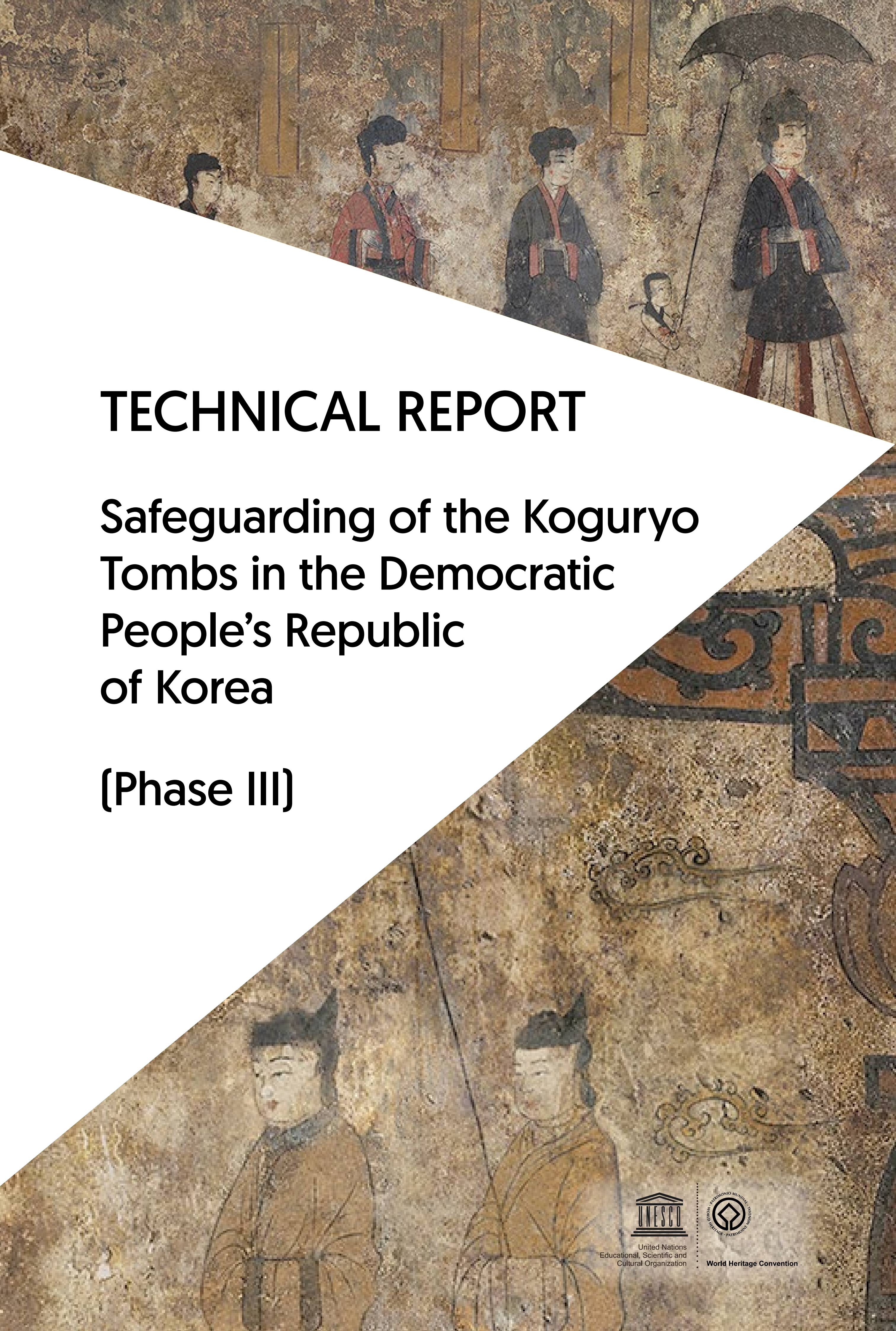

TECHNICAL REPORT

Safeguarding of the Koguryo Tombs in the Democratic People’s Republic of Korea

(Phase III)

UNESCO
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Preface

by Mechtild Rössler, Director of the UNESCO World Heritage Centre

The preservation of the Koguryo Tombs and mural paintings stands out as one of UNESCO's flagship projects in safeguarding the shared cultural heritage of humanity". This vast world Heritage property includes several group and individual tombs - totalling about 30 individual tombs - from the later period of the Koguryo Kingdom, one of the strongest kingdoms in nowadays northeast China and half of the Korean peninsula between the 3rd century BCE and the 7th century CE. Inscribed on the World Heritage List in 2004, the Complex of Koguryo Tombs, with its wealth of exquisite mural paintings, are masterpieces of the culture and period of the Koguryo Kingdom.

For almost two decades, UNESCO has been working closely with the Democratic People's Republic of Korea on the safeguarding of these tombs, many of which were discovered only recently and were sometimes in dangerously threatened condition. I am therefore very pleased to introduce this report on Phase III of this conservation project, which has been ongoing since 2001 thanks to the generous support of the Republic of Korea, via their UNESCO Funds-in-Trust available at the World Heritage Centre.

Between 2008 and 2015, large-scale conservation work was undertaken at the Susan-ri Tomb, whose mural paintings are some of the most significant remain of the Koguryo era in the whole of northeast Asia. International experts have been working closely with the national authorities, collaborating on the restoration of this tomb and putting their knowledge, experience and know-how at the service of this important interdisciplinary project. By reinforcing the Democratic People's Republic of Korea national capacities in the field of conservation through this cooperation between experts, we can guarantee that, in the future, such work can be carried out independently to the highest possible standards. I wish to take this opportunity to sincerely thank the authorities of the Democratic People's Republic of Korea for their commitment to ensuring the success of this undertaking and for facilitating the implementation of this project on site.

I also wish to extend my deep appreciation to the Republic of Korea, and especially the Cultural Heritage Administration (CHA), for their generous support over many years. In line with its mission to promote mutual understanding and peace, UNESCO protects cultural and natural heritage, which reinforces bonds between people, and this project proves the immense value of international cooperation around World Heritage.

Our common work was guided by the strong conviction that heritage conservation brings us together as a single human community, and that World Heritage properties, with their recognised Outstanding Universal Value, have the power to unite us beyond our differences. A complex, long-lasting project such as this proves that, even in challenging times, culture has a major role to play in laying the foundations for peace-building and international cooperation.

Like the reconstruction of the Mostar Bridge in Bosnia and Herzegovina or the Mausoleums in Timbuktu, Mali, this project reinforces UNESCO's fundamental belief that heritage can serve as a powerful tool for dialogue and reconciliation. I am convinced that this initiative to preserve a significant component of the common heritage of all Koreans marks an important step in the process of building bridges in the region, and I look forward to seeing the impact of this important work over many years to come.

This project also provided many lessons for us to learn from, and which we hope to integrate into upcoming new phases of this ongoing project. By granting public access to this publication, and therefore to the theoretical approaches, methods and processes used for the conservation of the Susan-ri Tomb, I hope to inspire many similar properties around the world to join us in a reflection on conservation practices, especially for mural paintings in damp environments. The 2015 Berlin Guidelines for the Conservation and Maintenance of Mural Paintings in Subterranean Environments marked an important step in this regard, and I look forward to building on this experience by pursuing our work with national authorities to enhance cultural heritage in the region.

Together, we must redouble our efforts to nurture such projects that bring people together across borders and divides, and give them the visibility and recognition that they deserve, as they showcase the exceptional, transformative power of heritage—namely to construct, as UNESCO's Constitution puts it, the defences of peace in the minds of people.

M. Rössler

Part I

Historical and Cultural Considerations

Introduction

by Dr Feng Jing, Chief of the Asia and the Pacific Unit,
UNESCO World Heritage Centre

Since October 1999, the UNESCO World Heritage Centre (WHC) has been actively assisting the authorities of the Democratic People's Republic of Korea (DPRK) in their efforts to preserve and protect their cultural heritage. The many fruitful results obtained since are largely due to the establishment of the UNESCO/Republic of Korea Funds-in-Trust for the preservation of the Cultural Heritage in the Democratic People's Republic of Korea.

The **first phase** of this large-scale extra-budgetary project (2000-2002, 100,000 USD) saw the establishment of a regular cooperation between the DPRK, WHC and international experts dispatched to the site to lead important conservation works and develop the capacities of local heritage professionals for the preservation of their national heritage. This first phase focused on a survey on the precarious conservation condition as well as most pressing needs in the field of conservation in the DPRK, as well as on provision of most basic equipment such as a basic conservation laboratory and conservation library including a truck. By involving the International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM) and the International Council on Monuments and Sites (ICOMOS) for the provision of technical expertise, the DPRK experts were able to access an international network of conservation specialists for long-term cooperation. This phase also ensured a strengthening of the national legislation and management system for the conservation of cultural heritage.

The **second phase** of the project (2004-2006, 500,000 USD) responded to the DPRK's urgent need for better conservation and preservation of the property "Complex of Koguryo Tombs", inscribed on the World Heritage List in 2004. The Yaksu-ri tomb was very much in need of urgent structural and conservation interventions, in order to safeguard the tomb and its mural paintings which, due to severe water infiltration, were showing serious signs of degradation. Aside from its conservation component, the project aimed to reinforce national capacities in the field of conservation, as the only sustainable way to preserve this outstanding heritage of the Koguryo Kingdom. The project therefore included intensive conservation training workshops, especially with the provision of a basic conservation laboratory, which did not exist in the DPRK. Through the project implementation, guidelines for monitoring the state of conservation of cultural heritage properties were formulated.

In addition, taking into account that a good understanding of the original techniques and materials is essential for the appropriate conservation of mural paintings, the scientific aspect of the project focused on the study of the ancient execution techniques and materials. This second phase of the project was considered very successful by the national authorities and experts in the DPRK, and the conservation works carried out in the Yaksu-ri tomb, along with the establishment of basic scientific and conservation laboratories, represented important achievements for the DPRK. National experts were trained to understand and implement conservation, protection and management systems to high international standards, and the establishment by the DPRK of a multi-disciplinary National Conservation Team for the conservation of the Koguryo tombs and their mural paintings marked a significant step forward. The works undertaken at the Yaksu-ri tomb, which was deteriorating rapidly at the beginning of this project, became a model for on-site training, under the leadership of UNESCO's conservation expert, Rodolfo Luján-Lunsford.

The **third phase** (2008-2015, 1M USD), which is the object of the present report, focused on capacity-building activities and on-site stabilisation and conservation activities for the Susan-ri Tomb, to address the urgent need for conservation interventions to safeguard the mural paintings found inside the tomb. This third phase was meant to serve as a pilot project, undertaking the full safeguarding of a tomb with the National Conservation Team from start to finish, using the highest available techniques and materials to ensure the best possible quality of restoration. This included conservation works on the mural paintings and structural interventions both for the Susan-ri and Yaksu-ri Tombs. The project also aimed to reinforce national capacities through on-site training and by organising a Study Tour in Europe for selected members of the DPRK National Conservation Team. Additionally, research activities focused on methods for the removal of mud encrustations on the mural paintings and on the monitoring of microclimate environments of the Koguryo Tombs, in order to establish a long-term preservation strategy for the Koguryo Tombs World Heritage site.

Upon completion of the activities, Phase III of the project achieved the following tangible outcomes:

- **Conservation:** Completion of the conservation of the Susan-ri Tomb's mural paintings, as well as the tomb's structural problems, such as serious water infiltration both for the Susan-ri and the Yaksu-ri Tombs, under the guidance of international experts, notably Rodolfo Luján, Sandro Massa and Claudio Margottini;
- **Research:** Completion of various research projects in collaboration with the Rathgen Research Laboratory of the Berlin State Museums, Korean mural painting conservator Mr Kwon Woong Lim, and international experts working with UNESCO. These were intended not only to carry out scientific research for conservation but also to establish a learning process about the conservation methodology, including its application for the DPRK National Conservation Team;
- **Capacity building for the DPRK National Conservation Team:** Through collaborative on-site work and a study tour, the project reinforced the national capacities for conservation and management of the World Heritage property 'Complex of the Koguryo Tombs' and ensure that works can be undertaken independently by the national authorities to the highest international standards in the future;
- **Provision of equipment/materials:** The project provided both basic infrastructure and technical/specialized equipment required for conservation (via Maccaferri Asia and GlasBau Hahn), continuing training and human resource building for

DPRK national experts through on-site training; also provided the project vehicle (mini-bus); The newly provided glass barrier through GlasBau Hahn considerably reinforced the presentation of the Susan ri Tomb' s mural paintings;

- **Promotion of the Koguryo Tombs and mural paintings**: Successful promotion of the Koguryo World Heritage and the work of UNESCO at the international level through various promotional activities, notably the exhibition organized at the UNESCO Headquarters in 2012.

The activities implemented in the framework of this project reinforced the national capacities in the field of conservation and management, which is one of the primary concerns in ensuring the sustainability of the Koguryo World Heritage site of the DPRK. The project also directly benefited experts from the DPRK, who had the opportunity to strengthen their theoretical and operational knowledge, which will in time allow them to independently lead restoration works and thereby guarantee the long-term conservation of the property.

The Project was monitored by the World Heritage Centre through regular meetings of experts gathered as a Steering Committee, which took place after each of the seasonal fieldwork sessions (one in the spring and one in the autumn of each operational year). Mr Rodolfo Luján, the main mural paintings conservator, and other experts who took part in fieldwork provided the Steering Committee with a detailed debrief on the activities undertaken, the degree of the co-operation with the DPRK authorities and the National Conservation Team, and any challenges (notably technical and practical) encountered during the fieldwork. As a coordination mechanism, the Steering Committee also offered a platform to discuss and plan activities for upcoming fieldwork, thereby allowing the World Heritage Centre to closely monitor the progress achieved with conservation work within Susan-ri Tomb.

Fig. 1: Irina Bokova, then Director-General of UNESCO, meets with the Ambassadors of the Democratic People's Republic of Korea (left) and the Republic of Korea (right) at the unveiling of the exhibit on the project in 2012,

Fig. 2: A panel from the 2012 exhibition showcasing restored Koguryo mural paintings

The main experts involved in the project were:

- Mr Rodolfo Luján Lunsford, senior mural painting conservator and main coordinator of the project;
- Prof. Claudio Margottini, geo-physical engineer;
- Prof. Stefan Simon, Director, Rathgen Forschungslabor, Berlin State Museums;
- Mr Tobias Hahn, CEO of Glassbau Hahn (Germany), a world-renowned glass manufacturing company specialized in museum-grade glass.

In order to reinforce the scientific aspect of the project, the World Heritage Centre cooperated with the Rathgen Research Laboratory of the Berlin State Museum (Germany), who acted as the project's scientific advisor during the period of the implementation of the Project.

Dr Stefan Simon, then Director of the Rathgen Research Laboratory, carried out a couple of missions to provide *in situ* advice to various conservation activities. In addition, the laboratory undertook various analyses on samples taken from Susan-ri mural paintings, notably to determine the pigments and material used in the mural paintings. On the basis of the analysis provided by the Rathgen Laboratory, the most appropriate methods for conservation could be identified, from cleaning to complex treatment and restoration.

Dipl. Restorer Mr Kwon Woong Lim, a Korean mural painting conservator, was invited by UNESCO to share his international experience in the field of conservation, notably to address the complex issue of finding the most appropriate method to safely remove mud encrustations. Mr Lim also focused on the consolidation of the mural paintings for the Susan-ri Tomb. To further improve the state of conservation using scientific methods, the results of his analyses were sent to the DPRK National Conservation Team, who carried out experiments to verify the effectiveness of his proposed consolidation methods, which were eventually used during conservation activities

As the following report will outline, the implementation of the project was very successful and the experts were able to work closely with the National Conservation Team on the stabilisation, conservation and presentation of Susan-ri Tomb. However, it should be noted that the operational implementation of the conservation activities was sometimes rendered extremely difficult due to the specific context of the beneficiary country. Although the project benefited from the full support of the Government of the DPRK, for which the World Heritage Centre is extremely grateful, the project encountered various delays due to the realities of the DPRK: for instance, the provision of a new glass barrier was extremely difficult, resulting in a delay of more than a year for delivery and installation. The lack of a monitoring system for the tombs and the absence of data loggers and weather stations proved to be great obstacles for the project, as they did not allow carrying out scientific conservation based on real data. This was due to the lack of basic materials (such as batteries), combined with difficult environmental/working conditions, which made the implementation of the project challenging. This is also representative of larger practical issues in the DPRK, as many monitoring and conservation tasks require the availability of a number of pre-existing facilities and conditions: vehicles, sufficient fuel and power sources, and the availability of various necessary tools and devices.

In spite of a broad range of obstacles and challenges, the World Heritage Centre noted with great satisfaction the significant, tangible outcomes of the project, and notably of Phase III. Since 2000, the notion of scientific conservation, which did not exist in the DPRK prior to the establishment of the UNESCO project, has been successfully introduced. In addition, the National Conservation Team established as part of Phase II of the project contributed not only to the conservation of Koguryo tombs and their mural paintings but also to other heritage sites and in museums in the DPRK. Therefore, the impact of the project has been felt nationwide, beyond the project activities themselves.

In celebration of the decade-long international cooperation in the framework of the UNESCO/Republic of Korea Fund-in-Trust project, a Photo Exhibition entitled '*Preservation of the World Heritage Site of the Koguryo Tombs and Mural Paintings of the Democratic People's Republic of Korea, 2001-2012*' was held at UNESCO Headquarters in Paris, from 12 to 26 October 2012. Reflecting the Donor's wish to increase the involvement of Korean experts in the project as much as possible, this exhibition was organized by the UNESCO World Heritage Centre, in close co-operation with Professor Hotae Jeon (Art Historian, expert on the Koguryo period), Kwon Woong Lim, and Sangran Kim (scenography expert).


Fig. 3: Irina Bokova and UNESCO representatives are being guided through the exhibit by the project experts

Inaugurated by the then-Director-General of UNESCO, Irina Bokova, and the ambassadors to UNESCO of the Democratic People's Republic of Korea and the Republic of Korea, along with many other dignitaries, the exhibition drew significant attention within and outside of UNESCO, receiving very positive feedback and further enhancing the visibility of the project as an important flagship project for UNESCO.[1] This project proves that, even in challenging times, cultural diplomacy can play an important role in laying foundations for peace-building and international cooperation, promoting dialogue between people.

Through the conservation work carried out as part of this project, under the guidance of UNESCO's international experts, the interdisciplinary National Conservation Team gained considerable expertise with regard to a holistic approach to the conservation of mural paintings. However, taking into account that they had never seen other mural paintings than the ones found in the DPRK's Koguryo Tombs, it was deemed important to provide the National Conservation Team with various case studies. Therefore, a study

1 See the event page on the World Hertiage Centre's website: http://whc.unesco.org/en/events/960

tour was organised in Paris (France), Rome (Italy) and the Vatican City (Holy See), from 4 to 9 March 2013, organised around visits to museums, sites and cultural organizations. Following the museum visits in Paris for the purpose of learning object conservation and visitor management, the four DPRK experts, under the leadership of Rodolfo Luján, embarked on a study journey in Italy (6-9 March 2013), mainly focusing on mural painting conservation and management *in situ*. The team visited the World Heritage property 'Etruscan Necropolises of Cerveteri and Tarquinia' and the *Museo Archeologico Nazionale Tarquiniense*, where they studied excellent examples of mural painting conservation and management could be studied in overall, learning various techniques used for the conservation of mural paintings and the details of the implementation of the management plan. In addition, they observed how the micro-climate environment of the underground tombs has been effectively addressed to enhance the state of conservation of the mural paintings.

Fig. 4: Opening of the 2012 exhibit at the UNESCO Headquarters in Paris

For the purpose of this study tour, the World Heritage Centre managed to obtain from the authorities of the DPRK the necessary permissions for three national experts to travel abroad, with the support of the Permanent Delegation of the DPRK to UNESCO. Through the study tour, the three participating members of the National Conservation Team were able not only to indirectly experience conservation processes for mural paintings in a different part of the world but could also meet peers and colleagues of various countries and discuss with them challenging issues related to the conservation of mural paintings. This helped considerably increase their knowledge of mural painting conservation and also benefited the National Conservation Team as a whole, thanks to a 'training of trainers' approach.

At the end of Phase III, the UNESCO Expert Workshop "Conservation of mural paintings: Access, Research, Conservation" was held on 2-4 June 2015 at the Museum of Asian Art (*Museum für asiatische Kunst*) in Berlin (Germany). This workshop was jointly organized by the World Heritage Centre, the Rathgen Research Laboratory of the Berlin State Museums, and the Asian Art Museum, in close cooperation with ICOMOS Germany. It was opened by the highest authorities from the Prussian Cultural Foundation and brought together 13 experts on mural paintings from 13 countries of Europe, Asia and North America. This workshop was also organized as part of the project's capacity-building activities and provided the national experts of the DPRK with a further opportunity to broaden their horizons and exchange with international experts. As a result of the project, a set of guidelines and recommendations for the conservation of mural paintings was formalized during the workshop. Focusing on mural paintings in damp and/or subterranean environments, these guidelines aim to put the experience gathered in the DPRK and via the Study Tour and provide a set of practical notes and recommendations for any conservation team preparing to tackle similar projects.[2]

2 The text of the Berlin Guidelines can be found here: https://whc.unesco.org/document/144129

The World Heritage Centre considers therefore that, in spite of great difficulties, the project reached its expected results for the conservation of the Susan-ri tomb, both with regard to the mural paintings and the structure while providing excellent visibility to the project and to the contribution of the Republic of Korea. This is considered very encouraging for upcoming phases of the project scheduled to start in early 2019 and will provide a very sound basis to tackle specific issues in a new set of tombs and continue broadening the knowledge and experience of the National Conservation Team, in collaboration with international UNESCO experts.

With the implementation of Phase III of the UNESCO-Republic of Korea Funds-In-Trust Project for the Safeguarding of Koguryo Tombs, we also achieved the following objectives:

1. Developing cooperation and contacts between conservation professionals of the DPRK, international organizations, and other networks for cultural heritage conservation;
2. Enhancing the level of conservation interventions at cultural heritage sites in the DPRK by introducing the latest scientific and technological methods.

The World Heritage Centre regularly updates the section of its website dedicated to the project, which can be consulted at the following address: http://whc.unesco.org/en/activities/275

As Chief of the Asia and the Pacific Unit of the World Heritage Centre and a professional who formulated the project from the very beginning, I am very proud of the results of the project in promoting international and regional cooperation. I also congratulate the efforts made by DPRK authorities in implementing the project and wish to extend my deep gratitude to the Cultural Heritage Administration of the Republic of Korea for the long-standing support to this operational extrabudgetary project.

This year, we are celebrating the 20th anniversary of DPRK's ratification of the 1972 World Heritage Convention. Publishing this Technical Report tells the story of UNESCO's efforts in safeguarding the Koguryo Tombs in the DPRK and is an excellent way to celebrate this important moment. The publication also has a significant meaning to strengthen cooperation between the DPRK and UNESCO. While reflecting on UNESCO's actions to safeguard cultural heritage and to promote peace and sustainable development, this publication can help us to look from the past to the future.

Aesthetical Value of Mural Paintings in the Susan-ri Tomb in a Transcultural Context

by Jeong-hee Lee-Kalisch[1]

At the turn of the 5th to 6th centuries, the Koguryo Kingdom, one of the most important powers in Northeast Asia, along with the Central or Inner Asian Empires and the Southern and Northern Dynasties in China, had established diplomatic relations with the Hephthalites and the Sassanid Persian Empires. The murals of the Koguryo tombs from this period present significant visual evidence through which one can reconstruct aspects of social status, lifestyle, and personal merit of the tombs' main occupants with regard to their civic and private lives as well as their ideal life in the afterworld. Above all, they provide an important point of reference for our understanding of the forms of visual communication between the Koguryo Kingdom, other empires and neighbouring countries.

The round tumulus situated in the Susan-ri district, in the Gangseo area of the city of Nampo, was discovered in 1971. The Susan-ri tomb, named after the district of its location and dated to the second half of the 5th century, is a stone plate construction bearing a 4.5 meter-long entrance corridor and one rectangular chamber of ca. 3.2 meters in width and length. It was originally covered by one baldachin stone plate (the stone covered by heaven, *cheongaeseok*), placed on two layers of triangular plates and three layers of ceiling lanterns. In spite of the tomb's small size, the murals painted on the walls and ceiling of its main chamber not only demonstrate the national strength and high cultural status of the Koguryo Kingdom, but also reflect the owner's personal lifestyle, especially with regard to religious practices, as is the case of other tomb murals of this time. In this paper, the aesthetical and art historical value of the Susan-ri tomb murals is to be discussed with regard to the intercultural meaning of Koguryo art as a phenomenon of cultural intertwinement, which becomes apparent through the depicted themes, the figures and their fashion, as well as other elements such as patterns and motifs. Furthermore, the conception of the Susan-ri tomb murals can be taken as an illustration of cultural

1 The pictures used in the article by Ms Lee-Kalish are reproduced with the kind authorisation of the Northeast Asian History Foundation. They may not be further reproduced without the express authorisation of this body.

originality and diversity among cultural traditions of East Asia and East Central Asia in a transcultural context.

Fig. 5: The corner of the northern and eastern walls with painted pillar, Susan-ri Tomb

1. Painted Pillar with Lotus-Shaped Capital

In all of its corners, the tomb chamber shows painted pillars holding a console system that visually "carries" the chamber walls and ceiling (fig. 1). This feature can be found in many other Koguryo tomb chambers of the same period, and it is comparable with the illusionary interior design of false architecture elements found in ancient Rome, as is the case, for example, of the wall decoration in the "Hall of Masks" (room 114) in the Roman Domus Aurea (64-68 CE).[2]

Very characteristic in Susan-ri is the design type of the round pillar and its capital: the shape of a lotus flower adorns the neck of the capital between shaft and abacus (fig. 2). Directly beneath the pedestal of this lotus-shaped capital, the pillar is very slim. It then widens and remains constant in width all the way to the bottom. The lotus-shaped capital is not of the widespread type found in Koguryo tombs. Only one comparable flower-shaped capital, made of stone, can be seen in the tomb Ssangyeongchong (Tumulus with Twin Pillars, 2nd half of the 5th century) in the same city district of Nampo: by the entrance of the main chamber there stand two octagonal pillars, each formed with a lotus-shaped capital.

However, this type of tapered pillar with a lotus-shaped capital can be seen in other regions of Asia. Examples are the two pilasters on the Buddha shrine located on the lower floor of Cave 6, and those on the stūpa with a standing Buddha in Cave 19 of the Ajanta caves in the Indian state of Mahārāṣtra. Pilasters decorated with lotus shapes are also preserved in the cave Guyangdong of the Longmen Grottoes, and in Cave 1 of the Tianlongshan Grottoes in China, which are also dated to the 5th to 6th centuries. In any case, the flower-shaped decoration of the capital almost certainly originates from the ancient Iranian and Greek cultures. The pillar capital and its scrolling-outward shape can for example be seen on the front two pilasters of the cross-legged Bodhisattva Maitreya in Cave 9 of the Yungang Grottoes in Datong in China (dated after 650), which clearly shows the influence of the Ionic column capital of Greek and Persian styles as seen in Persepolis,

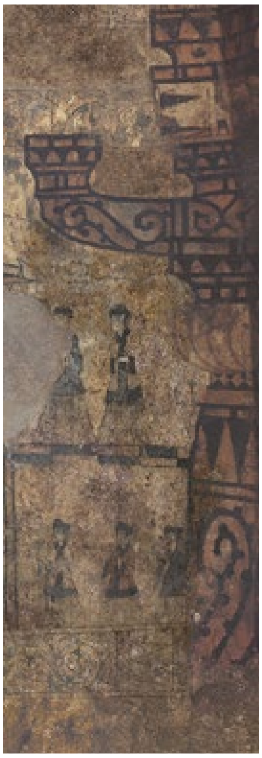


Fig. 6: The right-side pillar of the northern wall, Susan-ri Tomb

2 See the conservation report of Donatella Cavezzali, Annamaria Giovagnoli, Elisabetta Giani, Bruno Mazzone, Carlo Cacace, and Fabio Aramini: "Conservation works of the Hall of Masks in the Domus Aurea", Istituto Superiore per la Conservazione ed il Restauro (ISCR), Rome, Italy (http://www.icr.beniculturali.it/documenti/allegati/Relazione%20breve%20sulla%20Sala%20delle%20maschere.pdf, 21.04.2015)

the "City of Persians". The Susan-ri pillar with its lotus-shaped capital serves as an important reference for studying the no longer preserved wooden architectural elements of the Koguryo period, showing the inventiveness of design types of that time. The painted pillar can be taken as an image of the cultural originality of Koguryo, as well as of the diversity among cultural traditions in the context of Buddhist transmission along the Silk Road.

2. Scrolled-Line Patterns on the Bracket Arrangement

Fig. 7: The architectural elements with the scrolled-line frieze patterns on the northern wall, Susan-ri Tomb

The three-armed console system (*dugong*) on top of the previously discussed pillar type supports the lower and upper cross-beams. Between them, there can be seen diagonal V-shaped brackets in intimation of wooden architectural features. Along the inside, these architectural elements are ornamented with repeated abstract, partly intertwined scrolled-line frieze patterns (fig. 3). This is a variant of the plant-tendrils frieze pattern (*chomun dae*), often referred to as the Chinese Tang-period pattern (Chin. *Tang caowen*), which was widespread at the time. However, these already appear on architecture and ceramics of the Mediterranean Sea cultures of Ancient Egypt, Ancient Greece, and Assyria prior to the 8th century BCE. These scroll patterns developed in different cultures and periods, taking on the form of various plant leaves and variations of abstract tendrils. In the course of Hellenization, much earlier than the campaigns of Alexander the Great in the 4th century BCE, the scroll patterns were transmitted via the ancient Silk Road to almost all regions of Central, South, and East Asia, and can be seen on the wooden spindles, plaques, textile fragments, hand tattoes, and potteries excavated in the East Central Asian area (the Xinjiang Uygur Autonomous Region in China), and they are dated earlier than 500 BCE. Through the ages, they were combined with locally specific motifs: there are many features of various flowers and leaves, such as lilies and lotus flowers, honeysuckle, acanthus or palmette leaves, and grape vines, which belonged to the most characteristic and popular ornaments in East Asia.

Many variations of the scrolled-line patterns can also be seen in Koguryo tombs. Scrolled-line patterns appear in the tomb Susan-ri in form of two abstract structures: once in form of yellow-ocher tendrils defined by thin black outlines, partially set before a black background, and once in form of thick black lines before an ocher-coloured background. Such variants were already used in the other Koguryo tombs such as Deokheung-ri (dated 408), Yonggangdaemyo (5th century), and Anak No. 2 (late 5 th to early 6 th centuries), in imitation of wooden or stone pillars and console systems. Formally, the scroll lines with small curved dots are very similar to the scroll design of the frame border of the carved stone Sarcophagus with the filial piety representation from the Northern Wei dynasty (386-534 CE) 3, and these could be a fusion of the Chinese tendril-like birds and dragon ornaments4 with the from West originated scroll lines.

Comparable painted scrolled-line patterns on wooden pillars and console systems of the Northern Wei period can be seen in Cave 251 of the Mogao Grottoes in Dunhuang. A scrolled-line pattern is also engraved in the stone foundation for pillars excavated from the tomb of Sima Jinlong (d. 484) and his wife in Datong in Shanxi Province, which shows that the pattern was used for architectural elements in East Asia at that time. Several 7th-century roof and floor tiles with this decor are also known from the southern Korean kingdoms of Silla and Beakje, as well as from Nara, Japan.

3. Foreign Guardians: Yakṣa

On the north and west walls, within each of the triangularly shaped areas, a male figure can be vividly seen (fig.4). With both hands, the figures hold up the V-shaped brackets. One figure is depicted with his right leg in lunge position, while his left knee is bent. The legs of the other figure are widely spread and bent, the feet pointing outwards. The figures are clothed with only pants, and their muscular bodies are portly and dwarf-like. The faces are not recognizable in much detail, yet with their big eyes and nose their facial features indicate the Buddhist guardian and protector figure of Yakṣa. In other tombs of Koguryo, there exist some representations of Yakṣa who can also be seen as "holding up" the ceiling. The guardian of the tomb Jangcheon No. 1 is depicted with chest and leg hair, and with bared teeth.[5] The haired body is extremely similar to the "hand-fighting" (*subak*) figures in the tomb Muyongchong (Tumulus of Dancers). Befitting their ascribed attributes, the Yakṣa in the tomb Samsilchong (Tumulus of Three Chambers) is bejeweled and appears energy-loaded.

Particularly if compared with the representations of West and Central Asian wrestlers and fighting figures in the tombs Gakjeochong (Tumulus of Wrestlers) and Anak No. 3, the Yakṣas' bodies and faces to be seen in Koguryo tombs generally show mixed features of Indian or Central Asian Yakṣas and West Asian physiognomy. On grounds of recently identified figures in mural paintings in Afrasiab, Samarkand, as representatives of the Koguryo Kingdom which are depicted with a double bird-feathered headgear, it is believed that Koguryo held diplomatic relations with neighbouring and also distant Asian empires. Athletes and sportsmen from foreign regions were probably very welcome at the Koguryo court. Thus, it is obvious that Koguryo developed its own features of Yakṣa depiction through a significant and exemplary style, clearly integrating the beneficial aspects of athletic, strong, and fearsome Indian guardians.

3 Engraved grey limestone, 62.23 x 223.52 cm, The Nelson-Atkins Museum of Art.

4 See, for example, the stylized birds of the bronze *dou* vessel inlaid with turquoise from Leigudun, dated 433 BCE (Hubei Provincial Museum, Wuhan, China), and the dragon ornaments of the bronze mirror from Tomb No. 1 in Changsha as well as a Qin-period tomb, diameter 16.1 cm, excavated in 1956, Lintong District Museum, which have been dated to the 3rd century BCE. There exist many further variants of these scrolled-line patterns with dots dating from the Chinese Later Han period.

5 See also Ahn Hwi-joon, *Koguryo hoehwa* (Koguryo Painting), 2007, 91.

Fig. 8: The foreign guardian on the northern wall, Susan-ri Tomb

4. Paradise with Lotus Flower and Birds

Fig. 9: Procession Scene on the western wall, Susan-ri Tomb

Between the V-shaped brackets and pillars there is a frontally depicted lotus with eight petals, arranged in two layers, and centrally placed seeds (fig. 4). Around it, several parrot-like birds facing different directions convey a sense of vitality and liveliness. Two couples of similar parrots are depicted on the Chinese rosewood lute and on the five-stringed *biwa* lute, both with mother-of-pearl inlay, from the Japanese Shōsōin Collection in Nara[6]. The Koguryo tombs reveal differing variations of the lotus: the flowers are sometimes shown frontally, and sometimes in profile with the stems and leaves inside a pond (Tonggu Tomb No. 12, Ji'an, Jilin Province). The buds and petals have an abstract, reduced form, and the amount of petals varies between six and a countless number, arranged in many layers. The Susan-ri lotus depiction with eight petals and seeds is comparable with that of the tomb Deokhwa-ri No. 1 in Pyeongan Province (late 5th to early 6th centuries), in which the very well-preserved lotus depiction adorns the center of the tiered octagonal ceiling of the main chamber. Through the example of the oldest dated tomb of Anak No. 3 in South Hwanghae Province (dated 357 AD), we can see that most Koguryo tomb chambers were constructed with a so-called lantern ceiling system, which is named "sky well" (*cheonjeong*), and that the center is adorned by a lotus flower depicted in frontal view and in full bloom, around which the sun, moon, and star constellations, as well as animals, floating clouds, riding immortals, and further lotus flowers are often depicted in different views. Sometimes human figures (Oheo Tomb No. 4, Jilin Province, and Seonchong in South Pyeongan Province) or human faces (Jangcheon Tomb No. 1) are depicted on the lotus flowers themselves. In the tomb Anak No. 2, the flying Apsaras all carry lotus flowers. Particularly impressive is the illustration of lotus flowers in the main tomb chamber of Michanggu No. 1 (also named Janggunmyo, Tomb of a General): The whole wall is filled with only lotus flowers, to be seen in profile view.[7]

That is to say, the ceiling with its symbolic motifs represents a heavenly scenery, or paradise, in connection with different religious aspects. Adapted from the Central Asian

6 See also the bird depictions on the Korean Baduk playing pieces, called Go-game stones, of the Baekje Kingdom, Japanese Shōsōin Collection in Nara (Ahn Hwi-joon 2007, 211).

7 Jeon Ho-tae, "Documenting the dreams of the living and hopes of the dead: Koguryo tomb murals", in *Art of ancient Korea, Koguryo*, Exhibition Catalogue, Museum of East Asian Art, National Museums in Berlin (2005, 164-193), 181.

Fig. 10: Acrobats and the master on the western wall, Susan-ri Tomb

region, the lantern ceiling indicates heaven. In Hinduism, it symbolizes the cosmos and the heavenly world. In Buddhism, the flower is an emblem through which believers can be born over (*wangsheng*) into the Between-Paradise or reborn (*yeonhwa hwasheng*). The various illustrations of the lotus flower in the tombs is obviously an expression of this devout wish and hope of the tomb owners and their descendants. The murals on the ceiling in Susan-ri do not exist anymore, but they can be imagined in this context.

5. Procession Scene and Social Position of the Participants

The aesthetical and historical value of the Susan-ri murals lies in their depiction of an entire procession scene as well as individual persons, to be found on the west wall of the main chamber (fig. 5 and 6). The procession scene is set off visually through the illustration of the ground, which exactly alternates black and white tiles in double layers. In the tomb, no information is given on the main buried person. The social standing and function of this person is clearly indicated by his obviously differing body height, as is also the case in other Koguryo tombs, such as Samsilchong (5th century) and Anak No. 2 (late 5th to early 6th centuries). Moreover, the social rank of the figures in the Susan-ri procession scene becomes evident through their constellation, their demeanour, and the accentuation of their costumes in terms of colour and fashion style. The black-coloured, portable, and parasol-like baldachin which can be seen is also depicted in yellow as a parasol for the portable drum in a scene of musicians on the northern wall. The owner of the tomb, the tallest person under the baldachin in front of the procession, follows a group with his son and wife, who is characterized by the same emblems as her husband. Dressed in a long and heavy, spread-out garment with wide sleeves and decorated with black borders on the collar, sleeves, and garment endings, the master conveys his contentment through his sincere pose and gentle smile (fig. 6). His high social status is also stressed in another scene on the northern wall, where the person kneeling in front of the master is depicted evidently smaller.

The yeoui (Chin. ruyi) scepter-shaped clouds on the walls lend the procession scene a sense of spatial vastness, comparable with those in the tomb Daean-ri No. 1 in South Pyeongan Province (2nd half of the 5th century). Further, the figures' outfits and the appliance of natural lines can be similarly seen on the murals of the tomb Ssangyeongchong. The ground tiles are also accurately illustrated, just like those in the procession scene in the tomb Samsilchong.

6. Acrobats and Musicians for a Joyful Afterlife

The acrobats performing in casual and playful manner, especially in front of the procession, create a delightful mood (fig. 6). They execute various tricks including pole-walking, ball-rolling, and rolling and throwing wheels. The depiction of acrobats on relief bricks and the practice of placing miniature figures of entertainment into tombs for a joyful afterlife were already very wide-spread during the Chinese Han period. In his rhymed prose *Xijingfu*, the Han scholar Zhang Heng particularly describes the spectacular tricks performed by artists from the Central Asian kingdom of Duru.

Not only the illustration of the face, but also the naked torso and the wide knee-length pants of the ball-rolling acrobat in the middle are almost identical with the Chinese Han representations. Therefore, it stands to reason that Central Asian artists had been popular in Koguryo as well. The hair style of the artist balancing on a rod to right side of the master, which shows a symmetrical crest bound twice on both sides, probably indicates the person's origin as Central Asian as well as the hair trend of that time and thereafter. In

Fig. 11: Musicians on the eastern wall, Susan-ri Tomb

the Koguryo tomb murals of Deokheung-ri several servant figures are also depicted with this hairstyle. From Central Asia to Japan, silk paintings, too, show similar hairstyles, as with the servants depicted in the paintings excavated at Astana in Turfan[8], and the accompanying figures in the purported portrait of Crown Prince Shōtoku (574–622) in the Imperial Household Collection Japan.[9]

In the case of the musicians to be seen on the north wall, the large drum, or gong, is carried by two people on their shoulders, and beat by a person during the march (fig. 7). The skilful design of the portable drum with its mounted fancy parasol is so unique to Koguryo culture. The horn instrument and the demeanour of the horn player on the north wall of Susan-ri are comparable to the Xianbei figure of musician in clay[10] dated to the 5th to early 6th centuries. This indicates the cultural exchange between the Koguryo and the Mongolic nomadic people. Generally, such loud-sounding musical instruments were used in official or military marches. The acrobat figures together with the marching musicians not only give evidence of the social position of the deceased during their lifetime, they are also to bring joy to the deceased in the afterlife.

Fig. 12: The master's wife and the other accompanying women on the western wall, Susan-ri Tomb

8 See the painting on silk, Tang, (65 x 61,2 cm), excavated in 1972 from the tomb No. 187 at Astana, Turfan, Xinjiang Uygur Autonomous Region Museum; painting with figures under a tree, Tang, 8th century (138.6x53.2 cm), excavated probably at Astana in Turfan, Tokyo National Museum (TA1149); The Beauty under a tree, Tang, 8th century (139.6x53.3 cm), MOA, Japan.

9 Compare with Ahn Hwi-joon, *Han-guk gobun byeokhwa yeon-gu* (Research on Korean Ancient Mural Paintings) 2013, 158-162.

10 H. 39.9 cm, excavated in 1984 near Xinji Village, Pengyang District in Xingxia, Guyuan Municipal Museum, Ningxia Hui Autonomous Region.

7. Koguryo Women's Fashion in a Transcultural Context

The procession scene on the west wall of the main chamber raises a fashion-related issue that deserves our attention: the skirt of the women (fig. 8). The owner's wife, the noble lady depicted beneath a parasol with a soft and lovely smile on her face, appears particularly chic and trendy among the other accompanying women. Her face is made-up with a round dot on the cheek, and she is dressed elegantly with a long blue-coloured, red-hemmed jacket decorated with pretty scrolled-line in red and a long skirt in red-and-white tones. It is the most beautiful depiction of female costume among the tomb murals of Koguryo.

First, the aspect of makeup trends can be considered: The red dots on the cheek (*yeonji*) and forehead (*gonji*) must have been very much in fashion, and regardless of their social status, the women depicted in the Koguryo murals all carry this feature (see the murals in the tombs Cheonwang Jisinchong, Ssangyeongchong, Gaemachong, and Anak No. 2 and No. 3). Whether this really has something to do with the function of warding off evil spirits is difficult to prove. Up to today, this tradition has been handed down, and the bride bears the same feature during the wedding ceremony. Various flower-shaped marks on the face were widespread in Central Asia and China, however, the dot-shaped emblem was rarely to be seen; previously known examples are the donor figures in Cave 192 of the Mogao Grottoes in Dunhuang, and the representation of Nüwa in the painting of Nüwa-Fuxi excavated in Astana in Turfan, now in the collection of the National Museum in Seoul, Korea.[11]

It is already known that the noble lady's colourful skirt must have had an impact on the depiction of women's costumes in the Takamatsu Tomb in Japan, and the evident affinities suggest cultural exchanges between Koguryo and Asuka Japan prior to the 6th and 7th centuries.12 However, it is questionable whether the skirt depicted is really a pleated one, as is generally assumed.13 It is also possible that the skirt is made of different fabric panels sewn together vertically, so that the skirt looks as if it were pleated. Evidence for this theory is firstly that the colourful stripe pattern (saekdong) was very fashionable in Central Asia. Examples are the satin skirt fragment of three colours in eight tints and jacquard designs from Tomb No. 105 at Astana, and the silk painting showing two playing children who both wear multi-coloured stripe-pattern dungarees, excavated from Tomb No. 187 at Astana. The second indication supporting this theory could be the archaeological finds in Central Asia of similar skirts with very interestingly cut designs. The green- and orange-colour silk skirts from Tombs No. 187 and No. 230 at Astana in Turfan are decorated with plain floral patterns, but they obviously show the same cut and design of trapezoidal fabric panels that are vertically sewn together. The alternately

11 79 cm x 189 cm (Inventory no.: bon-gwan 4027).

12 See Ahn Hwi-joon 2013, 177-183.

13 See, for example, edited by Kim Lena, *World Cultural Heritage Koguryo Tomb Murals*, ICOMOS - Korea Cultural Properties Administration, ICOMOS - Korea Cultural Properties Administration, 2004, 40-41.

yellow-and-red-striped silk dress of a wooden female figure also excavated at Astana14, and the green-red skirts of two ladies in the mural painting the "Lifestyle on a country estate" (Chin. Zhuangyuan shenghuo tu) of Tomb No. 408 at the westside of Astana, which doubtlessly were cut and designed in the same way reinforce this argument. Comparing the representation of other female attendants in Susan-ri and Ssanyeongchong, who are probably wearing monochromatic white pleated skirts, which were also a remarkable fashion trend; the noble lady of Susan-ri shows her sophisticated taste through the combination of the colours and designs.

On the basis of comparing Chinese and Central Asian finds with Japanese murals, it can be said that this skirt design was popular in high societies across regional borders. The trend probably boomed from East Central Asia to Korea, and Japan, during a certain time. Therefore the fashionable taste of the Susan-ri lady indicates the visual communication that took place between the empires, and the global status of the Koguryo people.

8. Timeless Taste: The Dot Pattern

The son, and heir, who can be seen behind the master's parasol-carrier, is positioned before the master's wife in the Susan-ri depiction of the procession, which is interpreted as a clear illustration of the patriarchal Koguryo society. He wears long, wide trousers with trendy dot patterns consisting of vertical short strips (fig. 6). It is truly remarkable that so many Koguryo people, regardless of their gender and status, partook in this fashion trend (see particularly the tombs Muyongchong, Jangcheon No. 1, and Gakjeochong). One can say that this pattern was the most widespread one to be seen on clothing of that time, and it showed many variations. It could be composed of square, circle, and droplet shapes, or short strokes, as here.

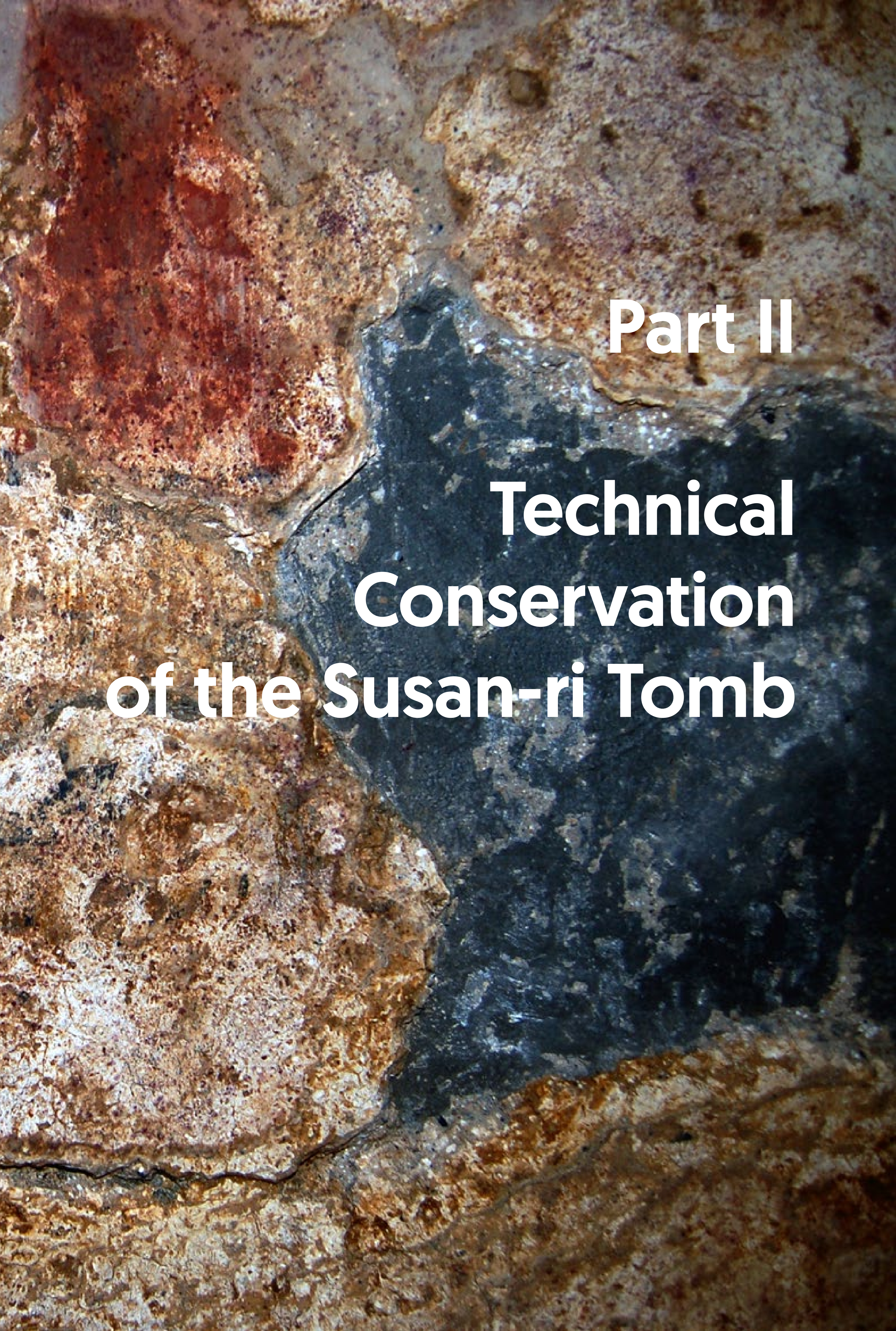
The origin of this highly modern design is not known. Some see the origin in the imitation of fur. If one looks closely at the Muyongchong landlord's pants, one gets the impression that its dot pattern may be derived from the combination of flowers, dots, small crosses and petals. The decor of the frame plate fragments excavated in the mausoleum Taewangreung also consists of such a cross-and-petal decor. The silk fragments with their regular, repetitive tie-dyed and printed patterns of flowers, triple dots, and rhombi excavated in the ancient Astana cemeteries in Turfan, Xinjiang (in Tomb 63TAM1:30, Nos.105, 108 and 117), show what the pattern looks like, and they indicate that the regularly repeated small dot pattern was in fashion for a while trans-regionally.

14 Unearthed in 1972 from the tomb No. 206 of Zhang Xiong (584-633) and his wife Lady Qu (607-688) at Astana, Turfan Tang (618–907), wood, silk, paper, H. 29.5 cm, , Xinjiang Uygur Autonomous Region Museum.

9. Conclusion

In spite of the damaged condition of the tomb Susan-ri, its remaining murals show not only the mastery of visual depiction, but also the status of Koguryo in the context of its diplomatic relations with the Far Western and the East Asian empires. Of course, the theme of the murals portrays the prideful tomb owner's activities pursued during his official and private life. It also points towards his belief in an afterlife. The procession scene, with its rank order of male and female figures, and the manner of their representation further reflect social structures of hierarchy. The feature of the imitated wooden chamber is a valuable reference for the study of wood architecture, which is not existent anymore. The lotus motifs on the pillars and walls, the scrolled-line patterns on the brackets, the dot patterns on the trousers, and the taste of the noble ladies all show in a representative way how fashion-conscious Koguryo people were in everyday life. Their clothing was either designed to be fashionable, or to be worn for representational purposes. Particularly, comparable archaeological finds in Central Asia, China, and Japan obviously indicate that the people of Koguryo at that time lived their life as cosmopolitans on the Silk Road in a global context.

Fig. 13: Guard in the tomb entrance passage, Susan-ri Tomb



Part II

Technical Conservation of the Susan-ri Tomb

Description and Location of the Susan-ri Tomb

by Rodolfo Luján Lunsford

Democratic People's Republic of Korea National Treasure Inventory Number: 30

Geographical Location: In the Kojung Mountains (Susan-ri-, Kangso-gu District, Nampho, Pyeongannam-do Province, Democratic People's Republic of Korea)

Geographical Coordinates: Latitude 38° 55' 14" North; Longitude 125° 21' 41" East

Overall Description: Built half underground on a mountainside in the Kojung Mountains, the southwest facing Susan-ri Tomb rests on a stone platform that levels the terrain at the south. Its characteristics are as follows: *dromos* or access corridor and entrance passage extending 450 cm north to south; open passageway, lost section of 134 cm

Fig. 14: Aerial Photograph of the Susan-Ri Site, 1989

Fig. 15: The entrance to the tomb with splayed granite wings since 1989

north to south; outer section: 160 cm east-west, 134 cm north-south, 238 cm in height; inner section: 150 cm east-west, 82 cm north-south, 210 cm in height; entrance passage: 102 cm east-west, 100 cm north-south, 180 cm in height; single square burial chamber: 320 cm east-west, 320 cm north-south, 300 cm walls height, with floor-to-ceiling height of 410 cm. (Dimensions as published in 1974 *Archaeological Report* and as per section).

Year of Excavation: 1971

Construction: The Susan-ri Tomb is constructed of stone masonry bound with mud-based mortar. Rough granite blocks are used for the walls and the first two tiers of the corbelling. The masonry joints are pointed with lime-based mortars, and the walls of the tomb are plastered with lime-based renders. The third tier of the corbelling and the *lanternendecke* (triangularly corbelled) ceiling in the burial chamber are made of dry masonry dressed stonework and are coated with lime-based renders.

Walls & Ceilings: The walls curve towards the top in the burial chamber and are upright in the entrance passage and access corridor. The ceilings are flat in the *dromos* and entrance passage. Elsewhere, there is a parallel corbelling *lanternendecke* ceiling in the burial chamber.

Flooring: Recent construction. Weathered gneiss is used in the burial chamber and concrete in the access corridor.

External Covering: tumulus/turf mound

Construction Period: Late 5th Century CE

Later Structures & Additions: Additions include: the first section of the buffer corridor (1973); concrete dome on top of the tomb and under the top of the turf mound (1985-86); and the second section of the buffer corridor (1989). The access corridor heights stated in the 1974 *Archaeological Report* were reduced because if the level of the floor is heightened the distance to the ceiling is less and as a result of increasing the level of the pavement to the present dimensions.

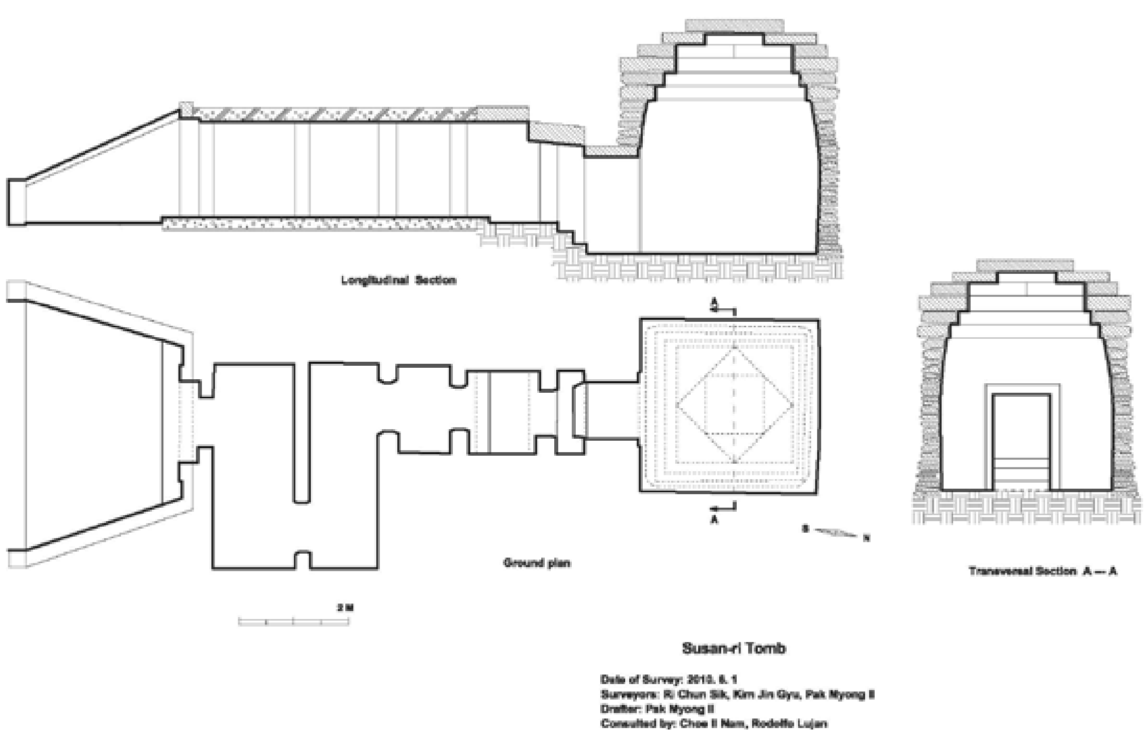


Fig. 16: Ground plan, N-S longitudinal section & E-W transversal section of the burial chamber, reproduced from 1974 *Archaeological Report* and 2010 Autocad version

Theoretical Approaches to the Conservation of the Mural Paintings of the Susan-ri Tomb

by Rodolfo Luján Lunsford

The mural paintings of the Susan-ri Tomb are an integral part of its architecture, and add to and enhance one another. The Tomb's structure acts as the 'material carrier' of the mural paintings it hosts within it, which have a different quality to paintings that exist simply as objects. This is because the intimate nature of the representation and its degree of reality are different, such that the spectator seems to be contained therein. Since the colours and figurative decoration of the mural paintings are integral parts of the architecture of the Tomb, it is necessary to describe the structure that is represented in order to gain a sense of the Tomb as part of an historical) creation.[1]

For the viewer of the mural paintings, the images give the impression that he or she is inside a wooden structure bearing scenes of everyday life, though in fact these scenes are painted onto the walls of a masonry structure and thus bring a degree of virtual reality into the material context. The paintings in the Susan-ri Tomb depict a wooden kiosk with four columns. These are connected together by a rail on their lower register, and at the top of the columns lotus-flower capitals support two simple armed brackets holding up two ranges of girders. These are then connected at the centre by a king post that supports two inverted struts and forms a pediment. At the corners, they are joined by elaborate brackets supporting the rafters of the kiosk and the ceiling, which is composed of three receding tiers of beams and a *lanternendecke* dome.

Previous techniques used in the past to preserve mural paintings, threatened by deterioration in the extremely damp subterranean conditions of tombs, for example, were highly invasive, since the paintings were removed from the wall by the use of either a *strappo* technique (the detachment of the paint layer from the render), a *stacco* technique (detachment of the paint layer with the render) or a *stacco a massello* technique (detachment of the paint layer with a portion of the support). Such techniques can be justified in cases of disasters such as earthquakes or floods, or during episodes of armed conflict

1 Mora P., Mora, L., & Philippot, P., *The Conservation of Wall Paintings*, London: Butterworths, 1984, pp. 1-7.

where the survival of the paintings is directly threatened. However, they cannot be used as a regular conservation measure, even if such measures have been used in the past.[2 3]

Treatments to conserve and preserve the underground heritage of the Democratic People's Republic of Korea (DPRK) that have been used in recent times, on the other hand, have not been extensively tested beforehand and have been applied without the use of a properly analytical approach, including the use of buffers to control the internal environment in the Tombs. Preservation policy has been decided upon on a case-by-case basis, but it seems that careful studies have not been carried out and the proposed interventions not properly thought through. As a result, methods have been used without proper awareness of their likely consequences where simpler and more effective solutions could have been found giving better outcomes.

The proper conservation of mural paintings requires the use of a critical approach that aims to assess their contribution to the architectural ensemble of which they are a part. It must always be born in mind that it is to this architectural complex that the mural paintings belong, and for this reason the conservation *in situ* of the mural paintings of the Susan-ri Tomb was the main principle adopted in the present conservation work, in accordance with the established codes that characterized the intervention as a whole.[4]

Moreover, the study of the techniques of execution used in the mural paintings, together with the causes of their deterioration and the treatments needed for their preservation, requires the use of an interdisciplinary approach that links up several branches of knowledge, including architecture, engineering, history, chemistry, physics, biology and archaeology. The principles adopted for the conservation and restoration of the mural paintings in the Susan-ri Tomb were in line with the latest recommendations for mural painting conservation, including the following:

1. That the conservation work should act on the causes rather than on the effects of the deterioration in order to achieve the comprehensive conservation of the paintings. In order to guarantee the paintings' preservation, the structure of the building needs to be sound and free from humidity. Aside from the natural humidity contained in any hypogeal environment, any surplus humidity must be eliminated if the paintings are to be properly conserved, including water infiltrating from above or from the area's water table. Once the internal environment has been stabilized such that it exhibits only modest variations of temperature and relative humidity, the safeguarding of the mural paintings is relatively assured and conservation work can take place;
2. That the entirety of the monument in its present state should be conserved with the minimum necessary modifications for improving or preventing the triggering of damaging factors. Thus, it is necessary to carry out regular monitoring through the installation of sensors and data-loggers as a preventive measure and in order that any maintenance work can be carried out in a timely manner;

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2 Ibid. pp. 245-246.

3 Borrelli, E. Vlad L., 'Il distacco delle pitture di una tomba tarquinese di recente scoperta,' in Bollettino dell'Istituto Centrale del Restauro, No. 34-35, Istituto Poligrafico dello Stato, 1958, pp. 71-93.

4 ICOMOS Principles for the Preservation and Conservation/Restoration of Wall Paintings (2003). Ratified by the ICOMOS 14th General Assembly, Victoria Falls, Zimbabwe, October 2003.

3. That a harmonious approach that relates the structure to its surrounding environment in its natural state be used. Contemporary technology can help here, though the invaluable lessons of the past should also be born in mind.

Before embarking on any treatment of the mural paintings, conservators should ensure that they have sufficient information at hand in order to carry out their task. This information should be provided not only from within their own areas of specialization, but should also be sought from scientific experts elsewhere, which is a fundamental component of the entire conservation and restoration process. As the conservation work proceeds, there should also be an exchange between the various specialists contributing to the work, in order to ensure that any necessary modifications to the methodology used are carried out. In general, comprehensive scientific research is necessary for carrying out conservation work, as there is a requirement that a range of data be examined in order to clarify the methodology used. One of the prerequisites for the correct conservation of a mural painting is the identification of the technique employed by the ancient masters, so as to define the methods and materials to be employed during the conservation work, which can be accurately achieved only by means of scientific analyses.

While the mural paintings found in tombs belonging to the Koguryo Dynasty have been much studied by archaeologists and art historians, systematic research regarding their technical means of execution has been neglected. The mural paintings have often been described as frescoes, but there is little technical literature on how they were executed. Such scientific studies as there are, hard to come by and written in Korean, argue that the mural paintings were executed using a *fresco* technique.

The study of the techniques used to produce the mural paintings has been based on three methods of approach. Firstly, there has been an investigation of written sources, such as manuals and treatises and so on, which explain, sometimes in non-technical language, the procedures used to execute the paintings. Unfortunately, this type of material has not yet been discovered as far as the mural paintings in the Koguryo Tombs are concerned. Secondly, conservators have carried out a meticulous examination of the paintings using magnifying glasses and light reflected at various angles of incidence to the painted surface in order to find evidence that could help to indicate the technique employed by the artist. Any hypotheses framed as a result of such an examination need to be verified by taking samples from representative areas of the paintings and analyzing these in the laboratory. The most useful type of sample for this purpose is a small fragment of paint together with its preparatory layers. From this, most of the information required can be obtained by various processes. Thirdly, there is scientific examination carried out at the site and later confirmed by laboratory analysis. Here, the structure of the painting and its components are studied by the stratigraphic examination of opaque and thin cross-sections employing several methods of identification.[5]

In the conservation work on the mural paintings in the Susan-ri Tomb, the most important conservation principles regarding the use of materials were *reversibility*, *minimal intervention* and *compatibility*. Here, the principle of reversibility states that it should be possible to undo what has been done for conservation purposes without undue risk to the original material or excessive cost.

5 Mora et al., pp. 20-23 & 82-83.

The principle of *minimal intervention* states that only necessary conservation work should be carried out and that this should not result in the transformation of the existing state of the object to be conserved. Conservation work carried out on the mural paintings should therefore be as limited as possible and should use the smallest possible amount of conservation materials. Work done in order to conserve the paintings should appear at first glance to be 'invisible,' and the paintings should look as they did at the time of their discovery.

The principle of *compatibility* refers to the physical application of conservation materials to the ancient structure and mural paintings within given mechanical, physical and chemical parameters. It also requires that the composite formed by the ancient and modern materials should behave in a favourable way under expected environmental conditions. Materials used in the conservation treatments should not accelerate the deterioration rate of the mural paintings, and they should be as similar as possible to the original materials. The range of materials employed must be limited as far as possible to inorganic materials, given the damp environment in which the mural paintings are housed, and the use of organic materials should be avoided.

Related to the overall principle of compatibility, the principle of *mechanical compatibility* requires that mechanical properties be properly matched and that original parts not become over-stressed because of differential thermal expansion rates in the old and new materials or other movements caused by changes in the surrounding environment. The principle of physical compatibility requires the matching of properties such as porosity and water vapour permeability, as well as the expected future behaviour of the composite structure when exposed to water. Lastly, the principle of chemical compatibility aims to insure against the risk of the formation of by-products as a result of setting up chemical reactions or producing products on the decomposition of the conservation materials used that could cause damage to the object being conserved.[6]

6 Torraca, G., Processes and Materials used in Conservation, SPC Course Notes, ICCROM, 1989.

Previous Work on the Susan-ri Tomb

by Rodolfo Luján Lunsford and Chun Sik Ri

In order to draw up a conservation methodology, it is useful to understand the causes that put the deterioration processes into motion resulting in the alterations and damage found in the mural paintings. Human actions usually act in conjunction with natural ones, working systematically to exacerbate each other. Therefore, it is very important to research the history of a given monument, in order to discern if the alterations in it were caused by modifications to the fabric or by natural factors. This then allows measures to be taken to remove or diminish the damaging factors.

Such historical and technical investigation also guarantees the implementation and effectiveness of preservation treatments aiming at eliminating the causes of the deterioration, or at least reducing or transforming their damaging effects, in order to ensure the monument's long-term safeguarding. From the time of its discovery onwards, the Susan-ri Tomb has been the subject of treatments that have aimed at its preservation and safeguarding. Data regarding these interventions have been excerpted from an unpublished report on the research carried out by a Korean Cultural Preservation Centre (KCPC) staff member in the summer of 2005 and by interviewing workers that participated in former conservation campaigns.[1]

1. 1. Relevant Dates

Date of discovery: 1971 by the IAASS (Institute of Archaeology of the Academy of Social Science).

Restoration of the mural paintings: 1973-74 by workers from the CRMO (Cultural Relics Management Office).

Construction of buffering passages: 1973 by workers from the CRMO and members of the CRMO repair team in 1989.

Construction of concrete dome: 1985-86 by 15 workers from the CRMO.

Maintenance repairs: 1993 by workers from the CPI (Cultural Preservation Institute), the former KCPC.

Glass barriers: 2001 by four workers from the CRMO and one KCPC member.

1 Ri, Chun Sik, Conservation History of Six Koguryo Mural Tombs, KCPC, Pyongyang, August 2005 (unpublished).

2. The 1971 Discovery of the Susan-ri Tomb

The Susan-ri Tomb was discovered in 1971, and the results of this were published by the DPRK Institute of Social Sciences in 1974. The 1971 archaeological report describes the findings, the structure of the Tomb and the mural-painting cycle as found at the moment of discovery, which does not correspond to what is discernible at present.[2]

Apparently, the mural-painting cycle was extant in its entirety at the moment of discovery, whereas today it is in a fragmentary state. The scene, so vividly described in the report, on the north wall in which the deceased couple is represented during an episode from daily life, no longer exists. Nor does the parade scene described on the east wall. Both walls at present show significant losses of painted renders, subsequently plastered over with cement, while fragments of painted render that had collapsed were re-adhered with cement on the lower area of the west wall.

According to Kim Myong Chol, a KCPC art historian speaking at the Third UNESCO Workshop on the Tomb in 2006, 'the cause of these detachments in the shape of large pockets that furthermore collapsed was due, most likely, to the roots of plants growing inside the walls and beneath the rendered surface, separating it away.' In addition to the extensive growth of vegetation above the Tomb, the migration towards the surface of the constitutive mud bonding the walls might have helped in this process. Perhaps the Tomb was left open after discovery, and, due to sudden variations in temperature and relative humidity, rapid deterioration processes were involuntarily set in motion.

3. History of the Tomb's Conservation

3.1. First Intervention (1973-1974)

During the first intervention on the Tomb, the first section of the buffering corridor was constructed and preservation treatments were carried out (March to May, 1973 and in 1974). The construction of the corridor did not impede carrying out work in the burial chamber, meaning that both activities could be carried out at the same time. According to the report, 'four metres of the first phase passageway work has been done to conserve [the] murals and preservation and repair works giv[ing] only to the inner room. The ceiling and northern and eastern walls, much detached or destroyed by illegal diggers, have been coated with white cement, and the parts of murals on the four walls, ruined partially or by degrees, were filled with mortar of cement, clay and lime similar in colour and material to those of the mural.[3]

The buffering corridor to which this description refers saw the construction in reinforced concrete of the pavement at a higher level than the original and of the doorway housing

2 Shim, H. S., *Interim Report on the Excavation of the Susan-ri Tomb* (1974), abridged version of Ri, J. H., *The Mural Paintings of the Susan-ri Tomb Excavation Report*, Institute of Social Sciences, Pyongyang, 1974, pp. 228-236 & plates 48-52, and Pak, C. Y. & Hong, S. C., *The Mural Paintings of the Susan-ri Tomb: Excavation Report and Preservation Record*, Pyongyang, May 2005, translated by the author, UNESCO, 2011.

3 Ri, 2.

a wooden door that had direct access to the covered dromos of the Tomb and was covered with cement plaster. Comparing the description and measurements of the dromos mentioned in the report with the present situation, and considering that the dromos was 450 cm long,[4] it can be surmised that 134 cm of original stone masonry (the open passage of the dromos) was lost during the construction of the doorway.[5] The walls of the dromos, covered with ancient lime-based renders at the time of the intervention, were plastered over with Portland cement. The two pillars at the sides supporting the ceiling slab of the inner section of the dromos were reinforced with cement, and a concrete beam was inserted at the south end to support the stone slab, broken into three main fragments. Two concrete pillars and beams were constructed at the south end to support the ceiling slab of the outer section of the dromos and form the doorway, whose ancillary posts were also made of concrete.

It is likely that the conservation and restoration of the mural paintings took place during this period. The large lacunae were filled with cement and some rendering fragments from the lower section of the collapsed west wall, and they were re-adhered with the same material. Unfortunately, some painted areas were spread over with cement during the work, and this was not properly removed, leaving a thin film that obscured the brilliance of the images.

The following statements are conjectural until a fully scientific report can be obtained. They are hypotheses based on visual examination under different illumination angles and made as a result of cleaning the paintings of foreign substances. The KCPC report states that 'the parts of [the] murals on the four walls, ruined partially or by degrees, were filled with mortar.[6] Therefore, the mural paintings were certainly restored at that time. Unfortunately, there are no available records of this intervention.

The façade and the walls of the entrance passage, as well as many areas of the walls in the burial chamber, appeared to be damaged at the moment of the 1971 discovery (eroded renders and lost areas of painting), and it was necessary to carry out restoration work. The intervention carried out at that time consisted of filling the lacunae of the lower sections of the rendered walls with a fine-grained plaster of hydrated lime covered with fine illite or white-yellowish clay. The lacunae in the upper sections of the walls were pictorially reconstructed in order to provide a better understanding of the painted cycle, and they were first filled with illite, or with a mixture of purplish sandy clay slightly below the paint layer level, and then coated with a thin layer of hydrated lime and sand. The reconstructions of the paintings were probably done with oil or enamel paint. For example, the depiction of the guardian of the Tomb on the west wall of the entrance passage was lost, and therefore it was partially reconstructed, the painter reproducing in a mirror-like manner the image depicted on the east wall. This was better preserved, though some lower areas of it were also reconstructed. The painted scroll motif on the façade was reconstructed as far as possible according to the traces thus far discovered. Other reconstructed sections of the paintings are also to be found in the burial chamber.

4 According to the author of the archaeological report, the *dromos* might have comprised the three-section access corridor (open, outer and inner) and the entrance passage, giving a total length of 450 cm.

5 Many granite blocks and fragments of renders were found during the 2009 excavation of the watercollecting trench around the Tomb on the south-western side of the mound.

6 Ri, *ibid.*

In order to conceal the pictorial reconstructions, the painted surfaces, cleaned of mud deposits, were re-soiled with mud, probably mixed with a fixative in order to make them appear 'old' and to match them with painted areas covered with so-called 'hard-mud' incrustations. This was a false procedure, because patina – the thin surface layer that has been aged due to atmospheric action – should not be confused with dirt. The background of the upper register of the north and west walls, just under the girder, was covered with thin glazes of black paint, seemingly as a result of the leaching of pigments. The original paint layer can be clearly discerned from the additions made during this intervention because the tonality of the original is brilliant and transparent, whereas the more recent one is dull and has a glossy appearance. The hue of the original red ochre is brilliant, with a warm-deep transparent tonality tending to orange, whereas the more recent one tends to dull-red.

The black paint recently used looks like a glossy amorphous mass of varying thickness, whereas the original appears as a thin flat layer in which tiny crystals of the pigment can be seen. The original thin red lines, produced by snapping a cord soaked in red pigment onto the render, notably differ from the thick lines produced with a brush on the horizontal divisions of the scenes that were reconstructed. Moreover, as mentioned above, reconstruction of lost painted areas or retouching and over-painting were carried out in order to render the painted cycle more legible. During this restoration work, a protective coating or fixative was probably applied to the walls' painted surfaces, as was the practice at the time.

3.2. Second and Third Interventions (1985-86 and 1989)

A concrete dome (20 cm thick, with iron bars of 1-1½ inch diameter inserted at the centre, and covered with a layer of bitumen) was constructed in 1985-86 some 1.50 metres below the top of the mound. According to the report, 'waterproof reinforced concrete project had been undertaken for preventing the leakage of water into the inner rooms through [the] soil of the mound. This arch-type reinforced concrete was made in the mound as wide as 30 m^2 after digging it up in a radius of 3.5 m from the apex of the Tomb.[7]

The second section of the buffering corridor was constructed in 1989. According to the report, this was 'a project to make a U-type passageway from the approach to the mound to the first entry of the passageway, in order to decrease the atmospheric impact on the interior of the inner room. Included in the project was also the work to make external wings (of granite). Total length of 2nd-phase project: 13 m.[8] The second section of the corridor comprised two wooden doors and the main door made of heavy iron that does not shut properly. During these engineering works, the level of the pavement of the corridor was raised to the current level. However, there was insufficient supervision, and the paintings were contaminated with dust, soil, mud, etc., and such deposits have been found on the white-yellowish clay applied in 1973.

It seems probably that the Tomb burial chamber was left open, or that the necessary precautions were not carried out for the protection of the mural paintings, leading to the

7 Ri, 2-3.

8 Ri, 4.

calcification of mud deposits. Small lacunae, especially on the west and north walls, were subsequently filled with grey clay.

3.3. General Maintenance Repairs (March 1993)

According to the report, 'chinking has been done to the cracks on the murals with inorganic adhesives. Location: 60 cm upward from below the right side of the southern wall, 1.4 m upward from the middle of the left side of the northern wall.

Adhesive materials:

Cement:	30-35 parts
Silica gel:	25-35 parts
Lime:	30-35 parts
Dehydrant:	1 part

The work of adhesion was administered by the workers of the CPI. Two years after the adhesion, no change was observed, and the same was again [seen] on May 9, 2005'.[9]

3.4. Installation of Glass Barriers (May-June 2001)

Glass barriers were installed as a buffer from the external environment in order to maintain constant values of temperature and relative humidity inside the Tomb. According to the report, 'airtight glass walls and 3 doors in [the] passageway were set up with home-made shaped aluminium. Installation and construction was carried through by 4 workers of the relic's management office and 1 KCPC members.[10] The gap between the irregular profile of the walls and the straight glass frames was filled with cement applied directly to the mural paintings without a buffering material, e.g. prolipropilene sheeting. The conservation and restoration work carried out in the Tomb was the product of the time, using the methodology, techniques and materials that were available in order to try to preserve the mural paintings. Understanding these factors explains many of the alterations to be seen at present. As has been seen, three main interventions can be distinguished, carried out in 1973, 1985-86 and 1989, and 2001.

9 Ri, 5.

10 Ri, *ibid.*

The Preservation and Conservation of the Mural Paintings of the Susan-ri Tomb

by Rodolfo Luján Lunsford

1. The Present Intervention

Given that the conservation of mural paintings is an interdisciplinary subject, finding solutions to the problems encountered in the conservation work was entrusted to different members of the team. Moreover, conservation treatments are never definitive, and they require constant monitoring, preventive measures and regular maintenance. As a result, it is necessary to have a team that can constantly carry out these tasks, whether located permanently on site or not, that can be available to carry out this work.

A work plan was drafted with the DPRK National Conservation Team, and a methodological approach adopted to treat the various issues arising. An extensive survey and assessment of the state of conservation of the mural paintings of the Susan-ri Tomb was first carried out, and this was supplemented by graphic and photographic recording.

The sampling of the paintings' constitutive materials, especially of paint layers, was carried out in order to determine the technique of execution of the mural paintings, such that proper techniques and materials could then be used during the conservation work. It was also necessary to analyze samples of products and materials used during previous interventions, notably in order to confirm previous hypotheses. Various conservation and restoration problems that arose as the work developed needed scientific and practical solutions, so research was also undertaken in order to provide guidance on suitable methodologies and materials. Since the surfaces of the paintings were very dirty at the moment work began, it was not possible to discover whether restoration to the paintings had indeed been carried out during a previous intervention, though as the work continued it was suspected that retouching and the application of protective coatings had indeed been done. As a result, the DPRK National Conservation Team was requested to investigate if records of former interventions existed in various archives, but unfortunately nothing was found.

Given that the Susan-ri Tomb needed suitable protection against environmental variations, it was necessary to monitor the Tomb's external and internal climate, and, following the evaluation of the gathered data, to propose an efficient buffer for the Tomb. In addition, the Tomb regularly flooded during the rainy season, and therefore it was also necessary to monitor water-table fluctuations in relation to climate data.

At first, operational work on the mural paintings consisted of preserving any endangered areas and then proceeding with standard conservation and restoration practice. When conservation and restoration is concluded, one thing that is rarely taken into account is maintenance, which is necessary in order to frame any further preventive measures.

1.1. Survey and Assessment of the Mural Paintings

The technique of execution and the condition of the paintings were assessed by close examination of the constitutive elements using either the naked eye or a magnifying glass under frontal and/or raking light. Both the techniques and materials employed and any alterations to them were assessed and the causes of decay hypothesized. Each finding was recorded *in situ* on working drawings done to the scale of each wall. A glossary was also produced, as a common language for the work could avoid any misunderstandings. This glossary of the working vocabulary used notably described the stratigraphy of the mural paintings and the terminology employed to describe a particular alteration or action produced (See *Glossary and Terminology for the Conservation of the Susan-ri Tomb* in the Appendices to the present publication.)

1.2. Graphic and Photographic Documentation

Graphic documentation consists of a visual report on the state of conservation of the mural paintings, along with the results of more detailed examinations (state of preservation, former interventions and technique of execution), laboratory analyses, the direct testing of products suspected of causing deterioration, measurements carried out *in situ*, and the present conservation-restoration treatment. Given that the colour reproduction of graphic recordings was difficult to carry out during the early stages of the project, it was decided to use black-and-white documentation instead.

Graphic documentation of mural paintings consists of the visual report (recording of information) in drawings of the results of examination (state of preservation, former interventions and technique of execution). This is enriched by annotating the sampling spots for laboratory analyses, the direct testing of products to counter deterioration, measurements carried out *in situ*, and the present conservation-restoration treatment.

A basic drawing to scale of each wall (architectural elevation) with the main outlines of the paintings was produced. Several superimposed layers of drafting paper were then placed over the basic drawing, each being used to explain a particular layer within the stratigraphy of the painting. As a result, a visual nomenclature was prepared, describing the work in a clear and simple manner with the aid of a drawing in section and photographs taken under frontal and raking light. This was then correlated to the graphic symbols (system of notation) used (See *Visual Nomenclature and Graphic Symbols* in the Appendices to the present publication). The hand-drafted graphic documentation was afterwards digitized and made available in an AutoCAD colour version. The architectural context was also documented with plans, sections and elevations.

The detailed graphic documentation was carried out after careful inspection and assessment of the state of preservation of the mural paintings, with former interventions identified and relevant traces noted indicating the technique of execution used. The current work was carefully recorded, in order to keep a record of all treatments carried out. Areas where testing was carried out were carefully marked so that on-the-spot testing could be performed again if needed in order to evaluate if any variation had occurred. (See *Graphic Documentation of the Susan-ri Tomb* in the Appendices to the present publication).

Photographic documentation was used together with graphic documentation in order to record significant details noted during the examination of the mural paintings. Special photographic techniques (various types of lighting, film sensitivity and shooting angles, UV, IR, etc.) are useful for such documentation work, but they cannot substitute for comprehensive and easy-to-understand drawings. However, black-and-white and colour photographs of all the walls and important details were taken before, during and after the cleaning of the paint surface and after the conservation and restoration work had taken place. These photographs are an essential record of the changes made[1]. The advent of digital photography has now rendered analogue photographic equipment obsolete, and it has the benefit of allowing immediate visualization to take place, even if the resolution and quality of the photographs can be inferior to analogue photographs.

The photographic recording of the mural paintings was composed as far as possible of shots of the entire surfaces, as well as details and alterations found in or on the paintings and under frontal and raking light. Working procedures were also photographed. Both graphic and photographic documentation are valuable sources of information for future comparison and evaluation, especially if the paintings are shown to be undergoing further changes or deterioration.

1.3. Sampling and Analysis

The taking of samples and their analysis are the main components of the scientific examination of mural paintings, and they are necessary for determining the components of the materials and techniques of execution employed, as well as for identifying any superimposed materials and diagnosing the nature and causes of any alterations. The value of the results of the analytical examination of samples in the laboratory depends on the relevance of the samples chosen and the comparison of the results with the technical knowledge relative to the painting and the correct interpretation of such comparisons[2]. (See the *List of the Koguryo Mural Paintings Samples* in the Appendices to the present publication.)

Samples of the paint layers were taken in order to identify the pictorial techniques, the pigments employed and the constituents of the preparatory layer. Samples of condensed water on the painted surfaces were also taken in order to identify the types of soluble salts they contained, if any. The extensive sampling of any micro-organisms present was carried out, employing various methods, in order to identify the variety thought to be damaging the mural paintings. Samples of constitutive mortars and renders were taken in order to establish their components, such that similar materials could be prepared for conservation purposes. Samples were also taken of materials employed during previous work on the paintings, such as cement or various fixatives, etc., with the aim of establishing safe techniques for their eventual removal. (See Part Three of the present publication for details.)

The extent of the scientific investigations depends on the questions posed by the conservator-restorer. They can vary from a simple microscope observation of the surface under different light sources and angles to more sophisticated analyses revealing the elemental and molecular compositions of the different layers.

The methodology used should be carried out in accordance with the questions posed by the conservator and not done systematically.

1.4. Monitoring of the Internal and External Environment

For conservation purposes, monitoring consists of the use of devices to measure a selection of phenomena occurring in a given environment over time by recording data at determinate intervals in order to keep track of any possible changes. The data obtained are collated and graphs produced in order to understand and provide an interpretation of these changes, with a view to making the necessary changes to the environment to safeguard the object under study. It is very important that the recordings are as exact as possible, in order that the interpretation of the data is correct.

The construction of the buffer corridor (1973 and 1989) and the glass barriers inside the Tomb (2001) aimed to prevent environmental impacts on the mural paintings. However, since they have given rise to inadequate results, a study to design a more efficient system was carried out (See *The environment and lighting system into the Susan-ri Tomb* later in Part three of this publication).

Since the Susan-ri Tomb flooded during each rainy season, it was necessary to find out whether the rainwater came in infiltrating through the mound, or whether it was due to fluctuations in the water-table.

Water was prevented from coming into the Tomb by infiltration through the mound by the building of a drainage trench around it for rainwater collection. (See *Water Infiltration and Waterproofing the Susan-ri Tomb* later in Part Two of this publication.). After the completion of the conservation work, monitoring of the micro-climate inside the Tomb was included in a maintenance programme, in order to evaluate the systems' efficiency and, if need be, carry out any necessary modifications.

1.5. Evaluation of the Data

The interpretation of the collected data is the most important part of designing a conservation plan. The correct understanding of laboratory results, for example, can serve as the basis for a specific operation, such as cleaning the mural paintings. On the other hand, if the data is not properly confirmed, or if completely reliable results are not obtained, then planned actions can be jeopardized. The same thing is true if figures in the data are not properly recorded, such as those relating to the micro-climate, etc. If this is the case, then the data can give rise to erroneous interpretations, with the consequent implementation of an incorrect response.

Previous analyses of hard-mud incrustations had indicated a high silica content, the incrustations being called 'mineralized' or 'silicated' mud as a result, so the interpretation of the analyses indicated that the samples contained a large amount of sand. However, it could also have been the case that they contained large amounts of silicates or a similar substance. But the crystallographic organization of sand and solidified salts of silicic acid is different, and this can be clearly observed by examining a thin cross section of the material under a petrographic microscope. ESEM analysis can be used to indicate the elemental composition of sample materials (using X-Ray fluorescence mapping), and this is useful in cases where a given element is detected as being the main element in a sample by other forms of analysis, but where it cannot otherwise be determined whether that sample is only made up of one form of that element, or whether it contains many different compounds.

Another example can be given of a case where a correct answer was not provided to the question posed. This example refers to samples taken from another tomb (the Yaksu-ri Tomb), which showed identical characteristics to those taken from the Susan-ri Tomb when analyzed. The aim of the analysis was to discover the nature of the colouring organic substance released by fungal activity that was staining the paint surfaces with purplish dots. This would then have led to the identification of the species of fungi responsible, as well as the identification of a substance that could be used to remove the stains. The results of the analysis, revealed that « blackening fungi » (Ulocladium spec.), *Stachybotrys chartarum* and *Acremonium strictum* were present, pathogenic species peculiar to cellulose and hazardous to human health were responsible. However, these were only approximate conclusions, because the samples were collected in wet cotton wool swabs and kept in sealed containers for about a week, raising the possibility that the cotton wool contained the spores of the above mentioned that had developed in the warm and damp environment of the containers.

The results of this piece of research were open to question. In order to confirm them, further aerobiological research was necessary with the taking of further samples.

1.6. Archival Research

The investigation of ancient and traditional painting techniques, as well as of the records of former interventions, in the archives of institutions dealing with the safeguarding of cultural heritage is of paramount importance because such investigation can provide first-hand information and save time and funds, allowing the conservation work to continue at a faster pace. The written record of an interview carried out by one DPRK National Conservation Team member with a former labourer who had worked on the preservation of the Susan-ri Tomb contained some invaluable information, providing clues to understanding certain problems and shedding light on their solutions.

1.7. Testing of Conservation Materials

The materials employed in the conservation treatments were limited to the strictly necessary and to those that had shown proven results in the literature and in the field. Very few organic materials were used, in order to reduce to the minimum any possibility of by-products being formed or of micro-organism activity. Most of the materials were obtained from abroad, but some were also procured in Pyongyang, and relevant analyses were carried out of these. (See *Technical Data of Materials Employed for Conservation* in the Appendices to the present publication.)

Research was carried out to establish a method for the removal of the hard-mud incrustations and the consolidation of renders and paint layers that lacked cohesion. The so-called hard-mud incrustations, or 'silicated mud', were the object of various theories amongst the scientists carrying out the analyses, and various methods and materials for their removal were tried without satisfactory results. Trials were carried out following methods found in the conservation literature, and these too gave poor results. Research on the safe removal of these deposits was therefore carried out and a methodology established. Additional research was carried out to consolidate the mortars and renders that lacked cohesion under cement layers, and this research also led to satisfactory results. (See *Consolidation of Renders and Removal Methods of Mud Encrustation of the Mural Paintings of the Susan-ri Tomb* in Part Three below.)

1.8. Operational Work and Maintenance Programme

Preventive conservation treatments comprise actions designed to preclude and/or minimize the development and consequences of further damage. They include the assessment of the causes of potential damage, the monitoring of possible factors in order to understand their behaviour, and the taking of measures aiming to eliminate or reduce such factors. Steps to control the sources of water into the Tomb and to prevent large fluctuations in temperature and relative humidity inside the Tomb were accordingly carried out as preventive measures to halt further deterioration, for example through the proliferation of micro-organisms.

In addition, the removal of polluting substances, such as soil, mud, etc., and the disinfection of surfaces inside the Tomb and in the buffer corridor was also carried out, in order to inhibit the activity of micro-organisms, especially fungi and bacteria. Micro-organisms were eliminated from the Tomb by using disinfectants based on quaternary salts and by applying solutions of ammonium bicarbonate and benzalkonium chloride. The disinfectant solutions were applied in different ways depending on the area of the Tomb concerned: poultices were locally applied to the surfaces where there was a major concentration of biological agents, and sprays or sponges soaked with the disinfectant solutions were applied to surfaces that were then rinsed with distilled water several times. Compresses saturated with distilled water were used to remove any residues of disinfectant from the treated surfaces, in order to prevent the formation of potentially harmful by-products.

The disinfection of the buffer entrance corridor was carried out by using a traditional practice consisting of applying lime-washes to ceilings and walls. Lime has disinfectant properties that are natural and are compatible with the environment, so it was decided that the Tomb corridor walls should be cleaned and then painted with lime-washes rather than cleaned with disinfectants. This is also a low-cost technique, though further thin lime-wash coatings should be applied at least once a year.

Preservation treatments aiming at the stabilization of vulnerable components of the mural paintings involved the re-adhesion of detached/separated renders to the wall, the fixing of separated paint layers and the consolidation of renders and paint layers lacking cohesion. Materials applied during former interventions, such as cement fillings, films and coatings, were removed.

Conservation and restoration treatments also comprised the removal of non-damaging materials that distracted attention from, or prevented the appreciation of, authentic elements in the mural paintings. These materials, including the grey clay employed for filling small lacunae, the yellowish clay spread over white surfaces of hydrated lime, and the stains caused by micro-organism activity, were removed in order to restore the tonalities of the paintings. Obscuring materials, such as mud, soil, clay, hard mud and calcium carbonate incrustations, were removed where feasible and where this could be done without damage to the pictorial surface.

Restoration work comprised treatments that deliberately aimed to reinforce the unity of the mural paintings, such as by removing distracting gaps in them, and it included the filling of lacunae, such as by re-pointing the stone blocks in the masonry, the filling in of grooves in the masonry, the edging of the borders of the lacunae and the filling in of any small lacunae under and/or at the paint layer level, as well as the dampening of visual tonality and the adequate reconstruction of painted areas to allow a better understanding of the pictures by the viewer.

Any maintenance programme on the mural paintings should aim to prevent the work carried out failing over the short term. It should be born in mind that conservation work only slows down deterioration processes and that it does not stop them, while minimal intervention work aims to ensure that the original materials can continue to perform without too much interference[3]. Therefore, regular monitoring of the environment, as well as inspections comparing the state of the original and the restored materials with the digitalized graphic documentation, should take place. There should also be a taking of samples of any condensed water on the surfaces to check if there is an increase in soluble salt content, by measuring the electrical conductivity. This can be helpful in determining other factors of decay, such as water infiltration. Such preventive actions can help to ensure that interventions designed to safeguard the monument are carried out in a timely fashion.

2. Methods, Materials and Results

The following is not a collection of recipes, but rather consists of guidelines that can be modified or adapted according to the situation encountered. The present work on the mural paintings of the Susan-ri Tomb was divided into two phases: preservation and conservation–restoration.

Fixing [F]	1F	Fixing of detached/separated renders up to 5 mm separation
	2F	Fixing of renders with considerable lack of adhesion, including large detachments with deformation [bulging] from 6 mm to several centimetres separation
	3F	Fixing of separated bubble-shaped paint layers
Consolidation [C]	C	Consolidation of renders and/or paint layers with lack of cohesion
Removal of Obsolete Fillings [RC]	1RC	Removal of cement films from renders
	2RC	Removal of cement filling lacunae, cracks and joins
Cleaning [CS]	1CS	Cleaning the surfaces of renders and paint layers from incoherent matter, such as soil/mud/clay concretions
	2CS	Cleaning the surfaces of renders and paint layers from coherent deposits, such as hard-mud and calcium carbonate incrustations
	3CS	Cleaning surfaces from micro-organism activity and associated staining
Filling Lacunae [FL]	1FL	Filling cuts and grooves accidentally made in the stone blocks during the removal of cement
	2FL	Re-pointing masonry joints
	3FL	Edging the open borders of the lacunae
	4FL	Filling of lacunae, cracks and grouting holes at the paint layer level
	5FL	Filling of lacunae, cracks and grouting holes under the paint layer level
Aesthetic Presentation [AP]	1AP	Dampening wear of the patina and paint layer
	2AP	Dampening the visual tonality of lacunae
	3AP	Reconstruction of the paint layer with tratteggio

Tab. 1: Grouping and arrangement of conservation and restoration work

2.1. Preservation Treatments

Preservation treatments aim to slow down deterioration processes that inevitably cannot be stopped. They involve carrying out specific interventions and maintenance work, and they do not have any aesthetic value. The treatments used on the mural paintings of the Susan-ri Tomb comprised the fixing of detached renders and paint layer, the consolidation of renders and paint layers lacking cohesion, and the removal of detrimental materials, such as cement and impermeable clay.

2.1.1. Fixing

Fixing consists of the re-adhesion of separated or detached preparatory or paint layers to the adjacent support. If the survival of the mural decoration is threatened by the separation or detachment of the preparatory layers from the walls, their re-adhesion is necessary. The re-adhesion of detached preparatory layers to the wall, or to each other, and paint layers from the preparatory layer is not easy, and there is no entirely satisfactory solution. The mechanical behaviour of ancient materials is usually not the same as that of modern ones employed in conservation work, and therefore the modern materials have to be suitably modified and adapted to each case. The use of materials that are similar to and compatible with the original fabric is one of the main requisites of reliable conservation practice. Reversibility, in this case, is no longer considered a prerequisite because the new material incorporated during the conservation work is in the interior of the structure and cannot be removed.

Grouts used must have the following characteristics: good penetrability and fluidity at low-pressure injection; long-lasting and sufficient penetrability; a minimum drying shrinkage coefficient; good adhesion to the void surfaces to be filled; mechanical resistance and porosity similar to the original materials; expansion coefficients as similar as possible to the original materials; the least possible amount of soluble salts and other substances that could cause the formation of by-products or alter the ancient structure [4, 5].

Definitions

Grout and grouting: the injection of slurry (liquid) mortars into fissured walls and separated renders to the wall in order to increase/achieve adhesion and strength

Surfactant: is a substance that decreases the surface tension of water.

Equipment:

Buckets	Plastic containers with lids of various sizes
Soft plastic sponges	Plastic cups
Hand drill and drill bits of 1, 2 & 3mm diameter	Sieves of 80 – 200 mesh
Syringes 20 & 50 cc capacity	Double-headed iron spatulas
Stainless steel needles 180 – 200 diameter	Bowls for mixing mortars
Thin hypodermic needles	Dry cloth or wiper
Graduated cylinder in cc	

Materials:

Demineralised water	Hydrophilic cotton wool
Grout in powder form	Slaked lime putty
Surfactant	Aggregates: sand & brick dust

Technical data:

Grouting material in powder form: Ledan TA1 from Tecno Edile Toscana.

<u>Surfactant</u>: solution of 10% benzalkonium chloride in water, subsequently diluted to 2%. (See *Technical Data* of *Materials Employed for the Conservation* in the Appendices for details.)

<u>Demineralised water</u>: water free from minerals, e.g. salt.

Preparation of the surfactant and grout mixtures:

For the surfactant: prepare a solution of surfactant in water in proportions that can vary from 1% to 3%.

For the grout: prepare the grouting mixture by sifting the powdered grout with a graduated mesh sieve (80 – 150 mesh). One to three units by volume of grout should be used for one unit by volume of water. Put the water into a container and slowly add the sieved grout, which will absorb the water. The proportions used can vary: in some cases, the grout should be very thin (for thin separation), or thicker if the separation is quite wide, in order to create anchoring points rather than fill the area entirely. Once the grouting powder is saturated with water, carefully mix the grout until a homogeneous mixture is obtained. It is important to keep the grouting mixture covered while not in use, as it can be contaminated by extraneous materials. This can then obstruct the needle or syringe used to inject the mixture. The grout has a pot-life and workability of about two hours. As a result, use of the grout should be planned beforehand and small amounts prepared in order to prevent waste.

Procedure 1F: Fixing of detached/separated renders

1. Before carrying out any procedure to fix the renders, the surface must be carefully inspected, especially under raking light, in order to establish if the paint layer is sound enough to tolerate mechanical action such as rubbing and knocking.

Fig. 17: Examination of the painted surface of the west wall under frontal light

Fig. 18: Inspection of the painted surface of the west wall under raking light

2. Find the most suitable point for injecting/grouting, which is done by gently tapping the surface with the fingertips. A dull sound will be produced that will

Fig. 19: During tapping the surface with the fingertips of one hand while the other 'feels' the vibrations produced so as to establish the degree of detachment/separation

change according to the type of separation. It is advisable to tap with one hand while gently putting the other nearby so as to physically feel the vibrations produced. Once the best point for injecting is found (care must be taken not to use vital points in the painting, such as faces, hands, important lines, etc.), drill a hole of equal diameter to the needle to be employed, or, even better, employ existing cracks, the borders of lacunae, etc.

3. Open borders and cracks in the renders must be filled with a plaster similar to the original, and this should then be allowed to dry. If the space is relatively narrow, like a thin crack, this can be filled with cotton wool using an iron spatula to fit into the interstices. These preliminary sealing operations should avoid the leakage of surfactant mixture or grouting over the surfaces beneath. For a detailed explanation, see the section below regarding the filling of lacunae (3FL).

Fig. 20: Drilling of injection point. Notice that the hole produced is practically of the diameter as the needle for injecting the grout as on the lower left side of the photograph

Fig. 22: Detail showing a section of open border of lacuna and cracks filled with lime-based plaster (at the left hand side of the photograph) and the other gaps filled with cotton wool

Fig. 21: Closing the open borders of the lacuna with cotton wool from which the grout can flow out

Fig. 23: Siphoning dust from holes. The rubber siphon must be air vacuum before aspiring the dust so this is not blown inside but sucked

4. The hole produced by drilling or the best point(s) selected for injecting should be cleaned of dust using a rubber siphon.

5. Inject the surfactant solution with a syringe and check if it flows from the open areas. If this occurs, block or fill the area with suitable materials. In the Susan-ri Tomb, the separation of the renders from the wall was large enough to allow the penetration of the grouting mixture without clogging, obtaining a good diffusion. It was assumed that the internal surfaces were damp, so the use of a surfactant was avoided, reducing the use of chemical products to a minimum.

Fig. 24: Injecting the surfactant

6. Suck up the grout mixed with water with a syringe, clean the aperture with water, and insert the needle. Introduce the needle into the selected grouting point or hole in the render and slowly inject the grout. In order to avoid side-leakage of the grout from the grouting point and the needle while injecting, fasten a washer made out of cotton wool around the needle and tighten against the injecting point in the render. A bucket filled with clean water, soft plastic sponges and a dry cloth should also be within easy reach, such that if the grouting mixture overflows from any unforeseen point (crack, hole, etc.), the area can be immediately sealed with cotton wool and the grout wiped away with a damp sponge. The surface should be washed thoroughly in order to ensure that no residues remain. Once the grout dries, it can be very difficult to remove the resulting whitish stain, especially on a porous surface.

7. The fixing of large areas of detached renders must be done gradually, starting from the lower sections and allowing the grout and renders to set and dry so that not too much wet weight is added to the interior of the gap that could result in breakage of the render. Once one section has set (usually about 24 hours), the next one can be grouted and so on until the work is finished. If one point of injection is used for grouting several times, e.g. after the last day's injection, it is recommended that the hole be cleaned by injecting water into it and placing a sort of cotton wool tap on it.

Fig. 25: The needle for injecting the grout is fastened by a sort of a 'washer' made out of cotton wool tightened around the needle and the hole in the render so as to prevent the flow of the grout.

Fig. 26: Grouting (injecting the grout)

Procedure 2F: Fixing of renders with considerable lack of adhesion, including large detachments with deformation (bulging)

1. Apply propping if necessary, taking care that the painted surface is insulated, e.g. with plastic sheeting, and well protected with a buffer like a soft plastic sponge from any eventual breakage from hard/stiff materials, such as planks, etc. The propping must be stable and independent of scaffolding, as no movements should occur.
2. Find the most suitable point for injection (see point No. 1 in Procedure 1 above). It is preferable to use upper areas or cracks: drill a hole only if strictly necessary. Clean the interior of the render, void, crack, etc., from dust using the rubber siphon as before. Once again, fill any point or area (cracks, borders, etc.) from which the grouting material could flow out.

Fig. 27: Section of bulging rendering on the northern lower side of the east wall, under raking light

Fig. 28: The bulged render protected by polythene sheeting and sponge, kept in position with wooden planks and propped with green wood poles so as to assure flexibility during the setting of the grout

3. Inject the surfactant mixture.
4. Inject the grout. Grouting must be carried out at different stages from 12 to 24 hours so as not to overload the area to be fixed and allow the mixture to set properly between one application and the next. The grout must not be allowed to overflow, resulting in leakage onto the surface.
5. It is very important to keep the grouting mixture covered while not in use.
6. Remove the propping when the void is completely filled and dry. In some cases, the bulged render will change dimensions because it is 'pulled' or 'sucked' back to the wall by some millimetres/centimetres due to the shrinkage of the grout during setting. This happened in the lower northern section of the east wall, where the bulged became practically flat.

Procedure 3F: Fixing of separated bubble-shaped paint layers

Fig. 30: Injecting the grout or micro-grouting

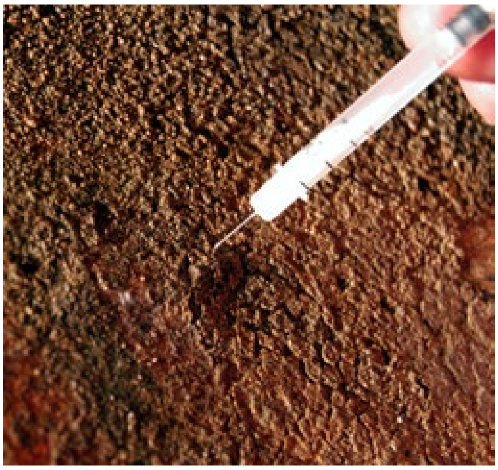

Fig. 29: Injecting the surfactant and water mixture

1. Before any procedure for fixing paint layers separated from the substrate in the shape of bubbles can be carried out, the surface must be carefully inspected under raking light and the dimensions and eventual points through which injections can be done identified.

2. Once the point from which injections can be done is identified, carefully inject a mixture of surfactant and water with a subcutaneous needle. Given the fragility of the deformed crust of the paint layer, it is indispensable that the equipment be handled with extreme care.

3. Inject the grout mixed in water. Given the small dimensions of the bubbles, the dry grout should be sifted through a very high mesh sieve, so that it can pass through the syringe needle and fill the small cavity. Allow to set and dry. In order to find out whether the void or bubble has been completely filled with grout, dimensional change or shrinkage, even minimal, of the bulge should occur. If this does not happen, inject the mixture again.

4. Clean the surface with a soft damp sponge if any grouting material has leached out.

Fig. 31: While injecting the grout it is advisable to put a damp sponge beneath so as to immediately collect any eventual flow of grouting mixture. The grouting of bubble-shaped paint layer must begin from the lower areas and wait for these to set, and then continue with the upper row and so on.

Results

The fixed renders should make a hard sound when knocked similar to that made by adjacent firm renders. It is not necessary to fill all the voids completely when fixing the preparatory layers, but a series of anchors should be produced at strategic points in order to fasten the renders to the wall. Excessive grouting of every void could lead to mechanical stress within the original fabric or within the layers themselves, and this could result in their separation from the sound adjacent and untreated areas. Therefore, it is necessary to equalize as far as possible the distribution of the grouting. The paint layer should make a sharp sound not dull but glittering when brushed with the fingernails using the upper side of the hand.

2.4.1. Consolidation

Consolidation denotes the strengthening of materials that lack cohesion. It should be carried out when the links or connections between aggregate and binder are weak, or when they have entirely lost cohesion, characterized by a powdery appearance, and therefore when the stability of these areas is vulnerable to disintegration. The restoration of a sound, cohesive state prevents the loss of constitutive material.

Properties required of materials employed in consolidation (*consolidants*) include: the chosen consolidant and application method should not cause damage to the render or hinder further consolidation; the consolidated render must be strong enough, but not too strong; in fact the consolidated render must e strong enough similarly to the adjacent sound renders; the consolidant should penetrate as deeply and homogeneously as possible in order to avoid lamination effects that could cause stress between the weaker and stronger layers, as these stress points could then cause damage to the render itself, or loosen cohesion from the support.

In addition, the chemical composition of the consolidant should be as similar as possible to the material to be consolidated, and a new composite material should not be formed by the consolidant. The consolidant should behave similarly in terms of ageing, thermal expansion and shrinking to the original material. It should not change the refractive index of the original, or cause discolouration or glossiness of the surfaces. It should not alter the porosity of the constitutive materials, and it should allow water vapour exchange. It should not acidify on ageing[6].

Research was conducted on a less-representative sample of a render from the Susan-ri Tomb, during which the mineralogical composition was determined but not the crystallographic arrangement. The sample's physical properties were studied (such as density and porosity, capillary water absorption coefficient (W), capillary water absorption velocity coefficient (B), and water vapour diffusion resistance (WD)) (See Consolidation of renders and the Removal methods of Mud-encrustations of the Mural Paintings in the Susan-ri Tomb later in part Three of this publication). Further samples were then prepared according to the given parameters, and these were treated with different types of organic and inorganic consolidants. Physical measurements were taken before and after the treatment, in order to compare and determine changes in the samples.

Obviously, the organic consolidants were discarded *a priori*, but they were still tested as points of comparison with the inorganic consolidants. Given that the interior of the Tomb was very damp, a frequently employed inorganic consolidant, ethyl silicate, could not be used, as it tends to hydrolyze in a wet environment. The other alternative was to employ lime-water containing small amounts of $Ca(OH)_2$. However, it has been shown that the properties of traditional lime-water do not meet the required consolidation parameters because it has unstable diffusion properties inside the material as well as poor penetration. It also forms internal crusts towards the surface, etc[7]. Therefore, a consolidant was tested that combined traditional lime-water with nanotechnologies that meet the given consolidation standards.

This consolidant, consisting of hydrated lime in powder form (calcium hydroxide), was dispersed in iso-propanol and was then injected into the area lacking cohesion. When the consolidant has homogeneously penetrated the interstices of the material lacking cohesion and the iso-propanol has evaporated, theoretically the calcium hydroxide contained in the mixture reacts with carbon dioxide to form calcium carbonate, which then leaves a thin network of calcite crystals. This consolidant requires prolonged and repeated applications to the crumbling structure of the renders and paint layers[8]. However, Ethyl silicate (70% Ethyl ethers of silicic acid in iso-propyl alcohol) gave better results *in vitro* even though was not employed for the consolidation of the large areas lacking cohesion because not available during the development of work.

Definitions

Consolidant and consolidation: a *consolidant* is a fluid having binding properties, consolidation being the provision of coherence by deep penetration and saturation of crumbly/ powdery material by the consolidant.

Delamination: separation of composite layers, e.g. in multi-layered renders.

Colloidal dispersion: any material where the size of the particles (dispersed material) varies between one ten-thousandth and one one-millionth of a millimetre in diameter distributed in a dispersing medium. A colloidal dispersion must not to be confused with an *emulsion*, which is a stable dispersion consisting of an immiscible liquid dispersed in another liquid by substances called emulsifiers.

Nanotechnology and nanometre: the field of engineering that deals with materials less than 100 nanometres (one-billionth of a metre) in size, especially single atoms or molecules. One nanometre is one one-millionth of a millimetre.

Equipment

Technical balance	Hermetic glass containers
Magnetic plate stirrer 80~100 rpm 750 W	Plastic containers
Agate mortar and pestle	Plastic spatula
Syringes 20 cc capacity	Timer
Thin hypodermic needles	Soft sable brushes

Materials

Iso-propanol	Hydrated lime in powder $Ca(OH)_2$

Technical data

Medium: Iso-propanol.

Consolidant: Hydrated lime in powder $Ca(OH)_2$ (See *Technical Data of Materials Employed for Conservation* in the Annexes to this publication.)

Preparation of the consolidant

Lime-based consolidant I (L-BC I): grind hydrated lime in powder $Ca(OH)_2$ in an agate mortar, reducing the grain size to 400 nm (nanometres) in diameter, sufficient that it can be dispersed in iso-propanol. Take 1.25 g of the nanometric hydrated lime and disperse in 200 g of iso-propanol, diffusing with the use of the magnetic plate stirrer in order to obtain a colloidal dispersion.

Lime-based consolidant II (L-BC II): the materials and the method of preparation are the same as described above, with the exception that the amount of nanometric hydrated lime is increased to 2.5 g in 200 g of iso-propanol.

Procedure C: Consolidation of renders and/or paint layers with lack of cohesion

1. Internal lack of cohesion located under a thin hard crust that can vary from 0.1 mm to 2-3 mm, of the constitutive material is consolidated with injections of L-BC I four to five times at intervals of six hours between each application. Care must be taken not to allow the consolidant to overflow onto the surface because it can form a thin white film of calcium carbonate. Allow the consolidant to set and check if by tapping the sound that is produced reverberates or it is sound enough that does not crumble back again, if necessary, repeat the treatment after two to three weeks.

Fig. 32: Close-up of area lacking cohesion before taking a sample

Fig. 33: Mortar lacking cohesion under raking light

Fig. 34: Mortar lacking cohesion under frontal light. Notice that in the preceding and this photographs, it is not really visible the lack of cohesion because the appearance of the mortar seems solid but in reality crumbles apart

Fig. 35: Injection of the consolidant

2. If the surface of the render or paint layer is powdery, then it is first consolidated with injections of L-BC I under the layer done four to five times at intervals of six hours between each application. The consolidant is then injected twice at six-hour intervals. Allow the consolidant to set and assess the results after two to three weeks. Repeat the treatment if necessary.

Fig. 36: Area of paint layer and render lacking cohesion on the west wall, north side, under frontal light

Fig. 37: The same section as per the previous photograph under raking light

Fig. 38: Consolidation of paint layer lacking cohesion by applying by brush and percolation of the consolidant.

Results

The consolidants temporarily named L-BC I & L-BC II were tested on those mortars and renders lacking cohesion. The consolidated renders and paint layers were found to have recuperated their stability and were sound enough to tolerate slight abrasion. It is not desirable that the consolidated sections have higher density ultrasonic wave velocity, etc. than the not consolidated ones that are sound enough. The porosity might have been maintained so water-vapour exchange from the interior towards the exterior and vice versa might have flown as in usual conditions. However, the treated areas must be monitored over time and the consolidation treatment repeated if required.

2.3. Removal of Obsolete Fillings

2.3.1. Hydraulic Cement fillings

During a previous intervention, cement was employed for filling lacunae in the renders, as well as cracks in the masonry and joints. The cement was applied in successive layers. The first, dark grey (blackish) in colour, was extremely hard and compact, while the second was slightly lighter in colour, but was just as dense. The third layer was softer, and hydrated lime had been incorporated into the mixture, which was spread onto the adjacent painted renders. Portland-type cement is incompatible with the original lime-based materials.

Portland-type cement is unsuitable for conservation because it is too strong (high compressive strength and high modulus). Should differential movement occur, stress will be transmitted to older sections of the structure, which will fail. Cement also has a high thermal expansion coefficient, which will result in stress and damage to the older, weaker masonry. Cement forms soluble salts when setting, and their leaching out takes place even a long time after setting when the cement comes into contact with water. Cement has low porosity because it has very small pores that hinder the movement of moisture in masonry and do not allow evaporation beneath the cement layers[9].

It was therefore necessary to remove this material, which, owing to fluctuations in thermal expansion, had already contributed to separating adjacent layers of renders from the wall. Dangerous soluble salts, as a result of water formed by condensation on those colder cement layers, had also leached out and re-crystallized upon water evaporation on the lower painted areas.

Definitions

Leaching of soluble salts: salts are dissolved from the cement and then deposited on lower surfaces by water run-off.

Thermal expansion: materials typically experience daily and seasonal temperature cycles, causing them to expand with the heat and contract on cooling. This produces deformation and cracks, and shear stresses are produced in the interior of the materials.

Condensation of water vapour: this refers to the formation of liquid water from the water vapour contained in hot air on a cold surface and is due to the cooling of the air. The temperature of the air drops to a point (dew point) at which condensation forms on surfaces that have the lowest thermal value.

Equipment

Hammers and carpentry/masonry chisels	Electric mini-drill with abrasive bits
Electric hand-drill and concrete drill bits	Ultrasound spatula
Angle cutter	Fibreglass pencils
Surgical scalpels	Brass, nylon and plastic brushes of several sizes
Hand water-sprayer	Soft plastic sponges
Buckets	Auto-adhesive thin plastic foil

Materials

Cationic ion-exchange resins	De-ionized distilled and pure water

Technical Data

Cationic ion-exchange resins (strong and weak): See *Technical Data of Materials Employed in the Conservation* in the Appendices to this publication.

De-ionized water: water from which ions have been removed by the use of cation and anion exchangers.

Distilled water: non-volatile substances are removed from water by a process involving heating, cooling and condensation.

Pure (clear) water: water that is free from any adulterant or extraneous substance.

Preparation of the ion-exchange resin

Prepare the ion-exchange resin by mixing with the de-ionized/demineralised water and check the pH of the resulting mixture. If the pH is near to 0, wash and rinse the resin until reaching values near pH 7. The dry resin is a soft powder. Keep the made-up mixture in a plastic container with a lid, taking care that it is covered by about 1 cm of water. It should not be allowed to dry out.

Procedure 1RC: Removal of cement films from renders

1. The films produced by the cement having been spread over the surfaces and then carelessly wiped away are hard and intimately linked. Evaluate resistance to dry and wet cleaning in an unobtrusive area of the underlying paint and preparatory layers. If one of the layers, or both, lacks adhesion or cohesion, fixing and/or consolidation of the layer must be done beforehand.

Fig. 39: Cement film on painted surface under frontal light

Fig. 40: Cement film on painted surface under raking light

2. Apply the strong cationic ion-exchange resin in a thin, homogeneous coating, so as to disrupt the cement film. Cover the area with auto-adhesive plastic foil and make sure that the resin remains damp. The resin should be smeared over the surface once in a while, in order to re-activate the exchange action of the resin with the surface under treatment. The time of application can vary, depending on the thickness and compactness of the film, from some minutes up to 12 to 48 hours or even longer, as the case may be. It is therefore necessary, before opting for the most suitable length of application, to carry out tests on unobtrusive areas of painting in order to evaluate their action over time. Rinse the surface using soft plastic sponges plunged into distilled water in order to remove the resin after the completion of the treatment.

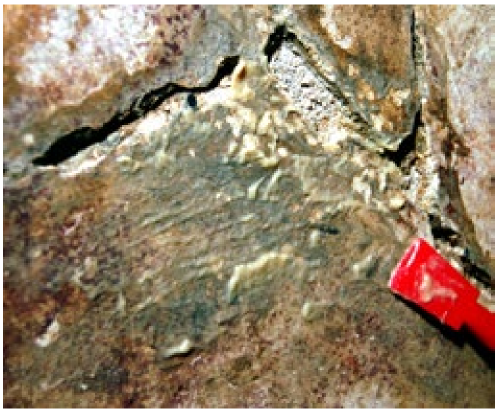

Fig. 41: During the application/spreading of strong cationic ion-exchange resin

Fig. 42: During the removal of the ion-exchange resin with distilled water and soft brush

3. The surface being treated is then thinned down using surgical scalpels, abrasive tools such as fibreglass pencils, and/or an ultrasound spatula. If employing scalpels or fibreglass pencils, it is necessary to check the level of the film vis-à-vis the paint layer by washing with sponges soaked in clear water. Areas in which the lime film has become a coating, e.g. of a millimetre or so thick, usually near the cement filling the lacunae, should be thinned down using surgical scalpels or other suitable tools and then treated as per procedure 2RC and as described above.

Fig. 43: Thinning-down of the cement film with surgical scalpel

Fig. 44: Removal of cement residues with ultrasound spatula

Fig. 45: Removing thin cement film with fibreglass pencil

Procedure 2RC: Removal of cement filling lacunae, cracks and joins

1. The borders of the original renders must be fixed in advance if they are separated or detached from the wall and the cement covering the painted renders removed as per procedure 1RC in order to discover the boundary between the cement filling and the original render.

Fig. 46: Before the removal of cement

Fig. 47: During the removal of cement from cracks and lacunae, notice the borders liberated from the cement film

Fig. 48: Removal of cement covering paint layer and discovery of the border of the lacuna

Fig. 49: Once the border of the original painting is discovered, the removal of cement can proceed safely

2. Make a groove using an angle cutter on the cement about 10 cm from the boundary line, forming a parallel strip or band. It is advisable to spray on water while carrying out this operation in order to avoid dust getting everywhere.

Fig. 50: During the removal of cement filling the lacuna at the north wall of the burial chamber, a band of cement is left around the border of the original painting. Notice the grooves accidentally made by the cutter on a stone block

Fig. 51: The cement layer is cut into squares with an angle cutter

3. Cut grooves in squares of about 10 cm per side and 2 cm from the surface, taking care not to cut the underlying masonry. An alternative is to drill holes using a hand-drill, though this takes longer. 'Test pits' should be made by hand using hammers and chisels in order to establish the thickness of the layer to be removed.
4. Cut out the squares of cement or the areas between the holes made with the drill and remove using hammers and chisels. Leave the strip of cement along the perimeter of the render.

Fig. 52: Drilling holes in the cement layer with percussion drill and cement drill bits

Fig. 53: During the removal of the cement in squares

Fig. 54: The cement band around the perimeter of the lacuna after having removed the most

5. Remove the cement band from the inner side towards the boundary, making several perpendicular cuts with the angle cutter and remove with the hammers and chisels while taking care not to touch or break the render.

6. Removal of the cement residues from the masonry surfaces is carried out by employing several tools, such as surgical scalpels, metal brushes of varying hardness, and toothbrushes, etc., according to the hardness of the material the cement is adhered to. Rinse with water. Another excellent instrument here is the ultrasound spatula.

Fig. 55: The lacuna at the north wall before removal of cement filling

Fig. 56: Many means were employed for removing residues of cement from the stones' surface. Hand made metal brushes from electric wiring proved excellent for this task

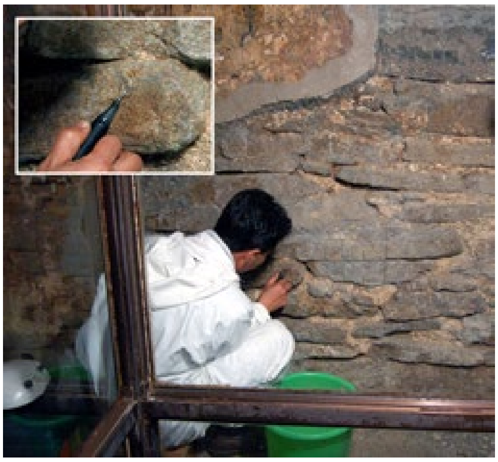

Fig. 57: The use of more sophisticated equipment makes accurate and safer the task

Fig. 58: The final cleaning with distilled water for removal of eventual residue of soluble salt and before re-pointing the stone blocks

Results

The removal of the cement improved the micro-climate in the interior of the Tomb, making it into a better and healthier environment for the safeguarding of the mural paintings. The relative humidity dropped from values that fluctuated around 98-100% to those much more in line with the natural hypogeal ambience and falling to around 85% and if possible lower. This was desirable in order to ensure that micro-organism development did not take place. Temperature adjustment of the walls increased to the point that water vapour condensation diminished. This was owing to the fact that the high thermal inertia of the cement had 'cooled' the surfaces, causing major water run-off from the surfaces in the spring and setting in motion the dissolution, transport, and re-crystallization of soluble salts. It was water that encouraged the development of micro-organisms. As a result of the intervention, the walls continue to be warmer in autumn and winter and less cold in spring and summer. Upon water evaporation, the soluble salts thus re-crystallize, and the micro-organisms, having no further provision of water, cannot then stain the surfaces due to their reduced metabolic activity.

Fig. 59: The lacuna at the north wall after removal of cement filling. Notice the superb masonry stonework.

2.7. Conservation and Restoration Treatments

Conservation and restoration treatments aim at the safeguarding of the object to be conserved and restored. Historical and aesthetic considerations should be taken into account in deciding on the alternatives considered during planning the work, these playing a determining role.

Conservation work is usually invisible, and therefore extensive and detailed graphic documentation is necessary in order to keep records of the completed treatments. The restoration component, on the other hand, generally includes the aesthetic presentation of the paintings and is the more visible outcome of the conservation campaign. It is necessary to plan all the activities and/or operations to be undertaken in sequential order from the beginning of the work, in order to have a clear vision of the final result and as part of a methodological approach.

2.7.1. Cleaning

Cleaning consists of the removal of extraneous deposits from the surfaces in order to reveal the present state of the original materials. The selection of the materials and methods used depends on the nature of the substances to be removed and the resistance of the underlying layers of the mural painting. Cleaning is begun by carrying out tests on unimportant areas of the painting, in order to establish any difficulties likely to be encountered in removing foreign substances in relation to the resistance/strength of the paint layer. Once a methodology has been established, which in some cases will need to be adapted to variable situations or differences in the behaviour of the foreign materials within the fabric, the cleaning of the surfaces can be begun.

In a damp environment, it is preferable to restrict the use of chemicals and cleaning mixtures that contain soluble salts and/or organic substances to the minimum, because over the long-term by-products or micro-organisms may develop and besides that undesired dirt products are transported deeper into the render if too much water or liquids are employed. Therefore, if possible it is advisable to employ mechanical means to remove hard or insoluble deposits. However, such dry cleaning methods can cause damage to the paint layers, or alter the condition of the surface of the painting if the manipulation of the tools and instruments is not correctly done.

The extraneous substances covering the mural paintings in the Susan-ri Tomb can be classified into two main categories: inorganic and organic. Surfaces soiled with incoherent deposits, such as hard mud and calcium carbonate incrustations, are included within the inorganic category, while organic substances comprise various coatings or varnishes, perhaps from previous interventions, that have given rise to the proliferation of micro-organisms with consequent stains on the surfaces due to their metabolic functioning. In many cases, organic coatings applied in the past may have transformed or disintegrated or have changed into thin films of insoluble salts. A yellowish-brownish transparent film can be found on the surfaces of abraded renders without paint layers appearing white after cleaning.

There are various considerations that should be taken into account with regard to cleaning hard-mud incrustations and related incoherent soil/mud/clay deposits, these behaving differently during removal depending upon their typology and according to the season. On the ceiling and walls of the entrance passage of the Tomb, which is a relatively small area, most of the various kinds of deposits were found, whether incoherent or coherent, naturally deposited or voluntarily applied.

Incoherent stratifications or accretions that have been naturally deposited onto the surfaces and are not calcified can be identified by their softness and by the fact that they can be removed with water and little mechanical action. They include: golden-brown/yellowish soil (GYS) found in the soil strata with weathered granite and sand; dark-red/brown mud (RBM) containing sand found in the sub-soil; dark-brown mud (DBM), apparently the constitutive mortar in the core of the walls, that is similar to RBM but contains very small amounts of sand and plenty of clayey matter.

Incoherent deposits applied onto the surfaces or filling lacunae in the renders during a former intervention can be removed by dry cleaning. They include: white-yellowish clay (WYC), (illite) or fine clays related to kaolin or bentonite, applied over hydrated lime plaster to visually reduce strong white impact and irregularities; purplish sand and fine clay (PSC) filling lacunae at the paint-layer level, which was thinly coated with hydrated lime on which the painting was reconstructed; grey clay (GC) employed to fill small lacunae. This is very similar in colour to cement and was applied during work possibly carried out in 1985-86.

Hard-mud incrustations can be classified into two main categories: mud incrustation 1 (MI-1) is quite porous, contains large amounts of sand, and is light brown in colour. It is not difficult to remove by dry cleaning and is perhaps associated with GYS and RBM; mud incrustation 2 (MI-2) is compact, contains very small amounts of sand, and is darker brown in colour and is perhaps embedded/mixed into a fixative or coating that makes it harder and more brittle. This substance is very similar in colour to the soft mud mortar (DBM) binding the stone blocks in the core of the walls.

The walls of the Tomb are cold in spring, and water vapour contained in warm air condenses on them, forming liquid water. In winter, the opposite is the case, with the walls being warm and dry. The behaviour of the deposits in relation to seasonal changes in temperature and humidity can be summarized as follows:

- incoherent soil (GYS) that contains consistent amounts of sand is easily removed by rasping with wooden tools and bristle brushes and cleaning with water at any season;
- mud (RBM) or clay (PSC) containing a certain amount of sand is soft and can be removed by scraping with wooden tools and water at any time;
- dry mud (DBM) and fine clay (WYC & GC) is hard and stiff in winter and needs to be saturated with water, making it plastic and malleable. Its removal requires mechanical action;
- porous mud incrustations (MI-1) are hard and offer considerable resistance to scraping in spring. In winter, they become porous, brittle and crumbly and can be scraped or ground down with surgical scalpels and abrasive tools;

- compact mud incrustations (MI-2) are extremely hard when wet and appear as an amorphous and translucent mass containing impurities. During winter, they are hard and resistant to scraping and abrasion.

Definitions

Wet cleaning: chemical cleaning agents (bases or acids) that work by breaking the primary bonds of the solids covering the surfaces or by exchanging ions, thus allowing their removal.

Dry cleaning: removal of solids by mechanical means without employing chemicals or reagents and only using tools to break, separate or disintegrate the solids, while also relying on the mechanical properties of water as when employing the ultrasound spatula, taking care, not to allow to penetrate in depth.

2.7.2. Cleaning the surfaces of renders and paint layers from incoherent matter, such as soil/mud/clay concretions

These surfaces bear obscuring matter, such as soil, mud and clay, this coming from the mound or from the inner core of the walls of the Tomb and being deposited onto the surface of the paintings as a result of water seepage or being voluntarily applied to selected areas of them. Unlike cement, this material is relatively easy and safe to remove if it has not been incorporated into insoluble salt formations, or into cement, or into a fixative. Such soil deposits also contain organic matter and retain sufficient amounts of water to encourage the growth of micro-organisms.

Definitions

Soil, mud and clay: *soil* consists of unconsolidated materials above bedrock level. *Mud* is a soft and sticky fine-grained earth material that can contain impurities such as sand. *Clay* is an earthy, extremely fine-grained sediment of soft rock composed primarily of clay-sized or colloidal particles. It has high plasticity and a considerable content of clay minerals, a group of hydrous silicate materials, essentially aluminium. Clay may be classified by use, origin, mineral composition or colour and has many uses.

Concretion: hard, solid and compact aggregate of mineral matter.

Equipment:

Bamboo sticks	Ultrasound spatula
Plastic brushes of various shapes and sizes	Soft plastic sponges
Bristle brushes of various sizes	Buckets
Hand water-sprayers	Plastic containers

Materials:

Clear and distilled water	Tissue paper
Auto-adhesive plastic foil	

Procedure 1CS: Cleaning the surfaces of renders and paint layers from incoherent matter, such as soil/mud/clay concretions

1. In this case, natural depositions of soil and mud, as well as various types of clays spread or applied during a former intervention, cover the surfaces (painted and non-painted), not allowing proper water vapour exchange within the structure. This is especially the case with the clay deposits, which block surface porosity.

Fig. 60: Deposits of mud on lower rendered areas of the north wall

Fig. 61: Example of different materials on the painted surface, grey clay filing small lacunae, brown mud stuck into other smaller lacunae, purplish and illite clays (indistinguishable), thin cement film all over the area and cement filling the large lacuna at the bottom right side of the photograph.

2. Dry concretions of mud on the surfaces can be cleaned by removing the matter with bristle or tooth brushes, bamboo sticks, scalpels, etc., and then using water. Wet the surface and the residual dry deposit with a hand water-sprayer so as to swell the deposits and then gently scrub with brush and water depending on the hardness of the deposits. Rinse by spraying water with the hand-sprayer and brush the mud away. In order to avoid overrun of the muddy material onto the lower areas, place a soft plastic sponge at the lower section of the area under treatment to collect the mud. Rinse the brushes, sponges, etc., thoroughly with clear water and replace as needed. Damage causing scrapes, grooves, etc., must be absolutely avoided, as should strong scrubbing, which can alter or destroy the sharpness of the edges of the lacunae, making them rounded.

Fig. 62: Removing illite layer on surface with cotton swab soaked with water

Fig. 63: Removing soil deposits with toothbrush and water

3. Harder residues of soil or mud can be removed with an ultrasound spatula and sharp surgical scalpels, taking care not to scratch the surface.

Fig. 64: Removing compact clay from the surface with bamboo stick and surgical scalpel. Photo taken by Rodolfo Luján Lunsford

Fig. 65: Removal of incoherent soil with soft plastic sponges soaked in water. Photo taken by Rodolfo Luján

4. Lacunae filled with clay harder than the soil deposits can be first removed using bamboo sticks, scalpels, spatulas, etc., and then the deeper areas inside the lacuna can be cleaned using soft bristle brushes, soft plastic sponges and water, or with the ultrasound spatula.

Fig. 67: Section of the north wall, east central side before the removal of soil, clays and micro-organisms

Fig. 68: The section of the north wall, east central side after removal of obscuring matter.

Fig. 66: Removing indented soil from small holes with bamboo stick

5. The eroded surfaces of the lower areas of the walls were filled during a former intervention with hydrated lime plaster and covered with compact yellowish clay like illite and later with a thin film of cement. Micro-organism activity had strongly developed in these lower sections of the walls due to regular flooding that had augmented their water content. (See procedure 3CS below for the disinfection of walls and removal of micro-organisms.) In the cleaning procedure, the surface is sprayed with water and scrubbed with a soft plastic brush in order to remove the cement and clay films. Water compresses can be applied for a short time in order to swell the clay beneath the film so that it can be easily removed. If the cement film tenaciously adheres, see procedure 1RC for guidance.

Fig. 69: Soil, mud and illite deposits on lower section of the south wall west side before treatment

Fig. 70: The same area of the south wall west side after cleaning

6. Surfaces should be thoroughly rinsed with clear water and subsequently with distilled water applied with tissue paper, in order to remove any eventual residues of the material.

Fig. 71: Removing soil deposits with soft bristle brush and water.

Fig. 72: Covering the surfaces with tissue paper and distilled water after removal of soil deposits

Results

The contaminating mud and other incoherent deposits were removed, allowing natural water vapour exchange between the surface and the interior layers making up the mural paintings. The removal of mud or soil, excellent media for the development of micro-organisms, discouraged their growth.

2.6.1. Cleaning the surfaces of renders and paint layers from coherent deposits, such as hard-mud and calcium carbonate incrustations

Calcium carbonate incrustations and so-called mineralized mud, silicated mud or hard-mud incrustations are formed by chemical processes due to the presence of water. Calcium carbonate is the main constitutive of lime-based renders and is formed by the reaction of carbon dioxide and calcium hydroxide becoming insoluble in water. Carbon dioxide contained in the air reacts with water and forms a weak acid, carbonic acid, which slowly dissolves the calcium carbonate contained in the renders, transforming it into calcium bicarbonate, which is then transported to other areas if there is a flow of water. Losing water and reacting once again with carbon dioxide, calcium bicarbonate changes into insoluble calcium carbonate, incorporating foreign matter like dust, soil, clay, sand, etc., which gives rise to the so-called hard-mud incrustation. These muddy crusts are hard and irregular in thickness. They have the same binding component as the painted renders therefore, wet treatments might be cautiously employed and they are difficult to remove.

The removal of the hard-mud incrustations in the hypogeal ambience of the Susan-ri Tomb proved to be easier in the autumn and winter than in the spring. In the autumn, the walls of the Tomb are warm and dry, and as a result the incrustations become porous and fragile so their elimination with surgical scalpels is relatively easy. In the spring, on the other hand, the walls are about 3 to 4°C colder than they are in autumn, and they are wet due to water vapour condensation. As a result, the incrustations are extremely hard, and the fragile underlying paint layer can be pulled away with them. The incrustations become hard in the presence of water. The role that temperature and water content play in the removal of the hard-mud incrustations should be further investigated.

Given the problems encountered in removing the hard-mud incrustations in the Susan-ri Tomb, research was undertaken by the Rathgen Forschungslabor in Berlin on samples from the Susan-ri and other Koguryo Tombs[10]. The laboratory's recommendation was that hard-mud incrustations should be removed using dry cleaning methods because the hard mud is englobed in the same material as the one constituting the renders. This went not in favour of the extensive trials performed employing materials such as AB 57 (composed of 30 g ammonium bicarbonate, 50 g sodium bicarbonate, 25 g surfactant & disinfectant [Desogen 10% from Ciba Geigy], 60 g carboxyl methyl cellulose and 1000 cc water), which offered modest results and could be unsuitable if residues penetrating into the paintings were not completely removed. The use of organic materials in the Tomb was limited to the minimum, given the damp conditions of the Tomb. Further research focusing on the issue of how to remove the hard-mud incrustations[11] established a methodology that used both wet and dry methods and gave excellent results by the combination of the use of ion-exchange resins and mechanical means. In this way, many of the incrustations were safely removed, the result of carrying out extensive trials beforehand. However, there was reticence from the side of the national team to use the ultrasonic spatula recommended by the Rathgen Forschungslabor, because fearful to remove as well the paint layer.

The first part of the research consisted of an evaluation of the existing literature and studies of similar cases. Samples of the hard-mud incrustations were studied at the Rathgen Forschungslabor using methods such as optical microscopy, ultraviolet fluorescence, scanning electron microscopy coupled with electron probe microanalysis (EDX), Fourier-transform Infrared Spectroscopy and X-ray diffraction in order to identify their constituents. The aim of the studies was to evaluate any alterations or damage caused by materials used in removing (wet cleaning) hard calcium carbonate incrustations (AB57 and strong cationic ion-exchange resins) from painted surfaces and particularly the effect of their components on the pigments and paint layer.

The reactivity of the components of the AB57 mixture and of the strong cationic ion-exchange resin was measured on five selected pigments, in order to determine the process of discolouration at given intervals of time. (See Consolidation of Renders and the Removal methods of Mud-encrustations of the Mural Paintings in the Susan-ri Tomb in part Three later in the present publication). It was found that malachite and green earth were very reactive to the solutions: malachite discoloured to a bluish hue in contact with the AB57 components, and green earth generated bubbles when reacting with the ammonium bicarbonate and sodium bicarbonate and strong cationic ion-exchange resin.

Tests for establishing paint-layer damage and the removal of hard-mud incrustations were conducted on 30 samples manufactured according to the stratigraphy of the mural paintings using a fresco technique The surfaces of some of the samples were soiled in a way similar to the hard-mud incrustations by material containing lime and clay minerals. The batch of samples prepared for the evaluation of any paint-layer damage after application of the cleaning agents showed that those prepared with malachite experienced significant change in colour, turning black in the presence of the AB57 mixture and decreasing in brightness in the presence of the ion-exchange resin. (Malachite, being a copper-based pigment, is sensitive to strong alkalis, and was usually employed in tempera painting.) Other samples (green earth, vermilion, red ochre and carbon black) treated with AB 57 and the cationic ion-exchange resin showed a decrease in brightness but not in colour, with the exception of the green earth sample that discoloured in some areas to violet. Degradation of the surface was observed after 6 hours application of the cleaning agents, exposing the render.

Samples soiled with material similar to the hard-mud incrustations and treated with the mixture of AB57 and the strong cationic ion-exchange resin demonstrated the best results, with the ion-exchange resin performing better than the AB57. There was no improvement to the removal effect of the ion-exchange resin when the latter was mixed with carboxyl methyl cellulose. The method was found to be safe and reliable if the necessary precautions were taken. In order to ensure the preservation of the paint layer, a thin 'veil' of the deposits on the painted surface should be allowed to remain as a buffer, both when the surface is cleaned and when it is buffed by the mechanical thinning-down of the concretions[12].

The strong cationic ion-exchange resin can be left to react for three hours, checking its behaviour every quarter of an hour. While revealing the painting under the hard-mud incrustations would be an outstanding discovery, it must be stressed that if their removal compromises the integrity of the painting they should not be removed.

Definitions

Incrustation: a hard layer or crust formed over a surface.

Matrix: a finer-grained material embedding larger solid grains, e.g. lime-sand mortar.

Equipment:

Ultrasound spatula	Surgical scalpels and exchangeable blades
Electric mini-drill and abrasive bits	Stainless steel surgical scalpels
Abrasive drill bits	Buckets
Fibreglass pencils and sticks	Hand water-sprayers
Plastic spatulas	Plastic containers
Soft plastic sponges	Auto-adhesive plastic foil
Bristle brushes of various sizes	Soft toothbrushes

Materials:

Clear distilled and de-ionized water	Cationic ion-exchange resins (strong and weak)

Technical data:

For the strong and weak cationic ion-exchange resins, see *Technical Data of Materials Employed in the Conservation* in the Appendices to the present publication.

Preparation of ion-exchange resins:

Prepare the ion-exchange resin by mixing with de-ionized/demineralised water and check the pH of the mixture. If the pH is near to 0, wash and rinse the resin until reaching values near a neutral pH of 7. The dry resin is a powder of soft consistency. The mixture should be kept in a plastic container with the lid on, taking care that it is covered by about 1 cm of water. It should not be allowed to dry out.

Fig. 73: Hard mud incrustation under frontal light

Fig. 74: Hard mud incrustation under raking light

Procedure 2CS: Cleaning the surfaces of renders and paint layers from coherent deposits, such as hard-mud and calcium carbonate incrustations

1. Theoretically, the paint layer beneath the calcium carbonate and hard-mud incrustations should be sound enough to tolerate slight abrasion, given that the binder in both is also calcium carbonate. Remove any loose deposits from the surface using bristle brushes and sponges soaked in clear water. Examine the surface under raking light in order to determine the method to be employed – whether to thin down the concretions' peaks using abrasive tools, or whether to apply the cationic ion-exchange resin to break the crust (see photos on the opposite page).
2. If the abrasive method is selected, thin down the incrustations' peaks using an electric mini-drill with conical corundum bits. Start from the summit of the peak and gradually thin down parallel to the surface using rounded movements. The speed of the drill should be medium and not high, in order to eliminate any risk of sliding onto the surface and making irreversible holes. While thinning down with abrasive tools, water should not be employed because this will make the clayey content of the incrustation swell, blocking porosity. Instead, a damp plastic sponge should be used to wipe the surface in order to check that the procedure has reached the correct level.

Fig. 75: Cutting hard mud incrustations peaks and thinning-down the thickness with mini drill and bits

3. Thin down the crusts to the same level and then change to a very sharp surgical scalpel, scalping down further to reach a thick film. Once the incrustation has become translucent, carefully thin down further using fibreglass sticks until the effect of a thin and almost transparent film has been reached.

Fig. 76: Removal of hard crust with fibreglass pencil

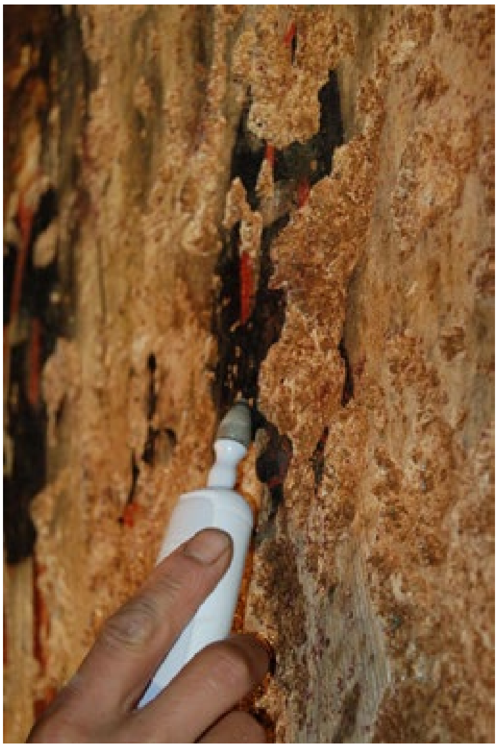

Fig. 77: Controlled and final thinning-down with finer polisher at low speed and soft bit

Fig. 78: Thinning-down and removing incrustations with surgical scalpel

4. If wet cleaning is adopted, apply the cationic ion-exchange resin to the areas to be treated only using a plastic spatula. The amount used will depend on the thickness of the concretion and if a fast or a slow response is required to thin it down. Strong cationic ion-exchange resin reacts rapidly, with the weaker version reacting more slowly. The deposits should be made quite regular and homogeneous, unless the intention is only to break the superficial bonding of the incrustation and then to continue with dry cleaning. Cover the area coated with the resin with auto-adhesive plastic foil and check every 10 minutes or so. Longer-term treatments can also be used, e.g. for 24-48 hours, after a test has been made on an unimportant area. It is important that the resins be kept wet, since if they dry out they can no longer act. They should also be regularly smeared/mixed, in order to obtain the maximum exchange contact with both surfaces. The exchange of calcium ions Ca^{2+}, which firmly bond to the resin, simultaneously liberating an H^{+} ion, depends on the temperature of the walls. If the temperature is low, the reaction will take more time.

Fig. 79: The chosen section on the eastern lower section (south side) of the entrance passage with a calcium carbonate crust mixed with soil and perhaps organic fixatives to be removed with strong cationic ion-exchange resin

Fig. 80: The strong cationic ion-exchange resin in action, notice the air bubbles (due to the reaction of the acid resin and the calcium carbonate that liberates carbon dioxide and transforms the carbonate in bicarbonate – soluble in water) trapped in the thin plastic foil that prevents rapid water evaporation in the resin

Fig. 81: Former trial tests for removing hard incrustations, mainly constituted by calcium carbonate, were carried out employing well-known materials and techniques that gave poor results. Perhaps the paintings were 'coated' with a substance that rendered impermeable the surface and therefore the negative result. The test used AB57 in CMC (carboxyl methyl cellulose) and a saturated solution in water of ammonium bicarbonate in cellulose pulp poultice

5. Once the desired level has been reached, brush the surface with bristle brushes or toothbrushes using distilled water and rinse thoroughly. Conclude the treatment if necessary by scraping away the incrustation residues using surgical scalpels or fibreglass sticks and repeat the treatment if not satisfied with the results.

Fig. 82: Section of painting covered by thin yellowish (calcium carbonate and soil) crust

Fig. 83: The same area of the preceding photograph after removal of the thin crust with scalpel

Fig. 84: The west side of the south wall shows the painted decoration covered by a possible impermeable coating that englobed during its application several fragments of paint layer. Therefore, the cleaning of the mural paintings in the Tomb was not perfectly achieved due perhaps, to those coatings formerly applied that impeded the proper performance of the cleaning substances employed so there are some areas that are obscured by those superimposed layers. However, the areas that were cleared from obstructing materiel have regained their natural condition

Results

As a result of the treatment, the painted surface was freed from the naturally added compact layer, increasing the water vapour exchange and condensation on soiled areas lessened. Equilibrium between the rendered walls and the environment was improved. The extant pictorial text could be better appreciated and the following treatments more neatly carried out.

2.5.1. Cleaning of surfaces from micro-organism activity and associated staining

Hypogeal environments are subject to micro-organism contamination due to humidity and the decomposition of the organic materials they contain. Excessive moisture in the Susan-ri Tomb had led to the development of micro-organisms that had produced stains on the paint surfaces resulting from their metabolic functions. This problem was also encouraged by an organic coating, apparently applied during a former intervention, which served as a fertile ground for micro-organism development. Micro-organisms cannot be completely eradicated, but they can be kept under control.

Definitions

Micro-organisms: minute organisms visible under the microscope that include bacteria, protozoa, algae and fungi. Although viruses are not considered living organisms, they are also classified as micro-organisms.

Metabolism: sum total of all the physical and chemical processes of a cell or organism, both anabolic and catabolic, that maintain its living state.

Bacteria: microscopic unicellular or filamentous organisms lacking chlorophyll and nuclear membranes and reproducing by binary fission. They are mostly saprophytic, but often parasitic, and are arranged into four groups according to their shape: bacilli (rod-shaped); cocci (spherical); commas (twisted); and spirilli (spiral).

Fungus(i): group of organisms having no photosynthetic pigments (chlorophyll) and leading a heterotrophic mode of life, either saprophyte or parasitic. Earlier included in the Plantae kingdom, they are now placed in the Protista kingdom, though some biologists classify fungi separately. There are some 90,000 species of fungi, and they include moulds, yeasts, mushrooms, etc.

Equipment:

Plastic brushes of various shapes and sizes	Soft plastic sponges
Bristle brushes of various sizes	Buckets
Hand water-sprayers	Plastic containers
Plastic spatulas	Graduated cylinder in cc
Weighing scale in grams	

Materials:

Clear and distilled water	Ammonium bicarbonate
Benzalkonium chloride	Anionic ion-exchange resins [strong and weak]
Auto-adhesive plastic foil	Tissue paper
Cellulose pulp – short fibre 200	

Technical data:

Ammonium bicarbonate: quaternary salt.

Benzalkonium chloride: wide-ranging disinfectant.

Strong and weak anionic ion-exchange resins: See above. For all these chemicals, refer to *Technical Data of Materials Employed in the Conservation* in the Appendices to this publication.

Preparation of 10% ammonium bicarbonate solution in water:

Measure 90% of the volume of the solvent required (water) in cubic centimetres in the graduated cylinder. Measure 10% of the mass (weight) in grams of solute (ammonium bicarbonate) on the weighing scale. Put the water in a plastic container, pour in the ammonium bicarbonate and mix until the salt is completely dissolved and cover with a lid.

Preparation of 2% benzalkonium chloride solution in water:

Measure 98% of the volume of the solvent required (water) in cubic centimetres in the graduated cylinder. Measure 2% of the mass (weight) in grams of benzalkonium chloride on the weighing scale. Put the water in a plastic container, pour in the benzalkonium chloride and mix until it is completely dissolved and cover with a lid.

Preparation of anionic ion-exchange resin:

Prepare the ion-exchange resin by mixing it with de-ionized/demineralised water and check the pH of the mixture. If the pH is near to 14, wash and rinse the resin until a value near neutral pH 7 is reached. The dry resin is a powder of soft consistency. Keep the mixture in a plastic container with the lid on, taking care that the mixture is covered by about one cm of water. It should not be allowed to dry out.

Procedure 3CS: Cleaning of surfaces from micro-organism activity and associated staining

1. Prior to any treatment for the removal of micro-organisms, operators must be protected with overalls, gloves, masks, eye-goggles, etc. After the treatment, they should wash thoroughly and change all clothing in order to avoid contamination. Surfaces to be treated should be cleaned with a vacuum cleaner with a HEPA filter, or, even better, with a water tank in which dust is collected and to which a disinfectant can be added, such as chlorine. Vacuum-cleaning the surfaces helps to clean them of micro-organisms and especially of fungal spores, reducing environmental contamination and allowing the safer application of disinfectants dissolved in water.

Fig. 85: Protective clothing, masks and gloves are necessary to wear while dealing with unknown micro-organisms. During taking of samples for laboratory analyses

Fig. 86: The white layer of velvety appearance on the paintings at the upper section of the west wall is a colony of micro-organisms (actynomyces) that developed due to the very damp environment

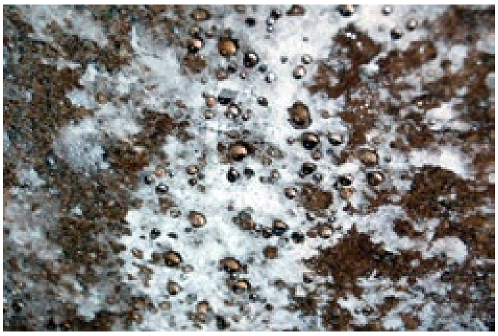

Fig. 87: Close-up photograph of the same micro-organisms as above but on the ceiling capping stone. Notice the water droplets formed.

Fig. 88: The resulting effect of microbial attack are the purplish spots caused by the metabolic functions of micro-organisms namely fungi. These stains are practically indelible

2. Methods for disinfecting the surfaces can be divided into spraying or washing and the application of poultices. Select the type of disinfectant to employ. This will depend on the type of micro-organisms found on the surface, as previously identified by sampling and laboratory analysis. Ammonium quaternary salts and wide-ranging disinfectants can be applied, as can anionic ion-exchange resins, used to remove organic matter from surfaces and useful for the removal of active micro-organism infestation. Water employed for rinsing should be systematically analyzed in order to verify its soluble salt content. It should be diluted until a negative result is obtained. Samples from the treated areas should later be analyzed to make sure that the treatment has been successful.

3. Put the disinfectant solution into a hand water-sprayer. Spray the disinfectant onto the surface and repeat in order to keep the surface wet for 24 to 48 hours. An alternative to spraying is to cover the surface under treatment with tissue paper and then to spray the disinfectant solution onto this or, spreading it with a brush. The paper will keep the solution working longer while wet. Rinse thoroughly using soft plastic sponges and clear water. When finished, apply a layer of tissue paper soaked in distilled water to the surface and allow to dry. Any remaining salt will be deposited onto the paper surface.

Fig. 89: Filling the pressure water sprayer with 2% solution of benzalkonium chloride in water

Fig. 90: During the spraying of the benzalkonium chloride solution on all surfaces.

Fig. 92: During the removal with water and brush of eventual remaining micro-organisms prior facing with tissue paper and distilled water

Fig. 91: The surfaces are faced with tissue paper and distilled water in order to remove eventual residues of benzalkonium chloride salt that deposit on the paper surface upon water evaporation

Fig. 93: Poultice of 10% solution of ammonium bicarbonate in water and cellulose pulp on the painted surface in order to extinguish micro-organic activity

Fig. 94: The anionic ion-exchange resin on an area stained by micro-organism's metabolism

4. Prepare a solution of 10% ammonium bicarbonate in water and spray onto the surface to be treated. Apply poultices containing the same solution in cellulose pulp for 24 to 72 hours as necessary. To prepare the poultices, dry cellulose pulp is put into a plastic container and mixed with the ammonium bicarbonate solution. The consistency of the resulting mixture should be neither too wet nor too dry, but should be plastic enough to be applied onto the vertical surface of the paintings. The poultices are applied to the surface to be disinfected in a uniform layer and then covered with thin auto-adhesive plastic foil. The mixture must be kept damp throughout the treatment. If it dries, water should be sprayed onto it. Once the treatment is finished, rinse the surface with the same solution and then with distilled water.

5. Prepare the anionic ion-exchange resin and apply to the surface to be treated, covering with auto-adhesive plastic foil. Allow the resin to react, wetting and smearing it onto the surface. Remove, and then rinse the surface with distilled water.

6. Removing stains caused by micro-organism activity, namely from fungi, is almost impossible, but poultices of ammonium bicarbonate can help to thin them down. Apply the poultice as explained above.

Fig. 95: The purplish stains caused by micro-organisms' metabolism are practically very difficult to remove with chemical agents without causing further damage to the paint layer

Results

Micro-organisms cannot be completely eradicated from a damp environment, but if levels of relative humidity and temperature are maintained within certain limits their development can be inhibited. However, the eradication of micro-organisms is an endless task, and frequent sampling and monitoring will help protect the mural paintings from them.

2.6.1. Filling lacunae

A vast range of operations come under this heading, aiming to fill voids and losses with different characteristics, such as those due to cuts and grooves in stonework, cavities between masonry joints, edges of lacunae, cracks and cavities in renders at varying depths, etc. Missing portions are filled with similar and/or compatible materials following the original stratigraphy.

The following should be taken into account when preparing mortars and plasters for conservation work. A restoration mortar should have values of mechanical strength and modulus in the same range as those of a good sand-lime mortar, or similar to those of masonry components (natural stones, bricks, etc.). Pore-size distribution should be comparable to that of a lime-sand mortar, and the mortar should contain the smallest possible amount of soluble salts. The mortar should be easily workable and should slow-shrink during setting. It should set rapidly and reliably both in a dry and in a wet environment[13].

Materials employed for filling lacunae in the Susan-ri Tomb, apart from those used for filling grooves and cuts in the stonework (here, crushed stone and ethyl silicate were used), were slaked lime putty, sand, brick dust, coal ash and inorganic pigments in powder form.

Definitions

<u>Lacuna</u>: a discountinuation of the visual fabric which asserts itself as an alien body, thus profoundly limiting the completion of the work.14

<u>Mortar</u>: a mixture composed of a hardening inorganic binder (mud/clay, gypsum and lime) of plastic consistency when mixed with water, aggregate(s) and, eventually, some additives that improve the final properties of the product, which has the capability to set/harden and bind together the construction materials.15

<u>Plaster</u>: pasty mixture similar to a mortar used for coating, levelling and protecting walls, ceilings, vaults, etc.

<u>Render</u>: coat(s) of plaster applied directly to masonry.

Filling cuts and grooves accidentally made in the stone blocks during the removal of cement

Cuts and grooves accidentally made in the stone masonry during the removal of cement from the large lacunae were filled up to the surface level and in accordance with the colour of adjacent stone areas. This filling operation must be carried out in winter, owing to environmental conditions when the walls are warm and dry.

Equipment:

Metal mortar and pestle	Small double-headed iron spatulas
Plastic containers	Sieve 80 mesh

Materials:

Ethyl silicate [OH] in 70% iso-propanol	Crushed granite
Pigments in powder form	

Technical data:

Ethyl silicate (OH) in 70% iso-propanol: this should be used only within certain temperature limits (between 20 and 30° C) and certain relative humidity limits (not over 65-70 %). Surfaces to be treated must be dry. Wetting surfaces of areas treated with ethyl silicate should be avoided for at least two weeks. (See *Technical Data of Materials Employed in the Conservation* in the Appendices to this publication for details.)

Procedure 1FL: Filling cuts and grooves accidentally made in the stone blocks during the removal of cement

1. Grooves and cuts in the stone blocks must be clean, free from dust, and completely dry.

Fig. 96: The area of masonry in which accidental grooves were done by the angle cutter during removal of cement filling the lacuna

Fig. 97: The grooves on stonework under raking light

Fig. 98: Pounding granite in a metal mortar until turning into a very fine powder.

2. Select fine-grained and recently quarried pieces of granite of a homogeneous light colour. Put them into a metal mortar, crush and grind the fragments into fine particles and sieve.

3. Mix the fine particles with small amounts of powdered pigments, in order to make them the same colour as the areas adjacent to the groove needing to be filled. Add a sufficient amount of ethyl silicate to obtain a dense paste.

Fig. 99: During the preparation of the stone filler with stone dust, pigments in powder and ethyl silicate

4. Fill the groove with the mixture, taking care not to go beyond its borders. Compress, and add more filler as the case may be. The area must be protected from water.

Fig. 100: During the filling of the accidental grooves done in the stonework. It is important to maintain the same characteristics of the surrounding stone such as texture, colour, etc.

Fig. 101: The area of masonry after treatment

Fig. 102: Detail showing the fillings of the cuts on the stone blocks

Results

The stone surfaces are homogeneous. However, the intervention is identifiable because the colour-matching with the surrounding is slightly different.

2.4.1. Filling lacunae with lime-based mortars and renders

The main binding material used in the various layers applied onto the walls and the vaulting in the Susan-ri Tomb is slaked lime putty mixed with aggregates of different kinds, showing that the Koguryo people had a significant understanding of the nature and use of lime when building the Tomb. The mortar binding the fabric of the stonework is mud, with the internal layers first applied, such as the pointing between the stone blocks, consisting of a mixture of lime putty, sand, crushed limestone and ash. The ash content of the mortar provides hydraulic properties to the mixture as it absorbs humidity, meaning that the internal mortars could have been allowed to set within a sealed environment. The roughing-in or rendering layer and subsequent preparatory layers are made of a mixture of slaked lime putty, sand and chopped rice straw that gets thinner towards the surface. The latter is coasted with a thin lime-wash.

Fig. 103: The mortar employed for pointing between the stone blocks was coarser and richer in inorganic aggregates such as sand and crushed stone

Fig. 104: Straw imprint in render under frontal light. Notice that the amount of chopped rice straw employed was considerable

Fig. 105: Detail of the straw imprint in render under raking light

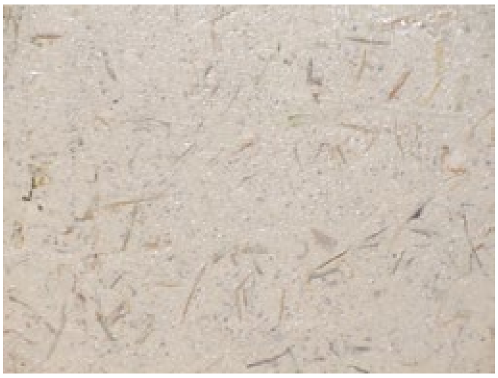

Fig. 106: Reproduction of the ancient Koguryo plaster employing the same materials as slaked lime, straw and little sand

The environment inside the Tomb does not allow for the rapid setting and drying of aerial binders like lime putty. Lime-based mortars are made with slaked lime putty and aggregates without hydraulic properties such as sand or crushed stone unless they are not modified to give them such properties through the addition of other aggregates that contain highly reactive silica or alumina. Chopped straw was originally a component of the renders, and this probably released carbon dioxide into the mixture allowing carbonation to take place during setting and drying. This material was excluded from the restoration work, as, being an organic material, it could have given rise to the development of micro-organism activity. Aggregates with hydraulic properties, such as brick dust, were therefore added to the mixture to improve its characteristics. Deeper voids were filled with lime-based mixtures containing slaked lime putty, small quantities of sand, and larger amounts of brick dust. The percentage of brick dust was reduced when filling the upper layers.

The following guidelines can be used to fill lacunae of various types, such as missing masonry pointing, voids in the borders of lacunae, drilled holes made for grouting, and lacunae or losses in renders, according to the specific prescriptions for treatment and presentation.

Definitions

Aerial (non-hydraulic) binder: slaked lime (such as lime putty or lime in powder form mixed with water) required for the setting process (hardening) to take place a percentage of water and reaction with carbon dioxide in the air.

Hydraulic binder: hydraulic lime and/or slaked lime with aggregates that contains highly reactive silica (SiO_2) or alumina (Al_2O_3) that sets by chemical reaction with water in the absence of air. (See *Technical Data of Materials Employed in the Conservation* in the Appendices to the present publication for details.)

Equipment:

Trowels	Hand water-sprayers
Buckets	Double-headed iron spatulas
Containers for mixing mortars	Measuring cups and spoons
Soft plastic sponges	Sieves of various mesh size

Materials:

Slaked lime putty	Hydraulic lime
Sand	Pigments in powder form
Brick dust	Coal ash

Technical Data

<u>Slaked lime</u>: purchased as quicklime in Pyongyang and slaked for three years.

<u>Hydraulic lime</u>: purchased from Lafarge.

<u>Sand</u>: collected from the neighbourhood of the Tomb, washed several times in order to remove soluble salts, clay and inappropriate substances, and finally dried.

<u>Brick dust</u>: prepared by crushing baked bricks, the soluble salt content of which had previously been analysed by the team in the project laboratory from samples taken from the same batch.

<u>Coal ash and pigments in powder form</u>: components with colouring properties such as coal ash and pigments in powder form were incorporated into the mixture in such a small amount not to produce by-products, such as dissolution and leaching over the surfaces. (See *Technical Data of Materials employed in the Conservation* in the Appendices to the present publication for details.)

Preparation of mixtures for filling lacunae

A gross mortar was prepared for filling deep cavities in the masonry and/or renders. The mixture must contain at least half or three-quarters of its total volume in the form of hydraulic lime or a hydraulic aggregate, e.g. brick dust. The grain size of the aggregates must be neither too small nor too large, and the mixture must be well-blended and mixed. This first layer of mortar should adhere well to the original mortar, and it should set in a relatively short time under damp conditions. The surface of the mortar once applied should be roughened, so as to provide a good adhesive surface for the next layer.

The final layer of mortar applied must be very similar to the surrounding original in terms of colour, texture and density. A series of mixtures can be produced of varying hues/colours that should match the tonality of the surrounding mortar/plaster and must be applied at a level beneath the original according to the original stratigraphy, so as to differentiate the present intervention from the original. The only exception to this rule is when filling lacunae at the painted surface level that will be reconstructed employing vertical hatching (*tratteggio*): these must be white, and the surface must be smooth enough for the treatment to be carried out. The surfaces of the new fillings (besides those for pictorial reconstruction) must be rendered roughly, so as to avoid any mirroring/shining effect, and they should match the roughness of the original while remaining recognizable.

Special attention should be given to the borders of joints, which must match perfectly without forming lines. The percentages of materials used in the mortars and plasters employed for filling voids/gaps listed in Table 1 can be modified in the preparation of other mixtures as the case may be. The proportions described are given as percentages in volume form (one glass (**G**) = 250 ml and one spoonful (**S**) = 5 ml).

Tab. 2: Proportions of mixtures employed for edging the borders of lacunae, filling voids/gaps and re-pointing masonry

Mixture	1 part in Vol. = 250 ml		1 part in Volume = 5 ml			
	SLP/HL	S	BD	CA	RS	RU
Masonry fillings in-depth	¼ ¾	2	1	---	---	---
Fillings in-depth	½ ½	2 ½	½	---	---	---
Fillings at intermediate depth	½ ½	2	¼	---	---	---
Superficial 1: light yellowish	¾ ¼	2	1	---	2	½
Superficial 2: light pinkish	¾ ¼	2	3	1	1	---
Superficial 3: dark brownish	¾ ¼	2	4	2	2	2
Superficial 4: dark pinkish	¾ ¼	2	4	2	1	1

SLP: slaked lime putty; HL: hydraulic lime; S: sand; BD: brick dust; CA: coal ash; RS: raw sienna; RU: raw umber.

General procedure for filling lacunae with lime-based mortars or plasters

1. The surfaces of the gap should be cleaned using brushes, spatulas, etc., with incoherent material removed and the area washed with water using bristle brushes and hand water-sprayers, such that no residues remain, especially of dust, soil or mud. Avoid leakage, dripping and run-off onto the lower surfaces by collecting the material with a soft plastic sponge placed under the area. Rinse the sponge thoroughly in water. Cleaning the area first will allow good adherence of the mortar with the surface to be filled.
2. It is essential that the void be wet. If it is dry, the hydrated lime is absorbed by the renders, resulting in poor binding. When applying the mortar or plaster, be sure that it does not come into contact with the surrounding surfaces. If this happens, wipe the splashed area with dry cotton wool and then with damp cotton wool so that the mortar mixture does not cause staining.
3. Apply the first layer of mortar or plaster and wait until it sets and dries. It is important to scratch the surface of the mortar layer to ensure good adherence of the next layer. Apply the subsequent layers (two to three) in this way also.
4. The final layer must be applied according to the methodology established at the beginning of work: it should be at the paint layer level if the area can be reconstructed employing vertical hatching (*tratteggio*), and it should be under the paint layer level if

the lacuna is not subject to reconstruction. The surfaces of the plastered areas must be treated according to the established codes.

Re-pointing masonry joints

Re-pointing masonry is the re-sealing of joints in masonry using similar material to the original mortar. This was executed in the Tomb in order to avoid the dark visual impact of cavities found in the walls' masonry after having removed the cement fillings. Re-pointing is usually done to avoid rainwater penetration into masonry joints on the exterior of a building.

Procedure 2FL: Re-pointing masonry joints

1. Clean the masonry joints by removing loose material and dust. Wet thoroughly using the hand water-sprayer and put a plastic sponge underneath to collect water percolating downwards.

Fig. 107: Exposed section of masonry of the north wall after the removal of the cement that covered it. The white patches on the upper left side are residues of the grout employed for fixing the renders that percolated between the cement and the wall. Notice the open masonry joints.

Fig. 108: The exposed masonry surface cleaned before the re-pointing of the joints.

2. Prepare the internal re-pointing mortar using preferably hydraulic lime, or, if not, slaked lime putty, sand and brick dust in proportions of 1:3.

Fig. 109: The mortars employed for re-pointing masonry joints. Mortar N° 1 made out of slaked lime putty, brick dust and sand was employed for filling the inner section of the gaps, whereas mortar N° 2 was applied as a finishing layer on the surface not just for aesthetic reason but for matching in colour and texture with the original pointing.

3. Fill voids of a maximum of five cm in depth with the mortar and press down well. Continue filling with the hydraulic mortar until the level is three to four cm below the stone surface.

4. Prepare the final mixture according to the surrounding hues of the renders as per the table above. Fill the joint to a level of two to three mm below the surface level and compress. Scratch the surface when it begins to set in order to make it rough and to remove the thin white veil of calcium carbonate that is formed so a new one is formed that is less white.

Fig. 110: The east wall and vault after removal of cement, cleaned stonework and initial filling with hydraulic type mortar

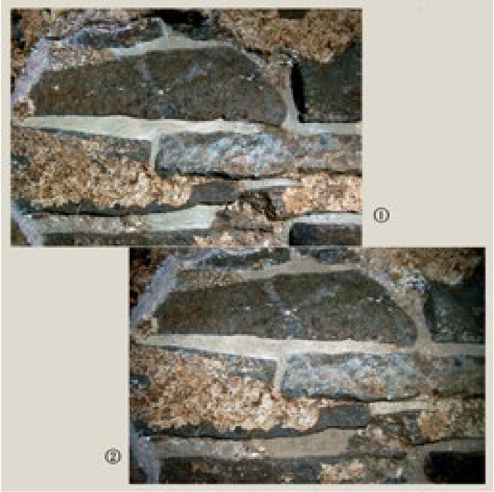

Fig. 112: The final layer similar in colour to the original mortar employed for pointing masonry stone blocks. The photograph N° 1 shows the plaster just applied, compressed and polished giving a shining effect. The photograph N° 2 illustrates that the plaster is opaque and rough therefore, less shining and visually impacting

Fig. 114: Area of the north wall with original fillings and renders that blend together with the re-pointed joints, under raking light

Fig. 111: During the application of the final coloured layer over the lime, brick dust and sand mortar. Detail of treatment on the lower left side of the photograph

Fig. 113: The final treatment on the masonry re-pointed joints is to slightly scratch the surface rendering it rough so as to avoid the mirror-like effect of the compressed and polished new mortar

Edging the open borders of the lacunae

Edging or sealing the open borders of lacunae is a treatment that employs similar materials to the original and is carried out before fixing back the detached renders to reinforce the area or to fill in any gaps. Edging the borders of lacunae in a continuous slope was once a conservation practice that aimed to provide support to separated renders and then degenerated into a widespread technique for protecting borders with the belief that will be enough to fix separated renders from the support. The edging must be very carefully done in such a way that it blends with the present state of the paintings. If not extra bands are formed, spoiling the visual impact.

Procedure 3FL: Edging the open borders of the lacunae

1. Remove dust and clean the borders of the lacunae, wetting before the application of the plaster.
2. Prepare a mixture similar to the original material and fill the gap between the render(s) and/or support using a small spatula. It is not necessary to cover the entire borders of the lacunae, and instead the gap should be concentrated on, avoiding overlapping onto the original material. If the lacunae cannot be filled, such edging will be visually disturbing and will smooth the broken contours, forming a fillet. The procedure must be done carefully, and the plaster must be applied while compressing it well to avoid any cracks.

Fig. 115: The gap between render and wall at the upper part of the large lacuna of the north wall is about 1 cm. Before intervention, this was filled with mud that later was removed.

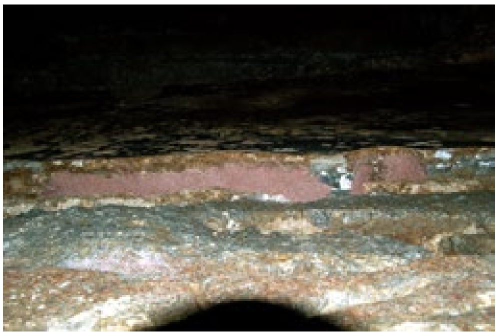

Fig. 116: The gap was firstly filled with a hydraulic mortar so could set without air, in the close environment. Since it was not possible to completely fill the void, grouting was done from upper parts (above or the top) so as to fix the render back to the wall as an anchor.

3. If the edging is intended to seal joints and therefore to prevent the flow of grout, the area should be dry when grouting. Water can be injected to check if the sealing is effective. If it flows out, the gap must be resealed.

4. The appearance of the filled border must be as similar as possible to the original untouched borders, and not, as found in many examples, looking like a fillet or band of compressed plaster that frames the original painting. This is distracting since it is seen even before the viewer looks at the painting.

Fig. 117: The border was subsequently filled with a final layer of plaster similar to the original in terms of colour and texture

Fig. 118: Frontal view of the border of the lacuna just after being filled. The intention is to discreetly match the original and the new so as to give the impression of natural endurance as it has been like that since ever.

Fig. 119: The same area of the previous photograph before intervention. Punctual treatments were carried out in order to preserve as much as possible the authentic text.

2.4.1. Filling of lacunae, cracks and holes made for grouting

The losses of renders and paint layers are filled according to the principles of aesthetic re-integration and presentation, which is the reconstitution of the potential unity of the work of art:

- **at the paint layer level:** limited in surface area and capable of being ethically (according to a code of best practices) reconstructed;
- **under the paint layer level:** the renders should match in colour and texture with the original that are not subject to pictorial integration. The filling of lacunae under the paint layer level involves a series of technical treatments that must be carried out with great sensitivity and skill, in that the appearance of the original and the new must be perfectly blended.

2.4.2. Filling of lacunae, cracks and grouting holes at the paint layer level

The lacunae that can and should be filled at the paint layer level are those that can be necessarily reconstructed according to a code of best practices for a better comprehension of the pictorial text by matching/jointing lines, etc., found in the composition. Important details such as figures, heads, hands, etc., or elements of which the exact outline is unknown must be avoided since these can be subject to artistic and subjective interpretation, falsifying the original artist's intentions.

Procedure 4FL: Filling of lacunae, cracks and grouting holes at the paint layer level

1. Remove dust and other deposits from the surface to be filled.
2. Prepare a mixture of similar materials and components as found in the preparatory layers to be filled and in order to restore the original stratigraphy. The thickness, granulometry and colour of each layer should match those of the surrounding renders.

Fig. 120: Area with superficial lacunae of which, one was filled as example, under frontal light

Fig. 121: The area of the previous photograph under raking light

3. Wet the area to be filled taking care that water does not run over the painting beneath.
4. Apply the mixture with a trowel or double-headed iron spatula depending on the size of the lacuna to be filled. It is recommended that the plaster be applied at the centre of the lacuna and then spread towards the border with the point of the spatula, paying attention not to go beyond that border. Care must be taken to press along the border between the lacuna and the original render so good adhesion is provided. It is essential not to cover the adjacent areas of renders and painting.

Fig. 122: During the application of the plaster from the centre of the lacuna towards the border, taking care not spread out beyond

5. The reconstitution of the original stratigraphy must take into account the deformities of the surrounding renders so as to match the ancient craftsmanship with the new one. Moreover, lacunae filled up to the paint layer level are subject to pictorial restoration and therefore their surfaces must be smooth but slightly rough (the roughness can be achieved by passing the fingertips with a rotating movement over the surface while setting) so as to allow the pigments to adhere. Avoid smearing the mixture onto adjacent areas in order to avoid white stains.

Fig. 123: During the filling of the lacuna at the paint layer level under raking light. Notice that the surface is slightly irregular before compacting and levelling

Fig. 124: The lacuna filled at the paint layer level under frontal light. Notice the smooth surfac

2.5.1. Filling of lacunae, cracks and grouting holes under the paint layer level

The filling of lacunae under the paint layer level should be carried out only if this is necessary to enhance the pictorial text, avoiding deep contrasts of shadow and light in order to allow the visual appreciation of the paintings without abrupt interruptions.

Procedure 5FL: Filling of lacunae, cracks and grouting holes under the paint layer level

1. The procedure is explained in point 4FL, filling lacunae at the paint layer level. The exception is that the layer under the paint layer level should match the characteristics of the stratigraphy of the preparatory layers. The filling should be applied without sloping towards the border of the lacuna, but should appear flat, as if passing underneath it. The mixture of the plaster should be similar to the original, taking into account that texture and colour must exactly match.

Fig. 125: Example of punctual filling a hole done in the render for grouting. The hole is wet and filled with the plaster putty exactly on the area and not beyond. The light render is subsequently when dry, toned-down to match with the surrounding

Fig. 126: Lacuna filled under the paint layer level according to the original stratigraphy, under frontal light

Fig. 127: The colour and as well the texture of the plaster filling the lacuna must match with the original surrounding conditions of the renders

Results

The filling of lacunae in general is a technical operation that requires great sensitivity and sense of unity within a given pictorial context. The treatment reinforces the structure that supports the painted scenes and decoration, but it must not physically or visually overwhelm the pictorial text. In addition, the technical skill required to fill deeper voids and gaps within the pictorial context should aim to enhance perception, avoiding problems that can be created by contrasts of brightness and shade.

3. Aesthetic Presentation

The aesthetic or pictorial presentation aims to minimise disturbances caused by losses of the pictorial text, restoring the image to the maximum possible while respecting its authenticity as a work of art and historical document. This operation completes the cleaning of the mural paintings, especially when there are problems in re-establishing the unity of a fragmentary context.

The unitary characteristic of mural paintings is that they should be taken as a whole and not seen as a sum of their various parts. This determines the interpretation of losses and the way in which they should be treated. In order to restore the potential unity of the mural paintings in the Susan-ri Tomb, lacunae in the paint and preparatory layers were treated according to the following methods:

- **wear of the patina and paint layer,** such as abrasions, were dampened by darkening lighter areas, smoothing out the visual tonality and providing continuity to the pictorial text. Losses of the paint layer in addition to altering the state of the surface also alter the perception of the image. Therefore, it is necessary to make losses visually recede by toning them down with glazes of colour that are slightly lighter and cooler in tonality than the original in order to distinguish the original from the intervention. As illegibility caused by wear or losses disappears, the pictorial forms recover their continuity, and improving the precision of the image means that the treatment of the remaining losses can be properly judged and the reconstruction of losses decided upon in order to enhance the comprehensibility of the image.

- **dampening the visual tonality of the lacunae** consists of the toning-down of losses of the paint layer and renders that are not subject to reconstruction, darkening the lacunae so as to send them backwards in the plane of perception and allowing the re-emergence of the pictorial fabric.
- **reconstruction of the paint layer** with vertical hatching (*tratteggio*) consists of transposing the modelling and drawing of a painting by a system of hatching based on the principle of the division of tones by thin, parallel, vertical lines that adequately recompose the pictorial fabric when seen from afar, while keeping the tratteggio easily identifiable as aiming solely at restoring the pictorial unity. This method should only be used for the reconstruction of missing parts in order to provide a better perception of the image without conjectural interpretation and one based on the evidence provided by the surrounding painting. The operation must stop where hypothesis begins[16].

General procedures for the aesthetic presentation of mural paintings

The procedures listed below are a simplified version of a much more complex process for the aesthetic presentation of mural painting surfaces that develops, if innate sensitivity exists, over countless hours of practice and experience.

1. The surfaces must have been washed with distilled water and be free from dust and dry.
2. The lacunae previously filled with plaster (under or at the paint layer level) must have set and be dry.
3. The scaffolding must be perfectly clean.
4. Illumination must be soft and not direct and from the opposite side of the hand being used, e.g. from the left if the right hand is being used.
5. The application of colour must be done with a dry pointed brush and avoiding excessive wetness, so that the colour is not spread all over the surface but is circumscribed to the area where it is applied. Between each application, the colour should be allowed to dry such that it overlaps but does not mix. Generally light tones with a cold hue should be used, and quite large areas of about 1 m^2 should be treated. The use of a maulstick is indispensable, not only to provide support to the hand but also to avoid the involuntary spreading of colour onto other areas.
6. Check from a distance once in a while the effect so as to dampen any emerging light areas or points that strike the eye. Keep a homogeneous level of hues when toning-down.
7. It is important to tone down minute lacunae in the paint layer and patina first and then to proceed to small lacunae in the paint layer and renders and then larger lacunae in order to maintain a balance in the hues, tonalities and colours of the area, bearing in mind that this belongs to the entirety of the pictorial ensemble. The paintings must appear to be harmonious and without abrupt contrasts, so the retouching must be, in terms of matter, light and not heavy, and in terms of perception relatively neutral and insubstantial.

Definitions

Patina: a kind of anomalous *addition* or adjustment due to natural ageing of the artefact's constituent materials, the effect of which was, nonetheless, often foreseen (and planned for) by the artist. The patina should always be conserved due to its function as an 'imperceptible damper on the material' that facilitates the perception of the image with respect to the material and that is valuable from the operational point of view as it delineates the point beyond which one should not go (e.g. in cleaning the work)[17].

Colour: a term used not only to indicate a certain region of the visible light spectrum, but also to indicate the substances of pigments and dyes, or, frequently a synonym for pigment or paint. Colour is the property of a given substance in reflecting light of a particular wavelength. The primary colours are red, blue and yellow, and when mixed in various ways these produce the secondary colours such as green, orange, violet, etc. White, black and grey are usually called colours (achromatic colours), although black is caused by the complete absorption of light rays, white by the reflection of rays that produce colour, and grey by the imperfect absorption of these rays.

Tone and tonality: quality or value of colour, tint or shade. Tone is any slight modification to a particular colour or the difference in intensity in a colour. Tonality is the arrangement of tones or colour scheme in a painting.

Hue: the particular tint or shade in a given colour.

Saturation: the degree of intensity of a hue.

Equipment:

Plastic palettes for 12 colours	Sable pointed brushes of various sizes
Small plastic container with lid	Flat bristle brushes of various sizes
Maulstick or rest-stick	Soft plastic sponge
Plastic bucket	Plastic containers with lid

Materials:

Lime water	Hydrophilic cotton wool
Pigments in powder: ivory black, raw & burnt umber, raw & burnt Sienna, red & yellow ochre, dark terra verde (green earth). Optional: vermillion, Venetian red & Indian red.	

Technical data:

Lime water: an aqueous solution of calcium hydroxide $Ca(OH)_2$. When saturated at 20° C this contains at least 1700 mg/L of water and is strongly alkaline (pH = c. 9). There is no indication that the solution is saturated unless a white film of carbonate caused by interaction with carbon dioxide in the atmosphere forms on the surface of the solution. See the *Technical Data of Materials Employed for Conservation* in the Appendices to this volume.

Pigments in powder: classified as mineral, natural or artificial, organic and mixed (mineral and organic), whether amorphous or crystalline, these are ground and reduced to uniform particles capable of mixing with a binder in which they remain insoluble. Natural pigments are found in the ground in the form of oxides, sulphides, carbonates, sulphates, etc. Artificial mineral pigments are usually chemical products of well-defined composition that have been obtained by dry or wet methods. Natural organic pigments are obtained from substances contained in some parts of animals, from decoction or maceration of wood, fruits, leaves, bark or the roots of plants[18].

Preparation of colours

The retouching of mural paintings is usually carried out employing watercolours, given that these are different from the material of which they are constituted and their qualities of being transparent and reversible (easy to remove) make them simple to use. Watercolours should not be employed in humid environments, e.g. hypogeal ones, since they can give rise to the development of micro-organism activity because they contain Gum Arabic. It was therefore decided to employ finely powdered pigments mixed with lime-water so as to avoid the use of organic materials. This technique is not easy to apply, given the lack of perfect adherence with the substrate and the fact that the colour can become opaque if thickly spread. However, the materials are compatible with the original and can be easily removed with a sponge soaked in water because of the limited amount of calcium hydroxide they contain that transforms into calcium carbonate and forms an immaterial thin crust.

Prepare the lime-water and keep preferably in a glass container with a bakelite lid. Pour the lime-water into other glass containers with bakelite lids and put in a certain amount of each pigment in powder so it can saturate and stabilise with the strong alkalinity of lime-water. Take, when needed, the quantity of the soaked pigments desired, put each into the cavities of the palette in an established order and remove excess water so that the pigments are moist and not dry. Soak a flat piece of cotton wool in water and wring it out so it is damp but not wet. Then flatten it and make a groove with the handle of the paintbrush such that the sable brushes contain a sufficient amount of pigment and water and can be pointed by a spiral movement and put on the palette. It is indispensable that colours not be mixed, and they should be kept as pure as possible. It is therefore recommended that the brush is rinsed every time a pigment is taken for mixing with others.

Fig. 128: The necessary materials for retouching the mural paintings that in the case of this Tomb, pigments in powder were employed with lime water

Fig. 129: During pictorial integration, mixing the colours in the palette, notice that there is not only one colour but many combinations that should overlap as a glaze, according to the need and sensitivity of the restorer.

Fig. 130: The correct use of the maulstick avoids the deposition of hand's grease on the painted surface and help for an accurate pictorial integration

Procedure 1AP: Dampening wear of the patina and paint layer

1. Mix small amounts of yellow ochre and black, producing a greenish/bluish colour and apply as a thin glaze on the area to be toned down. This can be used as a base for applying successive layers of colour to treat losses in the paint layer.

Fig. 131: Abraded and full of gaps paint layer before treatment

Fig. 132: The smallest lacunae are the first to be toned-down so as to gradually integrate an area that interact with the larger lacunae reaching the correct tonality

Fig. 133: Gradually dampening the visual impact of the white losses, the image reconstitutes and integrates

2. Mix the colours to reach a lighter tonality than the surrounding one and spread over the base. The lacuna must appear as an abraded surface with the remains of the pigments.

3. If necessary continue to darken the area, but not too much as it is necessary to maintain transparency. Colours can be darkened with glazes of their complementary, e.g. violet is the complementary colour of yellow.

Fig. 134: The abrasions and losses of the paint layer were toned-down without reconstructing the outlines, etc. the image gained comprehensibility when perceived.

Procedure 2AP: Dampening the visual tonality of lacunae

1. Prepare a colour with a similar tone to the medium one (slightly soiled) found in the lacunae to be treated. The hue should be slightly colder, and the mix should be spread as a glaze only on the lighter areas. Allow to dry.
2. Continue toning-down the light areas in the lacunae. Proceed in the same way with the others in the section under treatment, keeping a careful balance. Check from a distance and evaluate if necessary in order further to darken the lacunae, bearing in mind that they should not be perceived as flat.

Fig. 135: The outstanding light plastering in the lacuna is toned-down so as to match it with the surrounding and to visually unify the appreciation of the ensemble

Fig. 136: A selected area under raking light, of the west wall in which an example of dampening the visual tonality of light lacunae in order to visually send backwards the losses and to move the figure/image forward the spectator, was carried out

Fig. 137: The area under frontal light

Fig. 138: The losses were dampened making the remains of the figure to emerge

Procedure 3 AP: Reconstruction of the paint layer with *tratteggio*

Fig. 139: The lacuna filled at the paint layer level is subject to reconstruction. The reconstruction in drawing with yellow ochre is the first step to carry out.

1. The main outlines of the area to be reconstructed are drawn with thinned yellow ochre.

2. The entire surface is hatched with regular vertical lines of the same thickness and distance with the basic tone of the area. This is the base for the colours, which must be pure and very transparent and alternate in warm (e.g. red and yellow ochre, raw and burnt Sienna), and cold (e.g. green, raw umber) colours and always with vertical lines. Allow to dry each time so the colours are not mixed, but superimposed.

Fig. 140: The vertical hatching which is the basic technique of *tratteggio* is done employing very thin and 'dry' colour in the brush and overlapping the lines of different colour one on another so when mixed in the eye, from a certain distance, integrate the image/figure.

3. Continue to apply transparent glazes of vertical lines until reaching the surrounding original areas.

Fig. 141: Upon completion of the vertical hatching that should not emerge but combine with the original painting

Fig. 142: The *tratteggio* is achieved when the perception of the reconstructed area blends into the original. If seen from a short distance appears as a series of vertical lines but from the distance completes the picture

Results

The perception of the painted cycle is ordered and clear, even if it is still fragmentary.

Notes

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State of Conservation of the Mural Paintings of the Susan-ri Tomb

by Rodolfo Luján Lunsford

The two most important factors that generally contribute to endangering the stability of mural paintings in the interiors of tombs are natural cycles, in which moisture plays the most important role since water infiltration frequently occurs, exacerbating many types of deterioration, and human intervention or intrusion. Alterations in the internal environment, leading to fluctuations in temperature and relative humidity, as well as other factors such as carbon dioxide levels and wind drafts, etc., can also occur, activating, individually or conjointly, chemical, physical, mechanical and biological modifications in the behaviour of the materials constituting the Tomb. Such micro- and macro-environmental processes cannot be stopped, but they can be kept under control and their inexorable progression slowed.

Previous work on the Tomb had aimed at the safeguarding of its historical fabric, but, given the diversity of methodologies, techniques and materials used, this work had become obsolete over time, and it now required modification or removal. From here comes the need to understand and to define the foreign elements added to the fabric of the Tomb and the mural paintings in the past that have caused, and continue to cause, damage and to implement actions aiming at restoring the original condition of the Tomb.

Early steps needed in establishing a reliable conservation programme include carefully assessing the monument through a complete inspection and examination of the state of preservation of the ancient fabric and the carrying out of detailed documentation. This diagnostic process should be supported by an interdisciplinary team to carry out monitoring, sampling, and the elaboration of data and analyses, in order to complete the picture of the state of preservation of the monument being surveyed and to suggest further survey work and/or analyses. An accurate survey of the Tomb is indispensable in defining the most suitable intervention work that needs to be carried out.[1]

Natural factors influencing the conservation of the Tomb, such as flooding inside the burial chamber due to a rise in the water-table, dispersed rainwater infiltrating through the mound, or water vapour condensing on the surfaces during the spring, were monitored through a programme that envisaged either their elimination, if this was possible, or their being kept under control through targeted interventions. (See the Annexes of the present publication for descriptions of the terminology used and an account of the visual nomenclature and graphic symbols.)

1 Mora P., Mora, L., & Philippot, P., *The Conservation of Wall Paintings*, London: Butterworths, 1984, pp. 165-187.

1. Structure of the Tomb

Main conservation problems encountered in the structure of the Tomb, such as cracks and lacunae, were most likely related to work aiming to waterproof the burial chamber by stonework insertions into the vaulting and repair of structural cracks at the corners of the north wall.

The lack of adhesion and cohesion in the lime-based pointing and roughing-in layers on the north and east walls, recently discovered under layers of cement plastering, were caused by the dissolution, movement and re-crystallization of soluble salts in the cement layer and in the structure of the wall, due to constant wet-dry cycles. The deterioration that takes place as a result is slow, but effective. Soluble salts are dissolved in water and transported to other areas due to capillary movement. When the water evaporates, the salts re-crystallize either beneath the surface (sub-florescence) or above it (efflorescence), exerting pressure and destroying the matrix of the pictorial layer.

Structural cracks could be seen at the south and north corners of the west wall, evidenced at the lower section of the northwest corner by the characteristic deformation of the render caused by compression from the upper parts. This damage could have occurred after the construction of the concrete dome in 1985-86. In 1993, it was found necessary to fill these cracks (chinking) with a special cement mixture. The causes could be ascribed to excessive load above the chamber, causing tensile stresses, and, probably, to an increase in the height of the water-table during the rainy season with consequent sub-soil subsidence.

The mechanical fractures and cracks could also have been the result of work to dismantle and reassemble the *lanternendecke* structure using iron dowels and cement. During this work, the stone slab at the north-western corner supporting the upper tier of stone blocks and the square capping stone could have cracked diagonally in half, as the stone beams at the third tier of the eastern corbelling were broken, leading to the insertion of stonework to link the blocks. The ceiling of the inner section of the access corridor (*dromos*), a flat monolith, was broken at the western extremity into three large pieces, so the original pilasters at the sides were reinforced with cement in order to support it.

The extensive lacunae in the rendering layer in the north and east walls, as well as of the vault, revealed the superb masonry work that a former intervention had covered over with cement.

2. Preparatory Layers

The Tomb was completely covered with lime-based renders that comprised from one to two or three layers of varying thickness, from a few millimetres (3-4) to 4-5 centimetres.

The alterations found in the preparatory layers were mainly related to their separation or detachment from the wall, with the causes being attributable to migration towards the surface of the constitutive mud-based mortar in the masonry, which had pressed on the render due to water infiltration and vegetation growing above. The formation of salt sub-florescence between the wall and the renders due to the rapid exsiccation of the latter had also provoked mechanical stresses due to the pressure exerted by the re-crystallized salt. Extensive areas of the renders were slightly separated from the walls to varying degrees. Fewer renders had been separated by mud penetration, particularly around the large lacunae, though above the north wall, or beneath the east wall in its northern section, the render was dangerously deformed in the shape of a bulge. Detachment was noticed, due to differences in the thermal expansion coefficient along the joins between the renders and the cement fillings of the large lacunae on the north and east walls, as well as at the junction of the upper areas of all four walls and the first tier of corbelling, also covered with cement.

Regarding lack of cohesion, the loss of constitutive material is an extreme case, in which salt re-crystallization plays an important role, but in the intermediary state lack of cohesion can be interpreted to mean that the render has lost its bonding properties. Such alteration could be seen on the south upper section of the west wall.

The northeast and southeast corners of the burial chamber showed thin cracks that passed throughout the entire thickness of the render, but it was not known if these crossed the wall to the other two corners. Cracks of mechanical origin were also found on the upper section of the east side of the south wall and the upper section of the north wall above the large lacuna.

The vaulting of the Tomb had practically lost all of its rendered coating. Large portions of the east and north walls also showed large losses, as did, in lesser proportions, the lower areas of the south and west walls.

Widespread eroded areas of the renders were found on the lower areas of the walls, as was a general distribution of small lacunae across the extant painted renders. This was due to the disintegration of the constitutive render, caused by salt sub-florescence and efflorescence. In this process, soluble salts are deposited by water movement into the pores beneath or over the render areas, and when the water evaporates the salts re-crystallize and increase in volume. This breaks the adjacent material, causing loss of the renders.

Lacunae caused by vandals or by the improper use of excavation tools were sharp and recognizable, and they were to be found on the west wall in the entrance passage and on the west side of the south wall.

The joints of the stonework of the vaulting, the first recess of the corbelling, and the in-depth lacunae of the north and east walls had been filled with cement during a previous intervention. Many of the numerous small lacunae in the east, north, and west walls were filled with grey clay. The eroded lower sections of the burial chamber were filled with a plaster made out of hydrated lime and fine-grained sand and covered with yellowish fine clay (illite). The lower section of the east wall, and practically the entire west wall of the entrance passage and its façade, had suffered from extensive loss of constitutive renders, the lacunae having been filled with fine hydrated lime plaster and covered with illite.

The lacunae were filled with fine-grained clays (yellowish illite, or reddish-grey clay mixed with sand) and finished with a thin layer of hydrated lime, on which the pictorial reconstruction was carried out. Probably the pictorial reconstruction was done using oil or enamel paint.

Some sections of the painted renders had fallen from the walls after the discovery of the Tomb and had been lost forever. However, the fragments of painting that had fallen from the lower area of the west wall had been rescued, and these had been more or less reassembled and inaccurately re-adhered using cement plaster, without the attentive matching of joins and without maintaining the surface level. (See the material on the graphic documentation of the Susan-ri Tomb in the Appendices to this volume and the material on previous work carried out on the Tomb in this section.)

3. The Paint Layer

The paint layer consists of a lime-wash coating forming the background to the depictions. These were sketched succinctly in a preparatory manner, before being filled in using colour and final drawing and outlines being done.

The paint layer as a whole showed good adhesion to the substrate, but some areas showed a thin or almost imperceptible separation from the render, as found on the east wall of the entrance passage. Another type of lack of adhesion in the shape of bubbles was found on some areas of the east and west walls of the entrance passage. The reason for this can be explained by noting that the hard concretions over the painted surface had separated the paint layer. This means that the outer layer of paint strongly adheres to the concretion, whereas the inner layer remains stuck to the lime-wash render. The cause of the bubble-shaped detachment can be attributed to the accumulation of soluble salts in solution beneath the surface, which is less porous or has probably been coated with an impermeable material, such as a resin. Upon water evaporation and salt re-crystallization (sub-florescence) these salts have 'pushed' outwards, causing the *strappo* of the paint layer and the bubble shape. It is probable that the shrinkage of a formerly applied concentrated fixative 'pulled' the incrustation outwards in those areas that were not perfectly adhered to the substrate. Lack of cohesion was also found on areas in which micro-organisms had extensively developed, as on the upper section of the west wall and the upper portion of the east side of the south wall.

Two types of pigment leaching were observed, the first where the black glaze of a too-liquid paint roughly applied to the paintings had trickled over the lower surface, and the second where black over-painting had lost its bonding properties and had run down due to water condensation, diffusing across the surface. However, this phenomenon was not widespread, but only applied to certain areas, so perhaps the black pigment leaching was a result of over-painting applied during a former intervention.

The existing paint layer appeared to be sound and resistant to water and slight abrasion. However, the original painted cycle was very fragmentary due to numerous small lacunae. The extant rendered lower areas had completely lost their paint layer, particularly on the east wall, where only traces remained. Small scratches and abrasions were nevertheless found elsewhere.

During former interventions, cement used for filling lacunae and cracks had been carelessly spread over the adjoining painted surfaces, and though this had been wiped away, unfortunately a thin film still remained. The same thing was true of the different types of clays employed for filling small lacunae and masking hydrated lime fillings.

It was apparent that a fixative had been applied as a coating on the central and lower painted areas after pictorial reconstruction and over-painting on selected areas. This was particularly noticeable on the lower section of the west side of the south wall, in which paint scales had been glued on by the coating.

During a former intervention losses in the painting had been filled with sand and reddish clay and coated with a thin layer of hydrated lime. The painting was subsequently reconstructed, in order to provide a better understanding of the images. Pictorial reconstruction was found at the eastern lower section of the north wall, the northern lower section of the east wall, and the west wall and façade of the entrance passage.

The white background of the upper section of the north wall was covered by black horizontal strokes that evidently constituted over-painting extending to the black roof of the building depicted on that wall. The same was true for the west wall above the scene. The original paint layer could be clearly discerned under strong light from the additions made during a former intervention because the tonality of the original was brilliant and transparent, whereas the more recent one was dull and had a glossy appearance. The hue of the original red ochre is brilliant, for example, with a warm-deep transparent tonality tending to orange, whereas the more recent one tends to dull-red. The black paint applied in a former intervention appeared as a glossy amorphous mass of varying levels, whereas the original appeared as a thin flat layer in which tiny crystals of pigment could be seen. In addition, the render under the original paint layer was smooth and compact, whereas under the reconstructed areas it was irregular and porous.

On the 5 samples delivered to the Rathgen Laboratory, two were of black pigment (ST-8 and ST-9) where carbon was identified, one was of red overpaint on black (ST-17) where hematite was found and two of red colour (ST-23 and 25) where hematite was found. See the Rathgen Report for detailed results and List of samples for resume.

4. Surface Deposits

The lower areas of the surfaces were covered by incoherent materials, such as mud and soil, residues that were probably not completely removed after the archaeological excavation, or were left over from a previous intervention.

The surfaces around the entrance passage on the south wall, the northern and central sections of the west wall, and the uppermost corners of the north wall were largely covered with so-called 'hard-mud' incrustations, actually calcium carbonate mixed with soil and sand. These incrustations are insoluble in water, and two types can be identified under the naked eye. Type 1 is rather porous, contains large amounts of sand, and is yellowish, whereas type 2 is compact, contains small amounts of sand, and is dark brown. It is extremely hard and of amorphous (glassy) appearance and is probably made of calcified mud mixed with a fixative. Type 2 mud is also very similar to the soft-mud mortar used to bind the stone blocks in the core of the walls, and this can be easily removed with water. This soft mud, identified as type 2-S, which is easy to remove was found on the ceiling of the entrance passage over a layer of white-yellowish clay and on the hydrated lime fillings applied during a previous intervention.

Given that the renders are made of calcium carbonate, because of a series of chemical processes in which water plays the most important role this is dissolved, transported and deposited elsewhere on the surface, re-crystallizing again to form strong compact incrustations. These incrustations were mainly found on the north wall.

The elevated humidity inside the Tomb and the coating probably formerly applied onto the surfaces had led to the development of micro-organic activity. This develops where major concentrations of water and suitable temperatures are found, like on the summit of the *lanternendecke* structure, the upper and lower sections of the west wall, and the lower portions of the entrance passage.

Stains are produced as a result of the metabolic activity of micro-organisms on the surfaces of the walls. The red-purplish stains found on the surfaces of the burial chamber were distributed elsewhere, but concentrations were found on the lower eastern and western sections of the north wall, the central part of the west wall, and on the east side of the south wall.

The extant mural-painting cycle depicted in the Tomb was threatened by high humidity and the different thermal behaviours of the cement fillings and the original constitutive materials. This situation was aggravated by regular yearly inundations during the rainy season. Water generates the movement and leaching of soluble salts, which upon evaporation re-crystallize, causing the breakage of adjacent areas and the proliferation of micro-organisms that cause damage to the constitutive materials due to their metabolic functions. Moreover, the poor fitting of the doors installed in the buffering corridor had not provided complete insulation from the external climate, and water vapour had condensed on painted areas not protected by the glass barriers, such as in the entrance passage.

Water Infiltration and Waterproofing the Susan-ri Tomb

by Claudio Margottini

1. Introduction

The Susan-ri Tomb is located about 35 km southwest of Pyongyang. It is located on top of a small hill and surrounded by pine trees. The archaeological remains can be classified as a stone-built (with stone blocks) chamber tomb covered with an earthen mound.

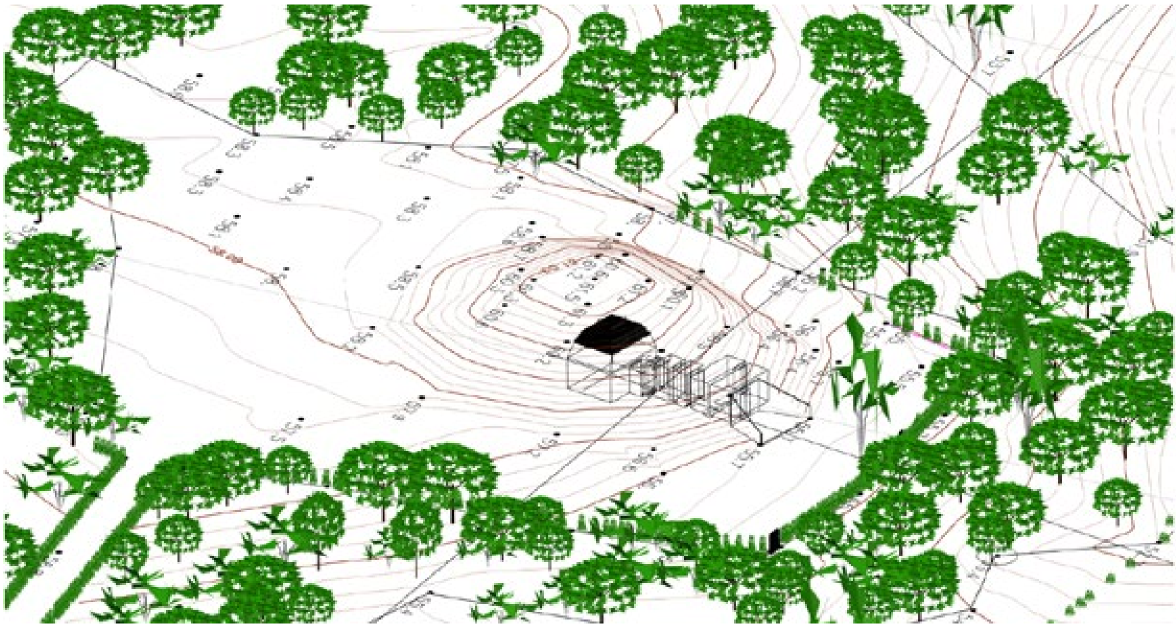

Fig. 143: 3D detailed view of the Susan-ri site

Despite water infiltration, the stone part is well preserved. The earthen mound according to photographs taken in the 1970s appears to be highly eroded. The present earthen mound was reconstructed during the earlier phases of restoration in the last century.

Fig. 144: The mound above the Susan-ri Tomb in the 1970s

The Tomb was strongly affected by water infiltration, generally during the rainfall season. The temporal relationship with rainfall was clear, but the cause of the infiltration inside the Tomb needed to be understood. The Tomb also has a concrete horizontal slab, apparently covering the whole perimeter, adding to the problem of water infiltration.

Due to the above uncertainties, the project focused on the evaluation of the geological condition of the site. Monitoring of the water-table fluctuations by setting up a piezometer system and of the water infiltration by collecting reliable rainfall data was carried out and the gathered information analysed in order to understand the reasons for the water infiltration and provide a waterproofing solution for the long-term safeguarding of the Tomb.

2. The Problem

The Tomb was mainly affected in the past by rising damp, the origin of which was not very clear. The first available information goes back to 2005. The last flooding was in 2010. Many years were necessary in order to investigate the local water table, the saturation of the mound, the condensation of humid air on the Tomb's walls and the combination of these factors.

The following Table lists the flooding problems of the Tomb.

Date	Event	Source
July-August 2005	400 buckets of water [1 bucket = 10 lt. equal to perhaps 10 kg] were removed from the Tomb's floor	Tomb keeper
14/07/2006	The beginning of heavy rain	Tomb keeper in Lujan [2006]
16/07/2006	Water began to infiltrate from the floor	Tomb keeper in Lujan [2006]
18/07/2006	300 buckets of water were removed from the Tomb's floor [1 bucket = 10 lt.]. The maximum height reached by the water inside the Tomb was 27 cm	Tomb keeper in Lujan [2006]
19/07/2006	Rain stopped but 200 buckets of water were removed	Tomb keeper in Lujan [2006]
20/07/2006	150 buckets of water were removed	Tomb keeper in Lujan [2006]
21/07/2006	70 buckets of water were removed	Tomb keeper in Lujan [2006]
	According to the Tomb keeper, in the period 14-21 July 2006, 720 buckets of water were removed, equal to 7,200 litres. No more rainwater has infiltrated since then.	
11/08/2007	300 buckets of water were removed = 3,000 lt.	Tomb keeper
12/08/2007	600 buckets = 6,000 lt.	Tomb keeper
13/08/2007	500 buckets = 5,000 lt.	Tomb keeper
14/08/2007	500 buckets = 5,000 lt.	Tomb keeper
15/08/2007	350 buckets = 3,500 lt.	Tomb keeper
16/08/2007	350 buckets = 3,500 lt.	Tomb keeper
19/08/2007	200 buckets = 2,000 lt.	Tomb keeper
20/08/2007	100 buckets = 1,000 lt.	Tomb keeper
	Water inside the Tomb up to 35 cm from the floor and persisting until October even if pumped away. The water was flowing from a small hole in the west wall of two cm in diameter 20 cm from the floor.	Tomb keeper
	No more rainwater infiltrated from August to April 2008	Tomb keeper in Lujan [2008/a]
2008	No water infiltration. According to KCPC experts the infiltration occurs only after three days of continuous rainfall	KCPC experts, personal communication
18/07/2009	Water started to infiltrate from the junction between the west wall and the floor. 34 cm of water.	Tomb keeper in Lujan [2009] and KCPC
19/07/2009	Some water remaining inside.	Tomb keeper in Lujan [2009] and KCPC
20/07/2009	Flooding level was 32cm.	Tomb keeper in Lujan [2009] and KCPC
21/07/2009	3.3 lt of water removed from the Tomb floor.	Tomb keeper in Lujan [2009] and KCPC
27/08/2010	20 cm of water. The Tomb keeper took away 160 buckets of water	Tomb keeper in KCPC
28/08/2010	20 cm of water. The Tomb keeper took away 200 buckets of water. The rain stops on 28 August	Tomb keeper in KCPC
29/08/2010	20 cm of water. The Tomb keeper did not take away any water.	Tomb keeper in KCPC
30/08/2010		Tomb keeper in KCPC
31/08/2010	The water level lowers to 15 cm	Tomb keeper in KCPC

Tab. 3: Flooding events in the Susan-ri Tomb

3. Geological Conditions of the Site

According to the geographical coordinates derived from the UNESCO Website, the Susan-ri Tomb is located in the Tanchon Complex, a geological formation composed of biotite granite, granodiorite and fine-grained granite (Paek Ryong Jun et al., 1996). Its origin is related to the magmatism – the development and movement of magma and its solidification into igneous rocks – that took place in the Jurassic Period in the middle of the region during the magmatic activity that affected the north of the Korean Peninsula in the Mesozoic Era.

In this part of the country, the geological arrangement is composed of three intrusive phases, and most of it consists of a granitic rock of the second phase, together with a certain amount of fine-grained alaskites (a plutonic rock consisting of oligoclase, microcline and quartz, with subordinate muscovite and few or no mafic constituents) of the third phase and a very few (rare) mafic and intermediate rocks generally having a silica content of 54 to 65 per cent, e.g. syenite and diorite, from the first phase. (Intermediate is one subdivision of a widely used system for classifying igneous rocks on the basis of their silica content; the other subdivisions are acidic, basic, and ultrabasic.)

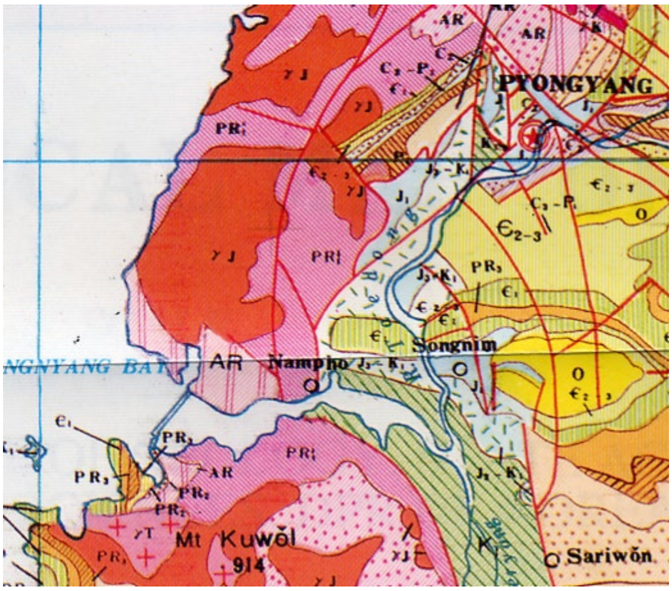

Fig. 145: Geological map of the Kangso area and location of the Susan-ri Tomb [from Paek Ryong Jun et al., 1996]

In order to understand the reason for the rising damp, six boreholes and one pit were executed in the area in 2009. The position is shown in Fig. 146. The reason for the drilling was the need to identify the stratigraphy of the site and to install an open standpipe piezometer inside each of the boreholes. An additional measurement/piezometer point was considered for the well of the Tomb keeper. The boreholes were executed using a mixed rotary-percussion machine and using rotary techniques in soil and/or soft rock and percussion in hard rock. A manual pit was also executed inside the Tomb, exactly where the water was detected in the past. In this case a piezometer was temporarily installed inside the ditch.

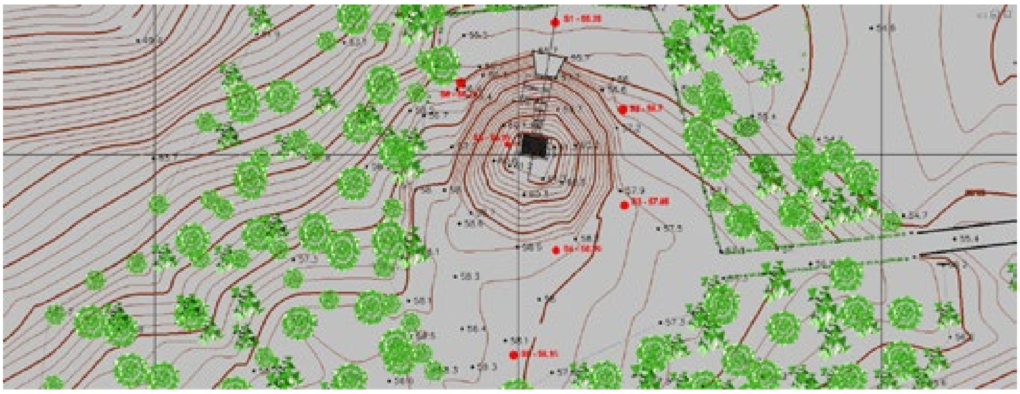

Fig. 146: Boreholes and pit in the Susan-ri Tomb. S8 is the pit inside the Tomb. The piezometer/measurement point in the Tomb keeper's well is off the map

The collected information allowed the following observations to be made:

- The stratigraphy of the terrain is composed from top to bottom as follows:
  - a. The upper part is of a granite/schistose formation (Tanchon Complex, a geological formation composed of biotite granite, granodiorite and fine grained granite (Paek Ryong Jun et al., 1996). This material can be considered of low permeability in terms of porosity and of medium permeability if fractured;
  - b. A regolith (the fragmented and unconsolidated rock material, whether residual or transported, that nearly everywhere forms the surface of the land and overlies the bedrock) deposit produced by the alteration of the granite/schistose formation. This material can be characterized by medium to high permeability due to medium porosity and incoherence; it is composed of the alternating of slightly different materials, with various degrees of weathering, and sometimes, as in borehole S1, also with an important occurrence of clay;
  - c. Earth fill mainly composed of yellow granitic sand; this material can be classified as of high permeability due to incoherence and high porosity.
- The water table was not detected during the dry season.

Fig. 147: The rotary/percussion machine in borehole S1

Fig. 148: The open standpipe piezometer during placing in the borehole and final installation

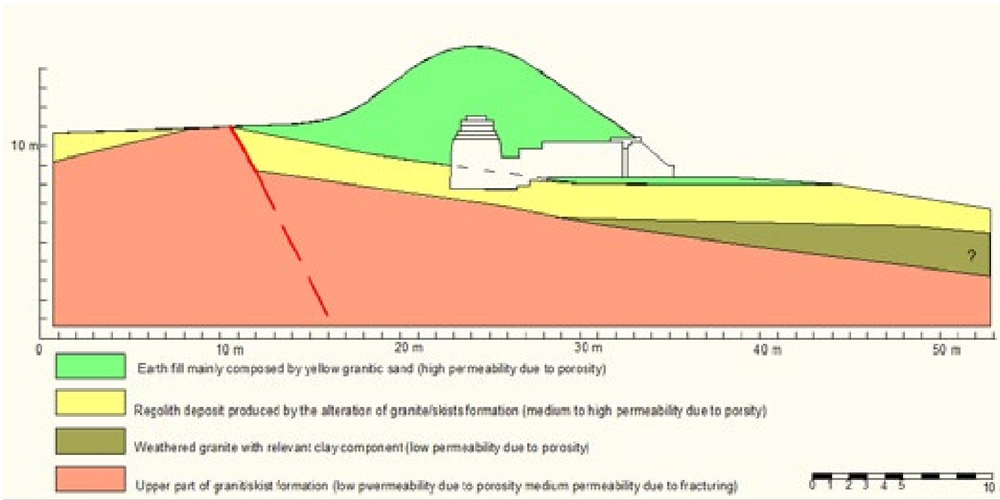

Fig. 149: Geological section of the area and the earthen mound

Fig. 149 and Fig. 150 show the geological map, a section of the mound and the Tomb. From the latter, it is possible to notice the sequence of the different materials composing the terrain, as well as a rough idea of permeability. From this it is possible to notice the granite formation outcropping in the northern part of the area and gently dipping towards the south. Since this material can be considered to be of low permeability and the upper regolith formation has a higher value of it, this contrast can generate a water table during heavy rainfall. This ephemeral water table was supposed to be the main cause of water infiltration into the Tomb from the floor and into the lower part of it in 2009. In fact, the limit between the permeable regolith deposit and the impermeable granite/schistose formation is only 70 cm, as was revealed in borehole S8, and even less in the northern part of the Tomb (see geological section).

Earth fill mainly composed of yellow granitic sand (high permeability due to incoherence and high porosity); Regolith deposit produced by the alteration of the granite/schistose formation (medium to high permeability due to medium porosity and incoherence); Weathered granite with relevant clay component (low permeability due to medium porosity); Upper part of granite/schistose formation (low permeability due to low porosity and medium permeability due to fracturing).

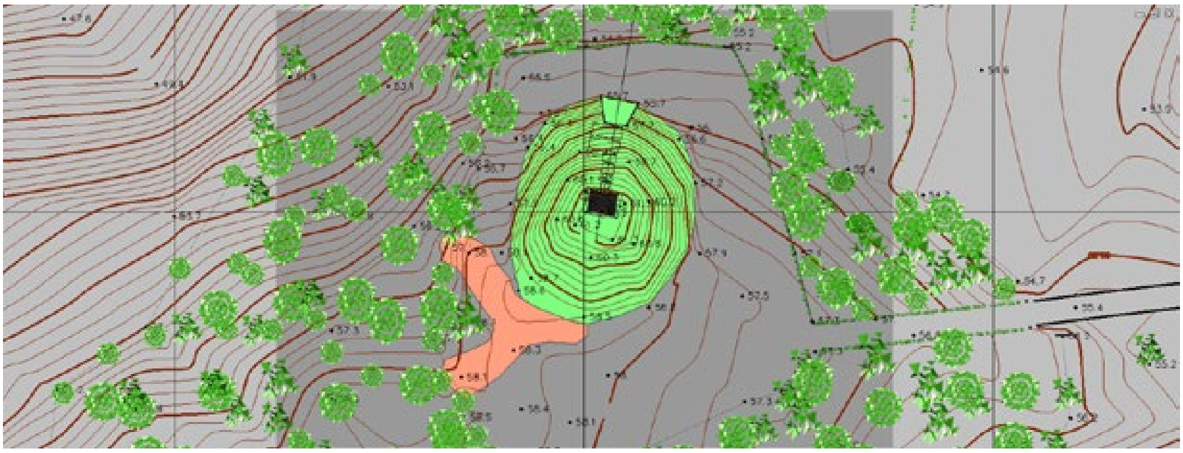

Fig. 150: Geological map of the area.
Orange is granite/schistose formation; dark grey is regolith deposit produced by the alteration of the granite/schistose formation; green is earth fill mainly composed of yellow granitic sand. The white line is the tracing of the geological section.

4. The Mechanism of Water Infiltration into the Tomb

As a result of the geological setting, during heavy rainfall infiltrating water is blocked by the impermeable bedrock and stagnates within the regolith permeable deposit. This hypothesis is confirmed from the Tomb keeper's well, which has been excavated from the regolith deposit to the granite/schistose formation. In this well the water is quite abundant during the rainy season, and it is scarce during the dry period. The refilling of the well is quite fast during the rainy period, thus confirming the idea that water is generously diffused into the terrain and consequently into the aquifer. In the meantime, the saturation of the mound due to rainfall generates water infiltration into the Tomb. The way water inundated the Tomb in 2010 verified the above-mentioned hypothesis. The full model of water infiltration into the Tomb is given in Fig. 151.

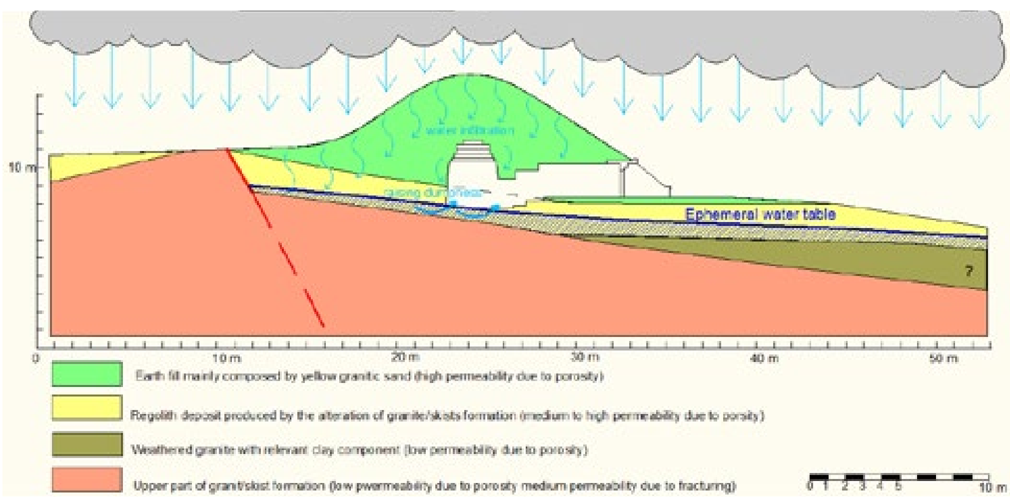

Fig. 151: Mechanism of water infiltration into the Tomb

The two figures below (Fig. 152, Fig. 153) illustrate the thickness of the permeable material (regolith deposit) and the topography of the granite formation on which an ephemeral (temporary) water table is formed if completely saturated. From these it is possible to theoretically describe the flux of water underground.

A definitive confirmation for this model comes from the analyses of the piezometer data obtained in 2009-10 and the comparison of this with the recorded rainfall during the same period. By comparing the piezometer and rainfall data of July 2009 when important flooding occurred in the Tomb, it is possible to notice the following:

1. The rainfall of 45.6 mm of 12 July did not affect the water level in the piezometers or in the Tomb keeper's well;
2. A rise of the water level in the piezometers on 16 July was recorded, two days after intense precipitation of about 111.4 mm occurred on 14 July. There is no piezometer data for 15 July, but the Tomb keeper's well was filled by this heavy rainfall;

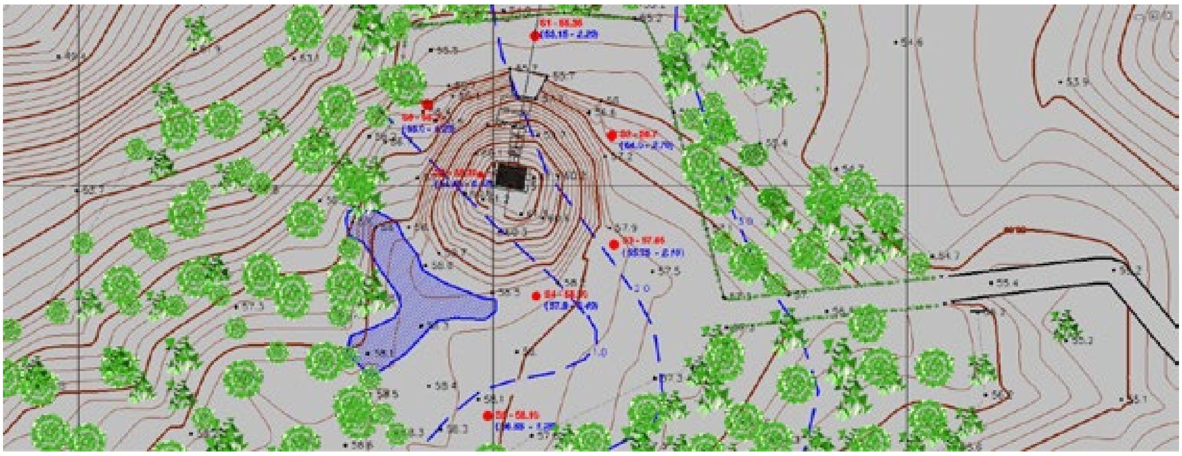

Fig. 152: Thickness of the permeable material

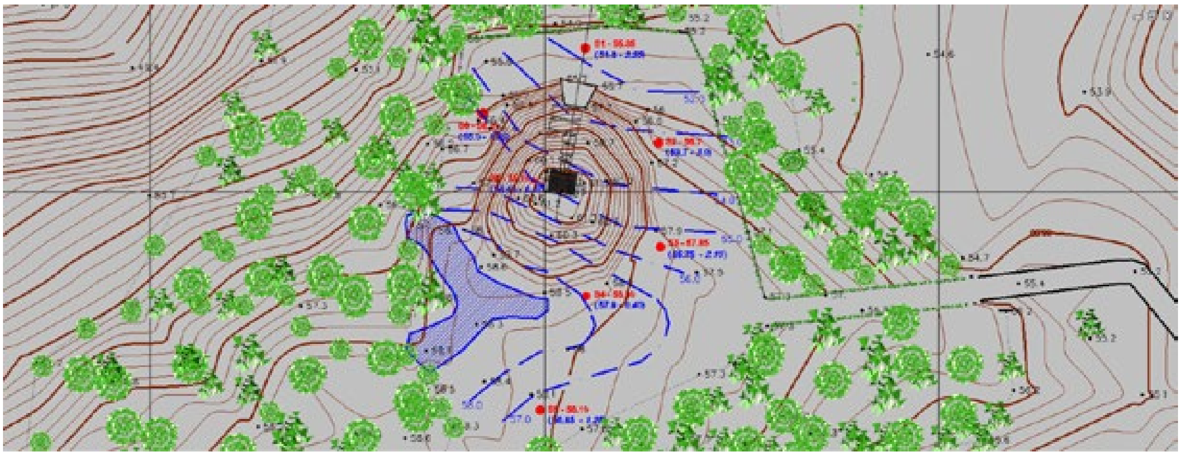

Fig. 153: Topography of the granite formation

3. 158.5 mm of rainfall occurred on 18 July, and the measurements on the following day showed the maximum level of the water table;
4. Water arrived at the same time in all the piezometers but not in the one inside the Tomb. The delay was about three days;
5. The maximum level of water recorded in the piezometers was in the most topographically elevated points of the granite formation, e.g. the northern side of the mound;
6. The Tomb was flooded one day before it reached the bottom of piezometer S8 located in the burial chamber;
7. The maximum peak of water contained inside the piezometers was reached on 19 July and then the amount of water began to decrease.

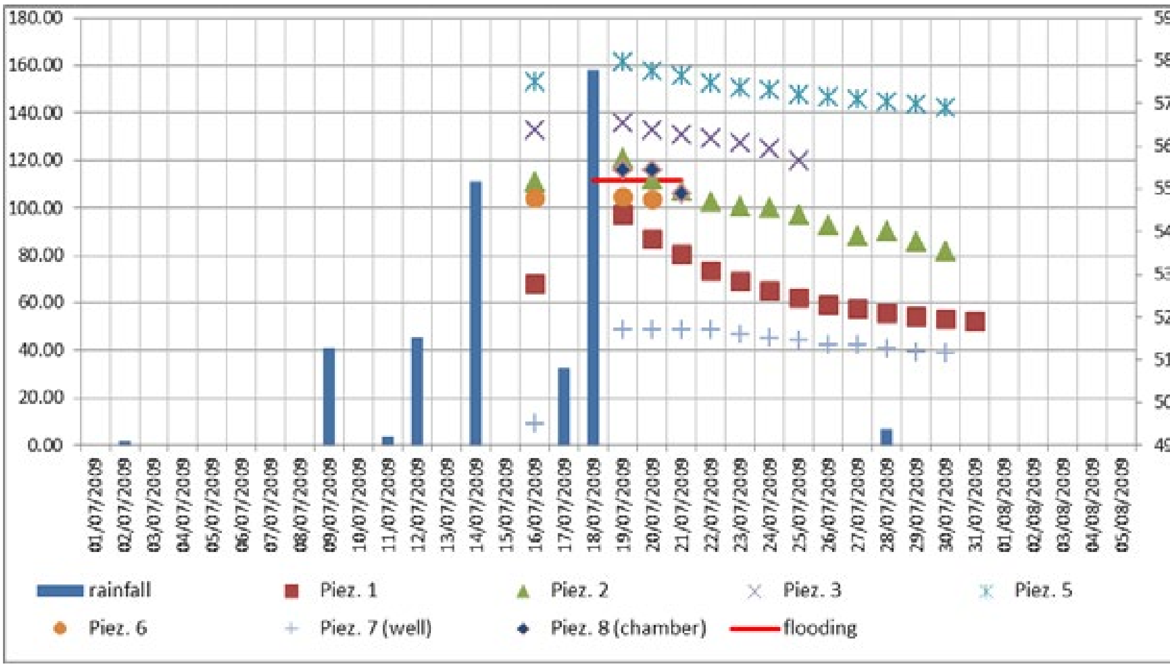

Fig. 154: Comparison of the 2009 data for rainfall, piezometers and flooding inside the Tomb. At the left of the chart the rainfall mm/day is marked and on the right side is the altitude a.s.l. of the piezometers.

The above points explain the rising of the ephemeral water table in the regolith formation as a consequence of water infiltration from the surface due to heavy rainfall. Water infiltrates into the soil and is blocked by the granite impermeable bedrock. The distribution of water that reaches the higher levels at the most elevated piezometers reflects the topography of the granite bedrock. Only then does water fill the area below the Tomb due to lateral infiltration, rising and inundating the burial chamber.

In spring 2010 a water-collecting trench was constructed around the Tomb (see below). The Tomb flooded in August-September due to heavy rainfall, and the data collected in 2010 was compared with that of 2009, meaning that the water-collecting trench was useful.

By comparing the piezometer data and the rainfall of August-September 2010, when significant flooding occurred in the Tomb, it is possible to notice the following:

1. The rainfall of 106.70 mm of 26 August soaked the mound above the Tomb;
2. An increase of the water level was found in four of the piezometers on 27 August, just one day after the heavy rainfall of 26 August;
3. The tomb flooded on 27 August, and the water remained for 16 days until 11 September;
4. The increase of the water level in piezometer S8 in the burial chamber was recorded seven days after the heavy rainfall of 26 August and six days after the inundation of the Tomb. Comparing the similar rainfall and flooding data collected in 2009 (see above), the infiltration behaviour is different because there is a delay in reaching the

floor of the Tomb, clearly demonstrating the efficacy of the drainage channel as well as the need for surface protection/drainage of the earth mound;

5. The water remained in the piezometers for seven days only until 2 September, while in the Tomb it remained for 16 days; the piezometer in the burial chamber contained water until 9 September.

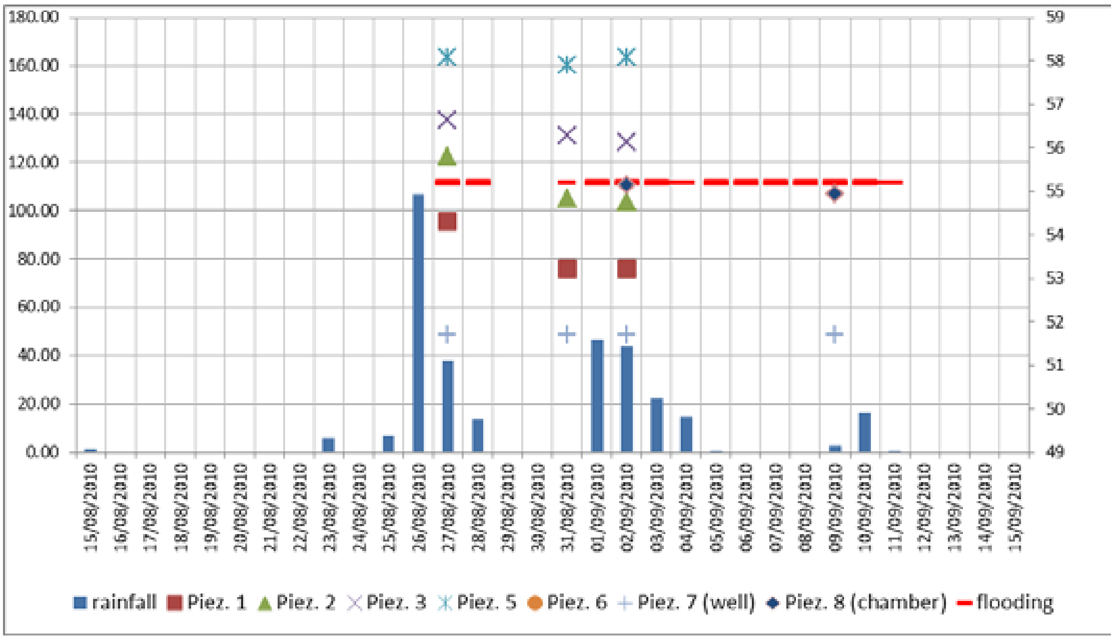

Fig. 155: Comparison of the 2010 data for rainfall, piezometers and flooding inside the Tomb. At the left of the chart the rainfall mm/day is marked and on the right side is the altitude a.s.l. of the piezometers.

The different behaviour of the 2010 inundation with respect to the 2009 one can also be explained by the different intensity of the precipitation and the total amount of water. Fig. 155 shows the rainfall, piezometer and inundation data of 2010 described above.

With respect to the triggering mechanism of inundation in the Tomb, the relationship with rainfall is quite evident. What is more complex is the identification of a possible threshold value above which flooding occurs. From the gathered information it is possible to identify the mechanism that generates water infiltration and an ephemeral water table, limited to the specific case studies of 2009 and 2010. These effects (infiltration and the water table) are connected to significant precipitation (>100 mm) in a scenario of cumulative rainfall more than to a single high-intensity event. This amount of water is necessary (1) to saturate the earth mound and (2) to saturate the regolith formation and generate the water table.

Only one day of extreme precipitation, as on 19 July 2010, is apparently not enough to satisfy the conditions for inundating the Tomb. The following Figure illustrates the rainfall, piezometer levels and flooding of the Tomb for the period 2009-2010, showing the importance of two/three days of cumulative precipitation rather than one day of high intensity (mm/hour) rain.

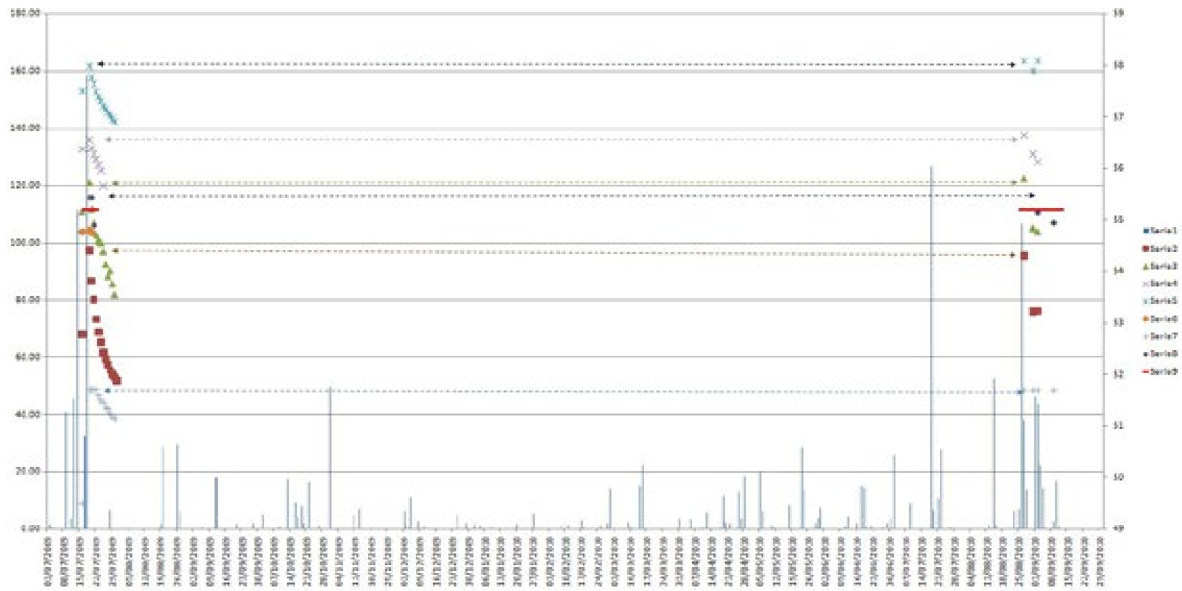

Fig. 156: Comparison of data from the period 2009-2010 for rainfall from the Kangso Meteorological Station, water levels in the piezometers and flooding in the Tomb, for understanding the inundation threshold.

Upon saturation of the regolith layer, the excess water refills the water table with a transfer of time falling within the order of hours and not days. The demonstration of this is that the heavy storm of 18 July 2009 (158.5 mm) produced a maximum peak of groundwater in the piezometers but did not influence the water table during the following days. The water level inside the piezometers slowly decreased day by day, due to the lack of subsequent water recharge, or no rainfall. This means that after the saturation of the regolith layer and within some hours of rainfall or even very extreme precipitation, water infiltrates almost immediately into the soil and does not just form surface run-off. This behaviour is also connected to the very shallow aquifer (water table) we are dealing with.

After the construction of the drainage channel in the spring of 2010, the above phenomena were reduced in the saturation of the earth mound. This was clearly demonstrated by the short delay between the rainfall and the flooding into the Tomb in 2010 and, in the meantime, the delay in the rise of water in the piezometers located in the Tomb. This can easily be explained by the major contribution made by the water that is now coming from the saturation of the mound as a consequence of the efficacy of the drainage system that is significantly lowering the level of the ephemeral water table.

Finally, when considering the mechanism of water inundation into the Tomb it is possible to say that the concrete slab above it does not influence water infiltration directly. On the other hand, constant (spring and winter) water vapour condensation on the *laternendecke* ceiling of the Tomb due to the cooler surface has been observed (information kindly provided by R. Luján), supporting the idea of the limited influence of the slab in reducing the infiltration of water.

5. Waterproofing the Tomb

According to the geological investigation and the meteorological and hydrological monitoring of 2009 and 2010, it is possible to say that rising damp in the Tomb is activated by the saturation of the earth mound and the generation of an ephemeral water table below the Tomb. The first infiltrates into the walls of the Tomb, while the latter produces the inundation from the ground.

In order to ensure the long-term safeguarding of the Tomb and to prevent flooding, it is necessary (1) to waterproof the earth mound and (2) to maintain the ephemeral water table below the level of the Tomb floor.

These are not separate points but have to be considered as elements of the same project. In order to satisfy the above requirements, the possibility of lowering the level of the ephemeral water table with a drainage trench and waterproofing the earth mound with a filter, allowing the water to freely flow outside the Tomb area, was investigated.

2.1. The Drainage Trench

The drainage trench was constructed in 2010 around the mound, according to the scheme given in Fig. 157. The initial points "A" and "D" were selected in the place where the regolith deposit showed a thickness of no more than 0.7-0.8 m. After the construction of the first part of the trench, its extension from point A towards the east was carried out (yellow dotted line) since the area of this granite/schistose formation shows a sharp cut, likely a fault in the terrains's morphology or paleomorphology.

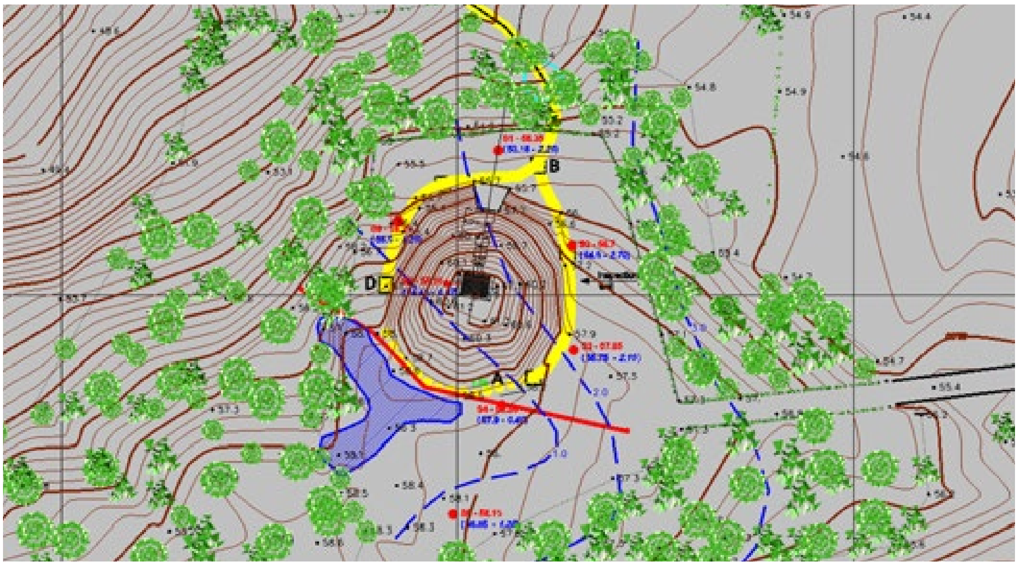

Fig. 157: Ground plan of the drainage trench built in spring 2010

The drainage trench has an average gradient of nine per cent, with a minimum value of 1.3 per cent outside the area to be fully drained. Generally, an average value of two to three per cent is recommended. The trench was constructed on the contact point between permeable and non-permeable materials, as shown in the following Figure. The last 10-12 metres were supposed to be built in the open air, as a channel because the maximum depth was only one metre. A waterway was executed by hand at the end of the trench, such that water flowing downwards would not be freely dispersed in the field.

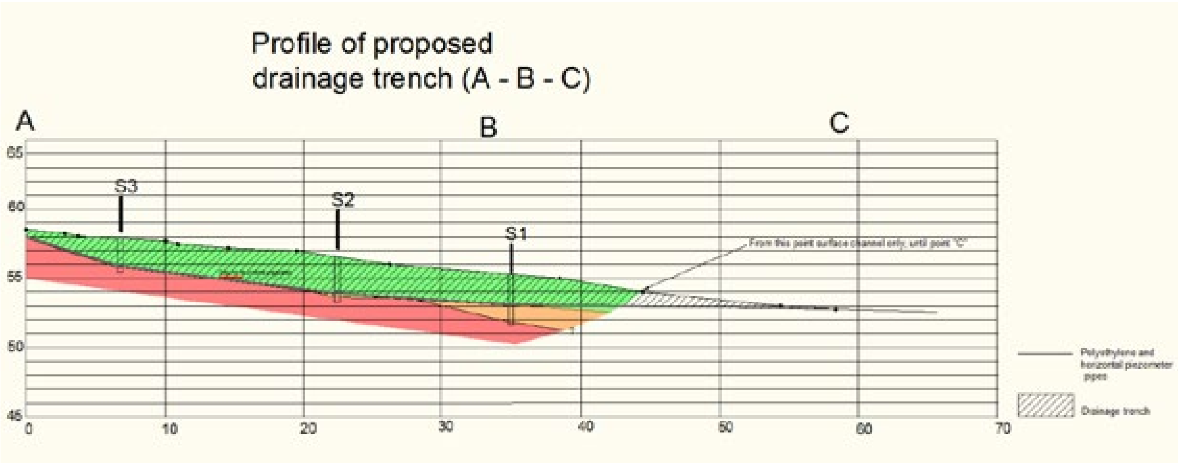

Fig. 158: Topographic profile of proposed drainage trench (west side). Values are in metres

The maximum depth was about 2.8 m from the surface, suitable for the NBCPC workers, according to national experts. In any case, it was recommended that the excavation be protected with wooden planks, as in the proposed scheme. Unfortunately, the available equipment did not allow the digging of a 2.8 m excavation. The trench was executed according to the following Figure.

The standardized 0.2 mm diameter grain size of sand was obtained with metal mesh sieves. Once the trench was excavated around the mound of the Tomb, polyethylene pipes were placed in the bottom. It was proposed by the expert that along with these polyethylene pipes, a second line of pipes be installed utilizing the already existing piezometer pipes, available since the previous mission in 2009. In such a way, even were the polyethylene pipes not to function correctly the piezometer pipes would help the

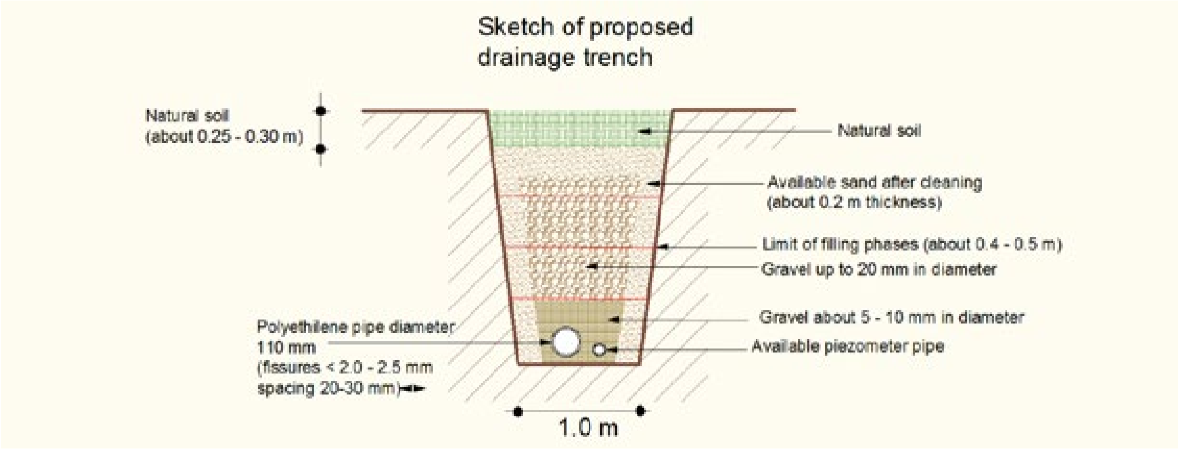

Fig. 159: Topographic profile of proposed drainage trench (west side). Values are in metres

functioning of the drainage system. The different sizes of gravel and sand were then put into the trench.

Details of the construction techniques and specifications are given in Margottini (2010). Two photographs of the construction period are given below.

Fig. 160: Construction of the drainage trench

2.2. Waterproofing the Earthen Mound

The identification of the best solution was not simple since there is almost no experience in Asia of the conservation of earthen mounds, and the technique of construction and waterproofing of burial earthen mounds is not very precise in Korea (Onitsuka et al., 2011). Nevertheless, it has to be emphasized that earthen mounds are an integral part of the cultural heritage in this case and not an additional component of the Tomb. They were designed and built to ensure the conservation of the Tombs for as long as possible in the climatic and meteorological condition of each site. Seen in this light, they are elements of the historic tradition of those who built the magnificent Koguryo Tombs. In this specific case, the mound was reconstructed after the excavation of the Tomb, and so the archaeological concern is of minor importance.

Preventing the saturation of the earth mound with water is a complex task that involves many aspects. Discussions among experts mainly concentrated on two different ones: the complete waterproofing of the earthen mound or the realization of a filter allowing water to freely flow outside the Tomb area. There are advantages and disadvantages to both systems. Full waterproofing (e.g. a stratum of clay or polyethylene) of the earthen mound, perhaps 50/100 cm below the surface, does not require any maintenance but may affect the 'transpiration' (water vapour exchange) of the Tomb, affecting the mural painting conservation. The construction of a drainage stratum located 50/100 cm below the surface level avoids the problem of transpiration but needs periodical maintenance. Sometimes the filter could be filled by soil particles, limiting effectiveness. In both cases, the proposed materials require that no sliding of natural soil above the 50/100 cm layer occurs.

After investigating all possible alternatives, the best solution was identified as the drainage surface filter 50/100 cm below the present surface (about 800 sq. m in area). This would allow the water on the surface to flow easily away in a short time in the direction of the drainage trench. The latter can be constructed in different ways: geotextile coupled with mini-drains regularly spaced; geotextile pack with highly permeable material in the middle; geotextile pack with sand strata in the middle; etc. In any case, the drainage surface and related collector of water needs to be connected to the existing drainage trench around the mound, like in the sheltering of tunnels.

The final solution, also taking into account the possibility of easily available material, was considered to be the use of a geotextile pack with highly permeable material in the middle, working as a filter and allowing the water to flow into the drainage trench. The filter also needs to be coupled with a special metal retention net, in order to avoid the sliding of the material. The drainage and retention sheet need to be connected with the drainage trench, in order to allow all the collected water to flow away from the Tomb area. The following Figures demonstrate the proposed scheme.

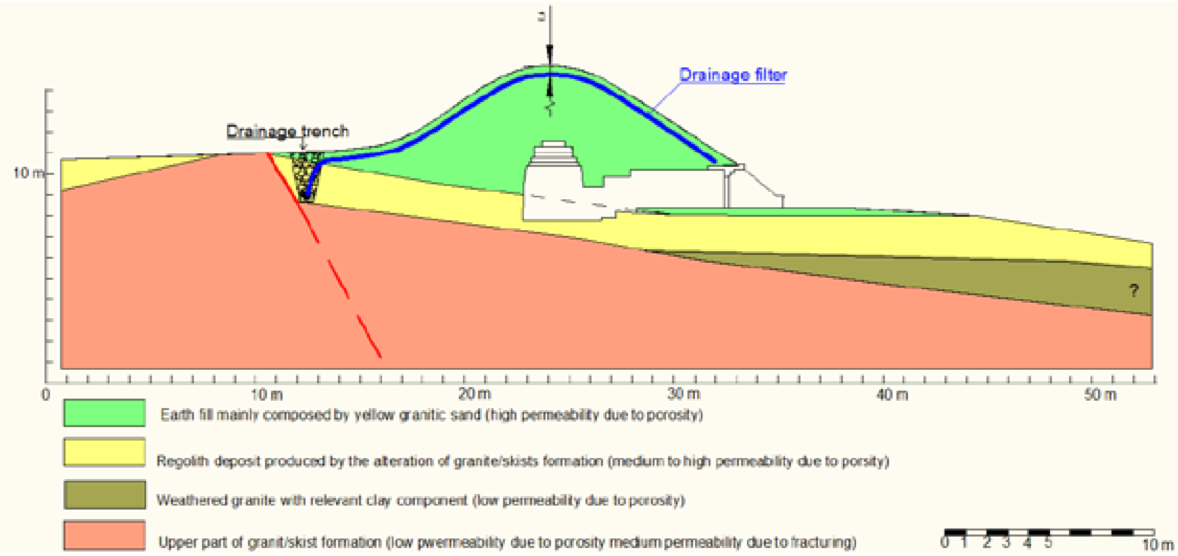

Fig. 161: Waterproofing the Tomb

The filter is placed 50-80 cm below the natural soil, as in the following Figure. Above the filter, on the most sloping sections of the earthen mound, and in order to avoid the sliding of the earth over the filter when this is completely saturated, it was proposed to install a metal net with special horizontal ridges to support the soil's weight.

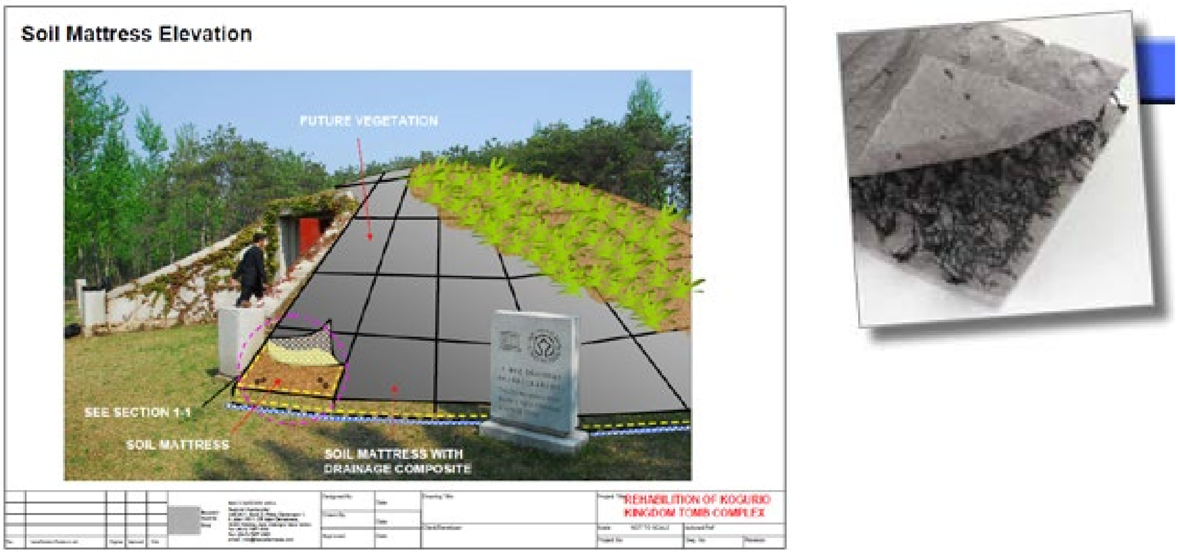

Fig. 162: Example of the position of the filter under the soil (courtesy of Maccaferri, China) and detail of the filter

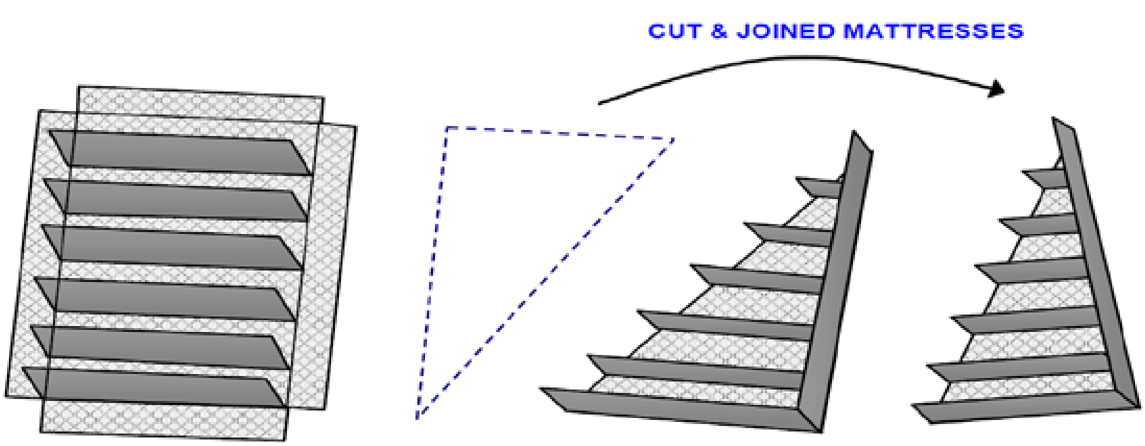

Fig. 163: The metal retention sheet to hold the soil on the inclined sides of the mound (courtesy of Maccaferri, China). The metal retention net is placed over the drainage filter.

6. Conclusion

In recent years much information has been collected to allow the long-term waterproofing of the Tomb. The available information includes a new topographical map, geological map and sections, data from permeability tests on the boreholes, meteorological data from the Kangso Meteorological Station, piezometer information from the instruments placed in 2009 and direct observation of inundation inside the Tomb. In the period 2009-2010, two inundation events were studied.

According to the above information it is possible to say that the inundation in the Tomb is correlated to two different factors: the saturation of the mound and the rising of an ephemeral water table. In order to ensure the long-term safeguarding of the Tomb and to prevent flooding it was necessary (1) to waterproof the earthen mound and (2) to maintain the ephemeral water table below the level of the Tomb floor. These are not separate points but have to be considered as elements of the same project.

In order to satisfy the above requirements, the possibility of lowering the ephemeral water table through the use of a drainage trench and of waterproofing the earth mound with a filter allowing the water to freely flow outside the Tomb area was investigated. The project was completed in Spring 2011.

Part III

Interdisciplinary Collaboration for the Conservation of Koguryo Tombs

Analysis of the Paint Samples Collected from the Tokhung-ri, Yaksu-ri and Jinpa-ri Tombs

by Rocco Mazzeo

Within the framework of the UNESCO/Republic of Korea Funds-in-Trust project 'Preservation of Cultural Heritage in the Democratic People's Republic of Korea, notably the Yaksu-ri Tomb and Capacity Building at the Korean Cultural Preservation Centre (KCPC), DPRK,' Rocco Mazzeo undertook a mission from May 26 to June 11, 2005, in order to take part in the implementation of the second training workshop for the conservation of the Koguryo mural paintings in the DPRK held in Pyongyang from May 29 to June 4 2005 and organised by the UNESCO Division of Cultural Heritage in close collaboration with the UNESCO Beijing Office, the Korean Cultural Preservation Centre of the National Bureau for Cultural Properties Conservation of the DPRK, and the National Commission of the DPRK for UNESCO. Subsequently, he undertook a one-week mission to Daejon, Republic of Korea, from June 4 to June 11, 2005, to carry out scientific investigations at the Research Institute for Cultural Heritage – Heritage Conservation Science Division.

1.1 Survey component

As far as the survey component was concerned, the role played by Rocco Mazzeo was mainly addressed to collecting new paint samples from the Yaksu-ri, the Susan-ri and the Tokun-ri Tombs. The collected samples are listed in Table 2. Two more paint samples should be added to the list: (a) JT1, which was previously collected from the Jinpa-ri Tomb and given to Rocco Mazzeo by the workshop participants, already prepared as paint cross-section; and (b) a red paint sample (ST2) in powder form, which was also previously collected by the workshop participants from the Susan-ri Tomb. These two samples were subsequently analyzed in collaborations with conservation scientists from the Conservation Science Division of the Research Institute of Cultural Heritage in Daejon (ROK).

Tomb	Sample	Colour	Location
YAKSU-RI	YT1	Brown	East wall, 1st chamber (88,5 cm from the ground, 41 cm from the right) from the horse
	YT2	Yellow	East wall, 1st chamber (97,0 cm from the ground, 62,5 cm from the right) from the dress of the horse driver
	YT3	Black	East wall, 1st chamber (138,0 cm from the ground, 85,7 cm from the right)
SUSAN-RI	ST1	Green	South wall, west side: from the upper friezes
	ST2 [x]	Red	No indication of the sampling location
TOKUN-RI	DPRK8[xx]	Black	North wall, 1st chamber: from the background behind the main figure
	DPRK9[xx]	Red	North wall, 1st chamber
JINPA-RI	JT1[xxx]	Red	No indication of the sampling location

[x] sample (prepared as cross-section) given by workshop participants with no indication of the sampling location (analysis carried out in Daejon).

[xx] The scientific results of these samples are given as an appendix to Annex 5
[xxx] sample (in a powder form) given by workshop participants with no indication of the sampling location (analysis carried out in Daejon).

Tab. 6: List of paint samples collected from the Yaksu-ri, Susan-ri and Tokun-ri Tombs with indication of the samples given by the workshop participants

1.2 Analytical results

The analytical results concerning the paint samples collected from the Yaksu-ri (YT1, YT2 and YT3) and Susan-ri (sample ST1) Tombs are presented respectively in Annex 10 and Annex 11. As far as the Tokun-ri samples' analyses (DPRK8 and DPRK9) are concerned, the results are presented in the Appendix to Annex 5.

1.3 General considerations

Unfortunately, it was not possible to collect a paint sample from the so-called 'blue dragon' in the Yaksu-ri Tomb. The reason was that even though the DPRK workshop organisers were well aware of the fact that the survey would have resulted in collecting samples from the mural paintings, the little door that sealed the Tomb's glass barrier was locked and participants were not able to open it. This is in line with the perception the author had about a certain distrust, showed by DPRK officials, in authorizing the sample collection.

To this purpose, and on the occasion of the workshop's closing meeting, the need for a more open-minded and collaborative attitude in the project implementation phases was stressed.

Apart from the analyses of more paint samples aimed at better clarifying the panting technique adopted, there is also the need to carry out, at the completion of the restoration procedures and in coordination with the mural painting restorer Rodolfo Lujan, analyses of the treated mural paintings in order to evaluate the effectiveness and interaction of the restoration materials and methods used with the mural painting substrates.

2. Scientific Investigations of the Tokhung-Ri Tomb Mural Paintings (408 CE) of the Koguryo Era, Democratic People's Republic Of Korea

R. Mazzeo[1*], E. Joseph[1], V. Minguzzi[2], G. Grillini[2], P. Baraldi[33] and D. Prandstraller[4]

2.1. Abstract

In the framework of the UNESCO workshops on the Conservation and Preservation of the Koguryo Mural Paintings which were held in Pyongyang in 2004 and 2005, paint samples were collected from the Tokhung-Ri Tomb located in suburban Pyongyang and analyzed by optical, polarized and FTIR microscopy, scanning electron microscopy coupled with energy-dispersive X-ray analysis (SEM-EDX), X-ray diffraction (XRD) as well as Raman spectroscopy in order to characterize the composition of pigments, the execution technique adopted and the murals' state of conservation The first scientific results seem to confirm what was suggested by local conservators about the adoption of a 'fresco technique,' even though it's not yet clear whether it was intentionally achieved by North Korean painters. In this regard, more analyses are needed, as well as confirmations from an historical literature survey.

Keywords: Koguryo Era, Tokhung-Ri Tomb, murals, fresco technique, analytical investigations

2.2. Introduction

The interest of the conservation science community in studying painting materials and techniques used in Far East Asian art has grown in the last decade thanks to the availability and use of integrated analytical approaches.[5 6 7 8 9 10] This paper, which makes use of such an integrated approach, presents the results of scientific examinations carried

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4 University of Bologna, Institute of Metallurgy, Bologna (Italy)

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6 Yi, Yonghee, Yu, Heisun, Kim, Soochul, Kang, Hyungtae, Jo, Yeontae, Aoki, Shigeo, Ohbayashi, Kentaro *Conservation Science in Museum*, 2003; 4(12), pp. 1-6.

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8 Chen, Qing, Sinkai, Tetuo, Inaba, Masamitsu, Sugisita, Ryutiro, Huang, Guozhang, *Bunkazai Hozon Shufuku Gakkai shi: kobunkazai no kagaku* 1997; 41, pp. 78-87.

9 Kang, Hyungtae, Yi, Yonghee, Yu, Heisun, Kim, Yeonmi, Jo, Yeontae, Aoki, Shigeo, Yamamoto, Noriko, Ohbayashi, Kentaro, *Conservation Science in Museum* 2001; 3, pp. 43-50.

10 Mazzeo, R., Baraldi, P., Luján R., Fagnano, C., *Journal of Raman Spectroscopy* 2004; 35, pp. 678-685.

out for the first time on North Korean mural paintings. Samples (Table 1) collected from the Tokhung-Ri Tomb of the Koguryo era (37 BCE – to 668 CE) which is located in suburban Pyongyang, Democratic People's Republic Korea, have been analyzed in the framework of the UNESCO workshops on the Conservation and Preservation of the Koguryo Mural Paintings organized in Pyongyang in 2004 and 2005. The research was aimed at characterizing the material constitution, the state of conservation and the mural painting technique in view of the planning of the most appropriate restoration procedures to be adopted.

The tomb dates from 408 CE and belongs to a minister Jing that had 13 districts under his jurisdiction. It consists of two chambers containing paintings and Chinese ideograms connected by a short passage through the dividing wall. It is covered by a turf mound and built in stone masonry with a mud-based mortar and external joints pointed with a mixture of lime and sand. The pavement consists of a succession of crushed charcoal and lime layers. The Tomb's vaults are formed by the decreasing span of the walls, and the topmost is closed by two tiers in a caisson receding ceiling of stones blocks.[11]

In the early years of the XXth century, the tomb was plundered and a stone slab from the vault was broken. As a result, the soil forming the mound slid inside, filling both chambers. Two years after its re-discovery in 1976, the soil that had penetrated into the Tomb was removed, and local conservators informed us that the paintings were cleaned with water and vegetable soap and a cement slab was built in order to avoid water infiltration. Today, the state of conservation is bad due to salt deposits and paint layer detachments caused by compression and cracks from the dome made of concrete and condensation caused by a double-glass barrier built in 1994.[11]

2.3. Experiment

The samples were submitted to a variety of analytical methods: (a) optical (OM), ultraviolet fluorescence (UV) and polarized light (PLM) microscopy; (b) scanning electron microscopy (SEM) coupled with electron probe microanalysis (EDX); (c) X-ray diffraction (XRD); (d) thermogravimetric (TG), derivative thermogravimetric (DTG) and differential thermal analyses (DTA); (e) Fourier transform infrared micro-spectroscopy (μFTIR) coupled with attenuated total reflectance (ATR), and (f) Raman micro-spectroscopy (μRaman).

2.3.1. Optical microscopy

Apart from sample DPRK6, the other samples were embedded in a polyester resin support, then cross-sectioned and polished with conventional methods using a silicon carbide card with a successive grid from 120, 400, 800, to 1000. Dark field observation of the cross-sectioned samples was performed using an optical microscope Olympus BX51M and photomicrographs recorded with a scanner digital camera Olympus DP70. Mineralogical, structural and textural data of the materials were obtained by optical analyses on thin sections of the whole sample (sample DPRK7).

11 Luján Lunsford R., UNESCO Symposium on the Conservation of Koguryo Tombs: Scientific and Methodological Approach, October 2004, Seoul, Republic of Korea, pp. 100-108.

2.3.2. Electron scanning microscopy

A scanning electron microscope, Philips XL 20 model SEM-EDX equipped with an energy dispersive X-ray analyzer, was used on the cross-sectioned samples DPRK1, DPRK2, DPRK3, DPRK4, DPRK5 and DPRK7. The elemental composition was carried out at an acceleration voltage of 25-30 keV, lifetime>50sec, CPS ≈2000 and working distance 34 mm. EDX-4 software equipped with a ZAF correction procedure for bulk specimens was used for semi-quantitative analyses of X-ray intensities.

Samples DPRK8 and DPRK9 were analyzed with the use of an extended pressure Scanning Electron Microscope Zeiss EVO 50 EP equipped with an INCA EDX detector run with an INCA energy software, variable pressure mode at an internal chamber pressure of 70 Pa. The elemental composition was carried out at an acceleration voltage of 20-25 keV, lifetime 400 sec, CPS≈ 12500 and working distance 8 mm.

2.3.3. X-ray diffraction

Semi-quantitative mineralogical analyses were performed on powdered samples by X-ray Diffraction (XRD) using a Philips PW 1710 diffractometer. Instrumental and measuring conditions were: CuK radiation, 40kV/30mA, divergence and detector slits of 1°, 0.02° 2 step size, and time for step of 1 s.

2.3.4. Thermogravimetric, derivative thermogravimetric and differential thermal analyses

Identification and quantitative analysis of carbonates content were carried out by thermogravimetric (TG), derivative thermogravimetric (DTG) and differential thermal (DTA) analyses using a Setaram TAG 24 apparatus. Operative conditions were: heating rate 20°C/min, CO_2 atmosphere, heating range from 20° to 1000°C.

2.3.5. FTIR micro-spectroscopy

Depending on the sample size available, FTIR analyses were performed with the KBr pellet technique in transmission mode or by using a Thermo Nicolet Continuμm FTIR microscope equipped with a slide-on micro ATR (Si crystal) device and spectra recorded in reflection mode or with diamond / NaCl compression cells with spectra recorded in transmission mode. The FTIR microscope, fitted with a MCT type A detector, cooled by liquid nitrogen, used a 15x Thermo-Electron Infinity Reflachromat objective and a tube factor of 10x. Single point ATR measurements were performed by placing cross-sectioned samples directly on a motorized XYZ microscope stage, which was also used for the ATR mapping. The latter was performed directly on selected areas of the cross-section of sample DPRK3. For each analyzed area a total of 16 spectra were collected with a step size of 60 microns. For transmittance measurements, either a micro diamond or NaCl compression cell on fragments of whole samples were used. A FTIR Thermo Nicolet Avatar 370 was used to record spectra from 4000 to 650 cm^{-1} (ATR and compression cells) and from 4,000 to 400 cm^{-1} (KBr pellet technique). A total of 64 scans were recorded and the resulting interferogram averaged. The mirror velocity was 1.8988 $cm.s^{-1}$, with a resolution of 4 cm^{-1} and triangular apodisation. Acquisition and post-run processing were carried out using a Nicolet 'Omnic' software.

2.3.6. Raman micro-spectroscopy

The micro-Raman analyses of the paint samples were performed directly on the fragment surface or by placing the cross-sectioned samples on the microscope stage and directing the laser light through a 50x objective of an Olympus microscope onto the different paint layers visible under cross-section. The Raman analyses were carried out with a Jobin Yvon-Horiba Labram and a laser at 632.8 nm at a power ranging from 0.5 to 5 mW (slit: 5 cm^{-1}), according to the thermal stability of the compounds to be investigated. A CCD (330x1,100 pixels) detector, cooled by the Peltier effect at 200°K, was used. For complete investigation, a Jasco 2000 spectrometer combined with an Olympus microscope was used. This instrument was cooled with liquid nitrogen and used the 488 nm laser with a power always lower than 1 mW. The spectral interval was changed according to the type of compounds, but was generally between 1,100 and 100 cm^{-1}. The organic compounds were studied at a high wavenumber range, whereas the inorganic ones, and in particular oxides and sulphides, at a lower wavenumber range. The spectra collection time was also variable according to the magnitude of the scattering signal. Each paint sample was investigated by analyzing an average of 30 particles distributed in the mass of the sample analyzed and in the subsequent layers in the case of cross sections. If the sample was strongly heterogeneous, up to one hundred measurements were carried out. The spectra recorded were elaborated and prepared for publication by using the programme Grams by Thermogalactic.

2.4. Results and Discussion

2.4.1. Stone substrate

The stone has a grayish colour and results indicated that it was constituted of a granite rock with a granular texture characterized by a partial pseudo-parallel orientation so that exfoliation with preferential detachments is produced within the stone structure.

Optical observations and XRD analyses revealed the presence of polycrystalline quartz, potassium feldspar, plagioclase, mica (mainly biotite with traces of muscovite) and additional minerals such as apatite, zircon and opaque minerals (probably sulphides and/or iron oxy-hydroxide). From the petrographic point of view, the stone can be classified as a quartz monzonite with an iso-oriented structure. The PLM examination of sample DPRK7 showed also that between the stone substrate and the preparation layer recrystallized calcite crystals with a 'secretion' structure were present. Their fibre-like texture was responsible for the observed detachment of the preparation layer from the stone substrate even though some contact points still existed between the two.

As far as its mechanisms of formation is concerned, there are probably different factors to be taken into consideration: (a) the very low porosity of the stone substrate that doesn't allow water to be absorbed; (b) the relatively high porosity of the preparation layer and its not good original adhesion to the stone substrate, and (c) the Tomb's environment, which is characterized by Relative Humidity (RH) values close to 100%. Therefore, a possible mechanism could be: (a) during the periods in which the RH is very high, water penetrates the preparation layer and partially dissolves the constituent calcite; (b) the calcite recrystallization happens at the interface with the stone substrate as a kind of sub-florescence phenomenon favoured by RH changes towards more dry environmental conditions. In this regard, a one-year monitoring campaign aimed at evaluating seasonal RH changes inside the Tomb would be indispensable in order to validate this mechanism of formation hypothesis.

2.4.2. Preparation layers

The only available information from local conservator-restorers referred to the use of two preparatory layers composed of lime, sand and organic aggregates which were applied to the vaulting and walls: the first layer (5 cm thick) composed of lime and sand /chopped straw in a proportion of 1:3; the second layer composed of a mixture in equal proportion of lime and sand, with a thickness of about 1.5 cm. A lime wash (0.8 to 1 mm thick) was then applied as a primer for the painted areas.

Only sample DPRK7 was collected in such a way that the stone substrate was included showing the overall stratigraphic morphology. Optical microscopy observations showed that over the stone substrate just one white preparation layer was present. Its thickness varies from about 0.5 to 1.5 mm and vegetal filaments and black carbon elements are embedded within the layer. Transversal crevices are present which are re-cemented by limpid spar calcite.

The SEM-EDX results indicated that not only pure calcite was present, together with traces of quartz and clay mineral components, but also calcite rich in magnesium or dolomite $CaMg(CO_3)_2$, as confirmed by TG and DTA analyses. μFTIR examination of the DPRK3 preparation layer indicated the contemporary presence of magnesite ($MgCO_3$) calcite and silicates. The preparation layers of the other samples are constituted of the same compounds. In addition, stereo microscopical observations of the preparation layer of samples DPRK4, DPRK5 and DPRK3 showed the presence of traces of a translucent material which turned out to be constituted of a siloxane material. Its FTIR spectrum in fact is characterized by a strong infrared band in the 1,130 to 1,000 cm^{-1} region due to the asymmetric Si-O-Si stretching vibration, the strong Si-H stretching vibration at 2158 cm^{-1} as well as a band at 1242 cm^{-1} associated with the symmetric Si-Et deformation[8]. This material, which is scarce and randomly present within the preparation layers, may represent the residue of the application of a siloxane-based protective coating or consolidant applied in the past on the painted surfaces. In this case, it should be more constantly distributed along the overall painted cross-section and a thin layer should also be present on the outermost external surface and easily detectable by μFTIR. More probably it represents the residue of antifoaming agents that are added to detergents and its presence is linked to the use of surface-cleaning procedures carried out in the past and mentioned by local conservators.

2.4.3. Paint layers

The paint palette is shown in Table 3. Observation of cross-sectioned paint samples showed that the colours were applied in single layers. Only sample DPRK4 showed the presence of a carbon black layer, probably belonging to an inscription, superimposed on a red layer composed of hematite. The other red paint layer (DPRK1) is principally composed of hematite with traces of magnetite. The yellow colours (DPRK2 and DPRK5) turned out to be composed of goethite and calcite. Polarized light microscopy, SEM-EDX and μFTIR allowed the identification of the green earth used for the green colour (DPRK3) . Furthermore, the surface of the green sample was covered by a thin organic layer, which was identified by μFTIR compression cell as constituted of a microcrystalline wax.

In a recent publication[1] the area from where the sample DPRK8 was collected is mentioned as being characterized by a blue colour (cheongna – blue silk) even though this assumption comes from typical Chinese iconography and is not supported by scientific analyses. In an attempt to clarify this issue, the sample was submitted to both optical microscope and extended pressure SEM-EDX analyses and the results showed how the paint layer was constituted of few green earth pigment particles and carbon black embedded into a calcite matrix.

In general, both elementary (SEM and extended pressure SEM/EDX) and molecular composition (μFTIR and μRaman) analyses showed how all the paint layers contained calcite as a binding material. In an attempt to better clarify the calcite distribution within both the preparation and paint layer, sample DPRK9 was submitted to extended pressure SEM-EDX mapping elemental analysis. The results confirmed how calcium was homogeneously present in both paint and preparation layers and how there was no discontinuity between the two. The cross-section micro-photograph of sample DPRK9 shows the presence in the outermost paint layer of very few red particles that turned out to be constituted of lead by EDX analyses and can be associated with the presence of an over-painting made of red lead. The same homogeneous distribution of calcium was observed in sample DPRK8. Furthermore, when observed under UV illumination, the cross-sectioned paint layers did not show any fluorescence, which could indicate the presence of an organic binding media. This observation was further confirmed by the negative results achieved through the submission of all paint samples to Pyrolysis Gas Chromatography Mass Spectrometry investigations. These are all features which are typical of a 'fresco technique' in which dry pigments are ground with water and then brushed onto wet lime plaster. As the pigmented lime dries, the calcium hydroxide reacts with carbon dioxide to form a pigmented calcium carbonate layer.

2.4.4. Salt and clay deposits

The white salt deposit (sample DPRK6), which showed a hard consistency, turned out to be constituted of $Mg(HCO_3)(OH)\cdot 2H_2O$, nesquehonite. This mineral, which may have both an acicular or a botryoidal texture, is commonly found as concretions on the vaults of mines linked to magnesite rocks. Therefore, its presence should be related to the composition of the preparation layer where both magnesite and dolomite were detected. The clay deposits, homogeneously present on the external surfaces of all the samples and showing a yellowish/brown colour, were mainly constituted of quartz, K-feldspars and traces of mica cemented by a micritic calcite. From the surface cleaning procedures point of view, the presence of calcite in the outermost external clayish deposits makes these layers very hard to be removed, either mechanically or chemically.

2.5. Conclusions

The analytical investigations carried out on the Tokhung-Ri mural paintings allowed us to draw some preliminary conclusions. All the identified pigments were suitable to be used with a fresco technique. Calcite is present in both preparation and paint layers, and the stratigraphic morphology of the cross-sectioned samples showed that they were strictly connected with each other without any visible discontinuity. These observations may represent clear evidence of the fact that the paint colours were applied over a white preparation layer when it was still in a wet lime plaster condition. Furthermore, there was no evidence of the presence of any organic binding media. At the present state of knowledge, these observations are very more in favour of a 'fresco technique' being used for the mural paintings' execution. It is not yet clear whether this technique was intentionally achieved by the North Korean painters, and it is also clear that before drawing any conclusive conclusions, the use of a 'fresco technique' in the DPRK should be confirmed by an historical literature survey. If both further scientific investigations and historical information confirm the use and existence of a 'fresco technique,' this could represent one of the first examples of fresco painting in Far East Asia, as the majority of the wall paintings studied so far[6,9] were painted with 'secco' techniques. It would also be advisable to perform similar scientific investigations on mural paintings located in China and belonging to the same Koguryo era.

As far as the state of conservation of the Tokhung-Ri mural paintings is concerned, they are not in a good state of conservation, as demonstrated by the observed detachment of the preparation and paint layers from the stone substrate. Furthermore, the presence of the double-glass barriers installed inside the Tomb has to be regarded only as a protection against vandalism and not for their safeguarding. The levels of Relative Humidity measured inside and outside the double-glass barriers are, in fact, of the same order of magnitude. The water infiltration from the surrounding turf mound, as well as the high RH levels, may be responsible for the observed paint layer detachments.

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[9] Mazzeo, R., Joseph, E., Minguzzi, V., Modugno, F., Prati, S., Ma, Tao, van Valen, L. M., Proceedings of the 2nd International Conference on the Conservation of Grotto Sites: Conservation of Ancient Sites on the Silk Road, Mogao Grottoes, 28 June to 3 July, 2004, Getty Conservation Institute, in press.

Further Documentation Below

- ► Scientific results of the Tokhun-ri Tomb (samples DPRK1 to DPRK7)
- ► Scientific results of the Tokhun-ri Tomb (samples DPRK8 and DPRK9)
- ► Scientific results of the Yaksu-ri Tomb (samples YT1 to YT3)
- ► Scientific results of the Susan-ri Tomb (sample ST1)
- ► Scientific results of the Susan-ri Tomb (sample ST2) and Jinpa-ri Tomb (sample JT1)

Sample	**Colour**	**Location/description**
DPRK1	Dark red	West wall, inner passage connecting the two chambers south side, upper section. Sample taken from the external dark-red band from 30 cm circa, from the top above a lacuna. The sampling area was covered with a salt deposition.
DPRK2	Yellow	East wall of inner passage connecting the two chambers, north side, upper section. Sample taken from the yellow band just beneath the ceiling. This area is slightly covered with mud.
DPRK3	Green	1^{st} chamber south wall, west section, lower area of frieze and 40 cm from corner. The appearance of the green paint layer appears bright and was taken near a nearby lacuna.
DPRK4	Black/red	1^{st} chamber west wall, south section, upper area of frieze near the corner.
DPRK5	Yellow	1^{st} chamber west wall, south section, upper row of dignitaries (south side of 3^{rd} from south).
DPRK6	White deposit on yellow paint layer	1^{st} chamber west wall, 4^{th} dignitary from south, upper row of dignitaries.
DPRK7	Brown	East wall of inner passage, sample of stone and preparation layer for painted decorations
DPRK8	Black	North wall, 1^{st} chamber, from the background behind the main figure
DPRK9	Red	North wall, 1^{st} chamber, upper part of east section.

Tab. 7: Position and description of the analyzed samples

Sample	Type of analysis							
	Stereo micro-scope	OM	PLM	SEM-EDX	extended pressure SEM-EDX	XRD	TG, DTG, DTA	FTIR, µFTIR	µRaman
DPRK1	×	×		×				×	×
DPRK2	×	×		×				×	×
DPRK3	×	×		×				×	×
DPRK4	×	×		×				×	×
DPRK5	×	×		×				×	×
DPRK6	×							×	
DPRK7	×	×	×	×		×	×		
DPRK8	×	×			×				
DPRK9	×	×			×				

Tab. 8: List of type of analysis performed on samples

Sample	Colour	Pigment identification	Other compounds	Method of identification
DPRK1	Dark red	Hematite, magnetite	calcite	SEM-EDX, μRaman
DPRK2	Yellow	Goethite	calcite	SEM-EDX, μRaman, μFTIR
DPRK3	Green	Green earth	calcite	SEM-EDX, PLM , μFTIR
DPRK4	Black/red	Hematite, carbon black	calcite	SEM-EDX, μRaman
DPRK5	Yellow	Goethite	calcite	SEM-EDX, μRaman, μFTIR
DPRK8	Black	Green earth, carbon black	calcite	extended pressure SEM-EDX
DPRK9	Red	Hematite, red lead	calcite	extended pressure SEM-EDX

Tab. 9: Paint palette composition and methods of identification

2.6. Tokun-Ri Tomb: Analytical Results of the Paint Samples

The list of the analyzed samples is shown in the table below. Fig. 188 and 189 show the location where samples were collected.

Tomb	Sample	Colour	Location
TOKUN-RI	DPRK8	Black	North wall, 1st chamber, from the background behind the main figure
TOKUN-RI	DPRK9	Red	North wall, 1st chamber

Tab. 10: Tokun-ri Tomb: list of analyzed samples

Fig. 188: Tokun-ri Tomb, north wall, 1st chamber, sampling location of DPRK8

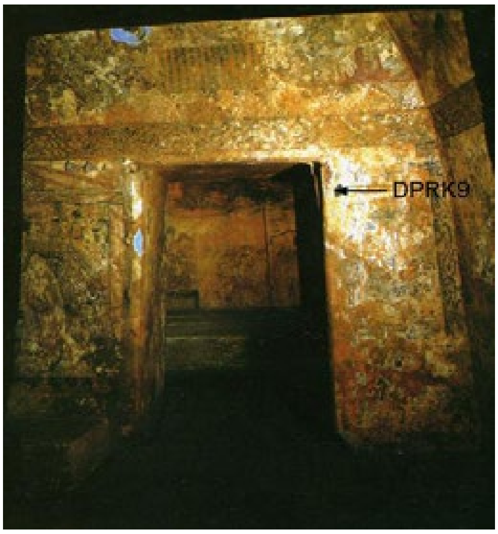


Fig. 189: Tokun-ri Tomb, north wall, 1st chamber, sampling location of DPRK9

2.6.1. Optical And Scanning Electron Microscopy (ESEM)

SAMPLE DPRK8

Comments

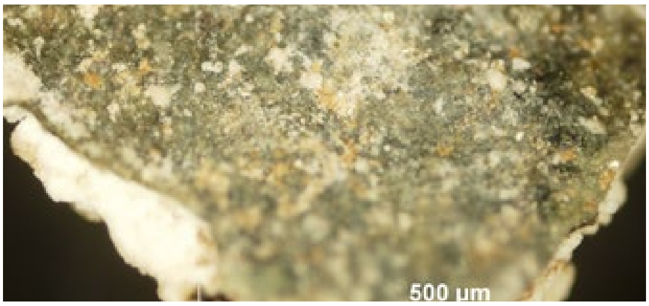


Fig. 164: Stereo microphotograph

Fig. 165: Optical microphotograph

A white preparation layer can be observed with a black irregular paint layer on top. Some green pigment particles are also present.

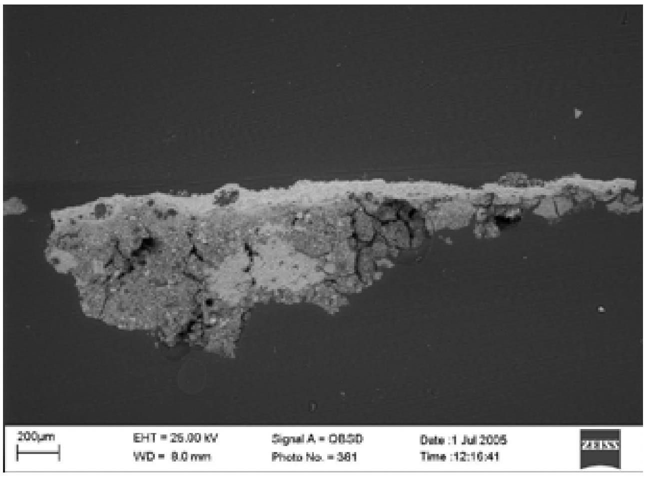


Fig. 166: ESEM-BSE microphotograph

The observation of the sample in back-scattered electrons indicates the presence of heavier chemical elements in connection with the black/green paint layer.

A few rounded particles, which appears black in colour, are also present within the paint layer.

The picture shows the presence of cracks within the white preparation layer.

2.6.2. ESEM – Energy Dispersive X-Ray Analysis (EDS)

Sample DPRK8

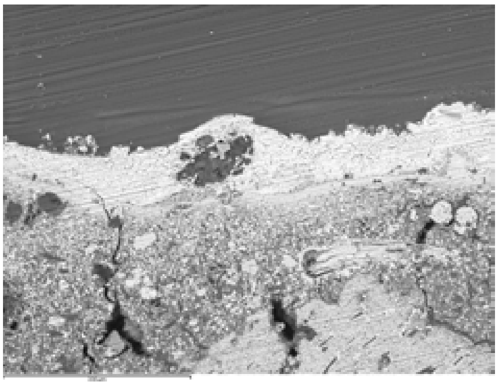
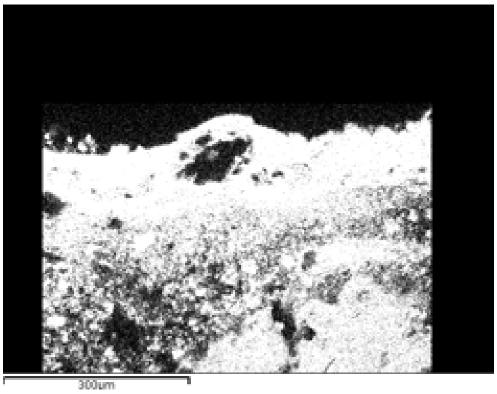
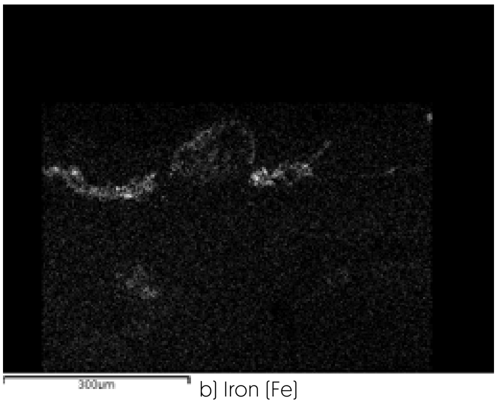


Fig. 167: ESEM-BSE microphotograph

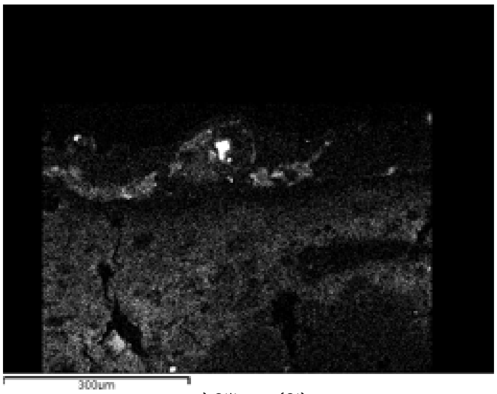


a) Calcium (Ca)

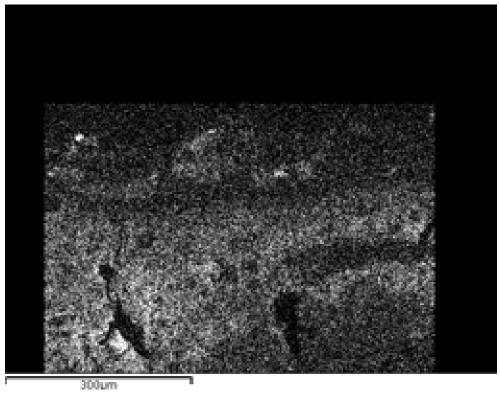
The picture indicates the site where elemental mapping was performed



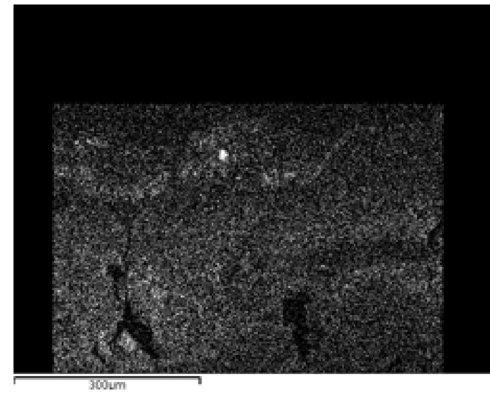
b) Iron (Fe)



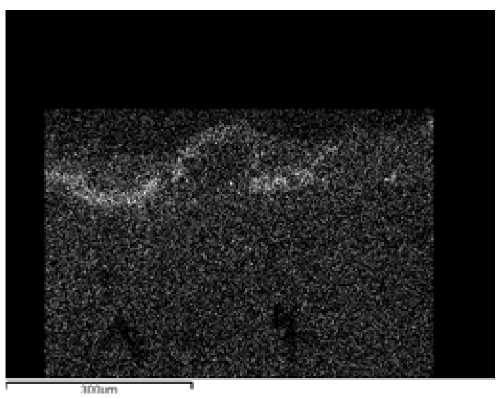
c) Silicon (Si)



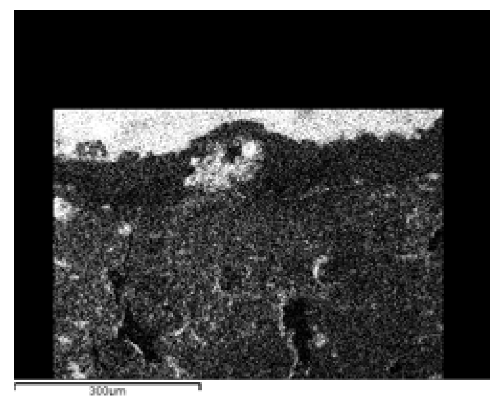
d) Magnesium (Mg)



e) Aluminium (Al)



f) Potassium (K)



g) Carbon (C)

The elemental composition clearly indicates how the white preparation layer is mainly constituted of calcite ($CaCO_3$), with the contemporary presence of Mg (probably a magnesite component), Si (rounded quartz particles) and Al. The black/green paint layer turned out to be constituted of Fe (Fig. 167.b), K (Fig. 167.f), Al (Fig. 167.e) Si (Fig. 167.c) and Mg (Fig. 167.d), which could be consistent with the composition of green earth (Fe, Mg, Al, K hydrosilicate). Apart from the presence of the external brown deposits, the stratigraphy and layer composition seems to be very similar to what resulted from the analyses of sample ST1 from the Susan-ri Tomb (see below).

The rounded black particle embedded into the black/green layer turned out to be constituted of carbon (Fig. 167.g), which is consistent with the presence of carbon black.

2.6.3. Optical and Scanning Electron Microscopy (ESEM)

SAMPLE DPRK9

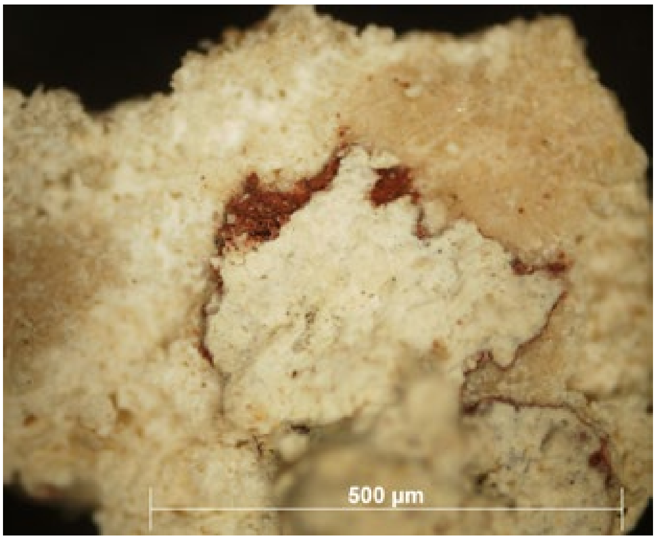


Fig. 168: Stereo microphotograph

Comments

This picture, taken from the back of the sample, shows the white preparation layer (1), the red paint layer (2), and another external white layer (3), which is more visible in Fig. 169.

Fig. 169: Optical microphotograph

The different layers are more visible in cross-section.

The white profiled area indicates the place where black particles are present. This area was submitted to elemental analyses aimed at understanding the composition of the above-mentioned black particles.

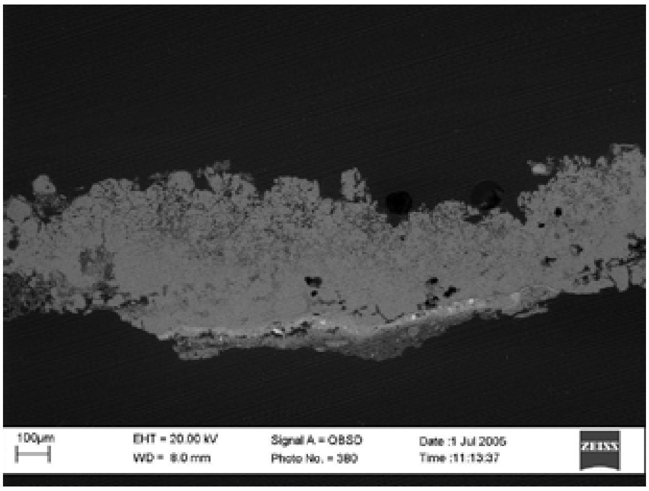


Fig. 170: ESEM-BSE microphotograph

Observation of the sample in back-scattered electrons indicates the presence of heavier chemical elements in connection with the red paint layer. The lighter area corresponds to the place where the black particles are present.

The white profiled area indicates the place where elemental mapping was performed.

2.6.4. ESEM – Energy Dispersive X-Ray Analysis (EDS)

Sample DPRK9

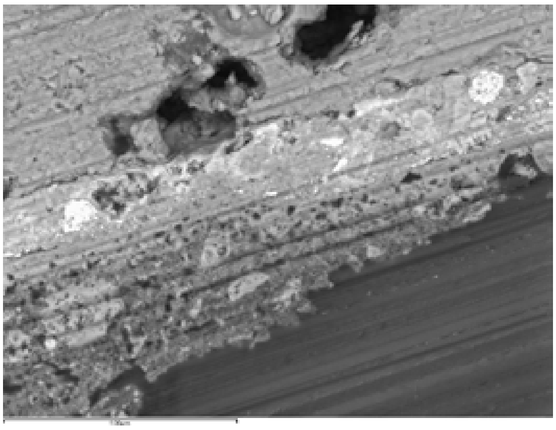
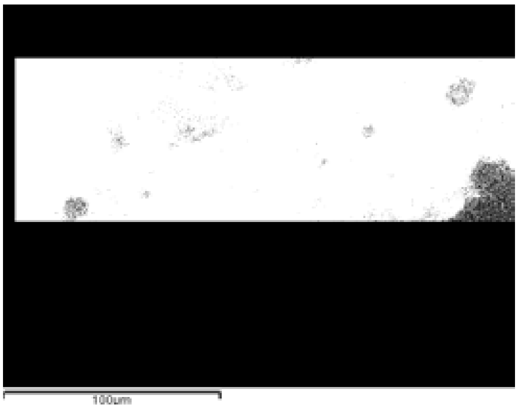
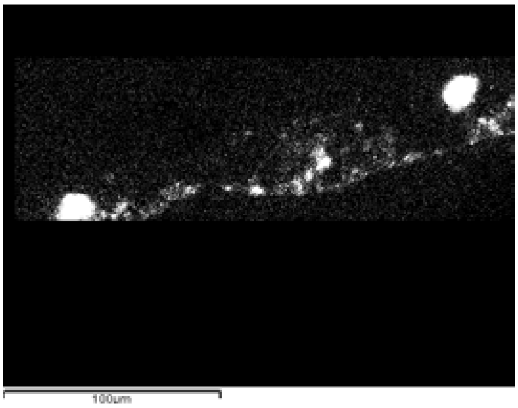


Fig. 171: ESEM-BSE microphotograph

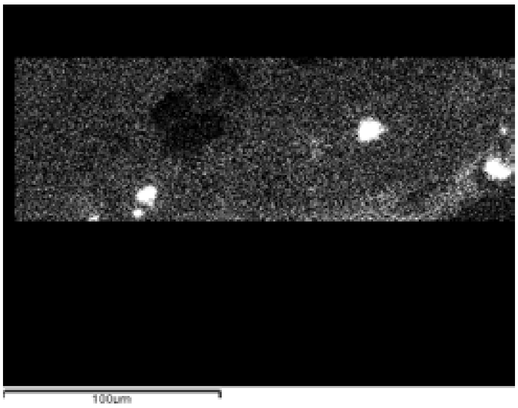


a) Calcium (Ca)

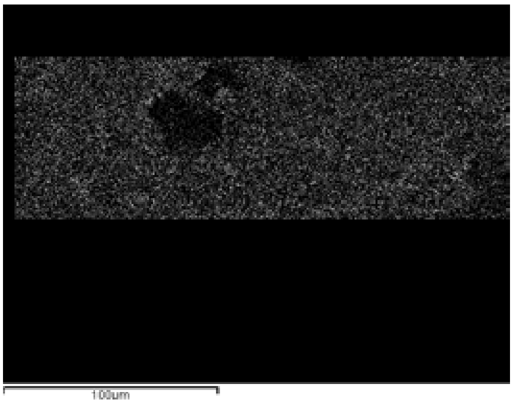
The picture indicates the site where elemental mapping was performed (picture upside down).



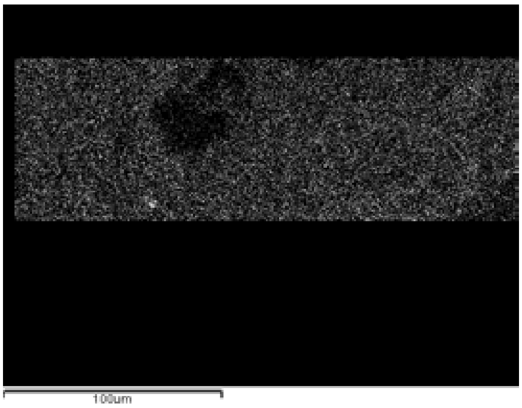
b) Iron (Fe)



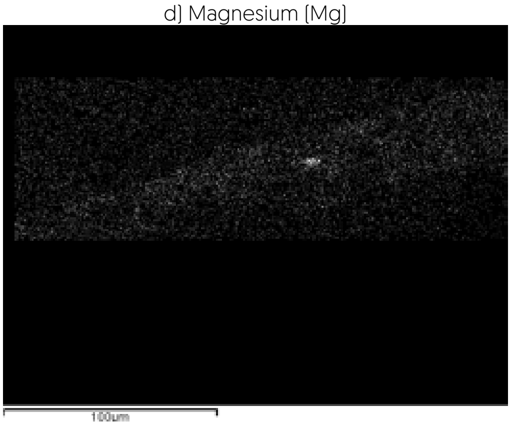
c) Silicon (Si)



d] Magnesium [Mg]



e] Aluminium [Al]



f] Lead [Pb]

The elemental composition clearly indicates that the white preparation layer is mainly constituted of calcite ($CaCO_3$), with the contemporary presence of Mg (probably a magnesite component), Si (rounded quartz particles) and Al.

The red paint layer is characterized by the presence of Fe (Figure b), which is consistent with the presence of red oxide (hematite) as well as a small percentage of Pb (Figure f), which indicates the presence of red lead (Pb_3O_4) pigments. Calcium ($CaCO_3$) is also present as a binding medium of the paint layer. A large amount of re-crystallized calcite, with the contemporary presence of rounded quartz, constitutes the external part of the stratigraphy

Sample DPRK9

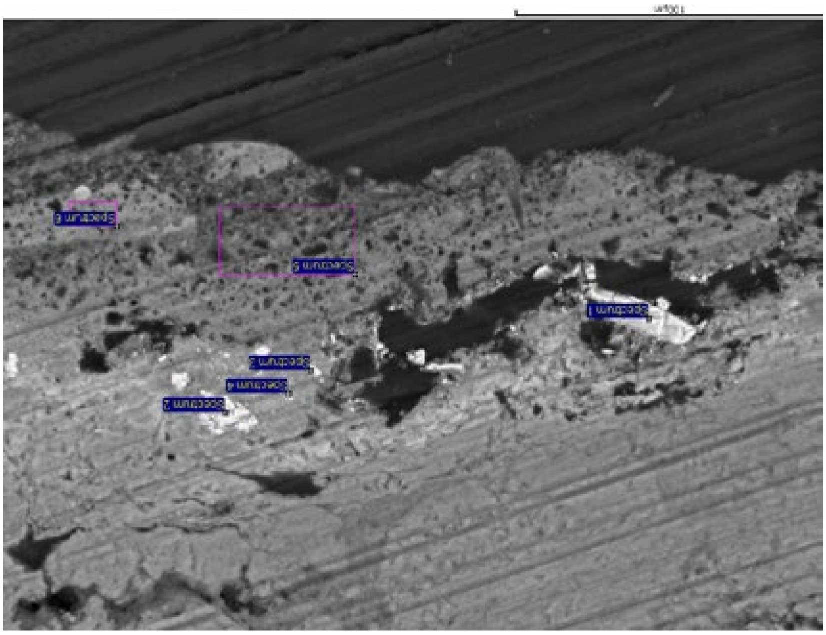
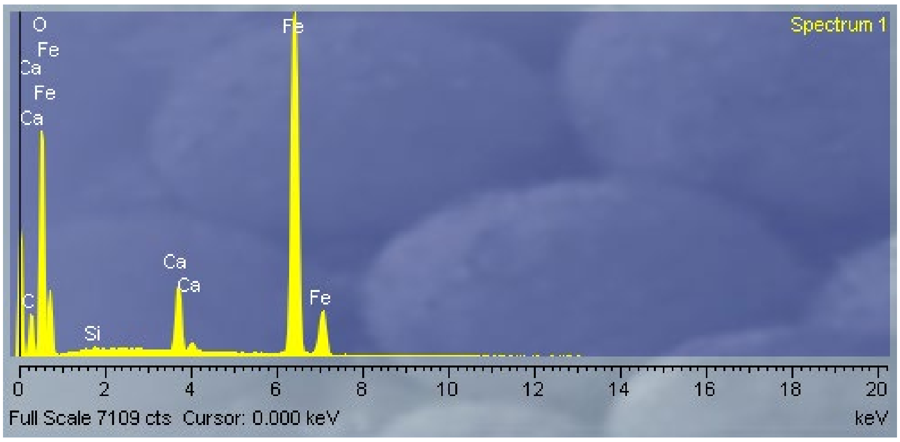
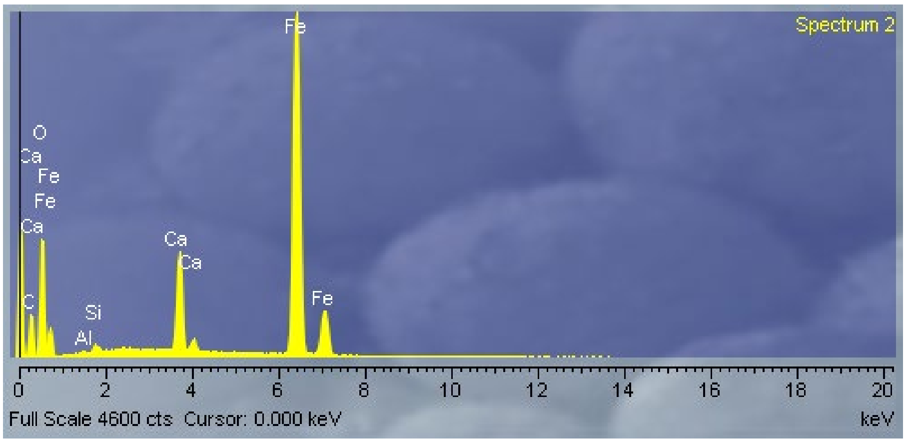


Fig. 172: ESEM-BSE microphotograph. The picture indicates the site where micro-analysis of the black particles (which appear white in the picture) was performed.



a) Spectrum 1



b) Spectrum 2

The elemental composition of the black particles is characterized by a large amount of iron with some calcium. The latter may belong to the surrounding calcite binding material. The black colour of the particles, together with their metallic appearance, is consistent with the presence of magnetite, which was also found in sample DPRK 1.

2.6.5. Conclusions

In *Koguryo Tomb Murals*, published in 2004 by ICOMOS-Korea and edited by Kim Lena, the area where the sample DPRK 8 was collected is said to be of a blue colour (cheongna – blue silk) (page 33). The analytical results, which showed many similarities with the analogous black paint sample (ST1) collected from the Susan-ri Tomb, did not demonstrate the presence of any blue, however. In fact, the paint layer composition and stratigraphy showed that it was constituted of a few green earth pigments embedded into carbon black. As far as the binding medium is concerned, the Py-GC-MS analyses did not show the presence of any organic material, and this leads to the conclusion that a fresco-painting technique was used.

The red sample DPRK 9 has almost the same composition as sample DPRK1, with the exception of the few red lead pigments found in the former. Furthermore, both samples were collected from the inner passage connecting the two chambers.

If compared with the composition and stratigraphy of the red paint layer of sample DPRK4 collected on the west wall of the 1st chamber, some differences can be observed. DPRK9 and DPRK1 are both characterized by traces of magnetite, which is not present in sample DPRK4.

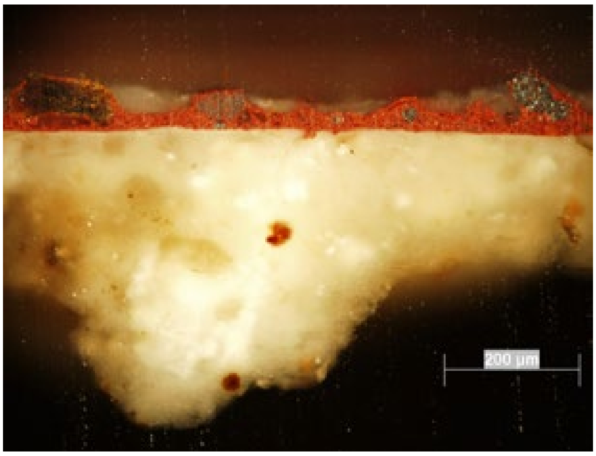


Fig. 173: Sample DPRK1 showing the presence of magnetite black particles embedded into the red hematite paint layer.

Almost all the samples showed the presence of a hard layer of external re-crystallized calcite mixed with a deposit of clayish material. This is a very important issue to be taken into account by restorers before planning any cleaning procedure.

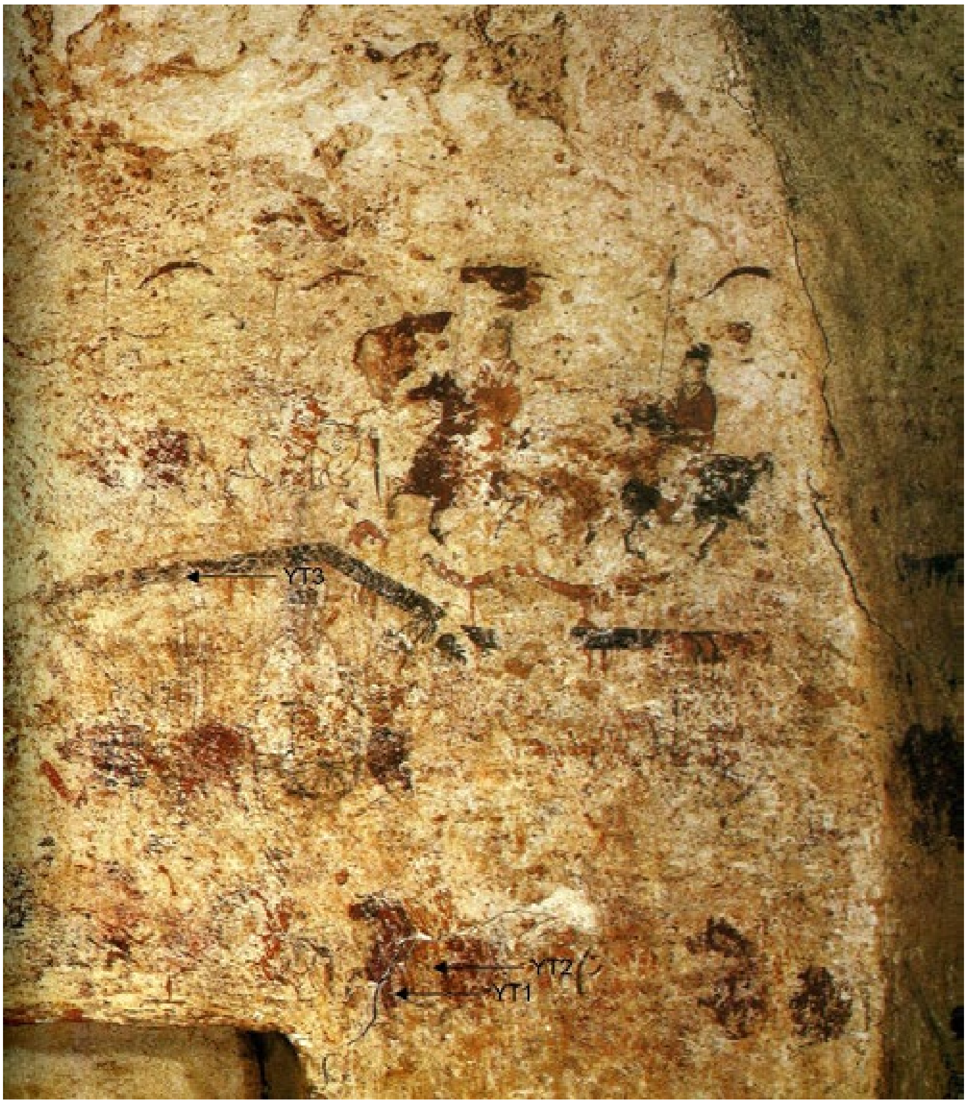
2.7. Yaksu-Ri Tomb: Analytical Results of the Paint Samples

The list of the analyzed samples is shown in Tab. 4. Fig. 174 shows the locations where samples were collected.

Tab. 4: Yaksu-ri Tomb: list of analyzed samples

Tomb	Sample	Colour	Location
YAKSU-RI	YT1	Brown	East wall, 1st chamber (88,5cm from the ground, 41cm from the right) from the horse
"	YT2	Yellow/ orange	East wall, 1st chamber (97,0cm from the ground, 62,5cm from the right) from the dress of the horse driver
"	YT3	Black	East wall, 1st chamber (138,0cm from the ground, 85,7cm from the right)

Fig. 174: Yaksu-ri Tomb, east wall, 1st chamber, samples location



2.7.1. Optical and Scanning Electron Microscopy (ESEM)

SAMPLE YT1

Fig. 175: Optical microphotograph

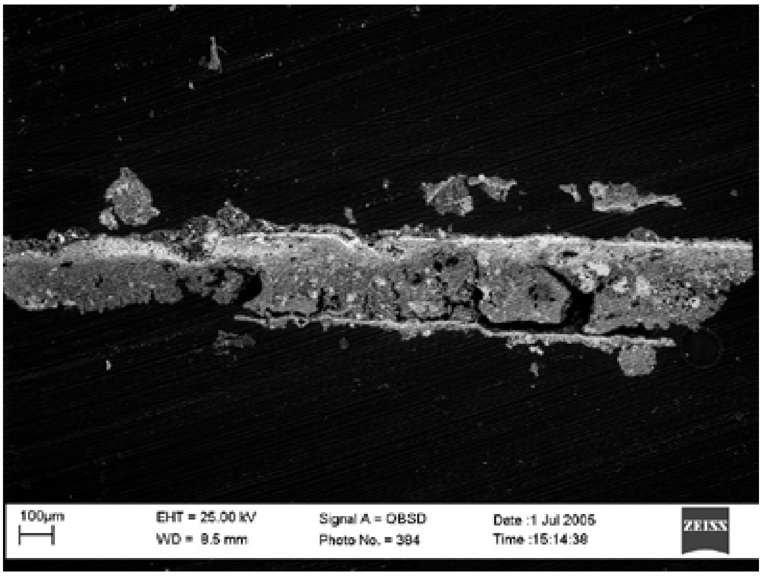


Fig. 176: ESEM-BSE microphotograph

Comments

A white preparation layer can be observed with a thin (~10 µm) red paint layer on top. The latter follows the asperities of the above-mentioned white layer.

Brown deposits are visible on the external surface.

Observation of the sample in back-scattered electrons indicates the presence of heavier chemical elements in connection with the red paint layer.

The picture shows how the white preparation layer seems to have been applied at two different times.

2.7.2. ESEM – Energy Dispersive X-Ray Analysis (EDS)

Sample YT1

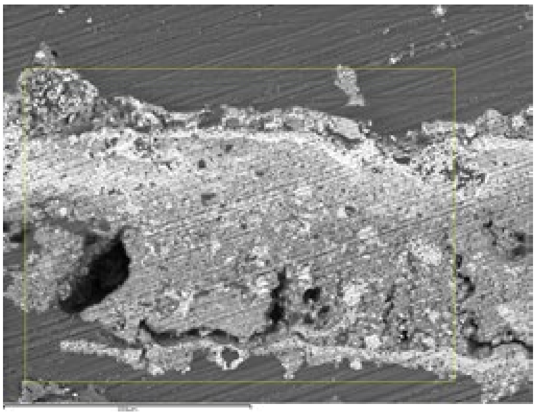
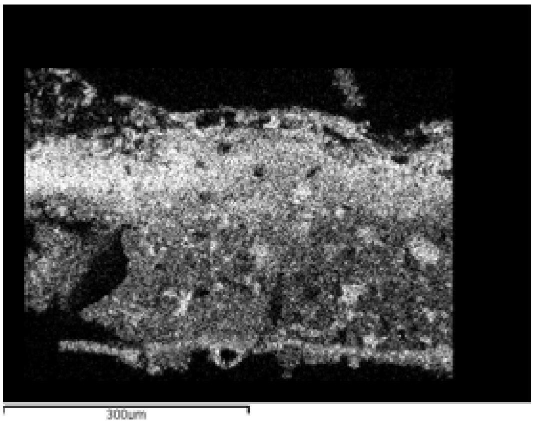
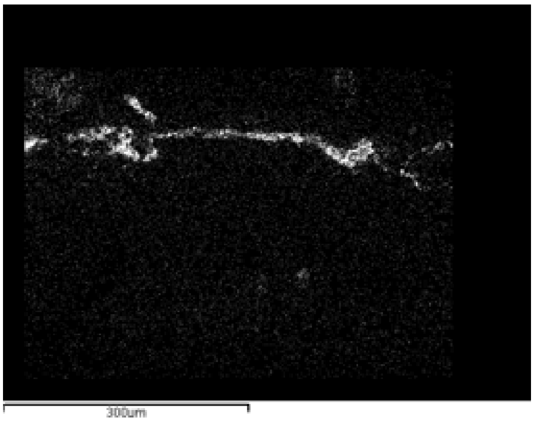


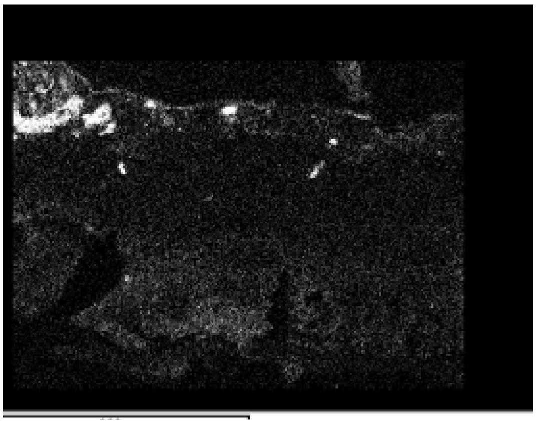
Fig. 177: ESEM-BSE microphotograph. The yellow area indicates the site where elemental mapping was performed



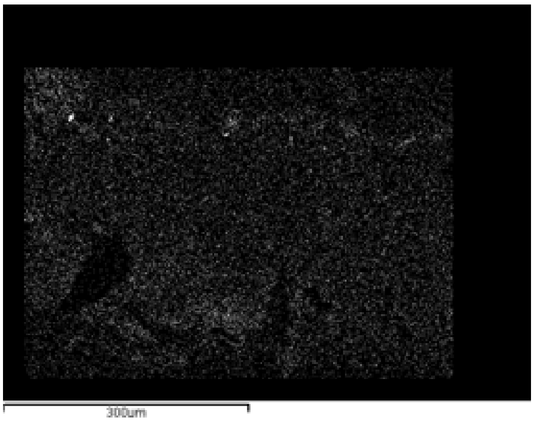
a) Calcium (Ca)



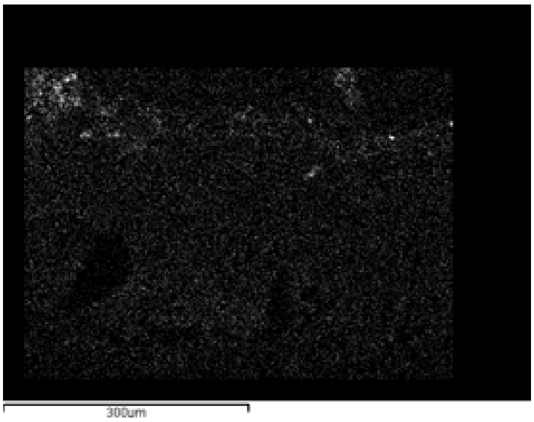
b) Iron (Fe)



c) Silicon (Si)



d) Magnesium (Mg)



e) Aluminium (Al)

The elemental composition clearly indicates that the white preparation layer is mainly constituted of calcite ($CaCO_3$) with the contemporary presence of Mg (probably a magnesite component) and traces of Si and Al. This white layer seems to have been applied at two different times. The red paint layer is composed of Fe, which can be associated with the presence of an iron oxide. The figure a) shows how Ca is also present within the paint layer, acting as a binding medium. The brown external layer seems to be constituted of clay material (Si, Mg and Al) with the contemporary presence of Ca, which may belong to re-crystallized calcite.

2.7.3. Optical And Scanning Electron Microscopy (ESEM)

SAMPLE YT2

Fig. 178: Optical microphotograph

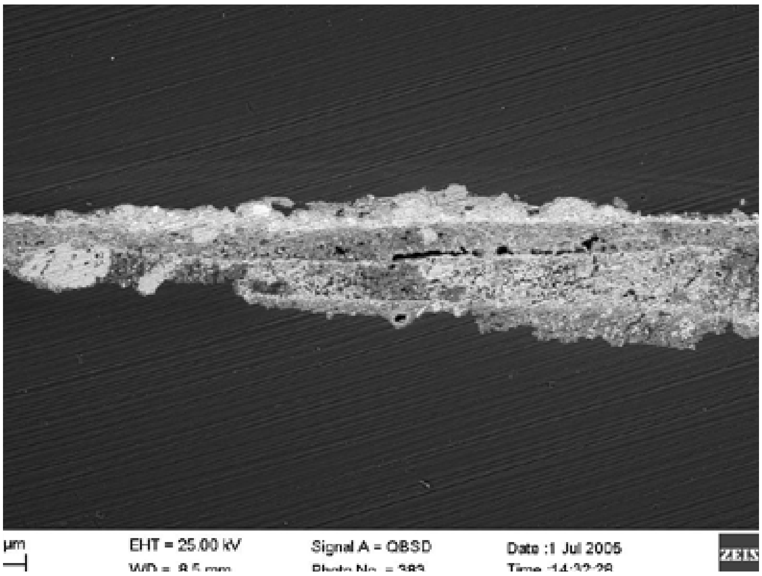


Fig. 179: ESEM-BSE microphotograph

Comments

A white preparation layer can be observed with a thin (~10 µm) yellow/orange paint layer on the top. The latter follows the asperities of the above-mentioned white layer.

Brown deposits are visible on the external surface.

Observation of the sample in back scattered electrons indicates the presence of heavier chemical elements in connection with the yellow/orange paint layer.

The picture shows how the white preparation layer seems to have been applied at three different times

2.7.4. ESEM – Energy Dispersive X-Ray Analysis (EDS)

Sample YT2

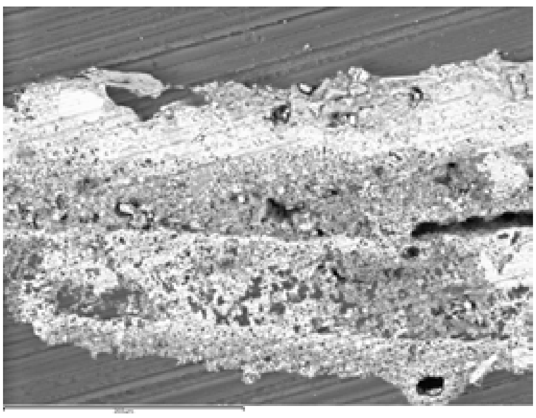
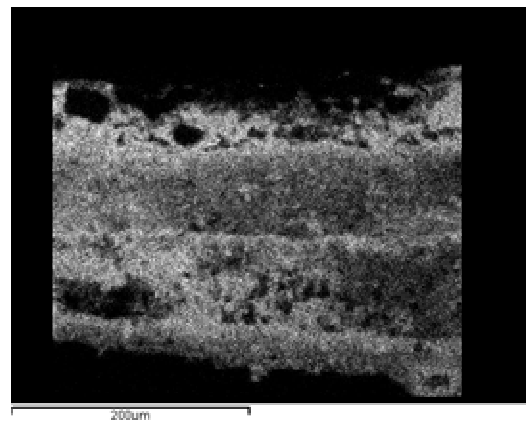
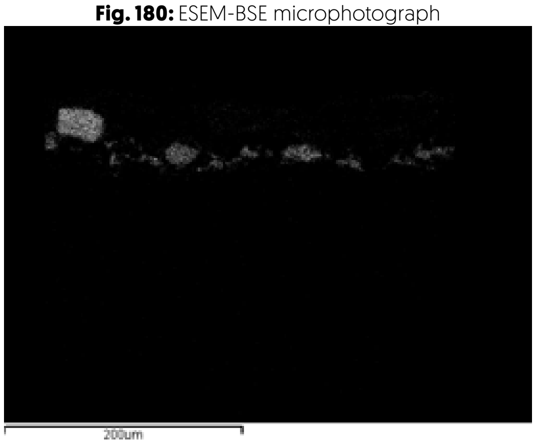


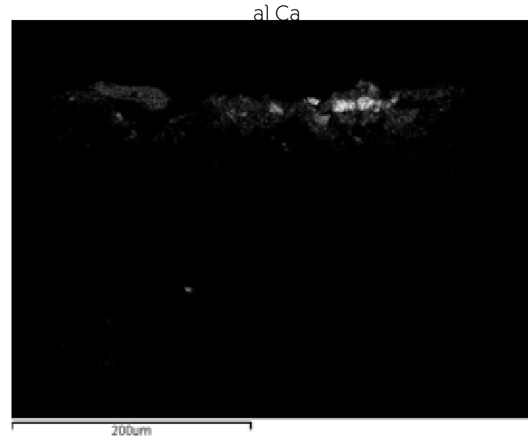
Fig. 180: ESEM-BSE microphotograph



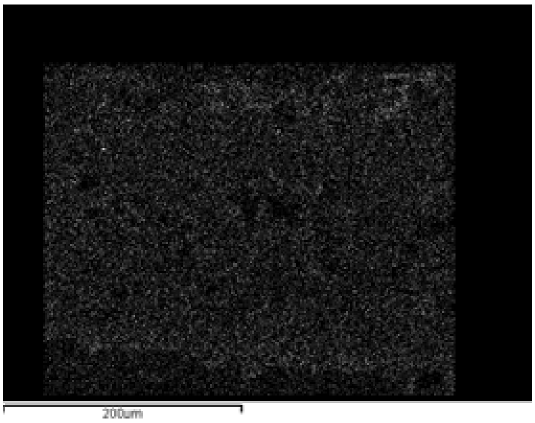
a) Ca



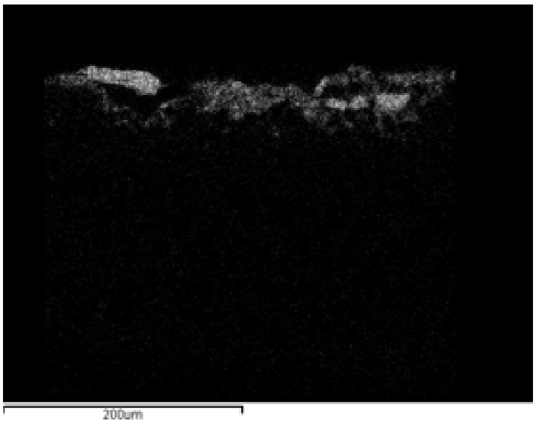
b) Fe



c) Si



d) Mg



e) Al

The elemental composition clearly indicates that the white preparation layer is mainly constituted of calcite ($CaCO_3$) with the contemporary presence of Mg (probably a magnesite component) and traces of Si and Al. This white layer seems to have been applied at three different times. The yellow/orange paint layer is composed of Fe, which can be associated with the presence of an iron oxide. Figure a) shows how Ca is also present within the paint layer, acting as a binding medium. The brown external layer seems to be constituted of clay material (Si, Mg and Al) with the contemporary presence of Ca, which may belong to re-crystallized calcite.

2.7.5. Optical and Scanning Electron Microscopy (ESEM)

SAMPLE YT3

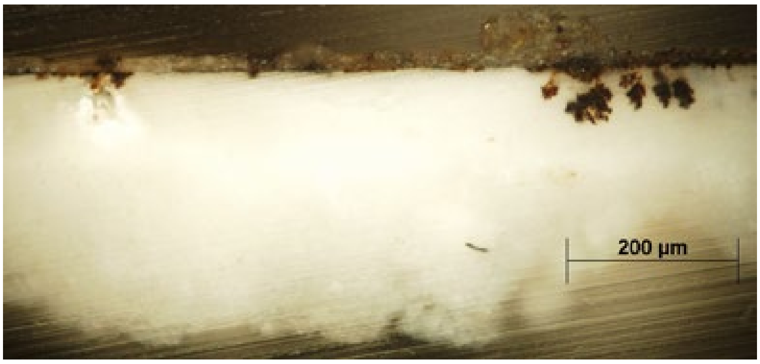


Fig. 181: Optical microphotograph

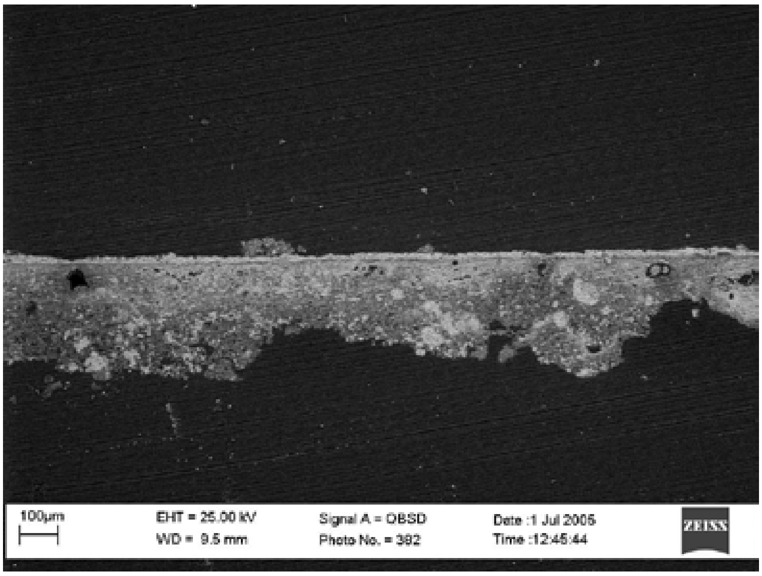


Fig. 182: ESEM-BSE microphotograph

Comments

A white preparation layer can be observed with a very thin (~5 µm) black paint layer on the top. The latter follows the asperities of the above-mentioned white layer and, in some instances, penetrates into the white layer underneath and shows a characteristic tree-leaf shape (see right and left side of the picture).

Brown deposits are visible on the external surface.

Observation of the sample in back-scattered electrons indicates the presence of heavier chemical elements in connection with the black paint layer.

The picture does not show any sub-division of the white preparation layer, as observed in the figures above (it may depend on the sample collection depth).

2.7.6. ESEM – Energy Dispersive X-Ray Analysis (EDS)

Sample YT3

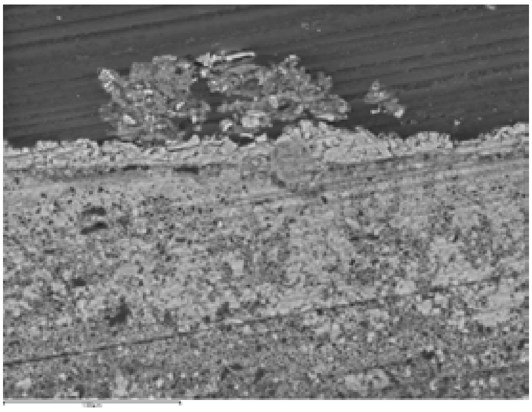
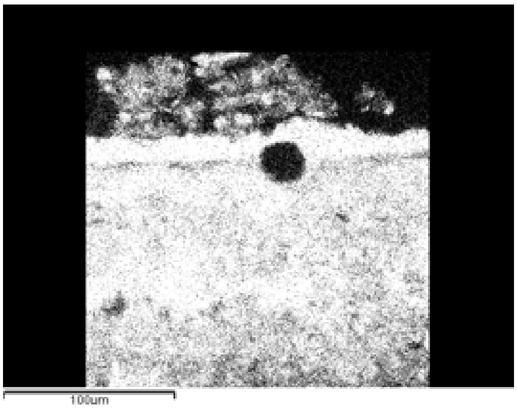
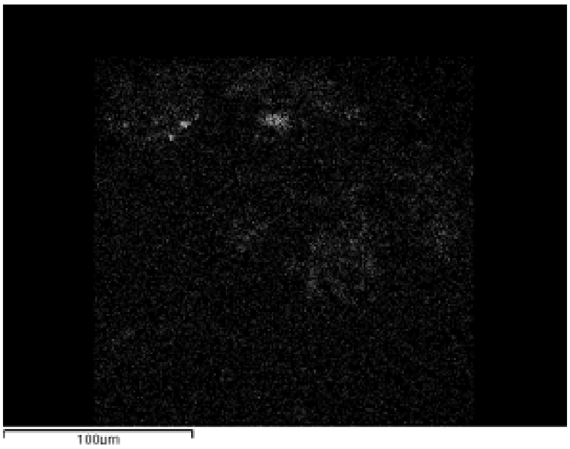


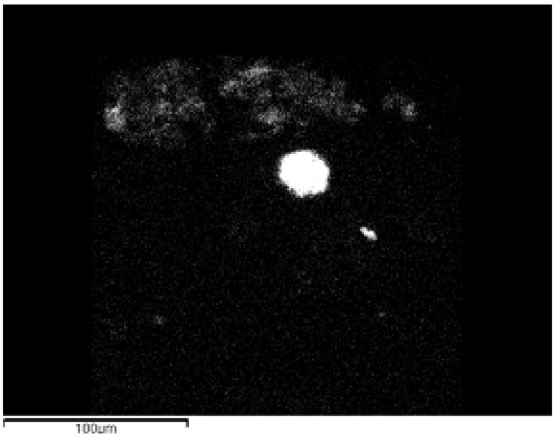
Fig. 183: ESEM-BSE microphotograph showing the area where the elemental mapping was performed.



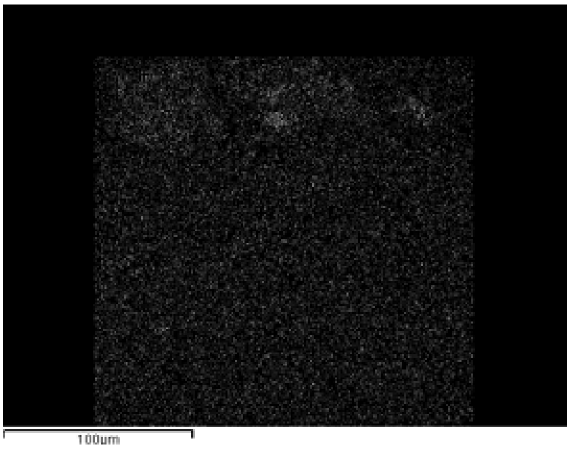
a) Ca



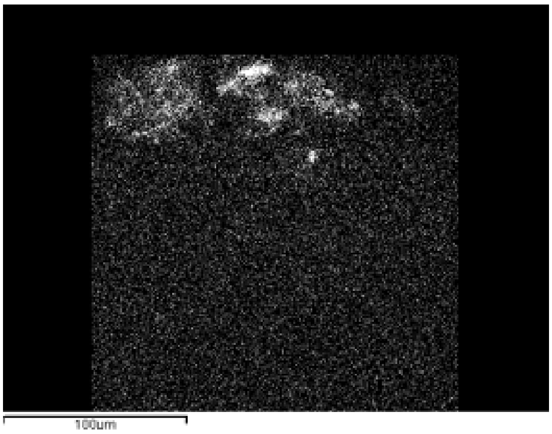
b) Fe



c) Si



d) Mg



e) Al

The elemental composition clearly indicates that the white preparation layer is mainly constituted of calcite ($CaCO_3$) with the contemporary presence of Mg (probably a magnesite component) and traces of Si and Al. The very thin black paint layer (Figure b) contains Fe, which is also present, with a characteristic tree-leaf shape, within the calcite layer underneath. Its presence could be associated with an iron gall ink. Figure a) shows how Ca is also present within the paint layer, acting as a binding medium. The brown external layer seems to be constituted of clay material (Si, Mg and Al) with the contemporary presence of Ca, which may belong to re-crystallized calcite. Figure c) shows an area with a high concentration of Si, which can be associated with the presence of a rounded quartz (SiO_2) inclusion.

2.7.7. Conclusions

The type of brown and yellow/orange pigments used, both constituted of iron oxides (probably brown and yellow ochre), and the contemporary presence of calcite within both the paint and preparation layers indicate that most probably a fresco technique was used for the execution of the Yaksu-ri mural paintings.

This conclusion is reinforced by the negative results obtained for the presence of organic substances, these having been performed with the use of pyrolysis – gas chromatography – mass spectrometry (Py –GC- MS) analysis of the paint samples.

The use of an iron gall ink to paint the black areas (sample YT3) needs to be confirmed. In any case, it seems that these areas were not applied with a fresco technique as visual observation carried out during the survey showed how these black colours had been leached by the high humidity present within the Tomb. Furthermore, the presence of iron within the white preparation layer seemed to indicate that the black colour was applied when the calcite layer was still damp (or during its carbonation phase).

It is worth mentioning that the ESEM-BSE images of the samples YT1 and YT2 showed that the white preparation layer was subdivided into *intonaco*[12] and *intonachino*[13].

A hypothesis that deserves further investigations is the possibility that these double or triple calcite layers may represent the vertical joints[14] between two different *pontate*[15].

12 *Intonaco*: medium grain lime-based render applied after the *arriccio* has dried. Proportions: 1:2 or 2:3.

13 *Intonachino*: final thin lime-based render applied over the *intonaco* on which fresco painting is executed.

14 Vertical joints: the vertical end of a plastered area overlapped by a subsequent one.

15 *Pontata(e)*: render horizontal joints that usually follow the scaffolding height.

2.8. Susan-Ri Tomb: Analytical Results of the Paint Samples

The list of the analyzed samples is shown in Tab. 5. Fig. 184 shows the location where the samples were collected.

Tab. 5: Susan-ri Tomb: list of analyzed samples

Tomb	Sample	Colour	Location
SUSAN-RI	ST1	Green/blue	South wall, west side, from the upper friezes
	ST2	Red	SEE ANNEX 12

Fig. 184: Susan-ri Tomb, south wall, west side, upper friezes. The black arrow indicates the collection place of sample ST1

2.8.1. Optical and Scanning Electron Microscopy (ESEM)

SAMPLE ST1

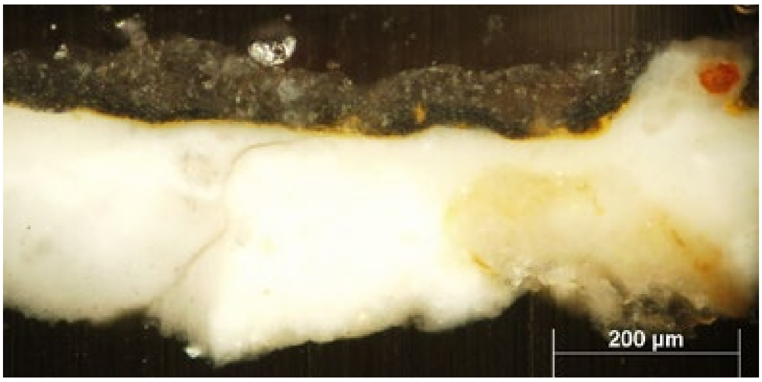


Fig. 185: Optical microphotograph

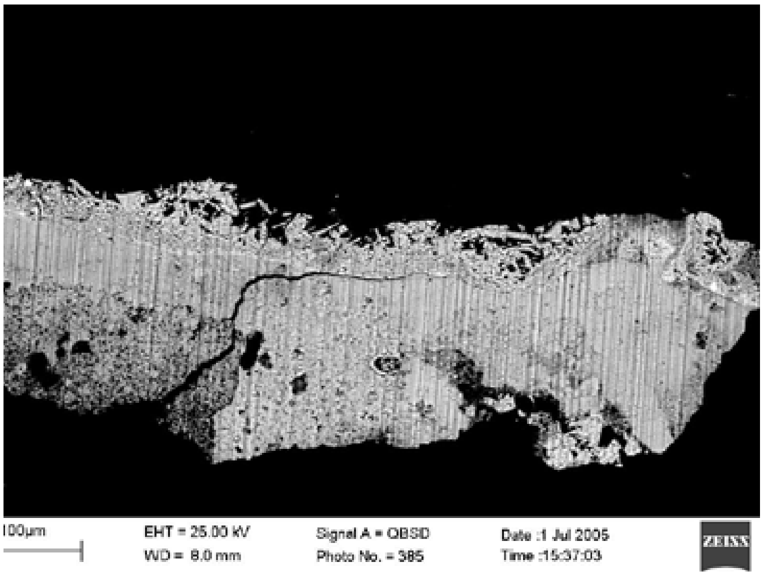


Fig. 186: ESEM-BSE microphotograph

Comments

A white preparation layer can be observed with a thin (~5 µm) yellow paint layer on top.

Over the yellow layer a discontinuous dark green/black layer is present.

Brown deposits are visible on the external surface.

On the right side of the picture a rounded red particle (hematite as confirmed by the micro-analysis investigations) is visibly embedded into the white preparation layer.

Observation of the sample in back-scattered electrons indicates the presence of heavier chemical elements in connection with the yellow paint layer.

The picture shows the presence of a crack within the white preparation layer.

2.8.2. ESEM – Energy Dispersive X-Ray Analysis (EDS)

Sample ST1

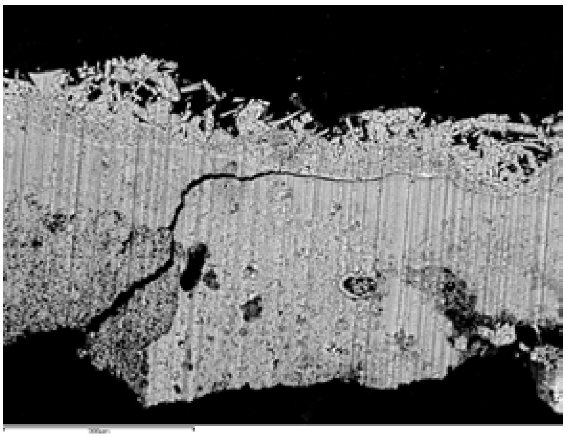
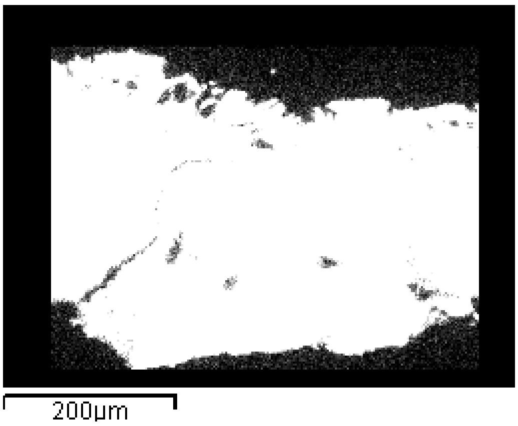
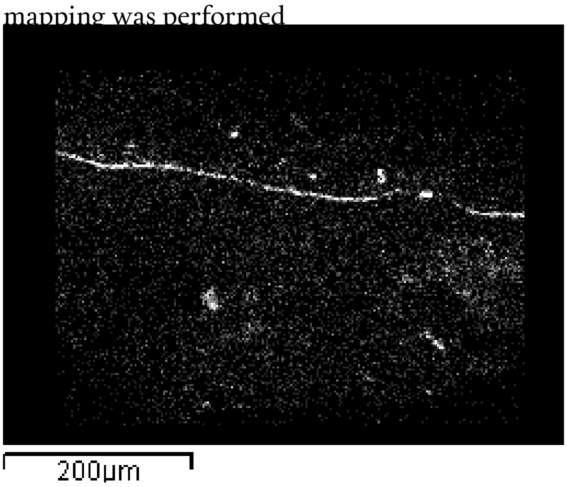


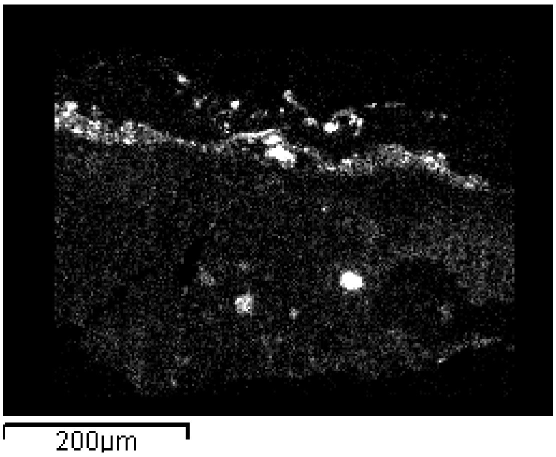
Fig. 187: ESEM-BSE microphotograph.
The picture indicates the site where elemental mapping was performed



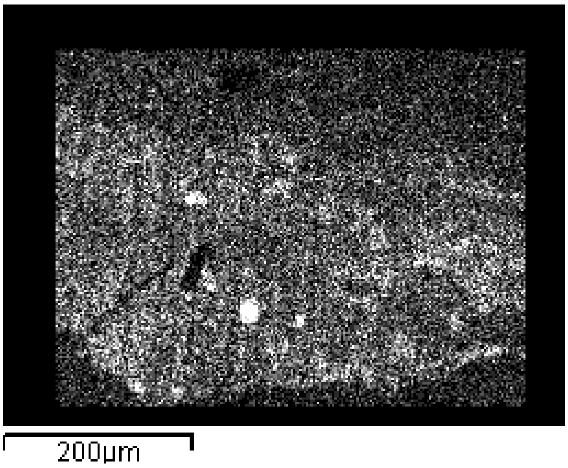
a) Calcium (Ca)



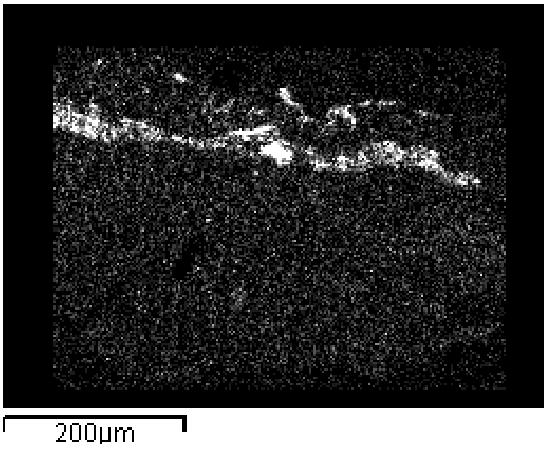
b) Iron (Fe)



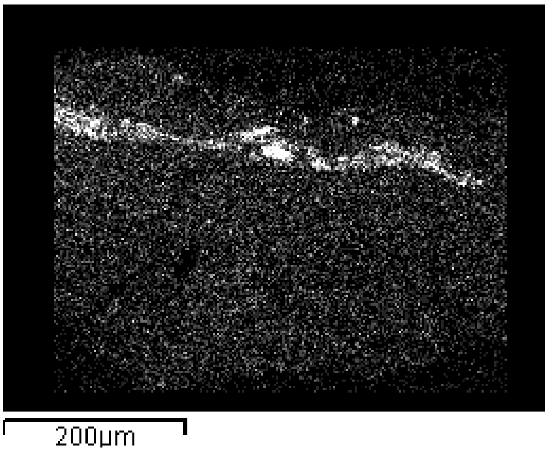
c) Silicon (Si)



d) Magnesium (Mg)



e) Aluminium (Al)



f) Potassium (K)

The elemental composition clearly indicates that the white preparation layer is mainly constituted of calcite ($CaCO_3$) with the contemporary presence of Mg (probably a magnesite component), Si (rounded quartz particles) and Al. The yellow paint layer is composed of Fe, which can be associated with the presence of an iron oxide (goethite). Figure a) shows how Ca is also present within both the yellow and dark green/black paint layers, acting as a binding medium. The latter turned out to be constituted of Fe (b), K (f), Al (e) and Si (c), which could be consistent with the composition of green earth (Fe, Mg, Al, K hydrosilicate). The brown external layer seems to be constituted of clay material (Si, Mg and Al) with the contemporary presence of Ca, which may belong to the presence of re-crystallized calcite.

2.8.3. Conclusions

The analysis of just one sample cannot be sufficient to draw final conclusions on the painting technique used, but these results are very close to those obtained from both the Tokun-ri and Yasksu-ri Tombs, which tests indicated were painted using a 'fresco technique.'

This conclusion is reinforced by the negative results obtained for the presence of organic substances, these having been performed with the use of pyrolysis – gas chromatography – mass spectrometry (Py –GC- MS) analysis of the paint samples.

Execution Techniques of the Mural Paintings in the Susan-ri Tomb

by Rodolfo Luján Lunsford

The Koguryo mural paintings appear at first glimpse as having been executed *a fresco*. Historical examples of this technique in the Far East have not been identified to date, but it is not excluded that the ancient inhabitants of Korea were familiar with this technique.[1] Certainly, the invention of the procedure was a consequence of the extensive knowledge that the ancient population had of the technology of lime. The use of lime-based renders for rendering the internal walls of tombs was employed, some of which were decorated with paintings depicting geometrical and floral patterns, the guardian deities, daily life, etc. The discovery of fresco as a technique, probably at an earlier stage, might have been accidental and perfected by further experience. Nevertheless, the marks found on the surface of the painted renders, detected under raking light, demonstrate that the renders were 'setting' or drying as the execution of painting proceeded and pigments distempered in water were applied onto the fresh render.[1]

1. The Construction of the Susan-ri Tomb

The Tomb was constructed semi-underground, slightly below the ground level, in a natural basin formed on the side of a sloping hill of which a portion was cut out on the north side to host the construction, namely the width of the walls and a portion of the burial chamber. The sloping southern side was piled up with stones from the lower section to level the ground and reinforcing stones were then laid on top to form a platform.2 Normally, large footing rocks were laid on this base in order to bear the weight of the Tomb structure so no sliding towards the valley would occur.[2] The Tomb was constructed in masonry of roughly dressed granite blocks bound with a mud-based mortar. The joints of the stone blocks were pointed on the interior with a greyish lime-based mortar (made of clay, slaked lime putty, sand, with possibly ash as an additive), and a whitish

1 The results of the analyses carried out hitherto on samples of painting taken from Tombs dating to the Koguryo era have been negative with regard to organic materials or their derivatives or by-products as a result of reaction with lime and humidity.

2 Evidence of this platform was found on the east and west sides of the Tomb during the excavation of a trench for water collection around the mound in 2009.

lime-based roughing-on or rendering layer (made of slaked lime putty, chopped rice straw and sand) was also applied in order to even out surface irregularities. The vaulting of the burial chamber is composed of three tiers of corbelling surmounted by a lanternendecke structure. The ceilings of the access corridor (dromos) and the entrance passage are flat and are made of monolithic granite slabs. The pavement in the entrance passage and in the burial chamber is now made of weathered granite gneiss,3 while the flooring of the dromos is in concrete linked to the u-shaped buffering corridor. The Tomb was covered by a turf mound4 and the entrance was sealed after the burial of the owner.

The interior of the Tomb was completely plastered with lime-based renders that according to tradition were made of lime, chopped rice straw, crushed limestone and sand. The paint layer was applied on the polished/compressed renders by firstly spreading a lime-wash coating that rendered the surface smooth and white. The lime-wash forms the background to the depictions. The division of the architectural ensemble and the scenes was then carried out and the preparatory drawing sketched. The final stage comprised the final drawing, the application of paint superimposing one colour on another where necessary, and the drawing of the final outlines.

2. Painting Technique in the Susan-ri Tomb

The renders applied to the walls in the Susan-ri Tomb were mainly constituted by lime and chopped straw (of which the imprint can be noticed) with minor amounts of sand and crushed limestone. Probably a brownish type of clay mineral was incorporated into the mixture as an additive.3 The lime employed as a binder for the renders was obtained from calcareous rocks containing magnesite and dolomite[4] and/or from shells (sea-shells) that form aragonite. The latter was at the time employed as a paint spread onto the renders as the background before painting. The renders in the Tomb also contain shell-lime, the first case thus far found in which aragonite was included in a render mixture.[5] However, fragments of limestone with rounded edges were discovered near the Tomb,[5] and one of these had a fragment of charcoal attached. The rounded shape of these fragments is due to a baking process in a kiln in which limestone is transformed into quicklime (calcium oxide) resulting in friable lumps employed for preparing lime putty when mixed with water.[6] Therefore, the possibility cannot be excluded that the limestone was processed on site, even though remains of kilns near the Tomb have not yet been found.

3 The traditional Koguryo flooring inside the Tombs was made by alternate layers of limestone and charcoal. This helped to reduced humidity in the interior. 'Over the terrain a layer of stones was laid covered with a layer of charcoal then a layer of large pebbles that was covered with charcoal then small pebbles and finally a layer of lime-based plaster of about 2-3 cm thick' (Ju).

4 'The conventional way of building the mound over the Tomb was to pile up stones over the burial chamber, then layers of clay, charcoal or slaked lime and lastly earth were put one upon another and then the top layer was covered with turf' (Ju). The layer(s) of clay and charcoal waterproofed the mound.

5 Found in the excavation soil while digging a trench for water collection around the mound in 2009.

6 These fragments might not transform completely into quicklime, so probably they were discarded leftovers of the Koguryo workers.

Kaolin and illite, two types of clay,[7] have been detected in the lime-wash coating on the renders of the Susan-ri Tomb.[6] The addition of clay into the renders made their spreading and polishing easier, trapping humidity and therefore increasing workability. The reason for adding chopped straw to a render, reminiscent of the Central Asian custom of adding it to mud-based renders in order to form a skeleton providing additional support, was technically employed with lime in order to maintain an elevated humidity content in the render for a long time that would ensure that the carbonatation process through the entire thickness of the render took place. Similarly, as per the Byzantine painting tradition in which chopped straw was added as the main aggregate with little sand content, the lime-based renders provided the possibility of continuing to paint a fresco for a longer time before they completely set. The number of preparatory layers in the Susan-ri Tomb varies from one to three, and the thickness can be from a few (3-4) millimetres up to 4-5 centimetres. These layers were applied in successive coatings, compressed and polished.

The above-mentioned typology of renders, also found in the Yaksu-ri and Tokhung-ri Tombs, is not applicable to all of the Koguryo Tombs. For example, the Jinpari Tomb N° 1 contains one thick layer of yellowish clay (as a first preparatory layer) and a final thin layer of lime-based render. The Anak Tomb III was built employing carved calcarenite and the Sammyo-ri group of tombs, namely Kangso I and Kangso II, were constructed with finely dressed granite slabs that made it unnecessary to plaster the surfaces for levelling and then painting. Only a lime-wash was applied to the surface before painting.[8]

The paint layer is normally constituted by colours spread onto a lime-wash coating on the final preparatory layer since the fresh render was dyed yellow due to the tannin contained in the straw. The Koguryo painters needed a white background on which to apply the brilliant colours of their limited palette, though the colouristic results are very effective. The pigments analyzed so far, especially in the Tokhung-ri Tomb,[7] were regularly employed in the other Koguryo Tombs and are all appropriate for *a fresco* painting. The pigments employed in the Susan-ri Tomb were white, made of aragonite,[8] black of carbon black, yellow of yellow ochre and three types of red – vermilion, haematite and red ochre.[9]

A variety of mineral pigments, including those that are copper-based[9] or lead-based, are not recommended for *a fresco* painting because they can alter when in contact with an alkaline or very humid environment, e.g. fresh lime, and as a result they are employed mainly in *secco* painting. Minium[10] and white led oxide were found on a fragment of wall painting that was detached from the wall, perhaps a result of restoration.[10]

7 Illite was without doubt a material employed during a former intervention, but this is not to exclude the use of kaolin as an additive for the lime-wash. The ancient Roman painting technique incorporated clay-based pigments such as boles, similar to kaolin, in the final coloured layer allowing the possibility of polishing.

8 The technique of painting *fresco* on a fresh lime-wash on top of a stone slab was replicated by Han Yong Chol and Sin Jae Bok in September 2006.

9 'Copper colours may be changed into copper sulphide by prolonged exposure to moisture and sulphur dioxide producing black stains' (Mora, 66).

10 Artificial pigment, red lead oxide.

Vermilion is found in nature as the mineral cinnabar, which on the whole is a permanent pigment but darkens on exposure to sunlight. The change is physical, and it is produced by a metastable black modification of mercuric sulphide. It alters much more when used in tempera or watercolour painting.[11] The use of vermillion in China dates from prehistoric times, and it was employed extensively by the Romans in *fresco* painting. It is a pigment that was employed in *fresco* painting throughout history, but it is not recommended because of its instability.[12] However, in the Susan-ri Tomb the painted sections in which vermilion has been employed are in perfect condition without any dark discolouration, such as a triangular band on the north wall, the contour of the little flowers, and the lips of the personages depicted on the walls, etc.

The black pigments employed by the Koguryo painters were not only of one type, such as the carbon black found in the Susan-ri Tomb, but also included magnetite11 and bone black.13 Perhaps glue or similar was added to these pigments that were not ground to powder; in fact, the black pigment employed in the Susan-ri Tomb when observed with a magnifying lens shows very small crystals of irregular sizes whereas the other pigments employed are very fine-grained.[12] Certainly, mixing a pigment with glue and spreading it on a fresh render does not imply a *secco* technique, given that the render is still fresh and carbonatation has yet not achieved, but only a painting practice.[13] Black was mixed with other pigments to obtain different colours such as dark red, or blue – the so-called silk blue that is a mixture of black and green or black and white that produces bluish hues.[14]

The marks revealing the use of tools on fresh renders can be detected under the naked eye and raking light, but in some cases thick incrustations on the surface do not allow this type of examination. This is equally the case when identifying the plastering joints: unless these incrustations are removed, a complete diagnosis cannot be given for certain. Such a survey was carried out in a small number of Koguryo Tombs,[14] and this revealed the imprint caused by snapping a cord from the point used as a compass centre for drawing circles, as well as the rounded incisions made through a cartoon and direct incisions produced on a fresh render, the compression and polishing by a trowel and stencil transfer drawing.

A cord soaked in pigment and fastened at both ends was 'snapped' on the surface to create straight vertical and horizontal lines, as well as to mark the main lines for the architecture, for the division of scenes or for diagonal lines like those for a sloping roof. The imprint of the cord can be seen under raking light, mainly in the Tokhung-ri and Anak III Tombs,[15] but it is also found in the Susan-ri Tomb even if it is difficult to discern

11 'Magnetic iron ore, natural black oxide of iron (Fe_3O_4)' (Khan, 190).

12 The black pigment that has leached onto the surfaces in the Susan-ri Tomb differs from the one described (with irregular crystals) because the other one is very fine-grained, almost like ink, perhaps a product of restoration work that was swollen with condensation water and moved onto lower areas.

13 'The addition of glue probably served, as it does today, to give these pigments the necessary cohesion for use' (Mora, 100-101).

14 The Tombs examined so far are by order of dating: Anak III (mid IV century, 357 CE); Yaksu-ri (late IV century - early V century): Tokhung-ri (early V century, 408 CE); Susan-ri (latter half of V century); Kangso I & II (late VI century – early VII century). Therefore, they all date to a period of around 250 years.

15 There is an extremely evident snapped cord imprint on the lower section of the east wall of the ante-chamber in the Tokhung-ri Tomb and on the very thin plastering (2-3 mm thick) of the lower section of the west wall of the west chamber in Anak III.

and only where the paint layer has detached. It can be seen, for example, on the band dividing the scenes of the west wall or on the poles of the house depicted on the north wall. The colour employed to soak the very thin cord employed in this Tomb was red, and it is possible to observe the tiny splashes, caused by the snapping action, on the adjacent white-wash. In spite of this, there are also other thick red lines drawn on the bands imitating the painted wooden beams that are thick and painted with a brush and are without the characteristic imprint of the twisted cord noticeable under raking light. These might be a product of the restoration work.

The centre of circles and round elements such as stars, planets, wheels, lotus flowers, drums or gongs, etc., painted on the walls and vaults of the Tokhung-ri Tomb reveal under raking light that a point was introduced into the fresh render. There is a notable difference between a point introduced into fresh plaster and a point set onto a dry render of the same composition. The borders of the 'flow' of the plaster after the introduction of a pointed instrument appear rounded, whereas those produced on a dry render are broken and flat. The process for painting circles consisted of introducing a pointed instrument, e.g. a thin nail, into the fresh render with a string tied to it, while at the other end a brush was tied soaked with paint. An assistant might have secured the nail while the master painter drew a circle with a uniform line of the same thickness and with no evidence of incision around it.[16] The round elements, such as the lotus flowers on the upper registers and a gong painted on the east wall of the Susan-ri Tomb, were executed using the same method even though between the decorations of these tombs there was an interval of three-quarters of a century.

The painting on the east wall of the passage connecting the chambers in the Tokhung-ri Tomb shows the marks of the centres of the wheels of the bullock cart and other rounded incisions corresponding to the horns of the ox that drags the chariot and those of the cart's roof. These incisions are of special interest because the pictorial execution does not correspond to these incisions, meaning that there was a change of idea by the artist, a *pentimento*. The borders of these incisions are rounded and not sharp, as if done through a soft, malleable material, like paper.[17] Traces of preparatory drawing in thin red lines are noticeable on the wall, as they are in the other Tombs, and this consists of a drawing of the main lines, indicating the proportions of figures roughly sketched on the lime-wash that forms the background before the spreading of the paint. Here again, *pentimenti* were frequent as the execution of the painting proceeded – as can be seen on the east wall of the ante-chamber in the Yaksu-ri Tomb where one leg of a horse was at first drawn bent while the final painting made it straight.

Some of the columns painted in the Susan-ri Tomb (at the southwest and southeast corners) show a rounded incision for marking a decreasing curvature towards the abacus that supports the capital. This was done to reproduce the same shape on all eight sides even though these traces are not found on the other columns. The vertical lines were certainly done by snapping a cord, including the horizontal divisions between the abacus and capital, for example, at the northwest corner. The columns are painted red with a

16 This method was reproduced in practice.

17 The manufacture of paper was known in Korea because on the west wall of the burial chamber of that Tomb there is a scene in which a man, with two witnesses at his sides, records on paper the results of an archery contest on horseback.

scroll design in black, but it can be noticed that the render was applied on one wall and painted, e.g. the south wall, and then the next wall was plastered and painted, e.g. the west wall. The corner which corresponds to the vertical joint clearly shows the juxtaposition of one render on top of the other with a red colour spread between them.

The Tokhung-ri Tomb is the one where most evidence has been found to date. The portrait of the deceased painted[18] at the west side of the north wall in the ante-chamber is five cm higher than the one painted on the north wall in the burial chamber, but the dimensions of the head, the sizes of the details (eyes, nose, mouth, etc.) and the distances these are located at are exactly the same. Perhaps a stencil was employed to repeat the same face on two different walls because even if free-hand drawing was precisely executed some differences would have been seen. Moreover, a rounded incised line marking the contour of the body is evident under raking light on the figure of the antechamber. Similarly, in the west chamber of the Anak III Tomb, thin incisions found on the portraits of the king and queen lead one to suppose that the drawings were transferred by indirect incision through a cartoon. Other incisions and marks of the centre for circles were found on the rendered surface of the east wall of the burial chamber.

In conclusion, the marks found on the rendered surfaces of the Tombs so far examined may have been produced while painting a *fresco* because these belong exclusively to that technique and are not necessary of an a secco painting technique. Corrections can be done while painting in distemper, oil, etc., whereas the *fresco* technique cannot admit mistakes: a wrong paint stroke is always noticeable. The time span between the construction of the tombs of Anak III and the Sammyo-ri group is long, but the painting technique employed for decorating the interiors is very similar in all of the inspected Tombs. These preliminary notes are not unquestionable in relation to the painting technique the ancient Koguryo artists employed. They are merely considerations that do not exclude the *fresco* technique at a developed stage being known of in the Far East, but not like those for the techniques developed in the Mediterranean area or in Mesoamerica. These were adjusted according to different needs.

In addition, the interior of the Tombs is characterized by elevated humidity that in contact with binding organic materials, such as gums, glues, etc., would have given rise to a tremendous development of micro-organisms that would have destroyed the paint layer.[15 19] The confirmation of this is that the straw employed for producing the renders has practically disappeared, with only the imprint remaining. Therefore, the lime-washes applied on the rendered surfaces as background for the pictorial depictions formed a barrier between the organic component and the paint layer.

Research on the technique of execution of the Koguryo mural paintings is in progress, but the results so far obtained have demonstrated that no organic material has been found binding the pigments employed for painting except calcite,[20] which is calcium

18 On a lime-wash that covers another painting on the wall.

19 'Another problem related to conservation at high relative humidity levels is the growth of micro-organisms. It is most likely that if organic material was involved in the original painting technique this is not preserved anymore due to the activity of micro-organisms. On the basis of this supposition it is rather certain that the paintings are mainly constituted of mineral (inorganic) compounds' (Schmid).

20 'The results confirmed how calcium is homogeneously present in both paint and preparation layers and how there is no discontinuity between the two' (Mazzeo).

carbonate.[16] Therefore, unless the contrary is established it can be stated that the technique used for the Koguryo mural paintings executed on a lime-based render or on a lime-wash is *fresco*.

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Environment and Lighting System

by Sandro Massa

1. External environmental conditions

By examining the official environmental statistical data we can try to define the external conditions of the Tomb. The average change in temperature throughout the year is well defined in the following graph that shows trends, with the average, maximum and minimum of temperature.

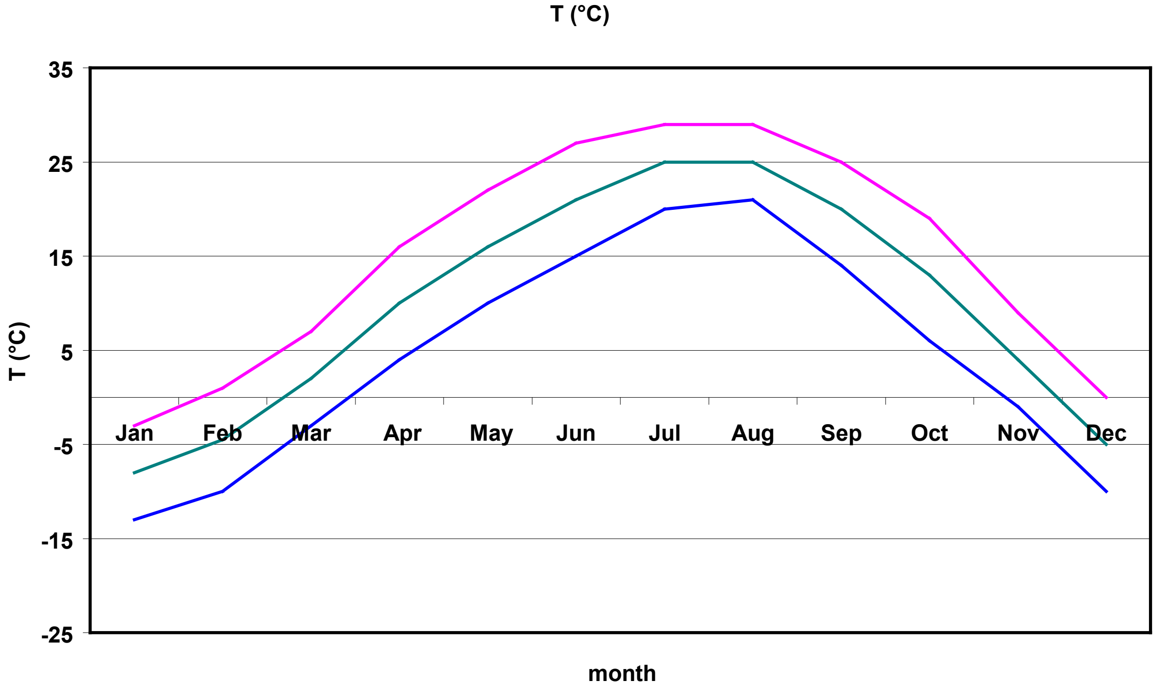


Fig. 190: Trends: temperature

The evolution of relative humidity was within the values shown in the figure below:

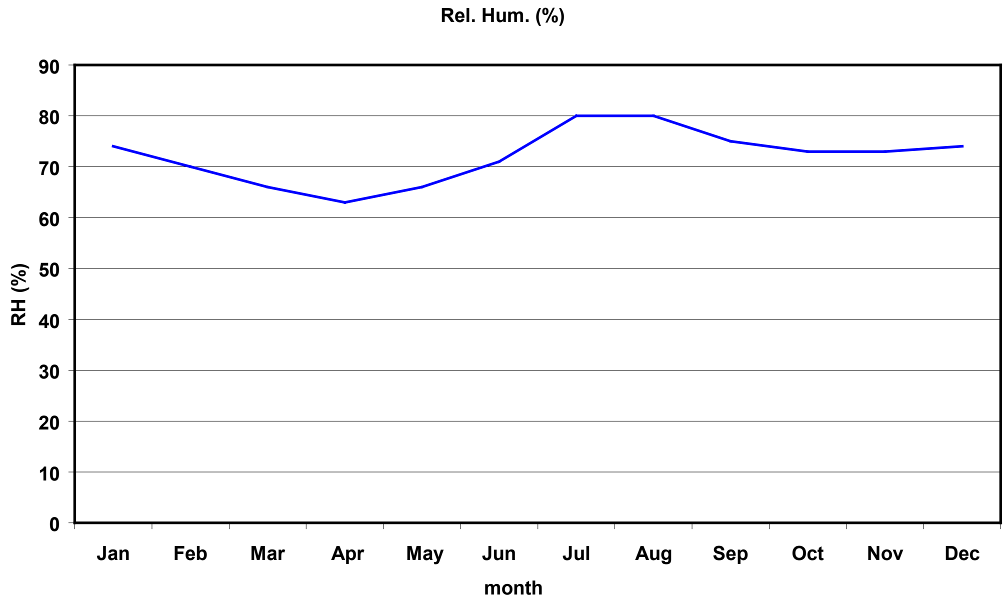


Fig. 191: Trends: relative humidity

From the above data we can derive the value of specific humidity using the following formula:

Sh=100(0,0063+0,038(Ur/100)(1,0618(Ur/100)^0,0073)^Ta [1]

Where: Sh = Specific Humidity (g/kg)
Ur= Relative Humidity (%)
Ta= Air temperature (°C)

The following illustration shows the trends of specific humidity thus collected:

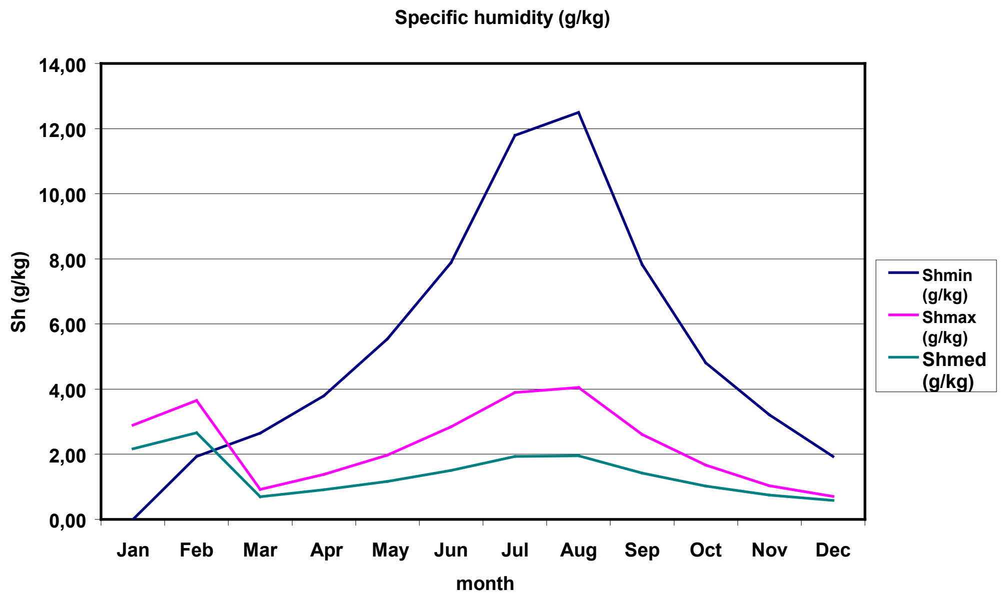


Fig. 192: Trends: specific humidity

From official statistics it was also possible to have indications of rain and sunshine. The following is the trend of rainfall:

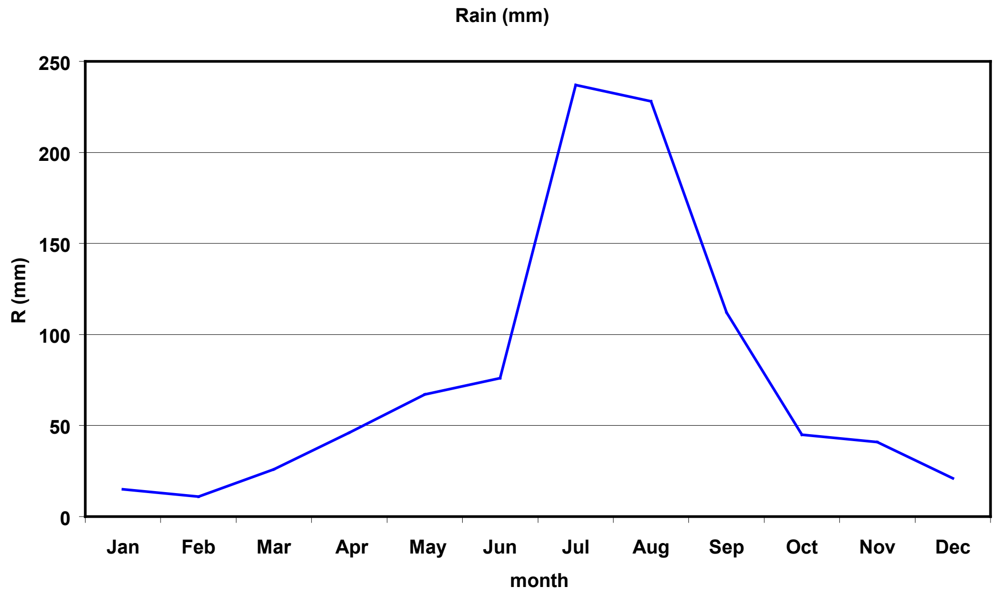


Fig. 193: Trend: rain

And the hours of daylight:

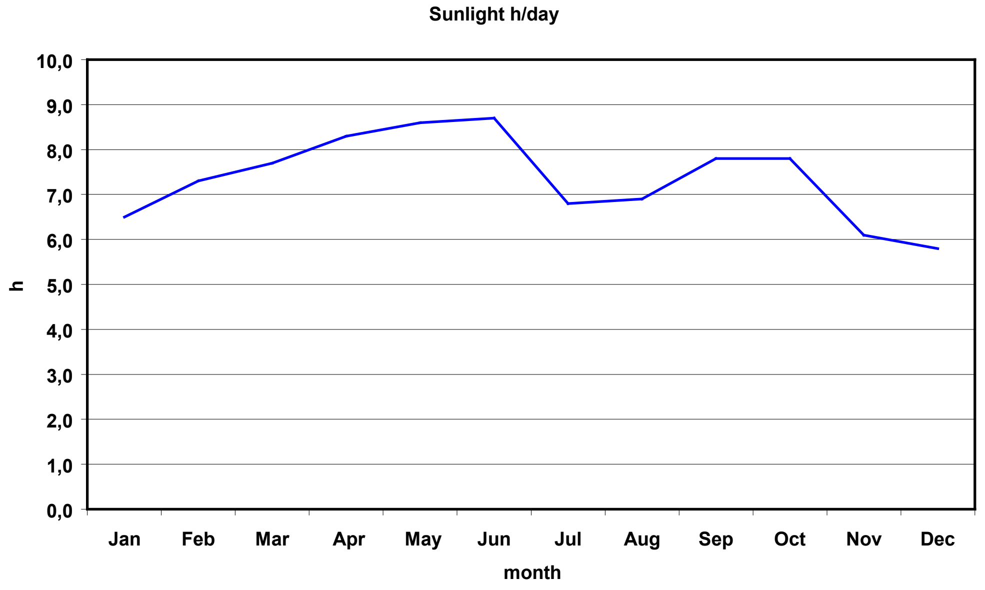


Fig. 194: Trend: sunshine hours

2. Considerations on the external weather

As can be appreciated from the graphs, the temperature in winter drops about 10 degrees (°C) below zero, and consequently there is the possibility of snow and frost, whereas in summer there is abundant rain and consequently a reduction of daylight due to the presence of clouds. Also note the high variability of the specific humidity that increases in summer due to heavy rains. This climatic situation results in a slight increase of relative humidity in summer even if it remains at 75% as average.

3. The environmental conditions inside the Tomb

The environmental conditions inside the Tomb are determined by the flux of heat that arrives from the ground and walls, by the air flux that passes through the door, by the percolation of water, by the evaporation from the walls and the condensation that could occur in some parts of the Tomb, and by the flux of visitors.

4. Heat transmission through the soil by radiation and thermal conduction

During the annual cycles of the seasons, there is a different heat transfer inside the Tomb. In summer, the heat flow will go into the Tomb, whereas in winter it will go out of it.

The sun's heat is transferred initially by radiation to the surface of the Tomb mound, and then by the flux of heat through the soil before arriving into the Tomb. The heat that flows through the layers of the mound above the Tomb is delayed. This delay is increased by the thickness of the layer. The heat-flow that passes through the layers of soil that reaches the interior of the Tomb is delayed due to the thickness and the composition of these layers (e.g. the mound) above it; the thicker the layer of soil is, the longer time is needed to reach the interior. Therefore, a maximum of temperature inside the Tomb should be reached around September/October. In addition to this delay, attenuation is manifested by the thickness of the soil and its nature, so the amplitude of the thermal oscillation gradually decreases. In fact, the thermal excursion temperature inside the Tomb is normally very small. The following graph illustrates the phenomenon. [2]

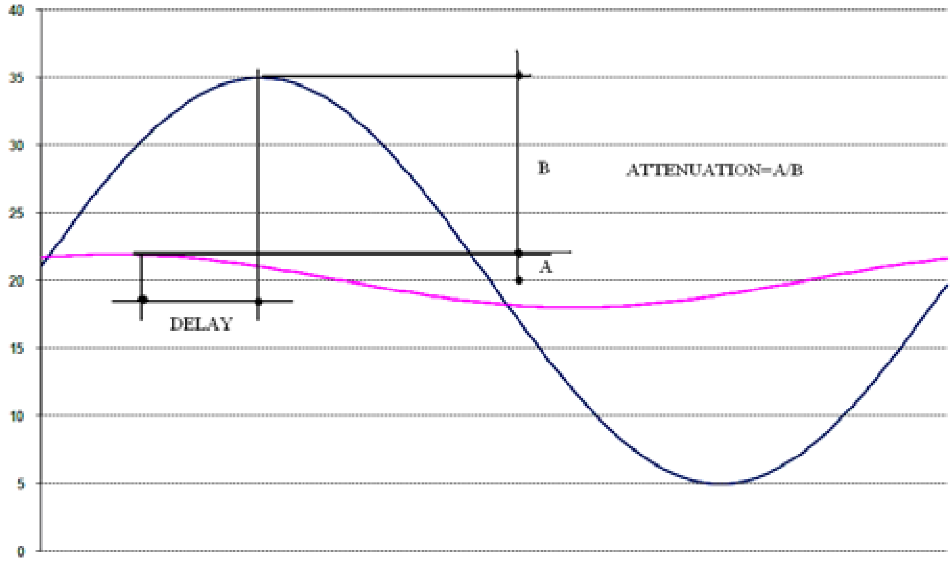


Fig. 195: Annual heat wave attenuation and delay

The fluctuations of temperature taken into account are obviously those related to the year. The daily one influences only a few centimetres of the Tomb's surface.

5. Heat transfer inside-outside by convection

The convection is linked to air exchange between the exterior and the interior of the Tomb through the corridors. The quantity of these exchanges is related to the difference of partial pressure between both environments, with the tendency for these to level. In summer, heat will be incoming and in winter outgoing. The environmental variation that can be produced in the Tomb is also related to the corridor's curves and to the time of opening the doors. Therefore, the values of temperature and the specific humidity content in the Tomb will tend to level with the exterior value.

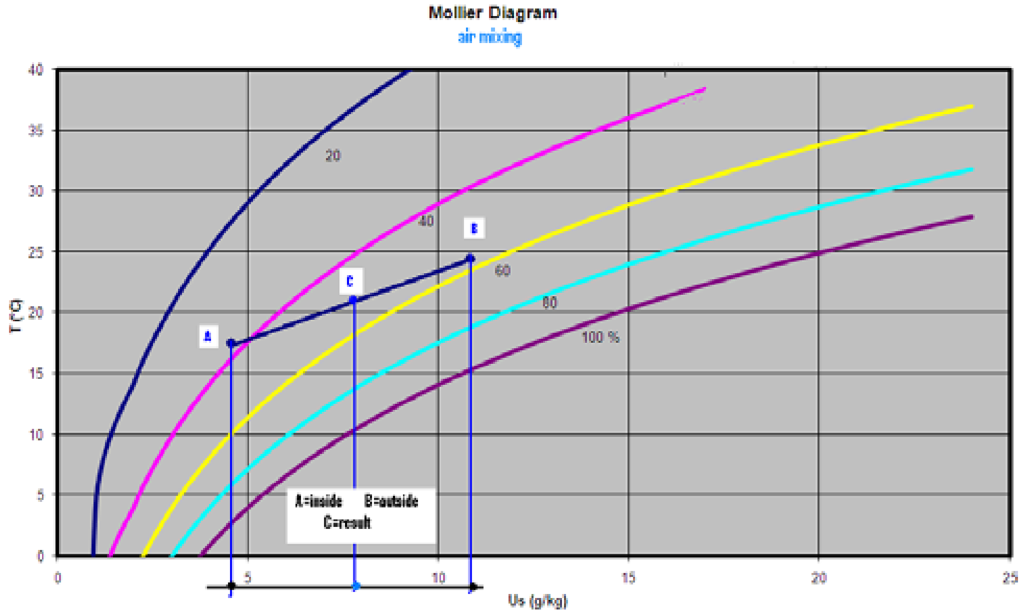


Fig. 196: Mixing of air (Mollier diagram)

6. Percolation and internal environmental conditions

As was noticed, in summer there are heavy rains, and this generates a flux of water that penetrates through the ground until it reaches the Tomb. The phenomenon is related to the type of soil and the thickness that the water passes through. Once water reaches the surface of the Tomb's walls, it will tend to evaporate if the relative humidity is less than 100%; otherwise, it will be visible in the form of water droplets on the fresco surfaces. Due to water percolation, as well as the rise of moisture from the soil, the relative humidity inside the Tomb will certainly be in a state of saturation.

In the following figure, the effects of increasing specific humidity and relative humidity due to water evaporation coming from above and from soil permeation can be seen.

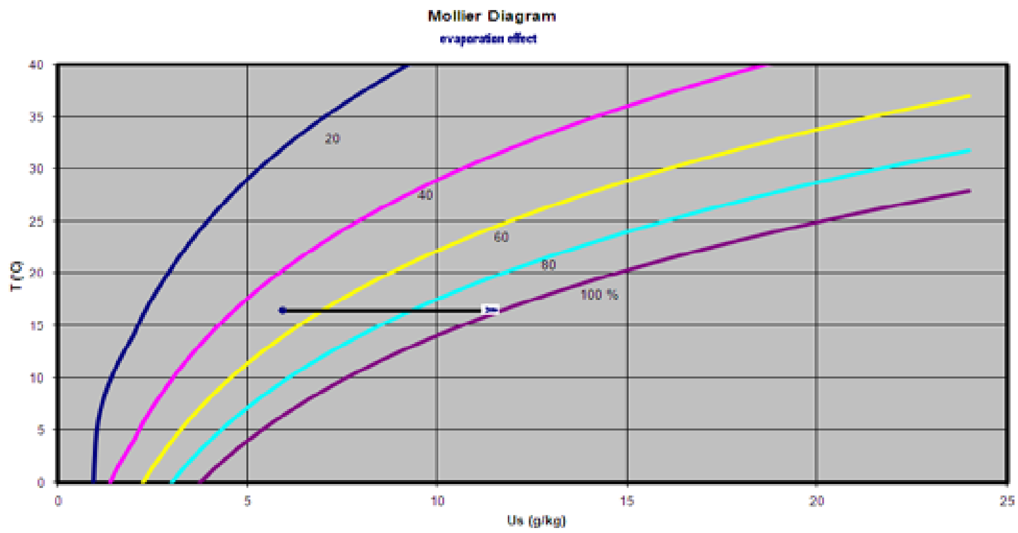


Fig. 197: Evaporation effect (Mollier Diagram)

7. Closed environment and conservation

The environmental degradation is linked to the fluxes of matter and energy that occur between the materials and the environment. These exchanges are of two types:

- Exchange of matter as evaporation, condensation, diffusion, etc., on the materials' surfaces;
- Exchanges of energy, significantly related to heat transfer, without underestimating other phenomena such as those that generate electrical corrosion in metals.

Materials at every change of external environmental conditions react by trying to resist these. This is often the main cause of degradation. So, a system in which there are continuous changes of environmental conditions is less conservative than one where these remain stable. This is the case even if these conditions are not the usual ones under which those materials were supposed to be exposed and the conditions under which those materials have adapted over time must be maintained to ensure their preservation.

A theoretical approach that describes the probability of deterioration caused by the fluxes exchanged with the environment is to evaluate the increase of entropy and may be described in a simplified way as follows: [3]

$H=\sum e^*i$

Where: H=entropy
e= extensive physical quantity flux (mass, volume, etc.)
i= intensive physical quantity flux (temperature, pressure, etc.)

The systems could be classified in:

- isolated systems: where no exchange of energy and mass are admitted;
- closed systems: where only the exchange of energy is possible, but is limited;
- open systems: which allow both types of exchange and that is the least conservative.

In order to realize an isolated system, as in the case of the Susan-ri Tomb, this would mean preventing the access of visitors and to reduce the exchanges of energy. This is possible with a transparent window between the two, made of suitable insulation, that reduces thermal heat transfer as shown below.

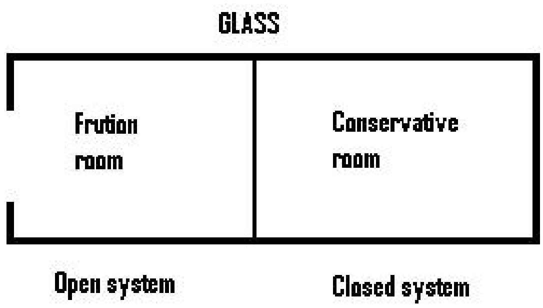


Fig. 198: Environment separation: fruition - conservation

8. Monitoring points inside the Susan-ri Tomb

The burial chamber in the Susan-ri Tomb at present contains a glass barrier that does not perfectly insulate the interior from the exterior. and therefore it was necessary to obtain data that would permit the realization of a new suitable buffer. The monitoring of the internal environment of the Susan-ri Tomb has required the continuous and simultaneous collection from all planned points of the real environmental values: entrance to the Tomb; near the glass structure; on the wall; on the outer side of the glass; on the inner side of the glass; and inside the glass structure.

This is shown below:

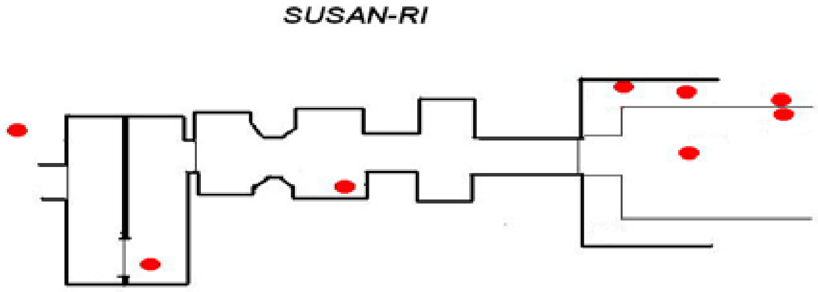


Fig. 199: Susan-ri Tomb ground plan

Data processing was complex and fragmentary due to data-acquisition difficulties in operating in a humid environment. In the following diagram, it can be seen that from June to August the average of temperature and relative humidity in the proximity of the entrance feels the effects of daily fluctuation, even though they are steady around an average point.

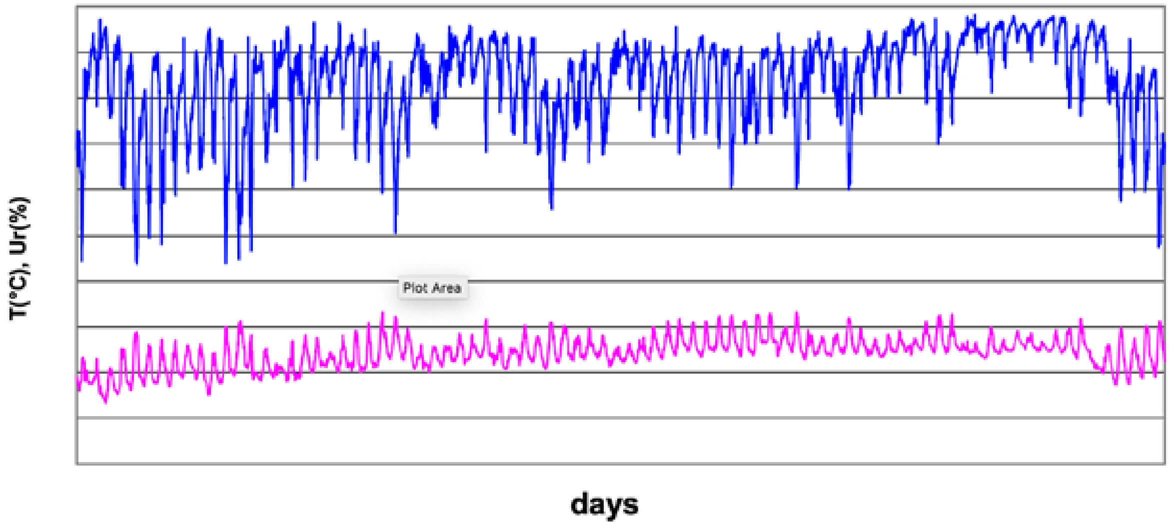


Fig. 200: Relative humidity and temperature at the entrance

In the figure below, it can be observed that temperature values inside the glass box would follow, with a certain reduction in fluctuations, the humidity value at the entrance.

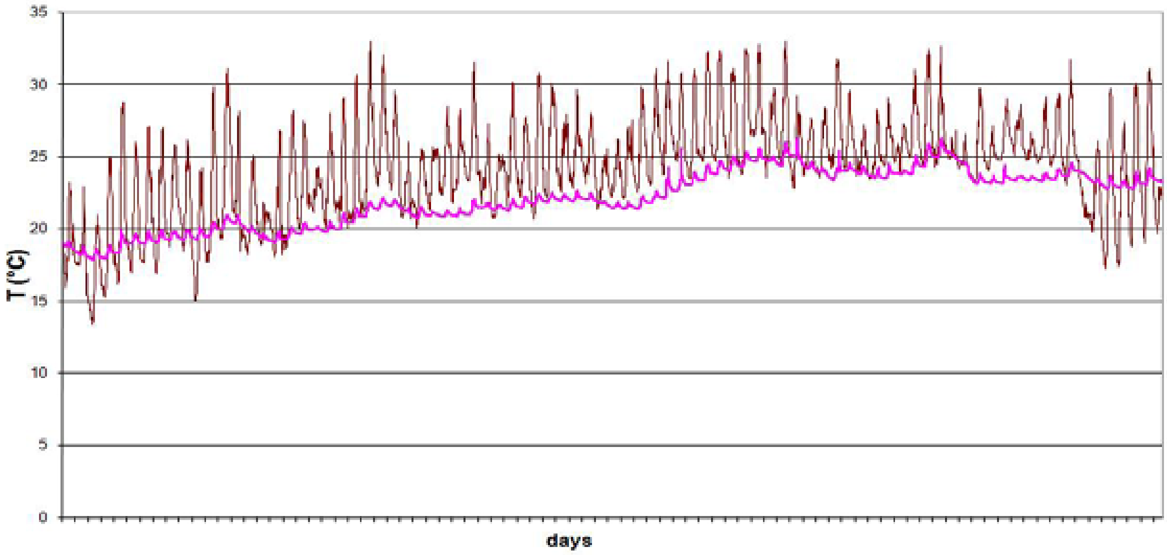


Fig. 201: Temperature variation at the corridor end

The figure below shows the relative humidity values that were measured. There is a slight reduction in relative humidity near the glass box and a corresponding decrease of its average value in comparison with the one at the Tomb's entrance.

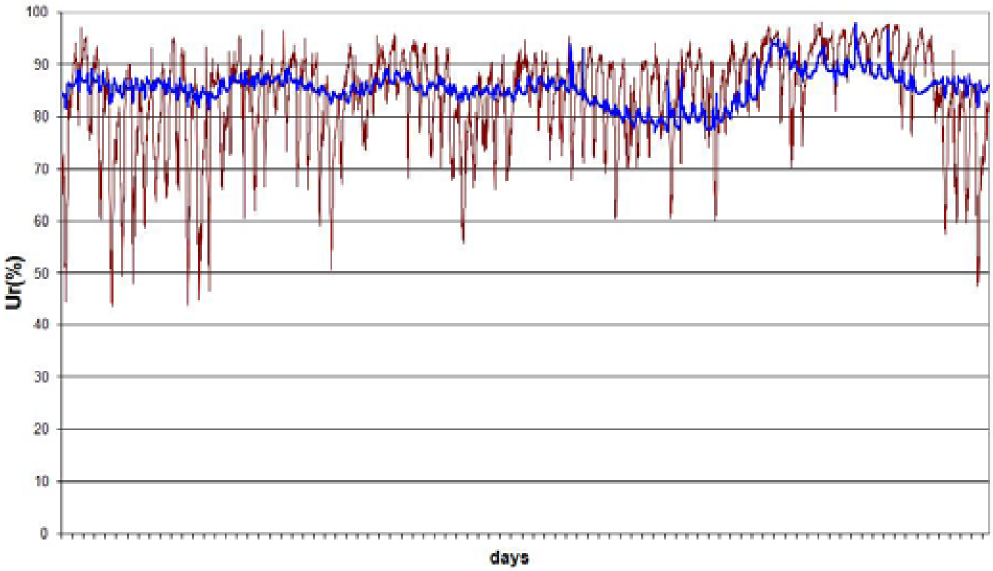


Fig. 202: Relative humidity variability at the corridor end

The humidity values inside the Tomb are almost constant and close to saturation. The temperature is kept around 20 ° C, as shown in Fig.14. The graph also shows the effect of opening the trap door of the Tomb.

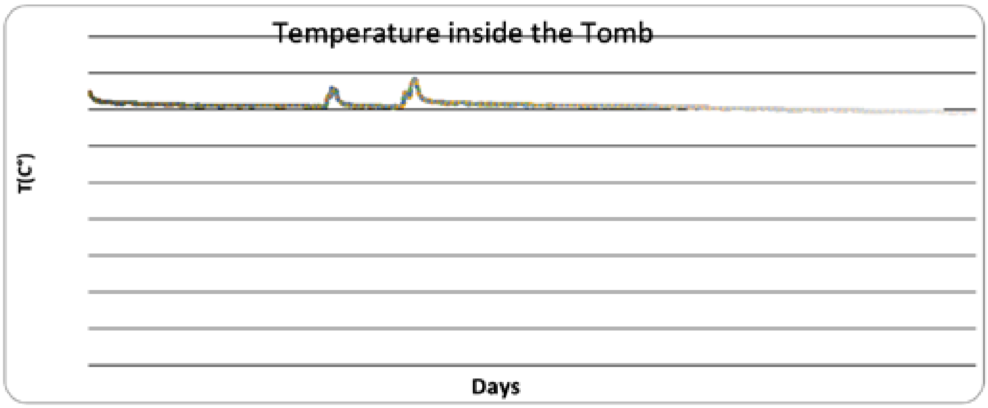


Fig. 203: Temperature inside the Tomb

Fluctuations in temperature and humidity near the Tomb are not negligible. The relative inner stability is due to the inertia of the internal structure, not to the insulation of the glass. It is necessary to maintain the temperature and humidity values near the Tomb as more stable and to have a glass box that is more insulated to reduce condensation on the glass.

9. Condensation on the walls: causes and effects

From the above, it must be considered that water condensation on the painted walls is a natural phenomenon that should not have significant adverse effects. The condensed water also ensures the reduction of bacterial growth that by gravity deposits on the unpainted floor that is made of soil. [4]

However, the permeated water passes through the layers of the flooring carrying with it soluble salts and pollutants that may create a problem on the frescoes' surfaces, because if the humidity levels drop the salts transferred with the water can re-crystallise and increase in volume producing degradation of the surfaces.

10. The transfer of heat through the glass

If a glass surface is interposed between the visitors and the painted area of the Tomb, it must be considered that heat transfer will occur from the area with the highest temperature to that with the lower temperature. In summer, the heat will tend to enter into the Tomb and in winter it will tend to get out.

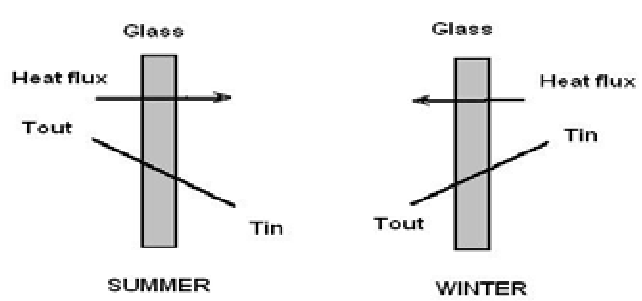


Fig. 204: Heat flow direction during the year

The heat flow is determined by the following relation: q=▯dT/s

Where: q = heat flux
▯ = thermal conductibility
dT = temperature difference between the two glass faces
s = thickness of the glass

The glass conductivity ▯ varies from 1,2 (W/m^2 K), which corresponds to normal glass, to 0.3 (W/m^2 K) for insulated glass. The flow of heat passing through the glass surface generates a thermal gradient on the glass. The higher the thermal conductivity, the greater the heat flow through the glass and the less the thermal gradient between the two sides.

It is to be noted that there is also a difference of temperature between the air and the surface of the glass. This difference in temperature is primarily related to the convection occurring on the surface of the glass and especially depends on the speed of the surrounding air. The heat transfer in this case is calculated according to q= hdT.

Where: h=convection coefficient
dT= temperature difference between the air and the glass surface

The heat flux that passes through the glass is determined by the following relation:

q= dT/(h1+h2+s/▯)

Where: q= heat flux
h1= convection (adduction) coefficient inside
h2= conv
s= glass thickness

11. Condensation on the glass

Condensation on the surface occurs when the temperature is <= the dew point value. The dew point can be calculated using the following formula:

Tr=Ta*(RH/100)^(1/8)+12,89*LN(RH/100)

Where Tr= dew point value (°C)
Ta= air temperature (°C)
RH= relative humidity (%)

The following diagram shows the phenomenon:

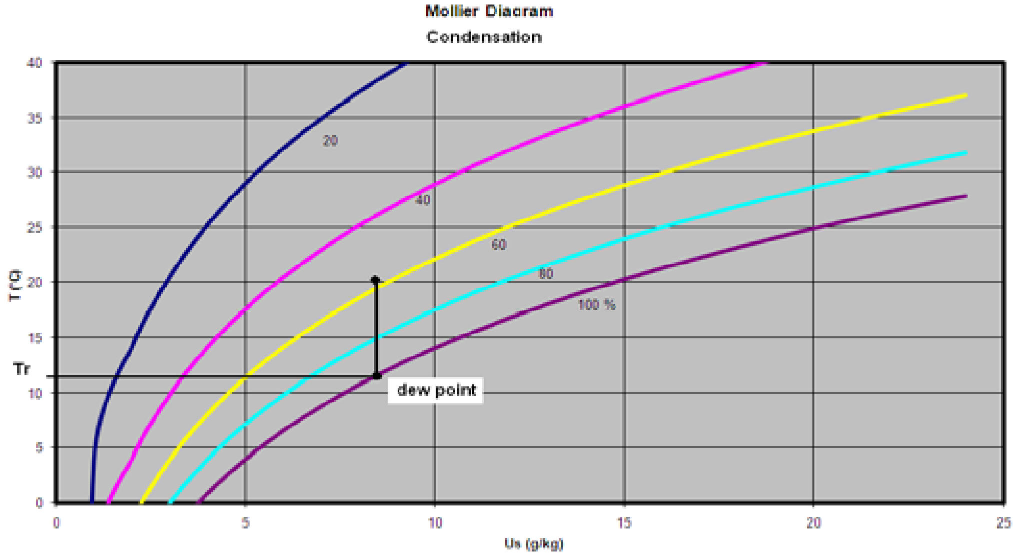


Fig. 205: Dew point temperature (Mollier diagram)

Note that condensation will manifest on the face of the glass at a higher temperature:

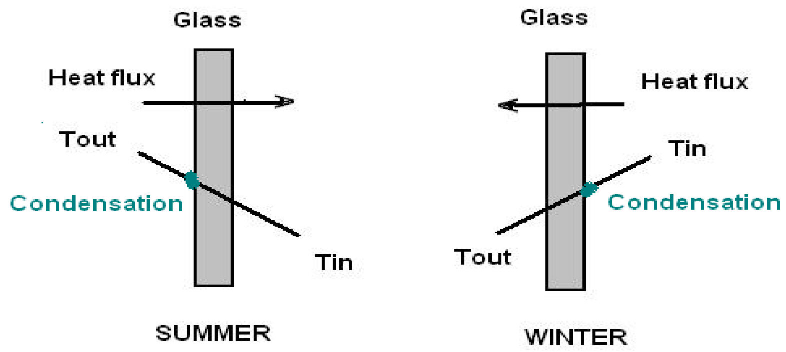


Fig. 206: Face of the glass where condensation could be formed

Consequently, as shown above, the condensation on the glass surface is certainly evident on the surface facing the Tomb during winter and could occur in summer on the other side. The term 'could occur' can be used when the environment outside the glass structure is not in saturation. In fact, the dew point temperature depends on the value of the relative humidity. A reduction in relative humidity could be ensured in order to prevent this occurrence.

The following figure shows the necessary conditions for condensation to occur. It depends on both the humidity and the temperature values present in the environment:

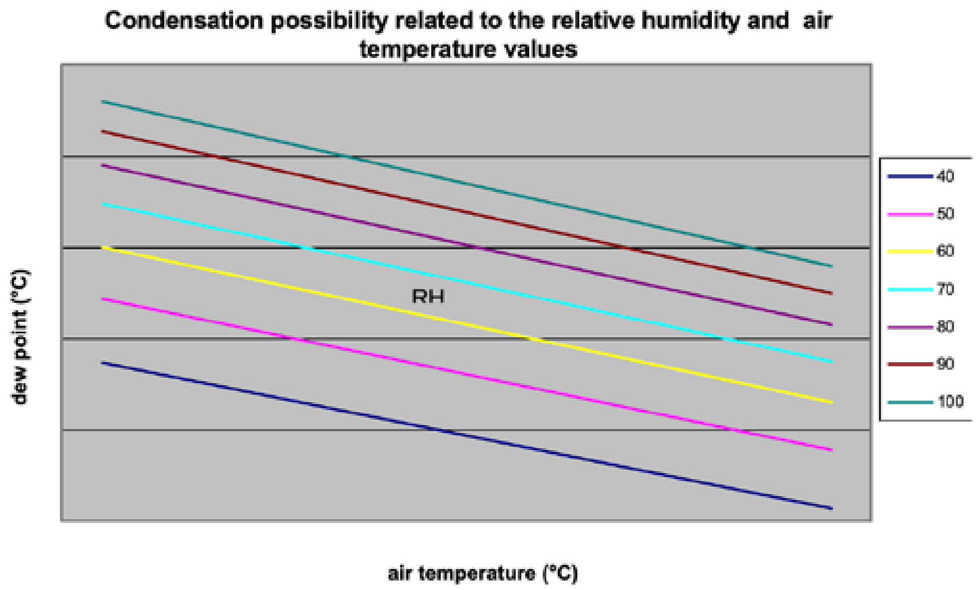


Fig. 207: Condensation possibility related to the relative humidity and air temperature values

12. When condensation on the glass occurs

The data received related to the values of the surface temperature on both sides of the glass confirms the above. The thermal gradient between the glass' faces concerns two seasonal periods, June and November, and shows that the differences (T_{out}-T_{in}) of temperature on the glass are always positive in June and negative in November.

Thus, in November, condensation occurs on the inner side of the glass, whereas in June it is not sure that condensation will occur on the outer face. Due to the time necessary for water evaporation on the glass surface, condensation on both glass faces can also occur.

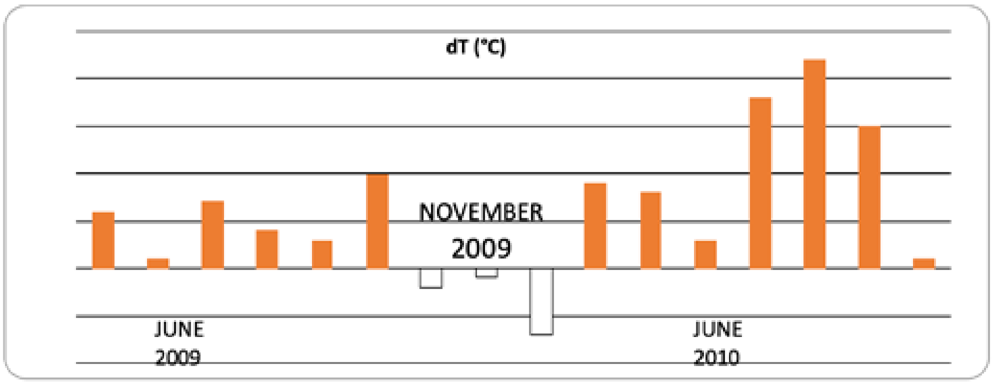


Fig. 208: Data evaluation related to glass thermal gradient

13. Systems to prevent condensation

To prevent condensation on the glass surface, it is necessary to heat the glass until the value of the surface temperature is higher than the dew point. Special manufactured glasses are necessary, with an inner wired grid in which the wires are so small that they are difficult to see.

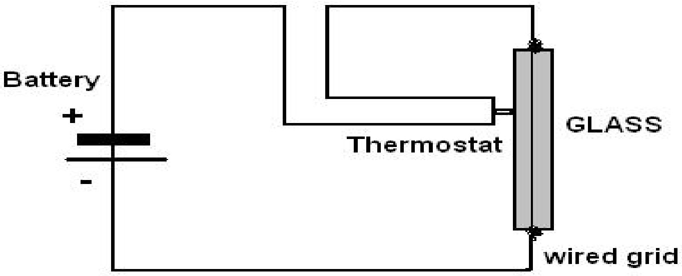


Fig. 209: Power-heated glass

To heat the 'invisible' wire grid set inside the glass the power consumption will be about 400W/m². For this reason, it is not advisable to create a very large heated glass surface, both because the electrical consumption and the alteration of the environmental conditions inside the Tomb. Consequently, it is not possible to heat the whole actual glass box but only a small area of it. The system must be equipped with a thermostat, possibly settable twice a year in order to further reduce electrical consumption.

14. Lighting of the mural paintings

The pigments contained in the paintings may be light-sensitive, so a low level of lighting must be used and the system only switched on during visits.

The lamps must be placed on the side of the visitor area and should be of low intensity. The best option is to use LED (Light Emitting Diodes) that also can be fed with a low voltage, as required for security reasons in damp environments and to perform with high efficiency. The position and the type of the LEDs should be selected appropriately in relation to the surface to be illuminated and lighting uniformity.

15. Lighting systems

In order to better use and save energy (electricity), it is necessary to evaluate two sorts of lighting: one for a guided route that should illuminate the visitor's route and the other for lighting the frescoes. In this way low levels of illumination can be directed onto the paintings. As a result of maintaining a low level of general illumination, the pupil of the eye dilates and becomes more sensitive to light.

For the guided route, a linear LED can be chosen to cover the entire corridor. There should also be a separate sensor for switching on the lighting along the route and near the burial chamber so as to increase the emotional effect.

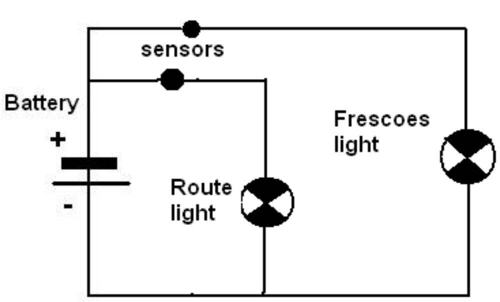


Fig. 210: Separate lighting installations

16. Considerations on the flow of visitors

The damage that can be produced to mural paintings is of double origin: thermo-hygrometric and mechanical. In the first case, the damage is due to the induced environmental variations in the Tomb that can change the present state of equilibrium. Water vapour condensation on the surfaces of the mural paintings is not necessarily interpreted as a factor of degradation, since this can manifest only in the cases of paint soluble in water. Worse is the case when evaporation occurs inside the Tomb when temperature increases and the relative humidity consequently diminishes. In this case, water evaporation is favoured and dissolved soluble salt re-crystallizes with the consequent increase in volume that can cause the splintering of the pictorial layer. This environmental alteration cannot be due to the existing considerable mass of soil above, but by air exchanges with the exterior through the corridor during the summer.

If the case is that the load of the mass of soil is excessive, inasmuch as it could cause mechanical stress to the structure, an eventual substitution must take into consideration the existing thermal inertia. Thus, the reconstruction must ensure a suitable attenuation and an appropriate displacement of the phase of the impending thermal wave, which allows seasonal alternations to reduce to the minimum the variability of the superficial temperature on the mural paintings. An alternative solution for reducing the mass of soil above without significantly altering the internal environmental conditions could be to construct a shelter above the mound, which would also eliminate water infiltration. Water penetration should be eliminated, and the humidity content in the ground should be kept constant since the percolating water transports polluting substances that can set off deterioration to all the mural surfaces.

Regarding mechanical damage to the painted surfaces, this should not subsist if visitors are watched over and are instructed to carry out their visit such that they do not come into contact, even accidentally, with any surface.

The current glass barriers certainly impede visitors from coming into contact with the mural paintings, but they do not ensure a suitable fruition as a result of the formation of water vapour condensation on the surfaces and do not ensure adequate insulation with the corridor and consequently with the external environment. Therefore, the glass barriers could be removed because they are inadequate. The glass must be better insulating in order to offer adequate thermal resistance to the transmission of heat.

The insulation of the glass reduces the existing difference in temperature between the air and the glass and consequently reduces the probability of superficial condensation on the glass. It is also important to know the estimated number of people that will visit the Tomb in order to define the most appropriate actions to undertake within a strict preservation point of view and those related to correct management.

17. Limited flux

If the flux of visitors is limited (a few persons per month), it is not necessary to undertake any protective intervention because with good visitor management that avoids direct exchange with the exterior and limited presence inside the Tomb the system will be capable of compensating for eventual alterations with its own inertia and not needing modifications.

For this to be the case, it would be useful to arrange a chamber of compensation in the corridor made out of two solid doors, suitably insulated and with hermetic shutting. These doors will delimitate a halt area for visitors for a moment in order to adjust them and the environment to the change. During this period of time, visitors can read plasticized posters located on the doors and walls of the chamber that explain the necessary safeguarding measures for the conservation of the mural paintings and the behaviour that they should observe in order to avoid mechanical damage by contact with the surfaces. The posters can include historical notes related to the Tomb during their visit.

The visit should proceed in the following way: the door is opened towards the exterior and three to five people enter depending on the size of the chamber between the two doors. The entrance door is shut and visitors acquaint themselves with the documentation on the walls and doors. After some minutes, the door that leads to the Tomb's chamber is opened and visitors can enter. This door is then immediately shut. Once the visit is over, it is necessary to reverse the entrance procedure, though avoiding the time spent in the compensation chamber. This means: opening of the inner door; entering of visitors; shutting of the inner door; opening of the outer door towards the exterior; exiting of visitors and shutting the door.

In this manner the environmental impact is minimized and the system will be capable of absorbing it without alterations. Therefore, it is advisable to remove the entire existing glass structure.

18. Medium flux of visitors

If the flux of visitors is higher by some dozens per week, it is necessary to install a transparent door at the entrance of the burial chamber. This should be provided with a glass panel with heating elements, avoiding the winter condensation problems that impede observing the interior. During winter, in fact, the internal temperature of the Tomb is higher than the external one, and therefore heat goes out from the Tomb. The glass temperature will thus be less than that of the internal air, and given relative humidity of nearly 100 %, condensation will occur on the internal surface of the glass.

During summer, heat enters the Tomb and condensation could happen on the external surface of the glass. Such phenomenon is conditional either by the direction of the thermal flux or by the relative humidity value in the corridor. If the latter is kept sufficiently low, around 70 %, the condensation phenomenon on the glass surface with consequent misting over could be eliminated.

The figure below shows the photograph of a door of this type installed in Tarquinia, Italy.

Fig. 211: Heated doors on Tarquinia Tomb

The reduction of relative humidity can be obtained with a de-humidifier equipped with a humidistat that turns on the device when the value surpasses a fixed limit.

19. High flux of visitors

If the flux of visitors is higher than the previous figures, it will be necessary to install a transparent structure (glass box) inside the burial chamber similar to the existing one but with high thermal resistance glass provided with heated sections at eye-height so as to allow visitors to see the mural paintings. A transparent door is not necessary in these circumstances.

In order to heat a transparent door, 400 W are necessary, but if the sections of glass with metallic wiring for demisting are to be heated 1.2 kW at least are necessary. This amount of power is quite elevated and it could alter the environmental conditions in the Tomb. As a result, precautions should be taken, such as alternating the times of visits so as to allow the system to re-establish its standard conditions.

If there is no electrical network to supply the transparent door, wind or solar power could be used but there would be a need for constant maintenance. In the case of the box in glass, it is practically impossible to find similar solutions since a large and costly installation would be necessary. It is not possible to defrost or demist glass at will, because the time needed to carry out such an operation would take some days and therefore during winter the system should always be functioning if the Tomb is to be visited.

An alternative solution if there is insufficient energy, one that is less good but still useful for the transparent door, would be to use two magnetic wiper blades positioned on both faces of the glass that are slid around to remove condensation water during visits.

In conclusion, the most immediate actions to undertake are the removal of the obsolete glass barriers and the construction of the compensation chamber as described above. Subsequently, depending on the frequency and number of visitors and on energy accessibility, the transparent door and the dehumidifier or the transparent box could be installed.

The lighting systems must be adequately installed, probably with LEDs of two different kinds.

The first one is of linear type for visitor safety that illuminates the pathway from the bottom and is turned on as soon as visitors approach the visiting structure (Fig.22), and the second one will turn on illuminating the mural paintings when someone is near the burial chamber thanks to a system that detects presence.

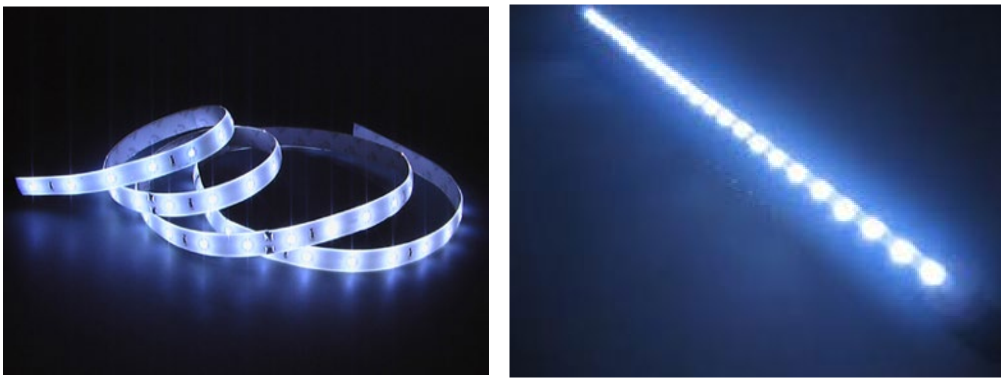
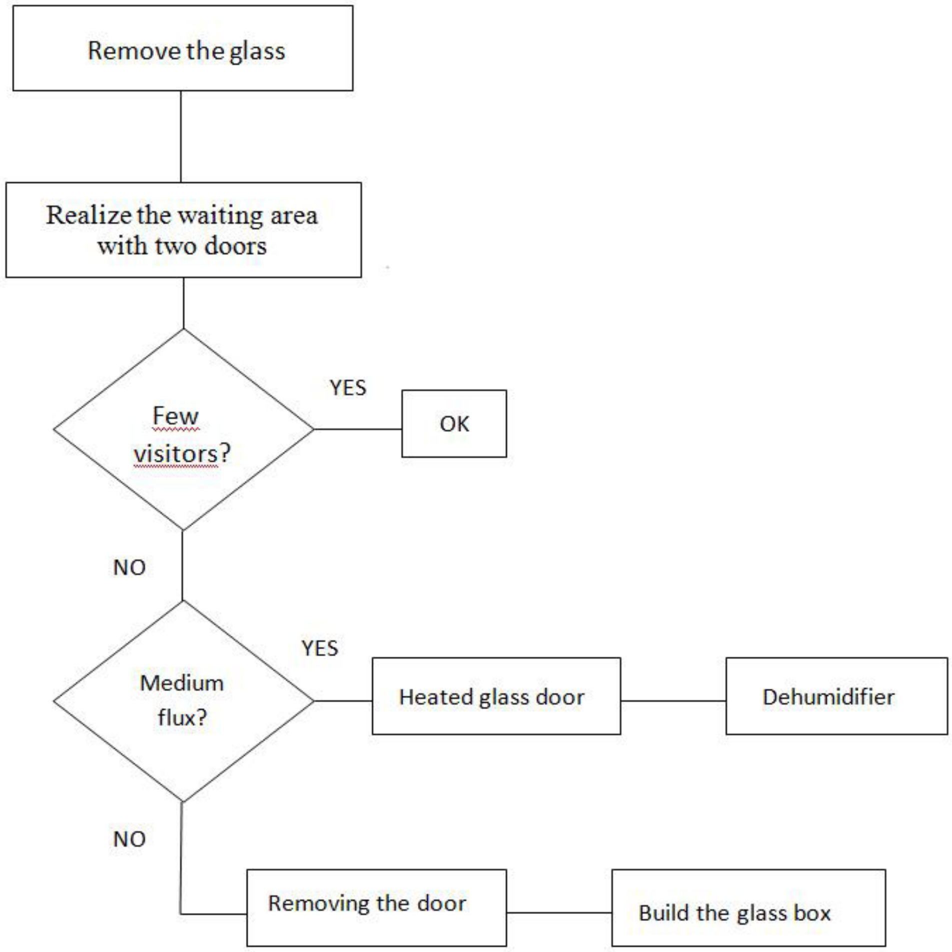


Fig. 212: Linear LED

The quality of light must also be distinguished: while for the linear type of LED the light could be cold, for the paintings the light must be warm and respectful of the type of illumination employed by the artists in the past.

The following scheme illustrates the several phases of the work:



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Consolidation of Renders and Removal of Mud Incrustation

by Kwon-Woong Lim

1. Introduction

Mural paintings have complex structures consisting of various materials rather than one substance. This complex structure may be damaged when the structural stability of the mural paintings or the micro-climate are changed. Damage requiring consolidation is manifested as a loss of paint layers and/or loss of render. Depending on the situation, consolidation/fixation can also be applied to cracks, craquelure, and flaking of paint layers. Previously employed consolidants may be divided into organic and inorganic.

The mural paintings inside the Tombs show different damage from that found in buildings above ground. The most typical are mud-incrustations and lime-incrustations, which are formed on the surface of the mural paintings over a long period of time in low temperatures and a high humidity environment similar to a semi-basement. It has been confirmed that the mud-incrustation is generally composed of lime and mud, while the lime-incrustation is composed of lime. Gypsum (a product of deterioration) is often found instead of lime in Tombs that are not closed.

Depending on the material composing the incrustations, different chemicals and methods should be selected for the removal of them. Samples collected from the mural paintings of the Koguryo Tombs were analyzed and reviewed in comparison with preceding studies. Application tests were then conducted after the selection of chemicals based on the samples.

2. Investigation of Render and Mud Incrustation

The sample of render taken for this study was collected from the front of the Susan-ri Tomb and was 90 mm long, 40 mm wide and 20-25 mm thick. It did not show specific damage, was very strong, and had been soiled by light yellow loam[1]. One side of the sample, assumed to be the surface, was relatively slippery, flat and very accurately

1 The sample used was collected by Han Yong Chol.

processed. The other side showed significant unevenness, with a light brown additive of 3-5mm in size and straw traces of 3-5mm thick (Fig. 1). Many brown additives and straw traces could be observed in the section, and it seems that they were added on purpose to improve the properties of the render made with lime. In a similar way to a render sample collected from the Jinpa-ri Tomb No. 4, a brown additive was observed in the white lime mortar.[2]

Fig. 213: Brown additive and straw traces in the Susan-ri Tomb sample

Fig. 214: Brown additive in a sample from the Jinpa-ri Tomb No. 4

2.1. Properties and Mineralogical Components of the Render

2.1.1. Physical properties

Important physical properties such as absolute density, bulk density, total porosity, saturation index, capillary water absorption coefficient, capillary water absorption velocity coefficient, water absorption rate under atmosphere/in vacuum and water vapour diffusion resistance were measured using geotechnical methods. The analytical results regarding the components forming the render provided very important information about the materials employed. Physical properties are used as standards to decide the appropriateness of mortars when they are manufactured and to select the proper consolidant for the conservation treatment of renders

	G_m [g/cm^3]	γ_m [g/cm^3]	n [Vol. %]	S.I.	w [kg/m^{2}h$^{0.5}$]	B [cm/h$^{0.5}$]	W.A. [wt.%]	W.V.
ST-R01	2.62	3.50	50.07	0.99	1.22	1.33	15.91	19.10`

Gm: Absolute density; γm: bulk density; n: total porosity; S.I.: saturation index; w: capillary water absorption coefficient; B: capillary water absorption velocity coefficient; W.A.: water absorption rate under atmosphere; W.V.: water absorption rate in vacuum

Tab. 13: Some important physical properties of the Susan-ri render sample

2 Lim, 2009

2.1.2. Mineralogical analyses of the render

X-ray diffraction analysis (Philips PW 3710) of the finely pulverized render sample was performed in order to identify the mineral crystalline phases of the render. Qualitative mineralogical analyses were performed by XRD on two representative samples using Cu $K\alpha$ radiation, 2θ range from 10 to 80°, □°, step size 0.05° 2θ.

The white area (ST-R01 w) and the brown additive (ST-R01 b) of the render were analyzed respectively. The results revealed that the brown additive was clay mineral. From the analysis result using XRD, it was found that the white component collected from the Susan-ri render sample consisted of quartz (SiO_2), calcite ($CaCO_3$) and aragonite ($CaCO_3$) (Fig. 3), and the brown sample consisted of quartz (SiO_2), calcite ($CaCO_3$), aragonite ($CaCO_3$) and a small peak shows the presence of a clay mineral (Fig. 4). Aragonite ($CaCO_3$) is detected in lime render when the shells of bivalve molluscs are used to make lime. Through the detection of aragonite ($CaCO_3$), it is possible to assume that lime made with limestone and lime made with shells was jointly used to make the renders of the Susan-ri Tomb. Although studies on the Koguryo Tomb's mural paintings have revealed that aragonite was used as a white pigment[3] and that shells in the form of $Ca(OH)_2$ and crushed shell fragments were mixed in the render of the Jinpa-ri Tomb No. 4[4], this was the first case that aragonite had been directly detected in a render.

In order to confirm whether the brown additive was clay mineral, it was necessary to collect additional samples, perform analyses through various methods, and carry out a synthetic analysis of the results.

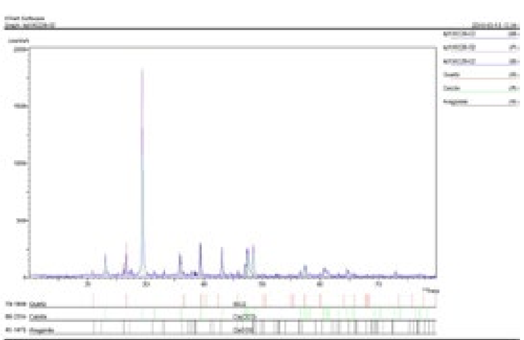

Fig. 215: XRD Analysis result of ST-R01 w

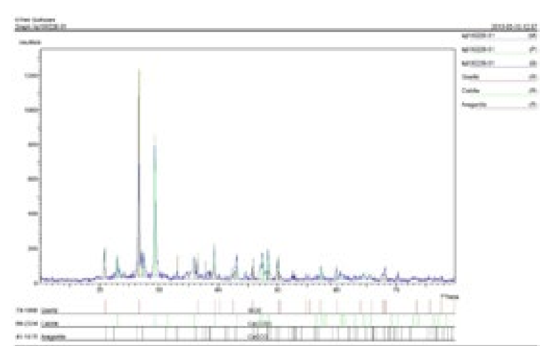

Fig. 216: Fig. 4 XRD Analysis result of ST-R01 b

2.1.3. Mineralogical components of mud-incrustations

According to the results obtained at the Rathgen Forschungslabor, muds are composed by microline ($KALSi_3O_3$), quartz and calcite.

3 Yu, 2005

4 Lim, 2009

3. The Experiment

3.1. Consolidation test to select a consolidant

Representative inorganic consolidants used for mural paintings consolidation include limewater (calcium hydroxide, $Ca(OH)_2$), barium hydroxide ($Ba(OH)_2$), tetraethoxysilane, ethyl silicate, and methyl silicate, etc. Limewater is the consolidant that has been most often used, but its effects have also been discussed[5]. Tetraethoxisilane, ethyl silicate or methyl silicate were originally developed to preserve stone cultural properties, but they have also been used for the consolidation of mural paintings, which are porous[6].

Among organic consolidants, synthetic resins, whose massive production was triggered by the development of polymer chemistry in 1970s, have been used for mural painting consolidation. Representative organic consolidants include acrylic resins, PEMA (poly ethyl methacrylate), a polymer of PMMA (poly methyl methacrylate), and Paraloid B72. PVAc (poly vinyl acetate) and PVA (poly vinyl alcohol) have also been used with various organic solvents.

The later ones may cause negative results depending on the usage method or the environment. Significant side effects caused by organic consolidants used for the consolidation of paint layers have been reported[7].

The purpose of this study was to select a suitable consolidant to consolidate renders that had become weak because of environmental factors and had exhibited the various damages shown in the Susan-ri Tomb. The study was performed on mock-up samples manufactured with similar materials and having a similar type damage as those of the renders of the Susan-ri Tomb. Firstly, selected organic and inorganic consolidants were applied and the changes of physical properties, including strength, were measured. The results were synthetically analyzed and the proper consolidant selected.

3.1.1. Materials

Consolidants:

- Paraloid B72 (ethyl-methacrylate copolymer): 5% solution in acetone
- Poly vinyl acetate (PVAc): Caparol ca. 5% dispersion in distilled water
- KSE 300E: ethyl silicate, by Remmers
- Nanometre calcium hydroxide (particle size 400 nm) 1.25 g in 200 g iso-propanol

Manufactured sample:

- Test sample (2 x 2 x 8 cm) mixing calcium hydroxide and sand

5 Koller, 1996, Brajer, 1999, Kretschmer, 2003, Ettl & Wendler, 2005
6 Hammer, 1987, Lhemkuhl, 2001, Haefner, 2001, Wehner, Woerz & Hammer, 2001
7 Danzl & Leitner, 2005

3.1.2. Method

The measured physical properties and the results of the mineralogical analyses were used as a basis to establish the physical properties of the 12 mortar samples[8] that were employed for the consolidation tests. The mortar samples were impregnated with the consolidants by immersion for 24 hours. The treated samples were kept at room conditions for 30 days. Then the physical properties of the treated samples were measured.

3.1.3. Results

Ultrasonic wave velocity

The high-density materials showed faster ultrasonic wave speed, while the porous inorganic materials, such as the renders, and those that were weathered or their strength was weakened had low density and showed low ultrasonic wave speed.

From comparing the measurement values of the ultrasonic wave velocity, which were measured on the samples before and after four types of consolidants were applied, it was found that the values increased in all samples, as expected. The measurement values of the samples to which KSE 300E was applied showed the highest increase ratio at an average of 25.79%. The sample to which the organic consolidant poly vinyl acetate (Caparol) 5% was applied showed a ratio increase of an average of 17%. The ultrasonic wave velocity of samples to which $Ca(OH)_2$ and Paraloid B72 5% were applied showed ratio increases of 5.82% and 4.52%, respectively.

Capillary water absorption coefficient (w) and capillary water penetration coefficient (B)

The capillary water absorption coefficient and capillary water absorption velocity coefficient were measured on the basis of the Deutsche Industrie Normen DIN 52 617. Among the samples to which consolidants were applied, the sample to which KSE 300E was applied showed the highest decrease of w (92.28%) and B (75.23%), respectively. For the sample to which Ca(OH) was applied, w increased by 17.99% and B showed the lowest ratio of 12.1%, which decreased after application. For the sample to which Caparol 5% was applied, w and B decreased by 23.5% and 31.04%, respectively. The sample to which Paraloid B72 5% was applied showed a ratio decrease of an average of 55.09% and 45.43%, respectively.

	W Kg/(m2.s2)	B cm/s2
KSE 300E	-92,3%	-75,25%
Ca(OH)2	+18%	-12%
Caparol	-23%	-31%
Paraloid B72	-55%	-45%

8 The samples were prepared with a similar pore distribution as the original sample from the Tomb.

Water vapour diffusion resistance coefficient (μ value)

Water vapour diffusion resistance is the value that shows the degree of H_2O vapour that evaporates through pores of equal-thickness samples. The measurement methods of water vapour diffusion resistance are dry-cup and wet-cup. In this study, the wet-cup method was adopted.

The water vapour diffusion resistance was as high as 14.11 in the samples to which KSE 300E was applied, and it was expected that the strength was the highest in this case. Other samples to which other consolidants were applied, the control group, and the Susan-ri sample showed similar values at 9.43~10.76.

For the sample to which KSE 300E was applied, the capillary water absorption coefficient and capillary water absorption velocity coefficient significantly decreased and water vapour diffusion resistance showed the highest increase among the four kinds of consolidants. This change means that there was a modification in the pore structure of the sample treated with KSE 300E. Generally speaking, this is determined by significant decreases in the capillary water absorption coefficient and capillary water absorption velocity coefficient, seen as a negative development. In the consolidation of renders lacking cohesion found in the Susan-ri Tomb, however, this was a positive factor. The increases of water vapour diffusion resistance were also regarded as very positive changes for consolidation in the Susan-ri Tomb. It was confirmed that for the sample to which $Ca(OH)_2$ was applied, the capillary water absorption coefficient had increased, but it was hard to grasp the precise cause because the study on the porous inorganic material to which $Ca(OH)_2$ was applied had not made sufficient progress.

3.2. Removal test of mud incrustation

In this part of the experiment, the removal effects of AB57 that was used in trial tests for removing mud-incrustations in the Susan-ri Tomb and of strong cationic ion exchange resin (Amber SH) were compared and considered over time in relation to the reaction with pigments and with the paint layer by measuring them with a colorimeter and a digital microscope.

3.2.1. Materials

AB57: Cleaning (removal of calcareous concretions) wall paintings with AB57 has been widely used. AB57 consists of one litre of distilled water, 30 g of ammonium bicarbonate $(NH_4)HCO_3$, 50 g of sodium bicarbonate $NaHCO_3$, 25 g of Desogen (a quaternary ammonium salt) 10% solution, and 60 g of carboxyl methyl cellulose (CMC).

Strong cationic ion exchange resin (Amber SH): Amber SH is a powder-type strong cationic ion exchange resin that is mixed with water in which H^+ is combined with SO_3^- functional groups. Strong cationic ion exchange resins are usually used for removing calcareous incrustations or thin lime-washes formed on the surface of wall paintings or stone.

Pigments: Regarding the pigments used for this study, among these found through studies of the wall paintings of the Koguryo Tombs five types of important pigments were selected for experimentation.

Pigment	Component	Tomb
Malachite*	$CuCO_3 \cdot Cu[OH]_2$	Jinpa-ri Tomb No. 4*, Anak III*, Kangso I*
Green Earth	$K[Mg,Fe,Al]Si_4O_{10}[OH]_2$, $[K,Na][Al,Fe,Mg]Si_4O_{10}[OH]_2$	Tokhung-ri Tomb* **, Jinpa-ri Tomb No. 4*
Red Ochre	$Fe_2O_3 \cdot H_2O$	Anak III*, Tokhung-ri Tomb*, Susan-ri Tomb*, Tokhung-ri Tomb*, Kangso I*
Vermilion	HgS	Anak III*, Tokhung-ri Tomb*, Jinpa-ri Tomb No. 4*, Jinpa-ri Tomb No. 1*, Kangso I*
Carbon Black	C	Anak III*, Jinpa-ri Tomb No. 1*, Jinpa-ri Tomb No. 4*, Tokhung-ri Tomb**

*Identified by a research project of the Republic of Korea in 2006 [Report on the Preservation of the Koguryo Mural Painting Tombs, 2006, National Research Institute for Cultural Heritage, Korea]

**Preservation of Koguryo Tombs – Phase II, World Heritage Centre, UNESCO

Tab. 14: Pigments of wall paintings of the Koguryo Tombs

3.2.2. Methods and Results

Since mud-incrustations mainly consist of calcite, which is the same constitutive element of the render and is the binding medium of the paint layer, there is a high possibility that the chemicals used for removing mud-incrustations may attack and remove the calcite contained in the paint layer, resulting in damage or discoloration.

For experimental measurement of the degree of paint-layer damage, Amber SH mixed with water and CMC and AB57 were applied to three mock-up samples of each colour and left to react for one, six and 12 hours. Once this process was completed, the structural changes and damage caused on the paint layers were observed in detail under a portable digital microscope. The products were also mixed with pure pigments to verify colour changes.

The colour change was quantified using colorimetry. The measured chromaticity values of the pigments was indicated using CIE L*, a* & b* defined by the CIE (International Commission on Illumination). The chromaticity change ratio was calculated using the following formula:

$\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$, where ΔE is classified into four grades depending on the grade suggested by the CIE (see table below).

ΔE Value	Degree of Colour Change
0~0.5	Can't be identified by a specialist
0.5~1.5	Can't be identified by a non-specialist but can be identified by a specialist
1.5~3.0	Can be identified by a non-specialist
3.0~6.0	Significant colour change

Tab. 11: Chromaticity change ratio according to ...

3.2.3. Reactivity

Ammonium bicarbonate $(NH_4)HCO_3$ (component from AB57)

After malachite was mixed with a saturated ammonium bicarbonate solution in water, it turned blue and continuously changed blue for 240 minutes until the observation was completed. In relation to the discoloration of malachite, a reactivity experiment using AB57, which contains a low concentration of ammonium bicarbonate, was also performed. After mixing 1 g of malachite and 6 ml of AB57, it was observed for one hour. Although there was no colour change in the mixture at the initial stage, this altered gradually into blue and changed to a light blue colour that was clear under the naked eye.

As the copper ion of malachite is combined with ammonium bicarbonate and forms a copper tetramin complex as a result, in this case the green colour of the malachite was changed blue:[9]

$$CuCO_3 \cdot Cu(OH)_2 + 8NH_3 + H_2O \text{ --> } 2[Cu(NH_3)_4]_2 + (OH)_2 + CO_2$$

After mixing the solution of ammonium bicarbonate and water with green earth, bubbles were continuously created during the observation period, but there was no change in colour. The other pigments excluding malachite and green earth did not show reactivity with ammonium bicarbonate.

Sodium bicarbonate $(NaHCO_3)$ (component from AB57)

In the mixture of the solution of sodium bicarbonate in water and the pigment, bubbles were generated as happened in the mixture of green earth and sodium bicarbonate solution. Other pigments did not react with the sodium bicarbonate solution.

Desogen (component from AB57)

It was found that Desogen did not react with the pigments.

Strong Cationic Ion Exchange Resin (Amber SH)

After mixing the pigment with Amber SH and 60 ml of distilled water, pigment discolouration was not observed. Although the mixture with green earth generated bubbles as shown in the mixture with ammonium bicarbonate or sodium bicarbonate, other pigments did now show any reaction such as discoloration or bubble generation.

9 Fritz, 2001

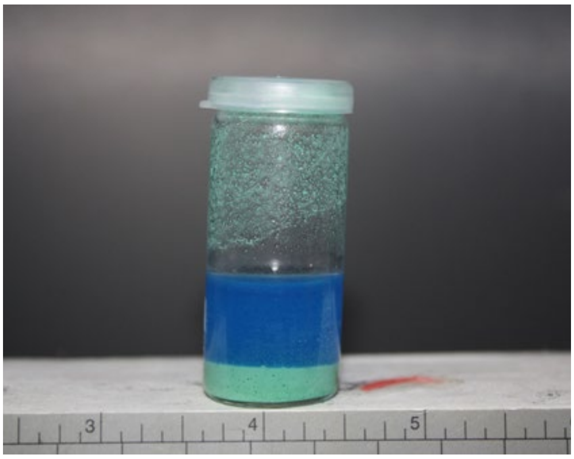

Fig. 217: Colour change of malachite mixed with $(NH_4)HCO_3$

Fig. 218: Colour change of malachite mixed with AB57

Fig. 219: Generation of bubbles when green earth was mixed with $(NH_4)HCO_3$

Fig. 220: Generation of bubbles when green earth was mixed with $NaHCO_3$

Fig. 221: Generation of bubbles when green earth was mixed with Amber SH

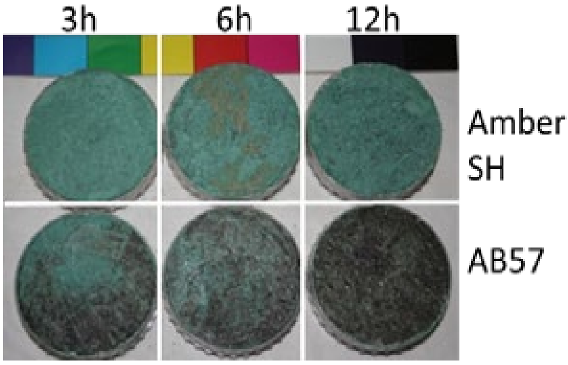

Fig. 222: After the reaction of malachite and Amber SH (upper: 3h, 6h, 12h) and AB57 (lower: 3h, 6h, 12h)

3.2.4. Damage to the Paint Layer

Malachite

The malachite pigment showed a significant change of colour when reacting with AB57 and Amber SH (Fig. 15).

It seemed from the resulting evidence that practically all the paint layer was lost after the removal of the lime-washes applied on the surface when the sample was manufactured using the fresco technique. The sample that was treated with Amber SH for six hours showed that the paint layer had been removed or destroyed and the render exposed (Fig. 16). ΔE showed a significant colour change from 3.27 to 10.18.

In the sample treated with AB57, the green colour of the paint layer discoloured to black after three, six and 12 hours. As the treatment continued, the range and degree of discoloration was significant, showing that the malachite turned black.

Green Earth

In all the samples treated with Amber SH and AB57, a decrease of brightness was observed. In other samples, excluding the sample treated with Amber SH for three hours, after treatment some sections showed a violet hue (Fig. 17). The ΔE changed from 10.49 to 14.54 ΔE after treatment, showing significant discolouration.

Ochre

The sample painted with yellow ochre was treated with Amber SH and AB57, and the brightness decreased significantly but there was no colour alteration at naked eye (Fig. 18). The reason that the range of ΔE fell from 4.42 to 8.25 in spite of no colour change was that its brightness decreased.

Vermilion

For the vermilion sample, the ΔE also changed from 0.97 to 7.62 because of a decrease in brightness, but there was no colour change visible at naked eye (Fig. 19). In the case of the sample processed with Amber SH and AB57 for 12 hours (Amber SH-12h & AB57-12h), the pigment layer was partially stripped of the quartz particles used for the manufacture of the render (Fig. 20).

Carbon Black

For carbon black, all the samples showed significantly decreased brightness regardless of the reaction time after treatment with Amber SH or AB57, but there was no significant colour change (Fig. 21) perceptible at naked eye. ΔE that indicates colour change showed a ratio that extended from 6.08 to 11.64.

Fig. 223: Exposed lime layer on sample with malachite treated with Amber SH for 6h (x50)

Fig. 224: After reaction of green earth and Amber SH (upper: 3h, 6h, 12h) and AB57 (lower: 3h, 6h, 12h)

Fig. 225: After reaction of ochre and Amber SH (upper: 3h, 6h, 12h) and AB57 (lower: 3h, 6h, 12h)

Fig. 226: After reaction of vermilion and Amber SH (upper: 3h, 6h, 12h) and AB57 (lower: 3h, 6h, 12h)

Fig. 227: Exposed quartz on sample with vermillion treated with Amber SH and AB 57 (x50)

Fig. 228: After reaction of carbon black and Amber SH (upper: 3h, 6h, 12h) and AB57 (lower: 3h, 6h, 12h)

3.2.5. Removal Effect

The samples that were manufactured on the basis of the analytical results of the constitutive and extraneous materials deposited on the wall paintings of the Susan-ri Tomb by employing four cleaning agents[10] including AB57, Amber SH and the mixture of the two materials were treated for six, 12 and 24 hours, respectively. After that, the mass (weight) of the samples was compared to those that were measured prior to processing. In order to measure the weight of the samples, these were dried at 60°C in a drier for 24 hours and adapted to an indoor environment for 24 hours before measurement.

It was found that the removal effect was very small when only AB57 was used. (Table 4, R'1). But there was a significant weight decrease when samples were treated with Amber SH only (Table 4, R'2). In addition, when CMC was added to Amber SH (R'3), it was found that there was no significant difference from using only Amber SH. It was found that AB57 showed the most significant weight decrease, especially when mixed with Amber SH (Table 4, R'4).

Fig. 229: Mud-incrustation samples

	R'1	R'2	R'3	R'4
6h	0.04	0.18	0.17	0.14
12h	0.03	0.17	0.21	0.26
24h	0.02	0.24	0.18	0.25

Tab. 12: Decrease of weight of samples before and after treatment [unit: g]

10 R'1: AB57, R'2: Amber SH + distilled water, R'3: R'2 + 2% CMC 10g, R'4: R'1 30g + R'2 30g

4. Conclusions

In order to select the most suitable consolidant for preparatory and paint layers lacking cohesion in the Susan-ri Tomb, the basic physical properties of the render sample were measured and mineralogical composition was obtained using XRD (X-ray diffraction). In addition, Paraloid B72 5% solution, Caparol 5% solution, KSE 300E and $Ca(OH)_2$ in iso-propanol dispersion were applied to the manufactured samples.

KSE 300E showed the most significant consolidation effect, and the study made clear that KSE 300E was the most suitable consolidant for the renders and paint layers lacking cohesion in the Susan-ri Tomb. Nevertheless, in terms of practical application the micro-climate conditions in the Tomb should be taken into consideration.

In addition, the use of hydrated lime in powder ($Ca(OH)_2$) in iso-propanol dispersion was found not to be appropriate for the consolidation of the renders in the Susan-ri Tomb because it did not show an immediate high consolidation effect. It might be applied for the consolidation of paint layers and renders in which powdering is in progress; however, the study of the properties and use of $Ca(OH)_2$ dispersion in iso-propanol should be continued.

It was found that a mixture of AB57 and Amber SH had the best removal effect during experiments performed on samples with mud incrustations. It was observed that the effect of Amber SH was better than that of AB57 when exclusively used. In addition, it was found that Amber SH mixed with carboxyl methyl cellulose did not show variations in the removal effect.

However, as demonstrated in the results of this study there might be damage to the paint layers during the removal of hard mud incrustations from the mural paintings, so different methods should be applied depending on the state of preservation of the pigment layer and the type of the pigment used.

In the Susan-ri Tomb, although there was no problem using existing methods for the removal of mud incrustations formed on surfaces where the paint layer has been lost, special attention should be paid to the removal of hard mud incrustations formed on the extant painted surfaces. First of all, AB57 should not be applied to sections in which pigments react with this mixture, and removal employing ion exchange resins should also be restricted to sections painted with green earth. When ion exchange resins are used for the removal of mud incrustations, the procedure should be checked every 15 minutes.

In general, mud incrustations formed on the pigment layer should not be entirely removed, and if possible, as also suggested by Rathgen Research Laborotory, they should be thinned down with physical methods such as ultrasound spatulas and fibreglass sticks and then removed with ion exchange resins in such a way that a thin veil of calcium carbonate remains on the surfaces in order to avoid the complete exposure of the paint layer as a protecting buffer.

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Investigation of the Painting Techniques and State of Preservation of Mural Paintings in the Complex of Koguryo Tombs

by Cristina Aibéo[1], Sara Bianchin[2,3], Marisa Pamplona[4], Thomas Warscheid[5] and Stefan Simon[6]

1. Introduction

In the frame of the UNESCO Project for the Conservation and Preservation of the Koguryo mural paintings, the Rathgen-Forschungslabor carried out several field missions between 2009 and 2013 and analysed samples with distinct origins from decorated surfaces in the complex of Koguryo Tombs, from the later period of the Koguryo Kingdom, dating between the 3rd century BC to 7th century AD. These samples included original strata and suspected over-paintings, mud incrustations, mortar and biological infestations. Furthermore, the record of climatic data inside one of the tombs, Susan-ri, was evaluated, recommendations for preventive conservation developed and the installation of the new glass barrier overseen. Four main questions were studied:

1. Painting technique: pigments and binding media were analysed in a variety of samples from all tombs on cross-sections and bulk samples. Past conservation materials were also identified.

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4 Deutsches Museum, Munich, Germany
5 LBW-Bioconsult, Wiefelstede, Germany
6 Institute for the Preservation of Cultural Heritage, Yale University, Connecticut, USA

2. Mud incrustations: the composition of mud incrustations was studied with the aim to inform the conservation team on their constitution and advise how to remove/clean.
3. Biological infestation: Microorganisms present on the decorated surfaces were isolated and identified, cleaning methods were suggested because besides having a negative visual impact, microbiological colonization can damage the materials, accelerate decay and pose a health hazard for conservators and tomb keepers.
4. Environmental conditions: Temperature and humidity records collected by the DPRK national team were evaluated, recommendations derived for the preventive conservation inside the tombs.

The painting technique of some Kogruyo murals has been investigated by Rocco Mazzeo in the first phase of the project[1]. In almost all samples, pigments were identified which can be used in fresco technique, namely hematite, goethite, green earth, magnetite and carbon black. No organic binder was identified, and it was therefore suggested that the paintings were made in fresco technique. The same samples and others from later missions were analysed at Rathgen-Forschungslabor.

The environmental conditions are an important factor for the maintenance of wall paintings, especially in the case hypogeal ones, where high humidity prevails and the risk of microbiological decay and salt damage are elevated, and the impact of visitors can be especially significant. Monitoring of the climatic conditions is a key aspect of providing minimal intervention and essential for the safeguarding of murals in subterranean sites. Furthermore, in North Korea there are monsoons which may cause floods, bringing water and mud inside the tombs and raising the relative humidity on long-term.

Samples were firstly analysed under the microscope, a representative part was separated and used for further analyses including preparation of cross-section (Microscopy and ESEM/EDX) and FTIR (Fourier Transform Infrared Spectroscopy).

2. Materials and Methods

A total of 42 samples provided by UNESCO have been subject to analysis. A brief description of these samples is resumed in the following table.

Fig. 230: List of samples analysed for muds, microorganisms and paint technique

Tomb*	Sample		Description by sampler
	RRL name	Restoration name	
ST	ST-6	ST1 (2008)	Mineralised mud.
	ST-10	N3 ST-09	Hard mud encrustation, sandy type.
	ST-16	N9 ST 09	Hard compact mud encrustation with residues of cement coating.
TT	TT-9	N1 TT 09	Hard mud encrustation with white film on surface.
	TT-11	N3 TT-09	Thick hard mud encrustation on render.
	TT-12	N4 TT-09	Thick hard mud with suspected mica crystals on render.
	TT-13	N5 TT-09	Reddish thin semi-hard mud encrustation on render.
	TT-14	N6 TT-09	Thick hard mud encrustation with suspected mica black.
YT	YT-13	N2 YT-09	Render with purple bio-organism for determination of deepness.
	YT-15	N4 YT-09	Rubbing of stain with cotton wool for identification.
	YT-16	N5 YT-09	Microbiological attack for determination of deepness.
	YT-17	N6 YT-09	Loose render with purple bio-organism for identification.
TT	TT-10	N2 TT-09	Suspected mud-inherent bacteria for identification.
ST	ST-1	ST1	Described as green but is actually red.
	ST-3	ST3	Carbonation on black layer.
	ST-4	ST4	Red bright paint layer.
	ST-5	ST5	Red bright paint layer.
	ST-8	N1 ST 09	Black stroke above white background.
	ST-9	N2 ST 09	Suspected black over-paint. Described as bitumen on white.
	ST-17	N10 ST 09	Red and black paint layer on plaster (probable reconstruction)
	ST-23	N16 ST 09	Drip of paint or altered fixative on the cement.
	ST-25	N18 ST 09	Suspected over-painting of red on red.
	ST-27	ST-B-09	Described as white but is red on black with white deposition.
	ST-28	ST-C-09	No description given.
YT	YT-1	YT1	Dark red paint layer.
	YT-2	YT2	Yellow paint layer.
	YT-3	YT3	Black paint layer.
	YT-4	YR-1-05	"Blue" from Blue Dragon.
	YT-8	YTP-E	Dark red paint layer.
	YT-9	YT-1	Probable over painting.

TT	TT-1	DPRK-1	Red paint layer.
	TT-2	DPKR-2	Yellow paint layer.
	TT-4	DPRK-4	Black paint layer.
	TT-5	DPRK-5	Yellow paint layer.
	TT-7	DPRK-8	Blue pigment.
	TT-8	DPKR-9	Dark red paint layer with white wash.
	TT-15	N7 TT-09	Yellow on dark background, probably over-paint.
	TT-16	N8 TT-09	Yellow coating on red paint. Maybe over-paint on a lime render.
AIIIT	AIIIT-2	AIII-2-05	Red over-painting on red.
	AIIIT-7	N3 AIII-09	Green pigment.
	AIIIT-12	N8 AIII-09	Yellow pigment.
	AIIIT-13	N9 AIII-09	Red pigment and salt efflorescence.

*ST: Susan-ri tomb; TT: Tohkung-ri tomb; YT: Yaksu-ri tomb and AIIIT: Anak III tomb

Various samples from the tombs Susan-ri (ST), Yaksu-ri (YT), Tohkung-ri (TT), Anak III (AIIIT) and Kangso II were analysed with the aim to study the painting technology.

The identification of the pigments was accomplished by analysing the cross-sections with Raman Spectroscopy and ESEM-EDX, whereas organic binder and consolidating material was analysed by FTIR, either directly on the bulk sample or by extracting the organic fraction with chloroform and analysing its dried residue.

Eight samples of mud were provided. The mud probably originated from water infiltrations and floods. The water carried mud which, when dried, became very hard and adhered to the decorative surfaces and walls. The samples were collected, characterised and a removal method was suggested, according not only to their composition but also to the composition and state of conservation of the render.

The mud samples were prepared as cross sections and subsequently analysed with different techniques according to their particular requirements. Regarding FTIR and XRD analyses, the samples were prepared by grating a very few quantity of mud from the surface of the fragment.

Five samples with biological organisms were collected with the aims of identification and assessment of their damage potential by maintaining sterile conditions. Sample YT-13 and YT-16 were provided as fragments for cross-section, the other two samples from Yaksu-ri were provided as swab tests on cotton swabs and the one from Tokhung-ri tomb as fragment in sealed containers and analysed at LBW-Bioconsult laboratory.

The samples were analysed with the following techniques:

- Optical microscopy - Performed with a digital microscope Keyence VHX-500FD with different objectives, VH-Z00R and VH-Z20 for magnification between x5 - x50 and x20 - x200 respectively or using an Axio Imager A2m microscope (Zeiss) and a ProgRes digital camera.
- ESEM-EDX - Performed with a Quanta 200 (FEI), equipped with a backscattered electron detector and energy dispersive x-ray analyser XFlash 4010 (Bruker)

- FTIR – The spectra were acquired with an IR-Spectrometer, Typ Paragon 1000 PC from Perkin Elmer, coupled to a microscope in transmission mode. Alternatively, in total reflection mode with a Nicolet 560 FT-IR system coupled to a Nicolet microscope, equipped with a Mercury Cadmium Telluride (MCT) detector. All spectra have a resolution of 4 cm^{-1}.
- Raman - Spectra were measured with a Horiba XploRa Raman-Microscope, equipped with a 532 nm, 638 nm and a 785 nm laser. For most measurements a 50x objective with long working distance was used.

Three Data Loggers were positioned inside the tomb according to Fig. 231. Each Data Logger measures: air temperature and relative humidity (2 internal channels) and air/surface humidity (2 external channels).

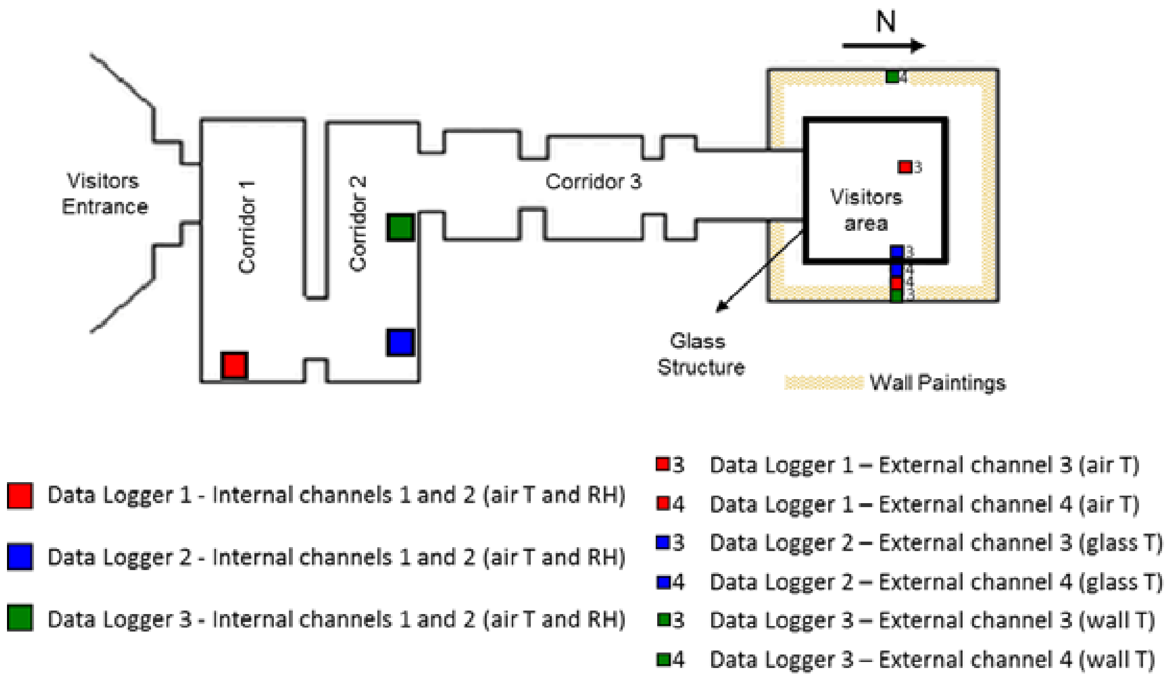

Fig. 231: Position of the data loggers inside Susan-ri Tomb: Each of the 3 Data Loggers (red, blue and green) has 4 channels, n.1 and n2 are internal and measure air T and RH and n. 3 and n.4 are external and measure only air or surface T.

Between January 2006 and May 2009, measurements of temperature, rain fall, relative humidity and wind speed were provided by the official meteorological station in Kangso[2].

The climatic data were recorded by HOBO U12 Temp/RH/2xExternal (U12-013]; HOBO Weather Station Data Logger (H21-001) and Wind Speed and Direction Sensor with 3m cable (S-WCA-M003). The outdoor devices were only for a limited time functional, indoor loggers and wiring suffered from the harsh humidity conditions and corroded quickly.

In the Nampho area, where the tombs are located, the average temperature of January is -7.6 °C and that of August is 23.8 °C. The average yearly rainfall is about 1000 mm[3].

3. Results

3.1. Painting Technique

In some samples the absence of calcitic compounds in the paint layer, such as in sample ST-1, indicates that the paint was applied in *lime-secco* or *secco* technique, which implies the use of an additional binding media.

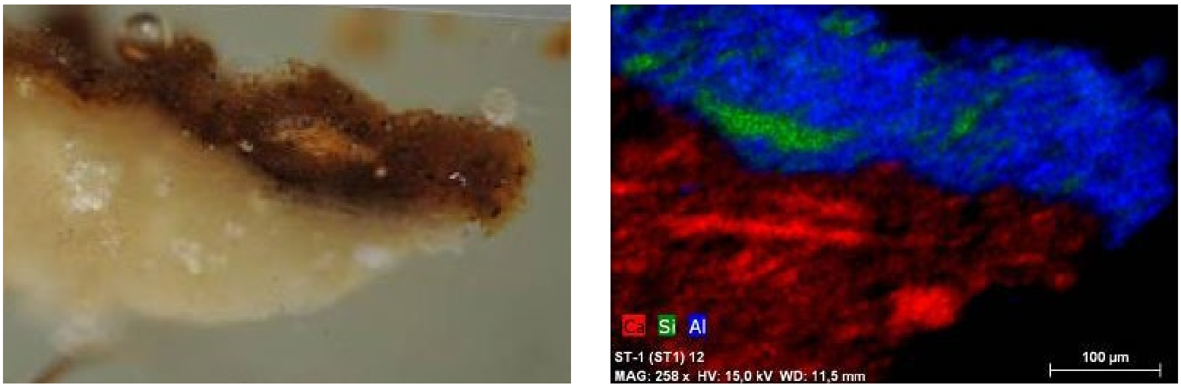

Fig. 242: Photo of the cross-section of sample ST-1 and mapping of its elements Ca (red), Si (green) and Al (blue) by ESEM-EDX

Calcitic layers frequently detected on the decorated surfaces, can be due to calcite deposition which are a quite common phenomena in hypogeal structures under high humidities or caused by calcite-forming microorganisms (e.g. algae, cyanobacteria or heterotrophic bacteria)[4], and not necessarily an evidence for a frescal technique (e.g. sampl e ST-8).

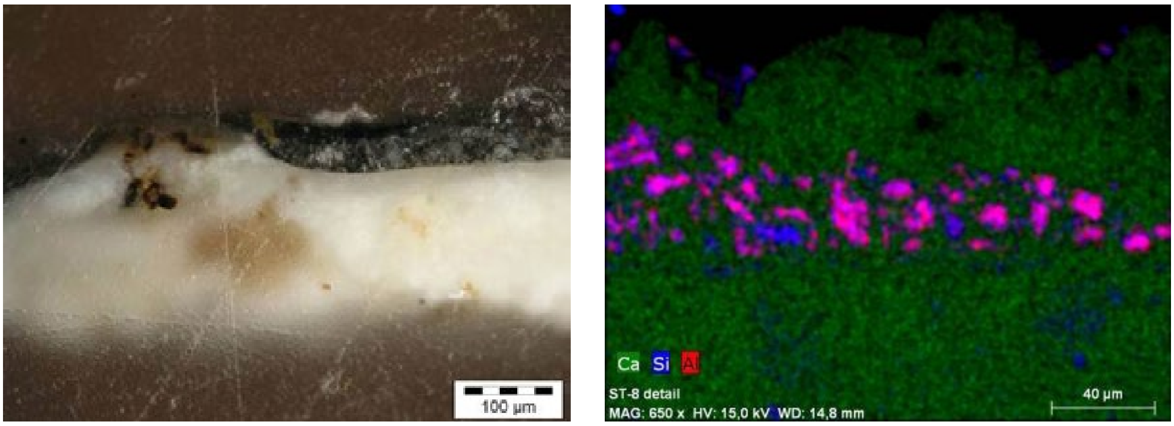

Fig. 243: Photo of the cross-section of sample ST-8 and mapping of its elements Ca (green), Si (blue) and Al (red) by ESEM-EDX (Aluminosilicates are magenta)

Among the pigments with lower stability when applied in fresco technique, cinnabar was identified, e.g. in sample ST-4. Most pigment analyses of earlier investigations could be confirmed. In some cases aragonite was found next to calcite, hematite, an interesting green in Anak III was found to consist of (blue) lazurite and (yellow) goethite[5,6]. The following table summarises these results.

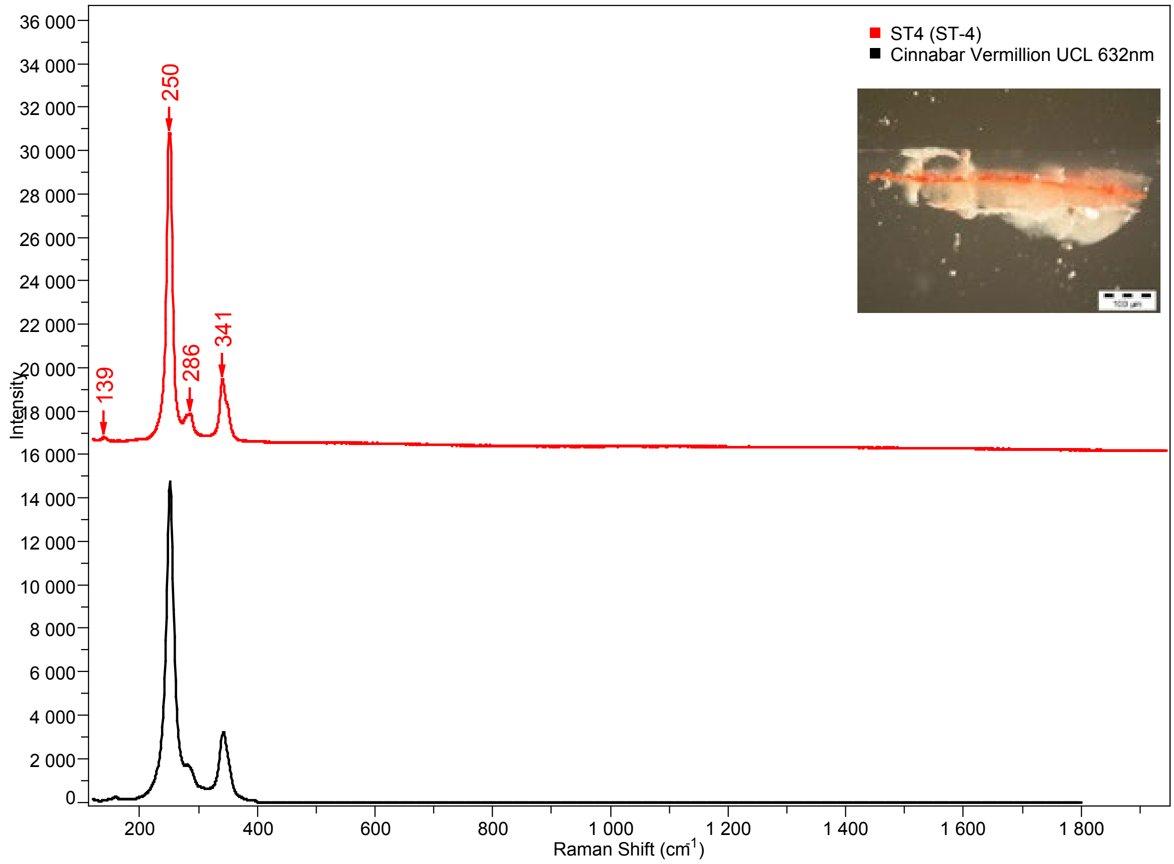

Fig. 244: Raman spectra of sample ST-4 and cinnabar; cross-section of the same sample

In various samples the presence of protein-based media could be detected. This implies that at least to some extent, the Koguryo mural paintings were made using a *lime-secco* or *secco* technique. Evidence found by the conservators for working on fresh plaster indicates a mixed technique like *lime-secco*. Protein was found e.g. in sample ST-1 (Fig. 245), characterised by its IR bands[7,8] at 3400-3200 cm^{-1} (N-H stretching); 3100-2800 cm^{-1} (C-H stretching); 1660-1600 cm^{-1} (Amid I); 1565-1500 cm^{-1} (Amid II) and 1480-1300 cm^{-1} (C-H bending).

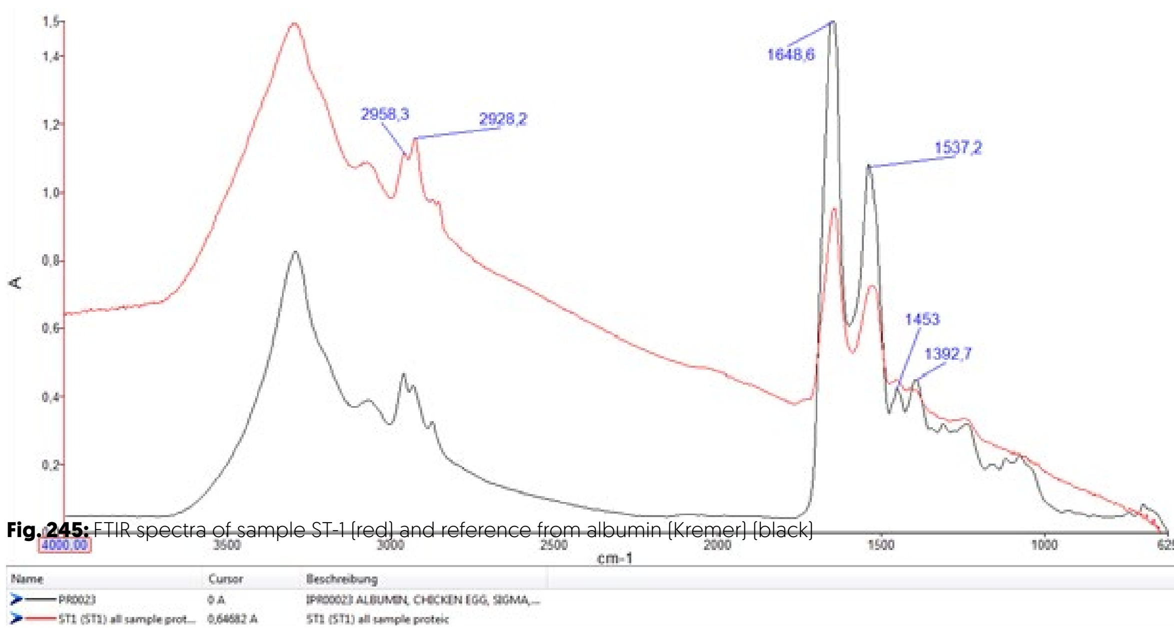

Fig. 245: FTIR spectra of sample ST-1 (red) and reference from albumin (Kremer) (black)

Ester wax was found in sample ST-3 from Susan-ri, as seen in the following figure. The spectrum of wax is characterised[7,8] mainly by its strong CH_2 stretching vibrations in the regions 3000-2800 cm^{-1}. Furthermore, this spectrum also schows the C=O stretching band at 1740 cm^{-1} for ester waxes, the C-H bending at 1463 cm^{-1}, the C-O stretching in the region 1300-900 cm^{-1} and the C-H torsion at 722 cm^{-1} in a characteristic duplett . In another case alkyd resin could be identified.

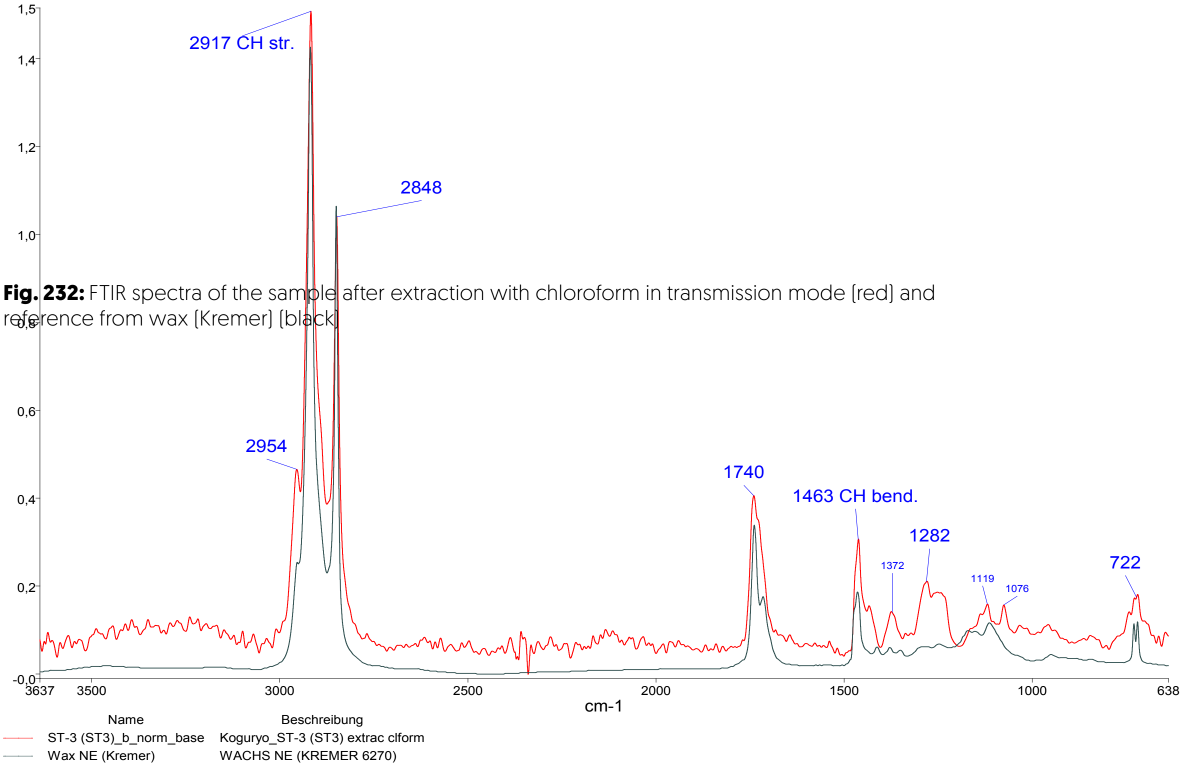

Fig. 232: FTIR spectra of the sample after extraction with chloroform in transmission mode (red) and reference from wax (Kremer) (black)

A spectrum from the sample TT-1 from Tokhung-ri Tomb shows besides the presence of a protein, the characteristic bands of an alkyd resin, probably from a former consolidation treatment: a broad hydroxyl group peak centred at 3440 cm^{-1}; CH_2 asymmetric and symmetric stretching at 2928 and 2856 cm^{-1} and its bending peaks at 1461 cm^{-1}; a strong C=O stretching band at 1731 cm^{-1}; C-O and fingerprint peaks at 1268 cm^{-1} (strong, likely due to esters) and 1122 cm^{-1}. The aromatic rings in the polyester backbone can be identified[9] by the strong unsaturated ring in-plane deformation peak at 1071 cm^{-1} and the out-of-plane deformation peaks at 743 and 706 cm^{-1} as seen in Fig. 233.

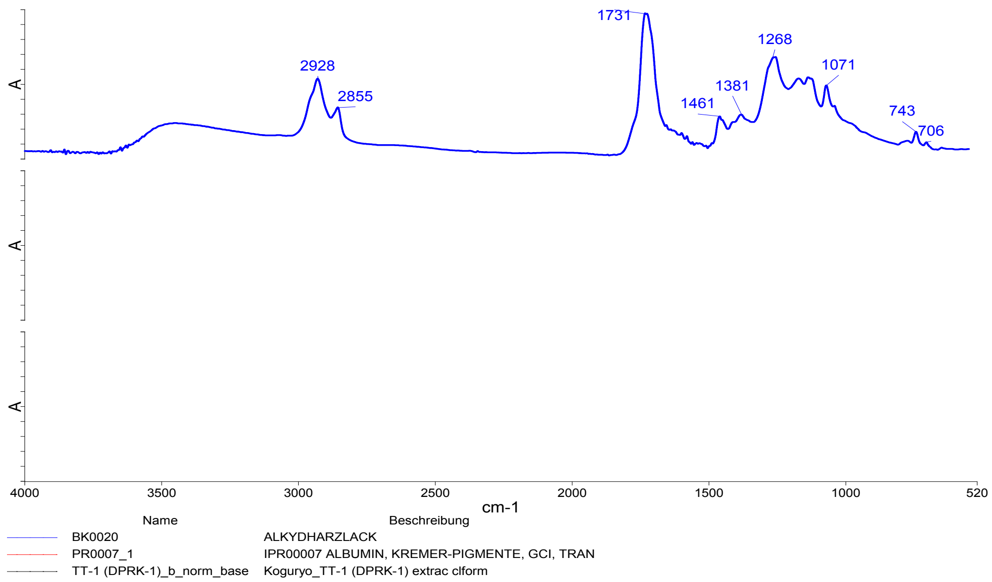

Fig. 233: FTIR spectra of the sample TT-1 after extraction with chloroform in transmission mode (black) and reference from alkyd resin (blue) and albumin (Kremer) (red)

In some samples, other organic substances were detected in the decorative surfaces, sometimes attributed to recent conservation interventions, their accurate identification was not in all cases possible. Taking into account the small quantity of each sample available, complimentary analysis of binding media is proposed in order to validate or reject our conclusions about the painting technique.

The table below summarises the results obtained on the painting technique.

Tab. 15: List of samples with pigments, their description according to former documents and the results obtained at the Rathgen-Forschungslabor

Tomb	RRL name	Description by sampler and former characterisation	Characterisation at the Rathgen[5,6,7,8]
Susan-ri	ST-1	Described as green but is actually red. Yellow ochre, carbon black and calcite.	Red layer 200 μm not mixed with Ca. Ochre, protein, calcite, silicates. Other organic material (probably wax).
	ST-3	Carbonation on black layer.	Black layer 50 μm. Ester wax. Calcite.
	ST-4	Red bright paint layer.	Red layer 10 μm. Cinnabar and protein (typical for *secco*). The paint layer is very thin and does not look like *fresco*. Protein, $CaCO_3$ (calcite and aragonite) and aluminosilicates.
	ST-5	Red bright paint layer.	Red layer with 40 μm. The paint layer does not seem to be applied *fresco*, probably *secco*. Hematite, protein and wax. Other organic material (probably resin and cellulose).
	ST-8	Black stroke above white background.	Black layer 30 μm. Ca mixed with the paint layer, but does not look painted *fresco*, support and paint layer clearly separated. Carbon black.
	ST-9	Suspected black over-paint. Described as bitumen on white.	Black layer 40 μm. Does not look painted fresco as the separation between support and paint layer is very clear. Carbon black, traces of calcite, protein.
	ST-17	Red and black paint layer on plaster (probable reconstruction)	Only red paint (up to 40 μm thick) and not black. Hematite, rutile.
	ST-23	Drip of paint or altered fixative on the cement.	Red layer up to 20 μm thick, too thin and not mixed with support (typical *secco*). Hematite.
	ST-25	Suspected over-painting of red on red.	Single red layer with 40 μm. Does not look like over-painting or *secco*. Aragonite, quartz, hematite.
	ST-27	Described as white paint but more likely red on black with white deposition.	Black layer 10 μm, red one with 30 μm and white one up to 300 μm. Calcite. Black and red paint layers not applied in *fresco*.
Yaksu-ri	YT-1	Dark red paint layer. Hematite on calcite.	Red layer up to 40 μm covered by a white layer (deposit/efflorescence). Hematite, calcite, aluminosilicates, protein and beeswax. Ca in the render and as deposit/ efflorescence on the paint layer.
	YT-2	Yellow paint layer. Yellow ochre.	Yellow layer 50 μm. Goethite, protein and wax. Support of calcium.

Yaksu-ri (contd.)	**YT-3**	Black paint layer. Carbon black on calcite.	Black layer 10 µm with whitish layer on top. Protein, carbon black, calcite, aragonite. White layer is Ca.
	YT-4	"Blue" from Blue Dragon. Carbon black on calcite.	Black layer 10 µm. Calcite, protein and other organic material.
	YT-8	Dark red paint layer.	Dark red layer 150 µm. Hematite, calcite and an organic material.
	YT-9	Probable over painting.	Red layer 10 µm and on top white-transparent one of about 20 µm. Hematite and an organic material.
Tokhung -ri	**TT-1**	Red paint layer. Hematite, magnetite and carbon black.	Red layer 20 µm. Hematite, protein and alkyd resin.
	TT-2	Yellow paint layer. Goethite on calcite.	Yellow layer 10 µm. Goethite, calcite, protein, traces of other organic material.
	TT-4	Black paint layer. Hematite, carbon black on calcite.	No paint layer is seen in the cross-section. Organic material.
	TT-5	Yellow paint layer. Goethite, calcite, siloxane.	Red layer 50 µm. Goethite, protein and calcite.
	TT-7	Blue pigment. Green earth, carbon black and calcite.	Black layer 30 µm. Carbon black, indigo, calcite, biotite.
	TT-8	Dark red paint layer with white wash. Hematite, magnetite and calcite.	Red layer 40 µm. Hematite, calcite, biotite, protein.
	TT-15	Yellow on dark background, probably over-paint.	Yellow layer ca. 10 µm and a black 10-20 µm. Goethite.
	TT-16	Yellowish coating on dark red paint, maybe over-paint on a lime render.	Red layer 40 – 200 µm, on top, a white 300 µm. Hematite, traces of calcite.
Anak III	**AIIIT-2**	Red over-painting on red.	Red paint layer 10-30 µm. Hematite, calcite.
	AIIIT-7	Green pigment.	Green paint layer 20 µm. Albite, calcite, lazurite (Na, Si, Al) and an iron pigment, probably goethite (which is yellow).
	AIIIT-12	Yellow pigment.	Yellow paint layer 20 µm. Minium and cinnabar. These pigments degrade when applied ***on a fresco*** and the paint layer is not mixed with Ca, so is it probably a ***secco***. No binding media analyses were made for this sample.
	AIIIT-13	Red pigment and salt efflorescence.	Red layer 50 µm with white deposition 10 µm. The paint layer is mixed with Ca, but this is not part of the render, rich in Na, K, Si and Al (aluminosilicates). Cinnabar and lead white or minium. No binding media analyses were made for this sample.

3.2. Composition of mud incrustations and suggestions for their removal

Fig. 246 shows the sampling spot of sample ST-10 and the appearance of the mud incrustation.

In the render of the samples it was possible to identify[7, 8]: calcite - $CaCO_3$, magnesium carbonate – a magnesium containing components, possibly dolomite ($CaMg(CO_3)_2$), aluminosilicates enriched in Mg and calcium phosphate ($Ca_3(PO_4)_2$). Carbonate and phosphate based materials were identified in the render layers from the investigated samples. In one sample, gypsum was also found in the render layer.

Regarding the mud layers, aluminosilicates were detected in all samples. Furthermore, it is likely that clay minerals (such as Kaolinite) are present in most of them and calcium phosphate in others. An example of a mud sample from Susan-ri containing calcite and kaolinite is shown in the figure below.

Fig. 246: Sampling spot of sample ST-10

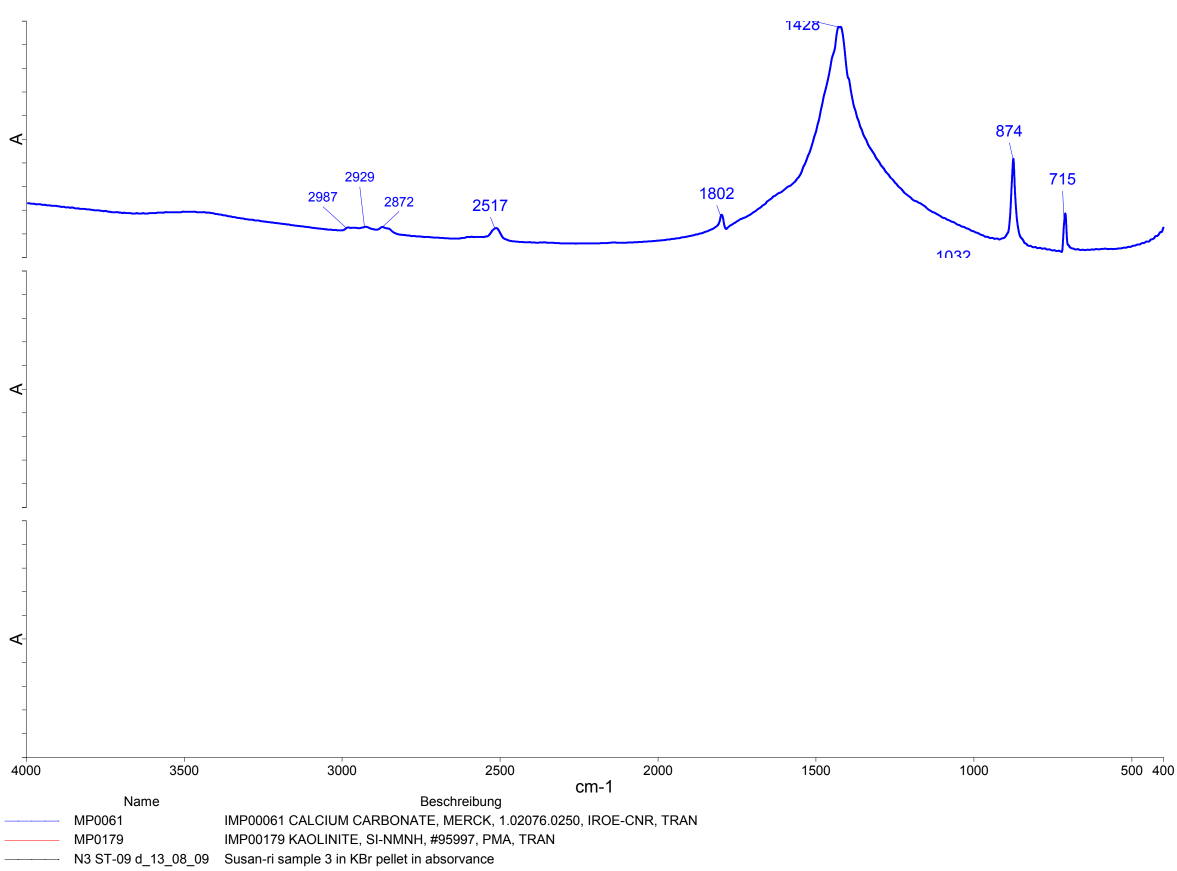

Fig. 234: FTIR spectra (KBr pellet) of render sample ST-10 (former N ST-09), calcite and kaolinite

Considering that calcium carbonate and phosphate seem to be major constituents of both render and mud layers, a chemical treatment for removing the mud should not be based on a reaction with calcium carbonate or phosphate, as this could endanger the render layer and the paint strata.

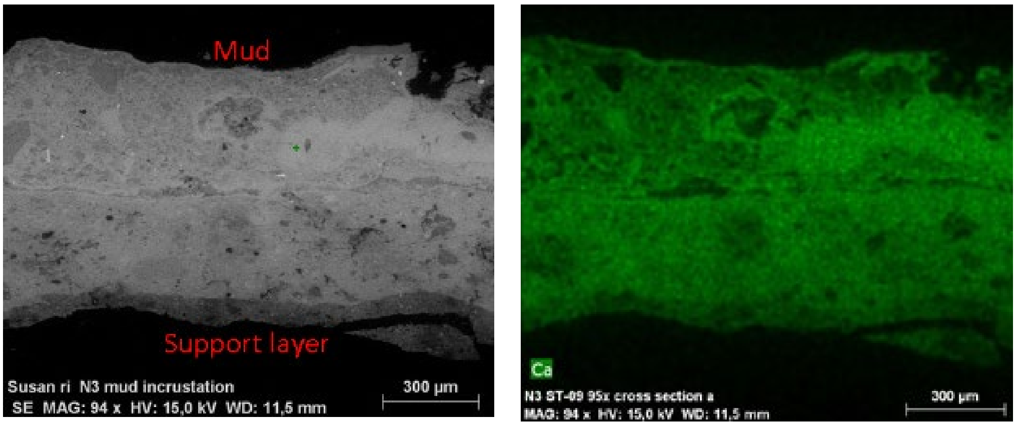

Fig. 235: Secondary electrons image and mapping of element Ca of sample ST-10 (former N3 ST-09)

A detachment of the mud without damaging the paint and/or render layer might be achieved with an ultrasonic spatula. The ESEM image of the cross-sections suggests indeed that the render layer is more cohesive and therefore more resistant to the mechanical cleaning than the mud layer that could be easier removed.

A cleaning method such as the ultrasonic spatula prevents the migration of dissolved products inside the mural paintings, which are likely to occur with a wet chemical cleaning method. With the so-called wet chemical applications, it is difficult to control the depth of penetration and interaction in paint layers and substrate.

Chemical reconversion e.g. by ammonium carbonate is inefficient as this salt is normally applied for re-converting sulphatation layers (gypsum) into calcite.

3.3. Biological infestation on the paint layer and suggestion for their cleaning

Two so-called "blackening" fungi (*Ulocladium spec.* and *Acremonium strictum*), commonly found in wet environments were identified. Furthermore, a health-related fungus was found (*Stachybotrys chartarum*). This is known to produce, under wet conditions, mycotoxins (*Trichothecene* produced by *Satratoxine*), which, if widely spread, cause headache, neurological impairment, asthma, immune suppression and nose bleeding. These can be avoided by using gloves, P 2/3 mask, protective clothing. HEPA-cleaning, careful disinfection and later ventilation should also be considered. *Stachybotrys chartarum* and *Acremonium strictum* inhabit materials rich in cellulose which should therefore be strictly avoided in future conservation interventions.

After a mechanical cleaning by soft brushes and HEPA vacuum-cleaner (the residues need to be disposed outside the place), a disinfecting solution (70 % Isopropanol or 3 % quaternary ammonia compounds) and a fungicidal solution (3 % Isothiazolinone, for example Parmetol DF 12, Schülke & Mayr) should be applied. In any case, any treatment should be accurately tested before applied widely at the mural paintings.

The microorganisms were observed under the microscope directly on the surface of sample and prepared as cross-sections.

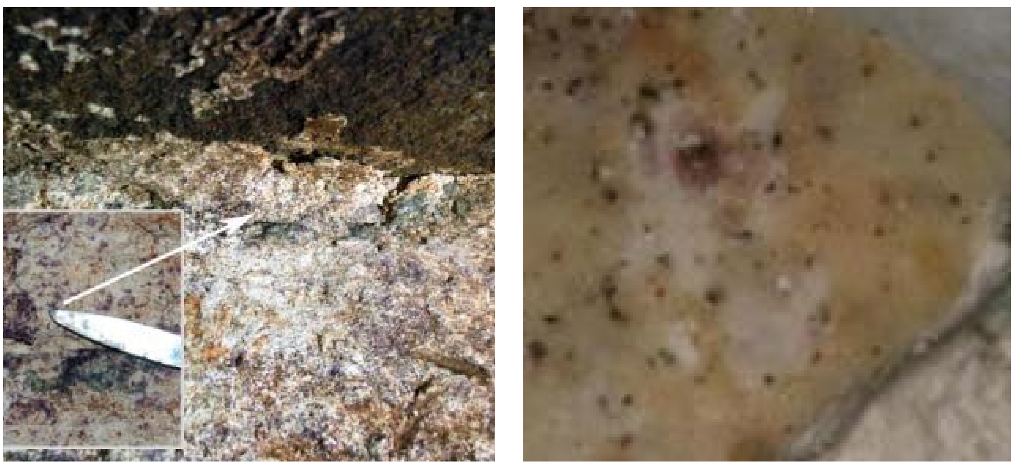

Fig. 236: Photos of sampling spot and microscope photo of the sample YT-13 (50x)

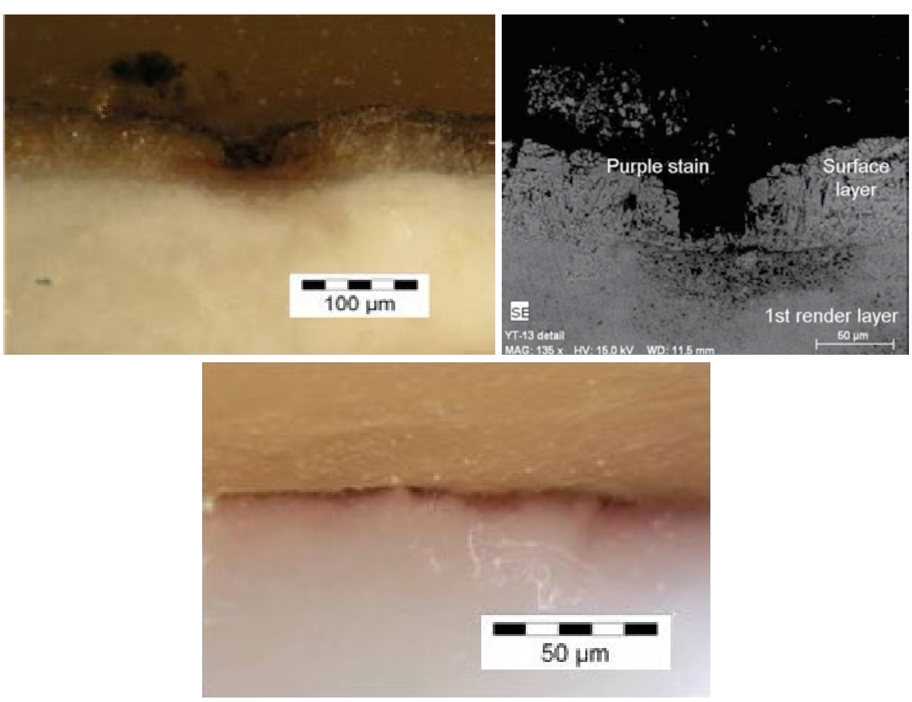

Fig. 237: Photo of cross-section and secondary electrons image of sample YT-13 and cross section of sample YT-16

The purple stains due to the microorganisms penetrate the surface layer of about 50 microns reaching the render. On the other sample, the purple layer lays on the surface and is only few microns thick.

The biological organisms seem to grow on a matrix of aluminosilicates enriched with iron and potassium and mixed with some calcium and magnesium material.

3.4. Environmental conditions

The temperatures inside the tomb are buffered with lower amplitudes than outside and some delay, i.e., warmer in winter and cooler in summer and they do not fluctuate as much in the diurnal cycle. The further inside the tomb, the larger the buffering effect on both temperature and humidity.

Fig. 238: Air temperature in 1st corridor (red) and 2nd corridor (green) and surface temperature of the paintings' walls in the last room (yellow and purple) (see Data Loggers 1 and 3)

The so-called glass barrier installed in 2001 has no thermal effect, on both sides of the glass, the same temperatures were recorded over most of the investigation period (Fig. 238). It also had no impact on the moisture movement, being sometimes covered by condensation of waters on the one, sometimes on the other side.

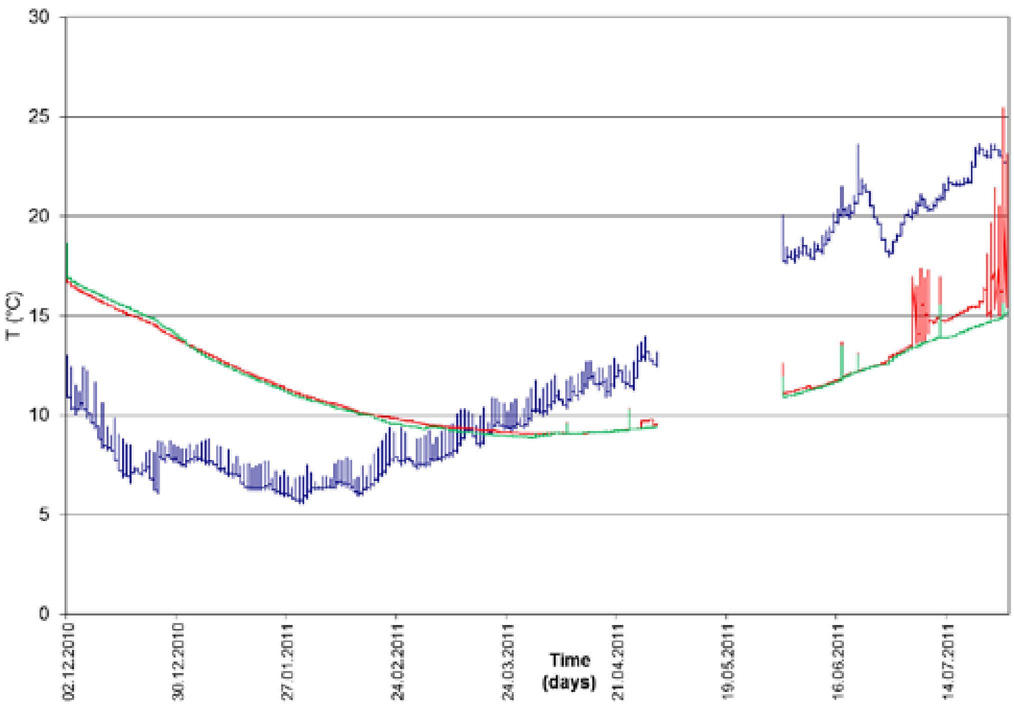

Fig. 239: Air temperature in 1st corridor (blue) and glass temperature in the inner room on visitors' side (red) and paintings side (green) (see Data Logger 2)

The sensors are very precise, for instance in the period around July 2011, higher fluctuations of the temperature were detected on one side of the glass than on the side of the mural paintings. These fluctuations were probably induced by the presence of visitors.

With the values from temperature and humidity it is possible to calculate the dew point (DP), a very important parameter to limit water intruding and condensing on solid surfaces, such as the mural paintings. If the temperature is lower than the dew point, vapour will condensate on solid surfaces in liquid form, which is highly damaging for the paintings. As seen in Fig. 239, the dew point distance gets very narrow especially in the winter and early spring, which implies that surface condensation and hence water intake (from the atmosphere) can take place on a regular pace.s

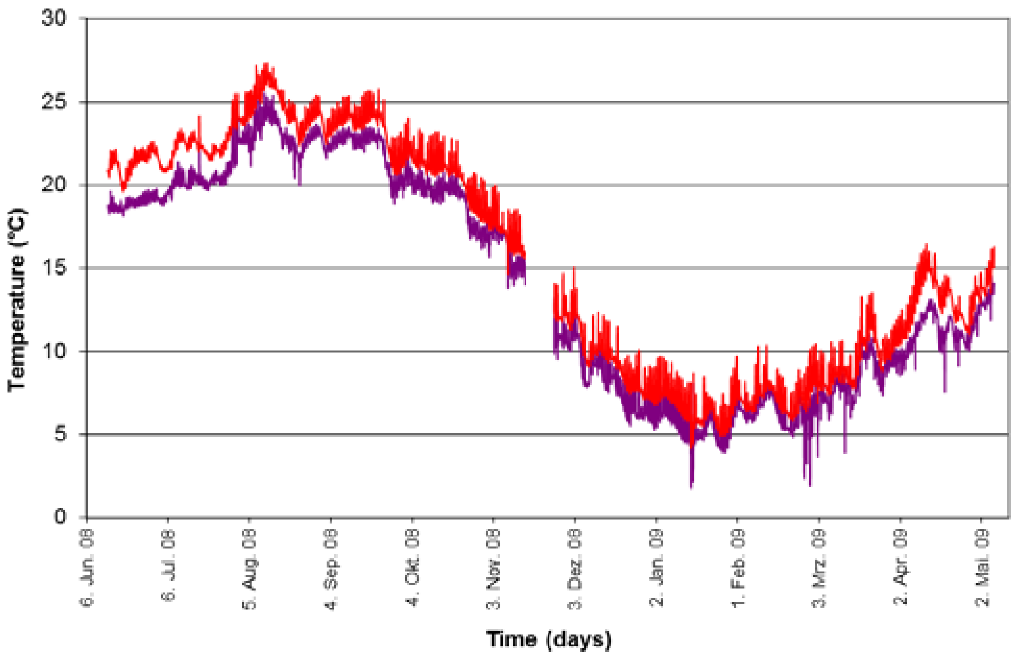

Fig. 240: Dew point (purple) and air temperature in the 1st corridor (red) (see fig.1 – Data logger 1)

Fig. 241: Water-covered glass barrier at Yaksu-ri (2008)

Fig. 247: Building the new glass barrier (2013)

After reassessing the climatic situation in December 2013, it is recommended to purchase and re-install a climatic monitoring system, to record regularly values for relative humidity, air temperature and selected points of surface temperature. The system should be able to work reliably under conditions of very high humidity. This is generally a challenge for all capacitive humidity sensors, which tend to undergo saturation at high humidity. However, through regular maintenance and control, even quite simple stand-alone loggers could possible fulfil this task.

It is underlined that only on the sound basis of long-term climatic recordings, indoor and outdoor, further decisions to deal with the humidity stress and its implications e.g. on the microbiological causes of further weathering can be taken.

The National Team was encouraged to collect and provide also the data from the official weather station near Kangso, as these data have been quite comparable to those measured at the weather station in Susan-ri.

As preventive conservation measures for immediate implementation the following were recommended:

- Insulate and seal steel entrance door (Styrofoam)
- Insulate glass doors in the buffering corridor through double glazing and seal
- Close gaps between doors and floor by adding rubber bands on the bottom of the doors
- Possibly install a farther glass door in the corridor

Stand-alone, battery-powered and simple RH-/T loggers are preferred over the wired systems, which have failed in the past. Wireless sensor networks (and GSM-based) are

Fig. 248: New glass barrier allows for low key visual access to the decorated surfaces

not yet applicable under the present conditions. Experience has shown, that in all tombs, water-proof RH/T loggers, o-ring sealed, which are suited for high RH and harsh environments are needed. It is proposed to select water-tight membrane filter covered RH sensors. Devices should have an IP66/67 rating. Specifically, IP 66 means that a device is dust proof and protected from strong water jets. IP 67 means the device is dust proof and continues proper operation after immersion in water one meter deep for 30 minutes. Accuracy of RH of 2-3% and of T measurements in the order of 0.5 K seems under the harsh environmental conditions in the tombs acceptable.

It may be expected, that such combined measures can have a significant impact on temperature gradients, and hence, humidity gradients between the tomb chamber and the external environment. Any resulting effect should be subject to control by the recommended environmental measurements on long term.

4. Conclusion

The painting technique of at least some of the Koguryo Murals was identified as a *lime-secco* or *secco* technique. Farther complimentary analyses could help validating, checking these conclusions and defining more accurately the techniques used.

The hard mud incrustations, constituted mainly by aluminosilicates, had to be removed mainly due to their vast extension and drastic visual impact. The use of chemicals should be avoided as these would also dissolve the render. A soft brush method is advisable in such cases.

The biological contaminations identified, seem to affect the paintings just superficially but are dangerous for human health. If the case of such infestations, workers and other personal entering the tombs should use proper protection and the microorganisms should be eliminated with appropriated disinfection and fungicidal solutions in combination with soft brush mechanical methods.

Atmospheric monitoring of tombs is a precondition of preventive conservation, especially on the rooms with mural paintings. It is advisable that temperature and humidity are carefully and systematically monitored and measures taken, to separate and isolate the tombs from the outdoor environment and reduce the fluctuation of temperature and humidity.

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Annexes

Glossary and Terminology

by Rodolfo Lujan Lunsford

The following vocabulary was adopted in order to prevent the misinterpretation of words, subjects, issues, concepts, and actions describing the stratigraphy of a mural painting, along with the terminology employed for describing a given alteration or action produced.

1. Technique of Execution	
A support is composed of walls (upright structures of stone serving to enclose and bear a specified weight, strain, prasure, etc., forming the sides or inner partitions of a building) and vaulting or roofing (the covering of the structure).	The support of the Koguryo mural paintings and specifically those of the Susan-ri Tomb are the walls and vaulting made of rough and dressed stone masonry and built semi-underground. The stone blocks of the wall are bound with mud-based mortar, the open masonry joints are pointed and a roughing-in layer or rendering was applied employing lime-based mortars. Mortar: a mixture of inorganic hardening binder and inert materials or aggregates that, mixed with water, forms a substance of plastic consistency able to stick together or cohere miscellaneous building materials such as stone, brick, etc. Mortars are composed of a binder mixed with aggregates that prevent the excessive shrinkage of the binder and some additives that improve their final properties. A binder is a material capable of sticking together or providing cohesion to heterogeneous materials such as sand, crushed stone, straw, etc. Traditional masonry binders were mud/clayey soil, gypsum and lime (calcium hydroxide). Aggregates or fillers are incoherent organic or inorganic materials of relatively fine grain that reduce the binders' high shrinkage coefficient, constituting an internal support and rigid skeleton. Additives are organic materials that, added in small quantities, improve the characteristics of a given mortar or render.
Pointing is the sealing of open joints in masonry.	The finishing of open joints of masonry at surface level. The joints are filled with a fine mortar that is further compressed to avoid water infiltrating into the wall. The pointing of the stone blocks in the Susan-ri Tomb was done with a mixture of slaked lime putty, clay, ash and sand.

The roughing-in or rendering layer is a levelling layer reducing irregularities in a wall.	The application of a preliminary levelling layer to reduce superficial irregularities in the support with a semi-liquid render applied to the surface. This rendering also has the function of providing sufficient roughness to the wall's surface so the preparatory layer(s) can be strongly anchored to it, preventing excessive absorption of the render's binder by the support, thereby weakening it. The roughing-in layer of the walls in the Susan-ri Tomb was made with a mixture of slaked lime putty, crushed limestone and chopped rice straw and husks.

Preparatory layer(s) is (are) a coating(s) applied onto the irregular surface of a structure in order to level it and protect it from the environment. The preparatory layer(s) can be composed of one or several renders that decrease in thickness towards the surface and can be made of different materials.	The preparatory layer(s) of the Susan-ri Tomb were made out of a mixture of slaked lime putty, crushed limestone, sand and chopped rice straw and husks. The preparatory layers comprise from one render of a few millimetres in thickness (3-4) to two or three applied in successive coatings with a thickness of up to 4-5 centimetres. During the application of each layer the render was apparently compressed and polished. A render is a coat of plaster applied to brickwork, stonework, etc., and in general to masonry to create a uniform surface. It is composed of an inorganic binder (clayey soil, gypsum or lime), an aggregate (organic and/or inorganic) and as the case may be organic and/or inorganic additives. The proportions as well as the grain size of aggregates vary in relation to the thickness of the layer.
Joins in the render	Given that the surfaces on which the preparatory layers are applied are larger than the height of a man, scaffolding is necessary. The renders are applied from the top of the building down the walls in accordance with the heights of the scaffolding and the width provided by the workability of the render. Horizontal joins are produced on a surface plastered at a single time and usually correspond to the rough height of one storey of the scaffolding. Vertical joins are produced by the area provided by the workable application of the render within one storey of the scaffolding. The vertical end of a rendered area overlaps the subsequent one.

The paint layer is the 'skin' of the image and is a mixture of pigments and a medium. The paint layer is spread over the final preparatory layer and follows a series of operations discernible within its stratified structure.	The pictorial layer applied onto the final render in the Susan-ri Tomb comprises a white ground on which the divisions of the architectural ensemble and images and preparatory drawings were executed before spreading on the pigments and final drawing. **The ground** is a white coating of lime-wash spread over the surface as a finishing layer. **The preparatory drawing** is the drawing executed on the render or whitewash before it is painted. The artist carries out a general sketch on the surface so that an idea of the composition and proportions is acquired. **The division of the surfaces with a snapping cord** is done according to the images to be painted by dividing the surfaces of the walls with vertical, horizontal or angled straight lines. A string is soaked in paint, fastened at both extremities, and 'snapped' onto the surface, leaving the imprint of the line. **An incised drawing through a cartoon** is the line obtained by tracing with a point through paper onto the fresh render and is characterised by a thin rounded groove or furrow. **A direct incised drawing** consists of lines incised directly onto the render with a pointed instrument. The lines' contours have clean, sharp edges if executed on fresh render, whereas the edges are broken and irregular when done on dry plaster. **Pigment** is colouring matter usually in the form of an insoluble powder. Pigments can be inorganic (of mineral origin and found in nature or artificially produced) and organic (obtained from substances contained in animals or plants or produced by synthesis). **The medium or binder** is the binding material or vehicle that holds together pigment particles in paint. Binding media are organic (oil, egg, casein, etc.) and inorganic (calcium carbonate). **The final drawing, shadows and highlights** are the concluding actions of painting by the juxtaposition or superimposition of paint.

2. State of Preservation

Structural cracks (related to the structure) involve the breakage or splitting of a building, usually without the separation of the parts. This type of crack passes through the entire structure.	**Assessment of the structure** means examining sub-soil subsidence linked with a building's irregular construction, causing differential settlements and thus forming cracks. **The load** is the appreciable tensile stress as a result of loading and includes the excessive weight of the superstructure exerted on determinate areas of the fabric, e.g. the walls, that cannot support the load. **Plant roots** penetrate into the structure causing separation and breakage.
Mechanical cracks (related to the preparatory and paint layers) are fractures or chinks found in a given layer within the structure or entirely crossing it.	**Thermal expansion**: materials are subject to daily and seasonal temperature cycles, and they expand with the heat and contract on cooling producing deformation and cracks. Shear stresses are produced in the interior. **Differential movement**: high compressive strength and modulus of one material adhering to a weaker one and resulting in the transmission of stress and failure of the weaker material. **Sub-florescence** of soluble salts beneath layers means that they expand and exert pressure that in the long term forms cracks and leads to disintegration.
Cracks due to drying are formed by the contraction of the binder due to rapid desiccation or the excessive content of water or medium in the mixture.	**Cracks in the preparatory layers:** the water content is higher than necessary in a render spread on the walls, resulting in excessive shrinkage with the consequent formation of cracks upon drying. **Cracks in the paint layer:** an excessive binding medium was employed during the preparation of the paint or due to rapid exsiccation.
Lack of cohesion means the loss of bonding properties within a given material resulting in powdering.	**Powdering of preparatory layers:** disintegration or breakage (loss of binding properties) of the binder (lime) in the render and reduction in compactness within the aggregates due to soluble salt sub-florescence, development of micro-organisms, etc. **Lack of cohesion of the paint layer**: weakening by disintegration of the binding medium as a result of abrasive action, biological activity, soluble salt formation, etc. **Leaching of pigments:** due to binding loss and subsequent dispersion/diffusion due to water run-off over the surface.

Lack of adhesion means the separation of interfaces between one material and another or amongst layers due to a loss of binding properties or mechanical action.	**Of the preparatory layers:** due to mechanical stresses from the superstructure, salt sub-florescence, plant roots, etc. **Separation/detachment** of the roughing-in layer or renders occurs when they are separated from the wall or from each other. **Separation with deformation:** the renders are bowed in the shape of large pocket or bulge. **Of the paint layer:** separation from the final preparatory layer. **Scaling/flaking** due to force exerted on the surface by contraction of fixatives or deposits. **Bubble-shaped** due to salt sub-florescence, or fast drying of the low porosity or coated paint layer that exerts pressure and causes deformation without breakage.

Lacunae/losses: interruption or discontinuation of the visual fabric seen as an extraneous body and limiting the natural succession or unity of the surface.	Of the preparatory layers: discontinuation of the render at varying depths and dimensions. In-depth lacunae: complete loss of preparatory and paint layers exposing the support due to mechanical breakage. Superficial lacunae: partial loss of render and paint layer due to erosion or mechanical action (misuse of tools or vandalism). Of the paint layer: disruption of the patina and paint layer at varying depths and dimensions. Wear of the patina is due to abrasion. Abrasion (superficial lacuna) is due to wear or loss of minute scales of paint beneath which a part of the pigment layer or at least the original render remains with pigment traces. In-depth lacunae: complete loss of paint layer revealing the render.
Surfaces soiled with incoherent deposits	Mud, soil and clayey concretions naturally carried or driven from the mound or from the walls of the tomb and subsequently deposited onto the surfaces as a result of water seepage.
Coherent deposits on surfaces	Hard mud and calcium carbonate incrustations formed by chemical processes due to the presence of water (see below). The so-called hard mud incrustations consist of mud and soil included (englobed) in a calcium carbonate matrix.
Micro-organisms and stains on surfaces	The excessive moisture inside the Tomb has given rise to the development of micro-organisms that have produced stains on the surfaces as a result of their metabolic functions.

3. Main Causes of Deterioration

Moisture is the most important of all the causes of deterioration because of its frequent occurrence and its role as an intermediary in many forms of deterioration.	Condensation of water vapour is the formation of liquid water from the water vapour contained in hot air on a cold surface and is due exclusively to the cooling of the air. The temperature of the air drops to a point at which it saturates (dew point) on surfaces that have a lower thermal value. Capillary action: water rises against the force of gravity inside the pores of porous materials and takes place from the water-table in the sub-soil, from dispersed water, and from rain. It produces erosion, which is the disintegration of constitutive materials by wet-dry cycles. Infiltration of water: water penetrates through walls or roofs through the capillary absorption of construction materials and is caused by rain and stagnant water. Presence of hygroscopic materials: these absorb water by osmosis, which is the tendency of a liquid to pass from a lower concentration in a solution to one of higher concentration, so as to equalise concentrations.
Chemical processes occur due to the presence of water.	The corrosion of building materials occurs only when buildings are wet and is a reaction in which a material is attacked by a substance in its environment and converted into an unwanted compound. Superficial incrustations are deposits of insoluble salts on the paint surface and are due to the passage of water through the render and paint layer, to water run-off over the surface, or to condensation moisture occurring as deposits. This process is favoured by chemical changes into more soluble compounds that are transported by water and upon evaporation form different crystalline arrangements. For example, calcium carbonate, which is the main constitutive of lime-based renders, is formed by the reaction of carbon dioxide and calcium hydroxide becoming insoluble in water. Moisture provokes an inverse reaction when carbon dioxide cannot react with calcium hydroxide any more. Carbon dioxide contained in the air reacts with water and forms a weak acid. This acid, carbonic acid, slowly dissolves the calcium carbonate in the renders, transforming it into calcium bicarbonate. Upon the loss of water and a new reaction with carbon dioxide, calcium bicarbonate changes once more into insoluble calcium carbonate containing other deposits such as dust, soil, sand, etc.

Mechanical stress: the humidity in the walls causes the movement of soluble salts through solution and re-crystallisation within the structure.	Construction materials are porous (porosity is the fraction of the total volume of a solid that is occupied by pores, or the empty spaces in a solid mass) and permeable (permeability is the ability to transmit liquid or gas from one place to another) and naturally contain soluble salts. The surface of the painted render (wall) is the most susceptible to moisture exchange because this is where major processes occur such as condensation, evaporation, and the movement of water in its liquid state. Soluble salts (naturally contained in the constitutive materials and originating from the soil or the atmosphere, from the animal kingdom, or from obsolete materials employed for conservation purposes) are dissolved by water and are transported through the pores of the structure to other areas by capillary action. Salt crystals while in their liquid state (deliquescence) do not cause harm, but upon evaporation they re-crystallise (become solid again) beneath the surface of the wall or render (sub-florescence) or above it (efflorescence), causing destruction (erosion) of the components if the pores are full of salt crystals.
Bio-deterioration is caused by biological attack and is always associated with moisture.	Micro-organisms in association with moisture (some species need light for growth, such as algae and lichens, while others need a rich organic substrate such as bacteria or fungi) can develop on an inorganic substrate without light (certain species of bacteria and fungi), causing staining and the disintegration of materials due to their metabolic functions. Superior plants grow above the ground and their roots can cause the splintering of the structure.

4. Former Interventions

Obsolete fillings and films carried out during former treatments do not meet with contemporary requirements and are damaging.	Cement fillings of lacunae in renders, masonry cracks and joins that also partially cover painted surfaces are incompatible with the original materials. Cement is unsuitable for the conservation of ancient fabric for the following reasons: Cement is too strong (high compressive strength and high modulus): in the case of differential movement, the stress will be transmitted to the older sections, which will fail; It has a high thermal expansion coefficient, which will result in stress and damage to the old 'weak' masonry; It forms soluble salts, whose setting and leaching takes place even a long time after setting when they come into contact with water; It has a low porosity consisting of very small pores that hinder the movement of moisture in masonry and do not allow evaporation beneath the cement layers. Impermeable clay fillings obstruct the porosity of lime-based renders and the passage/exchange of moisture within the structure.
Compatible fillings applied during earlier treatments do not cause damage.	Hydrated lime fillings similar to the original are not damaging to lime-based renders, but their appearance is much more compact and lighter in colour.
Renders adhered with cement	Collapsed fragments of painted renders reassembled and re-adhered to the wall with cement plaster.
Fixatives	Applied with the aim of protecting the surface but have proved damaging because obstructing the porosity of the painted surfaces does not allow moisture exchange and results in discolouration and hardening.
Pictorial integration	Over-painting or repainting carried out on abraded painted areas with the intention of reinforcing the images. Reconstruction: small lost areas reconstructed with the aim of providing a better understanding of the image.

5. Present Intervention

Fixation: the re-adhesion of separated/detached interfaces of the preparatory or paint layers or with adjacent layers.	Grouting: injections of liquid mortar similar in composition to the original render. Injections of thinned liquid mortars compatible with the original render and paint layer.
Consolidation: the strengthening of incoherent particles that have lost their bonding.	Preparatory layers: the linkage between the aggregates and powdery binder is reinforced by injecting compatible materials with the original binder. Paint layer: the restitution of the links between particles of pigment by replacing the lost medium.
Removal of obsolete former interventions: damaging or outdated fillings of the preparatory layers are removed by mechanical means.	Cement fillings: well-known to be a damaging material, especially when wet and forming derivatives that leach on original materials. Impermeable clay fillings do not allow proper water vapour exchange between the wall and the exterior.
Removal of obsolete former interventions: carried out on the paint layer employing wet methods.	Fixatives obstruct the permeability of the surfaces. Over-painting and reconstructed lost areas of painting: in most cases subjective interpretations that distort the formal qualities of the images.
Filling of lacunae, cracks and losses: lost constitutive sections which are filled with similar and compatible materials.	Losses of renders or the paint layer are filled with similar and compatible materials to the original according to the stratigraphy and the principles established for the problem of re-integration. Under the paint layer level: the renders should match in colour and texture the original and not be integrated into the images. At the paint layer level: limited in surface area and capable of being ethically reconstructed.
	Re-pointing of masonry is the re-sealing of joints in the masonry with a similar material to the original mortar.
	Edging the borders of lacunae is a treatment that employs a similar material to the original on the borders of lacunae, sealing these before fixing or as a reinforcement or a filler of gaps.

Cleaning: the removal of extraneous deposits from the surfaces revealing the present state of the original materials.	The choice of materials and methods depends upon the nature of the substances to be removed and the resistance of the underlying layers composing the mural painting. Dry cleaning: there is the risk of damaging the paint layer or altering the condition of the surface, but through careful manipulation of tools and instruments the result can be adequate. Wet cleaning: the primary bonds of the solids covering the surface are broken by the reaction of the chemical cleaning agents (bases and acids) or by exchanging ions, allowing their removal.

Pictorial presentation: the minimisation of disturbances caused by losses of the pictorial text, restoring the image to the maximum extent possible while respecting its authenticity as a creation and an historical document.	The unity characteristic of mural paintings means that they should be taken as a whole and not as the sum of their parts. This should determine the interpretation of any losses and the way to treat them. **Wear of patina and paint layer:** dampening of the visual tonality of abrasions by darkening the lighter areas. **Reconstruction of the paint layer with** *tratteggio*: this consists of thin, parallel and vertical lines that restore the pictorial fabric when seen from a distance while keeping the *tratteggio* easily identifiable as aiming solely at restoring the painting's unity. **Dampening of visual tonality:** losses in the paint layer and renders not subject to reconstruction, darkening the lacunae so as to push them backwards and allowing the re-emergence of the pictorial image.

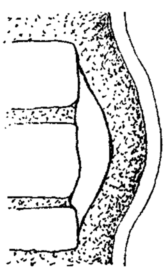
Visual Nomenclature

by Rodolfo Luján Lunsford, Dok-In Ryu and Jin-Gyu Kim

I STATE OF PRESERVATION – A

SUPPORT (wall) & PREPARATORY LAYERS (renders)

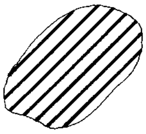
lack of adhesion - separation with deformation
renders are bowed in the shape of large pocket or bulged



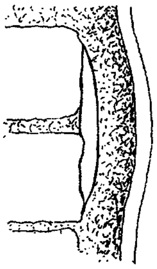
North wall, west side, lower section

under raking light

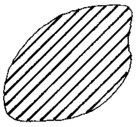
thick parallel lines (root. 1.0) wide spaced (4 mm separation) at 45° inserted in thin continuous line (root. 0.1) marking the perimeter of the area



lack of adhesion - separation/detachment
roughing-in layer or renders are separated from the wall or amongst themselves without major deformation

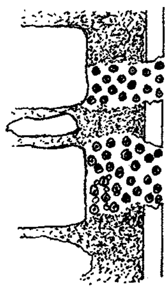


medium parallel lines (root. 0.5) normal spaced (2 mm separation) at 45° inserted in thin continuous line (root. 0.1) marking the perimeter of the area

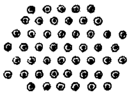


lack of cohesion – powdering

disintegration or breakage of the binder in the render and reduction in compactness

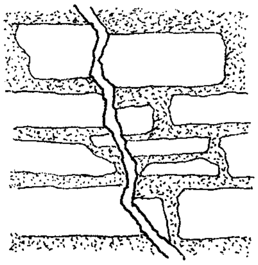


alternated rows (3 mm separation) of thin line (root 0.1) circles 2 mm ∅ with dots (root. 0.5) at the centre separated 2 mm marking the area

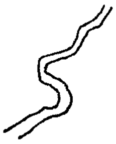


cracks – structural

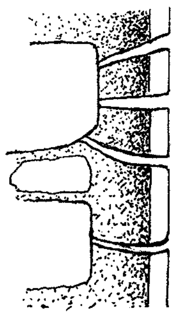
mechanical alteration that crosses throughout the structure, the renders and the paint layer

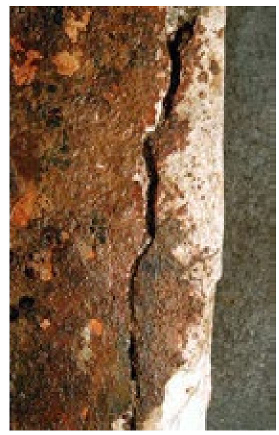


double thick line (root. 1.0) reproducing the cracks



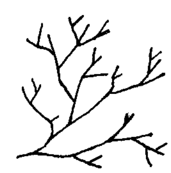
cracks – mechanical
fracture or chink found in a given layer within a structure



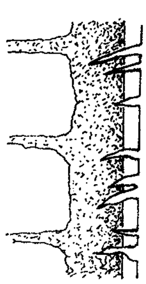


under raking light

medium line (root. 0.5) reproducing the cracks

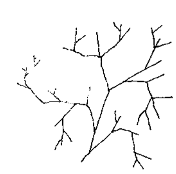


cracks - due to drying
contraction (shrinkage) of the render due to rapid evaporation or to excess of water in the mixture



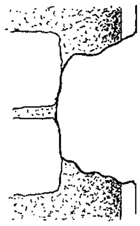
under raking light

thin line (root. 0.1) reproducing the cracks

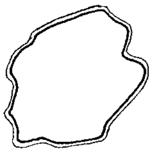


lacunae/losses - in-depth lacunae

interruption of the unity of a rendered surface revealing the support

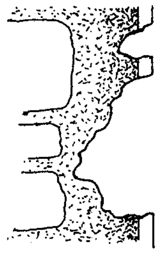


continuous thin line (root. 0.1) with a parallel inner medium line (root. 0.5) marking the area

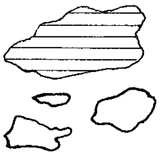


lacunae/losses - superficial lacunae

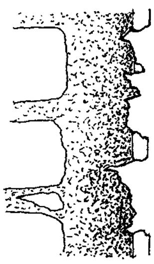
loss of a portion of preparatory layer(s) at varying depth and dimensions



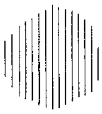
Continuous medium line (root. 0.5)marking the area. Areas with many small lacunae are marked as one, filled with thin (root. 0.1) horizontal lines wide spaced (4 mm separation)



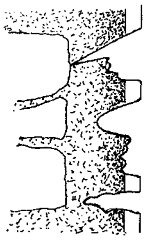
lacunae/losses – erosion
destruction and loss of constitutive material due to soluble salt sub-florescence



vertical thin parallel lines (root. 0.2) normal spaced (2 mm separation) marking the area



lacunae/losses – excavation tools and/or vandalism marks
mechanical marks caused consciously or by misuse of tools



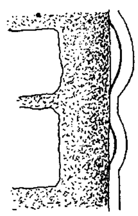
under raking light

continuous thin line (root. 0.2) representing the shape of the mark(s)

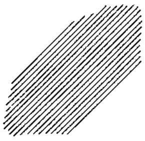
I STATE OF PRESERVATION – B

PAINT LAYER

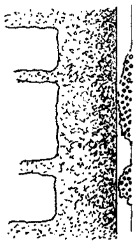
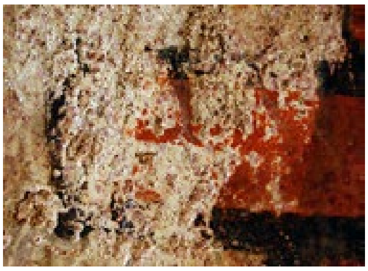
lack of adhesion - bubble-shaped
Thin separation of paint layer in the shape of semi-bubble due to soluble salt sub-florescence



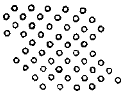
thin parallel lines (root. 0.1) narrow spaced (1 mm separation) at 45°
inserted in thin continuous line marking the area



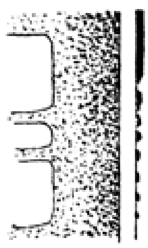
lack of cohesion – powdering
The paint layer surface is weakened by disintegration of the binding medium


alternated rows (2 mm separation) of thin-line (root. 0.1) circles 1 mm ∅ separated 1 mm marking the area.

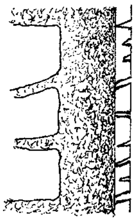


lack of cohesion - leaching of pigments
due to dissolution of the binder and subsequent dispersion/diffusion due to water run-off over the surface



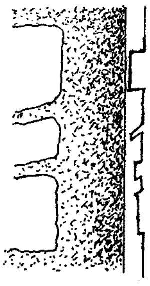
alternated rows of small dots(root. 0.5) separated 1 mm marking the area.

cracks - drying cracks
micro-cracks formed by contraction (shrinkage) by rapid water evaporation

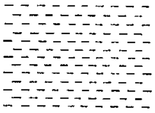


network of thin three convergent lines (root. 0.1) - only where evident

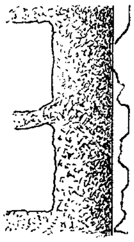
lacunae - abrasion/scratches
wear or loss of minute scales of paint beneath which, a part of the pigment layer or at least the original render remains with pigment traces



thin (root. 0.2) hyphen horizontal parallel lines separated 2 mm marking the area.



lacunae - in-depth lacunae
complete loss of paint layer revealing entirely the preparatory layer.

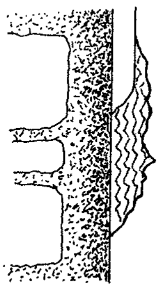


thin hyphen line (root. 0.2) marking the perimeter of the area

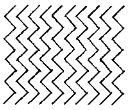
I STATE OF PRESERVATION – C

DEPOSITS ON SURFACES

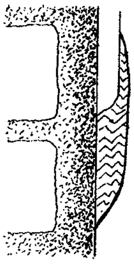
coherent deposits - hard mud incrustations
mud, soil and sand englobed into a compact calcium carbonate matrix



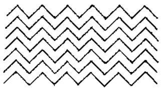
zigzag vertical thin (root. 0.1) parallel lines normal spaced (2 mm separation) marking the area



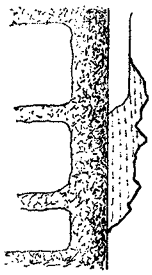
coherent deposits – calcium carbonate incrustations
calcium carbonate formation on the surface due to chemical processes in presence of water



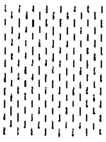
zigzag horizontal thin (root. 0.2) parallel lines normal spaced (2 mm separation) marking the area



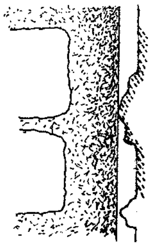
incoherent deposits - mud/soil/clayey concretions
natural deposition of earthen materials, which combined with water formed a semi-hard crust

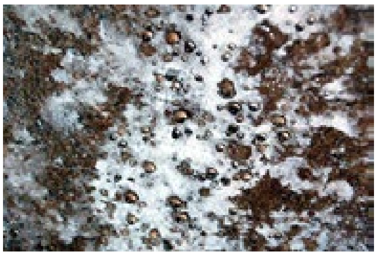


medium hyphen-alternated dot vertical lines (root. 0.5) normal spaced (2 mm separation) marking the area

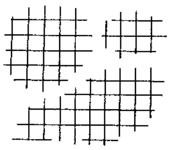


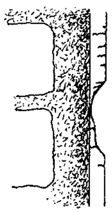
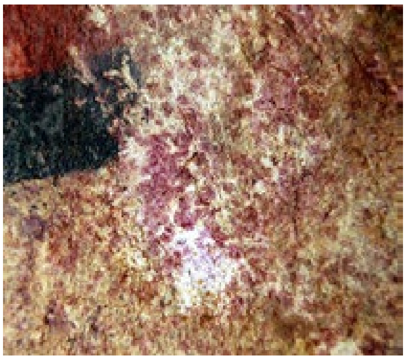
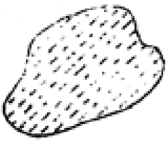
bio-activity - micro-organisms
active colonies of micro-organisms forming films on the surface





vertical & horizontal thin lines (root. 0.1) wide spaced (4 mm) forming a grid marking the contaminated area, only where evident and clear

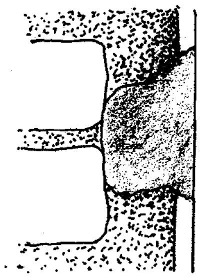


stains – biological products from metabolic activity of micro.-organisms that caused purplish/reddish stains		
		
medium hyphen parallel lines (root. 0.2) normal spaced (2 mm separation) at 135° within a thin perimeter continuous line marking the stained area		

II FORMER INTERVENTIONS – A

SUPPORT (wall) & PREPARATORY LAYERS (renders)

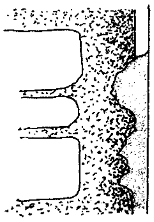
obsolete fillings of lacunae/cracks – cement
applied for filling large lacunae and voids between masonry and/or stone blocks



'v' large shape (root. 0.2) with a dot at the centre wide spaced (4 mm separation) in alternated rows marking the area

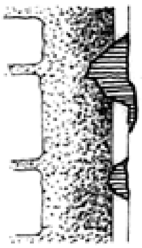
obsolete fillings of lacunae/cracks - white/yellowish clay
applied for filling small lacunae, abrasions or eroded areas of renders generally without paint layer

t

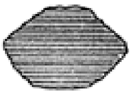


vertical thin parallel lines (root. 0.2) normal spaced (2 mm separation) marking the area

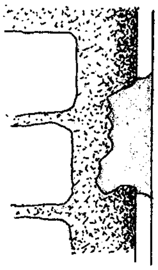
obsolete fillings of lacunae/cracks - grey clay
applied for filling small lacunae of the render



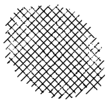
horizontal thin parallel lines (root. 0.1) narrow spaced (1 mm separation) contained into continuous line (root. 0.1) marking the area

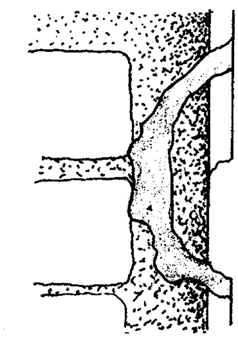
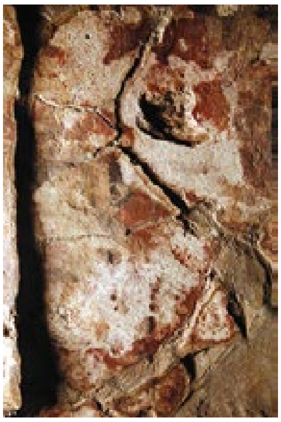
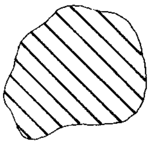


compatible fillings of lacunae/cracks - hydrated lime
applied for filling eroded areas of the renders that are not damaging but are much more compact and whiter than the original



crossed thin parallel lines (root. 0.1) normal spaced (2 mm separation) at 135° and 45°

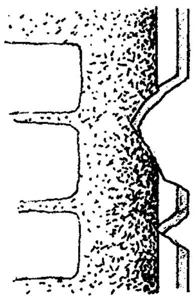


re-adhesion with cement - renders re-adhered with cement collapsed fragments of renders reassembled and re-adhered to the wall with cement plaster
  
thick parallel lines (root. 0.5) wide spaced (4 mm separation) at 135° inserted in thin (root. 0.10) continuous line marking the perimeter of the area 

II FORMER INTERVENTIONS – B

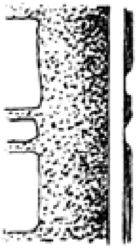
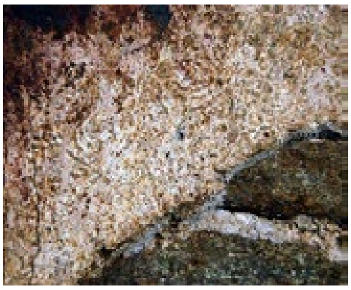
PAINT LAYER & SURFACE

deposits/films of foreign substances – cement film
spread over adjacent surfaces where cement was employed for filling lacunae

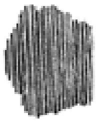


'v' small shape (root. 0.1) with a dot at the centre in alternated normal (2 mm separation) rows marking the area

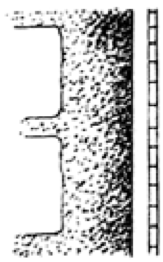
deposits/films of foreign substances - white/yellowish clay film
eventual spread of clay over painted surfaces

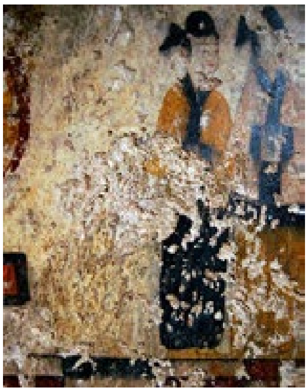



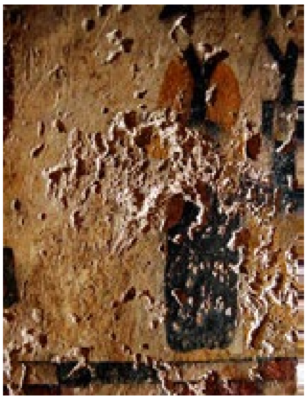

vertical thin parallel lines (root. 0.1) narrow spaced (1 mm separation) marking the area



deposits/films of foreign substances – coating/fixatives
applied in order to protect the painted surface or eventual pictorial integrations

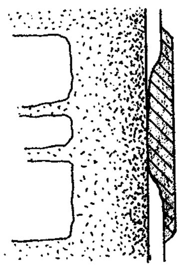




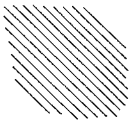


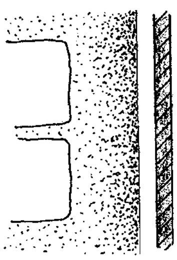
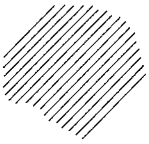
horizontal thin lines (root. 0.1) wide spaced (4 mm separation) marking the area

pictorial integration – reconstruction
lost areas of painting that were subject to reconstruction



thin lines (root. 0.1) normal spaced (2 mm separation) at 135°



<table>
<tr><td>pictorial integration - over-painting
areas of original painting that were covered by a second paint layer as restoration work</td></tr>
<tr><td>  </td></tr>
<tr><td>thin lines (root. 0.1) normal spaced (2 mm separation) at 45° </td></tr>
</table>

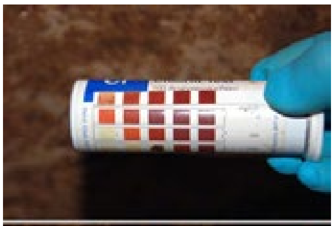
III SAMPLING/MEASUREMENTS
CHEMICAL/BIOLOGICAL/PHYSICAL

sampling for chemical analyses – pH
measurements of pH of condensation water on surfaces

rectangle with pH and a progressive number that gives the succession of the samples taken under a point 1 mm ∅ that marks the point of sampling

pH 1

sampling for chemical analyses – soluble salts
soluble salts dissolved in condensation water over the surfaces



rectangle with SS and a progressive number that gives the succession of the samples taken under a point 1 mm ∅ that marks the point of sampling

SS 1

sampling for chemical analyses –insoluble salts hard mud incrustations	
 	
rectangle with IS - MI and a progressive number that gives the succession of the samples taken under a point 1 mm ∅ that marks the point of sampling	**IS – MI 1**

sampling for chemical analyses –insoluble salts calcareous incrustations	
 	
rectangle with IS - CI and a progressive number that gives the succession of the samples taken under a point 1 mm ∅ that marks the point of sampling	**IS – CI 1**

sampling for chemical analyses – constitutive materials Stone
 
rectangle with CM - S and a progressive number that gives the succession of the samples taken under a point 1 mm ∅ that marks the point of sampling **CM – S 1**

sampling for chemical analyses – constitutive materials Mortars
t  
rectangle with CM - M and a progressive number that gives the succession of the samples taken under a point 1 mm ∅ that marks the point of sampling **CM – M 1**

sampling for chemical analyses – constitutive materials
Renders

rectangle with CM – R and a progressive number that gives the succession of the samples taken under a point 1 mm ∅ that marks the point of sampling

CM – R 1

sampling for chemical analyses – constitutive materials
paint layer

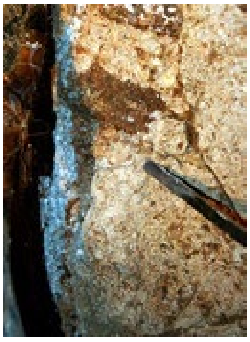
rectangle with CM – P and a progressive number that gives the succession of the samples taken under a point 1 mm ∅ that marks the point of sampling

CM – PL 1

sampling for chemical analyses – materials from former interventions
Portland cement fillings

rectangle with FM - CF and a progressive number that gives the succession of the samples taken under a point 1 mm ∅ that marks the point of sampling

FM – PC 1

sampling for chemical analyses – materials from former interventions clay fillings	
 	
rectangle with FM - CF and a progressive number that gives the succession of the samples taken under a point 1 mm ∅ that marks the point of sampling	**FM – CF 1**

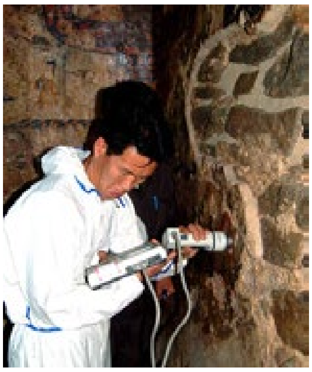
sampling for chemical analyses – materials from former interventions hydrated lime fillings	
 	
rectangle with FM - HL and a progressive number that gives the succession of the samples taken under a point 1 mm ∅ that marks the point of sampling	**FM – HL 1**

sampling for chemical analyses – materials from former interventions reconstruction/over-painting of paint layer	
 	
rectangle with FM - RO and a progressive number that gives the succession of the samples taken under a point 1 mm ∅ that marks the point of sampling	**FM – RO 1**

sampling for chemical analyses – materials from former interventions fixatives/coatings	
 	
rectangle with FM - FC and a progressive number that gives the succession of the samples taken under a point 1 mm ∅ that marks the point of sampling	**FM – FC 1**

sampling for biological analyses micro-organisms: rubbing/scale/fragment	
 	
rectangle with BIO - M and a progressive number that gives the succession of the samples taken under a point 1 mm ∅ that marks the point of sampling	**BIO – M 1**

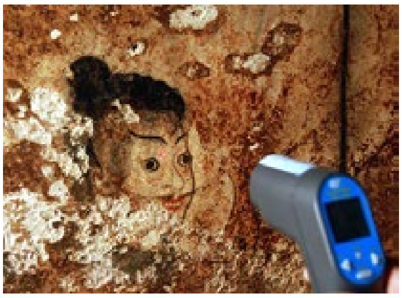
physical measurements and monitoring
Colorimetry

rectangle with PM - C and a progressive number that gives the succession of the samples taken under a point 1 mm ∅ that marks the point of sampling

PM – C 1

physical measurements and monitoring
surface's temperature

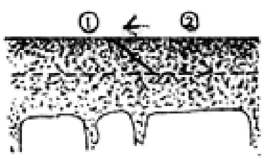
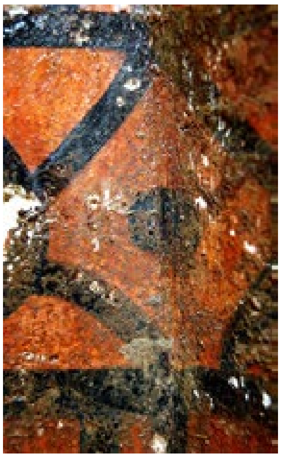
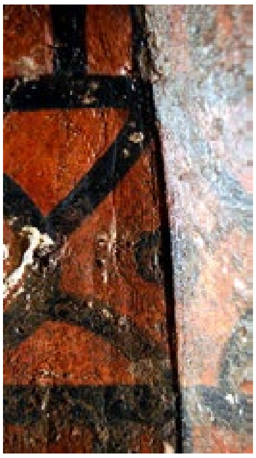



rectangle with PM - T and a progressive number that gives the succession of the samples taken under a point 1 mm ∅ that marks the point of sampling

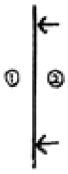
PM – T 1

IV TECHNIQUE OF EXECUTION – A
PREPARATORY LAYERS

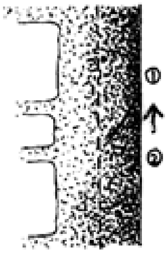
joints of renders – vertical
the vertical end of a plastered area overlapped by the subsequent

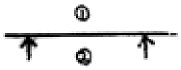
medium vertical lines (root. 0.5) marking the join and arrows indicating the overlap with progressive encircled numbers showing the sequence of application



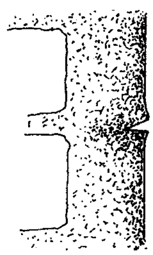
joints of renders – horizontal
the renders' horizontal joints that usually follow the heights given by scaffolding



medium horizontal lines (root. 0.5) marking the join and arrows indicating the overlap with progressive encircled numbers showing the sequence of application

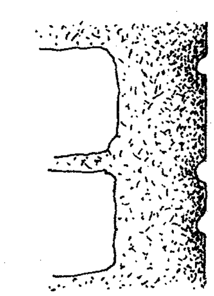


incisions - compass centre
the imprinted mark of a point into the render, if fresh the contours are rounded, if dry the contours are broken

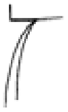


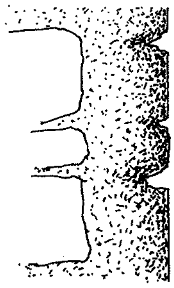
thick dot 1 mm ∅ marking the point encircled (3 mm ∅) in thin line (root 0.1)

incisions - indirect incisions (transfer through cartoon)
outlines are imprinted onto the fresh render by exerting pressure with a pointed stick. NB the borders of the incision are rounded



medium line (root. 0.5) reproducing the incision(s)

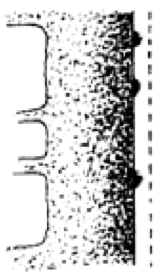


incisions - direct incisions guidelines are incised directly onto the fresh plaster as painting reference. NB the borders of the incision are rough and broken
  
medium hyphen line (root. 0.5) reproducing the incision(s) 

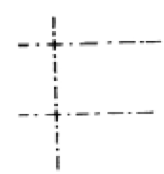
IV TECHNIQUE OF EXECUTION – B

PAINT LAYER

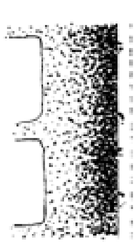
preparatory drawing - snapping cord
division of scenes by straight lines made by snapping a string soaked in paint

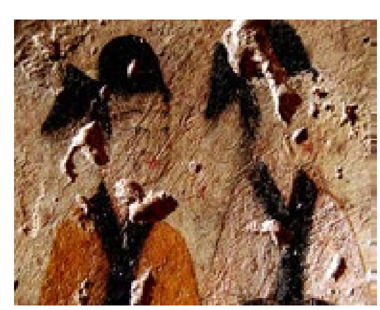


medium hyphen-alternated dot line (root. 0.5) marking the lines.

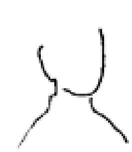


preparatory drawing - general sketch/drawing
free-hand outline directly drawn on the render or on the first painting layer



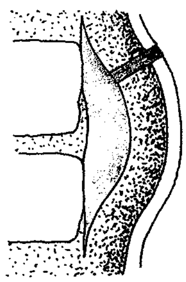


thin line (root. 0.1) reproducing the drawing

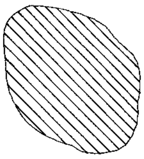


V PRESENT INTERVENTION/TREATMENTS – A
SUPPORT (WALL) AND PREPARATORY LAYERS (RENDERS)

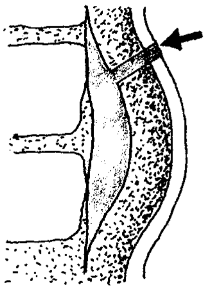
fixation – grouting
roughing-in layer or renders separated from the wall or amongst themselves were re-adhered or fixed back



thin parallel lines (root. 0.2) normal spaced (2 mm separation) at 135° inserted in thin continuous line marking the perimeter of the area



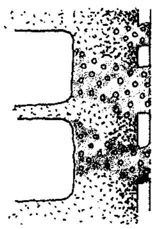
fixation - points of grouting
The points from which grouting was injected



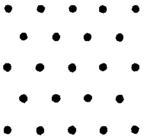
small circles 4 mm ∅ (root. 0.1) with a dot in the centre marking the point(s) of grouting

⊙

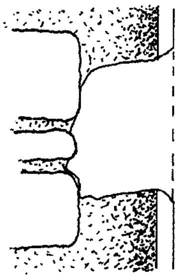
consolidation - roughing-in layer/renders lacking cohesion
the linkage between aggregates and powdery binder reinforced by injecting compatible/similar materials to the original binder



alternated rows wide spaced(4mm) of dots 2 mm ∅

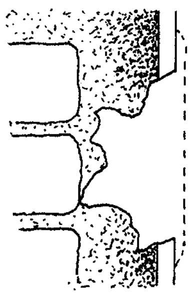


removal of obsolete fillings - cement fillings
This damaging material is incompatible with the original ones

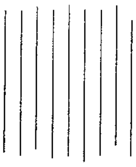


alternated rows of inverted V with a dot at the centre

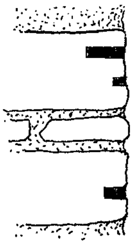
removal of obsolete fillings - grey & white/yellowish clay
obstructing the porosity of renders that reduce/impede water vapour exchange



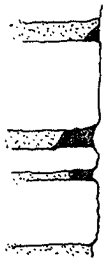
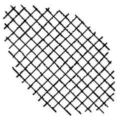
vertical thin parallel lines (root. 0.1) wide spaced (4 mm separation) marking the area

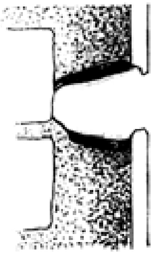
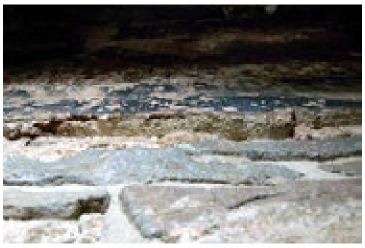


filling of lacunae compatible with the original – accidental grooves on stonework
employing stone powder mixed with a binder up to the surface level matching in colour and texture

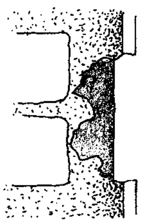


Thick lines (root. 1.0) as per the pattern of cuts

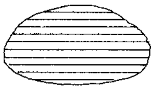
filling of lacunae compatible with the original – re-pointing masonry joints the sealing of joints of masonry with similar material to the original mortar	
  	
Thin parallel lines (root. 0.1) normal spaced (2 mm separation) at 45° & 135° marking the area.	

filling of lacunae compatible with the original - edging (filleting) borders of lacunae empty spaces or voids are filled for sealing these before fixation or as a reinforcement	
  	
Crossed thin lines (root. 0.1) marking the perimeter of the filled border	

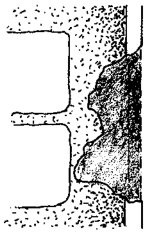
filling of lacunae compatible with the original - under the paint layer level
there is no sufficient evidence for re-integrating the paint layer (reconstruction)



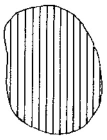
Horizontal thin lines (root. 0.1) normal spaced (2 mm separation) & thin line(root. 0.1) marking the area



filling of lacunae compatible with the original – at the paint layer level
referred to areas of paint layer subject to ethical reconstruction in order to achieve major legibility

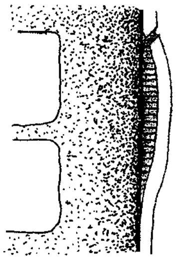


vertical thin lines (root. 0.2) normal spaced (2 mm separation)
thin outline marking the area

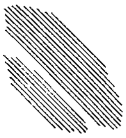


V PRESENT INTERVENTION/TREATMENTS – B
PAINT LAYER & SURFACES

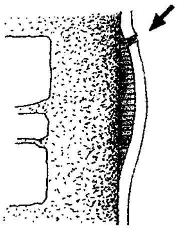
fixation – injection
Bubble-shaped separation of paint layer injected with thin/liquid grout



Thin parallel lines (root. 0.1) narrow spaced (1 mm separation) at 135° marking the area

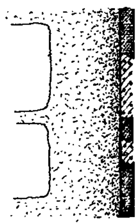


Fixation – point(s) of injection
points from which injections were done

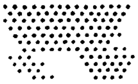


small circles 3 mm ∅ (root. 0.1) with a dot in the centre marking the point(s) of grouting

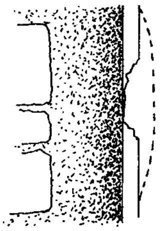
consolidation - lack of cohesion
paint layer lacking cohesion (powdering) was consolidated



alternated rows narrow spaced (1 mm separation)of filled circles 1 mm ∅ marking the area

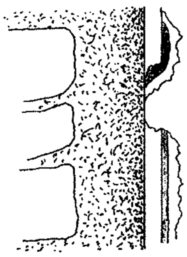


dry cleaning - removal of incoherent deposits
accretions of mud or soil naturally deposited are mechanically removed with water, brushes and sponges

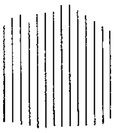


medium hyphen vertical parallel lines (root. 0.5)wide spaced (4 mm separation) marking the area

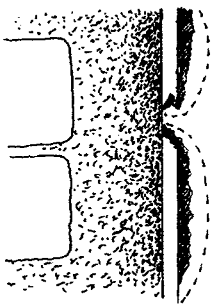
dry cleaning – thinning-down/removal of coherent deposits
calcium carbonate & hard mud incrustations removed with mechanical means

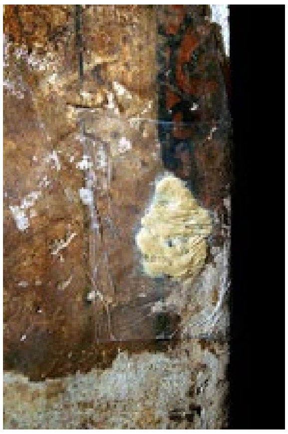


thin vertical parallel lines (root. 0.2) normal spaced (2 mm separation) marking the area



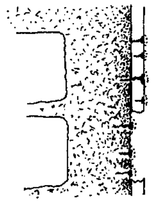
wet cleaning - removal of coherent deposits
where possible, Calcium carbonate & hard mud incrustations were removed by chemical agents



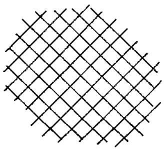


thin horizontal parallel lines (root. 0.2) normal spaced (2 mm separation) marking the area

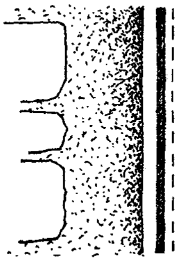
wet cleaning - removal of stains
purplish/reddish stains produced by metabolic activity of micro.-organisms removed with chemical products

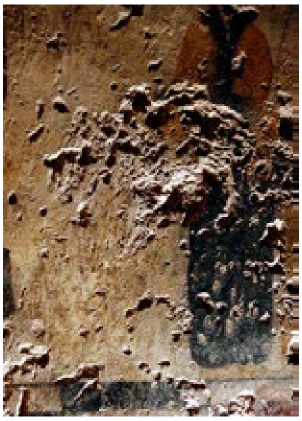


wide spaced (4 mm) thin parallel lines (root. 0.1) forming a grid at 45° & 135° marking the stained area

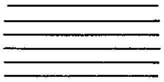


wet cleaning - removal of fixatives/coatings (this operation must be graphically represented only if limited to certain areas otherwise must be described in the written report)
with specific and tested solvents for the removal of the layer





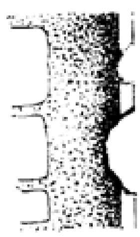
horizontal medium parallel lines (root. 0.5) wide spaced (4 mm separation) marking the area



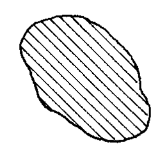
V PRESENT INTERVENTION/TREATMENTS – C
AESTHETICAL PRESENTATION OF PAINT LAYER & SURFACES

NB the following two headings (excepting *tratteggio*) are to be graphically represented only if the extent of the operation is limited otherwise must be described in the written report.

pictorial integration - neutral toning-down lighter areas of renders or filled areas
to damper the visual impact of lighter areas so as to provide unity to the painting's 'background'

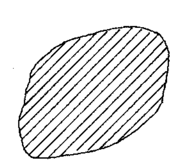


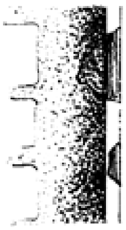
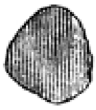
Thin parallel lines (root. 0.2) at 135° normal spaced (2mm) marking the area inserted in medium (root. 0.5) continuous line



pictorial integration - toning-down losses of paint layer
to damper the visual impact of abraded/lost small areas that usually are light

thin parallel lines (root. 0.1) at 45° normal spaced (2mm) marking the area inserted in thin (root. 02) continuous line



pictorial integration - *tratteggio* (vertical hatching) lost sections dependent on ethical reconstruction for major legibility of the painting
  
medium vertical parallel lines (root. 0.5) narrow spaced (1 mm) marking the area and contoured with a thin line (root. 0.1) 

Photographic Documentation (Before)

by Rodolofo Luján Lunsford and the DPRK National Expert Team

Location in Tomb	File Name	Image
Passage	Ceiling.jpg	
Passage	East wall.jpg	

Passage	Façade.jpg	
Passage	West wall.jpg	

Susan-ri East	1.jpg	
Susan-ri East	DSC_2614.jpg	
Susan-ri East	DSC_2616.jpg	

Susan-ri East	DSC_2618	
Susan-ri East	DSC_2619	
Susan-ri East	DCS_2620	

Susan-ri East	DSC_2621	
Susan-ri East	DSC_2624	
Susan-ri East	DSC_2629	

Susan-ri East	DSC_2630	
Susan-ri East	DSC_2631	
Susan-ri East	DSC_2633	

Susan-ri East	DSC_2635	
Susan-ri East	DSC_2637	
Susan-ri East	DSC_2639	

Susan-ri East	DSC_2642	
Susan-ri East	DSC_2643	
Susan-ri East	DSC_2644	

Susan-ri East	DSC_2648	
Susan-ri East	DSC_2649	
Susan-ri East	DSC_2652	

Susan-ri East	DSC_2654	
Susan-ri East	DSC_2657	
Susan-ri East	DSC_2661	

Susan-ri East	DSC_2662	
Susan-ri East	DSC_2664	
Susan-ri East	DSC_2666	

Susan-ri East	DSC_2667	
Susan-ri East	DSC_2668	

Susan-ri East	DSC_2673	
Susan-ri East	DSC_2674	

Susan-ri East	DSC_2675	
Susan-ri East	DSC_2681	

Susan-ri East DSC_2686

Susan-ri East DSC_2687

Susan-ri East	DSC_2689	
Susan-ri East	DSC_2691	

Susan-ri East	DSC_2692	
Susan-ri East	DSC_2693	

Susan-ri East Susan-ri East	DSC_2694	
Susan-ri East	DSC_2696	

Susan-ri East	DSC_2698	
Susan-ri East	DSC_2703	

Susan-ri East	DSC_2707	
Susan-ri East	DSC_2708	
Susan-ri East	DSC_2710	

Susan-ri North	1	
Susan-ri North	DSC_2317	
Susan-ri North	DSC_2321	

Susan-ri North	DSC_2322	
Susan-ri North	DSC_2324	
Susan-ri North	DSC_2325	

Susan-ri North	DSC_2332	
Susan-ri North	DSC_2337	
Susan-ri North	DSC_2341	

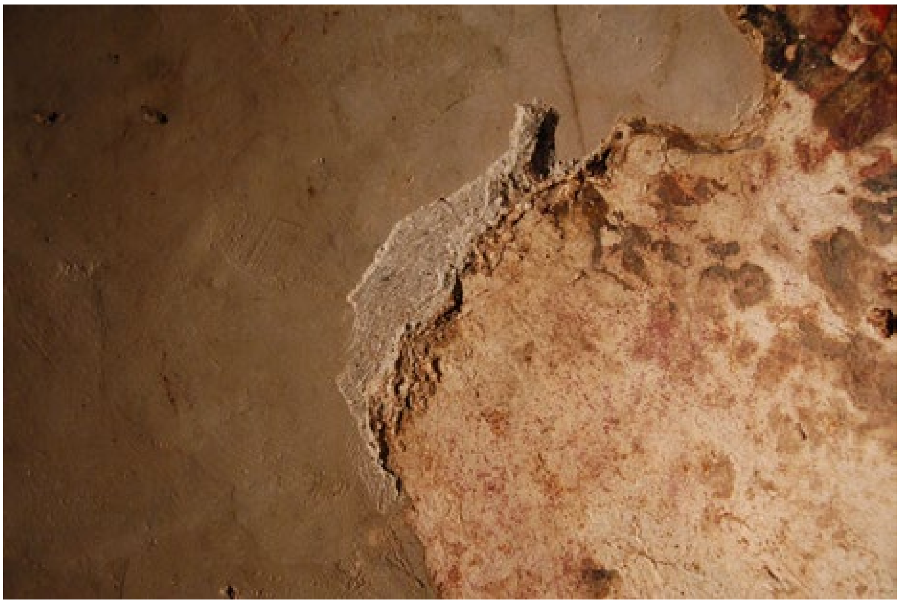
Susan-ri North	DSC_2342	
Susan-ri North	DSC_2343	
Susan-ri North	DSC_2344	

Susan-ri North	DSC_2352	
Susan-ri North	DSC_2354	
Susan-ri North	DSC_2355	

Susan-ri North	DSC_2358	
Susan-ri North	DSC_2359	
Susan-ri North	DSC_2369	

Susan-ri North	DSC_2371	
Susan-ri North	DSC_2380	

Susan-ri North	DSC_2383	
Susan-ri North	DSC_2385	

Susan-ri North	DSC_2387	
Susan-ri North	DSC_2390	

Susan-ri North	DSC_2404	
Susan-ri North	DSC_2408	

Susan-ri North	DSC_2409	
Susan-ri North	DSC_2411	
Susan-ri North	DSC_2413	

Susan-ri North	DSC_2418	
Susan-ri North	DSC_2419	
Susan-ri North	DSC_2420	

Susan-ri North	DSC_2422	
Susan-ri North	DSC_2423	

Susan-ri North	DSC_2424	
Susan-ri North	DSC_2425	

Susan-ri North	DSC_2427	
Susan-ri North	DSC_2434	

Susan-ri South	2	
Susan-ri South	DSC_2712	

Susan-ri South	DSC_2714	
Susan-ri South	DSC_2718	
Susan-ri South	DSC_2719	

Susan-ri South	DSC_2720	
Susan-ri South	DSC_2722	

Susan-ri South	DSC_2726	
Susan-ri South	DSC_2727	

Susan-ri South	DSC_2730	
Susan-ri South	DSC_2733	

Susan-ri South	DSC_2734	
Susan-ri South	DSC_2736	

Susan-ri South	DSC_2741	
Susan-ri South	DSC_2745	
Susan-ri South	DSC_2754	

Susan-ri West 1	
Susan-ri West DSC_2450	

Susan-ri West DSC_2451	
Susan-ri West DSC_2452	

Susan-ri West DSC_2453	
Susan-ri West DSC_2457	

Susan-ri West DSC_2458	
Susan-ri West DSC_2460	
Susan-ri West DSC_2461	

Susan-ri West	DSC_2467	
Susan-ri West	DSC_2470	

Susan-ri West DSC_2471

Susan-ri West DSC_2485

Susan-ri West DSC_2492

Susan-ri West DSC_2494	
Susan-ri West DSC_2495	
Susan-ri West DSC_2502	

Susan-ri West DSC_2503	
Susan-ri West DSC_2507	
Susan-ri West DSC_2508	

Susan-ri West DSC_2509

Susan-ri West DSC_2510

Susan-ri West DSC_2514

Susan-ri West	DSC_2515	
Susan-ri West	DSC_2536	
Susan-ri West	DSC_2539	

Susan-ri West	DSC_2544	
Susan-ri West	DSC_2557	

Susan-ri West DSC_2576

Susan-ri West DSC_2577

Susan-ri West DSC_2578

Susan-ri West DSC_2583

Susan-ri West DSC_2585	

Photographic Documentation (After)

File Name	Image
2005.10.24-3	
2005.10.24-8-1	

2005.10.24-8-2	
2005.10.24-9-1	
2005.10.24-17 Injecting grout	

2005.10.24 Removing hard crust with a fiberglass pencil	
2005.11.4-3 Cleaning micro-organism [from the surface]	

2005.11.4-4-1 Cleaning micro-organism [from the surface]	
2005.11.4-4-2 Cleaning micro-organism [from the surface]	

2005.11.4-4 Cleaning micro-organism (from the surface)	
2006,5,5-13-1	

2006.5.3.-5	
2006.5.3-1	
2006.5.3-2	

2006.5.3-3	
2006.5.3-4	

2006.5.5-13-2	
2006.5.8-7-1	
2006.5.8-13-3	

2006.5.8-13-4	
2006.5.8-13-5	

2006.5.8-13-6	
2010,5.26_-26,35	
2010,6,8-35	

2010,6,8-64 Matching the color	
2010,6,10-64 Matching the color on the north wall	

2010,6,10-64 Matching the color	
2010,6,11-26 Removing hard mud with a surgical scalpel	

2010,6,11-35 Removing hard mud with an electric mini-drill	
2010,6,11-43 Applying cationic ion-exchange resin	

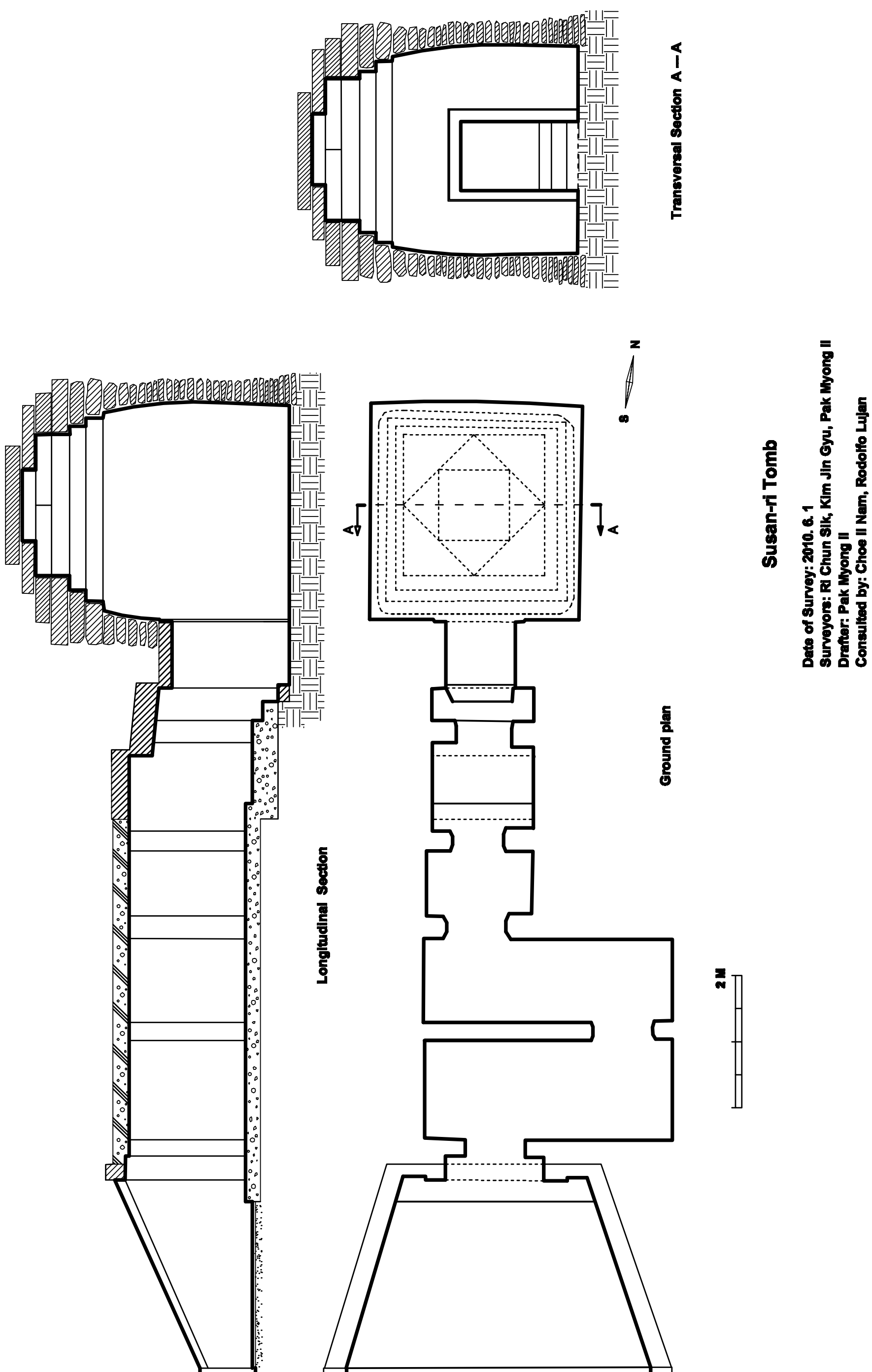
2010,6,11-48 Applying cationic ion-exchange resin	
2010,6,11-48 Applying cationic ion-exchange resin	

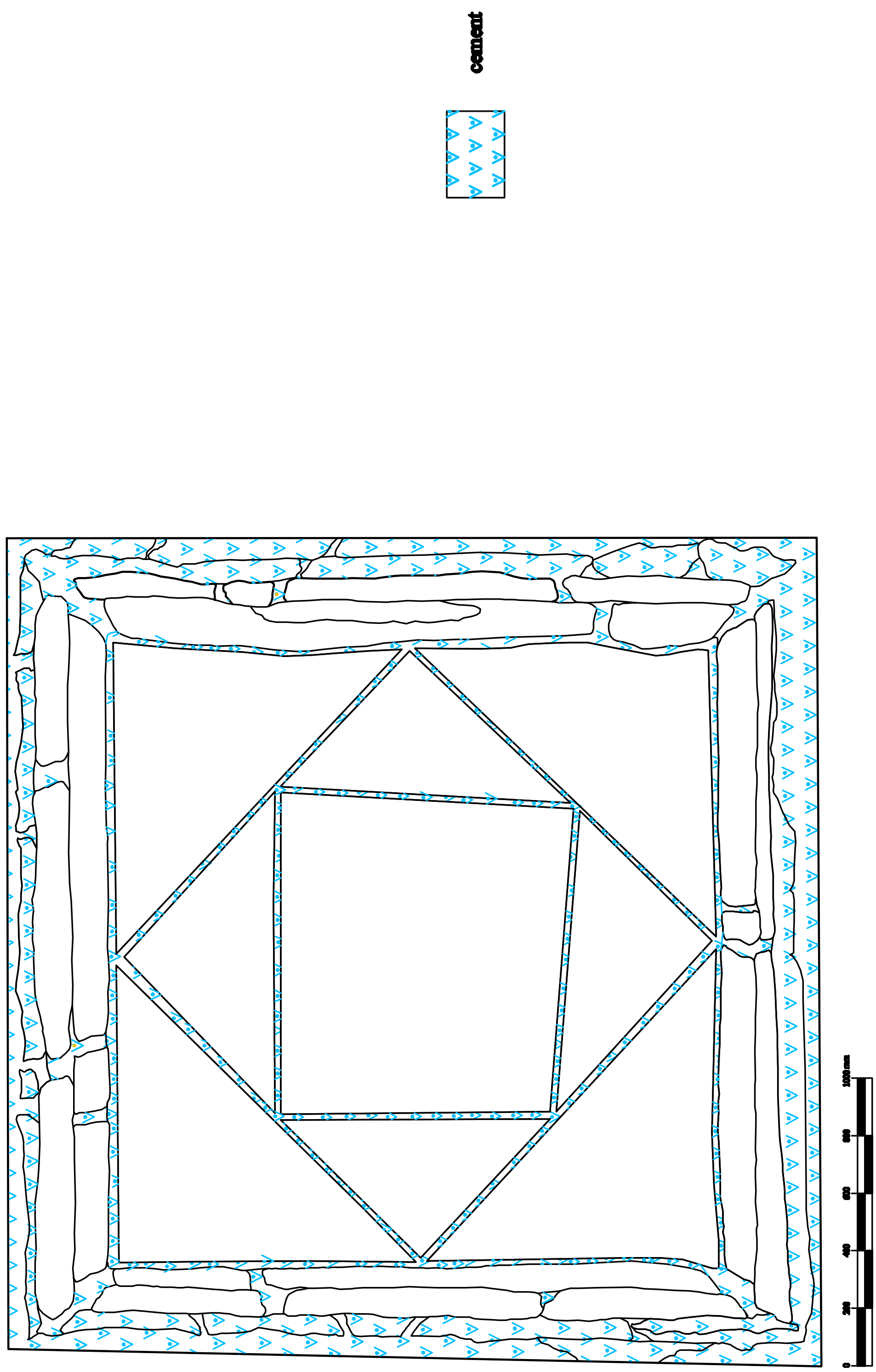
2010,6,15-37 Spraying disinfectant over the surface	
2010,6,17-35	
2010,6,17-40	

2010,6,17-41 Removing a layer of cement	
2010.6.8-66 Mixing powder pigment with lime water	
2010,6,4-10 Removing residues after the drilling	

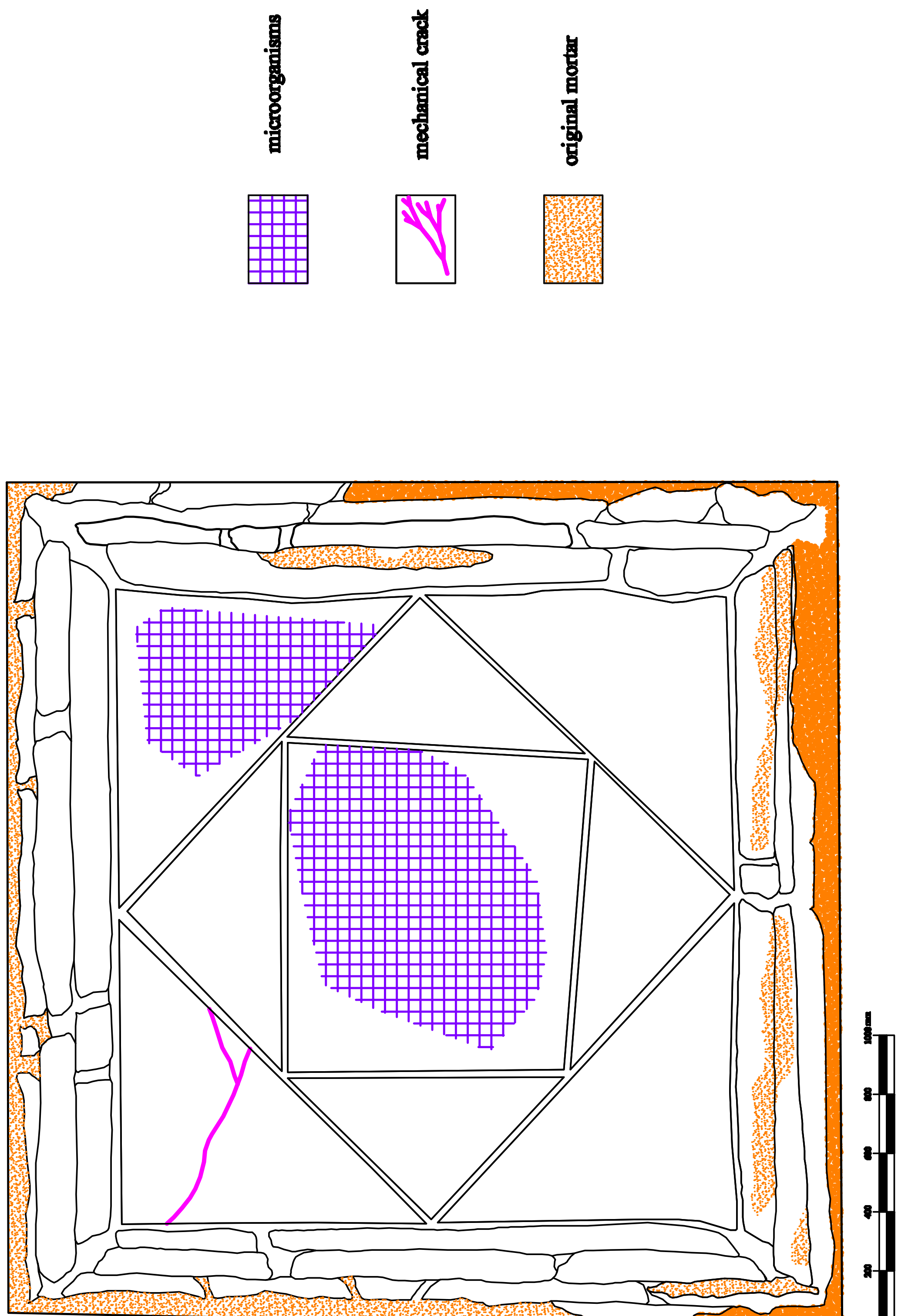
Graphic Documentation of the Susan-ri Tomb

by Rodolfo Luján and the DPRK National Experts Team

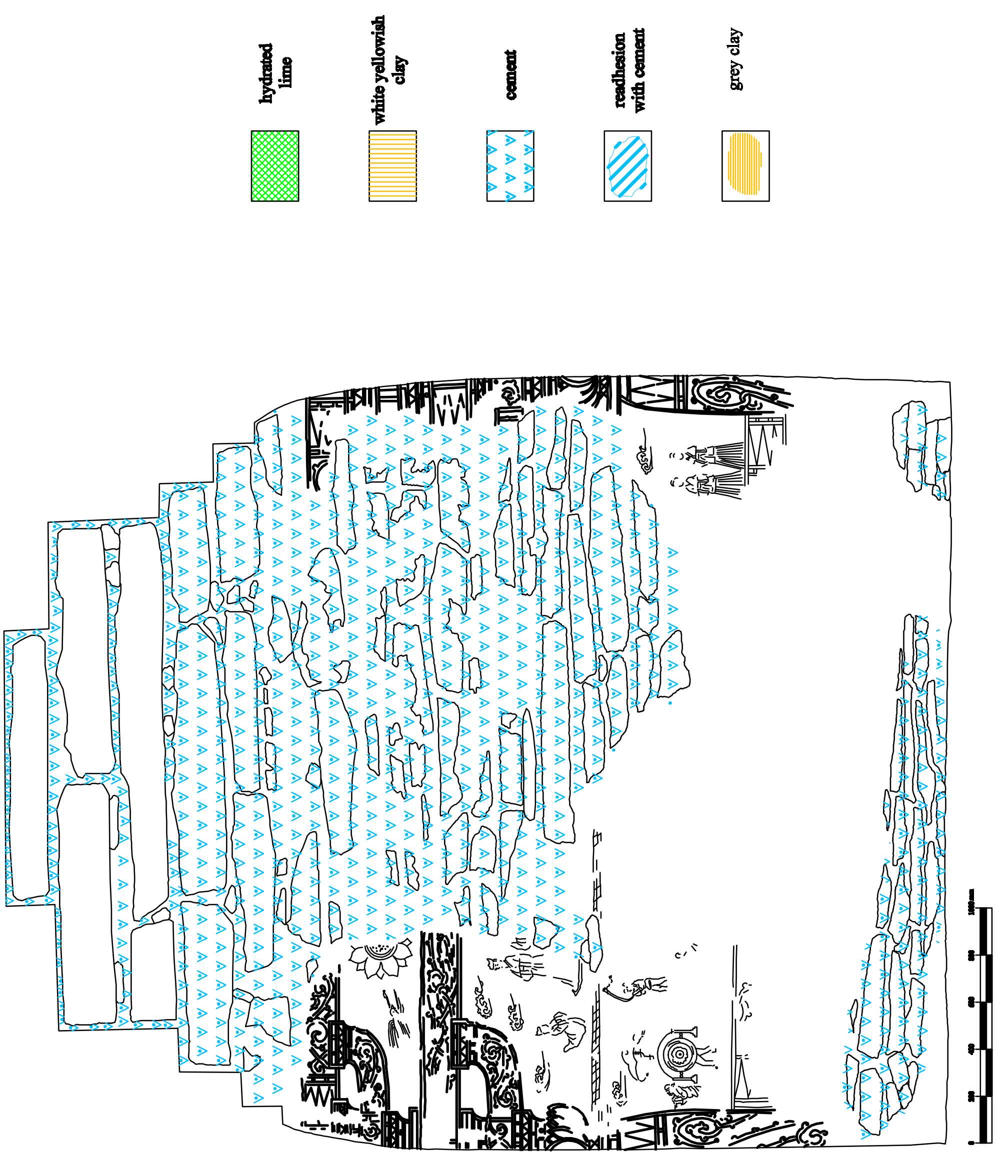




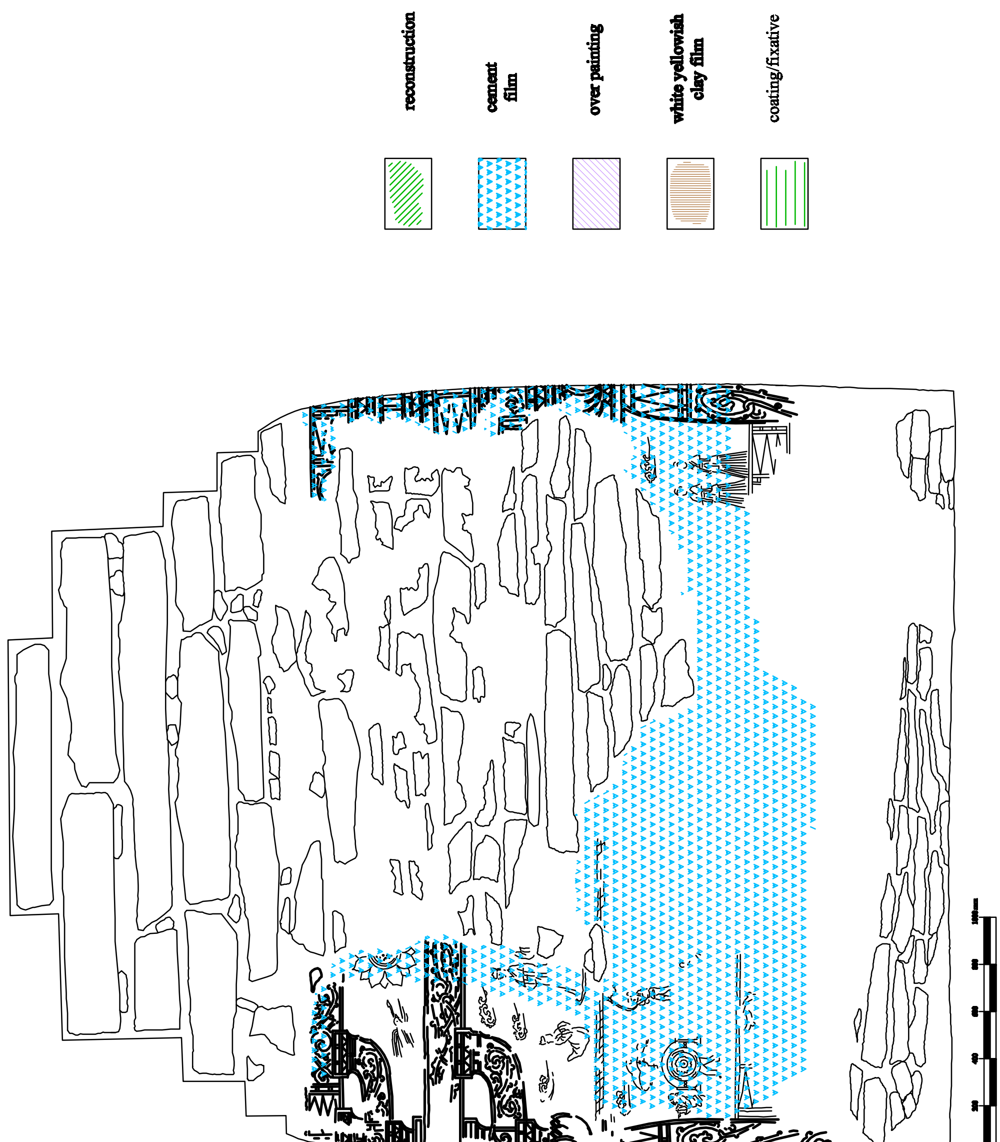
THE SUSAN-RI TOMB - CEILING - FORMER INTERVENTION



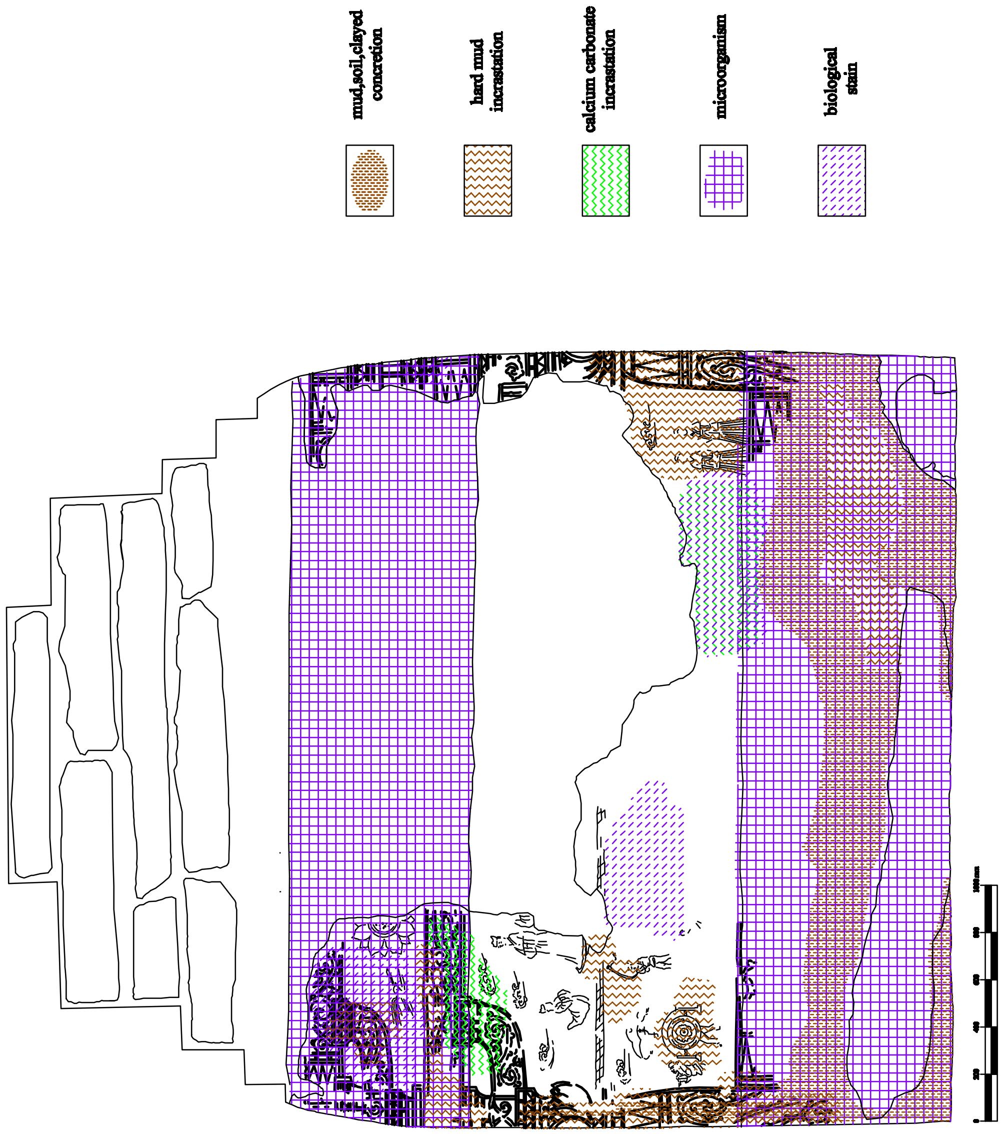
THE SUSAN-RI TOMB -CEILING - STATE OF PRESERVATION



THE SUSAN-RI TOMB - EAST WALL - FORMER INTERVENTION - A SUPPORT & PREPARATORY LAYERS

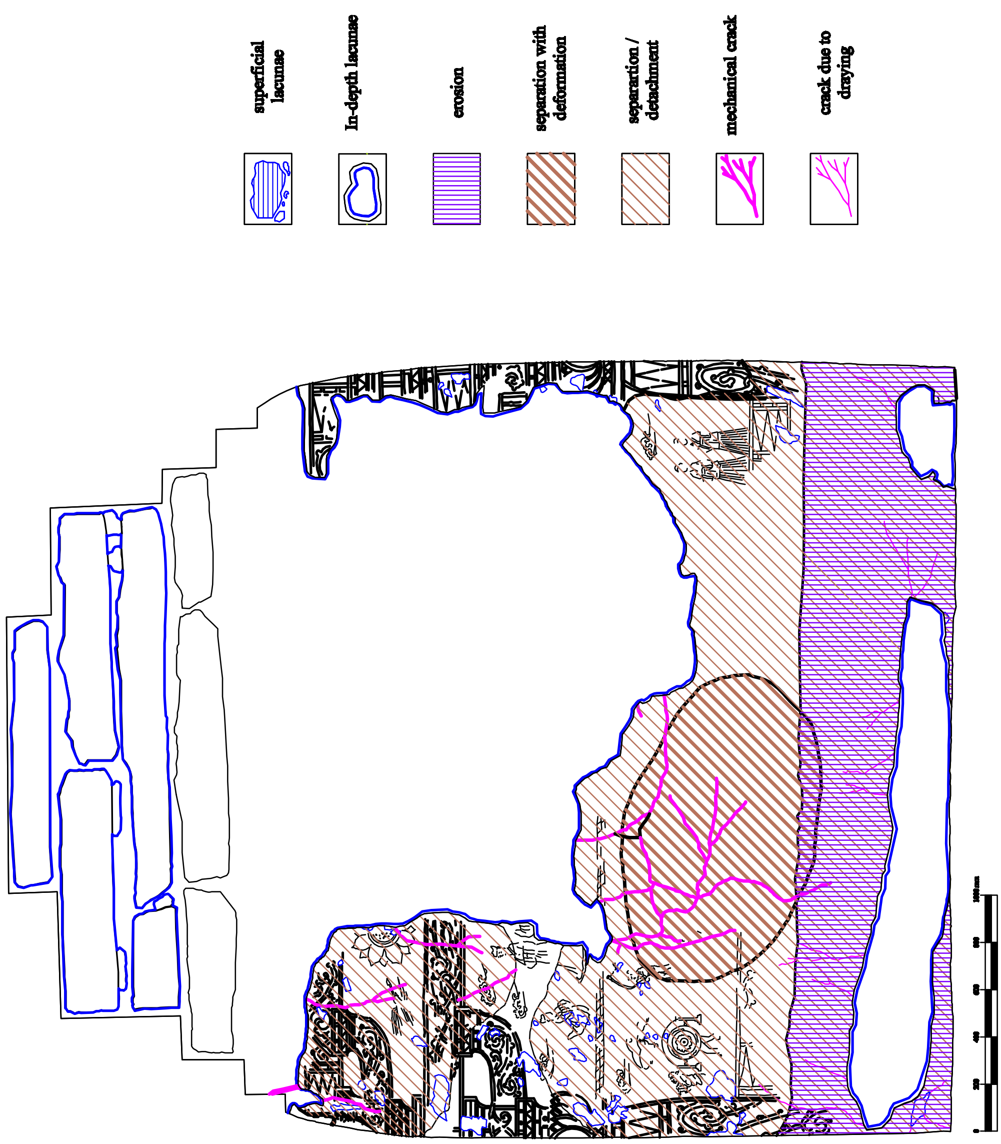


THE SUSAN-RI TOMB - EAST WALL - FORMER INTERVENTION B - PAINT LAYER & SURFACE

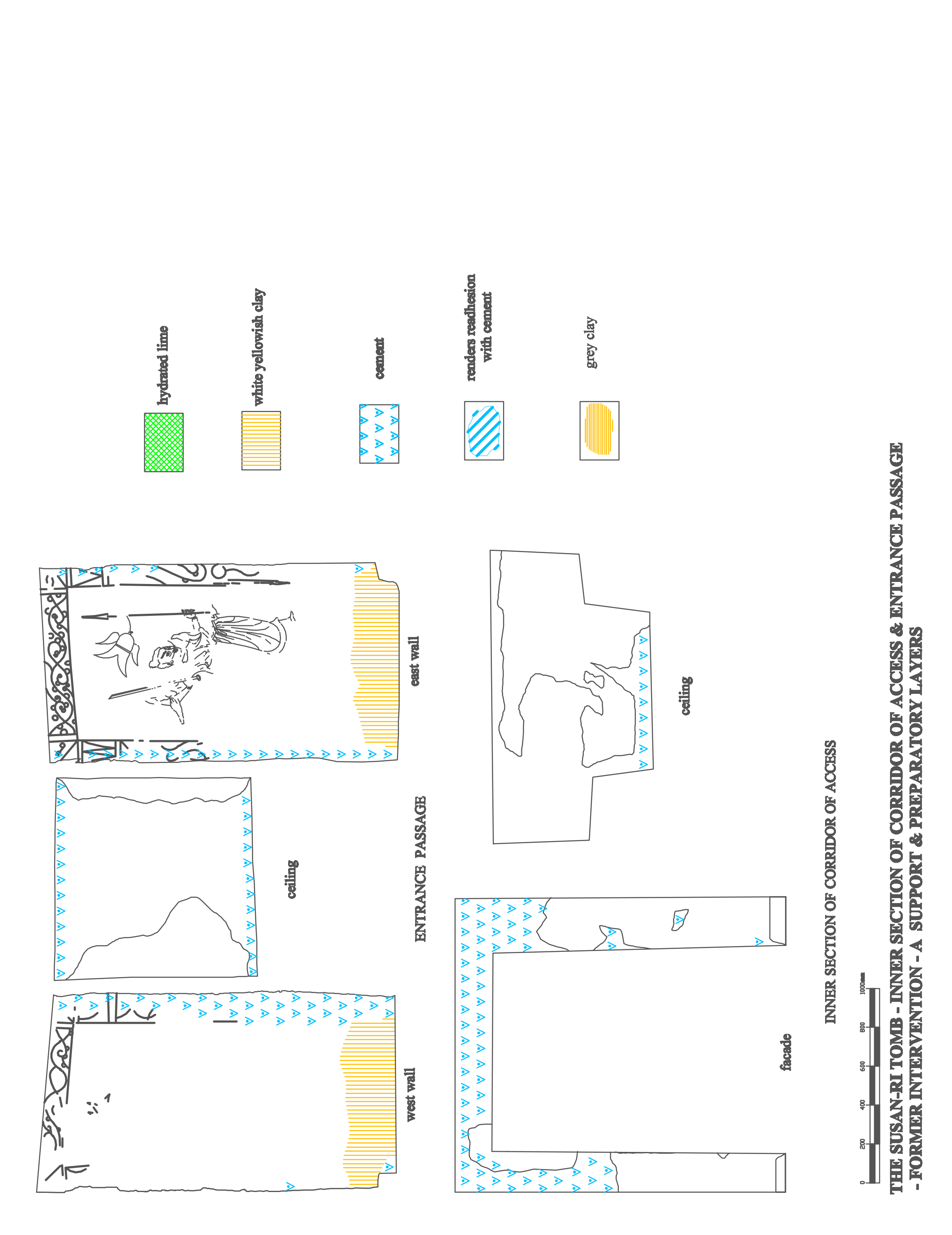


THE SUSAN-RI TOMB - EAST WALL - STATE OF PRESERVATION C - DEPOSITS ON SURFACE

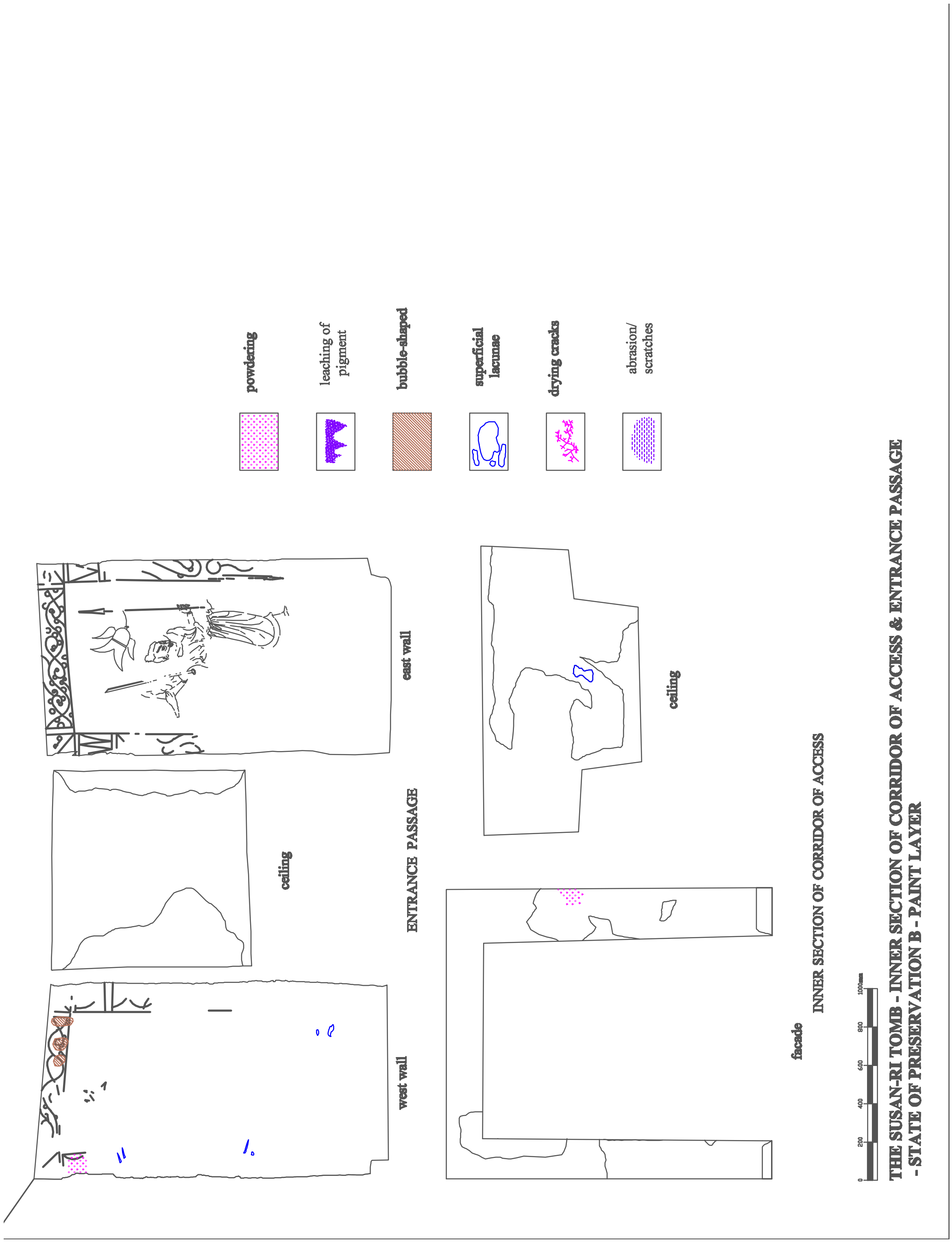

powdering
leaching of pigment
bubble-shaped
superficial lacunae
drying cracks
abrasion/ scratches
THE SUSAN-RI TOMB - EAST WALL - STATE OF PRESERVATION B - PAINT LAYER

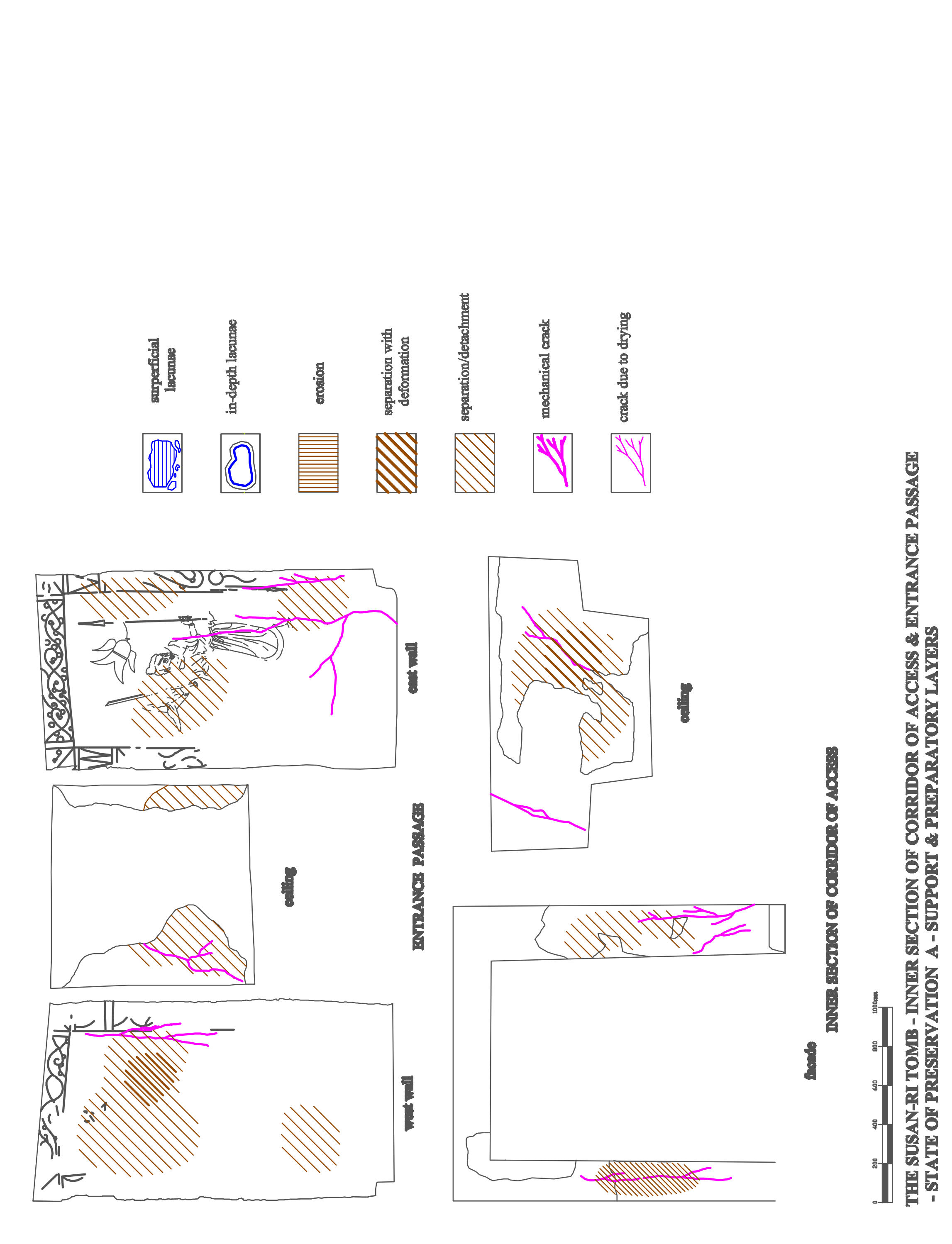


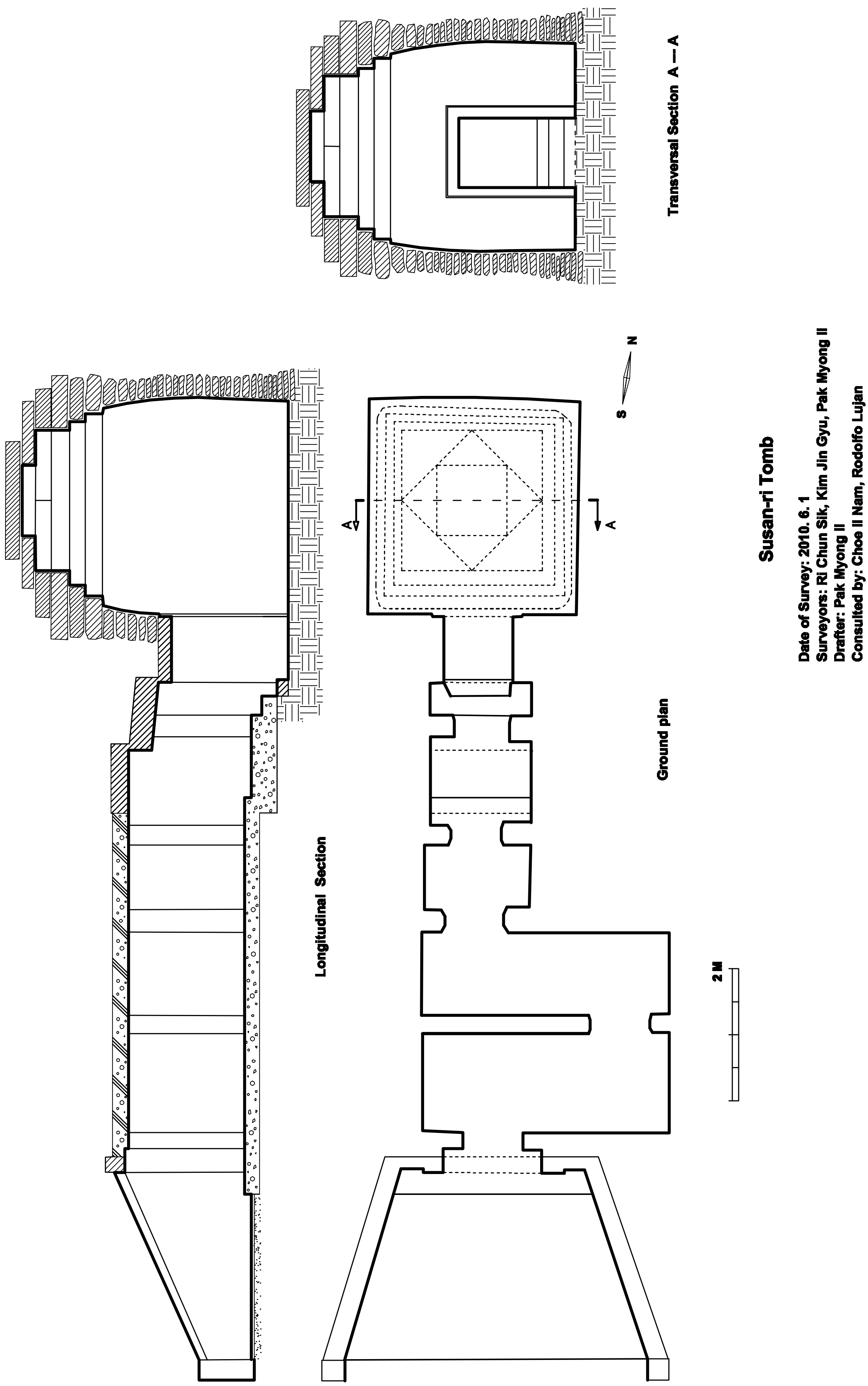
THE SUSAN-RI TOMB - EAST WALL - STATE OF PRESERVATION A -SUPPORT & PREPARATORY LAYERS

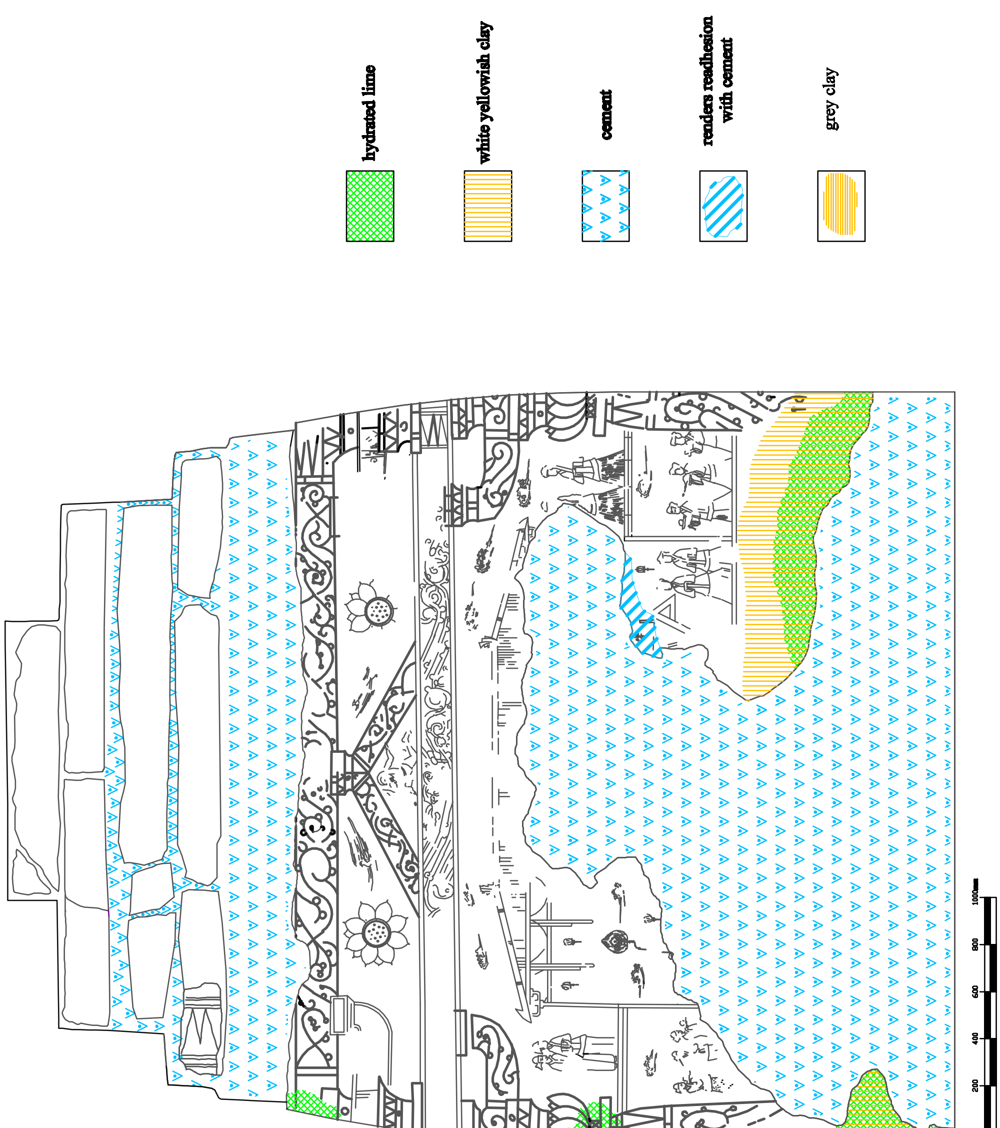

hydrated lime
white yellowish clay
cement
renders readhesion with cement
grey clay
east wall
ceiling
ENTRANCE PASSAGE
ceiling
west wall
facade
INNER SECTION OF CORRIDOR OF ACCESS
0
200
400
600
800
1000mm
THE SUSAN-RI TOMB - INNER SECTION OF CORRIDOR OF ACCESS & ENTRANCE PASSAGE
- FORMER INTERVENTION - A SUPPORT & PREPARATORY LAYERS


mud,soil,clayed concretion
hard mud incrustation
calcium carbonate incrustation
microorganism
biological stain
east wall
ceiling
ENTRANCE PASSAGE
ceiling
west wall
facade
INNER SECTION OF CORRIDOR OF ACCESS
0 200 400 600 800 1000mm
THE SUSAN-RI TOMB - INNER SECTION OF CORRIDOR OF ACCESS & ENTRANCE PASSAGE
- STATE OF PRESERVATION C - DEPOSITS ON SURFACE

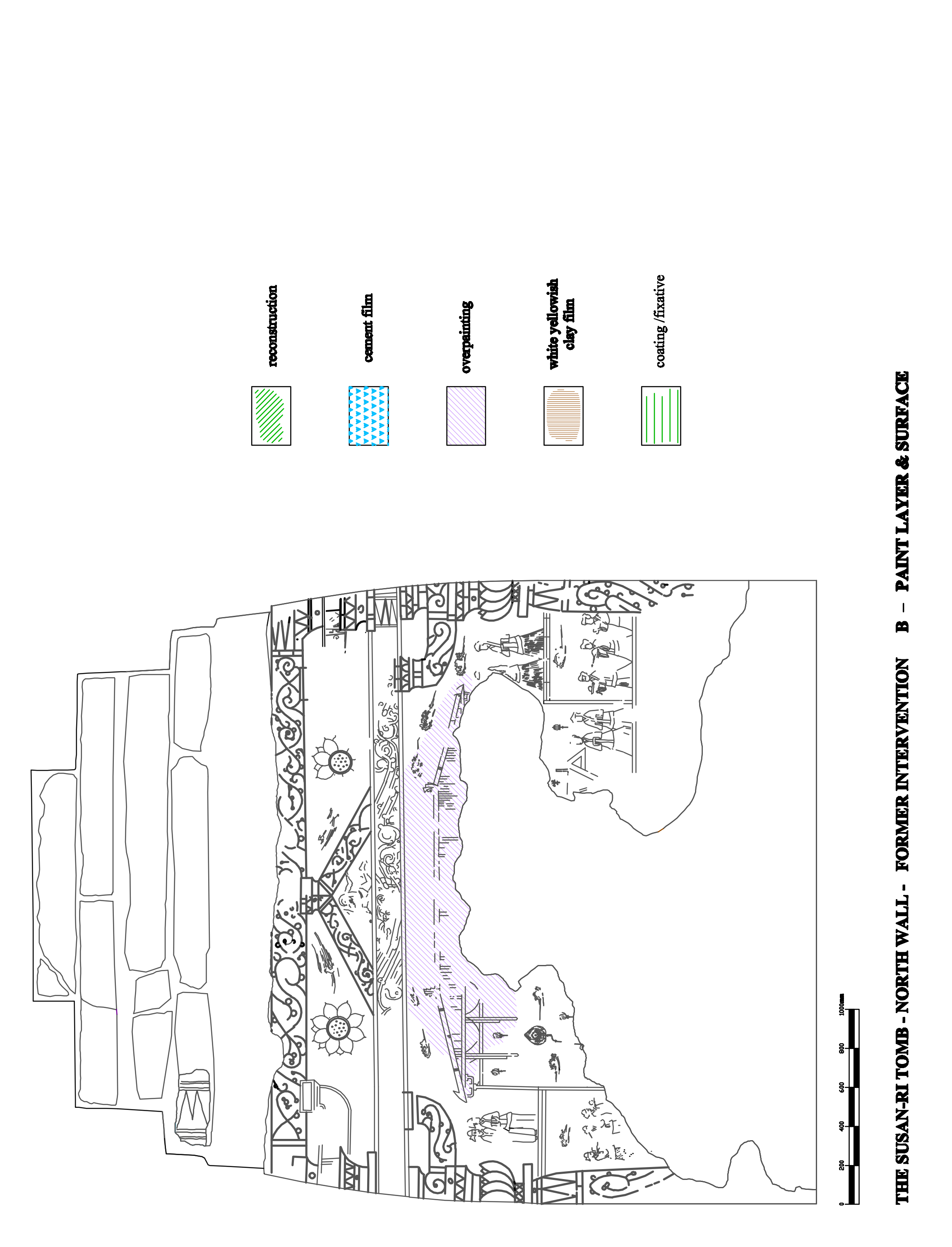

powdering
leaching of pigment
bubble-shaped
superficial lacunae
drying cracks
abrasion/ scratches
east wall
ceiling
ENTRANCE PASSAGE
west wall
ceiling
INNER SECTION OF CORRIDOR OF ACCESS
facade
THE SUSAN-RI TOMB - INNER SECTION OF CORRIDOR OF ACCESS & ENTRANCE PASSAGE
- STATE OF PRESERVATION B - PAINT LAYER

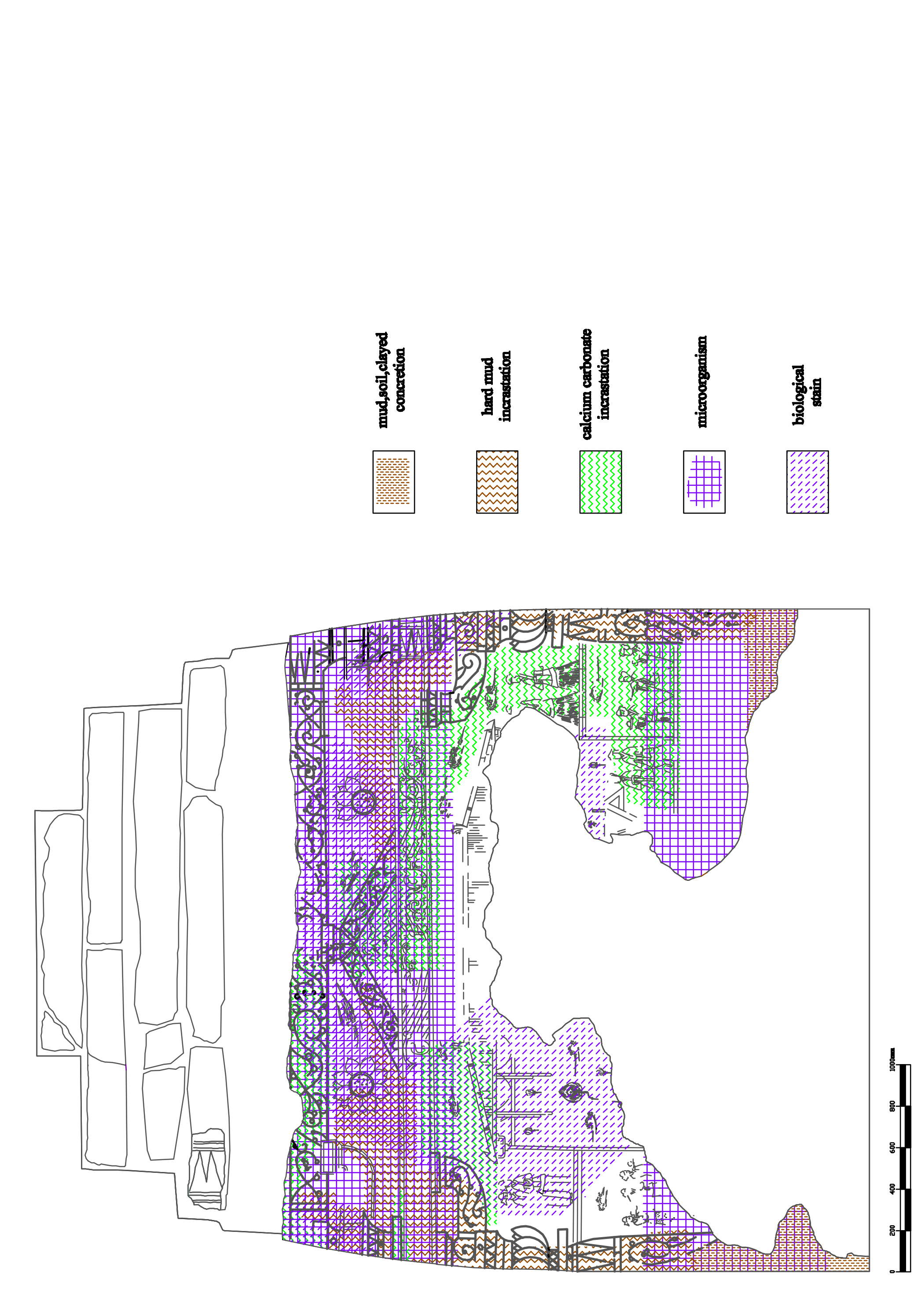

superficial lacunae
in-depth lacunae
erosion
separation with deformation
separation/detachment
mechanical crack
crack due to drying
east wall
ceiling
ENTRANCE PASSAGE
ceiling
west wall
INNER SECTION OF CORRIDOR OF ACCESS
facade
0
200
400
600
800
1000mm
THE SUSAN-RI TOMB - INNER SECTION OF CORRIDOR OF ACCESS & ENTRANCE PASSAGE
- STATE OF PRESERVATION A - SUPPORT & PREPARATORY LAYERS


Transversal Section A — A
Longitudinal Section
Ground plan
A
A
S
N
2 M
Susan-ri Tomb
Date of Survey: 2010. 6. 1
Surveyors: Ri Chun Sik, Kim Jin Gyu, Pak Myong Il
Drafter: Pak Myong Il
Consulted by: Choe Il Nam, Rodolfo Lujan

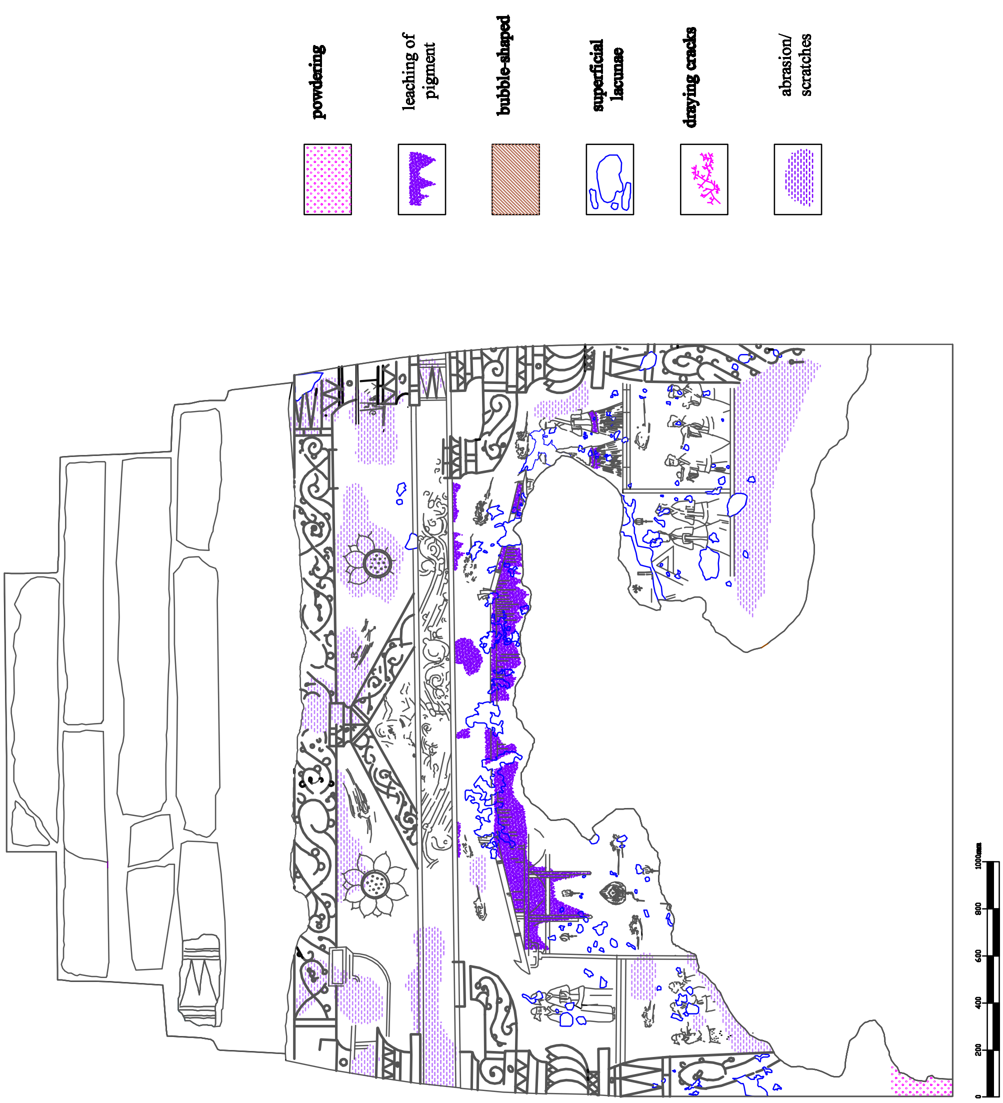


THE SUSAN-RI TOMB - NORTH WALL - FORMER INTERVENTION - A SUPPORT & PREPARATORY LAYERS

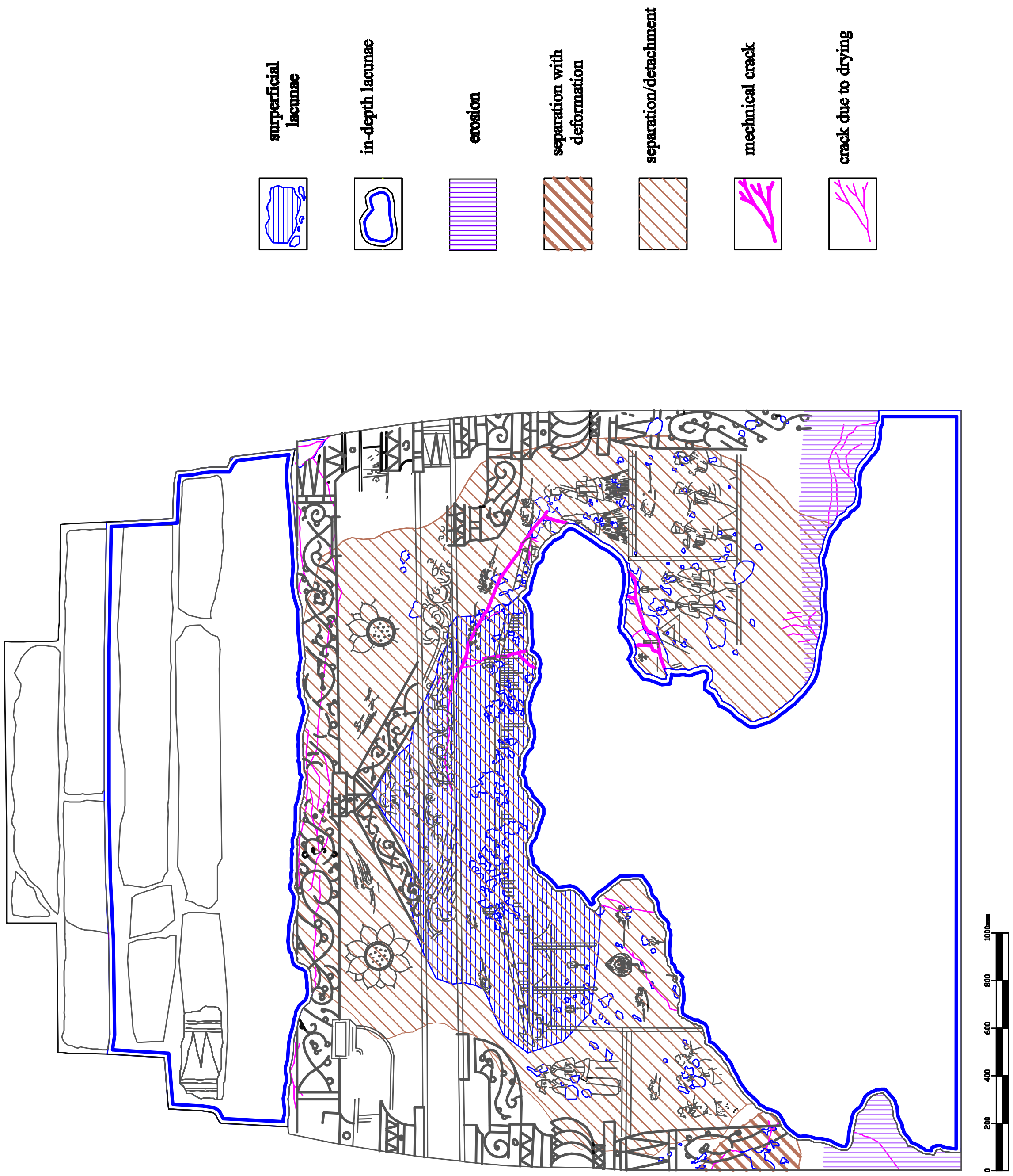

reconstruction
cement film
overpainting
white yellowish clay film
coating /fixative
THE SUSAN-RI TOMB - NORTH WALL - FORMER INTERVENTION B – PAINT LAYER & SURFACE

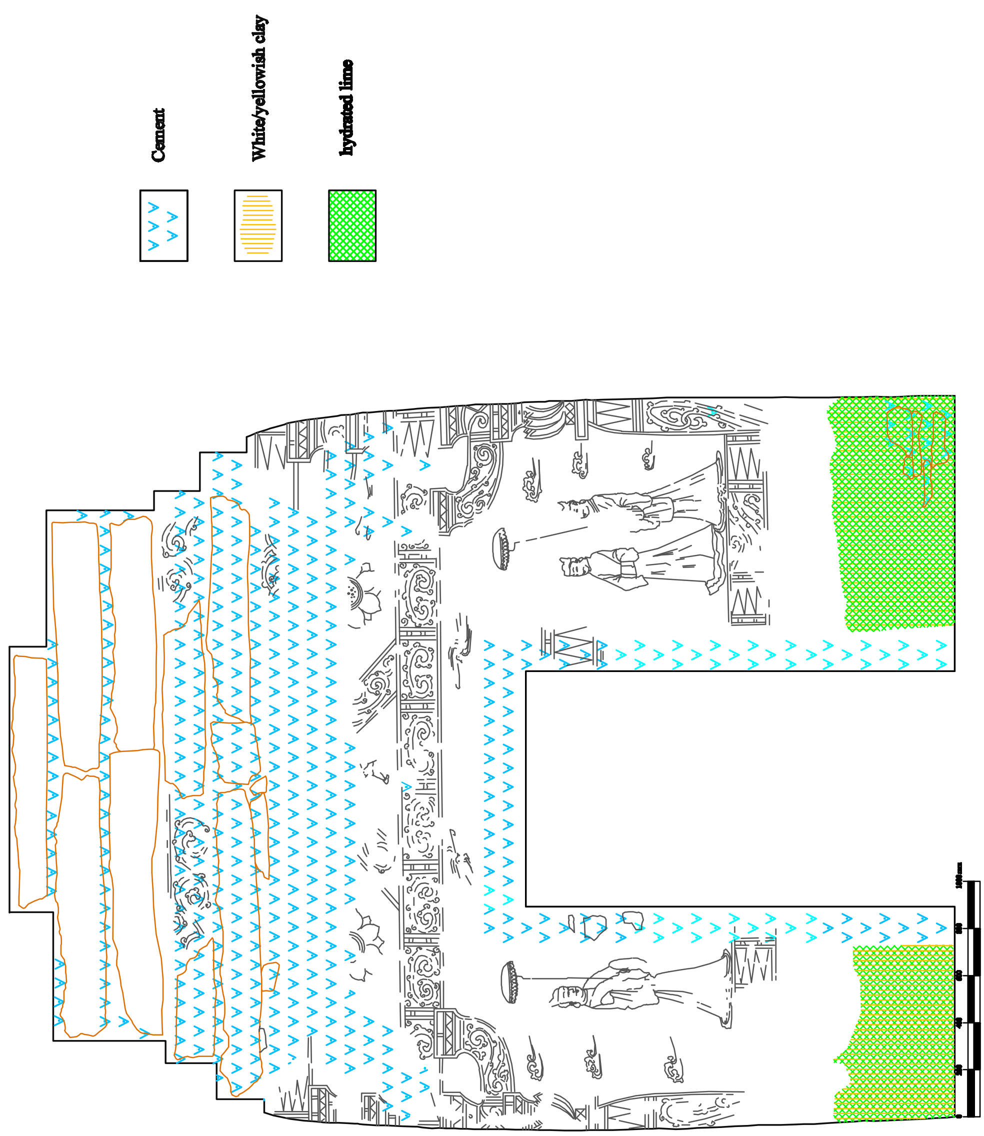


THE SUSAN-RI TOMB - NORTH WALL - STATE OF PRESERVATION C - DEPOSITS ON SURFACE

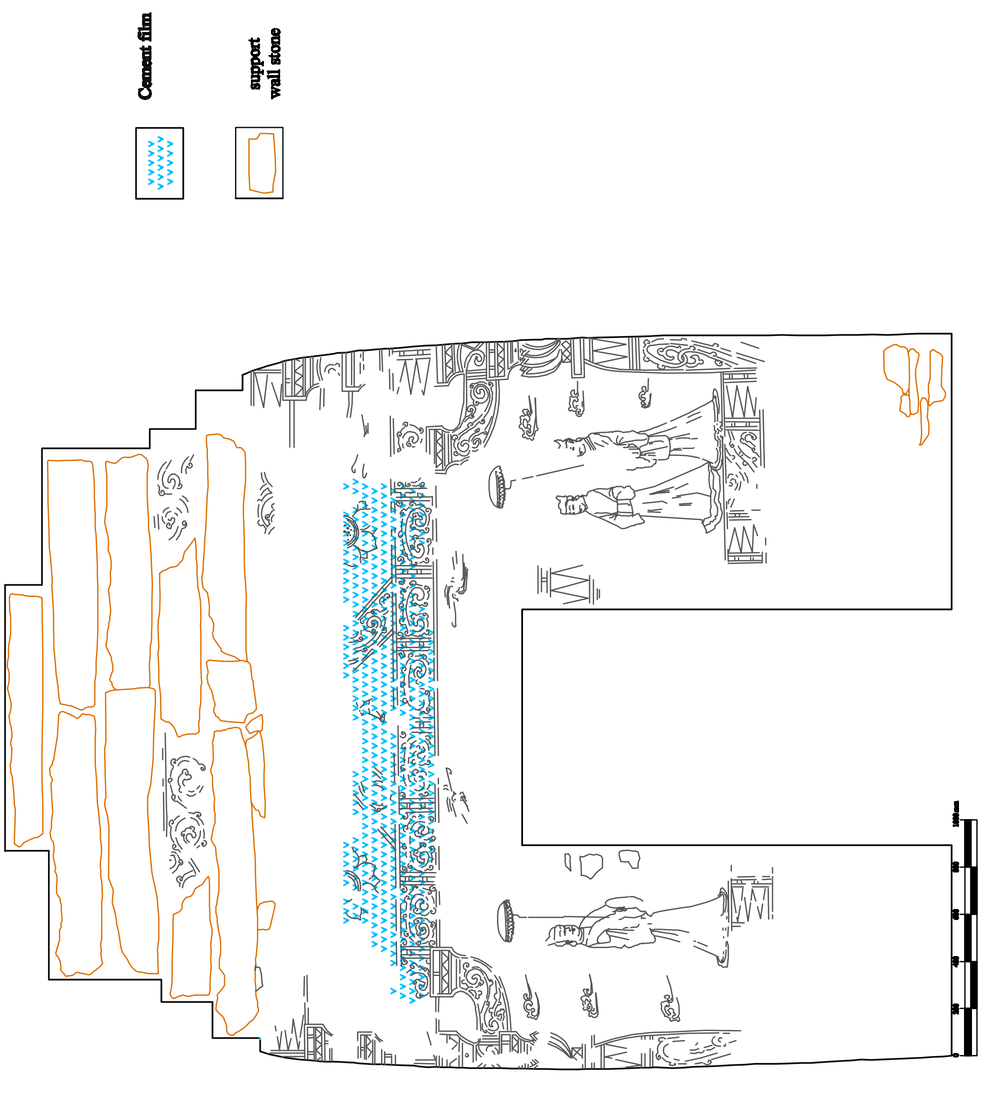


THE SUSAN-RI TOMB - NORTH WALL - STATE OF PRESERVATION B - PAINT LAYER

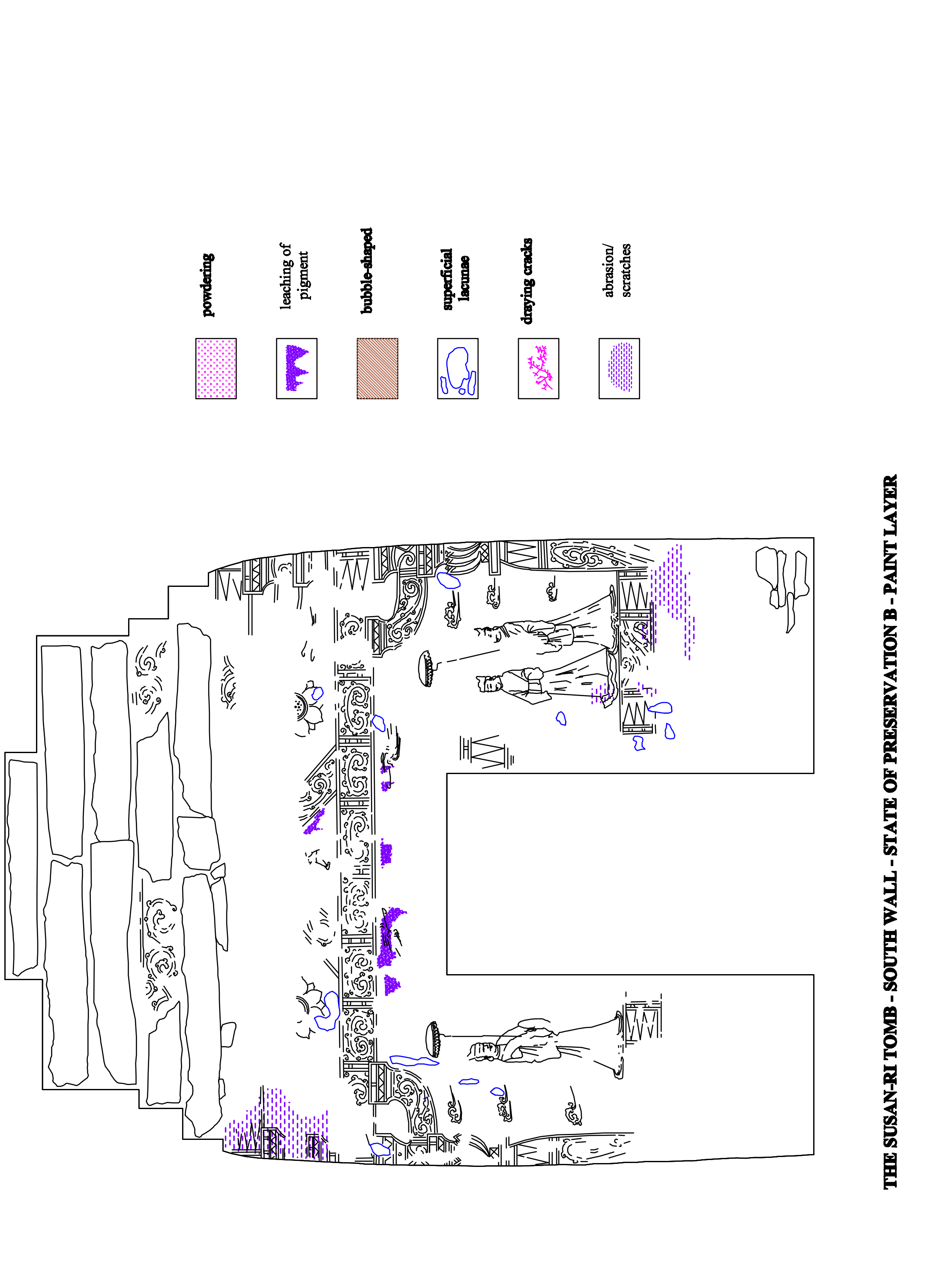

superficial lacunae
in-depth lacunae
erosion
separation with deformation
separation/detachment
mechnical crack
crack due to drying

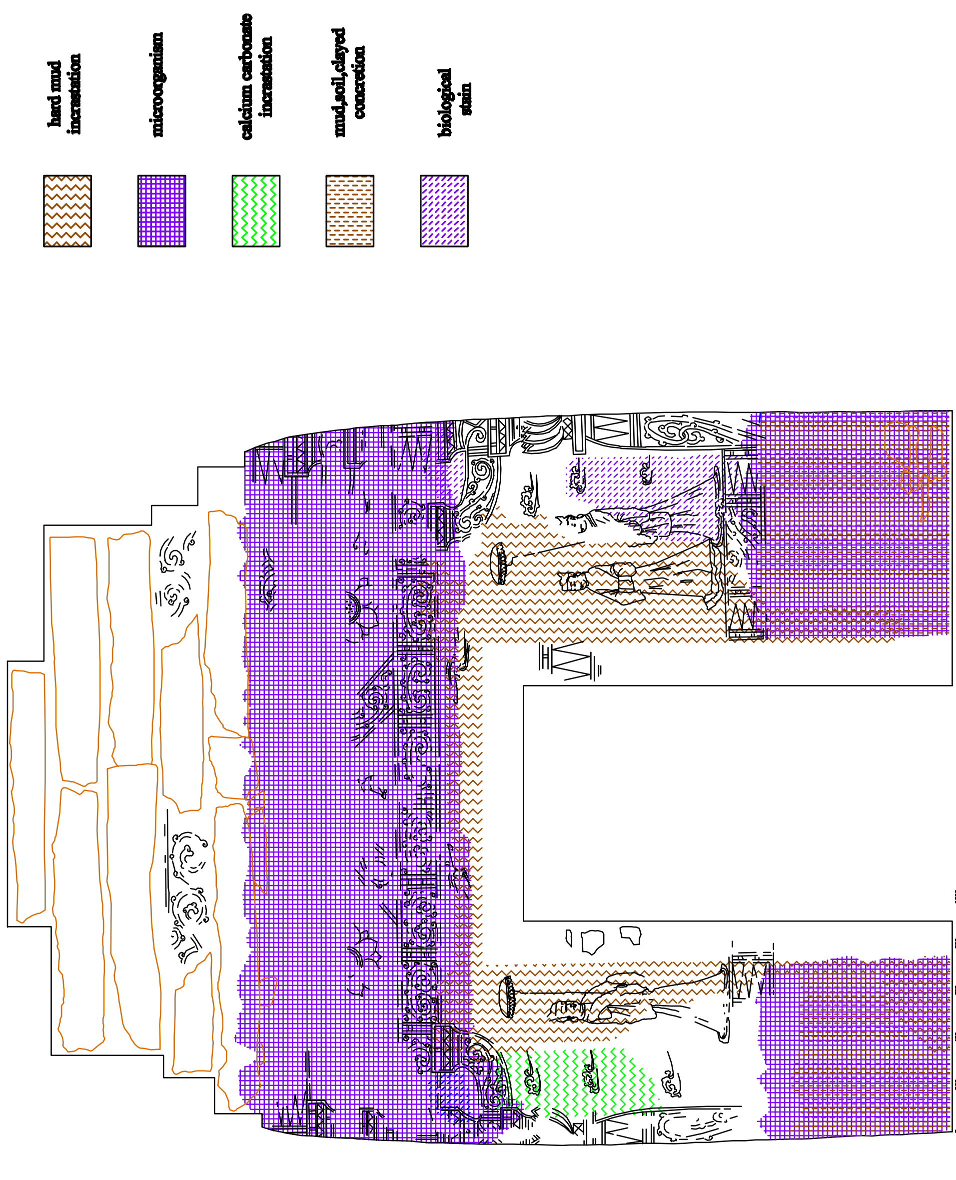


THE SUSAN - RI TOMB - SOUTH WALL - PREVIOUS INTERVENTIONS - PREPARATORY □ SUPPORT LAYERS

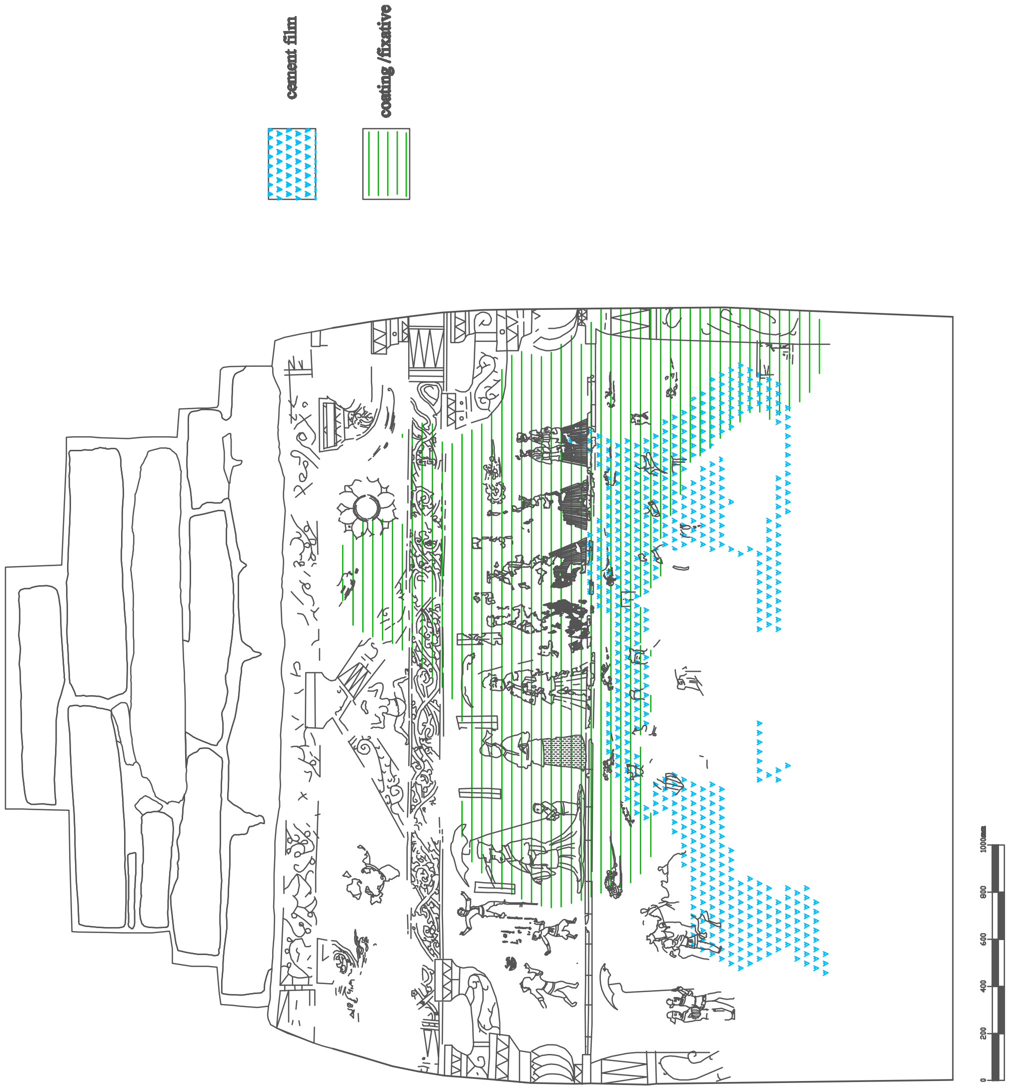


THE SUSAN - RI TOMB - SOUTH WALL - PREVIOUS INTERVENTIONS - PAINT LAYER & SURFACE

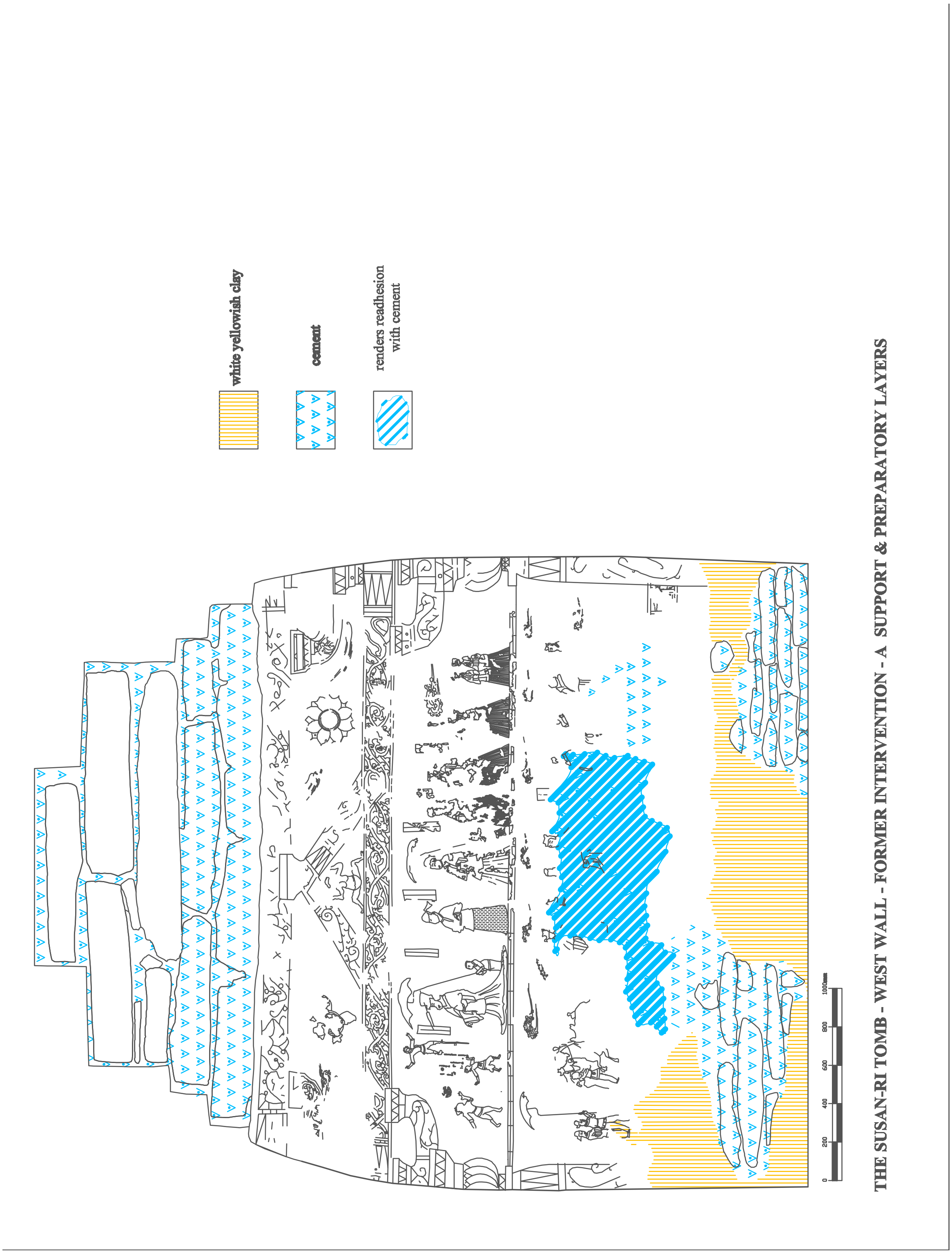

powdering
leaching of pigment
bubble-shaped
superficial lacunae
draying cracks
abrasion/ scratches
THE SUSAN-RI TOMB - SOUTH WALL - STATE OF PRESERVATION B - PAINT LAYER



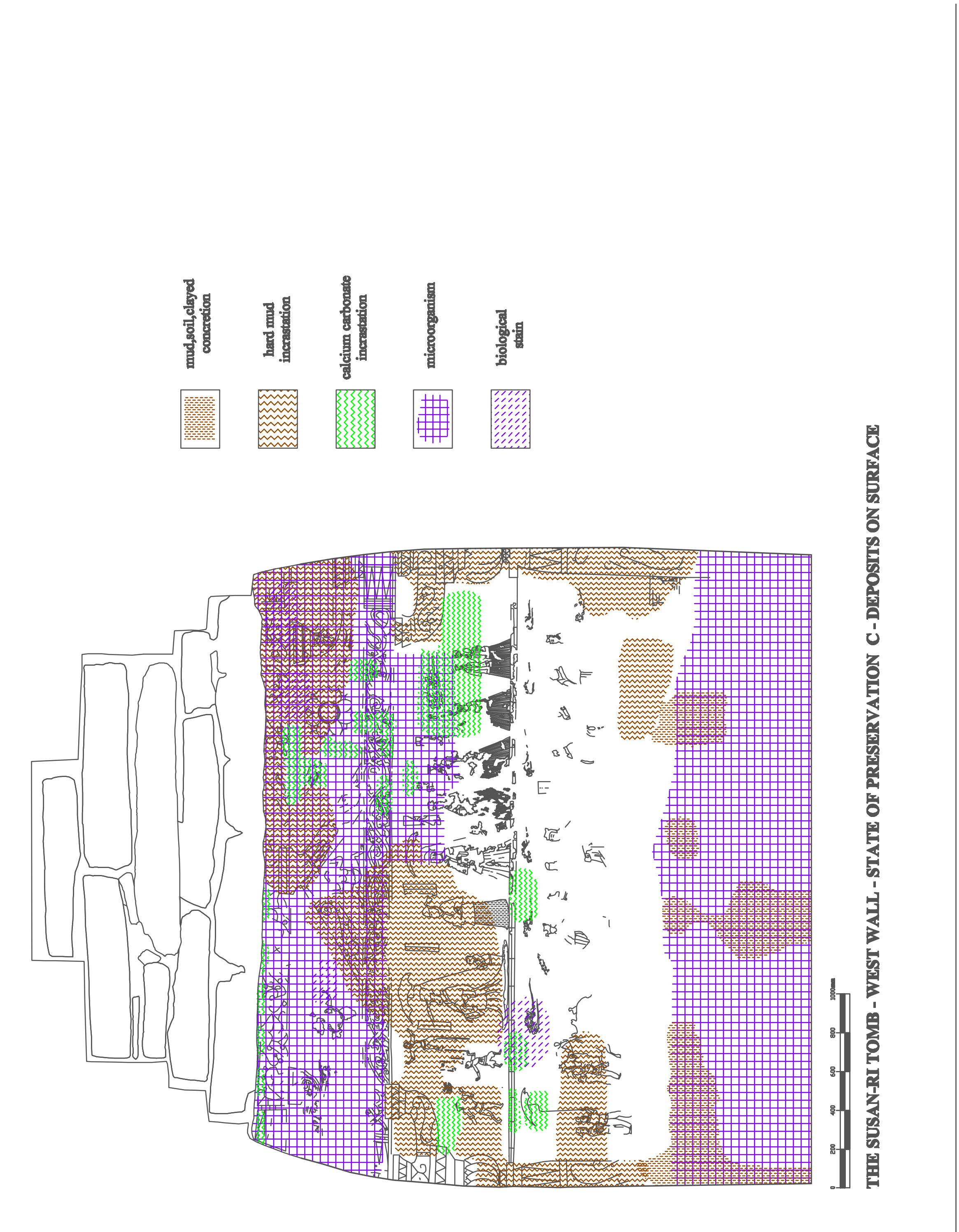
THE SUSAN-RI TOMB - SOUTH WALL - STATE OF PRESERVATION C - DEPOSITS ON SURFACES
PERIOD OF SURVEY 2005 - 2010 - SURVEYOR(S): RI CHUN SIK, HAN YONG CHOL, KIM JIN GYU - DRAFTER(S): KIM JIN GYU

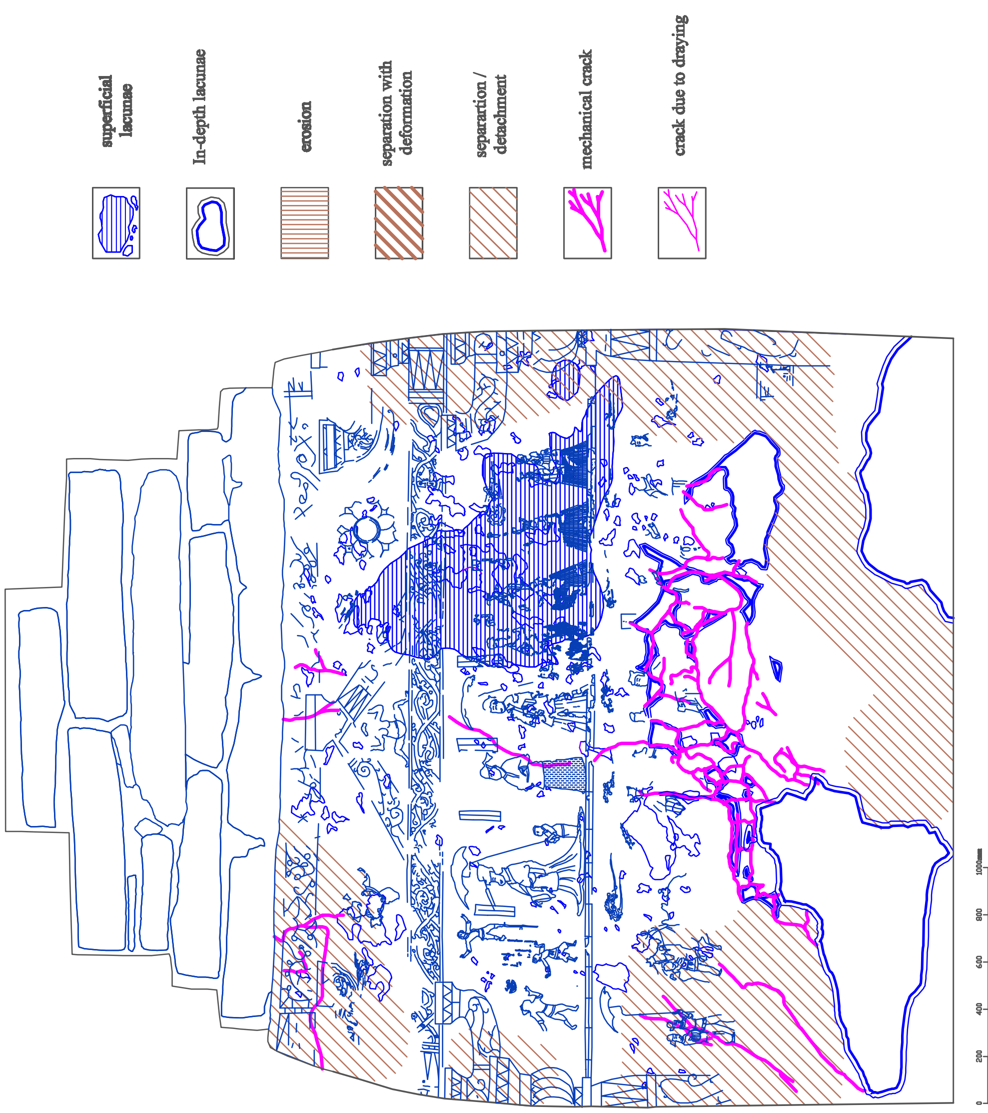


THE SUSAN-RI TOMB - WEST WALL - FORMER INTERVENTION B – PAINT LAYER & SURFACE

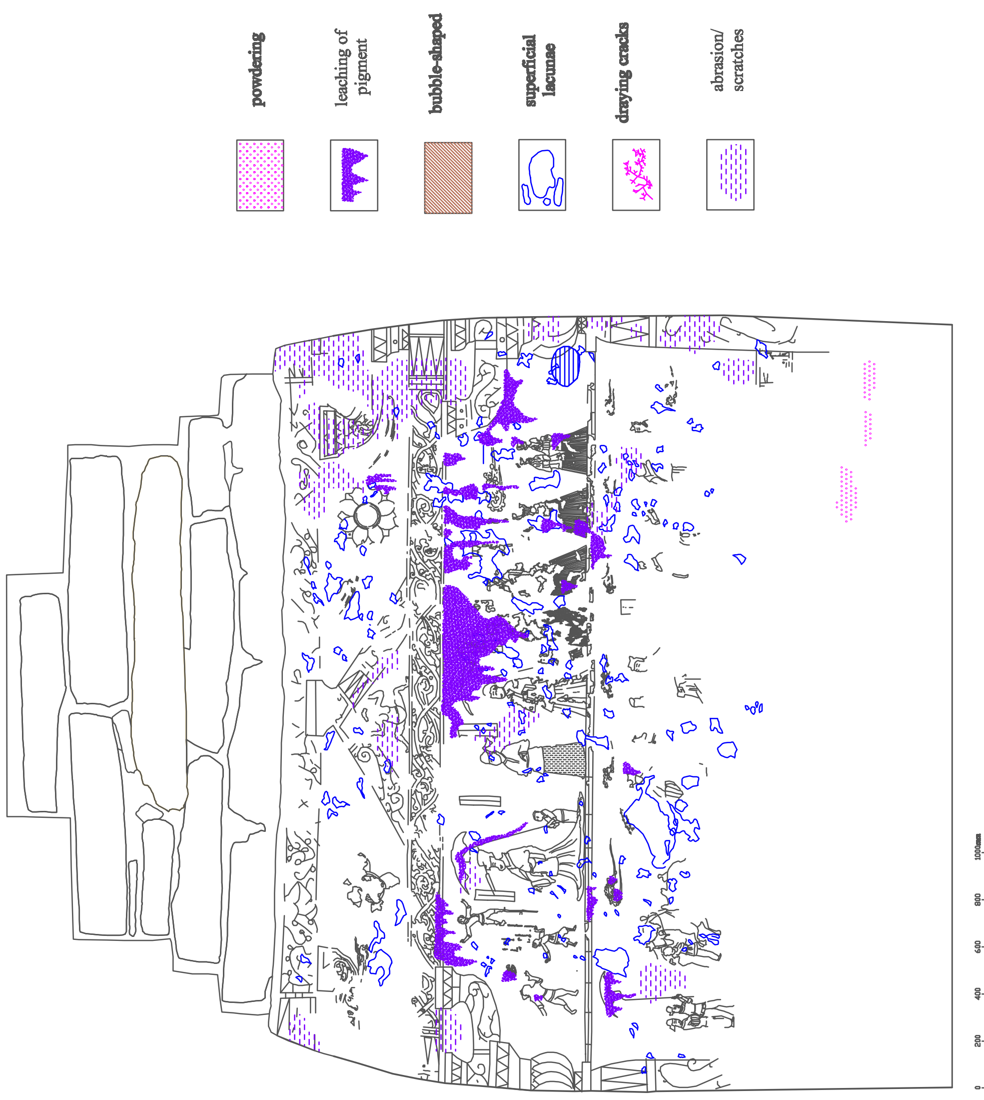


THE SUSAN-RI TOMB - WEST WALL - FORMER INTERVENTION - A SUPPORT & PREPARATORY LAYERS


mud,soil,clayed concretion
hard mud incrastation
calcium carbonate incrastation
microorganism
biological stain
THE SUSAN-RI TOMB - WEST WALL - STATE OF PRESERVATION C - DEPOSITS ON SURFACE



THE SUSAN-RI TOMB - WEST WALL - STATE OF PRESERVATION A -SUPPORT & PREPARATORY LAYERS



THE SUSAN-RI TOMB - WEST WALL - STATE OF PRESERVATION B - PAINT LAYER

Technical Data of Research and Conservation Materials in the Susan-ri Tomb

by Rodolfo Luján Lunsford

1. Ammonium bicarbonate [I]

Chemical name: Ammonium hydrogen carbonate

Chemical formula: $(NH_4)HCO_3$

Chemical-physical characteristics:

Physical state	Crystalline powder	Odour	Ammonia
Colour	White	Density	1.59 gr/cm^3
Solubility in water	11.9 gr/100 ml 0° C	Boiling point	41.9° C
	21.6 gr/100 ml 20° C	Flash point	Non flammable
	36.6 gr/100 ml 40° C	Toxicity	Irritant
Solubility in organic solvents	Insoluble in alcohol		

Properties: used in baking powder. It is utilised in weak solution in water (as a quaternary salt) for the disinfection of surfaces from fungi and eventually bacteria. Provides aid in the transformation of carbonates into bicarbonates, due to the development of carbon dioxide that acidifies water and breaks the carbonate link. Ammonium bicarbonate decomposes between 36 and 60° C into ammonia, carbon dioxide and water vapour in an endothermic (development of low temperature) reaction. It reacts with sulphates of alkaline earth metals, precipitating out their carbonates.

2. Benzalkonium chloride [II]

Chemical name: benzyl-dimethyl-tridecyl-azanium chloride

Other names: alkylbenzyldimethylammonium chloride or

N-decyl-N-benzyl-N,N-dimethylammonium chloride (with n=110 for alkyl side chain)

Chemical formula: variable

Chemical-physical characteristics:

Physical state	Powder	Odour	Almond-like
Colour	White or yellow	Density	0.98 gr/cm^3
Solubility in water	Very soluble	Flash point	250° C
Solubility in organic solvents	Ethanol & acetone	Toxicity	Irritation to skin mucosa

Properties: this product is a nitrogenous cationic surfactant agent belonging to the quaternary ammonium group. The main categories of use are as a biocide, a cationic surfactant, and for phase transfer in the chemical industry.

3. Propyl alcohol [III]

Chemical name: 2-propanol

Other names: Iso-propanol

Chemical formula: CH_3-CHOH-CH_3 denatured with 10% of CH_3-CO-CH_3 [IV]

Chemical-physical characteristics:

Physical state	Liquid at 25° C	Colour	Colourless
Viscosity	2.4 c.P at 20° C	Odour	characteristic
Density	0.78 kg/m3 at 20° C	Boiling point	82° C
Solidification point	- 90° C	Flash poinwt	20° C
Flammability point	11° C	Vapour pressure	21 mmHg at 25° C
Solubility in water	Soluble	Evaporation speed	202
Solubility in organic solvents	Soluble	Toxicity	400 ppm

NB: vapours can form explosive mixtures with air.

Toxicological information: [V]

Penetration: ingestion, inhalation. [1]

LD_{50} oral: 5840 mg/kg (rat).

LD_{50} cutaneous: 13 gr/kg (rabbit)

TLV: 980 mg/m3 (human)

Properties: has similar properties to ethanol (ethyl alcohol) but is much more toxic. It is used when necessary as an anhydrous alcoholic solvent and is not hygroscopic.

4. Ethyl silicate (OH) in 70% iso-propanol [VI]

Chemical name: tetraethoxysilane

Other names: tetraethyl orthosilicate, silicic acid

Chemical formula: $Si(OC_2H_5)_4$-

Chemical-physical characteristics:

Physical state	Liquid	Colour	Colourless
Viscosity		Odour	Characteristic
Density	0.94	Boiling point	168° C

1 Toxicity: the power of a substance to damage the vital organs or kill.

LD: lethal dose expressed in mg of product/kg of weight of the animal. The index for quantifying acute toxicity is by calculating the amount of active compound (administrated orally or cutaneously) that is lethal for 50% of the experimental animals tested.

LC: lethal concentration of gaseous compounds.

TLV: threshold limit value expressed in parts per million (ppm) or cubic centimetres per cubic metre of air. The smallest acceptable concentration of a solvent vapour in air that will allow work to be done during an eight-hour day in a 40-hour week without deleterious effects on the human organism.

Relative vapour density, air=1	7.22	Flash point	37° C
Explosive limits, vol % in air	1.3-23	Vapour pressure	200 at 20° C
Solubility in water	Slowly hydrolyses	Evaporation speed	As solvent
Solubility in organic solvents		Toxicity	Irritating

Toxicological information:

Penetration: inhalation of vapour, ingestion. Irritates eyes, skin and respiratory tract. May have effect on the kidneys after long exposure.

TLV: 10 ppm; 85 mg/m3 (human)

Properties: is mainly employed as a cross-linking agent in silicone polymers and as a precursor to silicon dioxide in the semiconductor industry. Has the remarkable property of easily converting into silicon dioxide. This reaction occurs upon the addition of water,

$Si(OC_2H_5)_4 + 2H_2O \rightarrow SiO_2 + 4C_2H_5OH$, and this hydrolysis reaction is an example of a sol-gel process. The by-product is ethanol. The reaction proceeds through a series of condensation reactions that convert the tetraethyl orthosilicate molecule into a mineral-like solid by the formation of Si-O-Si linkages. Employed in engineering work where the mechanical resistance of cement requires to be increased.

5. Slaked lime ($Ca(OH)_2$) and lime-based mortars and renders [VII] [VIII] [IX]

The use of lime as a binding material for making mortars or renders dates from antiquity in places where there was an abundance of forests and limestone or mollusc shells. The stones or shells were baked in kilns[2] at a calcination[3] temperature of 850-900° C, producing the fission (cleavage or splitting) of the main constituent, which is calcium carbonate ($CaCO_3$), obtaining carbon dioxide (CO_2) that mixes with the air and calcium oxide (CaO) or quicklime, which is a white porous mass that disintegrates in contact with the air.

The chemical-physical characteristics of quicklime depend on the quantity and quality of the types of minerals contained in the raw material or limestone, and impurities such as magnesium, silicates, aluminium and iron hydrates, etc., are found even though in very small percentages. The high porosity of quicklime is due to the fact that the granules reduce in volume with a contraction of 10-20% during calcination and the weight is reduced to 44%.

Subsequently, quicklime mixed with water generates an exothermic reaction (development of high temperature) producing calcium hydroxide ($Ca(OH)_2$) or slaked lime that increases in volume by about 10% and can be in the form of malleable putty or powder.

The methods currently employed for making **slaked lime putty** are by sprinkling and immersion in water. The first method requires that the quicklime is put inside small containers and watered until complete saturation with much more water than necessary forming ductile putty. The lime putty thus obtained is kept in lime-pits (large basins excavated in the ground and covered) and left for a long time soaked in water so as to complete the hydration process. The Ancient Romans, particularly Vitruvius, recommended stocking the lime putty for at least three years covered with water so as to avoid non-hydrated lumps of quicklime being found in mortars and/or plasters during work, which would result

2 The furnaces were of various types and became highly developed with time and experience, from open-air and underground trenches to kilns properly so called, such as flare kilns with discontinuous heating taking about one month for calcination, or draw kilns that carried on heating continuously in less time than the former, to the industrial rotary kilns, etc.

3 To change, to calx, or to reduce to powder by heating at high temperatures.

in an increase in volume due to retarded hydration causing breakage. The second method consists of immersing the quicklime lumps for a given time in iron baskets in a large container filled with water. Upon completion, the baskets are taken out containing the lime putty.

Hydrated lime in powder is obtained by rotating cylinders in which the quicklime is placed and sprinkled with the exact amount of water needed for the reaction of hydration. The resulting slaked lime powder is not very soluble in water and produces very strong alkaline solutions.

Slaked lime putty is an aerial binder, meaning that it needs air for setting (hardening) and the reaction is inverse to the process of transformation of calcium carbonate into calcium oxide and then into calcium hydroxide when mixed with water. This inverse process is called carbonatation in which calcium hydroxide reacts with the carbon dioxide contained in the air and by loss of water by evaporation reforms calcium carbonate. The loss of water causes a contraction in volume, and therefore slaked lime is never employed alone but always with an aggregate in order to avoid cracks.

The grain-size of the aggregates depends on the thickness of the mortar or renders to be employed and accurate mixing is necessary. The mixture of lime and an aggregate (the classical aggregate is sand[4] but inorganic as well organic were employed throughout history) is called mortar (if employed for masonry) and render (if used as a single or stratified layer to cover surfaces such as walls, ceilings, vaults, etc.). The carbonatation of these mixtures results from drying by evaporation of the water content and by hardening due to the reaction of carbon dioxide with calcium hydroxide in the presence of water, forming calcium carbonate. This is a long reaction that begins on the surface where a crust of calcium carbonate is formed and continues towards the core of the layer as far as there is water in the mortar or render. The chemical composition of lime is identical, after carbonatation, to the original limestone, maintaining unaltered the crystalline structure (rhombohedric) but differentiated by the crystals' size, which are smaller than those from the original material.

Certain methods employed for preparing mortars and renders once consisted of heaping quicklime together with aggregates and sprinkled with water and mixed. This technique[5] in the long-term has caused conservation problems because unslaked (hydrated) quicklime lumps in the mixtures continue to absorb humidity long after drying and setting, then expanding by hydration and causing blisters (in the shape of small craters) in the renders or the core of the walls. Therefore, the complete hydration of quicklime is absolutely necessary for a good and lasting result.

The lime processes can be summarized as follows:

<u>Baking (calcination)</u>:

$CaCO_3 + \Delta\ T\ (850\text{-}900\ °C) \rightarrow CaO + CO_2\ - 42.6\ Kcal$

<u>Slaked lime</u>:

$CaO + H_2O \rightarrow Ca\ (OH)_2 + \Delta T\ \ (15.3\ Kcal)$

<u>Drying (evaporation) and setting (hardening)</u>:

$Ca(OH)_2 + CO_2 + H_2O + \text{excess of } H_2O \rightarrow CaCO_3 + H_2O\ + \text{excess of } H_2O$

6. Slaked lime putty [$Ca(OH)_2$] - Pyongyang

The lime putty employed for preparing the mortars and plasters for conservation in the Susan-ri Tomb was obtained from quicklime purchased near Pyongyang and slaked in water for three years. A lump of slaked lime putty and lime water was analysed at the Kim Il Sung University in Pyongyang on 30 April 2009, finding it suitable for conservation purposes because it contained low amounts (below the standardized values) of soluble salts.

4 Sand must be washed to remove salts (that cause efflorescence) and clay or organic materials (that slow-down the hardening process).

5 Mortars and renders prepared without removing lumps of non-hydrated lime cause the same problem.

Results of slaked lime analyses carried out at the Kim Il Sung University on 30/4/2009						
	Fe %	K %	Na %	Mg %	Ca %	
Lime putty $Ca(OH)_2$	$6.9 \cdot 10^{-2}$	$7.0 \cdot 10^{-3}$	$1.0 \cdot 10^{-3}$	0-.28	25.3	100 gr (100%)
Lime water $Ca(OH)_2$	$2.8 \cdot 10^{-6}$	$1.0 \cdot 10^{-4}$	$3.7 \cdot 10^{-4}$	-------	$2.2 \cdot 10^{-2}$	100 gr (100%)
Analysis carried out with atomic absorption photometer PERKZH – EUHE – K – 5000PC						
Ions	Cl^-		SO_4^{--}		NO_3^-	
	0.28 gr./Lt		$6.4 \cdot 10^{-5}$ gr./Lt		< 1 mg/Lt	
Analysis carried out with UV – 2202 ultraviolet visual spectrophotometer						

Tab. 16: Results of the analyses of slaked lime employed in the Susan-ri Tomb.

7. Hydraulic Lime [X]

Hydraulic lime is obtained from clayey limestone or marl baked at a high temperature between 1000-1300° C. The main characteristic of hydraulic lime and hydraulic mortars is that the setting process (hardening) takes place by chemical reaction with water in the absence of air despite the aerial binder (slaked lime) that needs carbon dioxide to complete this process. The properties of aerial binders such as slaked lime modify to hydraulic when mixed with aggregates that contain highly reactive silica (SiO_2) or alumina (Al_2O_3). The natural hydraulic aggregates of volcanic origin such as tuff, pozzolana, pumice or trass and the artificial or synthetic ones such as crushed tiles, pots or bricks (clay fired at high temperature) and iron slag (obtained from high temperature smelting of iron) contain silicates and aluminates in a vitrified state and are very reactive with water and lime. Hydraulic lime contains an elevated amount of clay components (8-27%), of which the main elements are silica, aluminium and iron.

The reaction between slaked lime and hydraulic aggregates that are naturally reactive occurs at room temperature without preventive baking.

Chemical formulas	**Technological abbreviations**
$3CaO + SiO_2 \rightarrow 3CaO \cdot Si\,O_2$	C_3S
$2CaO + SiO_2 \rightarrow 2CaO \cdot\cdot SiO_2$	C_2S
$4CaO + Al_2O_3 \rightarrow 4CaO \cdot Al_2O_3$	C_4A

The setting reaction can be summarized as follows:

$$\left.\begin{matrix} C_3S \\ C_2S \\ C_4A \end{matrix}\right\} + H_2O \ ▯ \ Ca(OH)_2 + \text{hydrated silicates or aluminates of Ca}$$

↑

The resulting compounds form an array of fine crystals that cause the hardening of the mixture.

8. Hydraulic Lime Lafarge [XI]

Manufacture: Cruas establishment in Ardèche, France.

Composition: natural hydraulic lime.

Resistance to pressure: minimum guaranteed in mortar 1: 3 according to regulation P 15 401: 30 bars after seven days, 60 bars after 28 days. 1 bar[6] = 1.02 Kg/cm².

Applications: for decorative internal and external renders according to the French Standard DTU N° 26.1 regarding the application of hydraulic-based plasters. Used for jointing masonry stone blocks, for the restoration and renovation of historic buildings, and for executing rustic renders.

Laying applications:

Granulates: eliminate the dirty grains or those that are powdery or improper in colour.

Unauthentic mortars: by addition of cement for obtaining renders with faster setting and with higher mechanical resistance.

Tools: do not employ steel tools (rust traces) in final polishing.

Atmospheric conditions: precautionary measures during hot and dry weather or strong drying winds and avoid any work below 5° C.

9. Ledan TA1 Tecno Edile Toscana XII

Manufacture: Tecno Edile Toscana establishment in Latina, Italy.

Composition: chemically stable hydraulic binding agent components with calcareous-siliceous and pozzolanic aggregates and a special combination of additives to improve fluidity, water containment and pores formation with a minimal amount of soluble salts. The mixture is finely ground and mixed in a micronised dispersion of 1/10,000 for not less than 20 minutes. Ledan TA 1 is pure white.

Application: employed to strengthen the surface of masonry wall structures. Further fields of application are masonry arches, pillars, archaeological walls and masonry walls with paintings.

Properties: excellent penetration and flowing ability even without wetting the interfaces; compatibility and chemical-physical characteristics similar to lime and hydraulic lime. High mechanical resistance and lack of salt efflorescence even in very damp environment.

Mixture: mix the grout thoroughly with demineralised water for about three minutes. It is recommended to filter the blend to remove possible clots.

Mixing recommendations:

Application	Ledan TA 1	Water
Strengthening of loose surfaces:	10 kg	16 lt
Strengthening of masonry and arches:	10 kg	8 lt

The grout can be mixed with sand. Not very absorbent marble dust or quartz powder is mixed with the grout in a ratio of 1: 1. This mixture can be further mixed in a ratio of one part Ledan TA 1 with seven parts of sand when the strength and bonding force should be reduced.

Limited areas of application: Ledan TA 1 is a binding agent containing lime, thus the temperatures should not be below 5° C and not above 35° C when working with this mortar.

Properties:

	Value[7]	Evaluation
Specific weight	1.40 kg / dm³	medium
Start of hardening	18 hours	medium
End of hardening	24 hours	medium

6 Metric unit of pressure equal to one million dynes per square centimetre.

7 The numerical values are referred to as average and come from laboratory samples.

Workability	2 hours	medium
Compressive strength	13 N / mm^2 at 28 days	good
Flexion strength	3.5 N / mm^2 at 28 days	good
Adhesive capacity	1.4 N / mm^2	very good
Exudation	Insignificant	very good
Vapour permeability	9 µ	good
Elasticity module	11000N / mm^2	medium
Water retention	> 70%	very good
Absorbency	None	very good

Soluble salt efflorescence: Ledan TA 1 was subjected to laboratory analyses in order to verify the quantity of soluble salt content according to the Italian Standard RAL 544/3. The results were negative, so salt efflorescence should not occur.

Stability: stability tests have been carried out with samples of Ledan TA 1 which correspond to an ageing process of about 20 years. These tests showed a change of properties of less than 5%.

References: the grout has been used for 20 years in Italy, Germany and other European countries. The Department of Historical Monuments in Matera (rupestrian churches) and Etruria (Necropolis of Tarquinia) in Italy have successfully employed the grout and recommend it for the applications listed above.

10. Ion Exchange Resins [XIII VIII]

The chemistry of ion exchange resins

Ion[8] exchange resins are polymers that contain weak bonding in their macromolecule ions that can exchange with ions from the surroundings without producing a change in the physical structure of the product.

The resins are composed of:

- **The matrix**: a polymer (organic macromolecule) and
- The active ionic groups.

The resins are divided into two main categories:

- Resins that exchange cations, simply called **cationic resins**;
- Resins that exchange anions, or simply **anionic resins**.

Main properties:

When employing the most suitable type of resin for a specific problem encountered, the **physical and chemical parameters** that determine the resin's properties should be taken into account.

The most important parameters are:

- **The capacity of exchange** is the most important characteristic of a resin. This is the total amount of active groups capable of exchanging ions, and it is expressed in exchanged ions milliequivalents to a gram of dry resin (meq/gr) or in milliequivalents per millilitre (meq/ml).
- **The grain size** (round-shaped) refers to the diameter of the resin particles. Depending on the type of application in conservation work, a determinate particle size is needed, especially bearing in mind the morphological characteristics of the material on which these will be applied.

8 Ion: an electrically charged atom or group of atoms. Positively charged ions are cations and negatively charged ions are anions.

Cation: a positive ion obtained by removal of electrons from atoms or molecules.

Anion: a negatively charged ion formed by the addition of an electron to atom or molecule.

- **The hydration water content** is the measurement of the amount of water retained by the resin.
- **The apparent density** is the amount of material (in dry type) per litre of resin expressed in gr/ml.
- **The porosity** refers to the total volume of pores per unit of volume. With major porosity there is a major capacity of exchange.

Fundamental concepts when ion exchange occurs

It is necessary, for a resin to behave as an exchanger, for it to be soaked in an aqueous medium in which the saline species dissociates into cations and anions. In this case as an example, we call $\mathbf{R{\cdot}H^+}$ a cationic resin and $\mathbf{R{\cdot}OH^-}$ an anionic resin, and with $\mathbf{C^+}$ and $\mathbf{A^-}$ as the monovalent generic cation and anion, respectively, the reactions of ion exchange can be synthesized as follows:

Cationic exchange: $R{\cdot}H^+ + C^+ \rightleftharpoons R{\cdot}C^+ + H^+$

For example, if $\mathbf{C^+}$ corresponds to a sodium ion (Na^+) this firmly bonds to the resin that simultaneously liberates an $\mathbf{H^+}$ ion.

Anionic exchange: $R{\cdot}OH^- + A^- \rightleftharpoons R{\cdot}A^- + OH^-$

Similarly to the previous example, if $\mathbf{A^-}$ corresponds to a chloride ion (Cl^-) this firmly bonds to the resin that frees an $\mathbf{OH^-}$ ion.

* There are two types of strength in ion exchange resins, strong and weak, and these have been produced in order to behave differently depending on the nature of the substances to be removed and whether a fast or a slow reaction is to be expected.

Regeneration of ion exchange resins

The resins employed can be re-used more than once (regenerated) since it is possible to regenerate them in order to regain their capacity of initial exchange. The procedure of regeneration differs from one resin to another. The cationic resins are treated with hydrochloric acid and the anionic resins are treated with sodium chloride. The treatment is concluded by washing/rinsing the resin with water until a neutral reaction is obtained. Each brand of resin has its own method of regeneration, and therefore the producers should supply the necessary instructions for carrying out this operation.

Problems of the use of ion exchange resins in conservation

The use of ion exchange resins in the field of conservation dates back some 50-60 years. Nevertheless, there are few publications regarding their use.

The different methods of application as well as guidelines for their selection and working procedures have not followed unified criteria. Moreover, the scientific information available is incomplete.

The ion exchange resins applied to the conservation of mural paintings and stonework are basically employed for salt extraction and for the removal of determinate types of deposits from the surfaces. Therefore their use and employment must be carefully controlled.

Factors to be taken into account when employing ion exchange resins

- **Determination of the nature (type) of the substance to be removed.**

The **cationic resins** are usually employed for the removal of layers of carbonation since the $\mathbf{H^+}$ ions of the resin exchange with the $\mathbf{Ca^{++}}$ cations. However, it must be borne in mind that frescoes are nothing but calcium carbonate and therefore the resin can also react with the constitutive calcium of the work of art.

* Regarding the selection of the resins, it is suggested to employ a strong cationic resin to break the calcium carbonate layer, but caution must be used because of the strong acid reaction. A weak cationic resin can be tested for the same objective, and in this case it performs a weak acid action similar to the use of acetic acid.

The **anionic resins** are normally employed for the removal of sulphate films. The $\mathbf{OH^-}$ ions of the resin exchange with the sulphate ($\mathbf{SO_4^-}$) groups. It has been found that this type of resin can be employed for the removal of protein-based substances from surfaces, since this type of resin is capable of swelling and softening proteins.

* Regarding the anionic resins, in this case it is suggested to employ the strong type that performs by exchanging 'anions' of the sulphate kind, releasing hydroxyls that are OH^- and involving an extremely strong alkaline reaction. Because these resins have an alkaline behaviour, this helps in the removal of oily substances and soot from surfaces, but the mechanism of reaction is different.

► **Possible alteration of pigments sensitive to an acid or base environment.**

The use of anionic resins must be avoided on paint layers made of malachite or azurite because these can become blackened given their sensitivity to alkaline substances.

Similarly, the use of cationic resins on pigments that are sensitive to acidic media should be avoided.

* The pH of the water in which the resins are contained must be measured and the resins washed/rinsed before use until values near to neutral pH are obtained. The **anionic resins** are <u>pH basic or alkaline</u> and the **cationic resins** are <u>pH acid</u>. Therefore the cationic resins must be carefully washed in order to remove the acids.

P.T.O

CATIONIC RESINS [XIV]

These resins act in the removal of lime-washes and calcareous incrustations and have no action on calcium sulphate (gypsum).

They are a synthetic polymer containing functional cationic groups (hydrogen form) capable of exchanging hydrogen ions H^+ with the calcium ions Ca^++ of calcium carbonate through an aqueous medium.

Chemical principle of cationic resins	$\left[\begin{matrix} H \\ \\ H \end{matrix}\right. + CaCO_3 \quad \text{resin} == Ca + H_2O + CO_2$
WEAK CATIONIC ION EXCHANGE RESIN – COMMERCIAL NAME AMBER WA/P	
Technical Characteristics	
Type	Pulverized weak cationic resin in hydrogen form
Matrix	Polyacrylic
Functional groups	Carboxylic
Hydration (water content)	48-52%
Total exchange capacity	Min. 9.8 eq/kg dry resin
Ionic form	Minimum 99% H^+
Particle size (powder)	85-95 % comprehended between 100-400 mesh max. 5% < 60 mesh max. 5% > 400 mesh
Maximum impurities	
Max. temperature of use	
pH manipulation range	Acidic 0-6
STRONG CATIONIC ION EXCHANGE RESIN – COMMERCIAL NAME AMBER SH	
Technical Characteristics	
Type	Pulverized strong cationic resin in hydrogen form
Matrix	Copolymer styrene DVB
Functional groups	Sulphonicitic SO_3
Hydration (water content)	50-60%
Total exchange capacity	Min. 4.9 eq/kg dry resin
Ionic form	Minimum 99% H^+
Particle size (powder)	95% comprehended between 30-150 microns
Maximum impurities	Heavy metals 100mg/kg dry resin
Stability to temperature	Above 120° C
Max. temperature of use	150° C
pH manipulation range	Acidic 0-6
Method of Application	

The resin is used as a poultice or compress with demineralized (distilled) water and cellulose pulp some millimetres thick. The addition of cellulose fibres slows down the resin's ion exchange action.

The time of application and the ratio of resin to be mixed with cellulose fibres must be experimentally derived by trial tests. It is advised to carry out control tests every 5-10 minutes.

The functioning of the ion exchange occurs in a damp environment; therefore, to prevent desiccation the compresses should be covered with polythene foil.

It is recommended for the correct conservation of the product to maintain the resins in a damp state because if excessive desiccation occurs the resins degenerate. The product cannot then be regenerated. It is inadvisable to add fume silica (micronised silica gel) as a thickener.

ANIONIC RESINS These resins remove calcium sulphate (gypsum) as well as protein-based and oily substances from frescoes and stonework. They are a synthetic polymer containing functional anionic groups (hydroxyl form) capable of exchanging the resin's OH- ions with the CO3- ions of calcium carbonate through an aqueous medium.	
Chemical principle of anionic resins	OH (+ $CaCO_3$ resin == CO + $Ca(OH)_2$ OH
WEAK ANIONIC ION EXCHANGE RESIN – COMMERCIAL NAME AMBER WB/P	
Technical Characteristics	
Type	Pulverized weak anionic resin in hydroxyl form
Matrix	Copolymer styrene DVB
Functional groups	Quaternary ammonium type 1
Hydration (water content)	50-60%
Total exchange capacity	min. 4.2 eq/kg dry resin
Ionic form	Minimum 96% OH^-
Particle size (powder)	85-95 % comprehended between 100-400 mesh
Maximum impurities	
Max. temperature of use	60° C in OH type / 100° C in Cl type
pH manipulation range	Alkaline 8-14
STRONG ANIONIC ION EXCHANGE RESIN – COMMERCIAL NAME AMBER SOH	
Technical Characteristics	
Type	Pulverized strong anionic resin in hydroxyl form
Matrix	Polystyrene
Functional groups	Quaternary ammonium type 1
Hydration (water content)	55-60%
Total exchange capacity	Min. 4.0 eq/kg dry resin
Ionic form	Minimum 96% OH^-
Particle size (powder)	95% comprehended between 30-150 μ
Maximum impurities	Na 50 mg/kg dry resin & chlorides 700 mm/kg dry resin
Max. temperature of use	Above 70° C (maximum 60° C for removal of SiO_2)
pH manipulation range	Alkaline 8-14
Method of Application	
The resin is used as a poultice or compress with demineralized (distilled) water and cellulose pulp some millimetres thick. The addition of cellulose fibres slows down the resin's ion exchange action. The time of application and the ratio of resin mixed with cellulose fibres must be experimentally derived by trial tests. It is advised to carry out essays (controlled testing) every 5-10 minutes. The functioning of the ion exchange occurs in a damp environment; therefore, to prevent desiccation the compresses should be covered with polythene foil. It is recommended for the correct conservation of the product to maintain the resins in damp state because if excessive desiccation occurs the resins degenerate. The product cannot then be regenerated. It is inadvisable to add fume silica (micronised silica gel) as a thickener.	

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Interim Report on the Excavation of the Susan-ri Tomb (1974)

From 'The Mural Paintings of the Susan-ri Tomb Excavation Report' and 'Summary of the Excavation Report' (2005).

Institute of Social Sciences, Pyongyang[1]

1. Location of the Susan-ri Tomb and Description of the Excavation

Name	Susan-ri Tomb Mural Paintings
Property Category	National Treasure 30 of the Democratic People's Republic of Korea
Period	Late 5th Century CE (Koguryo)
Geographical Location	Latitude 38° 55′ 14″; Longitude 125° 21′ 41″
Location of the Tomb	Pyeongannam-do, Kangso-gun (district), Susan-ri

The Susan-ri site is located approximately 15 km west of the Kangso district. It is approximately four km northeast from Mt. Kojung. The Susan-ri Tomb lies on a hill at the edge of the Mt. Kojung range.

Relics of the Koguryo period are distributed widely across the surroundings of the Susan-ri Tomb. The Kangso (Sammyo-ri) Tombs are located four km east of Susan-ri and the Yaksu-ri Tomb four km southeast. The Ssanggidung Tomb and the Ryonggang-kun Tomb are also located in the southern section. Ruins of the Koguryo period, such as the Mt. Hwangrong fortress wall, are widely scattered around this area.

The Susan-ri Tomb was excavated in 1971. The excavation was started in the southern section of the Susan-ri Tomb. Afterwards, the walls of the Tomb's *dromos* were uncovered. The ceiling stone of these walls can be seen when entering 140 cm into the inner side of the *dromos* walls.

1 Translated by Hye-seung Shim with Rodolfo Lujan and the DPRK National Conservation Team.

The ceiling stone, made of granite, is between 26 and 28 cm thick. The upper side of this stone is covered with a mixture of gravel and mud. A large stone slab, believed to be the stone gate of the Tomb, was found here. This stone gate inclines at a plane of 25° on the outside; its upper part has been broken off. A similar object, possibly a doorframe, was found in the place occupied by the stone gate.

The doorframe is made of wood covered with lime plaster. The doorsill is 20 cm in length and 18 cm in width. The stone door is filled with soil. One broken iron nail was discovered in the lower section of the stone door. The nail, originally plated with silver, has eroded. Another stone door was discovered, but no remains were found.

A burial chamber filled with soil was found. On the floor of the chamber were several human bones and coffin nails, scattered in an untidy manner. The original shapes of the human bones and coffin were hardly recognizable because of rotting. Specifically, the decomposed coffin had disintegrated, with only black traces remaining.

A part of the triangular lintel and a cover, which formed the ceiling stones, were destroyed. Some parts of the mural paintings on the northern and eastern walls were also damaged. However, the remaining mural paintings were in a good state of conservation.

2. Structure of the Susan-ri Tomb

As the Susan-ri Tomb is located on the slope of a hill that slopes down from north to south, this southern section is lower than the original level of the burial chamber of the Tomb.

The shape of the burial chamber was originally square. From the southern side of the Susan-ri Tomb, confirming the shape of the Tomb is difficult because the southern side is sloping. However, from the northern side of the Tomb, which is a 'ㄷ' shape, it would appear that the original setting of the Tomb was square.

The Susan-ri Tomb consists of the *dromos* and the burial chamber, both of granite. The ceiling stones of both the *dromos* and the burial chamber are approximately 20 to 30 cm thick. The lengths of these stones are more than 1 m. The internal walls are made of granite aggregate and sealed with mud mixed with the lime plaster used to finish the surface of the walls. The lime plaster is about 2 or 3 cm thick in the *dromos*, burial chamber, and ceiling of the Susan-ri Tomb. The *dromos* is 450 cm in length. Its floor is flat, narrowing towards the inside of the Tomb.

Three large stone slabs cover the ceiling of the *dromos*. The stone slabs form a kind of stairway on the inside to prevent the stone door from collapsing inwards.

The right- and left-hand sides of the walls of the *dromos* are piled with stones. The section where the ceiling is located is covered by lime plaster.

The Tomb's entrance was initially enclosed by two stone doors and was blocked by a heap of stones. This structure commonly features at the entrance of a building above ground. A block stone made of gravel mixed with soil was placed right below an external section of the blocked-up ceiling stone. Adjacent to this was a doorframe built beneath the southern part of the ceiling stone. Its location was concealed by a 230 cm granite slab.

To build the doorframe, wood was attached to the surface of the wall after drawing a straight line on the wall. The wooden frame was covered by lime plaster. However, only the limed-plastered wall remained, as the wooden frame had deteriorated. One more stone door was discovered after opening this door. Patterns of black clouds on a reddish background were depicted on the doorframe.

The four walls inside the burial chamber have equal thicknesses from the base to a height of 200 cm, narrowing towards the top. The ceiling is of the *lanternendecke* type, a common feature of the Koguryo Tombs, being of triangle corner truss-bracket construction. The floor of the burial chamber was formed by trampling down earth on the floor's ground, consisting of a mixture of soil and soft stone.

The dimensions of the Tomb are as follows:

- ▶ Dimensions of the *dromos*
  - Length – 450 cm
  - External width – 160 cm
  - Central width – 150 cm
  - Internal width – 102 cm
  - External height – 238 cm
  - Central height - 210 cm
  - Internal height – 180 cm
- ▶ Dimensions of the burial chamber
  - Length of the lower part of the eastern wall – 321 cm
  - Length of the lower part of the western wall – 320 cm
  - Length of the lower part of the northern wall – 320 cm
  - Length of the lower part of the southern wall – 320 cm
  - Height of the wall – 300 cm
  - Height between the ground floor and the ceiling – 410 cm

3. Description of the Mural Paintings

The main theme of the Susan-ri Tomb's mural paintings is living customs.

- ▶ *Dromos*: a gate guardian
- ▶ **Southern wall**: the main male character (the husband) receives a parasol and there is a person who steps out without wearing a hat

- **Western wall**: the main couple enjoying themselves
  - Upper part of the wall: the couple together with a tall male and a female retinue watching the circus
  - Lower part of the wall: men marching, a person holding a parasol, and horses
- **Northern wall**: daily life of the ruling class as depicted by the main couple in an elegant room served by servants
- **Eastern wall**: the main male character's private life
  - Upper part of the wall: a parade of men
  - Lower part of the wall: a procession of wheeled vehicles

The general layout or setting of the interior of the Tomb is similar to the wooden structure of a pergola. Each corner of the four walls of the Tomb is decorated by cursive columns, which feature brackets embellished with lotus flowers. These columns support a lower girder that runs on all four sides of the pergola.

The brackets of the four corners support an upper girder linked to and supporting a lower one. At the centre of each side, a short king post supports two inverted diagonal struts (*Samgakgoim*), forming a kind of triangular pediment.

This pediment depicts an athletic figure similar to a security guard (*Him-jang-su*). The area between these central elements and the corner brackets features a lotus flower flanked by two symmetrically arranged phoenixes. The ceiling of the pergola is composed of three receding tiers of beams that support a *lanternendecke* ceiling. The lower sections of the columns are joined by a rail, similar to the girders that create a sort of skirting-board. Daily life scenes are illustrated in the areas between the sills and the girders. The entire composition gives the impression of being inside a wooden gazebo watching the various scenes unfolding outside.

The wooden elements, such as the columns, brackets and beams, are painted red with floral decorations in black and are outlined in white. The girders and sills are in yellow and black, whereas the lotus capitals of the columns are in yellow outlined in dark red.

In the section above the door, parallel wavy lines are painted as various cloud patterns. The columns and the girder are painted with various beautiful floral patterns, giving the impression of a magnificent above-ground wooden building.

3.1. Mural Paintings in the *Dromos*

Gate guardians who seem to be protecting the burial chamber are illustrated en route to the burial chamber. On the right (east) side of this passage, the guardian is shown to hold a straight sword in his right hand and a long spear in his left hand.

The guardian wears a golden yellow overcoat fastened by a belt. His sleeves are turned up; he does not wear a hat. This painting illustrates the guardian's characteristics: bulging eyes, bared teeth, beard stretching up to his ears, and so on.

The painting of the guardian on the left side has faded, so its details are impossible to see.

3.2. Mural Paintings on the Southern Wall

The lower part of the southern wall is divided into eastern and western halves, as this wall is connected to the passage to the burial chamber. In the western section, the husband is depicted as going out wearing a black hat and a golden yellow overcoat. He is followed by a retinue carrying a floral parasol.

The eastern part of the southern wall features a scene illustrating a person who is stepping out. This person wears a golden yellow overcoat and holds a yellow parasol. However, this person does not wear a hat and wears his/her hair down.

On the beam in the upper section of the southern wall, a security guard (*Him-jang-su*) is depicted inside the triangle-shaped element. The images of round lotus flower patterns and a phoenix in this section have been preserved excellently.

3.3. Mural Paintings on the Western Wall

The mural paintings on the western wall are separated into two areas by a sash pattern painted horizontally. Specifically, on the upper part of the western wall, the painting shows a beautiful scene of the main couple watching the circus together with a large male and a female retinue.

A circus scene is depicted on the southern end of the western wall.

To show as many images as possible within a limited space, the mural paintings are illustrated as follows:

First, a person is shown on top doing balancing stunts and holding two long wooden poles. Other people are juggling five round rings and three sticks with rings attached to their ends.

The person holding the two long wooden poles wears a light orange-coloured short-sleeved traditional Korean top (*jeogory*), dark yellow trousers, belt, and black boots. He wears no hat. Black lines outline the *jeogory*'s collar, cuffs, and trimmings.

The person depicted below wears a light orange-coloured short-sleeved *jeogory*, dark purple trousers, and a black hat, which is worn with the back a little higher than the front. This person seems to be wearing golden yellow leggings.

A third person wears the same costume as the previous one, except that he is wearing black boots. The painting shows them standing, using their arms for balance, and quickly moving their arms and legs to juggle rings, sticks, and wheels. This illustration excellently reflects the movement and vivacity of a real circus performing in front of an audience.

Adjacent to the circus scene is the illustration of the husband, who is under a black parasol that is held by an assistant; the husband is followed by a young man. The husband wears golden yellow outerwear (*durumagi*) decorated with black lines along the hem; he sports a handlebar moustache and a beard. Behind him, the assistant wears the same costume as the acrobat. The assistant is shown to be half the size of the husband in height. The different sizes of the paintings represent the different social classes of the feudal society of the Koguryo period.

As regards the young man, he wears a black hat of the style commonly worn by a servant. However, he is also wearing a black spotted *jeogory* and trousers, which are also depicted in the mural painting of the husband's domestic life on the northern side of the wall. Moreover, this man is shown to be almost as tall as the husband. Presumably, he belongs to a social class higher than that of the servants.

The wife is shown wearing a rainbow-striped skirt. She appears to convey the image of a beautiful Koguryo lady. Her pretty clothes, made-up face, and appearance represent Koguryo beauty. Similarly to the husband, the wife watches the circus from under a black parasol. Her clothes are very attractive. The painting shows her wearing a beautiful *jeogory* embroidered neatly with a red pattern on the collar, cuffs, and trimmings and a rainbow-striped skirt. Her fashion style vividly represents the uniqueness of high-class Koguryo females.

Behind the wife, six other females are shown wearing beautiful *jeogory* and pleated skirts.

The mural paintings on the lower part of the western wall from its southern end show the following: in the foreground, two servants hold a bat-shaped parasol for the master ahead of them. A stableman in front of a horse is shown holding the reins. Behind the horse are eight people standing side by side wearing black hats and a traditional Korean outer coat (*durumagi*); they seem to be awaiting their master's arrival. The first and fifth persons are wearing purple *durumagi,* and the rest are wearing golden yellow *durumagi.* Like on the upper part of the western wall where the rectangular cartouches are above the people observing the circus scene, a similar rectangular sign is also placed in front of the people wearing the purple costumes.

3.4. Mural Paintings on the Northern Wall

The paintings on the northern wall depict the domestic life of the main couple. They show the luxurious life of the Koguryo noble class.

At the centre of the wall is a building with an *Ujingak* roof, which is a type of traditional Korean glazed roof with terracotta ridgepole ends. The tiles on the roof and the curved eaves on each side emphasise the architectural beauty of the building. The main couple live a life of luxury inside the house, where there is a wooden bed with open curtains. Many servants attend them.

The husband is wearing red clothes and sits to the west, whereas the wife sits to the east. The wife is wearing the same clothes as the women watching the circus depicted in the upper section of the western wall. The wife is wearing beautiful indoor clothes of a long black *jeogory* and a rainbow-striped skirt. Moreover, her face and lips are adorned by dots of a red colour.

The wife seems to be saying something to her husband because the drawing shows her sitting on the wooden bed with her face turned towards him. Their servants are shown to either be waiting for the master's orders or carrying various foods.

3.5. Mural Paintings on the Eastern Wall

The mural paintings on the eastern wall are divided into upper and lower sections by bands of horizontal chess-shaped patterns (*Reunghyong* band patterns) across the middle of the eastern wall.

In the upper section, the painting shows men wearing black hats and golden yellow overcoats. One is shown to be kneeling in front of two people who are standing with their arms folded. This scene appears to show a retainer reporting for duty to his senior officers.

On the lower part of the wall is a parade scene. The parade marches forward in a northerly direction to where the master's luxurious house is located.

A brass band is at the forefront of the parade; two people each carry a large drum on their shoulders, and one person beats the drums while marching. The faint drawing shows trumpeters, a brass band, and people holding flags behind them.

Following the parade are women wearing long-sleeved *jeogory* and pleated skirts.

Further excavation work was carried out in 1973, 1991 and 2001.

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ICOMOS Evaluation No. 1091: Koguryo Tombs and Mural Paintings (2004)

by ICOMOS International

P.T.O.

Koguryo Tombs (D. P. R. of Korea)

No 1091

1. BASIC DATA

State Party:	Democratic Peoples' Rep. of Korea
Name of property:	Complex of Koguryo Tombs
Location:	Pyongyang, South Phyongan Province, Nampho, South Hwangghae Province
Date received:	25 January 2002

Category of property:

In terms of the categories of cultural property set out in Article 1 of the 1972 World Heritage Convention, it could be a *monument*. It is a serial nomination.

Brief description:

Several groups and individual tombs from the period of the Koguryo Kingdom. The Koguryo was one of the strongest kingdoms in northeast China and half of the Korean peninsula between the 3rd century BC and 7th century AD. These tombs, from the later period of the kingdom, many with beautiful wall paintings, are almost the only remains of this culture.

2. THE PROPERTY

Description

Complexes of tombs, all together consisting of about 30 individual ones, located mainly in agricultural areas and some in villages. Several types of these tombs exist – stone piled, stone chambered and earthen mound tombs. So far over 10,000 tombs belonging to the Koguryo kingdom have been identified, in China and Korea. Among those, some 90 are decorated with wall paintings, 70 of which are in Korea and almost half are the subject of this nomination. These decorated tombs are supposed to be specially made for kings, members of the royal family and other aristocrats.

The paintings in the tombs are divided into several types: paintings of portraits, portraits and Four Deities, Four Deities alone, decorative patterns.

There are also several types of tombs, according to the number of burial chambers – single chamber, two chamber, multi chamber and side chamber types. They are built of stone and corridors lead into the burial chambers.

The tombs have varied shapes of ceilings some quite elaborate, having to solve the need of roofing wide spaces without columns, with stone slabs which had to carry the heavy load of a stone or earth tumulus (mound).

History

The Koguryo kingdom existed for nearly 1,000 years, from 277 BC to 668 AD. It was established in Huanren, Liaoning Province in China, relocated in the year 3 AD to Taesong area in Pyongyang, in 427 AD and finally to the Jangan Castle in the centre of the present day city of Pyongyang.

Pyongyang, situated in a strategic location, had long been the political, economic and cultural centre, as the capital of ancient Korea (Kojoson) which is the reason why the Koguryo kingdom moved its capital here and made great efforts in developing it.

The Koguryo kingdom expanded its territory to cover northeast China and half of the Korean peninsula, becoming one of the strongest powers in the east. It collapsed in the year 668 AD.

The best known cultural heritage remains of this kingdom are thousands of tombs, built of stone and covered by stone or earthen mounds. Earthen mound tombs, including many with murals, were prevalent once Koguryo moved its capital to Pyongyang – but existed in other parts of the kingdom as well.

Most of the known tombs suffered of clandestine excavations in the last thousand years. As a result very few were scientifically excavated prior to such activity and there are very few complete objects coming from the tombs. The tombs received worldwide attention only in 1905, when during the Japanese occupation many of them were opened to the general public. The first scientific research and documentation were carried out by Japanese scholars between 1911 and the 1940s.

Regular surveys, excavations and documentation took place from 1945 on.

Minor conservation actions took place in early 1940's, such as restricting entry to tombs and creating entrances to some. Regular maintenance, protection and conservation works started in 1946, with proper legislation and nomination of site managers.

Management regime

Legal provision:

The main three laws protecting cultural heritage and its management are: Presidential decree 35, 'Socialist Constitution of the Democratic Peoples' Rep. of Korea' and the 'Law of the Dem. Peoples' Rep. of Korea'. Other relevant laws are land, environment, forests laws as well as different by-laws, regulations and operational guidelines.

Management structure:

I. MBCPC – Management Bureau of Cultural Property Conservation, under Ministry of Culture;

II. BCP – Bureau of Cultural Preservation, at provincial and city levels;

III. Cultural preservation departments of city, county or district;

IV. CRMO – Cultural Relics Management Office, prepares and implements the conservation and management;

V. Site Managers.

Resources:

Consists of national and local budget.

Justification by the State Party (summary)

Criterion i: Excellent artistic quality wall paintings depicting daily life pictures and other scenes. Important for its artistic and historic values. Outstanding architectural elements showing planning and technical skills.

Criterion ii: The burial practice of Koguryo had an influence on that of other cultures in the region, including Japan.

Criterion iii: The wall paintings document the history, religious beliefs, and customs of the contemporary people, as well as science and culture. They show costumes, arms, musical instruments, dance, astronomy, etc.

Criterion iv: The nominated tombs represent an important architectural form of tombs in this region and period.

3. ICOMOS EVALUATION

Actions by ICOMOS

An ICOMOS mission visited the sites between the 2nd and 9th of July 2002.

ICOMOS has consulted its International Scientific Committee on Wall Painting.

Conservation

State of conservation:

Most of the tombs are properly maintained and well preserved. Some of the tombs suffer of deterioration of the paintings. Some are regularly flooded. Old conservation interventions seem problematic. Several tombs have special doors installed to prevent direct impact of exterior environmental conditions.

Management:

The management structure and staffing is good and qualified. There are problems with monitoring, adequate equipment and with lighting.

Risk analysis:

Lack of any alarm system. Two of the tombs are in a village and have no buffer zone. Flooding of one tomb. Future tourism – no plans for its management.

Authenticity and integrity

The interiors of the tombs and the mural paintings are authentic and untouched. There were some authenticity issues raised regarding the Mausoleum of King Tongmyong, certain gravestones at the Jinpha-ri tomb and entrance to Tokhung-ri tomb.

These are certainly new, but are part of the presentation and interpretation of the sites – not pretending to be an authentic element, nor compromising the cultural values of the tombs.

Comparative evaluation

The Koguryo tombs are unique to this important culture. Therefore the only comparison can be of the different tombs of this culture to each other. It seems, comparing them also to those included in the nomination submitted by China, that a proper choice has been made.

Outstanding universal value

General statement:

Due to the importance of the culture and the excellent representation of the culture by the paintings, the property meets the requirement of Outstanding Universal Value.

Evaluation of criteria:

The high significance of the property comes from the importance of the Koguryo kingdom's culture to which the structural solutions of the tombs ceilings, as well as the testimony to daily life depicted on the wall paintings, are the only remains.

The nomination meets *criteria i, ii, iii and iv*:

Criterion i: It is certainly a representation of special engineering genius and solutions. Its wall paintings are art masterpieces of the culture and period of the Koguryo kingdom as well as important documentation.

Criterion ii: These special burial habits had influence on others cultures in the region, including in Japan.

Criterion iii: The nominated tombs are a unique testimony to the important Koguryo kingdom, its culture and civilization.

Criterion iv: The tombs, wall paintings and engineering solutions are all together an outstanding example of type of buildings and technology. The Koguryo culture had an impact on later cultures in the region, much of it represented by later, though similar type of burials (for example – in Japan).

4. ICOMOS RECOMMENDATIONS

Recommendation for the future

- Strengthen modern research, including on pigments;

- Prepare visitors management plan;

- Install signage which will tell the history of the kingdom and sites including the fact that some sculptures at entrance to tombs are reconstructed for interpretation purposes and that the tomb of the "First King" is his second tomb, which did not house his body.

- Improve monitoring equipment;

- Improve lighting.

Recommendation with respect to inscription

That the property be inscribed on the World Heritage List on the basis of ***criteria i, ii, iii, and iv***:

> ***Criterion i***: For the outstanding skills of the artist preparing the wall paintings and for ingenious engineering solutions for the construction of the tombs.
>
> ***Criterion ii***: For these special burial habits had influence on others cultures in the region, including in Japan.
>
> ***Criterion iii***: Being an exceptional testimony of the Koguryo culture, its burial habits as well as its daily life and beliefs.
>
> ***Criterion iv***: Being an important example for burial typology.

ICOMOS encourages DPR Korea and PR of China, who is also nominating a site of the Koguryan culture, to look in the future for a possibility of a joint nomination.

ICOMOS decides not to get into an existing conflict of the exact dating of the culture and the tombs. While these are important scientific and cultural questions, ICOMOS believes that they have no impact on the cultural values of the nomination.

ICOMOS, March 2004