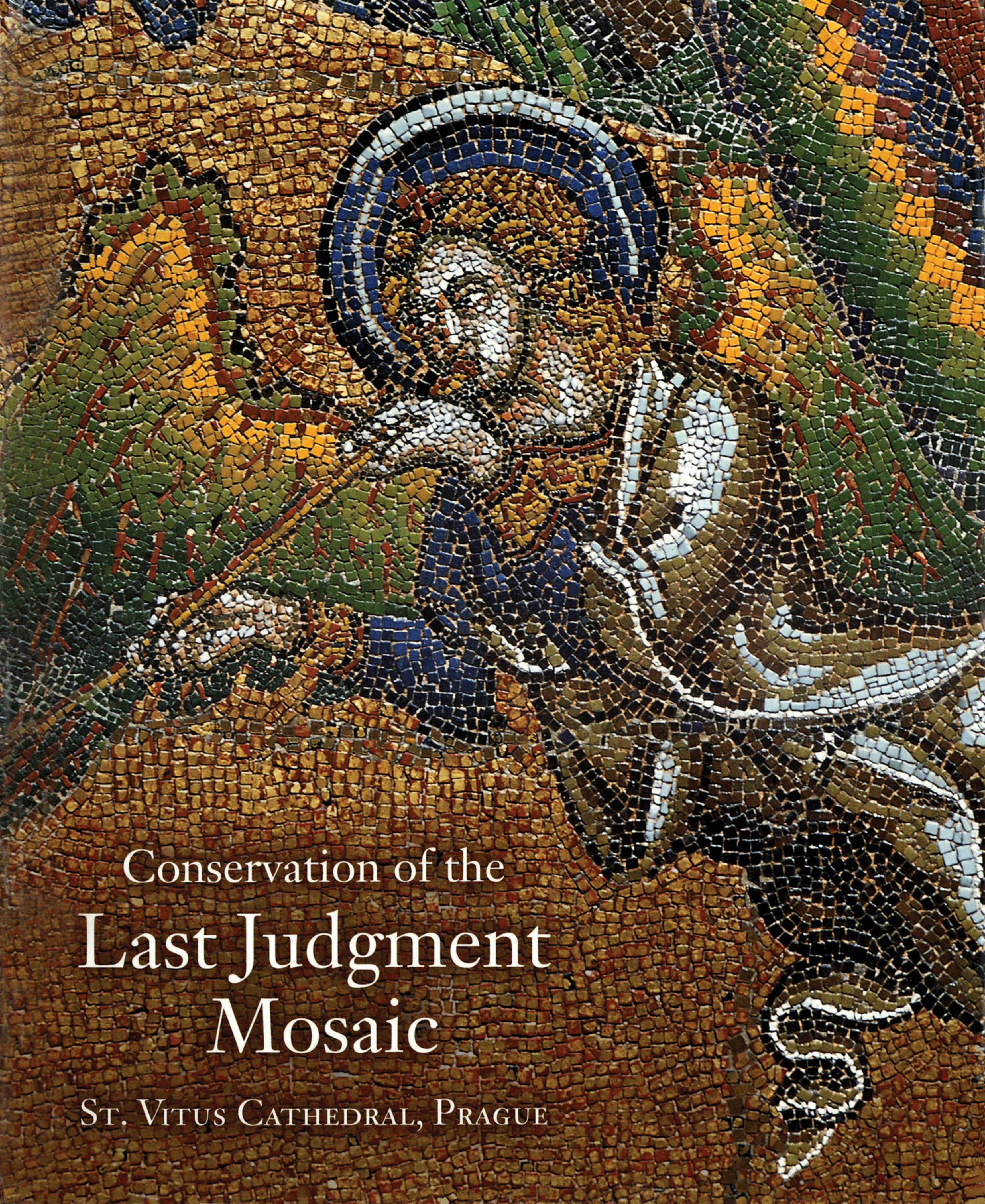

Conservation of the Last Judgment Mosaic

St. Vitus Cathedral, Prague

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Conservation of the Last Judgment Mosaic St. Vitus Cathedral, Prague

Edited by Francesca Piqué and Dusan C. Stulik

The Getty Conservation Institute, Los Angeles


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FRONT COVER: The Last Judgment mosaic, ca. 1371, St. Vitus Cathedral, Prague (detail): Angel with trumpet.
Photo by D. Stulik, 2003.

FRONTISPIECE: Overview of the Last Judgment mosaic, after restoration.
Photo by D. Stulik, 2003.

The Getty Conservation Institute works internationally to advance conservation and to enhance and encourage the preservation and understanding of the visual arts in all of their dimensions—objects, collections, architecture, and sites. The Institute serves the conservation community through scientific research; education and training; field projects; and the dissemination of the results of both its work and the work of others in the field. In all its endeavors, the Institute is committed to addressing unanswered questions and promoting the highest possible standards of conservation practice.

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Contents

Foreword

For centuries the Last Judgment mosaic, on an exterior wall of the St. Vitus Cathedral in Prague, has been a hidden jewel in this great city. For almost as long, the mosaic has suffered from a type of deterioration that caused corrosion of the surface, obscuring its brilliant colors. Indeed, historical sources tell us that the mosaic, which remains one of the few surviving examples of exterior medieval glass mosaic art north of the Alps, was deteriorating within one hundred years of its completion. Periodic cleanings have occasionally allowed it to be seen clearly, but the corrosion has always returned, and in modern times, chemicals introduced into the air by automobiles and other machines have hastened this corrosion.

In the early 1990s, Harold Williams, former President of the Getty Trust, had the vision to challenge the GCI to initiate relationships and collaborative projects with scientists and conservators in Central and Eastern European countries, which had for decades been isolated from the American and Western European conservation world. Under Harold's leadership, and the direction of my predecessor Miguel Angel Corzo, a partnership between the Office of the President of the Czech Republic, the Prague Castle Administration, and the Getty Conservation Institute to conserve the Last Judgment mosaic began. This undertaking included adopting an approach that would not only analyze the corrosion and restore the original beauty of the mosaic but also investigate the underlying causes of this deterioration and develop methods to address them. The project, which began in 1992 and concluded with a symposium in 2001, included five years of research to develop a method for protecting the mosaic and preventing further corrosion of its glass tesserae, followed by three years of conservation, followed in turn by the ongoing monitoring and maintenance essential to ensuring the mosaic's long-term preservation. The project to conserve the Last Judgment mosaic is an excellent example of the kinds of challenges conservators face in the conservation of important objects, and of the benefits that conservation science and technology can provide in helping to find solutions.

This book includes contributions from scholars, scientists, and conservators who have worked on the project and helped improve our understanding of the mosaic and its deterioration. In addition to the historical, art historical, scientific, and conservation essays, the reader will enjoy the color plates of details of the mosaic after treatment, showing once again its true colors and vibrancy. We hope that readers experience the same sense of astonishment felt by conservators when they removed the corrosion, and the mosaic's image was revealed at long last.

This book also suggests the great lengths to which a society will go to preserve an important work of art. The centuries of the mosaic's continuing deterioration never prevented the Czech government or people from seeking a way, first, to reveal the beauty of the mosaic and, second, to maintain it for all to see.

We at the Getty Conservation Institute are very proud to have been a part of this project, which has revealed once more the Last Judgment mosaic. We are equally pleased to be part of its ongoing conservation and maintenance. I am particularly grateful to Francesca Piqué, a former Project Specialist with the GCI, and Dusan C. Stulik, GCI Senior Scientist, for serving as our project team leaders, and as the editors of this volume. I am also grateful for the partnership and friendship of Eliška Fučíková, Director of the Heritage Conservation Department in the Office of the President of the Czech Republic, without whom this project never would have happened. In these pages readers will find both the story of the mosaic and of the conservation science that has preserved it for future generations.

Timothy P. Whalen
Director
The Getty Conservation Institute

Acknowledgments

In addition to the authors and to members of the project team, colleagues within the Getty, the Office of the President of the Czech Republic, the Prague Castle Administration, and members of the international conservation community made important contributions to the project.

We are grateful to the leadership of the Getty Trust and the Getty Conservation Institute. The former President of the Getty Trust, Harold Williams, initiated the collaboration between the Getty and countries of the former Soviet Bloc of Eastern Europe, including what was then Czechoslovakia. The current President of the Getty Trust, Barry Munitz, and GCI Director Tim Whalen and GCI Associate Director Jeanne Marie Teutonico provided full support during the critical conservation phase of the project, facilitating not only the completion of work on the mosaic but also dissemination of information about the project through the 2001 symposium at the Prague Castle. They also provided support for the long-term monitoring and maintenance of the mosaic.

The project team is extremely grateful to Vaclav Havel, former President of the Czech Republic, for his support and interest throughout the entire project, and to the current President of the Czech Republic, Vaclav Klaus, and the First Lady of the Czech Republic, Livia Klausova, for their pledge of continuous support of mosaic-related research, which ensures that the results of the project endure.

Many GCI colleagues contributed to the project. Neville Agnew was responsible for initial negotiations and for developing the overall conservation and scientific strategy. Michael Schilling, Joy Kenney, Herant Khanjian, and Jim Druzik assisted with scientific analyses of the mosaic. Francois LeBlanc lead the completion of the project while Chris Seki and Anna Zagorski provided assistance with logistics. Rand Eppich coordinated graphic documentation; Irene Sen carried out in-situ graphic documentation. Cynthia Godlewski and Cristina Iamandi worked on documentation and research.

Kristin Kelly oversaw the preparation of the manuscript of this book. A special debt of gratitude is owed to Cynthia Godlewski, at the GCI, and Tevvy Ball, at Getty Publications, who put in a great deal of dedicated work preparing and fine-tuning the manuscript for publication. We would also like to thank Sheila Berg and Paul Lipari for their work on the manuscript. We are also grateful to Hespenheide Design, who designed the volume, and Anita Keys, who coordinated its production.

Many people from the Office of the President of the Czech Republic and of the Prague Castle Administration made significant contributions. In the Cultural Heritage Department of the Office of the President, Petr Chotebor provided invaluable insight into the architecture of the St. Vitus Cathedral, and Jana Zakova dealt with project logistics and support. The former Director of the Prague Castle Administration, Zdenek Synacek and his office provide logistical support of the project. Martin Herda and Viktor Prochazka supervised all work related to the mosaic. The staff of the Prague Castle Archives, especially Frantisek Marek and Valerie Strobachova of the Department of Prague Castle Collections, gathered all written and photographic documentation related to the history and conservation of the mosaic. The mechanical, electrical, and woodworking workshops of the Prague Castle provided support and helped with maintenance of all the equipment used in the course of the project.

The initial studies of protective systems were conducted in collaboration with Hannelore Römich of the Fraunhofer Institute in Wurzburg and John Mackenzie and Eric Bescher at the University of California, Los Angeles. David Miller, California State University Northridge, and George Miller, University of California, Irvine, made major contributions to the study of the chemistry of mosaic glass.

Mahasti Afshar was responsible for film and video documentation. Jan Boněk of the LaBon agency in Prague, in collaboration with Milada Lachoutova and Josef Nekvasil, produced several documentary films on the project.

Our thanks also go to Dobroslav Libal, Josef Stulc of the National Cultural Heritage Institute, Ivo Hlobil of the Charles University and Anna Maria Giusti, who served as members of committees overseeing art historical and ethical issues of the conservation project, and to Eve Borsook of the Harvard University Center at Villa I Tatti, who shared with the project team results of her study of medieval mosaics.

The project team also gratefully acknowledges the contribution of the following institutions in Prague, which allowed access to their collections and helped to locate documents and photographs related to the Last Judgment project: Archives of the National Museum, the National Library, the National Gallery, the Stenc Archives, and the Archives of the Cultural Heritage Institute. Our special thanks are due to the Director of the Prague Archives, Vaclav Ledvinka, who provided copies of important historical negatives depicting the mosaic before 1890, and to Marie Secka of the Naprstek Museum in Prague, who lent the project team the oldest existing photograph of the Last Judgment mosaic. Zdena Slavikova conducted an in-depth search of Czech and German newspapers and journals and prepared an annotated bibliography of all articles related to the Last Judgment mosaic.

Jaroslav Zastoupil and Bohuslava Kunftova provided rectified photographs and large format photography of the mosaics at different stages of the conservation project and provided support for graphic recording of the mosaic conditions.

Peter Kotlik of the School of the Chemical Technology of the Technical University in Prague provided valuable consultation during various stages of the project and provided technical assistance during the cleaning phase of the project. The project team is also grateful to the Engineering Academy of the Czech Republic for their support and interest throughout the many phases of the conservation project.

Finally, the volume editors would like to especially acknowledge the expertise, dedication, and years of work on the mosaic of conservators Eliška Fučíková, Alois Martan, Martin Martan, and Milena Nečásková.

Francesca Piqué
Dusan C. Stulik

Francesca Piqué
Dusan C. Stulik

Introduction

The city of Prague boasts a diverse cultural heritage that reflects its long and rich history. Among the Czech capital's greatest cultural monuments is the Prague Castle, which overlooks the city from its hilltop site (fig. 1). Here, on the exterior of the south facade of St. Vitus Cathedral, is the last Judgment mosaic, one of the most important material works of medieval Prague, reflecting the efforts of Charles IV, king of Bohemia and Holy Roman Emperor, to make the city the crown jewel of his empire (fig. 2).

The Last Judgment mosaic is divided into three panels placed above three large archways (see frontispiece). In the central panel, Christ in a mandorla is surrounded by triumphant angels, poised above the patron saints of Bohemia. Below the saints, Charles IV is depicted with his fourth wife, Elizabeth of Pomerania. The left panel shows the resurrection of the dead from their tombs; the right panel depicts the damned being cast into hell. The mosaic is made from almost one million pieces of colored cut glass cubes, or tesserae, along with natural stone pebbles that create an opaque effect in the flesh tones.

Since its completion in the late fourteenth century, the mosaic has undergone a recurring problem of deterioration. The glass tesserae have corroded, a process that creates a grayish layer that covers the mosaic and makes it illegible. Until very recently mechanical removal of this corrosion and attempts to protect the cleaned mosaic against further corrosion by the application of more or less sophisticated coatings had only temporarily returned the mosaic to its original splendor. The glass corrosion process had always rapidly obscured the mosaic again.

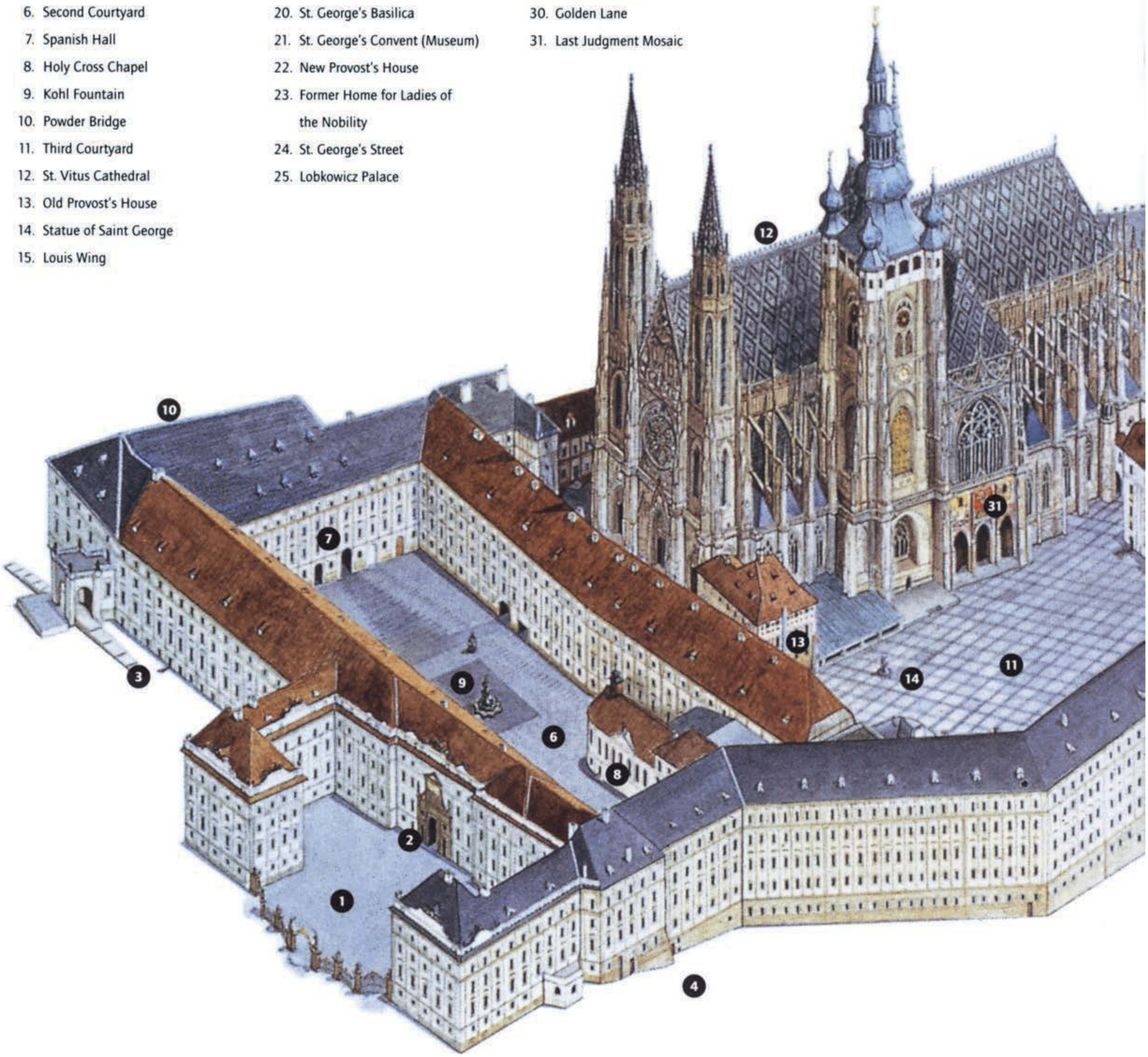
In 1992 the Office of the President of the Czech Republic and the Getty Conservation Institute (GCI) began a collaborative project to find a long-term solution to this centuries-old problem and to conserve and maintain the mosaic in the state close to its original magnificence for the benefit of society and the millions of visitors to the Prague Castle. The Prague project has been a long-term GCI initiative and an example of the application of science to solve a major conservation problem. The development of the necessary steps for conservation intervention took five years of research and testing, followed by three years of conservation treatment that was concluded in fall 2000.

In June 2001 the GCI and the Office of the President of the Czech Republic organized a symposium on the conservation project to inform specialists in all fields related to mosaic research and conservation on the latest art historical research, the latest advances in the scientific study of mosaic materials, and the conservation technology and methodology developed during the mosaic project. The symposium stimulated discussion on still-unresolved issues related to the origin of the mosaic and was a forum to promote research in conservation technology as needed for long-term maintenance of the mosaic.

This volume contains articles from selected symposium participants, as well as material that because of time constraints was not presented at the conference itself. The book is divided into three parts, reflecting the methodology of the project. Part 1 contains background information that elucidates the iconography and history of the mosaic. Part 2 focuses on the scientific research that was carried out

FIGURE 1 Prague Castle

1. First Courtyard
2. Matthias Gate
3. Garden on the Bastion
4. Paradise Garden
5. Garden over the Ramparts
6. Second Courtyard
7. Spanish Hall
8. Holy Cross Chapel
9. Kohl Fountain
10. Powder Bridge
11. Third Courtyard
12. St. Vitus Cathedral
13. Old Provost's House
14. Statue of Saint George
15. Louis Wing
16. Steps leading to the Garden over the Ramparts
17. Old Royal Palace
18. All Saints' Chapel
19. St. George's Square
20. St. George's Basilica
21. St. George's Convent (Museum)
22. New Provost's House
23. Former Home for Ladies of the Nobility
24. St. George's Street
25. Lobkowicz Palace
26. House of Czechoslovak Children or Burgraves Palace
27. Black Tower
28. White Tower
29. Daliborka Tower
30. Golden Lane
31. Last Judgment Mosaic



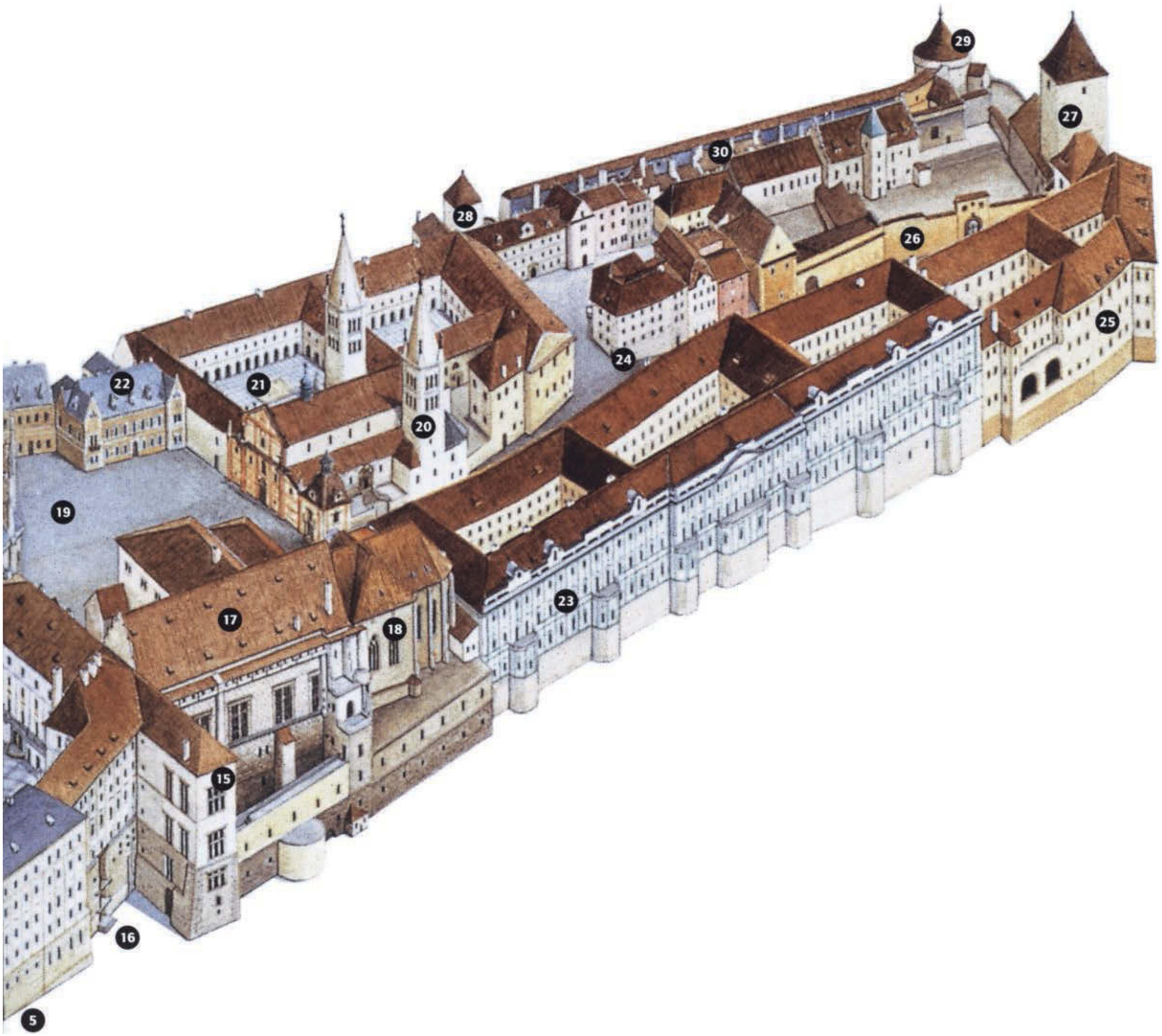


Illustration: Maurice Pommier, Prague Castle, in *Prague*, Guides Gallimard© Editions Nouveaux Loisirs

FIGURE 2 The south facade of St. Vitus Cathedral; the Last Judgment mosaic is seen over the south portal.
Photo: D. Stulik, 2003.

to prepare and develop the conservation intervention. Part 3 describes the conservation intervention itself as well as the plan for the long-term maintenance of the mosaic.

The project in Prague is a fitting example of the GCI's mission to advance art conservation and conservation science and to enhance and encourage the preservation and understanding of the visual arts. The project was undertaken based on the Last Judgment mosaic's extremely high historical, aesthetic, and social values and because it presented a particularly challenging and unresolved conservation problem, the understanding and resolution of which will stimulate solutions for a variety of other conservation problems related to glass mosaic, stained glass windows, and other environment-sensitive glass art objects.

The historical and art historical importance of the mosaic is well illustrated in part 1 by a series of contributions that provide detailed discussions of its creation, significance, and conservation history. In chapter 1, Marie Kostílková presents an overview of the conservation history of the mosaic, beginning immediately after its construction, in 1370, through the nineteeth century. Chapter 2, by Zdeňka Hledíková, describes Charles IV's travels in Italy, which are fascinating not only for illuminating his intellectual contacts but also for identifying specific artworks that may have influenced the making of the mosaic. Zuzana Všetečková, in chapter 3, examines the iconography and symbolism of the Last Judgment mosaic and its relationship to the subject matter of earlier mosaics in Italy and perhaps to wall paintings in medieval Bohemia. In chapter 4, Carlo Bertelli continues the search for influences from a different point of view, concentrating on the technical similarities that link the mosaic in Prague and the fourteenth-century mosaic that was on the facade of the cathedral in Orvieto. Chapter 5, by Eliška Fučíková, brings the mosaic's conservation history into and through the twentieth century.

Alois Martan describes in detail in chapter 6 the research and technical interventions carried out on the mosaic in 1959–60. Having participated personally in that intervention and in another major one carried out in 1998–2000, he offers insights that link the physical evidence found on the mosaic with the history of interventions. Martan also illustrates that the preventive conservation approach taken in 1959–60 was similar to that taken in our recent project. The former's failure was a result of the poor performance of the conservation materials used and the political authorities' neglect to adhere to the program of mosaic maintenance prescribed by conservators. Chapter 7, by Jan Boněk, is a richly illustrated and fascinating visual summary of the mosaic's history.

The second and third parts of this volume contain contributions exclusively about the project methodology, scientific research, and conservation intervention. These are presented in logical sequence, beginning with chapter 8, by Francesca Piqué, which describes the conservation methodology and the ethical issues that were addressed during the project, such as the question of whether to regild the mosaic. In chapter 9, Marco Verità provides an interesting picture of thirteenth- and fourteenth-century glassmaking technology in Italy that integrates recent analytic finds on medieval glass composition. Glass was traded extensively in the medieval period, and Verità's contribution illustrates how the composition of glass not only provides clues to the provenance of the material and trade between Europe and the Middle East but also influences its stability and conservation properties.

The corrosion of the mosaic is caused by rainwater coming in contact with the medieval glass. To maintain the mosaic in situ and to stop deterioration, it was necessary to develop a system to protect the glass from water- and airborne pollutants. Diagnosis began with evidence of active deterioration. Scientific investigations were necessary to understand the physical and chemical composition of the original materials and of the corrosion products, as described by Dusan C. Stulik in chapter 10. Shin Maekawa, in chapter 11, describes the environmental monitoring conducted during the initial phase of the project to measure fluctuations in humidity and temperature surrounding the mosaic that would affect a protective coating. The harsh climate, very cold in winter and hot and humid in summer, makes it very difficult for any protective material to remain stable and to keep its adhesion on the surface of the glass. The environmental data provided the basis for subsequent testing of possible conservation solutions in the laboratory. In chapter 12, Milena Nečásková describes the glass corrosion mechanism and the development of a corrosion removal method that would not harm the mosaic's original surface, including traces of original gold. In chapter 13, Eric Bescher and J. D. Mackenzie describe the complex research and testing to develop the long-term, sustainable protective coating needed to preserve the Last Judgment mosaic in situ. Chapters 14, 15, and 16, by Milena Nečásková and Francesca Piqué; Milena Nečásková; and Martin Martan, Francesca Piqué, and Dusan C. Stulik, deal with project documentation, conservation treatment, and the long-term maintenance plan, respectively.

It was during the conservation intervention, as the corrosion materials were carefully removed, that the astonishing artistic values of the mosaic became visible. Even if historical photographs had shown the beauty of the mosaic, the color and refined detail were much more than expected, and it was obvious that the project had brought back a wonderful work of art.

From the beginning, efforts were made to inform the public of the project's progress toward meeting its objectives. The various stages of the project were documented on film, and short pieces have regularly aired on Czech television. In addition, signs and panels at St. Vitus Cathedral described to the many visitors the glass deterioration problem and the research that was being undertaken.

The Last Judgment mosaic project was characterized by continuous, beneficial collaboration among art historians, conservators, and scientists. It was exceptional in the fact that there was an agreement from the start that no intervention would be undertaken if the scientific research did not provide completely satisfactory results. After several years of research, a coating system that prevented glass deterioration from reoccurring was developed and tested successfully. For this scientific achievement, the Czech Engineering Academy awarded the Czech Engineering Academy Prize 2000 to the project team. The project serves as an excellent example of the integration of science and conservation and will continue to demonstrate the importance of long-term monitoring and maintenance as integral part of every conservation project of this kind.

In addition to the illustrations that accompany the chapters, this volume contains a plate section with key images of the mosaic that are referred to by various authors. These significant contemporary images provide an important resource for art historians and scientists who will continue the study of the mosaic in the future. The plate section primarily contains details of the fully conserved Last Judgment mosaic that make available for the first time a record of the remarkably sophisticated techniques of the unknown fourteenth-century artists who created it.

Part I
Historical and Art Historical Context

Marie Kostílková

Chapter 1
The Last Judgment Mosaic: The Historical Record, 1370–1910

As is so often the case with medieval works of art, we do not have enough information to ascertain the authorship of the mosaic installed above the festive southern entrance to St. Vitus Cathedral at the Prague Castle. Nor can we reliably determine the origin of the materials used in its composition or the methods of its maintenance before the nineteenth century. However, although the historical record for the first 450 years of the mosaic's existence is quite spotty and many details remain unknown, reliable information is not entirely lacking; careful reading of the extant sources allows us at least to sketch in broad outline some elements of the history of this remarkable work.

Perhaps the most important single source of information about the making of the mosaic is Beneš Krabice of Weitmile, a learned canon of the chapter of the Church of Prague, who held the office of building supervisor at the time the mosaic was created. He was also a member of the court of Charles IV, who commissioned the mosaic; and in his Chronicle of the Church of Prague, Beneš noted that a "magnificent work of sculpture, that is, a grand portal and a hall of columns at St. Wenceslas' Chapel and a new sacristy above," was completed in December 1367. The grand entrance was solemnly consecrated on July 9 the following year (fig. 1).[1]

The original design for the southern facade of the cathedral by the architect Peter of Gmünd, also known as Peter Parleř, did not provide for a large mosaic on the outer wall of the new sacristy. A window, corresponding to the two still seen in the side panels, once existed where we now see the central representation of Christ summoning humankind to the Last Judgment. It was walled up shortly after the

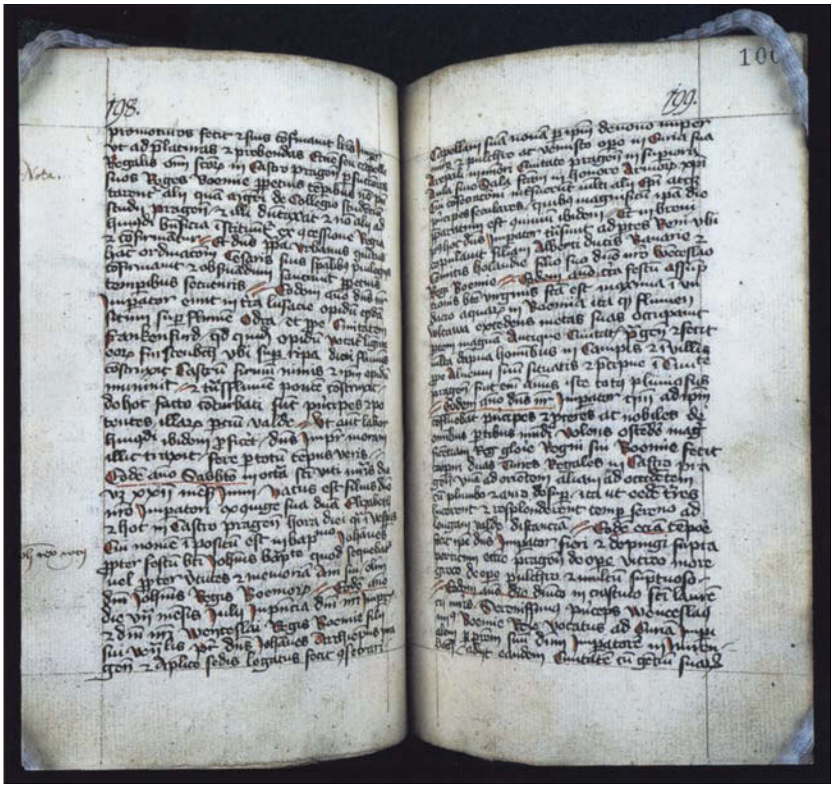


FIGURE 1 The Chronicle of Beneš Krabice of Weitmile. Archives of Prague Castle.

completion of the Golden Gate.[2] Beneš explains when and why this was done. His brief but reliable account makes it clear that Charles IV became attracted to mosaic art in Italy and in particular that the idea of portraying the Last Judgment in a mosaic ripened during the Charles's lengthy sojourn in Italy on the occasion of his second coronation. A mosaic had never been seen before north of the Alps, where sculpture, above the high portals of cathedrals, was the medium usually reserved for these scenes. Charles's wife, Elizabeth of Pomerania, now empress, preceded Charles on the return to Prague in August 1369, but Charles was delayed, first in Lombardy and later in Poland, and returned to the Prague Castle, amid great rejoicing, only on January 6, 1370. Also in 1370, he decided to demonstrate to princes and other visitors the splendor and glory of the kingdom of Bohemia. Charles therefore ordered that two towers of the castle be covered with lead and their surfaces gilded, so that they would shine far and wide when the weather was clear. He also commissioned a splendid and very expensive glass mosaic to be installed above the portico of the Church of Prague.[3] As the cathedral's building supervisor, Beneš undoubtedly oversaw the installation of the mosaic personally and could study it under various weather conditions. He wrote of its completion in 1371, with admiration and even wonder at this remarkable and unprecedented work of art; he also observed that the mosaic looked even cleaner and clearer the more it was washed by rain. There is no doubt that this work, executed in a fashion whose origins date back to the ancient traditions of Byzantine art, was meant to enhance the grandeur of the sovereign's majesty and the splendor of the imperial residence. If it was truly completed within the short one-year period specified by Beneš, we have even more reason for wonder about authorship.[4]

Several theories have been advanced by art historians about the possible authorship of the mosaic, but all of them remain speculative in the absence of written sources. Reliable evidence is available only concerning the mode of the mosaic's installation. Workers involved in the restoration (in particular, the removal) of the mosaic in 1890 ascertained that the mosaic was originally mounted as follows. Stonemasons' hooks, made of iron and covered with lead, were fastened to the smooth sandstone wall at regular quadratic intervals of 37 centimeters. The hooks, 18 centimeters long and 4 millimeters thick, were double forked, and a wire was attached to the forks. The masons first covered the wall with a rough plaster, then leveled it with trowels and made irregular scores in the mortar. This layer served as the background, to which a second layer of plaster was added.[5] The composition of the second layer was similar to the layer into which polished precious stones were laid on the walls of St. Wenceslas Chapel a year later. (From the expense accounts of the works performed in St. Wenceslas Chapel by Peter Parleř's St. Vitus building workshop in 1372, we know that raw eggs were bought for this purpose and that a dust made of finely crushed bricks was added to the mortar.) It is almost certain that the creators of the mosaic collaborated with the Parleř workshop.[6] Most likely, the Last Judgment was painstakingly assembled on that second plaster while it was still wet, in the following fashion. Colored glass tesserae, most of them cut in the shape of truncated pyramids (though some resembled triangular or quadrangular prisms), were inserted following the outlines of the artist's background drawing. The upper sides of these pieces were rarely larger than one square centimeter. For flesh tones in the mosaic, small reddish pink pebbles would be employed as well. Unfortunately, the composition of the plaster can now be studied only on the modest remnants we still have, because in 1890 the stonemasons working for the Society for the Completion of St. Vitus Cathedral at the Prague Castle removed the plaster with the help of small pointed tools and wire brushes, to facilitate the remounting of the mosaic. In so doing, they appear to have obliterated most remaining traces of the background drawing originally made in the plaster. In the early 1990s original cut tesserae could still be examined in the Prague Castle Archives in the Society's archive fund.[7]

Considerable archival research has been carried out to determine the origin of the mosaic's tesserae and precisely how they were manufactured, but until now it has failed to produce satisfactory results. Chemical analyses of medieval glass have provided more conclusive results, which confirm that the tesserae used for the St. Vitus mosaic came from the territory of the kingdom of Bohemia.[8] Archaeological findings have demonstrated that the technique of glass production was known in the Czech Lands in the early Middle Ages and that its manufacture continued in the ensuing centuries. Indeed, man-made gems were valued as highly as precious stones in the High Middle Ages, as accounts in the inventories of the articles kept at St. Vitus Cathedral attest;[9] and the technique of glassmaking was discussed in a Latin treatise included in the cathedral library collection of manuscripts on Czech affairs that dates to pre-Hussite (before 1415) times. In the introduction, the unknown author describes the art of glassmaking as a branch of alchemy and urges manufacturers to proceed with care, so as to demonstrate unequivocally that a work of glass is an artistic creation. The writer describes the method of crushing raw materials, their sieving, melting, thickening, roasting, and firing, and goes on to point out that no two batches were ever quite the same and that the relative proportions of their ingredients inevitably determined the color. The text, written in the Czech Lands in the early fifteenth century, is unfortunately incomplete, and we have been unable thus far, either from this or from any other manuscript, to reconstruct fully the directions for the manufacture of colored glass—which is of particular interest to us.[10] Czech medieval documents list the names of glassmakers and glaziers in large numbers in the same guild as painters, but nothing has come to light to suggest a possible involvement on the St. Vitus mosaic. It may be worth noting, however, that older crushed glass was used for the glazing of the cathedral's windows in the second half of the fifteenth century; after remelting, small circular glass pieces were made thereof and then united by lead to create larger surfaces.[11]

Historians over the centuries have referred repeatedly to attempts to rescue and repair this remarkable work of mosaic art.[12] The first attempt was allegedly carried out approximately one hundred years after the initial mounting. Another reportedly followed in the second half of the sixteenth century, as part of the effort to repair larger damage done to the cathedral by a fire in 1541. Papers referring to such repairs do not specify either their scope or the techniques involved because the authors could find no particulars in the available contemporary sources. The assumption that the mosaic was repaired in the 1470s probably originated in an incorrect interpretation of the accounting ledgers for money spent in 1477 on new roofing above the hall on whose southern side the mosaic is placed.[13] The devastating fire in the cathedral in 1541, along with the impact it had on various parts of the building and its furnishings, was described in detail by a contemporary, Václav Hájek of Libočany. Readers familiar with Hájek's chronicle know him to be gifted with a great deal of imagination, so sometimes his facts must be taken with caution. Shaken by the horror of the event, Hájek carefully described how the fire spread through the Prague Cathedral, what it destroyed, and what it damaged, in his chronicle, "On the Unfortunate Occurrence That Happened through Fire at the Lesser Town of Prague, St. Wenceslas's Castle and Hradčany in the Year 1541."[14] He does not mention the mosaic on the front of the southern transept, which probably means that it was unscathed. There is no doubt, however, that the fire consumed not only the shingle roofing above the vaulted room on whose outer southern wall the mosaic was mounted, but all of the other roofing in the cathedral as well. It appears, however, that the heat was not strong enough near the mosaic to destroy the tesserae. An interesting if laconic note in Hájek's chronicle refers to the timepiece installed, by order of Emperor Ferdinand I, "as a mosaic above the pinnacle where relics are kept at St. Wenceslas's." This may have been a sun dial intended in part to replace the cathedral's horologe, which fell victim to the 1541 fire. According to an entry in the records of the Metropolitan Chapter at St. Vitus, the pinnacle was torn down by a severe storm in October 1592.[15]

There is no evidence to substantiate the often mentioned assumption that the mosaic was plastered over during the brief reign of Frederick of the Palatinate (August–November 1619) and uncovered again under Ferdinand II (r. 1619–37). To my knowledge, no such plastering was mentioned either by Caspar Arsenius of Radbuza (a dean of the chapter, who left us a thorough account of the events associated with the reformation of the cathedral and with its restoration after the departure of the Winter King and his court), or by Jakob Hübel (a clerk of the Building Office of Prague Castle, who was put in charge of the technical side of the iconoclasm.)[16]

We have no other documents to draw on until the first half of the nineteenth century. Records made at that time note that a repair of the mosaic was launched in 1837 through the intervention of Karel Chotek, Supreme Burgrave of Prague, and that the professional supervision of the project was entrusted to the court painter Eduard Gurk. Portions of the mosaic were falling off; they were fastened by nails with large, flat heads. Loosened parts were supplemented by mortar, and missing segments were replaced by wall paintings by Vilém Kandler and Antonín Lhota.[17] Gurk had the mosaic coated with a varnish that revived its colors for a brief period. Unfortunately, the benefits of that repair did not last long. The air outside turned the varnish into an opaque substance under which only the brightest colors showed through. The painted plaster came off, and parts of the mosaic began to deteriorate again, tempting the schoolchildren of Hradčany to try to bring them down by throwing stones at the mosaic.[18]

The Society, established with a view to completing the cathedral in the neo-Gothic style, was deeply concerned with the mosaic's preservation. Before the foundation stone was laid for the new construction in 1873, the Society engaged in the restoration of the Gothic torso of the cathedral. In 1865 the Society's board of directors instructed master builder Josef Kranner to discuss the possibility of saving the mosaic with Italian mosaic makers in Venice and to propose a project for its repair, including a budget.[19] Under Kranner's successor, Josef Mokr, the board had the lower portions of the mosaic mechanically cleaned in 1879; at that point they realized that the corrosion and opacity were not caused by the varnish applied at the time of Gurk's repair but by corrosion of the glass tesserae. Corrosion made the mosaic illegible; the extent and even the type of corrosion varies according to the color of the glass. White glass was reportedly least affected, and there was less damage to the red and green tesserae, which remained almost completely intact. Yellows and greens tended to be among the least affected, closely followed by reds; and because the corrosion layers were usually very thin—no thicker than a sheet of paper—it was believed that the best way to revive the colors would be to scrape off the corrosion layers. Mokr's 1879 commission also stated that, because the mosaic was literally falling off the wall in numerous places, it would be impossible to preserve it in the conditions prevailing at that time.[20] The Society's board of directors commissioned photographs from Jindrich Eckert and decided to ask specialists for their expert opinions. The director of the mosaic factory in Murano, Campagnia Venezia, recommended that the mosaic be entirely re-created. He believed that it could not be saved otherwise, and estimated the cost at 40,000 francs.[21]

In April 1880 another opinion was delivered by Luigi Solerti, manager of the Albert Neuhauser mosaic workshop at Innsbruck. He noted that there had been several previous repairs and that the only parts left of the originally mounted mosaic were those whose stucco consisted of lime and crushed bricks. Solerti also analyzed the proportion of potash to metal oxides, which he considered incorrect, and determined that the glass requiring a larger quantity of color oxides to retain their brilliancy suffered less deterioration. Those containing oxides in smaller quantities, along with the golden tesserae covered by clear glass, were ruined almost without exception. Solerti recommended that the crust be removed mechanically and was strongly against the use of chemicals. He concluded that if this work were to be preserved for posterity, it had to be re-created, at an estimated cost of 12,000 guilders. Solerti proposed that the original mosaic be taken down and the best-preserved parts remounted in solid wooden frames.[22]

In an 1880 report the board noted with satisfaction that after the mosaic had been abraded with sandstone, the colors reappeared; and after it was coated with varnish, the colors were present with considerable clarity. It was decided that a painted copy should be made of the entire mosaic under the leadership of the cathedral's master builder, Josef Mokr, and painter, Frantisek Sequens. Most of this painted copy is preserved at the Prague Castle Archives.[23]

Nevertheless, problems relating to the method of the mosaic's preservation emerged again. The colors were covered by corrosion once more—some within the space of only a few weeks—and tesserae continued to fall off.[24] In 1888 the board deliberated on how to take the mosaic down and where to transfer it. Removal was recommended both by Mokr and by the K.K. Zentral Kommission für Kunst- und historische Denkmale (Central Commission for the Preservation of Works of Art and Historical Monuments) based in Vienna, which was Austria's supreme heritage conservation authority.

The Czech historiographer František Palacký suggested that the mosaic should be placed at a sheltered site in the cathedral's antechamber, but Mokr pointed out that there was no space in the cathedral for a mosaic of ninety-seven square meters.[25] In 1889 the board of directors again turned to foreign experts for advice on how to save the mosaic. They approached Francesco Grandi, from the Vatican mosaic factory in Rome; Albert Neuhauser, owner of the mosaic workshops in Innsbruck; and, for the second time, Neuhauser's workshop manager, Luigi Solerti. Pursuant to a previous agreement with the Society's board of directors and backed by the written consent of the archbishop of Prague and of the Metropolitan Chapter of St. Vitus, Solerti, accompanied by an assistant, a man named Pfeffer, came to Prague on August 28, 1890, and proceeded to detach the mosaic. They started by drawing the contours of the mosaic on paper, according to an old painted copy at Vladislav Hall of the Prague Castle, with lines indicating the segments in which the mosaic was to be divided. When dividing the mosaic into parts, close attention was paid to the shape of the figures and to prominent lines. The next step was marking the contours of the individual parts, which totaled 274, on the original mosaic with black oil paint. The loosened portions of the mosaic were taken off fairly easily, but those that held fast had to be pried off the wall with a chisel. This work took three weeks. It turned out that the wire originally extended between the hooks was completely rusted away in large areas, which led not only to the disintegration of segments of the mosaic's mortar base but also to the falling away of separate glass pieces and pebbles and even to the mosaic's loosening from the wall and the crumbling of whole sections in various spots. The rusting of the wire was caused by the gradual penetration of rainwater, over the course of several centuries, through breaches in the roof above the Gothic hall whose southern wall held the mosaic and through an old crack in the wall above the mosaic. After its removal, the mosaic was mounted in wooden frames and deposited in the Old Royal Palace.[26]

At the beginning of the twentieth century, Mokr's successor, the architect Kamil Hilbert, turned his attention to the ways in which the original mosaic could be preserved. After studying the documents in the Society's archives and thoroughly inspecting the dismounted sections, Hilbert decided that the mosaic's condition was not as bad as had previously been believed. He therefore suggested that instead of mounting a copy on the southern front of the cathedral, the original work should be reinstalled. In October 1907, with the concurrence of the Society's board, he communicated his opinion in writing to the Austrian Central Commission, and in January 1908 he submitted to the artistic section of Sklárny Union (Union Glassworks) a proposal concerning the method of the mosaic's restoration.[27] In the presence of the Central Commission's conservator general, Max Dvořák, a lively discussion took place on whether the missing parts of the mosaic should be reconstructed. In view of the weight of the builder's responsibility for the preservation of a unique work of art, the Society's board suggested once again consulting foreign experts. The Austrian Central Commission was of the opinion that the only specialists possessing the skills to perform such work were conservators of the San Marco workshop in Venice, but in a letter signed by the Commission's president, Josef Helfert, it was stated that even the experience of the San Marco workshop could not be simply transferred to the Prague project because the technique used for the Prague mosaic differed from that of ancient mosaics of Venice. The Central Commission eventually recommended that several parts of the mosaic be entrusted, by way of a trial, to Viktor Förster, a Czech painter, and to withhold a final decision until after his work was completed.[28] In a letter to the San Marco building workshop in February 1909, Hilbert inquired if the workshop could make its experts available for work on the Prague mosaic; how he might obtain material resembling the originals for the restoration; and whether the execution of the mosaic suggested Italian authorship. A reply came in July, through the Venetian firm of Eugenio de Marchi, to the effect that the mosaic makers of San Marco were not in a position to accept commissions outside their workshop and that, in their opinion, the Prague mosaic was not an Italian creation. Following a series of working sessions, Hilbert invited Förster to submit to the Society a proposal for the restoration of the original mosaic. In the presented bid, the painter requested a fee of approximately 220 crowns for treating one square meter of the surface—that is, for restoration, supplementation of missing parts where necessary, and mounting. In July of the same year, Hilbert advised the Society's board that Förster had reassembled eleven sections of the first group of apostles. His work had shown that only minuscule fragments of these sections were missing and that fissures had affected only the single-colored background and the dark contours of the figures.

On July 23, 1909, a working meeting was held to discuss the method of the mosaic's restoration. Conservator General Dvořák was present on behalf of the Austrian Central Commission. Other participants included August Agazzi, the chief mosaic maker of the San Marco workshop of Venice; J. Th. Reuecker, owner of a mosaic workshop in Munich; Viktor Förster, painter and owner of a mosaic workshop in Prague; Franz Count Thun, president of the Society; and members of the artistic department and the master builder of the cathedral. They decided that the ornamental frieze, of which only a very small portion had survived, should be left as a fragment. The missing single-colored background above the left third of the mosaic was to be supplemented with patinated gold, carefully calibrated to match the original but with dark blue and red glass tesserae to be blended under the gold in the incomplete parts. The missing geometric borders surrounding the principal scenes were to be supplemented with stones patinated in the same way, and the new bond would be the same color as the old one. Coating the restored mosaic for the purpose of achieving a patina was considered improper.[29] Förster and four Venetian craftsmen began restoration of the dismounted mosaic on

May 17, 1910. (See chap. 7, fig. 18a–f.) After cleaning the individual sections, he fastened the loosened pebbles and supplemented the missing border according to the painted copy. On the whole, the mosaic's condition was not critical, but the following portions were broken or scattered: the bosom of Christ; the chin and neck of Empress Elizabeth; the wing joint of the angel to the right of the mandorla; and the skull of the highest-placed apostle on the left. The golden surface and the single-colored skirting belts were supplemented as well.[30] Hilbert's letter to Förster, dated May 23, 1910, revealed that minuscule parts of the mosaic known to have belonged to the human figures were kept in special boxes. They were part of the section portraying hell that broke off in windy weather. The repaired mosaic was remounted between June 28 and August 27, 1910 (see chap. 7, fig. 17), after which its entire surface was repeatedly washed with water. The corrosion clouding certain parts of the mosaic would be subjected to additional chemical examination at the Institute of Glass-Making, Ceramics, Technology and Testing of Building Materials attached to the Czech University of Technology in Prague. The remounted mosaic was inspected on October 22, 1910, by a commission in the presence of Conservator General Dvořák. In a letter dated January 18, 1911, the Central Commission for the Preservation of Works of Art and Historical Monuments in Vienna expressed its appreciation of and satisfaction with the commendable accomplishment of the transfer of the mosaic.[31]

NOTES

1. "Eodem anno et tempore [1367] completum et perfectum est opus pulchrum, videlicet hostium magnum et porticus penes capellam sancti Wenceslai in ecclesia Pragensi de opere sculpto et sumptuoso nimis, et sacristia nova desuper" (Fontes rerum Bohemicarum IV. [Praha, 1884], 536; further FRB IV). The grand entrance was consecrated 1368 (FRB IV, 538).
2. This became clear when the mosaic was taken down for the restoration of 1890, under the auspices of Jednota pro dostavění hl. chrámu sv. Víta na hradě Pražském (Society for the Completion of St. Vitus Cathedral at the Prague Castle). Ročník Jednoty pro dostavění hl. chrámu sv. Víta na hradě Pražském za správní rok 1890, 8 (further APH, Jednota).
3. "Eodem anno [1370] dominus noster imperator, quoniam ad ipsum confluebant principes et proceres ac nobiles de omnibus partibus mundi, volens ostendere magnificenciam glorie regni sui Boemie, fecit cooperiri duas turres regales in castro Pragansi, unam ad orientem, alium ad occidentem cum plumbo et auro desuper, ita ut eedem turres lucerent et resplenderent tempore sereno ad longam valde distanciam. Eodem eciam tempore fecit ipse dominus imperator fieri et depingi [picturam] supra porticum ecclesie Pragensis de opere vitreo more greco, de opere pulchro et multum sumptuoso" (FRB IV, 540, 544). For more recent literature on Emperor Charles IV, see Jiří Spěváček, *Karl IV., Sein leben und seine staatsmännische Leistung* (Prague, 1984); František Kavka, *Vláda Karla IV. za jeho císařství I, II* (Prague, 1993).
4. FRB IV 4, 544.
5. APH, Jednota, Roč., 1890, 8.
6. APH, Archiv metropolitní kapituly u sv. Víta (further KA), cod XI/1, fol. 9r, 28v.
7. See note 5.
8. Karel Hetteš, On the origin of the glass of the St. Vitus mosaic in Prague, *Czechoslovak Glass Review* (1958):3–10; Karel Hetteš, Böhmische Glas in Mittelalter, *Tschechoslovakische Glasrevue* 1, no. 7 (1958):2–7; Karel Hetteš, Glas in Czechoslovakia, *Tschechoslovakische Glasrevue* 12 (1958):4–9; Michal Ajvaz, Mozaika Poslední soud na jižním portálu katedrály sv. Víta na Hradě pražském (Prague, 1992); František Mareš, České sklo; příspěvky k dějinám jeho až do konce XVIII. století, Rozpravy České akademie c. Fr. Josefa pro vědy, slovesnost a umění v Praze (Prague, 1893); Karel Hetteš, Sklářství, in Dějiny techniky v Československu (Prague, 1974), 253–60.
9. For ex. inventory of 1387: "Rubrica de insigniis pontificalibus . . . infula de perlis argentea deaurata, quam dedit regina Elisabeth, habens superiori parte duo vitra ad modum zaphirum" (APH, KA CCLII).
10. APH, Knihovna metropolitní kapituly u sv. Víta (further KK), M VIII, fol. 81r–82r. APH, KA CCLXIII.
11. APH, KACCLXIII.
12. For more, see Antonín Matějček, Das Mosaikbild des Jüngsten Gerichtes am Prager Dome, in *Jahrbuch des kunsthistorischen Institutes der k. k. Zentralkommission fur Denkmalpflege. Herangegeben von Professor Max Dvořák*, Band IX (Vienna, 1915), 106–39.
13. APH, KA CCLXIII.
14. Václav Hájek z Libočan, O nešastné příhodě, kteráž se stala skrze oheň v Menším Městě pražském a na Hradě svatého Václava i na Hradčanech léta MDXXXXI (Státní knihovna / State Library / Prague, sign. 54 B 129).
15. Acta capituli . . . 1592, de funere Wilhelmi a Rosis: de "musaico opere horologii a caesare Ferdinando supra pinaculum ubi reliquie apud s. Wenceslaum conservantur positi" (APH, KA cod. XXXV/1, fol. 19r).
16. APH, KA, cod. VI/9, cod. XCIII/1, cod. XCIII/2, sign. LXV/52. The literature: Antonín Podlaha and Eduard Šittler, *Chrámový poklad u sv. Víta, jeho dějiny a popis* (Prague, 1903), 105–13; Václav Kramář, Zpustošení chrámu sv. Víta v roce 1619, in *Fontes historiae artium VI*, Artefactum UDU AV ČR (Prague, 1998). For evidence substantiating the assumption that the mosaic was plastered over during the reign of Frederick of the Palatine and uncovered again under Ferdinand II, see Anton Honsatko, *Die Metropolitankirche zu St. Veit* (České Budějovice, 1833), 72–73. See also W. A. Gerle, Prag und seine Merkwürdigkeiten. 2. *Auflage Prag* (1836):48. Note: The term "iconoclasm" refers to the destruction of the decoration of the cathedral.
17. APH, The royal authority for construction (further HBA) 3016, case 185, clearance of accounts: "Summary of the following expenses: for

masonry, 27 FL. 24 koruny; for carpentry, 23 Fl. 36 koruny; for masonry and carpentry material, 8 Fl. 25½ ? koruny; for brick work and materials ,9 Fl. 4 koruny; for stonemasonry (stone mason Gedlicka), 39 Fl. 6½ koruny; for coppersmith work (coppersmith Ringhofer), 288 Fl. 51 koruny; for locksmith work, 72 Fl. 39 koruny. Total, 469 Fl. 6 koruny. Eduard Gurk clearance of accounts: "Mr. Kandler and Mr. Lhotta each worked nine days on the mosaic; therefore, together they worked eighteen days. Each day they received a payment of 2 F.C. M.; together, F.C.M. 36. Their expenses: 4¼ portions of cobalt green for 2 F.C.M. 8 F. 30, for brushes 2.10, for the remaining paint 4.08; together 50 F. 48 koruny. Prague, July 21 1837. Eduard Gurk. Hereunto for the clerk Miklas for the inscription 8 F. . . . 56 F. 48 koruny" (APH, HBA, 4261, case 288).

18. Gustav Amros, *The Cathedral in Prague* (Prague, 1858), 275, wrote: "The entire image shows a certain specific technique, but its workmanship is raw and has a dull heavy coloring. Its style is Byzantine throughout, of a Byzantine concept."
19. APH, Jednota, Ročník 1864/1865, 18. The literature: Karel Vl. Zap, Svatováclavská kaple a korunní komora při hl. chrámě u sv. Víta na hradě Pražském, in *Památky archeologické VIII* (1868–1869) (Prague, 1870), 95.
20. APH, Jednota, Ročník 1879, 12.
21. APH, Jednota, case Mozaika.
22. From L. Solerti's report: 1. The various techniques, especially the different kinds of mortar used, show clearly that the mosaic was restored several times. The oldest and the most original technique is that of the mortar composed only of lime and brick dust, a technique frequently found in Italy in old mosaics, stuccoes, and even in frescos. The mortar used in the mosaics contains only lime and coarse-grained sand, a little or no brick dust or marble dust, in disadvantageous proportions, causing the mosaics to separate from the wall. Currently the mosaics remain in a loose or detached state.
2. The glass paste, including the gold base, is for the most part damaged and disintegrated. The disintegration seems to be caused by faulty glass composition, the main ingredient of the paste. That glass is an incorrectly composed window glass, which becomes stale or blind by being often exposed to humidity and sun. Our glass paste gradually chemically disintegrates in the same way because of weather. Also, the glass contains too much alkali and not enough lime or metal oxides (not enough to balance the bases). The insoluble product of decomposition remains on the surface as a white or dark crust, which covers the color underneath. This explanation is confirmed by the fact that deeper-colored glass with a high level of metal oxides remained unaltered. To the contrary, white and red stones containing a low level of oxides and the gold paste covered only with a layer of transparent white glass were almost entirely destroyed.
3. The question of whether the decomposition of the outer surface might have been caused or accelerated by a fire, believed to have taken place, can be answered in the following way: a short and slow fire would not cause the paste to melt or to break by its sudden emergence; it also would not change the outer layer of the glass. Some colors would become darken or dull, but the change would not have the properties or appearance of the outer crust. The result would have been different if the heat had lasted several days. If you take a piece of a perfectly well composed glass and dissolve it for several days in the kiln or in another place exposed to scorching heat, it will become covered by a matte crust, which will sink toward the inside of the glass and gradually change it. This type of glass is known in chemistry as Roman glass. Therefore, the decomposition of the glass could be explained by heat preserved after the fire for several days in hot ash.
4. A varnish on slick glass would last only a short time and would not leave a trace after 30 to 40 years. Therefore, the crust cannot be varnish. A varnish could be found only because its particles were held by the matte and porous glass, thus further damaging the already damaged glass.
5. It is not possible to chemically remove the crust from the glass: even the diluted hydrofluoric acid, which could not have been applied because of the decomposition of the mortar, would not completely remove the deterioration products. Single stones could be cleaned mechanically by polishing, but not the whole mosaic. Sanding would be difficult because of the coarse-grained sand, not detected in the mortar of the second mortar, and also because the mosaic is only loosely attached to the wall. Even if this were not be the case, the gold ground cannot be sanded and would have to be replaced. Furthermore, almost all of the small parts used in the repair process are wedge-shaped (pyramidal) and would become much smaller when sanded. Even if all this were not the case, sanding would only expose material that would soon be damaged.

"It certainly would be a pity not to restore this artwork to its original state, as it is one of only a few mosaics existing outside of Italy and the Orient that are so valuable art historically, and not to preserve the remaining fragments of the old half-destroyed mosaic. To return the mosaic to its original state, it is highly desirable to make a faithful image; also because the loosely attached mosaic might easily loose parts, which will make a copy even more difficult.

"The making of a copy might be facilitated by treating the glass with linseed oil, which would make the crust more transparent and would allow the artist to pause. The better-preserved parts of the image will be better conserved when removed and put into firm, wooden or metallic cases" (APH, Jednota, case Mozaika).

23. APH, Jednota, case Mozaika; APH, Jednota, Ročník 1880, 10.
24. APH, Jednota, case Mozaika.
25. APH, Jednota, case Mozaika.
26. APH, Jednota, Ročník 1889, 9–10. APH, Jednota, Ročník 1890, 6–9. APH, Jednota, case Mozaika. APH, Jednota, Minutes from the meeting of the artistic section 1889, 1890.
27. On October 4, 1907, master builder Kamil Hilbert presented his proposals to the meeting of the directorate of the Society for the Completion of St. Vitus Cathedral at the Prague Castle and on October 1, 1907, to the Central Commission for the Preservation of Works of Art and Historical Monuments based in Vienna: "Due to the restoration of the south entrance hall in 1890 the mosaic was divided into 274 parts, taken off and deposited in the castle. Before this, life-size color tracings were made showing the position of the 274 parts. The parts will be put together again to form the complete

mosaic. Some of the spaces between the parts are several centimeters wide and have to be filled using old as well as new material. Parts that were missing before the mosaic was taken off the wall and parts that were damaged also need to be replaced. This applies mainly to the ornamental parts of the frieze below the cornice in the entrance hall and part of the ceiling. The replacement should of course be done using material equal to the old in color, fading, dullness, and size, and it should be made using the old irregular process. It will be necessary to employ only a skilled and experienced hand. . . . The total cost of the reconstruction is 10,000 koruny. The reconstruction should take place as soon as possible, since the mosaic, once taken off and stored for several years, will not improve . . ." (APH, Jednota, case Mozaika; see documentation in two copies collected by the GCI and in the Archives of the Prague Castle).

28. The letter from the Austrian Central Commission to the architect Hilbert, on March 7, 1908: "Concerning the employment of an Italian conservator, the Central Commission would like to point out that only conservators of the Opera S. Marco may be considered, since only they have the necessary expertise. It is not advisable to entrust a private Italian firm with such work, because the employees of such firms are not up to the task. Not only is the artistic quality of the mosaics produced in Venetian factories appallingly low, but they apply a specific technique of molding. The application of this Venetian technique, regardless of modality, should be avoided by the restoration of the mosaic in Prague. On the contrary, the old technique of mosaics should be adopted. Oddly, this old technique does not correspond to the technique used in old Venetian mosaics. Therefore, the conservators of S. Marco cannot simply use their experience but should seek an individual solution. Also, not an ordinary worker from Opera S. Marco should be appointed to Prague but one of the masters. This would require special permission from the Italian government and would also be very costly.

"For these reasons, the Central Commission recommends appointing the restorer Förster, who should be taken seriously as an artist. For this purpose he would be entrusted with a small part of a painting to be restored according to a specific program, and his work would then be judged" (APH, Jednota, case Mozaika).

29. Minutes of a meeting on July 23, 1909: "(a) The horizontally positioned ornamental frieze, of which only a small fragment is left, should be preserved as a fragment. Within the missing parts, the stone should remain visible, and the leveling of the stone should not be deepened. (b) The missing one-color background above the left third of the image will be filled with patina-coated gold matching the old gold. In the replaced areas dark blue and red glass paste will be mixed beneath the gold. (c) The missing geometrical border, which framed the figural composition, will be reconstructed, including the stones covered with patina. (d) The new visible plaster should be dyed to match the old one. (e) The glass paste should be coated with patina. It is not acceptable to paint over the restored mosaic to achieve the effect of patina."

30. APH, Jednota, Ročník 1910, 10–11.

31. The Austrian Central Commission wrote to the Society for the Completion of St. Vitus Cathedral on January 18, 1911: "The Central Commission is taking the liberty to express its fullest approval of and satisfaction with the exemplary execution of the transer of the abovesaid mosaic" (APH, Jednota, case Mozaika).

Zdeňka Hledíková

Chapter 2
Charles IV's Italian Travels: An Inspiration for the Mosaic?

The question of Italian influence on the Last Judgment mosaic has long been discussed by scholars. One source of possible influence is Charles IV. Born in 1316, he succeeded his father, John of Luxembourg, as king of Bohemia in 1346 and became Holy Roman Emperor in 1355. Charles spent considerable periods of time in Italy on three occasions. From 1331 to 1333, when he was a young man, he led King John's *signori*—nobles owing John their allegiance—in northern Italy and directed the administration of his father's acquisitions in that region. The second visit, lasting nine months, was his imperial coronation journey in 1355, when as Holy Roman Emperor he traveled to Rome to receive the crown. Finally, in 1368–69, he returned to attend the coronation of his fourth wife, Elizabeth of Pomerania.

According to Beneš Krabice of Weitmile (see chap. 1, fig. 1),[1] the mosaic above the Golden Gate of St. Vitus Cathedral was created in 1370–71. If Italian influences lay behind the idea for the mosaic or the theme that it portrayed, they would probably date from the third of Charles's sojourns in Italy. It is worthwhile, however, to also examine the character and the principal purposes of the earlier visits, to look at the sites that the emperor's procession passed through and at those places where they lingered, and to delve into the question of what might have impressed a youth, a mature man, and a man on the threshold of old age. In doing so, we cannot but tread on a speculative field of deduction and conjecture. No other avenue is open, however; and such speculation—which will adhere closely to the historical record—allows us to explore a potentially fruitful area of inquiry.

We can be fairly brief with regard to Charles's first stay in Italy (fig. 1).[2] The young prince arrived from Luxembourg via Savoy, Lausanne, and Novara and initially took up residence in Pavia in March 1331. Afterward he joined his father in Parma, where he remained—except during the military campaign in which King John was trying to extend his power in Lombardy and which included the battle of San Felice—until the end of 1332. Early in 1333 he was in Lucca. He moved largely among these three places and in the surrounding territories until his departure from Italy for the Tyrol, via Verona and Marano, in October 1333.

In Italy Charles proved himself a very capable administrator—indeed, his father would eventually become jealous of his abilities—but the enterprise itself, lacking long-term vision, was largely inconclusive. King John's success in the beginning was considerable, and by 1332 he controlled most of northern Italy. When a powerful league of nobles formed against him, however, resulting in a broader revolt and several military defeats, he withdrew, returned to Germany, and lost interest in Italy. To Charles, the Italian campaign was essentially an adventure—which he enjoyed immensely. Italy charmed him altogether, with its brilliant and highly varied scenery, its delightful villages, its climate, its people, the imposing architecture of its cities, and not least its magnificent food and wine. Young Charles enjoyed all of this to the full and yet kept a measured distance; and he never lost sight of his main objective, the preservation of Luxembourg rule in northern Italy for as long as it could be maintained.

This lighthearted youthful adventure belied his essentially serious nature.[3] We can say that Charles, while

FIGURE 1 Map of Central Europe in the late fourteenth century indicating the cities Charles visited during his journeys to Italy.

indulging in occasional pleasures, nonetheless arrived at a conscious realization of his true character during his time in Italy. For the remainder of his life, his conduct was governed by a clear and statesmanlike purpose; and although he was willing to modify his methods according to the circumstances of the moment, he always kept his true objective in view. It is obvious that this first contact with Italy left both a lasting affection for the fine traits of that country and an acute vigilance toward it. He appears to have forgotten none of his general impressions, even including mention of his Terenzo dream later in the foundation charter for the corps of mansionaries of Prague's St. Vitus Cathedral. Specific impressions are another matter; and for various reasons, it appears unlikely that any particular work of art he saw during his first Italian period, including mosaics, served as a direct inspiration for his later pursuits. But the influence of the Italian ethos remained. This, together with Charles's wide-ranging education, may well have contributed to the refinement of his taste and to his openness to new currents of thought and artistic creation.

We have a more detailed picture of Charles's coronation journey to Rome in 1355,[4] derived partly from contemporary reports by Johannis Porta de Annoniaco[5] and partly from the wealth of political gains Charles achieved during this undertaking. At the time of this journey he was a mature politician, and he had always preferred diplomacy to war. In his clearly defined quest for the imperial crown, he negotiated peace treaties and obtained financial benefits from the Italian city-states but never allowed himself to be drawn into the internal political squabbles among them. Charles was among the most cultured monarchs of his era, and in the course of his second journey to Italy, he pursued a number of interests having little or nothing to do with politics. His personal piety led him to collect holy relics—yet even in this he had in mind the future imperial greatness of Prague, where he planned to concentrate the treasures he acquired. Two days before his coronation, Charles visited—privately and incognito—Rome's principal basilicas and monuments. We can only guess at his impressions of their beauty and to what extent he took notice of the mosaics he found there. But mosaics there were, in profusion; and one might at least suggest, as a hypothesis, that it was then that he first formed the idea that he would one day have such a work created in his own residence.

Charles's attitude toward Italy during his coronation journey is best illustrated by his contacts with Italian humanists. His personal relationships with these learned men reached their apogee at this time, although the origins of these contacts lie in a much earlier period: above all, in Cola di Rienzo's visit to Prague in 1350 and the influence he left behind and in an exchange of letters between Charles and Petrarch.[6] The poet joined the monarch in Mantua in mid-December 1354, and the long hours they spent together in conversation indicated that they had a great deal to talk about, although their objectives differed. The king could certainly have had no more than a forbearing smile for Petrarch's dream of restoring the bygone glory of Rome and making it the unifying center of a triumphant Italy, and even more amusement at the suggestion that he should leave his own kingdom for the sake of that cause. The general concept of empire was close to his heart, however, and he was willing to incorporate features rooted in classical antiquity into this new and Christian version.[7] His general interest in and affection for Italy turned easily into a desire to understand and absorb the ideas of early Italian humanism—to which Petrarch (and indeed Cola di Rienzo) was so central. Nevertheless, Charles, as always, chose carefully and judiciously; and Petrarch felt betrayed after Charles left Rome without having promulgated his humanist (and Rome-centered) ideals. Petrarch had fully expected Charles to make Rome the center of the empire; when he did not, Petrarch responded with bitter censure.

This expectation appears to have been shared by a number of humanists of that early period, because the appeal that Charles should leave his home country to assume the reign of the beautiful Italy and reconstitute its glory was made once again on a later occasion, when he was heading back north after his departure from Rome. It happened in Pisa—traditionally a Ghibelline city, in favor of the Holy Roman Empire and in league against the papal Guelphs—which the emperor visited in May 1355. During a festive gathering, the emperor decorated the poet Zenobius da Strada with laurels. Zenobius, who initially had served as headmaster of the municipal school in Florence and later worked at the court of the seneschal of Naples,[8] was a friend of Petrarch's and an older companion to Boccaccio. Although Petrarch's appeal to Charles is known only from the letters he sent to his friends, including Zenobius,[9] Zenobius's speech has been preserved in full.[10] The appeal itself constitutes only a small part of the text, which also includes an extensive learned commentary preceding the final exhortation; but it seems that only the appeal itself was delivered orally in the emperor's presence, whereas the full text was presented to him in writing. Petrarch was so irritated by the conferring of the title *poeta laureatus* on Zenobius, and even by the latter's appeal, that it apparently marked the end of the two men's friendship.[11] To Charles, this was clearly a minor episode; at that point he was paying but little attention to the repeated calls urging him to rule Italy.

It might be interesting, however, to examine his reasons for crowning such an author poet laureate. Zenobius was principally a scholar; his talent as a poet could bear no comparison to Petrarch's. The speech he delivered to Charles IV is the only one of his Latin writings to survive in full, and in many respects it resembles a contemporary tractate intending to point out the difference between glory and name; that is, Charles should win real glory, not merely a name as a sovereign, by assuming imperial rule over Italy. Instead of employing biblical and patristic quotations, however, Zenobius used statements by classical authors. The rest of his writings consist largely of shorter occasional pieces or translations of Latin works into Italian. After the break with Petrarch, when Zenobius moved to the papal court in Avignon, he devoted himself to translating Gregory the Great's *Moralia* into Italian. His endeavor to promote the use of demotic language in literature—a course alien to Petrarch, though very dear to Charles—may have been a factor in the emperor's appreciation, along with Zenobius's impressive education and refined style. In any case, it was similar to his conversations with Petrarch: both men attracted the emperor's interest, but here, as always, the emperor chose that which he could embrace as his own.

Charles's second Roman journey, in 1368, was his third to Italy overall.[12] It began with a ride across the Alps from Villach to Udine, where he stayed for about a week before continuing via Treviso to the Po River lowlands. Between late May and early July, expecting a military encounter with Bernabò Visconti (against whom Pope Urban V and a powerful league of nobles were waging war), Charles moved to the territory surrounding Mantua; on July 8 he withdrew into that city and remained there for almost a month. While engaging in preliminary peace talks between the Viscontis and the anti-Viscontian coalitions, he also devoted his attention to the local relic and its acquisition. Most of August was spent in Modena, where the first phase of the peace arrangements with the Visconti was completed on August 27. Soon thereafter he proceeded to Castiglione, Lucca, San Miniato, back to Lucca, then to Pisa, and, via Siena, to Viterbo, where he met with the pope. Then he headed toward Rome, making only brief stops (five days to a week) in Lucca and Pisa. On October 19 he was in Rome, where he immediately proceeded to the grave of St. Peter—no longer incognito, as during his first Roman journey, but still without a ceremonial procession. On October 21 he greeted Pope Urban V beneath Monte Mario and ceremonially escorted him to St. Peter's Basilica and to St. Peter's tomb. The coronation of his wife, Elizabeth of Pomerania, followed on November 1.

Charles and an intimate circle of advisers remained in Rome for two months, staying in the papal palaces. In addition to continued talks with Urban V and a number of agreements, in whole or in part, on contemporary European politics, he was very concerned with holy relics. Pope Urban V provided relics from six ancient Roman basilicas:[13] from S. Giovanni in Laterano, a part of Christ's bloodstained side cloth, a piece of the clothing of St. John the Evangelist, and one link of the chain with which St. John was fettered on the ship that carried him to Patmos; from S. Maria Maggiore, a fragment of the Bethlehem manger; from S. Agnese and S. Sebastiano, parts of the arms of the two patron saints; from S. Lorenzo fuori la mura, dust from the skull of St. Lawrence; and from S. Pietro, the undercloth covering the sudarium. A copy of the Vatican vera icon[14] was another precious specimen among these sacred objects. The long stay in Rome provided sufficient opportunity not only for conducting a series of talks of fundamental importance but also for experiencing the city's climate and getting acquainted with its treasures. From among the humanist community, it was a younger author this time—Coluccio Salutati, who wrote in Italian—who now devoted his attention to Charles, but Salutati's hope for a revival of Roman and Italian glory and unity were largely associated with the return of the pope rather than with a lasting presence of the emperor.[15]

In the second half of December, Charles embarked on the return journey. At Christmas he was back in Siena, where he spent a month. It was a rather troubled period. Yet another of the numerous uprisings in the city broke out during his visit, and Charles was even besieged in his residence, but he succeeded in calming the disturbance with an impressive if somewhat theatrical appearance. He then continued to Lucca, where he arrived on February 2. He was occupied here with affairs of local importance. From there—at a safe distance—he watched and informally intervened in the developments at Pisa, supporting the return of Piero Gambacorta (who had been expelled in 1355) in order to thwart the Visconti influence in that city. Gambacorta was soon overthrown, then murdered. The subsequent plundering served the emperor as a reason for punitive action against Pisa, which was finalized by removing Lucca from Pisan rule in April 1369. All these actions were subordinated to the emperor's principal objective, which was to secure peace with the Viscontis. The peace arrangement was actually proclaimed in Bologna on February 11, and on February 17 Charles confirmed the status of Vicars of the Empire for Bernabò and his heirs for all time. However, the vicariate did not include Pisa and Lucca, which Bernabò Visconti had most wanted to acquire. Charles concluded a peace agreement with Florence on February 28 and appointed the city's representatives Vicars of the Empire for the municipality. The final act in this intricate web of relations, disputes, and diplomatic arrangements was the appointment of Cardinal Guy de Boulogne as Vicar General of the Empire for the whole of Tuscany at the end of June 1369, in keeping with Urban V's original intention.[16]

An increasingly complicated situation concerning the inheritance of a powerful noble back home prompted Charles to return to the lands of the Crown of Bohemia. On July 4 Empress Elizabeth and her entourage left Lucca; the emperor followed on July 10. They were reunited in Bologna, after which the responsibility for their escort was assumed by Margrave Nicolò d'Este, at whose court in Ferrara they stayed for four days starting on July 14. On July 18 they proceeded to Friuli. At Corbola the escort of the imperial procession was taken over by the Republic of Venice. The arrangements for this were made with Desiderato, a secretary to the Venetian Doge, with whom Charles had negotiated escort arrangements when passing through Venetian territory on his way south and who had stayed at Charles's court. According to the agreements, the Republic pledged to provide horses for the entire traveling party, to send twelve envoys to accompany the emperor from Corbola to Chioggio, and to provide galleys to take the emperor and his entourage across the sea bay to the port of Marano in the Friuli lagoon. From there the emperor's party, now fewer, continued to Udine, where they arrived on July 28. Afterward, most of the traveling party, including the empress, proceeded straight back to the Czech Lands, but the emperor, detained by certain local disputes, did not cross the border until August 15. Before returning to Bohemia, he went first to Moravia (he was in Brno on September 1) and then to Silesia and Upper Lusatia, where he visited Wroclaw, Swidnica, Bautzen, and Zittau. In December 1369[17] he proceeded to Litoměřice and Roudnice and finally returned to Prague on the Epiphany of the year 1370.[18]

Although the second coronation journey, unlike the first, allowed for fewer private occasions and personal activitities, the emperor obtained in July 1368 yet another valuable relic from Mantua: several drops of Christ's blood.[19] And in Udine, in late April 1368, he was again awaited by Petrarch,[20] who joined his entourage. (By now, Zenobius was dead.) The two men probably spoke to each other, but the keen mutual interest and expectation so manifest in the 1350s had long since evaporated, and it is doubtful that they engaged in the same kind of all-night conversations that they had shared on first meeting. No records have been preserved of the content of their discussions, nor can we be certain that they even took place. It is possible that the poet's presence at the emperor's court merely signified a mutual recognition at the social level, for it was an honor for the poet to be part of the emperor's entourage and equally appropriate for the emperor to be accompanied by a renowned poet and scholar. The looser, less intense character of their relationship was illustrated, among other things, by the fact that Petrarch occasionally left Charles's court; on one of these occasions, he attended the wedding of a daughter of Charles's principal Italian enemy, Bernabò Visconti. With fewer personal pursuits, the second Italian coronation journey was driven almost entirely by political objectives, and these were often not pursued actively. Charles's efforts appear, rather, to have been marked largely by an unhurried, wait-and-see attitude; he observed and influenced the conflicts among Italian communities from a distance, letting them ripen first and intervening only at the very end, through some normative act of imperial privilege. Inconspicuously, he thus moved—gradually but steadily—with the aim of establishing equilibrium.[21]

The third Italian journey, in 1368, was the undertaking of a man of very mature years, holding the highest position in the Western world, who had already achieved a great deal, had a clear picture both of his goals and of the best ways to attain them, and who, being a rational politician, no longer yielded to emotions. This is not to say that he was entirely unaffected by emotional impressions. He visited Modena on the way to Rome, then Rome itself, and Lucca on the way back. These stays were filled with political negotiations, of course, but their unhurried pace left enough time for personal explorations and private contemplation. In Modena he became acquainted with Tommaso da Modena;[22] and before receiving from Pope Urban V the holy relics from the six basilicas,[23] Charles certainly visited these shrines. He would have viewed them closely, including their mosaics—all of which, with the exception of the mosaic above the entrance to the atrium of the old St. Peter's Basilica, were situated in apses of the churches, on their inner walls, or in roofed loggias. A mosaic on an outer wall above the entrance to a church would have had the symbolic suggestion of a memento and of purification on entering a church—a concept dear to Charles. He obtained an intimate knowledge of such a mosaic, placed on an outer wall directly above the main church entrance, during his second and longer stopover on the journey, in Lucca. The old St. Peter's mosaic presented enthroned Christ between St. Peter and St. Paul, with signs of evangelists, and below them stood twenty-four old men. The outer mosaic placed high above the western entrance to Lucca's thirteenth-century church of S. Frediano (fig. 2), portraying an enthroned Christ in a mandorla with two angels, the Twelve Apostles in a belt below them, is certainly different from the Prague mosaic as regards both the theme and the execution—but not that different. I believe that it was during this stay in Lucca,[24] a longer visit allowing sufficient time both for non-Italian affairs and for private contemplations, that Charles embraced the idea of having an outer mosaic installed above the main entrance to the Prague Cathedral.

It is even possible that he took the first steps toward the implementation of this idea before leaving Italian soil. It has been argued that the design for the Prague mosaic is the work of the painter Nicoletto Semitecolo Venice;[25] in terms of geographic distance, Venetian mosaic makers were easily available for the kingdom of Bohemia. Their experience, among other things, may have been one of the reasons behind the choice of glass instead of stone as the material for the Prague mosaic. Here we may recall Charles's talks with the Venetian secretary, Desiderato, in Ferrara; in addition to securing an escort for the return portion of the journey, Charles might have taken the opportunity to ask privately for a recommendation and for the sending of skilled experts to design and execute a mosaic in Prague according to his wishes. I have no doubt that the principal theme—enthroned Christ with Czech patrons below, kneeling figures of the emperor and empress at the bottom in the central field, and the Last Judgment in the two side fields—was selected by the emperor himself.[26] He may have communicated his choice of subject to the artists during the passage on the Venetian galleys or elsewhere on Italian territory; the execution of the mosaic would have been left to them. Beneš Krabice indicated that one part of the mosaic was completed as early as 1370,[27] so work on it must have been launched

FIGURE 2 Facade of S. Frediano Cathedral in Lucca, showing the Last Judgment mosaic that may have inspired Charles IV during one of his trips to Italy. Photo: D. Stulik.

fairly soon. The elaboration of the design was probably accomplished in the winter of 1369–70; in all likelihood, Venetian experts proceeded to Bohemia with the empress's party. They undoubtedly created the central panel of the mosaic, which thus would date it to 1370.[28] (See pls. 3, 9, 18.) The two side panels, somewhat more primitive in artistic expression, were probably completed in 1371[29] by local masters trained during the previous year.

The Prague mosaic, in addition to portraying an enthroned Christ with angels, apostles, or saints—frequent representations in Italian mosaics—also included the theme of the Last Judgment, not of heavenly Jerusalem. This combination may have been inspired, or at least supported, by Charles's reaction to the instability of the Italian situation, the constant convulsions and fights, and their inappropriateness before the majesty of Jesus Christ. The concept of the representation of the Last Judgment as such has local roots, and the opening of graves—as was previously indicated by J. Krása—has its predecessor in Vratislav's collection of evangelical texts.[30] It seems likely, therefore, that local masters not only were the executors of the two side fields but also created the designs pursuant to the emperor's order.

Charles's personal contribution to the mosaic went beyond the suggestion of the general theme; he seems to have been involved in the details as well. Here I refer to the incorporation of local motifs into the central field, where Czech patron saints and the imperial couple are portrayed instead of apostles and donors (which was entirely consistent with the concept of Roman mosaics), but also to the way in which the angels in the central field have been represented. They bear the instruments of Christ's martyrdom, but they are not separate beings standing next to Christ or surrounding him; they are part of the glow emanating from the figure of Christ, and as such they constitute a spiritual outgrowth of divinity. Such representation obviously drew on profound theological sources and reflected a learned and abstract mode of thinking—precisely the attributes associated with Charles IV. The concept for the angels might actually have been his; otherwise he could have chosen it from several suggested designs, in full awareness of its broader implications.

But he would not have been Charles if he had limited himself merely to the mosaic's spiritual significance, however sophisticated. The tableau was mounted directly above the entrance to the cathedral (see pl. 1), the place where all those entering were to remind themselves that they were approaching divinity and were to purify their minds. A counterpart to the mosaic was constituted by the emperor's annual public hearings held at the castle courtyard in front of the entrance to the Royal Palace. The first of these hearings took place in 1371,[31] when the central part of the mosaic was already finished and work was continuing on the Last Judgment fields. According to Beneš's report, the latter were probably completed in June of the same year.[32] This representation of a symbolic relationship between solemn imperial judgments and the Last Judgment—the rule of the Holy Roman Emperor and the rule of Christ—constitutes a second, entirely new level of the mosaic's theme, which had no precedent in the content of the earlier tableaus above church entrances. This new element could have been introduced only by the emperor's closest collaborators, or even more likely, by the emperor himself.

Finally, we should turn our attention to the mosaic's vera icon. It is depicted among verdure motifs placed above the enthroned Christ, atop the belt skirting all three fields. We know that a portrayal of the "true face" of Christ was brought by Charles IV from Rome on his second trip and that two more replicas were subsequently created in the Czech Lands.[33] The placement of this motif in the highest point of the mosaic appears to be the first Czech reaction to that picture (see pl. 18). It is also possible that the skirting belts linking all three panels may date back to 1371, while the central panel might have been originally (in 1370) extended farther upward, so that the image of divinity—Christ in a mandorla with angels emerging from its glow—appeared to be crowned with the human "true face." This, along with the Czech patron saints and the imperial couple, lent the entire scene the authenticity of godly presence on Earth.

The symbolic significance of the mosaic is a separate chapter that will be dealt with in its place (see chap. 3). It is clear, however, that the theme of the mosaic's central panel was a direct response to the last Roman journey of the emperor and his empress; this is evident both in the portraits of the imperial couple and in the placement of the vera icon. Charles's knowledge of Italy and of the circumstances in that country obviously influenced the overall concept of the mosaic. The combination of the Italian inspiration and Charles's extraordinary intellect and education, in concert with Czech tradition, led to the mosaic's emergence as a work embracing both a multilayered religious symbolism and the majesty of sovereign temporal power.

Notes

1. FRB IV, 541, 544.
2. Charles IV described his stay in Italy in his autobiography, *Vita Karoli quarti* (published most recently by J. Spěváček, with a translation by J. Pavel [Prague, 1978]); as for the principal syntheses, compare J. Šusta, *Král cizinec* (The alien king) (Prague, 1939), 539–73, and, by the same author, *Karel IV. Otec a syn* (Charles IV: Father and son) (Prague, 1946), 20–28; J. Spěváček, *Karel IV. Život a dílo 1316–1378* (Charles IV: Life and work, 1316–1378) (Prague, 1979), 82–104. For a summary of Charles's three sojourns in Italy, see W. Goetz, Italien, in *Kaiser Karl IV, Stoatsmann und Mäzen*, ed. F. Seibt (Munich, 1978), 212–16.
3. *Vita Karoli quarti, VII*, ed. Spěváček, 62–65.
4. Šusta, *Karel IV. za císařskou koruonu* (Charles IV: In the quest for the imperial crown) (Prague, 1948), 360–94; Spěváček, *Karel IV* (Charles IV), 235–43; F. Seibt, *Karel IV. Císař v Evropě 1346–1378* (Charles IV: An emperor in Europe, 1346–1378) (Prague, 1999), 230–36.
5. Johannis Porta de Annoniaco, *Liber de coronation Karoli IV. Imperatoris*, ed. R. Salomon, in *Monumenta Germaniae Historica*, Scriptores 35 (Hannoverae et Lipriae, 1913).
6. Brief references can be found in all comprehensive works, particularly in *Vom Mittelalter zur Reformation. Forschungen zur Geschichte der deutschen Bildung*, Bd. 2, *Briefwechsel des Cola di Rienzo* (From the Middle Ages to the Reformation: Research on the history of German culture, vol. 2: Cola di Rienzo's correspondence) (Berlin: K. Burdach–P. Piur, 1913–29), Bd. 4, *Aus Petrarcas aeltestem deutschen Schuelerkreis* (vol. 4: From Petrarch's oldest German scholars' circle) (Berlin: R. Kienast–K. Burdach, 1929); Bd. 7, *Petrarcas Briefwechsel mit deutschen Zeitgenossen* (vol. 7: Petrarch's correspondence with German cotemporaries) (Berlin: K. Burdach–P. Piur, 1933).
7. F. Seibt, *Karel IV*, 207–20.
8. Nicolò Acciaiuoli, as described by Johannis Porta in chap. 69, 112.
9. *Petrarcas Briefwechsel*, 41.
10. Published by A. Veselovskij, *Boccaccio, ego sreda I sverstniki II* (Boccaccio, his environment and contemporaries (St. Petersburg, 1894), 639–60.
11. On Zenobius, see a brief reference in N. Sapegno, Il Trecento, in A. Balduino, *Storia letteraria d'Italia* (Padua, 1981), 157.
12. Described in detail by G. Pirchan, *Italien und Kaiser Karl IV. in der Zeit seiner zweiten Romfahrt I–II* (Italy and Emperor Charles IV at the time of his second Roman journey I–II) (Prague, 1930); Spěváček, *Karel IV*, 257–58, with detailed references to other sources, among which the *Chronicle of the City of Lucca* by Giovanni Sercambi, beginning with 1368, is of crucial importance. About this *Chronicle*, see O. Pujmanová, *Halské pobyty Karla IV. v kronnikách Giovanniko Sercambiko* (Umění, 1987), 498–505. More recently, see F. Kavka, *Vláda Karla IV. za jeho císařství 1355–1378* (The reign of Charles IV as emperor, 1355–1378), pt. 2: 1364–1378 (Prague, 1993), 65–97.
13. In contrast to the first coronation journey, Charles no longer sent holy relics to the Prague Chapter together with accompanying documents. The relics are mentioned, however, in the treasury inventories and in the list of relics from Karlštejn Castle. Their detailed identification is provided by Pirchen, *Italien*, II, 183–85.
14. The so-called Golden Vernacle, kept in the treasury of St. Vitus Cathedral under Reg. No. K 317/235. The vernacle (vera icon) and its creation in connection with Charles's stay in Rome in 1369 was dealt with most recently by O. Pujmanová, *Il volto di Cristo, a cura di G. Morello e G. Wolf* (Milan, 2000), 181–82, with bibliographical data included.
15. Numerous references in Pirchan, *Italien*; see the index.
16. The appointment was made after the defeat of the rebellious Perugians (who were in league with adherents of the Viscontis) by imperial troops at Arezzo on June 18. In reality, however, the cardinal's vicariate extended only to Lucca and partly to San Miniato, and Perugia's defeat was only temporary: war broke out again one year later. The Modena peace virtually collapsed right after Charles left Lucca, as Florence and the Viscontis started fighting for San Miniato again. The long-standing rivalry and repeated clashes between local communities and powerful families made any peace impossible. Of all the arrangements accompanying the Modena peace, only those on Lucca's independence and on the university founded by Charles in that city survived.
17. Pirchan, *Italien*, 433.
18. The sovereign's return was described by Beneš Krabice, FRB IV, 540.
19. No evidence has been traced concerning the relic's whereabouts in the Czech Lands.
20. Particulars concerning Petrarch's relationship to the emperor during the journey are referred to in Pirchan, *Italien*; see the index.
21. The ultimate political effect of this sojourn, unlike that of the first coronation journey, was negligible. The Modena peace with Bernabò Visconti, negotiated so skillfully and for so long, fell apart even before Charles left Italy. The pope's return to Rome did not last either; after the untimely death of Urban V, the papacy continued in Avignon. Only the coronation of Charles's last wife, Elizabeth of Pomerania, as empress remained an irreversible fact. Even Lucca's extrication from Pisan rule resulted in a decline of the importance of that original Ghibelline bastion.
22. Pirchan: *Italien*, II, 119–20.
23. MVB III, No. 1045; Pirchan, *Italien*, II, 183–85, including references to the new relics being deposited in the Czech Lands as part of the treasury of the Prague Cathedral.
24. Charles did not visit Orvieto or other towns with a mosaic placed on an outer wall.
25. Similarly also in Kavka, *Vláda Karla IV*, II, 108. On the other hand, V. Kotrba, *Der Dom zu St. Viet in Prag, Bohemia sacra. Das Christentum in Böhmen 973–1973* (St. Vitus Cathedral in Prague: Bohemia sacra. Christianity in Bohemia, 973–1973) (Düsseldorf, 1973), 531, refers to a design for a mosaic by a Czech painter working at the imperial court, with only the execution left to Venetian masters.
26. Fig. 34 in *Kaiser Karl IV.*
27. Charles visited often the building of the castle in Lucca and there communicated to masters and builders his opinions and comments, according to Sercambi, cited by Pujmanová, *Halské pobyty*, 502.
28. FRB IV, 541.
29. FRB IV, 544.

30. According to an oral tradition of which I was informed by M. Kostílková, whom I also thank for many other inspiring conversations.
31. Kavka, *Vláda Karla IV*, 107. A report on a public court session held by the emperor in 1371 during the week before and after Easter was written by Beneš Krabice, FRB IV, 543.
32. The preceding report about the consecration of several altars was composed as of June 8, the next one as of June 22; FRB IV, 544.
33. Between 1370 and 1390 the so-called Sad Vernacle in the church treasury, Reg. No. K 99/237; and the St. Vitus Vernacle of 1400–1410. (The latter is better known.) On both works, compare most recently the articles by Pujmanová in *Il volto di Cristo*, 182–83.

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Zuzana Všetečková

Chapter 3
The Iconography of the Last Judgment Mosaic and Its Medieval Context

The Last Judgment mosaic ranks among the most extraordinary mosaic works of art north of the Alps. Our understanding of its iconography benefits from understanding the broader art historical and religious context of fourteenth-century Europe. The mosaic bears intriguing similarities to a number of contemporary works, primarily Italian, while also treating certain motifs in a slightly different manner. These unique motifs may be attributable to historical, religious, and art historical influences specific to the Czech Lands during the reign of Charles IV.

The chronicler Beneš Krabice of Weitmile reported in 1370, "Eodem etiam tempore fecit ipse dominus imperator fieri et depingi supra porticum ecclesiae Pragensis de opere vitreo more greco, de opere pulchro et multum sumtuoso" (At that time the emperor had a glass image made in the Greek manner and set in the facade above the porch of the Prague Cathedral, a splendid and very costly work). (See chap. 1, fig. 1.) The following year, he wrote about the work's completion: "Eodem anno perfecta est pictura solemnis, quam dominus imperator fecit fieri in porticu ecclesiae Pragensis de opere Mosaico more Greacorum, quae quanto plus per pluviam abluitur, tanto mundior et clarior efficitur" (This year, a festive tableau has been completed above the portal of the Prague Church, at the wish of our Lord Emperor, in the form of a Greek-style mosaic, which gets cleaner and brighter each time it is washed by rain). According to another chronicler, also writing in 1370: "The Emperor wanted to show the splendor and glory of his Bohemian Kingdom, as princes, monarchs and aristocrats from all over the world came to visit him. This is why he had two towers of the Prague royal castle covered with gilded lead, so that, in clear weather, the towers shone and glistened at a long distance."[1]

Most literature on the mosaic has tended to deal with its style, which was closely related to that of mosaics in Italy, notably Venice, Florence, and Rome[2] and the more recently studied Orvieto, accounts of which have survived from the period 1321–90, when the mosaic on the west facade of the Orvieto Cathedral was installed.[3] The iconography of the Prague mosaic is reminiscent of the earlier Last Judgment in St. John the Baptist's Baptistery in Florence; the Last Judgment by Giotto in Padua; the mural painting in San Angelo in Formis; and the Last Judgment in Santa Maria Maggiore Church in Tuscania.[4]

Stylistically, certain analogies can also be found in the mural paintings in the cloister of the monastery Na Slovanech, particularly in the ornamentation featuring diamonds and vegetal tendrils, which survive in the paintings of the south and east wings and which, as we shall see, are important elements of the Last Judgment mosaic (figs. 1–5). There are common features in the faces as well, as in the scene of the Falling of Manna. The nudes of the figures in the cloister are also of interest, particularly those of Christ, Adam, and Eve. Similarities can also be seen in the mural paintings in the staircase cycles at Karlštejn Castle, where Italian masters were likely to have worked.[5]

The Prague mosaic on the Golden Gate is divided into three bays, or panels, separated by slim pinnacles, decorated with vegetal tendrils growing out of vases (see pl. 3). The upper part of the central panel depicts Christ in majesty according to Matthew 25:31 and 16:27. Christ is rendered both as the Son of God come in glory, which is emphasized

FIGURE 3 (ABOVE) The cloister of Na Slovanech monastery, Prague. Detail from the Collection of Manna scene, wall painting, turn of the 1360s. Photo: Z. Všetecková.

FIGURE 4 (BELOW) The cloister of Na Slovanech monastery, Prague. Expulsion of Adam and Eve from Paradise; detail of a Good Friday scene, wall painting, turn of the 1360s. Photo: Z. Všetecková.

FIGURE 1 (ABOVE) The cloister of Na Slovanech monastery, Prague. Detail of the decoration strip with diamonds, wall painting, turn of the 1360s. Photo: Z. Všetecková.

FIGURE 2 (BELOW) Na Slovanech monastery, the former imperial chapel, Prague. Detail of the decoration strip with diamonds and inserted emblems, wall painting, second half of the fourteenth century. Photo: Z. Všetecková.

FIGURE 5 The cloister of Na Slovanech monastery, Prague. Descent of Christ into Hell and the Delivery of the First Parents; detail of a Good Friday scene, wall painting, turn of the 1360s. Photo: Z. Všetecková.

by sun rays symbolizing *Sol iustitiae*, and as the Son of Man, with wounds in the side, on the hands, and on the feet, seated on two rainbows, which symbolize both the Old and the New Testament. The usual frontal rendition is accompanied by less common gestures of the hands, in which the right, freely hanging along the body, is meant to express the words "Come, ye blessed of my Father, inherit the kingdom" (Matt. 25:34); the uplifted left signifies "Depart from me, ye cursed, into everlasting fire" (Matt. 25:41).[6]

Christ's mandorla—the almond-shaped section in the central bay—is carried by five angels on each side: two seraphim above; three pairs of angels in the center to hold the Instruments of Passion, or Arma Christi; and two at the bottom to blow the trumpets (see pl. 9), which, according to Psalm 98, herald the Last Judgment. The angel at bottom left carries the cross and the crown of thorns, and the ones above him hold the spear and tongs—the implements that relate unequivocally to Golgotha. The angel at bottom right carries the pillar and the scourge; the one above him holds the hammer and the nails; and the highest has the sponge. These angels are also noteworthy for their garments, in particular, the central ones, who wear stoles like priests (see pl. 10). Below the mandorla the Bohemian patron saints kneel in prayer: Procopius, Sigismund, Vitus, Wenceslas, Ludmila, and Vojtěch (Adalbert) (see pl. 11). Below them their names are inscribed; and below the inscription, flanking the central arch, kneel Emperor Charles IV and Empress Elizabeth of Pomerania, also in prayer (see pls. 12, 13).

The Last Judgment is composed of the traditional Deesis, in which arrangement Christ is shown flanked by the Virgin and St. John the Baptist. Here, in the left panel the Virgin Mary (see pl. 14) and in the right panel St. John the Baptist (see pl. 15) kneel in prayer, each of them facing the central Christ. Alongside each is a group of six apostles. Below Mary the dead are being resurrected; angels help lift them from their tombs (see pl. 16). Below St. John the Archangel Michael, in armor and brandishing a sword, drives away sinners, who are bound with rope and are being pulled by devils into fiery hell, ruled by the bound Lucifer (see pl. 17).

A decorative strip once lay atop the Last Judgment composition proper, but only a small diamond-shaped panel with the vera icon—the "true face of Christ"—and surrounding vegetal ornament have survived (see pl. 18). As late as the nineteenth century another diamond could still be seen on the right above the window, depicting three nails. In earlier photographs dating from before the mosaic's removal in the late nineteenth century, another diamond can be seen above the left pinnacle. We can surmise that a spear might have been represented above the left window, a conjecture borne out by an 1837 description by Eduard Gurk, according to which "all the three bays are lined with a strip of green and red arabesques against a yellow background, between which there are distributed the tools of passion." This is corroborated by Vincent Morstadt's print, dating from about 1840 (see chap. 7, fig. 7), and the view of St. Vitus Cathedral from the south published by August Ambros in 1858.[7]

The representation of Christ the Judge with five wounds corresponds to Western mysticism and the popular fourteenth-century feast of Quinque vulnera Christi. According to Thomas Aquinas, the scars on Christ's body were a sign not of his weakness but of his superior power, allowing people to understand that his torture had led to his glory and to our subsequent redemption.[8]

The angels with the instruments of passion who surround the mandorla in the scenes of the Last Judgment have been discussed by several scholars. Beat Brenk treats this subject in his analysis of the Last Judgment of the church in Müster, which dates from the eighth century. Similarly, the Arma Christi in the Last Judgment has been studied in detail by Gertruda Schiller, who cites the Venerable Bede and the inscription above the Last Judgment in the Klosterneuburg altar, which reads as follows: "Those for whom I have suffered shall see me, whose judge I now am."[9] Czech literature gives us the "Sermon on the Last Day of the Lord" by Jan Milíč of Kroměříž.[10] A number of scholars have cited other Last Judgment compositions of this type surviving in, for example, St. John the Baptist's Baptistery in Florence; the apse mosaic of S. Michele Church in Affricisco (now in the Boden Museum in Berlin); and the wall paintings in S. Angelo in Formis. Another very similar composition, by Giusto de Menabuoi in Viboldone, dates from about 1350.[11]

The ornamental strip with diamonds lined with a decorative pattern, meanwhile, is common in fourteenth-century Italian painting, especially in the regions of Siena and Florence. Among the representations of the Arma Christi in monumental painting—as in the mural paintings dating from the early fourteenth century in the church in Spitz, Lower Austria (fig. 6)—their placement on the upper strip is of interest. The vera icon is also located in the center of the upper decorative cornice of the mural paintings in Goldegg im Pongau church (Salzburg),[12] dated from the 1340s. In Bohemia, the vera icon was placed at the top of the niche in St. Catherine's Chapel at Karlštejn Castle, at the top of the arch of the north portal of Týn Church, and above the entrance to the St. Wenceslas Chapel in St. Vitus Cathedral.[13] According to Václav M. Pešina's description, the vault was decorated with angels who carried the Arma Christi, as well as with the Bohemian patron saints.[14] We cannot ascertain the date of the decoration, however, for Antonín Podlaha conjectures a later date for the vault of St. Wenceslas Chapel.[15]

The Prague mosaic is exceptional in its double representation of the Arma Christi motif, which here is depicted in the upper ornamental strip, now partially missing, as well as in the seraphim flanking the Christ mandorla. The popularity of the Arma Christi in Bohemia in the late fourteenth century might be traced to several factors. It was doubtless related to older tradition, which in Bohemia was well

FIGURE 6 Spitz, Erlahof (Austria). Arma Christi in the upper strip, wall painting, ca. 1310. Reproduction: Vlado Bohdan.

described in the Passional of the Abbess Cunigund, in a tale written by a Dominican named Kolda, titled "A Brave Knight." This story explains the Arma Christi accompanying the Man of Sorrows, and Kolda describes at some length how Christ was roped to a pillar and flogged. He then points out the Coronation with the Crown of Thorns, which accompanied Christ to the highest station of the Cross. Kolda also refers to the spear with which one of the soldiers pierced Christ's side, thus releasing water and blood. He was nailed to the throne (cross) with hammers. The nails, as Kolda emphasized, caused five wounds. In the moment of death, the Savior asked for a drink and was offered a sponge suffused with vinegar. After Christ died, when his spirit had already left the body, "the nails were taken out with tongs."[16] The Dominicans developed the Passion mysticism with particular intensity, in many aspects following the works of Thomas Aquinas, who is often mentioned in relation to Charles IV.

In addition to older tradition, the importance of this motif in the Prague mosaic may reflect more recent influences as well. According to a report of February 13, 1354, Pope Innocent VI ordered the Prague archbishop and his bishops to announce in their dioceses that at the request of Charles IV, he was establishing the Feast of the Lord's Spear and Nails in all the German and Czech Lands, to be celebrated on a Friday, eight days after the Resurrection. He also granted indulgences to all those penitents and believers who would visit a church or chapel, where these holy remains were kept, on that day.[17] This document may have related to Karlštejn, but the feast must also have been celebrated in the Prague Cathedral, in the presence of Archbishop Ernest of Pardubice. After his death in 1364, he was succeeded by Jan Očko of Vlašim, who had been the bishop of Olomouc since 1351 and who, according to the chronicler Beneš of Weitmile, "had a new chapel consecrated on July 7, 1370, recently built at the Archbishop's Court in the Lesser Quarter of Prague to commemorate the Arma Christi."[18] Another respectable source is the recording of the Officium of this new feast in the Liber Viaticus of Jan of Středa.[19] According to Gustav Friedrich, the feast would have been called Armorum Christi festum (the Feast of the Arma Christi), celebrated on the Friday after Quasimodo Sunday.[20] In his inventory of the relics in St. Vitus Cathedral connected with the Rood Day (May 3), Tomáš Pešina of Čechorod names the relics of the Holy Cross, which Emperor Charles IV acquired in Trier and inserted in a cross. This was then shown with other holy relics related to the Lord's Passion and exhibited on the Feast of the Arma Christi.[21]

That the mosaic actually featured a double representation of the Arma Christi—in the angels surrounding the mandorla, which echoed earlier representations of the Last Judgment with the Arma Christi, and on the upper decorative strip—probably related to the new feast introduced by Charles IV in 1354 and to the well-known officium, "Christ's Face."[22] The question can certainly be raised whether this strip was also related to the exhibition of the relics, which in Viktor Kotrba's view were shown to the assembled people during important ceremonies, together with the royal insignia.[23] Kotrba speculated that the terrace balustrade platform above the Golden Gate and the west part of the St. Wenceslas Chapel in the south arm of the transept was accessible by a spiral staircase from the Crown Chamber, the so-called New Sacristy, and was to serve as a stage for showing the Bohemian coronation jewels and holy relics, which included St. Wenceslas's remains and "Arma sancti Wenceslaii." The exhibition of the relics took place especially during the years when special indulgences could be granted. In the Czech Lands, this was in 1368, when the porch of the Golden Gate was consecrated—but, judging from the reports by Beneš Krabice, it was still without the mosaic.[24]

If the ornamental strip contained at least five diamonds, it is possible to conjecture that in addition to the central representation of the vera icon (whose image Charles IV brought from Rome in 1355), the nails (which were situated above the right-hand bay), and the probable spear (above the left), the crown of thorns may also have been represented, for we know that Emperor Charles IV owned at least two of the thorns of the crown. In view of the famous relic scenes at Karlštejn Castle (fig. 7), the representation of the sponge may also be conjectured. Other tools might have included the rope with which Christ was scourged and whose relic was placed in the St. Vitus Cross, together with two fragments of the Holy Cross wood, a nail, spear, sponge, and other important relics.[25] The respect that the emperor accorded the Passion relics can be seen in the 1350 indulgence documents, in which a request is expressed to grant indulgences, so that on feast days it would be allowed "to show all the people one of the nails with which the Savior was crucified, and the spear with which his side was pierced, and some other relics of the same Savior."[26] Pope Innocent VI's granting of indulgences for the Feast of the Spear and Nails, already quoted from above, followed in 1354.[27]

FIGURE 7 Karlstejn Castle, capitular church of the Virgin Mary. Relic Scene—Charles IV depositing the cross with a sponge and thorns into the Cross of the Kingdom of Bohemia, wall painting, 1357. Photo: Z. Všetecková.

The iconographic importance of the instruments of Christ's suffering is also expressed in the twelfth-century reliquary from St. Croix in Lüttich.[28] The reliquary triptych contains the relics of the Holy Cross, kept in the cross in the central part, with the inscription LIGNŪ VITĒ in the background. The framed cross is held by two standing angels, beneath whose hands appear some of the Arma Christi, the most evident being the nails and the vinegar vessel. In a semiarch above the central composition is the half figure of Christ the Judge, with the inscription IHS CHRS. The representation shows Christ risen from the dead as the Son of Man, who is coming on the Last Judgment day. Below the angels, the patron saints are represented in an arch, with the inscription *resurrectio sanctorum* above them. Lateral representations show pairs of apostle half-figures, marked by names and rendered in dialogue. Their presence is reminiscent of the composition of the St. Vitus mosaic, although this reliquary does not show the apostles as representing the typical tribunal, which was common in the thirteenth and fourteenth centuries.

Charles IV doubtless wanted to show believers and visitors to Prague a representation made in an ancient manner, described by the chronicler as "opus graecorum," which refers to a technique usually applied in decorating Italian and Byzantine churches. As can be judged from period mural paintings, the eschatological meaning of the Last Judgment, a typical subject for the sculpted tympani of cathedrals, was extended by the new "public" devotion to the relics of the instruments or tools of the Lord's Passion. Given that it was because of the construction of the mosaic that the original lighting of the Crown Chamber changed from three to two windows and that it was behind the mosaic that the most valuable relics and royal insignia were kept, it might be concluded that the Crown Chamber might have served also as a reliquary housing objects relating to the Last Judgment theme that had earlier been inaccessible to the general public. The importance during this period of paying respect to the Arma Christi, which Charles IV was so keen on assembling, together with the introduction of the Feast of the Spear and Nails in 1354, could have been the determining factors for the unusual double representation of the Arma Christi in the Prague mosaic.

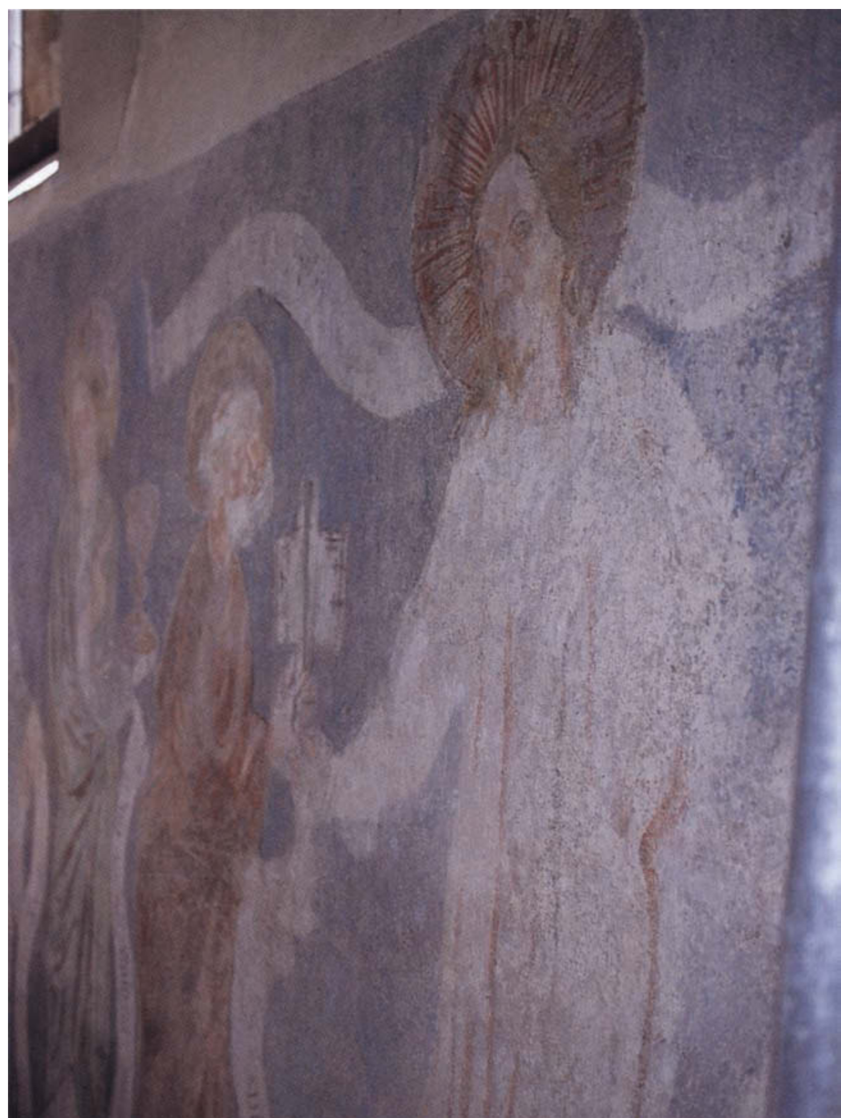
Among the apostles represented in the left bay, St. Peter is the first in the bottom row. In his right hand, he holds the key to the heavenly kingdom, which is also the sign of papal power; in his left hand rests the cross. (See

FIGURE 8 Pilgrimage emblem with St. Peter and the Kneeling Charles IV. Prague, Municipal Museum, second half of the fourteenth century.

pl. 7.) (In "The Power of the Keys," Thomas Aquinas says that the key represents the mystical body of Christ and that in St. Peter's hand it is a symbol of his power as an ecclesiastical judge to receive the good and reject the evil.)[29] St. Peter with the key and cross is also represented on the left in the pilgrimage emblem, now in the Museum of the City of Prague, and the kneeling and praying Emperor Charles IV is depicted in front of the Holy Spear on the right (fig. 8). The pilgrimage emblem could express the emperor's relationship to Rome or to the Vysehrad Chapter and its Church of St. Peter.[30]

Next to St. Peter, the half-figure of St. John the Evangelist, with a chalice in his hand, can be seen. Charles IV had a close affinity to the Gospel According to St. John, which is evident in the St. Wenceslas Chapel: two Crucifixions are represented there on the east wall.[31] In Charles's works, both the texts of St. John's Gospel and the Apocalypse are often quoted. St. Peter and St. John were the first of the apostles who saw the empty tomb after Christ's Resurrection, and they informed the other apostles of the fact. It is thus interesting that these two apostles can be found in the immediate vicinity of the standing Christ, who in the Church of St. Apollinarius in Prague (fig. 9)[32] hands the keys to St. Peter, standing among other apostles carrying the Credo inscription ribbons.[33] Jaromír Homolka related this depiction to Archbishop Jan of Jenštejn and his tract "De potestate clavium."[34]

FIGURE 9 Church of St. Apollinarius, Prague. Christ Handing the Keys to St. Peter, wall painting, after 1380. Photo: Z. Všetecková.



The six kneeling and praying patron saints and intercessors for the kingdom of Bohemia can be seen below the mandorla—Sts. Procopius, Sigismund, and Vitus on the left, Sts. Vojtěch (Adalbert), Ludmila, and Wenceslas on the right. Their garments and physiognomies fully correspond to traditional iconography. They kneel on a prismatic brown platform, reminiscent of landscapes characteristic of Italian painting and known from the earlier panel painting of the Master of the Altar in Vyšší Brod. A band below them inscribes their names, but its authenticity is in question, for it could have been reconstructed by Václav Hanka during the repairs of 1837. The choice of the Bohemian patron saints is closely related to the cathedral, which had always been consecrated to the Virgin Mary and Sts. Vitus, Wenceslas, and Adalbert. Respect was also paid to St. Ludmila and St. Procopius by Bishop Jan IV of Dražice.[35] At a synod held on October 17, 1365, Jan Očko of Vlašim added the feast of the King of Burgundy, St. Sigismund, whose relics Charles IV had acquired and which were taken to Prague on August 28, 1365.[36]

According to Brenk, those who commissioned the representation of the saints at the Last Judgment wanted to be buried in the vicinity of the saints' tombs, so that the saints could intercede for them.[37] He quoted, among others, St. Augustine and his *De civitate Dei*, the last two chapters of which, on the Last Judgment, say that merciful God heeds the requests and intercessions of his saints: "For if they prayed for them when they had to bear their persecution, the more they will pray for them when they see them humble and praying on their knees. The saints will pray for their charges all the more when they are free from any sins."[38] Here we can quote Thomas Aquinas again, who says that the saint's prayer is said doubly, as both an express request and a request interpreted. Both kinds of prayer are efficient, as the saints turn to their supreme ruler with wishes likely to be heard.[39]

The lower half of the left panel (see pl. 6) shows a monumentally treated Resurrection of the Dead from the tombs, assisted by the elaborately rendered Archangel Michael in the middle, with two other angels on the right and left of him, who are treated in a less sumptuous manner. They help with the bodily resurrection of the individuals with whose protection they were charged. The space allotted to the representation of the Resurrection of the Dead from the sarcophagi is especially interesting in the horizontally placed tombs and above all in the nudes of the dead. The group of the saved, to whom St. Michael bends, includes a woman, which was rather rare. She has long hair and covers her breasts with her crossed arms. This image of the Resurrection derives from Isaiah 26:19, "The dead men shall live," whose text was taken over by St. Augustine. Like Thomas Aquinas, this saint, in *De civitate Dei*, expressed no doubts about the bodily resurrection.[40]

In the right panel, Archangel Michael drives a group of figures into hell with a gesture of his right hand. (See pl. 4.) He is depicted as a knight in a tight-fitting skirted coat, inlaid with green gems of varied color intensity, from under which white sleeves protrude. His narrow red hose ends in footwear suggested by a strap. A short blue-and-red mantle with a circular clasp below the throat billows in the windstorm of the Damnation. Certain analogies can be traced to the St. Michael in the Campo Santo in Pisa. St. Michael armed with a sword can rightly be considered a knight reflecting the angelic hosts at God's throne; he forces before him a group of figures bound with rope and drawn by two devils into hell. The damned turn for a last look at their Judge, who has definitively condemned them after having considered their sins. This central strip of figures consists mainly of men, all of whose physiognomies are distinctly varied. (This was clearly an effort by the master to treat them as portraits.) Above a praying, tonsured monk among the sinners on the left, however, we find a woman with a cloth on her head, rendered in profile, with carefully drawn features and a deep line near her mouth. Below her we see two other men whose faces are equally distinct; above her a man lightly bends his head backward. Darker shades are used to treat the features of the cheeks, particularly the mouths. The figures awaiting damnation display almost naturalistically treated faces, which corresponds to the 1370s style. Among the damned, the mosaic maker rendered one other woman in profile. Her head is also covered with a cloth, but in addition she holds a round mirror in her hand, symbolizing vanity. This group may be deliberately suggesting that the damned reconsidered the evil they had done. Their faces express the fear of torture that awaits them, for through their deeds they have forfeited the supreme good they might have achieved; but there is something in their gazes (especially those turned not only to St. Michael but also to Christ's beatific glory) that suggests painful envy. Dread now possesses them. Nevertheless, the presence of the saints and intercessors is a certain guarantee that those who are most loved by God pray for divine mercy to be granted even the damned, who can thus hope they will be freed from their punishment.[41]

The group bound by rope is drawn by two devils. The meaning of the image can be interpreted through Charles's autobiography (*Vita Caroli*), in which he quotes Psalm 119:61: "The bands of the wicked have robbed me: but I have not forgotten thy law."[42] The devils lead the damned to Lucifer, seated on a simple throne in a dark blue hell filled with red flames. Like Lucifer, the devils have part-human, part-animal forms; their wolf's heads, white fangs, pointed ears, and horns are of particular interest. Lucifer, hell's monarch, sits motionless among the flames and watches the sinners. His bound hands and the chains around his throat and waist can be explained from the Apocalypse (Rev. 20:1–2): "And I saw an angel come down from heaven, having the key of the bottomless pit and a great chain in his hand. And he laid hold on the dragon, that old serpent, which is the Devil, and Satan, and bound him a thousand years." According to Isaiah 14:12, this is the fallen angel Lucifer, whose hell is located in a crater under the ground, in which flames flicker, announcing the future torment. Though Dante's hell has been mentioned by scholars in this connection, it was unquestionably not the literary model. We propose a simpler work, such as "George's Vision," in which St. George is guided around purgatory, hell, and paradise by St. Michael.[43]

A recent article by Barbara Lane is very useful for explaining why the Last Judgment mosaic was set in the Golden Gate. She has related the Last Judgment by Rogier van der Weyden to its liturgical context and interpreted it as a link to a mass for the dead.[44] In this sense, the mosaic could be understood not only as the emperor's request for the salvation of his soul and that of his wife, Elizabeth of Pomerania (both of whom are represented as praying below the composition of the Last Judgment), but also for the salvation of all the saints buried in the cathedral (Sts. Wenceslas, Vitus, Adalbert, and Sigismund), the Przemyslid monarchs (whose tombstones were later executed by Peter Parleř), the previous wives of the emperor, and the clergy. Archbishop Jan IV of Dražice, like a number of his predecessors, was buried in the former St. Vitus Basilica, while the second Prague archbishop, Jan Očko of Vlašim, established the Chapel of Sts. Erhard and Otilia in the south part of the cathedral's choir, where he was also buried in 1380. It perhaps remains to add that Archbishop Očko commissioned the votive panel in which Charles IV is represented, along with Wenceslas IV, the Virgin Mary, and six Bohemian patron saints.[45] The idea of a link between the Last Judgments and a mass for the dead was also suggested by K. Werckmeister in his interpretation of the west portal of the Autun Cathedral, which overlooks the graveyard.[46]

In its program, the Golden Gate could have been modeled after the early Christian mosaic with Christ in the mandorla located above the triple entrance to the atrium of the Marian oratory in S. Maria in Turri, built outside the Romanesque entrance to St. Peter's in Rome.[47] The Marian oratory was an important place where the pope and the emperor met during the ceremonial coronation proceedings and in which ceremonial trials were held. It is probable that the Prague mosaic was thus related to the Bohemian Coronation Order dating from 1348 and compiled by Charles IV. All the coronations of Charles IV, however, took place before the mosaic was executed.

It therefore seems more probable that the mosaic was related to ceremonial royal trials, which, according to the chronicler Beneš Krabice of Weitmile, took place as early as 1368. In recent years, a report recorded in 1371 has frequently been quoted to the effect that the monarch in person chaired the court proceedings held during the week of Christ's Passion, the week after Easter, and the time following that, at the front gate to the royal court at the Prague Castle. He himself heard and judged the cases of his subjects, orphans, and widows, and doing justice without harm and delay to any complainant, he left a great and memorable example to his heirs and successors.

Monarchs were not to refer cases to other people but were to try and hear them themselves and decide according to the law.[48] The chronicler's report responds to the Bohemian legal code, Maiestas Carolina, which included constitutional, penal, trial, and private laws. The code was applicable to Bohemian subjects only. In his introduction, probably conceived according to Fridrich's code of the Sicilian Constitutions, Charles IV drew on the notion that the ruler is the exclusive source of law, the main administrator of the country, and its only judge, a notion in complete contradiction to the traditional dual concept in the Czech Lands.[49] He drew on Thomas Aquinas's doctrine of the origin of the state, according to which God created man "to his image and own appearance and made him a little inferior than an angel, but superior to all the other creatures." Abusing his free will, man caused his own fall. People became angry and malevolent. The ownership of property, "which according to natural rights was to be common, was divided, they started stealing and robbing each other, then wars broke out, bringing troubles and other evils of human misery." "Thus, under the pressure of necessity and by an impulse of divine providence, rulers of nations were established, to prevent criminals from committing crimes and to guarantee security to the peace-loving and peaceful, to set up laws and rights and to decide everything according to legal order; to settle future cases after having considered the complainants and their disputes." What is remarkable is the first argument, which justifies the ruler's power rationally; the divine origin comes second. Grounded in these authorities (Thomas Aquinas and the Sicilian Code of Fridrich II), Charles IV set to work on a new legal code, emphasizing the fact that he became the heir of the kingdom of Bohemia by divine favor. The ruler gives laws, but he himself stands above them (*legibus solutus*), "being authorized to judge people subjected to him, yet never being judged himself" (sec. 42). At the same time, Charles IV conceded that a good custom was "bound by the laws of the country." The kings had power from God over the believers, and by their anointment they were sanctified to the art of judging. Human judgment was to imitate God's judgment in clear-cut cases. This may have been one of the ideas that led Charles IV to choose the subject of the Last Judgment for the sumptuous mosaic above the portico of the ceremonial entrance to St. Vitus Cathedral.

Notes

1. *Kroniky doby Karla IV* (Chronicles of Charles IV's time, ed. M. Bláhová) (Prague, 1987), 243, 244. Latin text from Fontes Rerum Bohemicarum IV (J. Emler) (Prague, 1884).
2. Antonín Matějček, Das Mosaikbild des Jüngsten Gerichtes am Prager Dome, *Jahrbuch des Kunsthist. Institut d.k.k. Zentralkommission für Denkmalpflege* 9 (1915):106–39; Josef Krása and Josef Němec, Svatovítská mozaika. K restauraci obrazu Posledního soudu na jižním portálu katedrály (The St. Vitus mosaic: The restoration of the Last Judgment image on the south portal of the cathedral), *Umění* 8 (1960):374–86; Lionello Puppi, Il Giudizio e l'empero: Sul mosaiko della porta d'oro di S. Vito a Praga, *Arte Veneta* 33 (1979):9–18; Karel Stejskal, Klášter Na Slovanech, pražská katedrála a dvorská malba doby Karlovy (The monastery Na Slovanech, the Prague Cathedral, and the court painting of Charles IV's time), in *Dějiny českého výtvarného umění* 1/1 (Prague, 1985), 334–35.
3. Catherine Harding, *The Production of Medieval Mosaics: The Orvieto Evidence*, Dumbarton Oaks Papers (1989), 73–102.
4. The descriptions by Eduard Gurck, August Ambros, Josef Mokr, and Antonín Podlaha remain iconographically important. Eduard Gurck, Mosaika na polednj straně chrámu sw. Wjta w Praze (The Mosaic on the south side of St. Vitus Cathedral in Prague), *Časopis pro katolické duchovenstvo* (1837): 504–10; August Ambros, *Der Dom zu Prag* (Prague, 1858), 272–76; Josef Mokr, Obrazy mosaikové (Mosaic images), *Časopis katolického duchovenstva* 24 (1883), vol. 4, 193–99; Antonín Podlaha, Mosaikový obraz na chrámu svatovítském (The mosaic image on St. Vitus Cathedral), *Památky archeologické* 21 (1904–5):220–28; Zuzana Všetečková, Monumentální středověká malba (Monumental medieval painting), in *Katedrála sv. Víta v Praze*, ed. A. Merhautová (Prague, 1994), 96–104.
5. Selected works on the paintings in the monastery Na Slovanech in Prague: Joseph Neuwirth, *Die Wandgemälde im Kreuzgange des Emausklosters in Prag* (Prague, 1898); Emanuel Poche and Jan Krofta, *Na Slovanech* (Prague, 1956); Karel Stejskal, *Klášter Na Slovanech* (Prague, 1974); Zuzana Všetečková, Gotické nástěnné malby v křížové chodbě klástera Na Slovanech (Gothic wall paintings in the cloister of the monastery Na Slovanech), *Umění* 44 (1996):131–48.

   As concerns Karlštejn Castle, the staircase cycles describing the legends of Sts. Wenceslas and Ludmila were restored in 1996–2001 by Petr Bareš and Pavel Brodsky, who managed to remove the late-nineteenth-century overpainting and in many places uncover the original paintings dating from the early 1370s. The staircase cycles were described by Vlasta Dvořáková, Karlštejnské schodištní cykly. K otázce jejich vzniku a slohového zařazení (The Karlštejn Staircase Cycles: Their origin and style), *Umění* 9 (1961):109–71.
6. These unusual gestures also appear in the composition by Lorenzo Maitani on the sculpted front of the Orvieto Cathedral. John White, The reliefs on the facade of the Duomo at Orvieto, *Journal of the Warburg and Courtauld Institutes* 22 (1959):253–302; Michael Semff, Textiler Festschmuck in Stein? Überlebungen zu den Orvietaner Fassadenreliefs, *Münchner Jahrbuch d. bildenden Kunst* 38 (1987):83–106; Wolfram Pichler, Der Dom von Orvieto als Residenz und Reliquiar. Baupolitik und Bedeutungswandel in der Genese eines Städtischen Monuments, *Wiener Jahrbuch für Kunstgeschichte* 49 (1966):137–63.
7. See citations in note 4, above.
8. Tomáš Akvinský, *Teologická Summa*, ed. E. Soukup (Olomouc, 1990), 636; Robert Suckale, Arma Christi. Überlegungen zur Zeichenhaftigkeit mittelalterlicher Andachtsbilder, *Städel Jahrbuch* NF 6 (1977):177–208. See, more recently, Nigel Morgan, Longinus and the wounded heart, *Wiener Jahrbuch für Kunstgeschichte* 47–48 (1993–94):507–18.
9. Beat Brenk, *Tradition und Neuerung in der christlichen Kunst des ersten Jahrhunderts*, Wiener byzantinische Studien 3 (Vienna, 1966), 134; Gertruda Schiller, *Iconography of Christian Art* II (London, 1974), 206–7.
10. "My Lord, judge those who do me harm, overcome them, attack them, grasp arms and a shield. And in that very moment all the signs of the tools with which Christ was tortured, namely the cross, nails, spear and the crown, all that will be shown by the Judge at the Judgment. This is why Bernard says, What can be your answer when your conscience speaks against you, the elements indict you, Christ's cross is held against you, the wounds speak, the nails howl, the scars give evidence, as Chrisostomus says. Thus will they reproach you, I became a man for you, I was killed, slain on the scaffold of the cross.

This is the revenge for my blood. And then all the land shall cry." Miloslav Kaňák, *Milíč z Kroměříže* (Prague, 1975), 109–19.

11. Irene Hueck, Das Programm der Kuppelmosaiken im Florentiner Baptisterium, Diss. thesis, Munich, 1966; Michael V. Schwarz, Die Mosaiken des Baptisteriums in Florenz und die Florentiner Malerei von Giotto (Hab. Thesis, Freiburg, 1990); Iris Grötecke, *Das Bild des Jüngsten Gerichts* (Worms, 1997). See, more recently, Robert Suckale's extensive study of the Last Judgment: Die Weltgerichtstafel aus dem römischen Frauenkonvent S. Maria in Campo Marzio als programmatisches Bild der einsetzenden Gregorianischen Kirchenreform, in Robert Suckale, *Das mittelalterliche Bild als Zeitzeuge* (Berlin, 2002), 12–122.
12. Elga Lanc, *Die mittelalterliche Wandmalereien in Wien und Niederösterreich* (Vienna, 1983), 286–87; F. Walliser, Die Entdeckung und Sicherung eines gotischen Wandgemäldes in der Pfarrkirche von Goldegg im Pongau, *Österreichisches Zeitschrift für Kunstgeschichte und Denkmalpflege* (1967):27–31.
13. Ivo Kořán, Gotické Veraikony a Svatolukášské Madony v Pražské katedrále (Gothic vera icons and St. Luke Madonnas in the Prague Cathedral), *Umění* 39 (1991):286–316.
14. Václav M. Pešina z Čechorodu, *Stručné popsání Pražského hlavního chrámu sv. Víta* (A brief description of Prague's St. Vitus Cathedral) (Prague, 1868).
15. Antonin Podlaha and Kaunie Hilbert, *Soupis památek uměleckych a historickych. Metropolitní chrám sv. Víta v Praze* (A list of art and historical monuments: Metropolitan Church of St. Vitus in Prague) (Prague, 1906), 35–41, fig. 56.
16. Pavel Špunar, *Frater Colda ordinis praedicatorum. Tractatus Mystici* (Mystical treatises) (Prague, 1997), 25 ff.
17. Quoted by Libor Gottfried in his catalog accompanying the exhibition Magister Theodoricus: Libor Gottfried, Výběr archivních pramenci k historii hradu Karlštejna a jeho umělecké vyzdoby (Selected archival sources for the history of Karlštejn Castle and its artistic decoration), in *Magister Theodoricus. Dvorní malíř Karla IV*, ed. J. Fajt (Prague, 1997), 37 ff.
18. Beneš Krabice z Weitmile, *Kroniky doby Karla IV* (Chronicles of Charles IV's time) (Prague, 1987), 242.
19. His text could even have served as a source for the decoration of the upper strip, for Quido Maria Dreves, "In festo s. Lanceae," notes, "Tibi dedit rex virtutis, Suis de vulneribus, clavos, lanceam et crucem, Haec sacra magnalia. . . . Tres clavos cum lancea Sole clariores, Michael tunc afferet contra peccatores. Sempiterna gaudia Christus tunc donavit, cum clavis et lancea mortem superavit" (The King gave you valor, you live off your wounds inflicted by the ails, spear and cross, being very sacred. . . . The three nails and spear are brighter than the sun and will be used by Michael against the sinners. Christ gave you eternal joy, having conquered death with the nails and spear). Quido Maria Dreves, *Analecta hymnica madieva* V (Leipzig, 1889), 35–36, no. 7.
20. Gustav Fridrich, *Rukovĕt Křestanské chronologie* (A manual of Christian chronology) (Prague, Litomyšl, 1997), 34–35.
21. Tomáš Pessina z Czechorodu, *Swatych Tel Ostatkŭw Reliquigi* (The holy relics) (Prague, 1673).
22. Quido Maria Dreves (note 19), vol. 4 (Leipzig, 1888), 24–25.
23. Viktor Kotrba, Architektura (Architecture), in *České umění gotické 1350–1420* (Prague, 1970), 56 ff.
24. Beneš Krabice z Weitmile, Kronika Pražského kostela (A chronicle of the Prague Church), in *Kroniky doby Karla IV* (Prague, 1987), 240.
25. Emanuel Poche, Einige Erwägungen über die kameen Karls IV., in *Sbornik k sedmdesatinam Jana Kuĕta* (Prague, 1965), 82–93.
26. In his attempt to interpret the Týn tympanon in Prague, Jaromír Homolka also touched on the respect paid to Longinus and the Feast of the Spear and Nails: Studie k počátkům krásného slohu (A study on the beginnings of the beautiful style), AUC Prague, *Phil. et Hist. Mon.* 60 (1974):65 ff.; Libor Gottfried (note 16), 36–37.
27. This passage is especially interesting: "Thus it is polite to revere the holy passion of Our Redeemer Jesus Christ, who saved and freed us, in such a way as to name all the mysteries of his passion and his merits, priding ourselves in the redeeming instruments and fruits." The wound in his holy side, whence we have received the price of our redemption, the purifying baptism and resurrection, the sacraments of the Church itself, is emphasized, as are the "happy spear and sweet nails with which the Redeemer was nailed to the cross." "Be thus the spear, the nails and other instruments of this passion which brought redemption revered by Christ's faithful anywhere."
28. Hiltrud Westermann-Angerhausen, Das Ottonische Kreuzreliquiar im Reliquien-Triptychon von Ste. Croix in Lüttich, *Wallraf-Richartz-Jahrbuch* 36 (1974):7–22.
29. Tomáš Akvinský, *Teologická Summa* (E. Soukup) (Olomouc, 1990), vol. 2, *Doplnĕk*, 96 ff.
30. Jaromír Homolka (note 26), 65.
31. Zuzana Všetečková (note 5), 109 ff.
32. Rudolf Kuchyňka, Nástĕnné malby v kostele sv. Apolináře v Praze (Wall paintings in St. Apollinarius's Church in Prague), *Památky archeologické* 33 (1922–23):41–44; Václav Wagner, Nástĕnné malby v kostele sv. Apolináře v Praze (Wall paintings in St. Apollinarius's Church in Prague), *Za starou Prahu* 9 (1922):6–8; Karel Stejskal, Nástĕnné malířství (Wall painting), in České umění gotické 1350–1420 (Prague, 1970), 199; Jaromír Homolka (note 25), 81–83; Zuzana Všetečková, Gotické nástĕnné malby v kostele sv. Apolináře v Praze (Gothic wall paintings in St. Apollinarius's Church in Prague), in *Pro arte. Sborník k poctĕ Ivo Hlobila* (Prague, 2002):157–68.
33. In the 1380s the dean of the St. Apollinarius Chapter was Václav of Radeč, one of the St. Vitus canons and the fifth supervisor of the St. Vitus Cathedral construction. He is also known to have commissioned the Missal in the Capitular Library in Prague. This late-fourteenth-century manuscript contains the officiums to all the six Bohemian patron saints represented in the mosaic. According to Jiří Kozina, this was not typical of the cathedral but rather of the St. Apollinarius Church, where the saints were also represented. Jiří Kozina, Provenience misálu Václava z Radeč (Provenance of the missal of Václav of Radeč), *Studie o rukopisech* 33 (1999–2000):19–27.
34. Jaromír Homolka (note 26), 81–83.
35. Zdeňka Hledíková, *Biskup Jan IV. z Dražic* (Bishop Jan IV of Dražice) (Prague, 1992), 155 ff.

36. Jaroslav V. Polc, Councils and synods of Prague and their statutes (1362–1395), *Apollinaris* 52 (1979):200–237, 495–527.
37. Beat Brenk (note 9), 30–34.
38. Aurelius Augustinus, *O Boží obci* (City of God) (Prague, 1950), 568 ff.
39. Tomáš Akvinský (note 27), 745 ff.
40. Ibid., 522 ff.; Augustinus Aurelius (note 38), 647.
41. Tomáš Akvinský (note 27), 736 ff.
42. Karel IV. Vlastní životopis (Charles IV: Autobiography), in *Kroniky doby Karla IV* (Prague, 1987), 37.
43. Dante Alighieri, *Božská komedie* (Divine comedy) (Prague, 1965), Peklo (Hell); Jan Vilikovsky, *Próza doby Karla IV* (Fiction in Charles IV's time) (Prague, 1938), 200–218.
44. Barbara G. Lane, " 'Requiem aeternam dona eis': The Beaune Last Judgment and the Mass of the Dead," *Simiolus* 19, no. 3 (1989):166–80.
45. David Žofák, Jan Očko z Vlašimě (1364–1379), in *Pražské arcibiskupství 1344–1994* (Prague, 1994), 301–2.
46. Werckmeister described the Last Judgment according to John 5:25–29, the text of which was read during the mass for the dead: "Verily, verily, I say unto you, The hour is coming, and now is, when the dead shall hear the voice of the Son of God: and they that hear shall live. For as the Father hath life in himself; so hath he given to the Son to have life in himself; And hath given him authority to execute judgment also, because he is the Son of man. Marvel not at this: for the hour is coming, in the which all that are in the graves shall hear his voice, And shall come forth; they that have done good, unto the resurrection of life; and they that have done evil, unto the resurrection of damnation." Otto Karl Werckmeister, Die Auferstehung der Toten am Westportal von St. Lazare in Autun, *Frühmittelalterliche Studien* 16 (1982):208–36.
47. Hans Belting, Das Fassadenmosaik des Atriums von alt. St. Peter in Rom, *Wallraf-Richartz-Jahrbuch* 23 (1961):37–54.
48. "For the judges entrusted with the subjects' cases often hesitate to decide, or delay the decision for love, hate or fear of the powerful involved in those cases. It is thus useful if the monarch himself can hear the cases and judge them as often as possible, following the example of the famous Emperor, if he wants to achieve recompense for his good deeds from God both now and in the future." Beneš Krabice z Weitmile, in *Kroniky doby Karla IV* (Prague, 1987), 243–44; Iva Rosario, *Art and Propaganda: Charles IV of Bohemia, 1346–1378* (Woodbridge, 2000), 89 ff.
49. Zdeněk Kalista, *Karel IV* (Charles IV) (Prague, 1971), 71 ff.

Carlo Bertelli

Chapter 4
The Last Judgment Mosaic: Bohemian Originality and the Italian Example

At the time the Last Judgment mosaic was fashioned in the late fourteenth century, mosaic art had reached its apogee in the Italian states. There are clear similarities between some Italian mosaics and the Prague work, and the Italian experience may well have influenced in some ways the great Bohemian mosaic. However, there are important differences as well, and the question of Italian influence is perhaps more complex than previously thought. The mosaic masters in Prague, in fact, though probably working among a team that included Italian colleagues (who in all likelihood hailed not from Venice but from central Italy), were experimenting with an independent approach to the craft of mosaics and inventing a truly new language.

Mosaics themselves were undergoing a new discovery of sorts in the late Middle Ages; and throughout the thirteenth century, the revival of mosaics had been promoted, with great energy and at considerable expense, by the popes. The papacy saw in the technique of mosaics a unique sign of its authority, even if the artists employed were not Roman. This appraisal had started early in the century, when a diplomatic agreement enabled Venetian mosaicists to restore the apse of St. Paul's Outside the Walls, and continued to century's end, with the mosaics by Torriti in St. John the Lateran and in Santa Maria Maggiore. Indeed, it did not stop even during the Avignon exile (1309–76) when Cardinal Colonna vindicated the pride of his own family by commissioning a new mosaic decoration on the exterior of Santa Maria Maggiore. About the same time, Cardinal Stefaneschi of Avignon commissioned Giotto to execute the famous mosaic of the *Navicella* in St. Peter's, with the intention of thereby establishing the spiritual presence of the absentee pope.

By the late fourteenth century, when the Prague work was created, the craft of mosaics had acquired definite imperial and Roman connotations. Mosaics covered the interior of the imperial chapel in Aachen, where emperors were crowned. They also adorned the exteriors of such Roman basilicas as St. Peter's, Santa Maria Maggiore, and Santa Maria in Trastevere (fig. 1). The facade of the cathedral in Orvieto was adorned with mosaics (fig. 2), and Siena marked its loyalty to the Guelph party, which supported the papacy, by adding a second story to the facade of its cathedral, which then became resplendent with mosaics. Both cathedrals are monuments of Italian Gothic architecture, so the introduction of mosaics into their sculptural context was quite a novelty in terms of style, but it had strong Roman significance politically.

The Orvieto and Siena facades also have the enormous appeal of being visible from a considerable distance and in this regard bear a marked similarity with the Prague work. Orvieto Cathedral dominates a vast horizon of hills, woods, vine groves, and winding country roads. Today the Siena facade is partially hidden by a hospital, but its pinnacles and the uppermost golden gable still can be seen by travelers from miles away. Similar to these is the church of the Aracoeli in Rome, situated on a summit of the Capitoline Hill and reached through a monumental staircase built at the time of the great humanist Cola di Rienzo. The Aracoeli, too, was decorated with exterior mosaics, of which only a few fragments remain. They shine at sunset. In all these cases we have a facade glittering with a mosaic poised atop an acropolis—exactly as exists in Prague. And in Prague, too, the tripartite section of the south side of the cathedral rises

FIGURE 1 Santa Maria in Trastevere, Rome. Example of an outdoor mosaic existing at the time the Last Judgment mosaic was made.
Photo: Alinari/Art Resource, NY.

FIGURE 2 Duomo in Orvieto, with numerous outdoor mosaics.
Photo: Alinari/Art Resource, NY.

well above the roofs of the town, imparting to everyone the Christian message of the final justice. It looks like a Gothic triumphal arch of sorts: the triumph of the Lord.

These Italian examples, with their suggestive connections to the Prague work, all bear the imprint of Rome, where mosaics, as in other cities within the borders of the papal state, were still being crafted in the late fourteenth century. And therefore they invite us to reconsider the traditional ascription of the Prague mosaic to a Venetian team, which was first introduced by A. Matějček in 1915, was confirmed by R. Pallucchini in 1964, and has been taken for granted by other scholars since.[1] A careless attribution of Venetian influence can blind us to the significance—*and the originality*—of the remarkable enterprise in Prague.

To investigate more fully the question of Bohemian originality and Italian—specifically Venetian—influence, we must compare the Italian and Prague mosaics not in terms of iconography but of style and technique. Venetian mosaics of the late fourteenth century have distinct characteristics. Those in the baptistery of San Marco, Venice, present regularly cut cubes, with a marked difference between the very small ones used for draperies and flesh and the larger ones fit for golden backgrounds and architectural representations. In general, these mosaics tend to a smooth, even, and uniform surface, with delicate transitions from light to shadows in the skin tones. In the Sant'Isidoro chapel, also in San Marco, the technique, although different from others in the same basilica, is also different from Prague. Here the distinction in cube size is less marked, and the outlines are strong and simplified; red is frequently used for the hands.[2] Moreover, San Marco also once housed an enormous representation of the Last Judgment. Of the details we know nothing, but we may presume it to have been in the Byzantine tradition, perhaps comparable to the one still existing in Torcello.[3] If this was the case, then the mosaic in Prague would be very different indeed from any Venetian example (see fig. 3). (It is possible, of course, that any putative Venetian mosaicists might have been simple craftsmen, working on cartoons drawn by other, possibly Bohemian, artists.)

In considering the frescoes by Niccolò Semitecolo in the Lucchesi chapel of Venice, which Pallucchini compared to the Prague mosaic when he attributed the Bohemian work to Venetian masters, such differences in fact emerge even more clearly. Indeed, it is precisely when we compare the architectural frames in the mosaic with those in the Semitecolo frescoes that we can best evaluate these differences. In the Prague mosaic, the fillets composing the frames are represented in three dimensions, with an obvious logic and clear distinction of light and shadow; for Semitecolo, they are simply white strips without thickness or definition.[4] In the ornamentation as well, we find that the Mediterranean acanthus motif is much more classically articulated in Prague than it is in Venice.

Differences are also evident in comparing the acanthus scrolls on the buttresses of

FIGURE 3 Torcello, example of a Venetian mosaic. Photo: Osvaldo Bohm–Venice. Research Library, The Getty Research Institute, Los Angeles.

Prague Cathedral with those we find, in the same position, in the famous reliquary by Ugolino di Vieri in the treasure of Orvieto Cathedral, dated 1338. It is also quoted, in 1342–45, by Bonensegna, the goldsmith of the Pala d'Oro in Venice, but with considerable differences in both the continuous flow of the scrolls and the placement of the acanthus—not on the sides of the buttress, as in Ugolino and the masters from Prague, but flattened out in front.[5]

The question of purported Venetian preeminence in the practice of Italian mosaic art is further illuminated by consideration of the curious fact that when, in 1419, the Republic was looking for an expert mosaicist to restore the damaged mosaics on the exterior of San Marco, no expert in that craft could be found in Venice. The Republic had to turn to an emigrated Venetian master, who at that time was in Genoa—and who declined to return to his native country. In the end, Paolo Uccello was called from Florence. Thanks to him, the art of mosaics was restored to the city that had once taught the art to the rest of Italy, Florence included.[6] The latest, dated mosaic in Venice is in Santi Giovanni e Paolo, on the tomb of Doge Michele Morosini, who died in 1382, and is certainly the work of a Florentine master; Cavalcaselle considered it a possible work by Agnolo Gaddi.[7] Perhaps equally remarkable—or simply strange—is the fact that in the treatise on painting he wrote toward the end of the fourteenth century, Cennino Cennini, the Florentine who spent part of his life in Padua, ignores completely not only how mosaics were made but also what they looked like.

These various matters—the related questions of Venetian preeminence and Italian influence on the Prague mosaic—are illuminated by consideration of the great Orvieto mosaic. In about 1310 a drawing for the facade of Orvieto Cathedral introduces in the upper gable a representation, obviously intended for mosaic, of the enthroned Virgin and Child;[8] but work on the Orvieto facade proceeded slowly. By 1337–39 the level of the main transverse gallery appears to have been reached. In the third quarter of the century the alabaster and the stained glass windows were installed, and frequent journeys to Venice to procure materials have been documented. In 1386 the mosaicist Piero di Puccio, who was paid on an established salary of four florins a month, declared that he would not work any longer if his salary was not increased to at least six florins. That Piero di Puccio is not a Venetian name but typically Umbrian suggests that the mosaics were in the hands of local craftsmen and that these craftsmen felt so little pressed by competition as to demand better wages.

Orvieto's bishopric was an important see in the papal state, and its authority was only enhanced by a rumor that a miracle of the bleeding host, which had stained a corporal with blood, had taken place there. This event turned the cathedral into a monument to true faith.

Orvieto was also significant to Charles IV; indeed, the miracle of the host had occurred during a mass officiated by a doubting priest from Bohemia. Other Italian mosaic works were also appreciated by the emperor. During his three Italian sojourns, he had had numerous opportunities to admire the enormous mosaics on the facades of Aracoeli, St. Paul's, and Santa Maria Maggiore in Rome, as well as of San Frediano in Lucca. If the date given by Beneš Krabice for the mosaic is correct and it was fashioned between 1370 and 1371, then the presence of the Holy Face in a conspicuous position in the frame of the central section would seem the result of the permission the emperor had been granted, in 1369, to have an authentic copy made of the vera icon.

Like the Last Judgment mosaic in Prague, the mosaics in Orvieto were stripped off in a nineteenth-century restoration, although, as opposed to the Bohemian work, they were never reinstated on the cathedral's facade. They were presented to the pope, but their current location is unknown, apart from the lucky exception of the north gable decoration. The latter represents the *Birth of the Virgin* and is now in the Victoria and Albert Museum in London (fig. 4). It is a fundamental example for the craft of Italian mosaics in the late fourteenth century. Still, the neglect it long suffered had repercussions not merely in what concerns Italy but also on the debate about the Prague mosaic.

Of all the Italian mosaics of the late fourteenth century, the one from Orvieto appears to be the closest to that in Prague. They both try to translate the novelties of Gothic painting into mosaic technique, and they have various other points in common. One is an interest in the modeling of flesh. (It is easy, for example, to compare the muscular body of the Christ child with the heroic nudes of the Prague mosaicists.) Another similarity is the accentuation of the

FIGURE 4 Detail of Birth of Mary mosaic from the duomo in Orvieto, detached (currently in Victoria and Albert Museum, London). Photo: V&A Picture Library.

faces through highlights. Technically as well, although the Prague masters had fewer of the precious stones to work with and had to do their best with what was available, both mosaics are formed of very large cubes with wide interstices in order to provide a more glittering and irregular surface in better harmony with the surrounding Gothic architecture.

Nevertheless, to ascribe the mosaic in Prague to a team from Orvieto would be going too far. The Prague mosaics are imbued with a variety of Gothic traits—swirling angels, tormented portraits—that correspond to nothing in contemporary Italian painting. Their greatest novelty, however, consists in a new and unprecedented use of light and color, and it is perhaps in this regard that the originality of the Prague work emerges most clearly. Colors are never blocked into circumscribed areas. Instead they tend to expand and to model the bodies in a purely colorist way. See, for example, in plate 10, the passages from brown to gray (two shades) and then to white in the tunics of the angels and from yellow to green in the angels' wings on a scale of colors that does not occur in the Italian scheme for angel wings. While we can detect certain hints of this colorist tendency in the Victoria and Albert example, as in the changing colors of the draperies, we find nothing as strong as the dramatic change from blue or green to gold that we see in the garments of the Christ figure in the Prague Last Judgment mosaic (see pl. 9). We must conclude that the mosaic in Prague is not a piece of driftwood from elsewhere, or an artifact that can simply be studied in a regional context. It is in fact a masterpiece of that complex experience that was Bohemian art under Charles IV.

Notes

1. The first attribution to Venetian masters comes from A. Matějček, Das Mosaiblid des Jungtsen Gerichtes am Pragwer Dome, in *Jahrbuch des Kaiserlichen-Instituts der K.K. Zentralkommission* 9 (1915). It was confirmed by R. Pallucchini, *La pittura veneziana del Trecento* (Venice and Rome, 1964), 74, 224 ff. It is taken for granted by G. Rossi Scarpa in R. Polacco, ed., *San Marco, La basilica d'oro* (Milan, 1991), 265.
2. These mosaics have been discussed by Pallucchini, *La pittura*, cited by G. Rossi Scarpa in R. Polacco, and cited lately by D. Pincus, Andrea Dandolo (1343–54) and visible history: The San Marco projects, in Ch. M. Rosenberg, ed., *Art and Politics in Late Medieval and Early Renaissance Italy: 1250–1500*, Conferences in Medieval History 2 (Notre Dame, 1990), 191–206; and by G. Horn, Das Baptisterium der Markuskirche in Venedig (diss., Frankfurt am Main, 1991). A technical analysis is still needed.
3. O. Demus, *The Mosaics of San Marco in Venice* (Chicago, 1984), I, 1, 9, 18. Recently: M. V. Schwarz, *Die Mosaiken des Baptisteriums in Florenz* (Vienna, 1997), 67.
4. For reproductions, see Pallucchini, *La pittura*, figs. 380–91.
5. There are good reproductions of these details in the catalog of the exhibition *The Treasury of San Marco Venice*, at the Metropolitan Museum of Art in New York (Milan, 1984).
6. A. Chastel pointed out the shift of mosaic making from Venice to Florence in a pioneering article decades ago: La mosaïque à Venise et à Florence au XVe siècle, *Arte Veneta* 8 (1954): 119–30.
7. Quoted by R. Pallucchini, *La pittura*, 214–15. For Pallucchini, he was a *toscaneggiante*, that is, possibly a Venetian master under the influence of Tuscan models, and not a master from Tuscany.
8. Documents concerning the cathedral have been published by L. Fumi, *Il duomo di Orvieto e i suoi restauri* (Rome, 1891).

Eliška Fučíková

Chapter 5
Conservation of the Last Judgment Mosaic, 1910–1992

In 1910, twenty years after it was detached, the restored Last Judgment mosaic was remounted on the facade of St. Vitus Cathedral (see chap. 7, fig. 17). On September 20, 1910, the architect Kamil Hilbert reported to the K. K. Zentral Kommission für Kunst- und historische Denkmale (Central Commission for the Preservation of Works of Art and Historical Monuments) in Vienna that the restoration of the mosaic was completed and requested that the conservator general, Max Dvořák, come to Prague for the finished work to be signed over.[1] Dvořák, with representatives of the board of directors of the civic organization Jednota pro dostavění hl. Chrámu sv. Víta na hradě Pražském (Society for the Completion of St. Vitus Cathedral at the Prague Castle) was to be present for the final evaluation of the completed project and for the signing-over, to be performed by an expert committee. Dvořák arrived a month later. In a letter dated January 18, 1911, the Central Commission expressed its appreciation and unreserved approval of the masterly accomplishment of the transfer of the St. Vitus mosaic.[2]

In the same year, however, some unpleasant negotiations had to be conducted with the Venetian assistants to the conservator Viktor Förster: they were demanding additional payment for their services, because the area on which they had done their mounting work was larger than had been paid for originally. As it turned out, the fault lay not with Förster but with Kamil Hilbert, who had incorrectly calculated the size.[3] The problem was resolved and additional payment eventually provided, but a second problem proved more complicated. After being washed several times, the mosaic shone brilliantly, but a grayish cloud soon began to form on certain parts of it, which disappeared only when it was thoroughly cleaned mechanically. Josef Burian, a professor at the University of Technology who worked for the Institute of Glassmaking, Ceramics, Technology and Testing of Building Materials, was invited to join the project to determine if the cause of this corrosion was the manner in which the mosaic had been scraped off in the previous century and subsequently coated: according to one version, with varnish; and to another, with water glass (Na_4SiO_4).[4] The following year, when the two-year guarantee period on the performed work expired, Förster had to reinstall several tesserae that had fallen off when an old fissure in the masonry reopened, before a meeting of the Society's board of directors.[5] The same problem of cracks and missing tesserae reappeared in 1919; the fissure was closed and the surface repaired with tesserae from the old stock.[6] At the same time, the mosaic was washed with water sprinkled from an extension ladder, which restored the vividness of its colors.

It was only after World War II that the St. Vitus mosaic became the focus of attention again. In April 1949 the Society requested the Sklárny Union (Union Glassworks) to examine the mosaic's condition, for fear that it might begin to decay.[7] The result of the examination showed no reason for alarm: several old fissures reappeared on the surface, and some of the tesserae around them fell out or came loose, but their number was minimal in proportion to the total. Although there was no danger that larger portions of the mosaic might begin to disintegrate, it was decided to replace the tesserae that fell out, to secure those that were coming loose, and to fill the fissures, all as soon as possible. It was also thought advisable to fill the cavities with cement mortar and to remedy the bulging that occurred in certain sections. The Glassworks then proposed a budget for the suggested repairs, but the Society was no longer in a position to finance the repair work on its own. Therefore, it applied to the Státní památkový úřad (State Heritage Institute) for a subsidy.

The institute proceeded rather slowly. Because of changes in personnel, the contribution requested for 1950 was not included in the financial plan and consequently was not awarded. At the end of the year, as the mosaic's condition worsened, the Society urgently appealed to the Ministry of Education, Sciences, and Arts for help, proposing two alternatives: supplement the portions from which material was falling out and secure the dilatation joints; or take the mosaic down, place it in the National Gallery, and install a perfect copy on the original site.[8] Several representatives of monuments conservation authorities favored the latter option, because they felt that the former would have been no more than a short-term solution.

It was remarkable that the same situation that had led to the removal of the mosaic in 1890 and to its subsequent reinstallation on the original site twenty years later should begin to repeat itself so soon—but now there was a fundamental difference. From the early twentieth century onward, mosaic workshops had experienced a period of great advancement. Mosaics had become a favorite feature in the decoration of both the interiors and the exteriors of new buildings, in Prague and throughout the country. This prosperous industry, however, had been hard hit by World War II, so a major new project at a site as prestigious as the Prague Castle would have meant an opportunity for its renaissance. The ministry's response was that for reasons of principle, it could not agree to the making of a copy—but it was willing to provide the funds needed for proper repair of the original mosaic.[9]

In May 1951 a commission was convened consisting of representatives of the Society, the State Heritage Institute, the Art History Institute of Charles University, and institutes specializing in mosaics. Members inspected the mosaic from scaffolding; they recommended that detailed photographic documentation should be compiled and archival research undertaken concerning the removal of the mosaic in 1890 and its reinstallation in 1910.[10] A chemical analysis of the glass was to be made as well. Progress of the preparatory work, especially action by the responsible officials, was rather slow, until 1953, when the director of the State Heritage Institute issued his opinion that the mosaic was on the verge of ruin.

His position paper reviewed the mosaic's history and requested that scaffolding be erected speedily so that the mosaic's condition could be subjected to detailed analysis. The paper also stated that more precise photographs were needed of both the mosaic as a whole and of individual details; microphotographic and chemical research had to be conducted in respect to the state of the glass melt, the solidity of the mosaic layer, and the extent to which it might have come loose from the masonry. In addition, the art historians' commission was expected to issue an opinion, based on on-site inspection, concerning the possibility of preserving the mosaic, and knowledgeable government officials were to decide on how the project could be financed. The public had to be alerted to the acute danger that threatened to rob the nation of this unique monument.

The commission met in September 1953 and concluded that the mosaic required conservation and should be moved to a sheltered place, preferably inside the cathedral.[11] The question of having a copy made, to be installed in place of the original, was to be dealt with separately. However, these conclusions failed to expedite progress toward saving the mosaic. In May of the following year, glassmaking experts issued their opinion on the mosaic's preservation.[12] They stated that the mortar into which the mosaic was set was for the most part original and preserved in good condition and that it had had no detrimental effect on the glass tesserae. A tentative reconstruction of the color scheme was complicated by the earlier scraping of the mosaic's surface, which had eradicated traces of gilding. The green tesserae, whose authenticity had been doubted, proved original. The question of the method of conservation was thus divided into two parts: how best to clean the mosaic's surface and how to prevent the access of air, which obviously could not be done in situ. The mosaic would have had to be taken down in large sections. Harsh mechanical scraping would only do more damage to the original appearance of the mosaic and to the authentic gilding. Nor could the tesserae have simply been removed and then reinstalled with the undamaged sides up, because they were conical, not flat. Conservation of the mosaic with silicone coating would have involved taking it apart cube by cube and preparing each individually, and in any case the use of silicones and acrylates would impose various disadvantages of their own. Silicone coating solidifies in low temperatures and is highly susceptible to adverse weather conditions; acrylates tend to change color and are very glossy. These drawbacks would have changed the artistic features of the mosaic. The commission therefore recommended that the mosaic be dismantled cube by cube, that the surface be covered with a layer of protective material, that the corroded portions be removed from the surface, and that the mosaic be installed in a safe environment—that is, a museum-type installation.

On August 30, 1954, a high-level meeting was held on the artistic decoration of St. Vitus Cathedral. It is useful to remember that work on the cathedral's decoration, both external and internal, continued in the period following the reconsecration in 1929, including the creation of stained-glass windows and new mosaics on the ceiling of the Golden Gate entryway. The Golden Gate mosaic—which until then had been the responsibility of the National Heritage Bureau of the Ministry of Culture but which would now be transferred, from this time onward, to the Office of the President of the Republic—was the first item on the agenda of that meeting. It was very fortunate for the mosaic that one of the representatives was Josef Cibulka, the renowned Czech expert on ancient Christian and medieval art. His arguments were so convincing that even now, almost half a century later, they seem irreproachable. Cibulka argued against taking the mosaic down and replacing it with a copy, and pointed out that the same kind of corrosion currently affecting it was also found on the Gothic windows of French cathedrals and that these would long ago have been eaten through and destroyed if the problem were fatal.[13] He was in favor of approaching prominent experts in the field of chemistry and asking them to identify, at the beginning of 1955, a method for saving the mosaic from disintegration and deterioration. He also opposed the recommendation, expressed by the broader commission the previous year, that the mosaic be placed inside the cathedral. Even in an interior, he argued, the same grayish coat would eventually have formed; and because of the mosaic's size and the locations available in the cathedral, the work would have to be divided into two parts. Every member of the later commission agreed on keeping the mosaic in its original site and preserving it in its original condition. The idea of having a copy made was also abandoned. Scaffolding was intended to remain in place only until the middle of the next year, for the purpose of conducting chemical research. This new conclusion was in line with the basic principle of monuments conservation, which was to keep ancient objets d'art on the sites for which they had been originally created and to preserve their original purpose. Thus common sense prevailed over a tendency to launch new initiatives at any cost and to take hasty decisions regardless of their potential adverse consequences. The decision to do nothing until the relevant research could identify an appropriate preservation method indicated that the condition of the mosaic, apart from its grayish coat, was not as alarming as previous reports had suggested.

In November 1955 the Institute of Theoretical and Applied Mechanics and the Chemistry Institute of the Czechoslovak Academy of Sciences presented a joint report on the preservation of the Last Judgment mosaic at the Golden Gate. They summarized the results of their research and of a test of chemical conservation on the bottom part of the mosaic's western arch.[14] It would have been possible to use a chemical procedure to remove the grayish corrosion layer, but the danger of efflorescence by soluble salts, which could have appeared both on the glass and on the bond—and perhaps have recurred repeatedly—dictated against it. Instead it was decided to do the cleaning mechanically, with a soft wire brush. The layer of impurities gave way quite easily to manual cleaning in a dry state, which proved that the glass was fairly well preserved in terms of color, hardness, and mechanical cohesion. Almost no corrosion was found on the side joints where the surface of the glass was covered by a bond, and none of the glass pieces suffered destructive restructuring of the kind that would have led to overall decomposition of the matter. It also transpired that the remnants of the extracts, which could not be completely removed from the minor surface cracks and cavities, in no way affected the appearance of the mosaic when seen from a distance. Colors, integrity, and overall clarity remained undimmed.

Another test was aimed at ascertaining the condition of the bond and the way it cohered with the mosaic. The largest original part of the mosaic was held together by hydraulic lime mortar; cement was used only during later repairs and at the time of the 1890 removal. Up to that point, the mosaic had held relatively firm in the bond. Tapping, however, revealed cavities in several places; and fissures, visible on the surface, were associated with a crack in the western section, extending upward to the left-hand side, from the top of the Gothic arcade across the entire picture. Fortunately, experts did not believe that the deterioration in the mosaic's cohesion with the background layer posed an imminent threat or that any part of the mosaic was in danger of falling off. After the experimental cleaning, Portland cement with 30 percent ground quartz was used to fill the joints with a view to attaining a shade resembling that of the original hydraulic lime mortar, in which the pleasant warm color was achieved by adding brick dust. Tesserae were falling off only in the few places where the background for the bond was seriously damaged.

The experience of the previous conservators led to one unequivocal conclusion: the surface of the mosaic, once cleaned, would require chemical conservation. For the first time in Czechoslovakia, artificial materials with suitable physical and mechanical qualities—polybutylmethacrylates and silicones—were used for the purpose of testing chemical conservation techniques. Experiments begun in May 1956, together with samples from a conditioning chamber,[15] revealed that the best results were achieved with a Swedish methacrylate, but it was decided to continue the tests and to obtain information on mosaic conservation results in Italy and France.

In 1957 a part of the mosaic was cleaned, a list of the glass pieces was made, and a chart indicating the location of cavities and cracks was drawn up. The year 1957 was essentially one of testing, of both materials and techniques.[16] It was only in 1959 that the western and central fields of the mosaic were actually restored, in two phases.[17] A commission that met on December 10, 1959, stated that this was the first occasion in Czechoslovakian history in which artificial resins had been used for renovation purposes and in which corrosion had been removed with the help of nylon brushes. A scientific analysis performed by the Chemistry Institute of the Czechoslovak Academy of Sciences helped to distinguish the medieval parts of the mosaic from those supplemented by nineteenth-century conservators. Although the experts expressed their great appreciation of the quality of protection accorded to the mosaic, they recommended regular examinations every five years and continuous monitoring of the influence of atmospheric changes on the surface of the final fixation of methylmethacrylate resin.

The following year, 1960, saw the completion of the last part of the restoration.[18] Special attention was paid to gilding, which had suffered the greatest damage in the past, because the thin glass layer protecting the gold plates on the tesserae was almost completely destroyed. Every remnant of the original gold plating was preserved, and additional gilding was adjusted to match the preserved fragments. The regilding was necessary for the mosaic images to remain legible against the blue and red background.

Unfortunately, the promise that the mosaic would receive constant attention and that its condition would be continuously monitored was not met.

Notes

1. Documentation collected by the Getty Conservation Institute and Administration of the Prague Castle for the St. Vitus mosaic, deposited both in the Archives of the Prague Castle and GCI (hereafter, Documentation), 1910; *Výroční zpráva Jednoty pro dostavění hl. chrámu sv. Víta na hradě Pražském* za správní rok (1910), 10–11.
2. Documentation, 1911.
3. See correspondence between Hilbert and Förster and Hilbert's notes to this subject in Documentation, 1911.
4. Ibid.
5. Documentation, 1912.
6. *Výroční zpráva*, 1919, 8.
7. Documentation, 1949.
8. Ibid., 1950.
9. Letter from December 12, 1950; see Documentation, 1950.
10. Documentation, 1951; *Katolické noviny* (Prague), July 8, 1951, 3.
11. Documentation, 1953.
12. Ibid., 1954.
13. This opinion would appear to be validated by the fact that the mosaic had survived in situ for almost six hundred years; if the views and proposals of the earlier commissions had been justified, it would have decomposed long before. And with regard to its removal, certain parts of it, previously repaired by Förster, were now set in concrete, which would have rendered the undertaking immensely difficult.
14. See the report in Documentation, 1955, no. 405.315/55.
15. See report and documentation in Documentation, 1956.
16. See all results in Documentation, 1957.
17. Documentation, 1959.
18. Ibid., 1960.

Alois Martan

Chapter 6
Research and Intervention on the Last Judgment Mosaic, 1956–1992

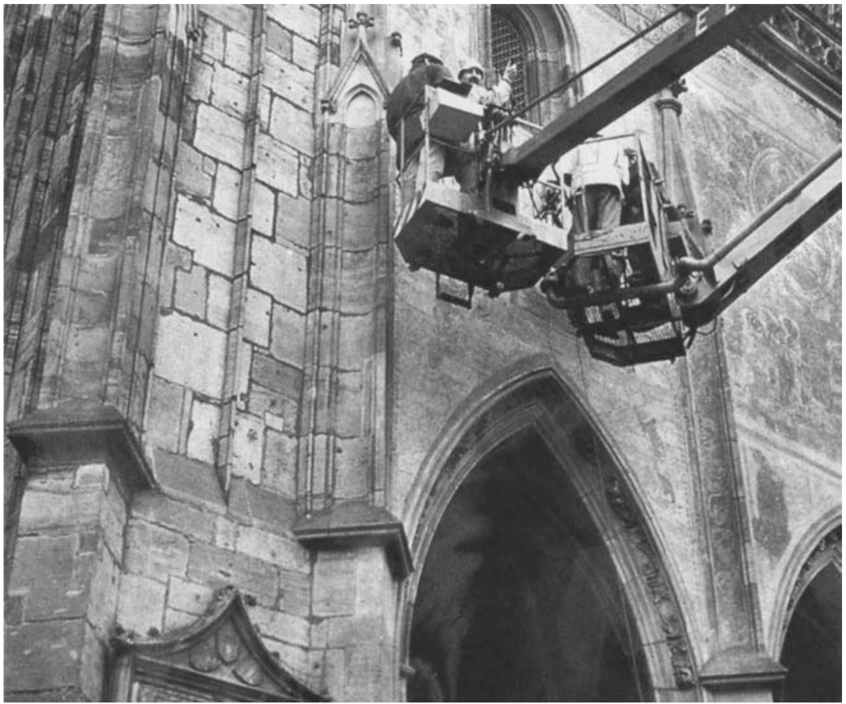
Various approaches to conservation and research on the Last Judgment mosaic were carried out in the forty years preceding the collaborative project between the Office of the President of the Czech Republic and the Getty Conservation Institute. None, however, was able to develop a successful way to prevent corrosion or resulted in agreement on the preferred approach to either treat the mosaic in situ or remove the mosaic and replace it with a copy.

Following the mosaic's detachment in 1890 and its reinstallation in 1910, its glass tesserae continued to suffer from corrosion, which resulted in a gray film of varied thickness covering individual motifs. In 1956 there were two basic opinions about the way to preserve the mosaic. One assumed that the bulk of the mosaic's glass was suffering from corrosion, and therefore it was necessary to remove the mosaic and store it indoors, where it would be minimally affected by the environment. The other opinion held that it was possible to preserve the mosaic in its original place by finding suitable conservation and protective materials. The Office of the President favored the second opinion.

Therefore, in 1956 the Office of the President commissioned Michal Ajvaz, Jiři Rathouský, and J. Doubrava, all at the Institute for Theoretical Basics of Chemical Technology of the Czechoslovak Academy of Sciences (CSAV), to examine the mosaic's condition and to propose a conservation method. On behalf of this team, Jiři Rathouský submitted to the Office of the President a detailed report on (1) the mosaic's condition; (2) the causes of the mosaic's deterioration; (3) suitable means for eliminating these causes; and (4) a proposal for conservation of the mosaic.

A detailed examination of the entire mosaic was conducted in 1958 (fig. 1), and samples of the glass tesserae were taken for analysis. In total, thirty-one hues of tesserae were found. Samples were evaluated visually, analyzed chemically, and examined by optical spectroscopy and X-ray fluorescence spectrometry. The conclusion was that the glass surface had deteriorated as a result of water from atmospheric humidity and precipitation and that this deterioration was present only on the tesserae's surface. Underneath the corroded surface, the body of the glass and its full color, density, and mechanical cohesion were sufficiently preserved. The glass

FIGURE 1 Inspection of the condition of the Last Judgment mosaic in 1958.



from which some of the tesserae were made had not been melted enough and had the character of porous sintered glass, rather than homogeneous glass. However, they did not need to be replaced. Chemical analysis confirmed that the glass contains a large amount of potassium that was introduced during the glass manufacturing process.

The binding materials used to fix the tesserae to the wall were characterized and found to be a lime-based mortar mixed with brick dust and fine sand. In some places cement used during previous restorations was found. Also, many voids were detected, but these did not pose a danger that sections of the mosaic would collapse.

Based on this assessment, an expert in concrete from the Czechoslovak Institute of Technology suggested using a liquid cement–based mortar to fix the detached portions of the mosaic. The team of chemists from ČSAV proposed using a mortar composed of epoxy resin, hardener, and mineral fillers (calcite, brick dust, and inorganic pigment) for setting missing tesserae and filling cracks. Soft brushes were recommended for removal of corrosion. Silicone, epoxy, and polybutylmethacrylate (PBM) resins, as well as beeswax and silicone hydrophobic substances, were tested as conservation materials to protect the mosaic surface against environmental factors. After evaluation of laboratory and practical tests, a three-layer protective coating was suggested for conservation treatment of the mosaic.

In the 1950s it was thought that moisture might be migrating from the mosaic bedding layer. Therefore, the first hydrophobic layer was designed to prevent humidity from penetrating from the mosaic's bed to its surface. A mixture of methyl-chlorosilanes (MCS) proved best in laboratory testing. For the second layer, the use of epoxy resin applied in toluene solution was recommended. For the third (top) layer, polybutylmethacrylate (PBM) resin dissolved in toluene and applied in a thickness of about 80 microns was recommended. This top, sacrificial layer could be easily replaced during future conservation treatments.

At the same time, reintegration of the gold background of the mosaic was considered, given that only small fragments of gold remained on the mosaic. The original thin sheet of glass that was supposed to protect the gold leaf on original golden tesserae was almost completely destroyed by corrosion or by harsh mechanical cleaning undertaken in the past. Epoxy resin was recommended to attach gold leaf to the tesserae to reconstruct the gold background.

In 1957 a series of tests of the recommended protective layers were conducted in situ on several fields of the mosaic.

1. First: hydrophobic layer:
   a) methyl-chlorosilane
   or
   b) silicon resin RK-14
   or
   c) methyl-chlorosiloxane
2. Second layer: epoxy resin (Epoxid 1200)
3. Third layer: polybutylmethacrylate in 50–70 micrometers of thickness.

Gold leaf was tested and applied over the first and third layers. In 1958 the in-situ tests were evaluated. It was determined in the test of the hydrophobization layer that MCS and silicon resin RK-14 performed equally well.

After four years of research in the ČSAV laboratories and in-situ tests on the mosaic, in January 1959 a proposal for conservation of the mosaic was submitted. The proposal called for the following protective treatment:

- First layer – 7% solution of MCS in toluene.
- Second layer – 20% solution of epoxy resin in acetone and toluene (Swiss epoxy recommended, or the West German Epoxy 162, Karinin 260C hardener).
- Third layer – PBM, applied twice in 5% toluene solution and four times in 15% toluene solution (Swedish brand Honosil E90).

On February 7, 1959, a team from Českého fondu výtvarného uměni (ČFUV) was formed to work on the conservation of the Last Judgment mosaic. The team was composed of Josef Němec, Karel Mezera, Alois Martan, and Jaroslav Kaděra. The restorers prepared a report that reflected the team's opinion regarding preservation of this precious monument, the development and accessibility of materials used, and the needed tools and instruments. After summarizing the unique and extremely difficult task of preserving the mosaic, the report recommended the following stages of conservation and restoration treatment:

1. Detailed research and documentation of the state of the mosaic.
2. Stabilization of the mosaic by reinforcement of the original plaster, as well as the plaster applied at later times, in the joins between the detached mosaic's

sections and by using appropriate mortar mixture for filling of cracks and other lacunae.

3. Total removal of surface corrosion from glass tesserae.
4. Careful replacement of missing tesserae and repair of inadequate past interventions.
5. Regilding of missing gold.
6. Application of the protective coating system and hydrophobization of the mosaic.

A large committee composed of the staff of Prague Castle, the Restoration Commission, and the ČSAV approved the technical and artistic methodology of treatment, as well as the proposed materials. The work on each panel was approved separately, and the restorers submitted a conservation report with photographic documentation. The actual restoration work began with the construction of scaffolding on May 16, 1959. Conservation of the left panel was completed on September 2, 1959; the center panel, on November 3, 1959; and the right panel, on April 29, 1960.

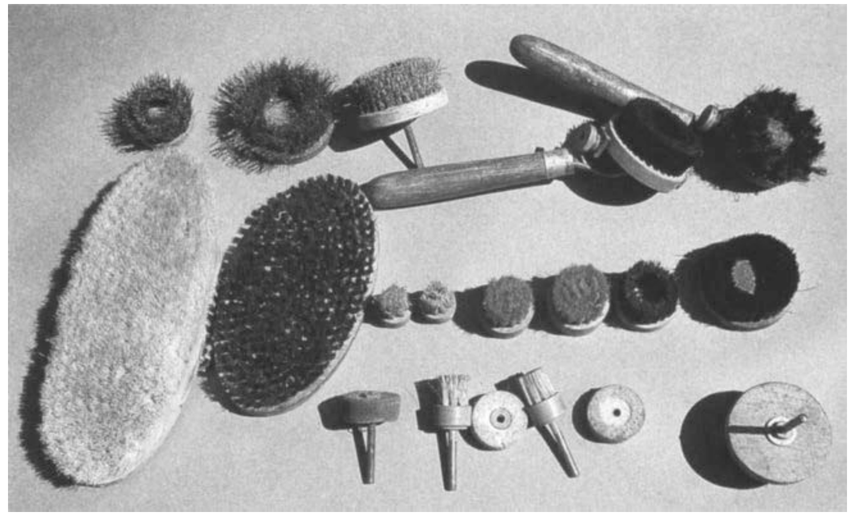


FIGURE 2 (ABOVE) Set of wire brushes used to remove corrosion.

FIGURE 3 (BELOW) The corrosion was removed using wire brushes mounted on an electric motor-driven flexible shaft.

1959–1960 Intervention on the Mosaic

Mosaic Stabilization

The loose mosaic areas were reattached under the direction of Professor Hačar. Other minor reinforcement of the plaster was performed during the restoration work. Loose sections and blisters were grouted with liquid cement mortar. In almost all cases only the top mortar layer, holding the mosaic tesserae, had deteriorated. All cracks were carefully filled. Surface plastering and reinstallation of tesserae in the epoxy mortar were performed only after partial conservation was finished.

Removal of Corrosion Using small brushes of various types and sizes (specially manufactured for this task), the corrosion removal was done manually and with an electric motor with a rotating shaft (figs. 2, 3). Brushes measuring 2.5 to 13 centimeters in diameter (2 cm of nylon, horsehair, brass, wire threads inserted in a wooden handle) were used in combinations for each tessera, depending on the thickness of the corrosion layer and the condition of the glass layer. On severely damaged tesserae, the corrosion was removed manually using similar brushes. In some cases, fine pumice on a felt disk 4 to 6 centimeters in diameter was used for the final cleaning (fig. 4). Because the corrosion was very hard and could only be removed mechanically, this work was

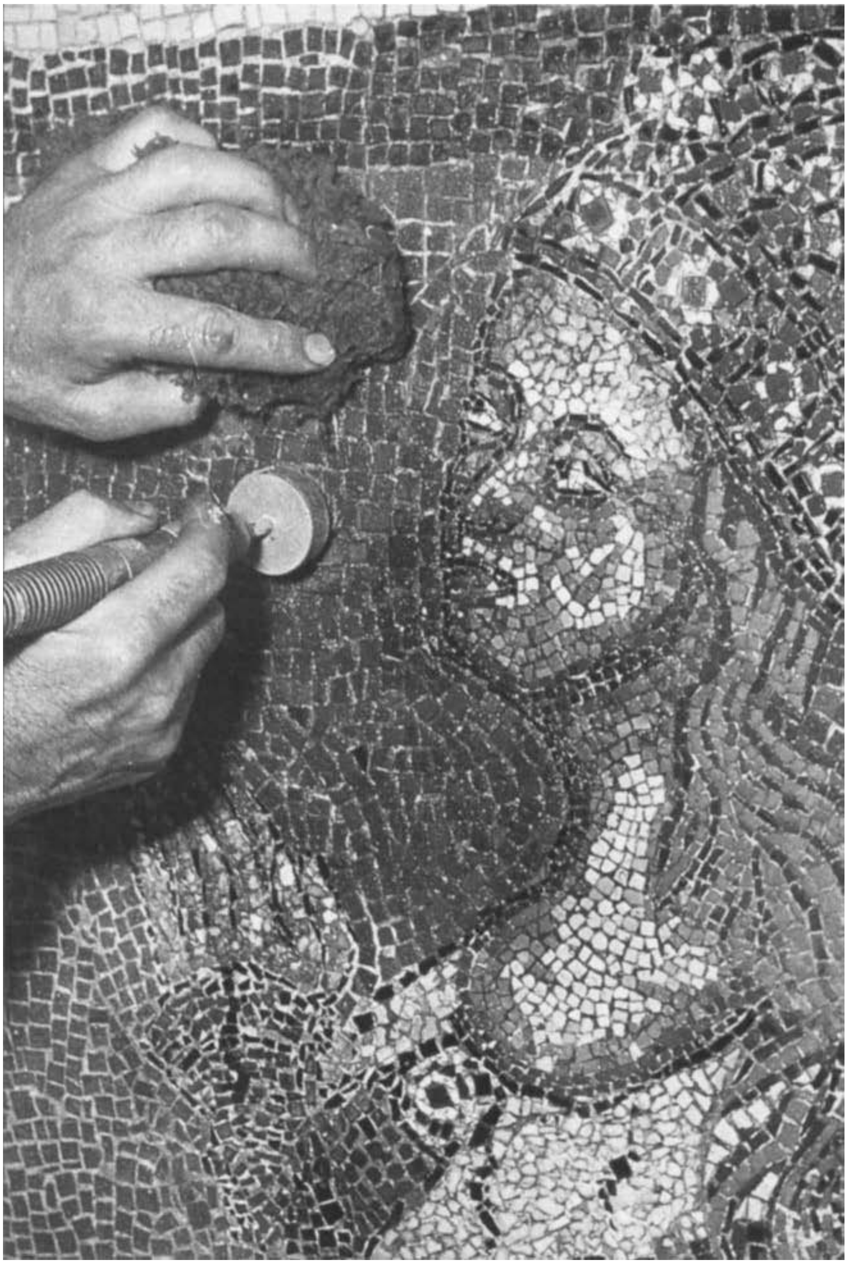


FIGURE 4 Portrait of Elizabeth of Pomerania, central panel, during removal of corrosion. Photo: A. Martan.

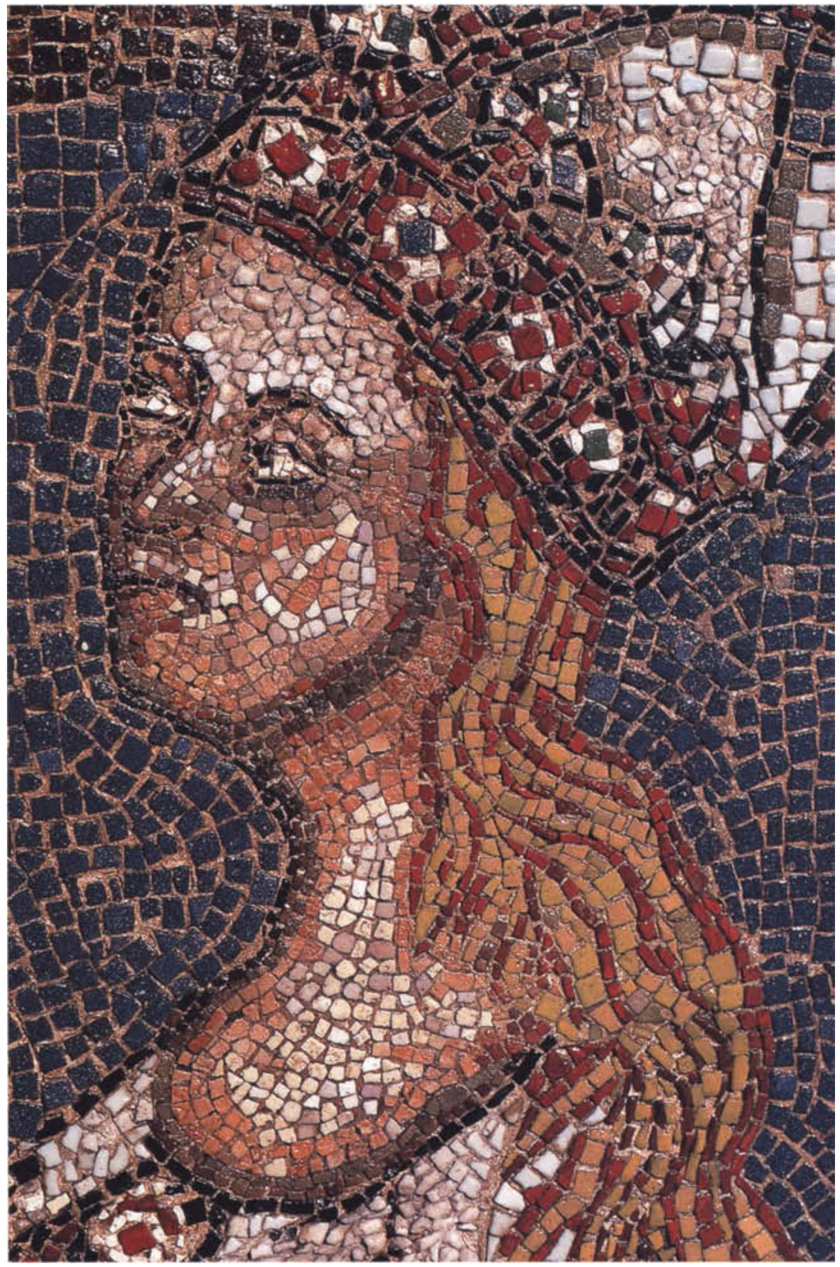


FIGURE 5 Portrait of Elizabeth of Pomerania, central panel, after removal of corrosion. Photo: A. Martan.

challenging. All attempts were made to preserve the original glass surfaces. After the white corrosion film was removed, hard yellow and brownish films, probably remnants of old varnish coating, were detected on the red and white tesserae. They significantly distorted the aesthetic value of the mosaic and were removed to reveal the original colors (figs. 5, 6). The team found also that removal of corrosion from the sides of tesserae proved difficult.

FIGURE 6 Emperor Charles IV, central panel, after removal of corrosion. Photo: A. Martan.

Removal of Previous Interventions The lower section of mosaic in the spandrel of the left panel presented another challenge. Workers from the Mozaika Company had attempted to make repairs by filling spaces between mosaic tesserae with cement-based mortar. Since the color as well as the structure of the cement conflicted with the appearance of the rest of the mosaic, it was necessary to remove the hard cement, which was possible only using electric drills on a flexible shaft.

Plastering and Retouching This phase of conservation treatment was performed after the second epoxy coating was applied and before regilding in order to strengthen the mortar as unobtrusively as possible. Only original tesserae from the castle's archives were used for replacing missing tesserae. These were available thanks to a Mr. Cermak, who for many years diligently collected the tesserae that had fallen off the mosaic.

Protection of the Mosaic The completely cleaned mosaic was coated with two layers of MCS. After the base layers had completely dried, three layers of epoxy resin were applied (one coating of 5% solution and two coatings of 10% epoxy) (fig. 7). Two applications of 5% solution and four applications of 15% polybutylmethacrylate (PBH) in toluene brushed on a partially cured epoxy coating formed the top, sacrificial layer of the whole protective coating system. The entire surface of the mosaic was covered with a layer of MCS to provide hydrophobicity; the other coatings were applied only over the glass tesserae. The natural stones in the figurative motifs of the mosaic were not coated to allow sufficient breathing of the mosaic mortar.

FIGURE 7 Application of protective coating. Photo: A. Martan.

Regilding Regilding was performed after the application of the second epoxy coating of the protective system and only on the tesserae in the image background where no original gold remained. Even the most fragmentary remains of the original gilding were preserved. Regilding was done taking into consideration the color fields of the mosaic. Gold leaf was attached using epoxy resin. The project committee that approved the protective layer technology also approved the proposal for partial regilding of the background and of the halo behind Christ's head. Otherwise, the remaining fragments of original gilding in the figures and draperies were left as they were.

Restoration work was completed in April 1960 (figs. 8–10). To maintain the protection provided by the conservation treatment, it was recommended that the top sacrificial layer of the protective system be replaced every three to five years, depending on the condition. The Prague Castle Administration assumed responsibility for this; however, in the ensuing years, no regular maintenance of the mosaic was carried out. Cleaning and coating have been done only for special occasions.

Findings

During the 1959–60 intervention, several types of plaster were found in the joints, as well as in the foundation layer of the mosaic. This plaster differs in color, structure, and age:

1. The original mosaic bedding plaster is pink and contains lime, sand, and crushed brick.
2. The plaster used in 1910 by Förster is also pink and contains cement. It is used mainly in several sections of the reconstructed golden background.
3. Gray plaster was found in areas where the removed mosaic section (during the detachment of the mosaic in 1890) were joined and in places where the original plaster crumbled and needed to be replaced during installation of tesserae.
4. A dark gray, rough coat of plaster was present in the old seams on the left mosaic panel, on the apostles' heads, reconstructed using pebbles.
5. There were the remains of cement grouting previously tested by the Česka Mozaika Company in the spandrel of the left mosaic panel. The restorers managed to remove most of this inappropriate treatment, but the cement grouting was very hard and had been strengthened by conservation coat-

FIGURE 8 Heads of four apostles, right panel, after restoration. Photo: A. Martan.

ings. Although electric drills were used, complete removal was not possible. The grout used to repair lower portions of the mosaic was the wrong color and distorted the mosaic's appearance. In the 1959–60 intervention the conservation team used epoxy resin grout that had the same structure and color as the original plaster.

Another observation made during the 1959–60 intervention relates to the mosaic's structural stability and conservation history. The mosaic was removed in 1890 and reinstalled in 1910 on two layers of plaster. Before the reinstallation, the wall was plastered with 4 centimeters of rough cement plaster. No wire mesh was detected in the mosaic plaster. On top of the foundation layer, another

FIGURE 9 Detail, head of an apostle, left panel, after restoration.
Photo: A. Martan.

4 centimeters of plaster were applied, and after partial drying, the mosaic panels were reinstalled. The original mortar was removed from the edges of tesserae before their installation. Therefore, some tesserae, even if original, are now completely embedded in cement plaster.

The 1890 mosaic detachment was probably not so difficult because many sections of the mosaic were loose, especially in the upper section. A fragment of the original material found in the 1960s in the Prague Castle's workshop provided evidence that the securing and removal of the mosaic was done using fine canvas and paper overlay. Starch with animal glue was used as adhesive.

The detachment of the mosaic and the reinstallation, repairs, and restoration conducted during the 1890–1910 treatment project, in general, were done very well from the technical point of view and also respected the authenticity of the mosaic. Although today cement plasters are not considered a suitable material, after fifty years the mosaic's foundation was still very firm, with the exception of a few areas. The reintegration of the mosaic image was performed with

FIGURE 10 Head of an apostle, left panel, after restoration. Previous repairs were left intact. Photo: A. Martan.

great care by Förster, although some of his additions have a rather disruptive effect (e.g., the completely reconstructed golden background in the upper parts of the mosaic's left and right panels).

Some loss of tesserae observed in the 1960s was caused by cracks in the masonry of the Golden Gate, which resulted in the loosening and detachment of tesserae, especially during heavy rains. In some places, the glass corrosion penetrated into the porous plaster along the sides of the tesserae, causing them to become loose and sometimes to fall off.

During the 1960s interventions, it was possible to examine the mosaic closely and verify its authenticity. This provided evidence to contradict Matějček's belief that the majority of the mosaic is not original.[1] It is understandable that as a theoretician he could not adequately study the mosaic's relatively complex technology and therefore considered all deformations interventions. These defects in shape occurred during imprecise reinstallation of individual panels—a fact that is supported by our study of the plaster composition. Originally, the tesserae were affixed to canvas, and therefore no changes in composition occurred.

Matějček failed to notice that some of the mosaic sections are not original. These are the heads of three apostles where large pebbles have been used to reconstruct the forehead and hair. Some reconstruction is visible also on the hand of St. Peter. The deformation of the clouds, also in the left panel, is caused by the inaccurate repositioning of the detached mosaic panels. In the lower section of the left panel, the interventions are mainly around the vertical static crack. The largest one is on the stomach, hand, and foot of the reclining figure. The crude repair work using ceramic tiles on the stomach was removed during the 1960s intervention and replaced by a similar material (quartz). Also on the left panel, a few new tiles were inserted in the back of a man lifting a coffin and on the kneeling man.

Few restoration interventions were carried out in the central panel. These were found mainly on the green wing of the angel with a lance, on a wing of the angel with pliers, and on the veil on Christ's head; there is an extensive restoration intervention on the portrait of Charles IV's wife, where almost one-half of the figure is new. The panel on the right, representing the damned sent to hell, is the best preserved. Here, the restoration interventions are only in the joins between detached mosaic sections, which were filled with tesserae, and small ceramic repairs in the representation of the ground in the image.

1960–1992 Research and Intervention on the Mosaic

1967 In 1967, after evaluating the mosaic's condition, Jiři Rathouský stated in his report to the Office of the President that the mosaic was badly soiled and coated with dust. The upper layer of polybutylmethacrylate was detached from the epoxy layer in many places, which had caused an air bubble to form between the firm, partly turbid PBM film and the layer of epoxy resin. Because of the air bubble and the partial turbidity of the polybutylmethacrylate film, the colors of the mosaic image had become muted. The epoxy resin layer was absolutely intact. Also intact was the gold leaf embedded between layers of the epoxy resin. The epoxy mortar, used for resetting lost tesserae and for replacing crumbled plaster in the seams, was also in very good condition.

Rathouský recommended cleaning the soiled mosaic with water, eventually using detergents and brushes. He also recommended dissolving the polybutylmethacrylate layer in xylene and applying two new coats of polybutylmethacrylate (5% toluene solution). He thought it would be suitable to soften the hard methacrylate film and improve its adhesion to the epoxy layer by adding to it about 10 to 20 percent fast-drying stand oil. This modified sacrificial layer was applied in 1967.

1974 In 1974 conservators found that the surface layer of PBM and stand oil had disintegrated into dust, but underlying the epoxy layer and the glass tesserae were intact.

1977–1978 A restoration survey conducted in 1977 showed that the mosaic's foundation, as well as its solidity, had not changed; only the tesserae near the static cracks were getting looser, and 80% of the polybutylmethacrylate layer and 30% of the epoxy coating layer were damaged. Several new materials were tested as possible replacements for badly performing PBM coating. Samples of PBM, wax, epoxy, Lucopren B 237, Silgel JHM 10, and Silgel JHM 20 were applied to several test areas on the mosaic. A new method of gilding using mixtion varnish was also tested. These materials were reommended for testing by the State Institute of Monuments and Nature Preservation (SUPPOP) research laboratories.

Conservation treatment of the mosaic was discussed on June 5, 1978, at a meeting of the representatives of the Prague Castle Administration, the Academy of Sciences, and restorers. It was decided to apply 40% to 60% silicone rubber to the center panel and encaustic carnauba wax on the side panels. The treatment work was conducted the same year.

1979 During the inspection of the mosaic in 1979, it was observed that none of the newly tested materials performed well. Therefore, several research institutions were asked to collaborate on the problem (Výzkumny ústav sklařský [Institute for Glass Research], the Institute for Chemical Technology–Laboratory for Artwork Restoration [VŠCHT], State Restoration Studios [StRA], and SUPPOP).

1980 In 1980 the restorers P. Bareš, J. Brodský, J. Němec, and K. Stádník performed surface cleaning of the mosaic, removed carnauba wax, Silgel, and corrosion films, grouted cracks in the mortar, and replaced missing tesserae. They applied a 5% solution of the Silgel primer on the entire mosaic and coated the central panel with a 30% solution of Silgel and both side panels with a 40% solution of Silgel. They also recommended reviewing the mosaic and coating every two to three years and requested that the making of a copy be considered seriously.

1986 In 1986 State Restoration Studios in Prague prepared a study, No. 345/1986 (5), which, among other things, stated that the methods used thus far for protection of the mosaic's surface were not optimal. However, they reported that the stability of the mosaic, with the exception of two main cracks in the wall, was still good. Also, the adhesion between the glass and the plaster also seemed to be intact. The clarity of the mosaic's image quickly deteriorated after each conservation intervention. This was related first to changes in conservation technologies; even the new materials used were partially porous and thus did not prevent water condensation and pollution from penetrating the coating and reaching the glass surface. The second reason was the ever-increasing content of sulfur dioxide and other pollutants in Prague's air.

The report observed that the epoxy layer applied in 1960 and evaluated in 1974, fifteen years after its application, continued to be in good condition. However, restorers' recommendation of periodic maintenance of the mosaic and replacement of the sacrificial coating was not followed. In addition, the report questioned the use of epoxy resins, which are practically irreversible and difficult to remove. Silicon rubber, or eventually carnauba wax, tested since 1977, did not meet expectations even during the tests; they degrade quickly and with time, become more difficult to remove.

The report concluded that based on research conducted so far, only two options can be considered for preservation of the mosaic.

Option I: In-situ conservation of the mosaic, using protective film based on resistant and easily reversible acrylate resin. The condition for this solution is periodic renewal of the protective film every five to six years. This renewal would consist of washing and removing the dirty and optically degraded film with a suitable solvent and applying a new one using a spray gun. By eliminating the mechanical cleaning of the surface—assuming that conservation treatment would be performed on a strict, regular schedule—the longevity of the mosaic could be ensured for tens of years. Acrylate films (e.g., VIACRYL), applied to a glass surface exposed to urban air quality, show longevity of twelve years, as proved by tests conducted by the Monuments Preservation Office in Vienna. The disadvantage of the acrylate film is that because of static electricity, it becomes covered with dust and particles from industrial emissions, so that its optical quality deteriorates more rapidly. Again, the practical impact of this method presumes that it is confirmed by testing on samples in the laboratory and in situ. In any event, with regard to application of Option I, we considered that it is necessary to address the question of a protective roof, which would protrude from the facade to such an extent as to provide the mosaic with maximum protection from running rainwater.

Option II: Transfer of the mosaic to lightweight panels and its installation in a suitable interior. This solution would be in keeping with the current international trend. A copy made from modern resistant mosaic glass would have to be mounted on the wall of the southern portal. A local supplier could provide mosaic glass in up to two thousand hues. Matching colors would be determined by using photometry (colorimetric measurements).

However, it is necessary to point out some serious problems with this option.

First, the mosaic is set in a very compact hydraulic cement binding material, and therefore it would be difficult to dislodge; a forceful mechanical process could endanger the artwork. Unfortunately, simple cutting off of the plaster layer is no longer possible since during the reinstallation in 1910, the foundation layer (mosaic bedding layer) was set below the masonry level. Second, there is the problem of suitable presentation of the original and the challenges of finding a suitable space large enough to accommodate the mosaic's dimensions and an interior with suitable climate quality.

The proposal of the two options is based mainly on the following facts: (a) the mosaic is clearly endangered by the corrosion process; (b) assuming that advances in conservation research continue, an improvement of Option I is possible, which, in any case, is less expensive; and (c) other types of mosaic surface protection (such as installation of a protective glass panel in front the mosaic) would probably not be accepted for aesthetic reasons (although similar solutions have been used on many important monuments in Europe).

1986 On December 9, 1986, another report on preservation of the Last Judgment mosaic was prepared by M. Schatz of the Institute for Chemical Technology. According to Schatz, the use of special epoxy resin proved that it could work well as a protective layer for a maximum of fifteen years. However, its removal is difficult; physical and chemical methods, such as solvents, cannot be used; and only mechanical removal is possible. Further hydrophobic treatments using silicone did not provide sufficient longevity. Schatz considered especially unsuitable the use of Lukopren N 1000. This pure polymer is soft and highly permeable to gases, especially polar gases such as SO_2. In general, the use of any wax or stand oil is problematic.

According to the written data and practical experience, two protective systems can be considered:

1. A combination of copolymer polybutylmethacrylate with the silicone resins, the way Siquieros used them as binding in his outdoor frescoes. This combination provides a long-lasting compact hydrophobic transparent film that is easy to remove or repair even after five years of outdoor exposure.
2. The commercially available polyvinylbutyrate-based material (Butaflex) used to repair damaged windshield glass is sufficiently stable against degeneration, since, as proved in practice, it remains transparent even after twenty years. At the same time, it is gas-permeable to some degree—and thus does not create pressure barriers. Such a material can be easily washed with water, and it has a low diffusion coefficient for water vapor.

Conclusion

The conservation treatments done in the past proved inadequate, and the studies discussed above did not offer any hope at the time for successful prevention of corrosion of the mosaic. This led to a situation in which various groups of historians, scientists, restorers, and others disagreed about whether to remove the mosaic and replace it with a copy or to try again to save it in situ.

Hope for the rescue of this important, much discussed monument appeared after 1990, when representatives of the Getty Conservation Institute decided to provide assistance to the central and eastern European countries. Contact was established with the Office of the President of the Czech Republic. And an agreement for collaboration between that office and the Getty Conservation Institute for the conservation of the Last Judgment mosaic was signed in late fall 1992.

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Notes

1. Matějček, Antonin, 1915, "Das Mosaikbild des Jungtes Gerichtes am Prager Dom," Vienna, *Jahrbuch des Kunsthistorische Institutes der K.K. Zentralkomission fur Denkmalpflege*

Jan Boněk

Chapter 7
The Use of Visual Records for Reconstructing the History of the Last Judgment Mosaic

When an agreement was signed between the Getty Conservation Institute and the Office of the President of the Czech Republic in 1992 for conservation of the Last Judgment mosaic, one of the first and initially most important tasks was to gather all the available visual documentation. This soon proved a difficult undertaking, since the Archive of the Prague Castle did not engage in collecting visual documents until the 1920s. Thus the only option was to search other Prague archives, as well as libraries, museums, antique shops, and private collections. Finally, between 1993 and 1995, almost one hundred drawings, copper engravings, lithographs, and photographs were found in various conditions in thirty collections depicting the mosaic in a variety of settings in the period between the beginning of the seventeenth century and the mid-twentieth century. It is logical that many of them capture the main, so-called Third Courtyard of the Prague Castle with the unique view of St. Vitus Cathedral. After all, it is one of the most beautiful places in the city. But it was surprising to discover that the artists, who were often well known and highly respected in the art world, had overlooked the large area of the mosaic despite their apparent effort to capture the reality of the scene with the utmost precision. Based on studies of *vedute* (city views) and the records of the artists' work styles, there can be only one conclusion: the artists did not see anything in the place where the mosaic was located; the mosaic was obscured by layers of corrosion, as well as ordinary grime. There is no other explanation for the fact that artists who used binoculars to capture the smallest details in their work repeatedly overlooked the important mosaic above the cathedral's main entrance or changed it beyond recognition.

The assembled collection of graphic depictions of the mosaic, although they did not provide the mosaic's conservators with substantial or useful information for their work, uniquely documented the importance of this artwork created in the time of King Charles IV. The photographs that have been discovered can help in future analyses of the changes presumably done to the mosaic by restorers in previous centuries. Initial attempts to compare historic photographs with the mosaic's current condition, using digital technology, have already brought some promising results.

Drawings and Graphic Art

The first suggestion of a mosaic, or more precisely of the Golden Gate of St. Vitus Cathedral, was captured by an artist in a famous *veduta* of Prague in 1606. This *veduta*, which was published by Jilji Sadeler, a leading draftsman at the court of Rudolf II but executed by Philip van den Bosche, another of the emperor's court artists, is 50 by 300 centimeters. It captures an unusual number of details, including the Golden Gate (fig. 1). This *veduta* is important mainly because it supports the statement in the contemporary chronicle of Beneš Krabice of Weitmile, "The golden mosaic glowed above Prague in the setting sun."

The oldest preserved *veduta* of the Third Courtyard of the Prague Castle (today only a black-and-white photograph exists) was included in a private collection of Bishop Antonin Podlaha, a renowned art historian and expert on the history of St. Vitus Cathedral. It was a gray-black, pen-and-ink wash drawing by Jan Josef Karel Dietzler, dated 1733 (fig. 2). This artist is also important because his occupation, surveyor for the State Land Register, meant that precision

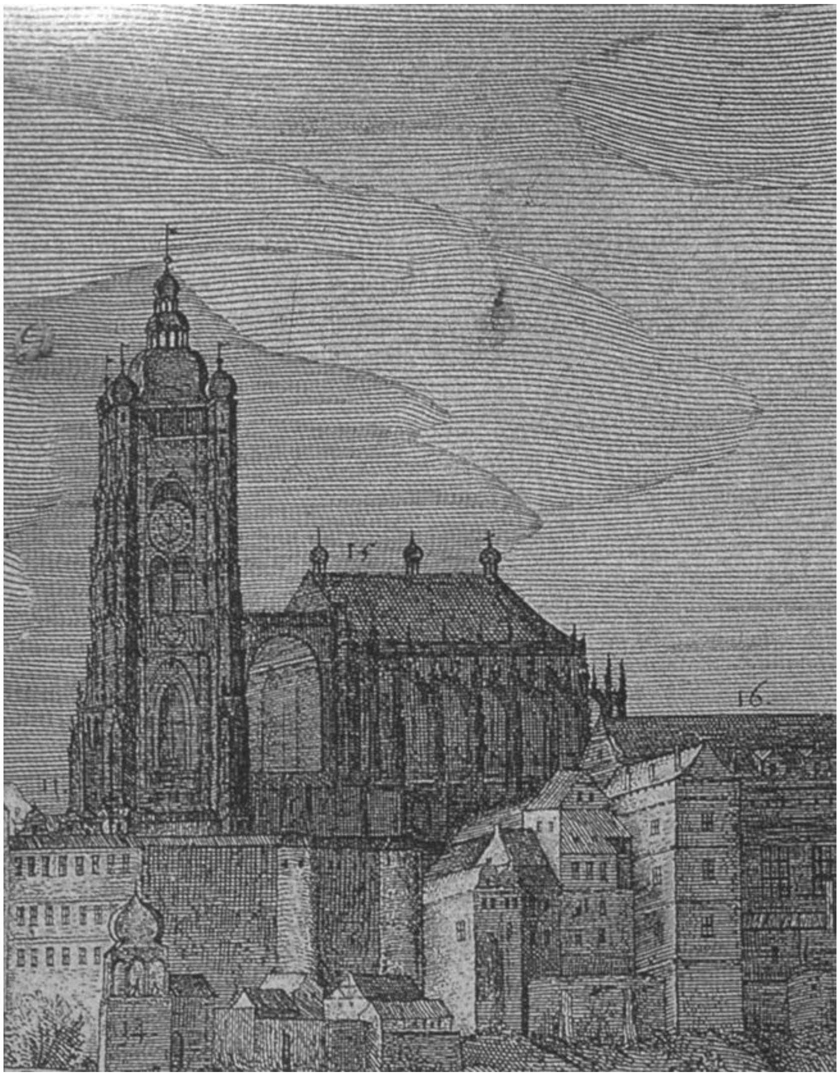


FIGURE 1 View of St. Vitus Cathedral; detail from the *veduta* that was published in 1606 by Jilji Sadeler. Reproduction by Jan Boněk, from the author's private archive.

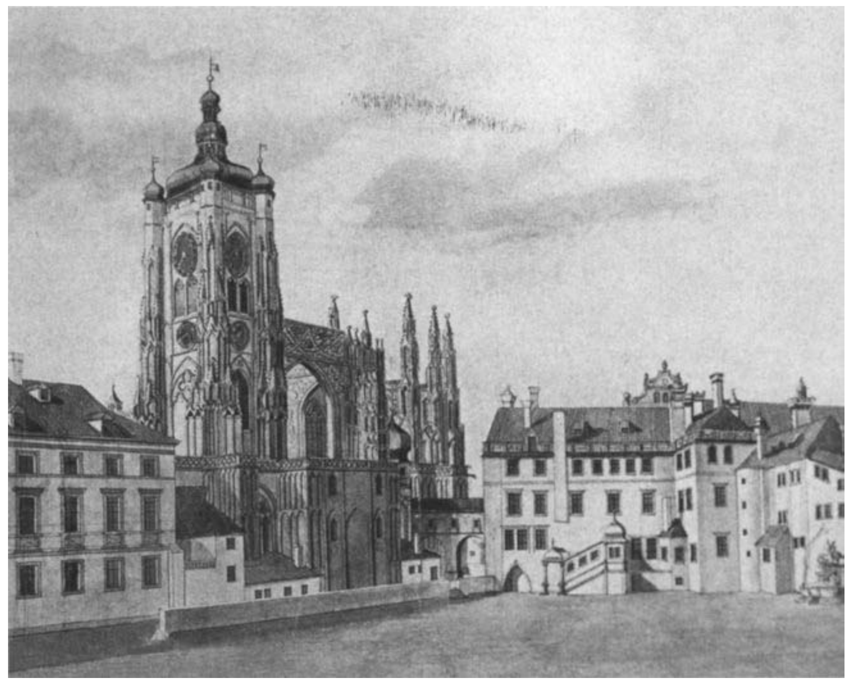


FIGURE 2 Drawing by Jan Dietzler, 1733. Reproduction by Jan Boněk, from the author's private archive.

was the law. In addition to producing many official city views of Czech towns and city plans, he was entrusted with a prestigious task: to capture in an extensive pictorial reportage the coronation of the Austrian empress and Bohemian queen, Maria Theresa. All of his works are very detailed, preserving correct proportions and perspective; only in his drawing of the Third Courtyard of the Prague Castle a neutral gray area appears in the place of the presumed mosaic. However, the drawing has an irreplaceable documentary value. It explains why there was not one record of the mosaic in the second half of the seventeenth century and during the eighteenth century: there was almost nothing to be seen on the large area above the cathedral's entrance. Dietzler's drawing unintentionally proves this.

In 1740 Bernard Friedrich Werner, a graphic artist and engraver, who was well respected throughout Europe,

FIGURE 3 St. Vitus Cathedral, portrayed in the engraving by F. B. Werner and M. Engelbrecht, 1740. Reproduction by Jana Jelínková, No. AMP-54, © Archive of the Capital City of Prague, 110 00 Prague 1, Husova 20.

created thirty-five individual copper engravings for a three-volume publication about Prague, which was published in Augsburg. The *Dictionary of Artists* states that his work also was considered very precise and realistic. Surprisingly, Werner captured the mosaic in his drawing of the Third Courtyard, although it is crudely distorted. But this is the first known depiction of the mosaic (fig. 3).

Fifty years later the father and son Philip and František Heger, both architects and recognized draftsmen, captured the mosaic in their work. Experts claim that the precision of their drawings was without comparison at the end of the eighteenth century and that it is of greater value than their architectural work. The straightforward quality of their entire collection of twenty-six views of the city is appreciated even today by monument preservation specialists, who use these drawings for the renovation and reconstruction of Old Prague. However, in their otherwise excellent copper engraving of the Third Courtyard of the Prague Castle from 1792, donated to Emperor Franz II, they depicted only an outline of the mosaic (fig. 4). Nevertheless, they were the first to try to capture the mosaic's composition. It is interesting that they managed to depict the central panel of the

FIGURE 4 The Third Courtyard of the Prague Castle, in the copper engraving by Philip Heger and František Heger, 1792. Reproduction by Jana Jelínková, No. AMP-124, © Archive of the Capital City of Prague, 110 00 Prague 1, Husova 20.

mosaic quite realistically, probably including the much-discussed inscription that identified individual figures of the Bohemian patrons. In contrast, the left and right panels only remotely correspond to reality, including the dimensions of the window that opens into the coronation chamber, which is completely out of proportion.

The unreliability of these preserved drawings is confirmed by one unique bit of evidence. At the same time that he was engraving pictures for the Hegers, Kaspar Pluth published his own versions of Prague city views, in the same year, 1791. Yet in his drawings he captured only a vague outline of the mosaic. Two years later Leopold Paukert published a series of eighteen Prague city views, and in the location of the mosaic he chose a gray, almost neutral area without any suggestion of visual motifs (fig. 5). Although he did not possess a sense for documentary depiction of reality, as is evidenced by his picture of St. Vitus Cathedral, he paid great attention to details such as horses and carriages of the imperial court, spectators with dogs, palace decorations, roof tiles, chimneys, and cobblestones. It thus remains a great mystery why he did not commit a single line to the mosaic.

Finally, there is the most renowned authority on drawing in nineteenth-century Prague, Vincenc Morstadt, by employment a counsel to the Regional High Court in Prague, by profession a self-taught draftsman and engraver. From the age of seventeen he painted the romantic Prague in the Empire style. His drawings, watercolors, etchings, and engravings were very popular at one time. Today approximately three thousand of his Prague city views are known. He had no rival in his time. Morstadt was an admirer of precise drawings and was one of those who used binoculars while he worked. His work is valued as a document of the period. Several times between 1826 and 1840 he depicted the view of the south side of St. Vitus Cathedral using various techniques, from pen-and-ink drawings to steel engravings. His pen-and-ink drawing of the unusual southeast view is considered the oldest. This precise drawing for the first time absolutely respects the mosaic's composition with all details, composition of figures, and the ornamental band above the mosaic (fig. 6). Thus far, it has not been satisfactorily explained how he could see all the details ten years before the mosaic's first major restoration. Other known works, excellent colored etchings, only capture the mosaic as a segmented swath of color within the overall

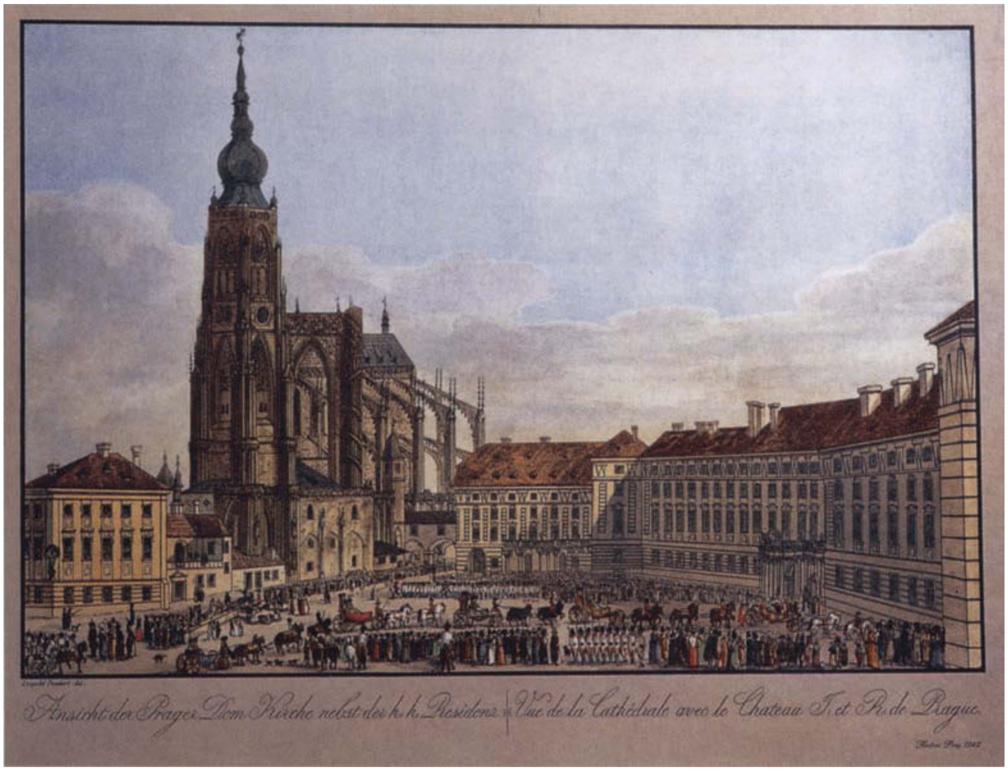


FIGURE 5a,b The Third Courtyard of the Prague Castle (detail below), by Leopold Paukert, 1793. Reproduction by Jan Boněk from the author's private archive.

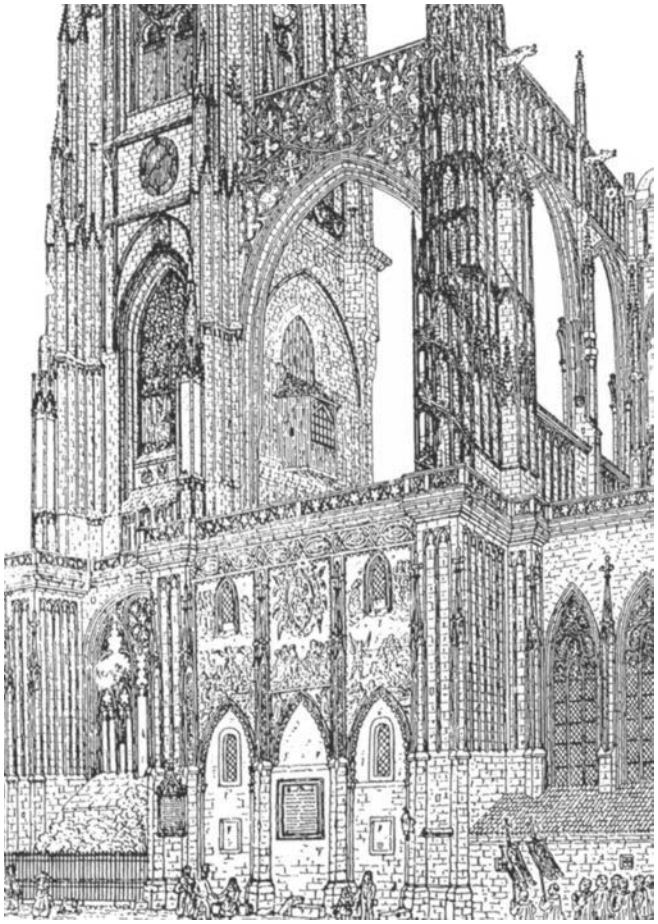


FIGURE 6 Rendering of the southeast view of the cathedral by Vincenc Morstadt, pen-and-ink drawing, 1827.

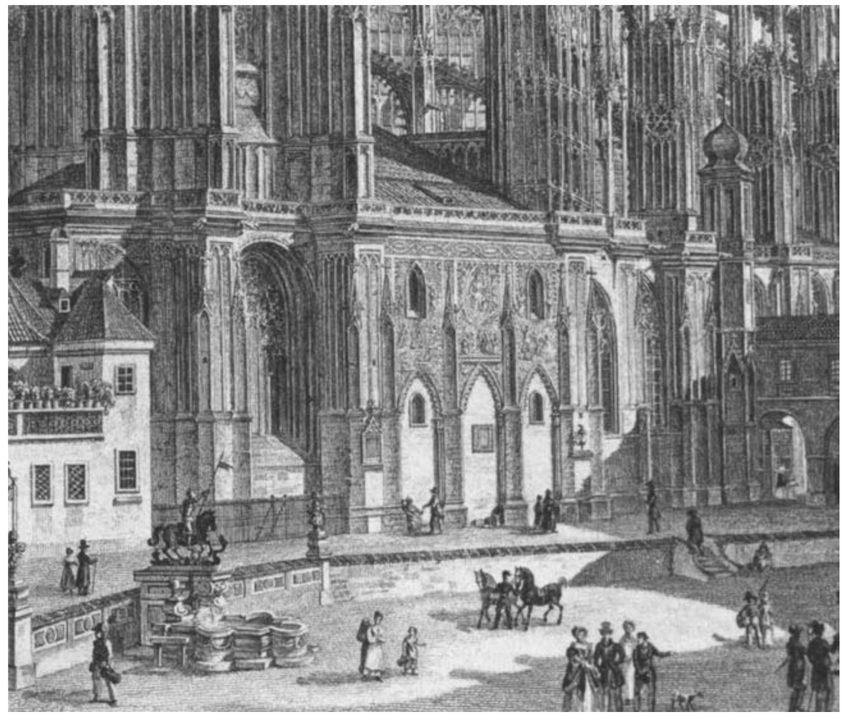


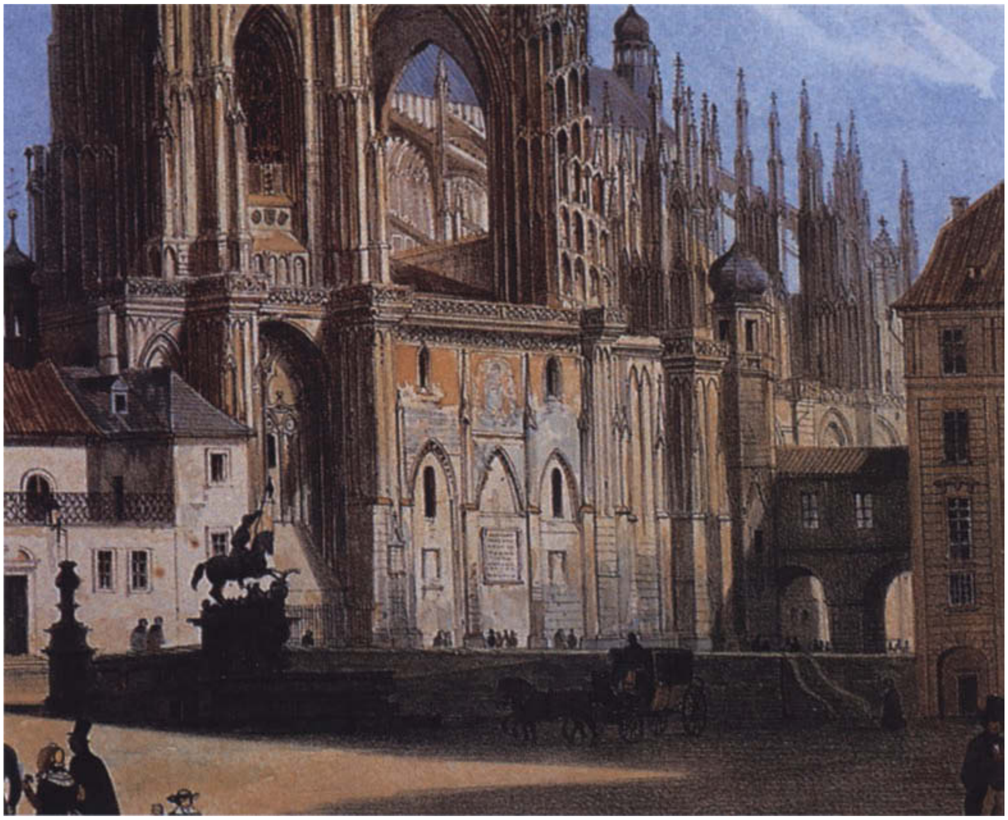
FIGURE 7 Vincenc Morstadt, steel engraving, 1835. Reproduction by Jan Boněk from the author's private archive.

scheme of the cathedral depiction. Thus Morstadt's series of steel engravings in *Prague in the Nineteenth Century*, by the Prague publisher Andre, is even more important. In these engravings the mosaic is captured in all its details, to the limit of this technique (fig. 7). It is interesting to note that Morstadt never again returned to steel engraving as an artistic method. He said that it was too cold and did not allow for capturing the *genius loci*. Nevertheless, this work represents the richest source of information for studying the mosaic before the invention of photography.

The 1836 color lithograph by the court artist Eduard Gurck is also important for studies of the mosaic's preservation history. It captured the Third Castle Courtyard during the coronation of Ferdinand V. The work shows why it was necessary to repair the entire 85 square meters of the mosaic. During this celebration, somebody may have finally noticed that its condition had seriously deteriorated. After all, the mosaic was located directly opposite the coronation balcony of the Bohemian royal residence (fig. 8). Gurck captured everything that had been preserved. The central panel with remains of gilding in the mandorla, the still intact upper ornamentation, and the remains of the mosaic on the side panels, including the large area where the mosaic was ripped all the way down to the stone facade of the building. By coincidence, three years later, in 1839, the Highest Burgrave of Prague, Count Chotek, commissioned

FIGURE 8 Coronation of Ferdinand V in 1836 in Prague, by Eduard Gurk. Reproduction by Jana Jelínková, No. AMP-1760a, © Archive of the Capital City of Prague, 110 00 Prague 1, Husova 20.

a



b

FIGURE 9a,b St. Vitus Cathedral in 1840, by Frantisek Xaver Sandmann (detail left). Reproduction by Jan Boněk from the author's private archive.

the author of this lithograph to repair the mosaic. A metal support grating had to be attached; sections that threatened to fall off were secured with large flat-head nails; the destroyed sections were covered with mortar; and two artists (Kandera and Lhota) were selected to paint in the missing motifs. The mosaic's surface was treated with varnish but in such an unprofessional way that within twenty years the colors again faded into a characterless gray. A note in the Annual Report (Ročenka) of the Union for Completion of St. Vitus Cathedral confirmed the bad condition of the mosaic, stating that local children had been throwing stones and managed to knock down the glass tesserae. In 1857, after a period of hard rain, almost all of the ornamental band had broken off, pulling with it sections of the gold background on the side panels. This initiated a thorough study of how the mosaic could be saved, and whether this was in fact possible.

When the idea of the completion of St. Vitus Cathedral was revived in the 1840s and 1850s, a number of artists proposed their versions of the cathedral's views. Often these were artists who lived in Vienna or Paris and who were highly respected in their time. Their professional specialty was capturing views of important European monuments in their drawings. Some had had their entire pictorial works published. Their names were Alt, Tübert, Mathieu, Remée, and Sandmann. In all of their work we can see an almost stubborn insistence on capturing everything that was visible on the mosaic. Their drawings clearly demonstrate that they were aware of the mosaic's significant role in the overall composition of the cathedral. The problem was that they could barely discern anything. For example, Frantisek Xaver Sandmann, a draftsman and lithographer living in Vienna who also published several books about important European cathedrals, was completely helpless in depicting the mosaic in his usual precise manner (one need only look at the grille from the Rudolf II period) (fig. 9). So was Rudolf Alt, who was one of the most renowned *veduta* artists, with commissions from all over Europe. He was knighted for his work and named an honorary member of the Academies of Fine Arts in Vienna and in Berlin. He too was unable to capture the mosaic in any other way than as a neutral area (fig. 10).

Completion of the Cathedral and Its Documentation

One exception that can be included among artistic works is the historically valuable paper copy of the mosaic, on a 1:1 scale, which was commissioned after 1881 by the architect Josef Mokr, the builder in charge of the completion of St. Vitus Cathedral. As recently proved, this copy was made directly on the mosaic. With the exception of some sections containing *incarnats* (flesh tone areas where natural stones were used), the composition of all tesserae was preserved as they had survived. According to Mokr's testimony, this copy, which was difficult to make, was commissioned as a backup, since during the preliminary inspection, the mosaic specialists who had been brought in expressed concern that the fragile artwork could crumble in the process of removal from the cathedral's facade. A second copy was made, which was later cut into 274 artistically logical sections that served as a guide during the mosaic's removal (fig. 11). These sections were copied to sheets of textile and hard cardboard, to which individual sections of mosaic were later glued. The original color "paper" copy served the restorers in the 1960s as objective proof that the mosaic restorers had acted haphazardly on some sections during the mosaic's reinstallation in 1910, especially on the left and right panels. The central panel, according to the same analysis, was transferred with great care. It is especially important that at the same time, and for the same reason that the paper copy was made, photographs were commissioned from the photographer Jindrich Eckert.

Photography

We will probably never know exactly when the oldest photograph of the mosaic was taken. Based on other circumstances, we can deduce that it was taken sometime between 1852 and 1857 by the photographer Jan Maloch (fig. 12). In 1852 Maloch opened his photography studio in Prague, and in 1857 a significant section of the mosaic fell off, which is missing in the later photographs. But under no circumstance is the author of the photograph the man who signed it. Maloch's son Karel (not born until 1858) merely took advantage of the situation when he acquired more than eighteen thousand negatives in his father's firm and started publishing collections of photographs of monuments in Bohemia. Although the only preserved photograph of the mosaic had lost its technical quality, Adobe Photoshop has made it possible to correct the image to the extent that in

FIGURE 10 (OPPOSITE) View of St. Vitus Cathedral and the Last Judgment mosaic in 1850 by Rudolf Alt. Reproduction by Jana Jelínková, No. AMP-906, © Archive of the Capital City of Prague, 110 00 Prague 1, Husova 20.

FIGURE 11 (ABOVE) One of the sections of the 1890 paper copy of the mosaic, now in the Prague Castle Archives. Photo: N. Agnew.

FIGURE 12 The oldest known photograph of the Last Judgment mosaic, taken between 1852 and 1857. Reproduction by Jan Boněk, © Naprstek Museum, 110 00 Prague 1, Betlemske nameští 1.

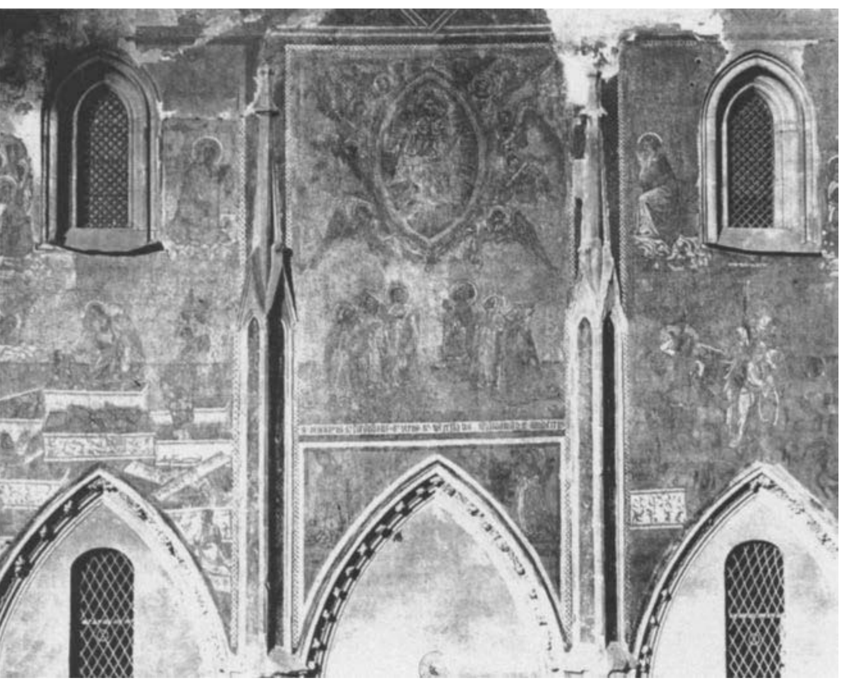


FIGURE 13 Computer version of the oldest known photograph of the mosaic. The image was processed by Martin Martan and Jan Boněk.

some sections of the photograph we can study, at a resolution of 800 dots per inch, individual tesserae as well as traces of the metal support grating and nails that held the mosaic to the cathedral's facade in the nineteenth century. (fig. 13) To the detriment of any research work—although the photograph was taken on a 24-by-30-centimeter negative—it had lost the necessary sharpness as a result of environmental chemical reactions.

The unique significance of this photograph for further historical research of the mosaic's condition lies in the fact that it was probably taken before 1857, when a significant section of the mosaic fell off in the area between the central and right panels due to long-term neglect. Only further research, using powerful computers, can elucidate the level of the quality of later repair work and additions.

Finally, we have the photograph commissioned from Jindřich Eckert, the most respected photographer in Bohemia at the time. According to the invoice from December 17, 1879, the photograph was taken on June 7 of that year (fig. 14). The excellent quality of this photograph, capturing virtually every detail of the mosaic's condition, was also confirmed by the original negative found in the depository of the Archive of the Capital City of Prague. The image has an irreplaceable value for evaluating the mosaic's condition (fig. 15). It enables us to examine in the smallest details the mosaic's condition before its removal from the cathedral's facade and to determine quite precisely the extensive subsequent repairs. Although the Union's records state that during the repairs a specially colored mortar was used, research on the mosaic would have been much more difficult if the original medieval tesserae were used.

At the end of the 1880s the cathedral was photographed many times. The images document the cathedral's phases of completion, but they also offer proof of the important role of the Golden Gate and the Last Judgment mosaic in the overall architectural composition. Although we cannot determine from looking at the construction stages captured in the pictures the exact date when the photographs were

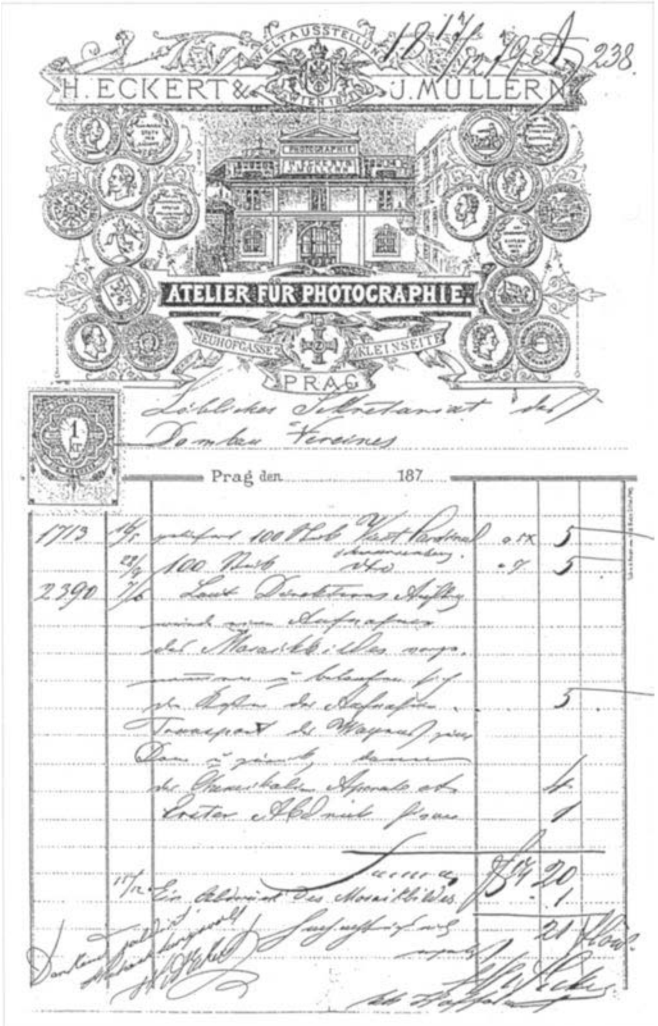


FIGURE 14 Invoice from the photographer Jindřich Eckert exactly documents the origin of the photograph. The original is in the Archive of the Prague Castle.

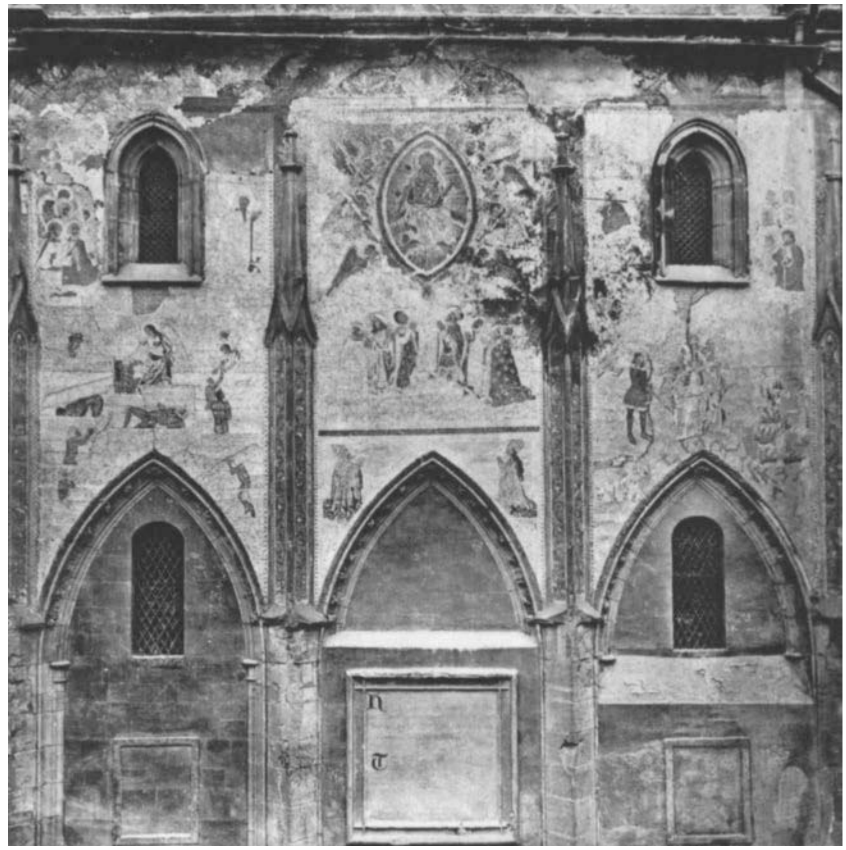


FIGURE 15 A copy of Jindřich Eckert's photograph from 1879 was made from the original negative. No. AMP-VI.32/20a/XI.2312/X.18499, © Archive of the Capital City of Prague, 110 00 Prague 1, Husova 20.

taken, for the purposes of studying the mosaic their importance is only that they were taken before 1890. All were taken from a distance, which allowed a view of the entire cathedral.

Two similar photographs are important for discerning the circumstances of the mosaic between the nineteenth and twentieth centuries, when the mosaic was removed and then reinstalled after twenty years. The negatives of these photographs were discovered in the most extensive and important private archive in Prague, which belonged to the publisher Jan Štenc. According to an entry in the firm's oldest catalog, one of the photographs was taken in 1908 and is probably part of the documentation of Viktor Förster's mosaic studio. It was Förster who, after much discussion about the fate of the mosaic, was entrusted with restoration of one panel, "as a test." A detailed study of the photographs reveals that the first panel had uneven edges when it was dismantled from the cathedral's facade. In the second photograph everything has already been replaced, cleaned, and repaired (fig. 16a, b). It is known that Viktor Förster proved himself through the quality of this work and therefore was commissioned to reinstall the original mosaic in its place.

FIGURE 16a,b Unique images of one panel before the repair in 1890 and after restoration in the mosaic studio in 1910. © Štenc Archive, Prague.

a

b

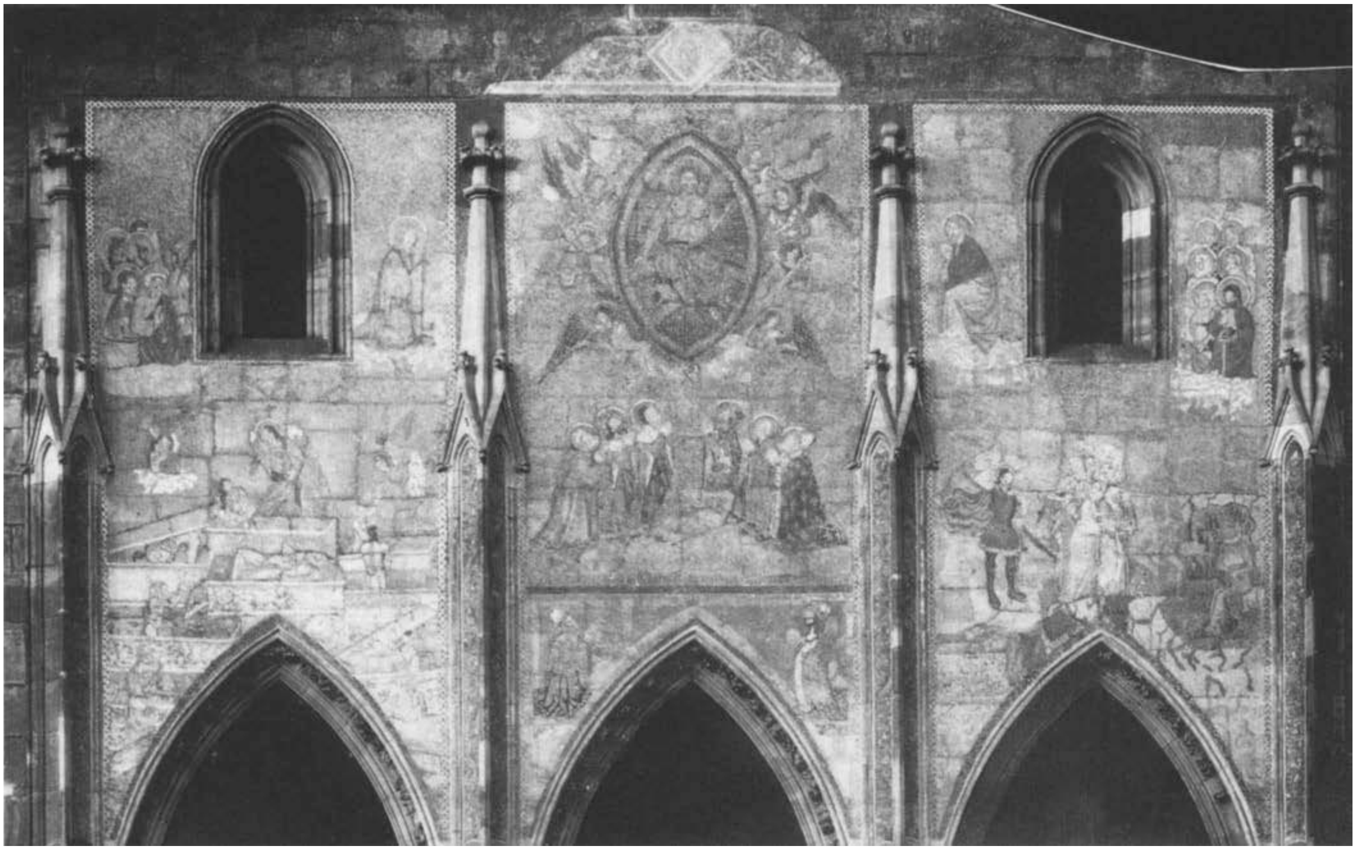


FIGURE 17 The only known image of the Last Judgment mosaic taken immediately after its reinstallation above the Golden Gate of St.Vitus Cathedral in 1910. © Štenc Archive, Prague.

The collection of detailed photographs of the mosaic, including one of the entire mosaic already reinstalled on the cathedral (fig. 17), dates from the time shortly after Jan Štenc opened his graphics studio in 1913. The pictures were taken before final treatment of the background was performed; individual panels can be recognized by the way they were originally set in the mosaic. Also, this information is very important for detailed studies of the original sections of the mosaic.

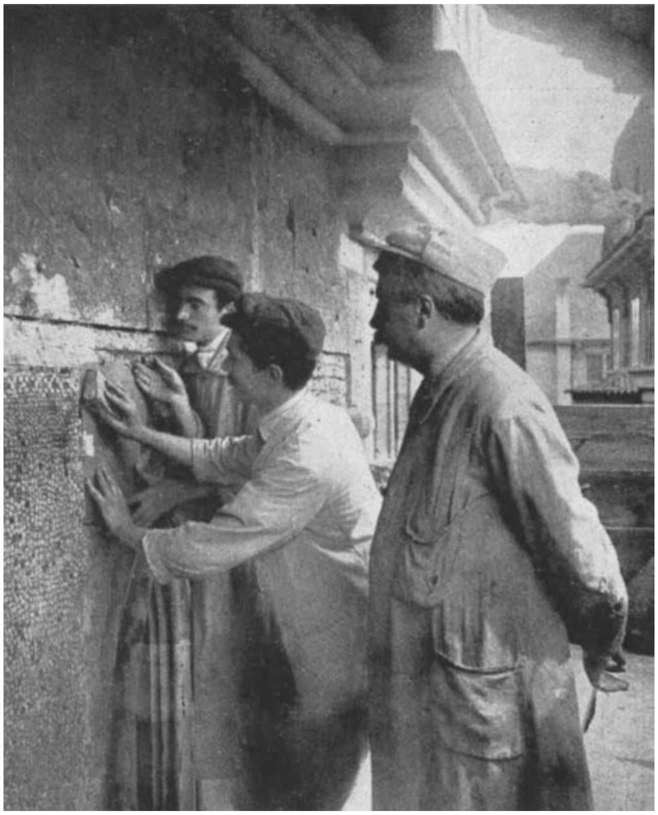
Another unique document capturing the work on the mosaic has been preserved: one of the first photographic documentaries in Europe. We must bear in mind that it was the year 1910. The entire collection captures Förster and his four Italian workers as they gradually reinstall the mosaic in sections. The photographs were taken by one of the first Czech photojournalists, František Pavlík, for *Český Svět* magazine (fig. 18a–f). It was the first photo reportage in the six-year history of this weekly, and was initiated by the public, which for twenty years followed the discussions about the fate of the dismantled mosaic. It seems that it would not be an overstatement to say that it was this same public interest that contributed largely to the decision to return the mosaic to its original place.

Although a number of photography books on Prague Castle and its cathedral were published in the twentieth century, the photographers avoided the location of the mosaic. This was logical. Every attempt to clean it and refresh its colors soon ended unsuccessfully, as evidenced in every photograph. In 1958 a special publication, *Medieval Mosaic*, by the photographer Alexander Paul and the art historian František Petăs, was made available to the international public (only in English); it contains fifty-two oversize close-up images of the mosaic's structure, thus failing to show the aesthetic beauty of the artwork as a whole. In addition,

FIGURE 18a–f Collection of images published at the readers' request in *Český svět* magazine, documenting the mosaic's return to the facade of St. Vitus Cathedral in 1910. Reproduction by Jan Boněk from the author's private archive.

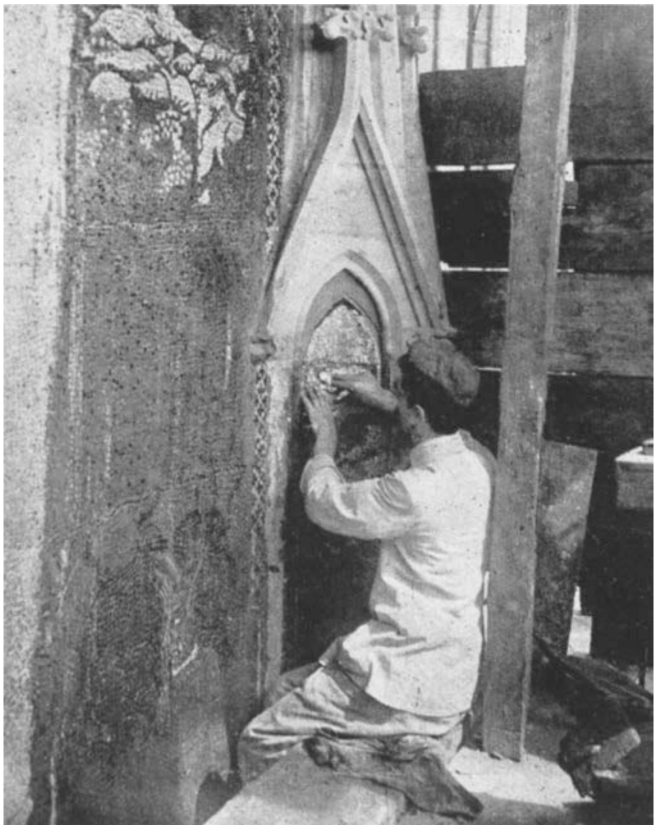
a

b



c

d



e

f

FIGURE 19 The mosaic immediately after conservation treatment in 1978.
Photo by Karel Neubert. ©Karel Neubert.

these photographs were taken before the first extensive restoration of the mosaic after the war. Only one image is worth mentioning—that of the entire mosaic. According to the photographer's documentation, even this image was taken before the first restoration in 1955. The image provides unique evidence of the catastrophic condition of the mosaic after so many unsuccessful attempts at restoration.

We must also pay attention to the 1978 photograph of the mosaic that was taken by another renowned Czech photographer of art monuments, Karel Neubert (fig. 19). This photograph, probably the most widely published, captures the mosaic before the completion of restoration and conservation work, when the central panel was not yet gilded. The viewer's eye is drawn to the red hues of the background. It is even possible to recognize in the individual panels traces of the mosaic's dismantling at the end of the nineteenth century, as well as the different colors of the replaced tesserae. Of course, the photographer knew that he was working on an unfinished project, and he therefore returned to the subject after several years. But by then the mosaic was again obscured under a gray film of corrosion. And the photograph was no longer usable.

Finally, a note about the classic Czech photographer whose work belongs to the golden age of Czech culture. Karel Plicka published his *Pražský hrad* (Prague Castle) to great public demand in eighteen editions, but he took his first photograph of the mosaic only for the seventh edition. Surely, he knew why. In the book's notes he wrote that the

photograph was taken immediately after the mosaic's restoration in 1978 (fig. 20). But by the beginning of the 1980s, there again was nothing to photograph. The deterioration of the Last Judgment mosaic's surface had resumed at murderous speed.

FIGURE 20 The great Czech photographer Karel Plicka waited fifty years for the opportunity to take a good photograph, seen here, of the Last Judgment mosaic. © 1978 Karel Plicka.

Appendix

Jindřich Eckert's invoice for the photograph of the mosaic, from Czech translation of the original German.

December 17, 1879

Photography Studio
Novodvorska Street 2, Mala Strana, Prague
The Esteemed Office of the Union for the Cathedral's Completion

1713	May 16	100 "cardinal" calling cards delivered	@ 5kr	5
	Sept 28	100 ditto	@ 5kr	5
2390	June 7	As per request from the director's office a photograph of the mosaic has been produced, and the cost incurred is		5
Transportation to the cathedral and back, chemicals, equipment, etc.				4
Cost of one copy				1
	Total in gulden			20
	Dec 15	Copy of the mosaic photograph		1
				21 gulden

Thank you for your payment.
Respectfully,
Jindřich Eckert
Photographer of the Royal Court

Chronology of the Last Judgment Mosaic

1370–71	Construction of the Last Judgment mosaic at St. Vitus Cathedral, initiated by Charles IV after his travels in Italy.
1471	Vladislav Jagelonský decides to repair St. Vitus Cathedral. The receipts are very unclear. The king wants "to bring the cathedral to its former glory."
1478	Vladislav Jagelonský allegedly orders repairs on the mosaic in connection with the repairs done on the St. Wenceslas Chapel (probable, but not documented).
1509	Roof repairs, masonry and carpentry work; scaffoldings on St. Wenceslas Church mentioned. No mention of the mosaic; its repairs can only be assumed.
1535	Bohemian Chamber releases funds for repair of the cathedral, including repairs on the mosaic.
1535	Ferdinand I gives orders to find a way to repair the cathedral. He writes to the Bohemian Chamber: "It is high time to pay attention to the building; it is very decrepit and in need of expeditious repair." The Turkish Wars interfere with his good intentions.
1541	Extensive fire at the Prague Castle.
1541	The Third Courtyard built; many houses torn down; the Golden Gate is bricked in.
1619	The mosaic is allegedly plastered (no archival records support this).
1621	Emperor Ferdinand II donated 15,000 guldens for the repair of the cathedral and supposedly the mosaic as well (specialized literature uses this information, but no archival record is known).
1791	Coronation of Leopold II.
1792	Coronation of Franz I.
1832	Small repairs on the mosaic.
1836	Count Chotek orders provisional repair of the mosaic by Gurck; frescoes by Kondera and Lhota replace missing sections.
1836	Coronation of Ferdinand V.
1857	Almost entire ornamental band breaks off (water damage), and portions of the gold background in the main sections are ripped off.
1862	Restoration of the cathedral begins; exterior shield of the St. Wenceslas Chapel.

1863	Bricklayers and stonemasons repair the spiral staircase and foundation masonry.
1864	Repair of the south side of the cathedral; repair of the spiral staircase; scaffoldings at the cathedral site.
1864	Architect Kranner has meetings in Venice regarding the mosaic's repairs.
1868	New roof truss installed at the cathedral.
1870	Bricklaying of the pillars for the new section of the cathedral.
1872–99	Period of Josef Mokr, when the least sensitive interventions are undertaken in the cathedral.
1873–99	Length of the cathedral's nave extended.
1874	Construction of pillars completed at the south side of the cathedral.
1877–88	Mokr's project to complete construction of the cathedral. Unfortunately, he does not understand that Charles IV designated the south portal, Porta Aurea, as the main entrance and includes this, together with the St. Wenceslas Chapel, in the coronation ceremony. Mokr also does not understand that the Golden Gate, the Chapel,and the Last Judgment mosaic form a single unit, which, created by Peter Parler, became a unique architectural artwork that defied the usual scheme of a Gothic cathedral. Nevertheless, Mokr's proposal for relocation of the main entrance was accepted.
1879	The mosaic was cleaned by sandstone and coated with varnish. The mosaic is badly damaged; within a few weeks(!) the motifs again disappear.
1880	Buildings, small constructions, cellars, sheds, and stables at the south side of the cathedral, next to the provost's residence, are torn down.
1880–82	Bottom section of the tower is reinforced.
1881	The mosaic is reinforced with large nails.
1881–82	Color paper copy made of the mosaic.
1884	Support pillars at the St. Wenceslas Chapel cut.
1888	Repair of the southern portal; entrance through the Golden Gate opened.
1890	A second paper copy made of the mosaic to help during its removal.
1890	Mosaic removed. Discussions about what to do next, with respect to preservation and aesthetics. Work completed in three weeks. Mosaic specialist from the Neuhauser firm in Innsbruck involved in restoration work.
	In the nineteenth century the motifs on the mosaic become so illegible that dozens of artists who attempt to draw the mosaic's motifs are forced to improvise. They do not successfully capture even the crudest of outlines; courage and imagination must be employed. No one dares to reproduce the mosaic's motifs.
1889–92	Construction of two western towers.
1892	Steeples on the western towers.
1897–99	Exterior support system of the new construction.
1898	Iron roof truss; laying of roof tiles.
1900	Both western towers completed; scaffolding removed from the south side of the cathedral.
1903–14	Repair of the large tower and pinnacles; reconstruction of a Renaissance grille.
1907	Installation of a large window above the mosaic .
1908	Förster (1868–1915) repairs several square meters of the mosaic "as a test."
1910	Section of the mosaic in Förster's studio at the castle (expert inspection by the architect Mokr and the art historian Max Dvořák).
1910	Mosaic reinstalled by four workers from Venice. Förster is recommended for many other projects around Prague but dies in 1915.
1919	Mosaic cleaned, detected crack in the mosaic filled, missing tesserae replaced.
1923	Experiments with refreshing coats on the mosaic.
1926	Stairs installed in front of the south gate, under the mosaic.
1925–29	Archaeological excavations in the Third Courtyard.
1925–28	Paving of the Third Courtyard.
1928	Construction of a granite monolith on the Third Courtyard.
1928–32	Leveling of the Third Courtyard surface; statue of St. Jilji moved to its present location.
1930	Determination made that the motifs of the mosaics are illegible.
1951	Documentation by the State Photometric Institute, 160 images (C. Sila); the documentation is lost.
1953	Recommendation made to remove the mosaic and apply conservation treatment.
1954	It is not necessary to remove the mosaic, the corrosive film does not damage the glass!
1955	Alexander Paul takes forty-three color photographs, the fate of which is unknown.
1956	First experiments with restoration of the mosaic.
1957	Mozaika Company commissioned to restore the mosaic.
1959–60	Restoration of the mosaic.
1966–67	Further restoration.
1977–78	Restoration of the mosaic for the occasion of the *Charles IV Exhibition*. No time for gilding.
1980	Next phase of restoration; mosaic's legibility is rapidly diminishing.
1991	First visit of the GCI team.

Part II
Conservation Planning and Methodology

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Francesca Piqué

Chapter 8
Methodology and Ethical Issues for the Conservation of the Last Judgment Mosaic

Today the Last Judgment mosaic is considered one of the most important objects of cultural heritage in the Czech Republic. It is the oldest and most significant external mosaic north of the Alps and is of great importance for its historical, art historical, and scientific value and for the scale of its technical execution.

The Problem

Since its completion in 1371, the mosaic has undergone several cleaning and restoration treatments, the first documented as early as the 1400s. The conservation history shows that despite numerous attempts to repair the mosaic, it continued to deteriorate. The main deterioration problem has been the corrosion of the glass tesserae, which creates a grayish corrosion layer that obscures the astonishing colors of the mosaic and makes it illegible (fig. 1). Mechanical removal of the corrosion does not halt the process, and very rapidly the corrosion layer covers the mosaic again.

Figure 2 shows the mosaic in its entire splendor after the 1960s conservation; figure 3 presents an image taken thirty years later, in 1992, showing the mosaic in its corroded state when the joint Getty Conservation Institute–Office of the President of the Czech Republic project started. This clearly demonstrates the active, rapid deterioration process. Previous interventions had entailed removing the deterioration products but did not address the causes. The glass corrosion process and its mechanism is complex. Although the principal factors responsible for the corrosion mechanism are water and the poor quality of the glass, varying pollutant gases and atmospheric particles have played a role over the centuries.

Method and Approach

Given the complex, long conservation history and the extent of the deterioration affecting the Last Judgment mosaic, it was necessary to follow a systematic and methodological approach to developing a successful conservation plan. We used a methodology that addressed the causes of deterioration and favored preventive conservation over uniquely remedial interventions.[1] The mosaic's conservation history illustrates well how ineffective it is to undertake only remedial intervention.

Following a preventive approach through a problem-solving methodology presents a number of difficulties. It requires understanding the nature, the cause, and the rate of deterioration. Therefore, when planning for the conservation of the Last Judgment mosaic, it was necessary to use a multidisciplinary approach, integrating various types of investigation and data with the aid of a wide range of specialists—scientists, conservators, art historians, architects, and surveyors.

In addition to the problem-solving approach, the Getty Conservation Institute has adopted and adapted to suit its field projects a value-based Conservation Process that follows the Australia International Council on Monuments and Sites (ICOMOS) Burra Charter. In the value-based approach, decision making is guided by respect for and protection of the values of the object under conservation.[2] The basic principles of this approach can be summarized as follows:

- The primary objective of conservation is to preserve the cultural significance of an object or a place.

FIGURE 1 Close-up of deteriorated tesserae covered with glass corrosion products.

Therefore, conservation decisions must be based on complete knowledge of the object (including its context and values) and respect for the existing physical fabric.

- Any intervention should aim to be minimal and reversible, or at least to allow for the possibility of retreatment.
- Conservation becomes part of the history of the object. Therefore, documentation of every stage is essential so that those who come after us will know what we have done.
- Conservation is never a final solution, especially for objects exposed to the external environment. Any intervention must be seen in the context of a much larger planning and management effort that aims to develop a long-term strategy for the conservation, monitoring, maintenance, and interpretation of the site or object.

The Project

The conservation process was carried out in consecutive phases:

- Identification and description
- Assessment and analysis
- Response
- Implementation

Each phase had several components, described below.

Identification and Description

The first phase of the project involved the collection and study of all the existing documentation such as historical and

FIGURE 2 The Last Judgment mosaic after 1960s conservation. Photo: I. Plicka.

FIGURE 3 The mosaic in 1992, covered with a corrosion layer, at the beginning of the project. Photo: D. Stulik.

art historical records concerning the mosaic, its creation, and its physical history. Of particular importance were the written and visual records of the nineteenth- and twentieth-century interventions on the mosaic and the extensive existing literature on the technology and deterioration of glass mosaic.[3]

During this phase, the project team was created, and the objectives of the project were clearly defined with the stakeholders, in this case the Office of the President of the Czech Republic. A series of essential decisions were taken. It was agreed that no remedial intervention would be implemented before the development of a solution to stop deterioration from reoccurring. It is rare for a conservation project to be carried out with this kind of agreement whereby, obviously, one of the conservation options would be not to intervene.

When the GCI–Prague Castle collaborative project to conserve the Last Judgment mosaic began in 1992, some members of the conservation community, aware of the difficult conservation history of the mosaic, believed that the only option to ensure its survival was to remove it again and house it in a protected environment. It was proposed that a copy be made to replace the original on the facade. Others maintained that the mosaic should be treated in situ. After careful consideration, the joint project team agreed that removing the mosaic from its original location would seriously compromise its religious, social, and historical values. In addition, the storage of the mosaic and its possible exhibition would have been very problematic given its large size. Therefore, the team agreed that the mosaic would be treated in situ and that detachment would not be considered an option.

Assessment and Analysis

The assessment and analysis phase was central to the project and surely the most time-consuming portion of the whole process. The assessment included study and consideration of three aspects: the mosaic's cultural significance and value, its condition and problems, and the management problems that might affect its long-term protection.

The assessment of the mosaic's cultural values was an essential component of the project, given that the principal goal of conservation is the preservation of these values. A clear understanding of the values is crucial to the conservation process and was pivotal to making decisions about the mosaic. It was determined that the mosaic has very high historical, scientific, social, spiritual, and aesthetic values.

The assessment of the mosaic's condition and its conservation problems involved several years of study and research. The historical records and all available visual records were analyzed to reconstruct the mosaic's physical history.[4] The extensive historical and contemporary scientific data on glass mosaic, as well as scientific studies focusing specifically on the Last Judgment mosaic, were reviewed. The assessment phase also entailed the characterization of the mosaic's construction material, the environment and climate surrounding the mosaic, and the mosaic's condition.

The condition assessment showed that the mosaic was basically structurally stable (with the exception of a few cracks and loose tesserae) and that corrosion of the glass was the only active deterioration. Although this result was anticipated given the history of the mosaic, the identification of the glass corrosion as the active deterioration process was a crucial step in the problem-solving methodology aimed at the development of a preventive conservation approach.

Extensive scientific research was required to clearly understand the cause of the glass corrosion and to design and test possible solutions. The comprehensive studies carried out by Czech scientists in the 1950s provided an excellent source of information and the basis for additional scientific research on the deterioration of the medieval glass.[5] Our research essentially confirmed what the Czech scientists had discovered several decades ago: the deterioration is related to the intrinsic nature of the medieval glass, in particular its high potassium content. When in contact with water, brought to the surface of the mosaic by condensation and rain, the potassium moves out and, interacting with pollutants in the air, forms a gray layer of corrosion over the surface. The mechanical removal of this layer has not only been ineffective but also extremely damaging. These repeated cleanings have removed, along with the corrosion, the first few micrometers of the glass terrerae's surface, causing thinning.

Once the deterioration mechanism was confirmed, it was necessary to begin a systematic testing program to identify a suitable method for cleaning the mosaic, to identify a material to shield the glass from water, and to develop an in situ application methodology. The objective of the cleaning intervention was to remove the corrosion layer from the mosaic surface without harming the original glass and the traces of gold that had survived the centuries. However, it was agreed at the beginning of the project that while the research and testing of cleaning methods would start, no cleaning would be implemented before the development of an appropriate protective coating material. Cleaning tests were carried out in the laboratory and in situ. During in situ cleaning tests, it was found that clean areas corroded again in a few months and were no longer visible after four years. This illustrates the speed of the corrosion process.

The scientific research on appropriate coating material that would adhere to the cleaned glass and shield it from water was conducted in collaboration with several institutions.[6] The final protective coating system was developed with the Material Science Department of the University of California, Los Angeles. Various types of coatings were tested extensively. The advanced technology of protective materials—mainly used for medical and aerospace purposes—was applied to this centuries-old conservation problem. It was important to conduct testing not only in the laboratory but also in situ. Bringing the testing to the site allowed evaluation of the treatment under real conditions and the development of the intervention with the conservators, the ultimate executors of the treatment who must take into consideration the constraints of working on a scaffolding in an extremely variable climate.

Response

The response phase began while research and testing was under way. This phase involved making decisions based on the results of the assessment phase and planning the conservation implementation. One particularly difficult issue needing resolution was the final presentation of the once-gilded background of the mosaic.

The process and reasoning for making a decision about regilding the mosaic is an example of how a value-based approach is implemented. The Last Judgment mosaic has a long and complex history of intervention, including its detachment and attempts to restore its gilded background.

In 1890, after parts of the mosaic were torn away by strong winds during a storm, the entire mosaic was removed from the facade because this was considered the only way to save it.[7] To accomplish the detachment, the mosaic was cut into 274 sections and moved indoors for treatment. In 1910, twenty years after being detached, the conservators responsible for the mosaic determined that it could survive in situ. The detached mosaic sections were cleaned and consolidated as separate panels and then repositioned with a cement-based mortar on the south facade of the cathedral, the mosaic's original position.[8] This intervention included regilding original tesserae and adding new gilded tessera in the joints between each of the 274 mosaic panels and in the upper left and right parts where large areas of the mosaic were lost. The gilded tesserae were made with a glass more stable than the original and did not suffer from the same corrosion mechanism. Following the reattachment, the mosaic glass began to deteriorate again. In the late 1950s the mosaic was treated once more in situ.

Originally, the entire background of the mosaic was gilded, as was common in many medieval altarpieces. Mosaic gilding consists of applying an extremely thin layer of gold leaf to individual tesserae, then adding a thin layer of protective glass (*cartella*) (fig. 4). The corrosion of the glass of the gilded tesserae caused deterioration and loss of both the *cartella* and the gold leaf itself. As a result, only the red or blue glass tesserae over which the gilding had originally been embedded were left with some traces of original gold remaining. Although the original gold has been almost completely lost, the gilded tesserae added in 1910 to fill large losses and to join the 274 sections of the mosaic as it was repositioned have kept their gilded appearance. The resulting optical effect, noticeable when the project began,

FIGURE 4 Cross section of gilded tessera.
Diagram by F. Piqué, photo by M. Verità.

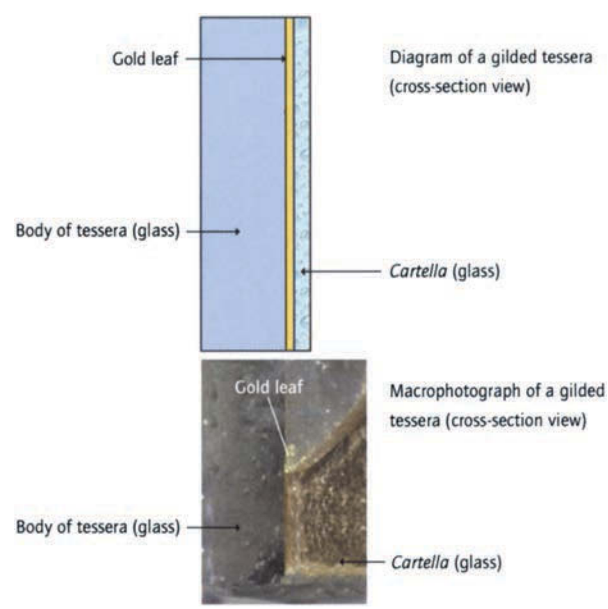


FIGURE 5 Central panel of the mosaic in May 1998, before cleaning. Photo: J. Zastoupil, 1998.

FIGURE 6 Central panel of the mosaic in July 1998, after cleaning and before regilding. Photo: J. Zastoupil, 1998.

was that of a gilded grid on a darker background—an effect particularly evident in the central panel (fig. 5). The same effect was evident on the rest of the mosaic's originally gilded background and was even more apparent after the tesserae were cleaned to remove the glass corrosion products (fig. 6).

To determine whether to regild the mosaic, it was first necessary to consider the importance of the gold. The golden color in the mosaic has significance that goes beyond aesthetics. It is intended to be the representation of heaven and has the added functional role of glowing and shining as it reflects sunlight. For these reasons—and because the entrance beneath the mosaic is called the Golden Gate—regilding had been undertaken in previous restorations.

Therefore, for aesthetic and symbolic reasons, our project team had to consider regilding. It was also clear that the ethical implications of regilding required thorough discussion. Was it appropriate to complete missing color? What should be done in the case of existing traces of old gold? What about places where it was not clear which tesserae were gilded? How much regilding should be applied, if any? Would regilding compromise authenticity and principles of minimum intervention?

To resolve these questions, an international advisory committee was formed.[9] Meeting in Prague in October 1996, the committee reached full consensus that the once-gilded background of the mosaic should be regilded. However, specific recommendations as to how the work should be carried out were as follows: nonbackground parts should be regilded only if there was certainty regarding their original color; tesserae with any traces of original gold should not be regilded; new gold leaf should not be applied to the whole surface of each tessera but only on parts of it; and some glass tesserae should be left ungilded. Thus an attempt was made to restore legibility and iconographic meaning without compromising authenticity and historical values.[10] (See fig. 7.)

Implementation

As agreed at the beginning of the project, the implementation phase started once the cleaning system and the protective

FIGURE 7 Central panel of the mosaic after regilding. Photo: J. Zastoupil, 2001.

coating were successfully tested. The treatment consisted of cleaning and coating application, including the gilded layer, and was performed in the following steps:

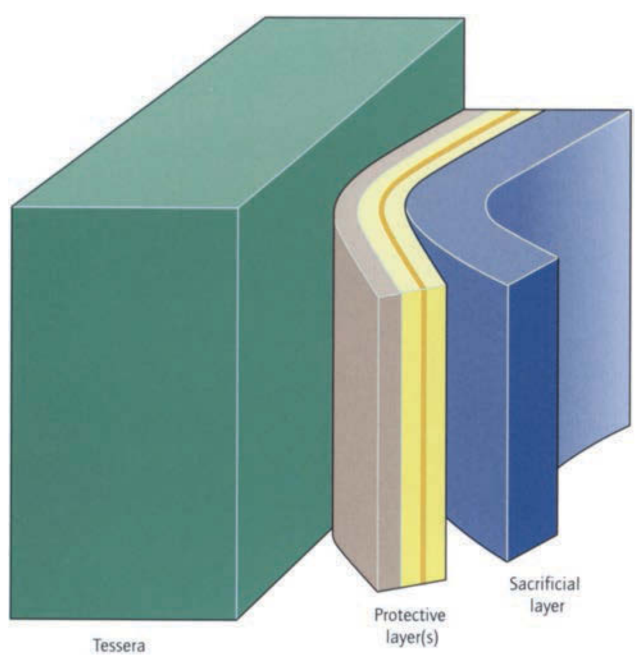
- mechanical cleaning of the mosaic surface to remove the corrosion products
- stabilization of the mosaic (filling of cracks and resetting of loose tesserae)
- solvent cleaning of the surface to prepare it for coating application
- application of first coating layer
- drying and setting of the coating using infrared lamps
- application of fluopolymer layer with cross-linking agent with gold leaf, where necessary
- application of fluopolymer without cross-linking agent (sacrificial layer)

The mosaic was cleaned with a stream of compressed air and microscopic crushed glass particles. It was determined that using glass particles harder then the corrosion layer but softer than the original glass would thoroughly clean the mosaic surface while automatically stopping the process once the surface corrosion was removed. The cleaned mosaic glass surface had to be prepared for the application of the protective coating to ensure good adhesion of the coatings. Adhesion was one of the most important properties of the coating to be achieved to ensure the long-term protection of the glass. Any zone without good adhesion is a potential entryway for water that can activate the corrosion process, which in turn can cause further detachment of coating, exposing more surface.[11] For this reason, before application of the coating the glass had to be cleaned with solvent to remove any dirt that might have accumulated after the mechanical cleaning.

The protective system developed is composed of several layers of coating that needed to set before the application of the next layer. The gilding was embedded in one of the layers. (See fig. 8.)

Each of the three mosaic panels was treated separately. It took approximately four months to carry out all the sequential operations on one panel. The conservation campaigns were carried out in late spring and summer to take advantage of good weather. The work started on the central panel in summer 1998; the whole mosaic was completed by September 2000.

FIGURE 8 Coating stratigraphy.



TREATMENT REVERSIBILITY

Reversibility is an ethical issue and one of the basic principles of conservation that must be addressed in treatment. Treatment reversibility is a concept that can rarely be achieved completely in practice. Realistically, conservators speak of *retreatability:* the principle that today's intervention will not compromise future conservation efforts and treatments. The challenge in any conservation project is to find the delicate balance between an effective intervention and one that is reversible or at the very least permits retreatment.

The intervention carried out during the Last Judgment mosaic project included cleaning, application of a protective coating, and regilding. Although reversibility was the team's goal in all cases, some aspects of the treatment are more reversible than others. Like all cleaning in conservation, removal of the corrosion layer was an irreversible operation that required great care so as to avoid damage to the historic surface. The protective coating, which is intended to function as a sacrificial layer that will inhibit future corrosion, is reversible technically; however, it is unlikely that attempts would be made to remove the protective coating. Instead, the treatment has been designed to permit maintenance and retreatment. The regilding technique was developed so that the new gold is embedded in the coating rather than deposited on the surface of the tesserae. It is, therefore, easily removable without affecting the historic material. In this sense, the aspect of the intervention that has the most striking visual consequences is also the most completely reversible.

Long-Term Protection

A monitoring and maintenance plan is essential to ensuring long-term results, especially for in-situ conservation projects. In the case of the Last Judgment mosaic, the principal deterioration mechanism—the corrosion of the glass tesserae—had already been well understood by Czech scientists in the 1950s. At that time, a conservation strategy similar in concept to the current intervention was developed. Essentially, the corroded mosaic was cleaned and then protected with a coating that would prevent water from reaching the cleaned glass tesserae. The failure of the 1950s intervention was due not only to the breakdown of the material chosen to act as a protective coating but also to the lack of maintenance following the intervention.

An important part of the Last Judgment mosaic project was the development of a monitoring and maintenance program that prevents deterioration from the cumulative effects of natural processes and human activities and enables those responsible for the preservation of the mosaic to quickly detect any failure in the protective coating. This should allow for rapid replacement of the coating and thus prevent a more widespread problem.

Project Sustainability

Sustainability is an issue that the GCI faces in all of its projects. The conservation solutions chosen in any particular case must be sustainable not only from the standpoint of materials and techniques but also in terms of economic, social, and political realities, that is, how will the artifact be cared for, managed, valued and curated in the future.

People are crucial to this endeavor. It is important that knowledge and skills are exchanged throughout the project so that those responsible for the continued conservation and maintenance of a site have the capabilities to do so. The Last Judgment mosaic project took place because of an extraordinarily fruitful collaboration in which dialogue and information exchange and dissemination were important to all participants. This project also had the benefit of the extensive knowledge of Alois Martan, who had been a member of the team that carried out the 1959–60 intervention. Moreover, the conservation team deliberately included both senior and junior conservators so as to ensure that the knowledge of the conservation project would be carried through to future generations.

In the case of the Last Judgment mosaic, one of the major challenges to sustainability is the technology developed for the protective coating and the fact that coating technology is changing rapidly. It is likely that some of the materials used in the conservation of the mosaic will not be available in their present form in the future. Thus it is essential that the project continue to include a research component through which new protective coating materials can be tested and evaluated for future use.

Notes

1. For a recent description of this methodology, see Cather 2003.
2. For a recent description of this conservation planning process, see Demas 2003.
3. Copies of written sources collected and studied are held in the archives at the GCI and the Prague Castle.
4. For mosaic visuals, see chapter 7.
5. Chapter 6 clearly illustrates that in the 1950s those responsible for the mosaic decided to use an approach similar to the one used today. The main difference is that at that time they thought moisture could be coming from the mosaic bedding layer and had designed the first coating layer to be hydrophobic to prevent this from occurring. During the current project, this possible source of water was ruled out. This led to the decision to design a proactive coating system to stop moisture from reaching the surface of the glass.
6. Thanks are due to Dr. Hannelore Römich of the Fraunhofer-Institut fur Silicatforschung, Wurzburg, Germany, for important preliminary testing with ORMOCER protective coating and for useful discussions on the topics.
7. There is no specific information on the amount of original gilding surviving in 1890 before the removal of the mosaic. Historical black-and-white photographs, particularly one dated 1879 (see chap. 7, fig. 15), show evident signs of deterioration in the upper parts of the mosaic but are difficult to interpret.
8. Although there is no documentary evidence, it is likely that when the new gold tesserae were introduced, the rest of the mosaic background was reintegrated by regilding original tesserae to ensure the homogeneous appearance of the whole. Therefore, this is very likely one of the regilding operations on the original tesserae.
9. The St. Vitus mosaic conservation ethic advisory board was composed of Annamaria Giusti, head, Stone Section, Opificio delle Pietre Dure, Florence, Italy; the late Baron Raymond Lemaire, honorary president of the R. Lemaire center for Conservation of Historic towns and Buildings, Leuven, Belgium; Dobroslav Libal, ICOMOS representative in Prague; Joseph Stulc, director, State Institute for the Care of Historic Monuments, Czech Republic; and M. Kirby

Talley Jr., project coordinator for conservation and restoration, Directorate for the Management of National Cultural property, the Netherlands.

10. Alois Martan reported that the ethical criteria followed in the late 1950s for gilding reintegration were the same as those recently proposed by the Prague regilding committee, with the exception that the issue of reversibility was not included. Before the 1959–60 restoration, the mosaic looked as it did at the beginning of this project in terms of the extent of gilding present. The background areas originally gilded were readily identifiable. The areas of missing gold on figures were less obvious. A decision was taken not to add any gold to the figures but only to the background.
11. This type of cyclic deterioration process occurred after the 1960s intervention.

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Color Plates

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PLATE 1 Overview of cathedral's south portal, with Last Judgment mosaic after treatment. Photo by D. Stulik, 2003.

PLATE 2 Last Judgment mosaic before treatment in 1995. Photo by D. Stulik, 1995.

PLATE 3 The Last Judgment mosaic, after conservation treatment in 2001.

Photo by J. Zastoupil, 2001.

PLATE 4 Lower half of right panel: sinners being condemned to hell.
Photo by J. Zastoupil, 2001.

PLATE 5 Lower half of central panel, including the tableaux of the patron saints of Bohemia, Charles IV, and Elizabeth of Pomerania.

Photo by J. Zastoupil, 2001.

PLATE 6 Lower half of left panel:
the Resurrection of the Dead.
Photo by J. Zastoupil, 2001.

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PLATE 8 Right panel (detail): six apostles. Photo by D. Stulik, 2000.

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PLATE 9 Central panel (detail): Christ in mandorla with angels. Photo by D. Stulik, 2003.

PLATE 11 Central panel (detail): the patron saints of Bohemia. Left to right: Sts. Procopius, Sigismund, Vitus, Wenceslas, Ludmila, and Adalbert. Photo by D. Stulik, 2003.

PLATE 12 Central panel (detail): Charles IV. Photo by D. Stulik, 2000.

PLATE 13 Central panel (detail): Elizabeth of Pomerania. Photo by D. Stulik, 2000.

PLATE 14 Left panel (detail): the Virgin Mary. Photo by D. Stulik, 2003.

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PLATE 15 Right panel (detail): John the Baptist. Photo by D. Stulik, 2000.

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Photo by D. Stulik, 2000.

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PLATE 22 Central panel (detail): angel. Photo by D. Stulik, 2000.

PLATE 23 Central panel (detail): angel. Photo by D. Stulik, 2000.

PLATE 24 Central panel (detail): St. Procopius. Photo by D. Stulik, 2000.

PLATE 25 Central panel (detail):

St. Sigismund. Photo by D. Stulik, 2000.

PLATE 26 Central panel (detail): St. Vitus. Photo by D. Stulik, 2000.

PLATE 27 Central panel (detail):
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PLATE 28 Central panel (detail): St. Ludmila. Photo by D. Stulik, 2000.

PLATE 29 Central panel (detail):
St. Adalbert. Photo by D. Stulik, 2000.

PLATE 30 Right panel (detail): the Archangel Michael banishing sinners to hell. Photo by D. Stulik, 2000.

PLATE 31 Right panel (detail): the condemned being banished to hell. Photo by D. Stulik, 2000.

PLATE 32 Right panel (detail): condemned souls being pulled into the fires of hell. Photo by D. Stulik, 2000.

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Marco Verità

Chapter 9
Technology of Italian Glass Mosaics

Until quite recently, mosaics have been studied in terms of their style or their iconology. Little attention has been paid to the production techniques of the tesserae. Some issues such as the fact that medieval Byzantine mosaics generally have a narrower color range than Western examples (three or four tones instead of eight to ten) and the use of marble instead of vitreous tesserae for carnations are still open to debate. Was this due to taste or technology? During the conservation campaigns of Italian medieval mosaics carried out in the past few years, a series of scientific and archaeological studies have been devoted to materials and working procedures, which coincided with compilations and interpretations of ancient documents and treatises connected with the Venetian and Tuscan glass industry and the fourteenth-century decorations of the Orvieto Cathedral. A considerable amount of new information became available about the production of mosaic glass, including raw materials, the technological parameters then available to obtain translucent or opaque colored glass and metal leaf tesserae, and the procedures and people involved.

Most of the tesserae of the Italian medieval mosaics were made of glass, and therefore a close relationship exists between mosaic work and glass production. Information on medieval glass workshops is still limited. Although a good deal is known about glassmaking in Venice and Orvieto, details concerning glassmaking in Rome, Florence, and other Italian centers are rather scant. A good number of medieval glass workshops have been identified in Italy, but an exhaustive list is still lacking, and additional sources of information should be retrieved (Mendera 2000). The description and interpretation of the production procedures of glass for mosaics in ancient treatises (glass recipe books) represent the most important source of information on glassmaking technology in medieval Italy.

In this chapter, the results of scientific analyses performed on vitreous tesserae of important medieval mosaics in Venice, Florence, and Rome and on the stained windows of the Orvieto Cathedral are discussed and compared with historical sources, with a view to establishing eventual relationships between local glass technology and the production of mosaic tesserae.

Glass Technology in the Thirteenth and Fourteenth Centuries

Recent archaeological finds and the chemical analyses of ancient artifacts compared with the recipes to make glass reported in ancient treatises are bringing new details to the outline of the medieval glass technology in Italy (Stiaffini 2000; Verità 2001). In Roman times and probably until the early Middle Ages, the batch consisted of natron (a natural mineral consisting mainly of sodium carbonate) and silica-lime sand. This type of two-component mixture to obtain a three-component glass (soda-lime-silica) appears to have been the standard format of glass recipes throughout the preindustrial world. The essential role of calcium oxide to render the glass insoluble and corrosion resistant was fully understood only during the eighteenth and nineteenth centuries. Recent studies have confirmed that during Roman times and late antiquity, only a few primary glass workshops existed, where the raw materials were melted in large furnaces and a huge quantity (several tons each time) of raw glass was produced. Some of these furnaces have been identified by archaeologists in the Middle East and Egypt, at sites where sand and natron, respectively, were extracted (Freestone, Gorin-Rosen, and Huges 2000). The raw glass was then shipped to secondary glass workshops throughout the Roman Empire, where it was remelted in pots in small furnaces. The molten glass was then colored and shaped and the artifacts were slowly cooled in the annealing chamber.

In about the ninth century new batches, consisting of plant ash and silica sand, began to be used. The composition of the vegetable ash varied (Barrera and Velde 1989; Verità and Toninato 1990; Wedehpol 1997). In the Mediterranean area, ashes obtained by calcination of coastal plants were used. A soda-lime-silica glass was obtained, which differed from the natron glass in its higher content of potassium, magnesium, and phosphorus. At the same time, ash from inland plants (wood ash) was used in northern Europe to make a potash-lime-silica glass. A third, less widely recognized composition, the so-called mixed-alkali glass (comparable amounts of soda and potash: soda-potash-lime-silica glass) appeared in the south of France and in other glassmaking centers. The glass melting technique changed too. The raw materials were calcined in a reverberatory furnace to obtain the frit, a crystalline semiproduct. The frit could be melted in the same workshop or shipped to a secondary workshop where it was melted and objects were shaped.

Several centuries elapsed before the Roman batch composition was completely displaced by the ash glass in Italian workshops (Verità and Toninato 1990). Scientific analyses seem to confirm that this change occurred later (the thirteenth century) for mosaic glass as compared to other artifacts (ninth–tenth century). However, the analytic data available are still scarce, and tesserae made with ash glass were found in the tenth-century Byzantine mosaics of Hosios Loukas, Greece (Freestone, Bimson, and Buckton 1990).

Vitreous mosaic tesserae were produced in two main types: glass pastes and metal leaf tesserae (Verità 1996). The glass pastes are translucent or opaque-colored tesserae in which microcrystals and/or bubbles are dispersed in a glass matrix. Some are made of intensely colored transparent glass (blue, green, purple, etc.); white crystals were added to obtain lighter tones for each color. The crystals were added to the melt as a fine powder, or they separated during cooling from a homogeneous melt containing suitable components. In this case, the tesserae are more homogeneous, with small, evenly distributed crystals. Other glass pastes (white, yellow, red) were colored with opaque, crystalline particles (pigments) dispersed in the vitreous phase. Others were made with a combination of pigments added to a colored glass, as for yellow-green and carnation.

In the metal leaf tesserae a hammered thin leaf of gold or silver is sandwiched between two glass layers: a top thin transparent layer (*cartellina*), usually of colorless, homogeneous glass, and a thicker support layer. The *cartellina* was applied both to protect the metal leaf from oxidation and to make the tesserae shinier.

Three treatises (*Codice* n. 797) held in the State Archive of Florence (Milanesi 1864), dated to the late fourteenth and early fifteenth centuries and abundantly annotated by Luigi Zecchin (1987:108–21; 1990:212–26) are a mine of information on Italian medieval glass technology. As Zecchin points out, the treatises are collections of recipes of different origins for glass as well as other materials, for the collector was not an expert in glassmaking. The first treatise, on the preparation of glass for mosaics, is probably of Florentine origin; the second, on the preparation of enamels and imitation of gems, and the third ones are of Venetian origin.

In these treatises, the technology of glassmaking with only two raw materials (silica and plant ash mixed in a ratio of 1:1) is described. The fluxer commonly indicated in the first treatise is fern ash (a kind of wood ash), a plant growing abundantly in Tuscany, suggested also by Antonio Neri (1980) in 1612 in *L'Arte vetraria*, the first book on glass technology. Analyses of fern ash have shown that potassium and calcium carbonates in almost equal proportion are the main components and that a certain amount of magnesium and phosphorus was also present (Verità 1985). Recipe 2 (yellow glass) suggests the use of tartar, the deposit found in wine casks. When calcined, it is an almost pure potassium carbonate. Few recipes in the three treatises prescribe the use of ash from coastal plants, which could be harvested also in the Tuscan *maremma*, or marshland (Zecchin 1990:214).

Silica was obtained by pulverizing carefully selected quartz pebbles (recipe 31), to reduce coloring contaminants such as iron. Silica and flux, mixed in a ratio of 1:1, were calcined in a reverbatory furnace (*calchera* in Venetian documents) to prepare the frit. The frit was then melted at high temperature for twenty-four hours in a pot positioned in a second furnace. The two-step procedure was necessary to transform the high-melting silica in silicates, to eliminate the carbon dioxide, to calcine completely the carbonaceous residual of the ash, and to obtain homogeneous glass (Verità

1985). In some recipes the resoftening of glass cullet alone is reported. The colorant (oxides of copper, iron, manganese, and cobalt, prepared in different ways) was added to the melt. To obtain green glass (recipe 3), a copper oxide powder prepared from the metal following a well-described procedure is suggested. For the same color also a powder of calcined brass (*polvere di auricalco*, alloy of copper and zinc) is prescribed in recipe 14. Violet was obtained with manganese dioxide, indicated as *manganese da bicchieri* in a Tuscan document of 1317 (Zecchin 1990:214). When ready, the molten glass was gathered with a long spoon and poured on a marble table to form round cakes. The cakes (slabs) were then transferred to the annealing chamber and slowly cooled.

The metal foil slabs had a rectangular form, following the shape of the foil. Because of their shape, they were often called *lingue* (tongue-shaped slabs) in medieval documents (Zecchin 1987:12). The procedure to make tongues is detailed in recipe 23 of the first manuscript. First, large bubbles of transparent, colorless glass were blown so as to obtain a thickness similar to glass lenses (a few tenths of a mm). Then the gold foil was fixed with egg white on a slab of glass (colored, transparent, or opaque; in a document of 1362 at Orvieto the use of red glass is reported) and a rectangular piece of blown glass was placed on the foil. This article was heated in an oven so as to soften the glass and then pressed to make the layers adhere, thus obtaining the glass tongue. This apparently simple process actually required a sophisticated technology to ensure the adhesion of the layers and the durability of these tesserae.

Historical evidence testifies to the practice of mosaic slabs being supplied to the yard where the cutting of the tesserae was carried out (Zecchin 1987:16, 18–19). Vasari (1966) describes instead the technique of cutting tesserae in the glass workshop. It is likely that both techniques were used, as needed.

Below is a brief review of the information available on the development of medieval glassmaking technology in the four towns where the investigated mosaic works were made. Luigi Zecchin's extensive studies brought to light a considerable number of documents and important information on the Venetian glass industry (Zecchin 1987, 1989, 1990). The flux was *allume catino*, an ash of coastal plants (probably Salsola Kali) imported to Venice from Syria and Egypt. The oldest document that reports its importation together with glass cullet (scrap glass) is dated 1255. It is interesting to observe that while in the three Florentine treatises the use of several wood ashes is suggested, their use was strictly forbidden in the Venetian workshops, as revealed by a resolution in 1306 of the Venetian Maggior Consiglio (Zecchin 1987:12). The Venetian glassmakers continuously endeavored to perfect the quality of their glass. For instance, at the end of the thirteenth century they began to replace silica sand with a high-purity source of quartz, pebbles from the Ticino and Adige Rivers (Zecchin 1990:17).

The ability of the Venetian glassmakers to produce glass for mosaics is confirmed by several documents from the Orvieto Cathedral. A document dated December 4, 1359, reports a list of the slabs to be ordered in Venice for the mosaics of the cathedral. Among the items listed are gold and silver *linguae* and colored slabs (including some colors that were very difficult to make, such as carnation and red), each in ten to twenty tones (Zecchin 1990:351–55). Although Venice was one of the few Italian places that had a permanent glass industry since the tenth century, the making of tesserae apparently constituted a relatively small part of the production. There were times when not enough tesserae were produced. The oldest evidence of the production of mosaic in the Venetian glassworks is a document of the Maggior Consiglio dated August 25, 1308, authorizing a glassmaker in Murano to reactivate his furnace during the summer months so that fifteen hundred gold foil tongues could be manufactured for the mosaics of St. Mark's Basilica (Zecchin 1987:12). This document demonstrates the inexactness of the nineteenth-century hypothesis that only around the mid-fifteenth century did the production of gold tesserae begin in Murano after Byzantine tesserae became scarce (Zecchin 1987:12).

Local production of glass tesserae seemed to be proved by archaeological finds at Torcello, an island in the Venetian lagoon, where, according to legend, people fleeing from the barbarian invasions took shelter. Here a glass furnace was excavated, where the tesserae for the famous mosaics of the local basilica of Santa Maria Assunta would have been produced (Leciejewicz, Tabaczynska, and Tabaczynsky 1977). Unfortunately, this interpretation, disputed earlier by several authors, recently has been refuted by further analyses (Verità, Renier, and Zecchin 2002) that demonstrate that none of the archaeological finds testifying to local glass production (fragments of crucibles with vitreous layers, scrap glass, etc.) are related to the production of mosaic tesserae.

The scientific analyses considered here have been carried out on a number of tesserae from the Baptistery of the of St. Mark's Basilica in Venice, formed into a mosaic on the order of the doge Andrea Dandolo in the first half of the fourteenth century (Vio 1999). The tesserae were sampled during the restoration performed on behalf of the Procuratoria di San Marco and completed in 1994. No serious weathering phenomena were observed, and sampling was performed to investigate manufacturing techniques. Gold foil and four to six hues for each color of the glass pastes were analyzed (Verità 1999).

Some of the most important Tuscan mosaics were built in the second half of the thirteenth century and the first half of the fourteenth, among them the Baptistery of St. John in Florence, the apse and facade of the Pisa dome, and the facades of San Miniato al Monte and the Siena cathedral. The question is still open as to whether the Tuscan glass factories were involved in the production of mosaics. The activity of the *bicchierai* (drinking-glass makers) is documented since the end of the thirteenth century in Val d'Elsa, between San Giminiano and Gambassi. In the fourteenth and fifteenth centuries glass production expanded to other towns, such as Pisa (documentation of the cathedral provides information on local mosaic production), Florence, Siena, and Arezzo. Documents of this period attest that the Tuscan glassmakers also used plant ash imported from Syria and southern France as a flux (Mendera 2000).

Tesserae of the Florentine Baptistery of St. John were sampled in the mosaics of the *loggia*. The style of these works dates them to the first half of the fourteenth century (Giusti 1994). The origin of these tesserae remains a mystery. Possible local production at nearby Val d'Elsa has been suggested (Borsook 1988:162–85). Some of the green and blue tesserae sampled by the restorers of the Opificio delle Pietre Dure of Florence were analyzed to determine the causes of their severe weathering. The tesserae show different levels of weathering, from apparently intact to yellowish and brittle. The results of the analyses are being published here for the first time.

In Orvieto, though little physical evidence remains of the original mosaics, the abundant documents in the Opera of the cathedral and in the state archives provide unique testimony to the technical and workshop procedures of Trecento mosaicists, the supply of materials, and so on. Some of these documents have been published (Fumi 1891), and they have been thoroughly studied by Zecchin (1990:351–55) and Harding (1989). They report detailed evidence on mosaic works between 1321 and 1390, when most of the mosaics were completed. Mosaic production was an expensive process; Harding calculated that the medieval mosaics of Orvieto cost more than four times as much as similar work in fresco. Skilled labor included mosaicists, glassmakers, and glass cutters who made the various sizes and shapes of tesserae. The tesserae as well as flat colored glass for stained windows and blown objects were partly prepared locally in an expressly built furnace near the cathedral. It probably was a secondary workshop, for no documents have been retrieved referring to the purchase of raw materials intended specifically for glassmaking, but one document reports that an amount of frit was bought in the neighboring town of Piegaro (Harding 1989:80). Local production was insufficient to meet the demand of the cathedral mosaicists. Glass slabs were frequently ordered from glass workshops in Rome and Venice. After 1360 slabs were purchased also in Siena, Florence, Perugia, and Ancona.

The figures of the prophets Isaiah and Naun over the portal in the center of the facade, signed 1360, are the only surviving parts of the original mosaics. At this time no analyses have been performed on these tesserae. Since extant documents attest that the furnace was made to produce both glass tesserae for the facade and glass sheets for the stained windows, recently published analyses of the stained windows have been considered here (Verità and Santopadre 2000).

Only a few documents attesting to glass production in Rome are available (Saguì 1993). However, the monuments in Rome testify to an uninterrupted tradition of mosaic works, made almost exclusively of vitreous tesserae, from the fourth and fifth centuries (Santa Pudenziana, Basilica of Santa Maria Maggiore) until well into the Middle Ages. The mosaics of Santa Maria in Trastevere are a later example of this tradition. The upper part of the apsidal mosaics, with the tales of St John's Apocalypse, is dated to the mid-twelfth century. The panels in the lower part represent important events in the life of the Virgin Mary and are attributed to Pietro Cavallini, as are the mosaics on the triumphal arch, and date to the end of the thirteenth century (Tiberia 1999). Some evident differences characterize the mosaic works of the two periods. Following the Roman tradition, the twelfth-century mosaic was almost exclusively made of vitreous tesserae, which were set leaving a certain distance between them. Instead, Cavallini used smaller tesserae closely set to obtain compact surfaces, similar to the pictorial technique, a clear indication of the decline in Rome of mosaic work and its replacement by the fresco technique. Some other innovations unknown to the Roman mosaic tradition were introduced by Cavallini. Yellow and red brick fragments were used for the roofs of the buildings and other applications, and gold foil tesserae with opaque red glass support were also used. During restoration work carried out over the past ten years, a number of tesserae of the twelfth- and thirteenth-century mosaics were sampled to examine differences in the glassmaking technology of the two periods. The results were published by Tiberia (1999:209–12).

The Scientific Analyses

The primary aim of scientific analyses of glass composition as well as the nature of the opacifiers and the colorants of ancient vitreous mosaic tesserae is to investigate their production technology: how they were made and how they differ from the tesserae of other mosaics or periods. Furthermore, analyses can help the work of restoration and conservation by ascertaining the state of preservation and characterizing deposits, products of corrosion, and weathered layers (Verità 2000a).

The tesserae discussed in this chapter were analyzed by scanning electron microscopy to identify the different phases and by X-ray microanalysis to determine their chemical composition. X-ray diffraction was used to identify the nature of the crystalline opacifiers. A description of the methods is reported elsewhere (Verità et al. 1994). The tables report the quantitative chemical compositions (wt% of the oxides) of colorless (table 1), opaque (table 2), and blue (table 3) samples representative of the works of art in Venice (V samples), Florence (F), Orvieto stained windows (O), and Rome (R).

The tesserae of St. Mark's Baptistery in Venice were made with a soda-lime-silica glass. Two compositional groups can be recognized (Verità 1999); most of the tesserae show a higher concentration of potassium, magnesium, and

Table 1 Chemical composition (weight percentage of oxides) of colorless glass of metal foil mosaic tesserae from Venice (V), Orvieto (O), and Rome (R)

The compositional group (CG: N, natron glass; Na, soda ash; K, potash glass) is reported for each sample.

Sample Origin	CG	SiO_2	Al_2O_3	Na_2O	K_2O	CaO	MgO	SO_3	P_2O_5	Cl	TiO_2	Fe_2O_3	MnO	Sb_2O_3	BaO
V1	N	65.3	2.30	19.0	0.60	7.9	0.95	0.40	0.07	1.00	0.12	0.78	1.55	–	–
V2	Na	67.0	1.00	12.7	2.50	10.5	3.55	0.18	0.40	0.90	0.08	0.32	0.83	–	–
O1	Na	65.3	4.00	13.5	3.70	8.2	2.90	0.23	0.28	0.85	0.17	0.37	0.45	–	–
O2	Na2	69.0	1.55	16.7	3.40	5.50	1.30	0.07	0.62	1.10	0.03	0.56	0.16	–	–
O3	K2	47.6	1.20	0.20	24.4	21.2	3.10	0.28	1.00	0.03	0.03	0.46	0.32	–	0.18
R1	N	67.8	2.20	19.3	0.58	6.3	0.75	0.27	0.12	1.00	0.10	0.60	0.60	0.45	–
R2	Na	67.0	1.35	13.5	2.40	9.7	3.60	0.21	0.40	0.70	0.08	0.55	0.50	–	–

Table 2 Chemical composition (weight percentage of oxides) of opaque glass pastes from Venice (V), Florence (F), and Rome (R)

The compositional group (CG: N, natron glass; Na, soda ash; K, potash glass) and the identified opacifier (OP: CaSb, calcium antimonate; Q, quartz; P, phosphates; Sn, calcine of lead and tin) and color are reported for each sample.

Sample Origin	CG	OP		SiO_2	Al_2O_3	Na_2O	K_2O	CaO	MgO	SO_3	P_2O_5	Cl	TiO_2	Fe_2O_3	MnO	Sb_2O_3	CuO	PbO	SnO_2
V3	Na	Q	purple	69.6	0.78	11.9	2.12	9.4	3.00	0.27	0.29	0.92	0.08	0.30	1.37	–	–	–	–
F1	Na	Sn	green	64.2	0.55	11.4	1.60	8.1	2.70	0.15	0.30	0.90	0.07	0.22	0.25	–	0.50	5.70	3.40
F2	K	Sn	l.blue	56.0	0.87	1.20	29.0	5.0	0.60	0.60	0.40	0.15	0.04	0.60	0.90	–	0.10	3.50	0.80
F3	K	P	white	44.4	1.20	1.5	29.0	14.0	0.70	0.28	7.40	0.35	0.10	0.43	0.48	–	–	0.15	–
R3	N	CaSb	white	68.0	2.25	16.0	0.45	6.8	1.05	0.35	0.15	0.65	0.06	0.40	0.15	3.70	–	–	–
R4	Na	Sn	white	58.0	0.93	10.5	1.75	7.7	2.60	0.20	0.30	0.70	0.04	0.40	0.35	–	–	10.00	6.50

Table 3 Chemical composition (weight percentage of oxides) of blue tesserae from Venice (v), Orvieto (o), and Rome (r)

The compositional group (CG: N, natron glass; Na, soda ash; K, potash glass) and the identified opacifier (OP: CaSb, calcium antimonate; Q, quartz; P, phosphates; Sn, calcine of lead and tin) are reported for each sample.

Sample Origin	CG	OP	SiO_2	Al_2O_3	Na_2O	K_2O	CaO	MgO	SO_3	P_2O_5	Cl	TiO_2	Fe_2O_3	MnO	Sb_2O_3	BaO	CuO	PbO	SnO_2	CoO	ZnO	NiO
V4	Na	Q	72.6	1.18	10.3	2.20	7.9	2.50	0.11	0.30	0.68	0.10	0.95	0.68	–	–	0.12	0.18	–	0.07	0.13	–
V5	Na	Q	68.0	2.15	13.7	1.82	7.7	1.90	0.23	0.30	0.80	0.15	1.37	0.80	0.15	–	0.15	0.55	0.08	0.07	0.05	–
F4	K	Sn	61.0	0.85	1.4	24.0	5.5	0.80	0.27	0.50	0.15	0.05	0.47	0.60	–	–	0.05	3.30	0.90	0.05	0.07	–
O4	Na		67.0	0.80	13.5	1.85	9.3	3.90	0.23	0.30	0.95	0.06	0.60	0.30	–	–	0.15	0.45	–	0.03	0.60	–
O5	K2		45.8	1.80	0.4	21.8	19.7	4.10	0.15	3.10	0.15	0.03	0.92	1.30	–	0.20	–	0.40	–	0.09	–	0.04
R5	N	CaSb	67.5	2.45	18.7	0.50	6.1	0.75	0.25	0.12	0.90	0.10	0.90	0.50	1.00	–	0.20	–	–	0.03	–	–
R6	Na	Sn	62.8	1.75	13.5	1.65	8.2	2.10	0.23	0.27	0.73	0.13	1.15	0.70	0.55	–	0.20	3.70	2.20	0.11	–	–
R7	Na	Sn	63.4	1.00	12.8	2.10	8.9	3.10	0.24	0.35	0.75	0.04	0.55	0.45	–	–	0.12	3.50	2.30	0.06	0.35	–

phosphorus (sample V2 in table 1), indicating the use of a batch made of silica and coastal plants ash. The second composition (V1 in table 1) is characteristic of glass made with natron and silica-lime sand (Verità 2000b). A third group of blue tesserae (V5 in table 3) shows intermediate concentrations of sodium, magnesium, and aluminium between the natron and the ash glass. This glass was probably obtained by adding a certain quantity of ancient natron glass cullet to the new plant ash glass. This hypothesis is supported also by the presence in this glass of traces of antimony, an element pertaining only to the natron tradition (Verità 2001). Analyses of glass finds excavated in the Venetian area and dated to between the ninth and thirteenth centuries revealed that both natron and ash compositions were used at that time. Only since the fourteenth century has the batch of plant ash and silica replaced completely the traditional batch of natron and silica-lime sand (Verità, Renier, and Zecchin 2002; Verità and Toninato 1989).

The darker hues are made of intensely colored transparent glass. The layered appearance of these tesserae, showing alternate colored and uncolored layers, confirms that coloration was obtained by adding minerals to the molten glass and subsequent rough homogenization. The glass of gold foil tesserae was decolorized by introducing manganese oxide to compensate for the coloring effect of iron present in the natural raw materials.

The Venetian glass pastes that were investigated do not contain the traditional opacifiers, calcium antimonate or tin oxide (sample V3 in table 2). Their opacity is due to relatively coarse crushed silica grains, ranging from 0.03 to 0.4 mm in size (fig. 1) added to the intensely colored glass to obtain pale hues (fig. 2).

Some questions arise concerning this use of quartz. The difference in the refraction index between glass and quartz is so small that the tesserae are translucent. Why was a weak opacifier used? Was it an aesthetic choice or a lack of technology? The latter hypothesis is considered the most probable. The use of the calcined lead and tin in the Venetian opaque glass is demonstrated to have occurred only since the end of the fourteenth century. These features suggested that

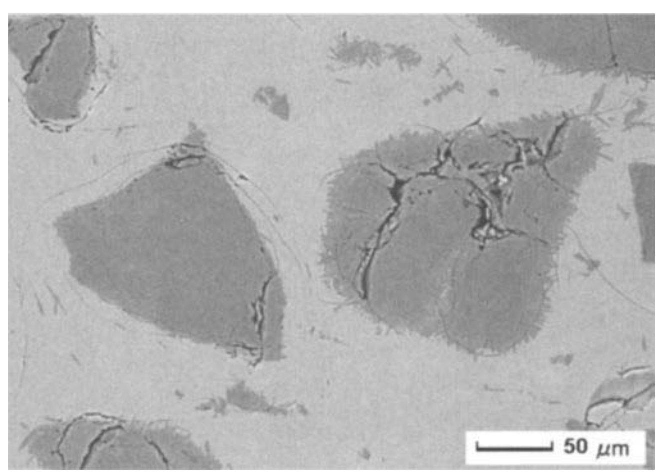


Figure 1 Scanning electron micrograph of the polished section of the blue tessera V4 of St. Mark's, showing the angular quartz grains (dark gray).

the tesserae may prove to have been produced locally with a still rough technology (Verità 1999). Also, tesserae opacified with quartz were found in the tenth-century Byzantine mosaics in Hosios Loukas, Greece (Brill 2001; Freestone, Bimson, and Buckton 1990).

In gold foil tesserae, the support and the *cartellina* were made of the same clear colorless glass, whereas in others the support was made of slightly purple glass. The purple glass pastes were colored with manganese, the green ones with copper and iron; for the blue tesserae, a cobalt mineral containing also zinc was used.

The analyses of six tesserae of the Baptistery of Florence revealed a complex and sophisticated production technology. Most of them were made with a potash-lime-silica glass (samples F2 and F3 in table 2), a composition indicating the use of inland plant ash. Although this would suggest a northern European composition, the potash and lime contents differ markedly (Barrera and Velde 1989; Wedepol 1997). An explanation for the unusual Florentine composition (high potash, low lime) can be found in the Florentine treatises, where the addition of tartar to another flux is reported in several recipes. In the case of these tesserae, a certain amount of calcined tartar would be added to fern ash. This addition was meant to obtain a low-melting, shining glass, but it inevitably lowered its chemical durability.

Only one of the examined Florentine tesserae was made with a soda-lime-silica glass prepared with coastal plant ash (F1 in table 2). Only a few recipes in the first treatise call for the use of *soda soriana* (ash imported from Syria), but this is the common flux prescribed in the recipes in the third treatise, to which a Venetian origin has been attributed (Zecchin 1990:221).

The cobalt minerals used in the Middle Ages have been the object of a number of studies that allowed the provenance of the mineral to be related to the presence in the blue glass of secondary elements associated with cobalt (Gratuze et al. 1996). The blue tesserae of Florence (F4 in table 3), like the Venetian ones (V4 and V5), were colored with a mineral of cobalt associated with zinc, probably imported from the Levant. The blue color was made (recipe 17) by adding *azzurro da vetro* (pale blue for glass), also called *cofaro*, to the melt. The preparation of *cofaro* is reported in recipe 25. The raw mineral was first mixed with sodium chloride, calcined, pulverized, and mixed with three parts of sand. The dilution with sand evidently aimed at carefully dosing this strong coloring mineral.

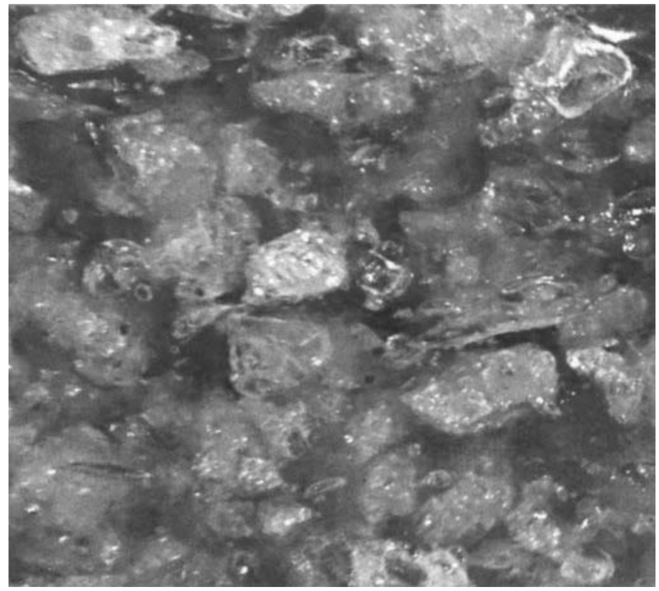


FIGURE 2 Micrograph (40×) of the polished section of the blue tessera V4 opacified with quartz grains and bubbles.

The analyses of the Florentine tesserae show the use of two opacifiers: tin oxide crystals (identified as cassiterite by XRD analysis) in a glass containing lead (samples F1 and F2 in table 2) and a potassium-calcium phosphate (F3 in table 2). Tin oxide gives an intense opacity (fig. 3) and a heterogeneous glass with large crystalline aggregates (fig. 4), while phosphates give a translucent effect (fig. 5) due to very small uniformly dispersed microcrystals (fig. 6). The two opacifiers correspond to the use of a calcine of lead and tin and of calcined bones, respectively. Florentine treatises report the use of both opacifiers. A mixture of tin and lead (ratio 2:1 in recipe 24, varying proportions in others) was calcined; the white powder was ground and melted with silica and soda ash. The addition of lead has been explained in different ways; most likely its role was to improve the dispersion of the tin oxide crystals in the melt (Mason and Tite 1997). The use of calcined bones is also reported in the recipes in the second treatise (Zecchin 1990:219). The sophisticated use of different opacifiers in Florence while quartz was being used contemporaneously in Venice opens up new questions.

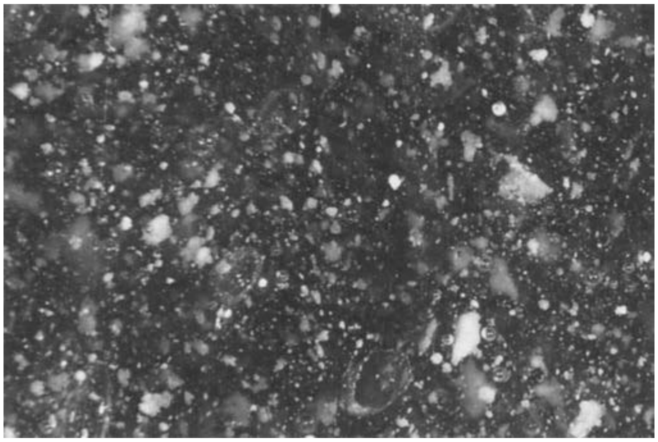


FIGURE 3 Micrograph (32×) of the polished section of the blue tessera F4 of the Florentine mosaics, opacified with tin oxide crystalline aggregates.

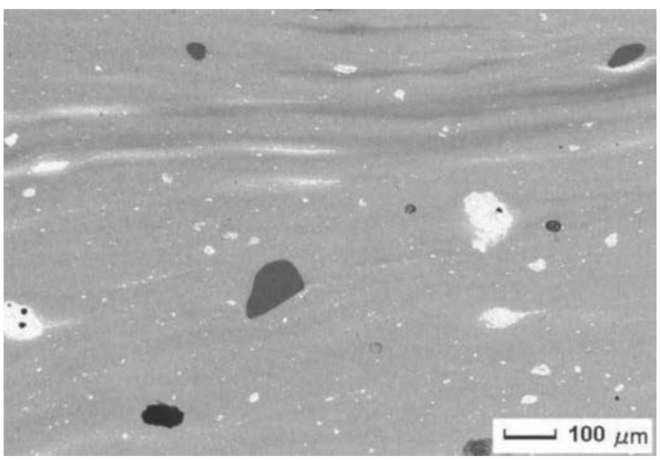


FIGURE 4 SEM micrograph showing the heterogeneous glass and the crystalline aggregates (white areas) of the polished section of the F1 Florentine tessera opacified with calcine of lead and tin.

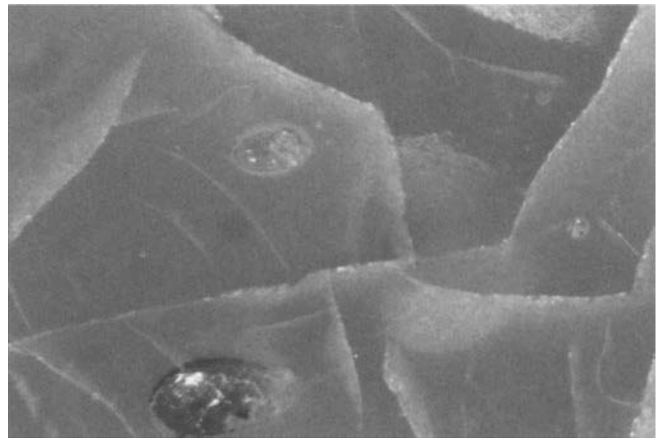


FIGURE 5 Micrograph (32×) of the polished section of the translucent light green tessera F3 of the Florentine mosaics, opacified with calcined bone. Fractures crossing the weathered tessera are also evident.

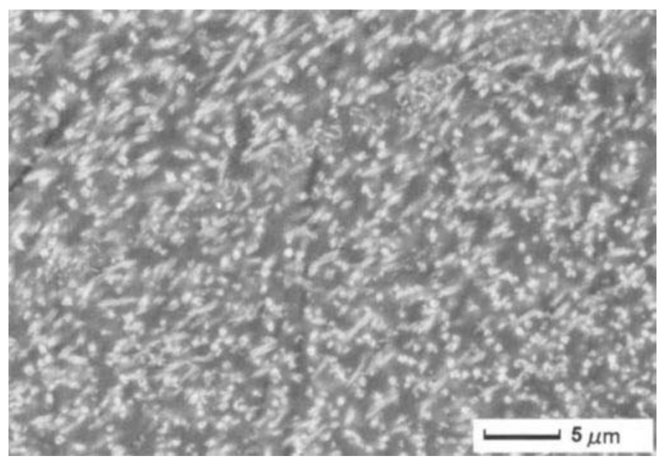


FIGURE 6 SEM micrograph of the tessera F3 opacified by small and homogeneously dispersed phosphates microcrystals.

These analyses performed on the stained windows of the Orvieto Cathedral identified three compositional groups for the glass from the fourteenth century (Verità, Marabelli, and Santopadre 2000). One group (sample O1 in table 1) is made of soda-lime-silica glass similar to the Venetian glass made with *allume catino*. A second soda-lime glass shows a lower content of calcium and magnesium and larger amounts of sodium and phosphorus (O2 in table 1). This composition has been identified up to now only in glass at Orvieto and Assisi and corresponds to the use of a particular coastal plant ash. This may indicate that this glass was produced in Umbria, probably also in the furnace built near the Orvieto Cathedral. The third group is made of potash-lime-silica glass (O3 in table 1). This composition (potassium to lime ratio of 1:1) corresponds to the glasses of German production (Wedepohl 1997), an origin confirmed by the fact that blue glass of this group (O5 in table 3) was colored with a cobalt-nickel mineral from the south of Germany (Zecchin 1990:227–29).

The analysis of the tesserae of the upper (twelfth-century) and lower (thirteenth-century) parts of the apsidal mosaics in Santa Maria in Trastevere, Rome (Tiberia 1999:209–12), revealed similar differences in the glass composition as found for the tesserae of St. Mark's in Venice. The twelfth-century mosaics were made with natron glass (sample R1 in table 1) following the Roman tradition, whereas the thirteenth-century tesserae were made with a soda-lime-silica plant ash glass (sample R2 in table 1). However, unlike the Venetian tesserae, they were opacified with calcium antimonate (R3 in table 2, natron glass) and with calcined lead and tin (R4 in table 2, soda ash glass), respectively. An intermediate composition is observed in some blue samples (R6 in table 3), made by adding ancient blue glass cullet to the new ash glass. Different cobalt minerals were used: in the thirteenth-century tesserae traces of zinc were detected (sample R7 in table 3), indicating the use of a mineral imported from the Levant (similar to that used in Florence and in Venice), while no zinc or nickel can be detected in the twelfth-century tesserae (samples R5 and R6 in table 3).

Weathering Phenomena

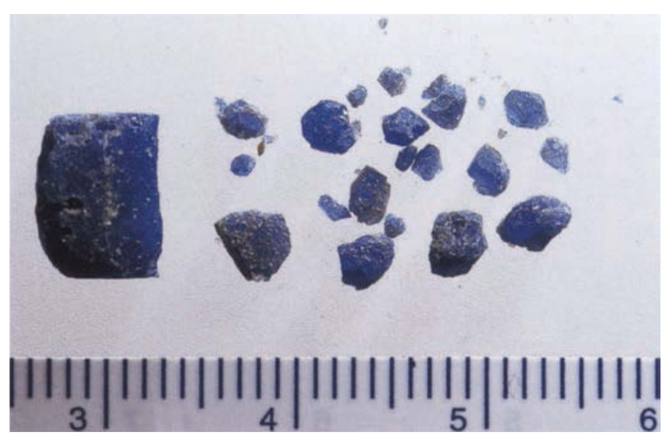
The durability of glass, that is, its ability to survive in time, depends on two main factors: the glass chemical composition and the environment of preservation. The weathering process causes different levels of alteration and the tesserae can be classified as durable, low durable and brittle. The durable tesserae exhibit good preservation conditions, taking into account the long period of exposure to sometimes unfavorable environments (moisture and condensation, high pollution, etc.). Only a slight loss of brilliance, sometimes associated with an imperceptible iridescence, can be observed. The deterioration of the low-durability tesserae varies from light crizzling and loss of brilliance to marked crizzling and the appearance of yellowish layers. Most of the Venetian and Roman glass pastes can be classified as durable, only few of them as having low durability.

The heavily weathered brittle tesserae appear to be sharply discolored and yellowish because of deep micro-cracks and thick weathered layers. Severest weathering makes them break up into small fragments or into a powder (fig. 7). The potash-lime-silica tesserae of Florence can be classified as brittle or low durability.

A characteristic alteration of the metal leaf tesserae consists in the detachment of the *cartellina* and the loss of the metal leaf. This phenomenon can be observed to a varying extent in all the mosaics examined.

When observed under the SEM, the polished sections of the tesserae show superficial weathered layers of modified composition. These layers appear darker than the glass in back-scattered effect (BSE) micrographs, because of the lower output of back-scattered electrons, indicating a lower mean atomic number (Verità et al. 2000). The thickness of

FIGURE 7 Sharply weathered and pulverized blue tesserae of the Florentine mosaic.



the weathered layer increases from durable to brittle tesserae. No fractures in the few µm thick layers of the durable tesserae are observed. The modified layer acts as an effective protective barrier against leaching. In the low-durability tesserae the thickness of the weathered layer reaches tenths of µm, thus showing that the leaching process has slowed but not stopped (partially protective layer). In these samples fractures penetrate the entire weathered layer (fig. 8), which has lost its protective efficacy.

The formation of micro-cracks can be attributed to the mechanical strains near the interface leached layer/glass, due to the different thermal expansion of the two materials and to the variation of volume of the hydrated layer during the dry-wet periods (variation in the water content). In the Florentine brittle tesserae a disordered propagation of micro-cracks from the weathered surface into the glass is observed (fig. 9). Water penetrating the micro-cracks leads to the formation of weathered layers around the fractures. Salt deposits are observed inside the fractures. They are mainly made of potassium sulfate formed as a reaction of the extracted alkali ions and SO_3 dissolved in the condensed water. The heavily polluted environment of Florence is the cause of the formation of deposits. The formation of salts inside the micro-fractures is one of the factors favoring their propagation in the bulk glass.

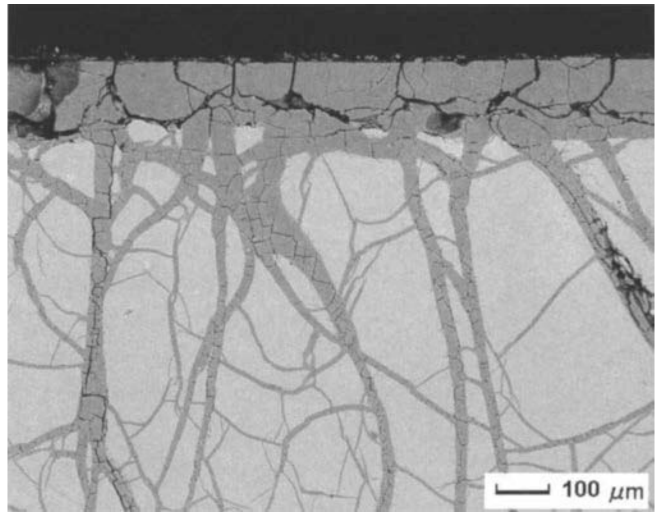


FIGURE 9 SEM micrograph of the cross section of a brittle tessera of the Florentine mosaic. The unweathered glass is crossed by micro-cracks.

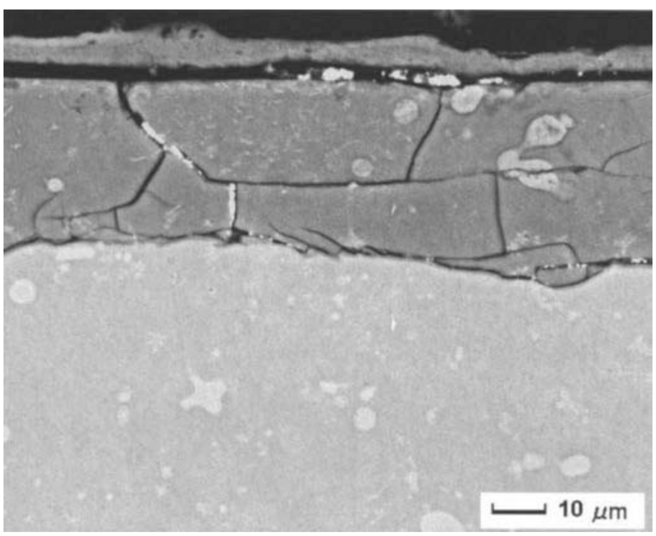


FIGURE 8 SEM micrograph of the cross section of the low durable tessera of Florence. The weathered layer is crossed by micro-cracks.

The loss of the *cartellina* in metal-leaf tesserae is due to a complex of reasons that are still not fully understood. Because of their specific structure, the manufacturing technique seems to be crucial for their preservation. Any strain at the boundary as well as imperfect adhesion can compromise the durability of these tesserae. The analyses have shown that this phenomenon appears in tesserae that exhibit weathered layers in the glass surrounding the metal foil (fig. 10). The infiltration of water at the glass–metal leaf boundary results in the formation of weathered layers. Even if they are only a few µm thick, these layers affect the poor adhesion between glass and metal foil and lead to the loss of the *cartellina*.

Some general remarks can be made about the composition of the weathered layers. Compared to the glass, they show an almost complete depletion in alkali (Na in soda-lime and K in potash-lime glasses). A combined partial extraction of Ca occurred only rarely. An increase in the Si content (silica-rich layer) is generally but not always observed. The total wt% of the analyzed oxides (100% in the glasses) ranges between 80 and 90 wt% in the layers. It has been demonstrated that the weathered glass consists of

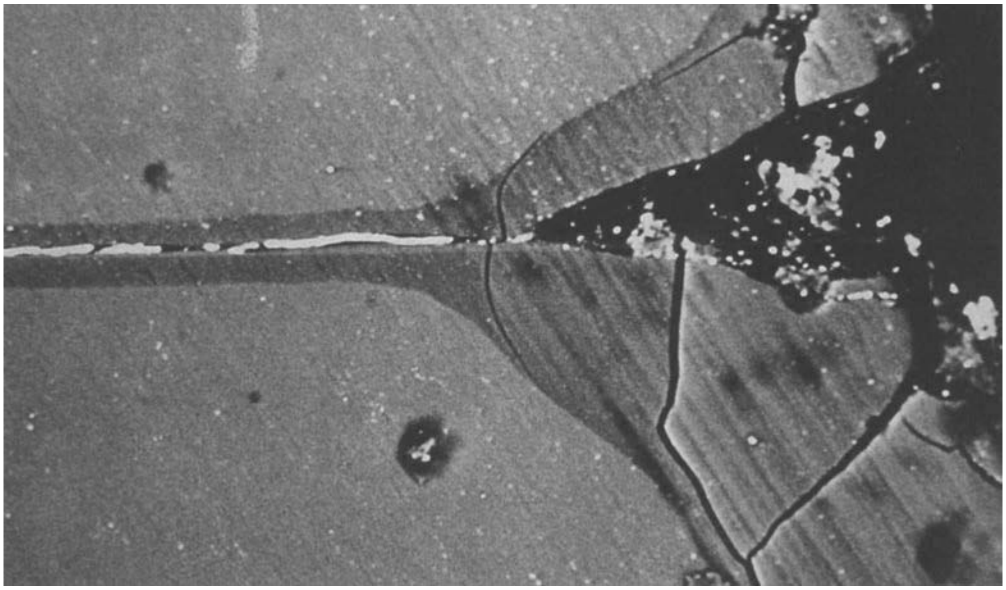


FIGURE 10 SEM micrograph of the polished section of the metal foil tessera V2 of St. Mark's in Venice. The gold foil (white line) is surrounded by a thin weathered glass layer.

hydrated (hydrogenated) glass where the extracted alkaline ions are replaced by water in the glass network. This means that the weathering goes on mainly following a mechanism of selective leaching due to condensed water. Sharp differences in the weathering behavior are due to small differences in the chemical composition. Small differences in the silica, calcium, and alkali contents can lead to marked changes in durability (Verità et al. 2000).

Conclusion

During the thirteenth and fourteenth centuries, many mosaics were created in Italy. The documentary and analytic data, though still fragmentary and insufficient to lead to definite conclusions, confirm that the technology of local workshops is interwined with the history of the medieval Italian mosaics in the realization of translucent and opaque colored glass pastes and metal foil tesserae. The historical sources attest to flourishing glass production in Venice, Orvieto, and Tuscany. Information available on medieval glassmaking in Rome, where an uninterrupted mosaic tradition existed since the first centuries A.D., is still rather poor.

Certainly since the fourteenth and probably since the thirteenth century, the Venetian and Tuscan workshops had acquired the technical knowledge necessary to produce both glass pastes and metal foil tesserae. Medieval treatises supply evidence for different specialized technologies being used to produce mosaic glass, thus confirming Italian manufacture at that time. The Orvieto documents testify to local production along with an important trade of mosaic slabs from the glass workshops of Venice and Rome.

The composition of glass and the nature of the opacifiers and colorants demonstrate that the tesserae were mostly the product of contemporary glassmaking and not reused earlier tesserae. The compositional grouping reflects their origin. Soda-lime-silica glass made with plant ash was widely used in Italy. The investigations demonstrate beyond any doubt that the production of metal foil tesserae in the thirteenth and fourteenth centuries was not a monopoly of Byzantine glass workshops; instead, there existed in Venice and in other Italian centers a number of workshops where such particular and delicate tesserae were made.

Tesserae of different composition and provenance were identified in Florence and Orvieto. Compositional data are more homogeneous in Venice and Rome, where the traditional natron glass of Roman origin had been replaced by the plant ash composition. The potash-lime-silica composition of Florentine tesserae and the use of different opacifiers (calcined bones and calcined lead and tin) make this material a still undisclosed secret. Other questions remain, and further research is needed to provide definitive answers.

The bad preservation condition of the Florentine mosaics is to be ascribed to the chemical composition of the glass. In Venice, the weathering of the tesserae of St. Mark's Basilica is limited. Evidently, the long glassmaking tradition of the Venetian workshops ensured better glass quality.

Acknowledgments

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Dusan C. Stulik

Chapter 10
Scientific Research in the Conservation of the Last Judgment Mosaic

It was very obvious in 1992, when the Getty Conservation Institute embarked on the challenging and complex conservation project to restore and conserve the Last Judgment mosaic, that the success of the project depended heavily on finding, developing, and testing a coating technology for the long-term protection of the mosaic.

Scientific research was also crucial in the development and testing of methods for cleaning surface corrosion and remnants of previous conservation treatments from the mosaic, providing new data for understanding the technology, and provenancing of mosaic glass, for understanding the deterioration processes of mosaic glass, and providing insight into the composition and character of the original mosaic plaster.

Advanced methods of image processing were used in an attempt to sharpen deteriorated photographic images of the mosaic from 1879 that are crucial for a detailed art historical analysis of the mosaic before its removal from the wall of the Golden Gate in 1890. Scientific methodology was also used for the long-term monitoring of environmental parameters in the vicinity of the mosaic and monitoring of changes in the surface temperature of the mosaic. A number of new scientific methodologies and testing procedures were developed for the project, and a number of interesting research ideas were put forward for future development of scientific and testing methods.

This chapter deals with scientific research targeted at the study of mosaic glass technology, deterioration of mosaic glass, mosaic plaster, and conditions of the mosaic bed. Some ideas for future directions of scientific research are also presented here.

History of Scientific Investigation of Mosaic Materials

Historical information, documents, and written reports show that problems of deterioration of the Last Judgment mosaic were recognized as early as the fifteenth century. Attempts to deal with these problems and to restore the beauty of the mosaic were undertaken at least once every century since.

There are no known records in existence that would provide information on sources of the mosaic glass, who prepared the mosaic cartoon, or who made and installed the mosaic. Detailed "weekly receipts" for expenses related to the construction and decoration of St. Vitus Cathedral exist and are preserved at the Archive of Prague Castle (Hlobil 1994). Unfortunately, these receipts cover the years 1372–78, commencing just one year after the documented completion of the mosaic. The only historical material available that can provide important clues to the technology and origin of the mosaic is the mosaic itself. A detailed study of the mosaic's materials together with a detailed art historical analysis of the mosaic's design, iconography, and details of execution when compared to other existing medieval mosaics, wall paintings, panel paintings, illuminated book illustrations, sculpture, and decorative arts of the period could advance understanding of the mosaic's origin.

The first fragmentary information relating to the composition of the mosaic tessarae and their deterioration dates to 1879 from a report by the mosaic expert Luigi Solerti, who was invited to the Prague Castle to evaluate the state of preservation of the Last Judgment mosaic by the Association for Completion of St. Vitus Cathedral (Jednota pro dostavěni chrámu sv. Vita). In his report Solerti states that the high concentration of potassium in the mosaic glass is responsible for the deterioration of the mosaic. We do not know whether his conclusion was based on chemical analysis or on his experience and good judgment. The first known analysis of mosaic tesserae was reported by the Czech expert in mosaic glass, Michal Ajvaz (pers. com. 1992), who claimed that analysis of mosaic glass was performed in the 1930s but that information on these analyses could not be located.

The first documented chemical analysis of the Last Judgment mosaic glass was conducted, according to Heteš (1958), in 1954 by the Glass Research Institutes in Hradec Kralové and Teplice (Sklařský vyzkumný ústav v Hradci Kralovém a Teplicích). Results of this analysis were cited by the minutes of the Expert Committee meeting organized by the Ministry of Culture of Czechoslovakia and the State Institute for the Protection of Cultural Heritage (Statní ústav pamatkové peče), which stated: "Chemical analysis of [mosaic] glass showed that glass used to make the mosaic has low concentration of silicon dioxide, high concentration of alkali metals and calcium oxide, thus, the glass has a very low chemical stability" (MC 1954). The results of the 1954 analysis are presented in table 1.

The gravimetric and volumetric quantitative analyses were performed on seven glass samples of different colors. Only a limited number of chemical elements were determined quantitatively during the analysis (SiO_2, CaO, MgO, K_2O, and Na_2O). The results for Al_2O_3 and Fe_2O_3 were not reported individually but only as a sum of sesquioxides R_2O_3. The analyses did not show or quantify any minor and trace elements present in the mosaic glass.

The second documented chemical analysis of the mosaic glass was commissioned by the Office of the President (Czechoslovakia) in 1957 at the Glass Research Institute (Vyzkumný ústav sklarský) in Hradec Kralové. The results were reported in 1958. Eight glass tesserae of different colors were removed from the mosaic and analyzed using unspecified but standard methods of wet chemical analysis, polarography, and flame photometry (KPR 1958). The results of the analysis are shown in table 2.

The analysis for both major and minor elements present in mosaic glass was performed, and the analytic results for both Al_2O_3 and Fe_2O_3 are reported individually. In addition, a semiquantitative analysis of all elements in twenty-eight samples of mosaic glass using optical emission spectrography was performed at the Research and Testing Institute in Pardubice–Rybitví (Uředně autorizovaný kontrolní a zkušební ústav Pardubice–Rybitví). A simple diagram of all sampling sites in the Last Judgment mosaic was also created. The results of the 1958 optical spectroscopic analysis of glass tesserae are shown in table 3.

During that time, scientists also studied the mechanism of glass deterioration. Surface corrosion was studied under the optical microscope and samples of glass corrosion were analyzed using X-ray diffraction analysis. Analytic research conducted in 1957 and 1958 on the mosaic glass and corrosion products helped to identify major mechanisms of deterioration and assisted scientists and conservators in developing and preparing the 1959–60 restoration and conservation campaign (Ajvaz, pers. com. 1992).

The next phase of interest in the deterioration of the glass tesserae and an attempt to advance knowledge of the

TABLE 1 ANALYSIS OF MOSAIC GLASS FROM 1954

	Sample number							
Component *	1	2	3	4	5	6	7	Average
SiO_2	41.76	44.83	44.28	46.32	45.56	48.12	43.28	44.92
R_2O_3	2.44	2.20	4.22	3.46	1.92	4.84	6.51	3.66
CaO	23.17	22.87	23.06	20.73	20.62	15.47	23.31	21.32
MgO	3.97	4.14	4.05	4.04	3.86	2.69	3.30	3.72
K_2O	26.06	22.45	22.31	23.20	19.16	18.25	21.45	21.84
Na_2O	0.80	2.51	0.60	1.15	2.18	1.55	0.95	1.39

R_2O_3 = (% Al_2O_3 + Fe_2O_3)

* analysis of minor and trace elements was not performed here

Table 2 Analysis of Mosaic Glass from 1958

Component	Red -1	Green -1	Green -4	Yellow -4	White -1	Violet -1	Brown -2	Blue -1
SiO_2	45.10	44.65	24.81	17.24	43.46	47.76	44.15	46.87
PbO	–	1.33	70.27	80.06	1.03	8.71	0.40	0.24
Al_2O_3	1.97	0.10	0.73	0.16	1.23	0.99	2.01	0.68
Fe_2O_3	4.69	0.30	0.02	0.14	0.27	0.84	0.23	0.16
CaO	18.10	24.65	1.01	0.44	22.30	18.89	23.40	23.88
MgO	2.52	3.40	–	–	2.50	–	2.20	0.52
ZnO	0.16	0.10	0.20	0.05	0.20	0.28	0.23	–
MnO	1.00	0.96	0.65	–	0.78	0.84	0.74	0.75
CuO	1.05	–	0.49	0.06	0.36	0.13	0.10	0.69
NiO	0.06	0.03	0.01	0.10	–	0.05	–	0.04
K_2O	23.83	20.76	0.33	–	27.06	17.50	23.40	25.00
Na_2O	–	traces	0.10	–	–	2.01	0.90	traces
P_2O_5	1.62	3.56	1.63	1.80	1.02	2.53	1.99	1.51

Table 3 Optimum Emission Spectroscopy—Analysis of Mosaic Glass

Sample	%	0.1%	0.01%	0.001%	Traces
White -1	Ka, Ca	–	Al, Cu, Na, Pb, Si	Mg, Mn	Ba, Fe
White -2	K, Ca	–	Al, Cu, Na, Pb, Si	Mg, Mn, Sr	Ba, Fe
Red -1	K	Ca, Cu, Pb	Ag, Fe, Na, Si, Sn	Al, Mg, Mn, Sb	Sr
Red -3	K	Ca	Cu, Na, Pb, Sn	Al, Mn, Si	Fe
Black -1	Na, Pb	Cu, Si	Ag, Ca, Fe, K, Mn, Sb, Sn	Al	Bi
Black -2	K, Ca	–	Al, Cu, In, Na, Pb, Si	Mg, Mn	Ba, Co, Fe, Sn, Sr
Black -3	K	Ca, Pb	Cu, Na, Si, Sn	Al, Mg, Mn	Ag, Ba, Fe, Sr
Violet -1	Na, Pb	Si	Cu, Mn, Sb	Al, Ca	Ag, Fe
Violet -2	Na, Pb	Si	Cu, Mn, Sb, K	Al, Ca, Sn	Ag, Fe
Brown -1	Na, Pb, K	Si	Cu, Mn, Sb	Al, Ca, Fe, Sn	Ag, Bi
Brown -2	K, Ca	–	Al, Cu, Na, Pb, Si	Mg, Mn	Sr
Brown -3	K, Ca	–	Al, Cu, Na, Pb, Si	Mg, Mn	Sr
Brown -4	K	Ca, Pb	Cu, Na, Si, Sn	Al, Mg, Mn	Ag
Blue -1	K	Ca	Cu, Na, Pb, Si	Al	Mg, Mn, Sn
Blue -2	K, Ca	–	Al, Cu, Na, Pb, Si	Ba, Mg, Mn	Fe, Sr
Blue -3	K, Ca	Na	Al, Cu, Pb, Si	Mn	Fe, Mg, Sn, Sr
Blue -4	K, Ca	Na	Al, Cu, Pb, Si	Ba, Fe, Mg, Mn	Sn, Sr
Blue -5	Na, K, Pb	Ca, Cu, Sb, Si	Al, Co	Ag, Fe, Mn, Sn	Mg, Ni
Green -1	K, Ca	Na, Pb	Al, Cu, Si	Ba, Mg, Mn, Sn	Ag, Fe, Sr
Green -2	K, Ca	–	Cu, Na, Pb, Si	Mn	Al, Mg
Green -3	Pb, Sn	Ag, Cu, Si	–	Al, Ca, Zn	As, Fe, Mg
Green -4	Pb, Sn	Ag, Cu, Si, K	–	Zn	Al, Ag, Ca, Fe, Mg
Green -5	Pb, Ag, Cu, Sn	Si, K	Al, Zn	Ca, Fe	As, Mg
Green -6	Na, Pb	Ca, Cu, Sb, Si	Al, Mn, Sn	Ag	Fe, Mg
Yellow -1	K	Ca	Na, Pb, Si	Mn	Al, Mg
Yellow -2	K, Ca	–	Al, Cu, Na, Pb, Si	Mn	Mg
Yellow -3	Pb, Sn	Ag, Cu, Si	–	Al, Zn	Ca, Fe, Sb
Yellow -4	Pb, Sn	Ag, Si	Al, Cu	Ca	Fe, Sb

mosaic's materials was initiated by scientists from research institutes of the Czechoslovak Academy of Sciences and the Institute of Chemical Technology in 1986. This investigation was performed on a limited number of glass samples; however, by using modern methods of chemical, surface analysis, and microanalysis such as electron microanalysis (EMPA), scanning electron microscopy (SEM), X-ray diffraction (XRD), electron spectrometry for chemical analysis (ESCA), and secondary ion mass spectrometry (SIMS), they were able to make an important contribution to understanding the deterioration mechanisms and corrosion processes of the mosaic glass (Perina, Cháb, and Jurek 1993).

Surface analysis (ESCA, SIMS) provided more detailed information about the structure of the corrosion layer on the glass surface and on changes in the distribution of different elements in the bulk of the glass tesserae as a result of surface corrosion: both ESCA and SIMS are analytic methods that probe a few top monoatomic layers of analyzed material; both methods can be used to perform so-called depth profile analysis of the samples by ion beam milling of the surface. The combination of the results of surface analysis and the results of mapping of the chemical composition of a cross section of the corrosion layer provided highly refined insight into the corrosion mechanisms of mosaic glass.

The research demonstrated that the structure of the corrosion layer was similar for all samples of analyzed glass. The corrosion layer contains a large concentration of sulfur in the form of both simple ($CaSO_4 \times {}_2H_2O$, gypsum; $PbSO_4$, anglezite) and complex ($K_2Ca(SO_4)_2 \times H_2O$, syngenite) sulfates and silicates (Ca_2SiO_4, calcium silicate). The concentration of potassium and calcium in the corrosion layer was found to be only about one-third of the concentration of these elements in the bulk of glass tesserae. The corrosion layer is also substantially richer in silicon dioxide (SiO_2).

Figure 1 shows a schematic cross section of the whole corroded glass tessera. The bulk of the tessera is made of more or less homogeneous glass. On the top of the solid glass is a relatively thick (~10 microns) layer of hydrated silicates (silicate gel layer) highly depleted of potassium and calcium.

On top of the gel layer is a layer of simple and complex sulfates mixed with hydrated silicates and carbonates. On top of the corrosion layer is a very thin (2–3 nm) layer of corrosion crust composed of very porous silicon dioxide (SiO_2).

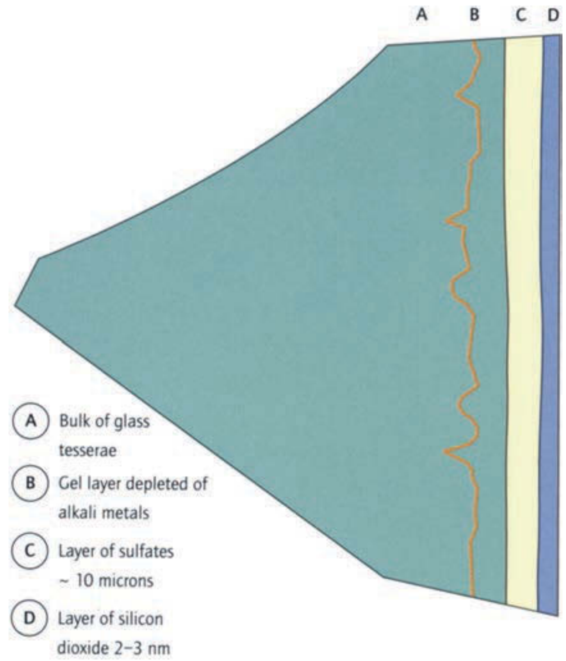


FIGURE 1 Schematic of the general structure of the corrosion layer on the tesserae of the Last Judgment mosaic as identified by a series of chemical and crystallographic analyses. (from Perina, Cháb, and Jurek, 1993)

Investigation of Mosaic Materials during the 1992–2000 Conservation Project

A number of samples of mosaic glass, glass corrosion, and mosaic plaster were analyzed in the course of our conservation project. Because the analysis of mosaic material had only a supporting role, we avoided any extensive sampling of the material directly from the mosaic. The analytic studies described here were conducted only on samples of mosaic tesserae available at the Prague Castle Archives.

Before its removal from the Golden Gate in 1890, the Last Judgment mosaic was in a very poor state of preservation and some individual glass tesserae and tesserae clusters could be, according to written records, found from time to time on the floor of the Third Square of the Prague Castle in front of the Golden Gate and were collected and preserved by the staff of the castle. We can assume that the collection of mosaic tessarae was enlarged later by an addition of some mosaic material after several parts of the mosaic were destroyed during a storm in January 1890. More material (including new material used for restoration and replacement of missing tesserae) was added to the collection during the restoration campaign in 1910.

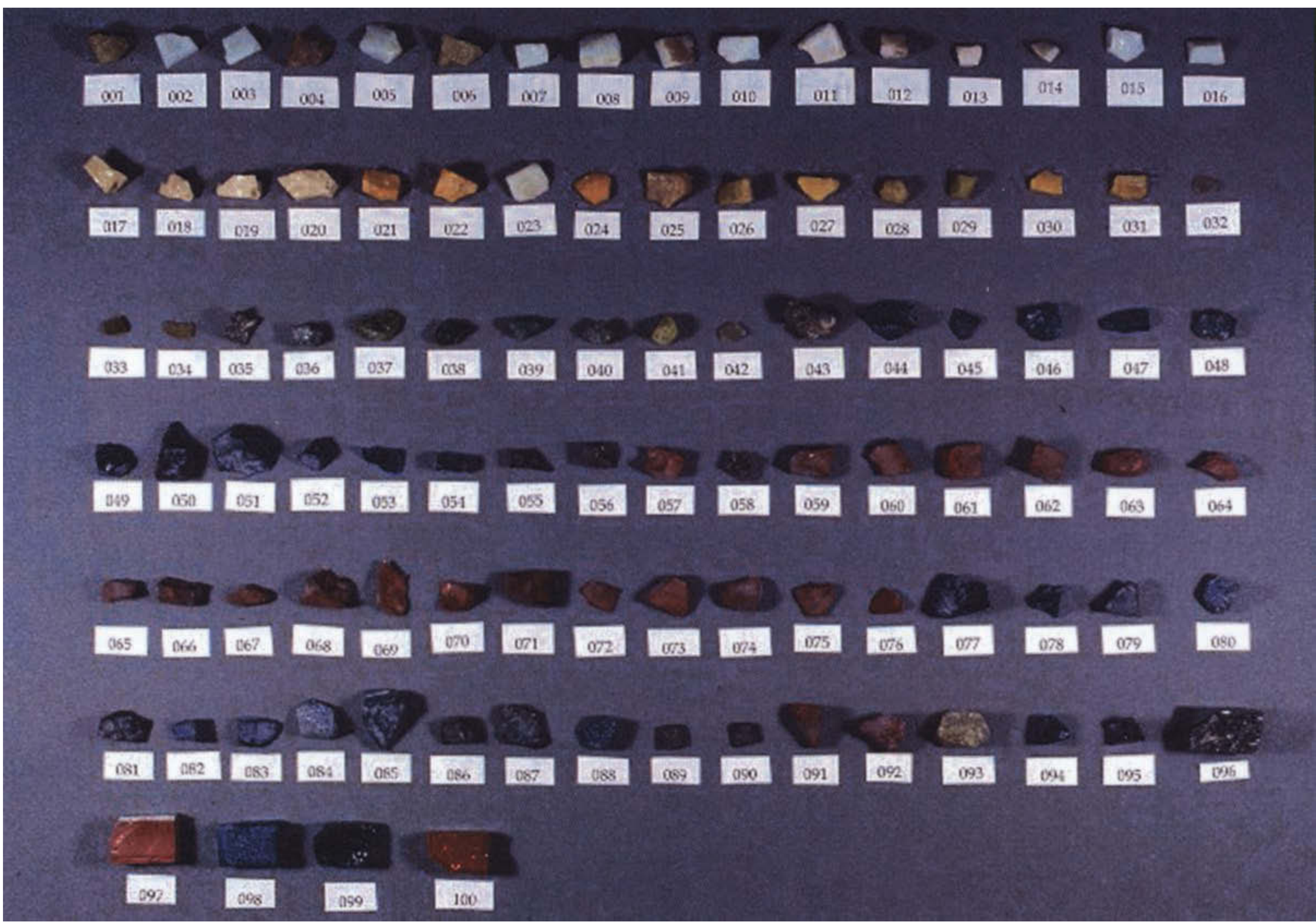
Working with this material, we were able to expand our understanding of the composition of mosaic glass, contribute information on various types of corrosion of the mosaic glass, and make a contribution to our knowledge of the composition of the mosaic mortar.

The Analysis of Mosaic Glass

A number of mosaic glass samples representing all possible colors, glass types, and states of preservation were selected for our analytic studies. Several samples were selected because they still had some remnants of the mosaic mortar attached to the sides of glass. All selected samples were documented and photographed before any sample manipulation or treatment (figs. 2, 3).

FIGURE 2 Samples of different types of mosaic tesserae selected for chemical analysis before cleaning. Photo: D. Stulik.

FIGURE 3 Samples of both old and new mosaic glass after removal of remaining mortar and corrosion products. Photo: D. Stulik.



Mortar still attached to some glass samples was separated, documented, and preserved for further investigation. A small portion of each tessera containing surface corrosion or surface gilding was cut using a diamond micro-saw to prepare cross sections for detailed studies of surface corrosion. The remaining parts of each tessera were thoroughly cleaned using a scalpel, and samples were pulverized for semiquantitative and quantitative chemical analysis of its composition. Both neutron activation analysis (NAA) and inductively coupled plasma mass spectrometry (ICP-MS) were used to obtain information on the concentration of major, minor, and trace elements in the bulk of the glass samples.

Neutron Activation Analysis (NAA) The NAA method has an advantage in its high sensitivity for most chemical elements, the ability to analyze qualitatively and quantitatively a large number of chemical elements with a minimum sample preparation, and the high accuracy of quantitative analysis (1–10%). The limitation of NAA is its inability to detect chemical elements such as hydrogen, carbon, nitrogen, oxygen, silicon, and lead, which do not create detectable radioisotopes.

One portion of each pulverized sample was prepared for the NAA analysis. About 20 mg of each glass sample were sealed into a contamination-free polyethylene capsule. The sample capsules were lowered, together with a number of well-known analytic standards of similar chemical composition, into a core of the Triga nuclear reactor at the Nuclear Reactor Center of the University of California, Irvine.

To analyze long half-life radionuclides in the glass samples, the samples were irradiated by a the neutron flux of 10^{12} neutrons/cm^2•s for three hours. The incident neutrons reacted with nuclei in the sample, producing corresponding radionuclides that decay via the emission of beta or gamma radiation. After the "cooling period"—at least twenty-four hours—the irradiated samples were transferred to the Radiochemistry Laboratory of the Chemistry Department of California State University, Northridge. There the irradiated samples were measured using the gamma ray germanium semiconductor detector (Camberra) linked to a computer-controlled multichannel analyzer.

The gamma spectrum of each irradiated sample can be used to identify chemical elements present in the irradiated sample. To accurately calculate the concentration of elements in an unknown sample, the sample is irradiated along with a known standard and both samples are measured using the same detector. The elemental concentrations are then calculated using a formula incorporating information on the radiation activity of the sample, the atomic density of the sample, the neutron flux of the reactor, the reaction cross section, the efficiency of the detector, decay constant for the isotopes, and elapsed decay time. The ratio of calculated values between the standard and the unknown sample will then provide a concentration of elements in the sample.

To analyze some short half-life elements in the glass samples requires much shorter irradiation time (30s) and immediate transfer to the gamma spectrometer. The pneumatic sample transfer system was used to achieve a rapid (~3s) transfer between the nuclear reactor and the gamma detector. This allowed the whole chemical analysis for the short-lived radionuclides to be finished in four minutes.

Figures 4a and 4b show typical gamma spectra of irradiated glass samples during analysis for both long half-life and short half-life elements. Table 4 shows the results of the quantitative NAA analysis of a number of elements in the mosaic tesserae.

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) About 20 mg to 30 mg of each glass sample were weighed into a platinum crucible and made soluble by high temperature (1000°C) fusion with a mixture of lithium metoborate and lithium bromide. When cooled, the fused samples were dissolved in a diluted solution of high purity nitric acid. Using the well-cleaned Nalgene volumetric flasks, 100 ml of solution of each sample was prepared for the ICP-MS analysis. Each sample was doped with internal standards (yttrium, germanium, and cerium). In the case of the semiquantitative analysis, parallel measurements were conducted using a certified multielement calibration standard. Single element calibration standards were used to prepare calibration curves for the quantitative analysis of selected elements of the glass samples.

During the ICP-MS analysis, the sample solution is drawn into a nebulizer of the ICP-MS spectrometer with argon gas, where it is converted into a fine aerosol. The fine droplets of the aerosol are separated from larger droplets using a spray chamber. The fine aerosol then emerges from the exit tube of the spray chamber and is transported into the plasma torch via a sample injector. The plasma is produced by the interaction of an intense radiofrequency field on a tangential flow of argon flowing through a concentric

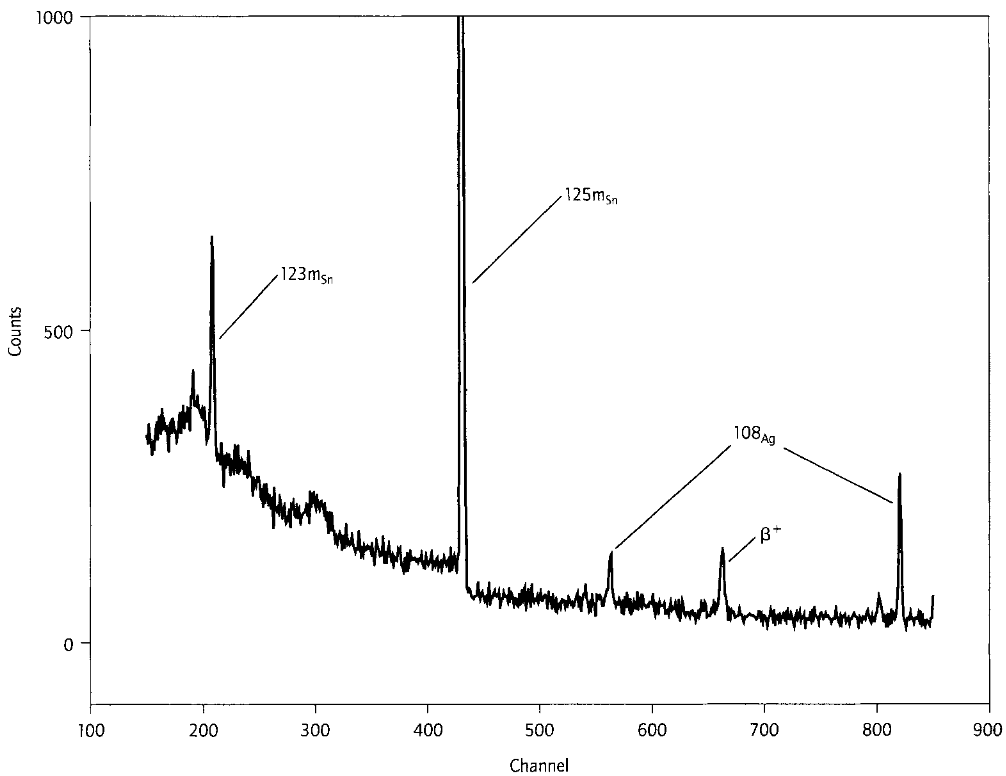


FIGURE 4a Gamma spectrum of the orange glass sample.

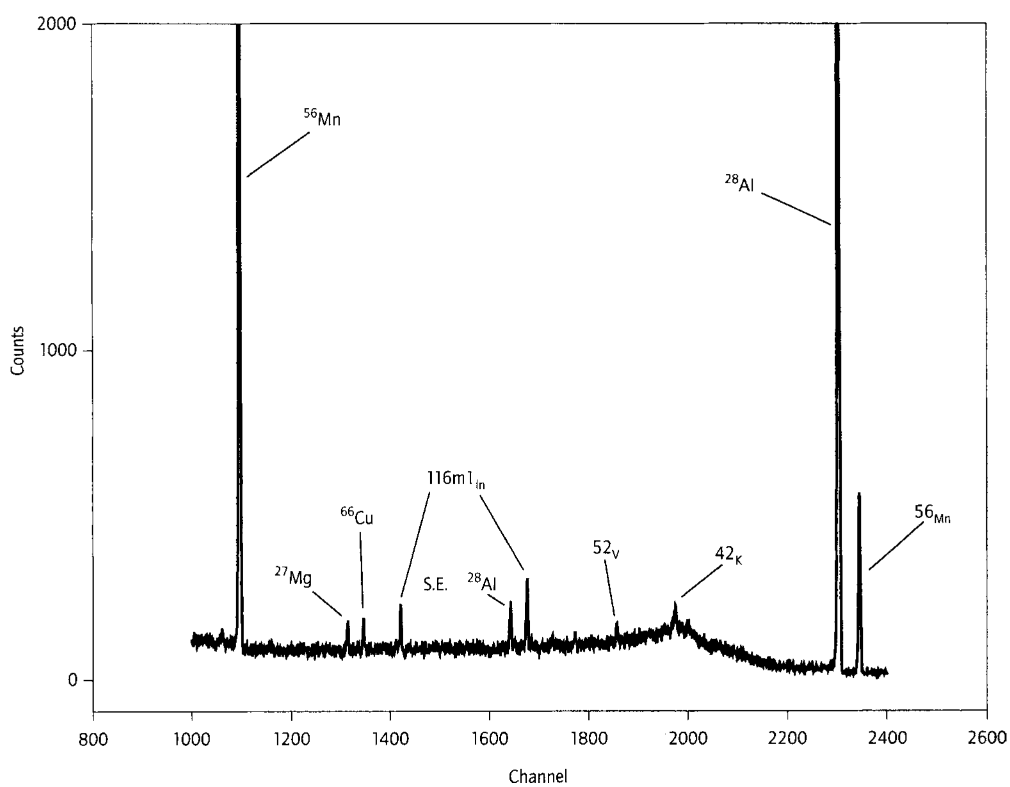


FIGURE 4b Gamma spectrum of the dark blue glass sample.

Table 4 NAA Mass Percent Results from the Analysis of Mosaic Glass

Sample	Color	La_2O_3	CaO	K_2O	Na_2O	Al_2O_3	CoO	Fe_2O_3	V_2O_5	MnO	ZnO	As_2O_5	BaO
1	chartreuse	0.00024%	25.0%	23.8%	0.15%	0.82%	n.d.	n.d.	0.0006%	0.63%	n.d.	n.d.	n.d.
2	white	n.d.	21.0%	28.8%	0.14%	0.89%	n.d.	n.d.	0.0007%	0.77%	n.d.	n.d.	0.21%
3	white	0.00033%	20.5%	27.5%	0.12%	0.93%	n.d.	n.d.	n.d.	0.95%	n.d.	n.d.	n.d.
4	amber	0.00022%	21.7%	26.0%	0.13%	0.82%	n.d.	n.d.	n.d.	0.80%	n.d.	n.d.	n.d.
5	white	0.00034%	23.9%	27.4%	0.33%	1.13%	n.d.	n.d.	0.0017%	0.35%	n.d.	0.0004%	0.41%
6	chartreuse	n.d.	24.5%	23.4%	0.15%	0.81%	0.0011%	0.41%	0.0009%	0.63%	n.d.	n.d.	0.20%
7	white	0.00024%	20.5%	27.9%	0.16%	0.97%	n.d.	n.d.	n.d.	0.86%	n.d.	n.d.	n.d.
8	white	0.00046%	22.2%	27.0%	0.17%	1.07%	n.d.	n.d.	0.0009%	0.72%	n.d.	n.d.	n.d.
9	white	0.00053%	21.0%	32.9%	0.096%	0.93%	0.0006%	0.25%	n.d.	1.19%	n.d.	n.d.	0.22%
10	white	0.00037%	21.6%	27.3%	0.12%	0.94%	n.d.	n.d.	0.0014%	0.96%	n.d.	n.d.	n.d.
11	white	0.00024%	26.4%	26.5%	0.20%	0.98%	n.d.	n.d.	0.0021%	0.33%	n.d.	0.0002%	n.d.
12	white	0.00049%	21.1%	27.0%	0.12%	0.95%	n.d.	1.62%	0.0010%	1.24%	n.d.	n.d.	n.d.
13	white	n.d.	23.4%	25.7%	0.32%	1.08%	n.d.	n.d.	0.0009%	0.71%	n.d.	n.d.	n.d.
14	white	0.00016%	21.1%	27.8%	0.21%	0.94%	n.d.	n.d.	0.0009%	0.95%	n.d.	n.d.	n.d.
15	white	n.d.	3.63%	N/A	21.7%	0.39%	n.d.	n.d.	n.d.	0.025%	0.21%	n.d.	n.d.
16	white	n.d.	0.76%	N/A	21.0%	0.41%	0.0076%	n.d.	n.d.	0.020%	0.15%	n.d.	n.d.
17	creamy beige	n.d.	1.44%	N/A	15.9%	0.42%	n.d.	n.d.	0.0012%	0.70%	0.15%	n.d.	n.d.
18	creamy beige	n.d.	3.53%	N/A	22.2%	0.39%	n.d.	n.d.	0.0005%	0.025%	0.19%	0.097%	n.d.
19	creamy beige	n.d.	3.68%	N/A	15.5%	0.40%	n.d.	n.d.	n.d.	0.028%	0.18%	0.091%	n.d.
20	creamy beige	0.00027%	2.46%	N/A	18.8%	0.45%	n.d.	n.d.	0.0004%	0.012%	0.18%	0.035%	n.d.
21	orange	0.00009%	n.d.	0.049%	0.030%	0.32%	n.d.	n.d.	0.0008%	n.d.	n.d.	0.0012%	n.d.
22	orange	0.00004%	n.d.	0.020%	0.037%	0.33%	n.d.	n.d.	0.0006%	n.d.	n.d.	0.0012%	n.d.
23	white	0.00037%	20.9%	26.4%	0.14%	0.92%	n.d.	n.d.	0.0009%	0.84%	n.d.	n.d.	0.15%
24	orange	n.d.	n.d.	n.d.	0.040%	0.33%	n.d.	n.d.	0.0005%	n.d.	n.d.	0.0012%	n.d.
25	beige-brown	n.d.	0.93%	n.d.	12.7%	0.61%	n.d.	n.d.	0.0019%	0.54%	0.095%	0.0098%	n.d.
26	yellow-green	0.00011%	n.d.	0.064%	0.045%	0.36%	n.d.	n.d.	0.0011%	n.d.	n.d.	0.0039%	n.d.
27	yellow-green	n.d.	1.83%	n.d.	16.0%	0.34%	n.d.	n.d.	0.0004%	0.028%	0.185%	0.071%	n.d.
28	yellow-green	n.d.	n.d.	0.070%	0.062%	0.36%	n.d.	n.d.	0.0006%	0.0014%	n.d.	0.0037%	n.d.
29	yellow-green	n.d.	n.d.	n.d.	14.2%	0.39%	n.d.	n.d.	0.0002%	0.052%	0.19%	0.013%	n.d.
30	yellow-green	n.d.	4.87%	n.d.	13.7%	0.60%	n.d.	n.d.	0.0019%	0.045%	0.30%	0.15%	n.d.
31	yellow-green	n.d.	n.d.	n.d.	0.088%	0.42%	n.d.	n.d.	n.d.	n.d.	n.d.	0.0024%	n.d.
35	dark green	0.00010%	n.d.	0.44%	0.051%	0.33%	n.d.	n.d.	0.0001%	0.010%	n.d.	0.046%	n.d.
36	dark green	0.00010%	0.32%	n.d.	0.041%	0.34%	0.0002%	0.15%	0.0006%	0.0060%	n.d.	0.040%	n.d.
37	medium green	n.d.	n.d.	n.d.	0.039%	0.53%	n.d.	n.d.	0.0004%	n.d.	n.d.	0.0064%	n.d.
38	medium green	n.d.	n.d.	0.0069%	0.081%	0.27%	n.d.	n.d.	n.d.	n.d.	n.d.	0.047%	n.d.
39	medium green	n.d.	1.14%	n.d.	15.9%	0.41%	n.d.	n.d.	0.0012%	0.26%	0.17%	0.048%	n.d.
40	medium green	n.d.	n.d.	n.d.	0.076%	0.29%	n.d.	n.d.	n.d.	n.d.	n.d.	0.048%	n.d.
41	yellow-green	0.00015%	n.d.	n.d.	0.15%	0.34%	n.d.	n.d.	n.d.	n.d.	n.d.	0.029%	n.d.
44	dark blue	n.d.	24.6%	25.4%	0.14%	0.81%	0.048%	n.d.	0.0017%	0.31%	n.d.	0.0010%	0.18%
46	dark blue	0.00019%	22.9%	24.0%	0.14%	0.76%	0.057%	n.d.	n.d.	0.77%	n.d.	n.d.	0.14%
47	dark blue	n.d.	1.97%	n.d.	17.7%	0.55%	0.055%	n.d.	0.0012%	0.22%	0.16%	0.089%	n.d.
48	dark blue	n.d.	24.0%	24.2%	0.17%	0.79%	0.055%	n.d.	n.d.	0.70%	n.d.	0.0009%	n.d.
49	dark blue	n.d.	20.3%	29.6%	0.17%	0.82%	n.d.	n.d.	0.0008%	0.94%	n.d.	n.d.	0.086%
50	dark blue	0.00060%	19.1%	24.8%	0.19%	1.79%	0.075%	n.d.	0.0028%	1.09%	n.d.	0.0015%	0.12%
51	dark blue	n.d.	21.2%	24.1%	0.16%	0.76%	0.084%	n.d.	n.d.	0.60%	n.d.	n.d.	0.24%
52	dark blue	0.00044%	16.7%	33.3%	0.11%	0.86%	0.072%	n.d.	n.d.	1.11%	n.d.	n.d.	0.11%
53	dark blue	n.d.	21.0%	23.2%	0.19%	0.79%	0.080%	n.d.	n.d.	0.59%	n.d.	n.d.	0.058%

Table 4 NAA Mass Percent Results from the Analysis of Mosaic Glass (continued)

Sample	Color	La_2O_3	CaO	K_2O	Na_2O	Al_2O_3	CoO	Fe_2O_3	V_2O_5	MnO	ZnO	As_2O_5	BaO
54	dark blue	0.00030%	19.5%	23.5%	0.20%	1.52%	0.085%	n.d.	0.0016%	0.90%	n.d.	0.0011%	0.095%
55	black	0.00029%	20.1%	26.2%	0.16%	0.97%	n.d.	n.d.	0.0016%	0.81%	n.d.	n.d.	n.d.
56	violet	n.d.	1.02%	4.5%	13.8%	0.51%	n.d.	n.d.	0.0019%	1.15%	0.088%	0.070%	n.d.
57	Indian red	0.00033%	17.69%	25.6%	0.19%	1.09%	n.d.	2.75%	n.d.	0.70%	n.d.	0.0030%	n.d.
58	violet	n.d.	n.d.	n.d.	13.8%	0.52%	n.d.	n.d.	0.0023%	1.17%	0.11%	0.070%	n.d.
59	Indian red	0.00022%	18.6%	25.8%	0.16%	0.86%	n.d.	4.41%	0.0006%	0.69%	n.d.	0.0042%	0.073%
60	Indian red	0.00029%	17.3%	24.6%	0.17%	1.05%	n.d.	3.45%	0.0016%	0.69%	n.d.	0.0033%	0.10%
61	Indian red	0.00021%	17.9%	23.6%	0.17%	1.06%	n.d.	3.50%	0.0003%	0.70%	n.d.	0.0027%	0.15%
62	Indian red	0.00044%	16.8%	22.5%	0.15%	1.12%	n.d.	6.93%	0.0015%	0.85%	n.d.	0.034%	n.d.
63	Indian red	0.00030%	17.2%	25.3%	0.16%	1.07%	n.d.	3.51%	n.d.	0.69%	n.d.	0.0030%	0.078%
64	Indian red	0.00042%	17.5%	26.0%	0.16%	1.06%	n.d.	3.74%	0.0014%	0.69%	n.d.	0.0030%	0.14%
65	Indian red	0.00034%	18.3%	25.2%	0.19%	1.12%	n.d.	3.71%	0.0015%	0.71%	n.d.	0.0030%	n.d.
66	Indian red	0.00064%	18.6%	25.6%	0.14%	1.43%	0.0041%	5.22%	0.0025%	0.74%	n.d.	0.0063%	0.082%
67	Indian red	n.d.	18.3%	26.8%	0.14%	1.05%	n.d.	4.05%	0.0015%	0.69%	n.d.	0.0031%	0.12%
68	Indian red	0.00035%	16.9%	22.8%	0.14%	1.01%	n.d.	6.45%	0.0007%	0.89%	n.d.	0.0024%	0.033%
69	Indian red	n.d.	18.1%	27.8%	0.19%	1.27%	n.d.	3.69%	0.0014%	0.73%	n.d.	0.0022%	0.093%
70	Indian red	0.00060%	18.4%	23.1%	0.18%	1.47%	0.0024%	2.91%	0.0024%	0.87%	n.d.	0.0062%	0.11%
71	Indian red	0.00047%	15.9%	22.6%	0.18%	1.39%	0.0041%	4.49%	0.0022%	0.73%	n.d.	0.0034%	n.d.
72	Indian red	0.00054%	18.2%	22.3%	0.21%	1.43%	n.d.	5.73%	0.0016%	0.74%	n.d.	0.0061%	n.d.
73	Indian red	n.d.	18.8%	N/A	0.27%	1.25%	0.0018%	4.00%	0.0006%	0.72%	n.d.	n.d.	0.51%
74	Indian red	n.d.	19.2%	N/A	n.d.	1.36%	0.0032%	3.99%	0.0014%	0.72%	n.d.	n.d.	0.27%
75	Indian red	n.d.	16.3%	N/A	0.15%	1.44%	n.d.	n.d.	0.0022%	0.74%	n.d.	0.0069%	n.d.
76	Indian red	n.d.	n.d.	N/A	0.20%	1.62%	n.d.	n.d.	n.d.	0.83%	n.d.	0.0060%	n.d.
77	black	n.d.	17.60%	N/A	0.19%	1.83%	0.088%	1.22%	0.0015%	1.08%	n.d.	n.d.	n.d.
78	black	n.d.	18.79%	N/A	0.095%	0.91%	0.057%	n.d.	0.0003%	1.17%	n.d.	0.0009%	0.11%
79	black	n.d.	19.30%	N/A	0.10%	1.00%	0.095%	n.d.	n.d.	0.83%	n.d.	0.0019%	n.d.
80	dark blue	n.d.	24.38%	N/A	0.12%	0.79%	0.059%	n.d.	n.d.	0.71%	n.d.	n.d.	0.33%
81	black	n.d.	17.83%	N/A	0.66%	0.94%	n.d.	0.81%	0.0011%	0.80%	n.d.	n.d.	0.33%
82	dark blue	n.d.	17.96%	N/A	0.45%	0.89%	0.062%	n.d.	n.d.	1.14%	n.d.	n.d.	0.32%
83	dark blue	n.d.	18.22%	N/A	0.080%	0.89%	0.066%	n.d.	n.d.	1.15%	n.d.	0.0011%	0.22%
84	blue	n.d.	23.09%	N/A	0.11%	0.75%	0.063%	0.51%	n.d.	0.67%	n.d.	0.0008%	0.38%
85	black	n.d.	17.33%	N/A	0.37%	1.73%	0.090%	n.d.	n.d.	1.04%	n.d.	n.d.	0.55%
86	black	n.d.	17.88%	N/A	0.10%	0.97%	n.d.	0.92%	n.d.	0.79%	n.d.	n.d.	0.26%
87	black	n.d.	18.13%	N/A	0.10%	0.95%	n.d.	n.d.	0.0015%	0.80%	n.d.	n.d.	n.d.
88	dark blue	n.d.	19.47%	N/A	0.093%	0.89%	0.068%	n.d.	0.0009%	1.18%	n.d.	n.d.	0.18%
89	black	n.d.	19.11%	N/A	0.88%	0.91%	0.0006%	0.63%	n.d.	0.78%	n.d.	n.d.	0.28%
90	black	n.d.	12.00%	N/A	0.22%	0.71%	n.d.	n.d.	n.d.	0.59%	n.d.	n.d.	n.d.
91	Indian red	n.d.	15.81%	N/A	0.092%	0.91%	0.0031%	5.24%	0.0012%	0.84%	n.d.	0.0051%	0.25%
92	violet	n.d.	19.47%	N/A	0.31%	0.98%	n.d.	n.d.	0.0005%	1.21%	n.d.	n.d.	0.35%
93	chartreuse	n.d.	23.87%	N/A	0.46%	0.82%	n.d.	n.d.	n.d.	0.60%	n.d.	n.d.	0.26%
94	blue	n.d.	3.48%	N/A	11.7%	0.58%	0.044%	n.d.	0.0014%	0.22%	0.13%	0.098%	n.d.
95	dark blue	n.d.	n.d.	N/A	11.9%	2.12%	n.d.	0.71%	0.0048%	4.37%	0.12%	n.d.	n.d.
96	dark green	n.d.	0.33%	N/A	20.2%	0.53%	n.d.	2.75%	0.0006%	0.59%	0.12%	0.027%	0.91%
98	dark blue	n.d.	5.78%	N/A	11.7%	0.73%	0.011%	n.d.	0.0009%	0.052%	0.10%	0.053%	n.d.
99	dark green	n.d.	4.18%	N/A	12.5%	0.70%	0.021%	n.d.	0.0007%	0.079%	0.13%	0.13%	n.d.
100	bright red	n.d.	4.90%	N/A	10.1%	0.97%	0.0001%	0.070%	0.0008%	0.0052%	0.10%	0.0022%	n.d.

quartz tube (torch). This ionizes the gas and, when seeded with a source of electrons from a high-voltage spark, forms a very high temperature plasma discharge (~ 6000–8000 K) at the open end of the tube. Once the ions are produced in the plasma, they are directed into the mass spectrometer via a skimmer cone.

After the ions have been successfully extracted from the interface region, they are directed into the main vacuum chamber by a series of electrostatic lenses called ion optics. The ion beam containing all the analyte and matrix ions exits the ion optics and passes into the quadrupole mass spectrometer to be separated according to their mass-to-charge ratio (m/z) In the final process, an ion detector converts the ions into an electronic signal. This electronic signal is then processed by the data handling system in the conventional way to provide a mass spectrum that allows qualitative identification of elements in the sample; or it is converted into analyte concentration using ICP-MS calibration standards. The results of quantitative ICP-MS analysis of mosaic glass are shown in table 5.

Results of chemical analysis performed on glass samples in this study shows that three major types of glass can be found on the Last Judgment mosaic. The most abundant is potassium-lime-silica and lead oxide-silica glass. Much better preserved glass tesserae made of sodium-lime-silica glass are of more recent origin and can be identified visually on the mosaic in the areas of restoration treatments or replacement of original tesserae.

The composition of Last Judgment mosaic glass stands out when compared with other samples of medieval glass (mosaics or stained glass windows). When plotting in three dimensions the concentration of silicon dioxide (SiO_2), against potassium oxide (K_2O) and sodium oxide (Na_2O) concentrations in glass samples using data both on composition of medieval glasses (Brill 1999) and on the composition of glass samples from the Last Judgment mosaic, it can be seen that there are three major areas in the plot corresponding to potassium-based glass, sodium-based glass with a less populated continuum between these two areas that corresponds to mixed potassium and sodium glasses (fig. 5).

TABLE 5 ICP-MS MASS PERCENT RESULTS FROM THE ANALYSIS OF MOSAIC GLASS

Sample	Color	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	MnO	Fe_2O_3	CoO	CuO	As_2O_5	SrO	Sb_2O_5	BaO	PbO	Total Mass %
1	chartreuse	0.18%	3.62%	0.68%	42.0%	20.7%	23.1%	0.76%	0.23%	0.0012%	0.072%	0.0002%	0.089%	0.0009%	0.17%	0.20%	91.8%
93	chartreuse	0.21%	4.77%	0.74%	55.5%	22.6%	23.5%	0.86%	0.18%	0.0014%	0.043%	0.0001%	0.090%	0.0010%	0.12%	0.29%	108.8%
15	white	14.5%	0.087%	0.17%	50.0%	0.26%	2.91%	0.024%	0.040%	0.0081%	0.035%	0.013%	0.0048%	3.93%	0.11%	21.4%	93.4%
17	creamy beige	13.3%	0.072%	0.18%	48.0%	0.075%	1.41%	0.85%	0.10%	0.0004%	0.050%	0.0090%	0.0016%	1.63%	0.0045%	22.5%	88.2%
20	creamy beige	14.7%	0.088%	0.24%	35.7%	0.23%	2.19%	0.015%	0.045%	0.0003%	0.010%	0.021%	0.0019%	1.97%	0.0037%	26.5%	81.7%
21	orange	0.077%	0.046%	0.27%	19.2%	0.013%	0.17%	0.0005%	0.030%	0.0003%	0.0054%	n.d.	0.0004%	0.0054%	0.0004%	74.6%	94.4%
24	orange	0.064%	0.045%	0.25%	19.6%	0.008%	0.14%	0.0006%	0.030%	0.0003%	0.0053%	n.d.	0.0004%	0.0030%	n.d.	80.0%	100.2%
25	beige-brown	12.7%	0.069%	0.36%	57.4%	0.071%	0.69%	0.68%	0.12%	0.0016%	0.063%	0.0060%	0.0061%	0.90%	0.12%	21.2%	94.4%
29	yellow-green	14.3%	0.058%	0.13%	59.8%	0.053%	0.39%	0.064%	0.075%	0.0007%	0.19%	0.0075%	0.0056%	0.38%	0.19%	22.0%	97.6%
41	yellow-green	0.069%	0.036%	0.23%	29.2%	0.031%	0.16%	0.0013%	0.068%	0.0002%	0.17%	0.010%	0.0033%	0.0082%	0.0006%	70.7%	100.6%
35	dark green	0.079%	0.045%	0.23%	28.8%	0.040%	0.17%	0.0014%	0.045%	0.0003%	1.85%	0.035%	0.0025%	0.0059%	0.0005%	67.1%	98.4%
36	dark green	0.23%	0.049%	0.24%	30.0%	0.092%	0.18%	0.0037%	0.050%	0.0003%	1.20%	0.032%	0.0028%	0.013%	0.0007%	66.5%	98.6%
39	medium green	14.3%	0.091%	0.15%	62.8%	0.67%	1.08%	0.33%	0.34%	0.0004%	0.45%	0.037%	0.0064%	0.074%	0.21%	17.3%	97.8%
46	dark blue	0.18%	4.69%	0.66%	55.5%	22.2%	22.6%	1.08%	0.28%	0.076%	0.10%	0.0012%	0.086%	0.0028%	0.14%	2.52%	110.1%
50	dark blue	0.21%	4.87%	1.67%	47.3%	21.9%	17.4%	1.43%	0.47%	0.092%	0.13%	0.0010%	0.083%	0.0053%	0.15%	0.33%	96.1%
55	black	0.16%	4.45%	0.81%	51.6%	25.4%	17.7%	1.09%	0.35%	0.0012%	0.020%	n.d.	0.087%	0.0013%	0.13%	0.14%	102.0%
85	black	0.23%	5.56%	1.82%	55.4%	22.6%	18.3%	1.56%	0.45%	0.095%	0.15%	0.0008%	0.084%	0.0047%	0.14%	0.27%	106.6%
56	violet	11.2%	0.17%	0.30%	61.0%	0.30%	1.19%	1.56%	0.088%	0.0005%	0.018%	0.051%	0.0023%	0.21%	0.0093%	23.8%	99.9%
58	violet	11.3%	0.16%	0.29%	59.9%	0.29%	1.09%	1.53%	0.085%	0.0005%	0.017%	0.049%	0.0022%	0.20%	0.0086%	23.5%	98.5%
62	Indian red	0.19%	4.18%	1.02%	50.8%	21.2%	16.0%	1.17%	3.15%	0.0037%	2.49%	0.0046%	0.073%	0.0059%	0.095%	0.46%	100.8%
73	Indian red	0.19%	4.99%	1.19%	52.2%	21.7%	17.7%	1.03%	1.70%	0.0030%	1.37%	0.0019%	0.090%	0.0034%	0.14%	0.27%	102.6%

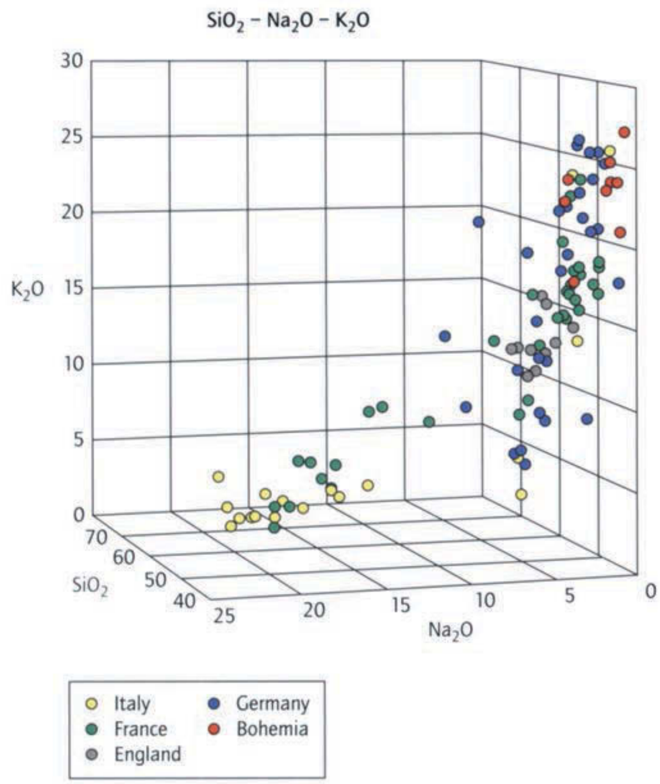


FIGURE 5 Three-dimensional plot of results of analysis of mosaic glass from the Last Judgment mosaic in comparison to results of published analyses of other medieval mosaic and stained glass.

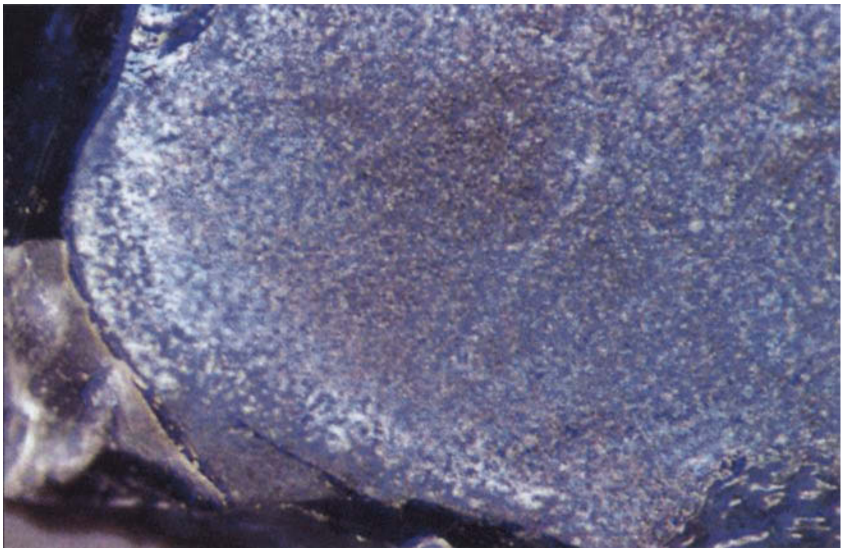
The samples from the Last Judgment mosaic are grouped with other potassium-based glass produced in central Europe and some areas of France and Spain. The Venetian mosaic glass has quite a different composition, and it is well known that, realizing the negative effect of potassium on the weather resistance of mosaic glass, the Venetian government in 1306 forbade the use of potash containing wood ashes for the production of glass (E. Borsook, pers. com. 2001).

The composition of the Last Judgment mosaic glass is very similar to the composition of glass samples obtained from the stained glass windows of the Kolin cathedral and the Kost castle in Bohemia and the Melice castle in Moravia (Heteš 1958). Based on the results of the chemical analysis of medieval glass found in Bohemia and Moravia, Heteš put forward a very interesting hypothesis on the origin of the Last Judgment mosaic glass. His working hypothesis is based on the idea of confusion among medieval glassmakers in Bohemia when interpreting recipes for making glass recommended by the twelfth-century century Benedictine monk Theophilus in his *De Diuersis Artibus:* "Deinde tollens duas partes cinerum de quibus supra diximus, at tertiam sabuli diligenter de terra et lapidibus purgati, quod de aqua tuleris, commisce in loco mundo" (Then take two parts of the ashes of which we have spoken above, and a third of sand from which you have carefully removed the earth and stones and which you have washed clean, and mix them in a clean spot) (Dodwell 1961). In his book Theophilus recommends mixing two parts of beech ash and one part of sand, but he does not specify whether to use weight or volume parts. Heteš suggests that the high concentration of potassium and the low concentration of silicon dioxide in the Last Judgment mosaic glass can be explained by using the weight instead of volume parts of components when making glass. He also stated that the practice of using weight parts might be typical for a Bohemian region in the second half of the fourteen century (Heteš 1958).

In contrast, Ajvaz (pers. com. 1992) theorized that the problem with the Last Judgment mosaic glass is not the high concentration of potassium but the wrong proportion of silicon dioxide and calcium oxide (SiO_2/CaO). This ratio, which is about 7.5 for "normal" chemically resistant glass, is only about 2.0 for the Last Judgment mosaic glass. He even expressed doubts if it is proper to include the Last Judgment mosaic glass in the category of glass at all.

Study of Mosaic Corrosion

Knowing that during the restoration and conservation treatment of the Last Judgment mosaic all corrosion products that accumulated on the surface of the glass tesserae since its last cleaning in the 1980s would be removed, we collected a number of samples of corrosion products to preserve for future analysis. We have also removed and preserved samples of various types of corrosion products found on mosaic tesserae when preparing samples of mosaic glass for both NAA and ICP-MS analyses. A more or less pronounced corrosion layer was found on all facets of the glass tesserae that were exposed to the elements. The sides and backs of glass tesserae embedded in the mortar of the mosaic were found to be in very good condition. Our studies identified two major types of corrosion on glass tesserae of the Last Judgment mosaic. Surfaces of white, yellow, orange, red, and dark blue tesserae were covered with a more or less uniform



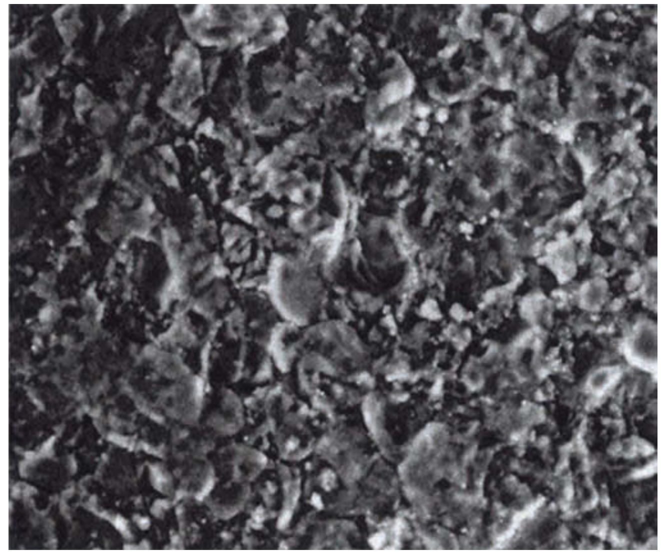


FIGURE 6 Optical micrograph of the uniform type of surface corrosion on the blue glass tessera. Photo: D. Stulik.

FIGURE 7 ESEM micrograph of the detail of the corrosion layer from figure 6.

layer of corrosion products and corrosion product aggregates (see fig. 6). The same surface under the E-SEM (fig. 7) shows that glass tessera is covered with a continuous layer of randomly oriented particles of corrosion products. These range in size from smaller than one micron to as large as about 30 microns.

Green, light blue, brown, and violet tesserae exhibit a tendency toward a pitting corrosion, as it is shown both under an optical microscope (fig. 8a) and under a higher magnification of the environmental scanning electron microscope (fig. 8b). These types of tesserae are also more translucent and exhibit both solid inclusions and air bubbles in the bulk of the mosaic glass. The light blue tesserae stand out in this group of mosaic glass by having the character of a sintered glass frit.

XRD was used to study the phase composition of corrosion products removed from surfaces of glass tesserae. The XRD instrument provided for fast and very sensitive phase analysis of microsamples of glass corrosion. The XRD diffractogram of corrosion products removed from the surface of the blue tessera (fig. 9) shows that the layer of surface corrosion is composed of a relatively high concentration of alfa-SiO_2 (tridymite).

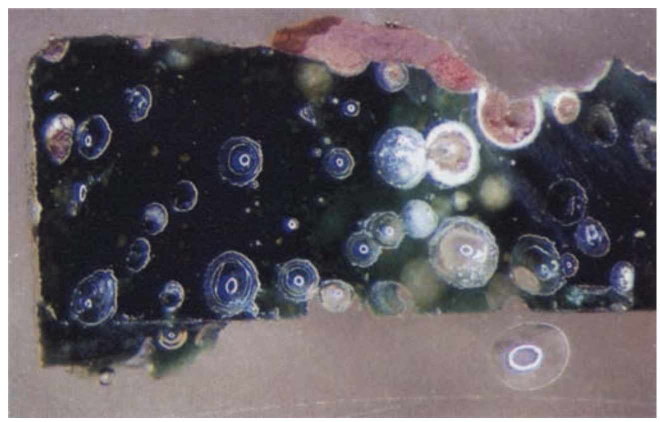


FIGURE 8a Optical micrograph of the pitting type of surface corrosion on the green glass tessera.

FIGURE 8b ESEM micrograph of the detail of the corrosion from figure 8a. Photo: D. Stulik.

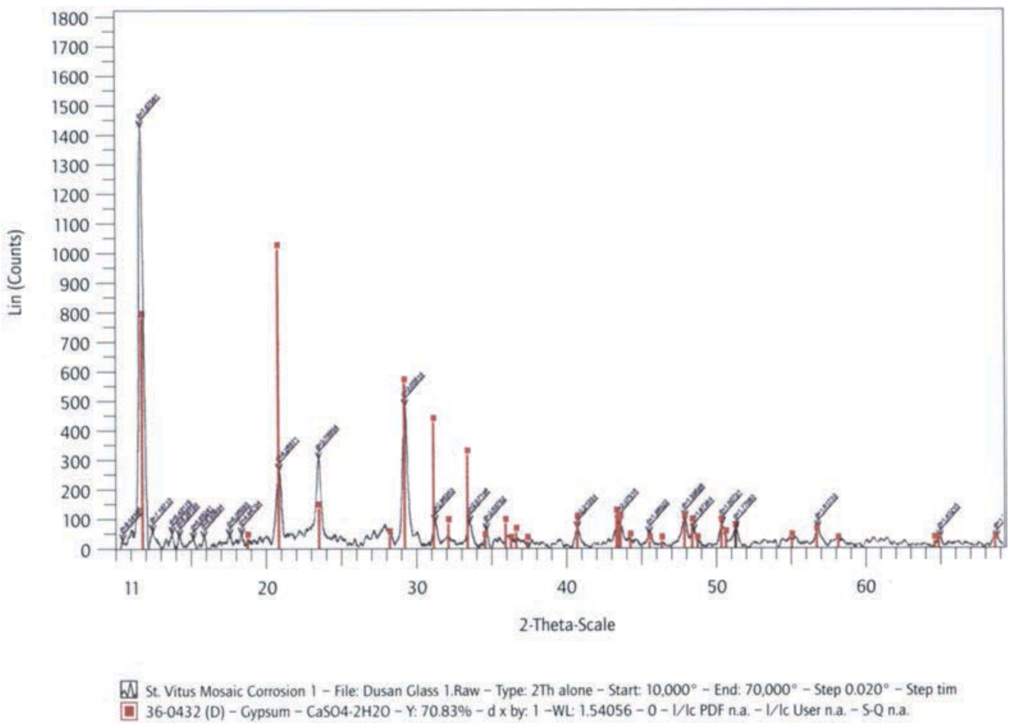


FIGURE 9 XRD diffractogram of corrosion products.

Other corrosion products were also detected:

$CaSO^4 \times 2H_2O$	gypsum
$K_2Ca(SO_4)_2 \times H_2O$	syngenite
$Ca_2(Si_4O_{10}) \times 4H_2O$	gyrolite
Ca_2SiO_4	calcium silicate
$PbSO_4$	anglezite (on Pb-rich tesserae)

On some areas of the mosaic the whitish gray layer of corrosion products was stained by hydrated iron oxide. Low concentration levels of manganese and copper were also detected in corrosion products sampled from the mosaic. The corrosion process results not only in the formation of a corrosion layer on the surface of glass tesserae but also in changes in the chemistry in subsurface areas. One of the best analytic techniques for studying the lateral distribution of chemical elements across the cross section of solid material is EMPA. In the electron microprobe a highly focused electron beam is scanned across a highly polished surface of a cross section of the material to be analyzed. The interaction of the electron beam with the surface of the sample results in emission of X-rays from each area where the electron beam hits. Emitted X-rays carry information about both qualitative and quantitative composition of the sample. By focusing the electron beam and scanning it across the analyzed sample, the emitted X-rays, when analyzed by a spectrometer, can provide information on the distribution of a number of chemical elements across the scanned area. The electron microprobe Cameca SX-100 was used to study the chemical changes in mosaic glass caused by water- and pollution-induced corrosion.

Figure 10 shows a series of elemental maps of the area of the pitting corrosion on the green tesserae from the Last Judgment mosaic. The mosaic surface is shown in the "color of concentration" of several key elements present in the glass sample. These concentration maps show clearly that material in the corrosion pits is made of calcium, silicon, chlorine, and sulfur. Potassium is highly depleted in the area of the corrosion pit. The concentration of chlorine, which is rather low in most of the glass, is relatively high in the pit wall. There are several calcium-rich pit areas across the analyzed surface, as well as a number of areas containing a high concentration of inorganic carbon.

Some Insight into the Chemistry of Mosaic Mortar The original subsurface structure of the mosaic was altered during the

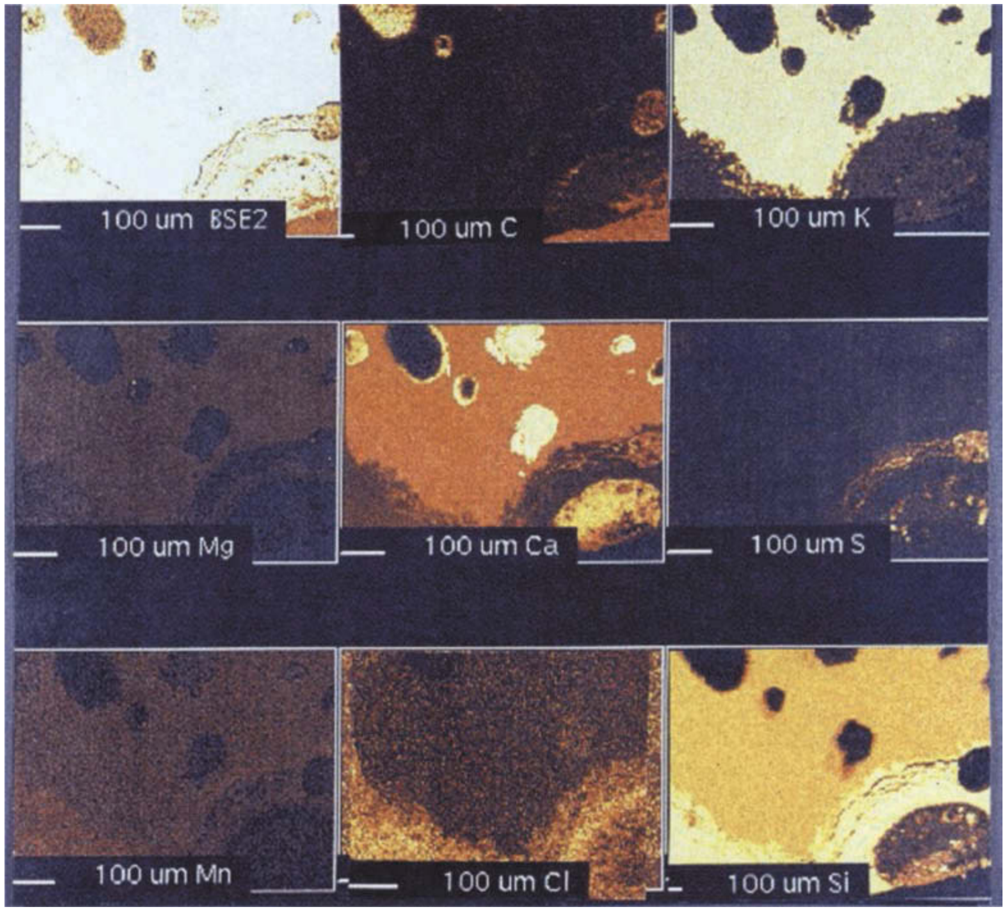


FIGURE 10 Series of maps with a backscattered image of eight elements (carbon, potassium, magnesium, calcium, sulfur, manganese, chlorine, and silica) in the area of the corrosion pitting on the green glass tesserae.

1890–1910 restoration of the mosaic. Therefore, we can learn about it only from previously published technical descriptions, pre-1890 photographs, and samples of mosaic glass in the Archives of the Prague Castle on which a portion of the original mortar is still preserved.

According to the technical descriptions, the original mosaic was installed on the face of the Golden Gate only after this entrance to St. Vitus Cathedral was finished in 1368. This is evident from our thermography experiments related to long-term monitoring and maintenance of the Last Judgment mosaic (see chap. 16). The original third window under the central panel of the mosaic, which was walled in for installation of the mosaic, is clearly visible in infrared thermographs.

To prepare for the installation of the mosaic, the stone wall of the Golden Gate was made rough to improve adhesion of the mortar, and the iron wire mesh was stretched between double hooked nails embedded in regular 37.5 cm intervals in the mosaic. Some filled holes indicating placement of these nails are still visible in the upper portion of the mosaic under the balcony. One of the double hooked nails from the original mosaic was preserved in the upper part of the right panel of the mosaic. A part of the original wire mesh is clearly visible in the upper left part of Eckert's 1879 photograph of the mosaic.

After the wire mesh was installed it was covered with a layer of rough mortar several centimeters thick. We could not find any existing samples of this mortar, but it is possible that some of it may still be preserved in now-filled holes in which wire mesh holding nails were inserted. We can expect that the top, mosaic bearing layer of mortar was applied in stages according to the progress of the installation. To this top layer of mosaic mortar made of lime, sand, and brick powder, the glass tesserae were installed. The top layer of mosaic mortar is still preserved in parts of the mosaic, and we feel that samples of it exist on some of the glass tesserae preserved in the Prague Castle Archives. Several previous technical descriptions of the mosaic mentioned the addition of egg white to fortify the mosaic mortar.

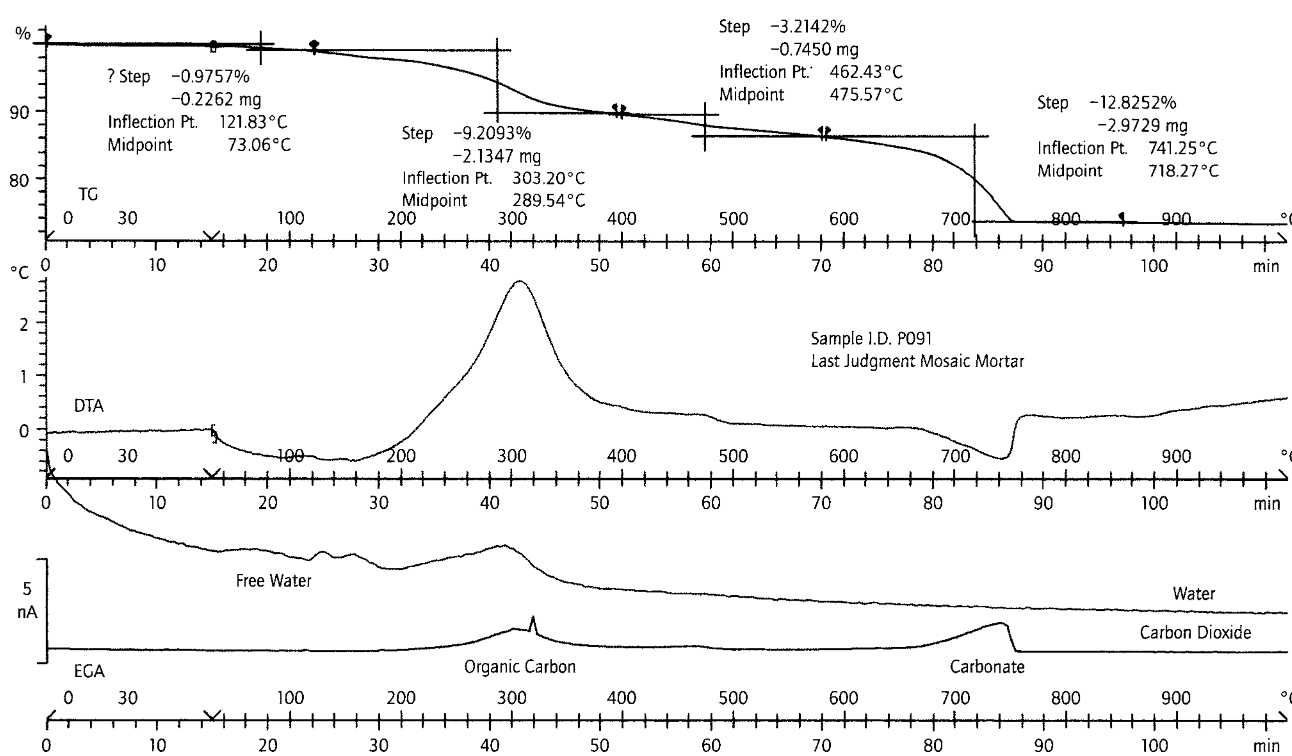
Several samples of the red mortar were separated during preparation of the samples of mosaic glass for chemical analysis. Several types of chemical analyses were performed to identify the inorganic and organic components of the mosaic mortar. The Thermogravimetric analyzer (Mettler Toledo Star) in combination with mass spectrometry (TGA-MS) was used to study the behavior of the mortar when heated.

The monitoring of changes in sample weight during heating from room temperature to 1000°C provided information on the amount of free water and the presence and amount of organic carbon in the sample. It also allowed for the quantitative determination of the amount of calcium carbonate in the stucco sample (fig. 11).

The elemental analyzer (EA) was used to identify the presence of organic compounds containing nitrogen in the mortar sample (fig. 12). The information available to us on past restoration and conservation treatments of the mosaic does not indicate the use of any organic coatings and consolidants containing nitrogen. The presence of organic material containing nitrogen in the mortar could indicate the presence of proteins, but this needed to be confirmed by detailed analysis of organic material in the mortar sample Fourier transform infrared spectrometry (FTIR) was used to study the rather complex composition of the mosaic mortar. The Nicolet FTIR microscope was used to obtained an infrared spectrum of the mortar and its components.

The infrared spectrum of the mortar sample contains a number of spectral peaks and spectral peak groups. A detailed interpretation of the recorded spectra was performed using our own spectral library of art and art conservation materials. The interpretation of the FTIR spectra of the mosaic mortar showed the presence of iron oxide from brick powder, gypsum formed by reaction of calcium carbonate with sulfur dioxide from the atmosphere, and calcium oxalate, which could have been formed as a result of some biological deterioration processes on the mortar surface (fig. 13).

FIGURE 11 TGA-MS data collected during heating of the sample of the mosaic mortar from room temperature to 1000°C.



The chloroform extract of the mosaic mortar also indicated the presence of oxidized linseed oil. This confirms historical information on the use of linseed oil during nineteenth-century attempts to restore and protect the mosaic surface from the effects of the environment. The FTIR analysis was not sensitive enough to detect any protein-based material in the mortar sample. To determine if the mortar was fortified using egg white required the use of an analytic technique more sensitive than FTIR spectrometry. Working for many years on the development of analytic methodologies for identification of organic binding media in paintings allowed the GCI scientists to use gas chromatography mass spectrometry (GC-MS) (Schilling 1998) to identify organic material present in the mortar samples. The samples were pulverized, and organic material was hydrolyzed overnight at 80°C in a reaction vial under nitrogen using diluted sulfuric acid. A mixture of products of acid hydrolysis were derivatized using the Met-Prep derivatizing reagent. The resulting mixture of volatile derivates of fatty acids and amino acids was analyzed using the GC-MS. The resulting total ion chromatogram (fig. 14) shows the presence of fatty acids from previous conservation treatment of the mosaic using the linseed oil as well as the presence of a series of amino acids consistent with amino acids found in egg proteins. The results of the GC-MS analysis also confirmed the presence of calcium oxalate in the mortar, which had already been identified using the FTIR.

Ideas for Future Studies of Mosaic Materials

The ultimate goal of the scientific research conducted during our work on the Last Judgment mosaic was to provide all the necessary data to support the development of a coating strategy that would provide long-term protection and preservation. We have not focused on material studies of the

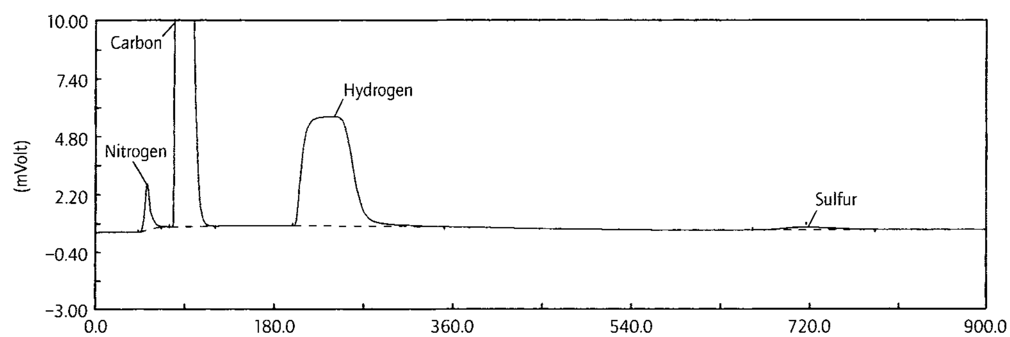
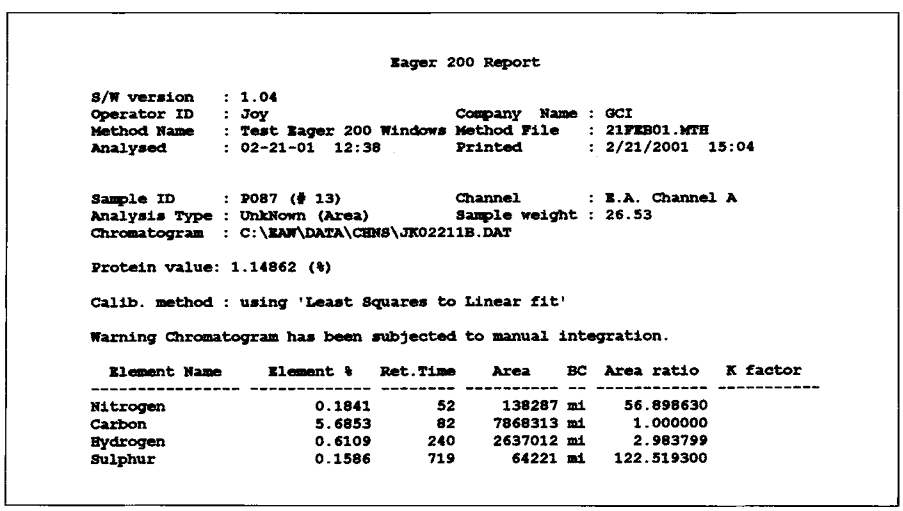


FIGURE 12 Results of the elemental analyzer that helped to identify nitrogen-containing compounds in the mosaic mortar.



Eager 200 Report

S/W version : 1.04
Operator ID : Joy Company Name : GCI
Method Name : Test Eager 200 Windows Method File : 21FEB01.MTH
Analysed : 02-21-01 12:38 Printed : 2/21/2001 15:04

Sample ID : P087 (# 13) Channel : E.A. Channel A
Analysis Type : UnkNown (Area) Sample weight : 26.53
Chromatogram : C:\EAW\DATA\CHNS\JK02211B.DAT

Protein value: 1.14862 (%)

Calib. method : using 'Least Squares to Linear fit'

Warning Chromatogram has been subjected to manual integration.

Element Name	Element %	Ret.Time	Area	BC	Area ratio	K factor
Nitrogen	0.1841	52	138287	mi	56.898630	
Carbon	5.6853	82	7868313	mi	1.000000	
Hydrogen	0.6109	240	2637012	mi	2.983799	
Sulphur	0.1586	719	64221	mi	122.519300	

mosaic or on solving some still remaining and very interesting questions related to provenancing mosaic glass. We also did not try to answer questions related to which segments of the mosaic were replaced or modified during previous past restorations and conservation treatments.

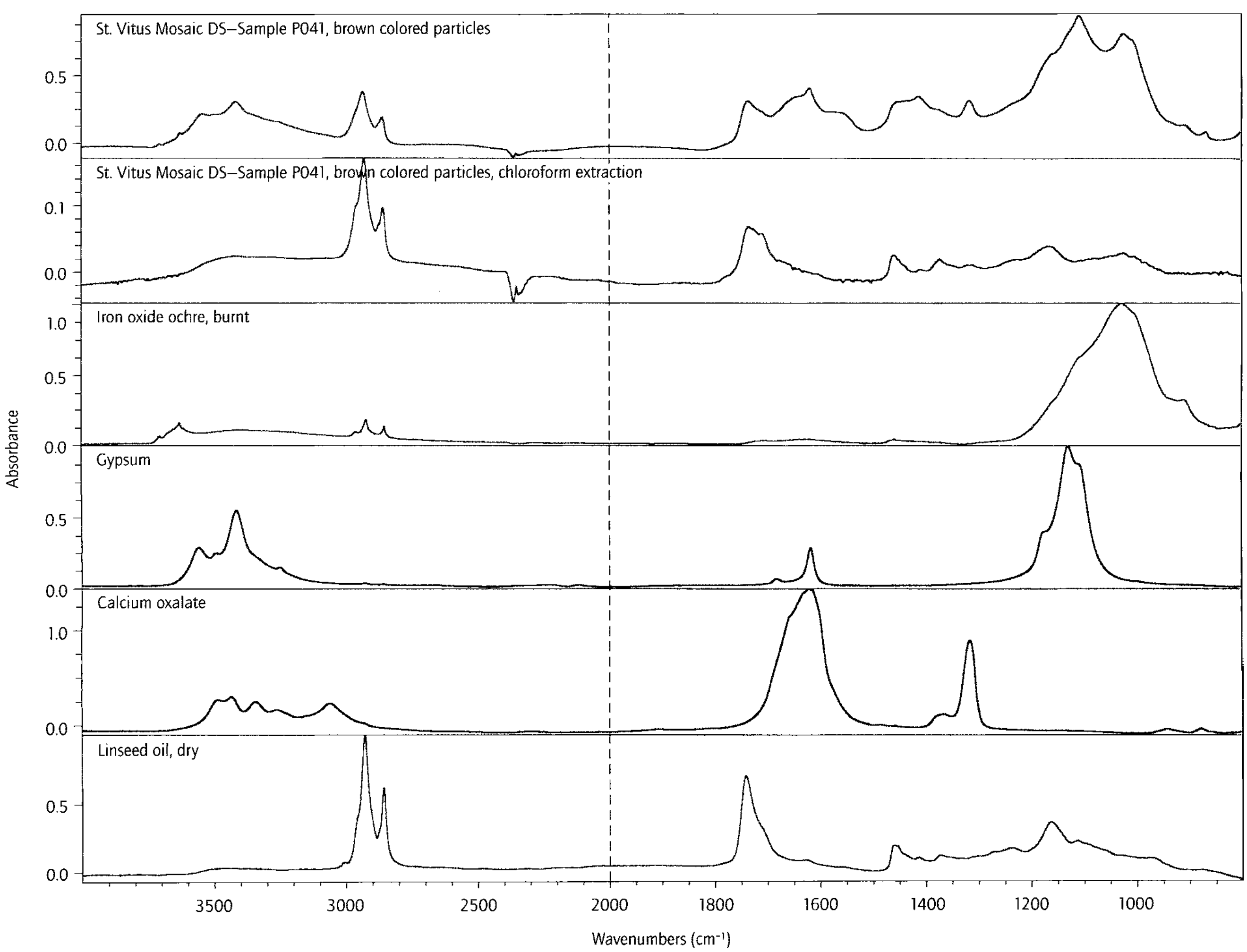
At the same time, it was logical that we had these problems in mind when working on various research tasks. We hope that the research ideas developed during our project will motivate future generations of scientists to investigate the still existing "mysteries" of the Last Judgment mosaic.

Provenancing of Mosaic Glass

The origin of the Last Judgment mosaic glass (Heteš 1958) is still a mystery. Its chemical composition, as shown above, indicates a great similarity to the composition of other samples of medieval glass found in the area of Bohemia, but recent expansion of databases on medieval glass samples from different medieval centers in Europe (Brill 1999) shows that there is not as sharp a distinction between the composition of glass produced in Italy and northern Europe as was previously believed and that instead of only two major types of glass we have to consider more gradual differences in chemical composition and a broader variety of glass types (Brill 1999).

Table 5 shows that some glass in the Last Judgment mosaic contains a substantial concentration of lead. The

FIGURE 13 FTIR spectra of the Last Judgment mosaic mortar together with spectra of individual components of the mortar.



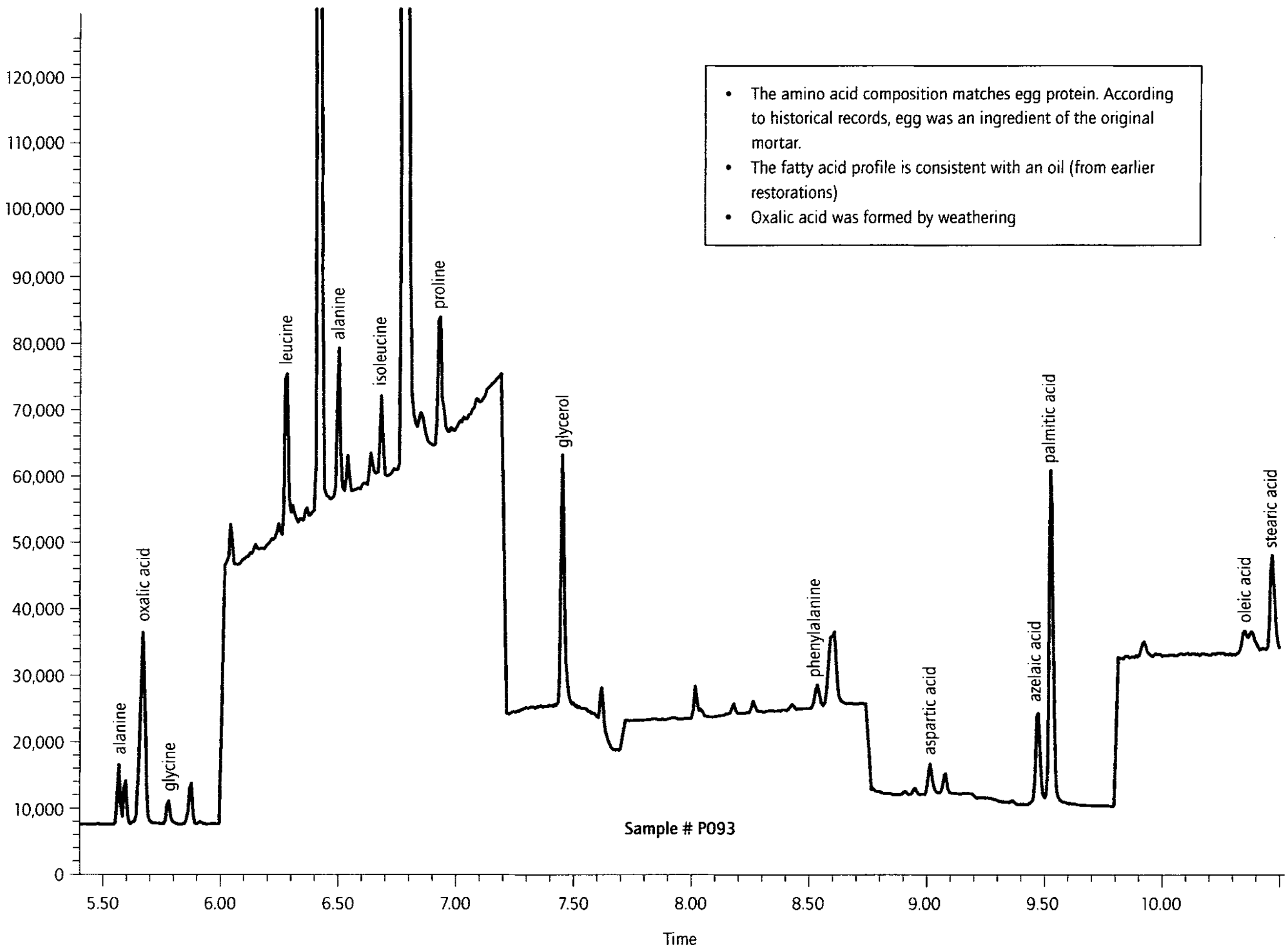


FIGURE 14 Results of GC-MS analysis of fatty acids and proteins in the mosaic mortar.

provenancing of lead and lead-containing archaeological and art objects based on measurement of ratios between individual lead isotopes is a well-established methodology in archaeological research. Lead, which is the end product of uranium and thorium radioactive decay series, has four naturally occurring stable isotopes of atomic masses 204, 206, 207, and 208. Only the first lead isotope of mass 204 was originally present in the primordial Earth crust. The three remaining lead isotopes were produced at different rates over geologic time in uranium- and thorium-rich minerals as a result of the radioactive decay of these radioactive elements. Depending on geologic age and uranium and thorium content of different lead deposits, lead ores, and lead minerals display a distinctive pattern of lead isotope ratios that is locality-sensitive. The isotope ratio is relatively stable and unaffected by the process of smelting and further chemical processing, so that all lead metal produced from ore found at a particular lead mine will share the same lead isotope composition.

Very precise measurements of lead isotope ratios can be done using thermal ionization mass spectrometry (TIMS), which was used for many years as an important tool of archaeological research. TIMS was also used to provide a database of lead isotope ratios for many historically important lead deposits and lead mines. For many years the TIMS technique was the only viable analytic methodology to provide high-quality data on lead isotope ratios, but during the past decade several other analytic methods, such as inductively coupled plasma mass spectrometry (ICP-MS) and time of flight inductively coupled plasma mass spectrometry (TOF-ICP-MS) started to be used to provide data for provenancing of lead-containing artifacts.

Our working hypothesis is that the lead isotope ratio measurements could provide information about sources of lead used to manufacture certain types of glass used on the Last Judgment mosaic. To verify if our hypothesis is valid would require the development of an analytic methodology for lead isotope ratio measurement of lead-containing glass, verification that the glassmaking process does not alter the lead isotope ratio, and the creation of a database of lead isotope ratios for medieval lead mines in Bohemia. By measuring the lead isotope ratio of lead present in the original glass of the Last Judgment mosaic and comparing the lead isotope ratio obtained from such an analysis with databases of lead isotope ratios of Bohemian, Italian, or other lead deposits could provide information that can be used to solve the problem of provenancing of the Last Judgment mosaic.

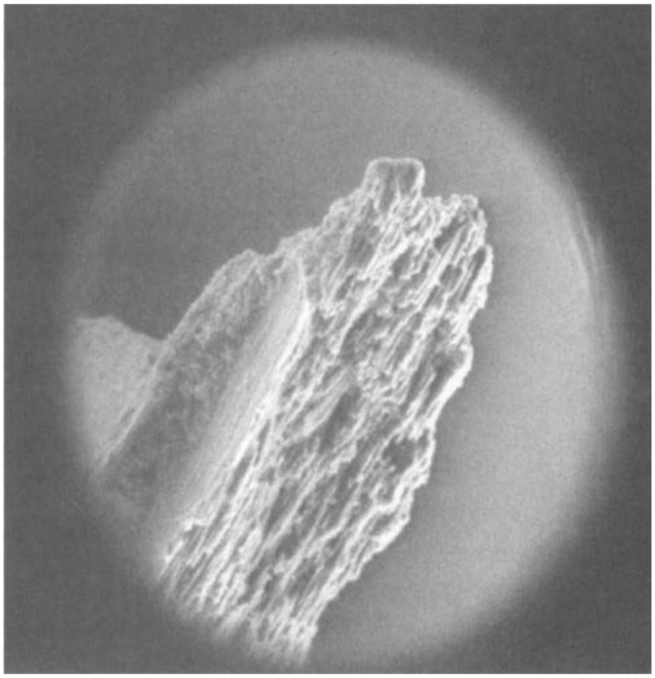
Radiocarbon Dating of the Last Judgment Mortar

It is very important for the art historical interpretation of the Last Judgment mosaic to know which parts of the mosaic are original, which are new, and which had been altered during previous restoration and conservation treatments. Detailed documentation of the mosaic based on visual inspection by conservators can provide some clues. These clues are based on observation of any signs of changes of the structure of the mosaic and mosaic topography and on the study of the different types of mosaic mortar applied during past restoration and conservation treatments. During our work on the mosaic, we studied a number of glass tesserae (from the collection preserved at the Prague Castle Archives) on whose sides some mortar was still attached. During a detailed microscopic investigation of these samples, we were able to differentiate between reddish mortar containing a red brick powder, whitish lime mortar without any red brick filler, and grayish cement containing mortar. Based on our knowledge of mosaic technology we can assume that the reddish mortar is original, but there is no objective proof that this is the case. Microscopic investigation has shown the presence of dark particles mixed into the bulk of the reddish mortar. We were able to remove one of the bigger dark particles and to examine closely using the ESEM. The electron micrograph in figure 15 shows that the dark particle in the mortar is a charcoal-like material.

It is not surprising to find charcoal in the mortar. In the Middle Ages, lime was prepared by high-temperature decomposition of chalk. Charcoal was a standard fuel used for such an operation, and we can expect that some unreacted particles of charcoal could have been mixed with the resulting lime. Because the charcoal is almost pure carbon, the charcoal particles could be radiocarbon dated to establish approximately when the lime for the mosaic was made and thus to establish if the reddish mortar is the original mortar of the mosaic.

One particle of charcoal extracted from the reddish mortar was just a few hundred micrograms in weight. That makes it too small for standard radiocarbon dating procedures, but there is enough carbon material in the particle to conduct radiocarbon dating using accelerator mass spectrometry (AMS). AMS has been used frequently to date archaeological objects and to identify the date of archaeological strata containing organic material. AMS has also been used to date important art objects (Stulik 1992).

FIGURE 15 ESEM micrograph of the charcoal particle removed from the mosaic mortar.



In the AMS procedure the carbon-containing material to be dated must be thoroughly cleaned to remove any possible "modern" or "old" carbon contaminants. Clean carbon material is burned in an oxygen atmosphere to produce carbon dioxide. Carbon dioxide is separated from hydrocarbons, water, and nitrogen contaminants using a sequence of adsorption and freezing steps in a vacuum line. Pure carbon dioxide is catalytically converted to solid graphite, which is used to prepare a sample target for the AMS instrument. In a compartment of the AMS instrument the graphite sample is bombarded by energetic (10 keV) Cs+ ions. During the bombardment of the graphite sample, secondary ions are sputtered away. These secondary ions ($^{14}C^+$, $^{13}C^+$, $^{12}C^+$ together with any remaining or impact-generated contaminants ($^{14}N^+$, $^{12}CH_2$, ^{13}CH, etc.) are extracted to the entrance of the accelerator, where they are accelerated to several MeV of energy. High-energy molecular ions are destroyed in the stripper by collision with atoms of inert gas. From the stripper region of the AMS spectrometer resulting ions are electrostatically injected to the double focusing mass spectrometer in which the carbon-14 ions are separated from other carbon ions and quantitatively measured using a Faraday cup detector. The signal of carbon-13 is measured as well to provide very precise information on the ratio of carbon-14 and carbon-13 in a dated material. Data from the AMS spectrometer are then evaluated using the internationally accepted Calibration Curve of the Radiocarbon Data to provide the age of a measured sample (fig. 16).

It should not be terribly difficult to obtain a rather good date for the charcoal particles, but interpretation of radiocarbon data needs to be done very carefully. Radiocarbon dating cannot provide information on when the Last Judgment mosaic was made. It can provide information only on when a tree, later used to make the charcoal for the preparation of the lime used on the mosaic, was cut down. In that moment a tree stops assimilating the radiocarbon from the air. From the moment the tree is cut, its wood decays with the half-life of 5,730 years. AMS measurements provide information on the concentration of remaining radiocarbon and thus the date when the tree was cut.

The interpretation of radiocarbon dates can be even more complicated. A tree grows continuously for a number of years, and only individual rings of the tree have the same date. Therefore, when interpreting radiocarbon dates of any wood or wood-based material (e.g., charcoal), it is important to realize that a measured radiocarbon date might be many years older than when the tree was cut, depending on the position of the dated sample of wood in the trunk of the tree. The radiocarbon date will never be younger than the age of the outer tree ring of a given tree. Radiocarbon dating works rather well on samples predating 1700, so an approximate date when the lime for the Last Judgment mosaic was made could be measured with a statistical precision of about +/− 50 years.

In-Situ Mapping of the Chemical Composition of the Mosaic Glass

There are important questions related to the modification of the mosaic image during past restoration and conservation treatments. Many outdoor mosaics still in existence have been heavily altered or replaced (Borsook, Superbi, and Pagliarulo, 2000). It is well known that most of the medieval mosaics on the Orvieto Cathedral were replaced (Bertelli 1989), and we find a similar situation in lunettes of the San Marco Basilica in Venice, where only one of the top lunettes has the original mosaic decoration (Mariacher 1992). Because even rather well protected medieval mosaics in Italy did not survive exposure to the elements, the originality of the Last Judgment mosaic was questioned by mosaic experts (E. Borsook, pers. com. 2001). It is important to answer all questions related to the originality of the mosaic, but thus far no documents have been found that describe any major work on the mosaic in the period between its completion in 1372 and its removal for restoration in 1890.

Medieval mosaic glass has a unique composition that differs markedly from the composition of the glass used in later restorations. Previous, obtaining information on the chemical composition of any individual glass tesserae in the mosaic required a glass sample; therefore, to preserve the integrity of the mosaic previous analytic studies were rather limited. A new analytic technology, portable X-ray fluorescence, recently has become available that makes it possible to conduct large-scale analytic studies and mapping of the chemical composition of mosaic glass in situ and nondestructively, without the need to remove samples.

Conclusion

The analytic research conducted to support our conservation project expanded knowledge of mosaic materials and provided new directions for scientific research on the materials of the Last Judgment mosaic. A number of mosaic glass samples, corrosion products, and mosaic mortar samples

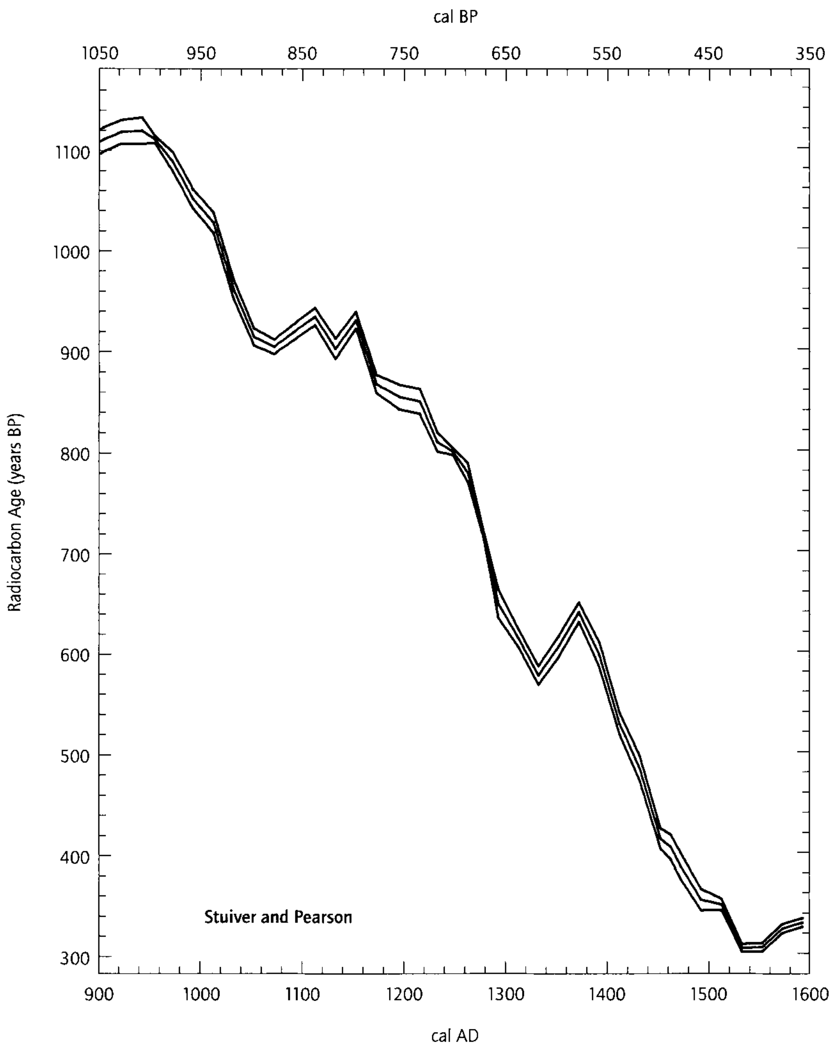


FIGURE 16 Radiocarbon calibration curve for dating of carbon-containing material corresponding to the period when the Last Judgment mosaic was installed (900–1600). Adapted from Stuiver and Pearson 1986.

analyzed in the course of our work have been preserved in the form of loose material or sample cross sections and will be available to future generations of researchers who will be able, with even more powerful analytic tools than we have today, to advance knowledge of medieval glass and glass technology. To facilitate their research, we are transferring all the samples and mosaic material collected during our work back to Prague to be deposited in the Archives of the Prague Castle (fig. 19).

We expect that future analytic investigations will build on our results as well as on the results of previous generations of scientists who worked on the Last Judgment mosaic and made important contributions to answering the many remaining questions about the mosaic's materials, mosaic, to its long-term preservation, and to solving the remaining mysteries of this magnificent monument.

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Shin Maekawa

Chapter 11
The Microclimate of the Last Judgment Mosaic

The historic city of Prague (longitude 14° 30' east, latitude 50° 10' north), "the Golden City of One Hundred Spires," is situated in the countryside of the Bohemian basin on the banks of the Vltava River. On the hillside above the western bank of the river lies the Prague Castle, over which looms the Gothic-style St. Vitus Cathedral (fig. 1). The Last Judgment mosaic is located on the south facade of the cathedral approximately 30 feet above courtyard ground (fig. 2). Above the mosaic lies a balcony, approximately 15 feet deep and 20 feet wide, and a tall stained-glass wall. Below the face of the mosaic lies a vaulted gateway structure (fig. 3).

The Last Judgment mosaic has been subject to weathering since its creation in the fourteenth century. To aid in the conservation effort, environmental conditions were monitored at and near the mosaic over the course of a year, from June 18, 1993, to May 21, 1994, using a GCI monitoring

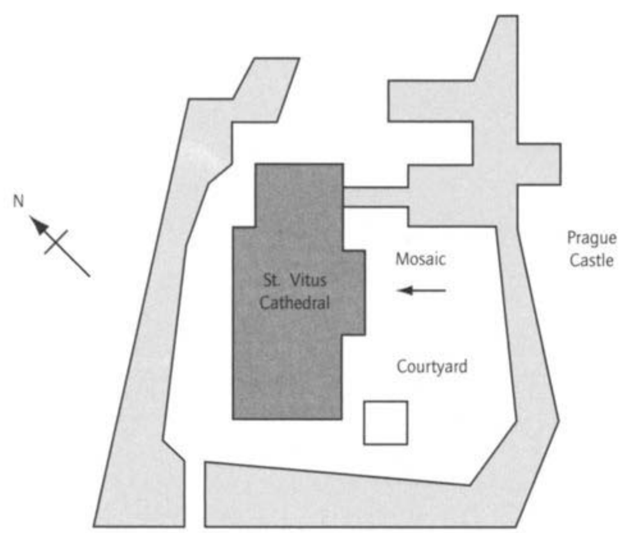


FIGURE 1 Schematic layout of St. Vitus Cathedral and the Prague Castle.

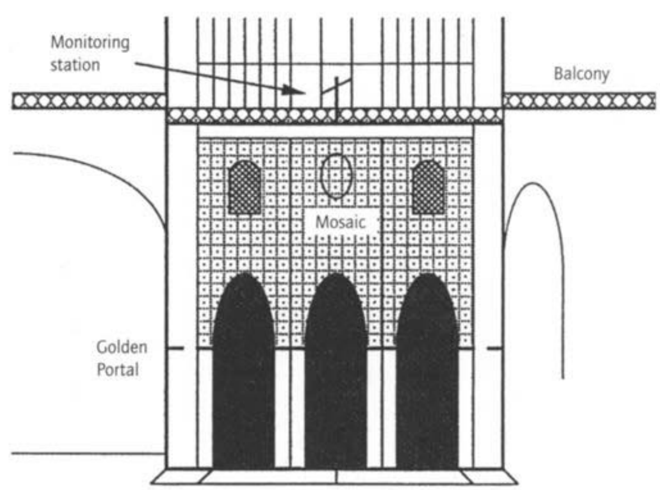


FIGURE 2 Diagram of south face of St. Vitus Cathedral showing the location of the Last Judgment mosaic and the monitoring station.

FIGURE 3 South face of St. Vitus Cathedral and orientation of the Last Judgment mosaic. Photo: S. Maekawa.

station. Analysis of the collected data was performed to determine the test conditions needed to simulate the mosaic environment for evaluating protective coatings for treatment of the mosaic.

Environmental Monitoring Station

A monitoring station was put in place on the balcony above the mosaic to monitor the microclimate at the south-facing wall of the cathedral and the mosaic on June 10, 1993. (See fig. 4 for the south-facing view of the station on the balcony.) The station was equipped with instrumentation to measure air temperature, relative humidity, wind speed, wind direction, and solar radiation. In addition, temperature probes were installed to measure surface temperatures at ten locations on the mosaic (temperature probes 1 through 5 and 7 through 11) (see fig. 5). The probes provided data on temperature changes of various glass tesserae at different parts of the mosaic and spatial orientations. Temperature probes 6 and 12 provided surface temperatures on the vaulted ceiling beneath the mosaic, which is shielded from sunlight. Table 1 lists locations, orientations, and glass tesserae colors where temperature probes were installed.

The environmental monitoring station was an autonomous weather station, which consisted of electronic sensors, a microprocessor controlled datalogger, self-powered storage modules, a solar panel, and a rechargeable battery. Measurements were made once a minute for all measured parameters, and average values over fifteen-minute periods were recorded by the station. The recorded values were electronically stored in solid state storage modules of the station, which were later transported to the GCI for data retrieval and subsequent analysis.

The solar radiation was measured in the visible and near-infrared range using a silicone photodiode, which responded between 400 nanometers and 1,100 nanometers,

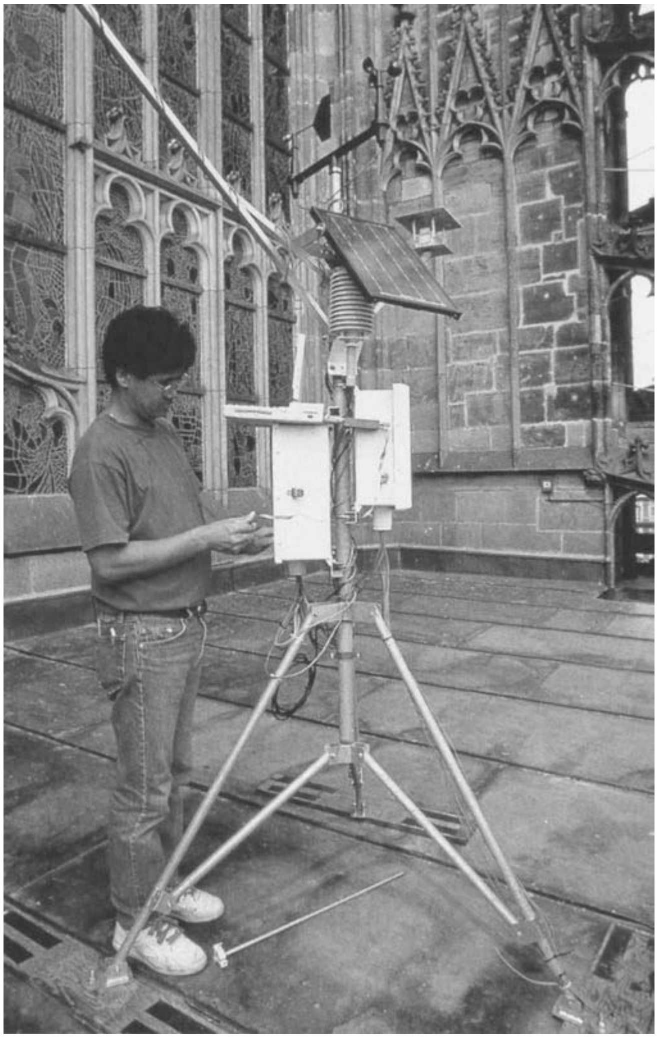


FIGURE 4 The environmental monitoring station being installed on the balcony of St. Vitus Cathedral. Photo: D. Stulik.

on the horizontal surface. A thermistor and a capacitive-type relative humidity sensor were placed in a vented radiation shield used to measure the air temperature and relative humidity, respectively. A three-cup anemometer, which uses a magnet-activated reed switch, measured wind speed, and a wind vane, mounted on a potentiometer, measured the wind direction. Both wind sensors had a wind speed threshold of 0.447 m/s for activation, and the vector averages of the wind over 15-minute periods were recorded. Surface temperature measurements were made using E-type thermocouples directly adhered to the surface of glass tesserae

TABLE 1 LOCATIONS, GLASS COLORS, AND ORIENTATIONS OF TEMPERATURE MEASUREMENTS ON THE LAST JUDGMENT MOSAIC

Temp. Probe #	Location	Substrate	Orientation
1	Center panel	Dark brown tessera	Southeast
2	Center panel	Dark brown tessera	Southeast
3	Column	Dark brown tessera	West
4	Column	Dark brown tessera	East
5	Center panel	Light brown tessera	Southeast
6	Vaulted ceiling	Stone	Ground
7	Center panel	Dark/light brown tessera	Southeast
8	Left column	Dark brown tessera	East
9	Center panel	Light brown tessera	Southeast
10	Left column	Dark brown tessera	West
11	Center panel	Dark/light brown tessera	Southeast
12	Vaulted ceiling	Stone	Ground

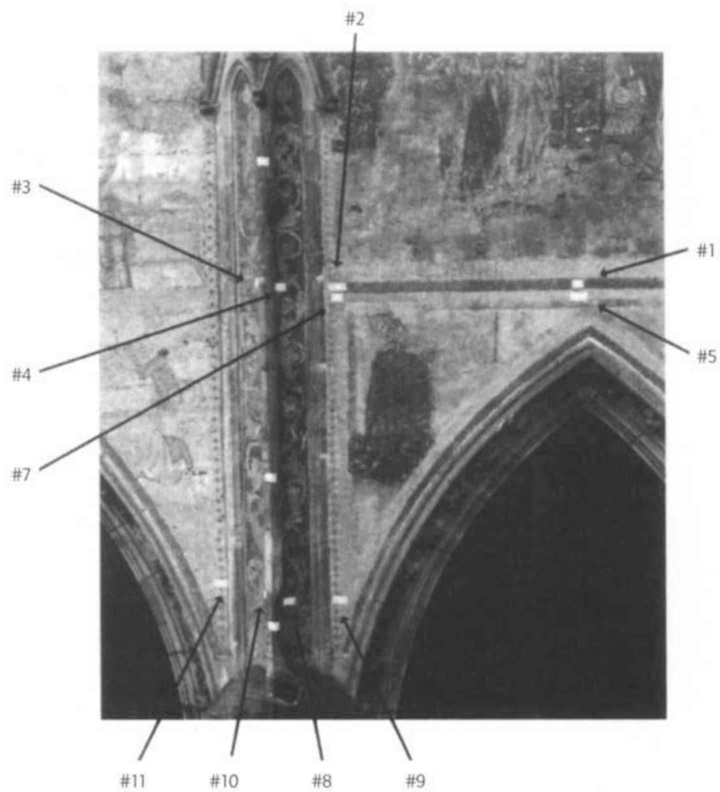


FIGURE 5 Locations of surface temperature probes on the Last Judgment mosaic.

using 2 cm × 2 cm gauze that was soaked with Poraloid B-72 solution.

Results of the Monitoring

Collected data were statistically processed at the GCI using SAS programs, a commercially available computer software package, to evaluate statistical values and to produce graphs for presentations. The analysis was made to evaluate daily (24-hour) statistical values as well as annual, seasonal, or monthly statistics at each 15 minutes over a 24-hour day. The complete data were presented in the final report of the project (Maekawa and Lawrence 1994).

Discussion of Data

The environment of the mosaic at St. Vitus Cathedral is characterized as a mild climate with moderate seasonal variations and occasional cold periods during the winter. Table 2 summarizes typical statistical values, minimum, maximum, mean, and standard deviation, for each of the climatic parameters over the one-year period.

Air Temperature

The yearly average of the air temperature was 9.9°C, with a standard deviation of 7.9°C and a symmetric distribution about its average value. Almost 70% of all the air temperature data remained within one standard deviation above and below the average. A tighter range of the recorded values places 50% of yearly air temperature between 4°C and 16°C. Air temperatures showed seasonal variations, with the summer average in August of 19.8°C and the winter average in February of 0.6°C. The maximum, 34°C, was recorded in August at approximately 1:00 P.M., and the minimum, -12°C, was logged in February at approximately 8:00 A.M. Periods of subzero temperature occurred 8% of the time. There were a total of approximately 38 days with subzero temperatures occurring between October and March. There were also three periods of subzero mornings occurring for more than a week between November and February. At the other extreme, daytime temperatures exceeding 30°C were recorded for 9 days from July through August. Above 30°C temperatures occurred mostly in August and lasted approximately 5 hours on average and in some cases for as long as 8 hours. Figure 6 shows a plot of daily maximums, minimums, and averages of the air temperature recorded by the station.

Table 2 Summary of Climatic Parameters Recorded at South-Facing Side of St. Vitus Cathedral (June 1993–May 1994)

Variable	Minimum	Maximum	Mean	Std. Dev.
Air temperature (°C)	−12	34	9.9	7.9
Relative humidity (% RH)	12	99	67.8	18.4
Dew point temperature (°C)	−20	18	3.5	6.3
Wind speed (m/s)	0.2	5.5	0.75	0.75
North wind component (m/s)	−5.3	3.9	0.0	0.9
East wind component (m/s)	−4.8	5.4	−0.1	0.6
Solar radiation (kW/m²)	0.0	0.93	0.08	0.16

Relative Humidity

Relative humidity (RH) data showed seasonal variations averaging 67.8% for the monitored year. The 70% range was from 49.4% RH to 86.2% RH, and the 50% range was from 54.3% to 81.3%, with a symmetric distribution above and below the average. The lowest value, 12% RH, was recorded in April 1994. The seasonal averages were 74.2% RH for winter (October through March) and 61.1 % RH for summer (April through September). It exceeded 90% for several periods, which were a total of 8% of the time and 48 days during the year. The longest periods of 90% RH or higher were recorded for 10 days between late October and early November and 9 days in February. Figure 7 shows a plot of daily maximums, minimums, and averages of the relative humidity recorded by the station.

Dew Point Temperature

The dew point temperature averaged 3.5°C for the year, with the 70% range from -3.2°C to 9.8°C and the 50% range from 0.5°C to 7.5°C, with, again, a symmetric distribution about its mean. The minimum dew point temperature, -20°C, was recorded during a cold and dry period in February, and the maximum, 18°C, was registered in August. Relative humidity fell below 0°C 25% of the time. Average values were 9°C and -4°C in August and February, respectively.

Solar Radiation

Effects of solar radiation are partially reduced by the surrounding castle structure. Solar radiation had a standard deviation range of 0 to 0.24 kW/m². The daily maximum

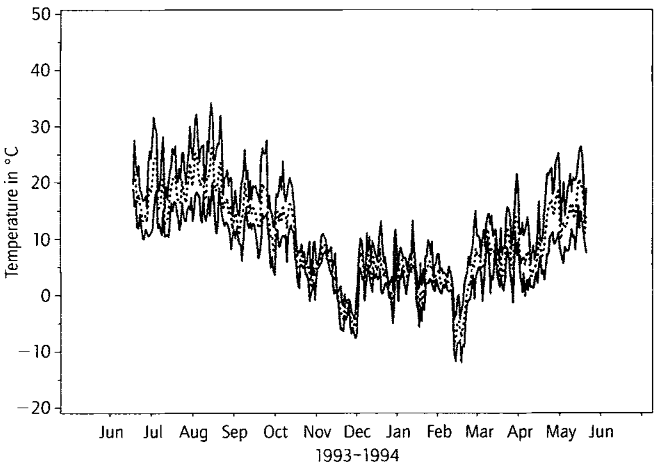


FIGURE 6 Plot of average, maximum, and minimum daily air temperatures observed at south-facing walls of St. Vitus Cathedral.

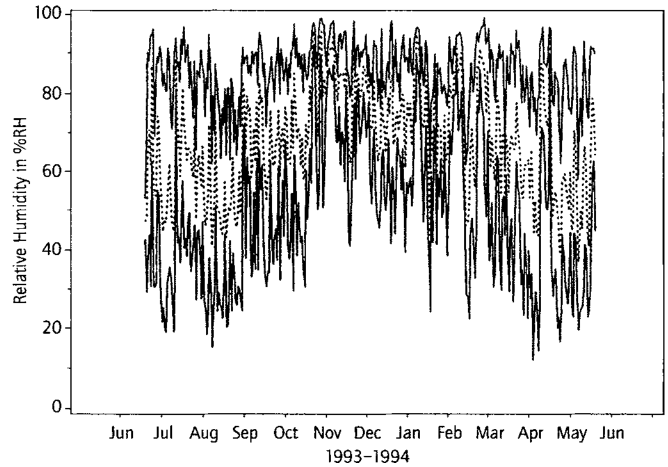


FIGURE 7 Plot of average, maximum, and minimum daily relative humidity observed at southfacing walls of St. Vitus Cathedral.

radiation, 0.93 kW/m^2, was recorded in June. Seasonal fluctuations of 24-hour average solar radiation ranged from 0.02 kW/m^2 in December to 0.13 kW/m^2 in June. Periods of low solar radiation occurred in November to March, which was an overcast period. The average durations for solar radiation (above 0.1 kW/m^2) for December and June were 6.6 hours and 11.5 hours, respectively. By averaging only daytime data (greater than 0.1 kW/m^2), the seasonal averages were 0.18 kW/m^2 for December and 0.40 kW/m^2 for June. The daytime solar radiation was below 0.66 kW/m^2 and 0.29 kW/m^2 for 90% and 50% of the time, respectively.

Wind Speed and Wind Direction

Wind speeds are greatly reduced because of sheltering by both the cathedral and the castle structures and only slightly favor from the north-north-west direction, while indicating a turbulence condition in the wake of the buildings. There was no significant variation in either direction or speed of wind throughout the year.

Wind speeds were low throughout the season at 0.75 m/s on average and a maximum value of 5.5 m/s during mid-March. The most frequent wind speed was less than 0.447 m/s, the threshold wind speed of the sensor. The wind speed was below 1.1 m/s 70% of the time, and winds exceeded 2.3 m/s only 5% of the time. The wind blew from the north-north-west direction approximately 30% of the time and from all other directions the rest of the time with equal probability. Periods of the north wind activity coincide with east wind activity, indicating probable turbulent conditions caused by the surrounding cathedral and castle structures. Figure 8 shows a plot of windrose produced from the twelve-month wind data. Each pixel in the polar plot represents the direction and speed of a vector average of the wind over a 15-minute period.

Mosaic Temperatures

A summary of surface temperatures of the mosaic is shown in table 3. The surface temperatures generally followed seasonal variations of the air temperature affected by one important factor, solar heating.

The mosaic temperatures almost always exceeded the air temperature on the daily average because of this effect. Mosaic temperature #1, a surface temperature of a flat and south-facing, dark gray glass mosaic piece, averaged 2.2°C higher than the air temperature and exceeded air temperature by as much as 11°C in the hot summer afternoon. Mosaic temperature #3, the surface temperature of a gray color mosaic piece on the west-oriented surface of an

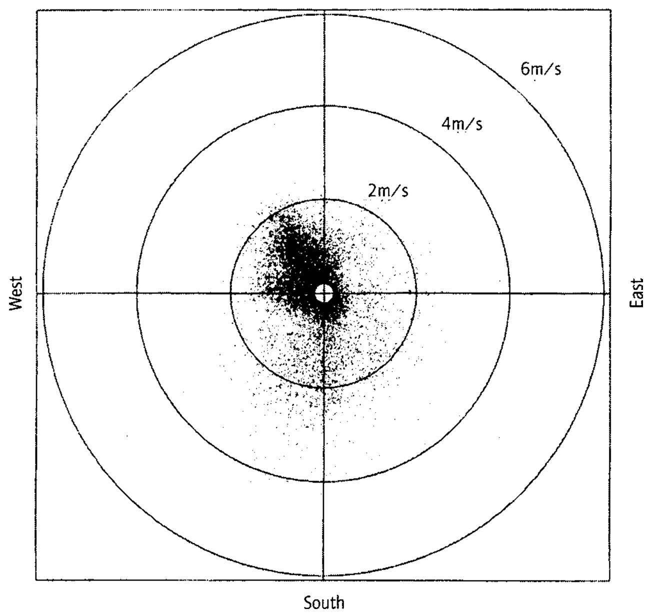


FIGURE 8 Annual windrose produced from wind data collected at south-facing side of St. Vitus Cathedral (June 1993–May 1994).

TABLE 3 SURFACE TEMPERATURES OF THE LAST JUDGMENT MOSAIC AND VAULTED CEILING AT SOUTH-FACING WALL OF ST. VITUS CATHEDRAL (JUNE 1993–MAY 1994)

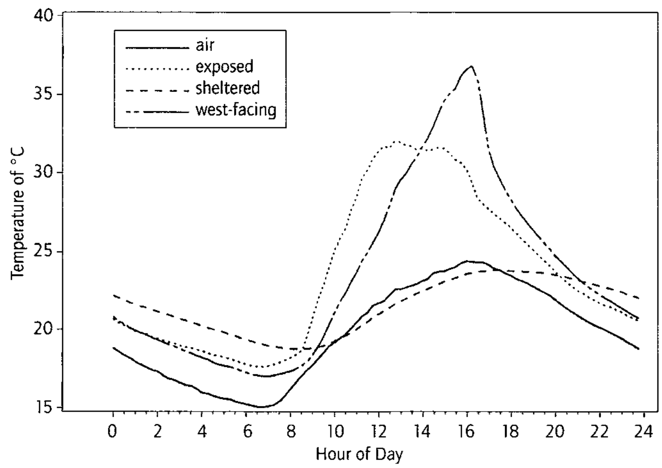
Variable	Min.	Max.	Mean	Std. Dev.
Mosaic temperature #1 (°C)	−10	45	12.1	9.4
Mosaic temperature #2 (°C)	−10	47	12.0	9.5
Mosaic temperature #3 (°C)	−11	52	11.8	9.7
Mosaic temperature #4 (°C)	−10	45	12.2	9.5
Mosaic temperature #5 (°C)	−9	47	12.5	9.5
Temperature of vaulted ceiling #6 (°C)	−9	31	10.9	7.8
Mosaic temperature #7 (°C)	−9	46	12.6	9.6
Mosaic temperature #8 (°C)	−10	42	11.6	9.4
Mosaic temperature #9 (°C)	−10	45	12.1	9.3
Mosaic temperature #10 (°C)	−10	53	12.3	9.8
Mosaic temperature #11 (°C)	−9	45	12.4	9.5
Temperature of vaulted ceiling #12 (°C)	−8	29	10.7	7.5

embedded column, responded similarly to mosaic temperature #1 with a greater peak, as much as 19.50°C, in the afternoon. All measured locations on the mosaic had very similar temperature changes, with only minor differences among the locations. On average, the mosaic surface temperatures exceeded air temperature by 20°C (and by as much as 18°C) during midday in summer. The surface of the vaulted ceiling had the least heating effect, with average temperatures higher by only 1°C than that of the air for the year. The shaded surface maintained surface temperatures closer to air temperature. However, it retained slightly higher temperature on average and by as much as 2°C.

The daily minimum temperatures of the mosaic remained similar to those of the air temperature. The minimums at the mosaic surfaces were from 1°C to 2°C and 3°C to 4°C lower than that of the air in summer and winter, respectively.

The surface of the mosaic had average temperatures higher than the air by approximately 10°C at noon, as shown in figure 9. The west-facing surface received more solar radiation in the afternoon than the south-facing surface, while the cathedral building was already warmed by the morning sun and the conduction from the warmed air and exceeded the air temperature on the average by 12°C. The shaded surface, in contrast, followed closely the changes in the air temperature. It peaked at 24°C approximately 2 hours after the daily maximum of the air temperature was reached. This was due to the thermal characteristics of the cathedral building. Sharp cutoffs of surface temperature at about 5:00 P.M. are seen as it is shaded by the surrounding castle structures. Sun exposure was approximately 10 hours per day, from 8:00 A.M. to 6:00 P.M. during August.

In February, 24-hour-day variations of the temperatures were similar to that of summer with reduced peak magnitudes. This was probably due to the decreased exposure time and amount of the solar radiation on the wall. Figure 10 shows a plot of maximums, minimums, averages, and standard deviation of the surface temperature on the west-facing mosaic evaluated every 15 minutes in a 24-hour-day during the month of February. The average temperature variation was approximately from -1°C to 10°C, and the average remained below 0°C for approximately 6 hours, between 4:00 A.M. and 10:00 A.M. The surface temperature started a sharp rise at 10:00 A.M., as the sun, low on the southern horizon in winter, rose above the surrounding castle. Solar heating does not appear as effective on mosaic glasses during winter, as surface temperatures were closer to



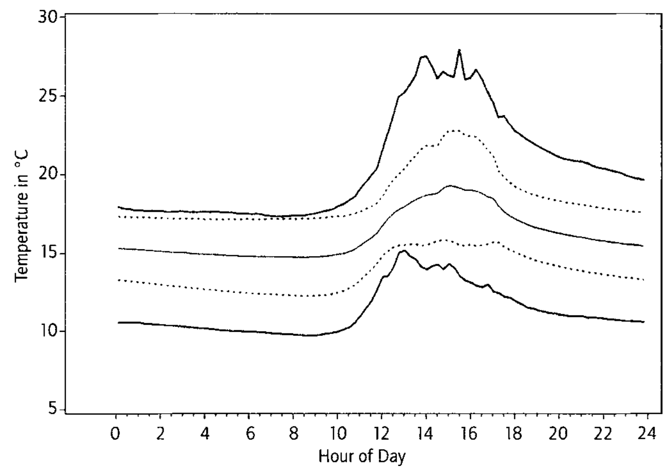


FIGURE 9 Twenty-four-hour-day variation in averages of air and surface temperatures on the westfacing mosaic and shaded surface in August 1994.

FIGURE 10 Twenty-four-hour-day variation of surface temperature (mosaic temperature #3), February 1994.

air temperature, on average. Sun exposure was approximately 7 hours, from 10:00 A.M. to 5:00 P.M., in February.

The surface relative humidity generally followed the relative humidity of the air, with the surface relative humidity higher than 90% occurring for approximately 50 days and saturating several times between November 1993 and March 1994. Figure 11 shows total hours per day that the relative humidity at mosaic surface #1 exceeded 90%. Each bar represents an occurrence of the condition, with its height corresponding to a total hours in which the mosaic surface remained at that condition. Close to 80% of the days in the months, the surface relative humidity exceeded 90% during the period. Over half of these occurrences lasted less than 5 hours, but four occurrences lasted more than a day and one incidence lasted 49 hours. The effect of high relative humidity was linked to periods of overcast skies (low or no solar radiation) when surface temperatures dropped below the air temperature. A period in early November was such an example: the relative humidity was 100%, the solar radiation was minimal, and the winds were light. Because the winds were light, wind chill did not appear to be a factor in lowering surface temperatures (and therefore the surface relative humidity rose). Temperatures on the shaded surfaces showed similar occurrences of surface relative humidity greater than 90%, yet they occurred on fewer occasions and for shorter durations. The surface relative humidity also dropped far below that of the air on hot summer days as a result of the solar heating. The average of the surface relative humidity was 43.4% in August 1993, which was 24.8% below that of the air. The lowest estimated surface relative humidity was 5% in August on the west-facing mosaic.

Conclusions and Recommended Test Conditions

An outdoor microenvironment of a south-facing wall of St. Vitus Cathedral and surface temperatures of the Last Judgment mosaic on the wall were monitored for approximately one year, from June 18, 1993, to May 21, 1994, using an environmental monitoring station installed by the author. Analysis of the collected data was performed to determine the range of test conditions for simulating the mosaic's environment in the laboratory. This information was used to test protective coating materials.

The wall on which the Last Judgment mosaic rests is partially protected from extreme winds and early and late day sun exposure because of the surrounding Prague Castle buildings. Solar heating of the mosaic glass tesserae during the day, as expected, is the most important factor causing higher surface temperatures, especially at midday during the summer. Solar heating follows a seasonal pattern and is affected by shading from the surrounding castle. The mosaic

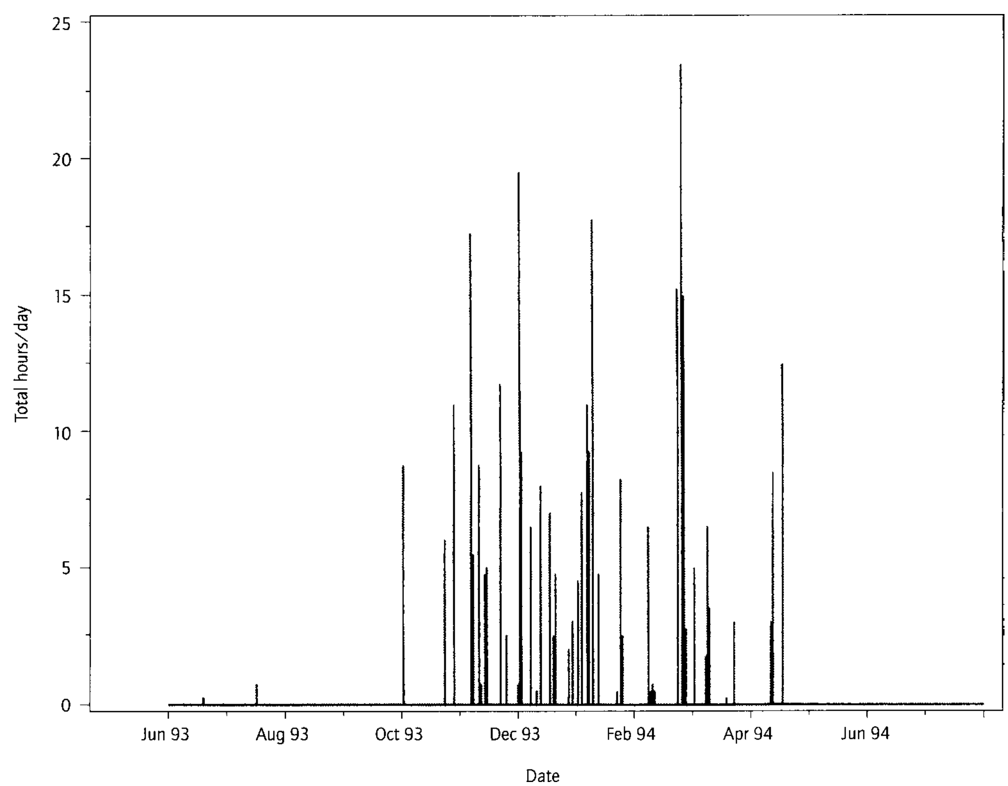


FIGURE 11 Daily total hours exceeding 90% RH on the surface of the Last Judgment mosaic (June 1993–May 1994).

glass tesserae are also exposed to rain, dew condensation, and frost. The temperature of the mosaic fell below the dew point temperatures only in winter, since the cathedral building retained solar heat throughout the night for the rest of the year. However, the building did not receive enough solar radiation to maintain the elevated temperature in winter, and the temperatures of the mosaic fell 3°C to 4°C below the air temperature in early mornings.

Blocking out the solar radiation would reduce heating and produce a more protected environment, as evidenced by the temperature measurements at the surface on the vaulted ceiling. Heating of the mosaic surface, either by the radiation or conduction, will maintain the temperature of the surface and thus prevent the dew condensation and frosting conditions in winter.

The following recommended test conditions for the proposed coating materials for the mosaic were developed based on the one-year monitoring of the environment at the mosaic. However, the volume of the data is not large enough to produce typical design values, such as once in 100 and 500 years occurrences. Therefore, the recommendations were made only within the data values recorded by the monitoring and were described in conditions at the surface of the mosaic, rather than the ambient conditions, since the surface conditions are complex products of both ambient conditions and the building's thermal mass. The temperature and relative humidity at the mosaic's surface have significantly larger both daily and seasonal variations than the ambient air, especially during summer months. This is as expected because of solar heating. This effect expands the range of temperature toward higher values and reduces relative humidity toward lower values.

The yearly standard deviation range of mosaic surface temperature and relative humidity, respectively, was 2.7°C to 21.5°C and 82.3% to 38.2%. This range covers 70% of all conditions the mosaic experienced during the monitored year; 100% of the conditions will be incorporated by a range produced by the extreme conditions, 52°C at 8% RH and -11°C at 100% RH. We recommended that the test conditions should include frequent wet-and-dry cycling at near-freezing temperatures, since the surface of the mosaic often fell below dew point temperatures in winter months. Proposed coating materials should also be subjected to frost conditions, which were observed only once during the monitoring for a period of three hours. Effects of winds or air movements are expected to be minimum and would not be a necessary factor in the tests.

Acknowledgments

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Milena Nečásková

Chapter 12
Research in Mosaic Cleaning

In 1370 a chronicler noted, "This year, a festive tableau has been completed above the portal of the Prague Church, at the wish of our Lord Emperor, in the form of a Greek-style mosaic, which gets cleaner and brighter each time it is washed by rain."[1] Indeed, the mosaic technique, until then unknown in Bohemia, must have seemed marvelous and indestructible in comparison to wall paintings, which at that time were primarily used on interiors and exteriors of buildings to communicate Christianity. Paintings on damp, rain-darkened walls could not compete with the glistening colors of shiny, freshly cut glass cubes. But in time, the brightness of the colored glass tesserae gradually dimmed, and we have good reason to believe that King Charles IV himself must have noticed this in his later years. Not until many centuries later was it discovered that the rain only seemingly deepened the colors and that the water was actually the main reason for the gradual obscuring of the tesserae surface with a gray veil of corrosion.

The removal of corrosion products is a basic task in mosaic restoration. After cleaning, the images covered with gray crust again become visible; the artwork comes to life and can once again be enjoyed (figs. 1, 2). The cleaning of the glass surfaces is also necessary for technical reasons, to allow proper adhesion of the protective coating that is later applied. Without prior cleaning, the protective function of the coating could be weakened. The corrosion products could reduce the coating's adhesion to the glass surface either because of their physical and chemical properties or because of water and soot and other particles of grime.

Origins of Corrosion

All types of glass corrode as a result of long-term or repeated contact with water. This seems to contradict our everyday experience with windows or dishwashing, but modern glass has a different composition from medieval glass and therefore is more resistant. Also, it has not been in use for centuries.

FIGURE 1 Surface corrosion of mosaic glass, detail. Half of the tesserae were cleaned using a scalpel. Photo: M. Nečásková.

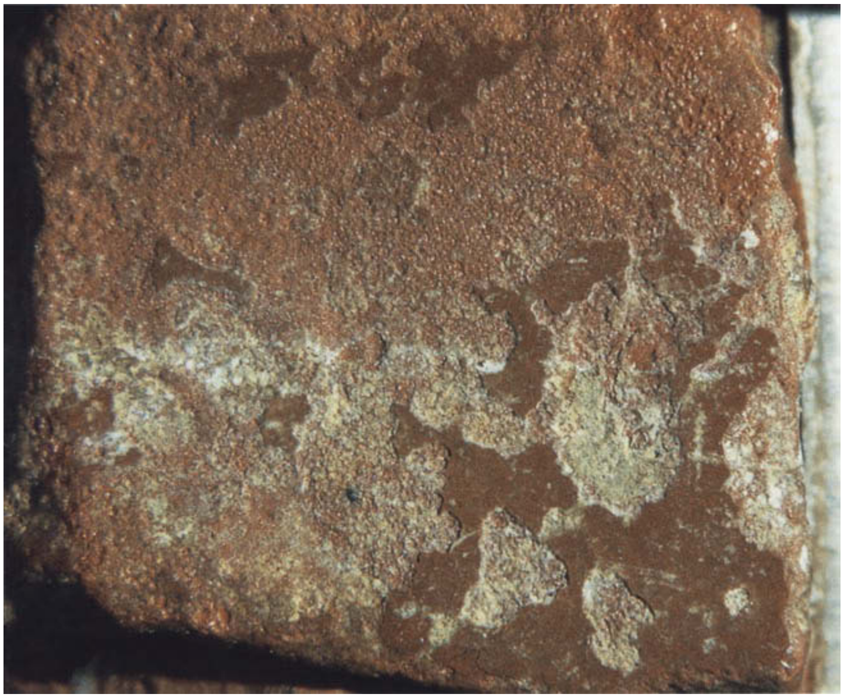


FIGURE 2 Red tessera partially cleaned using the micro-jet abrasive method. Photo: M. Nečásková.

A basic raw material for glass manufacturing was, and still is, silica sand. To melt pure sand, a temperature of 1700°C is required. However, this temperature could not be achieved in historic furnaces. Therefore, until recently, the art of glassmaking relied on knowledge of the flux, that is, additives that substantially lower the melting point of the composite when mixed with sand to make the so-called batch. For one thousand years, alkaline salts were used as flux. In classical times, the required alkaline metal salts were acquired by importing natural soda from mines in Egypt or were extracted from the ashes of certain plants. In the Mediterranean region, the ash from seaweed, rich in sodium, was often used. Imported natural soda also continued to play a role in the Middle Ages. Inland, the richest source of alkaline was ash from beech trees, which contains a significant amount of potassium. Aside from alkaline salts, a large amount of calcium was added to the smelt. Compounds of other metals such as copper or lead were also added to the batch to change the clear glass into colored or opaque glass.

The resistance of glass to corrosion depends on its chemical composition. The amount and type of flux components used during the glassmaking process determine its stability. The chemical stability is directly proportional to the silicon dioxide content of the glass. This stability diminishes when the levels of alkaline metal oxides are increased. Soda glass is more chemically resistant than potash glass. The reasons for different compositions of historic glass, from various periods and parts of medieval Europe, was limited access to some basic raw materials, impurities in the basic raw materials, and carefully guarded variations of old recipes in each glass workshop. Low temperatures in medieval furnaces were the major factor requiring high content of potassium in the old recipes. Smelting was done at a temperature of about 1100°C. Temperatures above 1200°C were practically impossible to achieve. Modern glass is made using temperatures up to 1700°C, and typical modern glass is composed of 70% SiO_2, 15% Na_2O, and 10% CaO. Most medieval glass contained only 50% to 60% SiO_2, and often more than 20% K_2O or Na_2O and 10% to 20% CaO. The colored glass of the Last Judgment mosaic is typical medieval glass, with a very high potassium and calcium content and a negligible amount of sodium, most probably manufactured in Bohemia. The composition of each tessera varies significantly according to its color. The majority of the Prague mosaic's tesserae contain approximately 40% to 57% SiO_2, 12% to 20% CaO, and 15% to 20% K_2O. The remaining percentages are made up of components and additives.

When water comes into contact with the glass surface of tesserae, which contain a high percentage of alkali, first the monofunctional metal and calcium ions are leached out and then a gradual hydrolysis of the glass occurs. The OH groups, from the disassociated water molecules, then bind to the vacant places left by the metal ions. The OH groups also react with the released metal ions on the glass surface, and metal hydroxides are created. Thus when water reacts with the glass surface, the siloxane link structure of the glass acquires hydroxyl groups, and the glass surface gradually changes into silica acid gel. On the glass surface, the aqueous solutions of alkaline hydroxides of the leached metal elements react further with carbon dioxide and sulfur trioxide in the environment, while relevant salts are formed, namely, potassium carbonate, potassium sulfate, calcium carbonate, and calcium sulfate. The suggested process can be described by the following equations:

Hydrolysis of glass, and forming of silica acid gel:

$$-\mathrm{Si}-\mathrm{O}-\mathrm{Si}- \ldots + \mathrm{H\text{-}OH} \rightarrow \ldots\text{-}\mathrm{Si\text{-}OH} + \mathrm{OH\text{-}Si}\text{-}\ldots..$$

Yielding of alkali ions, and forming of hydroxides:

$$\ldots\text{-}\mathrm{Si\text{-}O\text{-}K} + \mathrm{H\text{-}OH} \rightarrow \ldots\ \text{-}\mathrm{Si\text{-}OH} + \mathrm{K\text{-}OH}$$

Reaction of aqueous solutions of hydroxides with carbon dioxide and sulfur trioxide gases present in the air:

$$2(KOH) + CO_2 \rightarrow K_2CO_3 + H_2O$$
$$2(KOH) + SO_3 \rightarrow K_2SO_4 + H_2O$$
$$Ca(OH)_2 + SO_3 \rightarrow CaSO_4 + H_2O$$

The alkaline environment thus created on the glass surface further accelerates the transformation of the glass surface layer into silica acid gel. Alkaline salts, if they are not completely washed away by rain, crystallize after drying on the surface and form clusters that cannot be later dissolved; over time, these form into a crust. Since these corrosion products are mostly hygroscopic, they prolong the period of the water's reactivity with the glass surface, and the layer of corrosion further accelerates the hydrolysis of the glass surface. The irreversible corrosive reactions occur in humidity all the time, and gradually an opaque gray layer of corrosion obscures the brilliant colors of the tesserae and accelerates further gradual deterioration of the still-intact glass. In addition, the porous structure of the corrosion layer itself easily adsorbs dust and thus contributes to the illegibility of the mosaic motifs.

It seems that the speed of corrosive reactions is not very high. After six centuries, most of the glass surface remained untouched by hydrolysis, even though since the nineteenth century corrosion must have accumulated from the increased use of coal by rapidly expanding industries and by households for heating. This resulted in massive air pollution from sulfur oxides. Only in the last few years has their level again begun to abate in Prague. In the twentieth century, sulfates were the main components of the corrosive products, and the speed of corrosion was highly accelerated. This was confirmed by a simple experiment performed during the early stages of the project. An area of approximately two square decimeters of the mosaic's surface was cleaned and left without any protection so as to observe the corrosion's progress. Clusters of corrosion products were apparent after just one year, and four years after the cleaning the original color of the tesserae could not be distinguished due to corrosion. It is not possible to estimate how rapid the growth of corrosion was before the industrial revolution, in an unpolluted environment. From old written records and visual documentation, it is apparent that at least during the entire nineteenth century, the mosaic was barely visible, and there were several attempts to clean its surface.

Cleaning of the Mosaic in the Past and Experience from Other Places

Until the nineteenth century, we have no records of specific methods used in the mosaic's maintenance. More detailed records of the mosaic's condition and maintenance come from the nineteenth century, primarily in the annual reports of the Union for Completion of St. Vitus Cathedral. The entry from 1879 mentions sanding of the mosaic's lowest section with sandstone and indicates that the level of corrosion on the tesserae varied according to their color. It is hard to imagine how this aggressive method could have been applied. The uneven surface of the tesserae, whose face sides were not on the same level, practically prohibited effective and careful sanding at the same time. The same annual report also cites an opinion of an invited expert, Luigi Solerti from Innsbruck, that it was impossible to remove the corrosion layer with solvents and that the sanding method should be considered only for individual tesserae, not for the entire mosaic. The unresolved problem of a cleaning method was one of the reasons the mosaic was later detached.

Before the mosaic was reinstalled under the supervision of Viktor Förster, each panel was cleaned and repaired. The cleaning method is not specified in the old records. However, there is mention of a faint gray veil that clouded some sections of the motifs even after the mosaic's reinstallation and also of the plan to further examine it chemically and remove it if this could be achieved without damaging the mosaic. From these scanty records we conclude that the cleaning was done mechanically and that even the restorers at that time were aware of the danger of damaging the mosaic by aggressive mechanical cleaning and therefore preferred leaving the remains of the corrosion on the mosaic. Photographs from that time provide proof of the result of their work. The motifs are easily visible in the photographs; the background is quite integrated, with just a few faint traces of the transfer (see chap. 7, fig. 17). The amount of remaining corrosion cannot be determined from these black-and-white images.

In the early 1960s the mosaic underwent major restoration. In the fifty years since its reinstallation, a gray opaque layer again obscured the motifs and their outlines became barely visible. Restorers Kaděra, Martan, Mezera, and Němec removed the corrosion layer with the help of electric rotating brushes made of hard bristles and soft metal wires.[2] The result is documented by numerous photographs of sections that regained their original color through this cleaning intervention. Chapter 6 describes in detail the methodology of the restoration, which also was the first attempt to protect the mosaic chemically.

Cleaning was performed again between the 1970s and 1980s. Restorers Bareš, Brodský, Frömlová, Němec, and Stádník had to quickly clean the mosaic before initiating a new attempt to protect the mosaic with an application of the (then new) silicon coating. The restorers struggled to remove the layer of corrosion growing through the degraded film of epoxies and acrylates from the 1960s. They combined the mechanical cleaning technique, using rotating brushes, with partial blistering of polymer remains with toluene and then used scalpels for final cleaning of the cracked layer.[3] The result of this cleaning was adequate given the possibilities of this method, which was limited by the insolubility of epoxy and by the risk of damaging the glass.

Removal of the corrosion layer from medieval mosaic glass is not typical work for a Czech restorer, since there are no other examples—except the Prague mosaic—of similarly damaged mosaic glass tesserae. Earlier methods cannot be recommended because of the great risk of damaging the surface of the glass and because the cleaning is not very effective on the dents and edges of the tesserae. Not even outside the borders of the old Bohemian kingdom do we find an adequate cleaning method among mosaic restoration practices. Since the Classical Age, the principal domain for mosaic art was always the Mediterranean region, with its mild climate; different materials were used to produce glass for the tesserae, and the majority of the mosaics were situated indoors, on the floors of houses, and on walls and vaulted ceilings of cathedrals. Glass rarely appears in classical mosaics; it was used only for color accents in the midst of prevailing limestone tesserae. The same is true of early Christian mosaics. Shining glass mosaics become more frequent with the advent of the Western Middle Ages and in Byzantium, and the masterpieces usually decorated the interiors of temples. Examples are the famous sixth-century mosaics in Ravenna, the eleventh-century mosaics in the Greek Daphne cloister, and fourteenth-century mosaic art on the facade of the cathedral in Lucca, protected by a small ledge. None of the medieval mosaics in the Mediterranean region was obscured by an opaque veil of corrosion and thus did not have to undergo a radical cleaning procedure. The modern mosaics on facades worldwide are made of resistant glass that remains quite stable even in freezing and heavily polluted environments.

To a large extent, similar problems arise in the cleaning of medieval windows in central and northern Europe. The stained glass of church windows usually has the same chemical composition as the Prague tesserae and thus becomes covered over time by a film of gray corrosion crystals, with gypsum as the main component. Corrosion in window glass is less problematic, since we look at this glass from the interior, with the light shining through, and not in reflected light, as is the case with the mosaic. Therefore, the beautiful colors of the windows disappear much later, not until a much thicker layer of corrosion accumulates than the one that suffices to dim the colors of a mosaic. In addition, window glass is flat, and it is usually cleaned only after being removed in a studio or laboratory from its lead matrix. To prevent the progress of corrosion, the windows are usually fitted with a double-glazed unit, and only rarely are the stained-glass windows conserved with a protective coating. Thus the corrosion on these windows does not need to be entirely removed, and a milder cleaning procedure is preferred because the risk of damaging the glass is lower. For the most part, traditional mechanical cleaning methods are applied, in particular, the use of the scalpel or glass fiber bounds. However, mechanical methods are hard to control especially when it comes to areas that still have original gold. Similarly, sand papers cannot be used because their hard, abrasive particles would scratch the soft glass surface. Chemical methods cannot be considered as the corrosion products are inorganic materials, which are totally insoluble in common organic solvents and do not react with basis. The corrosion salts are partially soluble in acids; on the contrary, glass is resistant to the majority of acids. But any acid quickly disintegrates calcium carbonate, which is the binding medium of all historical plasters, and therefore acids cannot be considered for the cleaning of mosaic glass. In recent decades, new technology has developed that can be used to remove corrosion from the mosaic, for example, chemical methods using ammonium carbonate, laser, and air-abrasion. The principle of removing glass corrosion with ammonium carbonate is the same as that of cleaning calcium sulfate from wall paintings, the so-called Florentine method.[4] In this method, ammonium carbonate can transform gypsum from insoluble to soluble and therefore removable salts. The disadvantages of this method are its relatively low efficiency and the difficulty of removing residual salts formed during the reaction.

The laser cleaning method is based on the principle that different materials absorb differently the energy of laser radiation. The surface molecules of the corrosion layer absorb the photons produced by laser radiation, change it to heat and evaporate, layer by layer. The molecules of the cleaned material, in this case glass, reflect the laser radiation and remain unchanged. In practice the process is more complicated, because the cleaned glass surface would also partially absorb the laser radiation and could be damaged. It would be necessary to determine the appropriate type of laser, with suitable wave- and pulse length and optimal density of radiation, for the specific situation. Comprehensive research on cleaning historical glass using lasers and UV wavelengths was carried out by several German institutions and coordinated by the Frauenhofer-Institut für Silicatforschung.[5] Their research showed that using this method, which requires high-energy radiation, carries the risk of damaging the surface of the cleaned glass. In addition, the energy required for cleaning varies significantly with the color and chemical composition of the glass and the degree of corrosion. This variability complicates considerably the use of laser to clean a work of art such as the Last Judgment mosaic, which is made up of millions of different glass tesserae. This method would be highly efficient if cleaning were aimed at removing organic coatings applied in the 1960s.

The corrosion layer can be removed with ultrasound baths by sinking the glass to be cleaned into a liquid bath, whose ultrasound oscillating molecules destroy the layer of corrosion. However, the mosaic tesserae cannot be immersed and taken out of the liquid bath. Theoretically, it is possible to clean the surface of the cubes with an electric instrument, whose point oscillates in the frequency of ultrasound. The daily progress of such work, however, can be measured only in square centimeters, and the cleaning of the whole surface would take several years. Therefore, this cleaning method is not realistic for the mosaic.

The so-called air-abrasive method can be used as well. The principal technique of this type of cleaning consists of the mechanical effect of solid abrasive material being forced by compressed air through a fine nozzle. This method has been used for years in the stained-glass restoration studios of Canterbury Cathedral. The first tests of this method for cleaning the tesserae—made possible by Sebastian Štrobl, director of the Canterbury restoration studios—were promising as a potential solution for the challenge of mosaic cleaning.[6]

The Air-abrasive Method and Its History

The idea of cleaning with solid particles carried by a stream of air is relatively old. An American, Benjamin Chew Tilgham, first came up with this idea and made it a reality. During a sandstorm in 1870, he noticed the effect that windblown sand had on window glass. He then founded the Tilgham Patent Sand Blast Company, which later produced etched glass and still manufactures heavy industrial blasting machinery.[7]

Air-abrasive technology gradually spread. During the 1920s, casts were regularly cleaned with fine sand propelled by forced air or steam. In the beginning of the twentieth century, the first tests were conducted cleaning the exhibits of natural history museums. The first sandblasting work chambers were constructed in about 1930, and in the following decades, the research focused on finding new abrasive materials since sandblasting was banned because of the risk of contracting silicosis by personnel operating the machinery. As safer abrasives were developed, the industrial use of this cleaning method expanded, for example, in bridge structure cleaning. The air-abrasive method is also used for final surface finishing of products made of metal, plastic, ceramic, and wood. A wide range of equipment is manufactured, from large industrial units for outdoor work and small, enclosed isolated cabinets to miniature instruments used in medicine and for restoration of fine, delicate objects.[8]

Today the air-abrasive method is used mainly in museums for restoration of various ethnographic objects. In this way it is possible to clean fossils and metal objects, wood, bones, ceramic, and even hide, paper, wicker products, and textiles. A wide range of abrasive materials, from the hardest particles such as aluminum oxide to soft marble dust and sodium hydrogen carbonate to the softest powders of plant origin, can be used according to the properties of each treated object. An important role is played by microscopic glass beads (*balotina*), which, due to their shape, have a specific effect on some surfaces and can be used as tools for further finishing, such as polishing.[9]

The micro-air-abrasive method has been applied to glass cleaning since the beginning of the 1970s. The safety of this method was widely discussed by experts in the 1970s and 1980s, with the conclusion that the apparent risks could be avoided by selection of appropriate configurations for each cleaning, that is, selection of appropriate abrasive material, pressure, distance and angle of the nozzle, and duration of the cleaning process.

The Last Judgment mosaic is probably the first example of a mosaic cleaned by the airbrasive method. But it does not remain the only example. The air-abrasive method using aluminum oxide was employed recently during removal of very hard corrosion products on the stone floor mosaic in the Villa Domizia in Grosseto, Italy,[10] and similar cleaning was done on the reverse sides of some mosaics removed from a villa in Zeugma, Turkey.[11]

Technical Equipment Needed for Mosaic Cleaning

The Getty Conservation Institute tested and provided a Swam-blaster MV1, made by Crystal Mark, Inc., of Glendale, California (fig. 3), for cleaning the mosaic. The equipment has an auxiliary chamber with an abrasive material and a vibration system that homogenizes the flow of the abrasive material, thus ensuring continuous and uniform cleaning. A foot pedal enables the operator to stop the machine. Independent regulation of the powder flow and air pressure and exchangeable nozzles enables the operator to set the equipment exactly to the levels needed for each situation. The microblasting equipment has regular compressors and filters for dehumidification.

Adaptation of the Air-abrasive Method for Mosaic Cleaning

Current developments in equipment for microblasting and a wide selection of soft abrasives make it possible to adapt the method to the special requirements of mosaic cleaning. The advantage of this method is its effectiveness, ability to uniformly clean even nonhomogeneous surfaces and complicated shapes, and the ability to instantly regulate the velocity and intensity of the cleaning by moving the nozzle farther from the surface. This method does not contribute to environmental pollution. Its disadvantages are its reduced selectivity during the removal of solid brittle materials of similar properties and more stringent work safety requirements.

The quality and amount of the abrasive material passing through the nozzle, the air pressure, and the nozzle's distance from the surface determine how effective and gentle the method will be. The amount of abrasive material passing through the nozzle can be set directly on the equipment. The air pressure is determined by the basic setting on the compressor and on the device and then controlled by the nozzle's distance from the surface, which is regulated by the operator. The greater the distance, the larger the area affected by the stream of particles and the lower the precision of cleaning. Therefore, it is necessary to fine-tune other factors to reach the optimal working distance of the nozzle, which is about 12 to 15 mm above the surface and at a 45° angle. The decisive factor is the quality of the abrasive material.

Therefore, during the search for the optimal variation of this method for cleaning of the Last Judgment mosaic, the focus was on finding the optimal abrasive material. About a

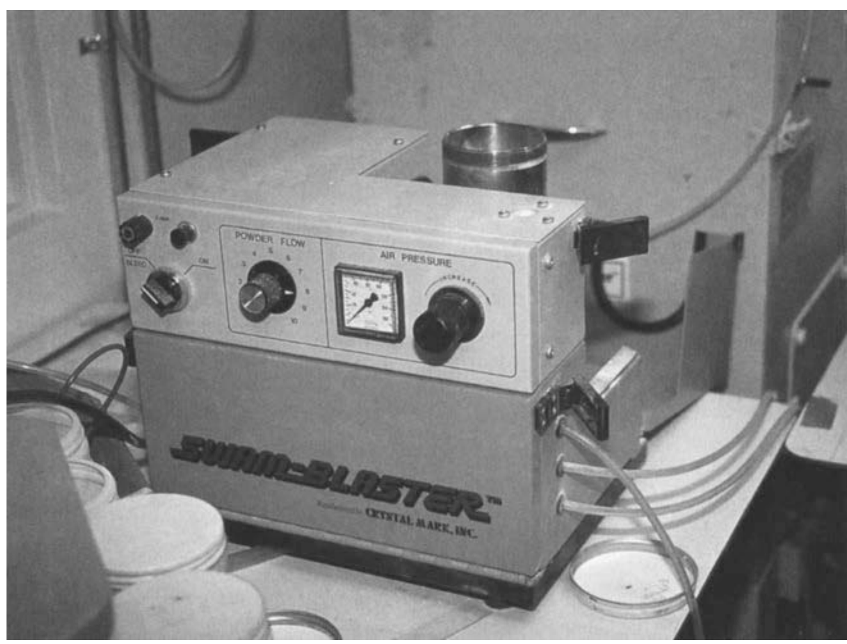
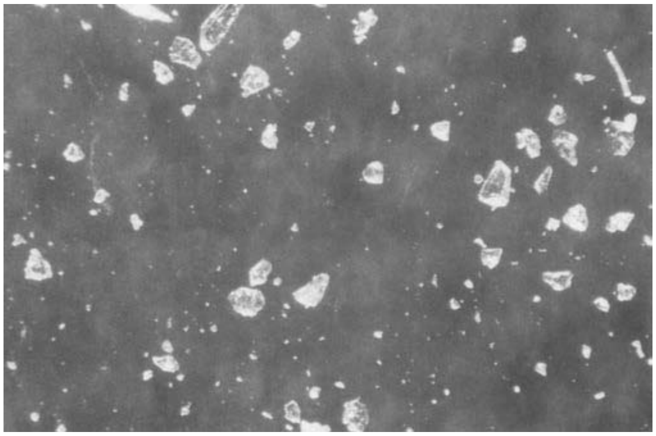


FIGURE 3 SWAM-BLASTER MV-1 micro-jet air-abrasive instrument. Photo: D. Stulik.

dozen various granulose and ground materials were tested, including rice flour, ground bran, pulverized walnut shell, ground olive kernels, ammonium bicarbonate, crushed glass dust, glass microbeads, and crushed polymer (fig. 4 a–c).

Most of the tests were conducted at air pressure of cca 3kg/cm^2 and 20% of maximum powder flow. The round carbide nozzles with an orifice diameter of 0.8 mm were used. Time was not measured. The cleaning resulted in the removal of corrosion on the glass surface. The problem was to supply appropriate corroded glass for these tests, since for ethical and technical reasons it was not possible to conduct these preliminary tests in situ. The original tesserae that were left after the extensive restoration of the mosaic in 1910, and were until now kept in the Archives of the Prague Castle, served as an ideal test material. In addition to this small number of tesserae, shards from archaeological finds were used that were provided by the Institute of Archaeology of the Czech Academy of the Sciences (ČSAV). The results of the tests conducted on these shards helped with basic orientation regarding the possibilities of this method and its evaluation and provided the basic classification of materials, which were later further tested on the original tesserae. The original individual tesserae were then gradually cleaned with the selected materials in laboratories of the Getty Conservation Institute and the Crystal Mark factory. During the cleaning, the surfaces of the tesserae were inspected under optical and electron microscopes. The results of the air-abrasive cleaning were compared with scalpel cleaning of control samples (fig. 5a–d). The findings were then verified in situ during the cleaning of small test fields where various conservation materials and gilding had been tested.

It became apparent that the best result, with minimal damage to the glass, was provided by middle-range soft materials with edged particles, such as sodium bicarbonate, crushed soft glass with particles measuring less than 50 microns, and ground olive kernels. The glass microbeads did not perform uniformly, since they hollowed out small craters on the glass surface, sometimes even before all the corrosion could be removed. The materials with larger particles, such as crushed polymer, also caused damage. The difference between the effect of crushed glass and glass beads can be explained theoretically. Crushed glass particles have irregular shapes and sizes, with a variety of angled surfaces (see fig. 4a), whereas glass beads are always spherical, even if they are of different sizes (see fig. 4b). Because of their shape, glass beads have a



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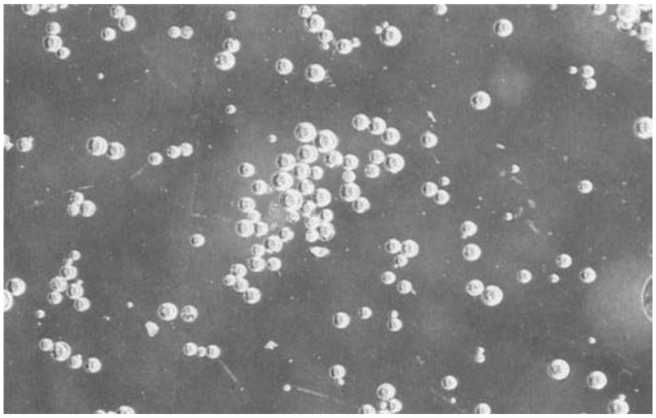

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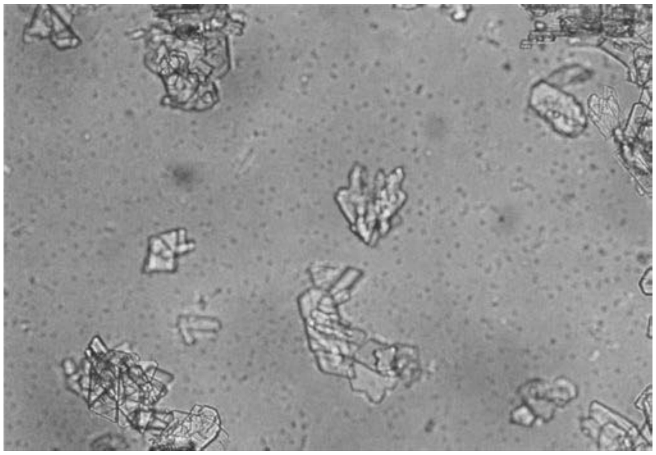
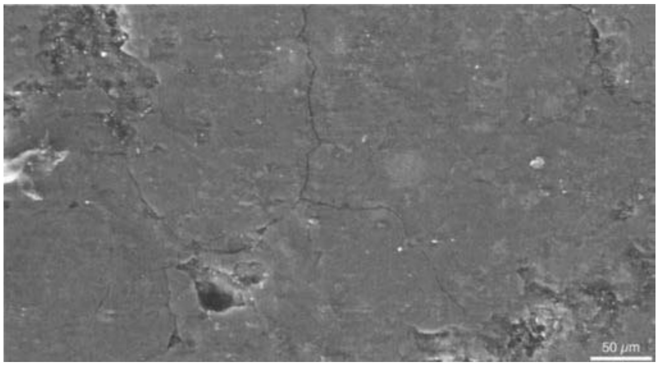


c

FIGURE 4a–c Optical microscope images of different abrasive materials: (a) crushed glass; (b) glass microspheres; (c) bicarbonate of sodium.
Photos: I. Kučerova.



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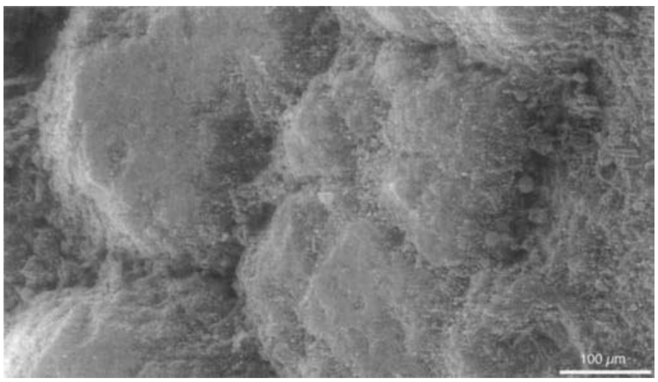

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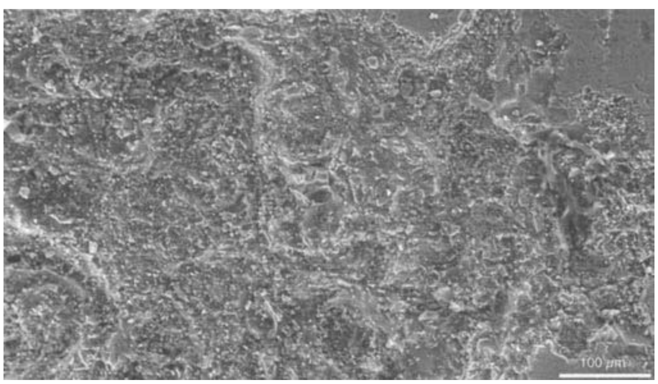

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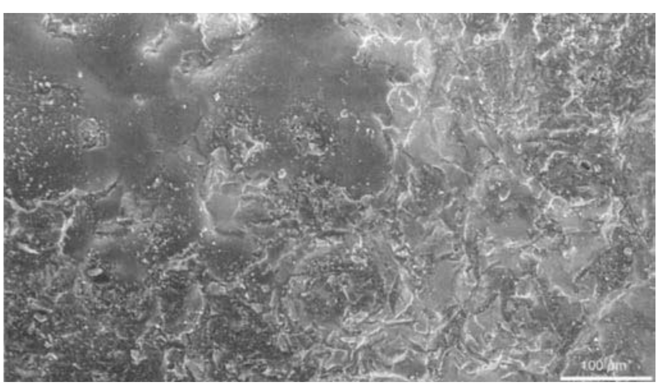

d

FIGURE 5a–d SEM micrographs of different types of surface corrosion: (a) surface of glass tessera protected against corrosion by mosaic plaster; (b) corrosion on an unprotected side of the same tessera; (c) surface of the original mosaic glass after mechanical cleaning using a scalpel; (d) surface of the original mosaic glass after micro-jet air-abrasive cleaning. Electron micrograph: E. Doehne.

more aggressive effect on the surface than does crushed glass, assuming that the same force is applied on the particles. The pressure on the surface is obtained from the force of the particle divided by the area of contact between the particle and the surface. In the case of beads, the area of contact can be approximated to a point, and therefore the pressure on the surface coincides for all practical purposes with the force applied by the sandblasting machine. In the case of crushed glass particles, whose edges and sides vary, there are times when the area in contact with the surface is much greater, and therefore the resulting pressure is reduced. The final choice was among several softer materials with edged particles. Sodium bicarbonate is highly alkaline, and given the dimension of the mosaic, which must be cleaned in open space with frequent wind, it was not realistic to expect that it would be possible to vacuum all the excess abrasive material during the work. Its residues could become a new source of alkaline ions and thus reinforce the growth of the corrosion layer on the mosaic's surface. Therefore, this otherwise suitable abrasive material was rejected. Similarly, the crushed olive kernels could leave a large amount of greasy impurities on the glass and thus have a negative effect on the adhesion of future protective coatings. In the case of natural organic materials, there was another concern regarding their hygroscopic character, which could cause the particles to clump together during frequent humid days and jam the nozzle of the instrument despite the use of predried air. For the reasons mentioned above, the crushed glass with particles measuring less than 50 microns was evaluated as the optimal abrasive material.

Before transferring the method from a laboratory to the real, corroded surface of the mosaic, there was discussion about the possible effect the remains of polymer coats, which were applied to the mosaic in the second half of the twentieth century, could have on the safety and effectiveness of the method. The concern was that particles of the grout between the tesserae would loosen during the airbrasive cleaning of their sides. None of the concerns proved an issue. Almost all of the old polymer coatings had disintegrated, and some remaining chips with loose edges, usually no larger than 2 mm^2, were easily removed together with the corrosion. The rare large chips from former coatings were easily removed with a scalpel. The original reddish mortar in the joints between the tesserae was still firm and did not crumble, undoubtedly because it was reinforced by the old conservation treatments that seeped in during previous attempts to conserve the mosaic. During the cleaning, no loosening of the original mortar was observed.

In the laboratory, cleaning is performed in small portable work chambers, measuring 60 × 60 × 40 cm, equipped with vacuum systems. The restorer inserts his or her hands into the chamber through side openings and views the work through a front glass panel. For in-situ work, on the vertical facade with the mosaic, the issue of vacuuming, which would help to keep the work area relatively clean, had to be resolved. A suspended work chamber with an open back panel, similar to the one used in laboratories, did not prove suitable. It was not possible to tightly attach the work chamber to the uneven surface of the mosaic, and this minimized the effectiveness of the vacuuming. Manipulating the suspended work chambers on such a large area that was also blocked by scaffolding was very difficult. The vacuuming issue was resolved by using smaller hand-held boxes about 10 cm in diameter. These small boxes were hooked by a hose to powerful dust collectors and rested with their open backsides on the surface that was being cleaned. A nozzle was inserted through the small side opening in this cabinet, and the cleaning was monitored either through the plexiglass front side or directly through the side opening for the nozzle (see chapter 15, fig. 2). Restorers spontaneously designed variations of these practical work cabinets and constructed them using ordinary packaging materials. Despite the relatively high effectiveness of these work cabinets, it was necessary, for safety reasons, to wear face masks with dust filters.

Conclusion

The application of the air-abrasive method resulted in high-quality and safe cleaning of the glass tesserae, including the side edges above the mortar level (see figure 6). The cleaning restored the original bright colors to the glass and made

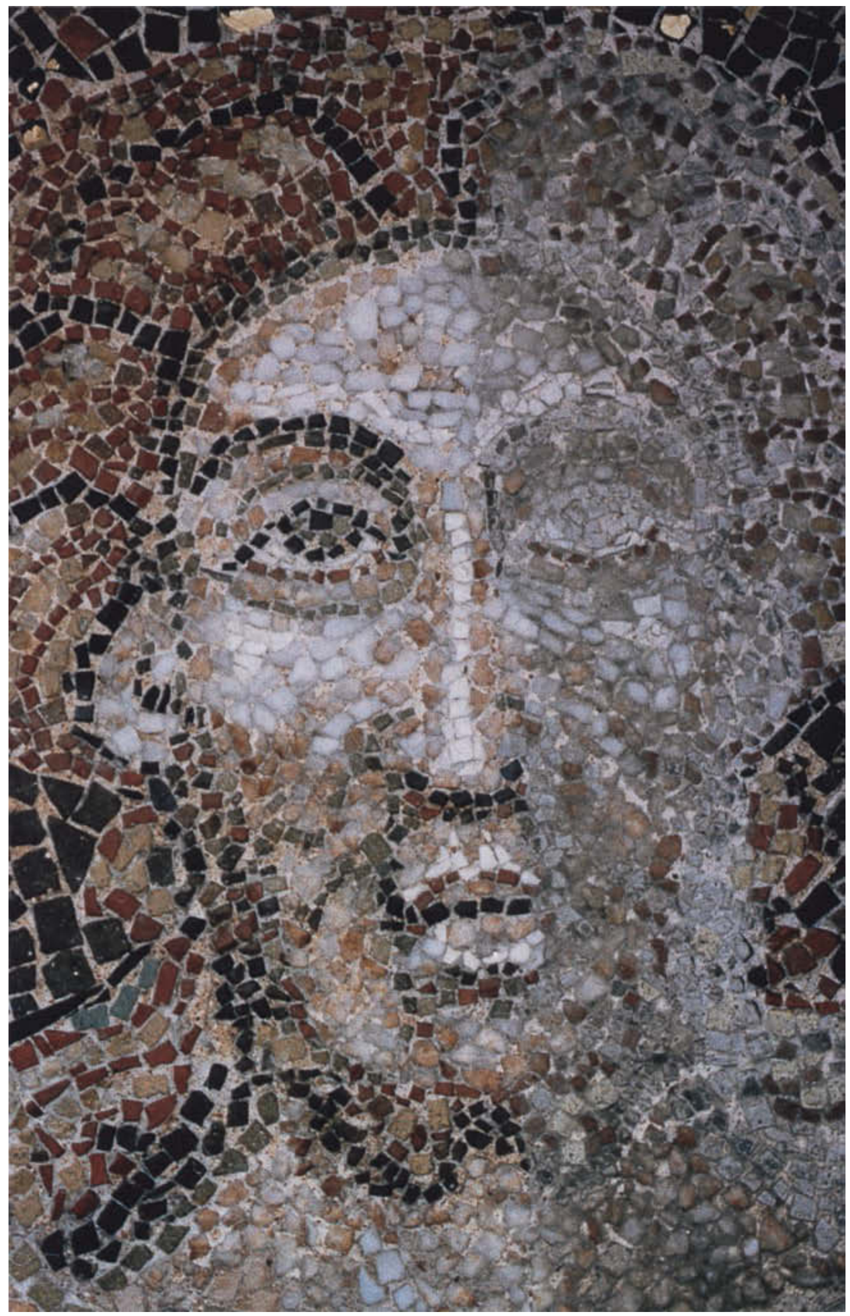

FIGURE 6 Head of Christ partially cleaned using the micro-jet air-abrasive method. Photo: M. Nečásková.

possible an application of the protective lacquer coating. The minuscule isolated remains of corrosion, noticeable only at very close inspection, were left in some open blisters and indents since their removal could cause damage to the glass. These remnants are not normally visible.

The future of the mosaic relies on regular care. The reapplication of the top coating is expected in several-year cycles, and complete reapplication of the entire protective system is expected in decade-long cycles. The protective coating system should be soluble with organic solvents, in such a way that the upper layer would be more readily soluble than the underlayers. During the maintenance of the mosaic, only organic solvents are to be used for coating removal and cleaning of glass tesserae. The air-abrasive method is not suitable for coating removal. The elastic and sturdy films provide extended resistance to the mechanical effect of the blasted particles, and when the film finally cracks in some places, the glass is often damaged under the cracks before the film is successfully removed. This, which in theory is an easily explicable fact, was fully visible during an attempt to remove the insoluble coatings from several small test fields on the mosaic. In such a situation, the less risky use of a scalpel becomes a necessity. This confirms that insoluble coatings may not be considered for protection of the mosaic. Because of the difficulties posed by mechanical removal of coatings, it is absolutely necessary to regularly monitor their solubility, which can diminish over the years. Equally important is the careful monitoring of the coating condition. It is also necessary to act before the corrosion starts expanding through the cracks in the coating. The conglomerate of polymers and ingrown crystals could be practically irreversible, and the lack of maintenance could return the mosaic to an untenable situation. At the same time, it is necessary to follow developments in cleaning technology, since it is possible that the future will bring new, even gentler methods that are applicable to mosaic cleaning.

Notes

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Eric Bescher
J. D. Mackenzie

Chapter 13
The Last Judgment Mosaic: Development of Coating Technologies

Materials science is often described as the study of the relationship between the structure of materials and their properties. In this respect, the conservation of the Last Judgment mosaic was first and foremost a *materials science* challenge. First, the corrosion of medieval glass in outdoor environments is a very complex series of chemical reactions that should be understood in order to design an effective protective coating. Second, the selection and design of the protective coating material cannot be done efficiently without an understanding of the relationship between coating structure and properties, which brings us back to a definition of materials science. The performance of a material for a given application is governed by two main factors: the intrinsic properties of the material, such as chemical structure, elastic modulus, hardness, porosity; and its design characteristics such as thickness, morphology, microstructure, and monolayer versus multilayer. The conservation of the mosaic should preferably encompass a study of all these factors. It also presents us with an opportunity to evaluate some of the most promising materials born out of research in materials science. It was a unique opportunity for the use of new materials and strategies in the treatment of inorganic surfaces against corrosion.

It was apparent that in most previous conservation efforts failure was due to either the inadequacy of materials used or the lack of upkeep of the mosaic, perhaps both. Organic polymers such as acrylates or beeswax previously used on the mosaic had failed primarily because they typically exhibit no chemical bonding mechanism to the surface of the glass and because their inherently open chemical structures make them ineffective barriers against diffusion of gases such as water or sulfur dioxide. But even with such odds against them, these materials might have performed adequately if their performance had been monitored closely and if they had been removed and replaced frequently. This underscores the importance of maintenance in the success of all conservation efforts, the present one included.

The Problem

The conservation of the mosaic is a complex problem having its origins in the unstable nature of the medieval glass used in the fabrication of the tesserae. Because of limitations of the glass melting technologies in the thirteenth century, large amounts of alkali were used. While the high alkali content allowed processing of the glass at relatively low temperatures, it also sealed the fate of the glass exposed to the harsh Prague climate. This high-alkali glass is well known to be highly prone to a complex corrosion process leading to the progressive dissolution of the glass into more stable, insoluble compounds on its surface. The unstable glass can react with water vapor and rains, as well as with sulfur dioxide in the atmosphere. This process is schematically represented in figure 1. Although the decaying process might have accelerated during the industrial revolution because of intensive coal burning, which generated acid rains in Czechoslovakia, it is likely that the mosaic was virtually never seen as it was intended. As a result of these reactions between the glass and its environment, the condition of the mosaic deteriorated to the extent seen in a photograph taken in 1995 (fig. 2). The tesserae were covered with a thick (>1 mm) layer of gray corrosion salts. When the corrosion

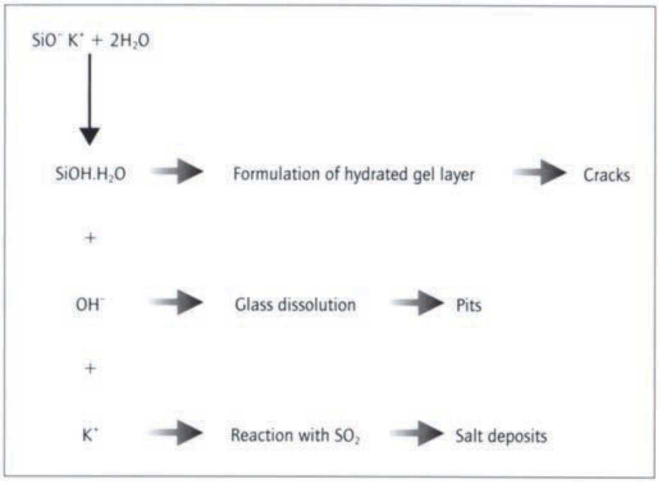


FIGURE 1 Corrosion mechanism of high-potassium glass in the presence of water and sulfur dioxide.

salts were removed mechanically, they revealed a highly irregular glass surface, replete with corrosion pits and cracks. Traces of original and twentieth-century gilding, as well as replacement tesserae, were visible. It was obvious that a complete treatment of the mosaic would require removal of corrosion salts, in a process not described here, and the design and application of a coating system that if it could not stop corrosion completely, would at least make it manageable. To prevent corrosion of the glass tesserae, it was desirable to design a protective coating that would slow down significantly diffusion of water and sulfur reactants toward the surface of the glass.

Complexity of a Coating: Materials and Design

Designing a protective coating for this application cannot be done without at least considering the many complex parameters that may affect its performance. In figure 3, we summarize some of the most important factors involved, many of which are interdependent. For example, let us consider the issue of thermal expansion coefficient (CTE). The linear coefficient of thermal expansion of high potassium oxide glass is approximately 9×10^{-6} °C^{-1}. A typical CTE for polymethylmethacrylate (PMMA) is 150×10^{-6} °C^{-1}. A PMMA coating on glass is therefore likely to delaminate when subjected to large temperature differences, particularly since no strong chemical bonding exists between coating and substrate. Other important considerations, also illustrated in figure 3, are as follows:

- Is the bonding between substrate and coating physical or chemical?
- What is the chemical structure of the coating material (is it cross-linked or not, etc.)?
- What is the optimum thickness?

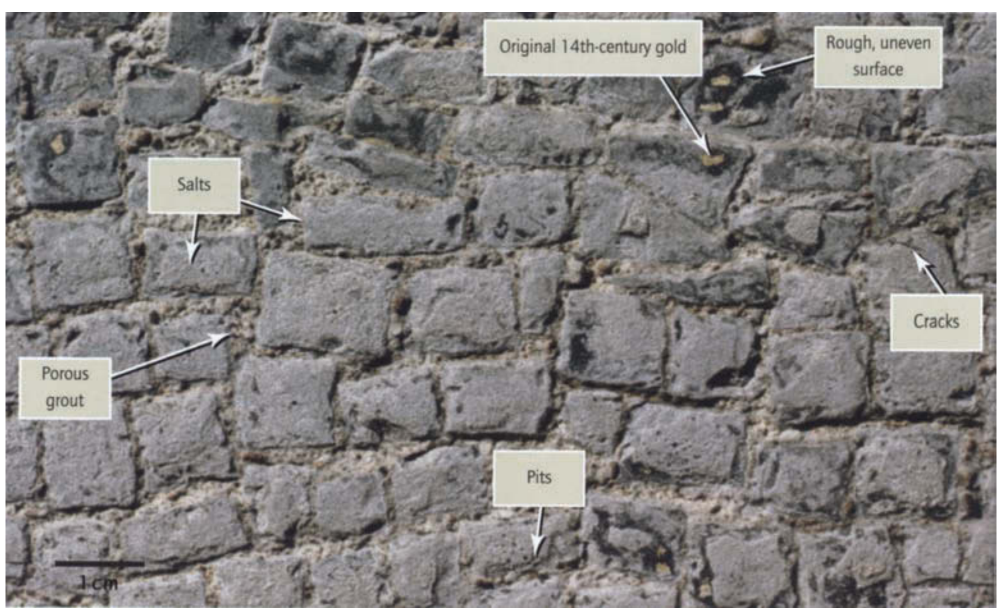


FIGURE 2 Photograph of a section of the mosaic before treatment, illustrating the complexity of the problem.

- What is the desirable property of the coating (diffusion barrier, UV absorber, etc.)?

An additional complexity specific to conservation applications is that it is usually desirable for the coating to be "reversible," meaning that it should be possible to remove the coating easily after application. On its face, this requirement is somewhat incompatible with the requirement of chemical stability. If a cross-linked coating is likely to be chemically stable, it will also be poorly reversible. This illustrates the need for compromises in the design of such protective coatings. The design of the coating, perhaps as much as the intrinsic properties of the material themselves, becomes paramount. One important element that had to be considered was the requirement of periodic maintenance. It was desirable that the upper part of the coating (the so-called sacrificial layer) should be removed and reapplied every five years or so. The part of the coating in contact with the tesserae (the so-called protective layer) should last twenty-five years. As a consequence, it is unlikely that a single material will be able to address suitably all considerations shown in figure 3. Therefore, a multilayer design might be necessary.

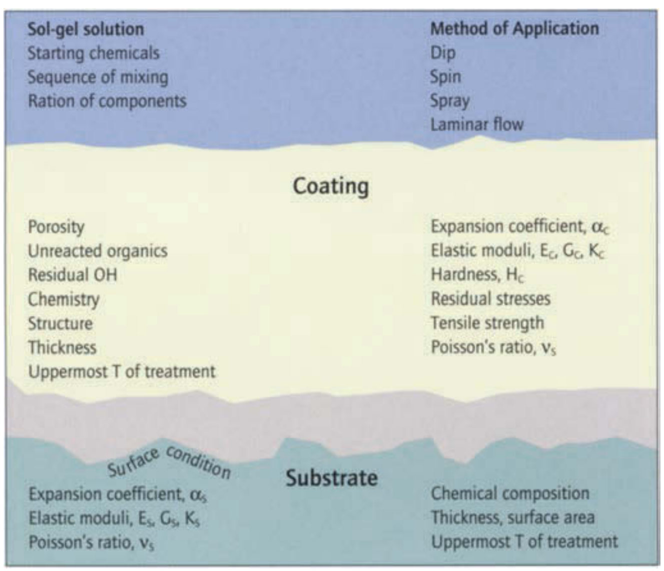


FIGURE 3 A number of the parameters that affect the performance of a coating.

The selection of materials in this design is of paramount importance. Some of these properties of materials as they apply to conservation have been explored in excellent reviews (Horrie 1987). Organic materials, with the possible exception of some fluoropolymers, usually do not exhibit the appropriate properties for long-term exposure on the mosaic. First, the diffusion coefficients of most gaseous species are usually too large to allow the materials to be effective barriers against corrosion. Second, the lack of binding mechanism between glass and polymer usually leads to delamination of the coating in the long term. Third, most organic coatings such as polyurethanes or epoxies undergo changes over time under ultraviolet exposure, leading to structural changes. Such chemical instability causes yellowing and hardening. Inorganic oxides would be desirable because of their structural similarity to glass tesserae and their lower diffusion coefficients. However, they would be nearly impossible to fabricate via conventional methods on the mosaic. It was proposed that sol-gel–derived materials, which are derived from the room temperature processing of organometallic compounds, could be excellent candidates.

Sol-Gel Technology

The sol-gel process involves the reaction of liquid precursors at room temperature for the fabrication of glasses and ceramics (Brinker and Scherrer 1990; Pierre 1998). It has been used for the fabrication of many amorphous and crystalline oxides such as SiO_2, AL_2O_3 and many rare-earth doped oxides. Usually, the process involves hydrolysis and condensation of organometallic precursors. In the case of silica, a silicon alkoxide such as tetraethoxysilane (TEOS) is mixed with an alcohol, such as ethanol, in the presence of water. A reaction of hydrolysis follows, during which alcohol is released:

$$Si(OR)_4 + 4H_2O \longrightarrow Si(OH)_4 + 4ROH \qquad (1)$$

This step is followed in solution by condensation of the silanols to form Si-O-Si links:

$$2Si(OH)_4 \longrightarrow (OH)_3\, Si\text{-}O\text{-}Si(OH)_3 + H_2O \qquad (2)$$

As reaction (2) proceeds, the viscosity of the solution increases until a solid network is formed, at which point the solution has "gelled." On careful drying, organics are removed and an amorphous oxide is usually formed that can be converted to the corresponding crystalline phase on further heating. The advantages of the sol-gel process over conventional ceramic processes have been described as being related to (1) the improved purity of the precursors, (2) the lower processing temperatures, (3) the ease of fabrication of coatings and films, and (4) the possibility of intimate mixing of components (homogeneity at the molecular level).

An advantage of the sol-gel process in the case of coatings on inorganic oxide substrates is that the large amounts of hydroxy groups present in the solution facilitate easy bonding between coating and substrate (fig. 4). This is a unique advantage that most polymeric materials do not have. Because of these advantages, the sol-gel process has been used in many applications, but the field of coatings and films has probably benefited the most from advances in sol-gel technology. Examples of the use of the process in the context of conservation have been described (Horrie 1987; Pilz and Romich 1987). Sol-gel silicates have been proposed in the conservation of porous stones (Mosquera et al. 2002). Other metal alkoxides have been proposed as well (Wheeler 2003). A drawback of the use of inorganic alkoxides such as TEOS is that the resulting silicate is usually a high-surface-area material, brittle and porous if not heat-treated to elevated temperatures. Recently, however, there have been many developments in the field of organically modified silicates, also known as organic-inorganic hybrids.

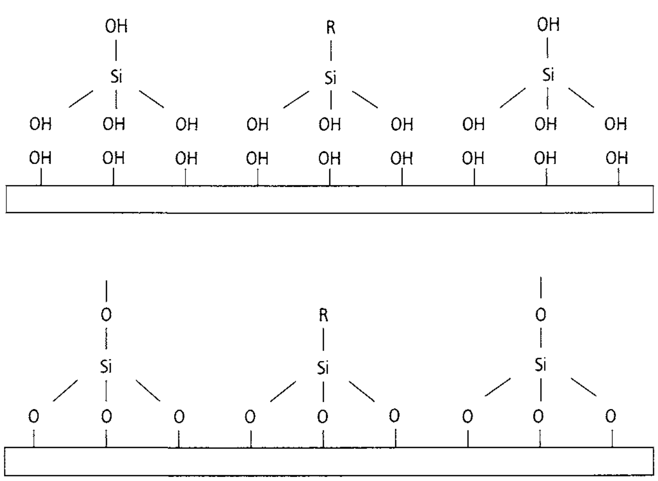
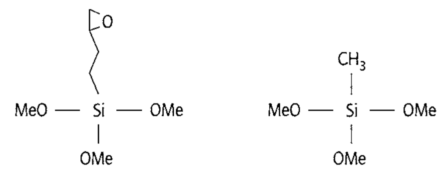


FIGURE 4 Bonding of a sol-gel solution to an oxide substrate through condensation.

Organic-Inorganic Hybrids

The tetraethoxysilane precursor can be organically modified to provide some additional functionality, as in the glycidoxy and methyl silanes shown here:

One particularly interesting example of hybrids is that of the polydimethylsiloxane (PDMS)-SiO_2 system, which exhibits a continuous variation of mechanical properties between that of ceramics and that of polymers (fig. 5).



PDMS if used alone is a transparent, flexible silicone polymer with low elastic modulus. The properties are due to the linear chain structures of the polymer. SiO_2 by itself is a brittle, transparent material with high elastic modulus. The structure of the PDMS-SiO_2 hybrid consists of chains of PDMS linking islands of SiO_2 (Iwamoto and Mackenzie 1995; Mackenzie et al. 1996). When the PDMS content reaches a sufficiently high concentration, it tends to control

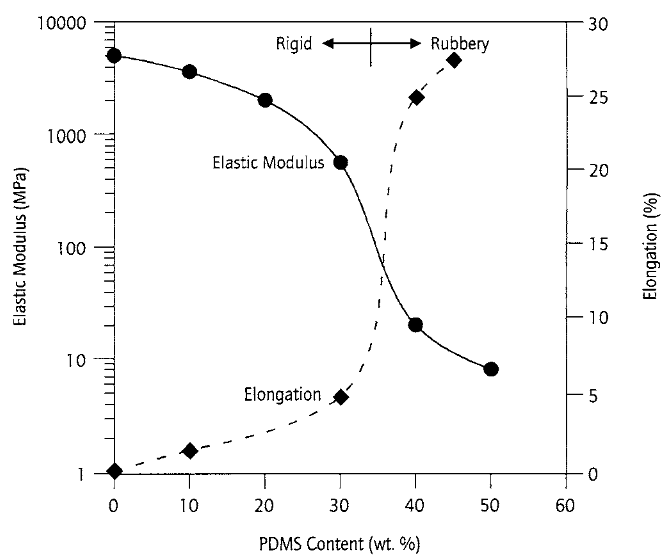


FIGURE 5 Some mechanical properties of organic-inorganic hybrids, as in the case of a SiO_2-polydimethylsiloxane system.

the deformation of the hybrid. But the addition of organic functionalities to an inorganic ceramic can go well beyond modification of its brittleness. For example, barrier coatings have been synthesized using glycidoxy precursors described above (Amber-Schwab et al. 2000). Many other combinations and properties are possible (Laine 2000; Schaeffer et al. 1996). There are many different ways of fabricating organic-inorganic hybrids. One may impregnate a solid porous oxide with a polymer. One may add an organic molecule into an inorganic sol-gel solution. One may mix organic-inorganic precursors together, as in the case of SiO_2-PDMS. In the first two cases, there is not a strong bond between organic and inorganic constituents. In the latter situation, a covalent bond exists between both constituents, which makes for a stabler material. This classification of hybrids has been discussed in detail (Sanchez and Ribot 1994). Since the early pioneering research of Schmidt (1985), more than four hundred publications on this third type of hybrids have appeared. These processing routes are summarized in figure 6. Many applications have been proposed for hybrids, such as sensors (Bescher 1998) or many types of coatings. The mechanical properties of these coatings are of particular interest (Mackenzie and Bescher 2000). It is likely that coating technologies will tend to benefit the most from developments in sol-gel–derived organic-inorganic hybrids. Therefore, it became apparent that they would make ideal testing candidates in the protection of the Last Judgment mosaic.

It became apparent during the initial testing phase that the combination of a sol-gel coating with an organic fluoropolymer coating would give the most promising results. The best-performing fluoropolymer was Lumiflon®, manufactured by Asahi Glass, Japan. Its chemical structure (fig. 7) is instrumental to helping it to achieve the following characteristics:

- Excellent weather resistance. Accelerated weathering tests show that the coating does not change in appearance after 10,000 hours of exposure in an accelerated weatherometer. Outdoors exposure tests conducted in a very corrosive marine environment in Okinawa showed excellent retention of properties after seven years of exposure.
- Excellent transparency. The transparency of the polymer is above 95% throughout the visible part of the spectrum.

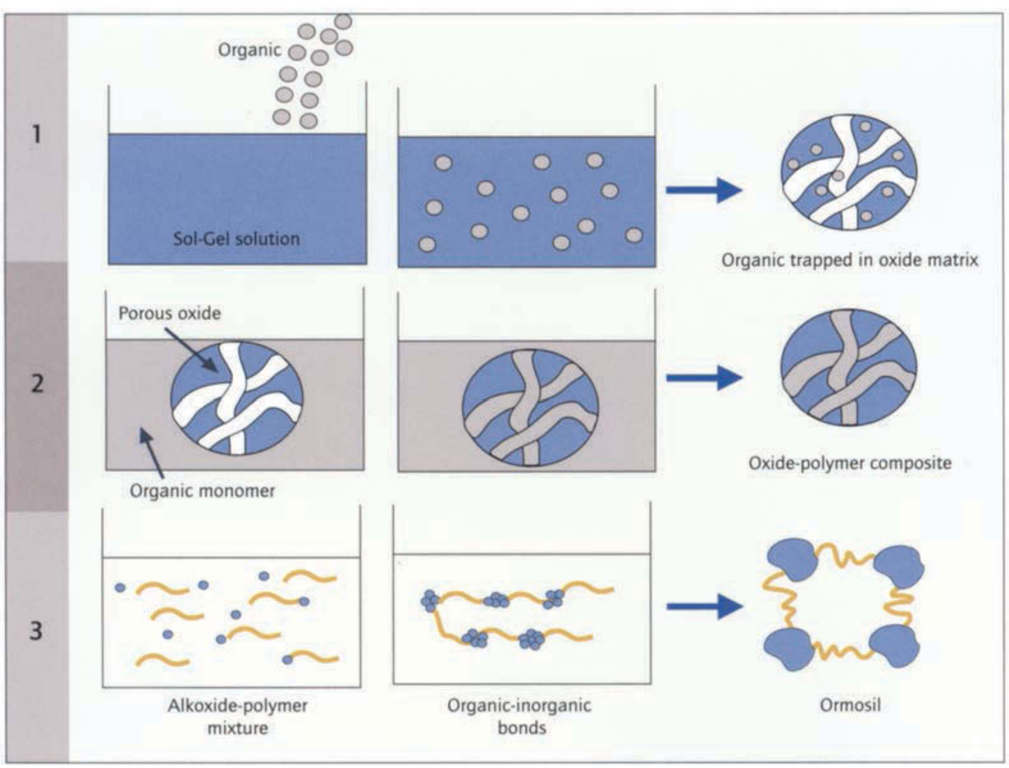


FIGURE 6 Processing routes of organic-inorganic hybrids (ormosils).

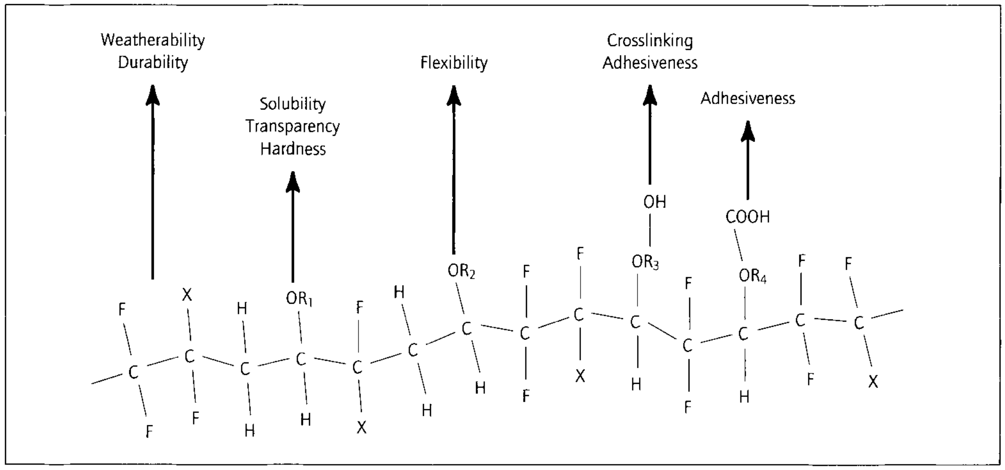


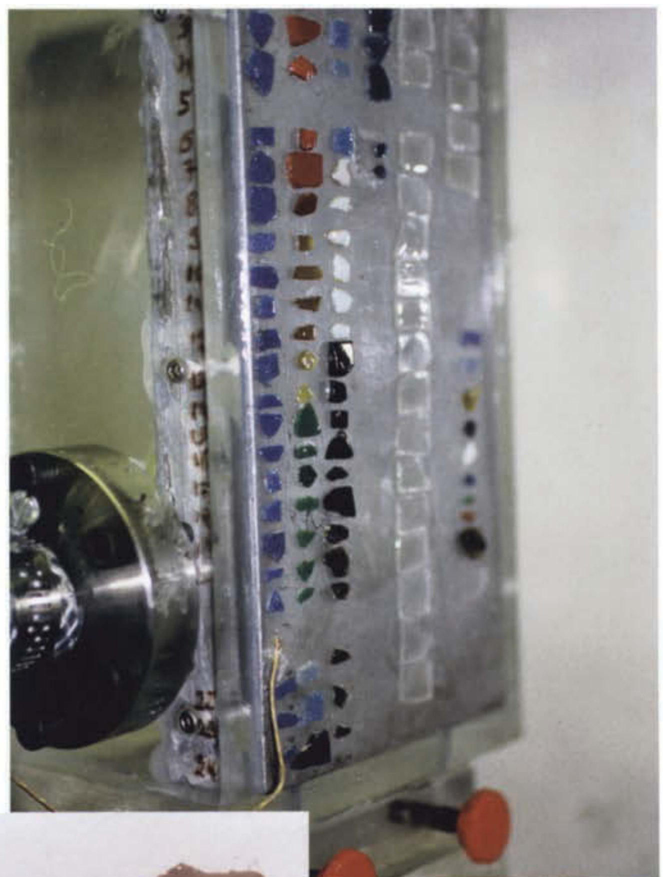
FIGURE 7 Structure of Lumiflon fluoropolymer.

- Good adhesion to many kinds of substrate. Lumiflon® has been applied to many kinds of substrates and metals, and the adhesion properties (tested with the tape method) are very good.
- Wide selection of coating formulations. There are several grades of Lumiflon, some of which are cross-linked. The fully cross-linked grades are difficult to remove, whereas the non-cross-linked grades are easier to remove. Typically, because usual applications of the coating do not require removability, the coat is cross-linked with a large amount isocyanate (for room temperature drying) or melamine (for baked coatings). It also contains –OH groups, which can react with surface hydroxyls of a substrate.

Laboratory and On-Site Testing

Laboratory Testing

In situ testing required the construction of an aging chamber replicating the weather conditions in Prague. A weathering chamber was built in which an atmosphere containing 0.1 wt% SO_2 was circulated. Coating materials to be tested were applied on thinly cut and polished slices of actual tesserae and on high-potassium glass substrates. The coated samples were then glued on the surface of a hollow metallic plate (fig. 8a) in which a liquid coolant was run periodically, bringing the test samples to -7°C. At the end of that "freezing" period, two lamps, one infrared and one ultraviolet, were switched on to simulate hot and sunny conditions. Under the lamps, the coatings reached



a

b

FIGURE 8 a, b Testing plate with coated original tesserae and artificial high-potassium glass (a). Delamination of epoxy coating after eight days of exposure in test chamber (b).

TABLE 1 WEATHER CONDITIONS ON THE TESSERAE SURFACE DURING LABORATORY TESTING

Condition	Duration (minutes)	Duration (% of cycle)
Freezing	32	13
Dew	94	39
Dry	114	48

TABLE 2 OTHER ATMOSPHERIC CONDITIONS IN THE WEATHERING CHAMBER

T_{min}	−5.8°C
T_{max}	+63.6°C
Average relative humidity	60%
SO_2 concentration	10 ppm

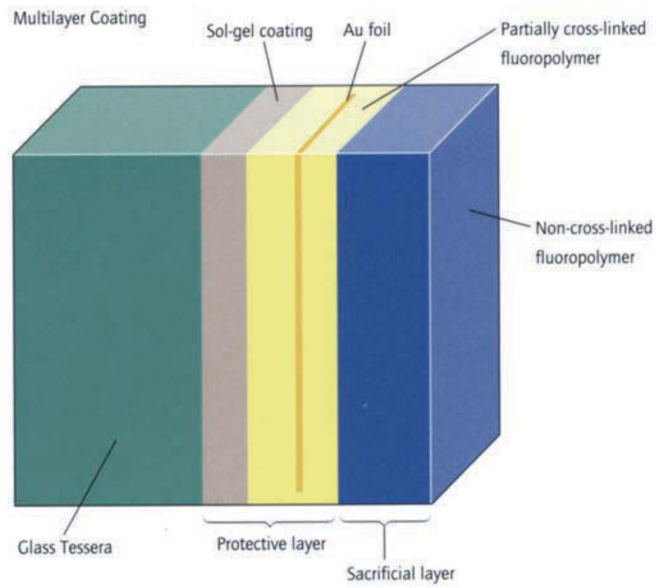


FIGURE 9 The final coating strategy, comprising a protective layer in contact with the tesserae and incorporating the gilding and a sacrificial layer.

+45°C. During the cooling phase, dew would form on the surface of the coating, followed by the formation of frost. The alternating sequence would repeat itself four times a day, as shown in figure 8. (See also tables 1, 2.) This allowed a simulation of weather conditions similar to those of the mosaic. This setup was used to quickly eliminate coatings that would fail on site and select the ones most likely to succeed. For example, many epoxy coatings failed very quickly in the chamber, mostly through delamination (fig. 8b). The coating systems that passed the accelerated weathering tests were, in order of best performance,

1. Sol-gel layer/ Lumiflon®
2. Sol-gel layer with colloidal particles/ Lumiflon®
3. Lumiflon®/ Lumiflon®

The sol-gel layer contained the glycidoxy and methyl silane precursors described earlier. A sol-gel solution containing colloidal silica was also found to perform very well in the laboratory. The final coating strategy is represented in the cross section shown in figure 9. The other systems failed due to cracking or delamination. The best coating (sol-gel layer/Lumiflon®) also performed best on on-site test panel # 3.

A number of additional tests, such as coating reversibility, were carried out in the laboratory. The tests involved doping the coating with a colored dye, applying and curing the coating onto a quartz slide, and subsequently immersing the coated slide in methyl ethyl ketone for various lengths of time. Optical absorption of the coating in the visible range confirmed that the coating was reversible (fig. 10). Additional testing on the influence of coating the mortar between tesserae was carried out. It was concluded that it was best not to coat the mortar in order to allow for flow of rainwater through the mortar.

ON-SITE TESTING

Three on-site testing campaigns took place using materials selected after laboratory evaluation. A testing panel consisted of a one-square-meter area of the mosaic, cleaned of corrosion, on which the coating materials were applied. More than thirty combinations of materials that had passed the laboratory tests were applied on the on-site panels. One such area is presented in figure 11, the panel tested during the last year. Figure 12 is a close-up of the test panel after two years' exposure, showing delamination of an epoxy/Lumiflon® coating but good performance of the sol-gel/Lumiflon® multilayer. Reversibility of the coatings was also tested on site, as shown in figure 13. There appeared to be no issue with the

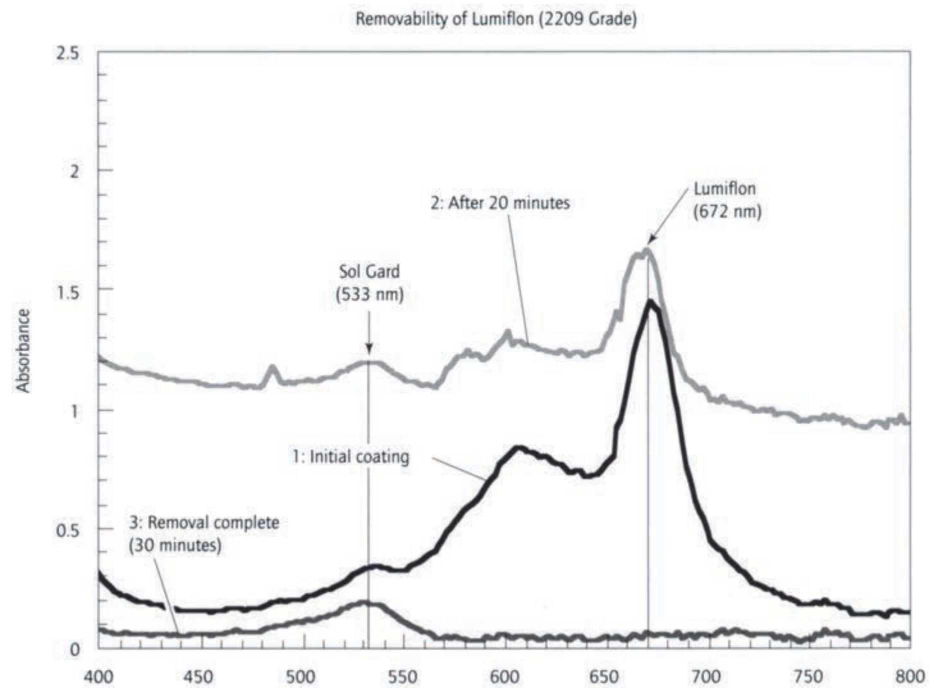


FIGURE 10 Tests of the reversibility of the Lumiflon coating, monitored by optical spectrometry.

FIGURE 11 On-site testing panel.

removability of the coating using acetone or methylethylketone. At the end of the last testing period on site, in which it was confirmed that the sol-gel/Lumiflon® coating system was performing very well, it was decided to use this materials combination for treatment of the entire mosaic.

Application Techniques

A flawed application technique can lead to a defective coating that will not perform as intended. Of particular importance is the tessera surface preparation prior to coating. Because of the complexity of the application process, in-situ

FIGURE 12 On-site testing after two years of exposure. Left: sol-gel/functionalized fluoropolymer coating combination. Right: epoxy polymer exhibiting onset of delamination. The numbers 6 and 1 are coating identifiers used during monitoring.

FIGURE 13 Reversibility of the final coating system. Left: coating before removal. Right: coating after removal using a cotton-tipped applicator dipped in methylethylketone.

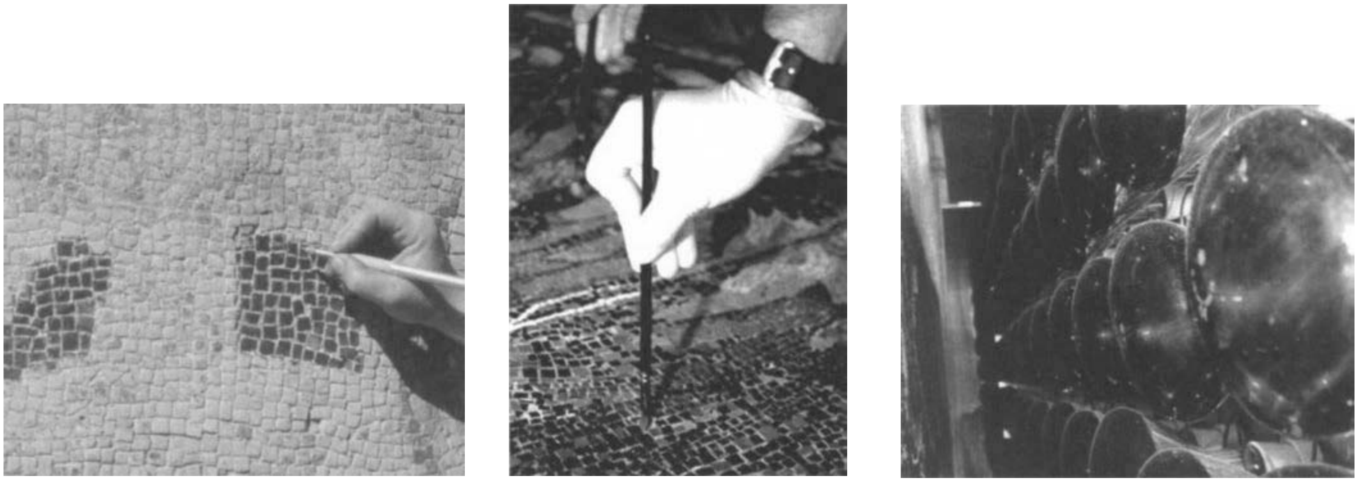
treatment of the mosaic took place during the summer only, three summers in a row. The first central panel was treated in summer 1998. The various steps of the treatment are shown in figure 14a–e. The Lumiflon® 200 solution used for the sacrificial layer was a clear, viscous material containing about 50% solids. The solution used for the sacrificial layer did not contain any cross-linking agent. The coating solutions for Lumiflon® were prepared as shown in table 3.

Step 1. Preparation of the tessera surface

(a) *Removal of the corrosion layer.* This was accomplished using a compressed air–glass spheres system that has been tested on site and allowed removal of corrosion products without affecting the tesserae. Care was taken to remove corrosion from the pits in the tesserae and at the tessera-mortar interface.

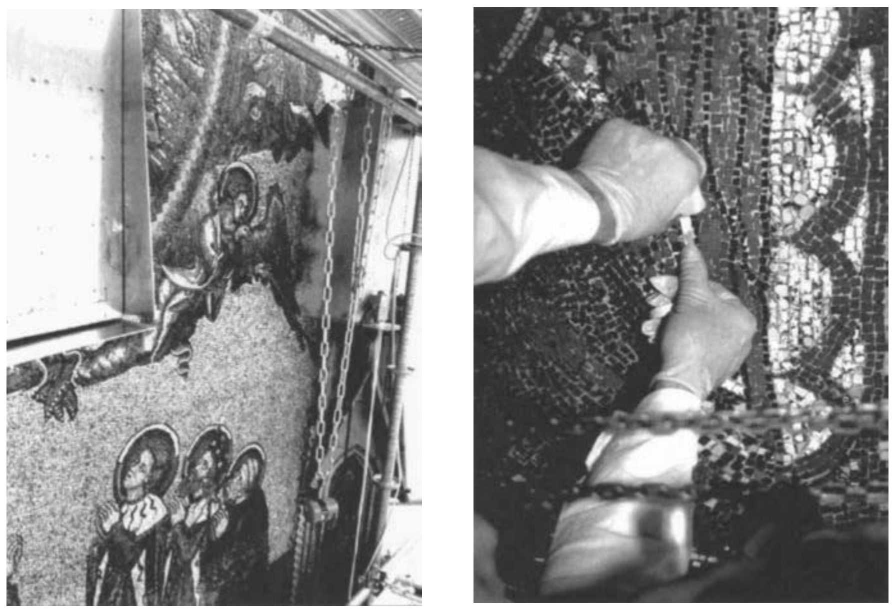
(b) *Washing.* The mosaic was washed with water to remove dust and glass spheres remaining in the pits and asperities of the mosaic. This step was essential, as previous tests had shown that these particles contaminate the coating solution during application and seriously affect the performance of the coating system.

(c) *Cleaning of the tesserae surface.* Using alcohol first and then acetone, the surfaces of the tesserae were cleaned immediately prior to application of the first coating material. This cleaning was done with cotton-tipped applicators, taking care to not leave any fibrous residue on the tessera. At this stage, extreme care was taken not to leave fingerprints on the tesserae: we had observed that residual oil from the skin would lead to delamination of the coating. At this stage, as in all subsequent stages of treatment, conservators wore protective, powderless gloves to prevent contamination of the coating solution and the cleaned surfaces. It was also recommended that conservators wear protective gear such as goggles and respirators when handling chemicals.



a b c

FIGURE 14a–e Mosaic treatment: (a) removal of corrosion products using compressed air/glass; (b) application of the coating solutions; (c) infrared lamps used for heat treatment; (d) heat treatment of a panel; (e) gilding in the protective layer.



d e

TABLE 3 LUMIFLON® SOLUTIONS COMPOSITIONS FOR VARIOUS PARTS OF THE COATING

	Lumiflon® 200	Xylene	Methyl Ethyl Ketone	Cymel 303
Protective layer	100 parts	200 parts	100 parts	5.5 parts
Gilding	100 parts	400 parts	200 parts	5.5 parts
Sacrificial layer	100 parts	200 parts	100 parts	0

Step 2. Application of the protective layer and gilding

It was crucial the application of all coating materials take place under dry and clean conditions. The presence of water on the tesserae or in the grout will alter the structure of the coating solutions and lead to inadequate coating properties. Therefore, it was advised to interrupt coating processes during significant rain, even if the scaffolding is shielded from the rain.

(a) *Application of the sol-gel layer.* The coating sol-gel solution was applied to individual tesserae using a small brush. The tesserae sides were coated as well. Care was taken to coat the inside of corrosion pits. Coating the mortar was avoided. Loose residue or ceramic particles could be picked up by the brush and contaminate the coating. The applied coat remained tacky prior to heat treatment. The coating was not touched during drying. After a panel had been treated, the coating was cured at 90°C for two hours.

(b) *Application of the protective polymer layer and gilding.* The protective layer contained the gilding. The gold foil must not be in direct contact with the sol-gel layer, nor must it be in contact with the removable sacrificial layer. Damage to the previous layer had to be be avoided during gilding. Therefore, this 5-step process was followed:

- A first layer of Lumiflon® was applied and cured at 90°C for 30 minutes.
- A diluted Lumiflon® solution (previous solution diluted in 75% solvent) was applied.
- Gold foil was applied immediately on the tacky layer. This allowed the gold layer to stick to the polymer. Since the underlying Lumiflon® layer was cured, minimal mechanical force could be used to burnish the gold layer. Burnishing was carried out using oil-free, clean utensils such as a clean brush. *Contact of the coating with the skin must be avoided.*
- Lumiflon® was applied on top of the gilding.
- The completed protective layer was cured at 90°C for two hours.

Step 3. Application of the sacrificial layer

The sacrificial layer was applied above the protective layer and cured at 90°C for two hours.

Conclusion

Conservation of the last Judgment mosaic was a unique opportunity to apply recent advances in materials science to an ancient, unique, and complex materials challenge. More specifically, this effort highlights one interesting application of the sol-gel technology. To date, the conservation appears to have been a success, but in order for this success to last, one must keep in mind two important facts. First, new materials will constantly be developed with properties superior to those of the materials described here; and second, it is impossible to completely arrest the diffusion of gases through any material. Therefore, the importance of constant periodic maintenance cannot be overemphasized. This maintenance is not only recommended, it was specifically built into the design of the coating. It is an intrinsic element of the coating performance that must not be overlooked. We hope that with proper care and the necessary updates in materials the splendor of this fourteenth-century masterpiece of Czech art will be visible for many years to come.

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Part III
Conservation Implementation and Maintenance

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Francesca Piqué

Chapter 14
Documentation of the Last Judgment Mosaic

Documentation is an essential component of conservation programs, and it involves the collection and organization of the body of information acquired during the project. In the Last Judgment mosaic project, information was collected during the preliminary investigation, scientific research, and treatment phases and continues to be collected during monitoring and maintenance. Documentation can be divided into four types: historical, technical, current condition, and treatment. The data are preserved in written, graphic, and photographic form.

Historical documentation is the collection of written and visual information concerning the history of the mosaic and its context. It includes archival records, writings and report on previous interventions, and as historical photographs or sketches of St. Vitus Cathedral and the mosaic. This documentation was one of the first steps toward understanding the significance and cultural values of the mosaic. For example, the historical records revealed the influence of Charles IV and Italian art on the creation of the mosaic.

The other important objective of historical documentation in this project was to trace the mosaic's history from its construction to the present day. The visual renderings (drawing, sketches, and photographs) of the mosaic make it possible to establish this chronology (see chap. 7).

Technical documentation, that is, the record of the mosaic's physical and conservation history, is an essential tool for understanding the causes of its deterioration. The archival record, for example, showed that it was necessary to clean the Last Judgment mosaic only one hundred years after its creation and several more times after that. This tells us that corrosion and legibility are old problems and that the deterioration was most likely related to the composition of the original medieval glass, exacerbated in recent times by air pollution and other environmental conditions.

Documentation of the mosaic's *current condition* involved recording signs of its conservation history that are still visible: the original material, construction technique, evidence of past intervention, and the type and distribution of deterioration.[1]

Treatment documentation is the collection of information on treatment, methods, and materials. Some of the interventions, such as cleaning of the corrosion products and the coating application, were carried out on the entire mosaic glass surface. Therefore, these interventions were described in written form rather than graphically.

Recording Techniques

The first documentation step typically involves photographic documentation to record the condition of the mosaic and to plot various kinds of information observed during the phases of the project. The team anticipated three significant phases of conservation:

1. Before treatment (mosaic covered with corrosion layer);
2. After cleaning (mosaic cleaned and all colors exposed); and
3. After treatment (mosaic regilded and coated).

The photographic and graphic documentation was planned accordingly. All information was collected or transformed in digital form to enable quantitative evaluation and interpretation to enable overlapping (fig. 1) and comparison of the three different situations.[2]

The phenomena recorded graphically included condition and previous interventions and current intervention (see table 1).[3] The graphic records are in digital form. Figures 2 through 6 are examples of these records.

General Description of the Mosaic and Its Iconography

The Last Judgment mosaic is located on the south portal of St. Vitus Cathedral (see Introduction, fig. 1). Thermographs of the facade taken during the project show the presence of a closed-up window underneath the central part of the mosaic (fig. 7). The presence of this window, already revealed in the nineteenth century when the mosaic was detached,

FIGURE 1 Overlapping of images of the central panel before cleaning, after cleaning, and after regilding.
By Rand Eppich.

TABLE 1 Information Recorded in Graphic Form

Condition

Level of corrosion: Corrosion was categorized as *light, medium, heavy,* and *forming a crust.* Information about corrosion had to be collected and recorded before cleaning.

Traces of original gilding: Areas with original gold. Due to the glass corrosion process, the mosaic had lost almost all traces of the original gilding.

Cracks: Location of fractures in the mosaic.

Previous Interventions

Borders of sections detached in the nineteenth century: The mosaic was detached from the wall in 1890 because of the condition of the plaster. The mosaic was then repaired and reinstated in 1910, and many new tesserae were placed along the edges of the detached sections. After cleaning, the outlines of the detached sections were visible.

Reintegration with tesserae: Throughout its history, different areas of the mosaic underwent a variety of repairs and reintegration. The restored areas of the mosaic reintegrated with mosaic tesserae were divided into four categories:

1. *All new tesserae.*
2. *Majority of new (nineteenth- and twentieth-century) with few original tesserae.*
3. *Mixture of original and new tesserae.*
4. *Majority of original (fourteenth-century) tesserae.*

Plaster reinforcement of the original setting: Areas where plaster was applied to stabilize loose original tesserae without removing them.

Current Interventions *

Fills: Lime-based fills of cracks and losses present but very sporadic.

Test areas: Area of the mosaic where protective coating and cleaning treatment was tested before its implementation.

* The conservation team performed cleaning and coating on the entire mosaic with the exception of the parts made of stone. Therefore, these types of interventions were not recorded graphically.

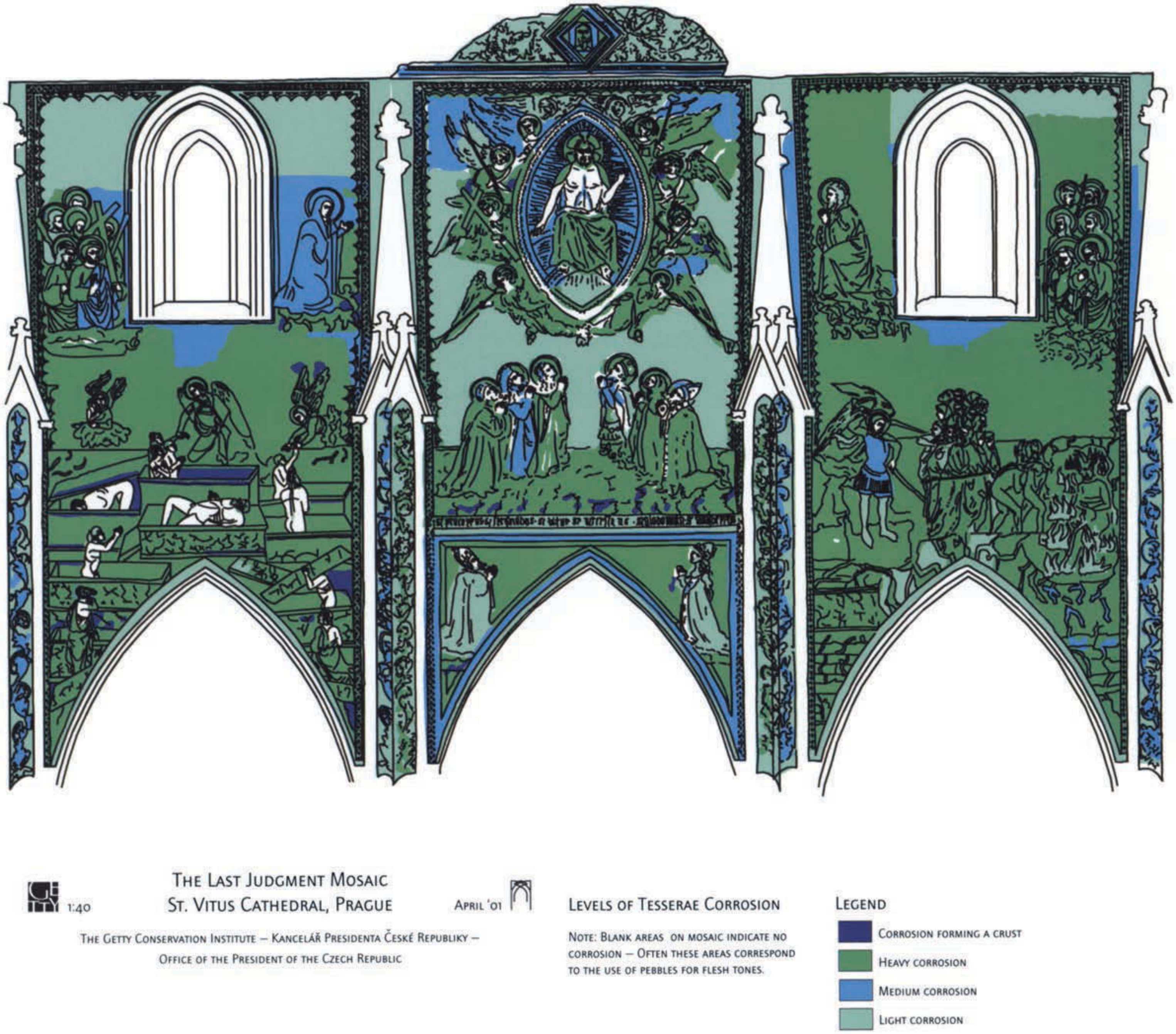


FIGURE 2 Graphic documentation: distribution of the different types of glass tessera corrosion. By authors, with Rand Eppich and Irene Sen.

FIGURE 3 Graphic documentation: distribution of the different types of glass tessera gilding. By authors, with Rand Eppich and Irene Sen.

FIGURE 4 Graphic documentation: distribution of the different types of previous interventions (1910).

By authors, with Rand Eppich and Irene Sen.

FIGURE 5 Graphic documentation: distribution of the different types of previous interventions (1910) and reintegration with tesserae. By authors, with Rand Eppich and Irene Sen.

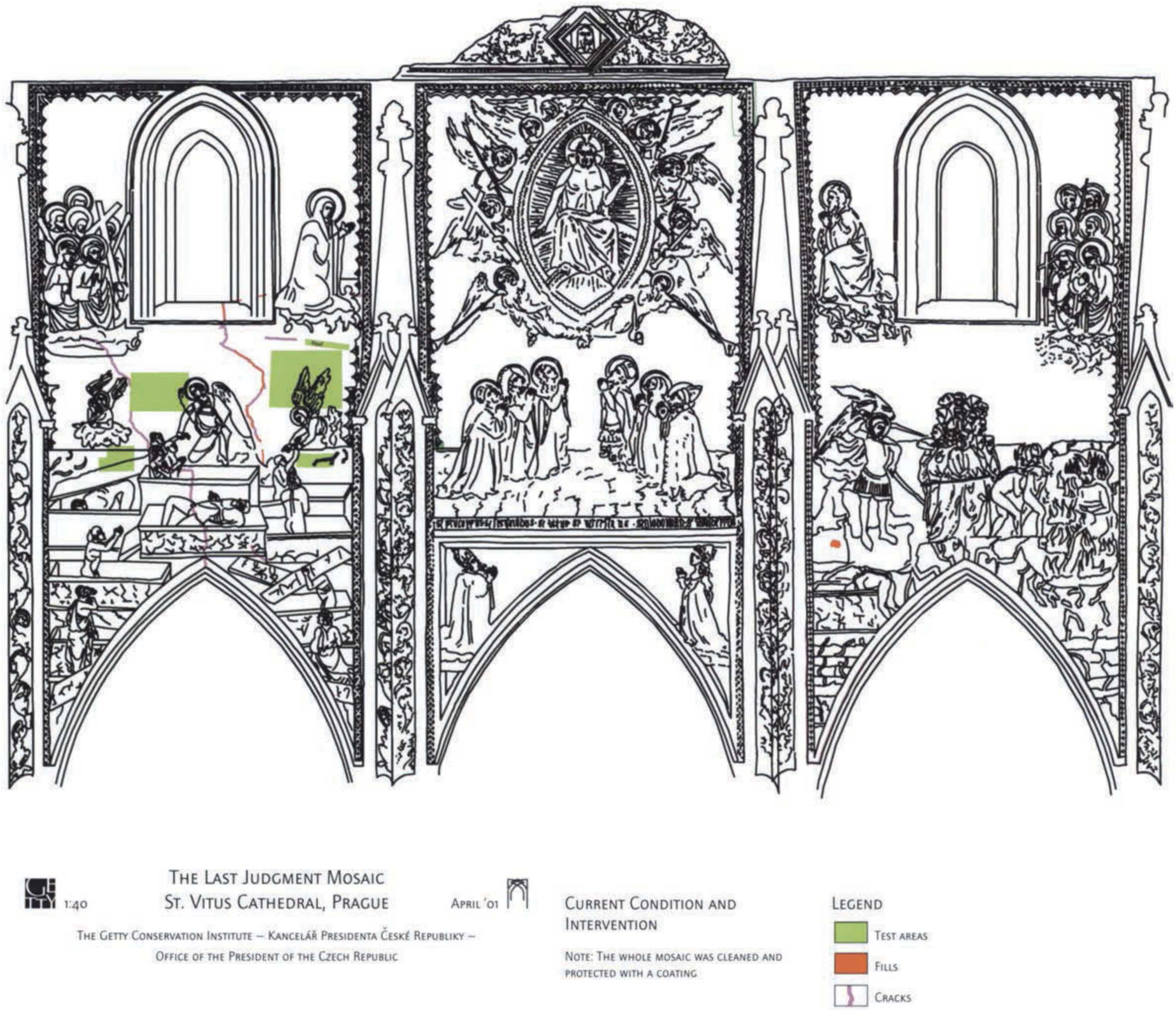


FIGURE 6 Graphic documentation: distribution of the condition of the mosaic in 1997 and intervention carried out as part of the GCI–Prague Castle project. By authors, with Rand Eppich and Irene Sen.

indicates that the plan to construct a mosaic on this wall was developed after 1367, the year this portion of the cathedral was completed.

The mosaic consists of three panels (see pls. 3–9). In the middle panel, Christ as supreme judge is seated on a rainbow inside a mandorla surrounded by angels. Six patron saints of the kingdom of Bohemia kneel below him. An inscription band separates the kneeling King and Holy Roman Emperor Charles IV and his fourth wife, Elizabeth, from the main motif. On the left panel, the Virgin Mary and six apostles intercede for the resurrected, who are being helped from their graves by angels. On the right panel, St. John the Baptist and six other apostles are interceding while Archangel Michael raises his sword and devils lead the damned into hell. The mosaic is framed at the top by a decorative border fragment with a vera icon and at the sides, by six narrow strips with acanthus motifs set in the grooves of the tall pinnacles architecturally dividing the mosaic.

Technical Documentation

Technique Used to Make the Mosaic

The mosaic was built on a wall made from stone blocks (see fig. 8 for original stratigraphy). The surface of the stone was keyed to ensure good adhesion of the first layer of plaster. Double-hooked iron nails, approximately 18 cm long and 4 mm thick, were hammered between the stones and secured with lead. These nails were placed at intervals of approximately 37.5 cm. One of these nails is still embedded in the wall under the ledge, where the previous wall finish is also still apparent (fig. 9, 10). Wires were stretched between the nails in a crisscross and diagonal fashion to create a mesh net.[4] A lime-based plaster, 8 to 12 mm thick, was applied on this wall and wire net. The plaster was leveled with a trowel and roughened with irregular nicks; then the artist drew a rough outline of the artwork on this surface. The mosaic artist tightly embedded glass tesserae and pebbles, according to the sketch, into an additional layer of fresh fine mortar. The mortar was gradually added in patches while the mosaic was created, similar to the patches of plaster, or *giornate*, applied for a fresco wall painting. Most of this upper layer of pink-colored mortar has been preserved and is visible between the tesserae. This mortar is made of lime, sand, and powdered brick. Laboratory testing has also confirmed the presence in small amounts of egg white.[5]

The current stratigraphy of the mosaic plaster is the result of the detachment and repositioning of the mosaic on the wall facade, a treatment carried out by Förster in 1910 (see fig. 9). Unlike the original mounting, the mosaic and its base plasters do not protrude from the facade but are flush with the wall's surface. Before repositioning the mosaic on the south facade of the cathedral, Förster had the stone surface carved out to create the space to embed the mosaic deep in the wall. This intervention was done to prevent water from running over the mosaic and to avoid a new detachment problem. A rough cement plaster, made from river

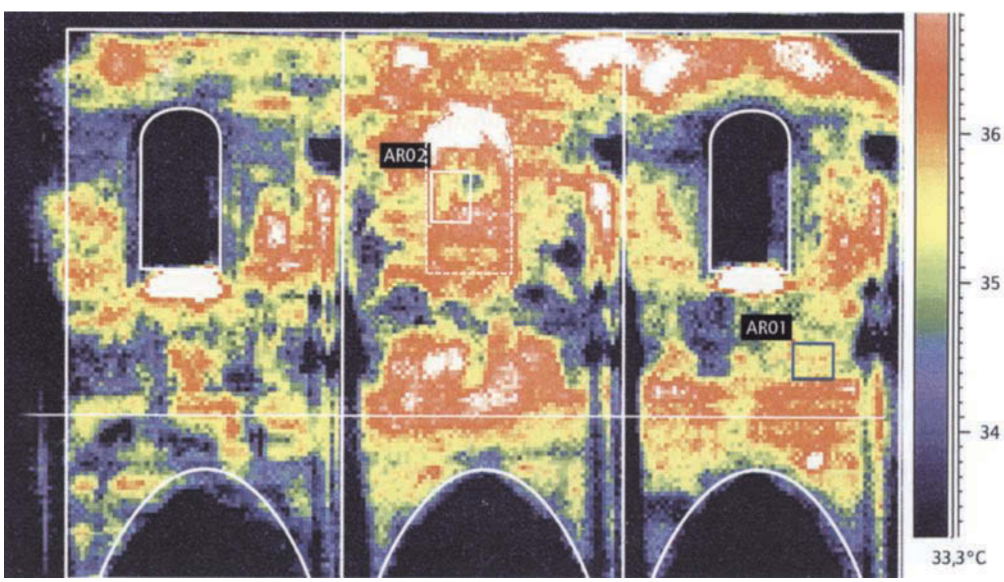


FIGURE 7 Thermographs of the mosaic's facade showing the presence of the closed-up window. By Ing. Svoboda and M. Martan.

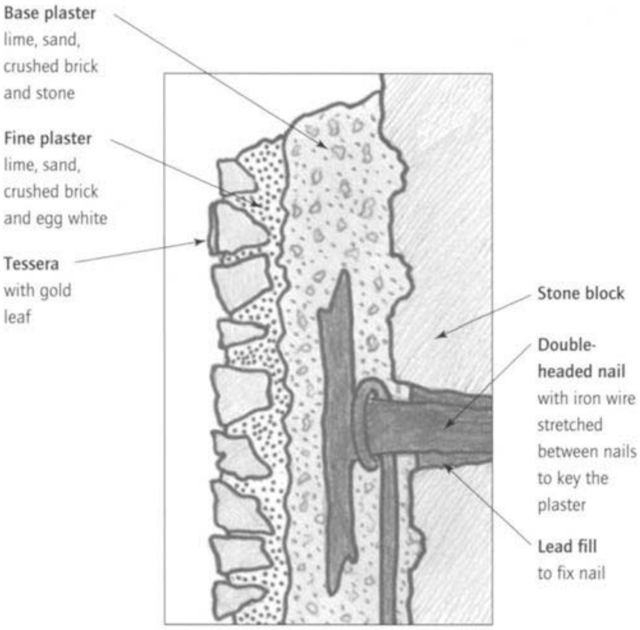


FIGURE 8 Diagram I: approximate stratigraphy of the original mosaic before its detachment in 1890 (not to scale).

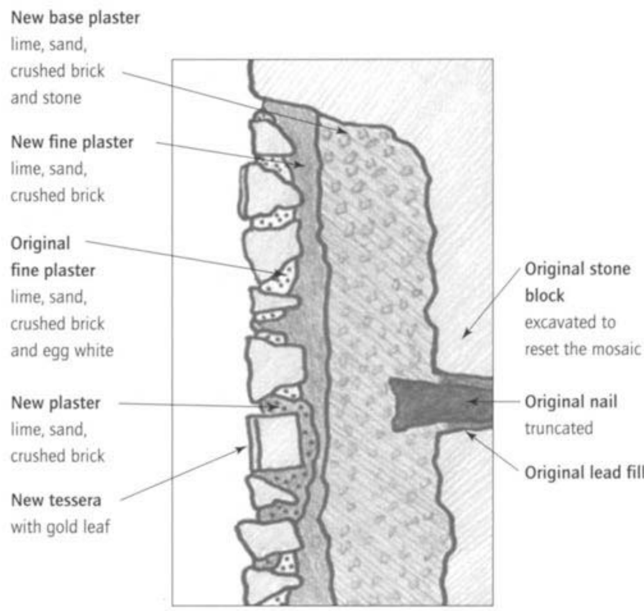


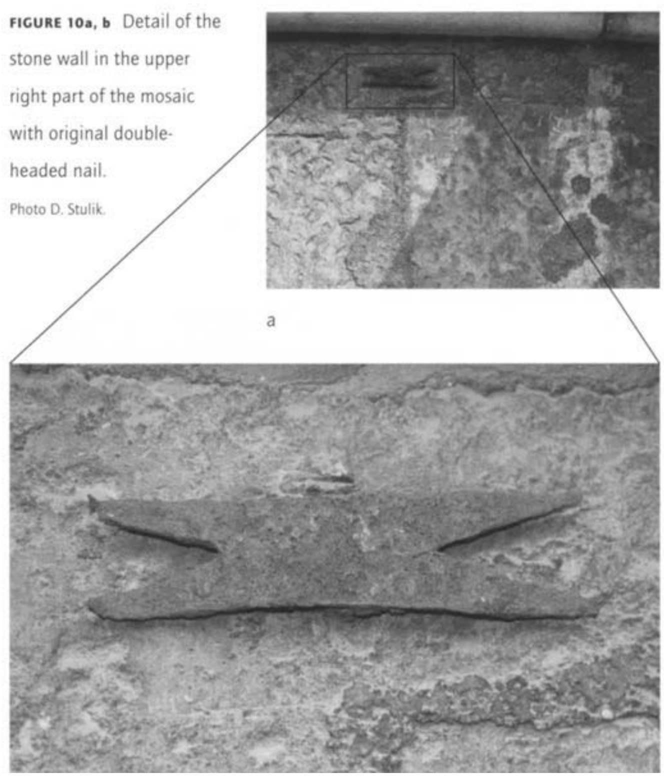
FIGURE 9 Diagram II: approximate stratigraphy (not to scale) of the original mosaic after its detachment and repositioning in 1910.

sand with pebbles in a 1:1 ratio, was first applied to the stone wall. The mosaic panels were reinstalled into this base with the help of a fine mortar made of lime, cement made from fine sand, and brick dust.

Glass Tesserae The mosaic is composed mainly of colored glass tesserae in many shades.[6] The dimensions and shapes of the tesserae vary; however, their exposed area rarely exceeds 1 cm^2. The background tesserae are mostly in the shape of an irregular prism or truncated pyramid with an almost square front face. Most of the tesserae are less than 8 to 10 mm thick. To depict fine facial expressions, hair, or wings, smaller tesserae of various shapes were used. Tesserae with narrow rectangular front faces are used as lines in contours, as strands of hair, or as feathers in the wings (see pl. 19).

During the GCI-Czech project, after removal of the corrosion layer conservators conducted a close examination of the mosaic and identified a total of twenty-five colors (excluding gilded tesserae and stones). In the 1950s, following the first serious analytic work on the mosaic, thirty or

FIGURE 10a, b Detail of the stone wall in the upper right part of the mosaic with original double-headed nail.
Photo D. Stulik.



a

b

thirty-one colors were identified.[7] The mosaic is made with several types of colored glass, and at times it is difficult to clearly differentiate the color. Some tesserae have just slightly different shades of color and should not be considered separate colors but the result of small differences in preparing the same batch of glass, for example, imprecise measuring of ingredients, the addition of common impurities and natural variability of raw materials, or the common volatility of physical conditions during the glass melting process in medieval furnaces.[8] Results from the same recipe often must have varied from batch to batch, and hue variation can be observed even in the glass of a single tessera. This color instability in glass pastes, prepared according to identical recipes, probably produced an entire range of mossy brown hues or similar brownish hues of seedy glass tesserae, which the artist used to shape the lower section of the background.

An example of significant optical difference can be seen in the blue originally gilded tesserae. These tesserae are either opaque, in a color similar to dark Parisian blue, or very transparent glass tesserae, in a deep ultramarine color. Both these variations of blue glass are present side by side on the originally gilded background. Underneath the gold, these differences would have not been noted. We can therefore assume that different tones of blue were not intentional.

Molten glass from the pots was formed into flat sheets or cakes of the required thickness. From these cooled cakes of colored glass, tesserae were then chipped off with a small hammer.[9] The thickness of tesserae varies, although it is generally about 6 to 9 mm. With the estimated average density of medieval glass being 2300 kg/m^3, a glass sheet 7 mm thick and covering roughly 85 m^2—the original size of the mosaic—would weigh approximately 1350 kg. Certainly it was necessary to produce at least this amount of glass to create the tesserae. This estimate does not take into consideration seams or the waste produced during cutting of the tesserae. The waste was probably added into the next batch, and thus significantly less glass could be used. However, this would not actually decrease the number of pots of glass needed for melting. If the estimated weight of glass from one pot is 25 kg, at least fifty-five pots would have to be melted to produce a sufficient amount of glass. If a great deal of waste was produced during cutting of the tesserae, more batches would need to be melted. Thus tesserae in the most frequently occurring colors could not be produced in one batch. If we estimate the area of red tesserae in the background at 14.5 m^2 and the area of blue tesserae in the background at 13 m^2, it would mean that at least nine batches were needed for the red glass and eight batches for the blue.[10]

Gilded Glass Tesserae The gilded tesserae were manufactured by a classic method known for hundreds of years. Alcohol, or limewater, was applied to the cake of cooled, (often) colored glass, and then the surface of the glass was covered with gold leaf. The entire cake was inserted into the furnace on a pan shovel to bake, and a thin layer of transparent glass was added on top by blowpipe. This sandwich was again baked and, still warm, compressed between iron sheets. After it cooled, tesserae were broken off from the cake. The final shades of the gilded tesserae varied according to the color of the base glass.

Gilding is an intrinsic part of the intended aesthetic impact and iconography of the mosaic. The gilded tesserae with red or blue base glass were used for the background of heaven on all three panels. In addition to the background, numerous important details were gilded, such as rays of the aureole in the mandorla around Christ's body and under his feet, the crowns and jewels of kings and angels, luminous accents on the folds and patterns of some cloaks, the feathers on the wings of angels, and the chains of the devils. The base glass of gilded tesserae of some details is black.

Stone Tesserae Flesh tones and other details are composed primarily of natural stones, usually small quartz pebbles varying from white to red in hue. The reason for using these stones was undoubtedly their naturally smooth color transition, as well as their crystal structure, which differed from smooth glass. The uneven surface of the quartz crystals deflects light in several directions and therefore appears softer than light deflected by freshly cut glass. By using this optical difference and adding areas that are partially transparent, with a matte or gently lustrous surface, the artist intentionally enriched the mosaic's expressive power. Quartz pebbles are used in other soft details, such as folds in the velvet cloaks of St. Wenceslas and St. Sigmund, the fur hems of their vestments, and the clouds under the apostles. Here, the sections composed from white quartz pebbles are almost identical in color to the white smooth glass tesserae in the surrounding areas, but they differ significantly in structure and luster (see pl. 20). In addition to quartz, the mosaic contains small, opaque, uniformly cut white limestone pebbles. These are found in the whites of eyes, upper arches of some halos, and faces in the middle panel. The whiteness of these smooth stones is very bright and warm in comparison to the cool greenish white of the glass. These white stones were used to broaden the mosaic's range of colors and to create, especially in the facial nuances, a desired luminous accent complementing the deflected whiteness of warm quartz and cool glass.

Use of Tesserae in the Mosaic and Differences among the Three Panels It is interesting to note that a different type of glass was used for the gilded tesserae in the background of the middle and lateral panels. The middle panel has red glass under the gilding, whereas the other panels have dark blue base glass. Different colors of the base glass under the gilding were clearly intended by the artist. The color of the glass tesserae in the gilded mosaic background creates a hierarchy in the imaginary space of the work. The central motif of the heavens is the most important and has a red base glass that provides a warmer glow to the gold, while the two-side motifs linked with the earth have instead a cooler-toned gold given by the blue base tesserae in the background. The background behind the "secular" figures of Charles IV and his wife is a midrange blue and was never gilded.

Another, less apparent difference is the way in which the figures are composed. In the side panels, larger tesserae and stones are often used in the facial features and the color shading is simple, graded only by the saturation of the warm tones of quartz. Olive green and cool white tesserae, laid next to the warm tones of the quartz and bright white limestone, expressively model the face and body of Christ. But on the faces and hands of the figures on the side panels, these only trace facial outlines. The difference cannot be explained only in terms of the hierarchy of figures; for example, the composition of the faces of the angels surrounding the mandorla, where only a few hundred stones and glass tesserae create an expressive and complete rendering of a face—from green shadows to brightest white accents—that is more refined than the simpler composition of the faces of the Virgin Mary, St. John the Baptist, and an angel helping a resurrected man from his coffin. Here a simple flat drawing, only slightly contoured by a line of green glass tesserae, provides facial definition. The areas of the latter faces are filled with quartz stones of limited color range, rarely complemented by whiter limestone. Nowhere is the cool white tone used to brighten the light color sections, or the red hues, which are the highest on the scale of warm colors, used on the faces in the central panel. The hair is created primarily with two colors of fine, long, contrasting strips of rectangular tesserae. The curly hair of the apostle in the left panel is uniquely created from tiny brown-green spirals. (See pl. 7.)

In the left panel, blue has often been used to outline the figures. In the central panel, the outlines are black. In the right panel, the contours are rendered in both blue and black, with black dominant.

In conclusion, all three panels are almost identical with regard to the materials used; but the level of artistry varies. The technique in the central panel is of higher quality than that of the side panels. The Czech art historian Antonín Matějček first noted the different compositional quality of the central panel and side panels in his dissertation in 1915. He speculated that an Italian master had personally installed the central panel and that local helpers, who were not trained in the art of mosaic, had installed the side panels.

Physical Evidence of Previous Interventions

The mosaic was repaired several times during its existence. For a short time in the seventeenth century, it seems that it was covered with plaster for political reasons tied to the Czech throne's brief embrace of Protestantism. Until the beginning of the nineteenth century, there are only indirect records documenting the repairs. None of the apparent changes on the mosaic can be credited, even hypothetically, to the much earlier repairs.

In the nineteenth century the mosaic was repeatedly cleaned, and sections that had become loose and fallen off were reattached and replaced in various ways. Historic records mention, among other things, stabilization of the mosaic with flat-headed nails and replacement of a fallen section with a fresco in 1837 (see chap. 7, fig. 12). All attempts to permanently consolidate the mosaic in situ were unsuccessful; by the end of the nineteenth century, the base plaster disintegrated, heavily damaged by rain and freezing temperatures and by water running off the roof. Rain and dripping water were washing off upper sections of the mosaic, which broke off under both windows and at the edges. In about 1890 there were attempts to hand-clean the mosaic's surface using small sandstones and to revive the faded colors by using coats of varnish. Traces of sandstone cleaning have been covered over time and can be held responsible for the loss of most of the original gilding. Nothing is left from the wall paintings that replaced missing sections of tesserae or the nails that were supposed to reinforce the mosaic (see chap. 7, fig. 15). In a few places, we can see nonoriginal materials applied to fill and replace the missing section.

The most apparent earlier repairs are made with large stones in the foreheads of two apostles in the left panel. These were clearly identified in the 1960s intervention (see chap. 6, fig. 10). Further evidence of previous repairs can be seen in the brown ceramic convex shards that someone used to fill the terrain background in the lower section of the left panel.

In the 1880s serious consideration was given to the idea of removing the entire mosaic and replacing it with a copy. In preparation, the mosaic was professionally photographed and copied by tracing over it in a 1:1 scale under the supervision of the architect Mokr. Most of these drawings have been preserved in the Prague Castle Archives and have great documentary value because they reproduce the most important parts of the mosaic, tessera by tessera (figs. 11, 12).

Since the mosaic had suffered extensive deterioration, it was divided into 274 sections and dismantled by Luigi Solerti, director of a mosaic firm in Innsbruck. The division lines were carefully planned to avoid the figures; when this was not possible, the lines would follow the edge of the drawing, such as the fold in a cloak (see figs. 4, 12). In the uniform background, the division lines were created horizontally and vertically to so that sections would be a manageable size. Before removal, each section was covered with several layers of facing paper. The mosaic was then cut into these sections. Along the division lines some tesserae had to be removed and some were probably lost. The speed of the mosaic removal proves the seriousness of the delamination from the supporting wall. The removal of the entire right panel took only half a day.[11]

The detached sections of the mosaic were stored for twenty years, in a nearby storage space under Vladislav

FIGURE 11 Water color of a detail of the mosaic, 1880. Photo: J. Boněk.

FIGURE 12 Detail, corresponding to the area shown in figure 11, of mosaic after treatment. Photo: D. Stulik.

Hall. According to Viktor Förster, who was commissioned to restore the mosaic in 1910, this long period in storage caused further loss of the original tesserae. The paper facing had deteriorated on many sections, and several tesserae had become loose. Förster reported that the loosened tesserae in the section from the chest of Christ had completely dispersed. He also reported problems with the edges of several sections, such as a joint of the wing of an angel at the bottom right edge of the mandorla and on the face of Queen Elizabeth.[12] Similar damage can be assumed at the edges of many other sections.

Before reinstallation most of the original mortar was removed from the back of the detached sections and a new pink-colored mortar applied. Then the paper facing was removed. Some of the lacunae were filled before reinstallation, but most replacement and reconstruction operations were performed in situ following the design documented in the painted copy created in 1890. Tesserae along separation lines were reinstalled using original and new tesserae, not always in a color that matched the surrounding areas. Many missing tesserae were replaced. Areas in the background of the three panels that had fallen off before removal of the mosaic were fully reconstructed using mainly old tesserae, or new ones prepared in Förster's studio (see figs. 4, 5). Plaster, into which the tesserae were inserted, simulated the original plaster in color and structure, except that it was somewhat darker and can easily be distinguished. Occasionally, on the front face of the mosaic, a fine cement-based thin gray mortar can be seen. This mortar was applied during reinstallation onto the backside of the sections and later leaked between tesserae through the remains of the old pink plaster, which still fills the seams (fig. 13).

Because of its strength, cement was used by Förster for reinstalling the mosaic. The cement has performed well for nearly one hundred years and the mosaic has not suffered the classic cement problems related to soluble salts. Adhesion problems have been virtually nonexistent up to the present day because Förster had deepened the foundation bed into the stone wall before reinstallation, so that it could hold all the foundation layers. The face of the mosaic is flush with the wall, so the water does not run between the wall and the plaster in which the mosaic is embedded. This arrangement remains effective. The mosaic's removal and its reinstallation remain the most drastic intervention in the almost

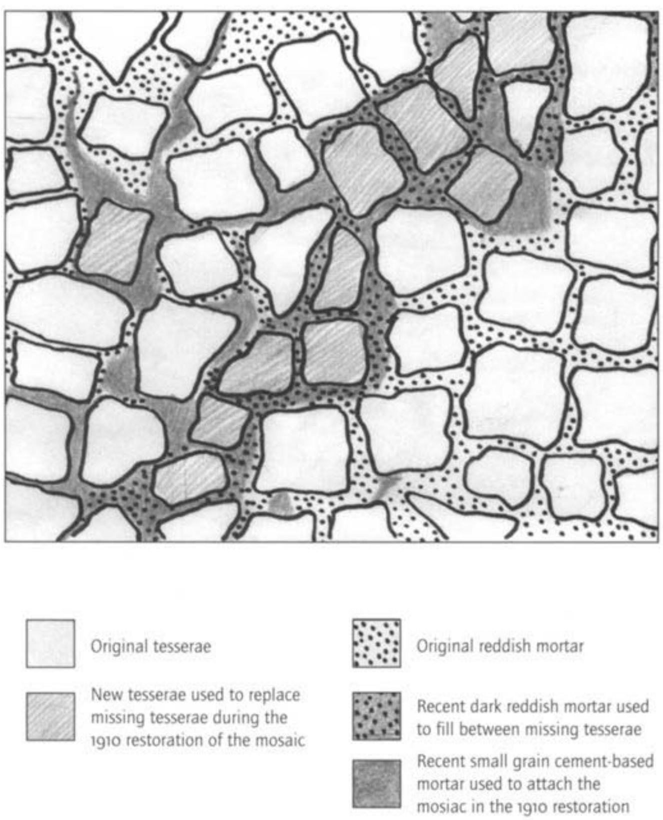


FIGURE 13 Detail of the mosaic's plasters: Original light pink plaster and later plasters as indicated by diagram. Photo: M. Nečásková.

six hundred years of its existence. Considering the mosaic's poor condition at the end of the nineteenth century, its removal and reinstallation solved the structural crisis. Clearly, both of these restoration treatments saved this precious artwork.

Later twentieth-century repairs were aimed primarily at removing the corrosion layer and did not cause any long-lasting changes in the mosaic's condition. During the extensive intervention in 1959–60, it was possible to make repairs in the gilding of the original tesserae. However, the new gilding of the background gradually disappeared as the protective lacquers disintegrated, and in the 1990s it became practically invisible.

The majority of new additions date from 1910. In addition to ensuring the structural stability of the mosaic, Förster's task was to repair any damage that had occurred as a result of the mosaic's removal. The goal was to rejoin the sections of the removed mosaic and replace missing tesserae in such a way that the mosaic could again give an impression of continuity. Förster achieved this by supplementing missing tesserae along the separation lines with a mixture of original and new tesserae, repairing heavily damaged areas, and reconstructing sections with missing background. He did not attempt, due to lack of supporting information, to reconstruct the sides of the upper border with acanthus decorations.

The mosaic currently measures 70 m^2. Originally, it was 15 m^2 larger. The lost area comprises the upper ornamental border, which did not survive. Only its middle fragment inside the rhombus around the vera icon has been preserved. The right part of the border with a similar rhomboid frame containing the nails of Christ's Crucifixion and the corresponding left side of the border vanished before the end of the nineteenth century. The preserved fragment of the upper border shows clear traces of extensive repairs, especially at the edges with acanthus decorations. Most of the original tesserae here remain in their original positions, but in addition to the original plaster, new plaster, into which the original and new tesserae were set, is often visible at the seams of the reinstalled areas. The vera icon itself is original, with no new tesserae or other obvious interventions, and its rhombus frame is also well preserved.

The extensively gilded background in the upper left and right panels is a result of the reconstruction in 1910 (see fig. 3). On the left panel, the entire upper section of the background, measuring approximately 2.2 m^2, was reconstructed, including the ornamental border. This reconstruction reaches up to the heads of the apostles and down to only a few centimeters above the Madonna's head. On the right panel, a similar reconstruction was performed on part of the background above and to the right of the window, approximately 50 cm from the upper rim. The total area of this reconstruction is approximately 1.2 m^2. For this reconstruction of the gilded background, mostly new tesserae were used that were gilded by employing the classic technique of gold foil baked under a layer of transparent glass. Förster wanted to mute the effect of the new gilding by combining a large number of original dark tesserae with new ones. In addition, on the left panel, the gold foil on the new tesserae was intentionally scratched before being baked in the glass sandwich.

There are many repaired and reconstructed areas in the borders of the mosaic. Partial reconstruction was performed in areas of the upper background in the middle panel, from the top to about the level of the third group of angel wings (see fig. 5). The separation lines are apparent, and many original red tesserae remained, but about the same number of tesserae, mostly original but blue, supplemented the missing tesserae. The heavily damaged background above the heads of the Virgin Mary and St. John the Baptist were similarly repaired. Here, the repairs are less obvious because the original and the majority of new tesserae, are blue. No other extensive repairs are apparent in the background. But there are many small repairs, and they appear even outside the separation lines. In some places, the separation lines are not limited to only one row of tesserae. It is obvious that after the nineteenth-century detachment, edges of many sections were disturbed and some tesserae fell off. A large number of newly installed tesserae, most often a combination of old and new gilded tesserae, are found mainly in areas where the separation lines cross. Newly installed tesserae are also more often found around cracks that kept opening in the same places over the centuries (see fig. 6). During repairs, preference was given to the original tesserae, which had been collected over the years as they fell from other sections. A small number of original tesserae still remain in the Archives of the Prague Castle. The original tesserae were preferred for repairs even if their color was not suitable. The small area in the green-brown background, near the left foot of the Archangel Michael, which is filled with blue tesserae, serves as an example (see pl. 4). Only rarely were the original, especially white tesserae, replaced with white stones, and seldom were ceramic shards used. Ceramic shards were not consistent with the materials used in Förster's extensive and careful restoration and therefore must be evidence of an earlier intervention.

Relatively few repairs can be found in the figure motifs; more extensive reconstruction is the exception. Most apparent is the damage on the faces of two apostles in the second row of the left group, which was repaired with large pebbles. These additions come from the time before the mosaic's removal, and Förster intentionally respected them. He reconstructed (from original material) a portion of the head of an apostle who stands at the top of the left group and the lower half of the face, neck, and chest of Queen Elizabeth. Both of these reconstructions are identifiable; the second stands out because Förster used only new glass instead of the original combination of quartz and glass.

The reconstruction performed on Queen Elizabeth's figure is also the most extensive of a figure motif (fig. 14).

FIGURE 14 Portrait of Queen Elizabeth before restoration. The damaged lower part of her face, hair, and chest was replaced with modern glass tesserae in 1910.

No larger reconstruction can be noticed on Christ's chest, where, according to one reliable source, the section broke during removal, dispersing the tesserae. It can be assumed that in this case no large area disintegrated, and only a number of tesserae became detached from the paper used for facing, which were reattached while still in the studio, and thus the section was stabilized. All the tesserae that were reattached in this way to their original spot were then reinstalled into cement-based plaster, which was in many places pushed up along the sides of tesserae. Some small-area reconstructions can also be seen in the wings of angels. The largest is on top of a wing of the right angel under the mandorla. The transfer of the mosaic caused damage to the outline of the back of the devil emptying the sarcophagus, the finger and contour of the body of the man lying in the coffin, and the contour of a child being carried away by an angel, as well as other smaller defects.

Plaster Colors

The first criterion for determining the originality of the composition is the glass tessera that was used. The degree to which we can be certain about visually distinguishing, with some practice, original glass from newer glass, depends on color. We can almost certainly distinguish the original glass from new in the case of original tesserae that do not appear in a range of color mutations or in the case of seedy glass pastes with varying hues. But the majority of glass fits this description. Sometimes an error can be made in the case of homogeneous glass and glass in varying hues, such as red or very dark black or blue, where oxidation of the glass surface has created difficulties in detecting any such difference. However, even absolute certainty about the originality of the tesserae does not provide certainty about the originality of their installation, since they could have been installed in their present location during one of the later repair interventions. Therefore, the decisive criterion for determining the original composition is the quality and homogeneity of the plaster in the seams between the tesserae. The original plaster is pink with clearly visible chips of crushed brick. It can be readily distinguished from the darker pink plaster that Förster used for reinstallation. Clearly different is the gray to gray-white cement plaster used before the final reinstallation to reattach the loose tesserae to the removed sections of the mosaic and which was often pushed up between tesserae. In other areas we can see individual tesserae that were inserted into standard, ocher-colored plaster. The presence of light lime and sand plaster can also be confusing. At one time this was applied in small amounts over the tesserae and particularly over smaller pebbles to stabilize them. They protruded too much from the original pink plaster and were in danger of falling off. This type of stabilization applied on top of the tesserae can be found also in the face of Charles IV and elsewhere. At first sight, this plaster can cast doubts on the originality of the composition thus treated. In the lower part of the left panel, traces can be seen of an unfortunate attempt in the second half of the 1950s to cover seams with cement.

Mosaic Authenticity

The distinction of reconstructions and repairs, based on detailed examination of glass and plaster conducted by a specialist very familiar with the mosaic, can be considered relatively objective. New findings employing this method are consistent with statements about the mosaic's previous interventions recorded in the Annual Report of the Union for Completion of St. Vitus Cathedral after the work was completed in 1910. Matějček discussed in detail the originality of the mosaic's composition in his 1915 dissertation. He based his hypothesis on evaluation of the composition from the perspective of art and history.

In accordance with our observations, Matějček mentions repairs in the faces of two apostles and in the face and chest of Queen Elizabeth. On the right panel, he notices damage on the figure of a devil searching through the coffin and repairs above the arcade arch. A close-up inspection made during our conservation project did not reveal other hypothetically nonoriginal details, mentioned by Matějček's contention that there is evidence of intervention on the back of a man carrying the lid of his coffin, on the figure beneath him, on an angel carrying one of the resurrected and his cloud, St. Peter's hand with a key, and clouds under the apostles on both sides. Even the cloak draping the herald angels on the middle panel seems to Matějček to contain Baroque elements that are not consistent with the fourteenth-century style. He finds traces of renovation in the portrait of Charles IV and in the bottom section of the ground supporting the saints. Based on an old record and an evaluation of styles, Matějček also considers the inscription bearing the names of saints not authentic. In our detailed examination of the mosaic's glass and plaster, we found no supporting evidence for these hypothetical reconstructions.

These areas are mostly well preserved, composed from original tesserae or quartz pebbles with intact plaster in the seams. Perhaps some doubts can be raised by the presence of whitish plaster between tesserae in Charles's face. However, this plaster does not provide evidence that the portrait was reworked, since it is applied over the original pink plaster simply to reinforce the cohesiveness of the original composition.

Originality of the Inscription

Finally, let us consider the question of the originality of the inscription band bearing the names of Czech patron saints, which is set beneath the kneeling saints in the middle panel. Occasionally, a debate is revived regarding the originality of the inscription, on the basis of the *Guidebook to St. Vitus Cathedral* by L. Glückselig, published in 1855. At the end of the one-page appendix dedicated to the mosaic, Glückselig mentions in one sentence a repair performed by Eduard Gurck in 1837, and he claims that a new inscription, drafted by Hanka, was added under the middle panel. This claim attracts attention because Hanka is a Czech patriot and scholar known as the author of one of the forged medieval manuscripts that so stirred up the Czech cultural and political scene in the second half of the nineteenth-century. The material of which the inscription is composed does not provide any evidence of remaking or inauthenticity. The inscription is still well preserved. The black glass tesserae of letters as well as the white glass tesserae in the background are, with very few exceptions, undoubtedly original. The original pink plaster in the seams outside the transfer separation line is intact.

A natural explanation for the discrepancy between the apparent authenticity of inscription material and the claim about the addition of a new inscription is that Glückselig was in fact not referring to the inscription of saints' names, which is part of the middle panel, but to another inscription that was added below the mosaic, somewhere on the wall between the pillars of the arcade in 1837. This new inscription on a stone plaque described the mosaic's history and its repair by Gurck and was later removed. The existence of this inscription and its wording is documented in other written sources. This explanation is also logical in the larger context of Glückselig's writing, because immediately before he mentions the repair in 1837 and the new added inscription, he concludes his description of the mosaic with this sentence: "The old inscription under the middle panel reads: Sc. Procopius. Sc. Sigismundus. Sc.Vitus. Sc. Wenceslas. Sc. Lodomilla. Sc. Adalbertus." Honsatko quotes the same inscription in 1825 exactly the same way, as we know it today, including an atypical spelling for St. Ludmila. It does not make any sense to posit a connection between the mention of a new inscription and this unchanging text, described even by Glückselig as old.

Condition of the Mosaic

When the project started it included an assessment of the mosaic's condition. The plaster layers were basically in good condition, and the adhesion to the foundation was good.[13] In some places the plaster sounded hollow when tapped, but nowhere did it move or threaten to fall off. The mortar between the tessera was also sound, probably because it had been reinforced by previous conservation treatments. There were no larger cracks in the middle panel. In the entire middle panel, only a few tesserae were missing.

On the right panel, there were only a few narrow cracks under the window, in the middle panel and above the arch. These cracks did not endanger stability, but a few tesserae had become loose in their vicinity. On the entire right panel, only a few tesserae were missing along the cracks, and on the left side in the terrain background (see fig. 6). Structurally, the left panel was the most damaged, with several deep cracks starting near the base of the window, extending across the middle field, and continuing toward the top and sides of the portal arch. The widest crack stretched across the middle of this panel, above the arch. The cracks were old and had been documented in the earliest photographs (see chap. 7). They were repaired several times in the past without lasting success. These cracks, which were probably caused by the micromotion of the building foundation, permeated through the entire thickness of the walls and cannot be permanently closed. According to Petr Chotěbor, head of the Art Collection of the Prague Castle, expert static evaluations were repeatedly conducted confirming the static safety of the mosaic. In some places around the cracks, the tesserae became loose, and the filling mortar, made from classic, less elastic materials, gradually disintegrated. As with the other panels, the total number of missing tesserae on the left panel was estimated to be only in the dozens.

Corrosion

The surface of all colored glass tesserae was covered with corrosion products. The chemical composition of glass with a high potassium and calcium content enables cations of these minerals to leach out in water. Their consequent reaction with carbon dioxide in the air and even faster reaction with sulfur dioxide results in the creation of complex potassium and calcium salts whose main component is gypsum. The crystals of the corrosion salts adhere to the surface of the glass and gradually create an all-encompassing gray layer. The extent of the corrosion varies according to the color of the glass. Four levels of corrosions were defined and recorded (see fig. 2). A compact dense white layer of corrosion appears on dark glass; compact brown corrosion with an upper white porous layer appears on white glass; and pink-brown with an upper white layer covers light blue glass. Some colors, such as yellow and green, suffer minimal corrosion. Red glass tesserae with gilding are also minimally affected. The red color remained visible through the thin corrosion layer, looking like grayish ice. It is interesting that the red tesserae show several distinguishable grades of corrosion, as if some batches of red tesserae corroded more than others. Other colors do not show such variations in corrosion. The newly replaced modern glass tesserae corrode substantially less, but even these are eventually covered with a continuous thin colorless coat of corrosion. At the start of the project, the mosaic was practically invisible due to the corrosion.

The original gilding had already disappeared in the past, and its remaining fragments were obscured by the corrosion of the top glass. However, the gilding applied in the beginning of the twentieth century was quite visible. In the upper section, the gilding created noticeable and defined areas and made the separation lines between the mosaic's detached sections much more visible. Repairs to the upper area of the background, above the angels around the mandorla, were also very noticeable. The mixture of corroded original red tesserae and newly replaced tesserae, mostly dark blue original and new gilded ones, provided an unpleasant chromatic balance of the artwork there. Gilding from the 1960s survived only sporadically as small shreds of gold foil embedded in scales of degraded remains of epoxy resin.

The glass mass of tesserae seemed to be well preserved under the corrosion and not affected by the environment. The glass quality fluctuates according to color. In addition to homogeneous and thoroughly fired glass, there are also many tesserae, especially light blue and light green, that are full of bubbles and surface indentations. This glass is much more vulnerable and much more difficult to clean. However, the inhomogeneous structure is part of the authentic substance of this glass, since this property was introduced during its manufacture and is a result of the technology of medieval glassmaking.

Conclusion

Every conservation project is an opportunity for the in-depth study and documentation of the work of art. The project for the conservation of the Last Judgment mosaic involved almost five years of research and three years of treatment. This gave the project team the opportunity to study the mosaic in great detail. It was possible to confirm the information provided by the historical documentation on the mosaic, in particular, to confirm that the numerous interventions did not have an impact on its authenticity. Signs of the physical history were interpreted by examining the materials composing the mosaic and the millions of colored glass tesserae and stone and the way in which they were laid down. Traces of original gold were identified, as were areas where the tesserae were relaid.

The observations made during the project were recorded in written, graphic, and photographic form.This documentation will remain an important record of the state of the mosaic during the years of the project and is essential to future evaluation of the mosaic's condition over time.

Documentation was carried out with a simple but efficient technology. As it is in digital form, it is a valuable and practical tool for the ongoing monitoring and maintenance of this important work of art. At the same time, digital technology can easily become obsolete, and therefore the information must be updated as technology advances and preserved in hard copy.

Notes

1. The thick layer of corrosion on the glass made examination of the mosaic difficult. Information on materials and technique was collected after cleaning and removal of corrosion.
2. Photographic documentation was planned with the support of Rand Eppich at the GCI. It was carried out by Jaroslav Zastoupil of AfG, an independent Czech survey firm. One dozen tesserae served as "targets" for accurately measuring the mosaic with a total station or electronic distance measurement device (Leica TCR110). The mosaic and the targets were photographed with a large-format camera (Zeiss/Jena UMK 10/1318 with a Zeiss/Jena Lamegon 8/100 lens using Kodak Ektachrome 100s film). The negatives were then digitally scanned using a Leica scanner (DSW200 by Helava, pixel size 12.5 um). The survey measurements of the targets were combined with the digital images to rectify or "stretch" the images to the real

measurements. The digital image was inserted in a CAD drawing and used as a base map for all the graphic information. This allowed measurements of the image and its condition as well as alignment of the images from the various phases of conservation.

3. Graphic documentation is a record of phenomena or other data created by superimposing symbols, patterns, or colors over a base map representation of the mosaic. In the past few years the GCI has developed a protocol for graphic documentation, and this was applied to the Prague project. For a description of the protocol, see Piqué 2000. The conservation team recorded graphically on site with markers over transparent overlays over photographic base maps. Sections of the image were printed on A4 paper in 1:8 scale, a manageable size for work on the scaffolding. The conditions recorded on the transparencies were then scanned, converted, and organized into the original survey file. (The transparencies were converted or vectorized using Hitachi raster-to-vector software.)
4. A sketch of this net (done during the detachment of the mosaic in the 1890s) is available in the Archives of the Prague Castle.
5. The original base plaster was lost during the mosaic's detachment in 1890 and reinstallation in 1910. Castle records report that egg white was traditionally added to the mortar of important construction to increase solidity. This tradition has a rational explanation. Egg white, a natural hydrogel, can sigificantly lengthen the drying time of plaster and thus increase its strength through the gradual transition from slacked lime to carbonated lime. For the analytic results, see chap. 10.
6. Karel Heteš studied the chemical composition of the Last Judgment mosaic tesserae and compared them with glass tesserae from other sources. In 1958, in his seminal study, "On the Origin of Glass in the St. Vitus Mosaic in Prague," he first hypothesized that the St. Vitus tesserae were produced locally. The historically documented development of the glass industry in the kingdom of Bohemia in the fourteenth century supports this hypothesis. For a detailed discussion of the results of historical and contemporary scientific studies of the glass used in the mosaic, see chap. 10 in this volume.
7. Another "historical" estimate that needs revision is the total number of tesserae used to make the mosaic. The 1950s calculation of one million is based on the assumption that each tessera's side averages 9 mm; however, a great number of tesserae and stones are substantially smaller, so the total number of tesserae is probably a few hundred thousand more.
8. In the Middle Ages weight was often measured by the ratio of unspecified volumes, and no standards for various volume units existed. Oak ash was used as the basic flux in medieval central Europe. Glass was melted in iron pots in furnaces heated by wood under relatively low temperatures, approximately 1100°C. The molten glass was very inhomogeneous, insufficiently melted, and often cooled while still foamy.
9. A general description of tesserae manufacturing is in Mokr 1883. And see Strobl 1990 for valuable general information on medieval glass production and medieval furnaces.
10. This estimate is based on an archaeological discovery in Bohemia of a 12-liter pot, which is considered the most common size. The actual number of batches was certainly much higher. Attempts were made by Czech archaeologists using a similar pot in experiments to reproduce glass with medieval methods, equipment, and materials. See Černá, Kirsch, and Brabenec 1993. This estimate is also in agreement with those contained in Strobl 1990. Strobl notes pots of about 5 liters (the entire output of a furnace when using more pots together is 40 liters), on the basis of the archaeologically proven dimensions of medieval furnaces. A pot of 12 liters is considered the average. Estimates of the necessary batch number are derived based on the known minimal number of batches.
11. Unpublished detailed information concerning Förster's work, including his written proposals for the treatment, his letters and notices, and the reports of the committee consultations are available in the Archives of the Prague Castle.
12. A border with small blue arches and crosses on the white background, at the edgegs of the areas described above, was also reconstructed. The left panel border was reconstructed using new tesserae. The right panel has a combination of original and new tesserae. Almost all of the red borders on the sides of the mosaic and above the arcade were reconstructed with new tesserae or a combination of old and new tesserae. The reconstruction above the right arch extends into the background at the top of the arch. Partly original areas with only a few repairs are found in the red border above the middle arch. The border of small crosses with is original for almost its entire length, except for minor repairs. In the middle panel, the original border of small crosses is preserved only along the upper ridge of the mosaic and it has many repairs. The areas of roughly triangular shape in the background under both windows, each approximately 1 to 3 m^2,were reconstructed, as were the narrow strips of color bordering both windows. These reconstructions were performed using mostly original blue tesserae with fragments of original gilding.
13. The Italian conservators Ambra Tomeucci and Bettina Elten of the Rome-based conservation group ARKE examined the mosaic in 1992.

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Milena Nečásková

Chapter 15
Conservation Treatment of the Last Judgment Mosaic

The Last Judgment mosaic, located on the south facade of St. Vitus Cathedral, was created between 1370 and 1371 at the wish of the king and emperor Charles IV to dominate the cathedral's festive entry point for royal coronations. This monumental artwork is the only preserved example of medieval glass mosaic north of the Alps. The mosaic's placement on the exterior facade of the cathedral, its exposure to the harsh elements, and the chemical composition of the tesserae greatly contributed to the mosaic's condition. At the end of the nineteenth century, rainwater penetrating into the mosaic bed from a balcony above it caused serious damage to the upper part of the mosaic and entire sections of the mosaic began breaking off. Furthermore, over the centuries the limited chemical resistance of medieval glass to the harsh climate of central Europe, with its frequent rains and winter frosts, caused corrosion problems that eventually obscured the colorful mosaic under a gray veil (fig. 1).

Previous restoration treatments successfully solved the mosaic's structural problems, which began with the disintegration of the original mortar and culminated at the end of the nineteenth century when the mosaic was detached and removed in sections. At that time, the problem of glass corrosion was beyond solution. After each difficult cleaning treatment, the glass quickly began to be covered with a new layer of crystallized salts. Attempts at restoration in the 1960s and 1980s were also unsuccessful in the long run. These unsuccessful restoration attempts led to a proposal to replace the original mosaic with a copy.

The signing of a collaboration agreement between the Office of the President of the Czech Republic and the Getty Conservation Institute brought new hope. After several years of scientific research, all three panels of the Last Judgment mosaic were gradually restored, starting with the middle panel in 1998 and ending with the left panel in September 2000. The restoration process also provided a rare opportunity for more in-depth study of the artwork. This chapter discusses the development and implementation of the conservation intervention.[1]

1998–2000 Conservation

Principles of Conservation

Given that the mosaic's composition of original tesserae must remain unchanged and it must also remain in its originally intended location, the only way to prevent glass corrosion is to stop water from coming into contact with the glass surface. This can be achieved by application of suitable protective coatings. The effectiveness of this treatment depends on the properties of the coatings, which must be waterproof, stable and resistant to the extremely variable climate of Prague, and adhere well to the glass, yet be easily removable without the danger of damaging the mosaic. The requirements for such a protective film are in many respects contradictory, and to identify an optimal protective material is an extremely difficult task. Therefore, the restoration process was preceded by several years of research with the goal of identifying the optimal coating system that would meet all the aforementioned requirements.[2]

Preparatory Work

The scientific research was conducted mainly in the laboratories of the GCI and at the University of California, Los Angeles, and was complemented by in-situ testing. The mosaic's condition prior to restoration was carefully

FIGURE 1 Mosaic before treatment. Corrosion has rendered the mosaic virtually illegible. Photo: J. Zastoupil.

documented. The extent and causes of deterioration were assessed, and various cleaning methods were tested. The local climate was studied, and most of all, various materials and methods for protecting the mosaic's surface were tested. The research was followed by testing the properties of potential coatings, selected during laboratory tests, on small trial sections of the mosaic in situ. Test samples were submitted for laboratory analysis, along with photographs documenting any changes in the condition of samples. This in-situ testing was performed with the cooperation of experts from both participating countries, and an expert commission discussed the methods and results.

After preliminary research and in-situ testing, the Getty Conservation Institute prepared an intervention proposal based on the results of the research for a protective coating system for the long-term protection of the mosaic. The proposal defines the conservation materials and methods of their application. This proposal was approved by the Monument Preservation Section of the Office of the President, and the Art Collections Division of the Prague Castle Administration, the mosaic's manager, in cooperation with the special expert commission headed by Eliska Fučiková, director of the Monument Preservation Section of the Office of the President. Czech senior restorers, Alois Martan and Milena Nečásková, who participated in the preparatory stages from the beginning of the project, together with Dusan Stulik and Francesca Piqué were assigned to carry out the restoration, along with junior restorers Martin Martan and Eva Skarolková. The participation of younger Czech conservators would ensure the continuity of professional care in the future.

Conservation Treatment

The conservation of the mosaic consisted of the following steps:

1. Removal of the corrosion layer from the glass surface using the air-abrasive method.
2. Stabilization of cracks and loose tesserae.
3. Cleaning of the glass surfaces with water and ethanol in preparation for the application of coatings.
4. Application of the first protective coating layer (sol-gel) and drying of this layer with heat.
5. Application of the second protective coating layer made of cross-linked Lumiflon and drying of this layer with heat.
6. Reintegration of the gilded background using gold leaf applied with cross-linked Lumiflon.
7. Application of additional cross-linked Lumiflon and drying of this layer with heat.
8. Application of the last layer of protective coating made of non-cross-linked Lumiflon and drying of this layer with heat.

The in-situ conservation intervention extended over a period of three years. The central panel representing Christ in throne was treated in 1998; the right panel, representing the sending of sinners to hell, was treated in 1999; and the left panel, representing the rising of the souls to heaven, was treated in 2000 and signaled completion of the project. Along each panel, the adjacent borders of mosaic located on the pinnacles were also treated.

1. Removal of the corrosion layer

The restoration work began with the removal of corrosion from the tesserae. Cleaning was performed by using the air-abrasive method, which, in principle, involves the mechanical effect of abrasive powder propelled by compressed air through a nozzle (fig. 2). The particles disturb and remove the corrosion layer covering the surface of the tesserae. A Swan-blaster, a micro-abrasive device, connected to a compressor was used. The compressed air was directed through a dehumidifying filter to prevent the particles of abrasive powder from clumping together due to the humidity in the air. Crushed glass powder of particle size, less than 50 microns in diameter, was used as the abrasive. Each tessera was cleaned separately, including its exposed lateral sides. Sporadic remains of coatings from previous conservation interventions were removed with the same method. Occasionally a scalpel was used when particularly hard old coating scales needed to be removed. Almost all corrosion was removed during this cleaning, with the exception of some fragments embedded deep in crevices where thorough cleaning could damage the crevice edges. All conservation

FIGURE 2 Removal of corrosion using a micro-abrasive device with crushed glass particles. Photo: D. Stulik.

coating residue from previous repairs was completely removed from the surface of tesserae. All the remains of the gilding reconstruction in 1960s were removed. Gilding from 1910 is much stronger and resistant because the gold foil is covered with a layer of more stable glass and therefore remained intact. A certain amount of old conservation material remains absorbed in the mortar between the tesserae. As long as these materials are not in a thick layer, they are not considered a problem. They still effectively stabilize the mortar in the seams, and because they are cracked in many places, any vapors from inside the wall can pass through. The residue of old coating on the mortar was partially cleaned only if it formed a thick or visible layer.[3]

Before the cleaning of the left panel containing the in-situ tests, the conservation team completed the examination and analysis of these tests and materials studied. Detailed documentation of the condition of each test field was carried out with macrophotography. Photographs and samples from the test areas were submitted to the GCI for final evaluation. At the same time, the reversibility of the studied materials was tested using regular solvents. Materials based on polyurethane and organically modified silicate, Ormocer, were practically irreversible. The organic-inorganic hybrid solgard showed only little blistering four years after its application. Polymer Lumiflon, used for conservation of the mosaic, remained easily reversible by using common solvents, such as acetone or propyl alcohol, two years after its application. All materials applied on the testing fields were removed by the air-abrasive method and by using scalpels. It was proved that the air-abrasive method, so effective and gentle for removal of corrosion, is not suitable for removal of coatings. Elastic and resistant films withstand the abrasive material for too long, and they are not disturbed gradually and continuously as is brittle corrosion. The time needed for removal of a coating is several times longer than for the removal of corrosion. In addition, use of the air-abrasive method for removal of some coatings increases the risk of damaging the soft glass. In the future, if new materials are proposed for conservation of the mosaic, it is imperative that they be easily removable, either chemically or by another suitable method, since the air-abrasive method has proved unsuitable.

For documentation purposes, after the corrosion removal for each panel, the scaffolding was dismantled to enable the photo documentation of the mosaic before application of the coatings and gilding of the background (fig. 3).

2. Stabilization of cracks and loose tesserae

After removal of the corrosion, mortar cracks were repaired. Cracks and fissures were filled with commercial brown-pink elastic silicone grout. Wider cracks were mechanically cleaned of the residue of old filling and regrouted with a mixture of lime plaster and brick dust, with an addition of 1% acrylate dispersion. Missing tesserae were relaid into this mortar. Original mosaic tesserae being stored at the Archives of the Prague Castle were used for the restoration as long as they were of the right color and shape; otherwise, modern tesserae of a similar color were used. In total, only about several dozen tesserae were installed. Grouting of cracks and re-laying of tesserae were necessary mainly on the left panel, with only limited work necessary on the right panel. The central panel did not need these repairs.

3. Cleaning of the glass surfaces with water and ethanol in preparation for the application of coatings

The mosaic's surface was cleaned of the residue of abrasive materials by compressed air, and by washing with a stream of water provided by the fire department. Immediately before the application of the first conservation coat, the surface of the treated tessera was wiped with prewashed cotton fabric soaked first in ethanol and then acetone. When applying the coatings, restorers wore latex gloves to avoid touching the surface of the mosaic with their hands (any grease or oil would affect the coating adhesion).

4. Application of the first protective layer (sol-gel) and drying with heat

The first layer of the protective coating system is Tokuyama HS-56TF/A sol-gel applied undiluted on the mosaic's central panel and diluted with isopropanol on the side panels.[4] The adhesion of the first coating layer to the tessera ensures the effectivness of the entire protective coating system and determines the longevity of the intervention. Sol-gel, an organically modified glasslike material, chemically adheres to the surface of the medieval glass and through its organic modification enables the adhesion of the second fluopolymer hydrophobic coating. With the exception of areas composed of quartz, the first coating was applied gradually over the entire treated surface of the mosaic in sections that could be easily dried with heating panels (fig. 4). Sol-gel or other coatings were not applied to sections composed of natural stones.

Heating was a complicated operation that was carefully planned. According to the methodology developed, the

FIGURE 3 Photomontage of mosaic after removal of corrosion, before regilding. Photos: J. Zastoupil.

FIGURE 4 Conservation team applying the coating on the mosaic's central panel. Photo: E. Bescher.

fresh coating was left to dry for 12 to 24 hours and then cured using controlled heating panels positioned next to the mosaic. The temperature of the heated section of mosaic was monitored by a touch probe and was automatically increased by 1°C per minute, until the surface reached 90°C. This temperature was maintained automatically for 2 hours, and then the heat was automatically turned off and the surface gradually cooled. The heat was produced by infrared bulbs set into three separate panels, custom-made for this purpose in the workshop of the Prague Castle Administration (fig. 5). Two large panels, each with 72 infrared lamps, covered an area of approximately 2 m^2 each. They were usually placed next to each other to heat an approximately meter-high band of a treated panel. On the sides of the mosaic, obstructed by the pinnacles, and for the

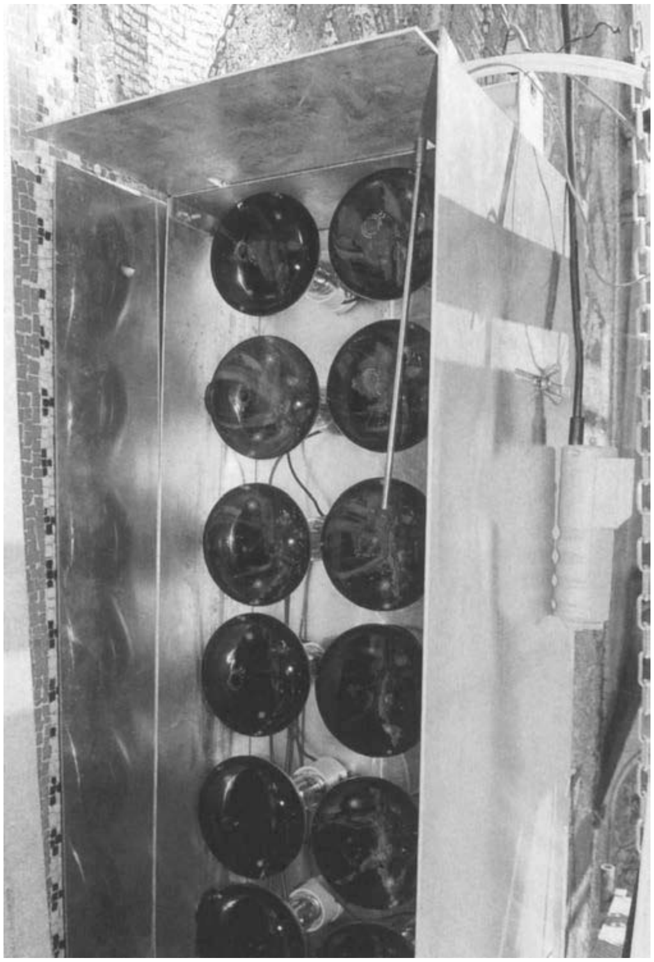

FIGURE 5 Suspended heating panel with automatic control used for drying the coating. Photo: E. Bescher.

vertical strips of mosaic inside the pinnacles, a smaller, narrow heating panel with 14 lamps in two columns was used. Two flaps on the sides of the heating panels, made from several layers of soft, easily adjustable aluminum foil, prevented heat loss. A programmable digital instrument, installed on each panel, automatically maintained the prescribed temperature regimen. The bulbs were automatically switched on and off according to the actual temperature readings that were provided by the heat sensors in the touch probe, positioned on the surface of the heated area. The bulky, heavy panels were suspended on chains and moved with the help of braking pulleys. The stability of the heating panels above the heated surface was secured by wedges resting against the legs of the scaffolding. The heating panels demand a large amount of electricity. Each infrared lamp has an input of 220W, and one big panel takes 15.4 kW at once. Several tenths of off-on switching happens during one minute. It was possible to do three consequent cycles of heating comfortably during one day with nice weather. The maximum daily amount was six cycles with a smaller panel, provided that the work started at 6:00 A.M. and finished at midnight. To dry all four coatings on the whole surface of the middle part of the mosaic it was necessary to go through approximately 120 cycles.[5]

5. Application of the second protective coating layer made of cross-linked Lumiflon and drying with heat

After the first layer dried, the second coating was applied. This layer is made of Lumiflon polymer L200, mixed with melamine C303, and was prepared as follows:

- polymer Lumiflon 200 (250g)
- cross-linking agent melamin (cymel 303) (5.5g)
- xylen (200g)
- MIBK (methylisobutylketon) (100g)

On the side panels of the mosaic the amounts of xylen and MIBK (methyl-isobutylketon) were doubled to increase the coating dilution.

Lumiflon is a resistant organic polymer containing fluorine and has strong hydrophobic properties. Lumiflon is soluble in regular solvents and therefore is easily removable. The Lumiflon layer presents a barrier for water molecules and thus effectively protects the coated surface from water-initiated corrosion. Twice a week the restorers prepared fresh solution in the prescribed concentration, less diluted for the central panel, more diluted for the side panels. The materials were supplied each year by the GCI (see Materials List, for a complete list of materials). The Lumiflon coat was heat dried without delay, usually during the same day of application, following the same procedure used for the first coat.

Since adhesion of the sol-gel and Lumiflon is a critical factor for the longevity of the conservation, special attention was paid to correct performance of all tasks and the absolute cleanliness of the mosaic surface. A mere touch of the hand can disturb this adhesion. Therefore, the first and second coats were applied immediately after each other on the section that was scheduled that day, in an area that could be easily dried by the heating panels. The work progressed from the top to bottom. Thus, in one day, after the glass surface was wiped with ethanol and acetone, sol-gel was then applied on the area to be treated that day. The next day, this area was heated, and after cooling, it was treated with a second coat and immediately heat-dried. The work continued in this manner, and the next area below, scheduled for that day, was treated with a first coat, and this process was repeated until the entire area, scheduled for the year, was treated with the first two coats.

6. Gilding

The next operation was gilding of the background. From the beginning of the project, there were discussions about the possibility of an aesthetic recovery of the mosaic by integrating the gilded background. Of course, it is not possible, or desirable, to reconstruct the gilding using the original technology, that is, baking the gold foil sandwiched between the colored glass body of tesserae and the colorless glass layer on top. The conservation team considered gilding methods that can be performed in situ and that would be easily reversible without the risk of damaging the original tesserae. Samples of easily reversible gilding of various levels were prepared on a small test mosaic made from modern glass. Partial gilding of the tesserae is not technically difficult. An application of gold foil with an adhesive can be distinguished from the original technology on close inspection. Neither this gilding method nor the consequent cleaning with solvents poses any risk to the mosaic's tesserae. Samples of full, front-face gilded tesserae were prepared, as well as samples of gilding using only shreds of gold foil. Various methods of controlling the intensity of the gilding layers were also tested, for example, by slightly cracking the gold foil by washing it with cotton swabbing saturated with acetone, or by thinning the foil by abrading it with bundles of glass fibers. Gilding with gold dust, mixed directly into the protective coating, was also tested. The samples convincingly showed that it was possible to achieve practically any intensity of the gilding, from glaring gold foil covering the entire surface to just a suggestion of gold, through which the color of the tesserae glass shines. It was also confirmed that moderate gilding would improve the legibility of the mosaic. Gilding with gold foil, rather than gold powder, is aesthetically more suitable. Gold powder mixed with the protective coating reflects and deflects light differently and differs strikingly from the original gilding and therefore is not suitable. In fall 1996 a three-day international symposium was dedicated to the issues of the ethically and aesthetically sensitive integration of the mosaic's background. After a discussion, the participants of the symposium recommended integration of the background by partial regilding.[6]

Background gilding was partially reconstructed after the second coat dried. The objective was to integrate the background where the gilding from the beginning of twentieth century was visually disruptive. The intensity of gilding was discussed several times and approved by the special expert commission, first on a small sample and later on an entire gilded section of each panel, at the stage when the intensity of gilding could be adjusted without problems. After approval by the expert commission, in addition to the background, the rays of the aureole encircling Christ, the chain and shackles of devils, St. Peter's key, and St. John's chalice were also regilded. Other, originally gilded details were not regilded. The prescribed Lumiflon bonding solution was applied by brush to the tesserae surface, under the gold. A gold foil for exterior use supplied in the form of strips rolled on paper tape, several meters long and 6, 8, and 10 mm wide, was used as indicated by the re-gilding committee. The gilding was only applied to front faces of tesserae where no original gold had been preserved. After the application, the gold foil was dusted off with a soft brush. No further patination of the gold surface was performed, because the result of this method was approved by the art historical commission. There was also concern that any patination would disturb the first two protective layers of the coating. The gilding is easily reversible because it is sandwiched between two layers of easily soluble Lumiflon. Gilding was not heat-dried. There are three types of gilded tesserae on the mosaic today: the original tesserae with fragments of original gold under the thin layer of glass, original tesserae with fragments of gold sandwiched between two layers of Lumiflon, and modern gilded tesserae from the beginning of the twentieth century. On close inspection, all three can be easily distinguished.

The gilding was needed to optically integrate the background of the mosaic, but there was a danger that too much gilding might jeopardize the mosaic's authenticity. Therefore, considerable time was devoted to professional discussions concerning the amount of gilding and the evaluation of the gilding samples. To judge the overall results from a longer distance, the scaffolding was partially removed. Figures 6 and 7 show the effect of a small area representing St. Wenceslas before and after re-gilding of the background.

FIGURE 6 Figure of St. Wenceslas in the central panel after removal of corrosion. In the background, the separation lines of the 1910 transfer are apparent, filled with a combination of original and new gilded tesserae.

Photo: M. Nečásková.

FIGURE 7 Figure of St. Wenceslas in the central panel after regilding of the background. Photo: M. Nečásková.

7. Application of additional cross-linked Lumiflon and drying of this layer with heat

After gilding was completed, the same material was applied and heat-dried using the same regimen of heat panels.

8. Application of the sacrificial layer made with non-cross-linked Lumiflon and drying of this layer with heat

The fourth and last coat, the sacrificial layer, is composed of Lumiflon prepared as follows:

- polymer Lumiflon 200 (250g)
- xylen (200 g)
- MIBK (methylisobutylketon) (100 g)

On the side panels the coating was applied more diluted, with double amounts of xylen and MIBK. This last coat differs from the second because it does not contain any cross-linking agent, so that it can remain more easily soluble than the preceding conservation layers. It is called the sacrificial layer because it is applied to protect the coatings underneath, and unlike these, it is expected to be renewed in several-year intervals. The sacrificial layer was also heat-dried as described earlier.

The three-year work plan proved optimal. It enabled completion of the work during the summer, without the threat of unstable humid or rainy weather that occurs in the spring and fall. At the same time, it allowed, during the restoration process, an evaluation of results from previous work phases that could be tested during the crucial winter period.

After the first year, only one change had been made in the technology, regarding coating dilution. The interruption of the works over the winter enabled verification of the durability of several methods directly on the test field of the mosaic and choice of the best option.

Each year the conservation work was begun in mid-May and finished in September. The side panels were treated from the beginning of June until the end of September of the second and third years. The removal of corrosion took about six weeks each year. Erecting and dismantling the scaffolding for washing the surface, photographic documentation, drawings took another week to ten days. The heating panels were fitted in two days. The application of the first two coatings together with the drying took about fourteen days. The gilding required another fourteen days. The last two coatings also could be applied in fourteen days. Along with this, documentation and certain small tasks were carried out.

An important segment of time was devoted to project dissemination. The mosaic work site was kept open to professionals and conservation students who could visit on particular days and become acquainted with the work process. It was also important to inform the public about the project and its progress. Regularly, the work was filmed and shown on television. The work schedule was also influenced by weather. The scaffolding was roofed and partially protected by nets, which enabled removal of the corrosion even on rainy days. Coating application and gilding can be done only a completely dry surface. Moreover, gilding cannot be done in strong wind. Similarly, strong wind prevented the drying of the coatings with the small panel, because the wind penetrates the heated space and diminishes the efficiency of the process.

In the course of restoration, all procedures were documented by color photographs. The restorers submitted two copies of a report, with photo documentation, after they completed restoration of each panel of the mosaic. One copy is kept by the management of the Prague Castle, the second by the GCI. In addition to this basic documentation, new findings acquired during restoration were recorded. These drawings noting the extent of the original gilded details, secondary additions, and other changes to the mosaic were transferred to digital form and edited at the GCI.

Conclusion

The Last Judgment mosaic conservation project brought a new approach and new materials to address the unique and difficult challenge posed by the degradation of medieval glass tesserae. It marks the beginning of modern managed care of this precious and fragile artwork. The intervention was developed on the basis of extensive scientific research and required sophisticated custom-made instruments. It also entailed addressing the problem of aesthetics in terms of reintegrating evidence of deterioration. For restorers, this project also represented a significant achievement in close, productive international cooperation. The result and the reward can be seen in the mosaic itself, which for the first time in more than five hundred years is free of corrosion.

The restoration brought back the mosaic's former beauty (fig. 8). This marvelous and timeless legacy has been made part of our chaotic present, brought back from the dis-

FIGURE 8 The mosaic after regilding.

Photo: J. Zastoupil.

tant glorious past of the Bohemian kingdom. Visitors experiencing the beauty of the mosaic for the first time, or those who routinely pass it every day, are probably unaware of the effort, research, labor, expense, and concern of those who participated in its rescue. The tremendous effort to bring this artwork back to life would not make sense if the result were to be short-lived. A onetime intervention, no matter how well conceived and executed, unfortunately cannot provide permanent protection for the mosaic. Its preservation is inconceivable without periodic care, monitoring, and maintenance, and this will require constant commitment.

Notes

1. The information presented in this chapter is the result of the team effort of Alois Martan and his son, Martin Martan, and Eva Skarolková. A team of Czech conservators, including the author, carried out the conservation intervention.
2. For a detailed description of the research on developing the coating, see chap. 13.
3. During the cleaning, abrasive powder and loosened corrosion products were vacuumed away by a dust collector attached to a small chamber that had an opening for a nozzle. The restorer held the chamber against the work area with one hand and manipulated the nozzle with the other; a foot pedal was used to control the blaster. The restorer was able to follow his or her progress through a window in the chamber. Not even constant vacuuming could prevent the abrasive powder and corrosion particles from escaping into the air, since it was impossible to attach the work chamber tightly to the uneven surface of the tesserae. For reasons of safety, the restorers wore full protective masks with high-quality dust filters and regularly vacuumed the scaffolding. During the work, several hours each day, technical problems often arose concerning the softer, flexible parts of the equipment, especially the tubes and joints that were stressed by the rapidly moving abrasive material. Maintenance of the equipment became a necessary daily routine. After experience acquired during the first year, a third machine was added to the two already being used, to ease the process and avoid interruption of work for maintenance.

Technical support to deal with more serious problems was provided by a specialized firm hired by the Office of the President.

4. The side panels were coated with sol-gel diluted 1:4 parts with isopropanol and stirred for 30 min. using a magnetic stirrer. This modification was the result of experience working on the central panel. The coating tended to dry very fast during the warm summer weather and become thicker than was desirable. Thinner coating films are potentially more adhesive and should perform better. Several coating dilutions were tested on small areas under the pinnacles and were in perfect condition after the winter season. It was decided to use the more diluted coatings on both side panels of the mosaic.
5. A test was conducted to determine whether the heat-drying process could be skipped without adversely affecting the stability of the coating. In a small area in the left pinnacle a fourth layer was tested that was applied with any heat drying. It dried naturally under normal climatic conditions. A similar test, but for the entire protective coating system, was conducted at the top of the left panel. Directly above the center of the window arch, an area 25 cm wide and several cm high was treated with all the protective layers, but none was heat dried. It is highly probable that there will be no significant difference in the longevity of the nonheated and heated coatings, especially the fourth coat. No chemical reaction occurs between the polymer molecules during the heating process. Heat is used only to completely dry the coating so that the solvents can evaporate and a new layer can be applied safely and evenly. Heat drying of the coatings is technically demanding and time consuming and cannot be performed without scaffolding. If the stability of a nonheating coating is confirmed, it would significantly simplify the technology for maintaining the mosaic in future.
6. For a description of the ethical issues of regilding and the established limitations, see chap. 8.

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Appendix: Materials List

Cleaning

Granulated glass powder, 50 microns in diameter, lot #3041, 35 lbs Abrasive Compound (Crystal Mark, Inc.)
Ethyl alcohol
Acetone
Water

Conservation Coatings and Gilding

Sol-gel TS-HF (A) (Tokuyama)
Propyl alcohol
Lumiflon LF 200 (Asahi Glass Co, Ltd.)
Xylene
Methyl-isobutylketon
CIMEL M 303 DYNO CYTEC (Bayer)
Gold foil, 24 carats (Busse, s.r.o)

All above-mentioned materials were provided by the Getty Conservation Institute.

Grouting and Replacement of Tesserae

Lime-sand mortar with brick dust, and addition of egg white and Sokrat 2802A acrylic dispersion (Chemicke zavody Sokolov a.s./ Sokolov Chemical Works)
Original tesserae from reserve of the Archive of the Prague Castle
New tesserae in various colors

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Chapter 16 Monitoring and Maintenance of the Last Judgment Mosaic

As conservation moves from a uniquely remedial approach to include preventive and passive approaches, regular monitoring and maintenance of a conserved work of art, such as the Last Judgment mosaic, becomes an essential ongoing effort for ensuring its long-lasting stable condition. The active deterioration problems affecting the Last Judgment mosaic are due to its original material, the poor quality of its glass, and its exposure to the environment. While these conditions cannot be eliminated, we have placed emphasis on preventive conservation by halting the deterioration-activating mechanism. This was done by applying a protective layer to the glass and thus creating a barrier between the glass and the environment—by shielding the glass and preventing water from reaching it. The project has been acclaimed as a wonderful example of the value and success of the integration of science and conservation. However, it is essential to realize that in cases of ongoing deterioration, follow-up monitoring and maintenance are as important as the conservation treatment.

Here we describe the protocol developed for the regular monitoring of the mosaic and the procedures designed for its maintenance. The monitoring protocol lists the procedures for regular examination of the mosaic and documentation of its condition to allow detection of possible changes. The maintenance procedures entail the planned replacement of the various layers of the mosaic protective coating system.

The Failure of Previous Conservation Efforts

The events and the condition of the Last Judgment mosaic following the 1959–60 intervention provide a good example of the importance of monitoring and maintenance. At that time, treatment of the mosaic was carried out after several years of study that provided the explanation for the reoccurring glass deterioration. The mosaic's corroded layers were mechanically removed, and a suitable material for protection of the glass tesserae was applied to complete the restoration work and to ensure long-term preservation. Unfortunately, even if it had been recommended that the mosaic be inspected regularly thereafter, these inspections were not carried out, and the brilliant colors of the mosaic started to disappear as corrosion recommenced. Obviously, the coating material had failed in its protective function. Without regular inspections, it was not possible to determine how and why the protective layer was damaged and how this process began—for example, whether extremely high or low temperatures or particularly wet conditions had been the catalyst. By neglecting to provide subsequent maintenance, the work of the Czech academic specialists was discredited. These specialists had attempted to select the best materials at that time, but they lacked information on the actual long-term behavior of their technologies.

Brief Description of Current Coating Technology

The collaborative project between the Office of the President of the Czech Republic and the Getty Conservation Institute follows the same basic principle of the 1950s treatment. The conservation strategy included cleaning the corrosion from the mosaic and preventing it from occurring again by applying a protective layer to shield the glass. The protective coating system developed and applied on the mosaic is made with a series of subsequent layers (see fig. 1)

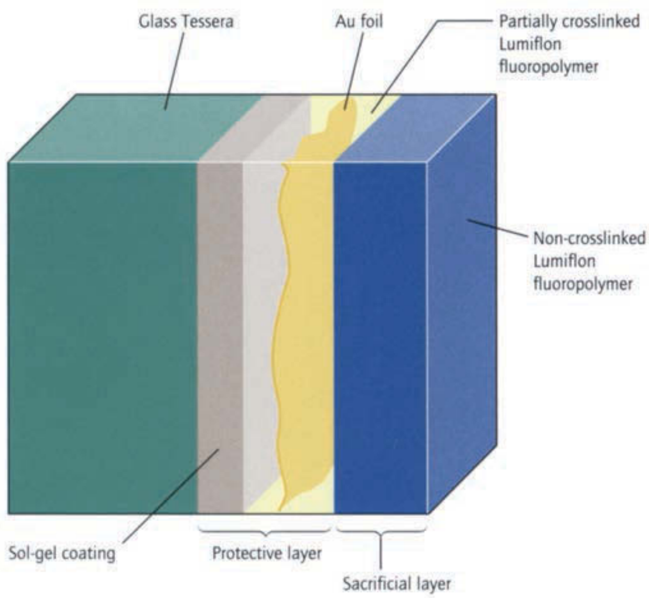

FIGURE 1 Diagram of protective multilayer coating system (not to scale).

The first of these layers is made with sol-gel, an organically modified glass that has excellent adhesion to the original glass tessera and was applied over a perfectly cleaned surface. The intact nature of this layer and its adhesion are crucial to avoid water from reaching the glass surface—the first step that causes the corrosion process to start again. The second layer is a fluoropolymer applied with a cross-linking agent. Once set, the resulting layer is soluble only in strongly polar solvents such as methyl-ethyl-ketone and acetone. The final layer, called sacrificial, is made of the same fluoropolymer but this time applied without a cross-linking agent. The resulting layer is therefore more easily dissolvable and not very polar solvents such as ethyl alcohol can remove it. The cross-linking agent is the difference between the last two overlapping layers. The function of these layers is to protect and prevent damage to the sol-gel layer. As described in chapter 13, this protective coating system was tested for more than four years in situ and in the laboratory under environmental conditions matching those of the mosaic and was found to be stable and to perform very well over time.

Monitoring Protocol

The main objective of monitoring is to detect changes as soon as possible so that precautions can be taken to stop deterioration from occurring and to repair small problems. Monitoring is carried out by visual examination by conservators who have worked on the mosaic and therefore know it well in all its weak points. Generally, structural damage and loose tesserae are identified by close inspection of the mosaic surface. This inspection, given the mosaic's location high on the south facade of St. Vitus Cathedral, requires the use of a scaffold or telescopic platform (fig. 2). Most important in the case of the mosaic, monitoring is aimed also at observing if any corrosion has started again or if the protective layer has failed in some areas. The determination of changes in the appearance of the coating is not an easy task. Typically, coating "problems" have manifested themselves as small cracks or small, round, opaque pockets, almost as if bubbles were formed underneath the layer. In some cases, the coating failure can be manifested as transparent flakes in the coating. In any case, the aim of monitoring is to detect the presence of "new" cracks, bubbles, or flakes indicating an active process of deterioration (fig. 3).

The history of previous intervention has shown the importance of monitoring and documenting the information collected at each monitoring event. As described in chapters 7 and 8, a great deal of attention was focused on collecting background information about previous treatments on the mosaic and their documentation. During the recent conservation work, documentation was carried out systematically to record the condition of the mosaic before, during, and after treatment. The documentation after treatment includes large-format photography of the mosaic, the rectified photographs of each of the three panels, and overlays that graphically indicate treatment. This documentation represents the baseline data from which to compare eventual changes in the mosaic after completion of this project. Regular photographs are very useful for observation of macroscopic changes such as cracks in the mosaic or loss of tesserae. Changes in the protective layers are much harder to detect as they occur on a small scale (see fig. 3), and therefore specific monitoring areas were selected for in-depth examination and regular close-up photography.

Monitoring is to be carried out at least once a year and includes visual inspection of the entire mosaic and of the architectural sections contiguous to the mosaic. Particular attention should be given to the static cracks on the exterior and interior sections of the wall, the roof, and the balcony. This inspection is helpful for determining whether existing problems are worsening or new ones are appearing. The

FIGURE 2 View of the mosaic's facade with conservators on a telescopic working platform. This kind of platform is necessary for monitoring and maintenance of the mosaic.

FIGURE 3 Coating problems: close-up view of blue tesserae with bubbles that formed underneath one of the tested (and rejected) coating systems.

spring 2002 inspection is a good example of the importance of regular control. At this time the team noticed that the "century-old" crack in the left panel (representing the raising of the dead), extending from the base of the window to the arch top and filled during the 2000 conservation intervention, had moved. The filling mortar and the tesserae along the edges of the crack had become loose, and a few of the tesserae were lost. This problem was recorded, the tesserae were reattached, and the crack was filled with a new mortar that has better elasticity and can adapt to movements of the mosaic and cracks. Monitoring has permitted prompt intervention and avoidance of more serious damage and loss of original tesserae. Moreover, it allowed for the introduction of mortar that should withstand the inevitable movements of that particular crack.

The performance of the coating is more difficult to evaluate. For this purpose, in addition to regular overall inspections of the mosaic, a few small areas in each mosaic were selected as close-up monitoring areas. These areas (see fig. 4) have been recorded regularly with macrophotography. The images taken during the regular inspections can be visually compared to evaluate if any change has occurred. In this way, it is possible to identify eventual changes in the protective layers. But it is still very difficult if not impossible to tell by simple visual comparison if, for example, the microscopic bubbles detected in the center panel are expanding.

The method developed consists of using close-up digital photography and subsequent evaluation of changes by digital subtraction of the images. For the purposes of documentation, the team selected a Nikon Coolpix 990 digital camera able to take images with up to 3.34 million pixels. The team selected three 18 cm by 24 cm sectors for close-up documentation with glass tesserae of different colors in each of the mosaic's three panels. Changes in the protective layer, typically showing up as white opaque, can more easily be detected over dark tones of glass. With the digital camera each sector can be recorded with high-pixel resolution. To ensure the reproducibility of the images and therefore make

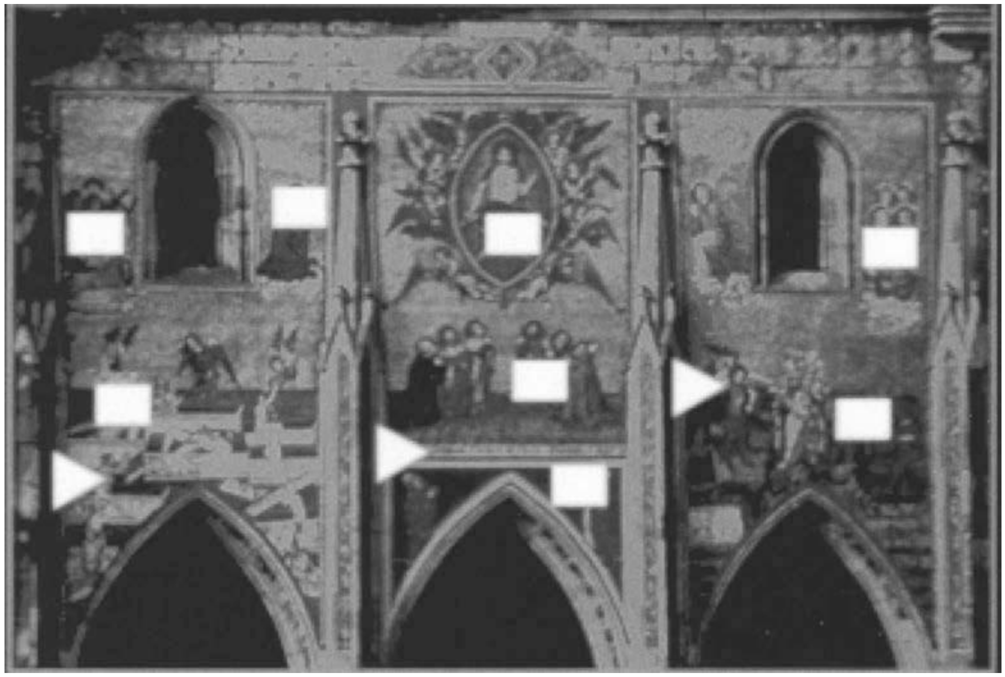

FIGURE 4 Mosaic monitoring areas. Areas of microphotography are indicated by rectangles. Fixed monitoring platforms are indicated by triangles.

it possible to perfectly overlap them, the camera was attached to a lightweight tripod that could be fixed to the mosaic surface (fig. 5). In each of the three sectors, the tripod's legs are positioned in the space between the glass tesserae where stainless casings were permanently inserted (fig. 6). These casings measure 35 mm long by 8 mm wide. They form an isosceles triangle with sides measuring 21cm in length. (See triangular areas A, B, and C in fig. 4.) The camera's lens is therefore always positioned 20 cm from the mosaic. The photographs were taken at maximum close-up but without using the digital zoom to avoid lowering the final quality. The final result is an enlargement of the glass tesserae in a close-up 5 by 7 cm photograph.

The first photographs were taken after the completion of restoration in 2000, and they served as references. Following a previously established time schedule, additional photographs were taken, and, using the LUCIA image processing and analysis program, the photographs were laid over the reference photographs.This program computes the image data and, after calibration, indicates eventual changes. As the data are in digital form, these changes can be calculated in terms of area and percentage. It is important that the photographs be taken under adequate lighting conditions, that is, when the light is diffused and there are no sharp shadows that could later be interpreted as new defects. It is also important to evaluate in-situ possible changes detected by the software. Thus far, close-up photographs have been taken twice a year and compared to the reference images; so far, no changes in the protective layers have been detected.

In addition to regular monitoring, the team has developed a maintenance schedule for the protective coating system. The sacrificial layer is to be removed and replaced every five years. The intervention on the first mosaic panel (the central one) was completed in 1998, and the two remaining panels were completed by 2000. The first maintenance of the sacrificial layer on all of the panels is planned for 2004. This operation does not require full scaffolding installation but can be conducted with the aid of two telescopic platforms. It will consist of the removal of the upper protective "sacrificial" layer and application of a new one. The surface dirt deposits are removed along with the layer that was most exposed to the elements. It is planned that this treatment will be repeated regularly every five years. Therefore, after 2005 the maintenance schedule will be synchronized, with the next treatment of all three panels of the mosaic scheduled for 2010 or sooner if needed.

A different maintenance cycle involves the protective coating and is planned, unless monitoring shows that there is a problem earlier, to take place in twenty to twenty-five

FIGURE 5 Conservator positioning the camera for photo documentation.

FIGURE 6 Close-up of sector showing position for tripod's leg. Photo: M. Martan.

years. This maintenance will entail the removal and replacement of the entire protective coating system. Because gilding is included in the protective layer, it will be removed at this time. In the event that delamination of the protective layers should occur in some area, or another problem should appear, an emergency treatment may be performed earlier, possibly in isolated areas.

With regard to the development and research of new materials, it is necessary to work on new protective technology well in advance to verify, based on laboratory testing and on mosaic test samples, the suitability of an application. To guarantee follow-up maintenance, it is recommended that the Prague Castle Administration assign specific restorers with the tasks of monitoring the mosaic's condition and taking part in the development of new protective strategies needed for the next major conservation treatment of the Last Judgment mosaic. To keep up with the development of coating technologies, a cooperative research plan has been made with the specialists at the Institute of Chemical Technology in Prague who are in contact with manufacturers of protective coating materials that can be used in the mosaic.

Already at the beginning of the recent conservation work, the conservation team was formed by two groups of restorers with significant age differences so as to ensure continuity in follow-up maintenance cycles. During the next regular inspections, other restorers should be involved in the process so that they can become familiar with the technology and practical methods during the inspections, as well as the replacement process of protective layers. The aforementioned methods of monitoring the mosaic's condition enable us to detect eventual defects at the onset and thus ensure that it will not suffer irreparable damage or loss in the future.

Conclusion

After the completion of restoration work in 1959, maintenance and monitoring of materials used in the process were neglected. Therefore, it was impossible to determine why the protective materials prevented corrosion for only a short time. After the restoration work in the mosaic's center field began in 1998, various methods were tested that would allow for precise monitoring of the protective layers. Visual observation and digital macrophotography with follow-up image evaluation proved suitable.

After the mosaic's conservation was completed, sections with various types of tesserae were selected, stainless casings were anchored, and a firmly attached digital camera was inserted. These sections were photographed at regular intervals and compared against the original images using the LUCIA imaging program. This enabled the precise observation of changes and their interpretation in terms of percentage of surface area and actual size.

Surface inspection must also include inspection of all architectural elements that relate to the mosaic and monitoring of previously known static cracks. The practice of inspections was justified in 2002 when a crack appeared and tesserae around it were loose. These inspections should be conducted regularly twice a year.

Another important issue is regular replacement of the protective layers. Every five years, the upper layer will be removed and replaced with a new one. Every twenty to twenty-five years, all layers will be removed and the entire protective system replaced. Therefore, it is necessary to establish communication with manufacturers of the materials used, follow scientific and technological advances, and make other restorers familiar with the technology and practical application.

Contributors

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