



CONSERVATION MANUAL OF MARITIME ARCHAEOLOGICAL OBJECTS IN KOREA

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Design patterns are from a celadon *maebyeong* (prunus vase) which is excavated from Tae'an Mado Shipwreck No. 2. It is designated a treasure in 2013 (No. 1783).



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Note

1. This publication is about conservation treatments and examples from the underwater excavation and conservation division, National Research Institute of Maritime Cultural Heritage (NRIMCH).
2. Each author and section may prefer different notation of materials and machines, but tried to use unified vocabulary if possible.
3. References are given as end notes at the end of each section.
4. All contents in this book were written and photographed by the staff of the underwater excavation division, NRIMCH.



Preface



The National Research Institute of Maritime Cultural Heritage (NRIMCH), Korea, has started the first conservation treatment of maritime archaeological objects since the 1981. It has been the sole body charged with conservation of maritime objects in Korea for over 30 years.

The objects were buried with their histories under the sea; after excavation and conservation these recovered objects are able to inform their value. Almost every maritime archaeological object shares a similar conservation treatment protocol with land-based archaeological or historical objects; however, there are special steps, such as a removal of a salt or marine organisms, and consolidation of soft wood, necessary because of the object having soaked in sea water for such a long time.

This is an English version of *Conservation Manual of Maritime Archaeological Objects in Korea* (2013) and consists of advice and examples of conservation treatment of each type of material recovered from Korean waters.

I hope that this publication will promote Korean conservation to the world and will be a little bridge among global conservators. I express my appreciation to the people who work in conservation and wrote the contents of this publication.

July, 2014

Director of NRIMCH So Jaegoo

A small, shallow, greenish-grey ceramic bowl with a repeating scale-like pattern. The bowl has a wide rim and a slightly flared base. The pattern consists of overlapping, teardrop-shaped scales arranged in concentric rows. The glaze is a muted, earthy green-grey color. The bowl is shown from a slightly elevated angle, highlighting its shallow profile.



SECTION

01

Introduction

Kim Hyoyun

The National Research Institute of Maritime Cultural Heritage (NRIMCH) started the treatment of maritime archaeological objects from the Shinan site in 1981. The Institute has been charged with the preservation and treatment of maritime archaeological objects for the past 30 years.

NRIMCH was formerly known as the Mokpo Maritime Heritage Conservation Centre in 1990, the National Maritime Museum in 1994 and the National Research Institute of Maritime Cultural Heritage in 2009. The institute has re-organized and expanded over the last 30 years but preservation and conservation of maritime archaeological objects remains the most important work in the institute.

The underwater excavation and conservation division is not only responsible for conservation but also studying of treatment methods and materials for excavated objects. NRIMCH has two conservation centers. One of the centers is located in Mokpo; the other center is in Taean. There are 14 conservators, specialist in wood, ceramics, metals and other objects. However, conservators may cooperate with each other on large composite objects or time-consuming work.



Table 1. The number of conserved objects by materials (updated Oct. 2013)

Excavation year	Type of material (quantity)						Site
	metals	shipwreck	wood	ceramics	others	total	
Before 2006		2		3,656	2	3,600	Wando shipwreck ('94), Shinan shipwreck('99), Gunsan Biando island, Gunsan Sipidongpado shipwreck, Boryeong Wonsando island, Shinan Anjwado island, Gunsan Yamido island
2007				10,897		10,897	Gunsan Yamido island, Taean Daeseom island
2008			30	19,358		19,388	Gunsan Yamido island, Taean Daeseom island, Taean Mado island
2009	3			4,299		4,302	Gunsan Yamido island, Gunsan Sipidongpado shipwreck, Taean Mado island
2010	112		21	5,508	5	5,646	Taean Daeseom island, Taean Mado island, Mokpo Dalido shipwreck
2011	24	1	6	527	50	608	Taean Mado island, Mokpo Dalido shipwreck
2012	62		59	3,193	1	3,315	Gunsan Sipidongpado shipwreck, Taean Mado island
2013			22	451	16	489	Incheon Seomeopeol, Jindo island Oryuri
total	201	3	138	47,889	74	48,305	

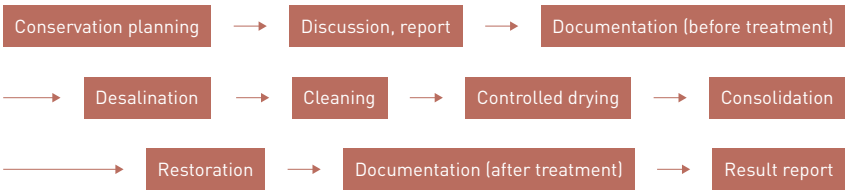
The table above shows the number of objects treated since 2006. The large majority are ceramic objects excavated from Taean Daeseom island and Mado island and the Gunsan Sipidongpado shipwreck. Metal and wooden objects are the next most numerous. Eight of shipwrecks have been treated so far: treatment takes a long time.

There are four workshops: the desalination laboratory, the consolidation laboratory, the conservation laboratory and the analytical laboratory. Desalination and consolidation facilities are essential for the best possible care of large shipwrecks.

Small objects are treated in the conservation laboratory, which has cleaning, consolidation and restoration equipment for the various types of objects. <Table 2> shows the variety of equipment in the analytical laboratory, such as scanning electron microscopes (SEM), fourier transform infrared (FT-IR), X-ray fluorescence (XRF), a chromameter and others.

The procedure for conservation of maritime archaeological objects is the same as for ordinary objects, except that because maritime archaeological objects have been underwater, cleaning and desalination are important steps.

The conservation work is carried out in the following order:



Objects that require treatment after excavation or during exhibition are transported to the conservation workshop with the description of the object’s condition.

Conservators propose various treatments depending on the goal of the treatment and the object’s condition. The conservation team discusses the treatment method and materials before treatment.

According to the materials in the object, treatment proposals are slightly different but generally, the conservator uses the conservation report in <Table 3>. The treatment proposal is then approved by the head of conservation, although standard treatments do not usually require permission.

Before treatment, the object’s condition must be checked with photography and detailed description. The treatment report contains information such as the treatment proposal, materials used and treatment method actually used.



1. Underwater excavation and conservation division, Mokpo



2. Taeon conservation centre



3. Conservation laboratory, Mokpo



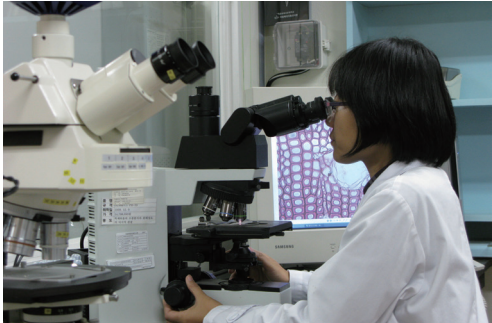
4. Conservation laboratory, Taeon



5. Desalination facility, Taeon



6. Consolidation facility, Taeon



7. Analysis equipment (Optical Microscope), Mokpo



8. Analysis equipment (XRD), Mokpo

Table 2. Conservation equipments

	Equipment	Manufacture	Purpose	Date acquired
1	Scanning Electron Microscope (SEM)	HITACHI S-2460N	Examination of microstructure of wood and metal, etc.	1996
2	Soft X-ray	HITACHI HP-150S	To see inside of and photograph opaque objects	1996
3	Vacuum chamber	SAMHEUNG SN-V1-02	Metal object consolidation	1998
4	Optical microscope	Olympus BX50	Identification of wood and its level of deterioration	1999
5	Automatic environment system	APM	Environmental monitoring	2001
6	Vacuum freeze dryer	Ilshin Bio Base	Treatment of waterlogged wood	2001
7	Optical microscope	ZEISS AXIOPLAN2	Examination of object structure	2002
8	Inductively coupled plasma atomic emission spectrometry (ICP)	SEIKO SPS 7800	Identification materials composition	2003
9	Polarizing microscope	ZEISS AXIOSKOP 40	Analysis of crystallization and characteristics of metal, ceramics and wood	2003
10	X-ray fluorescence (XRF) spectrometer	HORIBA XGT-5000	Identify the elemental composition of materials	2004
11	Sample crusher	FRITSCH PULVERISETTE 7	Preparation of samples for analysis	2005
12	X-ray Diffraction (XRD)	PHILPS US/D3	Identification of inorganic crystalline materials	2005
13	Microwave digestion system	Techlon QLAB-6000	Liquefaction of samples for analysis	2006
14	Tree ring measurement station	RINNTECH LINTAB 5	Measurement of ring width of wood	2007
15	Constant temperature water bath	Duri Science	Ceramics desalination	2007
16	Microtome	LEICA RM 2165	Cutting samples of wood objects for wood identification	2007
17	Infrared Camera	C2741-03	To identify ink, especially Chinese carbon blacks on wooden tablets	2008
18	Chromameter	MINOLTA C7900d	Recording of sample color	2009
19	Fourier transform infrared spectroscopy (FT-IR)	Perkin Elmer Spectrum 400	Identification of organic objects	2010
20	Immersion chamber for organic solvents	JEIOTECH	Immersion treatments of organic solvents for organic objects	2010
21*	Stereo microscope with video	LEICA S6D	Examination of cross-section of objects	2011
22*	Vacuum freeze dryer	Ilshin Bio Base, Lyoph Pride 100R	Waterlogged wood conservation	2012
23*	Optical microscope	Olympus BX53	Identification of organic objects and its level of deterioration	2013
24*	Vacuum chamber	INNOTECH DKVC-7	Metal object consolidation	2013
25*	Airbrasive	INNOTECH DKJB-200 H-TYPE	Removal substrate	2013

*Taeon Conservation Centre

Table 3. Condition report

Conservation Report

Type of material		Name of object		Quantity	
Name of Site		Date excavated		Period	
Object number		Date received		Conservator	

Before treatment

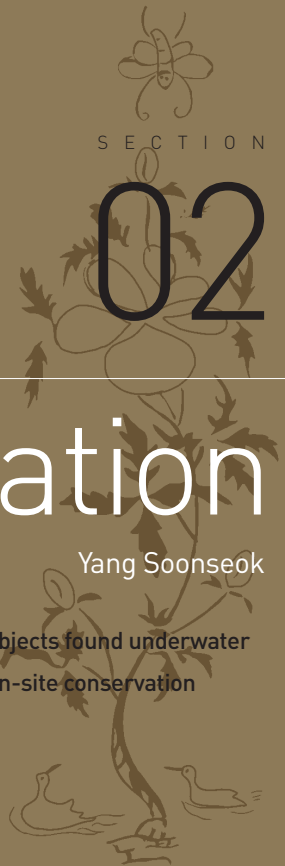
Proposed treatment

Treatment carried out

After treatment

Note

Date		Conservator		Signature	
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SECTION

02

On-site Conservation

Yang Soonseok

1. Objects found underwater
2. On-site conservation

Maritime archaeological objects are usually excavated from the foreshore or sand underwater. If part of the object is exposed to the seabed, it is normally damaged during excavation and it is difficult to keep its original shape. If the objects are in stable environmental conditions underwater, fair condition can be maintained.

Following excavation, the objects must be labeled in detail with the date of excavation, position where found and quantity. The labeling is done on coated paper with permanent ink so it must not bleed if it gets damp on-site. After only a brief time the excavated objects can easily alter in colour and shape, thus the objects are transported to the conservation department as quickly as possible. If they are not able to transported, they must be stored and preserved on-site.



1. Labeled iron pot ('13 Incheon Yeongheungdo shipwreck)



2. Labeled antler ('13 Incheon Yeongheungdo shipwreck)



1. Objects found underwater

(1) Plants

The excavated plants had been used on the ships for wrapping or wadding to prevent damage in transport. These plants are usually buried in the foreshore and mainly consist of rope and reed or straws used for ceramics packing.

(2) Grains

Grains are often buried in the foreshore like plants, but found with the straw bags and dishes that the sailors used. Generally the grains themselves have biodegraded but their hulls are may remain, flattened by water pressure and the pressure of the foreshore.

(3) Metals

Most metals object which are excavated are bronze, such as spoons, chopsticks, coins and iron pots. Iron nails, which were used join vessels, were excavated in Shinan shipwreck and Jindo shipwreck. Excavated bronze wares are covered with concretions on the surfaces but the layeris very thin, like paper, and easily damaged. Iron objects are recovered with corrosion products; furthermore, iron corrosion products may be impregnated in other objects such as wood.

(4) Wood

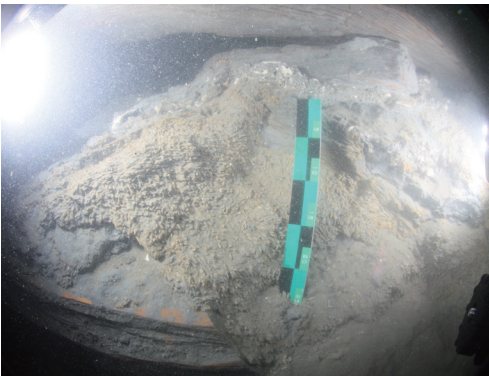
Wooden objects that are excavated are the ships themselves, wooden columns, wood used in packing, kitchen utensils and tablets. The wooden objects' conditions and types of damage can be very different depending on the environment in which they were buried. The objects exposed to seabed are seriously deteriorated by *Teredo navalis* and bacteria. However, wooden objects which are buried in the foreshore tend to be in fair condition.

(5) Other objects

Occasionally, gold, silver and bone objects are excavated. All of these objects have different conditions and require treatment on-site depending on the environment in which they were buried.



3. Buried rope ['05 Shinan Anjwado shipwreck]



4. Grain ['11 Tae'an Mado shipwreck No. 3]



5. Buried bamboo object ['11 Tae'an Mado shipwreck No. 3]



6. Bamboo object after excavation ['09 Tae'an Mado shipwreck No. 1]



7. Wrapping with wooden tablet ['09 Tae'an Mado shipwreck No. 1]



8. Rope, after excavation ['10 Tae'an Mado shipwreck No. 2]

2. On-site conservation

On-site conservation starts from salvage work. It works differently depending on objects' conditions and material types. Storage also should be considered. It is important to provide a stabilizing environment as soon as possible following excavation. The recovered objects easily alter in shape, therefore the objects' condition should be constantly checked until they get into a stable environment.

(1) Organic objects

The organic objects include wood, leather, rope, textile and grain. The objects are easily damaged and lost during excavation process. In particular, large wooden objects such as the hull of shipwreck are vulnerable during flood tide and before transportation. The hull usually is buried. If it had prolonged exposure to the seabed, that area could be rotted and lost to both waves and flood tide. Therefore the construction of the hull should be checked and exposure time minimized during excavation.

The best method of transportation is to store timber objects without taking them apart, and carry out treatment during transportation. However, the objects are usually broken up for transportation due to conditions at the site.



9. Packed shipwreck ['10 Tae'an Mado shipwreck No. 2]

Wooden tablets

The objects should be stored in sealable containers such as small cases or polyethylene bags. If the objects need to be taken out from the water for transport, the flow of the water on the objects' surface should be minimized.

Bamboo and textile objects

If the objects are discovered with foreshore, the foreshore should be carefully removed and detached using a board or plank. After that objects are stored in sealable containers.

Shipwrecks

A shipwreck is easily transported underwater but it is difficult to move in air because its weight and size. Thus, the objects should be supported on planks for lifting.

Grains

Grain is recovered attached to plants. It should be transported like the bamboo objects and stored in a sealable container.

It is important that the excavated organic objects never be allowed to dry out and should not be exposed to sunlight. If organic objects dry before treatment, the objects can shrink, crack and warp.

Exposure of the discovered objects to the atmosphere should be minimized while recording their condition. If the documentation time is prolonged then objects must be kept wet using damp cloth or a spray of water. It is best that the objects are put in a water tank if one is available, then the condition can be safely recorded.



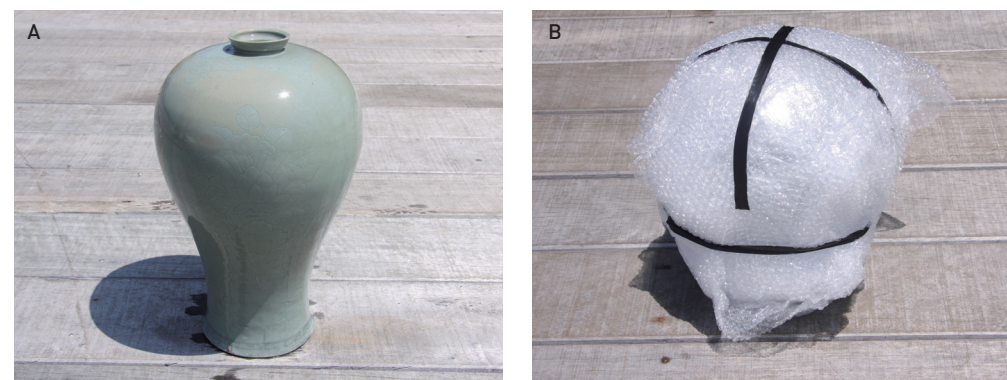
10. Packing with bubble wrap ('09 Tae'an Mado shipwreck No. 1, Bamboo board)

Wooden tablets with writing can immediately change color in light, and the writing can become completely bleached and disappear; thus they must be stored in the dark.

It is recommended that objects are stored in distilled water. However seawater can be used for short term depending on on-site environment. Biocides can be used in the storage solution to prevent biological activity on-site. However, the biocides can cause damage to the objects, so their condition should be constantly checked. If the object is to be used for radiocarbon dating, the biocides should not be added to a storage solution.

Small organic objects can be stored in sealed containers but large objects are difficult to pack in airtight container. In this case, they should be transported with supports. The supports are not only to physically support the objects but also to make transportation convenient. Polyethylene glycol (PEG) 200 solutions is applied to ship bodies; on the surface of the objects, and for the first layer of packing, each is wrapped in damp cloth. After this first packing, the object is wrapped again with bubble wrap and packed finally in a large plastic bag. The packed object should be stored in this way only for a short time, and needs to be kept at a low temperature. The object also should not be exposed to direct sunlight.

Organic objects may seem to be in fair condition with naked eye but they can be deteriorated to the point that they look like sponge under the microscope. Thus the objects should be handled sparingly and transported to the conservation room as soon as possible.



11. A: Before packing, B: After packing ('10 Tae'an Mado shipwreck No. 2, celadon maebyeong)

(2) Inorganic objects

The excavated inorganic objects are made up of a wide range of materials: iron, bronze, gold, silver, ceramic and stone. The large majority are ceramics: celadon, stoneware and white porcelain. These objects have been buried in a stable state for a long time; however, immediately after excavation the objects are vulnerable to corrosion. The objects require on-site treatment and packing to stabilize their physical condition before transportation to the conservation department.

While inorganic objects are generally recovered in fair condition, iron objects particularly fragile because they have been weakened by corrosion from being underwater for such a long time. Cast iron objects are at extra risk of this damage and must be kept in a stable environment to avoid further corrosion.

The inorganic objects are transported in the same method as organic objects. The objects' size, weight and housing are considered when they are transported with supports.



12. Buried iron pot ('13 Incheon Yeongheungdo shipwreck)



13. Packed iron pot ('13 Incheon Yeongheungdo shipwreck)



14. Stoneware urn, not cleaned inside ('10 Taeon Mado shipwreck No. 2)



15. Buried ceramics ('07 Taeon shipwreck)

The recovered metal objects are stored in freshwater immediately to prevent them drying out.

Iron objects are usually found in conjunction with other objects. The corrosion products adhere to surrounding materials such as marine growth, wood and stone. The adherent concretions are ideally removed but the objects are stored with adherent concretions if this is too difficult.

Lead objects require special care and handling in on-site. The objects are easily attacked by organic acids produced during the decay of organisms. Therefore, marine growth which adheres to the object should be removed. Following removal, the object should be placed in seawater or in freshwater containing sodium sulphate (0.1%). If lead objects are stored in deionised water, corrosion is accelerated.

Other metal objects which are stable condition as gold, silver and tin, could be desalinated using freshwater and then stored dry; it is better to first classify according to type of material and then store the objects in freshwater. The stored object is transported to the conservation department.

Ceramics could be damaged by salt contamination that is beginning to crystallize on surface; low-fired porous bodied ceramics are more sensitive to salt contamination than high-fired ceramics. The objects are also stored in freshwater and need treatment as soon as possible.

As said above, all inorganic objects are preserved and stored in liquid solution or wrapped with damp textile to avoid salt efflorescence process. Plastic containers or polyethylene bags are suitable on-site but if these packing materials are punctured by weight or sharp edges, the liquid is lost and the objects could dry out thus careful handling is required. After packing the objects are transported to the conservation department as soon as possible.

Bibliography

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Western Australian Museum, Materials conservation department
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SECTION

03

Organic Objects

Cha Miyoung, Yoon Yonghee

- **Introduction**
- **Archaeological shipwrecks**
 1. Introduction
 2. Treatment
 3. Case study
- **Wooden objects**
 1. Introduction
 2. Treatment
 3. Case study
- **Grains**
 1. Introduction
 2. Treatment
- **Bone / horn**
 1. Introduction
 2. Treatment

Introduction

Archaeological wood represents traces of past human activity; people have used wood for one purpose or another for a long time¹⁾. It can be divided into two classes by its moisture content: dry archaeological wood and waterlogged archaeological wood. Waterlogged archaeological wood would be excavated from marine environments, wetlands and peat deposit. The main component of the wood decomposes, and is replaced by water. All wood excavated from the sea by the National Research Institute of Maritime Cultural Heritage was waterlogged archaeological wood.

The main purpose of conservation treatment of waterlogged archaeological wood was to minimize the inevitable shrinkage upon drying and maintain stable conditions for the object through safe a dehydration process. For treatment at the NRIMCH, waterlogged wooden objects were classified into two categories according to size.

A side from water damage, waterlogged wooden objects are further deteriorated by maritime borers and micro-organisms; the damage caused by marine borers depends on the location of the object in the sea²⁾. <Figures 1 and 2> show examples of damage. While the deterioration from micro-organisms is difficult to ascertain visually, damage from maritime borers is plainly visible, especially on large shipwrecks.



1. Damaged by marine borers (Anjwado shipwreck)



2. Cavities, damaged surfaces (Anjwado shipwreck)

Microbial deterioration of waterlogged wood is mostly caused by soft rot, erosion bacteria and tunneling bacteria. Soft rot and tunneling bacteria were commonly found in oxygenated areas, and erosion bacteria was found in anaerobic environments³⁾.

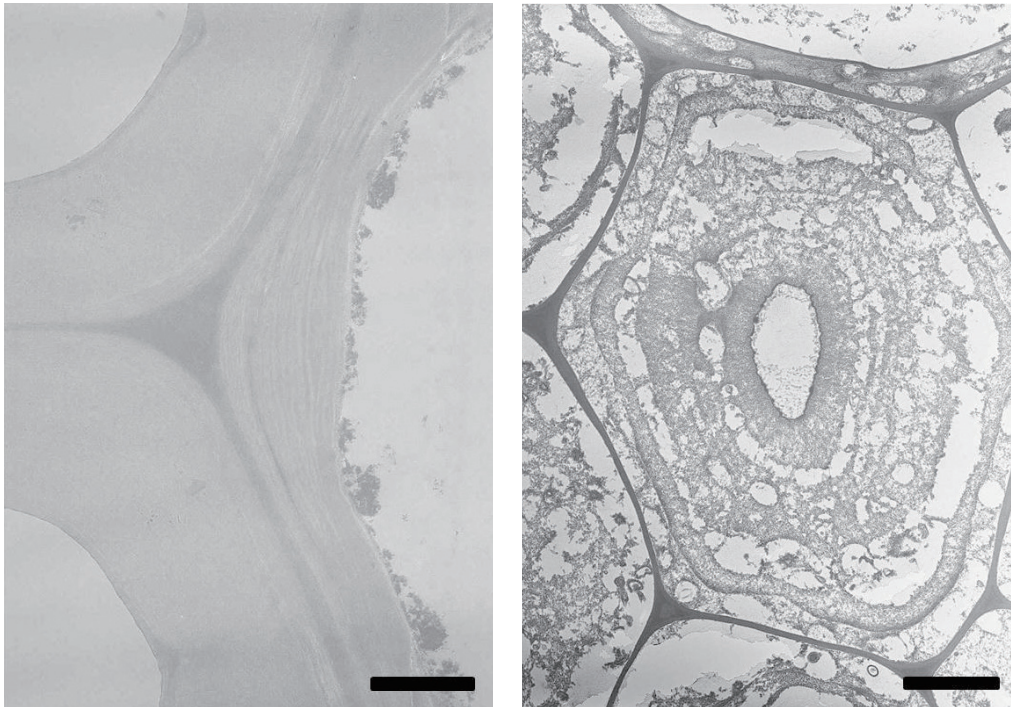
The chemical character of waterlogged wood is well identified in Kim’s⁴⁾ research on wooden pieces of the Shinan shipwreck. <Table 1> Holocellulose is decreased and lignin is increased; the amount of hot water and alkali extracts are increased, and the volume of organic solvent extracts is decreased. The ash content of waterlogged archaeological wood also tends to increase. If large-scale waterlogged archaeological wood (a shipwreck) was kept in the sea for more than a hundred years, any deterioration is limited to the surface only. <Table 1> shows a chemical composition comparison between the inner layer and outermost layer.

Table 1. Chemical composition of recent and waterlogged archaeological wood (*Pinus massoniana*)

	Waterlogged wood[%]		Normal wood[%]
	Outer part	Inner part	
Extraction			
Hot water extraction	7.80	3.00	2.8
Ethyl alcohol-cyclohexane	0.70	2.3	3.0
1% NaOH	18.73	12.58	12.67
Holocellulose	29.47	70.42	73.17
Lignin	64.18	28.19	26.85
Ash	7.6-11.7	1.58	0.2-0.5

The percentage of maximum water content in woody plants (trees) is around 100%; 1kg xylem holds 1kg of moisture. However, maximum water content in waterlogged archaeological wood depends on the type of wood and amount of deterioration; conifer was generally 100-500% water, hardwood tree range 300-800%. Some of highly deteriorated hardwood measured a maximum moisture content around 1200%⁵⁾. Maximum moisture content is related to the amount of decomposition, so the decomposition can be assessed by measuring the maximum moisture content.

<Figure 4> shows a sample of Oak that determined to have 600% maximum moisture content by transmission electron microscopy (TEM); in other words, that there is six times the amount of water than wood in the sample. <Figure 4> has a decomposed cell wall, assessed by comparison with a control group, <Figure 3>. The decomposed cell wall is replaced by moisture. If any waterlogged archaeological wood in similar condition is left to dry without any protection or proper action, the wood might lose its shape through shrinkage, therefore intervention is needed to dehydrate the object while still maintaining its shape.



3. Fibers (Oak), KMnO₄, bar=1.9μm

4. Fibers (Waterlogged Oak wood), KMnO₄, bar=2.7μm

Archaeological shipwrecks

1. Introduction

The 12 shipwrecks have been excavated below as <Table 2>.

Table 2. Conservation of shipwrecks (updated 08/'13)

	Shipwreck	Dimensions, length x width (Quantity of fragments)	Excavation methods	Treatment	Treatment period	Situation
1	Shinan	34m × 11m [729]	Individually	2-step PEG (400/4000)	'81-'04	Exhibition
2	Wando	9m × 3.5m [81]	Individually		'84-'98	Exhibition
3	Dalido	10.5m × 2.7m [33]	Together ^a		07/'95-12/'09	Exhibition
4	Sipidongpado	7m × 2.5m [14]	Individually		05/'04-in progress	Drying
5	Jindo	16.8m × 2.3m [1]	Together		06/'92-in progress	Drying
6	Anjwado	14.7m × 4.5m [39]	Individually		08/'05-in progress	Consolidation (40% PEG 4000)
7	Daebudo	6.6m × 1.4m [7]	Individually		12/'06-in progress	Consolidation (25% PEG 4000)
8	Tae'an	8.2m × 1.5m [7]	Individually		05/'08-in progress	Consolidation (25% PEG 4000)
9	Mado No. 1	10.8m × 3.7m [40]	Individually		10/'09-in progress	Consolidation (25% PEG 4000)
10	Mado No. 2	12.8m × 5m [41]	Individually		10/'10-in progress	Desalination
11	Mado No. 3 ^b	12m × 8m [21]	Individually		10/'11-in progress	Desalination
12	Yeongheungdo	6m × 1.5m [3]	Individually		07/'13-in progress	Desalination

a. Dalido and Jindo shipwrecks were excavated together (not separated each) with urethane foam. After coming to the conservation lab, it was unwrapped and treated.
b. Mado shipwreck No.3 was not excavated (still in underwater), only wooden fragments are on the conservation process

The first ship excavated, from Shinan, was transported piece by piece as the vessel was dismantled underwater. Later excavations (Wando, Sipidongpado, Anjwado, Tae'an, Mado No. 1 and Daebudo) followed the same method as that first excavation. For the remaining ships (Dalido and Jindo), urethane foam was used to temporally hold remains during transportation to the desalination space; once there, the pieces were dismantled. The wood transported in the Shinan shipwreck impregnated with polyethylene glycol (PEG); low concentration PEG 400 and high concentration PEG 4000 were used. The concentration was increased very slowly.

The Shinan, Wando and Dalido shipwrecks were treated in the same way and displayed in Shinan exhibition gallery and Goryeo shipwreck gallery (in the NRIMCH). The Sipidongpado and Jindo shipwrecks are being dried slowly. The Anjwado, Mado No. 1 and Daebudo shipwrecks are in the middle of the dimensional stabilization treatment. Finally, Yeongheungdo, Mado No. 2 and the parts of Mado No. 3 shipwrecks are still undergoing desalination.

2. Treatment

The conservation of the archaeological shipwrecks followed the following sequence:
Desalination→Recording condition on acceptance→Cleaning→Consolidation (Dimensional stabilization process)→Drying→Surface treatment→Recording treatment condition →Restoration→Exhibition or storage

Table 3. Conservation process

Desalination	Immersion in freshwater for desalination Storage to avoid drying out
Examination	Recordation of the condition of the object, including photography Identification of the type of materials
Cleaning	Mechanical cleaning: using small tools and an ultrasonic cleaner Chemical cleaning: using chelating agents
Consolidation	Replacement of water with consolidation solution PEG 2-step method PEG 400: 5 → 10 → 15 → 20% PEG 4000: 25 → 30 → 35 → 40 → 45 → 50 → 55 → 60 → 65 → 70%
Drying	Controlled drying
Surface treatment	Removal of remaining PEG
Documentation	After treatment, recordation of the condition of the objects
Restoration	Restoration
Exhibition and storage	Controlling environment between temperature ranges of 20-22℃ and relative humidity (RH) ranges of 50-55%

(1) Desalination

The condition of the objects needs to be thoroughly understood by gathering detailed information about the object, about the excavation environment and the condition should be documented with pictures. If more information is needed but not accessible, other parts or aspects of the object may become more available during the desalination process and documentation can be completed at that stage.

Desalination is the elimination of salts from the interior of the object; after excavation, the object is transported to the laboratory and soaked in still water (for the small scale objects, deionized water or distilled water is used) for desalination.

When an excavated object is brought into the laboratory, it is necessary to keep accurate records of its nature and condition. Condition and scale are also important to prepare the desalination space. Moreover, sometimes the object includes iron nails or some other iron compounds. In that case, one needs to check what other types of objects could use the same desalination space safely. If waterlogged wood and an iron compound are stuck together, the iron section would further corrode in the desalination process. The iron compound might also penetrate into an uncontaminated area of the wooden object. Superficial iron compounds can be easily removed with a brush; however, after penetration into the wood, mechanical cleaning will not succeed. Removal of mineral substance and cleaning prior to desalination is key to keeping the object safe.

<Figure 5> shows an excavated object from Yeongheungdo shipwreck in 2013; the remains of the wooden object has iron compounds and mineral substance on about 50% of its surface, making it look reddish. These deposits threatened to contaminate the rest of the object during the desalination process; therefore, the objects from the Yeongheungdo shipwreck were separated throughout the desalination process. Any very small objects or pieces of objects are contained in a net with notes about where they were found so they are not mixed up.

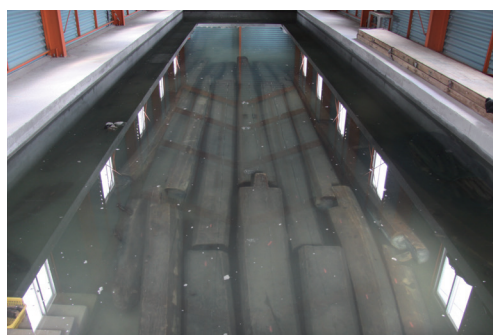
Desalination process takes advantage of osmotic pressure to change the concentration of salts; water was changed continuously to gradually eliminate the salts. The amount of time the object is left in each bath varied according to the stage of the treatment. When desalination and mineral substances are cleaned at the same time, the water would be changed once a month; later, as treatment progressed and only salt is being removed, the bath would only be changed every three or four months⁹⁾. When the salinity of the desalination solution became lower than salinity of the water alone, the desalination process would be complete.



5. The iron-affected timbers (Yeongheungdo shipwreck)



6. Mado shipwreck No. 2 timbers



7. Desalination process (Mado shipwreck No. 1 timbers)

8. Desalination process
(Mado shipwrecks No. 2 and No. 3 timbers)

(2) Examination

Primary research is done in the middle of the desalination process. This includes taking pictures of the objects, measuring accurate scale and noting condition with a researcher expert in archaeological shipwrecks. Samples of wood are taken to identify the type of wood, as well as its chemical make up and amount of degradation. Samples are also taken for radiocarbon dating and, if tree rings remain visible on the object, also for dendrochronology.

(3) Cleaning

Cleaning is done while the desalination solution is changed. Some mineral substance on the surface and inner body of the object are naturally removed in the desalination process. The base of the object could be checked. However, purposeful mechanical and chemical cleaning processes are still needed. Cleaning tools shown in <Figure 9 and 10> are the various types used to remove materials from the object and include brushes, toothbrushes, scrapers and sprayers. Smooth surfaces are treated with brushes <Figure 11>, but rough, damaged surfaces require washing with a spray and hose to be effective <Figure 12>.

Mineral substance on the surface are ideally removed in the early stages of the treatment, before desalination. When one or two cleans could not remove all mineral substance, the cleaning process would be carried into initial stages of the desalination. If the desalination process is extended too long, a biofilm could appear on the surface of the object, which would then need to be cleaned away as well.

When cleaning the object, a water hose is used. Damaged areas and edges need particular care. After desalination, the object is transported to the warm water tank for dimensional stabilization process. After that, for chemical cleaning, a solution of 2% w/v EDTA-2Na (disodium salt of ethylenediaminetetraacetic acid) with water is used to soak the object for seven days. After the EDTA treatment, the object is soaked in the water to remove residues, and the pH level is checked for complete elimination of the chelator. It takes around a month; using warm water (40 °C) could shorten the process time.



9. Cleaning tools



10. Sprays



11. Cleaning with a brush (Daebudo shipwreck)



12. Cleaning with hose (Daebudo shipwreck)

(4) Consolidation

The consolidation of shipwrecks follows the “PEG 2-step method” that uses PEG 400 and 4000. There are two types of PEG 4000 according to their average molecular weight: 3,350 and 3,900. The NRIMCH laboratory used 3,900. The conservation schedule (object scale, type and progress) is on display in a conspicuous area to be checked easily. Consolidation is carried out following order <Table 4>.

Table 4. Process of consolidation

Chemical Product	Concentration	Period	Note
PEG 400	5%	6 months	Add 2% biocide solution (boric acid and borax, 7:3)
	10%	6 months	
	15%	6 months	
	20%	6 months	
	Chemical wastes are disposed Wash the surface of the object using water hose and removed substances on the water tank.		
PEG 4000	25%	6 months	
	30%	6 months	
	35%	6 months	
	40%	6 months	
	45%	6 months	
	50%	6 months	
	55%	6 months	
	60%	6 months	
	65%	6 months	
	70%	12 months	
	Chemical wastes are disposed Careful handling is required After consolidation, residual PEG is removed with warm cloth		

When 5% PEG 400 is used, a 2% solution boric acid and borax (in a ratio of 7:3) in water is also used for moth proofing. Moreover, when cleaning of object is in completed, PEG could effect to residues to be extracted. In this case, object is needed to soak in 5% PEG 400 solution for a month, and remove solution and used hose to wash the surface of the object, and to do PEG process again.

The object is soaked in each successive concentration of PEG for at least six months; for the last stage, 70% concentration, 40℃ water is used for 12 months.

During the hardening treatment, a sour smell could appear, which indicates organic acids; in this case, more ventilation is needed. A thick layer of biofilm may appear when PEG 400 concentration is 5% to 20%; this must be continually removed. PEG 4000 is added to increase concentration between 25% and 70%. If the PEG 4000 is added as a solid to the

water tank it must be stirred with a water pump for 24 hours or until completely dissolved. The new concentration needs to be checked every day for a week with a saccharometer. The result is multiplied by a correction factor of 1.166 <Table 5>.

PEG 4000 is added until 70% concentration is achieved. Before completing the stabilizing process, the chemical waste is disposed. After that, the object is washed with warm water. The object will now be very heavy and slippery, so it needed to carefully handled.

When moving the object from the water tank, an expert lifts it out with a crane.



13. The schedule of treatment (Anjawado shipwreck)



14. Increased the concentration of PEG 400 (Anjawado shipwreck)



15. Biofilm (Anjawado shipwreck)



16. Increased the concentration of PEG 4000 (Anjawado shipwreck)

Table 5. Checking the concentration of PEG

	10%[w/v]	20%[w/v]	30%[w/v]	40%[w/v]	50%[w/v]	60%[w/v]
Result (saccharometer)	9.0(±0.1)	18.7(±0.3)	26.6(±0.4)	35.1(±0.6)	45.4(±0.5)	51.0(±0.1)
After correction	10.4(±0.1)	21.8(±0.4)	31.0(±0.4)	40.9(±0.7)	53.0(±0.6)	59.5(±0.2)
Note	Using ATAGO Master-M [Brix range 0.0–33.0%]			Using ATAGO Master-2M [Brix range 28.0–62.0%]		
	PEG 4000 Correction factor: 1.166					

(5) Drying

A controlled drying method is used to dry the object. The main goal of this drying process is to decrease drying stress and control the relative humidity to make object dry slowly. When some of the moisture content in waterlogged wood is transformed to water-soluble resin (PEG), it takes more time to dry. The higher the PEG concentration, the longer the drying process will take.

If constant temperature and humidity cannot be provided during the drying stage, especially for large objects such as archaeological shipwrecks, plastic wrap (to block the moisture travel between outer space and inner space of shipwrecks), dehumidifiers and air conditioners are used to dry locally. Pieces of object in the drying chamber are covered with plastic wrap to avoid drying out too quickly, and to maintain the humidity in the inner space. Mold and fungus could appear on the surface of the object, so it should be watched carefully.

When the humidity of the inner space of the plastic wrap is stabilized, the wrap should be removed to slightly decrease the humidity level, then replace the plastic again to retain now a slightly lower level of humidity. This process needs to be repeated many times. At this moment, if any PEG is stuck on the base of object, the object needs to be turned over.

When the humidity is the same as the outside environment and the surface of the object is not coated in PEG, the plastic wrap could be removed. The environmental stability of the lab should be checked first, and the flow of air should be controlled with air conditioner.

(6) Surface treatment

After the drying process, leftover PEG appears as whitish remains on the surface, which is removed by heating or with organic solvent. The heating process is executed with a cotton cloth soaked in hot water; holding the cloth on the area with PEG makes the resin become flexible. After that, heater is set to 60°C to slowly remove the PEG residue. Another method uses organic solvent; trichloroethylene dissolves PEG deposit. If solvent is used, it can prevent the object darkening in color, but the heating process is more common.



17. Drying process (Dalido shipwreck)



18. Drying stage, the objects are covered with plastic wrap (Dalido shipwreck)



19. Tools for the surface treatment



20. Surface treatment with clothes

(7) Recording treatment condition

Every conservation treatment procedure, the condition of the object after treatment, and any change in scale is recorded in writing and with photography.

(8) Restoration

The traditional ship and maritime folk life team in the maritime heritage research division takes responsibility of making a replica ship when necessary.

(9) Exhibition and storage

The conserved shipwrecks from Shinan, Wando and Dalido are exhibited in the NRMCH gallery. Wooden archaeological shipwrecks are weak and easily affected by their surrounding environment. The environment needs to be kept around $20\pm 2^{\circ}\text{C}$ and $50\pm 5\%$ RH. For safety reasons, temperature and humidity are checked regularly, and the objects are monitored with photography.

3. Case study

(1) Shinan shipwreck⁷⁻⁹⁾

The Shinan shipwreck was excavated piece by piece that shipwreck was dismantled underwater and transported, and placed into a desalination space. It was soaked in still water to lower the salinity until it reached 50ppm. Brushes and various tools were used to remove mineral substances. A replica was built in 1/5 scale to define precise structure information to aid with the conservation.

The shipwreck is pine, and the moisture content in areas of low deterioration was 150–237%, and around 280–650% the more badly deteriorated areas. The moisture content of unseasoned, new pine (green wood) has been reported to be around 150%^{8, 10)}.

That low moisture content is correlated with low levels of deterioration means moisture content measurements can be used as an indicator of degradation.

The 650% moisture content of areas of high deterioration meant they contained 4.3 times more moisture than original material and exhibited about as much more damage.

To treat dimensional stability the PEG 2-step process was applied, which involved the use of low molecular weight PEG 400 up to a concentration of 20% and then high molecular weight PEG 4000 around 60–80%, soaked at around $40\text{--}45^{\circ}\text{C}$ in warm water tank. The relative humidity was steadily lowered to dry the parts. After drying, any remains of the PEG were removed by using cotton cloths soaked in warmed water. The remains of the Shinan shipwreck were restored in an order that had been determined by information gained by the construction of the replica. A frame was created that gave both structural stability and an indication of the ship's original form.

The conservation of the Shinan shipwreck, involving desalination, cleaning, consolidation, drying and surface preservation¹¹⁾, took place from 1981 to 1999. A second phase of reconstruction and making it ready for display took place over a ten year period between 1994 and 2004.

With this type of PEG treatment it was important to monitor any environmental changes and a datalogger (SATO/SK-L200TH II α/JAPAN) was used to collect data.



21. Transported Shinan shipwreck



22. Desalination stage, changed the water



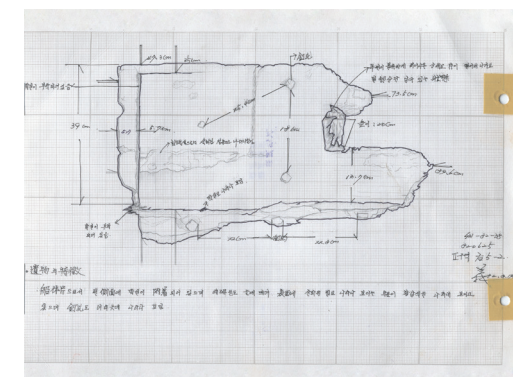
23. Washing with hose



24. Cleaning with tools



25. Examination



26. Condition report



27. Consolidation stage



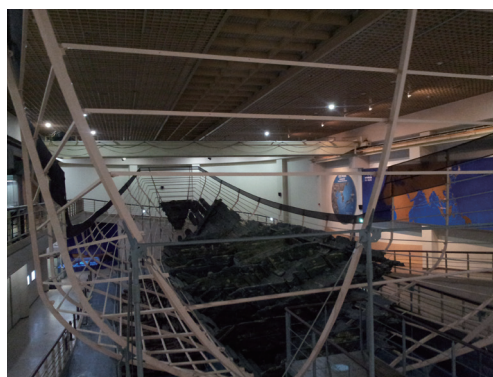
28. Removal PEG of surface



29. After dry, measured dimensional



30. Restoration



31. Exhibition

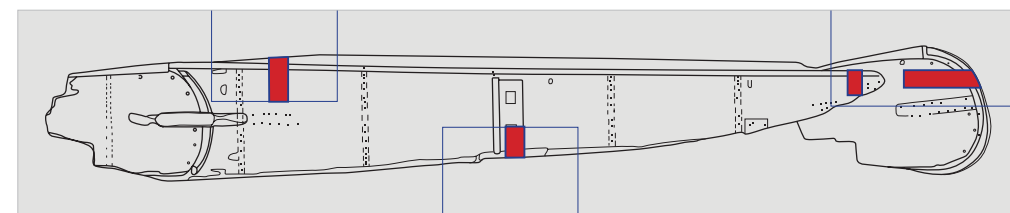


32. Conservation reports

(2) Jindo shipwreck

The Jindo shipwreck was excavated between 1991 and 1992. It measured 16.85m in length and 2.34m in width, with a depth of 0.7m. The thickness of the timber was around 100–230mm¹²⁾. The Jindo shipwreck was a log ship made from camphor wood, which has a tight grain that caused problems during the drying process. The PEG 2-step system was tried (low molecular weight PEG 400 saturated at 20% concentration in 40–45 °C warm temperature tank, and high molecular weight PEG 4000 saturated at 45% concentration); however, it was ineffective and gave poor results on drying. A slow drying process was chosen to avoid unexpected changes. After disposing of the PEG 400 from the tank the object restrained to prevent warpage. Fibre reinforced plastics (FRP) and polyurethane foam were used. Before the FRP was used to secure the object, a non-woven fabric was soaked with water and covered on the surface of the object. Copper nails were used to hold the non-woven fabric to avoid movement when the FRP was applied. Most parts of the object were covered with the FRP, but the base touched the bottom of the tank, so it could not be covered completely. Urethane foam was then applied over the whole body of the object to give more strength and rigidity. Before the urethane foam was applied, 37 drying windows were made to control the drying and for monitoring the object. Parts of the non-woven fabric were removed under the drying windows to allow for monitoring of the surface, and a datalogger was installed to check the environmental conditions regularly.

Reports from 2012 have shown that the relative humidity has been slowly decreasing over time. The temperature was maintained, fluctuating with the outer environment. The Jindo shipwreck appears visually to be completely dried but it was not possible to examine the sealed sections. Therefore, four parts of the urethane foam were removed (front side, middle side, rear side and poop deck side). A 100mm ribbon of FRP was removed from the inner side to the outer side of the object.



33. Monitoring dried statement (Blue line-removed urethane foam/ Red line-removed FRP)

The surface of the uncovered sections were mostly in the same condition. However, the situation was much different when monitoring from the drying window and monitoring the surface directly. When the surface was pressed the PEG came out of the wood and the deteriorated external parts of the object were soft and sponge-like. A solution was sought to deal with the dried and undried parts. All the urethane foam was removed from the object to get accurate information about temperature and humidity. The FRP anchoring armature was retained to avoid warpage. Plastic wrap was used to seal the tank completely. A datalogger was installed on the front, middle, rear, the inner and outer side of the protective shade; changes of temperature and relative humidity have been monitored. The drying process of the Jindo shipwreck will begin again after getting accurate information of its current temperature and relative humidity.



34. After removal FRP, the front and middle of shipwreck



35. After removal FRP, front and middle of shipwreck



36. PEG came out of the wood



37. Mold on the surface of shipwreck

Wooden objects

1. Introduction

<Table 6> shows the wooden objects treated in the past five years at The NRMCH.

Table 6. Wooden objects treated in the past five years

	Object	Amount	Site	Period	Treatment	
1	Wooden tablets	4	Taeon shipwreck	05/'09-04/'10	PEG treatment (with low concentration solution), vacuum freeze drying	
2	Presumed a spinning wheel	1	Taeon shipwreck	12/'10-12/'11		
3	Wood used in packing	6	Taeon shipwreck	01/'10-12/'11		
4	Wood used in packing	4	Taeon shipwreck	05/'09-04/'10		
5		3	Taeon shipwreck	05/'09-08/'10	PEG treatment (with high concentration solution), vacuum freeze drying	
6	Wooden tablets	18	Mado shipwreck No. 1	01/'10-01/'11	PEG treatment (in tert-butyl alcohol), vacuum freeze drying	
		1	Mado II site			
7	Wood used in packing	14	Mado shipwreck No. 1	09/'10-08/'11	PEG treatment (with low concentration solution), freeze drying	
8	Wooden combs	5	Mado shipwreck No. 1	01/'11-08/'11	Cetyl alcohol treatment	
9	Wooden object	1	Mado shipwreck No. 1	11/'11-11/'12	PEG treatment (in tert-butyl alcohol), vacuum freeze drying	
	Wooden tablets	23	Mado shipwreck No. 2			
	Wooden objects	2				
10	Wooden chopstick	1	Mado shipwreck No. 2	12/'11-11/'12	PEG treatment (with low concentration solution), vacuum freeze drying	
	Bamboo chopsticks	3				
11	Wooden tablets	11	Mado shipwreck No. 3	12/'11-12/'12.		
	Wooden object	1				
	Wooden tablets	2	Mado site			
12	Wooden lid	1	Mado shipwreck No. 1	12/'12-08/'13		PEG treatment (with low concentration solution), vacuum freeze drying
	Wooden tablet	1	Mado site			
	Wooden tablet	1	Mado shipwreck No. 2			
	Wooden lid	1				
	Wooden adze	1				
	Wooden object	1				
	Wooden tablets	3	Mado shipwreck No. 3			
	Wooden object	1				
13	Wooden objects	3	Mado shipwreck No. 1	12/'12-08/'13		
14	Wood used in packing	10	Mado shipwreck No. 2	01/'13-05/'13		

2. Treatment

Underwater excavation normally takes ten days because of the tides; then the recovered objects are transported to the conservation laboratory. Before transportation, conservators receive a list of objects with photos from archeologists so they can prepare containers and conservation materials.

Below, <Table 7> shows the process of conserving small wooden objects. Although the conservation procedures for shipwrecks and small wooden objects are identical, there are differences in the objects’ size and details that affect the logistics.

Table 7. Conservation process

Desalination	Immersion in freshwater for desalination Storage to prevent drying out
Examination	Recordation of the condition of object, including photography Identification of materials Treatment proposal
Cleaning	Mechanical cleaning, using small tools and ultrasonic cleaner Chemical cleaning, with chelating agents
Consolidation	PEG treatment
Drying	Controlled drying Vacuum freeze drying
Bonding Loss compensation	Using cyanoacrylate adhesives to bond fragments Using epoxy resins(HV 427 [®] and SV 427 [®]) and pigments for loss compensation
Documentation	After treatment, recordation of the condition of objects
Storage	In a controlled environment: temperature ranges of 20–22℃ and relative humidity(RH) ranges of 50–55%

(1) Desalination

Conservators measure the object’s size and weight. They also create the condition reports. Followed documentation, the objects are immersed in tap water or distilled water to remove salt. If the objects are recovered from the same site, they could be treated together. However, the iron-effected wooden objects or wood/iron composite objects must be separated from other objects and treated. <Figure 38> shows an object that is partly damaged by iron corrosion products. The object is further damaged on its surface during desalination as in <Figure 39>.



38. After excavation (Taeon Mado)



39. After desalination (Taeon Mado)

(2) Examination

If there is any writing in Chinese ink on the objects, photos are taken with an infrared camera to help decipher the text.

When the objects require destructive analysis, a specimen must be taken very carefully. Using a razor blade, a thin slice is taken from the object. In the case of a damaged object, the sample is taken from non- exposed area.

(3) Cleaning

Cleaning is important conservation work. Mineral substances include inorganic materials that were deposited into the surface and inside of waterlogged wood while it was buried because wood is a porous material¹¹⁾. The presence of mineral substances can be identified with chemical analysis; the ash content is increased by mineral substances¹²⁾.

Generally, particle size of sand is 2000-50 μ m, silt is 50-2 μ m and clay is less than 2 μ m ¹³⁾. However, the tracheid of pines are 40 μ m in diameter, the vessels in oak are 250 μ m and the diameter of most wood fibers is about 20 μ m¹⁴⁾. Most of soil particles easily get into the wood.

The mineral substances create a negative effect on the PEG treatment¹⁵⁾. If they are not removed completely, the residual substances will become attached to the object’s surface.

<Table 8> shows various cleaning methods. A cleaning method is chosen according to the object’s level of degradation. Cleaning process affect the effectiveness of the consolidation, so the objects should be cleaned properly. When chemical cleaning is required, the objects are immersed in a solution of 2% w/v EDTA-2NA with water for 72 hours. And then, the objects are soaked in clean water to remove leftover chemical products. The water is changed constantly until the pH level reaches that of the water supply being used. The EDTA solution may not be able to remove all corrosion products. In this case, a solution of

P.C.D.(5% PEG, 5% sodium dithionite, 2% diammonium citrate w/v in water) is used to remove the corrosion products¹⁶⁾.



40. Before P.C.D. treatment



41. After P.C.D. treatment

Table 8. Cleaning methods for waterlogged wooden objects

Cleaning	Method	Note
Mechanical	Using tools	Brushes, sprays and toothpicks
	Soaking	Saturation of specimen with aspirator
	Using an ultrasonic cleaner	At 40kHz for 30 minutes
Chemical	Using EDTA-2Na	2%w/v EDTA-2Na, 72 hours P.C.D. treatment

(4) Consolidation

The goal of the consolidation process is to give strength to and stabilize the size and the shape of the objects. The treatment can be different depending on the size and condition of the objects and drying methods. Polyethylene glycol 4000 (PEG 4000, the average molecular weight is 3900) and cetyl alcohol are used to consolidate wooden objects in the NRIMCH.

In the case of the high concentration PEG solution, the object is impregnated with 10% w/v PEG 4000 with water at 40℃ and the solution is slowly increased up to 70% in 10% increments. The object is normally soaked in each concentration for one month; however if the thickness of object is over 10cm, the impregnation period is extended to two to three months. Biocide (2%) can also be added to prevent biological activity at 10–20% PEG stage.

The low concentration PEG treatment regime uses PEG 4000 at 10%, 20%, 30% and 40% at 40℃. The object is impregnated for a period of time, depending on the object’s size. Furthermore, if the objects are smaller than vacuum freeze drying: the dryer is 120cm in the division at Mokpo and the other one in 150cm in Taeon conservation centre, the objects can

be treated with low concentration of PEG solution.

Before the low concentration PEG treatment, tert-butyl alcohol is used to replace the water in the wood, which can reduce the drying time. First, replacement of water with ethyl alcohol is carried out in the following stages: 50% ethyl alcohol, then 70%, 90%, 95%, 100% and finally a second bath at 100% concentration, all at room temperature. After that tert-butyl alcohol replaces ethyl alcohol: 50% tert-butyl alcohol/cetyl alcohol solution, then 70%, 90%, 95%, 100% and a second bath at 100%. It can be warmed by using aquarium heaters in an insulated bath. After replacement with tert-butyl alcohol, the object is soaked in PEG 4000 at 10%, 20%, 30% and 40% concentrations. During this process, if the water is not properly removed from the object, there may be negative consequences for the PEG treatment, so the treatment should be carefully carried out.

Cetyl alcohol is also used to consolidate wooden objects. Ethyl alcohol is first used to replace the water content in the wood, at room temperature. After that the object is impregnated in the solution of cetyl alcohol with ethyl alcohol: 10% w/v ethyl alcohol with ethyl alcohol, then 20%, 30%, 45%, 50%, 60% and finally a 70% solution. This process is worked in the aquarium heaters. The concentration of solution and the impregnation time can be different depending on the object’s condition.

Consolidation 1 - High concentration PEG treatment

Chemical	Concentration	Period	Note
PEG 4000	10%	1 month	Biocide added Treatment temperature of up to 40℃
	20%	1 month	
	30%	1 month	Treatment temperature of up to 40℃
	40%	1 month	
	50%	1 month	
	60%	1 month	
	70%	1 month	

Consolidation 2 - Low concentration PEG treatment

Chemical	Concentration	Period	Note
PEG 4000	10%	1 month	10–20% PEG used with biocide Treatment temperature of up to 40℃
	20%	1 month	
	30%	1 month	
	40%	1 month	

Consolidation 3 - Replacement of water with tert-butyl alcohol and low concentration PEG treatment

Chemical	Concentration	Period	Note
Ethyl alcohol	50%	1 week	Treated at room temperature
	70%	1 week	
	90%	1 week	
	95%	1 week	
	100%	1 week	
	100%	1 week	
Tert-butyl alcohol	50%	1 week	Treatment temperature of up to 50℃
	70%	1 week	
	90%	1 week	
	95%	1 week	
	100%	1 week	
	100%	1 week	
PEG 4000	10%	1 month	Treatment temperature of up to 50℃
	20%	1 month	
	30%	1 month	
	40%	1 month	

Consolidation 4 - Cetyl alcohol method

Chemical	Concentration	Period	Note
Ethyl alcohol	50%	1 week	Treated at room temperature
	70%	1 week	
	90%	1 week	
	95%	1 week	
	100%	1 week	
	100%	1 week	
Cetyl alcohol	10%	1 week	Treatment temperature of up to 50℃
	20%	1 week	
	30%	1 week	
	40%	1 week	
	50%	1 week	
	60%	1 week	
	70%	1 week	

(5) Drying

There are two drying methods: controlled drying and vacuum freeze drying.

The object that is treated with high concentration PEG solution and in fair condition is dried out slowly. At the beginning of the drying process, the object is stored in a container

or covered with clear plastic and a hygrometer to avoid drying out rapidly. The environment is held at a constant high humidity level for a while. Once the humidity stabilizes, the cover or plastic is opened slightly to decrease humidity. This process is continued until the object is completely dry.

In the vacuum freeze drying method, the water in the object is eliminated in a vacuum. Following treatment with PEG, the object is frozen in a vacuum freeze drying chamber at a temperature -40℃; this takes approximately three to seven days. The temperature of the rack in the chamber is -40℃ and of the cold trap is -80℃. There are three temperature sensors; two in the object and the third hanging in the air. During the process, the pressure remains at 5mTorr. At the beginning of the drying, the chamber is increased from -40℃ to -30℃. The eutectic point of PEG 4000 is -17℃, so the process must be carried out at temperatures below -17℃. After finished drying, the object is stored in a container at room temperature.

(6) Cleaning the surface of the objects

90% ethyl alcohol is used to remove residual PEG solution from the surface of objects with cotton swap. If the object is lighter in color after PEG treatment, the object could be made slightly darker by applying heat with a heat gun at 60℃.

(7) Bonding and loss compensation

If fragments of the objects need to be bonded, cyanoacrylate adhesives are used. After bonding, a mix of epoxy resins (SV 427® and HV 427®) and pigments are used to fill and add strength.

(8) Documentation and storage

Following completed treatment, the conservation process is recorded in detail with photos. The objects are stored in a stable environment: temperature ranges of 18-22℃ and relative humidity (RH) ranges of 45-55%. Their conditions are monitored.

3. Case study

(1) Wooden tablets from Mado shipwreck No. 1:

Low concentration PEG treatment and vacuum freezing-dry

The wooden tablets that were excavated from Mado shipwreck No.1 and the Mado II site in 2009s were photographed and immediately transported to the conservation studio. The objects were covered with mud and other deposits on the surface. Some objects were degraded or deteriorated by marine borers.

Completed checking the object's condition, the objects were immersed in freshwater to remove salt and avoid changing the dimensional of the objects

The objects were took photography with an infrared camera to check for writing. After that, the objects were cleaned with brushes to remove deposits on their surface and soaked in the solution 2% w/v EDTA-2Na with water to remove any iron. Followed chemical cleaning, the objects were thoroughly washed to remove residual EDTA. Then the water inside of the objects was substituted with ethyl alcohol. The concentration of ethyl alcohol was increased from 50% to 70%, 90%, 95%, 100% and another bath at 100%. After that ethyl alcohol was replaced with tert-butyl alcohol, according to the same system of increasing concentration. Following replacement, the objects were impregnated with PEG 4000 in tert-butyl alcohol solution. The concentration of the solution was constantly increased in 5% increments. The conservation work took one year (January 25, 2010–January 14, 2011). The consolidation process was finished in November and December. The room temperature was low for that stage so the PEG solution on the surface of the objects was immediately cured. The cured PEG on the surface of the object was removed with a heat gun set to 60°C. Cyanoacrylate was used to bond the fragments, with epoxy resins (HV 427®/SV 427®) mixed with pigments to make fills.



42. Before treatment



43. Before treatment



44. Cleaning with a brush



45. Chemical cleaning with EDTA



46. To increase concentration of PEG



47. Removal PEG deposit



48. Vacuum freeze drying



49. Bonding and loss compensation

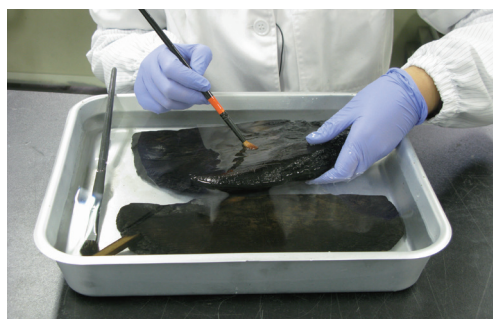
(2) Wooden objects from Mado shipwrecks No.1, 2 and 3: Low concentration PEG treatment and vacuum freeze drying

The objects were divided into two groups according to the condition of the objects: those in fair condition objects and those seriously degraded. Most of the objects were covered with foreshore and burn marks.

Low concentration PEG treatment and the vacuum freeze drying method were used to treat these objects.

Traces of marine organism and marine algae, air pockets inside of the object, and any deposit were removed and cleaned with an ultrasonic cleaner. If they were not removed, the consolidation process could be compromised.

After cleaning, the objects were soaked in 10% w/v PEG in water, and then the concentration of the PEG was constantly increased up to 40%. Upon completing the consolidation, the objects were frozen at -40°C for seven days and dried for five days using the freeze dryer. The residual PEG on the objects' surfaces was removed with ethyl alcohol and a heat gun set to 60°C . A solution of 5% w/v Paraloid B72 in acetone was applied on any burn marks to avoid further breakage. The fragments were bonded with cyanoacrylate. Mixed epoxy resins (HV 427[®]/SV 427[®]) and pigments were used to give strength to the bonds and fill in losses, at the same time giving an aesthetically pleasing result.



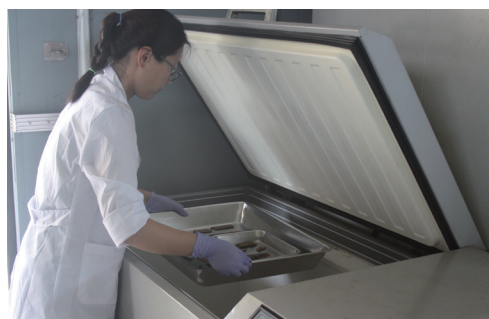
50. Cleaning with a brush



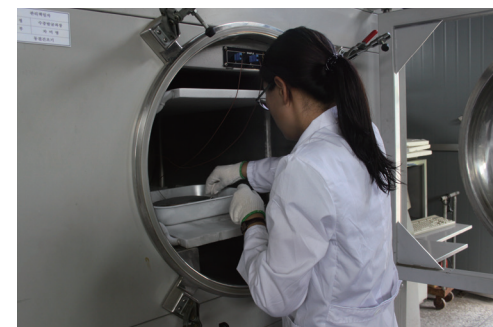
51. Cleaning with an ultrasonic cleaner



52. Consolidation



53. To frozen in a freeze drying chamber



54. Vacuum freeze drying



55. Retouching

(3) Wood used in packing from Taeon shipwreck: High concentration PEG treatment

22,000 ceramics were excavated from the Taeon shipwreck from 2007 to 2008. Wood that was used to pack these ceramics were also excavated. Most of excavated wood was less than 50cm high. It was treated with the low concentration PEG method and vacuum freeze drying. However, three objects long, thin were over one meter height (bigger than the vacuum freeze drier) were treated with the high concentration PEG treatment. The three objects measured 2.5cm wide, 110-134cm high and 0.6-1.2cm deep. There were longitudinal cracks and degradation, in addition to deposits over the surfaces. Two objects were warped (object numbers 5 and 7), thus careful handling was required. A box was made for convenience in handling and transportation.

The objects' conditions were recorded and pictures were taken before treatment, then they were cleaned with brushes, small tools and spray. PEG 4000 in water was used for consolidation, carried out at following successive levels of concentration for a month each: 10%, 20%, 30%, 40%, 50%, 60% and 70%. Consolidation occurred in a heat chamber (approximately 50°C).

Following the dimensional satiability process, residual PEG was removed, and then the controlled drying method was used to dry the objects. The objects were covered with clear plastic and slowly dried out. High concentration PEG treatment and controlled drying method do not need special equipment and easy to execute. However, the objects could alter in colour and become brittle by these methods.

Residue PEG on the object's surface was removed once the object was completely dry, using a heat gun set to $60-70^{\circ}\text{C}$.

Cyanoacrylate and epoxy resin (SV 472[®]/HV 472[®]) were applied on cracks and fragments to bond and fill.

After conservation work, conditions of the objects are recorded in detail with photography.



56. Before conservation



57. After conservation



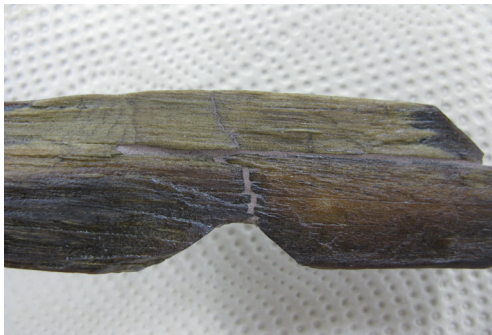
58. Controlled drying



59. Surface treatment using heat-gun



60. Bonding and loss compensation



61. After loss compensation

(4) Wooden combs from Taeon Mado: Cetyl alcohol method

Five wooden combs were excavated from Taeon Mado I site in 2009. The wooden comb teeth were tin thus they would be easily broken and bent during drying process. To improve dimensional stability of the wooden combs a cetyl alcohol system was used.

The objects were took a close-up with detail and recorded their condition. When cleaning the combs, brushes and a spray were used. Mineral substances between the teeth carefully removed. For chemical cleaning, a solution of 2% w/v EDTA-2Na with water is used to soak the combs for three days. After the EDTA treatment, the object is soaked in the water to remove residues EDTA.

For the consolidation, the combs were soaked in and ethyl alcohol in water solution {50%→70%→90%→95%→100%(1)→100%(2)} in room temperature and cetyl alcohol (10%→30%→50%) was substituted for the ethyl alcohol in a 50℃ impregnation machine. Each concentration was maintained for one week.

After consolidation was complete, the objects were dried at room temperature. The surface of combs became whitish, because cetyl alcohol was still left on the surface of the objects. A heater was set on 50℃ to remove the cetyl alcohol residue. This step was repeated until completely remove cetyl alcohol.

One of the wooden combs was broken by 3 fragments. The fragments were bonded with cyanoacrylate and epoxy resin (A mixture of Araldite SV 427® and HV 427®) with pigment were used to restoration. The fragments of teeth were bonded with cyanoacrylate and tweezers.



62. Before treatment (a wooden comb from Taeon Mado shipwreck No.1)



63. After treatment

Grains

1. Introduction

Plenty of grains such as rice, buckwheat, millet and other crops were found in Taean Mado shipwreck No. 1. Rice was found in Mado shipwrecks No. 2 and 3. Excavated grains had been buried for 800 years in the sea. The main ingredient of these grains, starch, was decomposed and gone, leaving only bran. The lost material had been replaced with water; therefore, excavated grains needed to conservation to be safely preserved outside of the ocean.

Table 9. Treated grains in the past five years

	Object	Amount	Excavated site	Period	Treatment
1	Rice	Group	Mado shipwreck No. 1	01/'10 - 12/'12	Using cetyl alcohol
2	Buckwheat	Group	Mado shipwreck No. 1	04/'10 - 12/'11	Using cetyl alcohol
3	Millet, pearl millet	Group	Mado shipwreck No. 1	01/'13 - in progress	Using cetyl alcohol

2. Treatment

<Table 10> shows the conservation process.

Table 10. Conservation process

Collecting objects	Transported in container with water
Desalination	Soaked in freshwater
Examination	Recorded the object's condition and took photos Analysis
Cleaning	Mechanical method: used a sieve Chemical method: solution of 2% w/v EDTA-2Na with water
Consolidation	Replacement of water with ethyl alcohol, at room temperature (50% ethyl alcohol → 70% → 90% → 95% → 100% → 100%) Immersed in the solution of cetyl alcohol with ethyl alcohol at 50℃ (increased concentration of solution from 10% → 30% → 50%)
Surface treatment	Removal of leftover cetyl alcohol Separate fragments
Recording condition	Complete condition reports
Storage	At temperature 20±2℃, RH 50±5%

(1) Collecting objects

After excavation and transportation of the object to the laboratory, the first step is to check the condition and take pictures. If the object is transported in an airtight container, it is kept as it came. But, as in picture one, if large number of grains are transported in a bag, they must be put straight into an airtight container, maintaining the same moisture levels. If they were left in the bag, the grains would loose their formation. Grains can harbor micro-organism more than waterlogged archaeological wood and waterlogged bone. It is best to keep them in a freezer at 4℃.

(2) Desalination

Grains are soaked in fresh water the same way as wood; they can be processed at the same time for a more efficient cleaning process.

(3) Examination

Most excavated grains are hard to classify, and their character must be carefully observed. Therefore, when grains are excavated, firstly an expert analyses them in the laboratory. Before species analysis, one needs to consult with an expert about the best method of cleaning and sampling the collection.

(4) Cleaning

Rice and buckwheat from Mado shipwreck No. 1 were not mixed with other grains but were contaminated with mud. Therefore, a small-mesh sieve was used to sift to remove micro deposits such as mud. If shell substrates and sand deposits were mixed together, tweezers are used for separation.

Before any further processing, the grains were put through a chemical process that involved soaking in 2% w/v EDTA-2Na in water for three days and soaking again into plain water to remove chemical remains. The completion point of this removal was determined by the point at which the pH of the solution matched the pH of the pure water used.

(5) Consolidation

For moving the fragile grains, a fine-mesh stainless steel sieve was used and grain was arranged in only one thin layer on the container. At each step it was necessary to hold the container carefully to prevent possible accident. To improve the dimensional stability of

the grains a cetyl alcohol system was used. The grains were soaked in an ethyl alcohol-in-water solution (50%→70%→90%→100%→100% ethyl alcohol) in room temperature. According to the condition of the grain, the ethyl alcohol concentration was increased, but they remained at each successive concentration for at least three days. After that, cetyl alcohol (10%→30%→50%) was substituted for the ethyl alcohol in a 50℃ impregnation machine for organic solvent. Each concentration was maintained for seven days. Stabilized grains were dried in desiccator to remove chemical residue. The surface of grains became whitish as seen in picture nine, because a large amount of cetyl alcohol was still left on the surface of the grains.

(6) Surface treatment

After dimensional stabilization was complete, the container was arranged upside down on a 65-70℃ heated hotplate, and a heat gun set to 60℃ was used on the base of the container to separate the grains from the container. After that, a large amount of cetyl alcohol was removed on the hot plate. At this point, filter paper (that had been laid on the hotplate) was also changed so that it could help remove the remains of cetyl alcohol on the grains' surface. When the surface treatment was finished, tweezers and scalpels were used to separate the fragments.

(7) Recording condition

Every process and resulting condition was recorded in detailed writing and with photographs.

(8) Storage

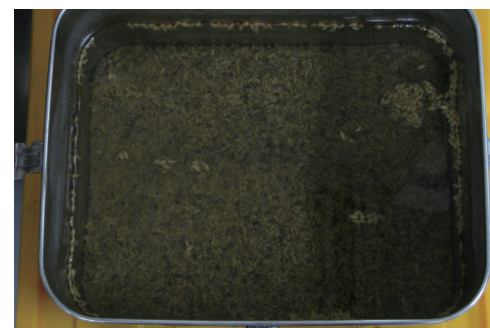
If cetyl alcohol was used, the object is not very affected by temperature; however it is displayed and stored in the conditions recommended by International Council of Museums (ICOM): 20±2℃ and 50±5%, and the objects' conditions are regularly checked.



64. Excavated rice with mud



65. Cleaning with sieves



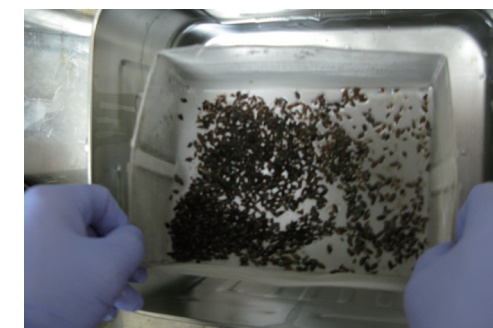
66. Before EDTA treatment



67. After EDTA treatment



68. Replacement of water with alcohol



69. Immersed in a solution of cetyl alcohol



70. Surface treatment of the rice



71. Separated fragments



72. Before treatment (rice)



73. After treatment



74. Before treatment (buckwheat)



75. After treatment



76. Before treatment (millet and pearl millet)



77. After treatment

Bone / horn

1. Introduction

Various bones or horns such as human, pig, fish, bird bones and horns were excavated from Taean Daeseom island and Mado shipwrecks No. 1, 2 and 3.

Approximately 70% of bone and horn is composed of an inorganic lattice that includes calcium phosphate and diverse carbonates and fluorides. Organic tissue (ossein) constitutes approximately 30% of bone and horn.

Both bone and horn are porous materials¹⁷⁾, therefore micro-organisms and water easily pass through them and can easily cause stains on the surface of bone/horn. These materials are also easily warped and cracked from heat and moisture. Ossein is disintegrated by hydrolysis and the inorganic framework is rapidly degraded by acid¹⁸⁾. The excavated bone and related materials from underwater could shrink and they tend to delaminate and fragment during drying¹⁹⁾. Because of all of this the materials need to be treated when recovered from the water.

Below the table shows treated bone and related materials in the four years.

Table 11. Treated bone and related materials in the past four years

	Site	Amount	Period	Treatment
1	Mado shipwreck No. 2 (2010)	35	05/'10-03/'11	Desalination, dry, consolidation (3% w/v Paraloid B72 in acetone)
2	Mado shipwreck No. 2 (2011)	14	05/'11-12/'11	Desalination, dry, consolidation (3% v/v Caparol in water)
3	Mado island II site (2012)	8	05/'12-05/'13	Desalination, dry, consolidation (3% w/v Paraloid B72 in acetone)

2. Treatment

Essential treatment approaches for bone and related materials are outlined below.

Table 12. Conservation process

Before treatment	Storage in containers with water
Desalination	Immersion in freshwater for desalination
Examination	Identification of type of materials Recording the condition of object and treatment proposal
Cleaning	Mechanical cleaning : using small tools and ultrasonic cleaner Chemical cleaning : optional methods, limited application on the surface of object
Drying	Drying in the shade
Consolidation	Application of 5% w/v Paraloid B72 in acetone with brushes or immersion.
Bonding	Using cyanoacrylate adhesives
Documentation	After treatment, recording the condition of object
Storage	In a controlled environment as temperature ranges of 20-22℃ and relative humidity (RH) ranges of 50-55%

(1) Before treatment

The recovered bone and related materials are transported using three methods: firstly, the largest objects are packed separately to avoid rapidly drying out. Fish or bird bones are stored in containers. The material which is excavated with pottery is transported to the conservation laboratory without packing. Bone and related materials should be differently treated depending on the condition of the objects.

Containers used for desalination should be prepared before treatment. The transported objects are photographed and the object’s condition is recorded, with all materials labelled in detail. The objects are unpacked and then immersed in fresh water. The objects found in pottery are normally surrounded by solid mud. The substances inside these vessels are removed with brushes and rinsed with water. The objects, once separated, are stored in containers.



78. Excavated the pottery/Modo shipwreck No.1



79. The inside of pottery

(2) Desalination

Bones and related materials are kept wet and stored in an opaque container. If they are stored in a transparent container, their surface may be negatively affected by light. Furthermore, the objects should be classified and stored according to their condition. In particular, iron-impregnated bones must be separated from other materials.

Deionized or tap water is used for the desalination process. The water is changed once a week and the chlorine level is checked until it reaches that of the deionized water or tap water supply being used. It normally takes one month.



80. Desalination



81. Moss covering some bones

(3) Examination

The recovered bone and related materials are often misclassified as wood or ceramics. If the identification of the materials not correct, microscopic examination or infrared spectroscopic analysis is used to identify the objects. All excavated bones must also be analysed for the species of the bone by specialists. When fish bones or crustaceans are recovered from inside of pottery, their condition should be checked and analysis carried out by specialists. In this case, they are examined or analyzed before cleaning.

(4) Cleaning

When desalination solution is changed, cleaning is carried out with small tools such as brushes and a bamboo knife. Shell and foreshore deposits are removed with these tools first. The surface of bone could be weak and fragile, thus careful cleaning is required to avoid further damage. Following desalination and removal of foreshore deposit, the objects are cleaned thoroughly with an ultrasonic cleaner.

(5) Drying

The bones and related materials are anisotropic and absorbent^{18, 20)}. These properties negatively affect the structure of the objects upon drying; they easily split and warp. Thus drying is an important and delicate process in the treatment of these objects.

Paper towels and cloth are used for the removal of moisture on the surface of objects. Following the first step, the materials undergo controlled drying in a container. The objects should not be rapidly dried out because they are weak and could fragment.

(6) Consolidation and bonding

Consolidation is an optional treatment. If the objects are to be used for radiocarbon dating or DNA analysis, consolidation solutions should not be applied.

There are two methods for consolidation according to the object's condition. One is applying consolidation solution to the surface of the objects with brushes or pipettes; the other method is to immerse the objects in consolidation solutions.

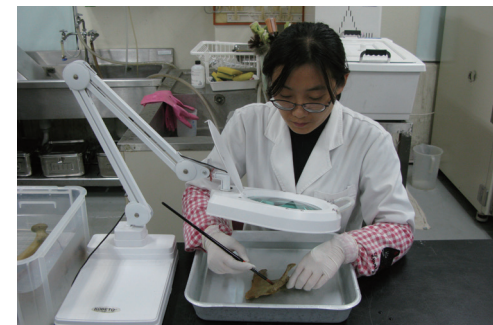
20% v/v Caparol-binder[®] with water²¹⁾, cetyl alcohol²²⁾ and 2-10 % w/v Paraloid B72^{18, 22-25)} with acetone are commonly used for consolidation.

A solution of approximately 3-5% w/v Paraloid B72 with acetone or 3% v/v Caparol-binder with water are mainly used for consolidation in the NRMCH. There are disadvantages of Caparol-binder: it has a high specific gravity, and is also vulnerable in high humidity environments.

After consolidation, any necessary bonding is carried out using cyanoacrylate adhesives.

(7) Storage

The bones and related materials are vulnerable to humidity. If the objects are exposed to high humidity, their surface could be covered with mould. On the contrary, if stored in dry conditions, the objects could shrink. The storage area therefore should be controlled with temperature ranges of $20\pm 2^{\circ}\text{C}$ and relative humidity (RH) $50\pm 5\%$.



82. Cleaning with brushes



83. Cleaning with an ultrasonic cleaner



84. Removal of moisture



85. Removal of moisture



86. Drying in containers



87. Drying slowly



88. Consolidation with 3% Caparol solution



89. Bonding



90. Before treatment/Taeon Mado II site

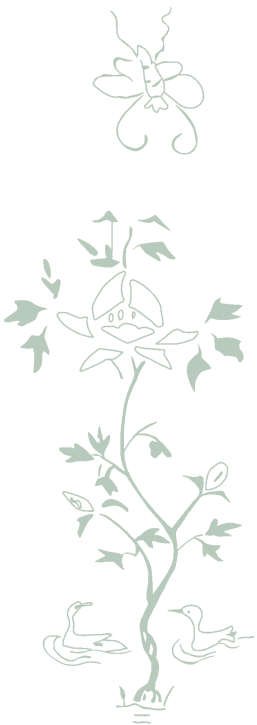


91. After treatment

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S E C T I O N

04

Metal

Lee Gyeongro

- **Introduction**
- **Ferrous objects**
 1. Introduction
 2. Treatment
 3. Case study
- **Non-ferrous objects**
 1. Introduction
 2. Treatment
 3. Case study

Introduction

Metals are extracted from ore through reduction, the opposite chemical process from oxidation. Metallic objects want to undergo chemical change to return to their oxidized form, a process known as corrosion. Objects that are buried underwater are in fair condition though exposed to water and salinity for a long time. After excavation and exposure to air, the objects are oxidized rapidly due to the change their environment. The metallic objects require treatment for long time to avoid this oxidation. This treatment focuses on consolidation and desalination.

Most metal objects that are excavated from the ocean by the National Research Institute of Maritime Cultural Heritage are iron and bronze. This section describes the treatment of iron and bronze objects.

Various types of bronze spoons and dishware have been excavated. The excavated objects including bronze spoons, dishware and iron pots are assumed to have been used by sailors at sea. <Table 1> shows the objects that were excavated from Taean Daeseom island and Mado shipwrecks No. 1, 2 and 3.

Table1. Type of metal objects

Site	Type of material	Type of objects
Taean Daeseom island	Bronze	Bowl
	Iron	Composite objects, pot
Mado shipwreck No. 1	Bronze	Spoon
	Iron	Pot
Mado shipwreck No. 2	Bronze	Spoon, dishware
	Iron	Pot, lid
Mado shipwreck No. 3	Bronze	Dishware, spoon, ladle, bell, coins
	Iron	Pot

The metal objects excavated from the sea have different type of degradation due to their environment: whether they were buried in foreshore, what exposure to salinity they had and the location of the site.

Iron pots usually are recovered from the foreshore with corrosion products or as part of composite objects, attached to ceramics and/or bronze. In this case, it is difficult to check original shape of object and to execute desalination.

Bronze objects are usually protected by patina which forms a layer on the object’s surface. However, bronze disease occasionally occurs in the part of object, thus the affected objects should be treated as soon as possible.

The table below shows the amount of treated metal objects from 2009 to 2012.

Table 2. Treated objects (2007 – 2012)

Date Excavated	Site	Amount
12/’07 - 10/’09	Taeon Daeseom island	3 Bronze tureens
09/’09 - 10/’09	Boryeong Oeyeondo island	76 Bronze coins, 1 bronze lion censer
05/’09 - 11/’10	Mado island I, II site	31 Bronze spoons, 13 bronze objects, 2 bronze coins
06/’10 - 11/’10	Mado island II site	2 Bronze spoons, 1 bronze coin
07/’11 - 11/’11	Mado island II site	2 Bronze spoons, 1 top-knot pin
07/’11 - 11/’11	Mado shipwreck No. 2	8 Bronze spoons, 4 bronze dishware
11/’10 - 04/’11	Bikyungdo island	69 Sangpyeongtongbo (coins)
05/’11 - 06/’12	Mado island II site	4 Bronze spoons, 2 bronze dishware, 3 bronze coins, 1 top-knot pin
05/’11 - 06/’12	Mado shipwreck No. 3	1 Bronze dishware, 1 bronze coin, 1 Bronze ladle
08/’11 - 10/’12	Mado island	85 Bronze objects, 1 pipe
10/’12 - 11/’12	Jindo island Oryuri	2 Bronze spoons, bronze coins
12/’07 - 05/’11	Taeon Daeseom island	1 Iron pot, 1 composite object
05/’09 - 12/’11	Mado shipwreck No. 1	3 Iron pots
05/’09 - 12/’11	Mado island II site	3 Iron lids
11/’11 - 12/’11	Wando island Eoduri	1 Iron pot (re-treatment)
05/’09 - 11/’12	Mado island	2 Iron pots
11/’12 - 12/’12	Mado island II site	4 Iron pots, 1 iron brazier, 1 iron lid

The metal object conservation work is carried out as <Table 3>. The order of conservation work can be changed depending on type of materials and the object’s condition and decoration.

Table 3. Conservation process

Examination	Condition report	Structure	Condition	Checking substrate	Drawing	Measuring the dimensions
		Observation of object's materials and condition.				
	Photography, Microscopy, X-ray	Photography		Microscopy	X-radiography	
		Photography and microscopy are used to take images the object's condition, decorations and patterns on the surface of the object. X-radiography is used to see the inside of object and manuscript.				
	Analysis	Micro-structure analysis	Measured hardness	SEM-EDS	ICP-ES	
Identification of the elemental composition of materials and manufacturing techniques.						
Treatment	Removal concretions	Ferrous object			Non-ferrous object	
		Any concretions are removed with physical methods.			Foreshore and shell deposit are removed with tools, unless the object is affected by bronze disease.	
	Desalination	An object is immersed in 0.1M sodium sesquicarbonate solution for desalination.				
	De-alkalization	Dealkalization			Dehydration	
		The object is soaked in distilled water. The water is changed every day until pH level reaches seven.			Ethyl alcohol is used to dehydrate the object.	
	Drying	The object is completely dried with dry oven over 80 °C				
	Corrosion inhibiting (bronze object)	The benzotriazole treatment is used to avoid corrosion.				
	Consolidation	Ferrous object			Non-ferrous object	
		30% Palaroid NAD10 solution is used to consolidate with vacuum chamber.			Non-ferrous object is immersed in Incralac solution for consolidation.	
	Bonding	Super glue™ and Epoxy resin are used.				
	Loss compensation	Ferrous object			Non-ferrous object	
		Epoxy resin with filler are used for loss compensation.				
Retouching	If a large section is filled, this needs to be matched in colour.					
Report	After treatment	Documentation			Photograph	
		After completing the treatment, the treatment process, conservation materials used and object's condition are recorded with photography.				
Storage		Environment should be controlled and monitored to avoid further corrosion.				

Ferrous objects

1. Introduction

Iron reacts with temperature, humidity and oxygen to form corrosion products. The rate of corrosion of underwater objects is in fact slowed by the resulting layer of corrosion product and the condition is relatively stable. However, the objects begin to corrode rapidly after they are excavated because of the change in their environment. The chloride ions in seawater might encourage corrosion on the surface of objects when exposed to air. Thus it is important that the objects should not be immediately dried out. Desalination is also an important process to remove the chloride ions.

If the cast iron object is not kept in steady state, there would be cracks in the object. The object can also exhibit a powder as known intergranular corrosion. Corrosion products which mainly occurred in iron objects are goethite (α -FeOOH), akaganeite (β -FeOOH), lepidocrocite (γ -FeOOH), magnetite (Fe_3O_4) and vivianite ($\text{Fe}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$).

2. Treatment

(1) Examination

Before treatment, the object’s condition is assessed then recorded in detail. The documentation includes archaeological information as well as conservation materials and methods. Analysis provides information about the way the objects were made, their decoration and degree of corrosion.

(2) Removal of concretions

The removal of concretions means removing corrosion products from the object. The iron objects excavated from the sea are heavily covered with solid corrosion products, shell deposits, traces of marine organisms and marine algae. These all need to be physically removed from objects by vibrating tools, dental picks and drills. The objects can be damaged during the removal of concretions thus the work should be carried out very carefully.

It is difficult to remove these concretions quickly; to speed up the process, the objects are soaked and stored in 0.1M sodium sesquicarbonate ($\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$) solution during treatment.

(3) Desalination and dealkalization

The recovered objects had been exposed to chloride ions for a long time while underwater. After removal of corrosion products, agents of corrosion such as chloride ions should be removed from the objects. The objects are soaked in 0.1M sodium sesquicarbonate solution to remove these corrosion agents. The solution is changed once a fortnight; and the overall process takes a long time.

After all chloride ions have been removed, the objects are soaked in distilled water to remove any alkaline deposits on the objects. The pH value of water is checked until it reaches seven, then a drying oven is used to dry the objects completely.

(4) Consolidation

Consolidation gives additional strength to corroded objects. Consolidation materials should quickly impregnate the object and dried when it applied to the object. After consolidation, the objects should be consistently checked the condition to avoid further corrosion.

The objects are immersed in the 30% w/v Paraloid NAD10 in naphtha in a vacuum chamber. Generally, the pressure within the chamber is reduced until it reaches 70cm/Hg. However, it can be changed depending on an object's condition. After consolidation, any solution remaining on the object's surface is removed with tissue and the object dried over a long period. The process is carried out three times.



(5) Bonding and loss compensation

The excavated iron objects are structurally weak and easily damaged. The fragile areas or fragments are treated with Super glueTM. Super glue, commonly known as cyanoacrylate adhesive, is quickly dried. Loctite 401[®], which has high viscosity, is applied to the large fragments. Altec[®], which has low viscosity, is used to consolidate the small fragments and fragile areas.

Restoration commonly uses two type of epoxy resin such as Araldite (rapid type) and Araldite SV 427[®]/HV 427[®] or AW 106[®]/HY 953 U[®]. Araldite Rapid type is quickly cured, as opposed to Araldite SV 427[®]/HV 427[®] and AW 106[®]/HY 953 U[®]. Any small missing sections are filled with Araldite Rapid type and filler. Araldite SV 427[®]/HV 427[®] and AW 106[®]/HY 953 U[®] with filling material are used to restore large missing areas.

(6) Retouching

The colour and texture of filled areas are matched with acrylic colours. Acrylic colour is convenient to use for retouching because it dries quickly and has good adhesion. When it is applied to the object's surface, it forms a thin film, that can help prevent discoloration of the body by UV radiation.

(7) Storage

After completing the treatment, the conservation process, materials used and resulting condition of the object are recorded. The treated objects can be corroded again by inappropriate environment conditions such as temperature and humidity; therefore, the objects are sealed with deoxidizing agents and desiccant. Storage environment should be controlled between temperature ranges of 20-22 °C and relative humidity (RH) below 45%.

3. Case study

(1) A composite object from Taean Mado island

Before treatment

The objects were excavated from Taean Mado island site in 2007. They are presumed to be sailor's supplies in the Goryeo dynasty period. The objects are found as a composite object comprising an iron pot, a rim of a bronze bowl, a piece of pottery with shell deposits and foreshore. The iron pot was filled with concretions, and the bronze bowl was badly corroded. Overall, the objects were seriously corroded and covered with heavy concretions. It was difficult to distinguish their original shape.

Removal concretions and desalination

The large concretions were carefully removed with only small force to minimize damage to the object. A scalpel was used to remove most of the concretions. A small knife also was used for more delicate work.

The object covered with concretions looks fair condition, but if it is exposed to air, it rapidly corrodes. The objects were soaked in 0.1M sodium sesquicarbonate solution as desalination process to prevent further corrosion.

Dealkalization, dehydration and dry

The objects were soaked in distilled water and the water changed every day until it had a neutral pH of seven. The objects were immersed in 95% ethyl alcohol (C_2H_5OH) and then dried at 80°C for eight hours in a drying oven.

Consolidation and restoration

The objects were immersed in the 30% w/v Paraloid NAD10 with naphtha solution for consolidation in a process as known the vacuum impregnation method. The iron pot had intergranular corrosion during treatment. Cyanoacrylate was used to bond and epoxy resin (a mixture of Araldite SV 427® and HV 427® in a 1:1 ratio) with filling material (microballoons) were used to restoration.



1. Before treatment



2. Removal of concretions



3. Consolidation



4. Retouching



5. After treatment (iron pot)



6. After treatment (pottery)

(2) An iron pot from Taeon Mado shipwreck No. 1

Before treatment

The iron pot was recovered from the Taeon Mado shipwreck No.1 in 2009. It is presumed to be a sailor's supplement in the Goryeo dynasty period. The concretions covered the area between the rim and the body of the pot. There was crack approximately seven centimeters long in the bottom of the pot. It was presumed that there were originally three legs but one leg was lost, one leg was detached and leaving only one complete leg.

Removal concretions and desalination

The concretion was extremely solid, thus it was difficult to remove with small tools. Electronic tools as vibratools were used to physically remove concretions. Removal of concretions and desalination were carried out at the same time. The pot was immersed in 0.1M sodium sesquicarbonate solution for two years and the desalination solution was changed once a month.

Dealkalization, dehydration and drying

After removing the concretions, the object was immersed in distilled water to remove remaining sodium sesquicarbonate solution. The 95% ethyl alcohol solution was used to remove moisture. After that, the pot was dried at 60°C for five hours in a drying oven.

Consolidation, bonding and restoration

A solution of 30% w/v Paraloid NAD10 with naphtha was used to give additional strength to the object, then Super Glue was applied to cracked areas for consolidation.

The detached leg was bonded to the body with mixed epoxy resin and microballoon filler. Paraffin wax was used to cast the leg and the casted leg was adhered to the bottom of pot.



7. Before treatment



8. Before treatment (the bottom of the pot)



9. The inside of the pot



10. Found spoon inside of the pot



11. After treatment



12. Spoon

(3) An iron pot from Wando shipwreck (re-treatment)

Before treatment

The iron pot excavated from Wando shipwreck was treated between 1988-1999 and displayed for exhibition; however, concretions and intergranular corrosion had occurred on the object’s surface.

Removal of concretion and drying

The first step was cleaning. The concretions were removed with small tools such as scalpels and tweezers. After that the pot was cleaned using a brush. If acetone was used for surface cleaning it would have caused cracking because the object had already been supported with consolidation materials. And so the object was immersed in 95% ethyl alcohol in water and cleaned with a brush. Following cleaning, a drying oven was used to dry the object at 60℃ for five hours.

Consolidation, Restoration and retouching

A solution of 50% w/v Paraloid NAD10 with naphtha was used to consolidate the object. It was applied to the surface of the object three times. The cracked areas and missing part were restored with Super Glue™ and SN-sheet. Restoration materials were synthetic resins such as SV 427®/HV 427® and microballoon filler. After this, acrylic colours such as black, brown and red were used to complete the retouching.



13. Before treatment



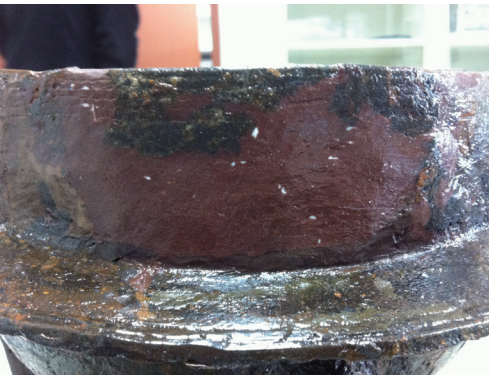
14. Corrosion on surface



15. Removal of concretion



16. Cleaning with ethyl alcohol solution



17. After removal of corrosion products



18. After treatment

Non-ferrous objects

1. Introduction

The bronze objects that are excavated from the Taeon Daeseom island site and Mado shipwrecks number one, two and three had been either cast or wrought. Wrought bronze is made with copper (Cu) and tin (Sn). For casting, lead (Pb) is added to help the fusion between the copper and tin. Occasionally, the added lead does not disperse evenly in copper alloys, and can separate.

In the case of the wrought bronze object, the corrosion products tend to be evenly spread over the entire surface. However, cast objects display an uneven corrosion pattern due to manufacturing techniques.

2. Treatment

(1) Examination

The condition of the objects and the proposed treatment are recorded with photography, material analysis and X-radiography. Any archaeological information and conservation materials are also recorded on the condition report.

(2) Removal corrosion product

For removal of concretions on bronze objects, the corrosion layers on the surface should be examined carefully first. Corrosion products such as malachite ($\text{CuCO}_3(\text{OH})_2$) and azurite ($\text{Cu}_3(\text{OH})_2(\text{CO}_3)_2$) may form layers. These layers of corrosion contribute to protecting the object below; paratacamite ($\text{CuCl}_2 \cdot 3\text{Cu}(\text{OH})_2$) and atacamite ($\text{Cu}_2\text{Cl}(\text{OH})_3$) are peroration corrosion as powder.

If original patina is retained on the surface of the object, the corrosion layer should not be removed and one should only remove any surface dirt with a cotton swab. The bronze objects excavated from the sea are will have solid foreshore adhered on part of their surface. This foreshore is gently removed with small tools.

If the object is affected by bronze disease, it is easily damaged during the cleaning process. In this case the corrosion products should not be completely removed and the object should only be minimally cleaned then treated with a corrosion inhibitor.

(3) Desalination

The objects recovered from the sea have been exposed to salt for a long period, thus desalination is a necessary process. The objects are put into 0.1M sodium sesquicarbonate ($\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$) solution for several months. The solution is changed at fortnightly intervals. Following complete desalination, the object is dealkalified to remove residue alkali and rinsed with distilled water.

(4) Corrosion inhibiting

If the chloride ions are retained in the object, they react with moisture in the atmosphere and cause further corrosion of the object. The object should therefore be stabilized with a corrosion-inhibiting treatment. Benzotriazole (BTA) is used to prevent corrosion and discoloration of patina. It forms a protective film on the corrosion layer. To apply BTA, the object is impregnated in solution of 3% w/v BTA in ethyl alcohol in the vacuum chamber. The pressure within the chamber is reduced until it reaches 70cm/Hg. After treatment, excess BTA can be retained on the object's surface, so ethyl alcohol with a cotton wool swab is used to take off the leftover BTA solution. Regarding health and safety, BTA is carcinogenic so while it is used conservators should wear a mask and not permit contact with the skin.

(5) Consolidation

After benzotriazole treatment, Incralac (14.6% Paraloid B72, 0.4% BTA, 14.17% acetone and 70.38% toluene) solution is used to consolidate the object. The object is put into in 3% Incralac solution in the vacuum chamber. The pressure within the chamber is reduced to 70cm/Hg. However, if patina has occurred on the object's surface, the solution does not penetrate the body well using this method. In this case, Incralac solution is applied to the object's surface with brushes. The solution can be left on the surface of the object. It is removed carefully to avoid staining.

(6) Bonding and loss compensation

Cyanoacrylate is used for bonding bronze objects. Alteco[®] which has low viscosity, is used to bond the small and delicate cracking areas, while Loctite 401[®] which has high viscosity, is applied to bond the large fragments.

Epoxy resin, filler and pigment are mixed and then used to fill in the missing sections. If it cures during the work, the surface of object is evened with small tools. After that, object is impregnated in Incralac solution for re-consolidation.

(7) Retouching

The retouching process expresses the colour and texture of the object. A retouching rule is followed: one must be able to distinguish between retouched and restored areas and the original object. Acrylic colours and bronze powder are used to match the colour.

(8) Storage

After completing the treatment, the treatment process, conservation materials used and the change of object's condition are recoded on the treatment report.

The bronze objects that developed a patina are relatively resistant to corrosion. However, they can be corroded again in an inappropriate environment. The treated objects should be stored in a controlled environment with a temperature range of 20–22°C and relative humidity (RH) below 45%.



3. Case study

(1) Bronze dishware from Mado shipwreck No. 3

Before treatment

Various bronze objects were excavated in Mado shipwreck No. 3: a bowl, a dish and a bell. The bottom of the bowl was partly missing and broken as a result of heavy corrosion. A patina was also formed on the surface of the bowl. The dish was fair condition and the patina was evenly distributed over the entire surface of the dish. In the case of the bell, the surface was uneven because the corrosion layers had separated from the surface of the bell.

Desalination

Desalination was carried out for three months. The 0.1M sodium sesquicarbonate ($\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$) solution was used to desalination and it was changed once a week. After that, the objects were immersed in distilled water to reduce the alkalinity. The remaining corrosion products and dirt were removed with brushes and tools. Ethyl alcohol was used to dehydrate the objects.

Consolidation and bonding

3% w/v BTA with ethyl alcohol solution was used to prevent corrosion. The objects were consolidated with Incralac solution. Cyanoacrylate was used to bond detached areas.



19. Before treatment (the bowl)



20. After treatment



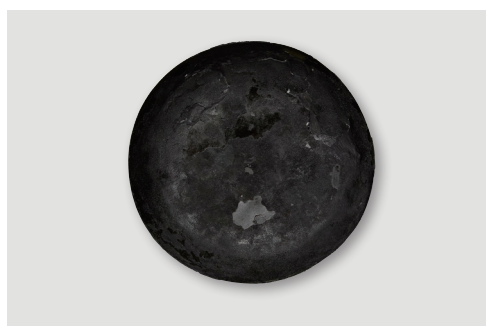
21. Before treatment (the dish)



22. After treatment



23. Before treatment (the dish)



24. After treatment

(2) Bronze coins from Boryeong Oeyeondo island

Before treatment

77 coins were recovered from Boryeong Oeyeondo island in 2009. These were round with a square hole in center of the coin. The coins were covered with foreshore and concretions. 35 of the coins were illegible with the naked eye due to corrosion.

Cleaning

The concretions on the surface of coins were examined and removed under a microscope. The 0.1M sodium sesquicarbonate solution was used to desalination. After desalination, ethyl alcohol was used to dehydrate the objects. The Incralac solution was used to consolidate the objects.

Consolidation

The objects were immersed in 3% w/v BTA with ethyl alcohol solution for a day and dried at room temperature for a week. Remaining BTA solution was removed with ethyl alcohol and cotton swabs. The coins were consolidated with the Incralac solution and residual Incralac solution was removed with tissue.

After treatment

Through treatment, the names of 35 of the coins could be deciphered. The coins were categorized into 15 types: Gaewontongbo(開元通寶), Kunwonjungbo(乾元重寶), Sunhwawonbo(醇化元寶), Hampyeongwonbo(咸平元寶), Gyeongdeokwonbo(景德元寶), Cheonseongwonbo(天聖元寶), Hwangsongtongbo(皇宋通寶), Jihwawonbo(至和元寶), Chipyeongwonbo(治平元寶), Huirryungwonbo(熙寧元寶), Wonpungdongbo(元豐通寶), Wonutongbo(元祐通寶), Soseongwonbo(紹聖元寶), Seongsongwonbo(聖宋元寶), Seonhwatongbo(宣和通寶). The objects were from the Song and Tang dynasties of China.



25. Before treatment (Kunwonjungbo)



26. After treatment



27. Before treatment (Chipyeongwonbo)



28. After treatment



29. Before treatment (Wonpungdongbo)



30. After treatment

(3) A bronze brazier from Jindo island Oryuri

Before treatment

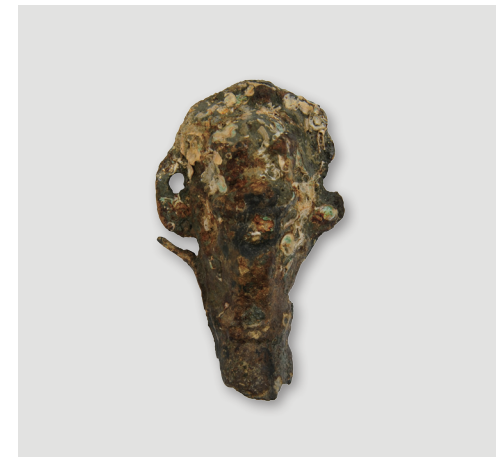
This bronze brazier was excavated from Jindo island Oryuri in 2012. The body of the brazier was badly corroded when it recovered. It was presumed that the brazier originally had three legs. One leg was excavated with the body of brazier but damaged in over half of its area. The other leg was detached from the body of object. One of three the legs was lost.

Removal concretions

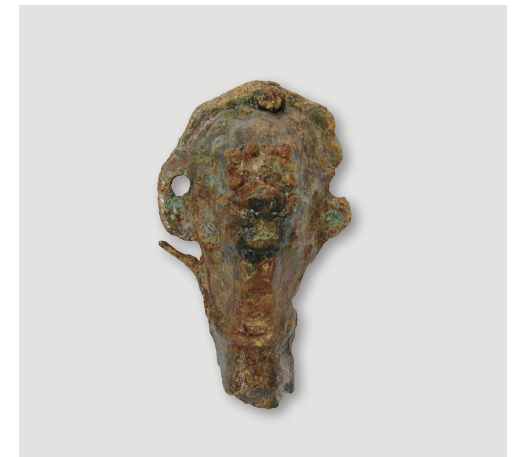
The shell deposits on the surface of legs were examined and removed with a scalpel under a microscope. Remaining foreshore and sand in the inside of the leg was cleaned with brushes under running water. The objects were soaked in the 0.1M sodium sesquicarbonate solution for desalination. Remaining concretions on the surface were removed with brushes.

Consolidation

The objects were immersed in solution of 3% w/v BTA with ethyl alcohol to create a corrosion-inhibiting layer and then they were dried at room temperature for a week. Incralac solution was used for consolidation; the objects were immersed in it for two hours, then remaining solution was cleaned off with tissue. After treatment, a lion's face was visible on the leg.



31. Before treatment (the front of the leg)



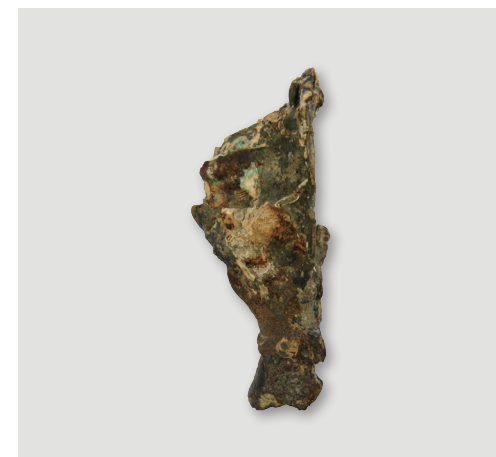
32. After treatment



33. Before treatment (the back of the leg)



34. After treatment



35. Before treatment (the side of the leg)

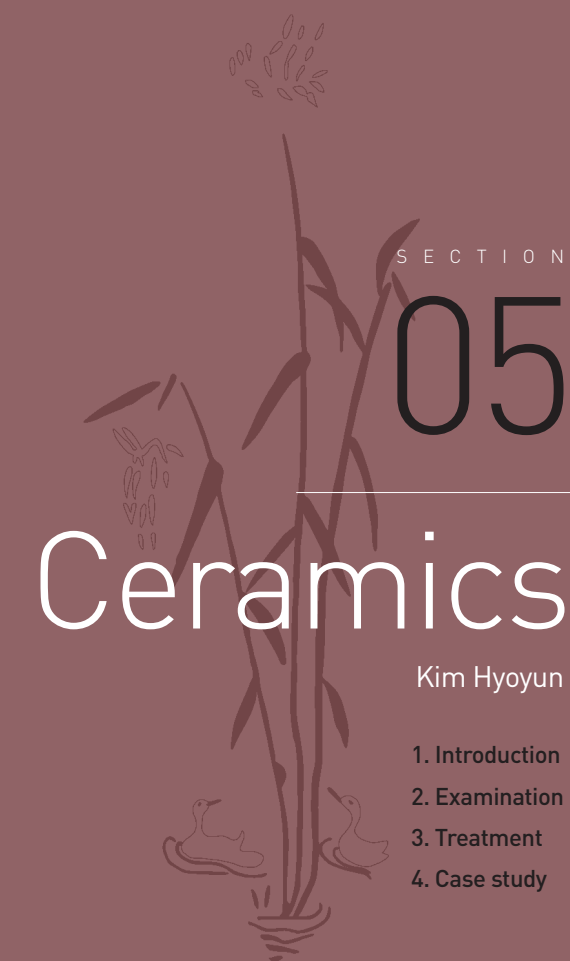


36. After treatment

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Taeon Mado shipwreck No. 1 underwater excavation report p.418
- 3. The National Research Institute of Maritime Cultural Heritage (2011)
Taeon Mado shipwreck No. 2 underwater excavation report p.310
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SECTION

05

Ceramics

Kim Hyoyun

1. Introduction
2. Examination
3. Treatment
4. Case study

1. Introduction

Wide ranges of ceramics found underwater are buried in a steady state but their condition begins to deteriorate immediately after they are excavated. Ceramic objects appear to be relatively more stable than other materials but can be damaged by salt water and improper preservation.

(1) Excavated ceramic objects

Most ceramics were excavated in Jeolla, Chungcheong, Gyeonggi and the western coast area. The majority of ceramics discovered were from the Goryeo dynasty. This could be inferred from the temporal signature of the marine transport system used in the Goryeo dynasty. These ceramics had various purposes that were classified as product, donation to the palace and sailors’ supplement. They were of different usage, types and quality¹⁾. The excavated Goryeo dynasty ceramics into from Mado shipwrecks No. 1, 2 and 3, divided broadly by ceramic type and usage, are shown in the table below.

Table 1. Types and usage of excavated ceramic

Excavated site	Form	Type	Usage
Mado shipwreck No. 1 (2009)	Stoneware	Dish, bottle, urn, steamer pot, bowl	Daily uses, water jar, to store sailor food items ²⁾
	Celadon	Soup bowl, dish, bowl, cup, cuplid, bottle, flowerpot, jar, dish-stand, ewer, pitcher, lid, saucer, openwork-stand	Presumed goods (the same types; many were excavated)
Mado shipwreck No. 2 (2010)	Stoneware	Bottle, urn, steamer pot	Presumed to be a sailor’s supplement
	Celadon	Bowl, vessel, soup bowl, cup, dish, prunus vase, bottle, urn	Poor quality, presumed to be a sailor’s supplement and better quality product presumed goods ³⁾ Prunus vase was used to contain honey and sesame oil
Mado shipwreck No. 3 (2011)	Stoneware	Dish, bottle, urn	Presumed from a shipment that contained salted fish Presumed to be a sailor’s supplement ⁴⁾
	Celadon	Soup bowl, dish, vessel, bowl, cup, lid	To follow, trace of use and poor quality, possibly sailor’s supplements ⁵⁾

(2) Condition of ceramics

The condition of the ceramics was mainly affected by their environment. The excavation environments have undergone various changes, meaning that some objects were buried in the foreshore, or half exposed, or in conditions affected by both ebb and flood tide⁶⁾. In addition, different types of ceramic objects may have been more or less affected. The damage could be roughly categorized as physical and biological.

The most common type of damage is physical effects from the pressure of surrounding water and submarine deposits⁷⁾; thus, the main concern of the conservation process was accurate bonding between fragments of stoneware, between fragments of porcelain. Secondly, biological damage was commonly caused by the surface adhesion of Balanidae (phylum Arthropoda), Hydroid worm (phylum Annelid), Pinctada and Ostreidae (phylum Porifera). There needed to be different approaches to the conservation of the glaze and the body strength of the ceramic.



1. Physical damage: status of excavated ceramic fragment of cargo Mado shipwreck No. 2, Taeon



2. Biological damage: surface contamination by marine organisms in Mado offshore

(3) Statement of ceramics conservation

Between 1976 and 2013, 47,700 ceramic objects have been treated. Ceramic accounts for nearly 99% of the conserved objects found because of the massive amount of ceramic goods (objects) that has been found on the Gunsan, Taeon Daeseom island and offshore of Mado.

<Table 2> shows the amount of ceramic excavated in the past two years, with site and the conservation process records of the underwater excavation team, main office in Mokpo and Taeon conservation centre. Most ceramic objects have been through the basic conservation process, which involves procedures such as removing shell substrates and water-soluble salt after excavation. Depending on the condition of each individual object, it may also be necessary to bond, fill and retouch with appropriate conservation materials.

Table 2. Conserved ceramic objects in the past two years

Category	Period	Site	Amount	Treatment
2013	08/'13–09/'13	Incheon Yeongheungdo	34	Removal of foreign substances, desalination, air-drying, bonding, loss compensation
	06/'13–07/'13	Taeon Gaiudo observation	2	Removal of foreign substances, desalination, air-drying
	03/'13–07/'13	Incheon Seomeopbeol, Taeon Mado offshore	7 Boxes of fragments	Removal of foreign substances, desalination, air-drying
	02/'13–03/'13	Boryeong Oeyeondo island, Janggodo island observation	28	Removal of foreign substances, desalination, air-drying
	12/'12–12/'13	Taeon Mado shipwreck No. 3	35 Stoneware items	Removal of foreign substances, desalination, air-drying, restoration
	12/'12–01/'13	Incheon Seomeopbeol	202 Celadon items	Removal of foreign substances, desalination, air-drying
2012	10/'12–12/'12	Taeon Mado II site	23	Removal of foreign substances, desalination, air-drying
			1 Celadon pillow	Removal of foreign substances, desalination, air-drying
	10/'12–12/'12	Jindo island Oryuri	73	Removal of foreign substances, desalination, air-drying
	07/'12–10/'12	'11, '12 Haenam, Jindo island observation	92	Removal of foreign substances, desalination, air-drying
	06/'12–09/'12	Taeon Mado II Site	1 Stoneware item	Bonding, loss compensation
	05/'12–10/'12	Taeon Mado I, II Site	45	Removal of foreign substances, desalination, air-drying
	05/'12–12/'12	Incheon Seomeopbeol	193	Removal of foreign substances, desalination, air-drying
	04/'12–10/'12	Incheon Seomeopbeol observation	99	Removal of foreign substances, desalination, air-drying
	04/'12–06/'12	'12 North and south Jeolla observation	17	Removal of foreign substances, desalination, air-drying
	04/'12–06/'12	Taeon Mado II site	4 Stoneware items	Dismantling, bonding, restoration
	04/'12–05/'12	Gunsan Yamido	853	Removal of foreign substances, desalination, air-drying
	02/'12–05/'12	Exhibition of ceramic objects in Goryeo Sailing Museum	3	Loss compensation
	02/'12–03/'12	Gunsan Yamido	1,495	Removal of foreign substances, desalination, air-drying
	02/'12–09/'12	Taeon Mado I, II Site, Padori	236	Removal of foreign substances, desalination, air-drying
	01/'12–02/'12	Gunsan Yamido	Fragment	Removal of foreign substances, desalination, air-drying

<Table 3> shows the conservation treatments. The conservation work is carried out in order from left to right. Generally, the recovered ceramics are worked on in this order but the whole process is not necessary for all treatments.

Table 3. Conservation process of ceramics

Examination	Categorisation	The type of materials, condition, purpose of analysis will influence the choice of conservation methods and materials.			
	Analysis of materials and components (optional)	XRD and XRF are used to analyze for the type of body and clay components. FT-IR is also used for analysis of the substrate.			
	Recording before the treatment	Photography		Recording	Report
	The objects are accessed with photography and detailed description.				
Treatment 1 (Essential)	Cleaning, removal shell deposits	Cleaning	Physical removal	Chemical removal (optional)	Cleaning
		Generally, tap water used for cleaning. Shell deposits are removed physically with tools. Otherwise, an acidic solution is used to remove these deposits. After using the acidic solution, the objects are rinsed many times with running water.			
	Desalination	After finishing the initial cleaning, the objects are soaked in tap water, which is ten times denser than the objects. The chlorine levels are checked twice a week and water changed for a month. If chlorine is found after four weeks, the desalination time is extended.			
	Drying, Stain removal	Removal of moisture (using cloth)	Controlled drying	Stain removal	Final surface cleaning
			Oven drying		
		Simple controlled drying is best for objects but the objects need to sit for one or two days until they completely dry out, and this time is also affected by weather and season. If there are a large number of objects and not enough spaces for dry, dry oven can be used to dry the objects approximately from 60 to 80 °C for 6 hours. If the dry oven is used, temperature is checked every two or three hours. After finishing dry, 50-100% ethyl alcohol is used to the surface of object cleaning.			
Treatment 2 (Optional)	Bonding	Binding	Paraloid B72 which has reversibility is used to bonding the ordinary ceramics.		
			Vitrified ceramics are used with epoxy resins.		
		Masking tape and Magic Tape™(pressure-sensitive tape) are used to hold the fragment. Use of Super Glue™(cyanoacrylate) is avoided for bonding.			
	Loss compensation	Plaster		Synthetic resin	
		Generally plaster filling is built as a removable fill.		A resin made into a paste is used for filling.	
	Retouching	Acrylic colour		Coloured epoxy	
		Acrylic colour is commonly used on fills for retouching. Various tools such as brushes, sponges and air brushes are used.		Epoxy resin with pigment is used to match the colour. It is commonly used for celadon.	
Reports	Documentation	Photography		Recording	Report
		After treatment, the treatment process, materials used, and methods are recorded with in detail. Photography should be taken in same area as before treatment.			

2. Examination

(1) Categorising ceramics

Categorising ceramics is essential work before treatment. Conservation work can be different depending on the material or condition of the objects. The basic criteria for categorising ceramics are as below.

Glaze

The presence of glaze should be checked because it can affect the method of removing shell substrates. If glaze exists on the object's surface, the shell substrates can be easily removed physically using tools. If there is no glaze, a hydrochloric acid solution can be used for removing shell deposit. Shell deposits should be removed to reveal the object's original shape.

Analysis

If ceramics require component analysis or analysis of contents (substrates) which are inside the object, the ceramics should be separated and stored from other materials. Also if there are shell deposits, they should not be removed using acidic solution. It is recommended that objects are stored in water until sampling rather than drying out in the air.

Stains

Any ceramics contaminated with corrosion products from careless handling or from the environment in which they were buried should be treated and separated from other type of ceramics. If objects are impregnated with metals such as iron are in the desalination tank with other ceramics, the corrosion agents can migrate to other ceramics. The stain or corrosion agents could be removed by various chemical products.

Physical damage

Recovered fragments of ceramics could be difficult to work on, for example removing shell deposits or desalination, because fragments are easily mixed together. Thus the fragments of objects are separated by colour and texture and kept together in an ordinary net.

(2) Analysis of materials and components

With most excavated ceramic objects it is possible to visually recognize what materials have been used to make them, such as normal celadon, white porcelain and greyish-blue celadon. However, the treatment process (removal of foreign substances and desalination) does not differ much for each ceramic type. Chemical and conservation material tests may be needed to collect safety data, but the details of chemical data from analysis may be omitted at this point to focus on conservation guidance.

(3) Recording before the treatment

When taking over the excavated objects, it was necessary to keep accurate lists to record the objects. This process was necessary even though it took time. Before the treatment could begin the condition of each object and proposed treatment were recorded, supplemented with photography, tagged numbers on the objects. Large numbers of objects from one excavated site could be processed as one combined category but photography was still necessary to treat each ceramic. Some processes could be performed with an oral report instead of a written report before the treatment. If this was the case, the details were recorded and the report completed after the treatment.



3. Treatment

(1) Cleaning

When excavated ceramic objects are transported to the conservation laboratory, it is better to keep them in water to maintain a similar environment status to the excavation area, rather than leaving them in the open air to dry. This would not give a difference of drying rate and might also leave foreign substances attached to the objects’ surfaces. It might create negative effects on the surface and glaze where the inner salt of the object would begin to crystallize and break the glaze layer⁸⁾.

Furthermore, after evacuating the objects from the sea, prompt conservation is needed because they give off a strong smell by foreign substances and to avoid further activity of micro-organisms.

The cleaning process is divided into two levels according to the amount of shell substrate on the object surface. If there is no shell substrate or the small amount of shell substrates can be easily removed with a bamboo knife and a scalpel, which are normally used to remove foreign deposits, then the objects are washed with running water. In some cases, the shell deposit is solid and cannot be removed physically without potentially damaging the surface. Instead, acid is used, a method which also reduces the conservation treatment time. Aqueous hydrochloric acid solutions of approximately 5% w/v are used to soak the objects to make shell deposit become brittle. When making hydrochloric acid solutions, hydrogen chloride gas may spread to the open air, so it is necessary to wear appropriate personal protective equipment and carry out the process in a well-ventilated area. The objects are soaked for a period of time, depending on how solid the shell deposits are. After removing the shell substrate, the objects are rinsed plenty of times with running water so that no residue is left.



3. Before shell deposit was removed, Mado offshore



4. After shell deposit was removed, Mado offshore
(Glaze was in good condition, therefore shell deposit was physically removed)

(2) Desalination

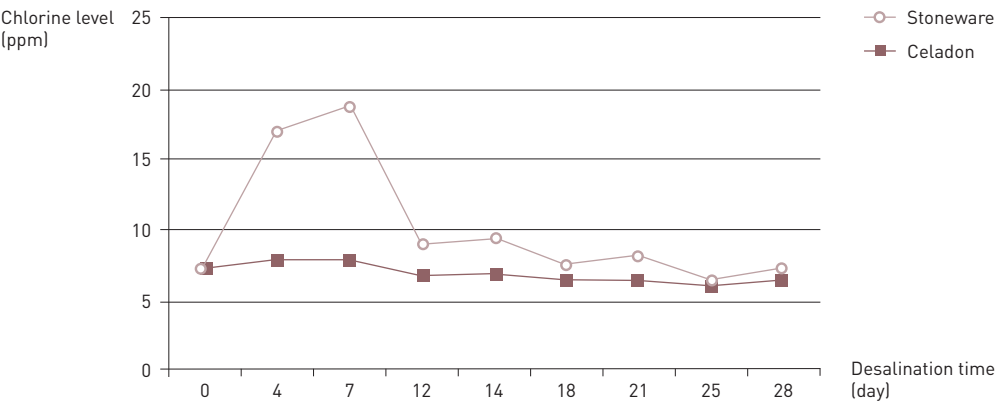
Desalination is an important part of excavating objects from the sea. It takes between a minimum of four and maximum of eight weeks depending on the condition of the object. In this case, following the advice of previous research, the process took four weeks using water ten times heavier than the objects’ weight. The water was changed every week and the residual chlorine concentration was also checked (with Thermo electron™, US/ORION 5-star) once or twice a week in order to predict the date when complete desalination would be achieved.

<Table 3> and <Graph 1> show the recorded levels of chlorine (Cl⁻) during the desalination period after the removal of foreign deposit from the ceramics, which in this case, were objects excavated from the Incheon Yeongheungdo shipwreck. The chlorine levels were checked twice a week and water changed once a week.

Table 3. Changes to chlorine levels (Unit = ppm)

Desalination date count	Measurement date		Celadon	Stoneware
0 days	16 Aug		8.06	8.06
4 days	20 Aug		8.48	18.83
7 days	23 Aug	Changed desalination solution	8.85	20.57
12 days	28 Aug		7.37	9.87
14 days	30 Aug	Changed desalination solution	7.72	10.33
18 days	03 Sep		7.26	8.05
21 days	06 Sep	Changed desalination solution	7.03	8.98
25 days	10 Sep		6.86	7.23
28 days	13 Sep	Desalination complete	7.25	7.79

Graph 1. Changes of chlorine level with desalination date
(Changed desalination solution after checking chlorine level on day 7, 14 and 21)



Some research shows that the porosity of ceramic can affect the length of the desalination period⁸⁾. High porosity ceramics, earthenware and greyish-blue celadon only take around one week to desalinate, whereas low porosity ceramics, high fired ceramic and celadon (porcelain) need a longer desalination period. The body type of white porcelain does not provide much space for the salt to flow so this takes particularly long.

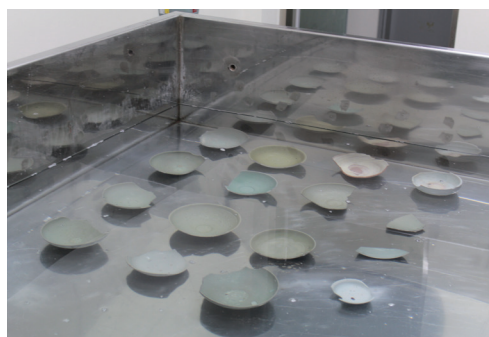
The numbers in <Graph 1> above show how the stoneware has dramatically changed until day seven and so on. After four weeks, chlorine number was similar to that of celadon. The chlorine level needed to be less than 10ppm, the concentration of chlorine in the normal tap water used. If the object's condition was classified as unsatisfactory it was decided that it would be safer to carry on the desalination just up to the four-week point. The elution level of chlorine and desalination time was affected by the state of different body types and conditions.

The pre-washed objects are separated by excavation date or excavation site with labels, and put into the desalination tank. An ordinary net is used to prevent them from mixing together.

Deionized water and purified water is the best to use for the desalination process. However, taking efficiency, cost and convenience into consideration, it is decided to use ordinary tap water. Moreover, it could also remove residue acid⁹⁾.



5. Desalination process: fragments (Mado offshore) separated by ordinary net



6. Desalination process: fragments (Mado offshore) in the desalination bath

(3) Rinsing and drying after desalination

Moisture from the objects is removed after desalination; if moisture is not removed before it dries out naturally, water marks will be left on the surface of the object and a special cleaning cloth must be used. Then the objects are arranged into a array for drying at room temperature. Sometimes, there are too many objects to fit at random, thus similar size objects are grouped together. This might give difference of drying rate between overlapped sections and others. Therefore, a drying oven is used to dry the objects at 80°C and the temperature is checked every hour.

(4) Final surface cleaning

The final stage of the cleaning process used 50-100% ethyl alcohol with a cotton wool swab and a scalpel to take off any foreign deposits left from the earlier acid cleaning process. This have to be done carefully as the cotton wool swab can leave contamination like cotton fibres on the rough surface and cross-section. It is therefore better to use stencil brushes or short brushes. If the contaminant is still in the cross-section and glaze layer through all that cleaning process, steam cleaner is the next option.



7. Removing moisture with cleaning cloth



8. Drying oven (Jeio tech) for ceramic object



9. Part of final surface cleaning



10. Cotton swab cleaning for part of final surface clean

(5) Bonding

The bonding plan of the ceramic is made in a dry run without adhesive that gives an indication of the fragment location and order. Masking tape (kraft paper substrate with acrylic adhesives) and Magic tape™ (cellulose acetate substrate with acrylate adhesive) is used to hold the fragments; both are easily removed. Where possible, using Super Glue™ is avoided and if the glue is necessary used to bond the fragments, only minimal quantities are used. Paraloid B72 (ethyl methacrylate copolymer) is removable adhesive and was mainly used on the stoneware. A solution of approximately 50% w/w Paraloid B72 with acetone is applied to bond. This is sometimes mixed with ethyl alcohol to control the evaporating of the solvent.

Vitrified ceramic (celadon and white porcelain) is bonded with epoxy resins (Araldite 2020®, Epo-tek 301-2®, Fynebond®). The fragment is first attached with tape and then small drops of epoxy resin put along the break-edges; capillary action pulls the adhesive into the join. Curing takes different amounts time with a variety of epoxy resins, about one to seven days.



11. Bonding with epoxy resin



12. Bonding with Paraloid B72

(6) Loss compensation

The excavated ceramic objects have suffered a lot of damage caused by water pressure and environmental matter; they are commonly excavated as fragments. Restoration of the missing areas could give additional strength to the original ceramic body. The fill material is normally a synthetic resin such as CDK 520®, SV 427®/HV 427® and Quick Wood®, but our department commonly uses plaster. Plaster is easy to retouch and when it is mixed with water, it becomes solid in ten minutes at room temperature.

Powdery plaster is hard to remove when it adhered on the object's surface. However, careful conservation may make it safe to use with a well-trained technique. Plaster is commonly used as a removable fill. The filling preparation used is Para film® to cover the

break-edge and dental wax to support one side. After that, plaster is applied with a spatula, which is used to make it similar to the surrounding surface. The plaster is taken off carefully after curing. Sandpaper is used to smooth the restored section; it may be used wet or dry. In the wet sanding technique, the restored section is soaked before polishing its surface under running water. This prevents dust but take more time to completely dry the object.

After the wet sanding has been performed, it is necessary to wait until the filled section has dried completely, before applying a solution of approximately 10% w/v Paraloid B72 with acetone to consolidate the surface. Consolidation with Paraloid B72 helps with subsequent retouching as it can just be removed with acetone. Moreover, if there are air bubbles in the plaster fill, Flügger™ (butyl methacrylate and calcium carbonate) is used to fill the section. Consolidation with Paraloid B72 also helps adhesion between the Flügger and plaster fill surface.

(7) Retouching

The retouching process commonly uses acrylic colours. Acrylic colour dries in a couple of hours in the open air, therefore a palette can be made with wet paper in the petri dish. This extends the period of use. However, the colour of celadon and white porcelain are difficult to express. In this case, epoxy with mineral pigment is used to match the colour. After that, a removable fill is adhered to the original ceramic section. Paraloid B72 is used as adhesive for reversibility reasons.



4. Case study

(1) A bottle 'Janggoon' from Incheon Yeongheungdo shipwreck

A bottle 'Janggoon' is a dark grey ceramic relic that was excavated from the Incheon Yeongheungdo shipwreck in 2013. Its width is 40cm, height 27cm and depth 6.5cm. White and brown coloured marine organisms had settled on the surface, and damaged one third of the total body, and the body had broken into three sections.

First of all, primary cleaning was executed under running water with a bamboo knife and a brush. Other foreign deposits were removed with aqueous hydrochloric acid solution. The object was put into a 5% w/v aqueous hydrochloric acid solution for a short time and then a bamboo knife and a scalpel were used to take off the shell deposits, which had become soft under the hydrochloric acid solution process. However, it was still important to be careful with the scalpel given the condition of the object's surface.

The object was cleaned several times with different types of brushes under running water. After this, the relic was put through the four-week desalination process to remove salt and any residual hydrochloric acid from the object's body. During the desalination period, the concentration of chlorine ion was checked (Thermo Scientific, Orion) every week and the latest chlorine concentration was 7.16ppm (similar to ordinary tap water). The relic was first dried with a cleaning cloth then put into a drying oven for three hours. After the drying process was complete, the surface of relic was cleaned with a solution of 50% w/v ethyl alcohol in water and the fragment was bonded together with Paraloid B72.



13. Before treatment



14. Removal of shell deposits with tools



15. Removal of shell deposits with hydrochloric acid solution



16. Desalination



17. Treatment complete 1



18. Treatment complete 2

(2) A stoneware from Mado shipwreck No. 3

This is one of the excavated objects from the Tae'an Mado shipwreck No. 3 in 2011. It did not have much shell deposit on the surface and was minimally cleaned with tools before going through the desalination process for four weeks.

Paraloid B72 was the main adhesive used to bond the fragments, however, the missing section was more than one third of the total body and the bonding edges were dislocated. It was decided to re-conservate the stoneware in order to maintain the structural stability of the object. Acetone was put into a small glass jar and sealed with the object for a day. The acetone evaporated and was absorbed by the adhesives in the object. This process was helped by dismantling of the object fragment, which meant that the adhesive had become soft and gently dismantled.

After dismantling, acetone was used to soften the residue left. Cotton swabs and a scalpel were also used. Paraloid B72 was used as the adhesive. The complete curing time of Paraloid B72 takes more than a day. Therefore, different sizes and shapes of clamps were used to hold the object in place.

The filling agent on the missing section was plaster. Para film® was used to cover the breakages and Dental wax™ to support the inside. It was made as a removable fill. If a large section was missing, this needs to be done several times to create the fill. After the plaster fill was completely cured, a wet sanding technique was used to smooth the surface of the fill. Finally, a solution of approximately 5% Paraloid B72 with acetone was applied to consolidate the surface of the fill and acrylic colour was used to complete the retouching.



19. Before treatment



20. Dismantling with acetone vapor



21. Removing previous residue



22. After dismantling



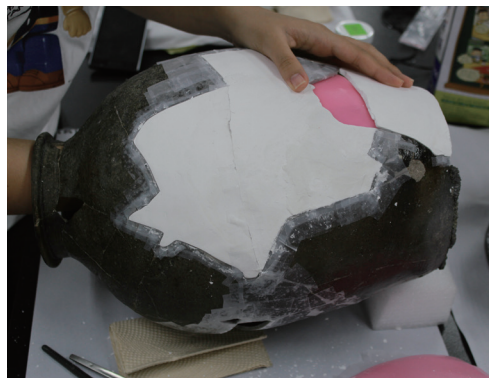
23. Bonding



24. Cover breakages with Para film®



25. Filling with plaster



26. Producing fill separately for large section



27. Wet sanding technique



28. Retouching



29. Completely retouched fragments



30. Complete treatment

(3) A celadon ewer from Tae'an Mado shipwreck No. 1

This object was excavated from the Mado shipwreck No. 1 in 2009. The inner section of spout was partly missing and broken. It was excavated in fairly good condition and the marine organisms had not affected it. Desalination took eight weeks. Toilon™ was temporarily used to support the inner section of spouse for exhibition. In 2012, it was decided to conserve the broken section that was bonded and the missing area was restored.

If the spout is bonded to the body first, it is difficult to access the inner area and to fill and retouch. Therefore, the first step was to fill the missing area and then bond it. The materials used for this were Epotek 301-2® (epoxy resin) with pigments (gold ochre, cadmium green, green earth light), talc (magnesium silicate hydroxide) and fumed silica (SiO₂).

A removable fill was made using Para film® (plastic paraffin film) to cover the break-edges and dental wax to support the inside. Epoxy resin, pigments and talc were mixed together and applied to the missing area. After three days, the surface was polished to a smooth and hexagonal shape. Epoxy resin and mineral pigments were used to create a visible look as similar as possible to the transplant glaze. The completed removable fill was attached to the object's body with Paraloid B72, which is removable. The relic has crackle glaze, so an attempt was made to match the crackle pattern on the fill section. Similar marksto the crackle glaze were made on the surface of the removable fill and mineral pigment (lamp black) put into the mark to make it look similar. Further research is needed to properly express the crackle pattern.





31. Before the treatment



32. After treatment



33. Restoration of missing section 1



34. Restoration of missing section 2



35. Restoration of missing section 3

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SECTION

06

Stone

Lim Seongtae

1. Introduction
2. Examination
3. Treatment

1. Introduction

Various stone objects, including anchor stones, were excavated from the seaside. Anchor stones were the most commonly excavated objects. This chapter describes the conservation process used to preserve anchor stones that have been excavated from the sea.

(1) Classification of the stone

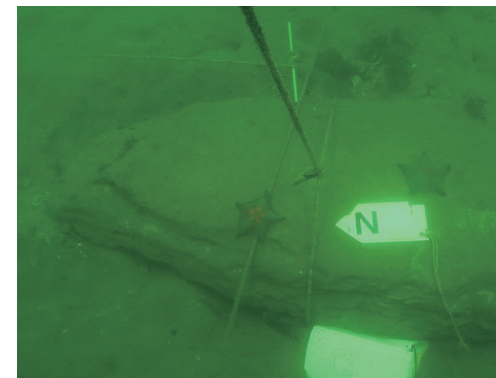
Stone can be broadly classified into igneous rock, sedimentary rock and metamorphic rock.

Igneous rock was created when cooling molten rock changed. It can be subdivided into eruptive rock, intrusive rock, abyssal rock and hypabyssal rock. Sedimentary rock is composed of rocks that have been weathered and eroded then transported and layered. There are various distinct types of rocks by sediment quality. Metamorphic rock was created from igneous rock and sedimentary rock; increased temperature and pressure had the effect of fusing them and changing their properties.

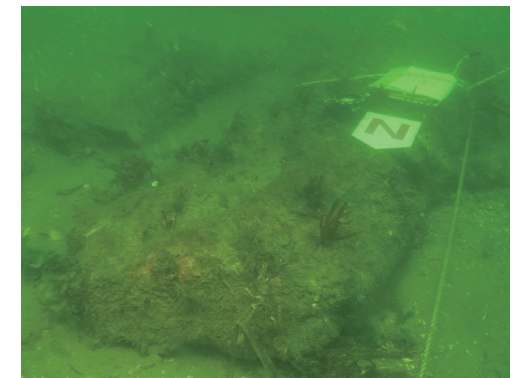
(2) Weathering causes of anchor stone

Weathering of rock is caused by water, air, plant and temperature, decomposing in tiny pieces that become part of the soil. It can be classified into mechanical weathering, chemical weathering and biological weathering.

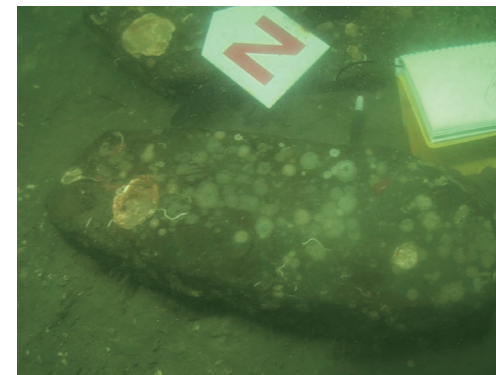
The weathering of excavated anchor stone from the sea was caused by salt, shell substances and marine plants on the surface of object. These substances promote physical and chemical degradation. Anchor stone is exposed directly to dissolved salts in the sea, and the salt crystallizes on the inside and on the surface of the object if the object is exposed to air. Crystallization of salt increases salt volume, meaning that the crystallized salt could cause exfoliation on the surface, unless the object was put through the appropriate desalination process.



1. Biofouling by marine animals



2. Biofouling by marine plants



3. Biofouling by shell substances



4. Biofouling by shell substances



5. Excavated anchor stones in Tae'an Mado island site

(3) Anchor stone from the sea

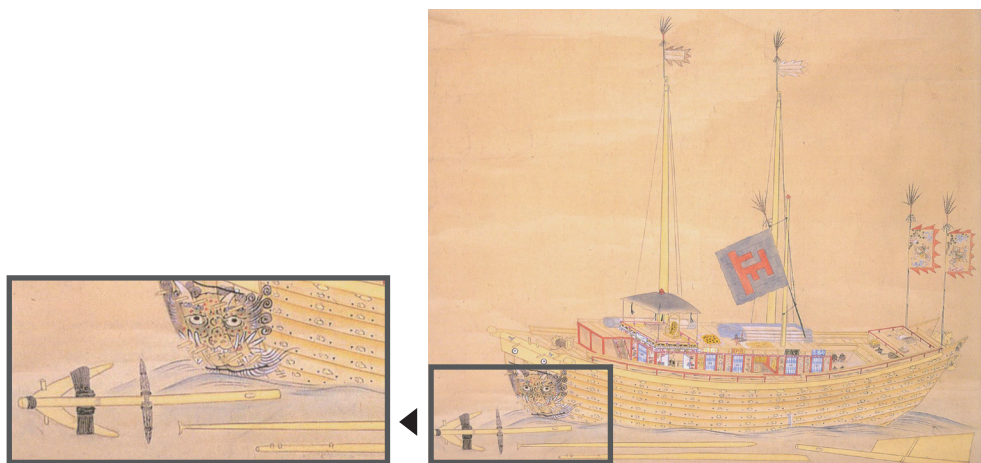
Various sizes of anchor stone have been excavated and the number of excavated objects was around 110 per year from 2004. An evacuation project was ordered to begin from the Sipidongpado shipwreck to Biando island, Taean Deseom island, Mado shipwreck No. 1, No. 2 and No. 3, Mado island site and lastly Oryu-ri in Jindo island.

The purpose of the anchor stone was to keep the ship from drifting away. In historical Chinese characters, 碇 (pronounced Jeong in Korean) is used to signify anchor. The character is composed of two different Chinese characters placed together: 石 (stone) + 定 (stable). This gives an idea of how anchor and anchor stone were connected historically:

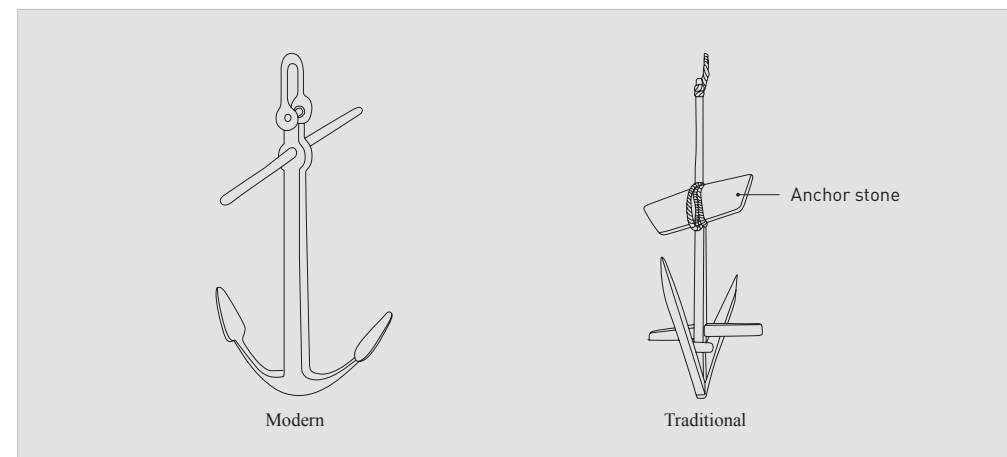
“Anchor was written in Chinese characters as ‘碇’ or ‘碇’’. In the past, the ship was held by the heavy stone at the end of the rope which was put into the water, thus this stone is called ‘Jeong (碇: Anchor)’, and the situation of the anchored ship called ‘Jeong-bak (碇泊: Anchorage).’¹⁾

“Anchor stone has got such a long history that natural stone was used at first, and then, artificially created to use, but it has not been standardized.”²⁾

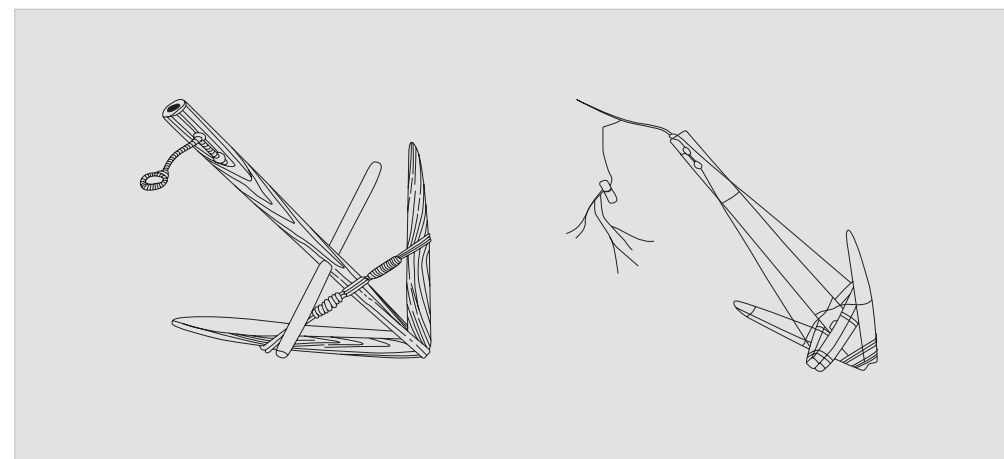
According to the above sources, stone was used as the anchor itself. Therefore, there was no different term for anchor stone and anchor. However, the development of anchors involved making changes to the shape to allow the anchor to be secured on the seabed speedily and safely. The development process caused anchor stone, now long and thin, to become a part of a larger anchor to give heaviness, and it was positioned at right angle to the anchor shank in the role of anchor stock (the anchor arm and anchor hand to be fixed on the seabed). This process started to divide the purpose of anchor and anchor stone. The anchor was thus made partly of wood and partly of stone; where the crossbar of the anchor was stone and the rest was made out of wood.



6. Anchor in the graphic depicting Chosun dynasty goodwill delegation



7. Comparison of modern and traditional anchors



8. Traditional anchor



9. Anchor stone

2. Examination

Diagnostic reporting and photography were used to analyze the material properties and weathered condition of anchor stone. In addition, a crane scale (Japanese, AMD, 1kg - 2.5tons) was used to check the weight. For geochemical and mineralogy analysis, fine fragments were put through a desalination process whereby each fragment was put into distilled water, and the water was changed every 24 hours, and three times in all.

A polarizing light microscope was used to give semi-quantitative mineral composition and altered minerals; X-ray diffraction (PANalytical, X'Pert pro MPO) was used to observed mineral composition; X-ray fluorescence (Rigaku company, RIX-2000) was done to observe the main component elements.

Through this primary research, the weight, composition mineral and material properties of anchor stone were established excavated object in Mado offshore in <Table 1>.

Table 1. Classification of the stone

No.	Samaple	Weight(kg)	Mineral composition	Material properties
1	10-30(Y)	444	Biotite, Quartz, Feldspar	Mica schist
2	10-22(S)	454	Biotite, Quartz, Feldspar	Leucocratic granite
3	09-2(B)	467	Quartz, Feldspar, Tuff fragment	Brecciated tuff
4	10-18(P)	482	Biotite, Quartz, Feldspar	Granite
5	10-21(R)	549	Quartz, Feldspar, Tuff fragment	Brecciated tuff
6	10-12(J)	694	Biotite, Quartz	Coarse grain granitic
7	09-15(O)	1,086	Biotite, Quartz, Feldspar	Mica schist



10. Gravimetric anchor stone with crane scale



11. Gravimetric anchor stone with crane scale



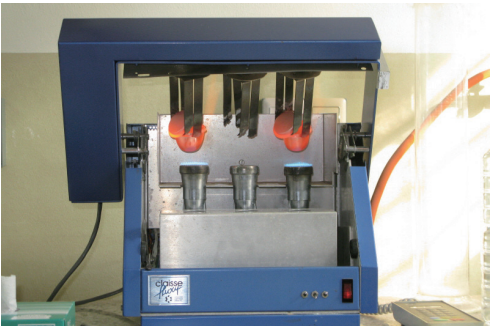
12. Measurement of whole-rock magnetic susceptibility rate



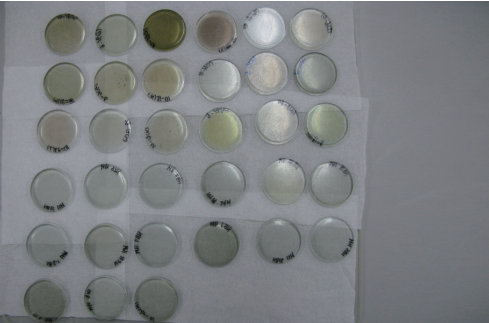
13. Investigating and recording condition of anchor stone



14. Sample preparation (powder)



15. Sample preparation



16. Sample preparation (bead)



17. XRF analysis

3. Treatment

Anchor stone is commonly excavated with marine organisms attached on the surface, including shell substrates and sea plants, as well as mud. When excavated anchor stone is transported to the conservation laboratory, it is better to keep it securely packed rather than leaving it in the open air without any protection. This might create negative effects (crystallized salt) on the damaged surface and between layers of rock where micro-organisms, mud and salt have been absorbed into the body.

(1) Cleaning and desalination

Because of its heavy weight and large size, each anchor stone was transported by crane to the laboratory, where the desalination process was started. In some cases, shell substrates, mud and sea plants could be removed naturally, but in other cases, tools (a brush and a chisel) were used to physically remove foreign deposits on the surface. After removing the foreign deposits, desalination was started.



18. In the middle of desalination



19. In the middle of desalination



20. Removing shell substances



21. Complete removal of shell substances

(2) Desalination and drying process

Anchor stone was used for anchoring, therefore it is heavy and large enough to hold the ship. Thus, the desalination process was arranged in the exclusive space used only for ancient ships. It needed to be placed in a safe position by crane, and took long time to desalinate. After desalination, it needed to be displayed in the open air for natural drying.

(3) Consolidation

Most of the excavated anchor stone was in good condition, but different types of rocks showed different conditions such as cracks or exfoliation on the surface. Treatment required an effective reinforcing agent for each different condition found amongst the objects.

110 pieces of objects are stored at the Taeon conservation centre and underwater excavation and conservation division, Mokpo. An experiment was conducted to determine proper treatment methodology and time. A procedure for removing foreign substrates and experiment of strengthening process were planned. Therefore, content of conservation treatment will be added in due course.

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SECTION

07

Preservation

Kim Seojin

1. Temperature and humidity
2. Air pollution
3. Biological risk factors
4. Integrated Pest Management (IPM)

It is important to maintain the correct environment in storage and exhibition spaces as the object could be negatively affected by improper indoor air quality, particularly those objects that have been exposed to sea salt. When objects evacuated from the sea are treated, the most important environmental factors to control are temperature, humidity, pollution and micro-organisms.

1. Temperature and humidity

Temperature and humidity are an essential and primary factor to consider for environmental control.

(1) Damage to object by temperature and humidity

Damage from temperature does not happen directly, but by accelerating degradation reactions, temperature can cause indirect effects at a microscopic level. Increasing the temperature causes may stimulate the type of reactions that degrade the strength of a material or that provide favourable conditions for mould growth. Moreover, increasing and decreasing the temperature of the substance could repeatedly contract and expand that substance, putting strain on the material, and weakening its physical properties. For example, if an anchor stone was displayed outdoor, it might be damaged by fluctuation of daily and nightly temperature¹⁾.

The type of damage caused by increased humidity is mostly oxidation of metallic objects (iron and bronze). The formation of the rust by oxidation rarely occurs under 40% humidity levels, but increasing humidity from there increases oxidation. Furthermore, polyethylene glycol (PEG), used to consolidate waterlogged wood, can leach out from a wooden object on display in a high humidity environment²⁾. High humidity can also react with aldehydes in the air to create organic acids. Formaldehyde (HCHO) in inappropriate exhibition materials can react with moisture in the air to create formic acid (HCOOH). Moreover, acetic aldehyde (CH₃CHO) also reacts with moisture in the air to create acetic acid (CH₃COOH). The organic acids created accelerate deterioration in both the metallic and organic objects. With other inorganics such as ceramic objects, increased humidity could cause the inner salts of the objects to crystallize and damage the glaze layer or surface³⁾.

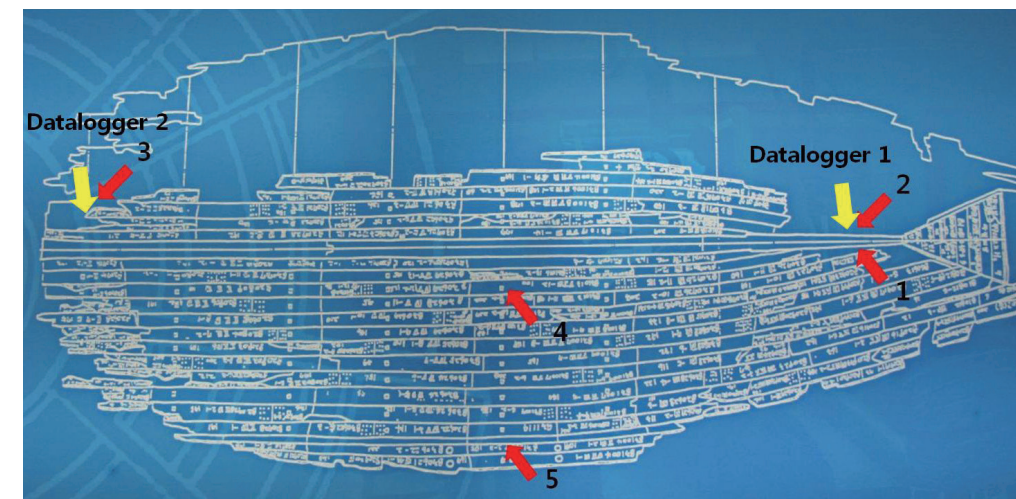
(2) Controlling temperature and humidity

To minimize the damage caused by temperature and humidity, the object needs to be monitored when it is stored. Temperature and humidity have to be regulated and monitored to maintain the optimum environment.

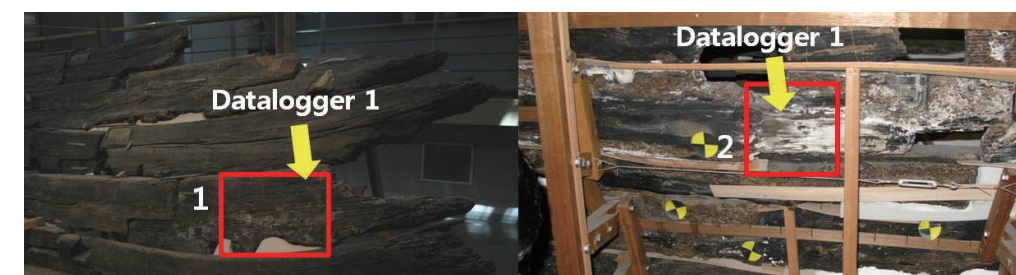
Temperature and humidity were monitored at the storage and exhibition spaces for the shipwreck salvage operations. At the National Research Institute of Maritime Cultural Heritage, objects from the Shinan and Wando shipwrecks were regularly monitored by temperature and relative humidity data logger, illuminometer and surface observations.



1, 2. Temperature and humidity monitoring (Testo 175H1, Humidity and Temperature data logger) in the storage



3. Location of data logger (Shinan shipwreck)



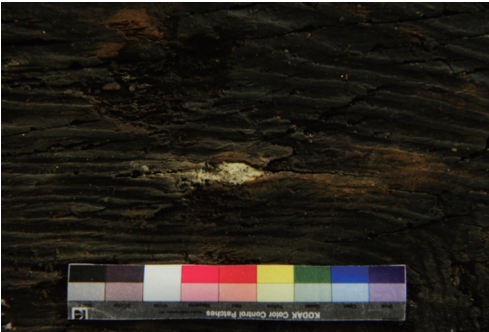
4. Location of data logger (Wando shipwreck)

Parameters for acceptable temperature and humidity are a bit different between different management agencies and for different types of objects, but they are generally at a similar level. Conditions for representative standard control were specified by The International Council of Museums (ICOM). ICOM suggests levels of temperature and humidity according to types of materials in the exhibition area. The NRMCH followed ICOM’s standard controls.

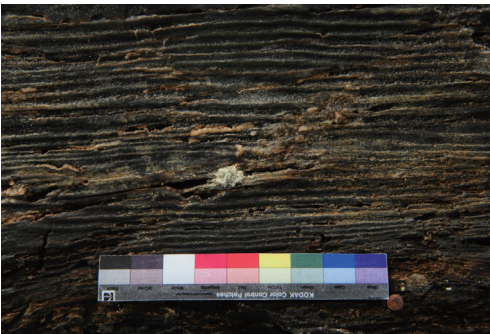
Condition monitoring (the surface of the Shinan shipwreck)



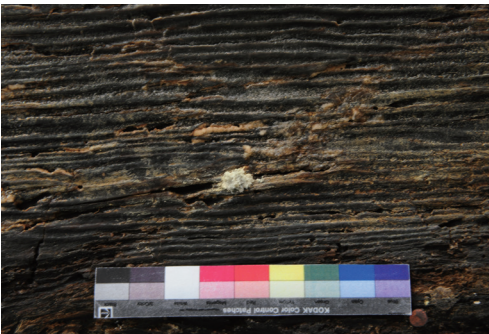
5. A point :June, 2013



6. A point :August, 2013



7. B point :June, 2013



8. B point :August, 2013

Table 1. Conditions of temperature and humidity level by objects (ICOM)

Type of objects	Temperature	Relative Humidity	Illuminance
Asian painting	20 ± 2℃	Below 45%	Below 50 lux
Textile	20 ± 2℃	55 - 65%	Below 50 lux
Painting	20 ± 2℃	50 - 55%	Below 150-180 lux
Leather	20 ± 2℃	50 - 65%	Below 150-180 lux (Dyed objects: below 50 lux)
Paper, wood	20 ± 2℃	55 - 65%	Below 150-180 lux (Paper: below 50 lux)
Metal, stone	20 ± 2℃	Below 45%	Below approximately 300 lux
Ceramics	20 ± 2℃	Below 45%	Below approximately 300 lux
Film	Black and white film : 15℃ Colourfilm : 2℃	30 - 45%	

2. Air pollution

Air pollution was one of the uncontrollable variables of the exhibition environment. The exhibition area of the NRMCH was controlled by the Environment Ministry under the ‘Indoor Air Quality Management Law’. This standard is for the public, not for objects. Substantial standards criteria needed to be established for the different conditions of objects in the museum, through the research exposure assessment. Our department used ‘Indoor Air Quality Management Law’ to rate indoor air quality two times a year. The indoor air quality list identifies levels of fine dust, carbon dioxide, formaldehyde, carbon monoxide, nitrogen dioxide, radon, total volatile organic compounds, asbestos and nine items of ozone.

(1) Damage caused to objects by air pollution

The most common causing factor of damage to objects was gaseous sulphuric acids (SO₂), nitrogen oxide (NO_x), formaldehyde (HCHO), total hydrocarbon (total HC), ozone (O₃), ammonia (NH₄), dust and total volatile organic compounds (VOCs). In the past, damage to objects from SO_x and NO_x was often reported in industrialized areas. However, at this point in time, the risk of damaging objects has been dramatically decreased by the regulation of vehicle exhaust emissions, dust and factory emissions. On the contrary, indoor air pollutants such as formaldehyde and total VOCs have become potential risk factors instead. Energy efficiency considerations were the sealed interior space of the museum and installed showcase of the object. It was rather create concentration of pollutant.

In the exhibition environment, formaldehyde, a reducing agent, can easily combine with various substances to create polymers. In particular, it can react with moisture in the air and become formic acid, which negatively affects exhibited objects. Examples of VOCs are benzene, toluene, ethylbenzene and xylene. These can be caused through a secondary reaction and further degradation.

(2) Indoor air pollutants

The typical pollutants found in the exhibition area were formaldehyde and VOCs. Formaldehyde was found in the paint on the building and it appeared in high concentrations in the new building. Many parts of the showcase in the exhibition area were made with medium density fibreboard (MDF), in which formaldehyde is used as an adhesive. A coating agent was used to varnish the plywood (which was also used to build the showcase) and the VOCs were mainly generated by this varnish.

(3) Proper control of air pollutants

It is necessary to block pollution from the outside and release inner pollution to the outside in order to control indoor air quality. Therefore, a ventilation system needs to be installed with a filter section, or an air curtain installed at the entrance to block outside pollution, and forced ventilation to emit indoor pollution regularly.

Pollution sources were removed completely or emissions reduced to solve the fundamental problem of the indoor environment in exhibition area. The interior materials used in the exhibition area needed to be of a low concentration level of pollution emission. The showcase is also built with materials that meet the emission standards for pollution. The special exhibitions case in the museum sometimes smelled sour and made the eyes smart. These symptoms were caused by accumulation of indoor pollutant concentration in the organic compounds to levels that the human body could detect. The museum needs to reduce pollutants before the exhibition by ventilating air and ‘bake-out’ method.

3. Biological risk factors

Living things like mould, fungus and insect can have negative effects on objects and create bio-deterioration. Mould and fungus start to grow when the level of relative humidity reaches 70%. It is also well known that mould and fungus generate organic acid and organic acid can directly affect (cause the deterioration of) the material of objects such as documents, fabric and waterlogged wood.

To prevent bio-deterioration, the temperature and humidity of the storage space were maintained under the role of material control standard in cultural assets. Regular monitoring was carried out and the condition of the organic cultural heritage such as documents, fabrics and waterlogged wood was regularly checked. If any spots and stains on the surface of the object appeared it was essential to take immediate action. In the exhibition storage space, it was also necessary to install a trap to collect insects and, following the results of the investigation, to take the right preventive care precautions⁴⁾.

4. Integrated Pest Management (IPM)

Organism control is one of the key elements of a proper exhibition and preservation environment. Indoor organism control should follow the Integrated Pest Management (IPM) system. IPM is a total control program that was developed by the Canadian Conservation Institute (CCI) and which has five different stages (avoid, block, detect, respond, recovery) to prevent harmful organisms. It has been used widely in the museum. The details of each stage are as follows⁵⁾:

(1) Avoid

Cleaning is the most effective way to prevent fungus or vermin damaging an object. Equally important is to avoid creating a habitat for harmful organisms, and to isolate food and waste. It is therefore better to place cafés and cafeterias outside. Ultraviolet-proof fluorescent light was used because ultraviolet radiation can attract vermin. When cleaning the floor of the storage space, a vacuum cleaner with an HEPA (High Efficiency Particular Air) filter should be used. The surfaces of the museum collection were regularly cleaned as they could easily collect dust, oils from hand and filth, which are the nutrients for pests. Moreover, insect corpses are a major attraction for pests, which take nutrients from the insect corpse. Cleaning is essential, as is collecting insect corpses to check why they have appeared and where they came from.

(2) Block

The intrusion pathway of pests was blocked. The entrance, storage door way and storage door needed to be sealed. Most gaps under 6mm (to prevent rodents) and 0.3mm (to prevent pests) had to be blocked. Insect netting (40-60 mesh) was also installed in the window. With stored documents and exhibit collections it is better to use a metal-framed cabinet and showcase. When wooden equipment was used, it had to be fumigated. Infected materials had to be isolated and fragile materials had to be kept safe in a sealed pack. High resistance materials for this use are polypropylene and polyester.

(3) Detect

Early discovery of problems is best, preferably before any damage has appeared. Thus, it is necessary to use traps, instead of depending on visual identification alone. Detailed records of detection of harmful organisms can also provide useful system-level information (to help avoid, block and respond). To use a concrete example, a space was isolated for items delivered from the outside. This led to accurate observations about which fungus and vermin were being brought in with delivered items. Moreover, regular patrols, inspections and visual checks were carried out to gauge the extent of harmful organisms. This was done to check whether pests inhabit the area through trace of the pest droppings, insect moult and loss to objects.

When installing pest traps, they need to be placed every five to ten metres in the corner where walls and floor meet. They need to be installed in latent places like corners, near the door, exhaust pipe areas and heaters (stoves). Moreover, it is best to place traps in dark and hidden areas, windowsills, cabinets and showcases where fragile materials were stored.

(4) Respond

Prevention and control techniques such as fumigation, air control (hypoxic density or carbon dioxide methods) and temperature control (high and low temperature treatment method) need to be carried out to remove harmful organisms from collections and buildings. When damage from pests occurs, access space and also equipment space needs to be reserved to control the pests easily and safely. Safe insecticide should be kept ready to prevent pests.

When pests appear, the space is isolated and damaged material sealed into the pack. Pests can be captured by visual observation, pheromone trap and sticky trap, and then the ecology, infestation range and movement of the captured pest examined; while also checking any materials that were moved. After that, the infected place had to be cleaned and insecticide and rodenticide used to prevent further problems.

If there is any material suspected of housing pests, those materials need to be treated with insecticides via the fumigation method, hypoxic density method, carbon dioxide method or high and low temperature treatment method. If fungus is found in the collection, check and manage temperature and relative humidity. The collection needs to be isolated and fumigated. Another management method is to re-examine the pest control system.

(5) Recovery

Any infected objects and spaces that have been through the ‘respond’ stage have to be recovered in a safe space.

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