RESTORING STONEWORK

RESEARCH

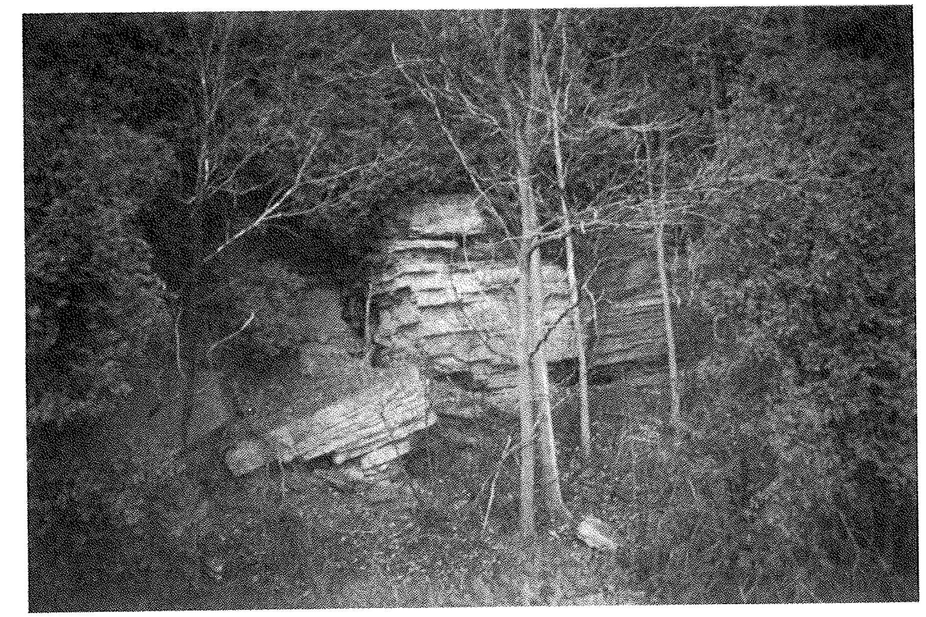
Many of our finest heritage buildings were built of stone or in more recent years were faced with a stone veneer over a steel or concrete frame. When the stonework deteriorates its restoration can pose many problems, especially for those who have not been trained in the conservation of buildings or those 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

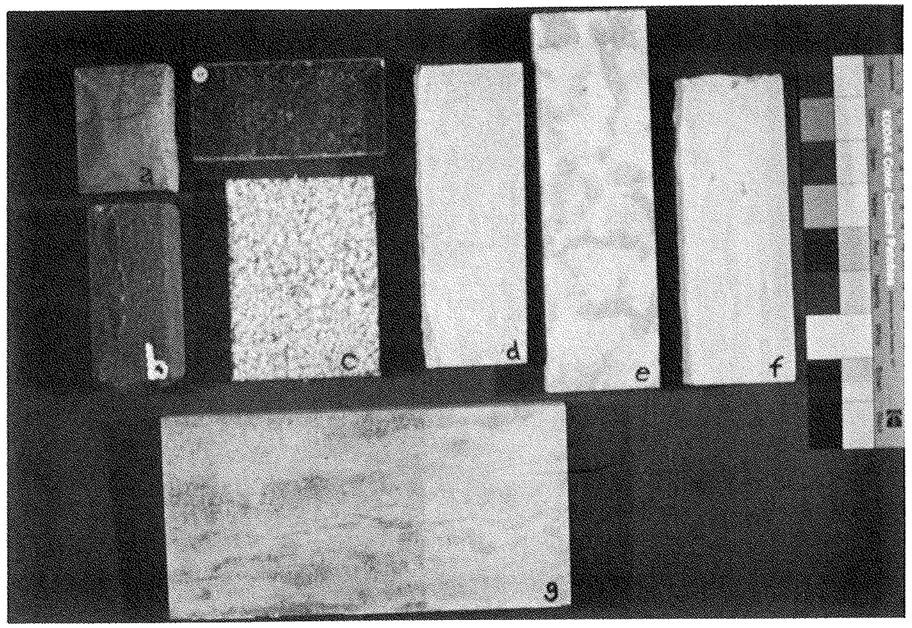


Small quarry close to 19th century Ontario house.

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

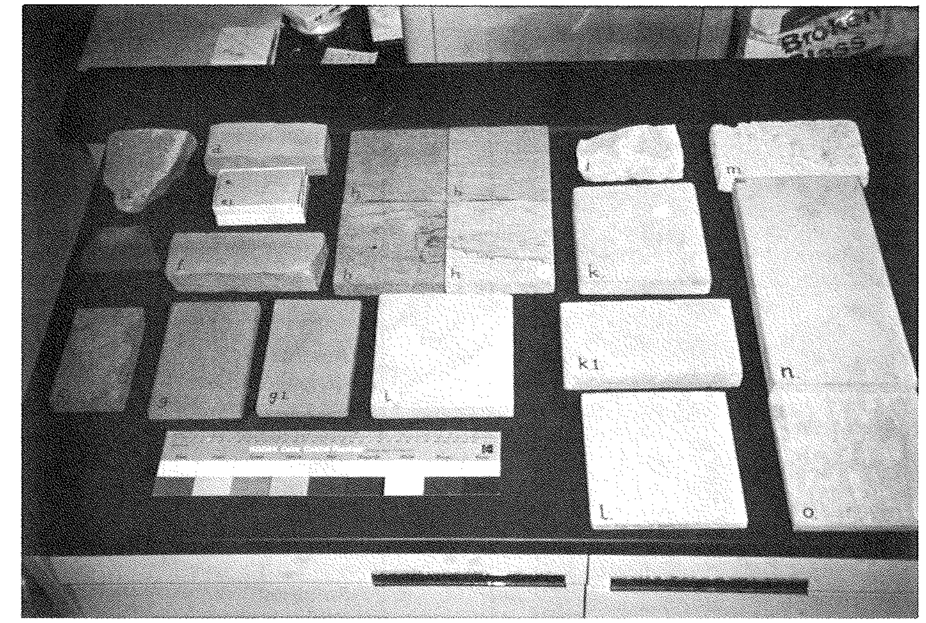
Where Did the Original Stone Come From and From What Specific Geological Formation? What historical data exist on the stone, for example, early geological reports and chemical analyses of the stone? Is this stone still available? If not, are there any similar stones which could be used as substitutes 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.

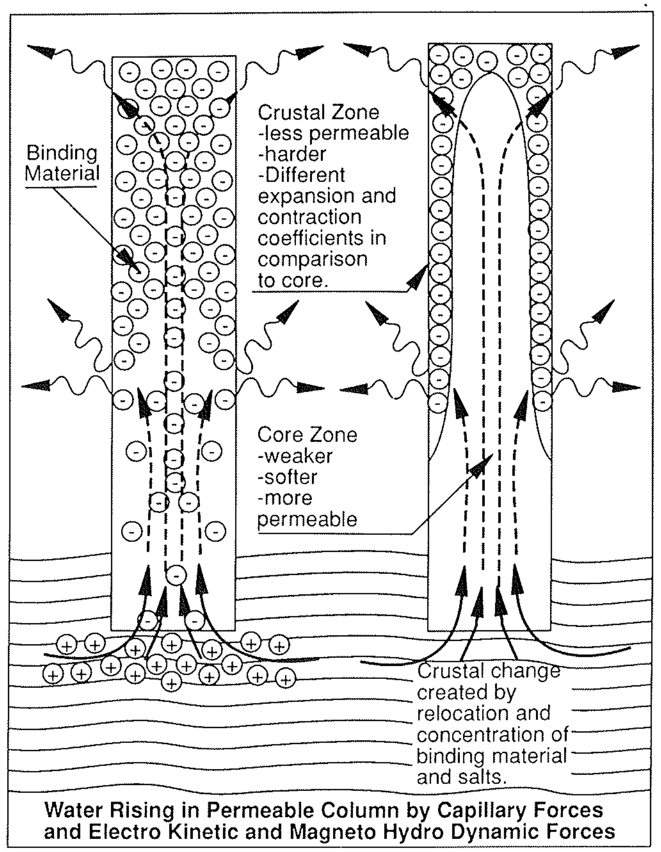
This group of granites from the United States shows the great diversity which is to be found even within such a small selection. (a) and (e) are Stoney Creek granites from Rhode Island. (c, c1) Grey Tapestry granite from the Baretto Granite Corp. New Hampshire. (f) is a Cold Spring Granite Co., Spring 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 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.

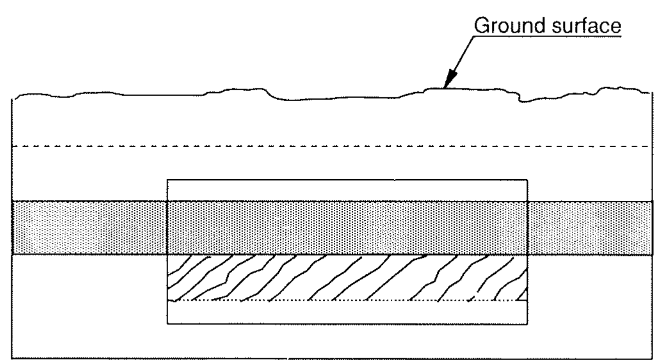


Figure 37a. Bedding planes: side view.

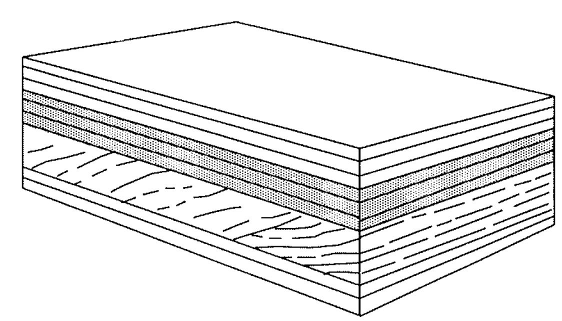


Figure 37b. Bedding planes: perspective view of removed section.

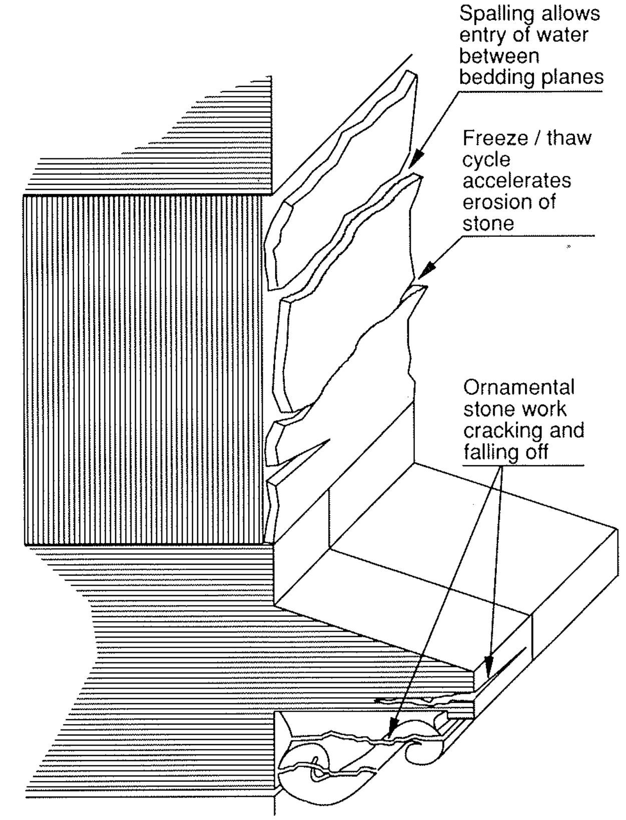
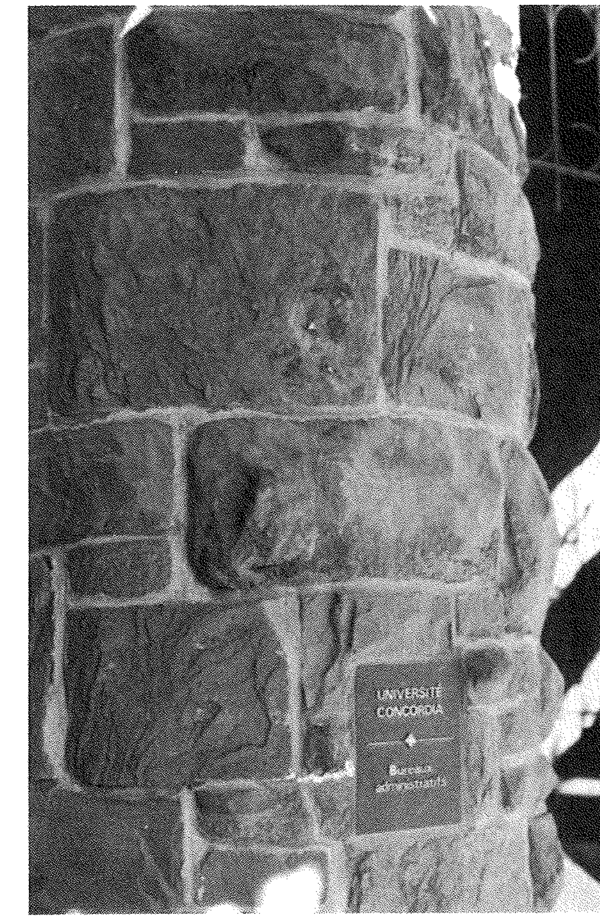


Figure 38. Incorrect orientation of bedding planes.



Face bedding problems.

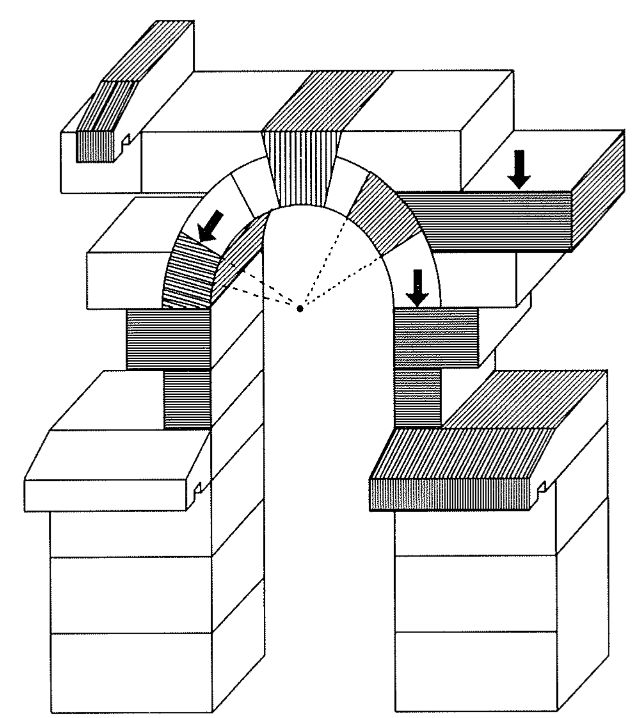
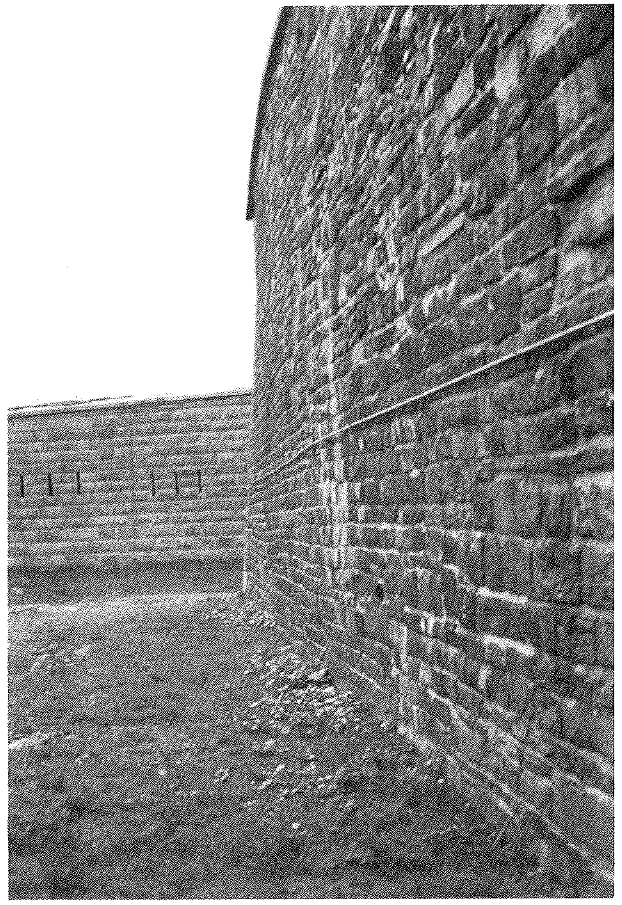


Figure 39. Correct orientation of bedding planes.

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.

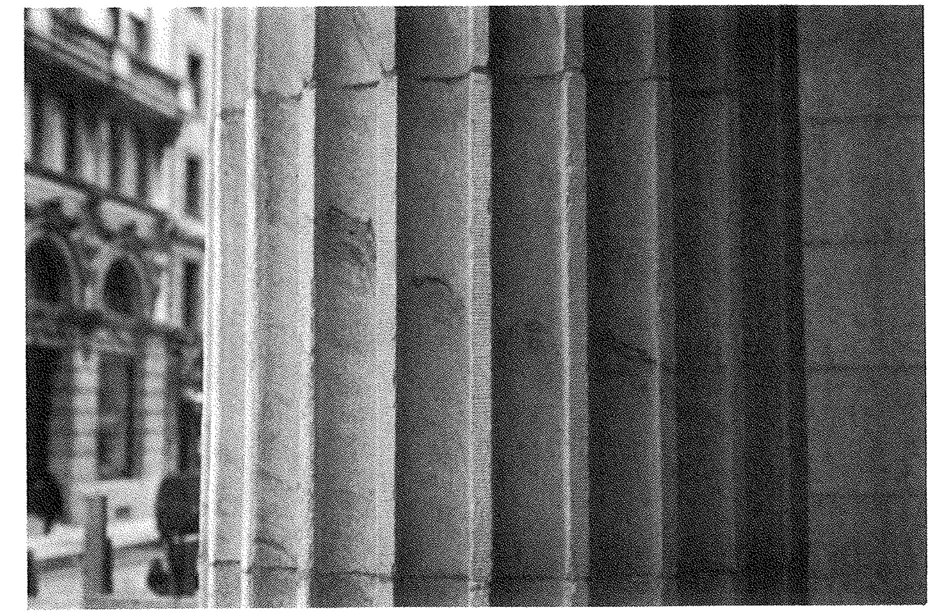
Are there Accumulations of Water-soluble Salts on or in the Surface of the Stones? Powdery deposits of crystals of various salts on the surface are termed efflorescence. When they occur in or below the surface they are termed subflorescence or cryptoflorescence.

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.

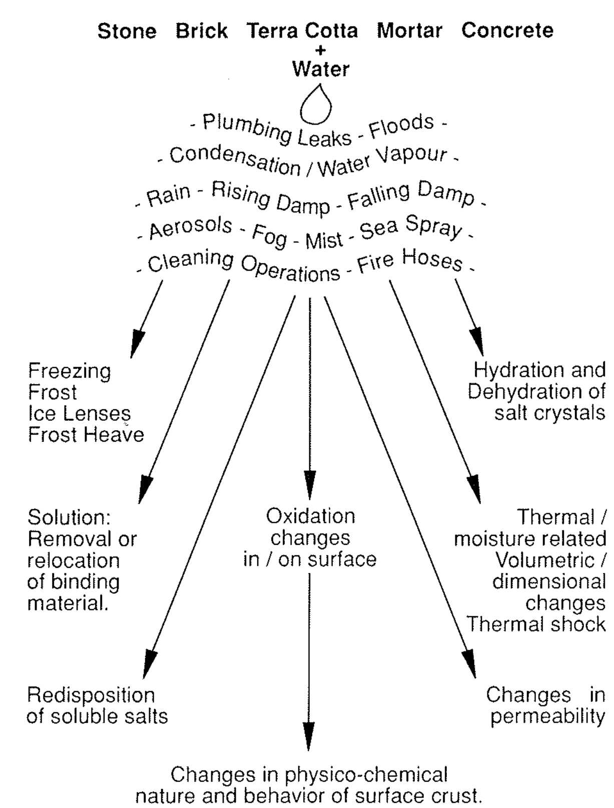


Figure 40. Deterioration of masonry materials and structures.

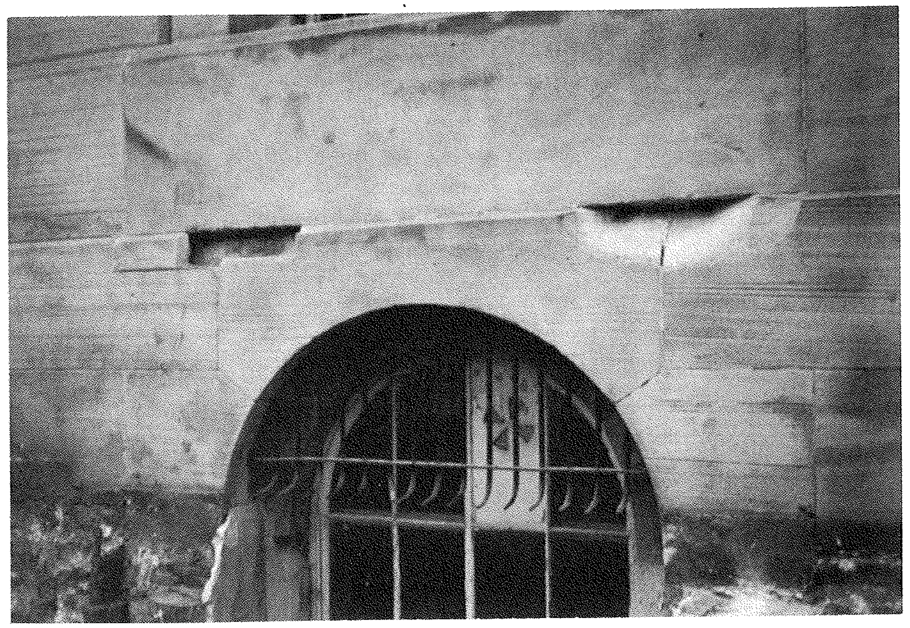
How were the Stone Surfaces Finished? What are the correct terms for these finishes, for example, punched, tooled, boasted, bush hammered?

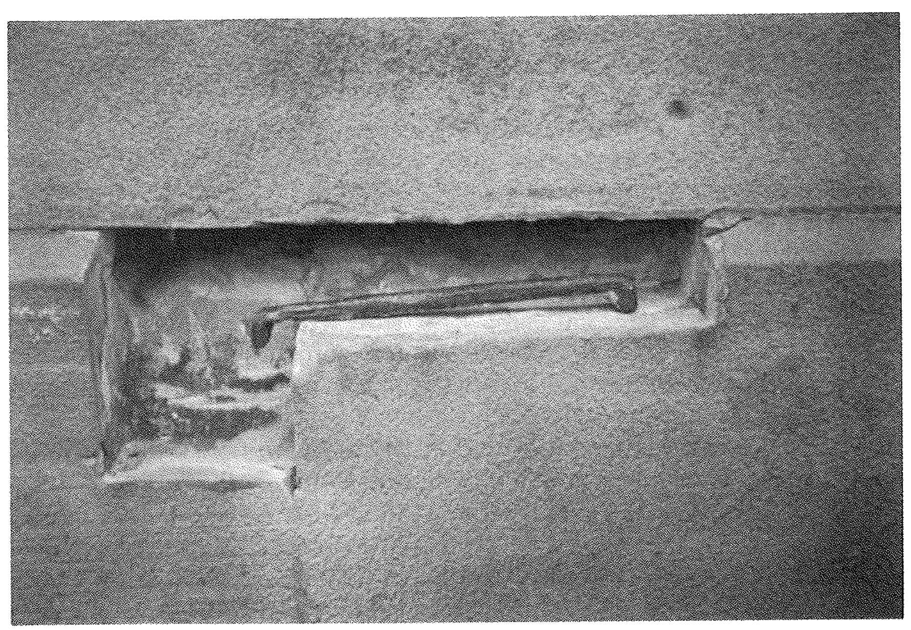
What is the Crushing or Compressive Strength of the Stone Both When Dry and When Wet? (ASTM C 170-87 Standard Test Method for Compressive Strength of Natural Building Stone.)

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

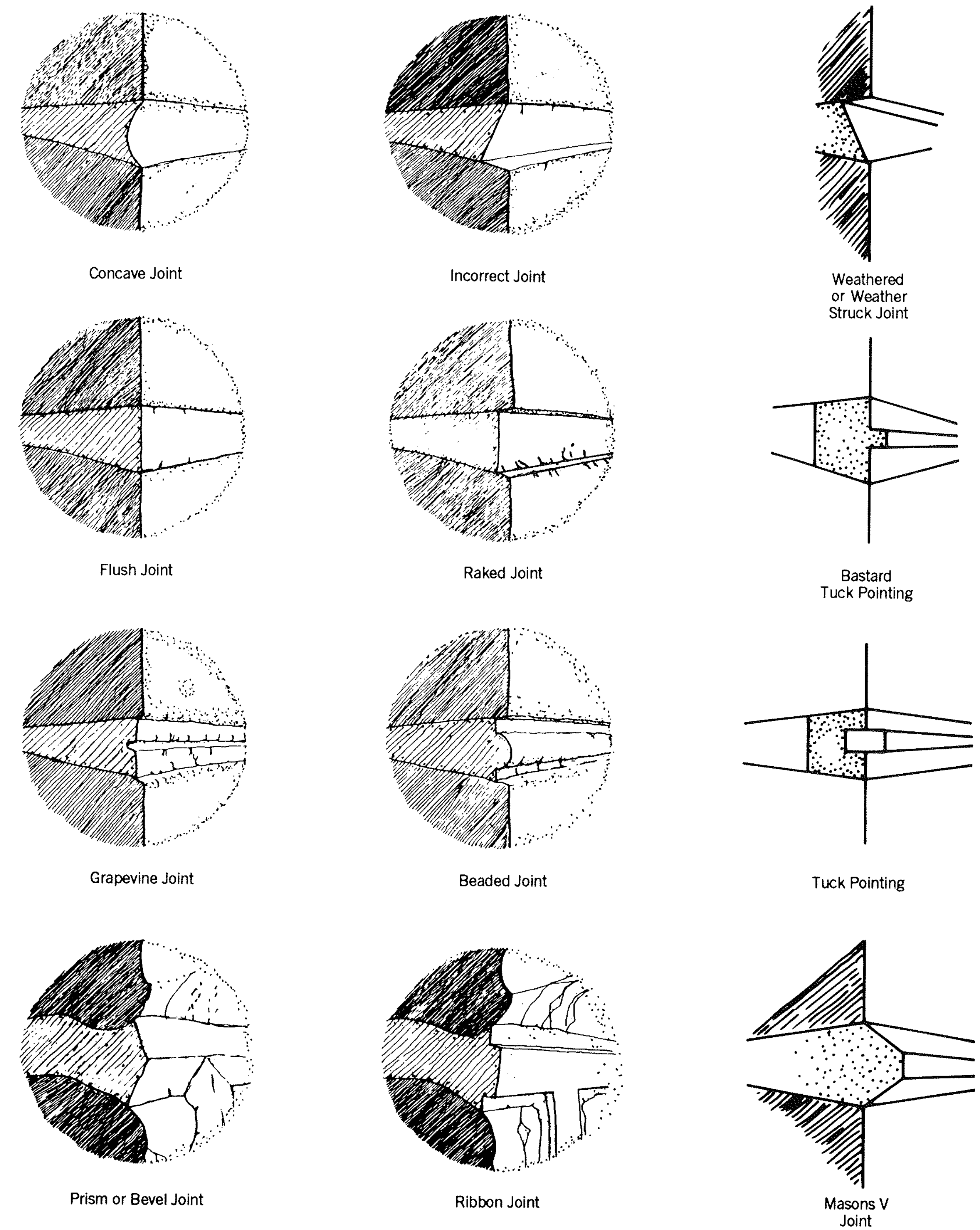


Figure 41a. Types of mortar joints.

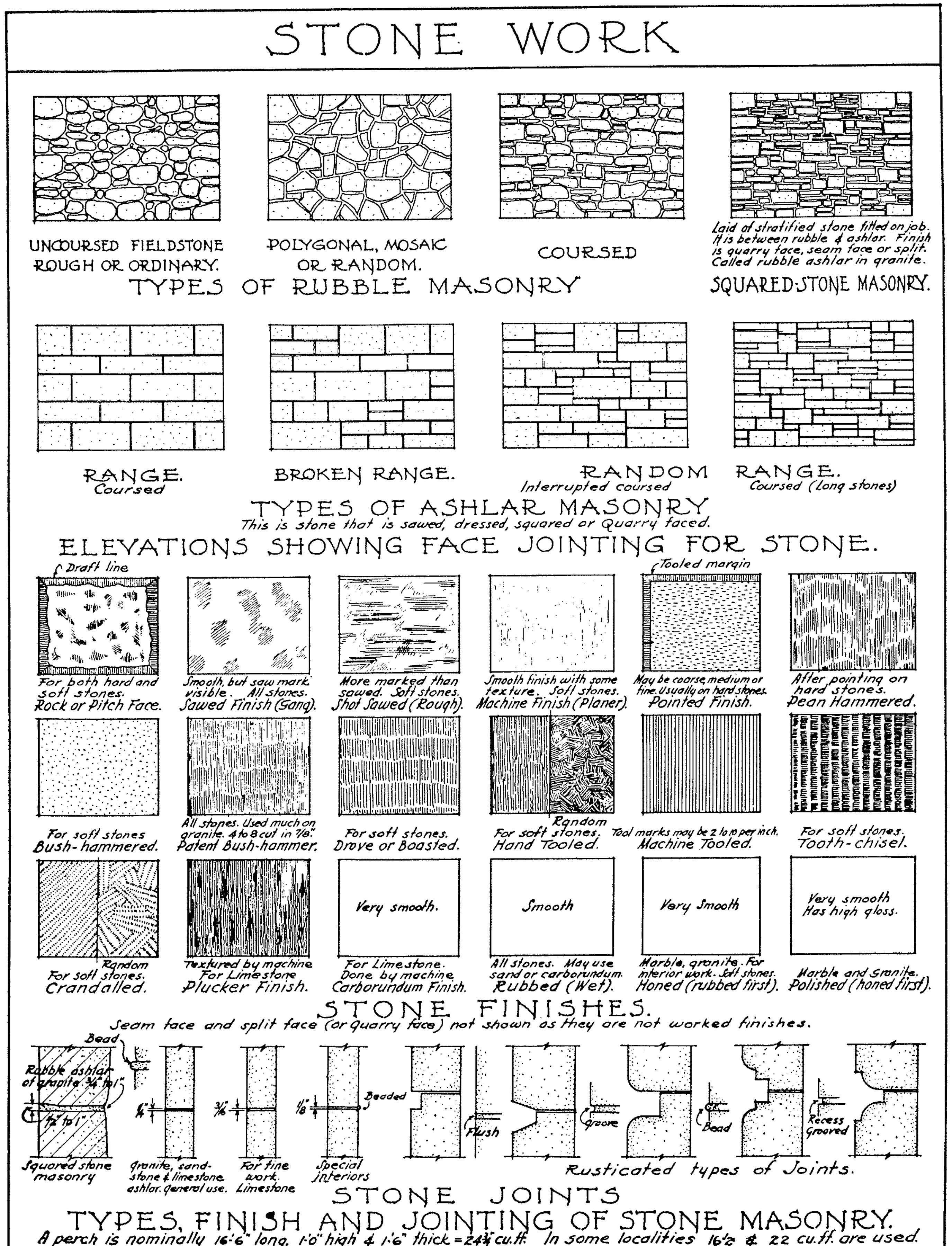
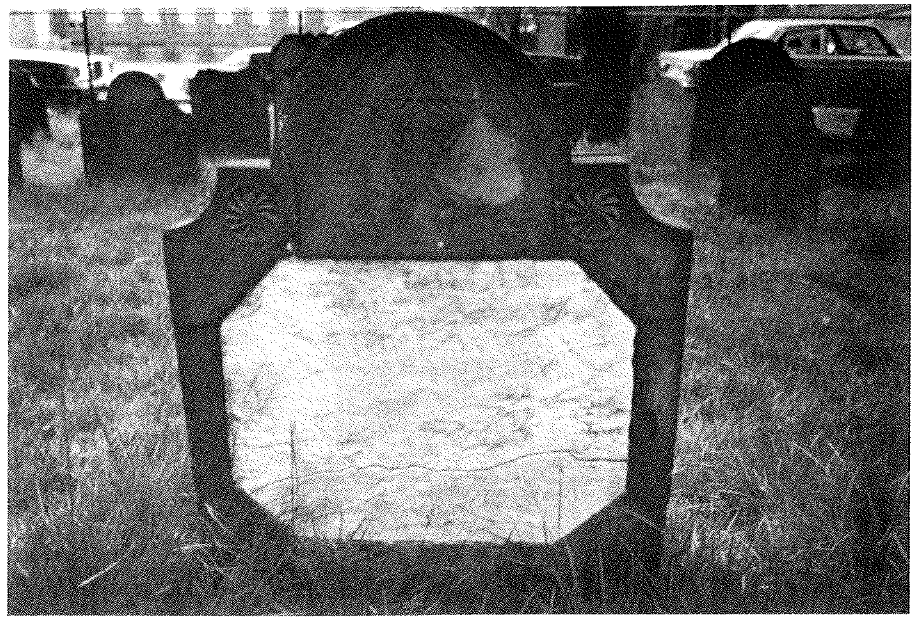


Figure 41b. Stone faces and finishes. (From *Architectural Graphic Standards*, 5th ed., (1956), John Wiley & Sons, Inc., New York.)

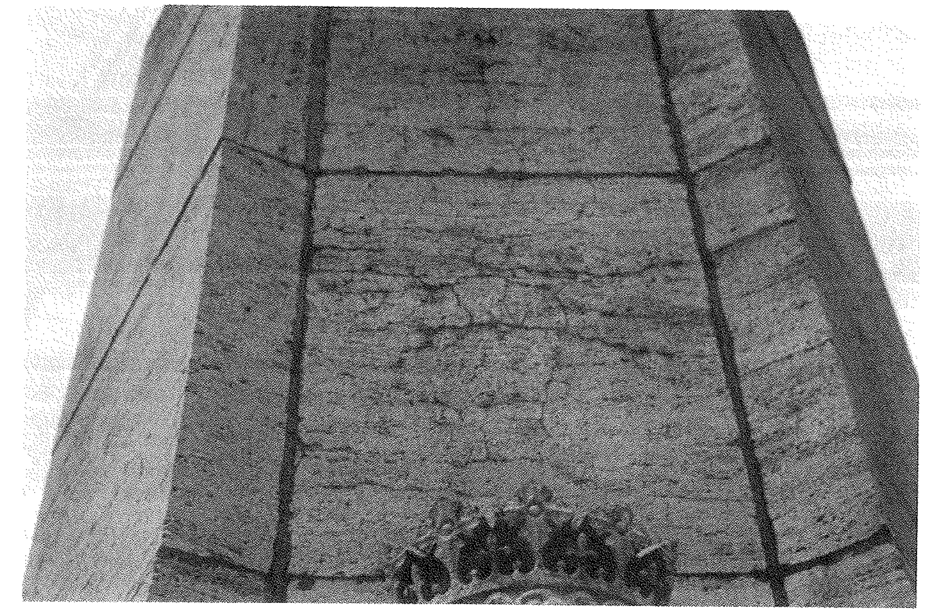
Mortar turned to sand by prolonged penetration of acid rain, St. Mary's Cathedral, Kingston, Ontario.

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