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Cleaning Techniques in Conservation Practice

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Cover Photograph: The scaffolding to the Dome and Cone at St Paul's Cathedral designed by RDG Engineering and erected by Palmers Ltd. (Angelo Hornak)

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Introduction

Nicola Ashurst

It is always good to discuss the important subject of the cleaning of traditional building materials in an informed way. There is no better way of doing this than through practical projects which have been undertaken on the basis of sound understanding of the substrate to be cleaned, the soiling to be removed and the intimate relationship between the two. This issue of the *Journal of Architectural Conservation* does just that, in a series of intriguing articles from around the world, written by experienced practitioners. The issue treats you to an in depth discussion on the cleaning of an excellent diversity of subjects – the interior of St Paul's Cathedral, the concrete at Sydney Opera House, a portion of the *Titanic*, the world's largest French Gothic Cathedral (in Manhattan) and no fewer than two Saturn V rockets. Important balance is also provided in the principles of cleaning and the public perception of soiling.

Deborah Slaton and Kyle Normandin begin with a description of the techniques currently in use in North America. In the UK, we have seen all the techniques described; some are in common use, some remain in specialist niches, while others have never really 'taken off'. BS 8221: Part 1, 'Code of Practice for the Cleaning and Repair of Traditional Materials' should be read by UK readers alongside this paper for better understanding of the local situation. Slaton and Normandin also include a well presented section on applying conservation policy to cleaning, which flags up the important difference between soiling (extra, undesirable) and patina (inherent, desirable).

The White Tower at the Tower of London is the setting for Carlota Grossi and Peter Brimblecombe's paper on public perception of soiling. Constructed of Kentish Rag, a relatively light coloured stone, members of the public were canvassed about its very noticeable, streaky soiling. For most, their first impression of the White Tower was not of dirtiness, but rather grandeur of age.

Grossi and Brimblecombe's research on the White Tower and a selection of other European cathedrals has found it quite possible for the blackened surfaces of landmark historic buildings to have a level of social acceptability. This certainly contrasts with the perceptions of developer clients who see cleaning as fundamentally important to the presentation of a refurbished or redeveloped building. Cleaning has also played a key role in the urban regeneration of many UK cities. So, there are still many exciting debates to be had about how cleaning is perceived. I expect a different debate would be had depending on whether buildings are built of naturally light or naturally dark coloured stones.

Remaining in London, the article on cleaning the interior of St Paul's Cathedral reinforces the value of researching substrates, the history of the building, the history of previous cleaning and surface treatments, and the undertaking of independently commissioned *in situ* cleaning trials, and much more. To achieve the cleaning of such a significant interior, to achieve it well, on time and on budget, reflects highly on the 'homework' and preparation phase which Martin Stancliffe, Surveyor to the Fabric of St Paul's and the Doctors De Witte, share with us in their paper. The interior was cleaned using a latex film with bespoke ingredients, achieving a good level of clean whilst overcoming many of the logistical nightmares that often plague the cleaning of interiors.

The preparation phase undertaken by Akhurst, Macdonald and Waters as part of their development of a methodology of the cleaning of the folded concrete beams at Sydney Opera House is exemplary. Based on the building's *Conservation Plan* and *Design Principles* set by designer Jørn Utzon, it also included some very clearly defined and useful scientific analysis of surface characteristics, soiling and deposits, capped with interviews with labourers, supervisors and engineers involved the Opera House's construction in the 1960s. The authors' understanding of the surfaces to be cleaned and their context, on a building which will undoubtedly one day be made a World Heritage Site, is breathtaking, but so worthwhile.

The cleaning process selected (termed a 'conservation treatment'), involved steam cleaning followed by application of a thin wash of fresh calcium bicarbonate solution, left to dry slowly, precipitating calcium carbonate into the pores of the concrete. Gentle buffing during drying using methods of the original construction changed the surfaces into an opaque glaze. This recaptured the character of the concrete beams as they appeared after removal of the original formwork; a solution as unique as the building itself.

The paper on the use of high and ultra high pressure waterjetting techniques in the conservation of historic metals comes to life immediately when you find out that its case studies are based on a portion of the *Titanic* and two Saturn V rockets. The techniques discussed will be of greatest interest to those involved in the cleaning of external ironwork and bronzework, either sculptural or architectural. Waterjetting technology which involves increasing the power of water, was reported on in the 1960's when Dr Norman Franz, a forestry engineer and professor at the University of British Columbia, was looking for a faster method of slicing large trees into 'lumber'. The article provides a very clear explanation of waterjetting, its many adjustable parameters and how these can be fine-tuned to the metal substrates and the cleaning result required. The selectivity and sensitivity of the process, designed by the right people, on the basis of well researched investigations, is impressive. Unfortunately waterjetting cannot be as predictably controllable on masonry because the characteristics of masonry and its joints are too variable. The article makes several memorable points. My favourite is: 'Dirt or unwanted material in crevices and cracks cannot be reached by a particle that is larger than the crevice opening, whereas water is not limited by the size of the pits or crevices.' We should remember this when considering abrasive cleaning on masonry.

Martin Cooper's article on laser cleaning clarifies what laser cleaning is and how it operates. He explains how laser cleaning is an extremely high quality method of cleaning which can be finely tuned to remove only the soiling from the finest and most delicate of surfaces. There is also a reassuring warning that, as with all cleaning techniques, damage to a surface will result if laser cleaning is carried out poorly.

At present, the bulk of laser cleaning undertaken in the UK takes place in museums or conservator workshops. In these contexts, the rate of cleaning can be as fast if not faster than other comparable techniques available in the conservator's toolbox.

Laser cleaning equipment which has been modified for building site conditions is also available and is being used primarily for cleaning monuments and sculptural and architectural detail on buildings. The logistical considerations of on-site laser cleaning are very clearly explained in this paper.

Most of us still consider laser cleaning as a relatively slow specialist process which is best suited to sculpture. However, in Europe whole façades have been cleaned by laser, e.g. the entire front façade of Rotterdam's City Hall. There, the laser unit remained on the ground linked by 45 metre long optical fibres to cleaning operatives in a 'cherry picker' personnel lift. This is an excellent example of thinking outside the box which should encourage us all to stretch our minds when designing any cleaning regime.

A fire in the Cathedral Church of Saint John the Divine in Manhattan, New York City, provided the material for the article by Kavenagh and Gembinski. During the fire, thick black smoke penetrated the entire building interior. The subsequent insurance claim required comprehensive and irrefutable documentation that all internal surfaces required cleaning because products of the fire had deposited on every surface. Cost control provided the mechanism for an in-depth analysis of the materials deposited on the granite and limestone interior, and the distribution of this.

Once this was established, on-site trials eliminated both chemical and abrasive cleaning processes as none tested successfully, and none had operational logistics that could fit in the environment of a busy, operational church.

Latex, with a chemical additive, was tested and proved successful on light and moderately soiled stone, but not on the heavily soiled stone. No method was found that could clean these surfaces where bitumen globules were the prime deposit.

All the projects described in the papers are fascinating to read about and learn from. Even when simple and less prominent buildings are cleaned, many of the principles and procedures described here can be applied.

It is my experience when it comes to masonry cleaning that assumptions are never wise. This is certainly true in the field of traditional masonry cleaning where the temptation must be resisted. We are particularly prone to assumptions about soiling.

On three projects over the last two years I commissioned petrographic analysis to determine the nature of the soiling, the nature and condition of the stone substrate and the inter-relationship between the two. No one was more surprised with the results than I. A Portland stone building on one of London's most trafficked 6-lane roads exhibited a moderate level of black soiling in a disfiguring weathering pattern. It was assumed that the diesel vehicle particulate emissions would be a predominant ingredient of the soiling. However, the analysis proved there was no carbon at all.

A large garden structure of sandstone located in a part of Yorkshire, heavily polluted with industrial emissions in the nineteenth century, was assumed to have a largely carbon-based soiling. Analysis proved the assumption wrong as it identified the soiling as a finely textured mat of organic growth.

Analysis of 1 cm thick black crusts on a magnesium limestone railway viaduct in an area of Nottinghamshire that was heavily industrialized in the nineteenth century, confirmed the crust to have no carbon constituents. Instead, it was found to be a thick layer of gypsum, formed by the reaction of the stone with sulphur, probably generated by the burning of coal in the area. The calcium required for the gypsum had been leached from the stonework itself, creating a highly porous layer of stone just beneath the surface. This porous layer was, in turn, protected by a thin layer of gypsum. There was no 'clean break' between the stone and the soiling.

We need to go back to first principles on every cleaning project in which we become involved. We need to check that our assumptions are correct, that we really do know about the materials we are cleaning and the soiling we are removing from them. Carefully selected analytical procedures will provide this, often at minimal cost. And we need to understand in detail the actual effect of what our selected cleaning processes are doing, before we inflict them on a whole building.

We also need to remember that there is still a lot of merit in the more common water-based, chemical-based and abrasive cleaning processes that have been in use for the last twenty years. The increased sophistication of many of these is producing excellent results, especially in the hands of skilled specialist contractors, despite the fact that they do not have glossy brochures.

The advertising of cleaning materials and equipment has become more sophisticated with the result that certain processes are better known for their name than they are for what they do. In all areas of consumer life, we need to stay vigilant, and this includes the cleaning of traditional materials.

Any preference for describing cleaning systems by proprietary name is best avoided – it helps us forget the fundamentals on which a cleaning process operates, and to lapse into a false sense of security that, at last, the cleaning process suited to every substrate, substrate condition, and to every soiling type has been found. There is a wish in all of us that one day a miracle cure will be invented which means we no longer have to understand substrates and soiling. Several brochures for cleaning systems try to persuade us we are there, at least nearly. The reality is that we still have to be informed and experienced about cleaning and, if we are not, we need to find someone who is.

Not many of us have the luxury of cleaning external façades that have not been cleaned before. The effect of previous cleaning regimes must be understood before any further cleaning is undertaken as it can significantly alter the selection of an appropriate cleaning regime. It is always worth talking to the operatives who undertook the work as they will remember what was actually done rather than what was specified.

Each cleaning operation has an effect on the masonry substrate. While the best designed cleaning regimes keep this to a minimum, the incremental effect of repeated cleaning will have a significant impact. This is of particular concern when lease terms require façade cleaning at short and regular frequency. There is no better example of this than the repeated removal of graffiti, where the incremental effect of even careful use of chemical cleaners and pressure water can soon produce noticeable damage.

We need to use more descriptive terms for cleaning. The word cleaning is not sufficient for the separation and removal of a wide variety of soiling types, from an even wider range of substrate types and substrate conditions to which they are bonded, in an equally complex range of ways.

We have come a long way in the field of masonry cleaning in the last 20 years. We also have much more to learn. The following papers are an excellent start in this education process.

Biography

Nicola Ashurst
Nicola is an established specialist in the conservation and cleaning of historic buildings. She was formerly working for the Research and Technical Advisory Services of English Heritage and is now Principal of Adriel Consultancy, Melrose, Scotland. Nicola is author of *Cleaning Historic Buildings*, Volumes one and two.

Saint John the Divine

Techniques to Assess Fire Soil

Claudia Kavenagh and Christopher John Gembinski

Abstract

The Cathedral Church of Saint John the Divine is the third largest church structure in the world. It is located on the upper west side of Manhattan in New York City. A fire in December of 2001 badly damaged the stonework of the unfinished north transept and spread thick black smoke through the entire building. After the fire, a comprehensive investigation was undertaken to identify the unique characteristics of the fire soil and then to use that information to determine the extent to which these materials had deposited on surfaces in the building. A direct correlation was made between the materials of construction that burned during the fire and the particles present in samples of soiling removed from throughout the Cathedral. It was therefore possible to establish that the fire soil had penetrated to all areas of the Cathedral and that all surfaces required cleaning. This paper describes the techniques used to carry out the investigation.

Introduction

A fire in December of 2001 at the Cathedral Church of Saint John the Divine resulted in significant damage to architectural stonework in and adjacent to the Cathedral's north transept and caused smoke to fill the entire Cathedral interior (Figure 1). In the days following the fire, assessment was made of the effects of the fire on the exterior and interior architectural elements of the Cathedral building. An important initial component of the assessment was to characterize the soiling left behind after the smoke cleared and to catalogue the surfaces on which fire soil was deposited.

The initial assessment indicated that the soiling from the fire had deposited on every surface throughout the building and that all surfaces

Figure 1 A view of the north transept during the fire, taken from an exterior parking area. (Michael Schwartz/New York Daily News)

would have to be cleaned. Because of the enormous cost associated with such an undertaking, the insurance claim for the damage caused by the fire had to include comprehensive and irrefutable documentation of these conclusions. It was therefore essential first to prove that the soiling from the fire had affected the entire interior and then to determine an appropriate means for cleaning the materials, so that the cost of this work could be established.

Surfaces exposed to smoke conditions and contaminated by-products of combustion are typically darkened or, in extreme cases, blackened. The composition of the particulate contamination depends on the articles that burned. Smoke and other by-products of the fire that were transported and subsequently deposited on surfaces in the Cathedral are generically referred to in this paper as fire soil.

History and description

The Cathedral Church of Saint John the Divine is the third largest church structure in the world and the largest cathedral in the French Gothic style.[1,2] It is located on the upper west side of Manhattan in New York City. The Cathedral was constructed in phases beginning in 1892. Architects George Lewis Heins and Christopher Grant Lafarge prepared the first designs for the structure in the Romanesque style. The initial phase of construction lasted from 1892 until 1911. In 1916, Ralph A. Cram took over as chief architect and modified the earlier Romanesque design to incorporate the French Gothic style that is visible today. Construction during this phase continued until the start of World War II. Work then occurred sporadically over the next few decades. The most recent phase of construction began in 1979 and ended in the 1980s. Although in use since its initial construction period, the Cathedral is still an unfinished structure. Most notably, the west (main) elevation and the two towers flanking the main entrance are only partially completed. On the interior, primarily in and adjacent to the crossing, cladding stone was never installed and the inner masonry wythes are exposed.

The Cathedral is a massive construction spanning a reported 183 metres from the narthex to the back of the apse and 38 metres from the floor to the vaulted ceiling. In addition to the architectural materials, the Cathedral has an extensive art collection. The much-loved Cathedral is constantly active and services are held in the building several times daily. The building is used by a school on the grounds and by theatrical companies; there are numerous concerts and other events throughout the year. Each day, hundreds of neighbourhood residents and tourists come to visit the Cathedral.

The primary material of construction on the Cathedral exterior is Mohegan granite, with some limestone trim elements. A fossiliferous calcitic limestone, most likely an Indiana limestone, and a smooth sawn granite, clad the nave and choir interior walls. Interior wythes of masonry are visible in the crossing and ambulatories, where the final cladding stone has not yet been installed. On the majority of unfinished walls, a rough cut

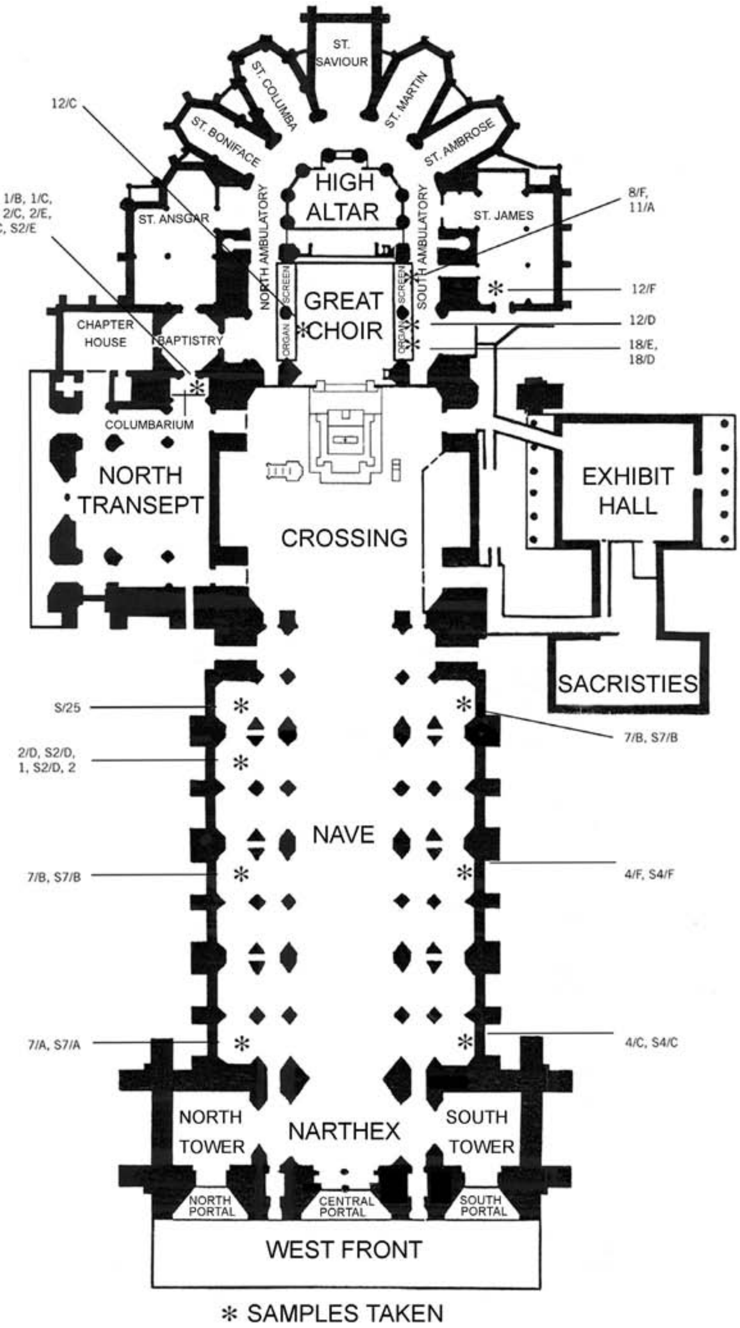

Figure 2 Plan of the Cathedral showing representative sample locations. Samples were collected at a variety of locations, close to and far from the north transept, and at different heights at each location.

granite is exposed. Common brick was also used for interior masonry wythes, though less typically than granite, and is exposed at a few locations in the crossing and ambulatories. The temporary north and south walls of the crossing are poured-in-place concrete. The dome of the crossing and the vaults of the ambulatory are Guastavino tiles. The ceiling vaults in the nave and choir are finished with a sound-absorbing type of Guastavino tile known as Akoustilith.

The fire

The fire that occurred in December of 2001 began in a small room in the northeast corner of the north transept. A temporary roof had been built on the unfinished north transept to allow for an interior use and comprised wood framing and sheathing, foam insulation, and bitumen-based built-up roofing. Since the 1980s, the ground level of the north transept had been used as a gift shop and this area was stocked with merchandise for the holiday season at the time of the fire. The fire began as a slow burning electrical fire which smouldered throughout the night and caught flame early the next morning.[3]

When the fire reached the temporary roof, it spread rapidly. However, since this roof structure was the only wood framing in the Cathedral, the fire did not spread rapidly to other areas of the building.

As the fire burned, it extended beyond the confines of the north transept at three general locations:

- onto the exterior north wall of the Cathedral, above the roof of the north transept;
- through the temporary concrete north wall of the crossing; and
- through a temporary wall construction of wood stud and gypsum drywall between the north transept and the columbarium.

The primary materials that burned were the roof and the merchandise in the gift shop. Two seventeenth-century tapestries that had been hanging on the north wall of the crossing were badly damaged by the fire. Eyewitnesses report that thick black smoke from the fire travelled throughout the entire interior of the Cathedral. The New York City Fire Department brought the fire under control within several hours (Figure 3).

The initial response

At the time of the fire, the Cathedral staff were able to respond immediately. Since the fire occurred in the early morning, some of the Cathedral staff were already at work. The Cathedral staff mobilized rapidly and acted as escorts for the firefighters. The escorts, who had good knowledge of the

Figure 3 A view of the interior of the north transept after the fire. Charred wood beams and partially melted bituminous materials from the roof structure are in piles on the floor. (Michael Schwartz/New York Daily News)

layout of the building, guided the Fire Department through the interior and assisted them by opening locked doors. The Cathedral was therefore able to avoid destruction of many valuable interior elements that would have otherwise been lost or damaged.

The smoke that filled the entire Cathedral greatly reduced visibility. This created difficulties for the firefighters, who were not familiar with the floor plan of this substantial building. It was suggested to the Cathedral staff that some of the stained glass windows be broken to allow the smoke to escape the nave. The Cathedral staff made the immediate decision not to break any of the stained glass windows with the knowledge that they would have to address the increased deposition of fire soil on interior surfaces that would occur.

After the fire was extinguished, the Cathedral wanted to re-open for holiday events and services. Because the fire occurred shortly before Christmas and large crowds were expected, it was decided that some measures were necessary to protect parishioners and tourists from contact with the heavy build up of particulate matter from the fire soil. The Cathedral staff mobilized a work crew that removed loose particulate matter from wall surfaces in the main interior of the Cathedral, from the floor up to a height of approximately 2.5 metres above the floor. Removal of the soiling was accomplished by wiping the surfaces with dry urethane sponges, similar to art sponges. The objective was to remove as much loose particulate matter as possible from the walls with a technique that would not damage the surfaces or leave a residue. The Cathedral successfully opened for Christmas 2001 services and has remained open to the public ever since.

The measured response

Initial assessment

The minimal intervention of limited sponge cleaning allowed for a rapid reopening of the building because the cleaning eliminated the risk that the public would come in contact with fire soil. It was then possible to research a logical long-term response and develop a long-range plan to address the damage and soiling caused by the fire.

The primary exterior materials that were affected by the fire were the smooth-sawn limestone, carved limestone, rough-cut granite, and poured-in-place concrete. The limestone and granite masonry in the north transept suffered severe spalling related to the heat of the fire and the rapid cooling caused by the use of water to put out the fire. Prevalent conditions included cracked, shattered, and spalled stone and thick accretions of a tar-like substance and other soiling. As the fire cooled and water infiltrated the now exterior stone walls, spalls continued to develop for days after the fire. Smaller losses occurred for some months (Figure 4).

The primary interior materials affected by the fire were the smooth-sawn limestone cladding and carved limestone, rough-cut and smooth granite, architectural woodwork, and the Akoustilith tile of the ceiling vaults. Smoke from the fire also travelled into the non-public spaces of the building, such as between the vaulted ceilings and the roofs, and into the circular stairways of the great choir and some of the access tower passages. The stairways and tower passages acted as chimneys, as smoke was drawn up through these areas, and large amounts of fire soil were deposited on the surfaces within them.

Additional materials in the interior affected by the fire included:

- limestone with polychrome coatings in the baptistery;
- decorative finish materials located primarily in the chapels, such as polished marble base boards and other trim elements, face brick with surface texture, ornamental metalwork, glazed ceramic tile, and mosaic tile;
- the monumental polished granite columns in the choir;
- ornamental woodwork with stain and clear coat finish lining the inner walls of the ambulatory;
- various pieces of artwork throughout the building;
- and the great organ and its related elements.

A series of objectives were developed to address the fire damage at the Cathedral systematically. The list of main objectives included:

- determine the extent to which the fire soil infiltrated the building;
- determine the appropriate methods for the removal of the fire soil;
- evaluate the damage to and potential restoration of the stone in the north transept;
- develop a plan for cleaning the entire interior of the building.

For purposes of this paper and in the context of this publication, the following discussion focuses on conditions and treatments related to soiling associated with the fire. Damage to the building, and repair and restoration work unrelated to cleaning treatments, are not further discussed here.

The fire soil darkened all surfaces to some degree; some materials were completely black. In addition to the north transept itself, the heaviest concentrations of soiling were directly adjacent to this space in two general locations: the baptistery and the columbarium. However, in other areas, it was not possible to macroscopically verify the presence of fire soil. The 109-year-old Cathedral had never been cleaned and, prior to the fire, interior surfaces had varying amounts of soiling on them. No comprehensive documentation of pre-fire soil conditions existed, so that it was not possible to prove by simple visual comparison that the coloration of surfaces was altered by the fire. In order to present a strong case for the insurance claim, it was necessary to provide clear evidence of the presence of fire soil.

Figure 4 The limestone in the north transept exhibits spalls from the stresses caused by the heat from the fire followed by sudden cooling when the water used to extinguish the fire hit the stone. The stone was blackened by the deposition of smoke, which was heavily laden with bitumen.

Sampling at the source of the fire

In order to determine on which surfaces in the Cathedral's interior fire soil was deposited during the fire, it was first necessary to identify and characterize fire and smoke deposits from known sources and then compare the identified fire soil with samples removed from throughout the interior of the Cathedral.

Samples of burned materials from the north transept were collected for analysis and placed in sealed plastic bags. These samples were collected from representative areas that included a partially burnt wood beam and several burnt modern roofing materials from the temporary roof and charred limestone spalls. In addition, three small objects (two ceramic figurines and a metal tea tin) that had been exhibited for sale in enclosed display cases at the time of the fire were removed and placed in sealed plastic bags. It was assumed that these items would have been relatively clean and free from soiling before the start of the fire. Accordingly, the soiling found on these items could unquestionably be documented as fire soil and therefore could serve as a means of comparison with soiling samples taken at other locations.

Visual microscopy was the primary means of comparing confirmed fire soil with unknown soiling samples removed from various locations throughout the building. Morphological characteristics of the particles found in the soiling, including colour, texture, shape, and size, were primary identifiers. In addition, semi-quantification of the amount of fire soil particles deposited in specific areas was attempted using visual microscopy.

First, visual characterization was performed of the typical burnt materials of construction in the north transept: pieces of charred wood, melted modern roofing materials, insulation and stone. Then, the soiling on the two ceramic figurines and the metal tea tin was examined and compared with the burned materials of construction.

Visual characterization was performed using a Nikon SMZ-U stereobinocular microscope with fibre-optic light source and a magnification up to 75X, as well as a Zeiss SV-11 stereobinocular microscope with fibre-optic illumination and a magnification up to 125X. Under magnification, small particles of burned construction materials and charred wood fibres were observed in the soiling found on the two ceramic figurines and the metal tea tin. Soil particle sizes ranged from very large fragments (up to 1 mm in length and visible to the naked eye) to very small fragments visible only under the highest magnification (125X). The particles were primarily rectangular or oblong fragments resembling thick splinters of charred wood. In addition, a black glassy substance visually resembling bitumen or tar was observed in varying shapes and sizes including perfect spheres, fragmented spheres and attenuated globules. The microscopic particles resembled the large globules of fused material found on the samples of building materials. Various other inorganic materials observed in the soil included: stone and mortar fragments; sand particles; and melted modern construction materials such as roofing felt and insulation (Figures 5a, 5b, 5c and 5d).

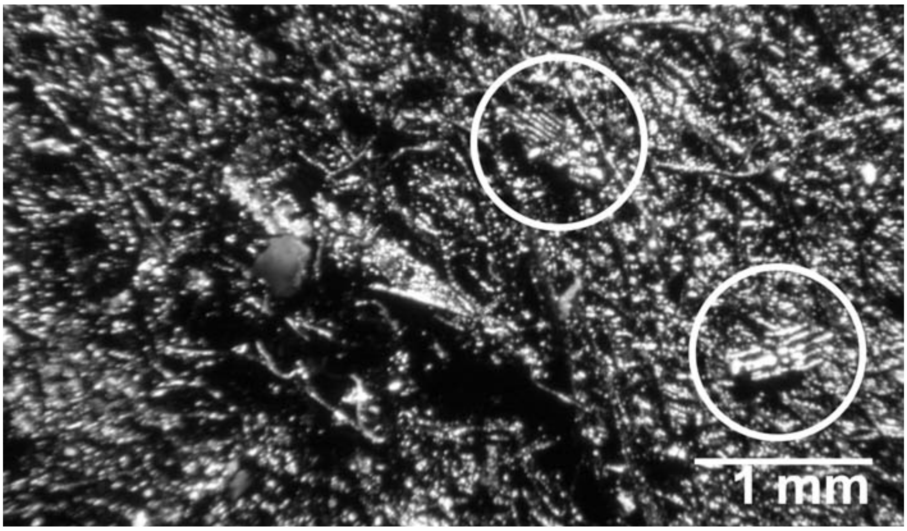

Figure 5a Particles from charred wood beams (in white circles) found on fire damaged roofing materials recovered from the north transept (25X).

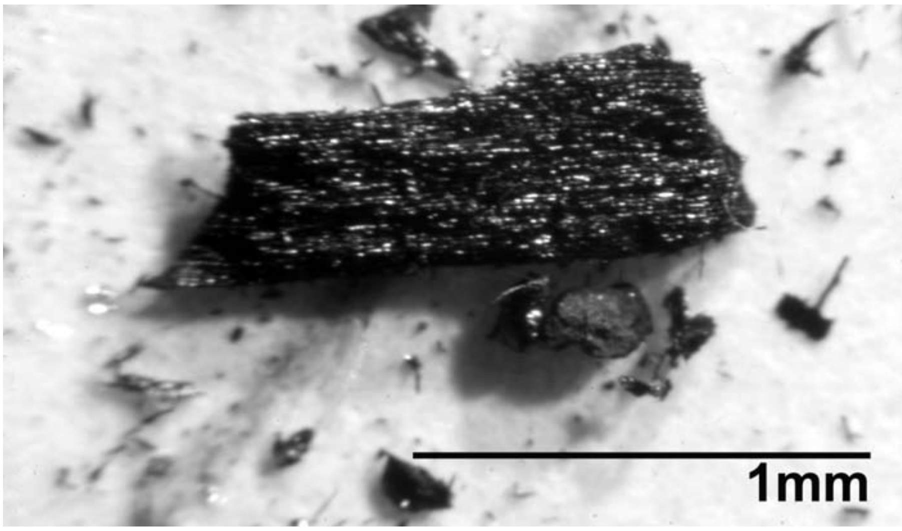

Figure 5b Charred wood particle isolated from a sample taken from the north transept represents the typical shape and colour of the smaller particles found in samples taken throughout the Cathedral (62.5X).

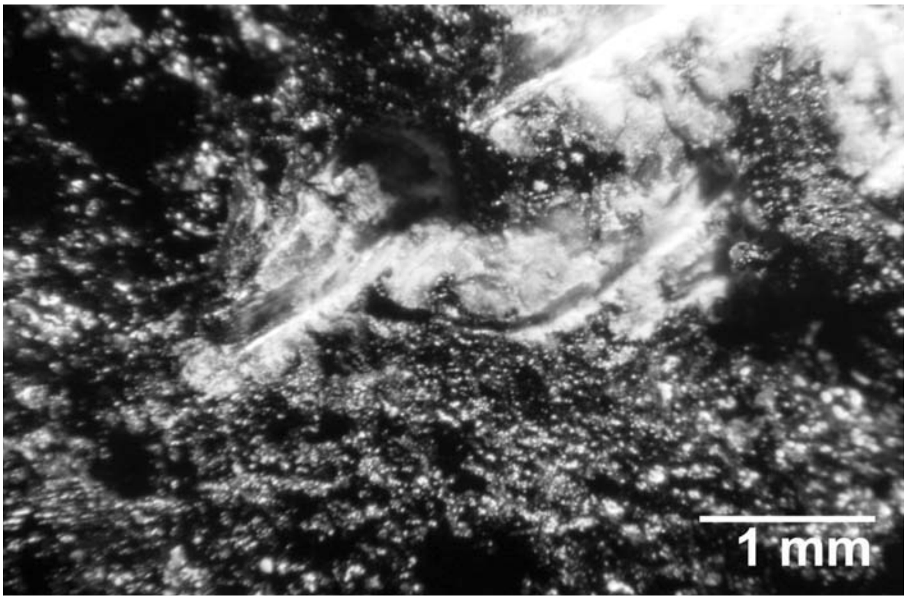

Figure 5c Burned bituminous roofing material on stone recovered from the north transept (25X).

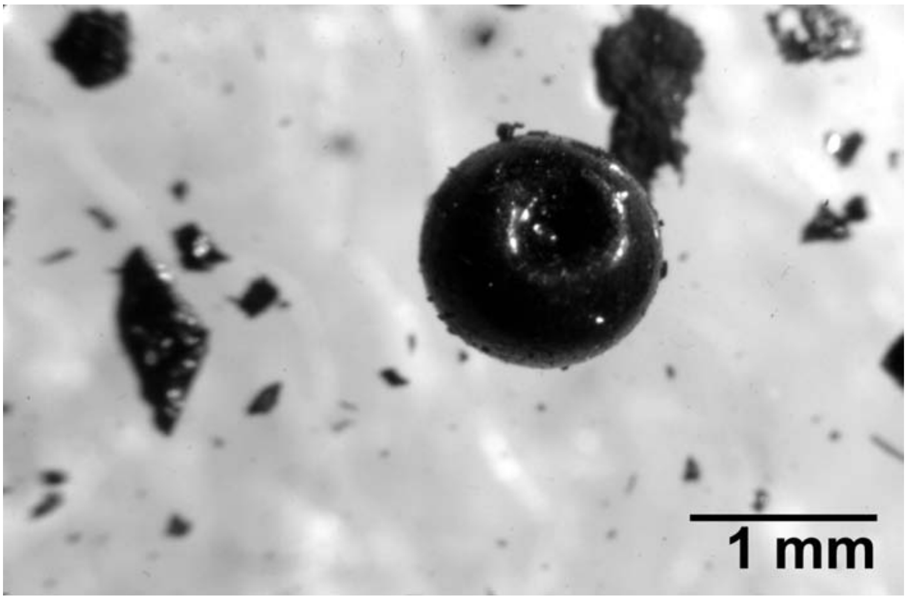

Figure 5d Large bitumen sample taken from the north transept represents the typical shape and colour of the smaller particles found in samples taken throughout the Cathedral (25X).

Through this microscopic examination, the source of the particles found in the soiling on the figurines and the tea tin – soil that was known to be a result of the fire – could be directly ascribed to the materials of construction that burned during the fire. In this way, the typical morphology of the fire soil was established. The characteristics identified in these observations became the primary identifiers for fire soil.

Interior sampling method

Once the characteristics of the fire soil were determined, the next step in the process was to confirm the deposition of fire soil on the interior surfaces. Accordingly, 144 soiling samples were systematically collected from the architectural surfaces. Samples were obtained from alternate bays in the nave at various heights from the floor to the ceiling vaults as well as in the ambulatory, chapels, columbarium, baptistery, spiral staircases, and roof access ladder wells. In addition, several samples were collected from behind a painting that was hanging on the wall of the Chapel of Saint Saviour at the time of the fire. It was hypothesized that the samples removed from behind the painting would represent the typical atmospheric soiling found on the interior of the Cathedral prior to the fire.

A two-part sampling method was developed for general qualitative analysis and semi-quantitative analysis. The first method used double-sided tape adhered to paper index cards. The tape and cards were pressed against the soiled stone surface, lightly rubbed, and then peeled back. The fire soil adhered to the double-sided tape (Figure 6). The cards were labelled and then stored in plastic cases manufactured for storage of compact discs. This method proved beneficial in identifying, cataloguing, protecting, and storing the samples. The tape method allowed for characterization of the fire soil under microscopic examination, and provided a semi-quantitative analysis of the concentration of the fire soil in specific areas.

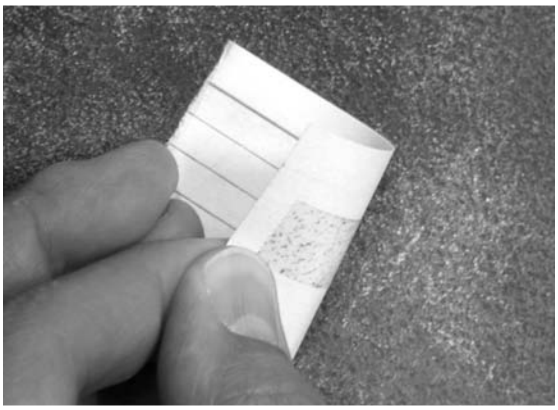

Figure 6 Double-sided tape was adhered to paper index cards and then pressed against the stone surface to remove samples of fire soil.

The second sample method used sterile rayon/cellulose gauze pads wiped across the soiled surfaces of the areas adjacent to the tape samples. The pads removed bulk samples of the fire soil for further analysis. They also served as a back-up method for areas where no fire soil appeared to attach to the tape.

In isolated areas, such as on polished marble surfaces, it was difficult to ascertain if any fire soil was collected by the above methods. In these areas samples were removed using a vacuum with a soft clean brush attachment and a fresh bag for each location. Following collection, the vacuum bags were placed in sealed plastic bags.

Characterization of samples

A systematic microscopic examination was conducted of the samples removed with tape from throughout the Cathedral. Observations showed that the charred wood fibres and the glassy bitumen globules were present in all samples, from the ones closest to the fire removed at the columbarium to the ones farthest away at the narthex. The charred wood fibres and the glassy bitumen globules were even found on the surfaces that had been dry wiped with a sponge immediately following the fire. Generally, the quantity of particles and particle size distribution varied depending on the distance from the fire and whether or not the surface had been partially cleaned; smaller quantity and size were typically found in the samples from locations farthest away from the fire and where the wall had been wiped with the dry sponges. However, the characteristics of the soil particles were virtually identical on every sample taken (Figures 7a, 7b, 7c, and 7d).

The only exception to this finding was the samples taken from behind the painting in the Chapel of Saint Saviour. Identified fire soil was not found in these samples. Lack of fire soil in this protected area allowed for a clear distinction between fire soil and the general, older atmospheric soiling present on the stone. Combined with evidence of fire soil on the unprotected stonework near the painting, lack of fire soil behind the painting offered further evidence of the spread of the fire soil.

No stone or sand particles and none of the more fibrous melted materials were observed on the samples removed with tape from the interior masonry surfaces. This suggests that the heaviest particles in the smoke from the fire fell out of the air relatively quickly and only the charred wood fibres and the bituminous particles travelled to the interior of the Cathedral. The bitumen particles are heavier than the charred wood fibres; the highest concentrations of bitumen particles were found closest to the fire and were most prevalent in samples removed from the columbarium. A high concentration of charred wood fibres, with relatively few particles

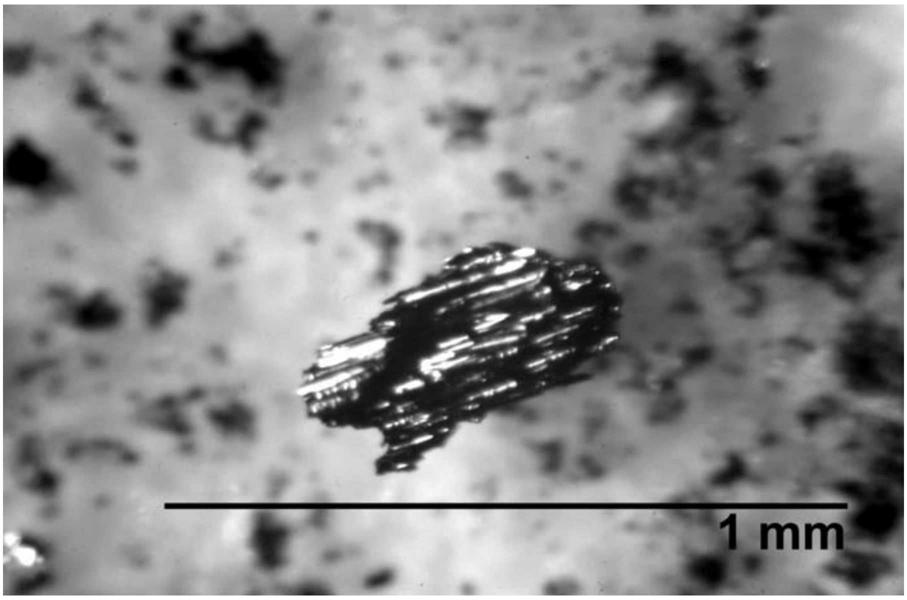

Figure 7a Sample removed from a bay in the nave at a height of 6 m (100X). Charred wood particle matches the morphology of those found in the north transept (as seen in Figures 5a and 5b), but is much smaller in size.

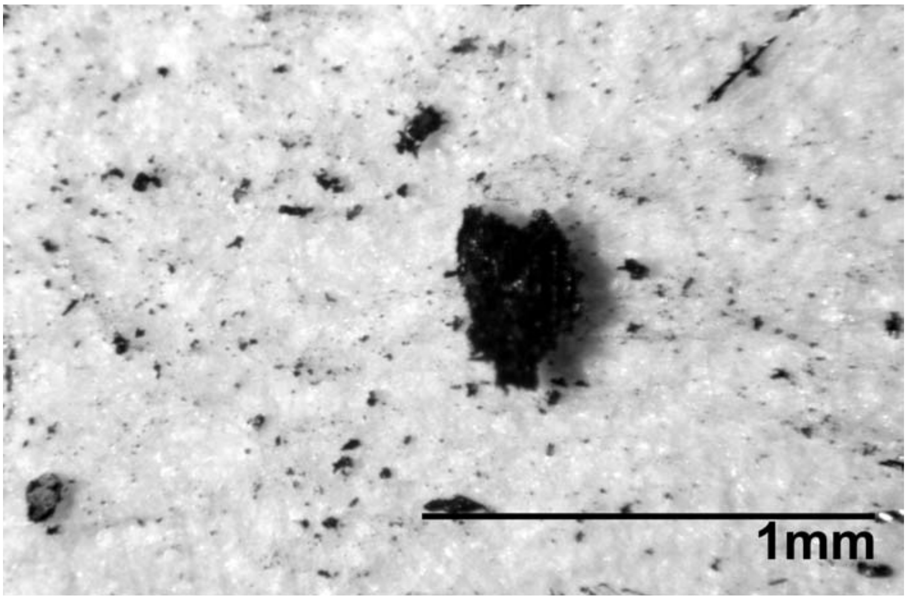

Figure 7b Sample removed from the narthex, more than 122 m from the north transept (62.5X). Charred wood particles reduce in size farther from the north transept.

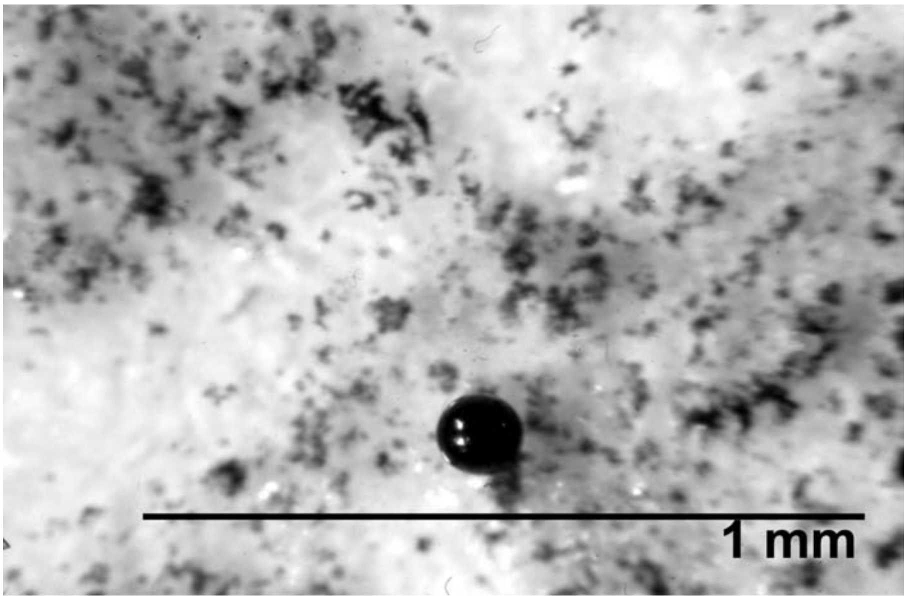

Figure 7c Sample removed from a bay in the nave at a height of 6 m (62.5X). Bitumen globule is much smaller in size than the one seen in Figure 5d but exactly matches in shape and colour.

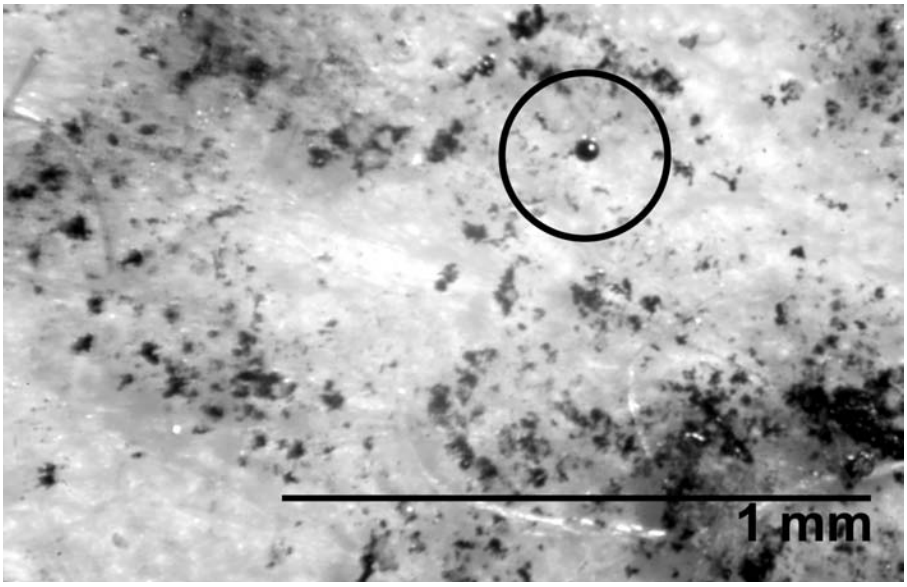

Figure 7d Sample removed from the narthex, more than 122 m from the north transept (80X). Small bitumen globule (in black circle) matches the shape and colour of those seen in both Figures 5d and 7c.

of bitumen present, was found at sampling locations farthest from the fire. In addition, very few bitumen particles were found in the samples removed from the ceilings.

Microscopic analysis of the samples removed with tape provided clear evidence of the prevalence of the fire soil in most cases, Therefore, with the exception of the Akoustilith ceiling tile, where it was not possible to remove a sample using tape, the bulk samples taken with sterile cotton were not analysed.

The analysis provided sufficient documentation to successfully file an insurance claim proving that fire soil penetrated to all areas of the building and that, consequently, there was a need to clean all interior surfaces. This was a crucial step in the planning process. With the knowledge that insurance monies would be available to clean the entire building, the Cathedral staff were able to move forward confidently with the development of a programme for comprehensive interior cleaning.

Cleaning test program

The next step in the process was the development of a comprehensive cleaning test programme for all interior materials. The large majority of interior surfaces are clad with either limestone or granite; there are over one million square feet of limestone and granite cladding on the interior of the Cathedral. Therefore, these stones became the primary focus of the cleaning test program. A cleaning test program was also developed for all other interior cladding materials, however, it will not be discussed further in this paper.

The fire soil on the granite and limestone was divided into two categories: lightly and moderately soiled stone (in areas more removed from the source of the fire); and heavily soiled stone (at and directly adjacent to the source of the fire). The analysis of fire soil had shown that the primary components of the fire soil were different close to and far from the source of the fire. The heavy bitumen particles fell out of the smoke more quickly and deposited on surfaces close to the fire. The charred wood and other light particulate matter travelled farther. The removal of the bitumen requires very different products and techniques from the remainder of the soil types.

Since an analysis of the soil on the walls where the initial cleaning had been performed using sponges showed that fire soil still remained on these surfaces, it was known that mild mechanical methods could not completely remove the fire soil. The two basic categories of cleaning methods for architectural surfaces of significant size are wet chemical cleaning and abrasive cleaning. Neither of these methods permits selective removal of fire soil from masonry. An attempt to partially remove soiling from the masonry carries the inherent risk of producing a surface that is not uniform in appearance, which would not be an improvement on the appearance of the building prior to the fire. It was therefore deemed necessary to develop cleaning methods that would remove both the fire soil, and the general soiling and stains that had developed over the course of time.

Another important consideration was that all work would be done on the interior of an occupied building. Although the Cathedral was large enough to permit work to proceed in one protected area while public activities continued in other areas, there was still a risk of the transport of cleaning agents, the migration of odours of cleaning agents, and the travel of noise created by the cleaning method. In addition, the control of water used to clean or rinse masonry is difficult on a building interior.

A third consideration was that, given the enormous size of the building and the consequent logistics of assembling equipment and performing any one cleaning method, it was desirable to develop a single method that would successfully clean both the limestone and the granite.

The generic types of chemical cleaning agents and methodologies that are appropriate for use on limestone and granite have been thoroughly addressed by others.[4] Limestone is a relatively soft calcareous stone. Granite is a much harder, essentially siliceous stone. The different mineral components of the two stones react differently when subjected to different chemical cleaning agents and, during abrasive cleaning or water rinsing, will safely withstand very different levels of pressure. Therefore, although similar cleaning tests were performed on both stones, the tests were tailored to ensure appropriate methods for the two types of stone.

A series of small (approximately 20 cm × 20 cm) wet chemical cleaning tests were conducted on both the limestone and the granite. A range of chemical agents were employed, including acids, bases, bases and acids applied in sequence, solvent, and detergent cleaners. The same general procedure was used for each test: the surface was pre-wet (if required by the type of chemical used), then the chemical was applied and kept on the surface for a pre-determined period of time, the surface was then scrubbed with a soft bristled brush, and it was finally rinsed with pressurized water. Very low pressure (less than 100 psi) was used wherever possible. When necessary to ensure complete removal of chemical, a 500–700 psi water rinse was employed (Figure 8).

Several different wet chemical cleaning methods successfully cleaned the lightly and moderately soiled surfaces. None of the tests were successful in removing the heavy bitumen build-up. A number of issues indicated that wet chemical cleaning would not be appropriate. Strong acids and bases have inherent risks in an interior occupied space and some chemicals have pungent odours that are unacceptable. Other chemicals release gases that

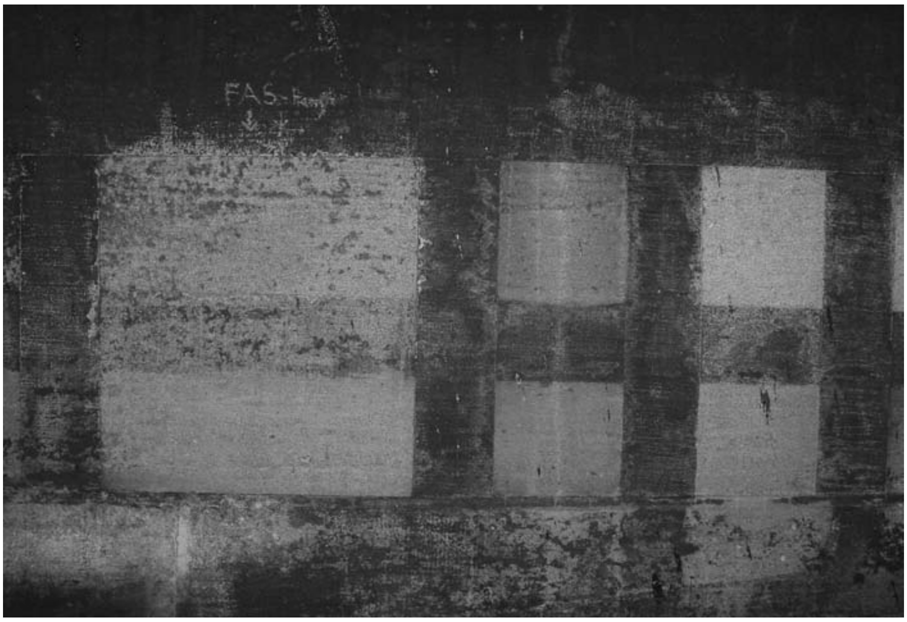

Figure 8 Tests were conducted to determine the effectiveness of wet chemical cleaning for the removal of the fire soil and pre-fire general soiling.

could have deleterious effects on interior materials such as glass and wood. All chemical cleaning agents require a thorough rinsing. Given the extent of surfaces to be cleaned, there would be an enormous amount of water to contain, collect, and dispose of. Even with thorough rinsing, chemical products can introduce the risk of leaving residues in the stone, where they can cause later damage. Use of copious amounts of water also introduced the risk that older soiling within the stone might be displaced by the cleaning action. Both organic materials and salts that had infiltrated the stone over the years – primarily from leaks in exterior walls – might be mobilized, creating additional stain issues and, more importantly, issues related to salt crystallization within the stone units.[5]

Low pressure abrasive methods were also tested, using a variety of abrasive media including dry ice, particles of sponge, particles of sponge with abrasives embedded in them, and mineral powders.[6] At very low pressures (less than 50 psi), both particles of sponge with abrasives embedded in them and mineral powders appeared to clean the lightly and moderately soiled stone without damaging the substrate. Dry ice caused damage to the stone at any pressure. None of the tests were successful in removing the heavy bitumen build-up. In order to confirm that the abrasive methods had not altered the substrate of successfully cleaned stone, 12 mm diameter cores were removed for analysis. Each core was located so that half the core was of the cleaned surface and the other half had not been abrasively cleaned. Each removed core was then split in half lengthwise and the surface was viewed in cross section under magnification. In this way, the surface topography of cleaned and uncleaned stone could be compared. Results showed that the surface of the stone had not been altered by the cleaning method. However, a number of issues indicated that abrasive cleaning would not be appropriate. The containment of abrasive media was of particular concern; not only would full containment of the work area be very costly, but any break in the protection would result in rapid spread of media to other areas. Importantly, the success of an abrasive system is highly dependent on the skill of the worker and his ability to achieve consistent results. Variations in working distance from the surface to be cleaned, in the amount of time spent cleaning each area, and even in the specific arm movement used can result in significant visible variations on the cleaned surface. Given the quantity of large flat surfaces to be cleaned, this was deemed a high risk factor. Finally, with proprietary abrasive systems it is not possible to follow the typical process in which a number of masonry cleaning contractors submit pricing for a project, and then the most competitive bid is awarded the job.

A series of tests were also conducted using a liquid latex with and without chemical additives as the cleaning agent.[7] All surfaces were vacuumed prior to application. The latex was applied to the surface using spray equipment. It remained on the surface until cured, at which time it was peeled off in sheets. The masonry was scrubbed with a soft bristled brush and then wiped with sponges dampened with water to remove residue. The latex with a chemical additive successfully cleaned the light and moderately soiled stone, but did not clean the heavily soiled stone. It was theorized that the latex would keep the chemical additive at or near the surface of the masonry, making it less likely that the salt component of the chemical would be absorbed into the stone and minimizing the amount of water needed to rinse the stone. Testing confirmed that this theory was correct.[8] The spray application was useful in that it would be possible to cover large surfaces in a short period of time. However, there was still concern that, despite protective measures, overspray could migrate to other areas in the building. The risk was felt to be much lower than for abrasive systems because the latex is heavy and tends to fall out of the air close to the expulsion point.

The positive and negative aspects of each cleaning system were assessed. The decision was made to clean the lightly and moderately soiled granite and limestone using the latex system. Because no method was found to clean the most heavily soiled stone, consideration is being given to replacing this stone in some cases and leaving it in its soiled state in others. Attics and some other secondary, non-public spaces will be vacuumed only, to ensure that no loose fire soil can migrate to cleaned spaces.

Cleaning began in February 2005. The work is being performed in phases so that at all times some areas of the building are open to the public. It is anticipated that all work will be complete within three years. The work is being performed by a masonry cleaning contractor, and monitored by a team of architectural conservators.

Conclusions

A direct correlation was made between the materials of construction that burned during the fire and the particles present in the samples of soiling removed from throughout the Cathedral. It was therefore possible to establish that the soil from the fire had penetrated to all areas of the Cathedral. Evidence of fire-related soil was found from the narthex to the ambulatory and from the lowest sections of the walls to the ceiling vaults. Evidence was also found in non-public areas, such as enclosed stair halls, walkways above the chapels, and the interstitial space between the ceiling vaults and the roof.

In almost every sample examined, charred wood particles and bitumen globules were present. The particles had the same morphologies, matching in colour, texture and shape. The one major differentiating characteristic was their size; variation in size had a direct correlation to the distance of the sample from the fire.

The immediate organization and the response of the Cathedral staff working in cooperation with the New York City Fire Department saved priceless materials and artwork in the building. The decision to remove a minimal amount of the loose particulate matter initially, using a method that did not adversely affect the existing historic materials, was a solution that did not interfere with the creation of a measured response. While the Cathedral continued to function, the project team was provided the time and opportunity to develop a testing matrix and use analytical techniques to characterize the fire soil and confirm that the fire was the source of the soiling found throughout the building. The systematic documentation contributed to the successful settlement of an insurance claim.

The information then assisted in the development of a comprehensive cleaning test program for all interior materials. The testing program resulted in the development of specific cleaning techniques for removal of fire soil. Cleaning of the Cathedral interior is currently in progress.

Biography

Claudia Kavenagh
Claudia Kavenagh received her MS in historic preservation from Columbia University's Graduate School of Architecture, Preservation, and Planning. She is director of the New York offices of Building Conservation Associates Inc (BCA), where her work combines the disciplines of historic preservation and materials conservation for the restoration of buildings and monuments.

Christopher John Gembinski
Christopher Gembinski has been with Building Conservation Associates Inc since 1998. Through his work on numerous large-scale projects, he is versed in restoration repairs for a wide range of historic building materials. As an experienced conservator, he has performed laboratory analyses using analytical techniques including visual microscopy, x-ray diffraction, ultrasonic testing and Fourier transfer infrared spectroscopy to characterize historic architectural materials. He has also worked for the contracting firm Archa Technology, Ltd. as the superintendent and project manager. He is a graduate of the University of New Hampshire and received an MS in preservation from the University of Pennsylvania.

Acknowledgements

Materials analysis was performed by George Wheeler, Director of Conservation in the Department of Historic Preservation at Columbia University and research scientist in the Department of Scientific Research at the Metropolitan Museum of Art. BCA's project team for the field and laboratory work also included Kevin Daly and Richard Pounds.

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