CHAPTER VIII.—THE DURABILITY OF BUILDING STONES IN NEW YORK CITY AND VICINITY. (*a*)

BY ALEXIS A. JULIEN, PH. D.

The ravages upon our building stones, by that complex association of forces which we call "the weather", are dangerous and rapid. The indications of interest in regard to the serious results, which are sure to come within a short period, are feeble and evanescent. A brief discussion of the main facts and of the principles involved may aid in forming a basis upon which future investigations may rest. The commissioners, appointed by the Department of the Interior "to test the several specimens of marble offered for the extension of the United States Capitol", said in their report of December 21, 1851:

> Though the art of building has been practiced from the earliest times, and constant demands have been made in every age for the means of determining the best materials, yet the process of ascertaining the strength and durability of stone appears to have received but little definite scientific attention, and the commission, who have never before made this subject a special object of study, have been surprised with unforeseen difficulties at every step of their progress, and have come to the conclusion that the processes usually employed for solving these questions are still in a very unsatisfactory state.

Over thirty years have passed since these words were written, and the same methods are still largely in use, although new instruments and processes and rich discoveries concerning the structure of stone have been made available within a quarter of a century. The facts presented have been gathered from many sources published and unpublished, and from long personal observation. It is but a question of time when careful and thorough investigation for the purpose of determining the best means to avert the coming destruction will be called for. It is necessary first to understand the number and the character of the natural foes which are making this deadly attack.

All varieties of soft, porous, and untested stones are being hurried into the masonry of the buildings of New York city and its vicinity. On many of them the ravages of the weather and the need of the repairer are apparent within five years after their erection, and a resistance to much decay for twenty or thirty years is usually considered wonderful and perfectly satisfactory.

Notwithstanding the general injury to the appearance of the rotten stone, and the enormous losses annually involved in the extensive repairs, painting, or demolition, little concern is yet manifested by either architects, builders, or house-owners. Hardly any department of technical science is so much neglected as that which embraces the study of the nature of stone, and all the varied resources of lithology in chemical, microscopical, and physical methods of investigation, wonderfully developed within the last quarter-century, have never yet been properly applied to the selection and protection of stone as used for building purposes.

The various suburbs and vacant districts have been gradually approaching a character sufficiently settled to justify the erection of entire and numerous blocks of private residences, huge buildings for business offices in the lower part of the city and for family flats in the central and upper wards, besides large numbers of public edifices, storage houses, manufactories, etc. The failure of stone to resist fire in the business district, and the offensive results of discoloration or serious exfoliation, which the poor durability of many varieties of stone has rendered manifest in all parts of the city, have already largely diminished its proportionate use, in reference to brick. Nevertheless great quantities of stone of many kinds are yet introduced, as ashlar or the trimmings of apertures, into the buildings now in progress, and will soon be further employed, if the present activity in building be continued, not only in the private enterprises already mentioned, but in others of more lasting and public importance; *e. g.*, the projected improvements and additions in connection with our water supply, as aqueducts and reservoirs; the new bridges proposed over our rivers; the replacement of our rotting wooden docks by more permanent structures; and perhaps, we may hope, the huge pedestal to support the statue of Liberty on an island in our harbor. As the kinds of building stone brought to this market for these purposes are increasing in number and variety, and their selection and mode of use, as it seems to me, are irregular and indiscriminate, whether from the ignorance or the carelessness likely to prevail in a busy, money-getting community, it would appear proper that a voice of warning should now be heard, calling attention to the dangers involved in the use of bad stone or the bad use of good stone; in the enormous waste and expense soon required for repairs in our severe climate, or in the consequent disuse of stone in favor of brick, by a natural reaction, to the injury of the beauty and comfort of our city.

a From the commercial relations of New York to the quarries of this country and of foreign countries, and from the enormous scale on which the practical value of building materials is tested in that city, this chapter, though local in title, forms the best available summary upon the durability of building stone for the United States, and is therefore placed in the present order.

There are three classes in the community to which such a warning is addressed:

1. A considerable number of house-owners, to whom it seems to come too late, since they have already expended tens of thousands of dollars in temporary repairs, patching and painting decayed stone, and many of whom have doubtless made rash vows to use hereafter, in construction, brick, iron, terra-cotta, wood—anything but stone.

2. House-owners, not yet aware of the coming dilapidation, and who can yet take precautions to delay or prevent its arrival—or others about to build, and who have implicit faith in the eternity of building-stone, since it comes from the "everlasting rock", or at least in a duration which will last their lifetimes—and also a certain proportion of builders and architects willing to learn, and who have much to learn, since the practical scientific study of building stones is yet to be made.

3. And lastly, the architects, builders, and contractors, who know all about the subject, or who do not care what happens to the houses they build, and that large part of our population who never expect to own any houses. To all these the decay of the stone in this city is a matter of indifference, and the quotation presented below—"scarcely a public building of recent date will be in existence a thousand years hence"—few of them, indeed, over a century or two, in fair condition—is only a matter of jest.

1.—EFFECTS OF WEATHERING UPON THE BUILDING STONE OF NEW YORK, ETC.

In foreign countries the subject of the attack of atmospheric agencies on building stones has received much attention, particularly within the last half century, and much earnest effort, though as yet ill-systematized and ill-regulated, has been exerted for their protection by means of the new light and facilities of modern sciences. The contrast between the durability of the stone buildings erected in modern and in the most ancient times is strongly marked:

> In modern Europe, and particularly in Great Britain, there is scarcely a public building, of recent date, which will be in existence a thousand years hence. Many of the most splendid works of modern architecture are hastening to decay in what may be justly called the infancy of their existence, if compared with the dates of public buildings that remain in Italy, in Greece, in Egypt, and the East.—*Gwilt's Encyclopedia of Architecture.*

In England this is largely due to the general use of soft freestones, both sandstones and, especially in London, earthy, loosely compacted limestones. Before the erection of the houses of parliament a royal board of commissioners was appointed for the selection of the proper building stones, and a large amount of information was collected on the subject of the modes and rapidity of weathering of the various building stones throughout the United Kingdom. So difficult and novel, however, was the investigation that the results obtained have been only partially successful, both in the selection of the stone, and, on its incipient attack by the atmosphere of London, in the artificial means suggested for its preservation. Only last year the statement was made, in reference to the building of the royal courts of justice, just erected and inaugurated in London:

> What will be the fate of its exterior carvings and frettings after another fifty years of London smoke, all of us can tell. The same may be said of a thousand other buildings, great and small, that the past generation of Londoners has raised as monuments of its own ignorance of the simplest conditions of good building. They carve their fronts with carvings of flowers and fruit, which in a year the soot will blacken past recovery, and in five years corrode beyond recall.
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> We see important and costly edifices restored in the lifetime of the architects who designed them, and palaces patched with cement and painted over every three or four years, before their builders have passed away. * * * No remedy has been found for the decay of soft calcareous stone in our smoky cities; and yet, in our childish helplessness, we continue to use it daily and year after year, as if we had no warnings of the folly of doing so. (*a*)

In a recent investigation of the subject, founded largely on a study of the stone monuments in the grave-yards of Edinburgh, Dr. A. Geikie, of the geological survey of Great Britain, has pointed out that in a town the weathering action differs from that which is normal in nature; on the one hand in the formation of sulphuric acid from smoke, causing more rapid decay of stone-work; on the other in the inferior range of temperature in towns and less severe action of frost.

Dr. Geikie also found that sandstones, if siliceous, were sometimes only roughened in two hundred years. When colored the destruction goes on by solution of cement, or of the matrix in which the particles of silica are embedded, *e. g.*, clay, carbonate of lime, and iron and hydrous and anhydrous ferric oxide. In this material he estimated the rate of lowering to amount to three-quarters of an inch in a century.

In the stone of the buildings of New York and adjacent cities the process of disintegration and destruction is widespread, and yearly becoming more prominent and offensive.

GNEISS.—The commissioners of the Croton Aqueduct department, in their annual report for 1862, page 67, make the following statement:

> The retaining-walls of the embankments in many cases require extensive rebuilding. Most of these walls have been constructed of the stone found in their immediate neighborhood—often of a very inferior and perishable character. Thus far we have been able to keep these walls in comparatively good order by removing every year portions of disintegrated stone and replacing them with durable material; but during the past year such large portions, and at so many points, are giving way in mass, that an increased amount must necessarily be expended on them during the coming season.

a The Builder, 1881, p. 708.

MARBLE.—Italian marble has been found incompetent to withstand the severity of our climate, when used for outdoor work; and of this good illustrations are shown in the pillars, once elegantly polished, in the portico of the church on the southeast corner of Fourth avenue and Twentieth street, etc. The same objection has been urged to the outdoor use of American marbles in our cities, supported at least by their rapid discoloration, but the question is yet unsettled.

Professor Hull observes:

From the manner in which the buildings and monuments of Italy, formed of calcareous materials, have retained to a wonderful degree the sharpness of their original sculpturing, unless disfigured by the hand of man, it is clear that a dry and smokeless atmosphere is the essential element of durability. In this respect, therefore, the humid sky and gaseous air of British towns must always place the buildings of this country at a comparative disadvantage as regards durability.

And again:

Under a smokeless atmosphere it is capable of resisting decay for lengthened periods, though it becomes discolored. * * * The perishable nature of the marble when exposed to the smoky atmosphere of a British city, is evinced by the decayed state of the tomb of Chantrey, erected in 1820, in the "God's acre" belonging to St. John's Wood chapel.

Another example of this decay is shown in the group of Queen Anne, etc., erected from Carrara marble, about the beginning of the eighteenth century, before the west front of St. Paul's, in London, England, and which has been covered throughout with a coat of paint in the hope of slightly retarding its inevitable decay. The dolomitic marble of Westchester county has been largely employed in our buildings, and some idea of its character for durability may now be gained. A fine-grained variety was used in the building of the United States assay-office, in Wall street; its surface is now much discolored, and the edges of many of the blocks show cracks. A variety of medium texture was employed in the hotel at the corner of Fulton and Pearl streets, erected in 1823; the surface is decomposed, after the exposure of exactly sixty years, with a gray exterior, in a crust from one-eighth to one-fourth inch in thickness, soft and orange-colored in section. Many crystals have fallen out of the surface on the weathered eastern face, producing a pitted appearance. A very coarse variety has been used in the bank building at Thirty-second street and Broadway, in large part being set on edge; very many of the blocks are more or less cracked, even in the highest story. In the United States Treasury building, in Wall street, a rather coarse dolomite-marble, rich in tremolite and phlogopite, was used, the blocks being laid on bed in the plinth and most of the ashlar, but largely on edge in the pillars, pilasters, etc.; in the latter case vertical fissures commonly mark the decay, but even elsewhere a deep pitting has been produced by the weathering out of the tremolite. The marble used in many other prominent buildings has been improperly laid, *e. g.*, in both of the buildings of the city hall, the Drexel building, at the corner of Broad and Wall streets, the Academy of Design, at Twenty-third street and Fourth avenue, etc. The same process of ultimate ruin in its incipient stages is abundantly shown, even in the marble slabs in Saint Paul's church-yard and monuments of Greenwood cemetery, by discoloration and disintegration of surface. In the United States hotel, on Fulton street, constructed of Westchester marble in 1823, we have the opportunity to study the effect of weathering for over a half century. Though presenting a good appearance at a distance, the stone has become pitted by the falling out of grains, especially on the east side, and is tinged a dirty orange by a crust of decomposition from one-sixteenth to a quarter of an inch in depth.

The horizontal tablets, supported on masonry which has partially settled (*e. g.*, J. G., 1821), generally show a slight curvature in center, only in part, possibly, produced through solution by standing rain-water.

Dolomieu first made the observation on an Italian marble, called betullio, that it possessed a degree of flexibility allied to that of the itacolumite of Brazil. Gwilt states (*Encyclopedia of Architecture*, p. 1274):

Some extremely fine specimens of white marble are to be seen in the Borghese palace at Rome, which, on being suspended by the center on a hard body, bend very considerably. It is found that statuary marble exposed to the sun acquires, in time, this property, thus indicating a less degree of adhesion of its parts than it naturally possessed.

In the white-marble veneering of the façade of St. Mark's, Venice, the same effect has been observed by Mr. C. M. Burns, jr., in the lower half of a slab of veined marble, 2 inches thick, on the south side of the northernmost of the five portals, just behind the columns and about 5 feet from the pavement. The slab is 11 feet 2 inches long, and 1 foot 6 inches wide; it is hung to the backing by copper hooks driven into the brick-work, but the lower part, for a distance of 5 feet 7 inches, bulges out 2¾ inches from the backing.

The exposure is directly westward, and I found that it became decidedly warm in the afternoon sun, while the backing would be likely to keep its temperature lower. Though the outer surface is somewhat weatherworn, I could not find the slightest tendency to fracture in any part.—*The American Architect and Building News*, 1882, p. 118.

Also at the palace of the Alhambra, in Grenada, Spain, one of the two doors that have been christened "La Mezquita" exhibits an ancient facing of three slabs of marble, the upper resting as a lintel upon the two others, which form uprights, 11 feet in height, 9 inches in width, and only 2½ inches in thickness. At 18½ inches from the top of the door the slab on the right begins to curve and to detach itself from the wall, attaining the distance of 3 inches at about 3 feet from the bottom. From a subsidence of the material of the wall an enormous thrust has been exerted upon the right, and the marble, instead of breaking or of rupturing its casings, has simply bent and curved as if it were wood.—*La Nature*, 1882.

I have also been informed at Sutherland Falls and other quarries near Rutland, Vermont, that the bending of thin slabs of marble exposed to the sunshine in the open air, and accidentally supported only at the ends, has been there repeatedly observed.

Fleurian de Bellevue discovered a dolomite possessed of the same property in the Val-Levantine, of Mount Saint Gothard. Dolomieu attributed the property to "a state of desiccation which has lessened the adherence of the molecules of the stone", and this was supposed to be confirmed by experiments of De Bellevue, who, on heating inflexible varieties of marble, found that they became flexible.

This change, however, cannot be connected with the remarkably small content of water existing in marbles, but with a peculiarity of their texture, which has been briefly discussed by Archibald Geikie (*Proc. Roy. Soc. Edinb.*, 1880), in an interesting investigation on the decay of the stones used in Scotch cemeteries. He has pointed out that the irregular and closely-contiguous grains of calcite which make up a white marble are united by no cement, and have apparently a very feeble coherence.

It appears to me probable also that their contiguous crystallization has left them in a state of tension, on account of which the least force applied, through pressure from without, or of the unsupported weight of the stone, or from internal expansion by heat or frost, produces a separation of the interstitial planes in minute rifts. Such a condition permits a play of the grains upon each other and considerable motion, as illustrated in the commonly-observed sharp foldings of strata of granular limestones, without fractures or faults. In such cases, also, I have observed that the mutual attrition of the grains has been sometimes sufficient to convert their angular, often rhomboidal, original contours into circular outlines, the interstices between the rounded grains being evidently filled up by much smaller fragments and rubbed-off particles; *e. g.*, in the white marble of the anticlinal axis at Sutherland Falls, Vermont.

These results are confirmed by the appearances, familiar to all lithologists, in the study of thin sections of marble, the latent interstices between the grains of calcite having been often developed by the insinuation of films and veinlets of iron-oxide, manganese-oxide, etc. While a polished slab of marble fresh from the stone-yard may not be particularly sensitive to stains, after it has been erected and used as a mantel-piece over a fire-place, its increased absorption of ink, fruit-juices, etc., becomes strongly marked. On this property are founded the processes, always preceded by heat, for the artificial coloring of marbles.

In the decay of the marble, largely Italian, in the atmosphere of Edinburgh, Geikie has recognized three phases:

1. Loss of polish, superficial solution, and production of a rough, loosely-granular surface. This is effected, Geikie states, by "exposure for not more than a year or two to our prevalent westerly rains". The solution of the surface may sometimes reach the depth of about a quarter of an inch, and the inscriptions may become almost illegible in sixteen years.

In our own dry climate, however, these results do not appear. The polish often survives ten years in our city cemeteries, and even for over half a century, near the ground, in the suburban cemeteries; in one instance, at Flatbush, it has remained intact for over 150 years, on the tombstone of F. and P. Stryker, dated 1730. Inscriptions are decipherable in Saint Paul's church-yard back to the date of 1798, but about one-tenth are illegible or obliterated; the latter effect was never seen in a single instance on the suburban stones, and is evidently due to the acid vapors in the rain-waters of the city.

2. Incrustation of the marble with a begrimed, blackish film, sometimes a millimeter in thickness, consisting of town-dust, cemented by calcium sulphate, and thorough internal disintegration of the stone, sufficient, after a century, to cause it to crumble into powder by very slight pressure.

Neither the crust nor any deep disintegration has been observed in the oldest marble tombstones in the cemeteries of New York; their absence is plainly attributable to the inferior humidity of our atmosphere and the absence of smoke from soft coals.

3. Curvature and fracture, observed in slabs of marble, firmly inserted into a solid frame-work of sandstone. This process consists in the bulging out of the marble, accompanied with a series of fractures, and has been accomplished by expansion due to frost. Tombstones are never constructed in this way in our cemeteries; but the curvature of horizontal slabs, observed in Saint Paul's church-yard, produced by the sagging of the supporting masonry beneath the center of the slab, is simply indicative of the flexibility of the material.

Geikie states:

> The results of my observations among our burial-grounds show that, save in exceptionally sheltered situations, slabs of marble exposed to the weather in such a climate and atmosphere as that of Edinburgh are entirely destroyed in less than a century. Where this destruction takes place by simple comparatively rapid superficial solution and removal of the stone, the rate of lowering of the surface amounts sometimes to about a third of an inch (or, roughly, 9 millimeters) in a century. Where it is effected by internal displacement, a curvature of 2½ inches, with abundant rents, a partial effacement of the inscription, and a reduction of the marble to a pulverulent condition, may be produced in about forty years, and a total disruption and effacement of the stone within one hundred. It is evident that white marble is here utterly unsuited for out-of-door use.

My own conclusion, from observations in New York, is that, in the cemeteries within the city, the polish on vertical slabs is usually destroyed in about ten years; that the inscriptions are only in small part effaced within from thirty to fifty years, and are for the most part perfectly legible on the oldest tombstones, dating 1798; and that, although the reduction of the surface to a loose granular condition may reach the depth of ten millimeters, the actual lowering of the surface seldom exceeds 5 or 6 millimeters, the internal disintegration is never sufficient to affect sensibly the strength of the stone during the periods of exposure which have been noted, and a slight flexure, perhaps to the amount of 12 or 15 millimeters, sometimes affects the center of horizontal slabs, 2 meters in length.

In the cemeteries without the city the polish may often survive near the ground, on the faces of vertical slabs, for over one hundred and fifty years, as the granulation of the surface rarely exceeds a depth of 3 or 4 millimeters; and all the inscriptions remain perfect on the oldest vertical tombstones, suffering partial effacement only on horizontal slabs.

Although these facts show the far greater durability of marble in our dry and pure atmosphere, the frequent obliteration of inscriptions, the general, and often rapid, granulation of the surface, and the occasional fissuring of slabs, show that the decay of marble—in the varieties hitherto long used in New York city—is steady, inevitable, and but a question of time; and with Geikie, I, too, am convinced that, if unprotected, such materials are utterly unsuited for out-of-door use, at least for decorative purposes or cemetery records, within the atmosphere of a city.

SANDSTONE.—In regard to brownstone there seems to be a common if not universal opinion—but, in my own view, too hasty, and by no means established—which is presented in the following quotation:

> The days of brownstone fronts for the better class of houses are probably numbered. A thin veneering of soft stone, hooped on to a brick wall, adds almost nothing to the strength of a building. On the exposure of the brownstone fronts for sixty or eighty years to the severity of our climate, in the opinion of intelligent stone-cutters, the majority of them will be in ruins, and the remainder much dilapidated.

In the widely-quoted opinion of one architect, this stone is of no more use for architectural work in this region than so much gingerbread.

Even the brown sandstone of the city hall, originally of a very superior quality, and the crumbling cornices, lintels, etc., of numberless houses which line some of the other streets of the city, evince the progress of the decay. It makes no very great difference whether the stone is laid parallel or perpendicular to its grain. In the former case its destruction is more rapid; in the latter, rottenness soon appears in the lintels, columns, cornices, and other projecting portions of the edifice. Several of the fronts along Fifth avenue, some of them less than ten years old, already look frightful to the experienced eye of an honest stone-cutter.

In regard to the name "Nova Scotia stone", it may be well to explain that it originated many years ago, when grindstone dealers obtained their supplies from some small surface quarries located in and near Nova Scotia. As that stone was of a yellow color, the stone trade has persisted ever since in calling every light-colored stone coming from anywhere in that section "Nova Scotia stone". However, 95 per cent. of the imported stone is derived from New Brunswick (probably 85 per cent. from Dorchester), and the remainder from Nova Scotia and other points. The popular name has been applied to light-colored stones of every quality, quarried at various points of eastern Canada, over a wide section of country, hundreds of square miles in extent, and variously worked out at tide-level, under tide-water, from exposed reefs running out into the sea, or, as at Dorchester, New Brunswick, from a hillside 900 feet high and a quarter of a mile from tide-water. The small quarries usually work out only such stones as they can obtain from outcropping ledges and bowlders, and these are apt to be of bad and varying color, more or less full of iron and other defects; for example, the surface quarries of Hillsboro', New Brunswick, long since abandoned, used in the houses in Forty-second street near Madison avenue, in Second avenue near Fifty-fifth street, some of the bridges in Central park, etc. At the quarries of Dorchester, New Brunswick, it is stated that from 35 to 50 feet of inferior rock and débris are first stripped off to reach the sound rock which is sent to this market. The introduction of this stone into the city as a building material has been too recent to allow any measure of its durability. A little exfoliation may be, however, distinguished near the ground line, and on the sides and posts of stoops, in many cases. Also, in panels, under heavy projecting moldings, cornices, etc., where the sun has no chance to reach and dry up the dampness, the stone molders away slightly over the surface. In the cemeteries it is rarely or never used; in one example, possibly of this material, in Saint Paul's church-yard, (W. J. M., 1841), the decay is plainly beginning around the carvings. The discoloration of good varieties of the stone would be very slow to affect vertical surfaces, properly protected by drips; but on sloping, horizontal, or shaded surfaces, especially near the street-level, street-dust is sure to lodge and cling, all the more after the surface becomes roughened by a slight disintegration; while the rough usage to which the stone of balustrades and stoops is always subjected in a busy street, renders this, as well as all other soft varieties of freestone, liable to chipping as well as offensive discoloration (*e. g.*, in the courses, trimmings, and posts of the church on the corner of Forty-second street and Madison avenue, etc.), and unsuitable for use near the ground line.

These freestones from New Brunswick and Nova Scotia, largely employed in our cities, rarely exhibit a laminated structure, and, though a softer stone than the Triassic sandstone just referred to, is rarely affected by exfoliation to any extent, partly perhaps because its introduction into this district has been much later than that of the brownstone. Many instances occur, however, where already an exfoliation has taken place, especially near the ground line and on peculiarly exposed surfaces, sufficient to mar offensively the appearance of the masonry. This is exceptional it is true, but only a proper investigation or a far longer trial—as yet little exceeding twenty-five years—will establish the fitness of this stone for this climate.

So also the freestone from Amherst, Berea, etc., Ohio, has been used to considerable extent, and in one building (on the corner of Broadway and Barclay streets) has stood well for twenty years. Its rich content of quartz, said to reach 97 per cent. in the buff stone from Amherst, renders this one of the most promising, in regard to durability, of all the freestones of the sandstone class yet introduced here. Buildings constructed of this material in this city since 1857 (*e. g.*, on the corner of Barclay street and Broadway, on the corner of Howard and Crosby streets, etc.), show no decay, but only discoloration. In other instances (*e. g.*, rows of houses on Fiftieth street, west of Fifth avenue, on Madison avenue between Thirty-fourth and Forty-third streets, etc.) the blackened discoloration and frequent chipping of edges of the soft stone are quite offensive. On the other hand, it must be admitted that a stone which cleans itself by the disintegration of its surface, the grains dropping out and so carrying away the dirt, as in the poorer and softer varieties of brownstone or of Nova Scotia stone, is by that very action still more objectionable from its want of durability; and the discoloration of the Ohio stone is offset, at least in part, in the best varieties, by their hardness and promise of durability. Nevertheless, all these light-colored freestones from New Brunswick or Ohio, as well as the light-colored limestones from Indiana, etc., and the light-colored granites from New England, are all open to the special objection of most offensive discoloration (described beyond) shown here in abundant instances as in the cities of the west. This is more likely to affect inclined than vertical surfaces, and those near the level of the street, *i. e.*, within the reach of deposit of street dust; and the objection might be largely obviated by our builders by discarding the light-colored stones of all kinds from projections (cornices, dressings of doors and windows, etc.), and from our stoops, where the additional softness of some varieties renders them liable to disfigurement from wear and blows (*e. g.*, the blocks of Nova Scotia stone fronts in Madison avenue, above Thirty-fourth street).

MEDINA SANDSTONE.—This material is of recent introduction (*e. g.*, Baptist church on Fifty-seventh street, west of Sixth avenue), and its true durability cannot yet be estimated.

BLUE-STONE (graywacke).—This stone is yearly coming into more general use, and, though somewhat somber in tone and difficult to dress, seems likely to prove a material of remarkable durability. In one building in Twenty-fourth street, between Madison and Fourth avenues, its condition appears to be excellent, after fifteen years' exposure perfectly retaining the tool marks. The variety reported to come from the Wyoming valley (*e. g.*, in the building on the north side of Union square) is really derived, as I am informed by Professor H. L. Fairchild, from Meshoppen, Pennsylvania.

The blue-stone or graywacke of central New York and of Pennsylvania has not only been of general use as a flag-stone, but, in compact varieties, has been yearly coming into greater use in our cities for the purpose of water-tables, ornamental bands, window-sills, etc., and, although not a freestone, has recently been introduced even for the fronts of residences (*e. g.*, on northwest corner of Madison avenue and Seventy-second street). It is likely to be one of the strongest and most durable stones, in my opinion, and, to judge by its weathering in outcrops, will be liable, only after a long exposure, to a reddish-brown discoloration.

LIMESTONE.—The Lockport limestone has been used to a small extent in this city, unfortunately for buildings of importance, since it is a loosely compacted mass made up of fragments of shells, corals, etc., extremely liable to disintegration, apparently more from the action of frost than any other cause. To this stone may be applied the observations of Professor F. A. Abel on the fossiliferous bands in the stone of the island of Portland. (*a*)

> Though petrifactions were shown by the results of experiments to impart, in many instances, great additional strength to the stone they frequently give rise by their existence to cavities, sometimes of considerable size, which not only serve to weaken those particular portions of the stone, but may also, if they exist in proximity to exposed surfaces of a block of stone, promote its partial disintegration by the action of frost.

The Lockport stone has evidently owed its rapid disintegration within ten years, wherever used in this city, in part to its careless mode of introduction into masonry. Thus, in the building of the Lenox library, at Seventieth street and Fifth avenue, about 40 per cent. of the material is set on edge, *e. g.*, the alternate receding courses of the ashlar, trimmings of apertures, gate-posts, etc. Consequently it betrayed decay long before the completion, fragments falling out of the face of the stone from the arris of cornices and bands, etc. In the abundant trimmings of the same stone in the building of the Presbyterian hospital in the vicinity the same disintegration is displayed, the surfaces peeling off and filled with fine and deep crevices, and the upright posts, *e. g.*, near the entrance archway or porte-cochère on the south side, in which the bedding-laminæ stand on edge, are already seamed throughout with long cracks, which betoken their steady destruction.

The oolitic stone from Ellettsville and Bedford, Indiana, shows an almost immediate and irregular discoloration, said to be produced by the exudation of oil. The oolite from Caen, France, has also been used in many buildings, and, unless protected by a coating of paint, has shown decay in several instances. Mr. G. Godwin, of London, has stated (*Soc. of Arts*, 1881), that "the Caen stone which was sent to this country (England) could not now be

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a *The Builder*, London, 1863, Vol. XXI, p. 859.

depended on, and ought not to be used for external work". The extensive decay of this, with other oolitic and magnesian limestones, in the walls of Westminster abbey, has recently caused great alarm, and will necessitate the renewal of its outer masonry at enormous expense.

One of the most thorough investigations, in regard to the porosity of a series of American building stones, was made by Dr. T. S. Hunt in 1864, and with the following conclusion (*Chemical and Geological Essays*, p. 164):

Other things being equal, it may probably be said that the value of a stone for building purposes is inversely as its porosity or absorbing power. From the results given on 39 specimens, the following may be here quoted as pertinent to stones used in New York city:

No. of specimens.	Absorption. Percentage.
1. Potsdam sandstone, hard and white	0.50 to 3.96 *a*
2. Medina sandstone	3.31 to 4.04
3. Ohio sandstone	9.59 to 10.22
3. Caen limestone	14.48 to 16.05

Of course the proviso, "other things being equal," covers a great deal of important ground, including the solvency of the material of a stone in the acidified rain-waters of a city. Some of the most impervious and non-absorbent readily decompose; while others, which are porous or even cellular, may afford an excellent resistance to decay. But judged in regard to both points, porosity and solvency, the Caen stone may be safely rejected hereafter as unfit for our climate.

Other limestones, oolitic or fine granular, have been brought into use in small quantity, but remain as yet untested by the conditions of our climate.

GRANITE.—As to granite, its tendency to decomposition, termed the "maladie du granit" by Dolomieu, depends chiefly upon climatic conditions. These differ vastly, it is well known, in this region and in that of the great granite-builders, the Egyptians. The obelisk of Heliopolis has stood for three thousand years, and is still in good condition. So, too, the obelisk of Luxor had stood for forty centuries in Egypt without being perceptibly affected by that climate, but since its transport to Paris, in the reign of Louis Philippe, it is reported as the result of but forty years' exposure—

It is now full of small cracks, and blanched, and evidently will crumble into fragments before four centuries have passed.

We have transported another obelisk, "Cleopatra's Needle", from Egypt, and, in defiance of the still greater dangers incident to our severe climate, have erected it, covered with delicate carvings, upon a hillock in Central park, exposed to our blazing sun, pelting rain, and biting frost, often successively within twenty-four hours—a monument to the public ignorance in regard to the protection of even our prized possessions—that indifference of our community to the practical value of science which was exemplified through its officials by wantonly paving the walks of the same park with the fragments of the restoration casts of Saurians, after their construction for three years by Waterhouse Hawkins. Granite is also found in many other of our larger buildings, both public and private, but as few of these exceed forty or fifty years in age, and all contain the most durable varieties of that stone, the effects of weathering are only beginning to appear. The bluish variety from Quincy, Massachusetts, has been used in many buildings and rarely shows as yet many signs of decay. In the United States custom-house, on Wall street, most of the huge blocks appear laid "on bed", but, nevertheless, show some pitting in places, by the attack and partial removal of the larger grains of hornblende. In the church at Fourth street and Lafayette place, erected in 1830, a little exfoliation has been produced by street-dust on the faces of some steps. In the Astor house, at Barclay street and Broadway, no decay was observed.

In the fine-grained granite from Concord, New Hampshire, employed in the building on the southeast corner of Twenty-third street and Sixth avenue, many of the blocks are set on edge, but the only change yet seen is that of discoloration by street-dust and iron oxide from the elevated railway.

The light-colored and fine-grained granite of Hallowell, Maine, has been used for the construction of the city prison, the "Halls of Justice" or "Tombs", in Center street. This stone consists of a white feldspar, which predominates, a grayish-white quartz, which is abundant, and a considerable quantity of a silvery white mica, thoroughly intermixed. The rock possesses several properties—fineness of grain, homogeneity of structure, and freedom from iron, as shown by the color of the feldspar—likely to render it durable; the only unfavorable conditions are the predominance of feldspar and the laminated structure. The rock is a granitoid gneiss, with lamination often clearly marked; these markings at once show to the eye that most of the blocks are set, not on bed, but irregularly on edge.

The building is square and occupies an entire block. On a study of the weathering the south face was found to present an exfoliation to the depth of from one-eighth to one-quarter of an inch at many points, up to the very summit of the building, particularly on the sides of the pillars at the southeast entrance, on the ashlar near the southwest gate, under and over the cornice and string-pieces. In some places the stone was loosened or peeled off in sheets of the area of a square foot. The west front presents much exfoliation all over the surface, though always thin; it seems to begin chiefly along and near the joints. In places fragments have separated from the corners of the blocks. The north front exhibits very little exfoliation; so also the east front, in a few small scattered spots.

a Usually about 1.

The exfoliation appears to be the result directly of the sun's heat, exerted most intensely on the southern and western sides of the building. An examination of the disintegrated material shows but little decomposition; a little kaolin may be distinguished in films, but the bulk of the feldspar, the weakest constituent, remains with bright facets, without change in color or luster. It is by no means characteristic of the "*maladie du granit*", first described by Dolomieu and later studied by Dr. T. Sterry Hunt; but here the action seems to be mainly and simply a disintegration of the grains, initiated by expansion under the sun's heat, during the summer, and developed by the expansion caused by frost during the winter. An architect of the city recently stated that he had built several large granite offices, and considered Quincy granite the most durable of all building material. He thought the weathering of granite would hardly amount to one thirty-second of an inch in a hundred years. According to that calculation many buildings might hope for a longer span than the thousand years spoken of by the professor.

However, it is a well-known fact that the weathering of granite does not proceed by a merely superficial wear, which can be measured or limited by fractions of an inch, but by a deep insinuation along the lines of weakness, between grains, through cleavage-planes, and into latent fissures. Thus, long before the surface has become much corroded or removed, a deep disintegration has taken place, by which large fragments are ready for separation by frost from the edges and angles of a block. When directly exposed to the heat of the sun an additional agency of destruction is involved, and the stone is suddenly found ready to exfoliate, layer after layer, concentrically. As yet we have little to guide us in the estimation of durability in years, since the best known granite monuments are those which have been exposed to the exceptionally mild climate of Egypt; but even there some exfoliation has been noticed, *e. g.*, on the inner walls of the so-called Temple of the Sphynx.

In the cemeteries within the city and on Long island much granite is now used in slabs and monuments, but its introduction has been everywhere of too recent a date to afford any measure of its durability. Geikie remarks:

> Traces of decay in some of its feldspar crystals may be detected, yet in no case that I have seen is the decay of a polished granite surface sensibly apparent after exposure for fifteen or twenty years. Even the most durable granite will probably be far surpassed in permanence by the best of our siliceous sandstones. But as yet the data do not exist for making any satisfactory comparison between them.

GNEISS.—The oldest building in this city in which this material has been used appears to be that of Saint Matthew's Lutheran church, on the northeast corner of Broome and Elizabeth streets, erected in 1841. The stone is the micaceous gneiss, in part hornblendic, from excavations on the island, with trimmings, string-pieces, etc., of brownstone, the latter, as usual, being in a state of decay. On the west front the gneiss is in excellent condition, occurring in small blocks, mostly laid on the bedding plane. In the south front many of the quoins are set on edge and are much decayed along the joints, sometimes with splitting or exfoliation, fracture of corners, and irregular chipping out of the surface to the depth of one-half to one inch below the level of the projecting cement joints.

SERPENTINE.—This rock has been of limited application as a building material, but the evidence thus far is not in favor of its durability in a city. For example, the serpentine of West Galway, Ireland, called "Connemara marble", has been used both externally and internally in the new museum of Trinity college, Dublin, but "does not withstand the influence of a smoky or gaseous atmosphere". "Small tablets let into the outside wall of the museum have become tarnished within the space of ten years". In Hoboken this stone has been used to some extent for unimportant masonry, and shows in places discoloration and disintegration.

Other stones which may prove to be more durable, and as yet rarely exfoliate, have already, however, become more or less disfigured by discoloration. In the Nova Scotia and Ohio sandstones this is universally seen in black films, streaks, and blotches, of which both the cause and the means of removal are but little understood. The marbles used for house fronts also soon assume a dirty yellow hue. This is sometimes produced by the exudation of salts of iron, as in the walls of the new court-house; sometimes by the adherence of smoke and street-dust. It has been removed by occasional scraping of the whole surface of the building, as has already been done on the old court-house, the new cathedral at Fiftieth street, etc.

2.—EXTERNAL AGENCIES OF DESTRUCTION.

The external agencies which slowly but insidiously and steadily accomplish the disintegration and destruction of our building stones are of three classes, chemical, mechanical, and organic.

A. CHEMICAL AGENCIES.

These chiefly consist of acids which attack and dissolve every constituent of stone except quartz, but, with particular rapidity, any stone into which carbonates enter as chief constituents or as cementing materials. Thus the abundant solution of lime from the stone as well as the mortar of one of our marble buildings may be shown by catching some of the rain-water which trickles down its sides, and adding a few drops of ammonium oxalate, the solution becoming clouded by a milky-white precipitate of calcium oxalate. The following may be enumerated:

SULPHUR ACIDS, *i. e.*, SULPHUROUS AND SULPHURIC ACIDS.—Of these Dr. Angus Smith found in the rain of Manchester from 1.4 to 5.6 grains per gallon. The gases are daily absorbed into the atmosphere of a large city from the consumption of illuminating gas, coal, and all kinds of fuel, the decomposition and oxidation of refuse organic matter and sewer-gas, the residuary gases belched forth from the chimneys of dye works, chemical works, and numerous other manufactories, etc.

As coal seldom contains less than one-half per cent. of sulphur, and frequently one per cent. or more, every ton of coal when burned produces from 30 to 60 pounds of oil of vitriol. When one considers the enormous quantities of coal that are consumed in cities, and the correspondingly great quantities of this corrosive agent that are thus disseminated in the atmosphere, we would naturally expect to find appreciable evidence of its effects on building stones.(*a*)

These effects are likely to be most marked in a large city like London or New York, and on certain stones, *e. g.*, the earthy or oolitic limestones and marbles. In London they are revealed in the magnesian sulphate, which imparts a bitter taste, and even forms an efflorescent crust of white crystals upon the disintegrated portions of the Portland stone, and in the calcium sulphate, amounting to 3.4 to 4.6 per cent. in the decayed crust of the Caen stone. (*b*). Little limestone has yet been introduced into New York, and the durability of a variety in a village or small town elsewhere gives no measure of its fitness to resist the corrosive agencies in the atmosphere of our cities.

CARBONIC ACID.—This is a universal product of combustion, but is indeed derived from all the sources above mentioned, as well as from the respiration of millions of men and animals. Dr. Smith found the air of Manchester to contain 0.04 to 0.08 per cent. of carbonic acid, while that of the highlands of Scotland contained but 0.03 per cent. The researches of Daubrée, T. S. Hunt, and others, have shown the active action which this gas exerts in the corrosion of the feldspar of granites.

NITRIC ACID.—Traces of this acid have been commonly found in the atmosphere and falling rain, but most perceptibly during and after thunder storms. It has been suggested that "every flash of lightning not only generates nitric acid—which, in solution in the rain, acts on the marble—but also, by its inductive effects at a distance, produces chemical changes along the moist wall, which are at the present time beyond our means of estimating. (*c*)

So far as its formation is due to electrical agency, it probably increases during the summer; but it is also one of the products of oxidation of the gases arising from the decomposition of organic matter, ammonia, and nitrates, and from our numerous gas works.

HYDROCHLORIC ACID.—This corrosive agent Dr. Angus Smith found in the rain of Manchester, to the amount of 1.25 grains per gallon. It is derived from the fumes of bleaching works, chemical works, potteries, and many factories, and from vicinity to the sea.

CARBOLIC, HIPPURIC, AND MANY OTHER ORGANIC ACIDS derived from smoke, street-dust, sewer-vapors, etc., have not been hitherto recognized, but, in my opinion, are among the most constant and efficient agencies in the corrosion of the building stones of a city. Whether they are present in the atmosphere and falling rain is still a matter of conjecture, though I think it probable; but no series of analyses has yet been made to determine the exact constitution of the air and rain-water in our cities. However, there can be no doubt of their presence, possibly in the smoke and unconsumed carbon which attach themselves to our rougher stones (freestones, marbles, etc.), certainly in the street-dust, chiefly ground-up horse manure, which is blown against our buildings and remains attached to their surfaces, often to a considerable height above the street level. That the corrosion thus resulting is due not merely to mechanical friction, but mainly to chemical action, is shown by the fact that it is sometimes most active on a surface which is sheltered from the rain, and to which the crust of dust can adhere more persistently. For example, I have noticed that the vertical faces of the steps of Quincy granite beneath the portico of the church on the northwest corner of Fourth street and Lafayette place, perfectly sheltered from the rain, and but little exposed to the wind, have been sometimes covered with a film of street-dust beneath which the smooth-dressed surface of the granite is deeply corroded, peeling off to the touch of one's fingers in flakes from 2 to 5 millimeters in thickness. As to the foundations of buildings, these are exposed to the quiet action of the vegetable acids derived from the decomposition of plants and of the humus of the soil.

OXYGEN.—This constituent of the atmosphere, especially in its more active form, *ozone*, attacks the sulphides (*e. g.*, the pyrite in the Vermont roofing slates and in the marble of Lee, Massachusetts, etc.), and, more slowly, the ferrous silicates in certain minerals (*e. g.*, the chlorite, biotite, hornblende, augite, etc., in our granites, gneisses, traps, etc.). The resulting oxygenation and hydration may be expected to produce expansion and a tendency to loosening of the constituents of a stone.

AMMONIA is another product of animal life and decomposition, the fumes of factories, and atmospheric reactions, whose existence in the air and rain-water has been proved, and which must do its part in the disintegration of stone.

COMMON SALT (sodium chloride) is constantly present in the atmosphere along the sea-board, and must affect the solubility of the cement of porous sandstones, etc. An English observer, however, considers that sea air is not injurious to stone, instancing Sandysfoot castle, near Weymouth, of which the stone is in perfect condition, although erected on the sea-shore and constantly washed by the spray since the time of Henry VIII. A comparison of the forms of decay of stone observed in the cemeteries within this city and in those nearer the ocean, *e. g.*, at New Utrecht, yielded no evidence of any results, attributable to this agency, in greater action at the latter locality.

a C. H. Porter: Paper on Building Stones, p. 24. Albany, 1868.
b J. Spiller, *Rep. Brit. Assoc. Adv. Sci.*, 1867.
c U. S. Commission, 1851.

B. MECHANICAL AGENCIES.

Some of these are probably, in our climate and conditions, the most efficient of all in the wear and disintegration of our building stones.

FROST.—The action of severe frost on stone must be usually one of the main causes of its rapid decay. Two elements are involved—the friability of the material and its power of absorption of moisture. The action may be expected to be most active where a material is repeatedly saturated with moisture, rain-water, or water derived from the thawing of snow and ice, and alternately frozen and thawed. The violence of the force resulting from the congelation of water within the pores of a stone may be understood from a recent estimate, that the effect produced by the freezing in a closed vessel, as it takes place very suddenly, resembles the blow of a hammer of 12 tons weight upon every square inch. However, the disintegration of our brownstones cannot be attributed entirely or mainly to this powerful agency, since the same decay is in progress in southern sea-ports where this brownstone has been used as a building stone; and I have been consulted by a correspondent at New Orleans in regard to the best means to arrest this decay in brownstone fronts there.

On other stones, *e. g.*, marble, this force may exert a very slow action; the experiments of Professor Joseph Henry and the calculations of Captain (now General) M. C. Meigs have shown the depth of exfoliation, after fifty alternations of freezing and thawing by artificial means, to amount to very nearly the ten-thousandth part of an inch. (*a*)

VARIATIONS IN TEMPERATURE.—The constant variations of temperature from day to day, and even from hour to hour, give rise to molecular motions which must affect the durability of the material of a building. Recent observations on the pendulum have shown that the Bunker Hill monument at Boston is scarcely for a moment in a state of rest, but is constantly warping and bending under the influence of the varying temperature of its different sides. (*b*)

The climate of New York must be far more trying than that of England, as the temperature may vary 120° or more in a single year, and even 70° in a single day, with many repetitions of similar extremes during the spring and fall, and sometimes during the winter months. The intensity of the direct rays of the sun, particularly in summer, and the frequent passing showers of cool rain-water falling upon the heated surfaces, are important elements in the attack upon the building stones.

The experiments of Colonel Totten, reported by Lieutenant William H. C. Bartlett in 1832, on the expansion and contraction of building stones by variations of temperature, yielded the following results, for the linear expansion, in fractions of an inch, of one inch of stone for 1° of Fahr.:

Granite bowlder at Buzzard's bay	0.000004825
Marble, Sing Sing, New York	0.000005668
Sandstone, Chatham, Connecticut	0.000009532

To apply these results to the case in question, let us suppose two coping stones, of 5 running feet each, to be laid in midsummer, when they have a temperature of 96° Fahr.; in winter their temperature may safely be assumed at zero, so that the total variation of temperature will be 96°.

The distance by which the ends of the stones would be separated would amount, for granite, to 0.027792 inch, giving a crack a little wider than the thickness of common pasteboard. For marble, this crack would have a width of 0.03264, nearly twice the thickness of common pasteboard; and for sandstone 0.054914, nearly three times the thickness of pasteboard. These cracks are not only distinctly visible, but they allow water to pass freely into the heart of the wall. The mischief does not stop here: by this constant motion, back and forth, in the coping, the cement, of whatever kind the joints might be made, would be crushed to powder, and in a short time be totally washed by the rains from its place, leaving the whole joint open.

WIND.—A gentle breeze dries out the moisture of a building stone and tends to preserve it, but a violent wind wears it away by dashing sand-grains, street-dust, ice particles, etc., against the face. The extreme of such action is illustrated by the vast erosion of the sandstones in the plateaus of Colorado, Arizona, etc., into tabular *mesas*, isolated pillars, and grotesquely-shaped hills, by the erosive force of sand-grains borne by the winds; in the window-panes of houses on Nantucket island, converted into ground-glass by flying sand; and in the artificial process of manufacture by the "sand-blast", carried on in our cities. A violent wind also forces the rain-water, with all the erosive acids it conveys, into the pores of stones, carries off the loosened grains from the surface, and so keeps fresh surfaces of stone exposed.

In this climate, buildings are most attacked by weathering agents on their north, northeast, and east fronts (the very reverse of the conditions prevailing in Great Britain), and, in this view, it is of course important to select stone of the greatest durability for the fronts into which the prevailing wind thus drives the rain, *i. e.*, those on the west sides of the avenues and the south sides of the cross-streets in New York city.

Again, the swaying of tall edifices by the wind, whose amount can only be appreciated by ascent of our church spires during a gale, must cause a continual motion, not only in the joints between the blocks, but among the grains of the stones themselves. Many of these have a certain degree of flexibility, it is true, and yet the play of the grains must gradually increase and a tendency to disintegration result.

RAIN.—The attack of rain on building stones depends upon its solvent action, partly due to the solvent agencies before mentioned, which it conveys, and upon its mechanical effect in the wear of pattering drops and streams

a Joseph Henry, *On the Mode of Testing Building Material.* *b* United States Commission, 1851.

trickling down the face of a building. In dry weather a stone is therefore less attacked, chiefly because the destructive acids cannot penetrate so deeply. The proportion of rainy days, and above all of frequent alternations of dry and rainy days, in any climate must exert a great influence on the durability of stone.

Professor Hull states:

In India, ancient temples formed of laterite—a modern deposit of gravel cemented by lime—are still in perfect preservation. Such examples, and many more which might be produced, all go to prove that even in regions subjected to very heavy periodical rains, provided the air be pure and free from acids, buildings of even friable and calcareous materials are capable of withstanding atmospheric disintegration for a lengthened period. Rains which fall at long intervals, though with tropical violence, do not act so injuriously on stone structures as those lessv iolent but more frequent. (*a*)

CRYSTALLIZATION BY EFFLORESCENCE.—This effect, too, must largely depend upon the climatic conditions—alternations of dryness and moisture—to which reference has just been made. Examples of efflorescence of various salts, sulphates of magnesium, sodium, etc., are by no means uncommon in New York city and vicinity, though more frequently on brick than stone, walls covered with snow-white powdery coatings having been observed in basements of stores in South street, in cellars of residences in West Fifty-second street, etc. The expansion produced by such an exuding crust is likely, slowly but surely, to disintegrate and loosen scales and flakes from the surface of stone.

In an important investigation of this subject by Mr. Wenworth L. Scott, of London, the following results were obtained: (*b*)

Thirty-seven specimens of salt, collected from the surface of various building materials, were determined as follows:

Thirty-one, sulphate of sodium (and traces of other salts).

Three, mainly sulphate of sodium, and of magnesium and aluminium.

Two, mainly sulphate of sodium, with various phosphates and nitrates of sodium and calcium (never over 18 per cent. of the whole).

One, sulphates of sodium and potassium, with small amount of nitrates, and much sodium chloride.

With regard to the preventive means, * * * I cannot help denouncing the too free use of resinous, oleaginous, or tarry matters, as my own experiments have shown me that, in the event of fire, the walls of a building treated with such substances would inflame the moment their temperature was raised to about 200°.

He suggests the prevention of upward percolation of moisture by a seam of asphalt, laid on every wall when 2 to 4 feet from ground, as used in St. James' hall, etc., London. He has cured the efflorescence of sulphate of sodium or magnesium by application of a weak solution of barium chloride.

Sulphate of ammonium has not an injurious effect until it meets with substances capable of converting it into the sodium salt.

Sulphurous acid or sulphite of ammonium exerts no harmful effect, but rather a preservative influence, occurring in too small quantity to produce efflorescence. The process of osmosis in building materials has been greatly exaggerated, and is probably very slow. It is important that mortars should be carefully chosen, that they may not contain efflorescent salts.

PRESSURE.—A large number of experiments have been carried on to determine the crushing weight of building stones, and the strength thereby indicated. However,

It is generally laid down that the compression to which a stone should be subjected in a structure should not exceed one-tenth of the crushing weight as found by experiment. Practically, however, the compression that comes upon a stone in any ordinary building is never sufficient to cause any danger of crushing. * * * The working stress allowed in practice upon ashlar blocks should not exceed one-twentieth of the crushing weight. (*c*)

Nevertheless it may be expected that when an ashlar block has become weakened by weathering, the rapidity of its disintegration and decay may be hastened by the superincumbent pressure, especially if unequally applied by the settling of the foundations.

FRICTION.—This agency of wear most commonly affects pavements, sidewalks, stoops, the facing of piers, etc. It may be derived from the impact of human feet, of wheels, or of the hoofs of animals; the handling of freight; the removal of dirt, snow, and ice; the flow of tidal currents; the blows of the waves of the bay and river, etc.

FIRE.—The fierce trials to which building materials of all kinds have been subjected, in the great fires in Chicago and in Boston, during the last decade, have shown that there are none, not even brick, which can withstand, in the form of thin walls, without warping or utter destruction, the tempest of flame evolved from the great magazines of combustibles gathered on every side in an American city.

It is a remarkable instance of the prevailing ignorance on this subject that there exist many varieties of sandstone (*e. g.*, the buff freestone from Amherst, Ohio, etc.), graywacke, and perhaps other rocks, which possess a fire-proof character that enables them to resist a white heat, as the linings and hearths of iron-furnaces, and which would seem to specially fit them for the ashlar of buildings desired to be fire-proof, or at least the window-sills, etc., of business buildings, storage houses, etc. It must be considered, however, that experiments are highly desirable to

a *Building and Ornamental Stones*, p. 312.
b On Salification, etc., *Jour. Soc. Arts*, 1860, Vol. IX, p. 274.
c *Notes on Building Construction*, p. 6.

determine the character of resistance of these and other stones, not only to the lateral application of flames or radiation of intense heat, when exposed in a building with a backing of brick, but also to the alternations, rapid and violent, of sudden expansion and contraction, produced by the sudden application of cold water from the streams of fire-engines upon the heated masonry. So far as present observations have gone, however, in regard to such sandstones, I see no necessity to reject the abundant materials supplied by nature, and will present additional reasons on a later page.

C. ORGANIC AGENCIES.

These are of a vegetable nature, in their attack upon the materials of building construction on land, and of animal nature in regard to the erosion of submarine walls.

VEGETABLE GROWTHS.—In regard to the influence of lichens on the durability of stone, very opposite views are held. On the one hand, it is acknowledged that, in the case of marbles and limestones, some lichens exercise a decidedly corrosive action, and Professor J. C. Draper, in a paper on the decay of stone and brick in New York city, maintains that the same "minute lichen, *Lepra antiquitatis*, grows with remarkable freedom on such hygroscopic rocks as the sandstones, as any one may satisfy himself on examining the houses on the cross, or east and west, streets of our city". (*a*)

So far as my observation has gone, lichens are markedly absent from the decayed stone-work of this city, and it is probable that the reference applies to some other form of vegetation. Thus they never occur in the church-yards of Trinity church and Saint Paul's chapel, though found abundantly in those of New Utrecht and Flatbush; *e. g.*, three species were distinguished upon a single tombstone (Rutgert Denyse, 1795) at New Utrecht. On their removal, the surface of the stone beneath is not found corroded, but only retains a fresh color.

In a report on the selection of the oolitic limestone used in the houses of parliament in London, the subject has been thus discussed by one of the commissioners:

A question has frequently been raised with reference to the effect of vegetation on the surface of stone-work. By attentively examining the magnesian limestone buildings of this part of the country, it would appear that lichens exercise a sort of pernicious influence. At Bolsover castle, the keep of which seems to be constructed with magnesian limestone, similar to that of Steetley, wherever lichens have vegetated on the exterior of that edifice, decomposition has certainly taken place; and where they were then growing, upon removing them, we found that the surface of the stone, for about one-sixteenth of an inch in thickness, was reduced to a state of white powder. In such instances the lichen seems to possess some inherent power of chemically acting upon the stone; but whether the plant appropriates only the carbon to its own use and leaves the lime and magnesia, or whether it takes up the carbonate of lime and rejects the carbonate of magnesia, is a question of great interest, although it has not yet been investigated by a scientific observer. (*b*)

The opposite view, advocating their beneficial influence, is represented in the following quotations:

Lichens are in many cases a protection from the weather, and tend to increase the durability of the stone. (*c*)

In the report on the selection of stone for the houses of parliament it is stated:

Buildings situated in the country appear to possess a great advantage over those in populous and smoky towns, owing to lichens, with which they almost invariably become covered in such situations, and which, when firmly established over their entire surface, seem to exercise a protective influence against the ordinary causes of decomposition of the stone upon which they grow.

Many blocks of stone quarried at the time of the erection of St. Paul's, in London, but left in the quarries, and now covered by lichens, still retain their sharp edges and tool marks beneath the lichens, while those on the exposed fronts of the cathedral are now moldering away.

The sandstone of Tintern abbey (thirteenth century), in part laminated, is covered with gray and green lichens, and is, for the most part, in perfect condition. In Tisbury church (thirteenth and fourteenth centuries) the ashlar, constructed of calciferous limestone, is, where undecomposed, covered with lichens.

The exact action of the lichens needs investigation, and will doubtless be found to differ widely according to the species and the material on which they grow. Few of our buildings in this district are sufficiently old to present much growth of this kind.

There is another vegetable growth, however, that of the *confervæ*, of which no notice seems to have been taken, but which flourish in damp weather all the year round, in New York and vicinity, upon shaded surfaces of our freestones, often coloring the vertical faces of the steps and the sides of stoops, and the lower portion of the ashlar, near the ground-line, and under the shadow of heavy copings and cornices, especially on the north shaded fronts of the houses on the south sides of the streets. Upon brownstone their eroding influence is shown in the common roughening of the dressed surfaces. Upon the Nova Scotia or Dorchester stone their action is apparently still more active, as shown in abundant instances on the walls and carved work throughout Central park, *e. g.*, the pillars of Albert quarry stone at the head of the steps at the end of the mall, where shaded surfaces are alternately seen colored green with *confervæ*, and again bare and crumbling, at different seasons of the year, and have needed frequent redressing. It may also be remarked that the heavy growth of vines trained up over the fronts of houses, sometimes seen in this city, would be apt to favor such growths and the decay of soft freestones.

The well-known destructive agency of the roots of grasses and higher plants on the durability of masonry is fortunately not a danger to be considered in our American cities.

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a *The Manufacturer and Builder*, 1872, IV, 170.
b C. H. Smith: *Lithology, or Observations on Stone used for Building*, p. 26. 1845.
c *Notes on Build. Const.*, Part III, 10.

Boring mollusks, sponges, etc.—The serious danger of the attack of these forms of animal life may be illustrated by the following example:

A limestone from Creston, near Plymouth, England, was originally employed in the construction of the Plymouth breakwater, but the boring mollusks (*Pholas dactylus*) so perforated the stone, between high and low water, that it was thought necessary to replace the blocks by granite. (*a*)

Little masonry is yet exposed in our bay and along our river fronts to the attack of these enemies; but the cargoes of Italian marble sunk off the harbor, which have been found thoroughly perforated and honey-combed by such agency, *e. g.*, that of a steamer sunk in 1871, and the similar erosion of the gneiss of Westchester county, along the sound, by marine sponges, as pointed out by Mr. J. D. Hyatt, of the New York Microscopical Society, indicate the dangers which may be in store for the bases of the piers of the New York and Brooklyn bridge, and for the masonry which will be hereafter introduced into our piers and docks. Birds also serve as destructive agencies; the sparrows and other small birds by their droppings deposited in abundance on cornices and projecting moldings, and the pigeons, as in the London Exchange building, by pecking away the cement between the blocks of masonry.

3.—INTERNAL ELEMENTS OF DURABILITY.

The durability of a building stone depends upon three conditions, the chemical and mineralogical nature of its constituents, its physical structure, and the character and position of its exposed surfaces.

A. CHEMICAL COMPOSITION.

In this view the following conditions need consideration:

Solubility.—The presence of calcium carbonate, as in the more calcareous forms of our Westchester dolomitic marbles, and in the earthy limestones (*e. g.*, that from Indiana recently introduced), is likely to render such materials liable to rapid attack by acid vapors. On the other hand, in England pure dolomite is considered extremely durable as a building stone, as is shown, for example, in the Norman part of the Southwell church, in Yorkshire.

The hydrated form of ferric oxide which acts as the cement in all the Triassic sandstones (*e. g.*, the brownstone of New Jersey and Connecticut) is far more soluble, and so may be more easily removed, to the injury of the stone, than the anhydrous or less hydrated ferric oxide predominating in the cement of our Potsdam sandstone and many foreign sandstones, which seem likely on that account to be better resistants to disintegration. The sandstones whose cement is siliceous (*e. g.*, the Craigleith stone of Great Britain, and some varieties, almost quartzitic, of our own Potsdam sandstone in this state) are likely to be the most durable, and hereafter the most sought for, where durability is appreciated, in spite of their difficulty in working and dressing.

Tendency to oxidation, hydration, and decomposition.—In the case of a roofing slate, the presence of a sulphide (*e. g.*, marcasite, more decidedly than pyrite) is likely to be very injurious; in a granite or marble (*e. g.*, the marble of Lee, Massachusetts, in the new court-house, New York city) the results may be confined to the discoloration and less objectionable. Nevertheless there are abundant instances, which yet need investigation, in which the pyrite occurs in a highly-crystalline condition, even in roofing slates, by which it has been enabled to resist decomposition during centuries. If the pyrite is uniformly and minutely distributed in small quantity, its presence may be even advantageous; thus, the marbles of Berkshire county, Massachusetts, when first cut, are cold gray, but by long weathering acquire a tint of exquisite warmth and transparency. (*a*)

The biotite in many of our granites seems peculiarly liable to decomposition, and apparently to the weakening of the surrounding stone. The brown freestones of New Jersey and Connecticut contain everywhere minute scales of biotite, though in much less proportion than that of muscovite, and the freestones of New Brunswick contain similar scales of a chlorite; both minerals in a state of decomposition more or less advanced.

The orthoclase, which largely enters into the composition of the Triassic and the Carboniferous sandstones, and of all the granites in this market, is the feldspar of most ready decomposition. It is found, on microscopic examination of a brownstone or granite, in various stages of alteration, from a mere dimming of its cleavage planes to a cloudy or opaque mass of the usual structure, and finally to a siliceous shelly network, with its interstices filled with iron oxide. In this condition the mineral has lost all its strength and ability to resist either pressure or atmospheric attack, and a stone in which it prevails must have reached the last degree of disintegration and decay.

The albite, oligoclase, and other feldspars are much better resistants to decomposition, and their abundance in granite or sandstone may be an important element in their durability.

Inclosure of fluids and moisture.—The thorough drying of a stone before, and the preservation of this dryness after, its insertion into masonry are commonly recognized as important adjuncts to its durability. But the exact nature of the process of seasoning, and of the composition of the "quarry-sap" thus removed by thorough drying, have never been investigated. The "quarry-water" may contain little else than ordinary well-water, or may be a solution more or less nearly saturated, at the ordinary temperature, with carbonate of calcium, silica, double salts of calcium and magnesium, etc.; in the latter case, hardening results by the drying and an exact knowledge of its nature might throw important light on the best means for the artificial preservation of stone.

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a *Gwilt's Encyc. Arch.*, p. 492.

a *Am. Arch. and Building News*, 1881, X, 13, 17.

Again, water may exist in large quantity in chemical combination in the silicates (*e. g.*, chlorite, kaolin, etc.), or in the hydrated iron oxides which constitute the cement of a building stone. Many hydrates of ferric oxide are known to exist, and of these a considerable number occur in nature, in concentrated form, as ores.

We do not yet know how these or other hydrates of ferric oxide are isolated or mixed in their distribution through the brown sandstones. I have elsewhere (*a*) pointed out the probability that, to a large extent, the red cement of the sandstones of most recent or Tertiary age may be probably referred to limonite or limnite, *e. g.*, those found in eastern New Jersey and to the southward along the Atlantic and Gulf sandy plateau; that of the sandstones of the Mesozoic period to turgite and limonite (possibly in part göthite?), *e. g.*, the brownstones of New Jersey and Connecticut; and that of the bright red sandstones of the Carboniferous and older rocks to anhydrous ferric oxide, *e. g.*, the red freestones of New Brunswick and of Scotland, the red sandstones of Potsdam, New York, etc. However, these distinctions cannot be drawn sharply, and the subject awaits investigation. Changes in the degree of hydration are constantly going on in stones of this character, and the absorption of water may exert a force for expansion and disruption. In regard to the vast amount of water feebly locked up in combinations such as these, the query has been recently offered:

> We venture to suggest, as a subject for careful chemical analysis how far the existence of water or the elements of water, not as moisture, but as chemically combined with lime, magnesia, or other elements in a stone, may render it susceptible to the attacks of frost. (*b*)

The more recent results of microscopic lithology have also established the fact that certain minerals, especially the quartz, in very many of our most common building stones abound in small cavities partly or wholly filled with fluids, viz, water, brine, and liquid carbon dioxide. These cavities vary in size from microscopic minuteness up to a diameter of several millimeters, and are often very abundant, so that a fragment of quartz clouded by them may explode on the application of heat. The varieties of our building stones in which they are known to particularly abound are the following: Brownstone—New Jersey and Connecticut; freestone—Dorchester, New Brunswick; biotitic gneiss and fibrolitic gneiss—New York island and Westchester county; granite—Quincy, Massachusetts, Clark's island, Maine, Mount Beatty, Connecticut, Fitzwilliam, New Hampshire, Saint Lawrence county, New York, etc.

The question of the influence of these cavities on the durability of the rock, when exposed to frost or to the intense heat of the summer sun or to fire, is one that yet awaits investigation. The violent explosions which attend the exposure of granites to fire, as illustrated in the great fires of Chicago and Boston, may imply some connection, in part, with the sudden expansion and rupture of such inclosed fluid cavities; while the similar action of frost seems to be suggested by the interesting paper of Mr. W. E. Hidden on the fracture of quartz with liquid cavities in North Carolina. (*c*)

B. PHYSICAL STRUCTURE.

This varies widely in the crystalline and sedimentary rocks; but three conditions, common to both, will be first discussed, then two confined to the former class, and finally two confined to the latter.

SIZE, FORM, AND POSITION OF THE CONSTITUENT MINERALS.—It has been established that the resistance to compression—and it may be supposed in some degree the durability—of a finely-granular rock exceeds that of a coarsely-crystallized variety of the same. Dr. J. S. Newberry has also pointed out that "mica is soft and fissile, and hence is an element of weaknesss. Where it exists in any considerable quantity the stone is easily crushed and unfit for use".

The scales of mica in a laminated sandstone, *e. g.*, the common micaceous variety of brownstone, lie largely in the plane of lamination, and diminish the strength of the rock when pressure is applied in the direction of the latter plane, *e. g.*, on edge, on account of the feeble adherence between their surfaces and the rock in contact. So also when used as ashlar, the expansion caused by frost tends to produce the first separation along those planes.

However, both in a granite and in a freestone, it is probable that a moderate amount of mica—much more an abundance of a tough and fibrous mineral, like hornblende, augite, fibrolite, etc.—may serve as an excellent binding material, like hair in mortar, and add to the strength of the rock, if uniformly mixed, with little or no parallelism of planes. Peculiarities of crystallization in crystalline rocks or of arrangement of tabular flakes of minerals in sedimentary rocks may also produce a coincidence in the position of planes of stronger cleavage, *e. g.*, of feldspar in granites or in feldspathic sandstones, which will diminish both the strength and durability of a rock. The disintegration of the freestones of the Triassic age is favored by both these conditions—abundance of mica and parallel position of feldspar plates.

POROSITY.—Bischoff has thrown much light on the percolation of water through the interstices and fissures of rocks. Even in the densest crystalline rocks, as trap and basalt, spots of moisture can be discovered on freshly fractured surfaces, generally connected with minute fissures. In the loosely-cemented material of the freestones the percolation must be far more free.

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a On the Geological Action of the Humus Acids, *Proc. Am. Ass. Adv. Sci.*, 1878.
b *The Builder*, 1882.
c *Trans. N. Y. Acad. Sci.*, I, 1882.

The excessive porosity of a building stone thickens the layer of decomposition which can be reached by the acids of the atmosphere and of the rain, and also deepens the entrance of the frost and its work of disintegration. This is illustrated, in the case of brownstone, in numberless instances throughout New York city, in the sills and lintels of windows, the projecting string-courses of stone in brick buildings, the steps of stoops and sills of doors, etc., with their edges rounded, their material pitted, honey-combed, fretted, and furrowed by the ridges of projecting or eroded laminæ, or the whole mass of the stone worn away flush with the front of the house, *e. g.*, in the older brownstone houses of the district styled "Greenwich village", in the Eighth ward, and in the old streets on the east side of the city. Even, too, in houses less than ten years old, the flat ceilings of the porticos, surfaces which appear to be perfectly sheltered from the weather, are peeling away into successively-loosened layers, *e. g.*, in the houses on the west side of Fifth avenue, between Forty-sixth and Fiftieth streets. In all these cases we plainly see the effect both of rain, and, above all, of water, derived from the thawing of the snow which is caught and rests upon the projecting ledge of stone, soaking down into the spongy mass below during the day, and again partially thrust out by the expansion of freezing during the night. With a light-colored stone an unusual and undesirable power of absorption is often indicated by its discoloration in streaks and circular patches. Several kinds of discoloration may be distinguished, all more or less dependent on the absorptive character of the stone. The one consists of a white calcareous efflorescence, very common in new masonry, in blotches spreading around the joints, and doubtless derived by permeation of the stone with solutions of calcium carbonate from the fresh mortar or cement. It appears to be usually of a temporary character, disappearing after a few years. This is sometimes seen in brownstone, but more frequently in the Ohio and the New Brunswick freestones; *e. g.*, in the fronts and stoops of most of the houses first built of that stone in Madison avenue above Fifty-fourth street, etc. Another form of discoloration is due merely to the street-dust and soot which are deposited upon the projections of a stone front. It results in long gray or blackish streaks, running down the front at either end of the window-sills and from below the line of projecting bands and cornices, and as a general blackish-gray discoloration of the surfaces of sheltered moldings of apertures, the pediments of porticos, etc.

The earlier stages of this discoloration may be easily studied in numerous instances among the older buildings constructed of light-colored freestone, *e. g.*, in the houses on the northwest corner of Sixth avenue and Twenty-ninth street, and between Thirty-seventh and Thirty-eighth streets, and in the building on southeast corner of Christopher street and Greenwich avenue, etc.; the sloping window-sills of the orphan asylum at Fifth avenue and Fifty-first street are thus blackened, while the vertical faces of the same stone in the façade are washed clean and uncolored.

A similar discoloration affects most of the varieties of white marble used in our city, *e. g.*, in several buildings on the north side of Murray street, between Church street and West Broadway; in the new court-house on Chambers street; the cornices, sills, and seams of the rusticated stone-work of the Union Dime Savings bank, at Sixth avenue and Thirty-second street.

Another form of discoloration, commonly associated with the preceding in the same light-colored freestones, presents black stains and streaks, whose material has not yet been identified, but apparently consists of manganese-oxide, probably derived from the decomposition of the feldspar and chlorite in the rock. This is of a more permanent and objectionable character, increasing both in extent and depth of color with the age of the masonry. Its progress is most rapid on stone surfaces exposed to the prevailing winds and rains, *i. e.*, the northeast. An illustration of this appears in the church on the corner of Fifty-seventh street and Madison avenue, whose faces fronting the south and west are entirely free from discoloration, while the spire, freely exposed above, is beginning to be tinted all around and from top to bottom.

Other forms of discoloration are shown in yellowish stains on the light freestones, certainly due to iron, and in films of confervous growth, which are green during rainy and damp weather, and become blackish-gray when dry.

HARDNESS AND TOUGHNESS.—Resistance to weathering does not necessarily depend upon hardness, since some soft rocks of peculiar composition (*e. g.*, some steatites, chlorite schists, etc.) are known to withstand atmospheric attack very well. However, a hard material of close and firm texture is, in those qualities, specially fitted at least to resist friction and artificial wear, as in stoops, pavements, sidewalks, and road metal, and the natural friction of rain-drops, dripping rain-water, the blows of the surf, etc. The graywacke and blue-stone of New York and Pennsylvania, is, in the form of flagging, unexcelled for paving, etc.; and no reason is apparent why its thicker beds should not be further applied as a material for ordinary construction. So far as yet introduced for this purpose, within a few years past, it preserves perfectly the arris in dressings, quoins, etc., without either chipping or discoloration.

CRYSTALLINE STRUCTURE.—Experience has shown that the crystalline structure in a stone is a better resistant to atmospheric attack than the amorphous. The following statement is made concerning this characteristic in an oolitic limestone of England:

> The Steetley stone is remarkable for its light specific gravity, great power of absorption, and yet extremely durable; its resistance to atmospheric influences may be attributed to its beautifully sparkling crystalline structure, without having any dusty incoherent matter in its formation, the crystals being all well cemented together. (*a*)

a C. H. Smith, *op. cit.*, 32.

It is also well illustrated in New York city in the better class of crystalline building stones, *e. g.*, the granite buildings in Murray, Warren, and other of the older streets, the Astor house, etc., which are not yet perceptibly affected by the tooth of time. The same fact is generally true with the sedimentary rocks also, a crystalline limestone or good marble resisting erosion better than an earthy limestone. Only the oolitic varieties of the latter seem to possess, in that structure, an advantage over those that are entirely earthy or amorphous. The durability of a limestone like that of Indiana, recently introduced into this city, must depend upon these conditions. So, too, the highly-crystalline varieties of the Potsdam sandstone, in New York, Wisconsin, etc., abounding in glittering facets which the microscope reveals to be in part quartz crystals of exceeding minuteness, may be expected to have in that respect a greater likelihood of durability, if well cemented, than the ordinary variety made up of rounded grains.

Tension of the grains.—A crystalline building stone (*e. g.*, granite, gneiss, marble, etc.) is made up almost entirely of imperfect crystals of its constituent minerals (of calcite, in a marble—of quartz, feldspar, etc., in a granite) closely compacted together, originally with intense mutual pressure. Sometimes no cement intervenes, but any two grains remain in close contact at an impalpable invisible line. Such a condition must be sensitive to very slight influences, the surfaces of the grains in a building stone being alternately pressed still more tightly together or separated to disruption, *e. g.*, by variations of temperature, above all at the extremes of severe cold and frost, of burning sunshine, and of fire. A good illustration is found in those marbles which seem to contain no cement in their interstices, *e. g.*, the coarse Tuckahoe marble, which soon becomes seamed with cracks, as in the building on the corner of Thirty-second street and Broadway.

In England it has been found that—

All varieties of Carrara marble have perishable qualities which ought to preclude them from being ever applied to external purposes in this country. After exposure to the weather for thirty or forty years, disintegration through its entire mass, but mostly on or near the surface, evidently takes place; after the lapse of about a century, more or less, according to the quality of the marble, the entire substance falls into a kind of sparkling sand. (*a*)

Frequent changes of temperature also tend to destroy Carrara marble more rapidly than atmospheric influences; thus the mantel of a chimney-piece is invariably disintegrated long before any other part.

Contiguity of the grains.—The principle which obtains in the application of an artificial cement, such as glue, in the thinnest film, in order to gain the increased binding force, by the closest approach of the cemented surfaces, finds its analogy in the building stones. The thinner the films of the natural cement, and the closer the grains of the predominant minerals, the stronger and more durable the stone. One source of weakness in our brownstones lies in the separation of the rounded grains of quartz and feldspar by a superabundance of ocherous cement. Of course, the further separation produced by fissures, looseness of lamination, empty cavities and geodes, and excess of mica, all tend to deteriorate still further a weak building stone.

Homogeneity.—A great difference of the hardness, texture, solubility, etc., in the material of the grains of a rock and of their cement, or of the successive laminæ, renders the weathering unequal, roughens the surface, and increases the sensibility of the stone to the action of frost. So also softer patches, of more easily decomposed veins and layers in the stone, produce unequal weathering, hollows, furrows, and projecting ridges. Even a hard crystalline and otherwise durable stone may be materially weakened by these defects. Illustrations of this are found in the same varieties of the dolomitic marbles, with irregularly mixed constituents, from the old quarries at Kingsbridge, on New York island, and in Westchester county.

C. CHARACTER AND POSITION OF SURFACE.

The rough or polished condition of the surface of the stone, its inclination from a vertical plane, and the position in which it stands with reference to the sun and to the prevailing direction of the wind, all constitute important elements of its durability.

Smooth dressing or polish.—It is generally assumed, and rightly, in the climate of New York, that a smooth or polished surface tends to protect a stone by facilitating the rapid discharge of rain-water from its surface. The present condition of most of our smoothly-dressed granite fronts seems to confirm the general accuracy of this opinion. Nevertheless some anomalies occur. It has been observed in London that, in the modern buildings, decay progresses far more rapidly than in the ancient, and it has been queried whether this may not in some way be due to the application of machinery.

A series of observations by Professor Pfaff, of Erlingen, Germany, in reference to granite, syenite, etc., have shown, among other results, that the superficial loss in a century, by exposure to the weather, may amount, on unpolished granite, to 0.0076^{mm}, on polished granite to 0.0085^{mm}.

These conclusions in regard to the more rapid weathering of polished granite yet need confirmation by more extended observations in other localities. But an investigation is yet needed to determine whether the vibration of the surface of a stone, produced by the jar of the machinery employed in sawing or polishing, as well as the bruising produced by the friction of the sand, diamond-saws, etc., and still more, the strain and pressure produced by the impact of the blows of chisel and hammer, in smooth and rough dressing, do not produce superficial changes of tension, minute fissures produced by the separation of surfaces of feeble adherence (*e. g.*, on smooth planes of

a Gwilt's *Encyc. of Arch.*, p. 491.