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RESEARCH ARTICLE

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SOME RESULTS OF THE STUDY ON THANGKA PAINTING MATERIALS

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ABSTRACT

In 2022, the 10 thangka paintings restored from the Choijin Lama Temple Museum by the National Center for Cultural Heritage were examined using portable hand tool "OXFORD X-Met 7500 X-Ray analytical microscope" for grounds and pigments and the "BIOBLUE" electron microscope for the canvases cloth. Along with this, many scientific research methods were used for this study. As a result of this study, it was shown what chemical elements are mainly composed of the ground and pigment of that 10 thangka paintings, and by comparing with similar studies, we determined the origin of grounds and pigments and new recommendations have been proposed. Also, the characteristics of fabric weaving, thread strength and origin were determined. This study has great importance for the conservation and restoration work identifying the pigments composition, fabric origin and characteristics of above thangka paintings. In the future, it will become part of the basic scientific research on the conservation and protection of tangible cultural heritage.

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INTRODUCTION

Today, many countries globally have achieved notable national heritage preservation through carrying out and implementing scientific and multifaceted activities to preserve and protect national heritage, customs, and traditions and pass them on to future generations. The cultural heritage created by the Mongolians since ancient time is a great contribution not only to the nomads of Central Asia, but also to world civilization. One of them is Buddhist art, of which the thangka painting occupies a significant share. Thangka painting, in addition to being a valuable national cultural heritage of Mongolia, has emerged and developed as an independent type of Mongolian fine art and passed down through generations. Hundreds of valuable heritage objects are preserved in many museums in Mongolia and are available to the public. Although we continue to see and admire the wonderful cultural heritage created at a high level, it should be emphasized that the research of preservation, protection, and restoration is not yet carried out at the proper level, and research on effective new scientific methods for this purpose are not enough. In 2022, the study of materials used for 10 thangka paintings restored from Choijin Lama Temple Museum by the National Center for Cultural Heritage was conducted using the portable hand tool called "OXFORD X-Met 7500 X-Ray analytical microscope" for survey of grounds and paints, and the "BIOBLUE" electron microscope for the fabric, as well as using variety of research methods. As a result of this study, it was shown the chemical composition and elements and origin of grounds and pigments from

above 10 thangka paintings have been identified and compared with results of similar studies. It also attempted to determine the features of fabric weaving, thread density, and origin of the fabric used.

Research objective: The aim of this study is to identify the dyes and pigments used in thangka paintings stored in the exhibition hall and treasury of the Mongolian Museum by analyzing their composition and techniques; create a suitable environment for preservation of paintings and prevention from damage; identify the suitable and unsuitable materials and paints used in the restoration of damaged thangka paintings; and further study them using basic scientific research methods based on instrumental analysis; reduce the damages caused by environmental effects, and to conduct preliminary research and make recommendations for the development of conservation and restoration methods that more suitable with the features of thangka paintings.

X-ray fluorescence analysis of pigments used in thangka painting: These 10 thangka paintings from the Choijin Lama Temple Museum were restored by the National Center for Cultural Heritage in 2022. The paintings were restored by restorer A. Munguntsooj, who documented the restoration with photographs before and after, described the damages, performed dry and mechanical cleaning, smoothed out wrinkles, repaired torn areas, applied paints to the repaired areas, and pulled them onto new plates. I. E. Batjargal, as the Chief Technologist personally examined the pigments of above thangka paintings using an "OXFORD X-Met 7500 X-Ray analytical

microscope” to show what chemical elements the pigments are mainly composed of, and the “BIOBLUE”electron microscope to determine and identify the origin and characteristics of the fabric and organic materials at the cellular level.

Mongolians traditionally used two main raw materials to produce mineral dyes:

- Dyes derived from plants or animals are broadly known as ‘bio dyes’ or natural dyes¹.
- Dyes made by processing various types of minerals, clay, and rocks were called “earthen paints” or “dirt paints”.

Therefore, determining the origin and features of dyes and pigments in these paintings is vital for conservation and will be great importance for the conservation, protection, and restoration works.

RESULTS OF ANALYSIS

The analysis and comparison of the results of X-ray fluorescence analysis of above 10 thangka paintings shows that composition and color of pigments used for nine paintings, namely Tavan khan (Image 1), Jigjid (Image 2), Shash(Image 3), Namsrai (Image 4), Tsamba(Image 5), Gombo(Image 6), Damdinchoijoo(Image 7), Jamsran (Image 8), Lkham(Image 9) are all the identical. Particularly: Bluepigment composed mainly ofS-Sulfur, Si-Silicon, Al-Aluminum, As-arsenic;Red and brownpigments composed ofS-Sulfur , Hg-Mercury, Si-Silicon, Orangepigments -Pb-Plumbum, S-Sulfur , Cl-Chlorine, Yellowpigments composed of S-Sulfur , Mg-Magnesium, As-Arsenic, dark and pale greenpigments composed of Mg-Magnesium, Cu-Copper, As-Arsenic, White pigments composed ofS-Sulfur , Pb-Plumbum, Cl-Chlorine.

Table 1. X-ray fluorescence analysis of the pigments used in the “Tavan-Khaan” painting

Image	Color	Chemical element composition (Oxford x-met 7500 /Soil LE FP/)
	Sky blue	Si, S,Al, As, Mg, Cu, Ca, Cl, K,Ti, Ba, Fe, V, Sn, Sr, Tl, Mo, Mn, Rb, Se
	Red	S, Hg, Si,Cl, Ca, Au, Al,K, Ba, Fe, P, Pb, Ti, Sr, Zn, As, Cu, Mo, Se
	Yellow of hat	S, Mg, As,Si, Ca, Cl, Al,K, Au, Fe, Ba, Ti, P, V, Sb, Hg, Tl, Sr, Se, Cu,
	Orange	Pb, S,Cl, Si, P, Au, K, As, Ba, Tl, Fe, Ca, Sr, Se, Zr, Cu, Rb
	Green of land	Mg, As, Cu, Cl,Ca, Si, S, K, Ba, Fe, Ti, V, Sr, Au, Tl, Mo, Rb, Se
	Bright green	As, Cu, Si, Mg,S, Al, Cl, Au, Ca, Ti,Ba, K, P, Fe, V, Sr, Tl, Se, Mn, W
	Body brown	S, Hg, Si,Cl, Al, Ca, K,Pb, Fe, P, Au, Ti, Sr, As, Zn, Rb, Mo, Se, Cu
	White	S, Pb,Cl, Si, Ba, Tl, P, Fe, Ca, Sr, Zr, Rb, Se, Cu
	Body blue	Si, S,Al, Mg, As, Cu, Ca, Cl, K,Fe, Ba, Ti, Sb, Sn, V, Sr, Tl, Mo, Rb, Se

Table 2. X-ray fluorescence analysis of pigments used in the “Jigjid” and“Shash”paintings

Image	Color	Chemical element composition (Oxford x-met 7500 /Soil LE FP/)
	Black	Si, S, Al, K,Cl, Ca, Fe, Ti, Zn, As, Mn, Sr, Mo, Zr, Cu, Se
	Blue	S, Si,Ca, K, Al, Cl, Fe, As, Cu,Pb, Ti, Zn, Sb, Sr, Rb, Zr, Tl, Mo, Se
	Green	Si, As, S, Mg, Cu,Ca, Cl, Al, K, Fe,Pd, Ti, Zn, Sr, Tl, Mo, Zr
	Red	Pb, S, Hg,Cl, Si, Sn, Cd,P, Ba, Tl, Fe, Ca, Zn, Zr, Se, Sr, Rb
	Redframe	S, Hg, Si,Cl, Al, K, Ca,Fe, Pb, Zn, P, Au, Ti, As, Sr, Rb, Se, Mo, Cu
	Yellowframe	S, Ca, Mg,As, Si, Al, Cl, K,Fe, Ti, Zn, Hg, Cu, Tl, Sr, Mo, Zr, Se
	White	Pb, S,Cl, Si,Fe, Ca, Tl, P, Zn, Zr, Sr, Rb, Se
	Orange	S, Pb,Cl, Si, K, Al, Ca, Fe, Ti, Zn, Hg, P, Au, Tl, Sr, Zr, Se
	Starch /backside/	Si, Al,Cl, K, Pb, S, Ca, Fe, Ti,Zn, Ba, Au, As, Sb, Sr, Tl, Mo, Zr, Se

Table 3. X-ray fluorescence analysis of the pigments and paints used in the “Namsrai”thangka painting

Image	Color	Chemical element composition (Oxford x-met 7500 /Soil LE FP/)
	Palegreen	Mg, As, Cu, Cl,K, S, Si,Fe, Ca, Ti, Zn, Sb, Tl, Hg, Sr, Se, W, Zr, Mn, Rb
	Bright green	As, Cu, Mg,S, Si, Cl, Ti, Al, Ba, K, Ca,V, Fe, Sr, Zn, Sb, Sn, Hg, Au, Mn,
	Yellow of face	S, Mg, As,Si, Cl, K, Pb, Al, Ca, Fe, Ti, Zn, Sb, Sn, Tl, Sr, Zr, Cu, Se
	Orange	S, Pb,Cl, Si,Cd, Sn, As, Fe, Tl, Zn, P, Ca, Zr, Rb, Se, Sr, Ti, Cu
	Sky blue	S, Si, Mg,As, Al, Cu, Cl, Ca, K,Fe, Ti, Zn, Sb, Hg, Tl, Mo, Sr
	Bright blue	S, Si, Al,As, Mg, Cl, Cu, K, Ca, Fe,Ti, Zn, Ba, P, Au, Sb, Hg, Sr, Tl, Zr,
	Red	S, Hg,Si, Cl,K, Al, Au, Zn, Fe, Pb, Ca, P, Sr, As, Ti, Se, Ta, Cu
	White	Pb, S,Cl, Si, Cd, Sn,Al, Tl, Fe, P, Ca, Se, Zr, Rb, Zn, Sr, Cu
	Yellow	S, Mg, As,K, Si, Cl, Al, Ca,Fe, Ti, Zn, Pb, Sb, Sn, Hg, Sr, Mo, Tl, Cu, Zr,
	Starch	Si, Pb, Al,K, Cl, S, As, Ti, Cu,Ca, Fe, Zn, Tl, Zr, Se, Rb, Mo

Table 4. X-ray fluorescence analysis of pigments used in the “Tsamba”thangka painting

Image	Color	Chemical element composition (Oxford x-met 7500 /Soil LE FP/)
	Sky blue	S, Si,As, Mg, Cu, Al, Ca, Cl, K, Fe, Ti, Zn, Sb, Hg, Tl, Sr, Mo, Zr, Se
	Palegreen	Mg, As, Cu, Cl, K, Si, S, Fe,Ca, Ti, Zn, Sb, Au, Tl, Hg, Sr, Se, Mo, Zr
	Greenkhadag	As, Cu, Mg,S, Si, Ti, Cl,Ba, Al, V, Ca, K, Fe, Sr, Zn, Au, Sb, Hg, Mn
	Red	S, Hg,Si, Cl, K,Al, Fe, Ca, Zn, P, Au, Ti, Sr, Pb, As, Rb, Se, Mo, Cu
	Orange	S, Pb,Cl, Si, P,Au, As, Fe, K, Tl, Zn, Sb, Ca, Zr, Ti, Se, Sr, Mo, W, Cu
	Yellow	S, Mg, As,Si, K, Cl, Ca, Al,Fe, Ti, Pb, Zn, Sb, Sn, Hg, Tl, Cu, Sr, Se, Mo
	White	S, Pb,Cl, Si,Tl, Sn, P, Fe, Zn, Se, Zr, Ca, Rb, Sr
	Brown	S, Pb, Cl, Si,As, Fe, Al, K, Hg, Tl, Zn, P, Ca, Ti, Zr, Sr, Rb, Se, Cu
	Starch	Si, Al,As, Cu, K, Cl, S,Ti, Ca, Fe, Pb, Au, Zn, Sb, Sn, Tl, Sr, Mo, Zr, Se

¹Adya B, Batsuuri J, Purevbat G, Urtnasan N, Khishigt D, Sharkhuu S. “A Guide to Mongolian Traditional Methods for Reviving the Art and Decoration of Buddhist Temples and Shrines”. UB. 2006

Table 5. X-ray fluorescence analysis of pigments used in the “Gombo”thangka painting

Image	Color	Chemical element composition (Oxford x-met 7500 /Soil LE FP/)
	Sky blue	S, Si, Al, As, Mg, Cu, Cl, Ca, K, Fe, Ti, Zn, Sb, Sr, Tl, Zr, Mo
	Heavy blue of the body	S, Si, Al, K, Cl, As, Cu, Ca, Fe, Ti, Zn, Tl
	Pale blue of the body	S, Pb, Cl, Si, As, Al, P, Cu, K, Fe, Ca, Au, Zn, Ti, Tl, Zr, Sr,
	Orange	S, Pb, Cl, Si, Sn, As, Fe, Ti, Zn, P, Zr, Ca, Sr, Rb, Ti, Se, Cu
	Yellow	S, Mg, As, Cl, Si, Pb, K, Ca, Al, Fe, Ba, Zn, Ti, Tl, Sb, Hg, Cd
	Red	S, Hg, Si, Cl, Al, K, Fe, Ca, P, Zn, Au, Pb, Ti, Sr, Rb, Se, Mo
	White	S, Pb, Cl, Si, Cd, Sn, Tl, P, Fe, Zn, Se, Rb, Zr, Sr
	Earth green	As, Mg, Cu, Cl, K, S, Si, Fe, Ca, Ti, Zn, Sb, Sn, Au, Hg, Tl
	Green of the khadag	As, Cu, Mg, Si, S, Ti, Al, Cl, Ba, Ca, V, K, Fe, Sr, Au, Zn, Sb
	Brown of the hair	S, Pb, Cl, P, Si, Au, As, Fe, K, Hg, Zn, Tl, Ca, Ti, Zr, Cu, Sr
	Gold	S, Pb, Cl, P, Si, Au, Al, Fe, As, K, Zn, Ca, Tl, Ti, Zr, Cu, W
	Gray	S, Pb, Cl, Si, As, Fe, P, Tl, Zn, Zr, Ca, Sr, Ti, Rb, Cu, Se
	Redframe	Pb, S, Cl, Hg, Ca, Si, Al, Sn, Fe, P, Zn, Tl, Zr, Sr, Rb
Starch (front side)	Si, Al, K, Cl, S, Ca, Ti, Fe, Zn, As, Pb, Sr, Cu, Zr	
Starch (backside)	Si, Al, As, K, Cu, Cl, S, Pb, Ti, Fe, Ca, Zn, Sb, Tl, Zr, Sr, Mo	

Table 6. X-ray fluorescence analysis of pigments used in the “Damdinchoijoo”thangka painting

Image	Color	Chemical element composition (Oxford x-met 7500 /Soil LE FP/)
	Sky blue	S, Si, As, Mg, Al, Cu, Ca, Cl, K, Fe, Ti, Zn, Sb, Hg, Tl, Zr, Mo, Sr,
	Lightblue (cattle)	S, Pb, Cl, Si, As, Cu, Al, Fe, Ca, K, Tl, Zn, Ti, Zr, Sr, Rb
	Darkblue	Pb, S, As, Si, Mg, Al, Cu, Cl, Ca, K, Fe, Tl, Ti, Zn, Zr, Se, Sr, Rb
	Orange	Pb, S, Cl, Si, Fe, Tl, P, Zr, Ca, Zn, Sr, Rb, Se, Ti
	Yellow	S, Mg, As, Cl, Si, Pb, K, Al, Ca, Fe, Ti, Zn, Tl, Hg, Zr, Se, Mo, Cu
	Earth green	Mg, As, Cu, Cl, Si, K, S, Fe, Ti, Ca, Zn, Sb, Tl, Zr, Sr, Mo, Rb
	B-pale green	As, Cu, Mg, S, Ti, Si, Cl, Ba, V, Ca, Sr, Au, Fe, Hg, Sb, Mn, Zn
	B-darkgreen	As, Cu, Mg, S, Pb, Si, Cl, Ti, Al, Ba, Fe, Ca, V, K, Sr, Hg, Tl, Zn
	Red	S, Hg, Si, Cl, Al, Fe, Ca, P, Au, Pb, Zn, Ti, Sr, As, Rb, Se, Mo, Cu
	Brown	S, Pb, Cl, P, Si, Hg, Fe, Au, Al, As, K, Ca, Zn, Ti, Tl, Cu, Sr, Zr
	Body red	S, Pb, Hg, Cl, Si, P, Fe, Sn, Ca, Zn, Tl, Sr, Zr, Ti, Rb, Se
	White	S, Pb, Cl, Si, Tl, Fe, P, Zr, Zn, Rb, Sr, Se
	Black	Pb, S, Cl, Si, Al, Cd, Sn, Fe, Tl, P, Ca, Zr, Rb, Se, Sr, Zn, Ti, Cu
	Pink of the legs	Pb, S, Cl, Si, Hg, Cd, Sn, Tl, Fe, P, Ca, Zr, Zn, Se, Rb, Cu, Sr

Table 7. X-ray fluorescence analysis of pigments used in the “Jamsran”thangka painting

Image	Color	Chemical element composition (Oxford x-met 7500 /Soil LE FP/)
	Sky blue	S, Si, Al, Mg, As, Cu, Cl, Ca, K, Fe, Ti, Zn, Sr, Mo, Tl, Zr, Rb, Se
	Darkblue	S, Si, Al, Cl, As, Cu, K, Ca, Fe, Pb, Ti, Zn, Sb, Sr, Tl, Mo, Rb, Zr
	Orange	Pb, S, Cl, Si, Fe, Tl, P, Zn, Ca, Zr, Sr, Rb, Se, Cu
	Yellow	S, As, Mg, Si, Cl, Ca, K, Al, Fe, Zn, Sb, Ti, Ag, Hg, Tl, Se, Cu, Sr
	Red	S, Hg, Si, Cl, K, Al, Fe, Ca, Zn, P, Au, Sr, Pb, Ti, As, Mo, Rb, Se
	Bodyred	S, Pb, Cl, Hg, Si, Sn, Cd, Al, P, Fe, Tl, Zn, Zr, Ca, Sr, Se, Rb
	Land's green	As, Mg, Cu, Cl, K, S, Si, Ca, Fe, Ti, Zn, Sb, Sn, Au, Tl, Mo, Sr, Se
	B-green	As, Cu, S, Mg, Si, Ti, Ca, Cl, Ba, Al, V, K, Fe, Sr, Zn, Sb, Mn, Sn,
	White	S, Pb, Cl, Si, Cd, Sn, Tl, Ba, Zr, Rb, Zn, Fe, Se, Sr
	Black	Pb, S, Cl, Si, Cd, Sn, Al, Tl, Fe, P, Hg, Zr, Se, Ca, Rd, Zn, Sr, Ti
	Gray	Pb, S, Cl, Si, As, Al, Fe, Tl, P, Ca, Zn, Zr, Sr, Rb, Se, Cu

Table 8. X-ray fluorescence analysis of pigments used in the “Lkham”thangka painting

Image	Color	Chemical element composition (Oxford x-met 7500 /Soil LE FP/)
	Sky blue	S, As, Si, Cu, Ca, Mg, Al, Cl, K, Fe, Ti, Zn, Sb, Hg, Tl, Se
	Blue of the Body	S, Si, Al, As, Mg, Cu, Cl, K, Ca, Fe, Ti, Zn, Sr, Tl, Rb, Zr, Mo
	Blue of the cattle	S, Pb, Cl, As, Si, Cu, Ca, Al, K, Fe, Tl, Zn, Hg, Ti, Se, Zr, Sr,
	Orange	S, Pb, Cl, P, Si, Au, Fe, As, Tl, Zn, Ca, Zr, Ti, Sr, Cu, Rb, Se
	Yellow	S, Mg, As, Cl, Pb, Si, K, Al, Ca, Fe, Zn, Tl, Ti, Sb, Sn, Hg, Se,
	Yellow of the khadag	S, Mg, As, Si, Cl, K, Ca, Al, Fe, Ti, Zn, Sb, Hg, Tl, Se, Sr, Cu,
	Red of the Body	S, Pb, Hg, Cl, Si, Al, P, Sn, Fe, Cd, Zn, Ca, Tl, Zr, Sr, Cu
	Earth green	As, Mg, Cu, Cl, K, S, Si, Fe, Ca, Zn, Ti, Sb, Sn, Au, Tl, Hg, Mo
	Bright green	As, Cu, S, Mg, Ti, Ba, Si, Ca, V, Cl, Al, K, Sr, Fe, Zn, Mn, Sb,
	White	S, Pb, Cl, Si, Cd, Sn, Tl, P, Zn, Fe, Zr, Se, Hg, Rb, Sr,
	Black	Pb, S, Cl, Si, Fe, As, Al, P, Tl, Ca, Zn, Au, Zr, Rb, Sr, Se, Ti
	Bronze	Pb, S, Cl, P, Au, Si, Al, Ca, Tl, Fe, Ag, Zn, Cu, Se, Zr, W, Sr
	Pink	S, Pb, Cl, Si, Hg, Sn, P, Tl, Ca, Fe, Zn, Zr, Sr, Rb, Se
	Brown	S, Cl, Si, K, Hg, Pb, Al, Ca, Fe, Ti, Zn, Ba, As, P, Au, Sr, Mo
	Brown of the camel	S, Pb, Cl, Si, Hg, As, Fe, P, Zn, Tl, Ca, Zr, Sr, Ti, Rb, Se, Cu
	Brown of the khadag	S, Hg, Cl, Si, Pb, K, Ca, Au, Al, Fe, Ti, P, Zn, Cu, Sr, Mo, Se

Table 9. X-ray fluorescence analysis of pigments used in the "Sansarynkhurd" thangka painting

Image	Color	Chemical element composition (Oxford x-met 7500 /Soil LE FP/)
	Sky bluecolor	Zn, Si, Al, S, Pb, Cl, Ti, Ca, Fe, Cr, Ta, Sb, Sn, Co, V, W, Sr, Ni
	Paleblue	Zn, Cl, S, Si, Al, Ta, Cu, Cr, Sb, Fe, Pb, Ca, Sn, Ti, Co, Ni
	Orange	Zn, Pb, S, Cl, Cu, Si, Cd, Sn, W, Ti, Fe, P, Ag, Se, Rb, Ca, Zr
	Yellowcolor	Zn, Si, Cr, Sr, Al, Cl, S, Ca, P, Ta, Pb, W, Ti, Co, Rb
	Red color of the frame	Pb, Zn, S, Cl, Ti, Si, Al, As, W, Ta, Se, Ca, Fe, K, Cd, Ti, Zr, Rb
	Body brown	Zn, Cd, S, K, Se, Al, Si, Cl, Pb, Ca, As, W, Ti, Ta, Fe, Co,
	Orange of the clothes	Zn, S, K, Cd, Cu, Al, Cl, Ca, Si, Ta, Ti, Co, As, Hg, Ni
	Earth green	Zn, Cr, Al, S, Cl, Si, Pb, Ca, Ta, Co, Fe, Ti, Cd, Ni
	Whitecolor	Zn, Cl, Ta, S, Si, Sb, Fe, Co, Ca, Pb, Ni
	Blackcolor	Zn, Cl, S, Al, Ta, Si, Ca, Sb, Pb, Fe, Ti, Sn, Co, Ni
	Bronze	Zn, Cu, Cl, S, Al, Si, Cr, Sr, Ta, Cd, Sn, Ca, Fe, Se, Ti, Pb, Co, N

The comparison of these detected chemical elements composition with the results of X-ray fluorescence analyses made in other similar studies shows that the composition of pigments is identical, particularly with the results of:

- X-ray fluorescence analysis of Erdene Zuu Museum exhibits specified in the article of "X-ray fluorescence spectrometry analysis of some cultural relics of World Heritage Orkhon Valley" published by E. Batjargal and M. Oyuntulga in 2022 at the Museum Studies Journal of National Museum of Mongolia; and
- X-ray fluorescence analysis of the Shankh's Western Monastery; and
- "Some results of X-ray fluorescence spectrometry analysis made for preservation and protection of mural paintings of Tsamba temple of Erdene Zuu monastery" published by O. Angaragsuren at the Research and Public Journal "Orkhon Valley Heritage-2018"; and
- "Characterization and Analysis of painted Pigments from Erdene Zuu museum, Mongolia" by L. Shinebat, published in the same journal;

Also, researcher Sangwook Riyu in his lecture: "A Scientific Study on Pigments of Ancient Mongolian Cultural Properties," on November 25, 2022 at the "Paint Damages in Cultural Heritage" online course under CULTURAL HERITAGE Discussion series held by the American Center for Mongolian Studies presented the results of his study of pigments on objects from the Zaamar Shoroon Bumbagar tomb related to Turkic period. These results align with the data obtained from X-ray fluorescence spectrometry of 9 paintings above. Researcher Sangwook Riyu studies ancient Mongolian pigments and dyes and the presented results of his research based on X-ray diffraction analysis, show that the red pigments often made from Cinnabar² (HgS), Hematite (Fe₂O₃), Minium, Red Lead (Pb₃O₄); and white pigments - from Calcite (CaCO₃), Aragonite (CaCO₃), Cerussite³ (PbCO₃), Hydrocerussite⁴ (Pb₃(CO₃)₂(OH)₂), White Earth-Muscovite (KAl₂(AlSi₃O₁₀)(F,OH)₂); and, green pigments - from Malachite⁵ (Cu₂CO₃(OH)₂), Rosasite ((Cu, Zn)₂(CO₃)(OH)₂),

²<https://en.wikipedia.org/wiki/Cinnabar> Cinnabar Cinnabar (/ˈsɪn.ə.bɑːr/; from Ancient Greek κιννάβαρι (kinnábari)), [7] or cinnabarite (/ˌsɪn.əˈbɑːr.aɪt/), is the bright scarlet to brick-red form of mercury(II) sulfide (HgS). It is the most common source ore for refining elemental mercury and is the historic source for the brilliant red or scarlet pigment termed vermilion and associated red mercury pigments.

³<https://en.wikipedia.org/wiki/Cerussite> Cerussite (also known as lead carbonate or white lead ore) is a mineral consisting of lead carbonate (PbCO₃), and is an important ore of lead.

⁴https://en.wikipedia.org/wiki/White_lead White lead occurs naturally as a mineral, in which context it is known as hydrocerussite,^[1] a hydrate of erussite. White lead has been the principal white pigment of classical European oil painting. There have been claims that it is partly responsible for darkening of old paintings over time, reacting with trace amounts of hydrogen sulfide in the air to produce black lead sulfide.

⁵<https://en.wikipedia.org/wiki/Malachite> Malachite was mined from deposits near the Isthmus of Suez and the Sinai as early as 4000 BCE. Archaeological evidence indicates that mining activity ended c. 600 BCE, with up to 1,760 tonnes of copper being produced from the mined malachite. The use of azurite and malachite as copper ore indicators led indirectly to the name of

Atacamite⁶ (Cu₂Cl(OH)₃), Green Earth, Celadonite (K(Mg, Fe²⁺)(Fe³⁺, Al)[Si₄O₁₀](OH)₂), Glauconite ((K, Na)(Fe, Al, Mg)₂(Si, Al)₄O₁₀(OH)₂), blue pigments - from Azurite (Cu₃(CO₃)₂(OH)₂), Lapis lazuli⁷ ((Na, Ca)₈(AlSiO₄)₆(S, SO₄, Cl)₁₋₂). The X-ray fluorescence analysis of the grounds of Jigjid, Shash, Namsrai, Tsamba, and Gombo paintings revealed mainly Si-Silicone and Al-Aluminum, which is similar to the results of analysis of the mortar or wall yellow clay as provided in research article "An Investigation of the pigments and materials used in some mural paintings of Mongolia" by Odkhuu Angaragsuren and Kohdzuma Yohsei, as well as the results of the analysis of clay objects within the scope of work of cultural heritage expert from National Center for Cultural Heritage. All the pigments and dyes of Sansarynkhurd (Wheel of Life) painting are mainly composed of Zn-Zinc⁸. This is consistent with the results of X-ray fluorescence analysis of the composition of paints and pigments, provided in the scientific article presented by E. Batjargal named "Restoration of A. Sengetsokhio's "Emneg Surgagch (Horse-breaker)" painting", published in the Journal of Museum Studies from 2022 by the National Museum of Mongolia.

Analysis of Thangka painting's Fabric: Although the fabric materials of these thangka paintings are seemingly similar, we have examined five thangka paintings, including Tavan Khaan, Shash, Bayan Namsrai, Tsamba, and Sansarynkhurd to determine the origin, thread density, and weaving features of the fabric. In these surveys we use the "BIOBLUE" electron microscope that identifies organic materials at the cellular level. In material science, the raw materials of textile artifacts are classified into 2 categories: natural and chemical⁹.

the element nickel in the English language. Large quantities of malachite have been mined in the Urals, Russia.

⁶<https://en.wikipedia.org/wiki/Atacamite> Atacamite is a comparatively rare mineral, formed from primary copper minerals in the oxidation or weathering zone of arid climates. The mineral has also been found naturally on oxidized copper deposits in Chile, China, Russia, Czech Republic, Arizona, and Australia.

⁷https://en.wikipedia.org/wiki/Lapis_lazuli As early as the 7th millennium BC, lapis lazuli was mined in the Sar-i Sang mines,^[1] in Shortugai, and in other mines in Badakhshan province in modern northeast Afghanistan. It was used in the funeral mask of Tutankhamun (1341–1323 BC). By the end of the Middle Ages, lapis lazuli began to be exported to Europe, where it was ground into powder and made into ultramarine, the finest and most expensive of all blue pigments. Mines in northeast Afghanistan continue to be a major source of lapis lazuli. Important amounts are also produced from mines west of Lake Baikal in Russia, and in the Andes mountains in Chile which is the source that the Inca used to carve artifacts and jewelry. Smaller quantities are mined in Pakistan, Italy, Mongolia, the United States, and Canada.

⁸Adiya D. Bayarmaa G., Encyclopedia of chemistry. UB. 2012. p-244., Zinc ore was known to man since ancient times. B.C., the Greeks were able to make brass from zinc and copper alloys. There is reason to believe that there was a production of zinc metal in India as early as the 12th century, but in Europe it appeared much later. Many zinc compounds have the ability to glow. The three colors of the kinescope screen of televisions depend on zinc compounds. Blue ZnS-Ag, Green ZnSe-Ag, and Red Zn₃(PO₄)₂ are formed.

⁹<https://mn.wikipedia.org/wiki/Zinc> This metal was first used in production in England in 1743. A thin layer of zinc is applied to the faces of televisions and X-ray tubes. It protects against corrosion. The adult human body also contains 2.3 g of zinc, which is involved in the composition of more than 300 enzymes that regulate energy metabolism in cells.

⁹Munkhtogoo D. "Researches and developments to improve the preservation

- Natural fabrics: 1. Plant-based
 2. Animal-based
 3. Mineral-based
- Chemical fabrics: 1. Organic
 2. Non-organic (synthetic materials)

Table 10. Types and origin of textiles

#	Origin of textiles	Types of materials	Name of textiles
1	Animal-origin	Silk and silk-like materials	Silk, Puusuu- Silk velvet ,Magnag- Brocade, Atlas, Durdan (Crepe), Silk embroidery, Khorgoi (Brocade), Chischuu (Tussah Silk), Pans (Thin Silk Gauze), Satin, Uiten khuar (Jacquard Silk) Minchuu (Chiffon Silk), Sambai (Taffeta Silk)
		Woolen materials	Wool, Tsembe (woolen cloth), Odonchuu (baize cloth), Knitted woolen, Mixed woolen
		Leather and fur materials	Suede fabric, Fur, Sable
2	Plant-origin	Cotton plant-based materials	Cotton fabric, decorated velvet, Daalimba (Twill), Yambu (Gauze), Tarpaulin, Jeans, Velvet, Khamba (velvet), Termen (Muslin), Taar (canvas)
3	Synthetic materials and fibers	Synthetic materials	Capron, Nylon, synthetic silk

Image 1. Types of textile weaves¹

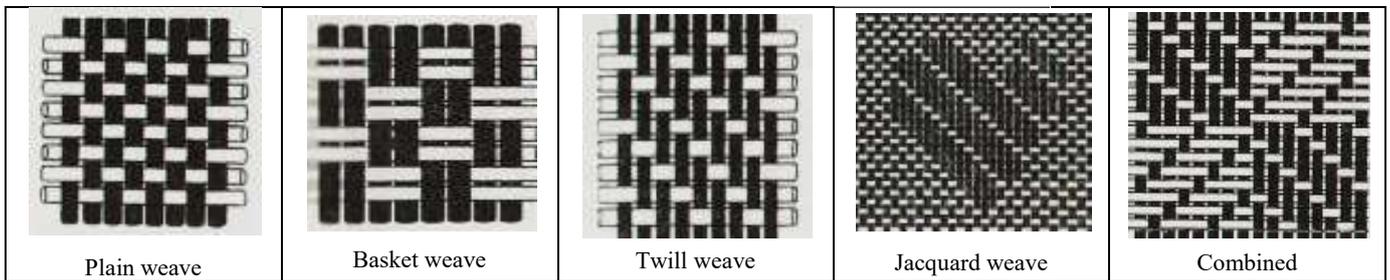


Image 2. Cell structure of textile fabrics¹



Image 3. Names and characteristics of yarn twists

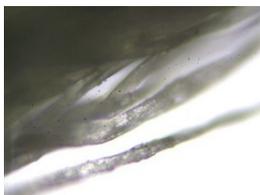
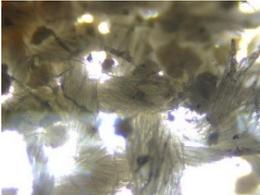
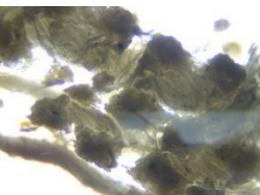
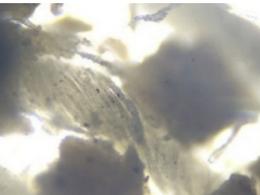
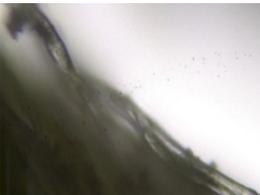
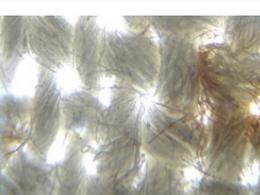
Yarn twists are classified by their direction: S-twist and Z-twist. The S-twist yarn is spun clockwise, while Z twist yarn is spun counterclockwise. However, if these yarns are twisted together, two individual “S”-twists form one “Z” twist, and two individual “Z” twists form one “S” twist¹.

As can be seen from the above table, the image of SP 4/0.10 Microscope objective shows the horizontal (warp) and vertical (weft) threads and the type of weaving, the image from SP 10/0.25 Microscope objective shows the warp of the fabric, and the SP 40/0.65 objective shows the thread fiber at cell levels.

RESULTS OF THE ANALYSIS OF PAINTING FABRIC

As shown in table 10 of electron microscope analysis of fabric, the horizontal and vertical threads and type of weaves at the image from SP 4/0.10 electron microscope display that all the fabrics have same plain weave pattern.

Table 10. Electron Microscope Analysis of Thangka painting Fabric

#	Painting name	Objective number (SP 4/0.10) (160/0.17)	Objective number (SP 10/0.25) (160/0.17)	Objective number (SP 40/0.65) (160/0.17)
1	Tavankhaan			
2	Bayan Namsrai			
3	Shash			
4	Tsamba			
5	Sansarynkhard			

The yarn twist shown at the SP 10/0.25 microscope image indicates that the yarn twist is "Z" or counterclockwise, and is twisted from right to left. The yarn fibers and cells at the SP 40/0.65 microscope image show that the material is plant origin cotton.

CONCLUSION

Based on the above results, it can be concluded that the pigments of nine paintings, namely Tavan khaan, Jigjid, Shash, Namsrai, Tsamba, Gombo, Damdinchoijoo, Jigjid, Lkham produced from minerals and precious stones, including blue pigments made from Lapis lazuli (azure) $(\text{Na,Ca})_8 (\text{AlSiO}_4)_6 (\text{S,SO}_4,\text{Cl})_{1-2}$, Red pigments – from Cinnabar (HgS), Green pigments – from Malachite (malachite) $(\text{Cu}_2\text{CO}_3(\text{OH})_2)$, Atacamite $(\text{Cu}_2\text{Cl}(\text{OH})_3)$, White pigments - from Cerussite (PbCO_3), Hydrocerussite $(\text{Pb}_3(\text{CO}_3)_2(\text{OH})_2)$. In prospect, the X-ray diffraction analysis is required to confirm this conclusion. According to the results of X-ray fluorescence analysis of the ground of Jigjid, Shash, Namsrai, Tsamba, and Gombo, it is believed that the ground was obtained from yellow clay.

It needs to be further studied, combining theory and practice. The composition of pigments used in "Sansaryn Khurd" painting is similar to the results of the X-ray fluorescence analysis of the pigments according to article "Restoration of A. Sengetsokhio's Emneg Surgagch painting" so it is clear that these paintings were painted at the same time and with the same process of painting. The "Sansaryn Khurd" painting was created by L. Darisuren in 1968, and the Emneg Surgagch painting was created by A. Sengetsokhio in 1963.

The results of the analysis of the fabric of the thangka paintings show that the fabrics all have the same plain weave, "Z" thread pattern, and are made of plant-based cotton fabric with mineral earth pigments. This study has great importance for the conservation and restoration work identifying the pigments composition, fabric origin and characteristics of above thangka paintings. In the future, it will become part of the basic scientific research on the conservation and protection of tangible cultural heritage.

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