〔報告〕 An Investigation of the Pigments and Materials Used in Some Mural Paintings of Mongolia

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1．INTRODUCTION

Based on its intent and significance, the murals were divided into two main categories, those that were inside the buildings, and tomb murals painted as a funeral ritual.

Steppe nomads have been herding livestock for many centuries, moving around and depending on pasture resources, thus, creating a way of life called the nomadic culture in world history. However, the nomads did not just move around during their thousands of years of reign in the central Asian plateau. They built cities and settlements. Some of the examples are Luut city of the Xiongnu dynasty, Mumu (Muum) city of the Rouran dynasty, the offering palace of the Turkic Imperial, the Ordu-Baliq capital of the Uighur dynasty, the Karakorum capital of the Great Mongol Empire, and the Erdene Zuu Monastery which was built when Buddhism spread across Mongolia for the third time. It still stands in Orkhon Valley in central Mongolia[1)].

During archaeological excavation at these historical sites, the remnants of several murals were found, which are being preserved at the Hermitage Museum of Russia[2)], the Mongolian National Museum, the Karakorum Museum, and the Institute of Archaeology, Mongolian Academy of Sciences.

Numerous tombs were found during archeological excavations in Mongolia during the recent decade, the largest of which is a royal tomb called the Shoroon Bumbagar tomb from the Turkic period.

In the field of conservation science of cultural heritage, painting materials used in mural paintings have not been investigated comprehensively in ancient underground tombs, and in the early and medieval historical ruins of Mongolia, except for studying the materials used in the mural painting of the Great Zuu temple (Dazhao temple) in Inner Mongolia[3)] and the mural painting in the Uvgun Monastery in Mongolia[4)]. This can be attributed to the fact that the investigation of materials used in mural paintings is still a nascent case study in the field of conservation science of cultural heritage in Mongolia. However, in the last several decades, mural paintings in the underground tombs and considerable fragments of mural paintings have been discovered as a result of archaeological excavations and it has provided a great opportunity to study Mongolian mural paintings.

This research aims to highlight the results of the investigations on painting materials used in the early mural paintings of underground tombs, as well as mural paintings that were found from the early and medieval historical buildings during excavations in Mongolia.

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1－1．Outline of the ruins and the samples

1－1－1．Shoroon Bumbagar tomb, Turkic period (6th-7th centuries)

The Shoroon Bumbagar tomb is located in the valley of the Tuul river, in the northern side of the Ulaan Kherem ruins, and in front of the Maikhan Mountain in Bayannuur soum, in the Bulgan province of Mongolia. The tomb was discovered in 2001 and an excavation operation was carried out by a joint team of archaeologists from the Institute of History of the Mongolian Academy of Sciences and the Eurasian University of Kazakhstan in July-August 2011. The Shoroon Bumbagar tomb revealed an internal structure comprising a downward-sloping ramp leading to a subterranean burial chamber. The tomb is 42 m long, with its entrance at the ground- level and the slope going downwards towards the burial chamber at a depth of 7m below the surface[5]. The wall of this long corridor has mural paintings (Figure 1_a). This tomb was designated as a national historic site of Mongolia in 2014.

1－1－2．Karabalgasun ruins, Uighur period (8th-9th centuries)

Karabalgasun was the capital of the Uighur dynasty. The ruins are known as Ordu-Baliq and they are located at the World Heritage Site Orkhon Valley Cultural Landscape, Khotont soum of the Arkhangai province. In 744, Karabalgasun was established as the capital, but it collapsed in 840 with the conquest of Yenisey Kyrgyzes. The Mongol-German Orkhon joint

Figure 1. Location of the tombs and ruins. The mural painting of the Shoroon Bumbagar tomb (a); A picture of the Karabalgasun ruins and fragments of the mural painting (b); The mural painting of the imperial tombs of the Kitan period (c); Plan of the Karakorum historical site, yellow rectangle: the ruin of the north part of the Karakorum historical site and fragments of the mural painting (d)

expedition excavated this site in 2007 and discovered many fragments of the wall painting[6] (Figure 1_b).

1－1－3. Imperial tombs of the Kitan period (10th-12th centuries)

The Imperial tombs named by Ch`i-tan (Qitay) emperor's mausoleums are located in Baarin Hoshuu in the Ulaan Had in Inner Mongolia. These underground tombs are called the "East tomb," the "Central tomb," and the "West tomb," based on their position. As part of this research, we investigated the pigments of a mural painting from "East tomb," which has been currently preserved in the Kyoto University Museum. The East tomb is hidden underground without a mound and it was built with bricks. The tomb consists of a rectangular room and six round rooms of various sizes, all of which are connected with one another by a passage. The wall is built in brick, covered with thick coatings of plaster, and painted with human figurines, horses, landscape and ornaments. The length of the tomb, from the entrance to the north wall of the inner chamber spans 21.4 m[7),8)] (Figure 1_c).

1－1－4. The ruins of the northern part of Karakorum capital, the Great Mongol empire (13th-14th centuries)

Karakorum was the capital of the Great Mongol Empire between the 13th and 14th centuries. The site lies in the northwestern corner of the Uvurkhangai province and it is part of the World Heritage Site Orkhon Valley Cultural Landscape. The ruins of the northern part of the Karakorum capital have been explored by archaeologists of the Mongol-German Karakorum expedition in 2009[6]. As a result, of the expedition, fragments of the ceramic, roof-tiles, ornaments of the building and many fragments of the mural painting were found (Figure 1_d).

2. SAMPLES AND ANALYTICAL METHODS

2－1. Samples

The samples are listed in Table 1 and shown in Figure 2. In order to investigate the materials used in the mural paintings, three samples were taken from the fragments of the mural painting of the Shoroon Bumbagar tomb conserved in the storage of the Kharakhorum Museum (Table 1, Figure 2). One section of the mural painting, which was located in the fourth well, in the north-west corner, and inside the burial chamber, collapsed face down during the excavation operation in 2011. The fallen fragments of the mural painting were retained in storage at the Kharakhorum Museum.

Seven samples were taken from the fragments of the mural painting which were found at the Karabalgasun ruins.

Five samples were also taken from the fragments of the mural painting at the Karakorum ruins which are preserved at the Kharakhorum Museum.

This study also poses, a great challenge in investigating the pigments and the current condition of the mural paintings of the "East tomb" of the imperial tombs of the Kitan period (Figure 1_c). This mural painting, which has been currently kept in the Kyoto University Museum, was examined. The object's size was 140 x 66.5 cm with a wooden frame, and the

Table 1. List of the samples which were obtained from the fragments of mural paintings of the Shoroon Bumbagar tomb, Kharabalgasun ruins and Karakorum ruins

Sample name	Color	Ruin (Century)
SHB 1	Red	Shoroon Bumbagar tomb (6th-7th centuries)
SHB 2	Red	Shoroon Bumbagar tomb (6th-7th centuries)
SHB 3	Light red	Shoroon Bumbagar tomb (6th-7th centuries)
HB 1	Red	Karabalgasun ruins (8th-9th centuries)
HB 2	Brown	Karabalgasun ruins (8th-9th centuries)
HB 15	Orange	Karabalgasun ruins (8th-9th centuries)
HB 16	Orange / brown	Karabalgasun ruins (8th-9th centuries)
HB 17	Gray	Karabalgasun ruins (8th-9th centuries)
HB 21	Red	Karabalgasun ruins (8th-9th centuries)
HB 22	Blue	Karabalgasun ruins (8th-9th centuries)
KH 4	Plaster	Karakorum ruins (13th-14th centuries)
KH 6	Red	Karakorum ruins (13th-14th centuries)
KH 10	Red	Karakorum ruins (13th-14th centuries)
KH 11	Blue	Karakorum ruins (13th-14th centuries)
KH 20	Blue	Karakorum ruins (13th-14th centuries)

surface of the mural painting had a rough appearance. The painting's structure consisted of a plaster layer that was about 2-3 cm thick and a paint layer.

2－2. Analytical methods

2－2－1. Optical microscopy

The surface appearance and the shape of the pigments were observed by using stereo microscopes (Leica Z16 APOA, Leica MZ16 and OMRON Corporation VCR-FRM20LZ). The observation distance from the objective lens to the object was 30 to 150 mm, while magnification was 10 to 120.

2－2－2. X-ray fluorescence analysis (XRF)

The elements of the plaster and the pigments of the mural paintings were measured by two types of X-ray fluorescence analyzers. For the samples from the fragments of mural paintings, a desktop type analyzer, Bruker EAGLE Ⅲ, was used and for the mural painting in situ, a handheld type, i.e., a nondestructive type, NITON XL3t. The conditions of the measurement with the former instrument were followed: molybdenum target, tube voltage, and current set to 40 kV and 30 μA, respectively, acquisition time 100 sec. The conditions with the latter were gold target, tube voltage 40 kV, tube current controlled automatically, acquisition time 100 sec.

2－2－3. Scanning electron microscopy (SEM)

The shape and elements of the pigment particles were observed and analyzed with the use of SEM/EDX, JEOL JSM-IT100. The observation magnification was 750 to 10000.

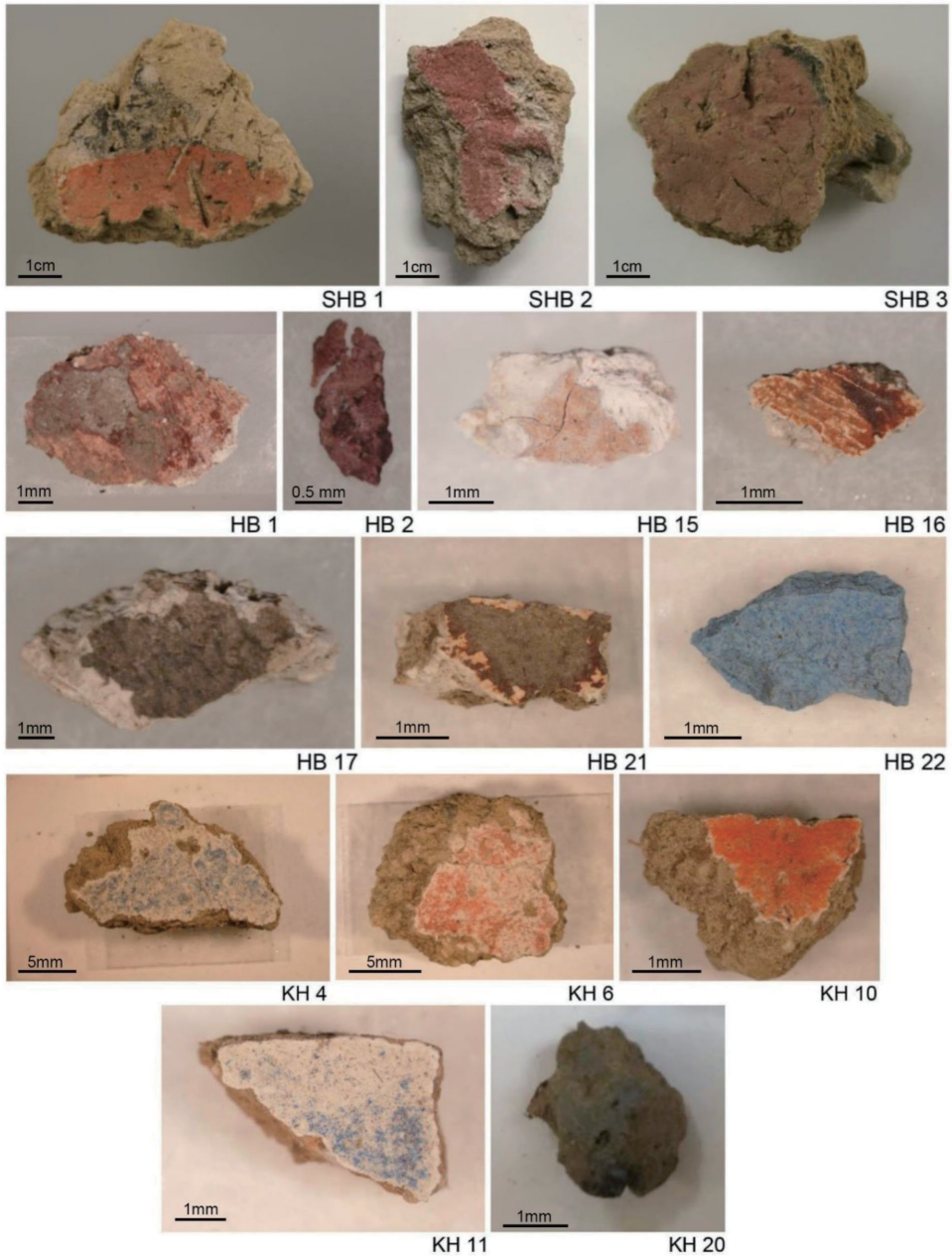

Figure 2. Samples of the mural painting of the Shoroon Bumbagar tomb, Karabalgasun and Karakorum ruins

2 − 2 − 4 . X-ray diffraction analysis (XRD)

The plaster and the pigments of the murals were identified consequently by XRD, Rigake Smartlab. The measurement conditions were as follows: Cu-K alpha radiation, tube voltage 40 kV, tube current 40 mA, and the scan range ($2\theta/\theta$) 5 to 90°.

3. RESULTS AND DISCUSSION

3－1. The fragments of the Shoroon Bumbagar tomb

It is evident that the structure of the underground tomb and the motifs of the mural paintings were greatly influenced by the burial rituals of the Tang dynasty. The results of some research works[9),10),11),12)] have shown that many pigments were used in the Tang dynasty period. However, the excavation report[5)] of the Shoroon Bumbagar tomb and the project report of the preservation and conservation of this ruin[13)] indicated that a few pigments such as red, brown, black, and blue were used in the mural painting of the Shoroon Bumbagar tomb. During the field survey, brown, light red, red, and black colors were observed on the mural painting, probably a very limited palette, and especially red color that consisted of a kind of red and black pigment was used in this painting. In this study, a red and light red pigment used in the mural painting of this tomb have only been identified.

It was very difficult to determine the pigment used in the mural painting of the Shoroon Bumbagar tomb, because a physical deterioration by a soluble salt crystallization and discoloration were confirmed on the surfaces of the wall. Therefore, in this paper, the results obtained from the two samples, which were not previously analyzed, will be introduced. The mural painting has a base mortar layer, a layer of plaster, and a paint layer. For the elemental analyses, red pigments in the samples and the plaster, as well as mortar could be identified. The results of the XRF analysis are summarized in Table 2. The elements Fe, Ca, Si, K, S, Al, and Ti were identified from the samples. A high content of Fe was detected from the red pigment area of all the samples, while mortar had a high content of silicon (Si). In addition, a high content of Ca was detected from the plaster area.

Identification of components in the materials with XRD relies on a pattern of diffracted X-rays resulting from interaction with the crystalline structure of the material. XRD was applied for the identification of the chemical compounds present in the paint and plaster layers, especially for the red pigment in Samples SHB 1, SHB 2, and light red pigment in sample SHB 3.

From the results obtained in the mineralogical analysis of the sample by XRD, hematite (Fe_2O_3), calcite ($CaCO_3$), and quartz (SiO_2) were observed from Sample SHB 1. However, a large amount of calcite was detected from the light red pigment of Sample SHB 3_02, which was probably estimated to be a mixture of hematite and calcite. Also, calcite and quartz were

Table 2. List of samples taken from the wall paintings of the Shoroon Bumbagar tomb in Bayannuur soum, Bulgan province, Mongolia. Their color and results were obtained by XRF

Sample name	Identified points of the sample			Elements determined by XRF
SHB 1	Red	–	–	Fe, Si, Ca, K, Al, Ti
SHB 2_01	Light red	–	–	Fe, Ca, Si, K, S, Al, Ti
SHB 2_02	–	–	Mortar	Si, Fe, Ca, K, Al, Ti, S
SHB 3_01	Red	–	–	Fe, Ca, Si, K, S, Al, Ti
SHB 3_02	–	Plaster	–	Ca, Fe, Si, K, Al, S, Ti
SHB 3_03	–	–	Mortar	Si, Fe, Ca, K, Al, Ti, S

detected from Sample SHB 2.

The scanning electron microscope (SEM) is a common imaging technique in conservation and for measuring small features.

Initially, we described the results of the analysis of the characteristics of the paint layer in Samples BT 3, CHS 3 and KH 1 by SEM. Two samples that have been taken from the Shoroon Bumbagar tomb showed the proliferation of subaerial biofilms-microbes on the surfaces and within the paint layers of the mural painting[14,15]. Some analytical results of the painting materials used in this mural were presented to the Mongolian archaeological conference[15]. Sample KH 1 which has been preserved in the storage room of the Kharakhorum Museum under investigation was found to be in a fine condition (Figure 3).

3－2. Mineralogical and chemical composition of the pigments used in the Karabalgasun mural painting

XRF, and XRD analysis were performed with the aim to obtain the mineralogical, and the chemical composition of the pigments.

Seven samples from the fragments of the Karabalgasun mural painting, which is kept in the Kharakhorum museum were investigated. Nine points on the fragments, such as blue, red, orange, and brown pigments, as well as the plaster layer of the fragments, were analyzed by XRF. The results of the XRF are summarized in Table 3 and some graphics are shown in Figure 4. The elements Ca, Fe, Cu, Si, Pb, K, Al, Ti, and S were detected.

Only Ca, Fe, Si, and S were detected from the plaster area of Sample HB.21_02. Samples HB. 1, HB.2, and HB.22 showed a high content of Fe. XRD patterns showed the red and brown pigments. Sample HB 2, HB 15, HB 16, and HB 21 showed the presence of hematite (Fe_2O_3) and calcite ($CaCO_3$). The results of the XRD are summarized in Table 4.

A high content of the element Cu was detected from the blue section in Sample HB 22. In the mineralogical analysis of this color by XRD, azurite ($Cu_3(CO_3)_2(OH)_2$) was mainly observed in the XRD spectrum (Table 4). The results of the XRF and XRD investigations clearly reveal that the plaster layer consists of a mixture of coarse sand (SiO_2) and calcite

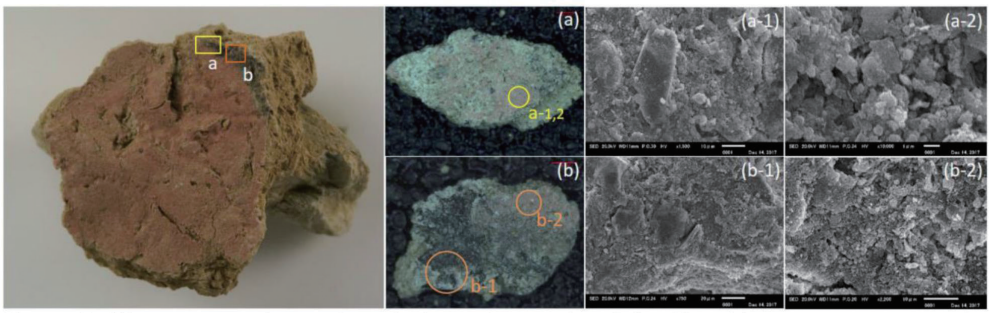

Figure 3. Microscope and scanning electron micrographs of the Kharakhorum museum sample. Picture of the sample (a), Scanning electronic micrographs of red color, magnification x 1500 (a-1), Scanning electronic micrographs of red color, magnification x 10000 (a-2), Scanning electronic micrographs of black color, magnification x 750 (b-1), Scanning electronic micrographs of red color, magnification x 2200 (b-2)

Table 3. The results of the x-ray fluorescence analysis on the Karabalgasun mural painting

Sample name	Measurement Point	Fe	Ca	Si	K	Al	Ti	S	Cu	Pb
HB 1	Red	+ + +	+	+	+	+	−	−	+	−
HB 2	Brown	+ + +	+ +	+	−	−	−	+	+	−
HB 15	Red	+	+ + +	+	+	+	+	−	−	−
HB 16_01	Brown	+	+ + +	+	−	+	+	−	−	−
HB 16_02	Red	+	+ + +	+	−	+	+	−	−	−
HB 17	Gray	+	+ + +	+	−	−	−	+	−	−
HB 21_01	Red	+ + +	+	+	+	+	+	+	+	−
HB 21_02	Plaster	+	+ + +	+	−	−	−	+	−	−
HB 22	Blue	+	−	+	−	−	−	−	+ + +	−

Non detected, + Low content, + + Middle content, + + + High content

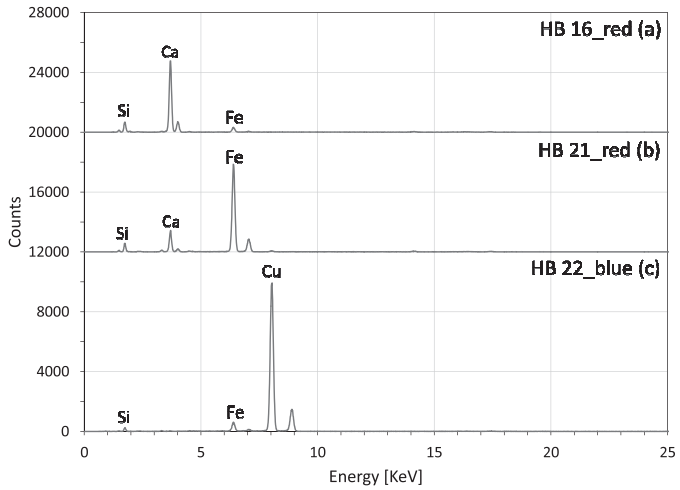

Figure 4. Results of the x-ray fluorescence analysis on measurement points HB 16 (a), HB 21 (b) and HB 22 (c)

Table 4. The results of the XRD analysis on the Karabalgasun mural painting

Sample name	Color	XRD result
HB 1_01	Red	Hematite (Fe_2O_3), Calcite ($CaCO_3$)
HB 1_02	Plaster	Calcite ($CaCO_3$)
HB 2	Brown	Hematite (Fe_2O_3), Calcite ($CaCO_3$)
HB 15	Orange	Calcite ($CaCO_3$)
HB 16_01	Orange	Calcite ($CaCO_3$)
HB 16_02	Brown	Hematite (Fe_2O_3), Calcite ($CaCO_3$)
HB 17	Gray	Calcite ($CaCO_3$)
HB 21	Red	Hematite (Fe_2O_3), Calcite ($CaCO_3$)
HB 22	Blue	Azurite ($Cu_3(CO_3)_2(OH)_2$)

($CaCO_3$).

3－3. Pigments and Plaster of Imperial tombs of the Kitan period

Eighteen points on the mural painting of the Imperial tombs of the Kitan period such as the red, light red, orange, reddish brown, black, and green pigments as well as the plaster layer, were analyzed (Figure 6). The results of the XRF are summarized in Table 5. The color and elements determined are listed in the middle two columns in Table 5. The elements Ca, Cu, Hg, Pb, Sr, Fe, and S were found to be present on the mural painting, while only Ca, Sr, and Fe

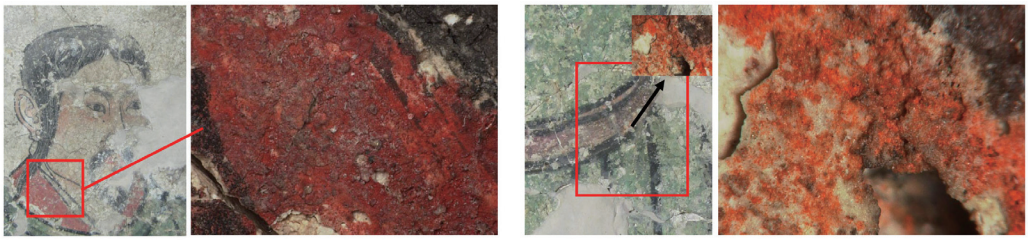

Figure 5. Images of the coat area, magnification 40 x (a); Image of the belt area magnification 40 x (b)

Table 5. The results of the handheld x-ray fluorescence analysis on the mural painting, Kitan period

Location	Identified points of the sample	Elements determined by XRF	Estimated materials
1 (2190)	Plaster	Ca, Sr, Fe	Calcite
2 (2191)	Plaster	Ca, Sr, Fe	Calcite
3 (2192)	Gray (Head)	Ca, Sr, Fe	Carbon black
4 (2193)	Black (Hair)	Ca, Sr, Fe	Carbon black
5 (2194)	Green	Cu, Ca, Sr, Fe	Malachite
6 (2195)	Black line	Cu, Ca, Sr, Fe	－
7 (2196)	Black spot	Cu, Ca, Sr, Fe, Pb	－
8 (2197)	Black spot	Cu, Ca, Sr, Fe	－
9 (2198)	Green	Cu, Ca, Sr, Fe	Malachite
10 (2199)	Yellowish red (Belt)	Pb, Ca, Sr, S, Fe	Minium
11 (2200)	Reddish brown (Belt)	Pb, Ca, Sr, Fe	Minium
12 (2201)	Green	Cu, Ca, Sr, Fe	Malachite
13 (2202)	Green	Cu, Ca, Sr, Fe	Malachite
14 (2203)	Dark green	Cu, Ca, Sr, Fe, Pb	Malachite
15 (2204)	Red	Ca, Hg, Sr, Fe, Pb	Cinnabar + Lead red
16 (2205)	Light red (Cheek)	Ca, Sr, Fe, Hg	Cinnabar
17 (2206)	Light red (Hand)	Ca, Sr, Fe, Hg, Pb	Cinnabar + Lead red
18 (2207)	Reddish brown (belt)	Pb, Ca, Sr, Hg, Fe	Lead red + Cinnabar

were detected from the plaster layer. The elements Cu, Ca, Sr, and Fe were detected in the green and dark green sections, the black line and the black spot, while Pb, Ca, Sr and Fe were found in the reddish-brown pigment. Ca, Hg, Sr, Fe, and Pb were detected in the red and light red pigments.

Cu was detected in high concentrations in the four measurement points 5, 9, 12, and 13 (Figure 6), which are painted with a green pigment. Figure 7_a shows the results of the XRF analysis on the measurement point of 5. A high amount of Cu was identified from the black drawing line, the black spot, and the dark green areas (measurement points: 6, 7, 8, and 14). A green pigment layer was covered by a light black surface.

The results of XRF at the red, light red, yellowish red, and reddish-brown areas show the presence of a high amount of Ca. The pigment could not be characterized reliably. Moreover, the results could be influenced by high levels of Ca in the plaster layer. Hg was found from measurement points 15 (Figure 7_b), 16, and 17, while a high amount of Pb was detected from the measurement points 11 and 18. Figure 7_c shows the result of the XRF analysis on measurement point 18. A Pb-based red pigment was estimated to be red lead (Pb_3O_4). A brown pigment is painted on top of a yellowish-red paint layer, which was on the belt part. Figure 5 shows the images of the coat and the belt area.

Figure 6. Measurement points of XRF

Black was found on the contours (the black drawing lines) of the painting and on the black spots. Light black paint was found on the folds of the costume and one human hair. Also, a gray pigment was found on the head of the human figurine. The results of XRF show a high level of Ca from the measurement points 3, 4, 6, 7, 8, and 14, which was influenced by the background plaster layer.

In the fine coating layer, a large amount of Ca was detected on the surface (the average Ca content was higher than 70%). The thick coating of plaster layer is made of lime and sand, mixed with straw.

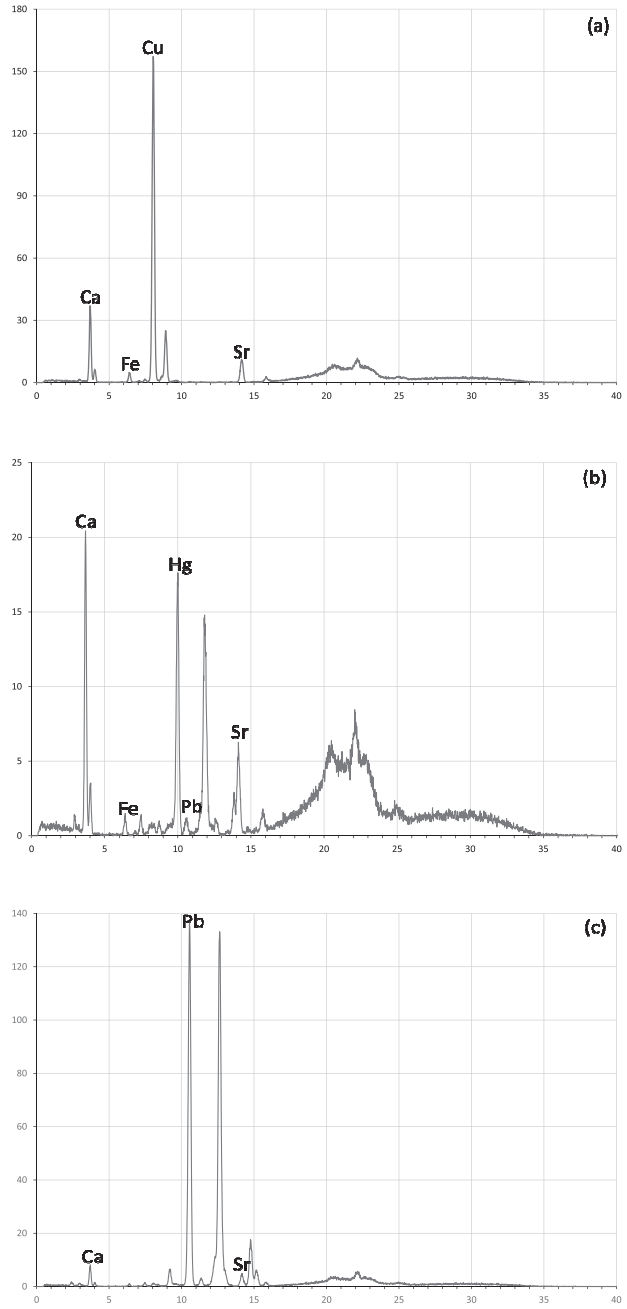

Figure 7. Results of the handheld x-ray fluorescence analysis on measurement point of 5, green (a), 15, red (b) and 18, reddish brown (c)

3－4．Mineralogical and chemical composition of the pigment used in the Karakorum mural painting

Ten points such as blue, red, orange, gray, brown, as well as the plaster area of the fragments of the Karakorum mural painting, were analyzed by XRF. The results of the XRF are

Table 6. The results of the x-ray fluorescence analysis on the Karakorum mural painting

Sample name	Measurement Point	Fe	Ca	Si	K	Al	Ti	S	Mn	Cu	Hg	Pb
KH 4_01	Blue	+ +	+ + +	+ +	+	+	−	−	−	+ + +	−	+
KH 4_02	Plaster	+	+ + +	+	−	−	−	−	−	−	−	+
KH 6_01	Red	+ +	+ + +	+ +	+	+	+	+ +	+	−	+ + +	+
KH 6_02	Plaster	+ +	+ + +	+	+	+	+	−	−	−	−	−
KH 6_03	Mortar	+ + +	+ + +	+ +	+	+	+	−	+	−	−	−
KH 10	Red	+	+	+	+	+	−	+ +	−	−	+ + +	+ + +
KH 11_01	Blue	+	+	+	+	+	+	−	−	+ + +	−	−
KH 11_02	Plaster	+ + +	+ + +	+ + +	+	+	+	−	−	+	−	−
KH 20_01	Blue	+ +	+	+	+	+	+	+	−	+ + +	−	−
KH 20_02	Plaster	+	+ + +	+	+	+	+	+	−	+	−	−

Non detected, + Low content, + + Middle content, + + + High content

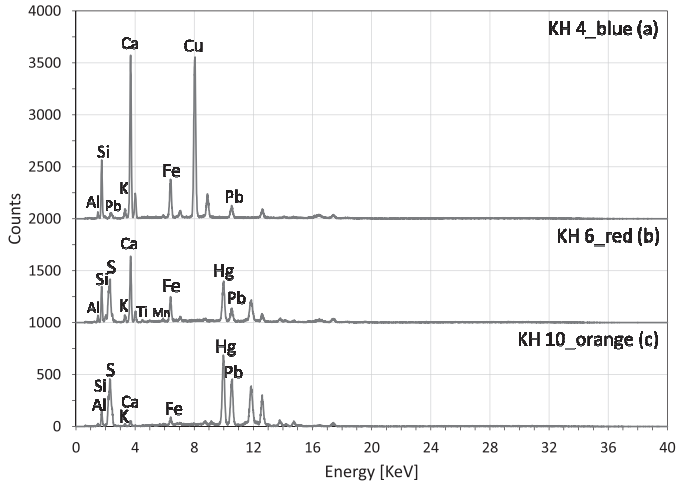

Figure 8. Results of the x-ray fluorescence analysis on sample KH 4 (a), KH 6 (b), and KH 10 (c)

summarized in Table 6 and some graphics are shown in Figure 8. The analysis showed the presence of Ca, Fe, Cu, Si, Hg, Pb, K, Al, Ti, S, and Mn.

A high content of Hg was detected in the red pigment used in Sample KH 6 (Figure 9). Also, the elements Hg and Pb were detected from Sample KH 10. In the mineralogical analysis of the sample by XRD, cinnabar HgS was detected from KH.6. Also, cinnabar (HgS) and minium (Pb_3O_4) were observed in KH.10 (Figure 9). According to the results, it can be deduced that the red pigment was prepared by mixing cinnabar and minium (Table 7).

High levels of Ca and Cu were detected from the blue pigment, in Samples KH 4 (Figure 9), KH 11, and KH 20 by XRF analysis. The results of the XRD analysis showed that the blue pigment was identified as azurite ($Cu_3(CO_3)_2(OH)_2$).

The basement layer included a high content of Fe and Ca (Sample KH 4, KH 11, and KH 20).

Table 7. The results of the XRD analysis on the Karakorum mural painting

Sample name	Color	XRD result
KH 4_1	Plaster	Calcite ($CaCO_3$)
KH 6	Red	Cinnabar (HgS)
KH 10	Red	Cinnabar (HgS), Minium (Pb_3O_4)
KH 11_01	Blue	Azurite ($Cu_3(CO_3)_2(OH)_2$)
KH 11_02	Plaster	Calcite ($CaCO_3$), Azurite ($Cu_3(CO_3)_2(OH)_2$)
KH 20_01	Blue	Azurite ($Cu_3(CO_3)_2(OH)_2$)
KH 20_02	Plaster	Calcite ($CaCO_3$)

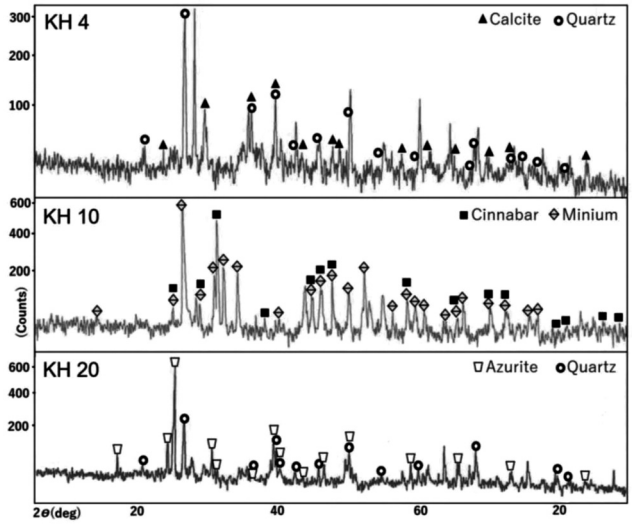

Figure 9. Results of the XRD analysis on sample KH 4 (Plaster), KH 10 (Red color), and KH 20 (Blue color)

The mineralogical analysis of the plaster layer revealed the presence of a mixture of coarse sand (SiO_2) and calcite ($CaCO_3$).

From the results obtained by analysis, the types of painting materials used in the mural painting of the Karakorum ruins have increased.

CONCLUSIONS

In this study, the materials used in the mural paintings of the two underground tombs, the early and medieval mural paintings of a temple, and a building in Mongolia, were investigated.

Blue is a symbol of the state, and it has been used for centuries as an “eternal and blue sky,” while the red and orange colors are widely used in daily life in Mongolia. We have reached several conclusions, which are as follows:

1) The red pigment used in the mural painting of the Shoroon Bumbagar tomb was hematite (Fe_2O_3), and the plaster layer was calcite ($CaCO_3$). It is necessary to investigate further to clarify the materials in some pigments such as brown, black, and blue used in this tomb.

2）The orange, red, and brown pigments used in the Karabalgasun mural painting were analyzed. The pigments were hematite (Fe_2O_3). We investigated only one sample that was painted in a blue pigment, and found that it was azurite ($Cu_3(CO_3)_2(OH)_2$). According to the analysis, calcite ($CaCO_3$) was used from the plaster layer, which was around 3-4 cm thick. It was distinct from the other mural paintings.

3）Cu was detected in high concentrations in the green pigment used in the mural painting of the Kitan period. Copper-based green pigment is estimated to be malachite. Hg element was found from some measurement points. Hg-based red was estimated to be cinnabar (HgS). It is well-known that cinnabar pigment was used extensively in mural paintings since ancient times. The collar of the coat and the hand area had a bottom color which is estimated to be a mixture of lead red and minium.

4）Cinnabar (HgS) and minium (Pb_3O_4) were detected from the red and orange pigments used in the mural painting of the Karakorum ruins. The blue pigment was azurite. The analysis detected calcite ($CaCO_3$) from a plaster layer.

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Key words: mural painting（壁画）; painting materials（色料）; underground tomb（古墳）; ruin（遺跡）; Mongolia（モンゴル）

An Investigation of the Pigments and Materials Used in Some Mural Paintings of Mongolia

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In the present study an investigation was conducted to examine the materials used in the early and medieval mural paintings of Mongolia.

As part of the research the following sites were examined using an X-ray analysis (XRF), X-ray diffraction analysis (XRD), and scanning electron microscopy (SEM): the Shoroon Bumbagar tomb from the Turkic period (6th-7th centuries), the Kalabargason ruins from the Uighur period (8th-9th centuries), the imperial tombs from the Kitan period (11th-12th centuries) located in Baarin Hoshuu, Ulaantsav city, Inner Mongolia and the mural paintings of the Karakorum ruins (13th-14th centuries), once the capital of the Great Mongol Empire.

Hematite (Fe_2O_3) was detected in the red portion following an investigation of the Shoroon Bumbagar tomb, which dates back to the 6th-7th centuries. In addition, calcite ($CaCO_3$) was identified from the plaster layer.

The investigation also revealed hematite formation in the wall paintings of the Karabalgasun ruins of the Uighur period, in the orange, red, and brown parts, and azurite ($Cu_3(CO_3)_2(OH)_2$) in the blue portions. Meanwhile, calcite ($CaCO_3$) was detected from the plaster layer.

A large amount of copper was noticed in the green pigment area during the investigation of the wall paintings of the imperial tomb of the Kitan period. This green pigment is estimated to be malachite. Cinnabar that was detected from the red part was assessed to be vermilion (HgS).

From the results of the investigation of the wall paintings of the Karakorum ruins of the Great Mongol Empire (13th-14th centuries), cinnabar (HgS) and red lead (Pb_3O_4) were detected from the red and orange parts, azurite from the blue portion, and calcite from the plaster layer.

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モンゴルの壁画に使用された壁画材料分析について

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本論文では，モンゴルの初期および中世の壁画に使用された材料調査の結果について検討を行なった。

調査では，モンゴルの突厥時代のショロンボンバガル古墳（6–7世紀），ウイグル時代のカラバルガソン遺跡（8–9世紀），契丹時代の王墓（ウランツァウ市バアリンホシュに所在，11–12世紀），モンゴル帝国時代の首都であったカラコルムの遺跡（14世紀）の壁画を対象とし，蛍光X線分析（XRF），X線回折分析（XRD），走査型電子顕微鏡観察（SEM）の手法を用いて壁画材料の同定を行なった。

突厥時代（6–7世紀）のショロンボンバガル古墳壁画の調査結果より，赤色部分からはヘマタイト（Fe_2O_3）が，漆喰層からはカルサイト（$CaCO_3$）が検出された。この古墳で使用された茶色，黒，青の顔料を明らかにするために，さらなる研究が必要である。

ウイグル時代（8–9世紀）のカルバルガソン遺跡の壁画の調査結果より，オレンジ色，赤色および茶色部分からはヘマタイトが，青色部分からはアズライト（$Cu_3(CO_3)_2(OH)_2$）が，漆喰層からはカルサイト（$CaCO_3$）が検出された。契丹時代（11–12世紀）の王墓の壁画の調査結果より，緑色顔料の部分から多量の銅が検出された。この緑色顔料はマラカイトであると推測される。赤色部分からは水銀が検出されたことから，これは水銀朱（HgS）であると推測された。モンゴル帝国時代（13–14世紀）のカラコルム遺跡の壁画の調査結果より，赤色，オレンジ色の部分からは水銀朱（HgS）と鉛丹（Pb_3O_4）が，青色部分からはアズライトが，ならびに漆喰層からはカルサイトが検出された。

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