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THE IMPACT OF ENVIRONMENT ON CULTURAL RELICS

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ABSTRACT

The environment in which cultural relics are preserved is an important factor that determines whether it has deteriorated, what kind of deterioration has occurred, and to what extent. By studying the causes and mechanisms of environmental changes in the natural environment within China, it is possible to infer the state of undiscovered heritage and formulate subsequent conservation and excavation plans, and this experience can also be used in the world's cultural relic conservation. By studying the impact of the artificial environment on cultural relics, an environmental control method can be explored in line with its protection. Starting from several common environmental factors, this paper studies the causes and mechanisms of environmental change and explores the relationship between such changes and relic status. It focuses on the impact of abrupt factors such as earthquakes, volcanoes, floods, and wars and the impact of gradual factors such as temperature, humidity, and pH on cultural heritage. Divide the abrupt environmental factors into natural factors and human activities; the gradual factors into primary natural factors, combined natural factors, and long-term human activities, and analyses the deterioration mechanism of cultural heritage under the influence of these factors and its relationship with the environment. It provides some help for the analysis, protection, and optimization of cultural relics conservation and methods from the perspective of the environment that has not yet been excavated. In addition, the analysis of the status of existing relics can also deduce changes in the historical environment, which is also helpful for the study of history.

KEYWORDS: Environment, Cultural Heritage Conservation, Abrupt Environmental Factors, Gradual Environmental Factors

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1. INTRODUCTION

Whether cultural relics are affected by the environment depends on the environment in which they are stored. For example, they can be preserved for a long time in a suitable environment. Some scholars (Wang et al., 2020) divided the environment of cultural relics into the natural environment, semi-exposed environment, and artificially created environment. Natural environment refers to cultural relics that are difficult to protect by manual intervention or can only be monitored, such as unexcavated cultural relics, buried cultural relics, immovable cultural relics, and under-water cultural relics; Semi-exposed environment refers to relics that have been excavated and protected to a certain extent, such as caves, murals, and sites protected in museum exhibition halls; the artificially created environment is completely controlled by humans, such as cultural relics in the museum and in laboratories. According to the different types of relics, different environments around them have different mechanisms of action on them. In addition, any environment is constantly changing, and different patterns of change in which cultural relics are stored can cause varying degrees of damage. Based on the existing research on the deterioration mechanism of cultural relics, this thesis classifies the deterioration process mainly into abrupt and gradual changes, and illustrates the specific mechanism with examples, and summarizes the deterioration of cultural relics by various environmental factors, and finally draws the relationship between the degree of deterioration and time of cultural relics to provide a certain degree of reference for the study of deterioration of cultural relics.

1.1. Current Status of Cultural Relics Conservation

The protection policies of cultural relics vary slightly from country to country, but the right to implement their protection belongs to the state. Therefore, the protection of movable cultural relics follows three basic forms: burial monitoring, excavation protection, and museum collection. Buried monitoring refers to the periodic monitoring of the surrounding environment of cultural relics that have not yet been excavated but have been detected, and their preservation status of them is inferred from environmental data gained from monitoring for later excavation; Excavation protection refers to the protective excavation of cultural relics that have been partially damaged or are not suitable for further conservation in the natural environment so that they can be later studied in laboratories or included in museums; Museum collection is to incorporate cultural relics that have excavated and relics purchased or collected from other channels into the collection for unified protection and monitoring. For immovable cultural relics, European countries represented by France, Italy, and other countries generally regard them as part of their cities to recognize the regeneration of social value; China, on the other hand, adopts a conservation model centred on "restrictive protection", which means establishing heritage parks, museums, and tourist at-tractions to achieve the protection of immovable cultural relics (Wang et al., 2020; Fan et al., 2008). Mean-while, the strategy of regular inspection and long-term maintenance of such im-movable cultural relics is adopted to achieve the purpose of protection.

1.2 An Overview of Environment Research

The environment in which cultural relics are stored is an important factor in their survival. Most of the existing research is carried out from the aspects of environmental change, microenvironment change, and the interaction between environment and cultural relics materials. However, the environment can be divided into human and non-human activity affect environments according to different changes. The former is the environment in which cultural relics are affected by human activities, such as any artificially protected environment and an environment that is undiscovered and buried underground but surrounded by humans or affected by human behaviours; The latter are environments in which no human activity is involved.

2. MATERIALS OF TYPES OF CHANGES IN THE ENVIRONMENT. DEFINITIONS, MECHANISMS, AND RESULTS BASED ON MATERIALS

The environment is constantly changing. Even when monitored, cultural relics are subject to various environmental factors. For example, sites exposed to the natural environment are affected by macroscopic factors such as temperature, humidity, and precipitation; Artifacts buried in soil or underwater are affected by microscopic factors such as pH, metal ion concentration, and microbial activity. Both macro and microenvironments change over time. This change is divided into abrupt and gradual so that the changing environmental factors can be divided into abrupt and gradual environmental factors (AEFs and GEFs).

Meanwhile, depending on the composition of relics materials, the influence of the environment on them is also different. Cultural relics can be divided into two categories: organic and inorganic cultural relics. Organic cultural relics, such as paper, wood artifacts, textiles, etc., are generally composed of natural polymer materials such as cellulose, hemicellulose, lignin, and protein. Biochemical action predominates in their deterioration process; Inorganic cultural relics, such as metals, stone artifacts, ceramic handicrafts, etc., are composed of inorganic sub-stances and are mainly affected by physical and chemical effects.

2.1. Abrupt Environmental Factors

Abrupt environmental factors refer to drastic environmental changes that occur in a short period of time or instantaneously. Such changes can cause irreversible damage to the original environment of cultural relics. According to the different reasons for change can be divided into natural environmental factors and human activity factors.

2.1.1. Natural environmental factors

Natural disasters such as volcanic eruptions, earthquakes, mudslides, floods, fires, and other abrupt and destructive events can directly cause physical damage to cultural relics. In China, for example, the spatial distribution of population, social activities, and cultural creation varies significantly, with a basic "east is dense and west is sparse" pattern (Atlas of Major Natural Disasters and Society in China, 2004). At the same time, most of China's major natural disasters have occurred in the east. As a result, historical natural disasters and current potential natural disaster threats have a greater impact on the preservation of China. Earthquakes, floods, and storms are the three main abrupt changes (Table 1) (Atlas of Major Natural Disasters and Society in China, 2004).

Table 1. Spatial distribution of major disasters in China (Atlas of Major Natural Disasters and Society in China, 2004)

Major disaster types	Predominant geospatial distribution
Earthquake	The Pacific Rim of the Volcanic Seismic Zone in China
Flood	The middle and lower reaches of China's major rivers, the low-lying areas along the southeast coast and east, and the historical floodwaters of the Yellow River
Storms	South of the Yangtze River, southeast coastal area
Land subsidence	Eastern part of China, especially in coastal cities and the North China Plain

The mode of action of AEFs on cultural relics can be subdivided according to the different attributes of them. That is, cultural relics are divided into museum cultural relics, movable cultural relics, buried cultural relics, and immovable cultural relics. Even if cultural relics are under protection, they can be damaged in the face of strong geological movements such as earthquakes. For example, the 8.0 magnitude earthquake in Wenchuan, China, caused damage to cultural relics in many museums in Sichuan. At the same time, Cultural heritage sites such as Dujiangyan have also been damaged to varying degrees. The damage caused to cultural relics by sudden environmental changes can be briefly summarized in the following Table 2:

Table 2. Main types of disasters and cases ©

Major disaster types	Influencing factors	Consequences
Earthquake	Shake, collapse, bury, etc.	Collapse, local damage, settlement, dislocation, cracks, etc.
Flood	Flood impact, soaking, silt burial, etc.	Collapse caused by flood impact, decay and mold caused by water
Storms/Heavy Rains	Heavy precipitation, air humidity surge/weathering, sand friction, etc.	Corrosion caused by precipitation; mildew/weathering erosion caused by sudden changes in humidity
Volcano	Vibration, ash, magma, etc.	Collapse, buried, burned, etc.

2.1.2. Human activities

Due to war, political struggle, religion and other human activities, relics belonging to different human camps are also subject to destruction. For example, *Historical Records · Biography of Emperor Qin* mentioned that "burn all the history of non-Qin records." That is, during the reign of Qin Shi Huang (around 213 BC), strategies such as burning and destroying Confucian classics and preventing any form of study of them were adopted. This apparently burned ritual-related artifacts. Another example is the massive destruction of relics in Constantinople during the Crusades. "All metal objects were melted down into blocks for distribution, while all artifacts made of stone, wood, and bone were exterminated." The military activities during the recent Gulf War period caused severe destruction of relics in Iraq, such as the ruins of the Temple of Ur and the ruins of Nimrud, which were severely damaged and difficult to repair.

However, the impact of such human activities is mainly direct and indirect. The direct impact of human activities on cultural heritage causes physical damage. Such as military bombardment, improper transportation, etc., while the indirect impact is more extensive, including the theft of cultural relics, burning, trading, illegal transport, and other abnormal behaviour that can lead to varying degrees of damage to cultural relics.

2.2. *Gradual Environmental Factors*

In contrast to AEFs, GEFs are those that change gradually over a considerable time. Existing research has generally focused on the prevention and management of damage to cultural relics caused by GEFs. Depending on the mechanism and mode of action, GEFs can be divided into primary natural factors, combined natural factors, and long-term human activities. The following is an overview of the common types of these three factors and a detailed analysis of the mechanism of action of GEFs on different materials in different environments.

2.2.1. Primary Natural Factors

The primary natural factors refer to the main environmental factors affecting the cultural relics in the natural environment; compared to the main factors, other environmental factors have less impact on the cultural relics. Take metal artifacts as an example, which are mainly made of iron, carbon-iron alloy, bronze, gold, and silver, etc., separately or mixed casting, so their deterioration is mainly affected by electrochemical corrosion. Since the iron and carbon iron alloy are exposed to the natural environment, the water vapor in the air will be attached to the surface of them to form an electrolyte solution, and iron will rust because of redox reaction with a small amount of carbon; for bronze artifacts, because bronze is an alloy of copper, lead, tin, etc., will produce different electrode potential, so bronze will also appear the phenomenon of electrochemical corrosion (Song et al., 1992).

2.2.2. Combined Natural Factors

In general, the deterioration of cultural relics is the result of a combination of environmental factors. Wooden artifacts, for example, are more sensitive to humidity. High humidity will cause its fibres to absorb water and swell, resulting in material deformation so that the internal structure is damaged. At the same time, high humidity will also accelerate the growth of moths and microorganisms. Organic acids and enzymes secreted by organisms in the process of their metabolism will dissolve the cellulose, hemicellulose, and other organic materials in the wooden artifacts, resulting in damage to their materials and leading to changes in their chemical properties, thus reducing the strength of the structure (Ma et al., 2012; Zhang, 2014). For example, the suitable moisture in wood is good for the growth of moths and decay bacteria, resulting in damage to the interior and surface of the wood.

In the buried environment, if the soil is wet and acidic, it will accelerate the hydrolysis of cellulose. Organic matter artifacts in atmospheric environments are susceptible to surface degradation by oxygen, ozone, oxides of carbon and nitrogen, and light. For example, the wood undergoes free radical photodegradation in the presence of ultraviolet radiation, leading to changes in its structural properties and strength (Li et al., 1989)

2.2.3. Long-term Human Activities

It is mentioned that the abrupt change of human factors will mainly cause irreversible physical damage to cultural relics, while in the gradual aspect, there are positive and negative effects of human factors on cultural relics, which are affected by natural disasters and the scope or frequentness of human activities. For example, cultural relics that are completely exposed to the natural environment but within the scope of human activities can be restored to their original state through human repair after being affected by an abrupt natural disaster; or cultural relics protected in museums, where the environment in which they are stored is completely under human control, and the change of their state depends exclusively on humans. It is important to note that whether it is artificial repair or control of the environment after an abrupt change, the impact on the relics is long-term and slow, and the heritage will eventually deteriorate completely.

The most important of the human factors discussed is the negative impact of the measures taken in the process of conserving the artifacts. It can be divided into improper preservation, improper restoration, improper transportation, and improper monitoring. In this paper, we discuss three types of human factors in the section of conservation, transportation, and monitoring, which are not related to the in-depth study of the materials of the artifacts themselves and are easier to ignore.

Improper conservation mainly refers to the means of preservation or preservation environment that can cause secondary harm to cultural relics or formalistic preservation. The first two (preservation or preservation environment) are more common, while the third case is mostly found in lesser-known and remote sites. This is shown in Fig. 1. The artifacts in Figure 1 are both a stone turtle from the site of Bas-reliefs on Precipices in Bazhong, China (hereafter referred to as Bas-reliefs) that was built during the Sui Dynasty and grew to its largest size during the Tang Dynasty (AD 518-AD 907).

Figure 1. Stone turtle in glass (Nankan Bas-reliefs, Bazhong, Sichuan, China) ©

It is obvious from Figure 1 that although the stone turtle was protected in the glass container, the staff did not remove the surrounding plants. Under the effect of the temperature differences between day and night and the transpiration of plants at night, water drops adhered to the inner wall of the container as well as the top. When the water drops gathered to a certain amount, they would drip down to the surface of the turtle. At high ambient temperatures, this process can occur repeatedly throughout the day, causing some damage to the surface of such stone artifacts. At the same time, the perimeter of the turtle is artificially built with modern tourist trails and does not leave any spare space at the original site. as shown in Fig. 2. Therefore, Consideration should be taken before the construction to avoid possible impact factors and to meet future protection methods.

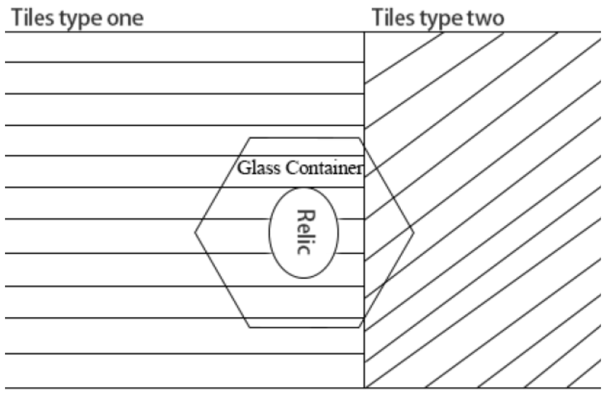

Figure 2. Top view of construction traces around the cultural relics ©

Improper transportation refers to the damage caused by irregular and unscientific transportation of cultural relics (see Fig. 3). We can see the traces caused by the wires and iron bars when it is transported.

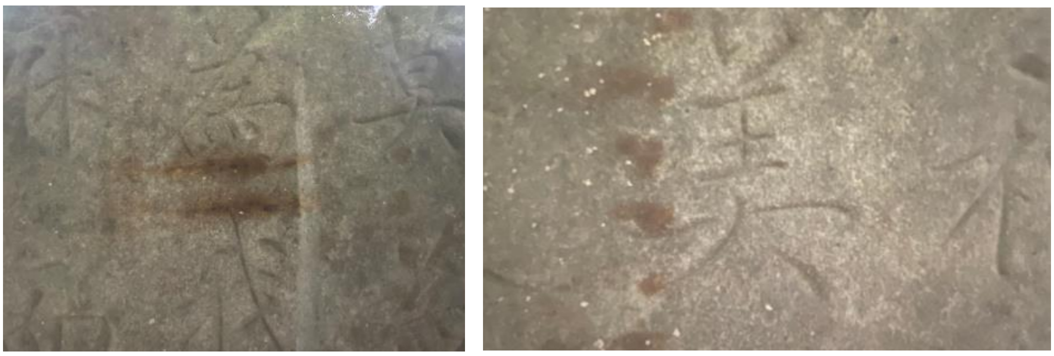

Figure 3. A monument reinforced with iron bars and wire for transportation (Nankan Bas-reliefs, Bazhong, Sichuan, China) ©

Improper monitoring refers to damage to cultural relics caused by inadequate monitoring of them. Usually divided into untimely responses and negligent behavior. The former often occurs in a certain monitoring system that has been established in cultural relics. The relevant personnel responsible for the cultural relics did not regularly pay attention to the monitoring data; the latter mainly occurs in large sites, and some of the areas are forgotten. For example, Fig. 4 shows a stone statue of Bas-reliefs, whose head is missing, the face of the side statue is blurred, and there are a lot of dead lichens and moss-like plant remains attached on their surface. Also, unlike other cave statues at the site, the statues here are not numbered.

Figure 4. Cave statues without numbered management and negligent monitoring (Nankan Bas-reliefs, Bazhong, Sichuan, China) ©

2.3. *Influence of the Environment on the Artifacts*

2.3.1. Water environment

The water environment is also a part of cultural relics protection cannot be ignored. Due to geological changes, natural disasters, human activities, and other influences, some of the cultural relics and sites are submerged in water. According to the UNESCO, underwater cultural heritage sites can be affected by natural factors such as climate change, stronger erosion and changes in ocean currents. Meanwhile, regulated seabed development (mineral extraction, pipeline, etc.) can also pose a threat to underwater cultural heritage sites to varying degrees. Moreover, human activities such as trawling and fishing can also have a direct or indirect impact on it. However, the water environment consists of suspended matter, dissolved substances, substrate, and aquatic organisms. Therefore, when examining the factors affecting the deterioration of cultural relics in the water environment, it is necessary to take the water environment in which the cultural relics are located into consideration.

The inland water environment system mainly consists of rivers, lakes, and groundwater. The salinity of river is generally 100-200mg/L, not more than 500mg/L, dissolved oxygen is saturated, $Ca^{+} > Na^{+}$, $HCO_3 > SO_4^{2-} > Cl^{-}$. The flow of the lake is slow, but the evaporation area is large, which contains more salt than the river The N and P elements are easily enriched in the lake, making it eutrophic and leading to the reduction of dissolved oxygen. And groundwater has more minerals dissolved in the process of infiltration, some organic matter in the process of decomposition by bacteria will produce such as CO_2, H_2S, etc. to make the water reductive, and have a certain corrosive effect on Fe, Mn, and other metals, and the lesser content of dissolved oxygen. In water that is not polluted, the acid-base balance in the water is still remains.

$$CO_2 + H_2O \leftrightharpoons H_2CO_3^- \quad (1)$$
$$H_2CO_3^- \leftrightharpoons HCO_3^- + H^+ \quad (2)$$
$$HCO_3^- \leftrightharpoons CO_3^{2-} + H^+ \quad (3)$$

This reaction will keep the pH in natural water stable, generally 6 to 9, because of the self-buffering capacity. In the natural and lake environment, the artifacts hardly suffer from acid corrosion, the main factors affecting them are different ions, biological actions, and water flow. For example, artifacts in the river will be affected by the impact of gravel, and some metal artifacts can be easily combined with dissolved oxygen, then corrosion happens. In the ground-water environment, due to the low dissolved oxygen and high salt content of the water, and the reducibility because of the former reason, the corrosion of metal cultural relics is more serious than the above two environments. At the same time, stone cultural relics and ceramic cultural relics in the groundwater environment will be damaged during the salvage due to the intrusion of salt solution.

For polluted water, the source of pollution and changes in its chemical and physical properties determine the impact of submerged artifacts. For example, acid and alkali pollution will affect the pH of the water, inhibit the self-purification process, accelerate the corrosion of metal and stone artifacts and the synergistic effect of dissolved salts and artifacts, etc.

2.3.1.1. Marine Environment

For the marine environment, the mechanism of deterioration of artifacts is more complex compared to the inland water environment. Once the artifacts are sunk into the sea floor, that is, the physical, chemical and biological effects will act on the artifacts (Jin, 2017). For example, remains of sea creatures such as barnacles and tubeworms are often visible on the surface of excavated ceramics. Stone artifacts are also clearly subject to the destructive effects of marine organisms which mostly cover their surfaces with sediments or hard crusts. Moreover, mussels, sea shoots, clams and sea urchins can penetrate all types of stone. Anaerobic bacteria (such as sulfate-reducing bacteria) can cause corrosion of iron artifacts and accelerate their corrosion process, which can trigger local corrosion or perforation corrosion, resulting in the mutilation and damage of underwater artifacts (Ward et al., 1999).

Artifacts in seawater are commonly in a salt-enriched state, in which salt crystallization and dissolution can occur, resulting in damage to the artifacts from the stress processes of salt crystallization and dissolution. The degree of impact of these ions in seawater on the artifacts depends on the different materials. For stone artifacts, the rate of chemical dissolution in seawater is 3-4 times faster than in freshwater (Jin, 2017).

The marine environment causes the most serious impact on metal-based artifacts. Due to the inhomogeneity of the physical and chemical properties of the metal surface, resulting in the inhomogeneity of the electrode potential at the metal seawater interface, forming a microscopic corrosion battery. And the electrical conductivity of seawater and chloride ion concentration are higher, will promote the corrosion of metal substances, the higher the salinity, the faster the corrosion rate. Take iron as an example, the one of the corrosion principles is shown in as follows:

ANODIC REACTION: $Fe \rightarrow Fe^{2+} + 2e$ (4)

CATHODIC REACTION: $\frac{1}{2}O_2 + H_2O + 2e \rightarrow 2OH^-$ (5)

In this process, a micro battery is formed on the surface of the iron. An oxidation reaction occurs at the anode (iron), causing its dissolution and a reduction reaction at the cathode (impurities). The formation of corrosion cells is mainly due to the adsorption of moisture from the air on the surface of the metal, forming an electrolyte solution. The anode of the corrosion cell thus formed is iron, while the cathode is a variety of impurities in the electrolyte solution. Meanwhile, the corrosion will continuously go on because of impurities that are on the surface of the iron. This process has been identified as an important intermediate reaction in the corrosion of iron marine ecosystems (Bethencourt et al., 2018).

For wooden artifacts, seawater immersion will lead to degradation and loss of its wood components, especially the hydrolysis of cellulose and hemi-cellulose, which will lead to the weakening of the wood structure and the reduction of its strength (Wang, 2019). For example, in the open seawater sediment erosion, or scour, in conjunction with wood boring organisms (shipworms and gribble), can lead to the relatively rapid deterioration of wooden materials of a wreck (Gregory et al., 2012). Moreover, the decomposition of α-cellulose and hemicellulose, the chemical components of wood components, is faster in the marine environment, and they are also affected by acids or microorganisms, resulting in the destruction of the wood structure and the reduction of its strength. (Royer et al., 2021; Zhang et al., 2007).

At the same time, the physical effects of the marine environment such as currents, tides, waves, and other effects can cause physical damage to cultural relics. Stone artifacts and porcelain subjected to water currents and sediment will lead to abrasion, cracking, and loss of surface texture and glaze, and the corrosion of the metal will be accelerated due to dissolved oxygen brought by water currents (Wang, 2019).

The types of different types of cultural relics affected in the water environment are roughly shown in Table 3:

Table 3. Corrosion difficulty of different cultural relics under the environment of water bodies

Type of artifact	Environmental factors of water bodies			
	Acidity and alkalinity	Soluble salts	Biological effects	Water movement
Metal artifacts	Easy to be corroded	Easy to be corroded	Easy to be corroded	Not easy to be corroded
Wooden artifacts	Very easy to be corrode	Easy to be corroded	Easy to be corroded	Easy to be corroded
Stone artifacts	Easy to be corroded	Easy to corrode	Easy to be corroded	Easy to be corroded
Leather, paper artifacts	Easy to be corroded	Very easy to be corroded	Easy to be corroded	Easy to be corroded

2.3.2. Soil Environment

The main factors that influence the soil environment on cultural relics are water content, pH, microorganisms, and soluble salts.

Soil moisture content varies according to different geographical locations, climates, etc. In general, the soil moisture content is directly proportional to soil depth. But the soil moisture content and the corrosion rate of metal relics do not have a positive relationship. Such as iron and bronze in a water content of 10% to 20%, and their surface will form a continuous non-uniform liquid phase film. By oxygen and water combined with charged ions in the soil into an oxygen concentration cell, electrochemical reactions occur to accelerate the corrosion on cultural relics. And in the water content of less than 10% of the soil, the surface of metal artifacts becomes passivation, which slow down the process of corrosion. Similarly, in the water content higher than 20% of the soil, the oxygen content is reduced, oxygen depolarization is difficult to occur, so the corrosion of metal relics in this environment is also slow.

Soil pH changes mainly due to H^+ generated by oxidation and OH^- generated by hydrolysis of salts, as well as the metabolic products of microorganisms and the effect of precipitation. The pH of the soil also affects the chemical processes. For example, when the pH value is greater than 7, the OH^- in the soil make metals form passivation layer, slowing down the occurrence of corrosion. When the pH value is greater than 8.5, there will be a large number of Na^+ in the soil, they will be in the form of soluble salts to make the artifacts become powdered.

The pH also affects the electrochemical reactions that occur in the soil environment. In cast iron, for example, an increase in pH will lead to an increase in its self-corrosion point and a decrease in self-corrosion current density, thus reducing the corrosion rate. In acidic conditions, the pH is less than 7, when the presence of H^+ in the soil will accelerate the cathodic hydrogen depolarization process in the corrosion reaction, thus accelerating the corrosion of cast iron. Under alkaline conditions, the soil pH value is greater than 7, the OH^- in the soil will make the cast iron surface cover by $Fe(OH)_2$ and other hydroxides, so that preventing corrosion further occurrence.

In addition, alkaline environment breaks the hydrogen bonds in the wood structure, and cellulose also reacts with alkali by saponification, breaking the lipid bonds that connect cellulose and lignin, which reduces wood strength. The higher the concentration of alkali the greater the effect on cellulose. And in an acidic environment, cellulose is degraded, leading to a decrease in its polymerization, as shown by the following reactions:

$$(C_6H_{10}O_5)_n + nH_2O \xrightarrow{H^+} nC_6H_{10}O_5 \tag{6}$$

However, the increase ratio in the rate of cellulose degradation decreases when the concentration of acid reaches a certain level. Therefore, the corrosion rate of wood artifacts will be accelerated with the decrease of soil pH, but the growth of corrosion rate will be slowed down.

For stone artifacts, one of the reasons for the impact of the soil environment is the corrosion of its material by the acidic substances in the soil and the structural corrosion that occurs when soluble salts penetrate deep into its interior. The combined effect of both factors leads to corrosion of the stone surface and stress damage to the interior, causing deterioration of stone artifacts.

The deterioration of leather and textile artifacts in the soil environment is also similar to the deterioration of wooden artifacts due to the degradation of their components accelerated by the acidic substances in the soil.

There are also many soluble salts in the soil, which will produce anions and cations to participate in the chemical process of the soil after being dissolved by water. For metal relics, common ones such as Cl^-, HCO_3^-, SO_4^{2-} etc. will be involved in the process of corrosion. Still take cast iron as an example, when Cl^- and SO_4^{2-} concentration increases, the corrosion rate increases. The reaction is shown as follows:

$$Fe + 2Cl^- \longrightarrow FeCl_2 + 2e^- \tag{7}$$
$$4FeCl_2 + 8OH^- + O_2 \longrightarrow 2Fe_2O_3 \cdot H_2O + 8Cl^- + 2H_2O \tag{8}$$
$$Fe + SO_4^{2-} \longrightarrow FeSO_4 + 2e^- \tag{9}$$
$$2FeSO_4 + 4OH^- + O_2 \longrightarrow Fe_2O_3 \cdot H_2O + 2SO_4^{2-} + H_2O \tag{10}$$

For HCO_3^-, with its concentration increases, the corrosion rate will increase at first, but after reaching a certain concentration level, the rate will in turn decrease; continue to increase the HCO_3^- concentration, the rate will increase again. The reaction is shown as follows:

$$Fe^{2+} + HCO_3^- = FeCO_3 + H^+ + 2e^- \tag{11}$$
$$Fe(OH)_2 + HCO_3^- = FeCO_3 + H_2O + OH^- \tag{12}$$

The above reaction forms $FeCO_3$ film to slow down the corrosion reactions. Continue to increase the concentration of HCO_3^-, $FeCO_3$ will be dissolved.

The types of different types of cultural relics affected in the water environment are roughly shown in Table 4:

$$FeCO_{3(s)} + HCO_3^- = Fe(CO_3)_2^{2-} + H^+ \tag{13}$$

Table 4. Corrosion difficulty of different cultural relics under the environment of water bodies ©

Type of artifact	Environmental factors of water bodies			
	Acidity and alkalinity	Soluble salts	Biological effects	Water body movement
Metal artifacts	Easy to be corroded	Easy to be corroded	Easy to be corroded	Not easy to be corroded
Wooden artifacts	Very easy to be corroded	Easy to be corroded	Easy to be corroded	Easy to be corroded
Stone artifacts	Easy to be corroded	Easy to be corroded	Easy to be corroded	Easy to be corroded
Leather, paper artifacts	Easy to be corroded	Very easy to be corroded	Easy to be corroded	Easy to be corroded

2.3.3. Atmospheric Environment

Artifacts in the atmospheric environment are mainly affected directly and indirectly by various gases, particulate matter, precipitation, water vapor, etc.

2.3.3.1. Acid Rain

Acid rain, for example, is rain, snow or other forms of precipitation with a pH less than 5.6. The degree of impact of acid rain on cultural relics is related to the material and the environment in which they are stored. For example, carbonate artifacts such as caves, rock paintings, and cliff statues are more susceptible to acid rain than wooden ancient structures and artifacts buried in the environment (Chen et al., 2017).

Stone artifacts are subject to the combined effects of acid rain and sulfides in the atmosphere. Such as sulfur dioxide and atmospheric water vapor combined to produce H_2SO_4 on carbonate stone artifacts, the reaction generated $CaCO_4 \cdot 2H_2O$ will be attached to the surface of the artifacts, hindering the further reaction, but the volume of its attachment will increase, resulting in surface hollow shell and fall off, after that the new surface will continue to react with H_2SO_4. So repeatedly destroy the surface of corrosion artifact, structural strength becomes weak, and finally become stone powder (see Fig. 5) (Chen et al., 2017). The reaction is shown below:

$$CaCO_3 + H_2SO_4 \longrightarrow Ca^{2+} + SO_4^{2-} + H_2O + CO_2 \uparrow \quad (14)$$

$$CaCO_3 + HNO_3 \longrightarrow Ca^{2+} + NO_3^{-} + H_2O + CO_2 \uparrow \quad (15)$$

$$CaCO_3 + H_2SO_4 \longrightarrow CaCO_4 \cdot 2H_2O + CO_2 \uparrow \quad (16)$$

Figure 5. Repeated erosion of the surface of the chalked artifacts (Nankan Bas-reliefs, Bazhong, Sichuan, China) ©

2.3.3.2. Humidity

Humidity also has a certain impact on the cultural relics in the atmospheric environment. Unsuitable humidity will not only lead to mildew, sur-face color layer falls off, cracking and other deterioration of cultural relics, but also stone cultural relics will be destroyed by dissolved salt movement. Thus, it is an important factor affecting the preservation of cultural relics (Wei, 1986; Fergus et al., 2009). The impact of water vapor on cultural relics mainly from the adsorption of solids on water vapor. For organic artifacts, the saturated vapor pressure of the water contained in its capillary and the vapor pressure of the environment is different, which will make its material water absorption or dehydration, resulting in changes in the water content of different materials artifacts. For example, wooden artifacts will shrink and crack due to dehydration, while paper artifacts will absorb water then mildew. For metal artifacts, the high concentration of water vapor will dissolve the air dioxide and sulfides and other corrosion of the metal surface, forming the environment of electrochemical corrosion (Wei, 1986).

2.3.3.3. SO_2, NO_2, CO_2

In addition, atmospheric SO_2, NO_2, CO_2 and other effects on cultural relics are mostly secondary products produced by the combination of atmospheric water vapor attached to the surface of cultural relics. For example, stone artifacts are susceptible to the corrosion of the surface by H_2SO_3, H_2SO_4 produced by the combination of SO_2 and water in the air, and paper artifacts are also susceptible to the hydrolysis of cellulose by inhalation of acidic vapors, resulting in a decrease in their strength.

The mechanism of murals affected by sulfur dioxide is also similar to the above reaction. At the same time, glass artifacts are also susceptible to reactions with sulfur dioxide. Sulfur dioxide can react with calcium oxide in glass to produce calcium bisulfite, which eventually oxidizes to calcium sulfate and thus corrodes. In addition, sulfur dioxide can also react with the coloring agent used on the artifact. Experiments have shown that sulfur dioxide can cause pigments to varying degrees of color change (Williams, 1993).

Nitrogen dioxide can produce nitric and nitrous acids with atmospheric water, which can corrode the surface of stone and metal artifacts. Nitrogen dioxide can also discolor and structurally age the pigments of textiles. At the same time, nitrogen dioxide is also an oxidizing agent, can make a variety of organic compounds containing C=C unsaturated double bond oxidation, for example, its ability to make most dyes and pigments fade (Whitmore et al., 1989). Figure 6 is a cave painting, the base color has been mostly faded, leaving only the more vivid colors.

Figure 6. Example of cave painting under atmospheric conditions (Nankan Bas-reliefs, Bazhong, Sichuan, China)©

For carbon dioxide, the carbonic acid produced by dissolving in the atmospheric water vapor can also have a corrosive effect on the artifacts, and its concentration is susceptible to large changes depending on the environment. For example, in the museum environment, the concentration of carbon dioxide is proportional to the number of visitors and in the natural environment the concentration of carbon dioxide is influenced by factors such as plant density and air flow.

The mechanism of SO_2, NO_2, CO_2 on the metal is generally electrochemical corrosion, the above gases and atmospheric water combined with the precipitation of the metal surface will occur electrochemical corrosion (Oesch et al., 1997; Arroyave et al., 1995). In neutral and alkaline environments, the cathodic reaction is:

$$O_2 + 2H_2O + 4e^- \longrightarrow 4OH^- \quad (17)$$

Under acidic conditions is：

$$O_2 + 4H^+ 4e^- \longrightarrow 2H_2O \quad (18)$$

And whether in an acidic, neutral or alkaline environment, the anodic process of electrochemical reactions is metal anode to lose electrons into ions, and other substances in the solution combined to cause corrosion of metals (water film affects the reaction) (Arroyave et al., 1995; Nishikata et al., 1997).

The types of different types of cultural relics affected in the atmospheric environment are roughly shown in Table 5:

Table 5. Corrosion difficulty of different cultural relics under atmospheric environment©

Type of artifact	Atmospheric environmental factors		
	Acid rain	Unsuitable humidity	SO_2, NO_2, CO_2
Metal artifacts	Easy to be corroded	Easy to be corroded	Easy to be corroded
Wooden artifacts	Easy to be corroded	Very easy to be corroded	Easy to be corroded
Stone artifacts	Easy to be corroded	Easy to be corroded	Easy to be corroded
Leather, paper artifacts	Easy to be corroded	Very easy to be corroded	Easy to be corroded
Mural artifacts	Easy to be corroded	Very easy to be corroded	Easy to be corroded

2.4. *Biological Impact*

The mechanism and result of biological action on cultural relics depend on the material of cultural relics and the environment in which cultural relics are stored. This phenomenon is also known as "biodegradation" and it is defined as "any undesirable change in a material brought about by the vital activities of organisms" (Allsopp, 2011). In general, cultural relics are more or less affected by microorganisms, which are the main influencing factors of cultural relics.

2.4.1. Influence of microorganisms on cultural relics

The influence of microorganisms on cultural relics widely exists in stone cultural relics, ancient buildings, objects displayed in museums and libraries, human remains and materials related to burial. Due to the different materials of the above cultural relics and the different environment, the causes, development trends and influence factors of microbial diseases present complex and complex relationships (Sterflinger et al., 2013).

For stone cultural relics, there are two main ways for microorganisms to act on them: chemical action and physical action. The former is that organic acids, inorganic acids and other chemical substances in the growth and metabolism process of microorganisms react with the stone itself, resulting in the deterioration of the stone; The latter is mainly caused by the physical and mechanical damage to the stone caused by the biological activities of fungi and other microorganisms, such as the penetration of the stone in the process of mycelium growth. The black spots on the surface of stone cultural relics can be caused by black yeast of Hortaea genus, while the white spots are caused by $CaCO_3$produced by microorganisms participating in the reaction (Scheerer et al., 2009; Rosling et al., 2009).

In addition, as for the symbiotic organisms of plants and microorganisms such as lichens and mosses, their impact on stone relics is more macroscopic (see Fig. 7), and it is conducive to the weathering of rocks in humid, semi-arid and arid environments (Cutler et al., 2013; Lamprinou et al., 2013).

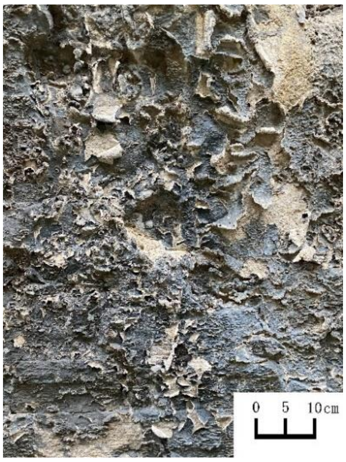

Figure 7. The surface of stone relics affected by lichen and moss (Nankan Bas-reliefs, Bazhong, Sichuan, China) ©

For metal relics, the metabolic products produced by the activities of microorganisms will acidify the soil and accelerate the corrosion of metals. Some microorganisms will use the elements in the metal, for example, the metabolic process of Bacillus aureus will react electrochemically with the metal to oxidize the bivalent iron in the iron cultural relics to trivalent iron and attach it to the surface of the cultural relics. The reaction equation is as follows (Bergey, 2001):

$$4Fe + 6H_2O + 3O_2 \longrightarrow 4Fe(OH)_3 \quad (19)$$

Microbial survival also needs to consume a part of organic matter, which will cause organic cultural relics such as silk and bone products to be corroded by microorganisms, making reduction difficult.

The main factor of wood artifact corrosion is the action of microorganisms in the soil. Wooden artifacts are mainly composed of cellulose, hemicellulose and lignin, all three of which can be used as a source of nutrients for microorganisms. In the case of suitable water content, microorganisms will proliferate, thus leading to the deterioration of wooden relics. In addition, Cl^-, K^+, Na^+ in the soil are important ions to maintain the osmotic pressure of microbial cells (Zhuang, 2020). when the concentration of above-mentioned ions in the soil is not proper, the activity of microorganisms will be reduced, so as the wood corrosion rate, therefore, Cl^-, K^+, Na^+ will only have a corrosive effect on wood when the concentration is appropriate. Therefore, discretionary judgment is needed.

As for paper and leather cultural relics, their deterioration is mainly affected by different organisms in different regions because their materials can be used as food for biological activities. Its deterioration mechanism is mainly the destruction and fracture of cellulose and hemicellulose in paper cultural relics; Protein denaturation and structural destruction of cortical cultural relics.

In addition, organisms can also have an impact on underwater artifacts. In the case of porcelain, for example, barnacles can adhere to its surface after death, making the restoration of artifacts difficult. Another example is that mussels, sea shoots, clams and sea urchins can penetrate all types of stone, which can do great harm to stone artifacts, while creatures such as ship maggots can corrode wood and make wooden structure broken (Jin, 2017).

At the same time, too high humidity in the air will also accelerate the growth of microorganisms, leading to accelerated corrosion of cultural relics. Taking fungi as an example, some study showed that when the relative humidity was 75% and above, the growth rate of fungi increased, and when the relative humidity was 97%, the growth of fungi reached its peak (Liu, 2020). At the same time, the pigment produced by fungus metabolism will also pollute the surface of cultural relics, which is difficult to remove. It will also produce a large number of spores, laying a hidden danger of deterioration for cultural relics.

2.5. *The Result about the Relationship Between Abrupt and Gradual Changes*

As mentioned above, abrupt changes are sudden and drastic environmental changes, while gradual changes are changes in environmental factors over a long span of time. Thus, gradual and abrupt changes occur simultaneously for artifacts. Artifacts undergo the effects of burial, abrupt change, gradual change, excavation, conservation, and restoration from the initial production to the final complete deterioration. Some of these factors will accelerate the deterioration of the artifact, some will slow it down, but ultimately cannot prevent its complete deterioration (see Fig. 8).

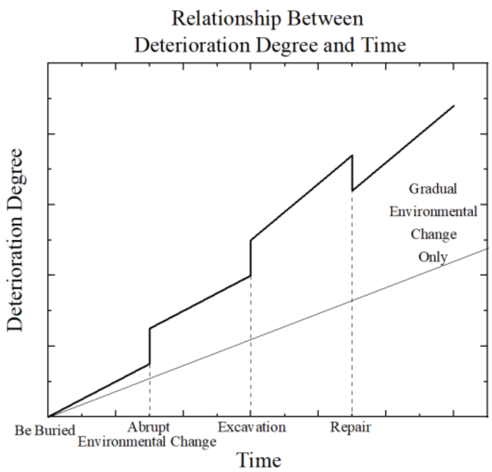

Figure 8. Relationship between heritage deterioration and time ©

3. DISCUSSIONS ABOUT THE RELATIONSHIP BETWEEN RELICS CONSERVATION AND THE ENVIRONMENT

Any form of cultural relics has its corresponding environment, and the study of cultural relics cannot be separated from the study of the environment. Changes in the environment will have an impact on the state of existence of cultural relics, and these changes affecting the environment will be reflected in the cultural relics to some extent. At the same time, the different types of cultural relics and the different environments will produce different conservation strategies, but basically, the abrupt change environment is based on prevention and prediction; the gradual change environment is based on control and monitoring.

3.1. *Relations*

For example, by analysing the material and producing method of ceramics, the type of soil and soil environment of the region in history can be inferred. Meanwhile, the cultural relics preserved to this day and carrying information, such as stone inscriptions, monuments, books and paintings, record certain historical social environment, natural environment and their evolution, from which inferences can be made about the state of contemporaneous cultural relics remaining to this day. For example, the Baiheliang inscription in Fuling, Chongqing, China, with about 30,000 words, records the hydrological and humanistic information along the Yangtze River, which is a rare written record of the ancient environment (Zhao et al., 2021). In addition, some studies have shown that most of the animal images depicted in rocks, bronzes, and jades have a strong correlation with the range of activities of these animals on the historical period and the approximate time of extinction; different animal species also have climatic indications that can be used to infer the historical environment (Li et al., 2013). In the study of the sites, the spore powder on the site artifacts, agricultural tools, and soil can be sampled and analysed, and all of these can be combined to infer the historical vegetation and climate, thus inferring the production and lifestyle of humans at that time. The more inferences are made for the ancient environment of the site, the more helpful it is to analyse artifacts of unidentified age and artifacts of unknown attribution. For the same period of documented artifacts, through the studies of the known ancient environment, the type of damage to the artifacts over time and the mechanism of deterioration can be analysed to provide a reference for its future conservation and restoration.

3.2. *Conservation strategy*

For AEFs, prediction and prevention are central to conservation. Through joint collaboration with the local meteorological centre and geological monitoring centre of cultural relics, a certain degree of prediction of possible future dis-asters can be made, so that the existing protection measures and future relocation of cultural relics can be developed.

For the GEFs, it is mostly the control and monitoring. For example, the aver-age temperature, humidity, light, etc. of the environment where the cultural relics are stored belong to the GEFs, which should be monitored while controlling the changes.

However, it should be clear that changes in the environment are unpredictable, so as the relationship between cultural relics and the environment. At the same time, it is not possible to predict what kind of conservation materials and measures will emerge in the future, or whether current conservation methods will be problematic in the future. With the passage of time and the increase of the confusion of the cultural relics themselves, they will eventually merge with their environment, i.e., deteriorated completely. Therefore, the conservation of cultural relics should be appropriately adjusted based on changes in the focal environment and predictable controls should be taken to minimize damage to the objects.

4. CONCLUSION

The impact of changes in the environment on cultural relics should be considered not only from the perspective of abrupt and gradual factors, but also in combination with the materials of cultural relics, only by this way can we objectively evaluate the impact factors on cultural relics and specify the corresponding conservation program. The distinction between organic and inorganic cultural relics affected by factors has a decisive role in their common protection in the same environment, and the linkage between various factors should be considered in a macroscopic manner to better protect cultural relics.

Moreover, in the context of contemporary heritage conservation research, both abrupt and gradual environmental factors can be restrained by human activities, thereby reducing the probability of deterioration and damage to cultural relics. Therefore, the conservation of unexcavated artifacts as well as excavated artifacts in the future can provide the benefit of human activities.

In recent years, the study of the mechanism of environmental factors on artifacts has become better and better, which is of great significance to the conservation. By analysing the mechanism of different factors on cultural relics, we can identify the same or similar factors affecting different relics, and thus establish certain macro-control measures. Therefore, the combination of environmental monitoring technology to achieve real-time monitoring and analysis of the environment in which cultural relics are stored, to study the impact of environmental factors on relics from the perspective of the environment, the integration of environmental research with the study of cultural relics conservation is a new way of thinking about their conservation and a necessary plan to protect heritage, which can help the development of cultural relics conservation to a greater extent.

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