The Production Method and Characteristics of the White Birch Bark Mudguard Flaps from Cheonmachong Tomb

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Introduction

A pair of white birch bark mudguard flaps featuring a now-famous image of a heavenly horse was discovered in 1973 during the excavation of Cheonmachong Tomb (Cultural Heritage Management Bureau, 1974). These flaps, which were likely applied as saddle attachments, were designated National Treasure No. 207 in 1974. Cheonmachong Tomb is a royal tomb located in Gyeongju, the capital of the Silla Kingdom. Originating in the southeast corner of the Korean Peninsula, the ancient kingdom of Silla endured for 992 years from 57 BCE to 935 CE. It is known that Cheonmachong Tomb was constructed in the early sixth century, but the identity of its occupant remains a mystery.

Mudguard flaps are used to keep a rider's garments clean and protect the rider from injury. They also help to prevent harm to the horse from the stirrups. Mudguard flaps were valuable objects that were included among prestige or grave goods by the Silla royalty and aristocracy, as evidenced by their discovery in Cheonmachong Tomb and Geumryeongchong Tomb (Chang Youngjoon 2015a, 62-73). However, the study of mudguard flaps (and particularly of their production process) has been limited due to the minimal number of related finds. The image featured on the mudguard flaps from Cheonmachong Tomb, on the other hand, has been intensively examined (Moon Gyeonghyun 2006, 1-38; Lee Songran 2002, 71-106; Lee Jaejoong 1991; 1994, 5-41; 2000, 23-59; 2002, 423-441), and it can now be identified with confidence as portraying a heavenly horse and not a Chimera Qilin (Chang Yongjoon 2015b, 74-95).

Little is known about the mudguard flaps from Cheonmachong Tomb apart from the fact that they were made from the bark of a white birch tree and that they feature a painted image. The flaps were found with one on top of the other. The heavenly horse image widely known among the public comes from the flap placed beneath. This lower flap was in a relatively good state of preservation since it had been protected by the flap on top. Conservation work had not previously been performed on this upper flap, but it was undertaken in preparation for the "Cheonmachong, a royal tomb of Silla" Special Exhibition organized by Gyeongju National Museum in 2014 and for the publication of *Mudguards with Heavenly Horse Design from the Cheonmachong Tomb of Silla* in 2015. This provided an opportunity for the study of the production method of both the upper flap and lower flap to take place.

This paper intends to examine the characteristics of the white birch bark used in the flaps in order to explore how mudguard flaps were manufactured during

Fig. 1. White birch bark mudguard flap from Cheonmachong Tomb (upper flap). Silla. Bark. Gyeongju National Museum Collection

Fig. 3. White birch bark mudguard flap from Cheonmachong Tomb (lower flap). Silla. Bark. Gyeongju National Museum Collection

Fig. 2. Infrared photo of the upper flap

Fig. 4. Infrared photo of the lower flap

the Silla period. The dating of the wood that provided the bark will also be considered. Various experimental and observational methods were applied to establish how the mudguard panels were made and to identify any differences that may exist between the images on the respective flaps. Three-dimensional scanning technology was also utilized in order to reconstruct how the mudguard flaps would have appeared at the time of their manufacture.

Mudguard Panel Dimensions and Materials

The two flaps are respectively referred to as the upper flap and the lower flap (Figs. 1–6) according to their position at the time of discovery. Each mudguard flap was made using three pieces of bark (one large and two small pieces).

Mudguard Flap Panel Dimensions

The front panels of both the upper and lower flap were each made from a single piece of bark. The back panels, in contrast, were made by connecting two pieces of bark, each of which was slightly larger than one-half of the front panel piece. The measurements for the panel pieces differ according to the point being measured, but the general dimensions are as follows.

The front panel of the upper flap, in its extant state, measures 73.4×54.7 centimeters. The back panel measures 72.6 ×52.6 centimeters. Of the two pieces forming the back panel, the left is 44×52 centimeters, and the right is 54.5×38.4 centimeters. The thickness of the front and back panels of the upper flap combined is 4–8 centimeters. The thickness of a given piece of bark can vary at different points due to the natural peeling of the surface or its intentional trimming during manufacture.

The mudguard flap panels are irregularly shaped due to the shrinkage of the bark components, making it difficult to precisely measure their dimensions. However, measurements taken with

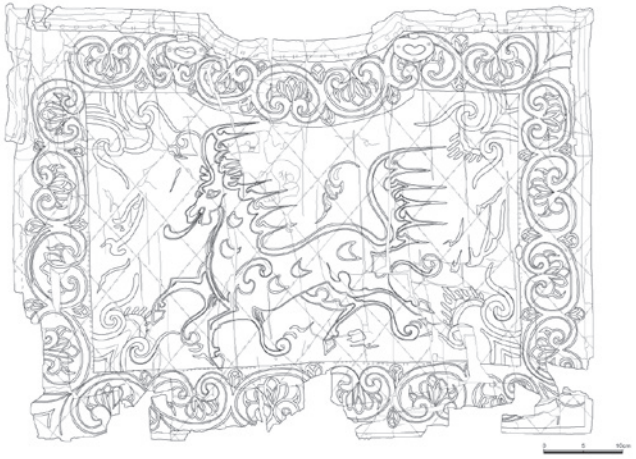


Fig. 5. White birch bark mudguard flap from Cheonmachong Tomb (upper flap)

Fig. 6. White birch bark mudguard flap from Cheonmachong Tomb (lower flap); The mudguard flap featuring a heavenly horse image widely known in Korea

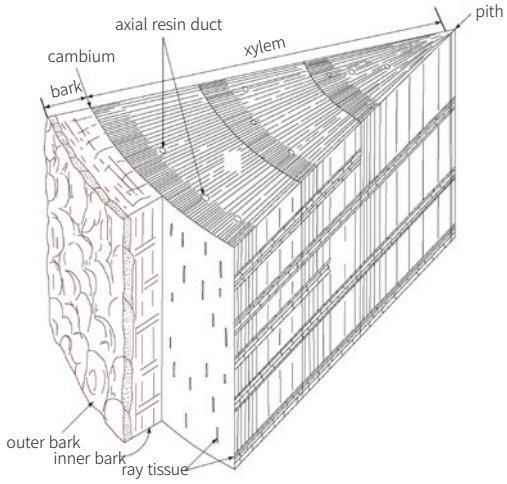


Fig. 7. Bark structure

Fig. 8. The bark and knots of a birch tree (from a birch grove in Inje, Gangwon-do Province) (Photograph by the author in January 2004)

a ruler and thread to accommodate the curved surfaces of the bark make it possible to estimate that the mudguard flap would have been 75.0 centimeters high, 56.8 centimeters wide, and 0.81 centimeters thick at the time of its production, slightly larger than its current size. The thickness of the front and back panels attached together is approximately 4.5 millimeters. However, at its thickest point, along a vertical line through center, the flap measured approximately 7–8 millimeters. This is the area where the two bark pieces forming the back panel overlap so the flap consists of three sheets of bark.

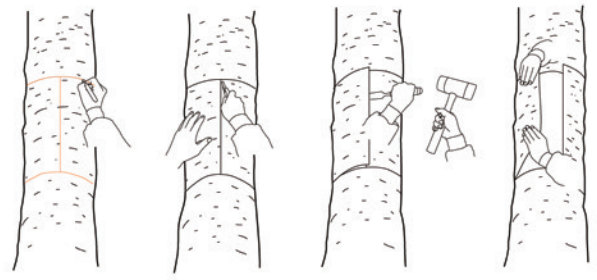
The front panel of the lower flap measures 73.2×55.2 centimeters in its present state. The left and right bark pieces forming the back panels measure 39.1×52.4 centimeters and 39.5×52.6 centimeters, respectively. The combined thickness of the front and back panels of the lower flap measures around 4–8 millimeters, varying at different points as in the case of the upper flap. It is estimated that the mudguard flap would have been 74.2 centimeters high, 56.0 centimeters wide, and 0.8 centimeters thick at the time of its production.

Based on the above, it can be established that the two mudguard flaps were similar in size at the time of their manufacture.

Mudguard Flap Materials and Characteristics

In the excavation report for Cheonmachong Tomb, the mudguard flap was identified as having been made from the bark of a white birch tree. The surface of a tree is conventionally covered by an outer and an inner bark (also known as *phloem*) (Fig. 7). The inner bark is formed from live parenchyma cells that serve to transport and store photosynthates and are sometimes active in carbon fixation. The outer bark is made up of dead tissues or cork structures which serve to protect the inner bark.[1] The bark panels of the Cheonmachong Tomb mudguard flaps were made from the outer bark of a white birch tree (Fig. 7).

However, the outer bark used for the mudguard flap panels could not have been obtained from simply any convenient white



1) Mark
Select a section of the bark where the surface is in a good condition and mark it out using the spine of a knife

2) Cut
Cut the marked section using a knife

3) Peel off using a tool
Peel off the bark by inserting a tool underneath the inner bark layer

4) Peel off using one's hands
Grab the bark as tightly as possible and pull away

Fig. 9. Method of detaching bark from a white birch tree

birch tree. Ideally, bark should be obtained from a tree with a clean and even surface free from significant knots, as shown in Figure 8. Birch bark that peeled off in single or multiple layers, as birch bark characteristically tends to do, or that shows a dirty surface or an excess of knots would not have been suitable for crafting these mudguard flaps. Therefore, it can be surmised that few knots, limited peeling, and an absence of branches would have been important factors in selecting outer bark for the manufacture of the mudguard flaps.

Late April or early May when the sap is flowing is considered the best time to harvest the bark of a white birch tree. Outside of this season, it is impossible to obtain good quality outer bark from these trees. The clean state of the inner surface of the outer bark used in both of the mudguard flaps. The absence of traces of discharge from the inner bark indicate that the bark is likely to have been obtained during this sap flow period (Fig. 9).

It is also important to estimate the age of the tree that provided the bark for the mudguard flaps, which can be done through an examination of tree rings. The thickness of the outer bark differs according to the growth conditions experienced by the tree, but if it is assumed that a new ring is formed each year, a supposition can be made regarding the age of a white birch tree by examining the layers of the outer bark.[2]

The layers of the bark used in the mudguard flaps were counted through microscopic observation. The thickness differed at points due to the natural peeling of the bark layers or as a result of human actions performed while processing the bark for use. In the case of both mudguard flaps, the bark forming the front panels was thinner than the bark used for the back panels.

The bark used in the front panel of the upper flap consisted of 34–36 layers, which indicates that the bark came from a white birch tree at least 36 years old. The bark used in the back panel showed 48–50 layers, indicating that the tree that provided the bark was at least 50 years old. In the case of the lower flap, the bark of the front panel consisted of at least 41 layers, and the thicker back panel consisted of at least 52 layers, thereby indicating respective minimum ages of 41 and 52 years old for the white birch trees that provided the bark.

The bark used for the back panels was thicker than that for the front panels. The reason for this is unclear, but it could be that due to difficulty with obtaining bark of high quality for the front panels, the back panels were made using two pieces of bark. In this regard, using thicker bark would have enhanced the strength of the panels and their ease of manufacture. The likelihood of this requires further consideration.

Production of the Mudguard Flaps

Connecting the bark pieces for the front and back panels

1. Overlapping the bark pieces for the back panel

The two bark pieces forming the back panel were connected before it was attached to the front panel (Figs. 10–12).

Processing the bark cannot entirely obscure the lenticels. Traces of them can clearly be seen on the surface of the bark used for the mudguard flaps. The front panel of the lower flap features lenticel traces running vertically, whereas the traces on the bark pieces forming the back panel run in a horizontal direction as they would have originally been oriented on the tree.

In the case of the upper flap, the inner surface of the outer bark was used for the front panel. The back panel was formed by placing two overlapping bark pieces (with the right-hand piece partially covering the left), and the entire panel was then stitched together at even intervals (Fig. 10). The back panel for the lower flap was made from two overlapping outer bark pieces with the inner surface facing outwards; this formed the back of the mudguard flap. The two bark pieces overlap by approximately 4.5–5.5 centimeters, with the right piece partially covered by the left and the overlapping area loosely stitched together. A thread consisting of two strands of fibers, similar to that used to attach the front and back panels of the mudguard flap, was applied to stitch together one-third of this overlapping section. The remaining two-thirds of the overlapping section of the back panel was stitched together using a single-fiber thread.

2. Combining the front and back panels

Fig. 10. The back side of the front panel of the upper flap (outer surface of the outer bark)

Fig. 11. The back side of the back panel of the upper flap (inner surface of the outer bark)

Fig. 12. The back side of the back panel of the lower flap (inner surface of the outer bark); the patterns observed are an imprint of the saddle blanket that was found beneath the lower mudguard flap at the time of its discovery

Fig. 13. Sewing traces and direction as seen in the cross section of the mudguard flap

The bark used in the lower flap shows a greater number of traces of large knots compared to the upper flap. In particular, the back panel features larger knot traces, and the state of its surface is in a poorer condition compared to the front panel, possibly because the front side of the back panel would have been covered by the front panel and not exposed. It is the front side of the front panel, crafted from the inner surface of the outer bark, that features the painted image.

If the bark surface had been left unworked, it would have been difficult to bind together two bark panels with their outer surfaces facing towards each other due to the uneven surfaces caused by knots. For this reason, the outer surfaces of the outer bark panels in both mudguard flaps were smoothed and flattened using a knife and other tools. Preventive measures were also taken to ensure that gaps did not appear between the two bark panels when they were bound together. It does not appear that any special adhesive was used when connecting the two pieces forming the back panel or when combining the front and back panels.

In order to bind the two pieces more securely, the two panels were adjusted to ensure that their lenticels alternated (Figs. 11–12). A quilting method was used to combine the two bark pieces forming the back panel and the single bark piece forming the front panel. This establishes that the method of quilting using a running stich was applied 1,500 years ago.

The stitching was performed by first carving grooved lines into the surface of the bark according to the intended final pattern. The width of the grooved lines was set so as to ensure that the threads did not protrude too much beyond the bark surface when the quilting had been completed. It is presumed that the grooves were cut into the surface using a metal tool such as a blunt knife. Given the thickness of the threads and the estimated size of the needle hole, it is also possible that the lines may have been established using the head of the needle. The stitching was executed at intervals of 0.2–0.4 centimeters. Each stitch is of a regular length (approximately 4 millimeters) and

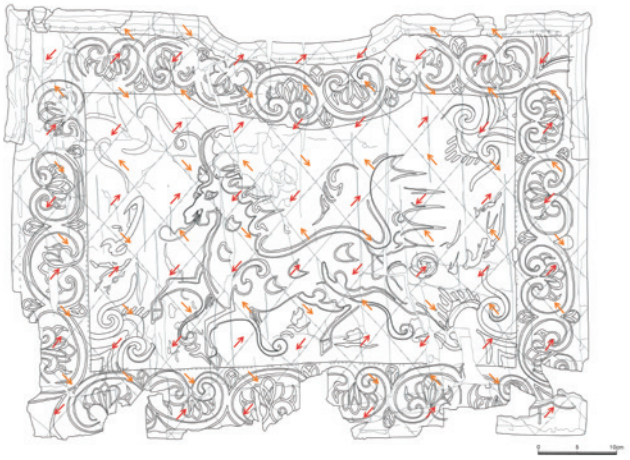


Fig. 14. Stitching direction used when quilting together the front and back panels of the upper flap

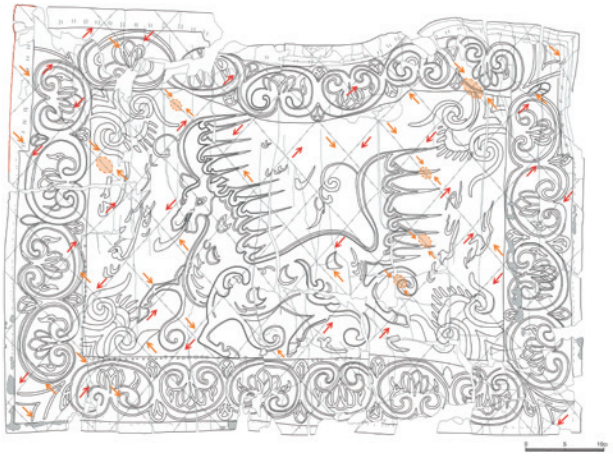


Fig. 15. Stitching direction used when quilting together the front and back panels of the lower flap; the dotted circles denote the points where the stitches end and new stitches begin

was made in a diagonal direction. Fourteen quilted lines run at an angle of approximately 45 degrees from the upper right to the lower left, and 15 quilted lines run from the upper left to the lower right. This is the case for both of the mudguard flaps.

The stitching did not involve the prior punching of holes for the needle to pass through; the holes were made by the needle at the moment of stitching. This can be established based on the fact the holes were observed to have been punched in alternating directions (as can be seen from their shape), which is to be expected when using a running stitch (Fig. 13). The stitching technique can also be established based on the shape of the holes: The needle first pierced the panel in an upward direction and then in a downwards direction.

Each section of the diamond-shaped pattern that was formed by the quilting tends to be around 6 centimeter long, although the lengths vary in between 5.5–6.0 centimeters. This level of regularity indicates that the intersecting intervals of the grooved lines for stitching were carefully measured beforehand.

Efforts were made to follow the grooved lines when stitching, but there were instances in which it was not properly observed and stitches strayed from the line. The grooved lines would have marked the place where the needle was to have penetrated the bark panel.

It can be observed from the lower flap that the direction of the stitches for the individual quilting lines could differ when required. The stitching directions in the upper flap and lower flap were found to vary (Figs. 14–15). In addition, there appears to have been no particular pattern to the knotting of the thread, as can be seen from the lower flap. It is possible to observe that the thread was knotted where it ran out or unexpectedly broke.

Framing the mudguard flaps

The mudguard flaps were bordered using leather on top and silk underneath. Different bordering techniques were used according to the material.

1. Underlying silk border

The silk used to border the mudguard flaps was a strip approximately 1.2 centimeter wide in the upper flap and 1.3 centimeter wide for the lower flap. The silk used to border the edges was fixed in place with stitches at intervals of approximately 5 millimeters. The silk was stitched to both the front and back sides of the flaps. Attempts were made, sometimes unsuccessfully, to align the stitches in a straight line. Observation of the boundary between the silk border and leather border reveals that the silk was covered by leather, which indicates that the silk was attached first. The absence of paint traces along the perimeters of the panel covered by the borders indicates that the mudguard flaps were bordered prior to their painting.

Several different types of fibers were used (Park Seungwon 2015, 194-201). In the case of the upper flap, a warp-faced compound woven silk (經錦) of combined construction, which is a figured cloth, and hemp were used. The woven silk for the back side of the upper flap is the same as that for the front. The silk covered an area 1.2 centimeter wide along the perimeters of the flap. The hemp thread is a loose right-twist thread. Decorative thread was also applied, as was the case for the front side of the flap. This yellow thread has an average diameter of 0.17 millimeters and is a loose right-twist thread.

2. Leather border

The upper edge and sides of the mudguard flaps were additionally bordered with leather 2.5–2.7 centimeters in width

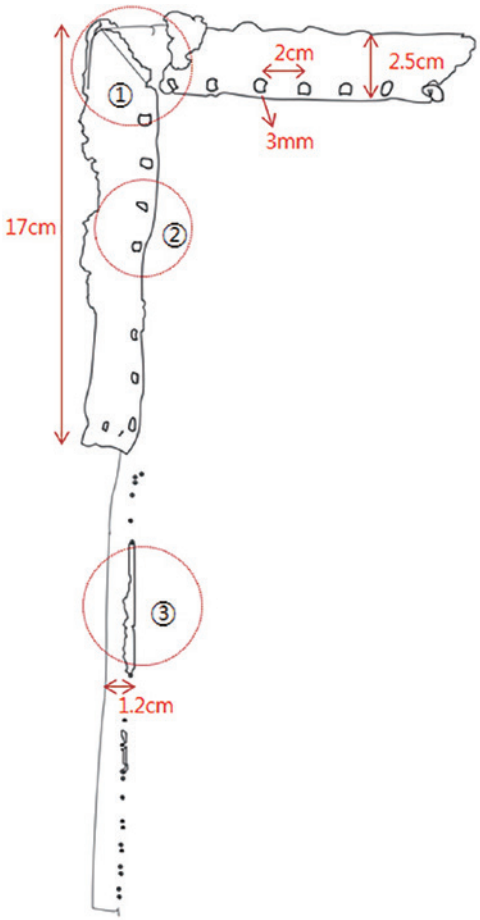


Fig. 16. Detail of the stitches and the treatment of the leather frame edges of the upper flap

attached by weaving a leather cord through pre-punched rectangular holes (Figs. 16–17). The leather cord was 3.7 millimeter wide and 1.3 millimeter thick.

The paired perforations for the leather cord form sets approximately 3 millimeters apart. In the underlying silk border, the distance between two stitches ranged from 1.3–1.5 millimeters. The holes were found to be located in a relatively regular manner.

The type of leather used could not be identified, but deer leather, which is supple and easy to manipulate, was often used for horse harnesses at the time.

The upper perimeters of the mudguard flaps were bordered with leather due to the gap between the front and back white birch bark panels, which made additional measures necessary in order to obtain a single edge. In addition, the leather served to protect the perimeters of the mudguard flaps from wear during use. The leather border also prevented the surface of the white birch bark from peeling off, which it tends to do, and restricted the bark panels from warping with fluctuations in temperature and humidity. Finally, the leather border also served to enhance the ornamental quality of the mudguard flaps. The thickness of the front and back panels attached together would have been substantial enough to allow the mudguard flaps to serve a practical function.

Fig. 17. The stitches and the treatment of the leather frame edges of the upper flap

Production of the image

1. Marking out the composition of the image

The area where the painting was to be made was marked onto the surface of the white birch bark using a pointed implement, such as a knife. The impressions can still be observed beneath the painted layer on the mudguard flap. Two types of incised lines guided the painting: those that divided the inner from the outer border of the mudguard flap and the grooved lines that guided the quilting stiches joining the front and back pieces. The grooved lines for the quilting stitches played an important role in structuring the composition of the painting.

The front side of the mudguard flap, which had been formed by combining the front and back panels, was composed of the inner surface of the outer bark layer of a white birch tree. The painting was made on this side. The background of the painting is a light yellowish-orange color, which is close to the natural color of the inner surface of the outer bark of a white birch tree, and it is quilted throughout. Pigment analysis carried out on this background revealed that it had not been painted.

It is believed that this unpainted background would have originally been lighter in shade. Such a light background color would have been ideal for successfully expressing the white color of the *cheonma* (天馬, heavenly horse).

2. Painting the image

1) Types of pigments

Previous analysis of the mudguard flap paintings and the bird painting (瑞鳥圖彩畵版, *seobongdochaewhapan*) from

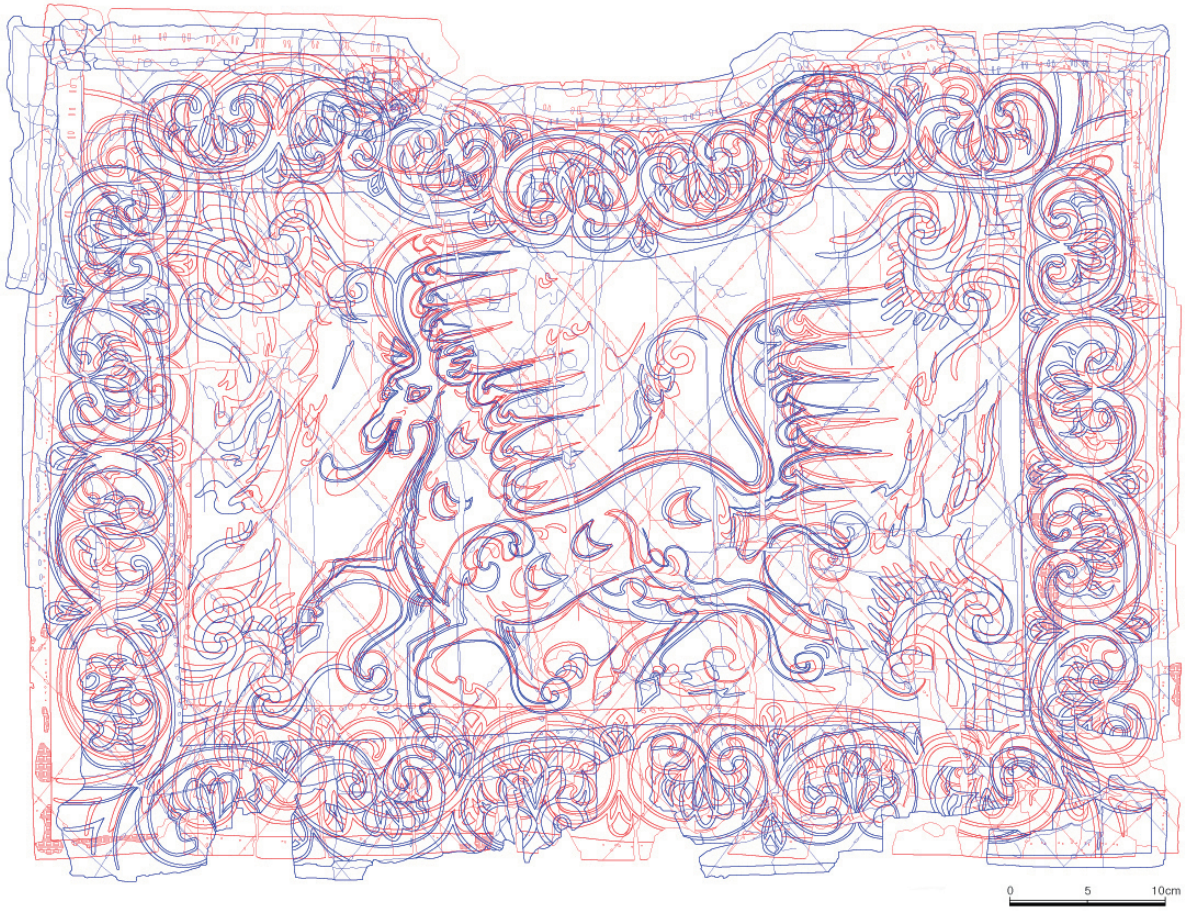


Fig. 18. Overlapped images of the paintings from the upper and lower mudguard flaps; the upper flap image is in blue and the lower flap image is in red

Cheonmachong Tomb revealed the use of white, red, and black pigments. Traces of malachite, which produced a green color, were also found (Yoo Hyeseon and Shin Yongbi 2015, 202-205). No remains of pigments were observed on the background of the mudguard flaps, indicating that it had been left unpainted. Four pigments were used in the painting on the flap: white lead for white, cinnabar for red, black from an ink stick, and malachite for green.

The red appearing in the Cheonmachong Tomb mudguard flap paintings and the bird painting was found to have been produced using a mixture of white lead (Pb) and cinnabar (Hg). In contrast, the red used in a horse-rider painting found in the tomb was produced by mixing iron oxide and lead. Similarities in the color composition and theme of the Cheonmachong Tomb mudguard flap paintings and the bird painting suggest that they were created using the same pigments.

2) Producing the image

It had previously been believed that the surface onto which the heavenly horse images were painted was the outer surface of the outer bark of a white birch tree. However, it was possible to confirm that the surface was in fact the inner surface of the outer bark. The inner and outer surfaces of the outer bark could be distinguished through differences in the knots, lenticels, color, and state of the epidermis. The images were painted onto an inner surface in the case of both the upper and the lower flap.

On the upper flap, attempts appear to have been made to avoid areas with knots while painting the images. Compared to the lower flap, the knots on the upper flap are smaller and less prominent. The lower flap, on the other hand, features relatively large knots, even on the front side where the image of the heavenly horse was produced. The rear portion of the horse is partially rendered over a knot. It is impossible to obtain birch bark strips that are entirely devoid of knots. However, the knots are less perceptible on the inner surface of the outer bark, resulting in a smoother surface. The inner surface of the outer bark also includes lenticels, but they are not highly visible through the painted surface and close inspection is required to identify them.

The outer surface of the outer bark of the white birch tree requires treatment prior to painting since it tends to peel off in layers. This peeling can also occur naturally during the treatment, painting, and drying process. The inner surface of the outer bark, on the other hand, is smooth and of an even color,

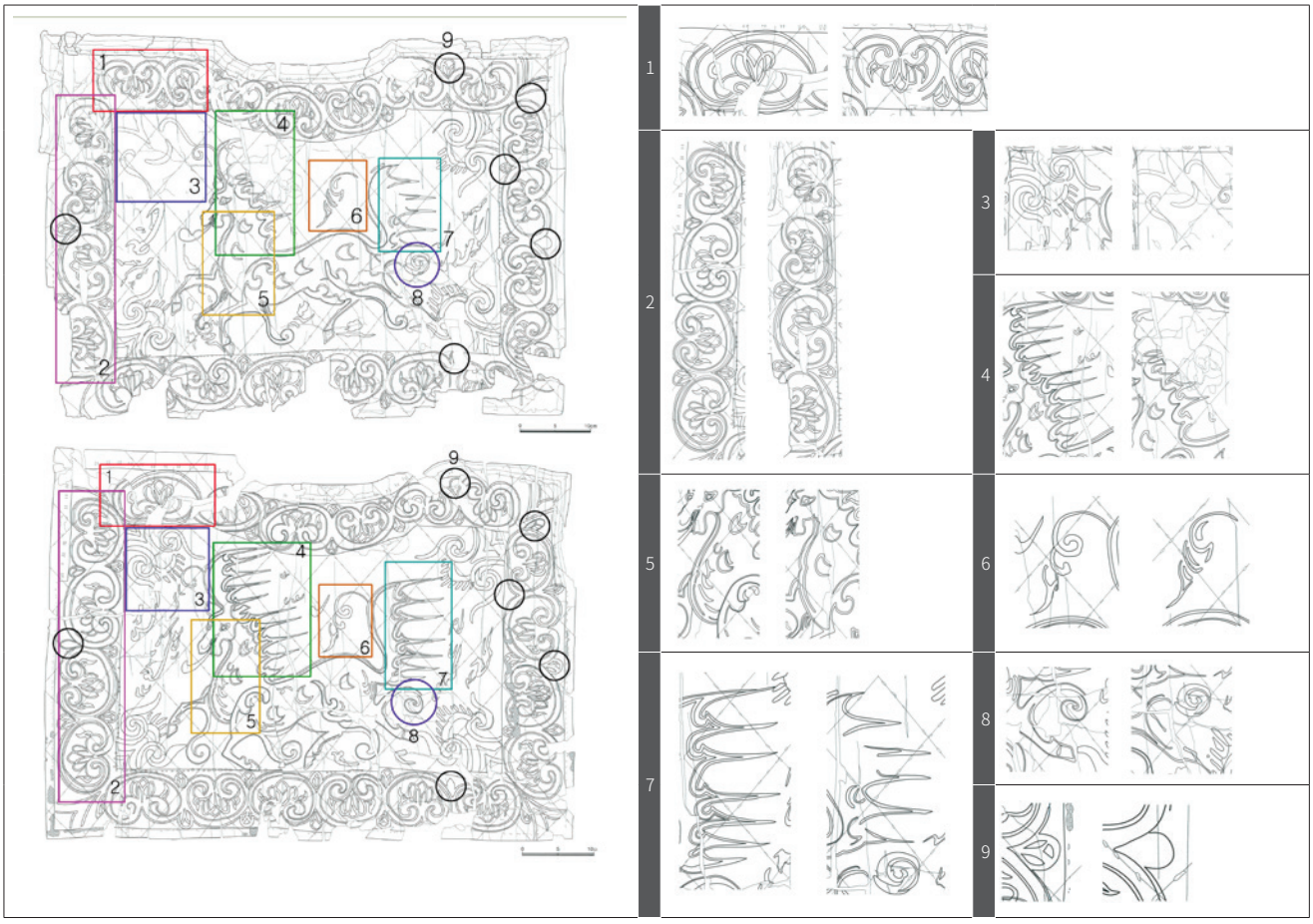


Fig. 19. Differences in the images of the upper and lower mudguard flaps

offering more favorable conditions for painting.

The lenticels of white birch bark cannot be entirely erased, even when layers of bark are peeled away. A more advantageous base for rendering the painted image would have been obtained if the full surface of the bark panel had been treated with a background color, but this was not the case. In addition to the risk of the bark peeling, one possible reason for the lack of a background may have been considerations related to the pigments. One of the four colors employed was a white produced with white lead. This white pigment was used for the key image on the mudguard flap, the white heavenly horse, and the lotus flowers as well. This white heavenly horse could not have been properly expressed against a white surface on the birch bark. It is therefore possible to presume that the painter limited the use of white pigments to ensure that the white heavenly horse would provide the focus of interest. It is likely due to such considerations, along with the condition of the bark surface and the characteristics of the pigments, that the mudguard flap paintings were rendered onto the inner surface of the white birch bark.

The painting sequence was as follows: peripheral images were produced first (this can be established based on the relationship between the hoof of the left foreleg and the right foreleg of the horse, and the peripheral lotus-flower patterns nearby), followed by the heavenly horse, and finally the four lotus buds featured within the lotus-flower pattern boundary. Black pigments were applied first in the painting of the lotus and arabesque pattern, followed by red and then by white.

3) Comparing the images of the upper and lower flap

The two mudguard flaps each featuring an image of a heavenly horse were attached one at either side of the saddle. It is interesting to note that each horse was painted facing in the same direction, which would have meant that when the mudguard flaps were attached to the saddle, one of the horses would have faced forwards while the other faced backwards.

In order to identity the differences between the two heavenly horses on the mudguard flaps, the two images were rendered in different colors and overlapped (Fig. 18). It can be observed that the two images are broadly similar in terms of composition. The interior space framed by the band of patterns running along the boundary of the flap features images of a heavenly horse, clouds, and lotus flowers. The peripheral band consists of lotus-flower and arabesque patterns, lotus-bud

patterns, and mountain-shaped patterns. However, differences can be identified in terms of the detailed form and size of the patterns, as well as other factors. This merits further discussion.

Firstly, in the case of the heavenly horse image, both horses are similar in size but unique in terms of their detailed patterns. The horse on the upper flap has a somewhat slighter build, while the chest of the horse on the lower flap is expressed in a more voluptuous manner. The location and number of crescent shapes on the bodies of the horses are also similar. However, three locks of hair can be seen on the chest of the upper-flap horse, but not on the horse on the lower flap (Fig. 19).

In the case of the horse on the upper flap, the left leg is bent to nearly a right angle, whereas the left leg of the horse on the lower flap is bent further towards the body. In addition, the joints and hoofs of the upper-flap horse are expressed in a more angular manner.

Various other minor discrepancies are apparent. Differences can also be identified in the location of the breath depicted as being expelled from the horses' mouths. The ears of the horse on the lower flap are expressed in a clearer manner, and the mane decorations above the forehead are longer and rendered in a more dynamic style (Fig. 19-4). The tails are of a similar length, but their positions vary slightly (Fig. 19-7). There is one area where a noticeable distinction can be observed in the patterns: the fern-shaped expressions of condensation emanating from the horses' bodies located between the rear leg and tail are curled in opposite directions (Fig. 19-8).

It is between the lotus and arabesque patterns forming the peripheral bands of the mudguard flaps that the images diverge most significantly (Figs. 19-1, 19-2). The upper portion of the peripheral band of the upper flap consists of seven arabesque and lotus-flower sections, but only six are apparent in the lower flap. The starting positions of the arabesque and lotus-flower sections also differ: the lotus-flower section furthest to the left points upwards in the case of the lower flap, but downwards in the upper flap (Fig. 19-1).

The lower portion of the peripheral band consists of an equal number of arabesque and lotus-flower sections (six each) in similar starting positions for both the upper and lower flap. Based on this fact, it is possible that both the upper and lower parts of the peripheral band had been intended to contain six arabesque and lotus-flower sections. Due to the slightly smaller size of the arabesque and lotus-flower motifs in the upper part of the peripheral band of the upper flap, an additional section had to be added in order to fill the gap in the band of patterns. The fact that the arabesque and lotus-flower section located second to the left on the upper part of the peripheral band of the upper flap is considerably smaller than the other sections provides evidence for this supposition. In addition, a single lotus bud can be found between the second- and third-left arabesque and lotus-flower sections in the lower flap, which is lacking in the upper flap (Fig. 19-1). As can be seen in section 9 in Figure 19, some of the lotus buds have their petals expressed while others do not.

In the case of both mudguard flaps, the left portion of the peripheral band consists of four arabesque and lotus-flower sections. However, the uppermost flower faces to the left in the upper flap and to the right in the lower flap. The size of the individual arabesque and lotus-flower sections also differs: The sections of the lower flap are slightly larger than those of the upper. The right part of the peripheral band demonstrates the greatest degree of uniformity in terms of the number, size, and positioning of the arabesque and lotus-flower sections. The only difference is the unique addition of lotus buds on the left part of the peripheral band of the respective flaps.

Based on the above, it can be considered unlikely that the images of the two flaps were produced by the same person. Clear differences can be seen in the detailed brushstrokes in the paintings and the techniques applied. However, it is difficult to know for certain whether the paintings referenced a common base sketch with the differences stemming from faulty execution. It would be expected that the appearance of the heavenly horse or the orientation of the peripheral band patterns would be the same if a base sketch had been referenced, but this is not the case. What is clear is that if both are copies of the same image, then one was a less-than-faithful reproduction.

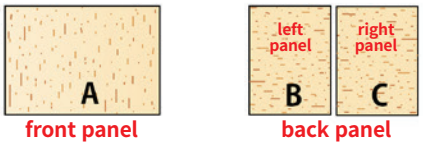
The attachment of horse ornaments

The horse ornaments attached to the mudguard flaps are all heart-shaped. The existence of these horse ornaments was unknown before their discovery during the preservation and reconstruction process. The rings of the ornaments were made of iron covered with gilt bronze. The central portion of the ornaments includes a silver covered heart-shaped design to enhance their decorative function. Each mudguard flap featured a pair of ornaments that were attached at the final stage of production.

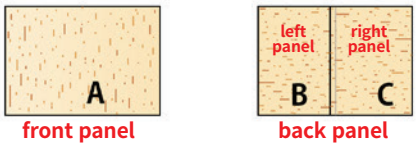
Production of a replica of the mudguard flaps

Three-dimensional scanning, infrared photography, X-ray photography, and observation with the naked eye were performed on the lower flap, which was relatively well preserved

1. Prepare the bark pieces for the mudguard flap panels

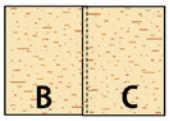


2. Overlap the bark pieces for the back panel

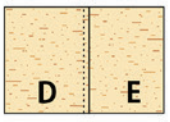


3. Stitch together the bark pieces of the back panel

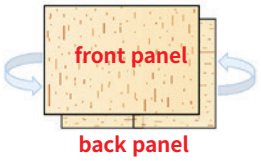
Place piece 'c' over piece 'b' for the 'upper flap'



Place piece 'd' over piece 'e' for the 'lower flap'



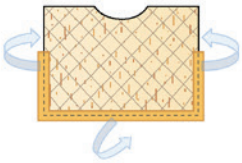
4. Combine the front and back panels



5. Form the upper indentation

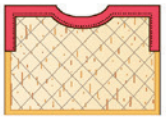
6. Stitch together the front and back panels

7. Trim the lower edges of mudguard flap using silk



Wrap the slik around the edges of the flap and affix by stitching

8. Trim the upper edges of the mudguard flap using leather



Wrap the leather around the edges of the flap
and affix by punching holes
and threading a leather cord

9. Paint the image

10. Attach the buckles

Fig. 20. Diagram of the production process of the mudguard flaps

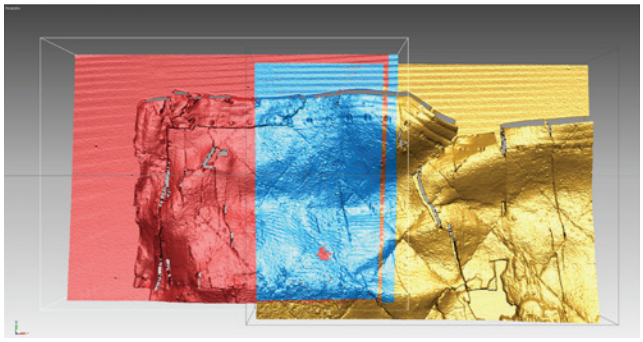


Fig. 21. Creation of polygon meshes

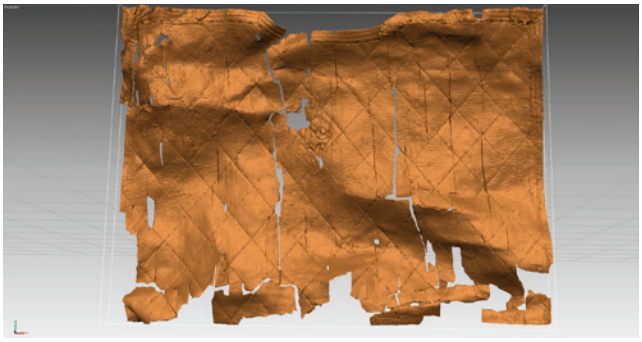


Fig. 22. Polygon mesh of the mudguard flap information

relative to the upper flap. These processes were used to craft a reproduction of the mudguard flap in its original state (Figs. 21–22).

Firstly, due to the uncertainty surrounding the original shape of the mudguard flap (given that it may have warped after it was buried), a detailed measured drawing of the mudguard flap was first produced using a 3-D scanner, and precise measurements were made to enhance the accuracy of the reproduction. Three-dimensional scanning was accomplished using a VIVID 910 scanner. The production of artifact drawings using a 3-D scanner has been widely applied to various artifacts on display, and the resultant information on the dimensions and colors of artifacts can contribute of the establishment of a database on such information. Three-dimensional scanning can involve direct and indirect contact; the Cheonmachong Tomb mudguard flap underwent the latter.

The data obtained through 3-D scanning can be directly accessed through a computer. If any of the resulting measurements or other types of data were unclear, the scanning was repeated. In the case of curved surfaces, the optical displacement measurement sensor was moved to a second position to scan and obtain measurements from an additional direction. Following the completion of the scanning, the data was edited using Rapidform software to create CAD models.

The polygon meshes generated using Rapidform software were compared with the X-ray images, infrared photos, and RGB data to make minor adjustments to the measured drawing, resulting in the final version. This measured drawing was compared with the actual mudguard flap, and color and detailed characteristics were then applied to produce a final reproduction (Fig. 23).

Conclusion

Various experiments and forms of observation were performed in order to establish facts concerning the production process of the Cheonmachong Tomb mudguard flaps, which had previously been unexamined. As a result, the following information could be obtained that provides important insights into the understanding of ancient cultures on the Korean Peninsula.

First, the bark used in the mudguard flaps came from a white birch tree and not a Korean birch (*Betula costata*). It should be noted that white birch is not indigenous to the Korean Peninsula.

Second, the mudguard flap image was painted on the inner surface of the outer bark rather than the outer surface.

Third, the background of the image was not painted, and the natural color of the inner surface of the outer bark of the white birch tree was utilized. Four different pigments were used: white lead for white, cinnabar for red, an ink stick for black, and malachite for green.

Fourth, the two heavenly horse paintings from the pair of mudguard flaps were not identical imitations of a single model. Their compositions are similar, but differences can be observed in the details of the iconography. It is possible that the pair of mudguard flaps may have been produced by the same person. However, given the complex nature of the detailed manufacturing process, a more likely scenario is that several people were involved in their manufacture through a division of labor.

Fifth, the Cheonmachong Tomb mudguard flaps may be regarded as an assemblage of diverse technologies that were in use in the ancient Korean societies of the time. The manufacturing process of the mudguard flaps took place in ten stages from the preparation of the white birch bark panels to the attachment of the horse ornaments. Some of these phases were complicated and involved several steps. For example, two pieces

Fig. 23. Proposed reconstruction of the lower mudguard flap

of bark were required to craft the two front panels and four were needed to make the two back panels.

Finally, a reproduction was created in order to reconstruct a pair of Silla mudguard flaps from the Three Kingdoms Period. These mudguard flaps would have been magnificent indeed at the time of their production. The heavenly horse is not only dynamic in nature, but almost seems to emanate a sacred aura.

This work represents the first stages of further study on these mudguard flaps. Additional research will be undertaken in order to supplement the limitations of the current paper.

Translated by Ko Ilhong

This article is an abridged and revised English version of "The Production Method of the White Birch Bark Mudguard Flaps" (白樺樹皮製 障泥의 製作 技法), previously published in 2015 in *Mudguards with Heavenly Horse Design from the Cheonmachong Tomb of Silla* (天馬塚出土 天馬文障泥).

1 Reference from article of the structure and characteristics of wood from the Korea Forest Service webpage http://forestland.go.kr.

2 The age of the birch bark was also discussed in the National Museum of Korea's "1997 Special Exhibition on the Conservation of Cultural Properties." Although this approach needs to be refined further, it has been proven that the layers of the outer birch bark and the tree rings are correlated.

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