CHAPTER 5

RESTORING STONEWORK

RESEARCH

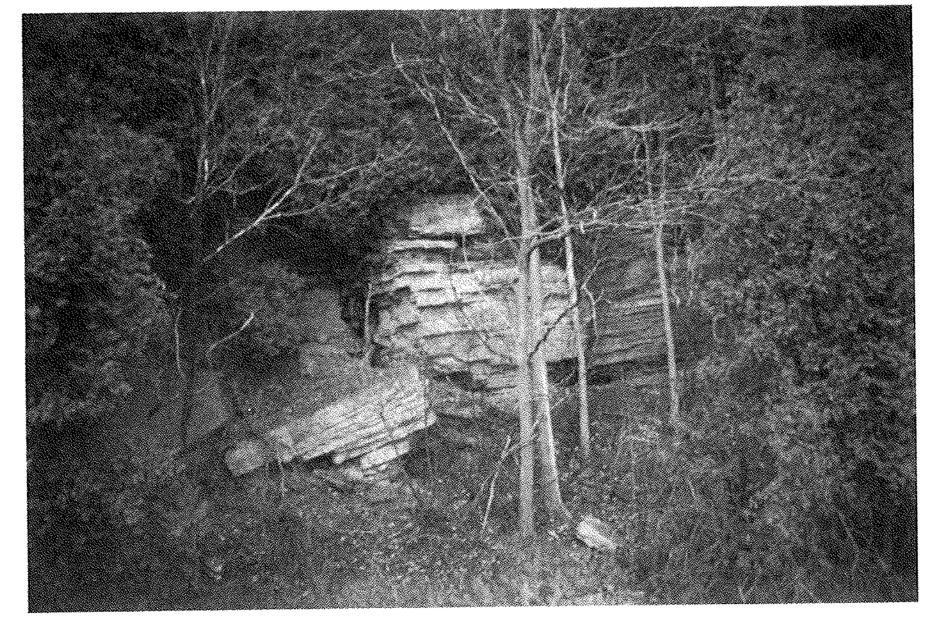
Many of our finest heritage buildings were built of stone or in more recent years were faced with a stone veneer over a steel or concrete frame. When the stonework deteriorates its restoration can pose many problems, especially for those who have not been trained in the conservation of buildings or those who have not had any experience in dealing with such materials and systems. This is the first of two sections to examine the whole process of stone restoration.

When the first European settlers came to North America they tended to use stone which could be simply picked up from the surface close to the site of the building. Sometimes stones were used just as they were and sometimes they were roughly squared. As more time became available for building purposes, stone was quarried from shallow excavations into hillsides or into river cliffs. The density and therefore great weight of stone made it difficult to move long distances over the primitive early roads. Thus a stone was often selected primarily for its accessibility and only secondarily for its durability. Stones were often quarried from sedimentary rock formations of limestone or sandstone. This was because the stone split very readily into roughly rectangular blocks which needed little or no further work to be used in coursed rubble work. From the beginning of the nineteenth century the quarries got larger and deeper and steam power was used both to cut larger stone blocks from their beds and to lift the blocks from the deeper quarries. Initially stones were carried long distances by boat or barge on various waterways, but by the middle of the century, the railroads were also being used to move large quantities of stone. While earlier public and commercial buildings tended to be built using stones from the same state or province, gradually the opening up of North America combined with the poor performances of some stones led to the development of certain major sources of excellent and more durable stones, particularly Ohio sandstones, Indiana limestones, and Vermont and Quebec granites. The earlier small quarries either ran out of usable stone or they were abandoned because of poor quality, inaccessibility, and flooding, or because they were simply uneconomic to run.

The stone industry flowered again for certain quarries in the early twentieth century and then faded, first with the growth of the use of architectural terracotta and then with the use of reinforced concrete. In more recent years technological advances particularly in the development of diamond sawing and flame cutting and finishing have started a new revival of interest in the use of stone as a beautiful and durable natural material.

When we are faced with deteriorated stonework in an old building, it is the current scientific practice to ask a series of questions and obtain answers by means of a combination of documentary and scientific research. The following list of questions with possible sources and methods for obtaining answers may be helpful.

What General Types of Stone Occur in the Masonry? For example, the stones may be of igneous, sedimentary, or metamorphic origin, such as granite, syenite, gabbro, calcareous sandstone, quartzite, limestone, dolomite, gneiss, and slate. The actual types are usually best recognized from experience and some spot tests, but records may exist. Extreme caution should be exercised with such sources because the actual

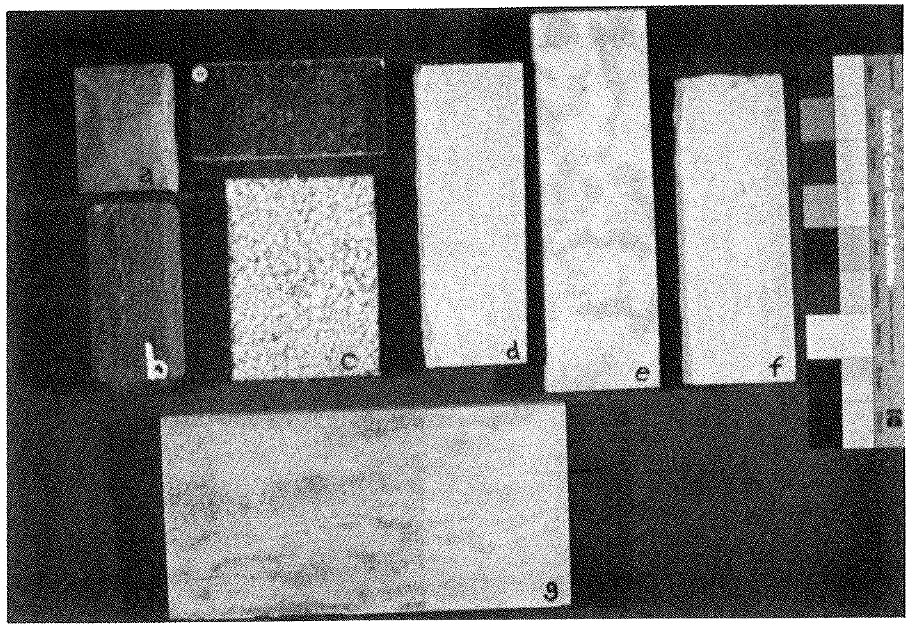


Small quarry close to 19th century Ontario house.

stones used were often not the same as the ones described in the specifications.

Where Did the Original Stone Come From and From What Specific Geological Formation? What historical data exist on the stone, for example, early geological reports and chemical analyses of the stone? Is this stone still available? If not, are there any similar stones which could be used as substitutes for restoration and/or repairs? In North America the primary sources for the historical information are the state geological surveys in the United States and William A Parks' *Report on the Building and Ornamental Stones of Canada*. The five volumes of this report were pub-

House built from very local stone.



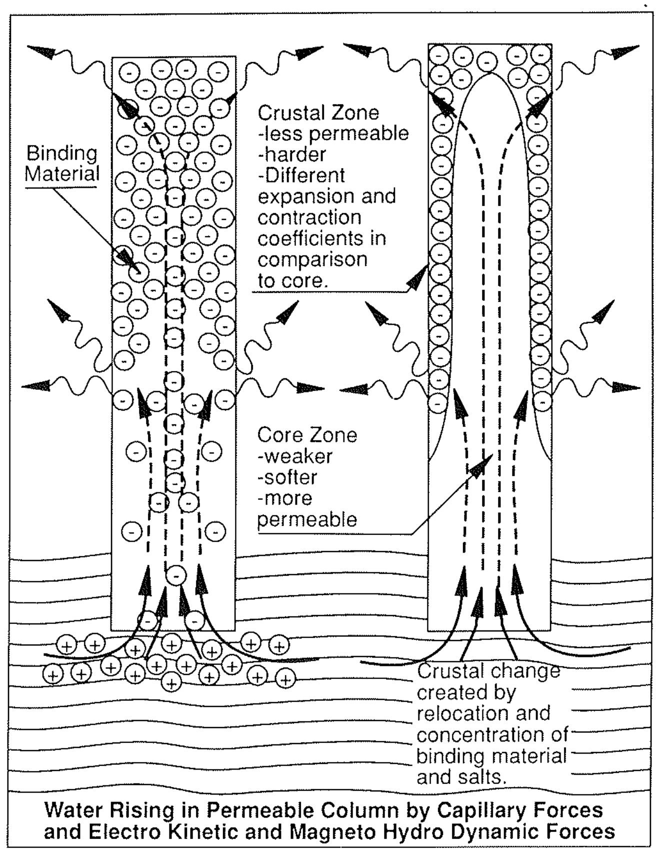
Canadian historical building stones include: a. Wallace olive grey sandstone, Nova Scotia; b. Sackville red sandstone, New Brunswick; c. Deschambault limestone polished and bush hammered, Saint Marc des Carrieres, Quebec; d. Queenston dolomite limestone, Ontario; e. Tyndall mottled magnesian limestone, Manitoba; f. Nepean sandstone, Ontario; g. Adare "marble", dolomite, Ontario.

This group of granites from the United States shows the great diversity which is to be found even within such a small selection. (a) and (e) are Stoney Creek granites from Rhode Island. (c, c1) Grey Tapestry granite from the Baretto Granite Corp. New Hampshire. (f) is a Cold Spring Granite Co., Spring Green (i, j1, j2) are Westerly blue, light and pink granites from Rhode Island. (l) is a Cold Spring Texas Red granite. (m) is a Barre blue grey granite from Vermont.

Similarly this group of sandstones and limestones from the United States again illustrates rich diversity. (b) and (c) are Bluestones from the Catskills, New York State. Two samples marked (e, e1) are Scioto sandstones from Ohio. Four examples marked (h) are Briar Hill sandstones from Ohio. (i) is a Berea sandstone from South Amherst, Ohio. (k, k1) and (n) are Indiana limestones with various finishes. (m) is a Texas shellstone, a fossiliferous limestone.

lished in Ottawa, Ontario, by the Department of Mines, in the first two decades of this century. Contemporary stone trade journals such as *Stone Magazine* or *Through the Ages* often described the stones used in major commercial and public buildings but such sources should be treated with caution since their articles were often based on press releases and these were not necessarily based on up-to-date information. To locate the same quarries if they still exist may take a lot of detective work but once again state and provincial geological and mineral resource agencies are among the best sources. Some stone supply companies may be able to match stones which are no longer available, by going to other sources and even to other countries.

What was the Geological and Mineralogical Nature of the Stone? What are the current chemical constituents of the stone? Current natural constituents and contaminants will need to be distinguished from each other. Once again this information comes partially from the state geological surveys and from Parks' *Report*. The documentary research is usually backed up by x-ray fluorescence (XRF) and x-ray diffraction (XRD) analyses to determine the chemical constituents of the stone both qualitatively and quantitatively. Scanning electron microscopy (SEM) is frequently used with XRF microprobe to show the actual structure of the stone, for example, with pollutant salts lodged in eroded fissures in the deteriorated stone surface. A great deal of the identification of minerals such as quartz and feldspar may also be accomplished by examining thin sections of the stone under a petrological microscope with transmitted light and polarized light. Thin sections are cut with a diamond saw and are mounted on glass slides where they are abraded down to a thickness of about 7 or 8 μm using water and carborundum papers. Once the microscopic analyses have been made, the information so gained can be passed on to the conservators. Why is this information so critical? The deterioration of stones can only be understood when one knows the chemical constituents of the stone, the cohesion between the crystals or grain structure of the stone, and the nature of pollutant salts and other substances deposited on and within the stone. The possibilities of chemical and physical transformation of crustal layers, for example, can also be understood only in the context of the chemical constituents of the stone. The stone can not even be cleaned without a basic knowledge of the chemical constituents. For example, if chemical cleaning methods are to



Biological Activity

Trees - Shrubs **Plants - Grasses** **Mosses - Lichens** **Fungi - Algae** **Bacteria**	**Insects** **Marine borers** **Burrowing animals** **Birds**

Aesthetic *Staining and discolouration* - Mud deposits - Algae - Fungi - Birds - Insects **Solution:** **Removal of binders** - Root secretions - Bird droppings **Formation or deposition of soluble salts** - Bacteria - Bird droppings	**Mechanical** *Splitting and prying apart* *Root action* *Abrasion;* *Moving branches* *Boring of holes* - Tree roots - Tree branches - Plant and lichen roots - Marine borers - Burrowing animals - Insects - Birds **Retention of moisture in or on surfaces** - Trees - Plants - Mosses

Figure 36. Deterioration of masonry material and structures.

be used, acidic cleaners tend to destroy stones based on carbonates and strong alkalis often tend to react with ferrous iron to form highly undesirable ferric hydroxide staining.

Does the Stone have a Pronounced "Grain," Bedding Plane, or Similar Structure? If pronounced grain or bedding planes are present, how was the stone placed in the structure in relation to them? Are any stone blocks delaminating because of incorrect orientation of the bedding planes? Usually there are standard orientations for the bedding planes in any masonry. The blocks are laid so that the bedding planes are perpendicular to the direction of loading.

In normal ashlar work the bedding planes should be parallel to the ground. In copings, projecting cornices, and belt courses, the bedding planes are arranged to lie vertically and at right angles to the face of the wall. In arches the bedding planes are so arranged that they are at right angles to the face of the wall and parallel to a line through the center of each voussoir to the center of the relevant arc of the arch.

In cases where the stone was laid with its bedding planes vertically and parallel to a major exposed face the stone tends to delaminate and peel away layer by

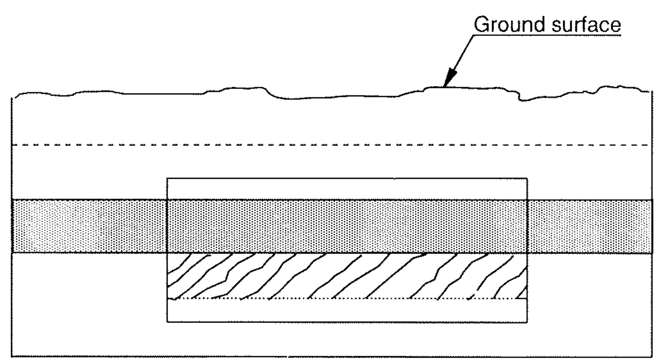


Figure 37a. Bedding planes: side view.

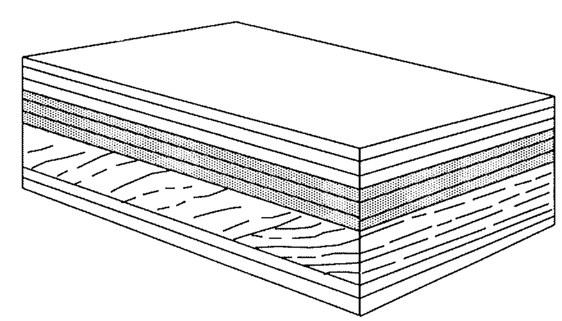


Figure 37b. Bedding planes: perspective view of removed section.

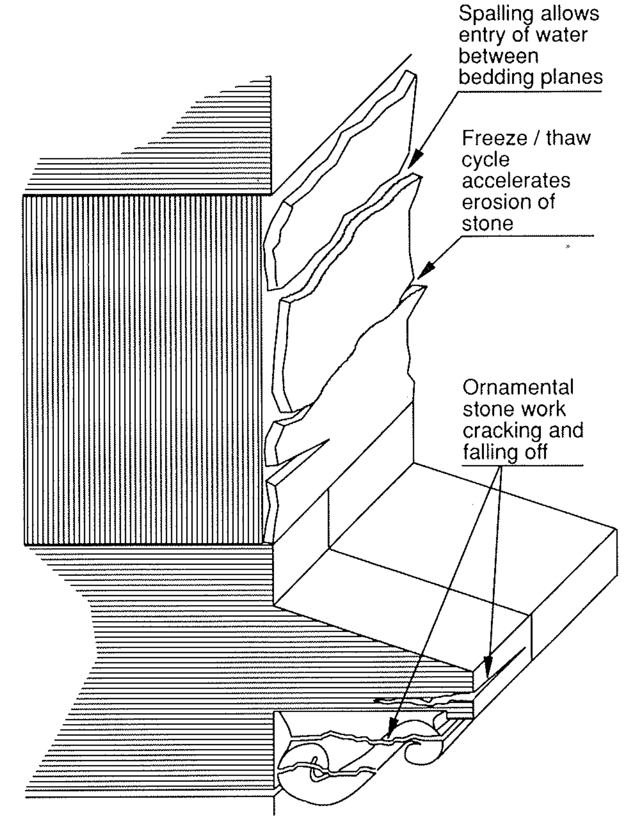
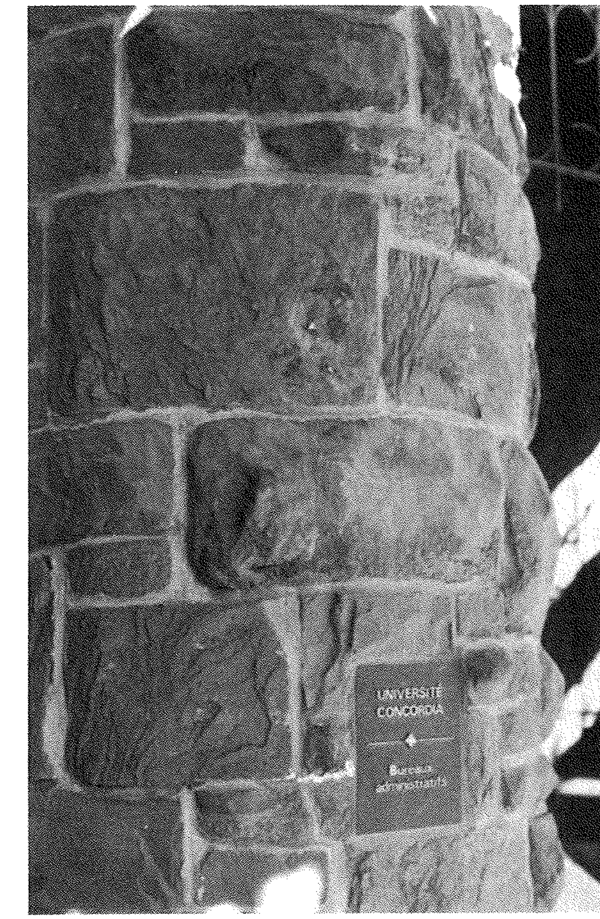


Figure 38. Incorrect orientation of bedding planes.



Face bedding problems.

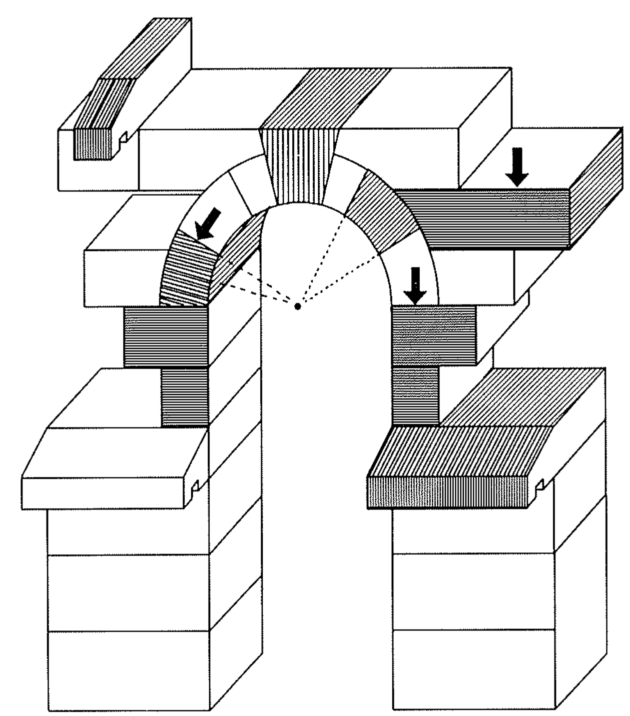
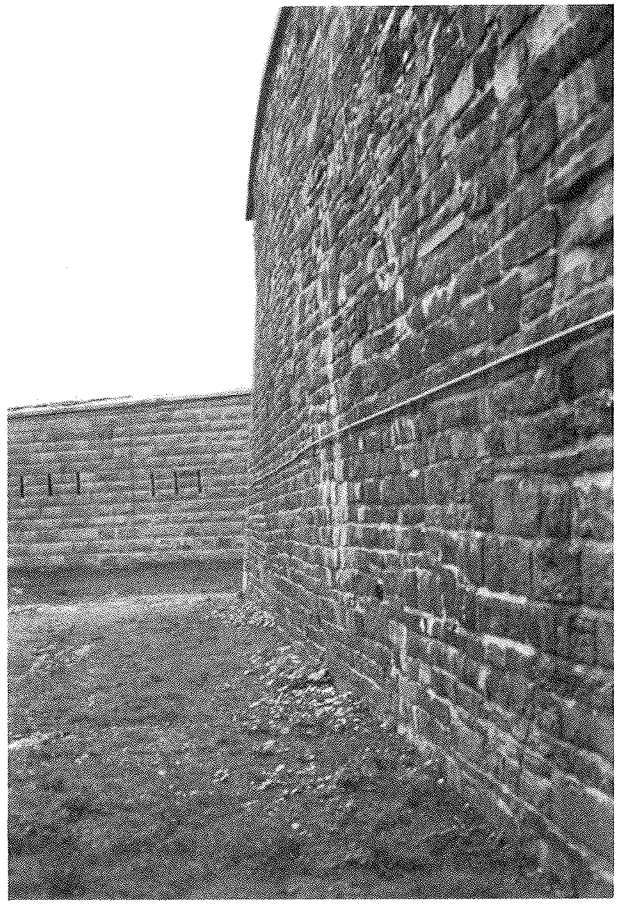


Figure 39. Correct orientation of bedding planes.

layer. This fault is referred to as "face bedding." Projecting cornices often tend to lose carved details and particularly modillions from their undersides where such details crack away along the bedding planes.

How were the Stone Units or Blocks Placed in the Walls? Is the masonry solid or are there inner and outer wythes separated by rubblework and/or cavities? How are the inner and outer wythes bonded together? Are the inner and outer wythes made from different types or qualities of stone?

Where the inner and outer wythes are insufficiently bonded together the outer wythe frequently buckles outward under load, first developing a major bulge and then possibly even collapsing. The buckling will often occur because of differential loading on the inner and outer wythes.



Bulging wall face caused by loss of internal mortar.

Are the Stones Wholly or Partly Water Soluble? For example, alabaster or crystalline calcium sulfate is partially water soluble. Are the stones wholly or partly acid soluble? Carbonate rocks such as limestone and marble are soluble in acids. Do the stones show any signs of having been partially dissolved? Stones which are partially soluble in water and acids such as acid rain will often hold up remarkably well until an open mortar joint, an eavestrough, or a rainwater pipe leaks into the masonry on a prolonged basis. Then the stones may be totally destroyed. In such situations, remedying leaks and carrying out limited repairs to mortar and some stones may greatly extend the life of the stone masonry.

Are there Accumulations of Water-soluble Salts on or in the Surface of the Stones? Powdery deposits of crystals of various salts on the surface are termed efflorescence. When they occur in or below the surface they are termed subflorescence or cryptoflorescence.

The most common salts appearing as contaminants in masonry are sulfates, chlorides, nitrates and phosphates. Sulfates and chlorides are often associated with acid precipitation and air pollution. Nitrates also come from air pollution but being highly soluble in water tend to be easily removed by any water passing through the masonry. Traces of actual nitrates are thus not often found in the stone although they may well have been present and have actually caused damage. If they are found in any quantity nitrates usually are found to have come from some other source, e.g., from an industrial storage facility or from "saltpetre" used historically in making gunpowder. If the salts are causing severe damage to the stone they may have to be removed by washing and by poulticing. Chlorides may be associated with severe corrosion in metals embedded in, or in contact with wet masonry. Chlorides are particularly dangerous to iron and steel, copper, bronze, aluminum and even to some forms of stainless steel.

Were Metal Clamps, Dowels or Other Forms of Fixings or Connectors Used in the Masonry and if so Were They Made of Iron or Steel Which has Corroded and Expanded, Shattering the Surrounding Masonry? Such corroded metal work is often most conveniently cored out using diamond-tipped coring bits of appropriate diameters. I have worked on the restoration of the 1858 Oswego, New York, Customs' House where thousands of dollars worth of damage had been caused by corroding cramps shattering sandstone blocks. In this case the cramps were originally set in molten sulfur or "brimstone" which contributed to the corrosion when acid rain penetrated to the wrought-iron cramps. In such cases all traces of the sulfur must be removed in addition to the corroded iron.

What are the Nature and Condition of the Mortar in Which the Stones Were Laid? Earlier mortars tend to be based on lime rather than hydraulic cements. Lime mortars are acid soluble and tend to be very badly damaged by acidic rainwater and snow melt water if leaks and cracks are left unattended for years. Ultimately the lime is removed and only wet sand remains. The deposition of sheets of redeposited carbonates on external surfaces of walls and on the soffits of arches are sure indicators that lime is being removed from within the wall and that the wall is being seriously weakened in the process.

How are the Mortar Joints Finished or Pointed? Careful note should be taken of the overall appearance of the original pointing mortar; the color, profile, and texture of the finished joints; and the grain sizes, colors, and shapes of aggregates. Examination of sand and mortar samples under a microscope at a magnification of about 20 to 30 with a built-in graticule to measure particle sizes is a most helpful part of the process here.

Acid soluble stone; note the damage to left face which was exposed to the rain.

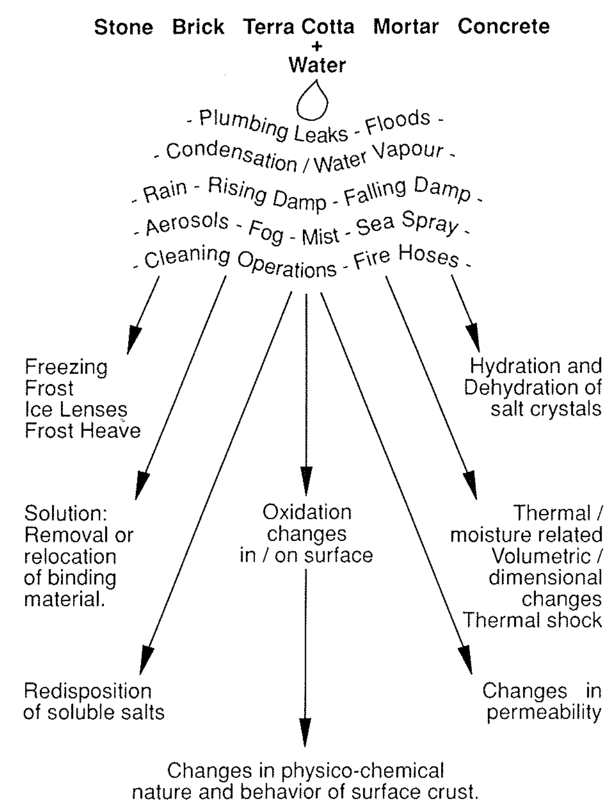


Figure 40. Deterioration of masonry materials and structures.

How were the Stone Surfaces Finished? What are the correct terms for these finishes, for example, punched, tooled, boasted, bush hammered?

What is the Crushing or Compressive Strength of the Stone Both When Dry and When Wet? (ASTM C 170-87 Standard Test Method for Compressive Strength of Natural Building Stone.)

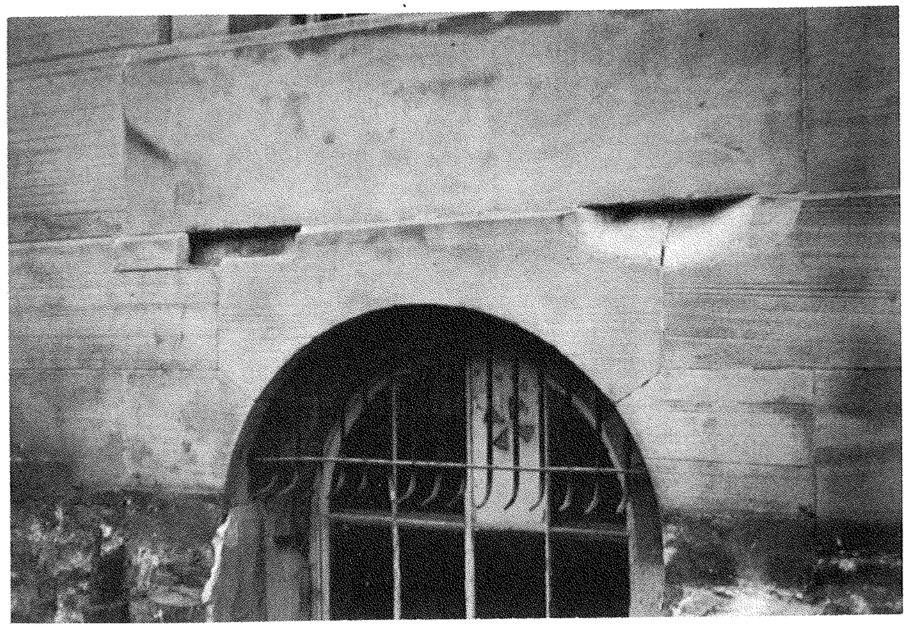
What is the Modulus of Rupture of the Stone Both When Dry and When Wet? (Adapted from ASTM C 99-87 Standard Test Method for Modulus of Rupture of Natural Building Stone.) In the cases of some sandstones, the strengths even of fresh samples are actually halved when the stones are wetted.

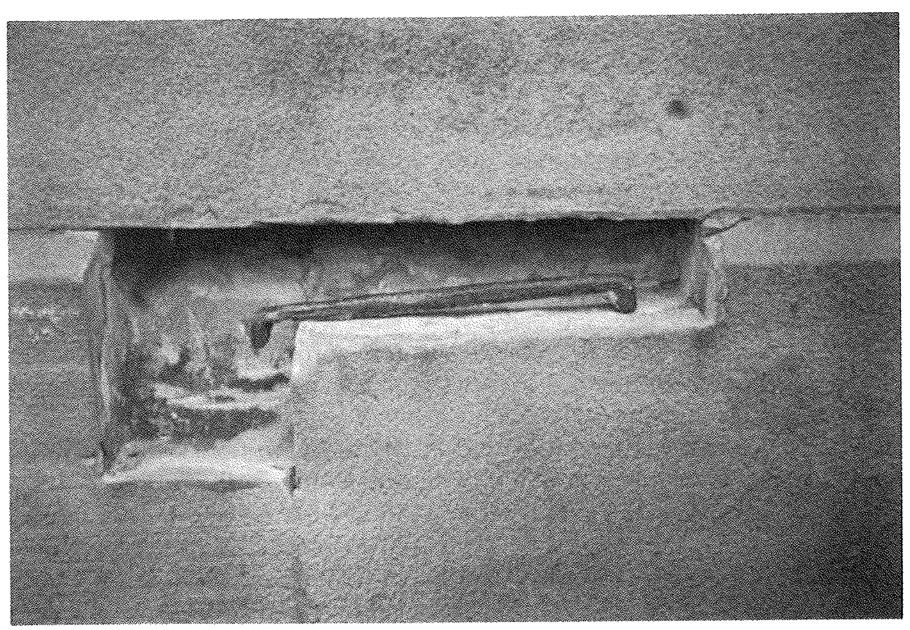
The performance of the stone should be compared with the relevant ASTM Standards:

C 503-85 Standard Specification for Marble Building Stone;

C 568-79 (Reapproved 1985) Standard Specification for Limestone Building Stone;

C 615-85 Standard Specification for Granite Building Stone;





Oswego Custom House, iron cramps set in sulfur corroded and shattered stone masonry.

C 616-85 Standard Specification for Sandstone Building Stone;
C 629-80 (Reapproved 1985) Standard Specifcation for Slate Building Stone;
C 406-84 Standard Specification for Roofing Slate.

What are the Absorption and Bulk Specific Gravities of the Stone? (ASTM Standard Test Method C 97-83 Absorption and Bulk Specific Gravity of Natural Building Stone.)

What are the Capillary Characteristics of the Stone? These may generally be calculated from the uptake of distilled water by the stone sample from surface contact with an inert wetted pad or permeable medium. The amount of water absorbed is calculated against the dry weight of the sample and plotted against

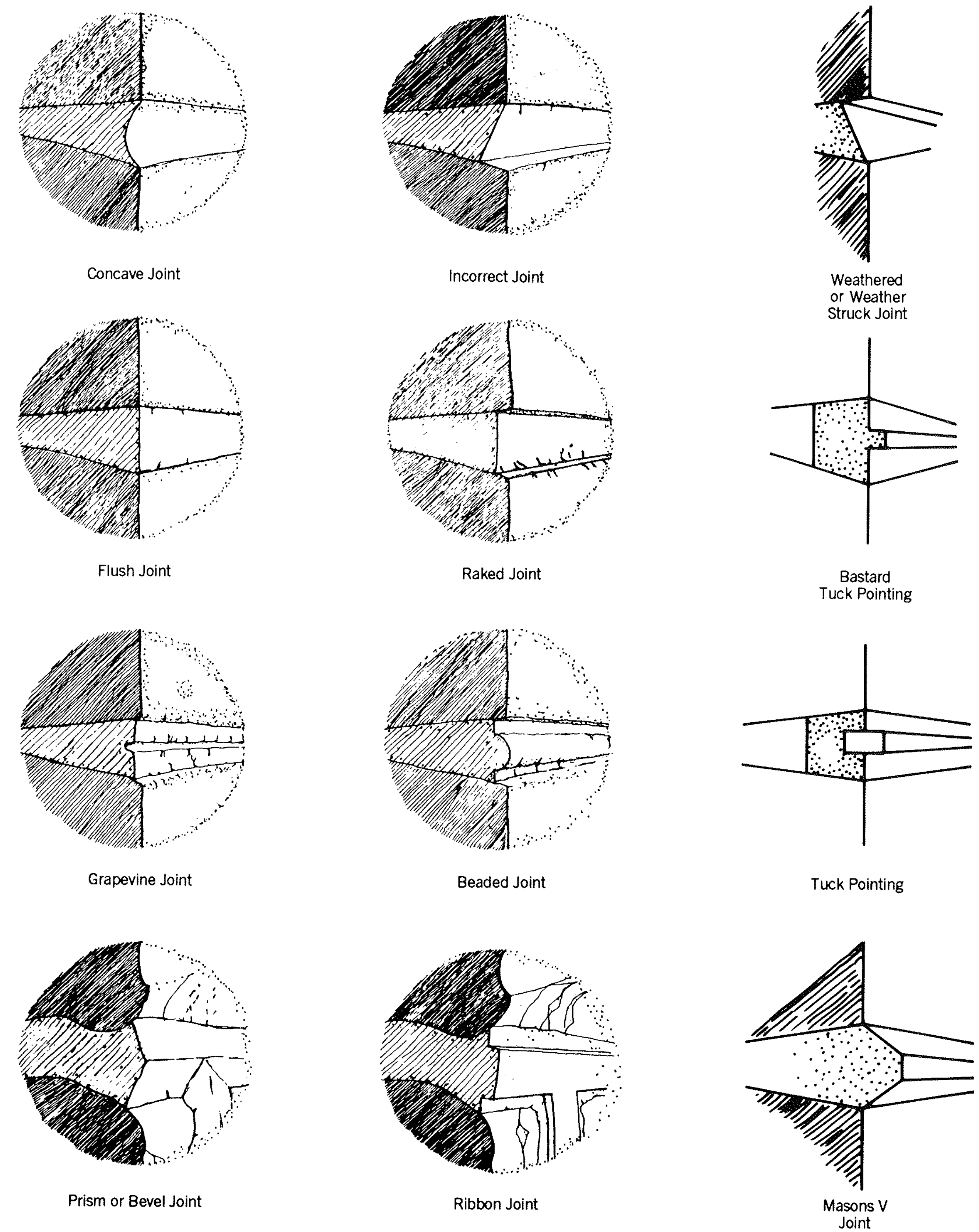


Figure 41a. Types of mortar joints.

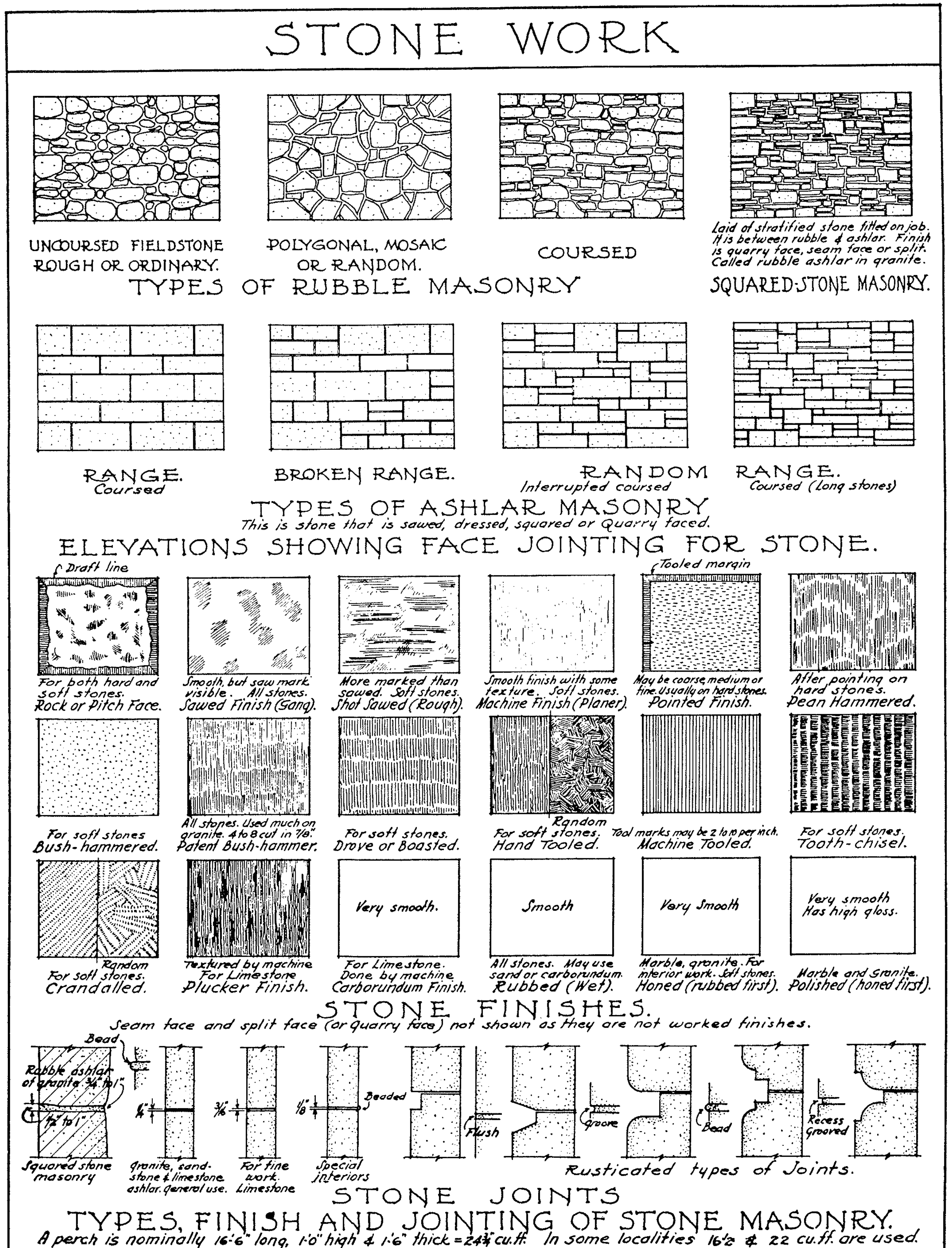
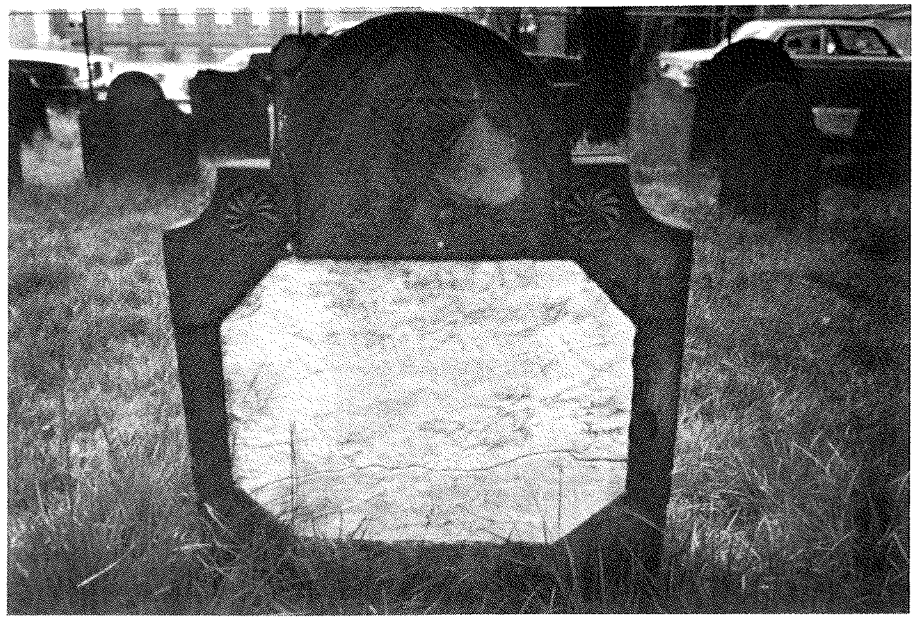


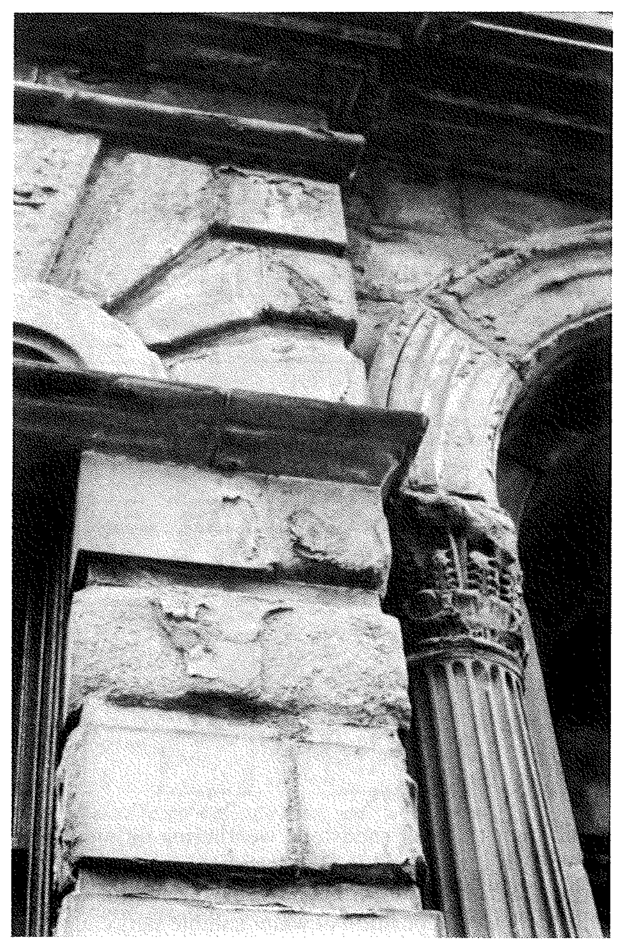
Figure 41b. Stone faces and finishes. (From *Architectural Graphic Standards*, 5th ed., (1956), John Wiley & Sons, Inc., New York.)

Mortar turned to sand by prolonged penetration of acid rain, St. Mary's Cathedral, Kingston, Ontario.

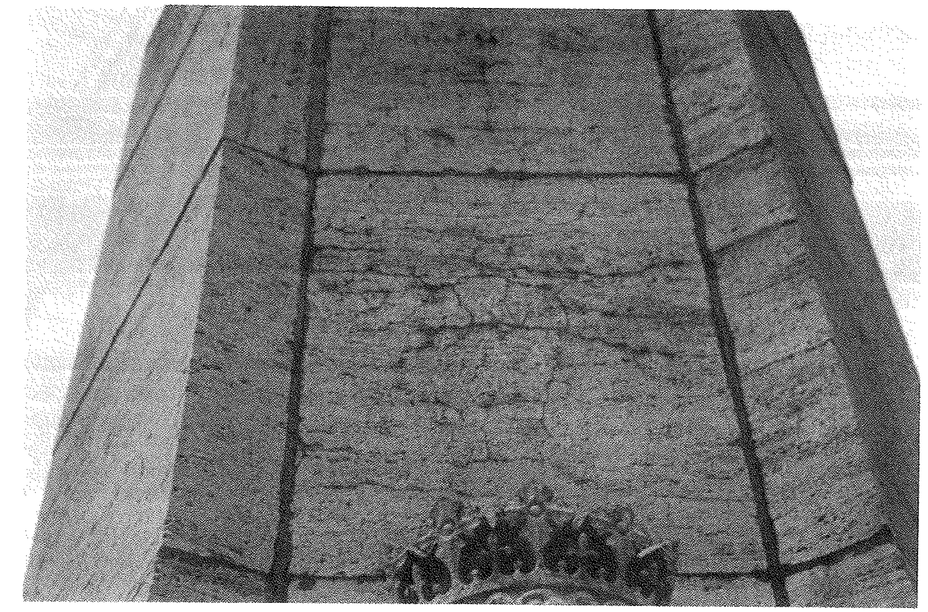
Two different types of sandstone weathering differently on the corner of a tower. The Ohio sandstone on the right is suffering from "alveolar erosion" caused by wind vortices and the increased deposition of water soluble salts caused by higher evaporation rates at the corner.



Sandstone and marble in a small area show the influences of microclimates on stone deterioration. Note how the sandstone surface is blistering as sulfate salts expand in and under the surface below the moulding where the rain does not wash the salts away. A little lower down where the acidic precipitation can wash the surface, the carbonates of the marble are being dissolved away.



Red sandstone blocks in a wall show what at first looks like "face bedding" problems, until close inspection reveals that the surface is exfoliating on all faces. The problem is caused by extreme physical and chemical changes in the surface crust.



A major structural crack passes through a block of limestone at an angle. Close inspection of the limestone blocks also reveals networks of microcracks which are being penetrated by acid rain. Ultimately these will cause the blocks to fall apart.

time. From these measurements, a capillary curve may be plotted.

What is the Extent and Nature of the Pore System Within the Stone? Two methods may be used to determine these parameters—water uptake at atmospheric temperature and pressure (ATP) and under vacuum; and mercury intrusion porosimetry (MP or MIP). Mercury porosimetry is limited by the fact that certain assumptions have to be made as to the geometry of the pores; and because the size of the mercury molecule limits measurement to pores of over 32 Ångstrom units diameter or greater. MP will however permit us to determine the total porosity and the relative amounts of pores of known diameters. This permits us to calculate the relative amounts of micropores to macropores. There is some argument currently as to the critical pore diameter or size below which frost or salt damage would be likely to occur. Current observations suggest that the cutoff point is at about 5 to 8 μm. Below that size the damage occurs on a regular basis. Below 1–2 μm pore diameter the damage is almost inevitable. Above that size the pores can dry out and disruptive internal pressures usually do not develop.

THE CONSERVATION OF STONEWORK

Restoration versus Conservation

In the preservation of old buildings the term "restoration" has the specific meaning of recreating their appearance or condition at some specific point in the past. "Conservation" means stabilizing and preventing or retarding further deterioration. This part of this chapter examines all the conservation options for historic stone masonry including replacement or substitution, consolidation, dismantling, and reerection and repairs. The principal problems are also reviewed with their solutions. Clearly, if a building was built with a stone which was selected without proper regard for its durability and which subsequently swiftly deteriorated because of its poor qualities, there would be little point in carefully finding exactly the same poor stone and recreating all the problems all over again. Replacement with more stone from the original source should be considered in cases where a basically durable stone has deteriorated only, for example, because of abnormal exposure to acid rain and air pollution, or because of lack of maintenance of the building leading to severe leaks in roofs, flashings, and rainwater disposal systems. Since many of the original quarries or sources have closed down or have been worked out of stone, it may be necessary to find a replacement from elsewhere giving a close match in strength, color, texture, and chemical composition to the original stone which will remain in the structure. In my experience, matching the above qualities is not usually difficult but matching original dimensions in terms of bed-depth may be a serious problem. I have had many cases where the desired limestones and sandstones were simply not available in blocks of sufficiently large vertical dimensions

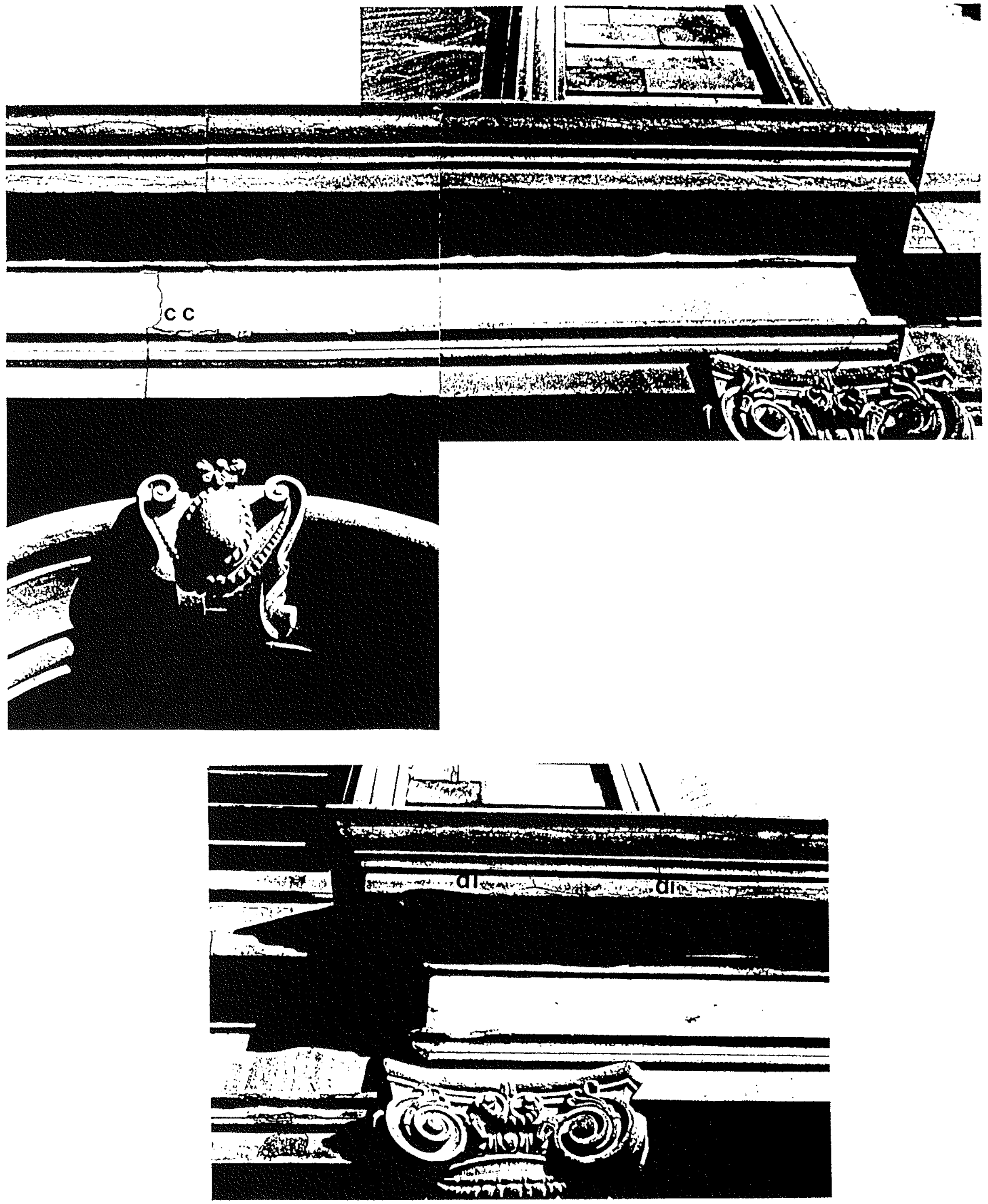


Figure 42. Stone repair: photographic montage.

for the bedding planes to be correctly oriented. Because of this potential problem anyone seeking stone for restoration work is well advised to check and double check that the bed depth or thickness of the quarried strata are sufficiently large to allow for the supply of sawn stone of the desired vertical dimensions.

Obtaining the Stone

When obtaining stone for restoration work the ideal situation is for the experienced restorer or conservator to go to the quarries and select the material for the specific project. At the same time the restorer presents

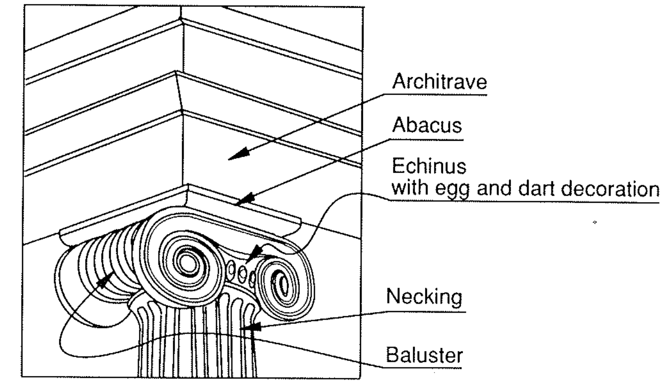


Figure 43a. Architectural details.

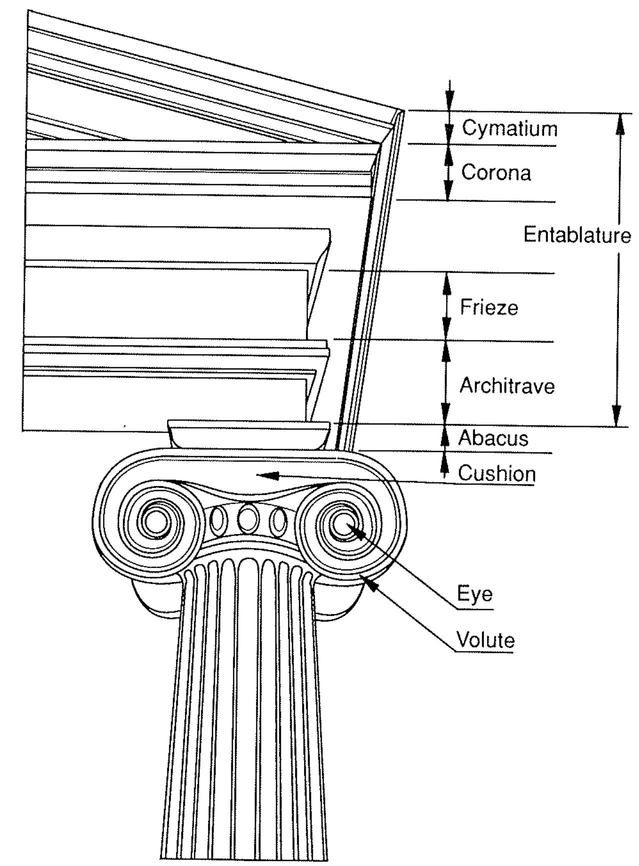


Figure 43b. Architectural details *continued*.

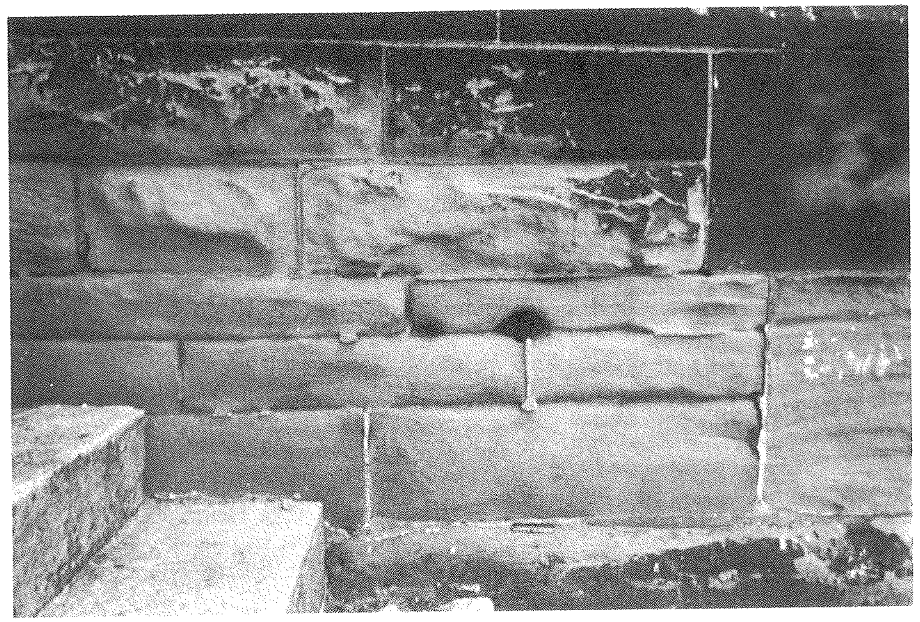
the quarry with dimensioned drawings with the bedding plane orientations clearly marked for all units individually. On the basis of this information, the quarry can supply accurate estimates for price and delivery times. Even in cases where the restorer is working through an intermediate stone dealer it is still advisable for the restorer to follow all these procedures. The restorer should also quote all the appropriate ASTM stone standards in the specifications for the job in order to ensure that the stone is of the requisite quality.

The Use of Substitutes

In cases where deicing salts have caused severe damage to sandstones used for paving, staircase treads and at the bases of buildings adjacent to the sidewalk it may be necessary to consider using a limestone for replacement work. Limestones are often much more resistant than sandstones to attacks by salts. But on no account should sandstones be replaced by limestones where the runoff from the limestone will cause carbonates to be redeposited in the adjacent sandstone units. The original sandstones can be destroyed as a result of such substitutions, particularly in polluted environments. The substitution of more durable stones in conditions of extreme weathering and pollutant exposure is prudent but it is recommended that acid-resistant stones of igneous or metamorphic origin should be employed instead of limestones. As an example of this process, a fine grained granite of similar color to a disintegrating original sandstone was used for restoration work on the base of the National Assembly Building in Quebec.

Avoiding Bedding Plane Problems

The restorer must pay careful attention to the correct orientation of bedding planes in original work and in new work. Obviously if the original units are in good condition and showing no signs of problems despite incorrect orientation of the bedding planes, then they should be left alone. If, however, definite face bedding problems are occurring the offending unit should be carefully cut out and, if possible, turned so that the orientation is corrected. This will not often be possible and the unit may have to be totally replaced. In my experience bedding plane problems generally occur in certain sandstones which tend to split very readily on planes where thin clay layers occur. Some of the Quebec limestones of the Trenton and Chazy formations also tend to split along fine horizontal crack lines. In some sandstones the inexperienced practitioner may be confused by "contour scaling" or the loss of the crustal layer through oxidation crust formation and other causes. Although at first gance this phenomenon may be confused with face bedding problems, further inspection will immediately reveal that the losses are not parallel to one plane but also proceed at right angles to that plane.



Deicing salt damage in sandstone next to staircase.

Stone Veneers and Double Walls

In cases where veneers of stonework or outer wythes have become detached from backing masonry or inner wythes, it is first necessary to establish their stability. If it is clear that stonework of the outer wythe is actually moving outward and could become unsafe, then there are a number of possible approaches to the restoration of the masonry. It is essential that the cause of the problem be established so that it can be remedied first. I have known of a number of cases where thick stone walls had their inner and outer wythes moving apart and major structural cracking and bulging occurring. In nearly all of these cases the problems were the

Contour scaling in red sandstone.

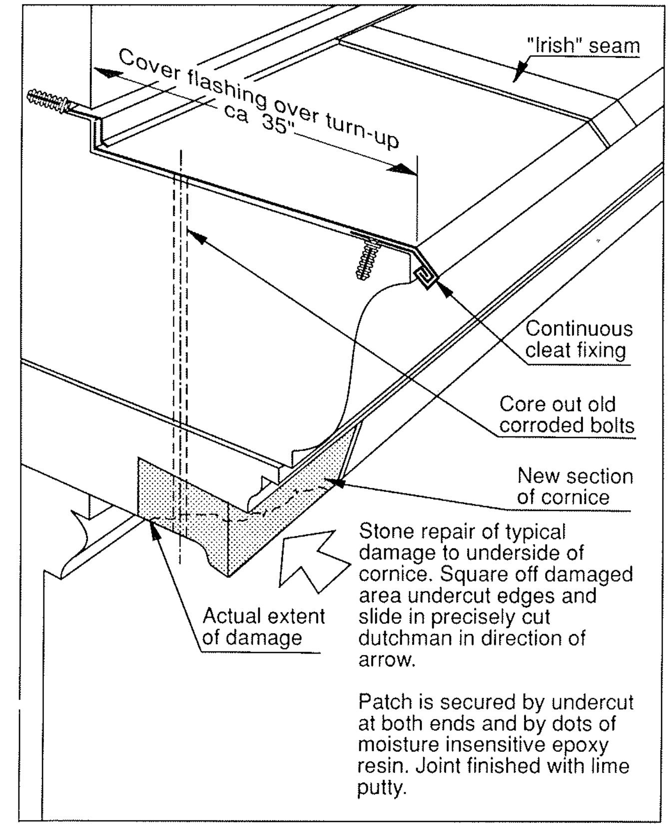


Figure 44a. Detail of flashing of main cornice: Vieux Palais de Justice, Montreal, Quebec.

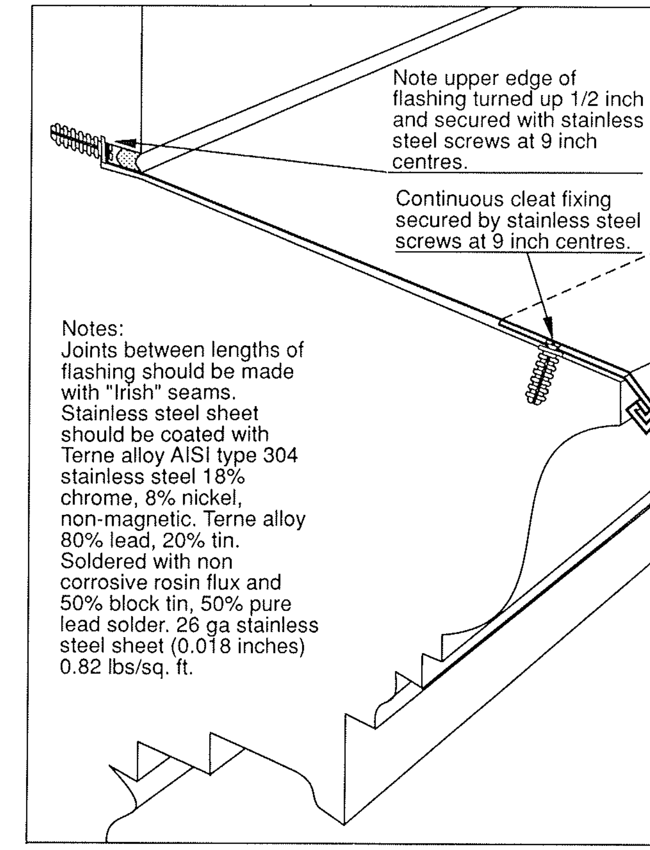
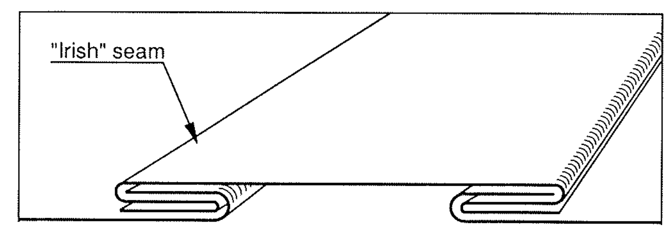


Figure 44c. New stainless steel flashing on belt course.



Seams at the ends of sheets of flashing should be secured with so called "Irish" seams which allow for expansion and contraction and do not involve any perforation of the sheet.

Figure 44b. Detail of flashing of main cornice.

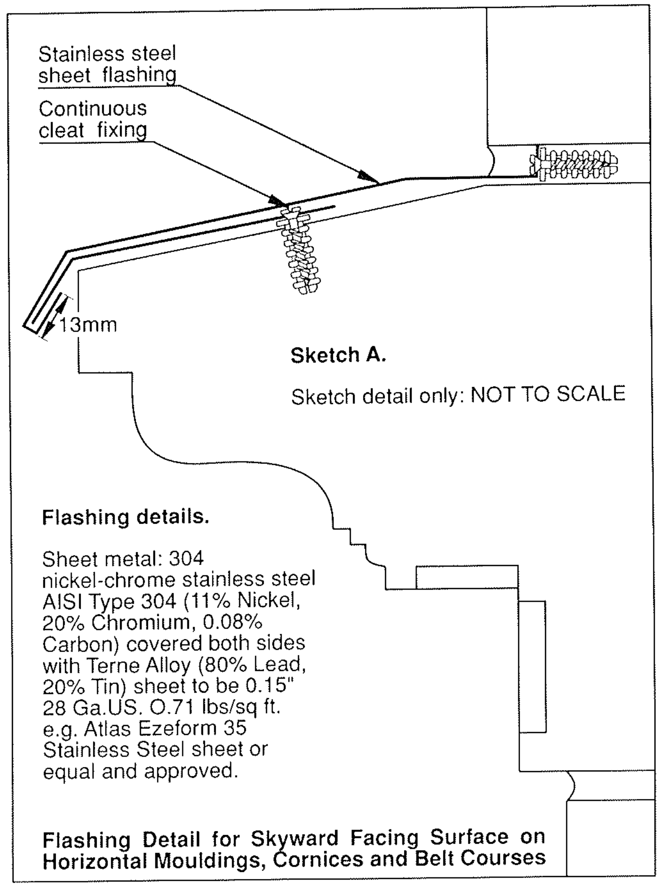
result of acid precipitation penetrating into the interior of the wall via open joints and defective flashings or roofing. The excessive quantities of water had removed most of the lime from the mortar leaving only wet sand. Obviously in all such cases the sources of unwanted water must first be eliminated by repointing joints and replacing flashings and roof finishes.

Once the cause of the bond failure has been eliminated the wythes can be stabilized either by the injection of a liquid grout into the core of the wall to replace the deteriorated mortar, or by drilling holes with diamond-tipped coring bits through the outer wythe into a stable core or masonry backing and then inserting stainless steel tubular injection anchors set in cementitious grout or threaded stainless steel rods which are set in a moisture insensitive epoxy resin-based grout. Various combinations of these techniques may also be used. I use AISI Type 316 stainless steel for such conservation work because of its very high corrosion resistance. In locations where the problems have clearly been caused by acid recipitation and air pollution it is a false economy to use anything other than such corrosion-resistant material despite its expense.

Any subsequent restoration necessitated by the failure of less durable materials will immediately cost a great deal more than was saved by their use.

Dismantling and Rebuilding

In extreme cases of bulging wythes and in other cases where stonemasonry is unstable, the stonework may have to be carefully taken down and totally rebuilt. Such rebuilding should be preceded by numbering and recording so that the stonework can be restored exactly



Continuous Cleats:
Same metal and thickness as sheet metal specified above. Make cleats at least 38mm wide and folded into stainless steel flashings 13mm as shown. Any seams in the sheet metal flashing are to be formed as double locked cross welts. The upper edge of the flashing is to be secured with No. 8 stainless steel screws set in lead plugs at 450mm centres.

The cleat is to be secured with No. 8 s.s. screws set in lead plugs at 300mm centres. The upper edge of the flashing is to be covered with a neatly struck fillet of 1:1:6 mortar finished with a slightly concave profile. (all parts by volume white non-staining Portland Cement: hydrated lime: sand)

Figure 45. Flashing details.

as it was. Temporary numbering in chalk is placed on the faces of the stone units for photographic recording. When the stonework is dismantled the permanent numbers are painted onto faces which will be hidden in the rebuilding. I normally use exterior quality latex paints for this numbering. A system of temporary and permanent numbering avoids the difficult problem of removing paint from the finished faces of the stone units. Special attention should be paid to recording the thickness of joints so that they can be reproduced. Without this precaution the masonry can never be accurately rebuilt. I usually specify the use of timber or plywood templates or profile boards which are cut to match the vertical profiles of the masonry at various critical points.

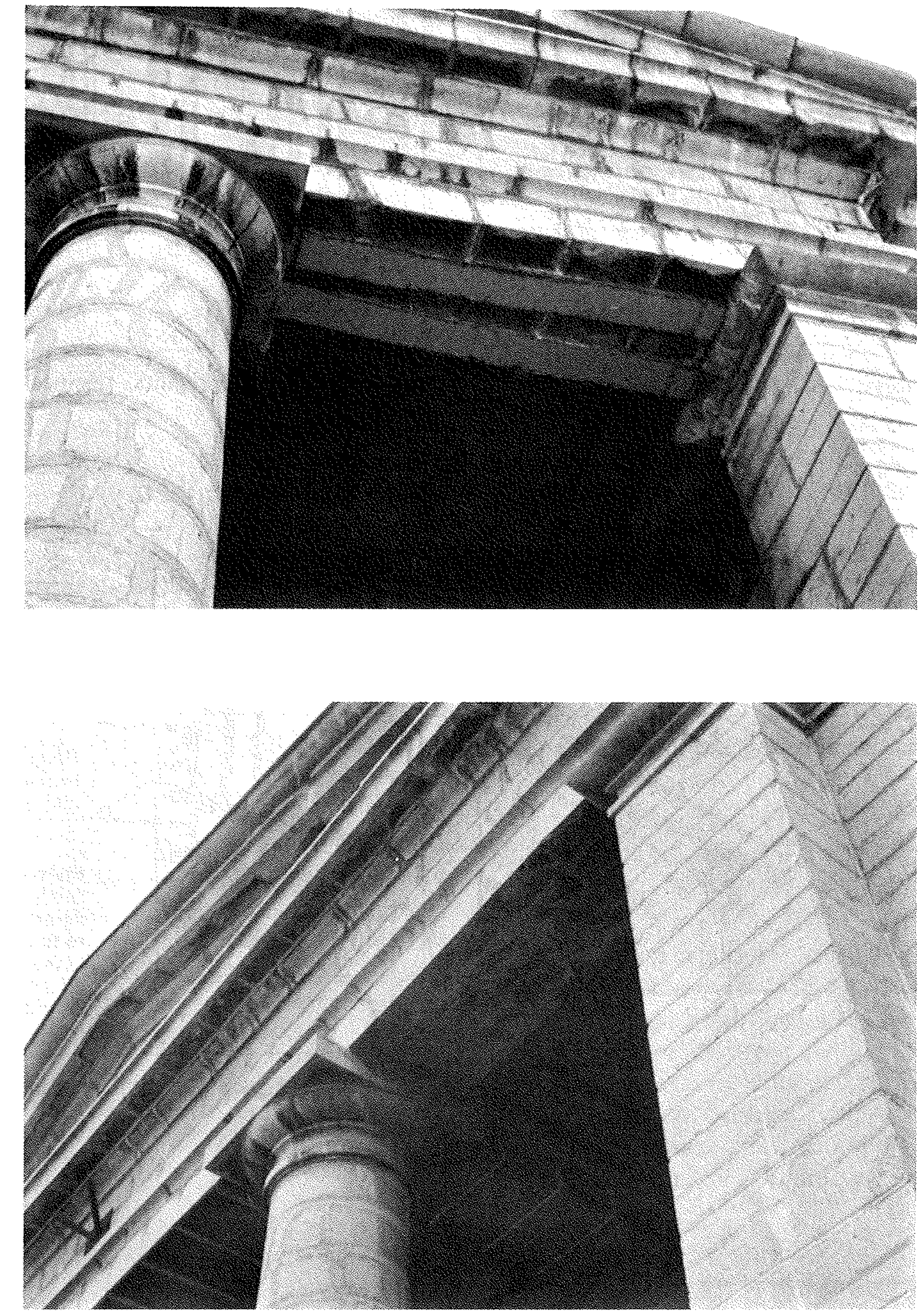
When the stonework is being rebuilt the blocks should be set on soaked hardwood wedges so that they are in their correct positions and so that the mortar has time to cure without the blocks settling out of position. When the mortar has cured, the wedges will have shrunk and can be removed. The resulting holes can be filled with mortar.

Refinishing, Inserts, Repairs, or Consolidation?

Where stones have been dissolved by water or acidic solutions they may simply be reduced in thickness or may have lost binding material to such an extent that they are liable to crumble and fail under load. In the former case the restorer must judge whether the surface loss in any way endangers the continued survival of the stone. If it is merely an aesthetic problem, the stone should be left as it is. Where the remaining surface has a totally unacceptable appearance, it may be redressed or retooled if the original unit is thick enough. If redressing produces too large a setback, the stone block can be carefully cut free and can be advanced and reset. Redressing is not a technique for use in all situations but should be reserved for cases of severe surface deterioration in otherwise sound blocks. Any new stone units which are set into old salt-infested stonework must be isolated from that work by having their back surfaces coated with an appropriate waterproof coating such as a sanded bitumen paint. The coatings should be kept away from surfaces which will be exposed and it is generally recommended that they are stopped about one inch short of the face to avoid staining problems.

When stones naturally containing ferrous compounds are placed in masonry in contact with large volumes of fresh concrete it is also necessary to coat their backs or the face of the concrete in order to prevent reactions with the strong alkalis in the concrete. Indiana limestone is a good example of a stone which suffers from "alkali staining" in just this way. The rust-colored stains are, in fact, formed by ferric hydroxide resulting from a reaction between calcium hydroxide in the concrete and iron ions in the stone.

When fragments of a stone block have spalled off or where critical drip edges have weathered away, it may be necessary to insert a patch into the original stone. The hole in the stone is carefully squared off, with the sides undercut to assist in holding the patch in place. The patching may then be carried out with a piece of matching stone which is carefully cut to match the hole and set in position with dots of a moisture-insensitive epoxy resin. The small gap between the patch and the



Stabilized and restored voussoired stone beam; before and after views, 1840's Gatehouse, Kingston Penitentiary, Ontario.

original stone is then "pointed" or filled with a lime putty or similar mortar to match the stone. As in wood conservation such patches are known as "Dutchmen."

Plastic Repair or Dentistry?

Small chips and spalls may also be patched with "plastic" repairs. A plastic repair is usually a mortar/synthetic resin composite mixed with stone dust and other materials to form a stable patch matching the original in color and texture and which can be placed in position and shaped. It will then cure and harden in place adhering to the prepared surface at the desired location. The adhesion of the patch is additionally ensured by the insertion of threaded stainless steel rods, teflon, or nylon rods or other noncorroding reinforcement into the old stone and through the patch. Any resins used in such mortar repairs must be nonreemulsifiable which

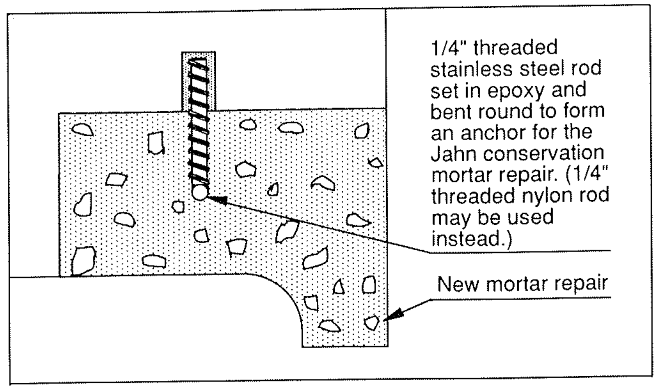


Figure 46. Mortar repair: detail of new patch.

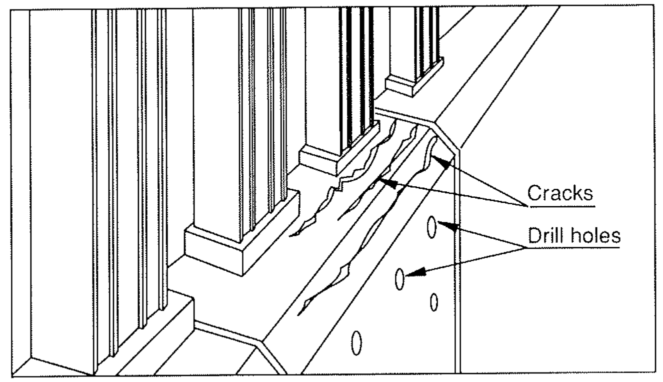


Figure 49a. Stone repairs: perspective view of damaged stone.

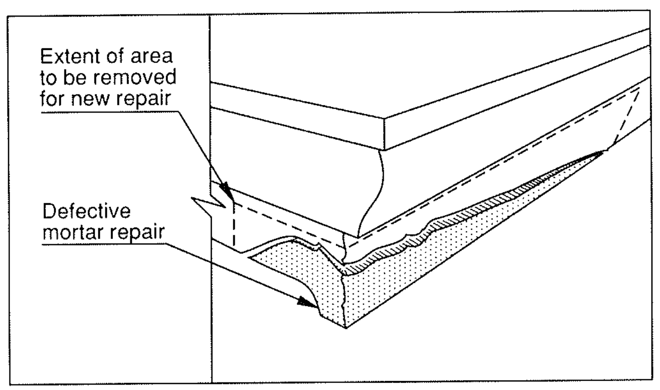


Figure 47. Mortar repair: Vieux de Palais Justice, Montreal, Quebec.

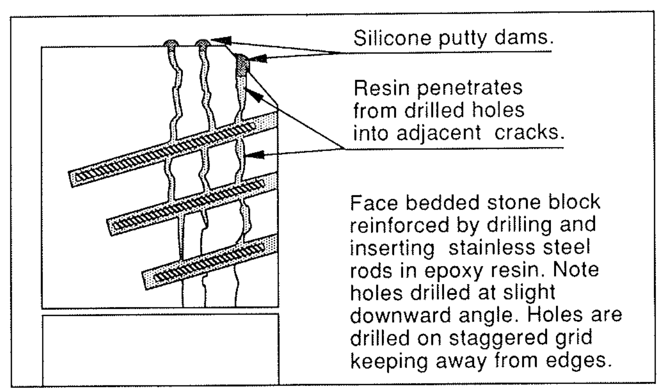


Figure 49b. Stone repairs: section.

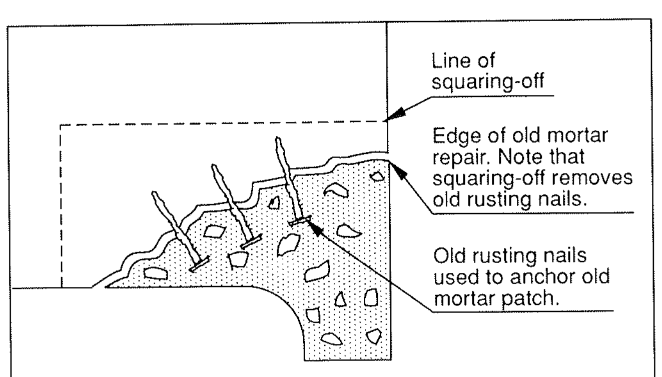


Figure 48. Mortar repair: detail of old patch.

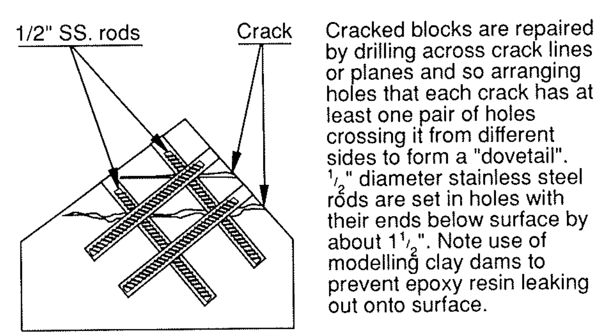


Figure 49c. Stone repair: section of typical coping block.

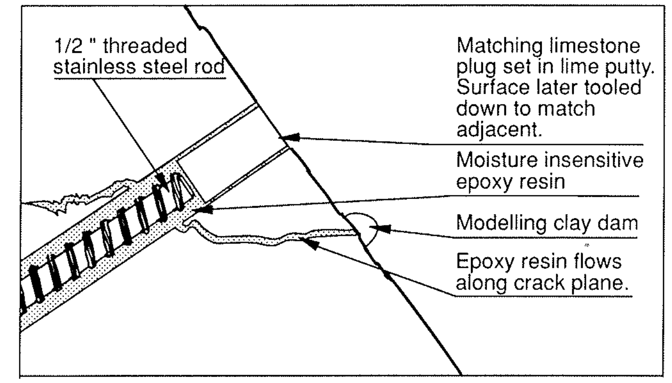


Figure 49d. Stone repair: enlargement of section.

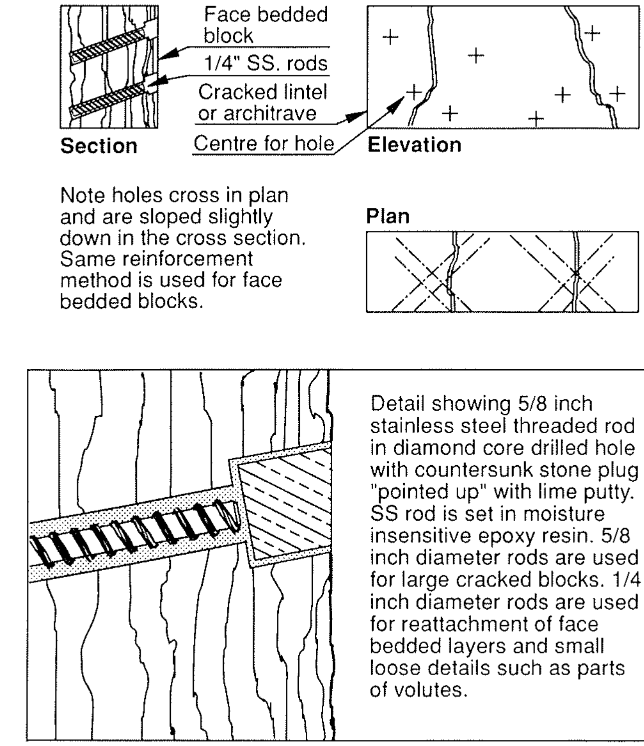


Figure 50. Repair of cracked stone lintels and architraves.

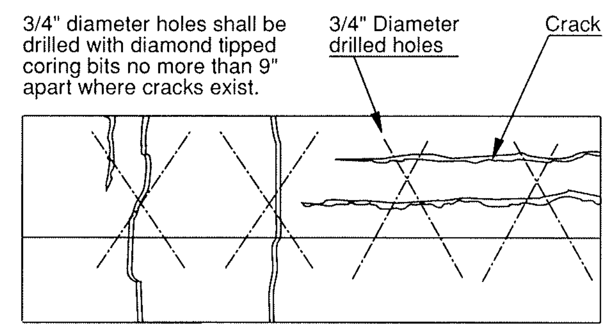


Figure 49e. Stone repair: side view of typical coping block.

means that when moisture passes through the patch, as it inevitably will, it will not reemulsify the resin and remove it.

Even when synthetic resins are used in such patches, experienced restorers avoid forming thin "feather" edges in the patches because these tend to be brittle and easily break away. Most restorers prefer to leave stones alone when the surface losses are non-threatening, first because restoration is unnecessary but second because the weathered surface of the stone is a part of its history, character, and authenticity.

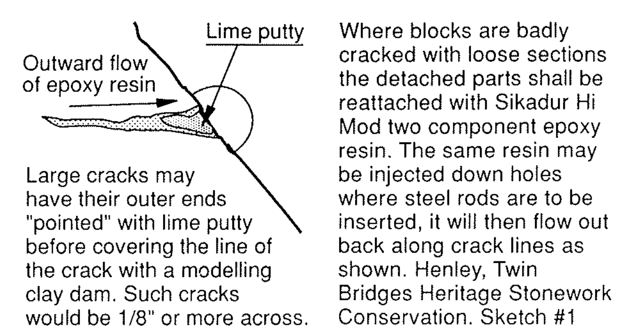


Figure 49f. Stone repair: enlargement of crack.

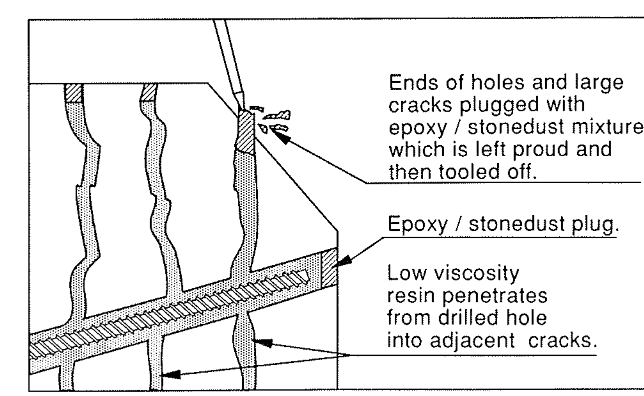


Figure 51. Stone repairs: section enlargement.

Consolidants

Where the loss of binding or cementing materials is causing the stone to crumble, the use of stone consolidants may be considered. Although sandstones, limestones, and some architectural ceramics may be treated with stone consolidants, sandstones with calcareous and argilaceous binders are perhaps the stones most frequently subject to binder or cement loss. The latter have been successfully consolidated with alkali silicates or with various types of alkoxysilanes and synthetic resins such as ethyl silicate, triethoxymethylsilane, or trimethoxymethylsilane. Although these two types of products are the most common, acrylic copolymers, epoxies, polyurethanes, and microcrystalline waxes have had some recorded successes in specific applications. For normal use on the exteror of buildings products of German origin of both types are available in North America. Bagrat silicates and ProSoCo's Conservare alkoxysilanes are the two major product ranges with proven long-term good performances. Consolidation with epoxy/solvent systems rather than pure low viscosity resins is the subject of apparently successful laboratory tests at the Getty Conservation Institute (personal communication). The lack of the frequently problematic darkening and reverse flow of the resin to the surface has been achieved by various means including solvent-saturated atmospheres in plastic film enclosures.

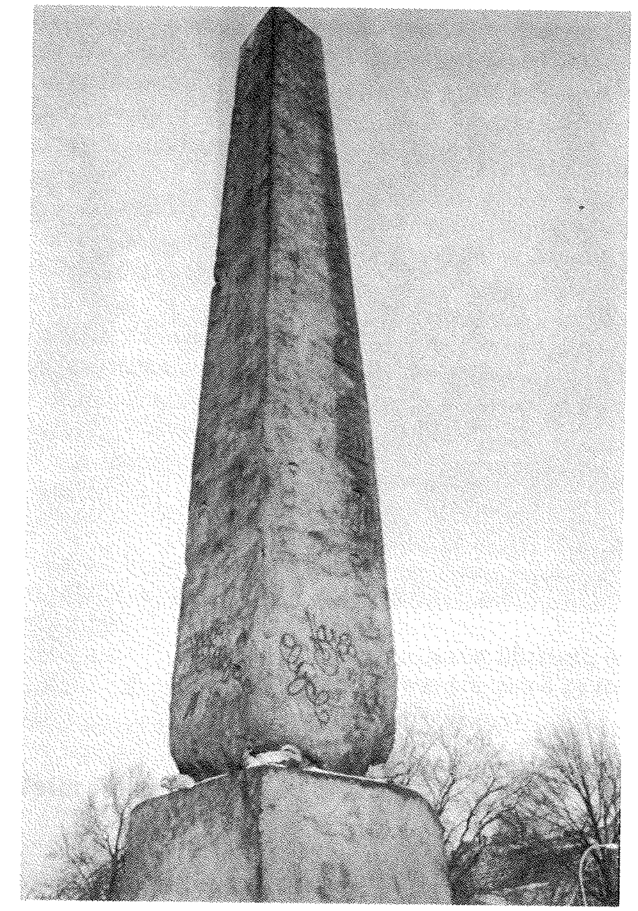
The history of the development of stone consolidants is marked with a long series of failures which have involved subsequent total losses of treated surfaces, severe discoloration, heavy soiling caused by the sticky nature of the treated surface, and many other problems caused particularly by entrapped moisture.

Early attempts to use resins with solvents were continuously dogged by the problem of the resin returning to the surface with the solvent as the latter evaporated. This typically caused darkening of the surface and sometimes an unpleasantly glossy, slick surface because of the resin concentration.

Consolidants will not function as grouts, void fillers, or means of reattaching flaking, exfoliating, or spalling surface layers. Spot use of moisture-insensitive epoxy resins may be appropriate for such purposes.

There have been many failures of historic stones which have been found to have been associated with earlier treatments with paraffin wax and/or beeswax. The "Caffal Process" or "Obelisk Process" which was still in use in the 1920s was based on the use of hot paraffin wax. This process was used on many New York landmarks, including "Cleopatra's Needle" in Central Park, and contributed to the deterioration of the stones.

This core from some historic concrete has been coated with an epoxy resin which has consolidated the concrete but has radically changed its appearance making it darker, yellow and glossy.



Cleopatra's Needle, Central Park, New York, showing deteriorated face.

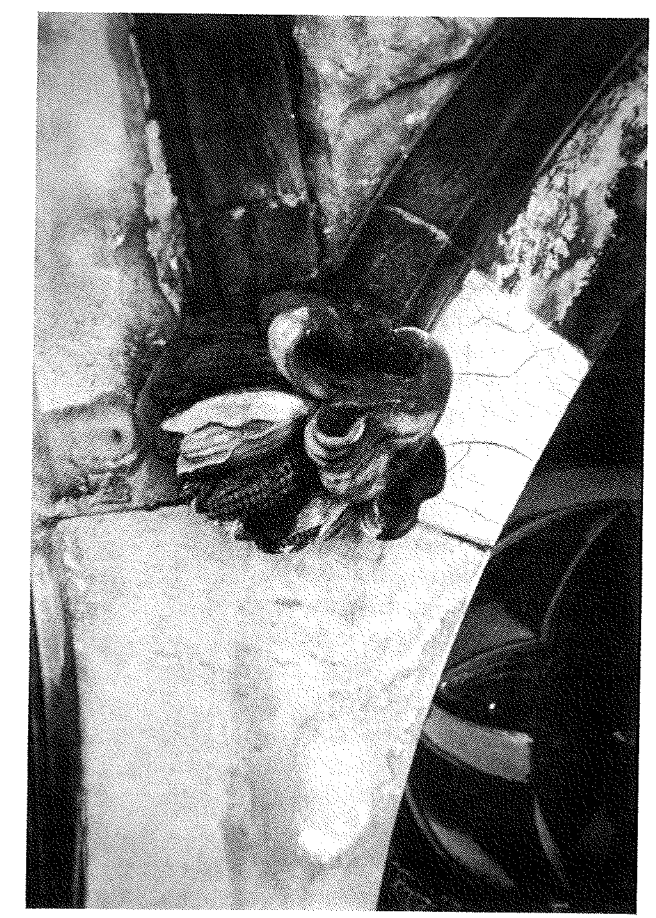
Salts and Their Removal

Harmful accumulations of water-soluble salts are best dealt with by poulticing techniques which use "inert" powders which may be mixed with water to form a stiff paste with about the consistency of runny peanut butter or stiff cream. The stiff paste is applied to a lighly wetted surface and then left to dry. In excessively dry or sunny conditions, the evaporation of moisture from the surface of the poultice may be helpfully retarded by covering the poultice with a sheet of polyethylene. The moisture from the poultice soaks into the stone, dissolves the salts, and returns to the surface with them in solution. When the moisture evaporates into the atmosphere, the poultice dries out and the salts are left behind in the temporary surface provided by the poultice, which is then removed. The process may be repeated a number of times to complete the removal of the salts. Suitable poultice materials include diatomaceous earth (available, for example, as Celite which is manufactured by Johns Manville); fullers earth, and kaolinite.

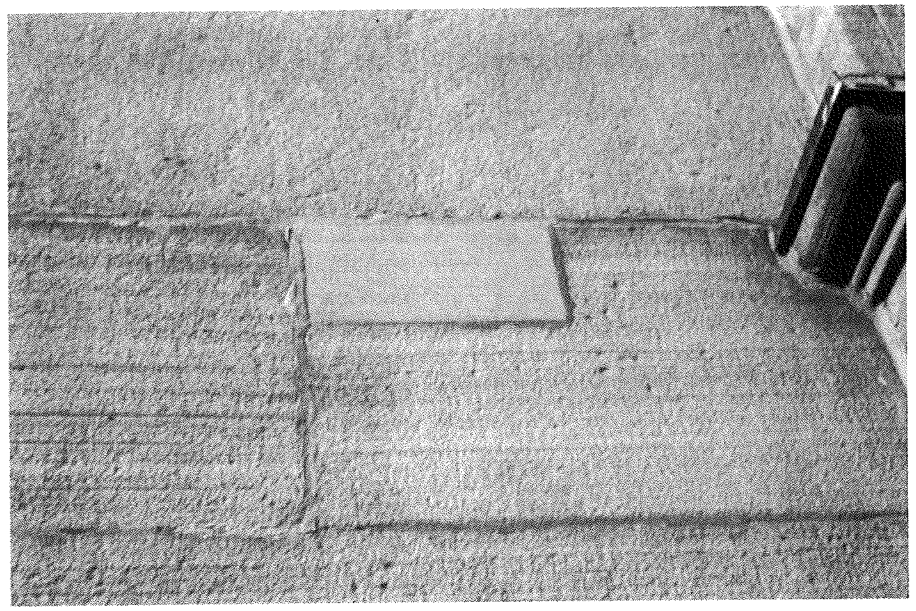
Corroded Metal Elements

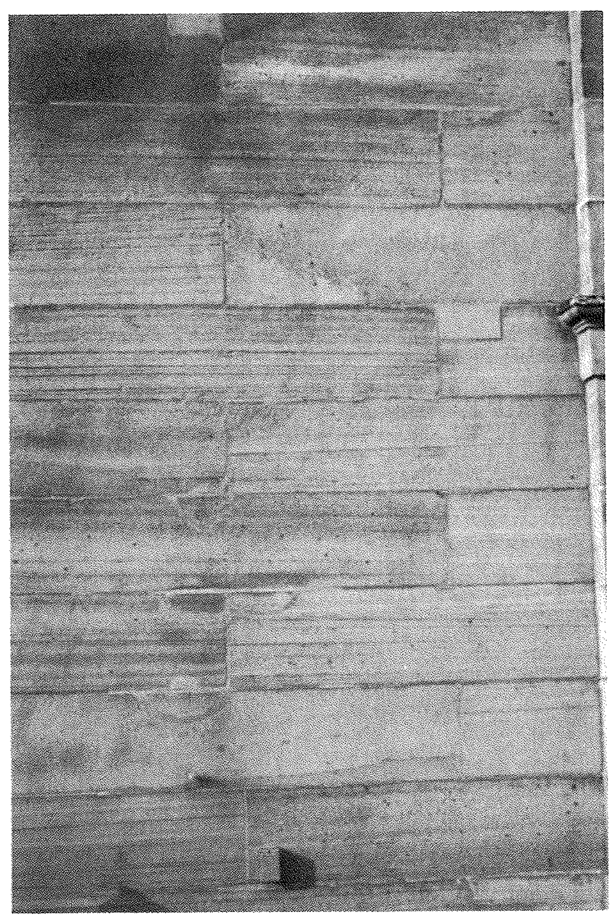
Where iron or steel cramps or dowels have corroded and shattered surrounding stonework through the expansion of their corrosion products, it is essential to remove the corroded remains and sulfur settings where these exist. A new cramp or dowel of a noncorroding metal such as an appropriate type of stainless steel may then be substituted for the original.

I have found that the easiest way to remove such corroded remains which may be jammed into the stone, is to drill them out with water-cooled diamond-tipped coring bits. Problems with mortars and repointing raise many major issues which are discussed in Chapter 7.



Poultice of diatomaceous earth and water being used to remove salts.





Repairs of cramp shattered stonework, Oswego, NY.

Median Monument, Queen Elizabeth highway bridge. St. Catherine's, Ontario. Further surface exfoliation was prevented by treating the stone surface with a water repellent.

Water Repellents

A final problem concerns stones which are excessively permeable or which have extensive networks of such small diameter pores or capillaries that they are subject to moisture-related problems. The water or moisture may be eliminated at its source or in some cases the stone surface may be treated with a water repellent or hydrophobic substance.

Water repellents, like stone consolidants, have a long history of unfortunate failures behind them. In situation where there are concentrations of water-soluble salts trapped behind the coating of water repellent, the latter may actually cause the destruction of the stone. In practice, only if and when all other methods for keeping water out of stonemasonry have been tried and found unsatisfactory, then there may be a case for the use of a water repellent. I have been consulted on a large number of cases of stone surface failures which have been traced to the use of silicone and less commonly metallic stearate water repellents. There have, of course, been thousands of examples of treatments with water repellents which have caused no problems but scientific research and field observations have suggested that in a large percentage of these cases there was, in fact, no need for the treatment in the first place. It should be clear, however, that water repellents have proved their value in certain specific applications, particularly where rain and spray are being driven through thin and permeable stonework in very exposed locations. Where such stonework is by the sea and the interior surfaces are powdering and crumbling, then the repellent should be applied to the exterior surface only. Stone window mullions and tracery are particularly prone to this problem.

I worked on a case where an oligomeric alkylalkoxysilane from the Conservare range of products was used to protect the surfaces of some vintage bridge pylons and median monuments built of dolomite. Fast moving trucks and cars constantly bombarded the surfaces of the stone with high velocity sprays of polluted water from puddles, causing deep penetration of pollutants and consequent damage. The additional feature of the alkali resistance of the selected repellent makes it an almost essential conservation material in this case because it will not be affected by the alkalis in fresh mortar or concrete used in the restoration work. Conservators generally agree that most water-repellent treatments are carried out unnecessarily and have added what may have been a substantial cost for no particular benefit. Most water repellents break down after a number of years and cease to function. Unfortunately, they do not break down evenly and can cause unsightly blotches and patches on surfaces as they deteriorate. Having broken down, water repellents then require replacement but difficulties of access usually prevent this essential maintenance.

BUILDING AND MONUMENTAL STONES OF THE UNITED STATES

Anyone who examines stones from existing buildings and monuments will at some point encounter a stone which they do not recognize. If they then go on to search for reference works to help them to identify not only the type of stone but its original source and even sources for replacements and repairs, they will most likely encounter some problems. The surveys and publications of the United States Geological Survey and the various state Geological Surveys will normally have described all of the stones and their sources in terms of counties, nearby towns, and even individual quarries. However, these publications may have appeared back in the nineteenth century, and there are hundreds of them. Clearly if one is starting with a totally unknown stone which comes from an old building in New York, for example, one cannot search every survey in the country for its source. There are no comprehensive works which are designed specifically for the needs of the restorer or conservator of buildings and monuments. The following schedules of names and descriptions are a first attempt at remedying this lacuna. Obviously such a short study cannot be comprehensive for all periods and for the whole of the United States, but it may be found to be helpful for the eighteenth and nineteenth centuries in the eastern part of the country. Seventeenth century stone sources were normally very small and very close to the building in which the stone was to be used. This could well mean that the "quarry" has never been identified let alone studied and the stone subjected to petrographic analysis.

NAMES AND DESCRIPTIONS OF STONES

Granites

Connecticut, New London County: Granite and gneiss. From 1643–1648, at East Lyme and Niantic the quarries produced an even-grained pinkish gray granite, marketed in the 1930s as "Golden Pink Niantic." At Groton the quarry produced a fine grained greenish gray granite; Millstone Quarry produced fine grained dark gray. Waterford granite is buff gray but light gray when hammered. It takes a fine polish and has been sold as "Connecticut White." Windham County produces a biotite granite gneiss quarried near Oneco. The "Oneco" granite is a fine-grained dark bluish gray stone.

Georgia, Elbert County: Elberton Granite, Elberton Blue, Elberton Gray, Oglesby Light Blue, Oglesby Dark Blue. Fine grained bluish gray biotite granite with black and dark gray grains, also a light gray medium grain granite.

Massachusetts: Quincy Granite, Medium Dark and Extra Dark Quincy Granite. A hornblende pyroxene granite quarried in and around Quincy, the general color ranges from a medium or bluish gray, to a very dark bluish gray all with blue or blue black spots (from 1825 at Bunker Hill Quarry). An unusual variety is known as "Goldleaf" and is characterized by yellowish and reddish specks of iron oxide derived partly from the oxidation of the unusual mineral aenigmatite (a titano-silicate of ferrous iron and sodium with aluminum and ferric iron). Quincy granites are unusual in that they do not contain mica.

Massachusetts: Rockport Granite, Moose-A-Bec Granite, Rockport. Hornblende granite of which the Rockport Gray and Sea Green are medium to coarse grained, hard, tough and durable taking a high polish; they are colored gray or olive green spotted with black. The Moose-a-Bec is a dark reddish gray, biotite granite with white and pinkish feldspars and smaller spots of black biotite. Example: Soldiers and Sailors World War Memorial, Pittsfield, MA.

Maine, Deer Island, Crotch Island: Goss Pink, Stonington Pink. Knox County: Vinalhaven Hurricane Island and Fox Island Granite. Coarse-grained gray biotite granite with pink to lavender; widely used for buildings and bridges. Contains orthoclase, microline, oligoclase, smoky quartz, and biotite. Crotch Island quarry opened in 1870. Compressive strength 23,620 lb/in^2. Example: St. John the Divine, New York.

Minnesota: St. Cloud, Rockville Pink, Minnesota Pearl and Cold Spring Rainbow Granite. A coarse grained red, pink, dark gray, or deep green background with swirling gneissic bands and knots of black. Takes and holds a fine polish. Weight 185 lb/ft^3. Crushing strength 23,000 lb/in^2. Modulus of rupture 3042 lb.

Minnestoa: St. Cloud, Rockville Pink, Minnesota Pearl Pink Granite. Medium grained pinkish gray, red, and fine grained gray; and coarse grained pink with gray quartz and biotite granites. Weight 175 lb/ft^3. Crushing strenght 20,000 lb/in^2. Modulus of rupture 2000 lb. SiO_2 62.15%; AlO_3 19.41%; Lime 2.27%; Phosphorus 0.13%.

New Hampshire: Milford Granite. Fine, medium, and coarse grained light gray, and pink granites with coarse black grains; a quartz monzonite. Examples: Columbia University Campus such as base of Low Library, New York.

New Hampshire: Concord Granite. Fine to medium grained light gray biotite-muscovite granite with the soft brownish color of the muscovite. The potassium feldspar crystals are very small giving the granite a fine grain. A second variety known in 1927 as Swenson's Antique Granite was colored warm buff and gray and was said to be reminiscent of old ivory in color. Examples: Concord State House 1816–1819 and Old State's Prison, Concord, 1812. Essex County Hall of Records, Newark, NJ.

North Carolina: Mount Airy Granite. Medium grained even textured light gray to white biotite granite, used for buildings and monuments. Biotite has some tendency to segregate in streaks. Quarry opened 1889, first shipment 1890. Examples: columns capitals and panels, Municipal Building, New York. SiO_2 70.70%; Al_2O_3 16.50%; Fe_2O_3 2.34%; MgO 0.29%; CaO 2.96%; Na_2O 4.56%; K_2O_3 .45%; FeS_2 0.09%. Weight 165 lb/ft^3. Crushing strength 23,068 lb/in^2.

Rhode Island: Westerly Blue, Dark Pink, and Light Pink Granite. Fine grained gray, bluish gray, and brown granites, typically all with "pepper and salt" appearance caused by fine black grains. A medium coarse grained variety is colored a reddish gray speckled with black; this stone is a medium red when polished. From ca. 1847. Examples: Declaration of Independence Monument, Boston, MA.

Rhode Island: Westerly Granite. A very fine grained white granite when hammered but a clear dark blue when polished.

Virginia: Petersburg Granite. Medium grained gray; used for buildings and monuments.

Virginia: Richmond Granite. Fine grained, light gray biotite granite; used for buildings and monuments.

Vermont: Barre. Fine textured, medium grained white to light and medium dark gray biotite granite; used for all purposes. There is also a dark blue gray used for polishing only and a light gray for hammered work. The first quarries at Barre operated ca. 1814. The dark Barre granite consists of about 65% feldspars, 27% quartz, and 8% mica. This is the largest producer of granite in the United States.

Marbles: Including Orthomarbles and Metamarbles

Alabama, Talladega County: Alabama Marble. A fine grained white marble with variations of more or less creamy color and two varieties with either fine pencil like grayish veins or heavier veins of a greenish or dark gray with orange or pink clouded borders to the veins. Example: Interior, United States Custom House, New York, (Cass Gilbert) 1899–1907; and the Arkansas State Capitol.

Colorado, Yule Creek: Leadville Quarries, upper part medium grained white calcitic marble; lower part dolomitic (primarily 1886–1940). Examples: Tomb of the Unknown Soldier and the Lincoln Memorial.

Georgia, Tate District, Tate and Marble Hill: Murphy Marble. Medium to coarse grained predominantly calcitic white, rose to deep pink, veined and mottled with greenish black actinolite and hornblende. In 1927, the Georgia Marble Company advertised that their White and Silver Grey Georgia Marbles were unexcelled for sculpture work exposed to the weather, the marble being unaffected by even the most severe weather. Examples: New York Stock Exchange is Georgia White; Buckingham Fountain, Grant Park Chicago is Georgia Pink. Columns and monoliths 30 ft long by 4 ft diameter. $CaCO_3$ 98.96%; $MgCO_3$ 0.13%; AlO 0.22%; SiO 0.61%; Loss 0.08%. Weight 165 lb/ft^3. Water absorbtion after 24-hr immersion 0.028%.

New York: Catskill Marble. Fossiliferous limestone dark brown in color with crinoids. Very hard and dense. Used in buildings and engineering works.

New York, Duchess County: South Dover, Dover White. Medium grained very white dolomitic marble used extensively for fine building work (by 1815).

New York: Tuckahoe. White coarse grained dolomitic marble. Once extensively used for building work.

Tennessee: Knoxville District, East Tennessee. A wide range of thick bedded Palaeozoic crystalline limestones which take a high polish and are known as Holston orthomarble; the predominant colors are pinks but there is a range from light gray and pinkish gray, via deep pink and red to a deep chocolate brown.

Usually used for interiors, the names of the Tennessee marbles are usually descriptive of the distinguishing features in a polished state, for example, Dark Cedar Tennessee (dark chocolate with fossil fragments), Appalachian Dark Chocolate, and Appalachian Roseal (fine grained grayish pink with splotches of white, pink, rich red, and black). Many varieties contain fossils which may range from indistinct fragments to very large straight shelled cephalopods as large as seven feet long. The United States Government opened the first quarries in 1838 for interior marble for the U.S. Capitol. In 1934 Bowles noted that Tennessee marble accounted for 35.5% of the total value of marble produced in the country.

Vermont: Clarendon marble. A number of varieties for both exterior and interior use, light in color generally with a white background with gray and green clouded and veined varieties; there is also a green veined cream and a cream with golden vein and blue. Example; Exterior, State Educational Building, Albany NY. Crushing strength 14,000 psi. Water absorbtion with immersion 0.01%.

Vermont: Pittsford District. Medium to coarse grain light bluish gray. Example: Scott Fountain, Belle Isle, Detroit made from single 65-ton block.

Vermont: Rochester Quarry. Serpentine marble, "Verde Antique" deep green with light green and almost white veining.

Vermont: Danby Quarry, Dorset Mountain. Close grained white with soft clouding of grey and green; occasional tints of light tan or "gold" (since 1907).

Vermont: Imperial Quarry Danby, Dorset Mountain. Close grained white with gray and beige markings; white with bold gray green veining (since 1907).

Limestones

Indiana or Bedford Limestone. Termed Salem limestone by the geological surveys of Indiana and Illinois, and Spergen limestone by the U.S. Geological Survey, a calcarenite or detrital limestone composed of oolites, fossil shells, and carbonate detritus. The stone occurs in massive beds; and single blocks 60 ft, long, 12 ft high, and 4 ft thick are commonly available. This stone comprises 60% of the dimension limestone produced in the United States. Production commenced in 1929.

Indiana limestone is gray or bluish gray below groundwater level but pale buff to light grey as it is exposed and weathered. Stylolites or "crowsfeet" may occur. These resemble graph lines in appearance and are present along bedding planes and locally throughout the rock. They consist of black shaly bituminous matter and occasional pyrites and other ferruginous material. They are not usually large enough to cause weathering and staining problems. Brown staining may result from contact with alkalis and organic matter, for example, ferric hydroxide staining from concrete.

Bedford Blue: 1.15% SiO_2; 1.91% Fe_2O_3; 53.25% CaO; 1.23% MgO; 42.40% CO_2.

Bedford Buff: 0.77% SiO_2; 0.63% Fe_2O_3; 3.0% Al_2O_3; 52.85% CaO; 1.18 MgO; 41.54% CO_2.

Weight per cubic foot: 140.3–152.4 lb/ft_3. Compressive strength: Buff 9012 psi; Blue 10,823 psi. Shear strength: Buff 1222 psi; Blue 1016 psi.

Tennessee: Holston orthomarble (see **Marbles**).

Sandstones

Connecticut: Portland Brown Stone. A medium to fine textured Upper Triassic sandstone of uniform reddish brown color, with flakes of muscovite parallel to the bedding planes. Quarries at Portland opened in 1665. Examples: Morris-Jumel Mansion, ca. 1765, New York; Cooper Union Building, New York 1859; Church of the Ascension, Fifth Ave and 10th St. New York, 1841. Also quarried at Middletown, Middlesex County, CN. Crushing strength 13,980–15,020 $lb/in.^2$. Specific gravity 2.35. Ratio of absorbtion 1:40. Silica 70.11%; alumina 13.49%; Fe_2O_3 4.85%; lime 2.39%; magnesia 1.44%; soda and potash etc. 7.37.

Massachusetts: East Longmeadow Sandstone. Upper Triassic sandstone evenly fine-grained brick red to reddish brown in color. Iron oxide cementing quartz grains. Examples: St. George's Church, Stuyvesant Sq. and East 16th St. New York, 1848: Bobst Library, New York University, 70 Washington Sq., New York, 1973.

New Jersey: New Jersey Brownstone. An Upper Triassic compact sandstone fine to coarse grained, thickly bedded with and without distinct lamination. The stone is arkosic with a cement of silica and sometimes iron oxide. The colors vary but include white–gray–brown and red. Examples: Trinity Church, Broadway and Wall St., New York, 1846; Villard Houses, Madison Ave. between 59 and 61 Sts., 1884. Quarries; Passaic, Belleville, North Arlington, Pleasantdale, Patterson, Little Falls and Osborne and Marsellis. The stone and hence the quarries extend in a belt 32 miles wide along the Delaware River above Trenton, and from the Palisades on the Hudson to the Ramapo River at Suffern NY.

New York: New York Bluestone, Genesee Valley Bluestone. A fine grained dense even gray-blue sandstone. Genesee Valley Bluestone is quoted in Sweet's in 1927 as having a crushing strength of 19,970 $lb/in.^2$. Weight 150 lb/ft^3. Silica 76.50%; alumina 14.75%; Fe_2O_3 6.35%; water 2.00%. The Genesee Valley Quarry opened in 1899 at Ambluco in Wyoming County, NY. Massive use for paving but also used for ashlar and bed courses. Extremely durable and wear resistant. An analysis for a sandstone from this region and known as Bigelow bluestone (also known as Ulster bluestone) by F.L. Nason and published by Dickinson in 1893 was as follows: Minerals: quartz and feldspar, quartz grains angular, some feldspar grains fresh and others almost completely decomposed; cementing material silica; no carbonate of lime and very little iron oxide.

New York, Catskills: Saugerties Bluestone. A fine grained dense, even gray-blue sandstone of the Upper Devonian period, with fine large slabs, some containing fossil brachiopods. Extensive quarrying for paving slabs for New York City all through the nineteenth century. The old quarries now contain Harvey Fite's famous monumental sculpture Opus 40 which was built 1939–1976. The grain structure is extremely fine and compact. Freshly broken surfaces are bluish gray but weathered surfaces oxidize to a grayish brown.

New York: Medina Sandstone. Upper Silurian fine-grained sandstone, quartz grains with minor amounts of kaolinized feldspar; colors gray to red and variegated. Locations: western New York with major deposits in Orleans County at Medina, also in Niagara County at Lockport, for example, and Monroe County at Brockport. The deposits extend into Canada where the stone was also extensively quarried.

New York: Potsdam Sandstone. An Upper Cambrian fine to medium grained sandstone with angular grains of clear quartz in a siliceous cement. The colors range from light pink to light red and reddish brown and there is also a variegated type. Sources: northern New York, Racquette River Valley, Lawrence County, northern Adirondacks. Potsdam Quarry since 1856.

Ohio, Cuyahoga County, Lorain County, northern Ohio: Berea, South Amherst Quarries. The Mississippian sandstone commonly occurs as fill in deep ancient channels cut in underlying shales. Some of the quarries at South Amherst are 235 ft deep. The colors and types vary but a typical Berea is light gray medium- to fine-grained protoquartzite with silica and some clay cement. Honey or buff colored variations exist with a coarser grain version with fine rust colored banding. In polluted environments rust-colored staining may be found to consist of individual rusting grains of ferric compounds (from ca. 1840.) Examples: carved stonework of the Ottawa Parliament Buildings, East Block, 1859; Oswego, NY, Custom House 1858.

Ohio: Massilon Sandstone, Middle Pottsville; Glenmont, Holmes County, Briar Hill; Ohio. The type consists of a wide variety of sandstones which tend to be cross-bedded and poorly sorted with grain sizes varying from fine to coarse. Typical dimensioned stone is buff to light ochre in color with darker rust colored and even dark red-brown fine irregular bands or veins. The latter are usually left in relief as the stone weathers. One variety of Briar Hill Sandstone is a warm Indian Red in color. Briar Hill Sandstone's chemical analysis is as follows: silicon dioxide 95.00%; aluminum oxide 2.75%; iron oxide 0.60%; calcium oxide 0.30%; magnesium oxide 0.25%; loss in ignition 1.10%. Absorbtion 6% by weight. Crushing strength 4000–6000 $lb/in.^2$.

Pennsylvania: Pennsylvania Brownstone. An Upper Triassic, fine-grained, even textured, reddish brown to purplish brown sandstone with fine angular quartz grains in a cement of clay and iron oxide. Principal quarry was at Hummelstown, Dauphin County from 1867.

Pennsylvania: Delaware Valley Sandstone, Lumberton Quarry, Lumberville, Bucks County. A variety of sandstones with colors ranging from buff and light bluish gray to dark gray to brown. Lumberton Quarry has operated since 1852. Used as ashlar but also as split face fieldstone and rubble.

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STONE CONSERVATION CASE HISTORIES

The following extracts from case histories and specification notes are taken from the files of the Center for Preservation Research, Columbia University, New York. They are included here to illustrate the form and contents of a series of typical conservation projects. They also illustrate precisely how typical technical problems are handled both in terms of techniques and materials, and how the specifications are written.*

A CHURCH IN NEW YORK

Purchase of scaffolding by the Church, in an amount determined by the dimensions of the Tower and Spire, could be extremely cost-effective. The Church should pay a contractor for dismantling and reerection as the project proceeds, but could sell the (now used) scaffolding upon completion of the work, recovering a considerable percentage of the cost. Consideration should also be given to the advance purchase of some materials, such as colored sands and replacement stone, that could become difficult to secure in the later years of the work.

Final contract documents should be distributed to a short list of qualified restoration contractors for negotiated bidding. Submittal requirements must include the identification of all proposed subcontractors, a list of references and of recent reviews, a proposed work schedule, and price. It may be appropriate to make an initial award (perhaps as early as summer, 1987) for a demonstration contract involving only 2 or 3 bays of the Church, or the Soldier's Monument, as an opportunity for full-scale field-testing of all methods. This would permit final reevaluation of many important aspects of the project, including coordination and supervision needs, contractor competence, safe storage, handling and disposal of commercial projects, impact upon Church operations, total cost, and visual aesthetics.

* Frank G. Matero was the author of the original studies and specifications.

Proper execution of the full project, which we estimate as 3 to 5 years in duration, will require close collaboration of the Church and its consultants in the matter of supervision. Technical judgments will certainly need to be made at all stages of the work; there must be established a mechanism to do so quickly and intelligently. Complete familiarity with the condition of the Church, with earlier restoration efforts, and with the materials and techniques being utilized by the contractor is necessary for all persons involved in on-site decision-making.

VII.2. Specific Operations

VII.2.1. Cleaning

Preliminary cleaning tests were carried out on June 25, 1986, on the Monument in the northeast corner of the Churchyard. The Monument, built shortly after completion of the Church, is said to be of the Little Falls sandstone, and has a treatment history that is similar to that of the Church. Testing was done on the north face (see Appendix B, Fig. 17), and the northeast corner. Acidic products conventionally used for the cleaning of sandstone did not remove the soiling effectively, because of the presence of organic coatings (the earlier treatments) that prevent the cleaners from coming into direct contact with the stone surface.[1]

The most complete series of tests was done to evaluate the possibility of alkaline degreasing, followed by acidic cleaning.[2] Four commercially manufactured alkaline products were tested. These were:

Heavy Duty Paint Stripper (HDPS);
Limestone Prewash (LP);
766 Prewash; and
T-792 Alkaline Prewash[3]

[1] Pressure washing without chemical treatment was also found to be ineffective. This surely would have been the case with water spraying, and with steam. Abrasive methods were ruled out as excessively damaging and dangerous. For a review of available techniques, see Ashurst, John, "Cleaning and surface repair," in *Conservation of Historic Stone Buildings and Monuments* (N.S. Baer, ed.). Washington: National Academy Press, 1982; also Weiss, Norman R., *Exterior Cleaning of Historic Masonry Buildings*. Washington: U.S. Dept. of the Interior, 1975.

[2] This two-step approach has become more common in recent years. We are currently involved in the cleaning of the General Electric Building, which is brick and terra cotta, by such a method. Earlier evaluation on sandstone and slate gravestones was done by us in the Trinity Churchyard, at King's Chapel Burying Ground, Boston, and the Ancient Burying Ground, Hartford. Some basic principles of chemical cleaning have been summarized by Heller, Harold L., "The chemistry of masonry cleaning," *Bulletin of the Association for Preservation Technology, IX* (2), 2–9 (1977).

The stone surface was prewetted only for the Limestone Prewash. All application was by brush. Air temperature was about 65 F, with some wind. Application time was 1 hour. The products were fully rinsed with water @ 500 psi. Restoration Cleaner (RC), diluted 1 part water to 2 parts concentrate, was then applied by brush, reapplied (and scrubbed) after 5 minutes, then rinsed fully @ 500 psi. (This was repeated in small areas within some of the test panels.) Surface pH was measured to ascertain that complete neutralization had taken place.

Performance of all systems was generally good, with the LP slightly worse than the others. The cleaning effect is dramatic; no loss of stone, etching, efflorescence or discoloration was observed. There appeared to be some drying or absorption of the 766 and the T-792 after 20–25 minutes, which lead to a procedural modification in the second set of tests, carried out on the Church, on November 7, 1986.

These later tests were done at the junction of elevations 18 and 20, that is, the southeast corner of the Chapel, where surfaces of both the Little Falls and the East Longmeadow sandstones could be cleaned. Air temperature was approximately 50 F. The 766 and the T-792 were tested again, with prewetting of the walls for about 2 minutes. Both were applied for only $\frac{1}{2}$ hour. (The HDPS and the LP were eliminated from the testing program for several reasons, including the greater difficulty of handling these products, especially on the higher elevations of the Church.) Another product, 859, an organic solvent-based stripper, was also tested here, with an application time of 15 minutes, and no prewetting.

All three were rinsed; the RC was then applied, diluted as in the earlier tests. After 5 minutes, a second application of the RC was made, then rinsed @ 500 psi.

Greater variation was seen in these tests, largely because of the shorter dwell time of the prewashes. In some areas, the 859 actually outperformed the other prewashes, but full interpretation of the several panels done in this location suggests that the T-792 may be the most generally useful product. It appears that prewetting will be possible with the T-792, which handled very well under these conditions. Supplemental use of the 859 for areas that resist cleaning seems feasible once such areas have dried.

Our recommendation, based on these test results, is that removal of surface coatings and heavy soiling can be done by use of ProSoCo's T-792 Alkaline Prewash (prewetting, applied for 1 hour, rinsed @ 500–1000 psi with a broad fan nozzle, minimum 6 gpm flow rate), followed immediately by RC (diluted as described earlier, applied for 5 minutes, then re-applied, scrubbed and rinsed). Tarpaulins may need to be used to protect the public, especially at the east and west ends of the Church, where the work will be near property lines, and control of pedestrians is thus not entirely possible. Windows will also require protection with polyethylene sheeting and/or a strippable masking material; of special concern are the clerestory windows, which are not double glazed.

[3] All are manufactured by ProSoCo, Inc., P.O. Box 1578, Kansas City, Kansas 66117. For product descriptions, see manufacturer's literature, including "Masonry cleaning weatherproofing and restoration products," and "Restoration products," both printed 1985.

We believe that, in this instance, cleaning is of more than cosmetic value. Thorough removal of the soiled wax (and silicone) layer constitutes an important measure for the preservation of the stone, as it should effectively reduce moisture entrapment. It is, moreover, necessary to eliminate this coating prior to any further conservation treatment, most especially impregnation with a consolidant (see section VII.2.4. of this report)

BURIAL GROUND PHASE I

5.2.2. ADHESIVE REPAIR AND REATTACHMENT

Fragmented markers should be repaired before pieces become lost. For smaller fragments a structural adhesive, such as a 2-part water insensitive polyamid epoxy resin, is adequate. For the majority of repairs at the Burial Ground, Sikadur Hi Mod Gel alone and in conjunction with threaded nylon pins was employed. In previous stone fragment repairs in other northeastern cemeteries, this has provided excellent bonding and continued performance.

For adhesive repair, fragments should be cleaned as described for masonry and dried thoroughly. For surface preparation, the contact edges should be swabbed with a suitable solvent system such as denatured alcohol followed by acetone to ensure clean, degreased, dry surfaces. All joints should be dry tested for fit before the adhesive is applied. Surfaces should be aligned with a straight edge to maintain original plane. The adhesive should be mixed in quantities readily applied within the setting time. It should be applied thinly and evenly to both surfaces to be joined, leaving an adequate margin ($\frac{1}{4}$ in.) toward the outer edges to prevent surface exposure. The surfaces should be immediately joined and held in position until the initial set has occurred (approximately 15 minutes). It may be necessary to secure the individual pieces to be joined with clamps or other means to insure complete immobilization during the curing set. Any excess adhesive visible at the cracks should be mechanically removed in its gel state but before it hardens as it will discolor and degrade when exposed to sunlight.

On those stones where areas of loss exist along narrow breaks, a fill of two parts white Portland Cement: one part hydrated lime (by volume) should be applied. The fill may be colored to match the stone by the addition of alkali-stable cement pigments in very small quantities (no more than 10% of the total binder component). Larger losses of stone along breaks require the addition of an appropriate aggregate to control shrinkage (see patching information below).

For most breaks, it is necessary to provide reasonable alignment by working on a horizontal support. Improperly aligned joins are unsightly. A sheet of plywood may be placed on sawhorses to provide a suitable work table on site. For tablets which have been deformed, temporary support of the deformation configuration must be constructed to achieve joint alignment and reduce stress at the joint. Masons' shims of various sizes are useful for this localized support.

For larger fragments or joins which require structural reinforcement, flexible threaded nylon or threaded stainless steel pins may be used, depending on the degree of strength or flexibility required. The diameter of the pin should not exceed one quarter the width of the stone. The length of the pin should be eight times the width of the drilled hole. Holes should be drilled with a masonry bit one-eighth inch larger than the diameter of the pin to be used. To determine the proper alignment of the pin holes, one edge is predrilled to the proper depth and its holes are filled with a colored chalk or crayon. Carefully assemble the adjacent section and the chalk will mark the respective location for pinning. These markings can then be rechecked using an adjustable scale such as that on a carpenters combination square. The second section should be drilled to the proper depth and angle using an adjustable carpenters angle for comparison, and then all holes should be cleaned of dust and debris with compressed air. Edges and holes should be swabbed with appropriate solvents such as denatured alcohol followed by acetone and allowed to dry. A dry assembly is essential to verify the hole placements and alignment of the fragments. Adhesive should be applied as described above and packed into holes before inserting pins, taking care to prevent excess from travelling to the surface of the stone.

Where original and replacement iron base pins were found, their removal or stabilization was considered essential for the future survival of the stones. This was achieved by either drilling the iron pins out and replacing them with threaded nylon rod as described above or by cleaning them down to bare metal (removing all corrosion) and priming them with a single-component, aluminum-pigmented moisture-cured urethane primer (Tnemec 50-330 Poly-Ura-Prime) before reuse. The latter option was only selected when removal was too difficult or dangerous to the stone and pins were found to be in relatively sound condition. Even broken tab assemblies were reattached by inserting nylon pins rather than recreating the same faulty design. Under no circumstances were markers completely adhered to their raised bases with structural (epoxy) adhesives, as this was considered too rigid and irreversible.

5.2.3. CLEANING

The decision to clean should be based on a genuine necessity to clean as all masonry cleaning subjects the stone to potential hazards. A monument which is darkened with soiling and biological growth is not only disfigured but also susceptible to accelerated masonry deterioration and therefore requires cleaning. A lightly soiled monument with legible details however, may not require a major cleaning. All cleaning methods must be tested in a discreet location for each stone before full-scale treatment. The gentlest methods should be tested first and if acceptable, should be chosen so as to avoid unnecessary damage to the stone.

5.2.3.1. Water Cleaning

Water cleaning is the gentlest, safest, and least expensive method of cleaning masonry especially for marbles and limestones. Most general surface soiling and some biological growth is easily removed with water. All open joints must be repaired to prevent penetration of quantities of water into the masonry. The water used should have a low metals content to avoid staining. Usually a potable water supply is adequate; however, the use of a particulate filter is advisable to secure against latent metallic staining.

Water can be applied at low pressure (up to 500–600 psi) and may be supplemented by gentle scrubbing with soft nonmetallic bristle brushes. However, cleaning with pressurized water and scrubbing should not be considered if the surface of the stone displays fragile condition.

Since black crusts, resulting from a carbonate stone's interaction with acid rain, are partially water soluble, they may be removed with a slow water misting soak. A perforated garden hose should be set up horizontally parallel to the surface to deliver water at city water pressure for 24 hours. Cleaning is done from top to bottom in this technique. As large amounts of water are used in this treatment, it is especially important that all joints and seams are watertight to prevent the introduction of water to the interior of the masonry and that drainage from the site is provided. Slight staining can sometimes develop on certain stones possessing iron-containing minerals which can react to form brown or yellow oxide stains.

5.2.3.2. Chemical Cleaning

For organic stains below the surface of the stone which are not removed by a water wash, the application of a bleaching poultice has proven to be very effective on

porous stones such as marble. A low concentration solution of technical grade calcium hypochlorite (1.5–6%) is mixed into an inert clay body, such as kaolin and attapulgite clays. This paste is then spread over the stone or in localized areas to a thickness of no less than $\frac{1}{4}$ in. and left on for 10–30 minutes. The paste is then removed using nonabrasive tools such as wood or rubber spatulas and the stone is rinsed thoroughly with clean water. No odor of calcium hypochlorite should remain after rinse.

Poultice applications may be repeated if staining remains.

5.2.3.3. Abrasive Cleaning

Abrasive cleaning involving any grit or aggregate applied under pressure should not be used on soft stone types such as those found in the Burial Ground. This technique is considered too aggressive and can cause irreversible damage. It may lead to accelerated weathering by pitting the surface, thus opening the masonry to increased moisture penetration and atmospheric reactivity and subsequent deterioration.

5.2.3.4. Metallic Stain Removal

For removal of iron staining resulting from the corrosion of pins and braces, a saturated solution of ammonium citrate with glycerin and buffered with ammonium hydroxide to a pH of 8.5 should be used locally in a poultice application as described above under chemical cleaning. In this case the poultice should be covered with plastic for 48 hours. After the plastic has been removed and the poultice has completely dried, the remaining material should be removed with dry brushing and nonabrasive tools. The area should then be thoroughly rinsed with clean water.

As above, poultice applications may be repeated if some staining remains.

5.2.4. CONDITION

Consolidation treatment should be carefully considered for individual stones only by a professional conservator. If consolidation is considered viable, it must be tested before a full-scale treatment program is attempted. Previous research and test data suggest the use of organo-silicates as promising stone consolidants. The model treatments done on site using an ethyl silicate (Conservare Stone Strengthener H and OH, manufactured by Wacker-Chemie and distributed by ProSoCo) have shown to increase abrasion resistance and water repellency without significantly reducing water vapor permeability or changing color and texture. Consolidation of friable fragments is necessary prior to reattachment in order to insure adequate joint adhesion at the break. In all cases consolidation should be preceded by cleaning where a hydrophobic consolidation system is selected, as cleaning will be difficult later on. Mortar repairs must be installed prior to treatment and allowed to cure for 1–2 weeks before application of the consolidant.

For stones of manageable size, the first choice of application is the immersion method, however, for stones in place or of sufficient size and/or weight, a spray application method is satisfactory.

5.2.5. GROUTING

Conservators, masons, and others in the allied building trades are often confronted with the problem of stabilizing exfoliating or delaminating masonry and plaster. When details of historic fabric such as decorative carving, tombstone inscriptions, or painted mural surfaces are endangered, reintegration or reattachment is central to their conservation. Grouting—the injection of fluid mortars or synthetic adhesive materials at low pressure—has been successful as an effective, easily duplicated, safe and inexpensive technique for reintegrating detaching and unsound material, particularly when used for nonstructural historic masonry. The majority of commercially available grouting products today have properties which render them unacceptable for use on historic fabric including flexural, tensile, and compressive strengths which may exceed 2000–10,000 psi each.

Lower strength and more vapor-permeable formulations are available either commercially (Jahn M-40, from Cathedral Stone) or can be formulated using (by volume) 2 parts white portland cement: 1 part (Type S) hydrated lime: 3 parts aggregate (equal amounts of fine banding sand and ceramic eccospheres); either of these formulations are suitable, both are used and recommended by Center for Preservation Research for this type of grouting. Formulations should be premixed dry and then well mixed with water to the consistency of heavy cream. Cavities to be grouted are first cleaned of debris with compressed air and then water flushed. Cracks and fissures are dammed with nonstaining potter's clay and the grout injected by gravity through tubes or with low pressure syringes. After voids are completely filled and delaminations attached, the work is covered with wet burlap or plastic for slow cure. Capping of the grouted areas with mortar mixes (see Patching) where necessary is done to deter water infiltration and visually reintegrate the losses.

All masonry work should be executed under optimum weather conditions to ensure the success of the repairs. No work should be executed nor cured during freezing weather (below 40°F). To prevent too rapid drying in temperatures over 85°F, particularly of thin finishes such as mortar repairs and washes, masonry work may require repeated misting and protection from the sun with damp burlap sacking.

A NEW YORK CHURCH

1. INTRODUCTION

The Center for Preservation Research (CPR) conducted an investigation of exterior stonework of a Church in New York, beginning in April 1986. The investigation was undertaken at the request of the Director of Administration, in preparation for up-coming restoration work. The Church was designed in the Gothic style popular for ecclesiastical architecture at the turn of the century. Construction was completed in 1914. The church has an asymmetrical form with a main tower at one corner. A parish house of the same materials and style adjoins the church.

Because of some difficulties recently encountered during exterior cleaning of the parish house, an in-depth investigation of conditions of the stonework of the church was requested. The investigation included a review of records of past preservation treatments, on-site and laboratory examination of materials, and small-scale tests of cleaning methods. The following report summarizes data obtained and provides recommendations for restoring the original appearance of the Church.

2. MATERIALS

The principal material used in the construction of the Church is Bowling Green limestone, an oolitic limestone from Warren County, Kentucky. Beds are generally 10–22 feet thick; freshly quarried stone contains oil (from petroleum deposits) which gives the stone a murky appearance. Upon exposure to the weather, the oil evaporates leaving the stone with a white or nearly white appearance. Oolites stand out conspicuously and are rounded or elongated in shape. The primary mineral is calcite. Occasionally iron pyrite is present.

Bowling Green limestone is known as "the aristocrat of limestones" because of its color, uniformity, strength, and ease of working. The stone is also known for its good weathering qualities; original tool marks are often retained long after construction.

Sculpture of the entries is of Indiana (Bedford) limestone. This stone consists mainly of somewhat rounded shell fragments cemented together with calcite. Its color and texture are similar to that of Bowling Green limestone.

3. PREVIOUS TREATMENTS

3.1 Fluorosilicate Treatment

Church records state that in 1928–1929, Nicholson and Galloway, Inc. applied a solution of "Magnesium-Silicon-Fluorite" to stonework of the Church for the purpose of hardening the stone. Church records suggest that soiling and discoloration of the stonework were present at the time of treatment.

The fluorosilicate or "fluate" treatment for preserving stone was first proposed by J.L. Kessler in France in 1883. Reports of the treatment were initially enthusiastic. A report from 1918 states that Kessler's method is "free from all objectionable features possessed by other methods proposed or adopted for preservation of building stones." The treatment was thought to harden the surface of the stone and impart resistance to frost damage. However, as early as 1921, others described difficulties encountered with the treatment: the formation of a hard surface film on treated stone resulted in subsequent flaking, scabbing, and scaling.

Success of the treatment is based on the reaction of magnesium fluorosilicate with calcium carbonate (calcite) of which this limestone is primarily composed.

Because the pH of the solution is low, the evolution of carbon dioxide gas accompanies its reaction with limestone. The calcium fluoride and silica are deposited as a superficial, often spongy, layer. Unfortunately, deterioration often continues underneath this crust. Today, conservators of art and architecture are generally negative about the long-term benefits of fluorosilicate treatment.

3.2 Plexi-Seal Treatment

Proposals were made by Plexi-Seal Protection Corp. during 1971–1974 to apply a coating of Plexi-Seal to stonework of the church and parish house. According to product data, the coating used was a partially cross-linked polyester material. (In a recent telephone conversation, J.S. Wyner, the President of Plexi-Seal Protection Crop., stated that the coating also contained an acrylic resin.) Plexi-Seal is supposed to provide masonry substrates with a protective coating that will reduce damage caused by water intrusion. Correspondence indicates that the coating was applied to elements of the main tower, "frontal areas" of buttresses, the northwest rear wall at the third floor level, and to the parish house facade. In addition, a modified acrylic latex formulation of Plexi-Seal was added to mortar used in patching and repointing. Limitations of this type of treatment include its inability to achieve more than superficial penetration and the risk of drastically reducing water vapor permeability. With some building materials, the latter can result in damage from the entrapment of water and soluble salts. Fortunately, it does not appear that the Plexi-Seal coating has accelerated deterioration of the stonework of the Church.

However, the mottled appearance of stonework of the parish house after its recent cleaning appears to be the direct result of this "preservation" treatment. In addition, patching and repointing executed in the early 1970s is considerably darker than adjacent stonework. Discoloration of the Plexi-Seal coating strongly suggests that it is not resistant to ultraviolet radiation.

4. EXISTING CONDITIONS

The existing condition of exterior stonework was surveyed during several site visits. In those locations where closeup examination was not possible (e.g., upper areas of the main tower), inspection was made from the ground and roof levels with the aid of binoculars.

Stonework of the Church is generally in good condition. As surface erosion has been moderate, carved ornamental details are still relatively crisp and arrisses sharp in most locations. Tool marks are still visible in many locations. A notable exception is the limestone of the turret where weathering has been severe.

A number of vertical and diagonal cracks were noted along the water table level of the church. As was earlier stated, these are patched with a now-darkened cementitious material. Repairs to limestone blocks can also be seen from the turret roof. Discoloration of the patching material in this location is similar to that noted on the crack repairs at the water table level.

A further description of several exterior masonry conditions (general soiling, coating residues, and localized stainings) provided in the paragraphs below. Deterioration mechanisms are discussed.

4.1. General Soiling

Dark soiling is present on exterior limestone in areas that are protected from direct contact with rainwater. This soiling pattern is typical for limestones and other calcareous stones. Although the condition was noted throughout, the pattern is perhaps most pronounced on the south elevation at street level. The mechanism resulting this condition is described below.

Acidic gases absorbed from the atmosphere by rainwater, cause it to be reactive with limestone and other calcareous stones. Sulfur dioxide, which (under typical atmospheric conditions) forms both sulfurous and sulfuric acid when dissolved in water, is perhaps the most destructive of these pollutant gases. In addition to the direct dissolution of calcium carbonate (calcite), the reaction of sulfur dioxide with limestone results in the formation of calcium sulfate dihydrate (gypsum) on the surface of the stone. As gypsum is more soluble in water than is calcium carbonate, the exposed surface becomes eroded when washed by the rain. Where this

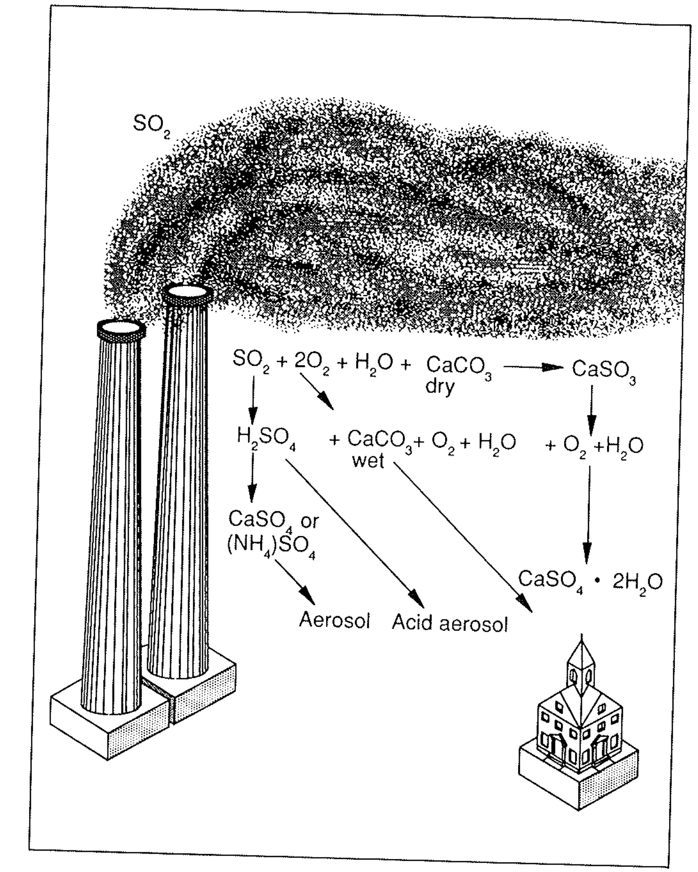

Figure 52. Air pollutants.

surface is protected from the flow of rainwater, the continued transormation of calcium carbonate into calcium sulfate dihydrate results in the formation of a "crust" of gypsum. Particulate matter becomes entrapped in the network of gypsum crystals, giving the surface of protected areas a blackened appearance.

At the Church, there is often an intermediate brownish-colored zone between the blackened gypsum crust and white, rainwashed stone. It is possible that this phenomenon is related to previous preservation treatments. In several locations leaching of calcium carbonate by rainwater has resulted in particularly heavy deposits of gypsum. Thick "framboidal" crusts can be seen at window tracery, decorative moldings of the entries, and ornamental carving of the turret.

Of particular note is alveolar erosion of the gypsum crust best seen at the turret. The reason for this differential deterioration is still uncertain. Possible causative factors are external conditions such as greater exposure to winds and heterogeneity of materials imposed by preservation treatments.

4.2. Coating Residues

Much of the stonework of the parish house is somewhat discolored with streaking and mottling. It appears that the recent cleaning of the parish house by Nicholson and Galloway, Inc. using the water method did not completely remove coating residues from the limestone surface. The appearance of the stonework as well as information from church records indicate that the residues are probably from the Plexi-Seal treatment of the early 1970s.

Stonework at the tops of buttresses and below the carved ornament of the turret display mottling that is similar in appearance of the dark-colored staining on brickwork at the northwest corner suggests the presence of a coating on the stonework above. Church records support the use of Plexi-Seal in these locations. Mottling, however, is not apparent on the main tower, where, according to Wyner, the coating was also applied.

Stonework of the entries also appears to have a coating residue. In these protected locations, mottling is less apparent. There is discoloration throughout with efflorescence visible above the doorway at the southeast entry.

4.3. Localized Staining

Metallic staining present on exterior masonry is of two types. Blue-green copper stains are present below the flashing on the inner wall below the turret and at the tracery of the clerestory level at the north facade. Solubility of the copper corrosion products in rainwater has resulted in this staining.

The reddish-brown color of stains below air conditioning units on the south elevation of the church and parish house suggests its ferrous source. However, there is no obvious source of similar colored staining on the limestone at the southwest corner of the clerestory level. Here, the staining may be related to the mineralogical composition of the limestone.

5. LABORATORY TESTS

Core drilling samples were obtained May 13 using $1\frac{1}{4}''$ diameter carbide tipped bit. Locations were as follows:

A. northwest corner at stair landing
B. parish house turret, north side
C. clerestory, south side below turret

Each sample was examined by Robert Koestler using a scanning electron microscope. Results of the examination are highlighted below.

Calcium fluoride and amorphous silica were seen on all samples, undoubtedly dating from the 1928–1929 treatment. Examination of the samples suggests that the treatment may have contributed to etching of calcite grains. The presence of silica deposits on the surface of gypsum crystals of sample C indicates that the surface was somewhat weathered at the time of treatment. It appears that the Plexi-Seal treatment, seen on sample A, may have contributed to flaking of the surface crust.

6. ON-SITE TESTS

After the review of records of previous treatments and a thorough inspection of existing conditions, locations representative of typical substrate conditions were designated for on-site testing. Small-scale tests of several cleaning methods were conducted *in situ* during May and early June. Because metallic staining is not visible from the street level, no on-site tests were carried out to treat this condition. Materials and methodologies are described below.

6.2. General Soiling

6.2.1. Chemical Cleaning Tests

Because of the difficulties encountered during the cleaning of the parish house stonework and the records of previous fluorosilicate and Plexi-Seal treatments, it was feared the water washing would not be effective in removing general soiling from limestone. Chemical cleaning tests were executed on the clerestory level of the street facade using both commercial products and custom formulations.

The following commercial products were applied according to the manufacturers' instructions:

Limestone Prewash, diluted 1 part concentrate to 3 parts water (ProSoCo, Inc.)
T-792 Prewash (ProSoCo, Inc.)
Limestone Restorer (Deidrich Chemical)

Dwell times were approximately 1 hour. After thoroughly rinsing the surface, Limestone Afterwash (ProSoCo, Inc), prediluted 1:3, was applied. After 3–5 minutes, the surface was again thoroughly rinsed.

Results: With each of the above, there was some lightening of the surface. Complete removal of general soiling, however, was not effected in any of the test areas. In addition to the above commercial products, the following custom formulations were tested:

AB-57
D-10

Each was applied as a poultice and covered with polyethylene for the first 48 hours. The poultice was then allowed to dry (approximately 72 hours) and removed with dry brushing followed by water rinsing.

Results: Removal of general soiling was good with AB-57 and moderate with D-10. However, the success of AB-57 may be due in part to the reaction of EDTA with the limestone rather than the removal of soiling from its surface.

6.2.2. Water Washing

Water washing is generally thought to be simplest, safest, and least expensive method for removing general soiling (gypsum crust) from limestones and other calcareous stones. The effectiveness of this method relies on the fact that the gypsum crust in which the dirt is incorporated is several times more soluble than is calcium carbonate. Thus, by partial dissolution, water loosens the gypsum crust and the material trapped within the network.

Water washing was tested at the southwest corner and at the north side of the passageway below the turret at the clerestory level of the street facade. A perforated garden hose using water at city pressure was aimed at soiling for approximately 24 hours.

Results: In both test areas, dark-colored soiling was successfully removed after a 24-hour water wash. In the passageway, some mottling was noticeable after drying was completed. The success of the small-scale tests suggests that the fluorosilicate treatment was probably applied to a weathered surface. (This determination is supported by the laboratory examination using the scanning electron microscope.) Water washing appears to penetrate the superficial crust of any surviving treatment residue, solubilizing the gypsum below.

6.3 Coating Residues

Tests to remove coating residues were first carried out on the parish house at the first story level.

The following commercial products (all ProSoCo, Inc.) were applied according to the manufacturers' instructions:

Limestone Prewash
T-792 Prewash
509 Paint Stripper
Heavy Duty Paint Stripper

Dwell times were approximately 1 hour. After thoroughly rinsing the surface, Limestone Afterwash (ProSoCo, Inc.), prediluted 1:3, was applied to all but the test where 509 Paint Stripper was used. After 3-5 minutes, the surface was again thoroughly rinsed.

Tests using the Limestone Prewash and the Heavy Duty Paint Stripper were also executed on the stonework of the southeast entry.

Results: At the parish house test areas, the yellow-colored mottling appears to be very resistant to chemical cleaning methods. The most effective product tested in this location was the Heavy Duty Paint Stripper.

At the southeast entry, the Heavy Duty Paint Stripper was only moderately successful after one application. In this location, however, removal of coating residues was easily accomplished using the Limestone Prewash. Success in the test area suggests that this product can be diluted for full-scale cleaning.

7. RECOMMENDATIONS

7.1. General Soiling

General soiling can be effectively removed from the stonework of most areas using the water wash method. Washing equipment should include manifolds, hoses and sprinkler heads capable of delivering a fine mist of water to *all* soiled surfaces. Equipment should be set up horizontally parallel to the topmost area of a wall. When washing is completed, the equipment should be lowered in a straight line to the lowest point. [Editor's note: all such equipment shall contain no ferrous materials which could corrode and cause rust staining.]

The time period required for the removal of general soiling (washing cycle) should be determined during on-site tests conducted by the contractor. After completion of the washing cycle, light brushing using natural bristle brushes or low pressure rinsing should be used to complete the cleaning operation.

In some areas, where soiling persists, supplemental cleaning may be required after water washing. Wherever necessary, chemical cleaning should be executed using the materials and procedures described in the section below (5.2. Coating Residues). To remove framboidal crusts, it may be necessary to supplement water washing with chemical and/or mechanical methods. The latter should be performed using blunt masonry chisels. Care should be taken to avoid damaging adjacent masonry surfaces.

As the water wash method necessitates the use of a considerable amount of water, it is important to guard against its intrusion to interior spaces. The contractor should inspect the condition of all interior surfaces before cleaning begins. Monitoring of the condition of materials should continue through full-scale operations. Cleaning should be *immediately* stopped upon any sign of dampness.

7.2. Coating Residues

Chemical cleaning will be necessary in areas where coating residues persist. In addition to stonework of the entries, it is expected that supplemental cleaning will be required on topmost areas of the turret and, possibly, on some elements of the main tower.

It is hoped that the Limestone Prewash can be used in a 1:3 dilution (concentrate to water). This may be possible if limestone surfaces are pre-washed with water just prior to chemical cleaning. Tests conducted by the contractor on stonework of the southeast entry will determine the feasibility of this modification. Chemical cleaning should be carried out by the procedure described below.

1. Prewet a 4′ section of limestone
2. Brush apply Limestone Prewash (prediluted 1 part concentrate to 3 parts water) to prewetted wall surface.
3. After allowing the cleaner to remain on the surface for approximately 1 hour, immediately flood the entire section with water, removing all alkaline cleaner from the surface.
4. Immediately apply Limestone Afterwash (prediluted 1:3) and allow to remain on the surface for 3–5 minutes.
5. Immediately flood the entry section with water, removing all acidic cleaner from the surface. Complete rinsing operation using pressure washing equipment.

Cleaning should *not* be conducted when the air temperature is below 40°F. The contractor should follow the manufacturer's recommended procedures for protecting surrounding nonmasonry surfaces during all phases of the cleaning operations. Workers should utilize protective safety glasses, gloves, clothing, and so on, as specifically recommended by the manufacturer.

7.3. Metallic Staining

Should metallic staining become apparent after the completion of general cleaning operations, remedial treatment may be desirable in some locations. The following recommendations are based on recent experiences with removing metallic stains from calcareous stones.

For copper stains, a 20% solution of ammonium carbonate should be used in poultice application. The poultice should be covered with plastic and allowed to remain on the surface for approximately 48 hours. After drying is complete, all remaining poultice material should be removed with dry brushing. The area should then be thoroughly rinsed.

For iron stains, a solution of ammonium oxalate or ammonium citrate should be applied in the manner described above. In both cases, small-scale tests should precede full-scale operations.

NOTES

1. Information about Bowling Green limestone was obtained from *The Building Stones of Kentucky* by Charles Henry Richardson (Frankfort, KY: The Kentucky Geological Society, 1923) and *Physical Properites of the Principal Commercial Limestones Used for Building Construction in the United States* by D.W. Kessler and W.H. Sligh (Technologic Papers of the Bureau of Standards, 21, No. 349, 497–590, July 23, 1927).
2. Cecil H. Desch, The Preservation of Building Stone, *J. Soc. Chemc. Ind.* 37 (April 30, 1918): 118T.
3. Noel Heaton, The Preservation of Stone, *J. Roy. Soc. Arts* 70 (1921): 124–139.

MUNICIPAL BUILDING

MASONRY STONEWORK

Description

According to the drawings and specifications (see Appendix A) the stonework of the North and South Entrance Halls and the main stairwells was built as planned using a "Light Botticino marble dressed rubbed to a half polish." This light buff colored Italian marble became increasingly popular by the end of the century as evidenced by its widespread use in many public interiors of the period. Largely composed of calcium carbonate, its color is due to secondary mineral impurities—limonite or hydrous iron oxide. The veneer ashlar and all trimmings appear to have been installed as specified with metallic anchors to the backing wall and with dowels connecting adjoining pieces (top to bottom). All work was set in a white cement mortar with narrow $\frac{1}{8}$-in. bedding joints.

Accent stone was used in the lunettes above the arched elevator openings and in the floor pavement. Although the lunette fields were of a gypsum plaster imitation stone (see Plasterwork), the roundels within were built as specified with "grey and yellow sienna marble" dressed as the Botticino walls.

The floor pavement design called for a more complicated mix of different colored stone and cast bronze circular insets of the seal of the City. The design specified and built was a patterned background of "light and dark Pink Knoxville Marble," geologically a crystallized limestone with small circular and diamond-shaped inset panels of "Oriental and Verde Antique Vermont Marble." Larger square and circular panels placed along the center axis were to be of various granites, "Cape Ann, Ascutney Green, Jersey Pink, and Stoney Creek." This was all executed as planned with the exception of the cast brass inlays which were never installed.

Also as specified, the risers, treads, and platforms of the entrance hall stairs were constructed of a "Pink Knoxville Marble" similar to the main pavement.

CONDITION

Only a general qualitative survey of the stonework was made to identify the major problems and to assist in setting up a treatment test program. In general the stonework of both lobbies appears to be in good condition. Overall soiling, observed as a gritty yellowish to brown film, occurs on most surfaces, except where it has been harshly removed by recent chemical cleaning along the lower walls. Both soiled and cleaned surfaces are dull in luster. This soiling is most likely the combined result of greasy air-borne particulates from fossil fuel combustion (automative exhaust and heating fuel), cigarette smoke, and body oils. The latter is most noticeable along the pier edges and lower walls of the stairwells due to high pedestrian traffic. No previous coatings appear to be present judging from a lack of surface anomalies; however, their presence sometimes can be difficult to ascertain.

An unusual white mottling of the Botticino marble occurring along hairline cracks, geological joints and veining, and construction joints is most prominent on the exterior walls, especially in the stairwells. This is most likely related to the transmission of water vapor or liquid through these openings and possibly the transport and deposition of water soluble salts. It is also possible these areas may appear lighter than the surrounding soiled surfaces because they have been kept clean by the migrating moisture. No salt fretting or spalling is evident except on the second floor landing of the South Hall stairwell.

In addition to these discolorations, localized stains from pressure tape adhesive, signage, chewing gum, and graffiti are also present. Previous fills, some of discolored adhesive resins, and many new losses from abrasion and impact are visible across much of the lower walls and arises. Isolated stress cracks exist as well.

MASONRY TESTING PROGRAM

In July and November of 1989, a small-scale testing program was conducted on the stonework and plaster ceilings to ascertain the most appropriate methods for restoration.

Cleaning tests of approximately 6 × 12 in. were performed on heavily soiled Botticino marble in the south stairwell and on the lower panel of the Directory and on a representative stair riser and tread of "Knoxville marble," all in the South Entrance Hall. Paint removal tests and restoration of the original plasterwork finish were also attempted in the northeast corner vault and lunette in the North Entrance Hall.

These tests and their results are outlined below:

0 No visible effect
+ Visible cleaning
– Negative or adverse effect

TEST AREA: SOUTH WALL OF SOUTH STAIRCASE SOUTH ENTRANCE HALL

X water scrub / 0

1 Ammoniated Triton X [20% 3*M* Ammonium hydroxide + 80% Triton X (Now Union Carbide) nonionic detergent (10 drops/gallon of water] /0

A Lacquer thinner
cotton pad applied/0

B Petroleum ether (technical grade)
cotton pad applied/0

C Denatured alcohol (technical grade)
cotton pad applied/0

D Sure Klean Marble Poultice with water (ProSoCo)
dwell time: 48 hours with scrub rinse/—surface alteration

E Sure Klean Marble Poultice (ProSoCo) with additive
dwell time: 48 hours with scrub rinse/—surface alteration

F Ammoniated Stripper (Manhattan Floor Supply)
[illegible]

+ +

ISC Sure Klean Interior Stone Cleaner (ProSoCo)
prewet, diluted 1 part concentrate: 2 parts water
dwell time: 3–5 minutes, scrub and water rinse/ +

Z Control

The results of these tests suggest that the surface soiling is most effectively removed with alkali and alkali-solvent mixtures. Test panels F and I both displayed the best cleaning leaving the stone a cool buff color. Test panel E displayed an unacceptable rough texture and whitish color alteration. The results of test panel D appeared to be effective in removing surface grime, however, its application as a poultice would not be as efficient or cost effective as a single application of the Ammoniated Stripper (F) or 859 Stripper (I). The Liquid Marble Cleaner and the Interior Stone Cleaner were not as effective in removing the white mottling as the Ammoniated Stripper (full strength and dilute) or the 859 Stripper.

In addition to the above cleaning tests, a small panel of Botticino marble was resurfaced with wet abrasive/acidic polishing by a professional stonemason. This technique both cleaned and restored a luster finish to the marble.