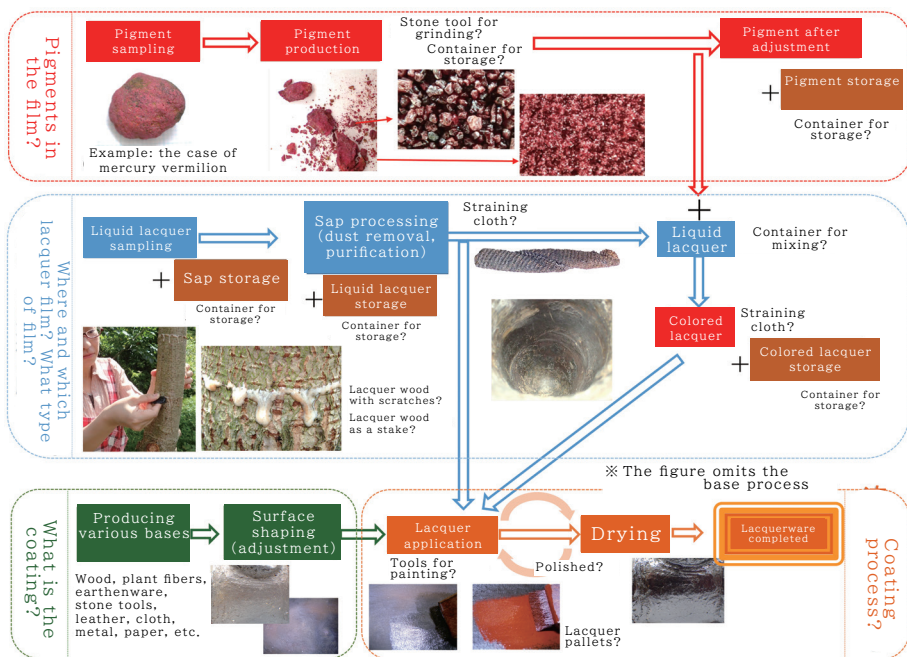
Modern walnut and starch granules

(Ayako Shibutani)

Lacquer

Complex lacquer production techniques

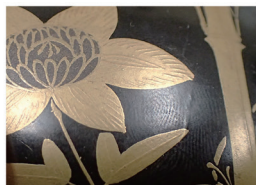
In recent years, there has been an increase in the analyses of lacquer artifacts involving natural science methods, thereby revealing a complex reality of lacquer painting that could not be known by external observation alone. Lacquerware is not finished simply by applying liquid lacquer once on the object to be coated (the base). In general, there is a multi-layer structure where the base layer on the object to be coated is covered by a paint layer, upon which other decorative layers are further formed in some cases. Consequently, lacquerware display a combination of various materials such as soil, pigments, and metals. Simply observing the outer surface misses the various pieces of information hidden underneath.



Lacquerware production involves a number of steps: (1) raw materials for pigments are procured for production, (2) liquid lacquer is harvested from lacquer trees, (3) the coating is prepared and the surface is adjusted, and (4) the harvested liquid lacquer is processed into paint and stored so as not to be in contact with the air. It is important to decide on the analytical method after considering the answers needed, such as clarifying the existence, type and use of pigments, discussing the lacquer components, or knowing the coating process.

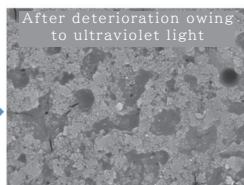
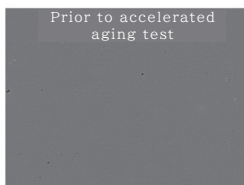
Some artifacts have weak adhesion between the coating film and the base, and you may not notice the fine lacquer film scattered in the soil at the excavation site. Although it means hard work, minute flakes extracted from the soil around lacquerware can be used effectively in destructive analysis. In addition, the lacquer film that has become frail and powdery owing to deterioration may be lost when the earthenware is cleaned.

When handling an article whose surface is apparently painted, the surface should be observed carefully. Hand sebum easily enters degraded film, therefore, it is safer to wear gloves if the article is to be analyzed. However, if lacquerware is handled with bare hands, hands should be wiped with alcohol beforehand.



Hand sebum having seeped into the deteriorated lacquer film remains as fingerprints (easy to spot in the black base part).

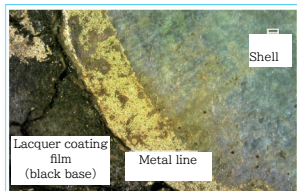
This is a case where it could not be removed despite cleaning with a solvent.



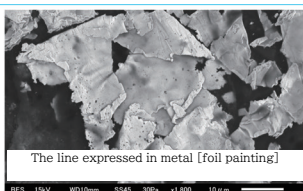
The surface of the coating film is observed with a scanning electron microscope (SEM). When the lacquer film has deteriorated, dirt and hand sebum easily adhere, becoming difficult to remove once they have seeped inside, therefore, oil pyrolysis products may be detected by Py-GC/MS. You may be wondering if lacquer sap with added oil was applied or whether it is from hand sebum long after.

Furthermore, if decorations have been added on top of the coating film layer, it is necessary to investigate the type of decoration technique, the materials used in combination (such as metal, shell, pigment, ceramic pieces), and the designs expressed.

Not all questions can be answered in one round of analysis. Although, as a rule, non-destructive surveys are required for cultural properties, non-destructive surveys alone are not sufficient for analysis of lacquerware. Only by combining multiple analytical methods can information be extracted. Moreover, to determine the details of the lacquer techniques, data for each layer is required, where approach to sampling and analysis plays an important role.



Magnified observation of the Makie decoration surface with a microscope



Magnified observation of metal shapes with a scanning electron microscope (SEM)



When the fine powder makes it difficult to discern with the naked eye, SEM can be used to clearly identify the metal shapes used.

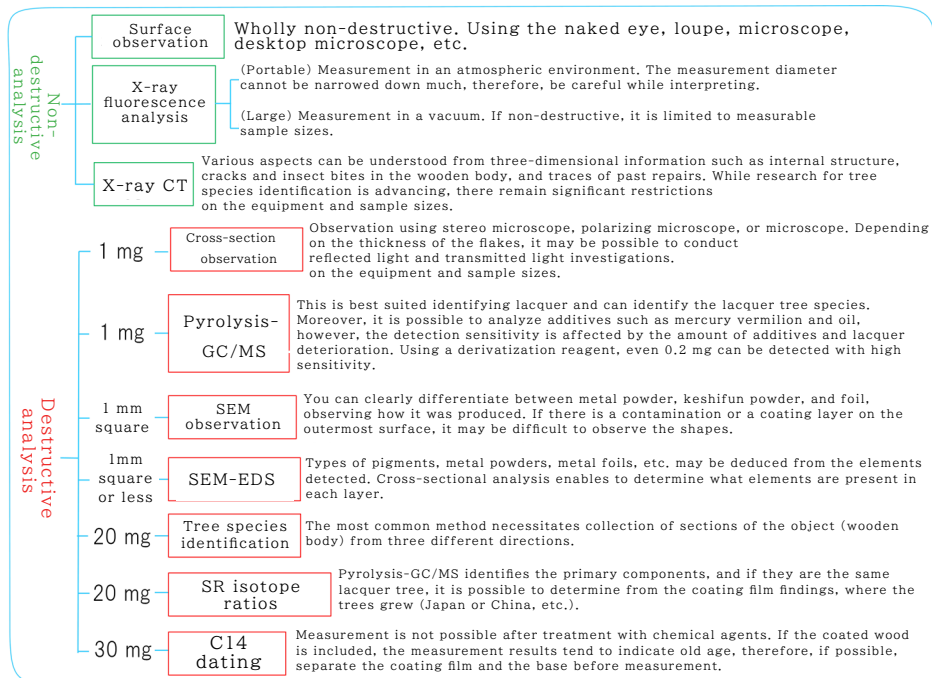
First, whether the lacquerware has been preserved with chemicals should be checked by observing the surface. If petroleum-derived preservative treatment materials have been mixed in, it makes it difficult to examine the sample using pyrolysis-gas chromatography-mass spectrometry [Py-GC/MS] as well as impossible to use radiocarbon dating [C14 age]. Even if the storage status is checked carefully, there will be times when synthetic resins that ought not to be used interfere with the data, preventing us from retrieving the lacquer peaks to be discussed.

Nonetheless, even if preservative treatment has been performed, the lacquering process can be determined using cross-sectional observation.

Methods for analyzing lacquered artifacts is linked to the question, "What do you want to know about the lacquerware and to what extent?" The amount of information that can be obtained from lacquered artifacts that does not dissolve in solvents varies significantly, depending on whether destructive analysis can be performed. Furthermore, the analytical accuracy varies

depending on the minimum required sample amount available for analysis. When performing analysis of trace amounts, it is difficult to detect the information required, for example if there are materials such as pigments mixed with the coating film or if the volume of lacquer components in the sample is low owing to deterioration. It is safest to perform surface and cross-sectional observation first, acquiring the basic information of the lacquerware in question, and then consider the sampling method to be used. Simultaneously, it is necessary to consider how much sampling is possible for each analysis.

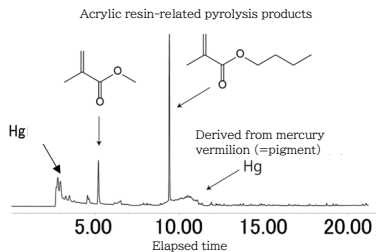
Various analytical methods for lacquered artifacts



Note: The sample volumes for destructive analysis are only indicative as they vary depending on the sample's condition and whether other materials have been mixed in.

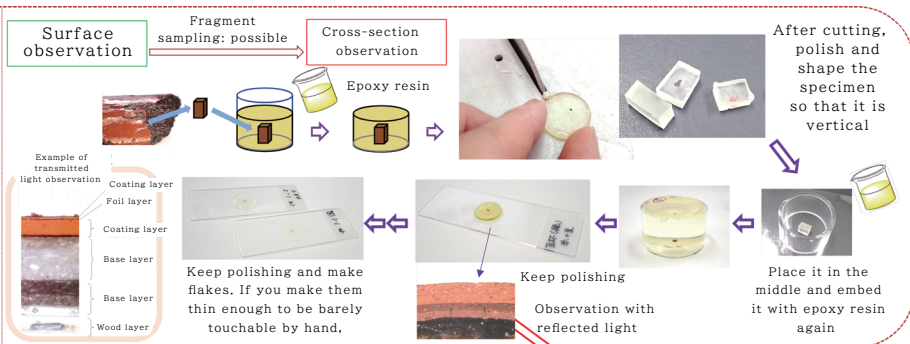
Infrared spectroscopy has been used to analyze organic matter as well as lacquer film. However, there are cases where infrared [IR] spectra is similar to asphalt, which may make the results difficult to interpret depending on artifact deterioration or if there are other materials mixed in. As the information on chemical structure that can be obtained becomes rough, it is currently not recommended for lacquer identification. The analytical method most used to determine the presence of lacquer in the last 30 years is pyrolysis analysis. Although the number of reported cases is small, pyrolysis-gas chromatography-mass spectrometry for thermally-assisted hydrolysis and methylation [THM-PY-GC/MS] using derivatizing reagents is an excellent method for trace analysis, and is increasingly being used in the field of cultural properties.

Py-GC/MS is a powerful tool for lacquerware analysis. Despite that, the analytical data is so complex that it is often difficult to interpret. This makes it important to build databases. Although simultaneous analysis of additives is possible, the inclusion of various types of mixed materials in the analytical sample makes it difficult to determine the thermal decomposition products of lacquer, whose data is required. After removing the dirt from the surface, the sample is obtained in a manner that ensures that it contains much lacquer component. It is difficult to obtain the information required for lacquer identification by including the underlying layers or the base, while artifacts that have been preserved using synthetic resin are not suitable for analysis. Moreover, polyethylene (PE), polypropylene (PP), or polyvinyl chloride (PVC) coming in direct contact with the artifact may cause strong detection of peaks derived from the phthalates in plasticizers. As such, care must be taken when using plastic bags or plastic film to store artifacts.

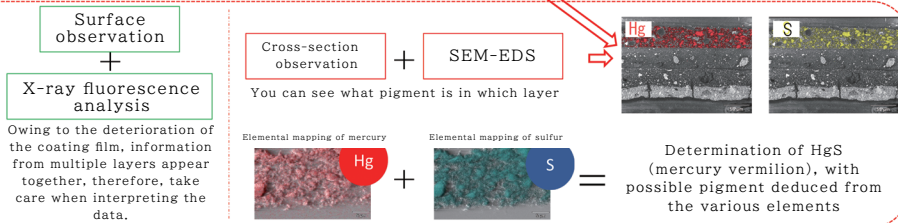


Data obstructed due pigments and storage treatment materials (total ion chromatogram, TIC)

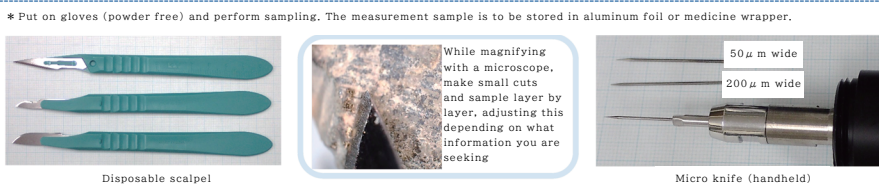
Coating process?



Types of pigments?



Sampling tools



Vermilion

Measurement sampling

Non-destructive analysis may be required when measuring vermillion attached to earthenware or stone tools excavated from archaeological sites. Yet, isotope analysis is a type of destructive analysis, which is why we have often been refused access to materials. This is the reason why the sampling for the ultra-trace sulfur isotope analysis system that we have developed enables measurements by simply pressing a sulfur-free adhesive tape against the sampling area, so that the material can be analyzed with almost no damage.



Adhesive tape for sampling



Samples are collected by pressing adhesive tape against vermillion applied to the concave part of the earthenware

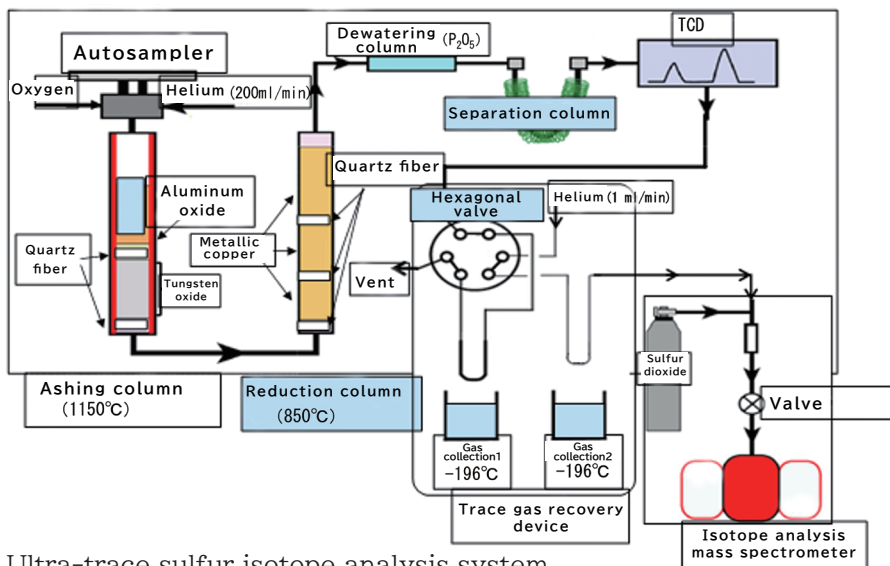


Analysis is possible with as less as one grain of vermillion collected with the adhesive tape

*One grain of vermillion is so small that it can barely be recognized with the naked eye
*Past analytical methods have required about 10 mg of vermillion

An ultra-trace sulfur isotope analysis system

This system comprises an elemental analyzer, a trace gas trap device, and a mass spectrometer for isotope analysis.



Ultra-trace sulfur isotope analysis system (Takahashi et al., RCMS 2018,32:1991-1998.)

Cut out vermilion sample collected along with the adhesive tape and place it in the aluminum boat

Make it into a small lump and insert it into the elemental analyzer's autosampler

The elemental analyzer generates sulfur dioxide gas from the vermilion and separates it from other components

Quickly introduce the sulfur dioxide gas with helium gas into the isotope analysis mass spectrometers

liquid nitrogen

- (1) The separated sulfur dioxide gas is led into the gas trap and solidified with liquid nitrogen
- (2) Repeat this twice to increase the concentration

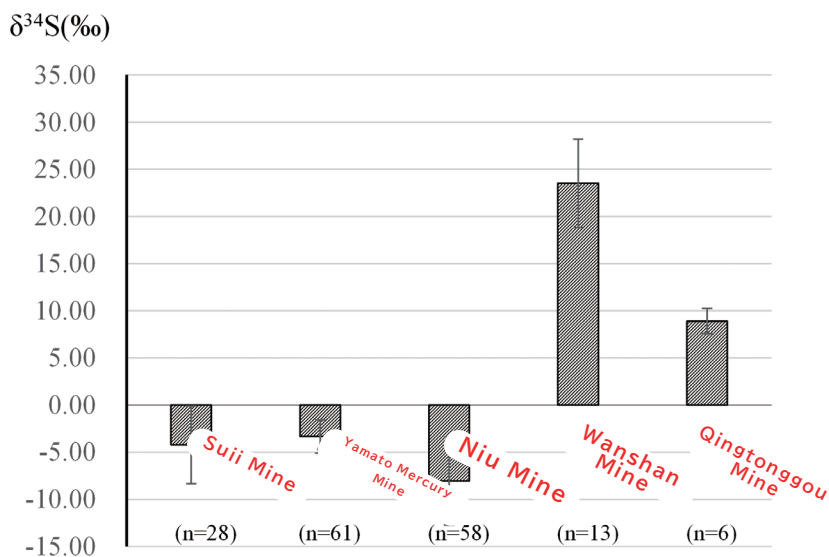
How does investigating the sulfur isotope ratio of vermilion excavated at an archaeological site make it possible to deduce the production site?

Sulfur has four stable isotopes (^{32}S , ^{33}S , ^{34}S , and ^{36}S) with different mass numbers in nature, whose abundance ratios are 95.02%, 0.75%, 4.21%, and 0.02%, respectively. Sulfur isotope ratio analysis expresses the ratio of ^{34}S to ^{32}S as a $\delta^{34}\text{S}\%$ value compared with the reference material that is the isotope ratio of the Canyon Diablo meteorite. For example, a negative $\delta^{34}\text{S}\%$ value signifies a higher proportion of ^{32}S than in the reference material, while a positive value indicates a higher ^{34}S .

$$\delta^{34}\text{S} (\%) = \left[\frac{\left[\frac{^{34}\text{S}}{^{32}\text{S}} \right]_{\text{sample}}}{\left[\frac{^{34}\text{S}}{^{32}\text{S}} \right]_{\text{standard}}} - 1 \right] \times 1000$$

It is well-known that the ratios of sulfur isotopes in nature fluctuate owing to evaporation, diffusion, chemical reactions, and uptake in organisms. Further, we know that the ratios do not differ from mineral to mineral, for example with cinnabar (mercury sulfide) or iron sulfide, but depend on the geographic location.

As such, when we investigated the sulfur isotope ratios of the mines from which vermilion would have been mined in ancient Japan and China, we found completely different values in Japan (Suii Mine in Tokushima Prefecture, Yamato Mercury Mine in Nara Prefecture, and Niu Mine in Mie Prefecture) and China (Wanshan Mine in Guizhou Province and Qingtonggou Mine in Shaanxi Province) as presented in the following figure.



Principal cinnabar ore sulfur isotope ratios in Japan and China

Furthermore, when we measured the sulfur isotope ratios of vermilion excavated from archaeological sites, we found vermilion with a positive $\delta^{34}\text{S}\text{‰}$ value in tombs from the late Yayoi period (presumably the tombs of influential persons) from northern Kyushu and along the Sea of Japan coast. This suggests that vermilion may have been brought to Japan from China during this period.

Is it possible to deduce the production site of vermilion based on sulfur isotope analysis?

Sulfur isotope analysis is an effective method for deducing where vermilion was produced, however, different veins may exhibit different sulfur isotope ratios even between neighboring mines. In extreme cases, a mine with negative $\delta^{34}\text{S}\text{‰}$ values may be the neighbor of a mine with positive values.

We have to consider other cases are combinations of vermilion from different production sites, used at the same archaeological site. In such cases, we increase the number of samples to be measured, and if we detect similar values, we may assume that vermilion from one production site was used.

In this manner, it is important to know the limits of production site deduction by sulfur isotope analysis. We need to be flexible when deducing production site by combining it with other methods such as lead isotope analysis and mercury isotope analysis as well as by adding information on the archaeological site itself, such as about grave goods.

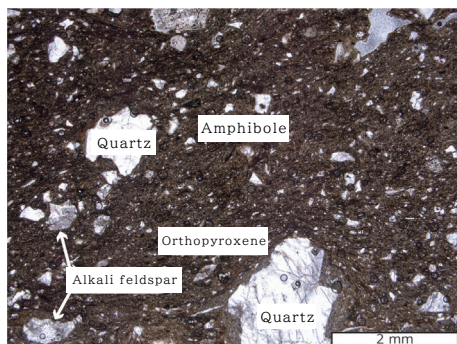
Pottery clay

Pottery clay analytical methods

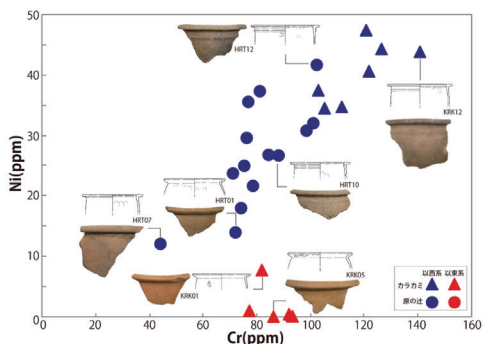
Pottery clay analysis is a method of analyzing the substances that create earthenware and characterize the source of material, manufacturing techniques, dating, paleoenvironmental restoration, and resource utilization. Pottery clay analysis can be broadly divided into two types.

The first method focuses on mixtures and organizational structures contained in earthenware. A closer inspection of earthenware reveal that they contain various minerals. Some minerals were in the clay from the beginning, while others were intentionally mixed in. They may also contain organic matter (e.g., plants) and microfossils (e.g., spicule and diatom fossils). Observation by naked eye, loupe, or stereo microscope allows for qualitative grouping of pottery clay according to amount, type, and composition of mixtures. By creating a flake specimen, observing the minerals contained with a polarizing microscope, and quantifying the contents, minerals can be accurately identified from a petrological perspective. Attempts at identification are also being made by X-ray diffraction (XRD) and analysis of mineral chemical composition by electron probe microanalyzer (EPMA).

The second method is elemental analysis, which measures the chemical composition of the substances that constitute the earthenware pottery clay. Toshikazu Mitsui measured six elements (Rb, Sr, K, Ca, Na, Fe), analyzed data from all over Japan, and indicated that “there are regional differences in the elemental composition of earthenware”. In recent years, there has been an increase in multi-element measurement by neutron activation analysis (NAA) and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), with analytical methods using trace elements and rare earth elements being developed. Advances are also being made in isotope analysis (Sr, Pb, Be).



Example of flake observation



Example of elemental analysis

When conducting elemental analysis, it is necessary to carefully handle elements sensitive to the environment they were buried in (elemental additions [Ca, P, Ba, etc.], elemental eluviation [Ca, K, Na, etc.]). Nonetheless, since it is difficult to quantify these effects, an effective approach is to focus on elements that do not change so easily because of the environment they are buried in.

There are various approaches to pottery clay analysis, however, no method allows for highly accurate analysis while being completely non-destructive. The required sample volume, analysis cost, time and effort, and data obtained also differ depending on the analytical method. Note the characteristics of each analytical method and select which one to use according to the required purpose and the research environment.

The material properties of earthenware

Before conducting any analysis, it is important to first understand the material properties of earthenware.

Examining ethnic cases of earthenware production, the raw materials (clay, mixtures, pigments) of earthenware tend to have been collected from familiar places within about 2 km of the place of residence. Raw clay displays the features of plasticity, viscosity, sintering, and fire resistance. Mixtures or multiple clays may be prepared depending on the condition of the clay. This implies that the raw material clay and the finished earthenware pottery clay are not homogeneous as the material has been modified in the earthenware production process, that is, having changed physically and chemically.

Moreover, as the material properties differ depending on the firing method, which pottery clay analytical method is most suitable also differs. In particular, prehistoric pottery is porous, therefore, it is vital to focus on the effects of the environment in which it was buried.



Yayoi earthenware



Sue pottery

Homogeneity	Heterogeneity	Homogeneity
State	Porosity	Rigidity
Firing method	Open burning	Kiln
Firing temperature	Low-heat firing (about 600~800°C)	High-heat firing (about 1000~1200°C)
Combustion state	Oxidation firing	Reducing flame firing
Pottery clay analysis	Elemental analysis, flake observation	Elemental analysis

Pottery clay analysis in practice

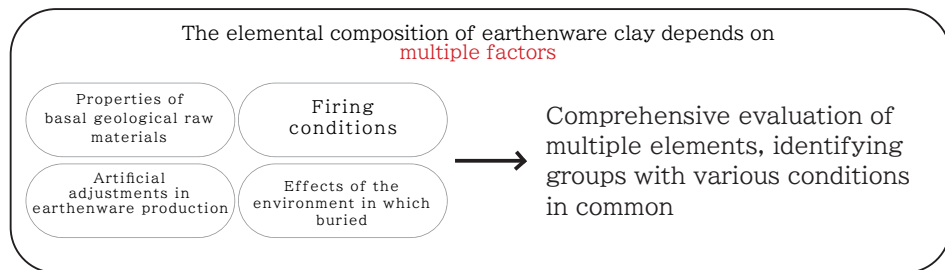
During the preliminary planning phase, the purpose of conducting the pottery clay analysis should be specified. Select the method of pottery clay analysis according to that purpose and collect the sample necessary for that method.

The stage of handling the earthenware is a suitable opportunity to comprehensively consider the timing of the organizing work. Carefully observe the earthenware clay and hues to note the overall variations, grouping what is available before selecting your samples. When doing so, select samples that can be investigated archaeologically rather than small fragments whose type, site, time period, form, and excavation location are unclear. Analytical data of samples that lack archaeological information cannot be used in research. Earthenware with adhesives and repair agents are not suitable for analysis. Therefore, for analyzing pottery clay analysis from the beginning, it is advisable to detach the analysis sample before joining the pieces or restoring the artifact. Precautions should be taken regarding contamination when sampling clay at an excavation site, taking blocks whose cores are then used in the analysis.

Once the necessary archaeological information has been recorded, a piece of earthenware should be severed to create the sample for the analysis. In elemental analysis, the sample is washed, dried, crushed, and made into glass beads, which are then measured with an instrument. When examining mixtures and organizational structure, flake specimens to be observed under a microscope should be prepared.

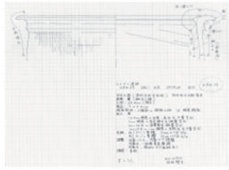
Refer to the bedrock geology of the relevant location when interpreting the analytical data. Using geological and geochemical maps, collect and analyze geological samples as necessary to understand the bedrock geological data of finer spaces. Thus, human activities and social backgrounds associated with the circulation of the earthenware can be examined, including whether they were locally produced or transported in and narrowing down the area from which they were transported.

In pottery clay analysis, it is important to comprehensively evaluate the analytical process as well as integrate the analytical results and archaeological information with each other. Similarly, it is important to disclose basic information (such as scale drawings, photographs, analytical data, measurement conditions) of the materials analyzed, encouraging verification and secondary use of the analytical data and interpretations. Therefore, it is necessary not to stop at one round of analysis but to develop a long-term systematic plan for analysis and a collaborative arrangement. Keeping the discussion alive will lead to new developments.



Archaeological documentation
(measurement
maps and photographs)

《Sample preparation》



Cutting



Washing & drying

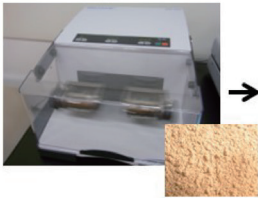


Coarse grinding

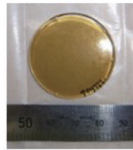


《Elemental measurement》

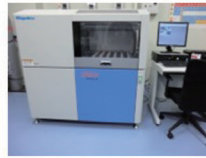
Fine grinding



Glass beads



XRF



XRF of major and trace elements



LA-ICP-MS



LA-ICP-MS of rare earth elements

Extra



A difficult issue is encountered when conducting pottery clay analysis, “collecting part of the earthenware as a sample”. As archaeological materials are unique, the general approach is non-destructive analysis. However, as earthenware clay is heterogeneously composed and earthenware surfaces are diverse (uneven, weathered, abraded), many aspects cannot be understood unless samples are collected and analyzed with precision.

Fragments stored in regional collection institutions can play a key role here. There exists a significant number of materials that were unearthed during excavations but never included in any excavation report and are kept in storage. Even fragmented materials have the potential to be an important cultural resource that reveals local history through the introduction of new research methods and technologies. By using analyzable materials and conducting research to the extent possible at the time, data is accumulated and analytical methods are improved, with these important materials likely coming to be used more effectively in the future.

(Tomoko Ishida)

Stone and jade artifacts

Chemical analysis of stone artifacts

Rocks are categorized into igneous, metamorphic, sedimentary, and carbonate rocks, and they are discriminated according to their origin, and further classified according to the types of minerals that compose them and how they are assembling. People have selected stones fit to purpose from various rock types and used them for tools, accessories, and building materials. To study stone artifacts, it is important to correctly understand stone materials (rock types) and their usages, compare regions and eras, and then advance understanding of manufacturing techniques and sourcing areas of stones.

In geology, when identifying rocks and minerals, the specimen should be polished or to make a thin-section is prepared, after which the sample is observed using an optical microscope or a scanning electron microscope, chemical analysis is performed using X-ray fluorescence and other techniques, and crystal analysis is conducted by X-ray diffraction and/or Raman spectroscopy. At archaeological excavation sites where various unearthed materials are handled, there are limits to the qualitative descriptions that can be made of stone materials based on empirical observation. Thus, it is not uncommon for reports to contain petrologically erroneous descriptions.

As stone tools such as axes, blades, and arrowheads excavated in large quantities as well as stone materials used as building materials tend to be made of rocks that are relatively easy to find, it may compare local rock (natural) samples with representative stone artifacts by using the petrographic analysis aforementioned. However, it is difficult to conduct destructive analysis on artifacts that are rare from an archaeological or geological point of view and that have only been excavated in small numbers. Thus, advances are being made in identification of rock species by using portable X-ray fluorescence spectrometer (hereinafter, “p-XRF”) that can be used in the field and storages without damaging the artifacts.

Non-invasive chemical analysis by a *portable* XRF

Compared to the scanning electron microscope (SEM), electron microprobe (EPMA), and X-ray fluorescence spectrometer (XRF), available in laboratories, the *p*-XRF is “relatively” inexpensive and are not difficult to operate. Moreover, there are no restrictions on the size of the object during the analysis, and there is no need for sample preparation such as cutting, polishing, or chemical processing. In a few minutes, values of chemical composition can be obtained “on site”. This is useful in places where it is difficult to transport cultural properties, particularly during overseas researches.

The *p*-XRF that we are currently operating can irradiate an object with X-rays at a diameter of less than 10mm, capable of measuring X-ray energy dispersive spectra (EDS) from magnesium to uranium excited from the surface. The measurement time is 60 seconds, and the analytical results are expressed as oxide weight percentages (wt.%).

While it is easy to operate, it is not able to analyze elements lighter than sodium, which exhibits considerable decay of X-ray energy in the atmosphere, as it must be operated while exposed to the atmosphere. Moreover, if there are irregularities, soils, or impurities on the surface of the object, this may lead the output data to contain such extra signals. Thus, select a surface that is as flat and clean as possible, measure each object at multiple locations, and verify any homogeneity or heterogeneity. In the case of monomineralic rocks, the elemental ratios or cation ratios are recalculated from the measured value to verify the accuracy of the analysis.

Stone materials differ not only in physical properties such as color, density, Mohs hardness, and toughness (suppleness and brittleness) but also in their composition of the major elements indicated in the chemical formula described below. In particular, it is possible to semi-quantitatively identify stone materials based on the detection and ratios of the following six elements, such as silicon (Si), aluminum (Al), magnesium (Mg), calcium (Ca), potassium (K), and iron (Fe). In the other case, malachite and turquoise are minerals that contain copper (Cu) and can be clearly distinguished from others if copper and phosphorus are detected. Similarly, jadeitite, which contains sodium (Na) that cannot be detected by *p*-XRF analysis, can also be distinguished from other minerals by the ratios of silicon and aluminum as well as the detection of other elements.

Principal stone materials

Ornamental accessories and small ritual objects are often made of “monomineralic rock”, which is rock composed of a single mineral, rather than of rock that is assemblage of several minerals. The following table shows representative monomineralic rocks used for polished stone axes and ornaments. For example, rocks composed of jadeite (mineral name) are called jadeitite (rock name), while rocks composed of serpentine (mineral name) are called serpentinite.

List of minerals

*Silicate minerals

(Anhydrous minerals)

#Jadeitite white to green

Na-pyroxene (solid solution): jadeite-omphacite: $\text{NaAlSi}_2\text{O}_6 \sim [\text{Ca,Na}][\text{Mg,Fe,Al}]\text{Si}_2\text{O}_6$

White to green (Mohs hardness H: 6.5-7, Density D: 3.2-3.4),

quartz, chalcedony: SiO_2 , transparent, white to light green (H: 7, D: 2.8)

anorthite: $\text{CaAl}_2\text{Si}_2\text{O}_8$, white to green (H: 6-6.5, D: 2.8)

orthoclase, amazonite: orthoclase: KAlSi_3O_8 , white to blue-green (H: 6-6.5, D: 2.6)

clinopyroxene: $\text{Ca}[\text{Mg,Fe}]\text{Si}_2\text{O}_6$, green (H: 5.5-6.5, D: 3.2-3.6)

uvarovite: $\text{Ca}_3\text{Cr}_2\text{Si}_3\text{O}_{12}$, green (H: 6.5-7, D: 3.8)

(Hydrous minerals)

#Nephrite white to green

Ca-amphibole (solid solution): tremolite-actinolite: $\text{Ca}_2[\text{Mg,Fe}]_5\text{Si}_8\text{O}_{22}[\text{OH}]_2$

White to green (H: 5.5-6, D: 3.0)

talc: $[\text{Mg,Fe}]_6[\text{Si}_8\text{O}_{20}][\text{OH}]_4$ white to green (H:1, D: 2.6-2.8)

serpentine: $[\text{Mg,Fe}]_3[\text{Si}_2\text{O}_5][\text{OH}]_4$ dark green to green (H: 3.5-4, D: 2.5-2.6)

chlorite: $[\text{Mg,Fe,Al}]_{12}[(\text{Si,Al})_8\text{O}_{20}][\text{OH}]_{16}$ dark green to green (H: 2-2.5, D: 2.6-3.3)

muscovite: $\text{K}_2\text{Al}[\text{Si}_6\text{Al}_2\text{O}_{20}][\text{OH}]_4$ white to green in rare cases (H: 2.5-3, D: 2.7-2.9)

pyrophyllite: $\text{Al}_2\text{Si}_4\text{O}_{10}[\text{OH}]_2$ white (H: 1-2, D:2.6-2.9)

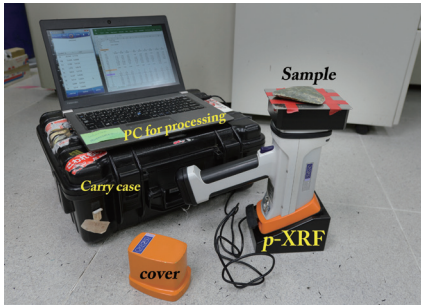
*Carbonate minerals

malachite: $\text{Cu}_2[\text{OH}]_2\text{CO}_3$ green (H: 3.5-4, D: 3.6-4)

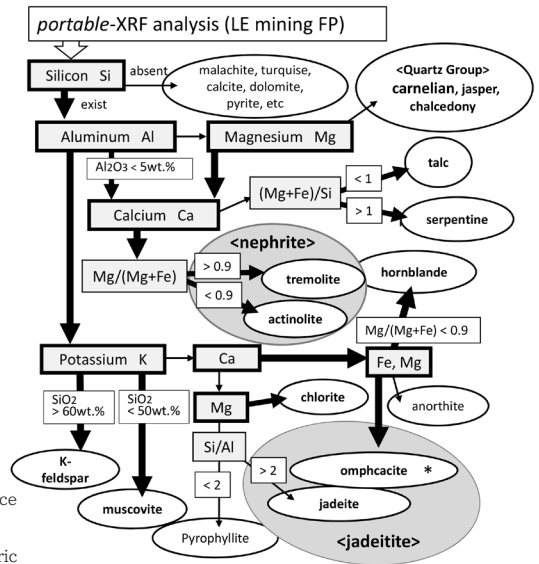
*Phosphate minerals

turquoise: $\text{CuAl}_6[\text{PO}_4]_4[\text{OH}]_8 \cdot 4\text{H}_2\text{O}$ blue to green (H: 5-6, D:2.6-2.9)

(# indicates rock name while others are mineral names, densities are reference values)



A portable-XRF (Oxford Instruments Co., UK: X-met 7500). During analysis, the target object is shielded by a protection cover for X-ray exposure.



Flowchart for mineral identification

Bold- and thin-arrows indicate the existence and absence of the element. Each ratio indicates the cation ratio.
 *: It may suggest clinopyroxene containing Al and Ca.
 Note: Sodium (Na) is not able to analyze under atmospheric environment.

Jade (jadeite and nephrite)

Jade is a general word and is a stone materials that has been prized by people since ancient times.

“Jadeite” is a monomineralic rock composed of more than 90% jadeite, known as “jadeite jade” in general. Chemically pure jadeite is white in color, however, it becomes green with a higher proportion of omphacite, which is a “solid solution”. What is commonly referred to as “jade” (*hisui* in Japanese) is composed of jadeite and omphacite. Since there are geological sources and workshop sites in the Itoigawa-Oumi area in western Niigata Prefecture, it has been believed it used considerable “jadeite” from this area.

Nephrite (rock name) is another monomineralic rock with a dense fibrous structure composed of more than 90% calcium amphibole. Calcium amphibole can be divided into tremolite and actinolite based on the cation ratios of magnesium (Mg) and iron (Fe). In mineralogy, tremolite is defined as having the Mg/(Mg+Fe) ratio of 0.9 or more, while actinolite is defined as having the ratio of less than 0.9 but 0.5 or more. Nephrite that primarily composed of tremolite is a metamorphic rock originating from carbonate rock less iron and has a white to transparent light gray in color, with the Mg/(Mg+Fe) ratio at about 1-0.98. By contrast, nephrite that primarily composed of actinolite is a metamorphic rock originating from serpentinite, with the Mg/(Mg+Fe) ratio in the range of 0.93-0.85 beyond the definitional boundaries of tremolite and actinolite. As nephrite is tougher than “jadeite (jadeite jade)” and better suited for use in stone axes and chisels, it has been used in eastern Eurasia since the Neolithic period.

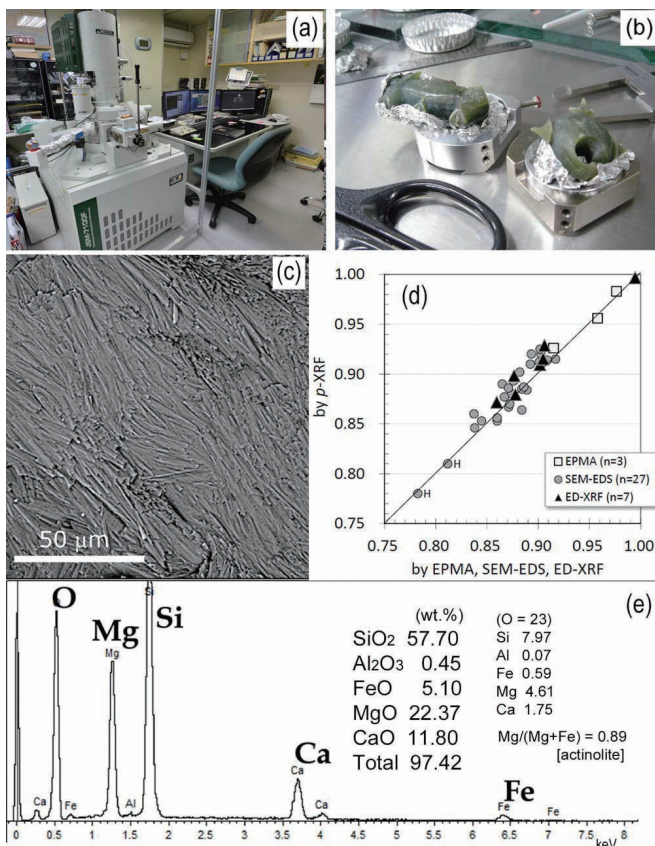
Japanese green nephrite of serpentinite origin has been produced in Itoigawa in western Niigata Prefecture, Hakuba Happo-One in northern Nagano Prefecture, and around Morioka area in Iwate Prefecture. Its existence has been confirmed in Japan in recent years, however, it was previously confused with serpentinite and described as such.

Stone and jade

Non-invasive analysis in the laboratory

Some artifacts identified by p -XRF are subjected to surface observation and quantitative chemical analysis using an energy-dispersive X-ray spectrometer (EDS) to verify on-site analysis and make comparisons with natural rocks. Although this is limited to stone artifacts that have been borrowed with permission, we are conducting non-invasive analysis using SEM-EDS from the Institute of Earth Sciences, Academia Sinica in Taipei. Furthermore, we are conducting quantitative analysis of natural rocks and minerals using EPMA to build a database for field surveys. This type of analytical approach can occasionally suggest the geological origin of the stone materials.

The non-invasive chemical analysis on stone artifacts by SEM-EDS



(a) Low-vacuum field emission scanning electron microscope (JEOL FE-SEM JSM-7100F, Institute of Earth Sciences, Academia Sinica in Taipei) (b) Nephrite artifacts (National Museum of the Philippines; inserted into SEM in this state) (c) Backscattered electron micrograph of the surface of a nephrite artifact (characteristic fibrous texture can be observed) (d) Comparison of analytical values between p -XRF and other instruments. Comparison of magnesium and iron in calcium amphibole (e) Energy-dispersive X-ray spectroscopy (EDS) and quantitative analysis values (weight percentages and element ratios) measured from the surface of the nephrite artifact

(Yoshiyuki Iizuka)



Analysis key points



Starch residue analysis is concerned with soil from archaeological remains, stone tools and earthenware, wooden tools, and calculus attached to the human and animal bones and teeth. The analytical procedure and the instruments and chemicals used differ depending on what is being analyzed. Please refer to relevant books and papers for further information.

Lacquer can be applied to various objects, including wooden tools, plant fibers, earthenware, stone tools, cloth, skin, paper, metal, porcelain, and plastic. Moreover, it is prepared by combining various materials such as wood, plant fibers, soil, pigments, metals, and additives (oils, etc.). Owing to its complex multi-layered structure, it is necessary to interpret the data while constantly considering “what you are seeing in what layer”.



Vermilion is an inorganic mercury compound that does not easily dissolve in water chemically, kidney damage if ingested. In addition, metallic mercury produced by microorganisms in the soil causes brain damage. Thus, gloves and face masks should be used on-site. In Japan, the vermilion within archaeological remains is a cultural property and not subject to mercury waste regulations, however, if vermilion is stuck to gloves or brushes, or artifacts or soil with vermilion attached to them, it should be the mercury waste guidelines of the relevant prefecture or municipality.

There are many ways to extract information from earthenware. Pottery clay analysis has undergone remarkable development in recent years, however, integration of findings from archaeological research based on basic earthenware research is essential for producing useful analytical results. Always begin with meticulous observation of the earthenware.



“Jade” is a general term usually considered as a precious rock, whereas, in academic terms, it refers to two different kinds of rocks: “jadeite (Na-pyroxene rock)” and “nephrite (Ca-amphibole rock)”. Limited attention used to be paid to the existence of “nephrite” in Japan, however, recent years have seen chemical analysis revealing that many stone artifacts are made of “nephrite” in the jomon Period, which are comparable to the prehistoric cultures of the eastern Eurasian continent.

Bibliography

Starch granule

- Henry, A. G. (ed.): Handbook for the analysis of micro-particles in archaeological samples, 304p, Springer Nature Switzerland AG, 2020.
- Ayako Shibuya: Plant Usage at the Shimoyakabe Site in Tokyo in Light of Analysis of Plant Remains Attached to Jomon pottery and Starch Residue on Stone Tools. Bulletin of the National Museum of Japanese History, 187, pp. 357-386, 2014. <https://doi.org/10.15024/00000296>
- Torrence, R. and Barton, H. (eds.): Ancient Starch Research, 256p, Left Coast Press, INC., 2006.
- Naoto Yamamoto, Ayako Shibuya, and Nobuhiko Kamijo: Plant Foods in the Jomon Period in Light of Starch Residue Analysis: Examining Remains in Ishikawa Prefecture. The Journal of the School of Letters, Nagoya University (History), pp. 51-82, 2016. <https://doi.org/10.18999/jouflh.62.51>

Lacquer

- Yoshimi Kamiya and Tetsuo Miyakoshi: "Damashi" Coating Technology in the Edo Period. Coatings Technology, 45, pp. 374-381, 2010.
- Yoshimi Kamiya: A Study on Hiramaki-e Techniques and Materials Centered on Nanban Lacquerware: Analysis of the Shapes of Metallic Materials with Scanning Electron Microscopy. The Journal of Art Studies, 429, pp. 43-64, 2020. <http://doi.org/10.18953/00008965>
- Kunio Yoshida, ed.: Archeometria: Archaeological Artifacts and Arts and Crafts through the Eyes of Science. The University Museum, University of Tokyo, 2012.
- Tamburini, D. : Analytical pyrolysis applied to the characterisation and identification of Asian lacquers in cultural heritage samples- A review. Journal of Analytical and Applied Pyrolysis, 157, 105202, 2021. <https://doi.org/10.1016/j.jaap.2021.105202>

Vermilion

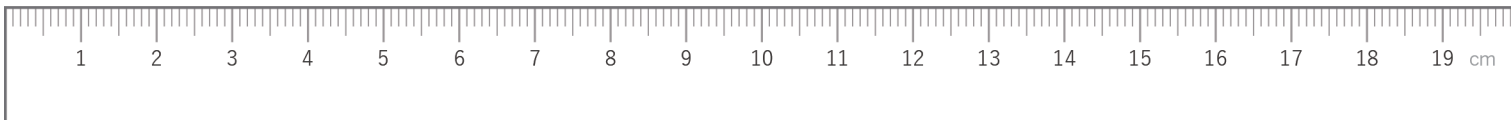
- Minami, T., Imai, A., Bunno, M., Kawakami, K., Imazu, S. : Using sulfur isotopes to determine the sources of vermilion in ancient burial mounds in Japan. Geoarchaeology, 20, pp. 79-84, 2005.
- Takeshi Minami, Yang Zhuming, Michiaki Bunno, and Hidehiko Shimazaki: Exploring Ancient Chinese Cinnabar Mines. Archaeology and Natural Science, 58, pp. 25-29, 2009 (in Japanese).
- Minami, T., Takeuchi, A., Imazu, S., Okuyama, M., Higashikage, Y., Mizuno, T., Okabayashi, K., Takahashi, K.: Identification of source mine using sulfur, mercury, and lead isotope analyses of vermilion used in three representative tombs from Kofun period in Japan. Journal of Archaeological Science: Reports, 37, 102970, 2021.
- Takahashi, K., Nakai, Y., Motizuki, Y., Ino, T., et al.: High-sensitivity sulfur isotopic measurements for Antarctic ice core analyses. Rapid Communications in Mass Spectrometry, 32, pp. 1991-1998, 2018. <https://doi.org/10.1016/j.jasrep.2021.102970>

Pottery clay

- Tomoko Ishida: Review and Prospects of Characterization Studies of Pottery: Application to Yayoi Pottery in Southern Kyushu. Kagoshima Journal of Archaeology, 45, pp. 3-13, 2015.
- Hunt, A. M. W. (ed.): The Oxford Handbook of Archaeological Ceramic Analysis, 768p. Oxford University Press, 2017.
- Kenji Kanegae: A Study of Yayoi Pottery Culture in Kyushu through Pottery Clay Analysis, 239 pages. Kyushu University Press, 2007.
- Yoshihiro Shimizu: Studies in Ancient Ceramics Technology, 258 pages. Yanagihara Publishing, 2010.
- Wakana Higuchi: The Science of Pottery: Understanding the Fundamentals and Chemical Mechanisms of Clay, Firing, and Glaze, 240 pages, Seibundo Shinkosha, 2021.
- Toshikazu Mitsuji: The New Archaeology of Pottery, 224 pages. Doseisha, 2013.
- Rice, P. M.: Pottery analysis: A sourcebook. Second Edition, 561p. The University of Chicago Press, 2015.

Stone and jade artifacts

- The Association for the Geological Collaboration in Japan, ed.: New Edition of the Dictionary of Earth Sciences, 1840 pages. Heibonsha, 1996.
- Turner, D. and Groat, L. A.: Geology and mineralogy of gemstones. Advanced Textbook 4, 228p. American Geophysical Union, Wiley, 2022.
- Iizuka Y., Bellwood, P., Hung, H.-C., Dizon, E.Z. A Non-Destructive Mineralogical Study of Nephritic Artifacts from Itbayat Island, Batanes, northern Philippines. Journal of Austronesian Studies, pp.80-105, 2005.



Periodic Table of the Elements vol.13

H 1 Hydrogen	He 2 Helium																
Li 3 Lithium	Be 4 Beryllium	B 5 Boron	C 6 Carbon	N 7 Nitrogen	O 8 Oxygen	F 9 Fluorine	Ne 10 Neon										
Na 11 Sodium	Mg 12 Magnesium	Al 13 Aluminum	Si 14 Silicon	P 15 Phosphorus	S 16 Sulfur	Cl 17 Chlorine	Ar 18 Argon										
K 19 Potassium	Ca 20 Calcium	Sc 21 Scandium	Ti 22 Titanium	V 23 Vanadium	Cr 24 Chromium	Mn 25 Manganese	Fe 26 Iron	Co 27 Cobalt	Ni 28 Nickel	Cu 29 Copper	Zn 30 Zinc	Ga 31 Gallium	Ge 32 Germanium	As 33 Arsenic	Se 34 Selenium	Br 35 Bromine	Kr 36 Krypton
Rb 37 Rubidium	Sr 38 Strontium	Y 39 Yttrium	Zr 40 Zirconium	Nb 41 Niobium	Mo 42 Molybdenum	Tc 43 Technetium	Ru 44 Ruthenium	Rh 45 Rhodium	Pd 46 Palladium	Ag 47 Silver	Cd 48 Cadmium	In 49 Indium	Sn 50 Tin	Sb 51 Antimony	Te 52 Tellurium	I 53 Iodine	Xe 54 Xenon
Cs 55 Cesium	Ba 56 Barium		Hf 72 Hafnium	Ta 73 Tantalum	W 74 Tungsten	Re 75 Rhenium	Os 76 Osmium	Ir 77 Iridium	Pt 78 Platinum	Au 79 Gold	Hg 80 Mercury	Tl 81 Thallium	Pb 82 Lead	Bi 83 Bismuth	Po 84 Polonium	At 85 Astatine	Rn 86 Radon
Fr 87 Francium	Ra 88 Radium		Rf 104 Rutherfordium	Db 105 Dubnium	Sg 106 Seaborgium	Bh 107 Bohrium	Hs 108 Hassium	Mt 109 Meitnerium	Ds 110 Darmstadtium	Rg 111 Roentgenium	Cn 112 Copernicium	Nh 113 Nihonium	Fl 114 Flerovium	Mc 115 Moscovium	Lv 116 Livermorium	Ts 117 Tennessine	Og 118 Oganesson
			La 57 Lanthanum	Ce 58 Cerium	Pr 59 Praseodymium	Nd 60 Neodymium	Pm 61 Promethium	Sm 62 Samarium	Eu 63 Europium	Gd 64 Gadolinium	Tb 65 Terbium	Dy 66 Dysprosium	Ho 67 Holmium	Er 68 Erbium	Tm 69 Thulium	Yb 70 Ytterbium	Lu 71 Lutetium
			Ac 89 Actinium	Th 90 Thorium	Pa 91 Protactinium	U 92 Uranium	Np 93 Neptunium	Pu 94 Plutonium	Am 95 Americium	Cm 96 Curium	Bk 97 Berkelium	Cf 98 Californium	Es 99 Einsteinium	Fm 100 Fermium	Md 101 Mendelevium	No 102 Nobelium	Lr 103 Lawrencium

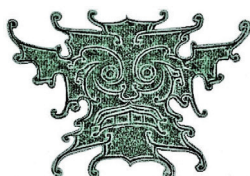
element
 symbol
 atomic
 number
 atomic
 weight
 element
 name

H
 1
 1.008
 Hydrogen

Grant-in-Aid for Transformative Research Areas (A)
“A New Archaeology Initiative to Elucidate the
Formation Process of Chinese Civilization”
(Area Representative: Shinichi Nakamura, Area No. 20A103)



Systematic Research Project A02
“Deduction of Production Sites through Analysis of Archaeological Remains”



In Search of the Origins...



Authors

- Ayako Shibutani : Archaeological science, cultural property science
(The Historiographical Institute of the University of Tokyo)
- Yoshimi Kamiya : Lacquer crafts, cultural property science
(Meiji University)
- Takeshi Minami : Analytical chemistry
(Nara Medical University)
- Tomoko Ishida : Archaeology, cultural property science
(Kagoshima University)
- Yoshiyuki Iizuka : Earth Sciences
(Institute of Earth Sciences, Academia Sinica / Kanazawa University)

Starting Guide Book for Scientific Analysis of Archeological Artifacts
:From Sampling to Interpretation

Published on February 29, 2024

Editing by Ayako Shibutani, Ayumi Yokota

Published and printed by Shobi Printing Co., Ltd.

5F Aqua Hakusan Bldg., 1-13-7 Hakusan, Bunkyo-ku, Tokyo 113-0001, JAPAN
Phone: +81-(0)3-3812-5203