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WEATHERING OF SANDSTONE IN THE IOWA STATE CAPITOL BUILDING

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Extreme weathering of some of the sandstone in the superstructure of the Iowa State Capitol at Des Moines has within recent years been a cause of considerable concern. The part of the building affected is that above the level of the basement story, and it is greatest toward the top of the building. Decorations, balustrades, cornices, architraves, pediments, hereafter to be referred to as trimmings and decorations, have been affected to the point where many pieces have fallen and crumbled away. The falling material is a source of danger, the appearance of the building is unfavorably affected, and the monetary damage to the structure is great. Considerable sums have already been spent in removing weakened stone, and in making replacements with cement or other materials, where possible. Certain parts of the exterior are however, apparently continuing to suffer progressive weathering which may be expected to persist and to be a cause of concern and expense. It will apparently be necessary to continue the work of removing weakened stone and of replacing and restoring the missing parts where it is thought to be desirable.

Thus far only decorations and trimmings have been affected, but since the masonry portion of the superstructure is also of sandstone it also might be thought of as under suspicion. If weathering in this should proceed as it has in the trimmings the danger from falling fragments would be increased, repairs would have to be continuous and costly, and the stability of the building might eventually come into question. It may be stated at the beginning that fortunately this stone is apparently not much affected, but only that which forms the trimmings or decorations.

The writer's problem has been to (a) arrive at the explanation of this extreme weathering of certain parts of the sandstone and of the factors which are affecting it; (b) to inquire into the situation with regard to the main mass of the masonry; (c) and to forecast so far as possible, what may be expected as to the continuance of this decay of affected parts.

HISTORY OF BUILDING; STONES USED

The cornerstone of the building, a prairie boulder from Buchanan Co., was laid on Nov. 23, 1871, and the legislative portion of the building was dedicated to use on Jan. 17, 1884. The stones of the exterior have thus been exposed to weathering for approximately 50 years. Fortunately most of them are durable rock. The foundation stone is a limestone obtained from the Bear Creek and Winterset quarries in Madison Co. The base course is of granite, secured from glacial boulders brought from Buchanan Co., and from the quarries of Sauk Rapids, Minnesota. The stone of the basement story is from the quarries at Iowa City, from which the stone for the old capitol at Iowa City was secured. It may be remarked in passing that some of the blocks of this stone are apparently showing rather pronounced surface weathering effects. It has of course been used as masonry only, and not as has some of the sandstone for decorations and trimmings. Various other stones were used to a lesser extent, in the interior as well as the exterior of the building, as for example "Forest City" stone, from Cleveland in the outside steps and platforms; Anamosa stone and Lemont (Illinois) stone in the rails, columns, piers, walls, and corridors of the basement and first floor.[1]

SOURCE AND CHARACTERISTICS OF SANDSTONE

The main portion of the building, that above the basement story, is of two kinds of sandstone. Since it is with these rocks that this study is concerned, their sources, field characteristics and field relations will first be described. One was secured, according to Lathrop,[2] from quarries at St. Genevieve, Missouri; the other, to be hereafter referred to as the blue stone, from Carroll Co., Missouri.

AUX VASES SANDSTONE

The stone from the quarry at St. Genevieve is the stone of the walls of the superstructure, and it will be considered first. It was also used in construction of the approaches to the Eads' bridge at St. Louis, in the Equitable Insurance, the McLean, and the Singer Sewing Machine buildings, in St. Louis, and in the Rock Island Arsenal.

The quarries are located three and one-half miles south of St. Genevieve, St. Genevieve Co., Missouri. They are in the Aux Vases formation at the base of the Chester Series of the Mississippian

1 Lathrop, H. W. The Capitals and Capitols of Iowa, Iowa Historical Record 4:114-116. 1888-90.
2 *Idem.* 115.

System. This lies unconformably upon the St. Genevieve formation which is largely limestone. It is overlain unconformably by the Renault Formation, chiefly limestone and shale, with some sandstone at the base. According to Stuart Weller and Stuart St. Clair [3] the Aux Vases in St. Genevieve Co. is restricted to a belt beginning about one and one-half miles back from the river bluff. It is stated to reach a thickness of 60 feet and in the quarry from which, according to all accounts, this stone was taken there are about 25 feet exposed. The quarry is located on a spur of the Mississippi River bluff between Cole Creek and River aux Vases. Other quarries lie south of the River aux Vases, between that river and Saline Creek, although presumably none of the capitol stone came from these.

Weller and St. Clair [4] in their consideration of the lithologic character of the formation state that in most localities "it is a fine grained, even textured rock, uniformly light yellow in color. Much of it occurs in massive beds which are well adapted for quarry stone, but portions of it, in some localities at least, are rather thinly bedded and locally it includes some arenaceous shale at the base. The more thinly bedded portions are commonly not cross-bedded, but upon the weathered surfaces of the more massive beds, obscure cross-bedding is commonly exhibited." Referring to the rock of this particular quarry they further say [5] that it "is perhaps somewhat finer-grained and of more even texture and color than in most localities, and little or no cross-bedding is shown."

The writer has inspected the rock in this quarry, in which as stated above, about 25 feet of sandstone are at present exposed. The quarry has been partially filled in however, and probably about 40 feet, according to Weller and St. Clair,[6] were actually exposed at one time. Operations were discontinued when the course of the Mississippi shifted so as to leave the quarry without convenient water transportation. Though it has probably not been worked for 40 or 50 years the quarry face shows very little affect from the exposure it has suffered during this period. The machined or channeled surfaces are still vertical; where they were smoothed by the cutting tools they are still smooth, where they were furrowed by the cutting tools they still retain the impression of these cutting tools. The rock is notably free of bedding and joints, though above the 25 foot bed from which the building material was taken there

3 Weller, S. and St. Clair, S. Missouri Bureau of Geology and Mines 22, 2nd series: 226-236. 1928.
4 *Idem.* 228.
5 *Idem.* 229.
6 *Idem.* 228

are several feet of rock which is thinly bedded. The worked face has however, been affected by weathering to such a degree as to bring out the fact that the rock is cross-bedded. Most of the cross-bedding is very faint, and gives no impression of constituting a source of weakness in the rock.

Projecting edges can be broken off with the hammer rather readily, but the rock does not crumble badly. Only a short distance in from the edges it is considerably sounder and tougher so that good sized pieces cannot be readily secured with a hammer. It is apparent from inspection at the quarry that calcite is absent as a bonding medium since neither the weathered face nor the freshly broken surfaces would effervesce with acid. The rock is apparently all fine grained, and shows little or no variation in grain size across the bedding. It is light yellow brown in color and the weathered faces are a very dark brown.

The resistance to weathering of this material is interestingly shown by the condition of a water tank made of it which is located on the quarry property. It is constructed of upright slabs of the stone, the largest of which are 10′x8′x1′. Although these slabs are on edge, and hence in the position most likely to bring about the maximum weathering along bedding and lamination planes, they have been but slightly affected by their exposure.

BLUE STONE

The other sandstone, the so-termed blue stone, apparently came from a quarry one and one-half miles west of Miami, Carroll Co., Missouri. It constitutes the stone used for trimmings and decorations in the capitol. Stone from the same source was used according to Buckley and Buehler [7] in the Methodist Church at Carrollton, Mo., the public library at Fulton, Mo., for bridge abutments along the Wabash R. R., and for miscellaneous purposes in many cities of Missouri, Nebraska and Iowa. This quarry is stated to have been one of the largest sandstone quarries operating in the state, so it may be judged that a large quantity of stone was taken from it. The bed rock of the vicinity is of the Des Moines series of Pennsylvanian age.

The following facts with regard to the stone and its field relations have been drawn from the work of Buckley and Buehler.[8] At the time of their study 110 feet of massive sandstone was exposed, of which the upper 30 feet was described as of a light buff color, the color being ascribed to disseminated particles of iron oxide and

[7] Buckley, E. R. and Buehler, H. A., The Quarrying Industry of Missouri, Missouri Bureau of Geology and Mines, 2, *2nd* series: 269. 1904.
[8] *Idem.* 268-270.

iron sulphide; and the lower 80 feet of a white color, this rock being free from iron oxide but containing an occasional nodule of iron sulphide. This stone from the lower part is stated to have been used, because of its hardness and uniformity of color and texture, for caps, sills, monument bases, and dressed building stone. It is presumably from this portion that the blue stone of the capitol came.

The stone is further described[9] as consisting of "fine rounded grains of translucent quartz, cemented together chiefly with calcium carbonate. Small flakes of mica, grains of iron oxide, and nodules of pyrite are lesser constituents of the rock." "Some of the stone contains carbonaceous material, in the form of very thin black layers having the appearance of long narrow leaves. As a rule they occur parallel to the bedding planes and only show as a dark line, when the stone is cut normal to the bedding. Occasionally these layers occur in an inclined position, in which case they show as irregular dark spots on the face of the stone." Thin sections are stated to show "chiefly roundish to sub-angular grains of quartz, with subordinate amounts of calcite, iron oxide, feldspar, and clay. Quartz grains are cemented rather firmly with calcite and to a lesser degree with iron oxide and bitumen." Thin sections of stone from the Capitol building were examined by the writer, and bear out this description. The stone thus seems to resemble in many particulars sandstones of the Des Moines Series in Iowa. It might also be noted that examination by these authors of quarry faces which had been exposed for 25 years showed little or no effect of weathering. Though the surface had been discolored by surface water carrying clay there was no evidence of alteration in the stone.

It may be remarked at this point that it is the stone from Carroll Co. which has suffered such extreme decay at the capitol. It evidently is a stone which can be easily carved and worked, and for this reason it found wide use in the decorative parts of buildings.

Weathering of Sandstones

In order that the manner of weathering of these Capitol sandstones may be properly considered it is believed desirable to go briefly into the origin and nature of sandstone, and of the effects of the weathering forces upon it.

Sandstones are formed from sand, the grains of which are commonly quartz, but with which there may be grains of other rather inert minerals such as mica, feldspar, clay minerals, etc. The sandstone differs chiefly from the original sand only in that there has

[9] *Idem.* 268.

been introduced into it through the action of percolating waters a natural cementing substance such as calcite, dolomite, quartz, or minerals which are oxides of iron or hydrated iron oxides. Clay present with the original sand grains may also serve as a cementing substance. The cementing substance may form a large part of the rock, so that the grains seem set in a matrix of it, or it may be present in such small quantities that it is difficult to determine its nature in thin section. It may form irregular masses between the grains or it may form thin shells about the grains.

The grains are generally resistant to the action of ordinary chemical weathering processes, particularly if as is usually the case, they are chiefly of the mineral quartz. As far as weathering is concerned either in natural outcrops or in buildings the cement is the material susceptible to change or removal. Of these cementing substances quartz is the most resistant. Quartzite, which may be considered the extreme of this type is exceedingly resistant to chemical weathering. Ferruginous cements are said to be resistant also, but less so if they form only a part of the cementing substance. Clay as a cementing substance is of course extremely weak. Calcite and dolomite cements are particularly subject to solution, either as a result of the presence of CO_2 in rainwater, or of sulphur gases in atmospheres which are polluted with smoke. Many sandstones which are calcareous have been used for building purposes and it is their behaviour in this connection that is of particular concern.

The process by which calcite is taken into solution is well known. Rain water dissolves CO_2 from the atmosphere. This solution reacts with $CaCO_3$ (calcite) to form the soluble carbonate $Ca(HCO_3)_2$ which is relatively soluble as compared with $CaCO_3$. Or in smoke polluted atmospheres an added affect may be produced through the presence of SO_2. The H_2SO_3 reacts with the $CaCO_3$ of the calcite or dolomite to form $CaSO_3$, which oxidizes to $CaSO_4$. Through the action of either of these two acids a calcite or dolomite cement may be removed from a sandstone, and with its removal the rock will tend to disintegrate. Removal of the cement increases the pore space and permits more water to enter for further solvent action. The effect of freezing of water in the increased pore space becomes pronounced. A further deleterious effect may apparently be produced when this material in solution crystallizes repeatedly from solution between the grains as the rock dries out, thus breaking down the internal structure of the rock and forming a crust at or near the surface. Blisters may also form and break open.

Sandstones cemented with calcite or dolomite are hence rather unsuitable as building materials particularly as projecting parts or in exposed places. If so used the cementing substance is gradually removed and the rock is weakened. Individual grains are blown away and washed away. Frost action finally enters in to an increasing degree as the pore space becomes greater. The rock may lose its strength to such an extent that projecting parts, further affected by frost action, will fall to the ground. Slabs at the bottom of balustrades will lose material from the under side and will finally break. Blistering and scaling may develope on vertical walls. The transferal of soluble materials to other porous rocks in the structure may produce blistering and scaling in them as well. A rock such as the blue stone might be expected to decay in this fashion.

SITUATION AT CAPITOL BUILDING

It has already been noted that decay of certain parts of the superstructure are the cause of concern. As roof parts were the only ones readily accessible to the writer, the study was confined to those parts.

The solid masonry composed of the Aux Vases stone is apparently not affected to any great degree, although the cross-bedding has been brought out by the weathering and in places scaling and blistering have occurred. (Fig. 1) The extreme decay is shown

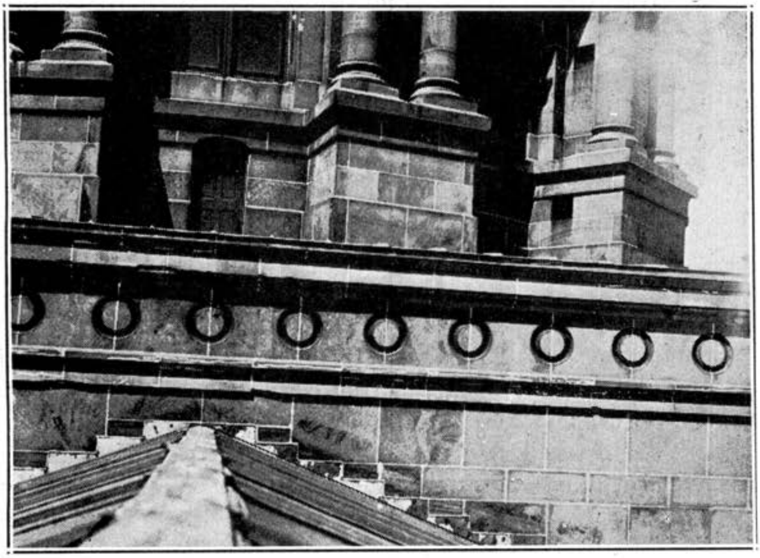

Fig. 1. South side of main dome. Most of the projecting parts are blue stone. Broken edges and cement replacements, showing white, are prominent. Most of the masonry is Aux Vases; weathering has made the cross-bedding apparent in the surface and has produced some surface hardening and blistering.

by the blue stone from Carroll Co. which constitutes such parts as the decorations, pediments, entablatures, cornices, etc., (Fig. 2) and it is to that stone and its weathering that most attention has been given.

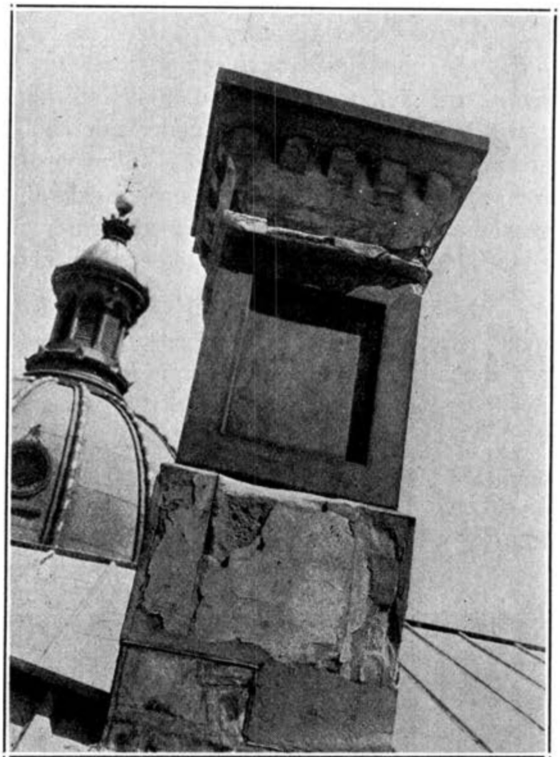

Fig. 2. The most decayed (west) side of chimney on south wing. Decay at the top and bottom are typical of the blue stone in exposed places. Aux Vases block in middle is only slightly decayed, and that near contacts. Thin repairs at base are shelling off.

CHARACTER OF DECAY OF BLUE STONE

Examination of material which has fallen away or been removed and of badly decayed material still in place on the building shows the affected sandstone to have lost its original strength and cohesiveness. Of that still in place which is badly deteriorated it may be noted that some of it has progressed to this extreme condition in the few years which have elapsed since the last repairs to the exterior were made. Many cases may be found in which the rock has lost so much of its cement that grains and smaller pieces can be rubbed off, or in which it breaks easily.

Many cracks, parallel to the lamination, have developed in material which is still in place. (Figs. 3 and 4) Some of the pieces of the bottom rails of balustrades have lost several inches by the development of this sort of weathering. Such weathering proceeds

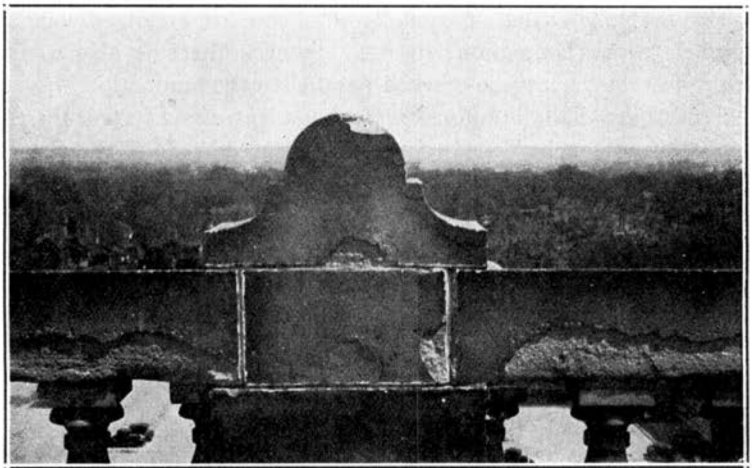

Fig. 3. West side of top of balustrade on the east side of south wing. Decayed blue stone has been chipped off. Shows decay at the bottom of the rail, and cracking, parallel to lamination and to surface, of the piece on top of the rail. Typical blue stone weathering.

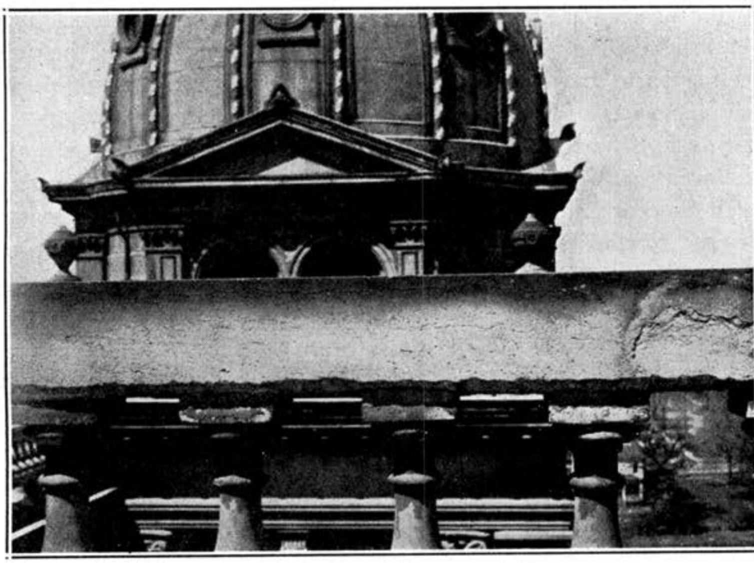

Fig. 4. South side of blue stone railing on north side of east wing. Cracking, parallel to surface and lamination, is evidently caused by loss of natural cement and subsequent frost action. Pronounced decay at the bottom is aided by repeated crystallization of soluble materials.

from the bottom, the material breaking away parallel to the bedding. In many of the small projecting decorations the bedding is at such a high angle with the horizontal that rock thus weakened has broken off along lamination planes.

Some of the rock surfaces are pitted with holes up to an inch or two in diameter and of equal depth. These are arranged roughly parallel to the lamination. In such material there is also a tendency for the rock to be cracked parallel to the lamination.

Sandstones like limestones may be adversely affected by the formation of a hardened outer crust or skin and of blisters, through the crystallization of soluble salts. Such skins have formed in places on the blue stone. The decay, where active, has generally gone on so rapidly however that skins, and blisters as well, have quickly broken away. Loose crusts of calcium carbonate and soot are found however on the surface of the under side of over-hanging members.

Distribution of Weathering of Blue Stone

The distribution of weathering of stones in buildings might obviously depend much upon the direction of its exposure. Blue stone in all parts of the capitol was found to be affected, but apparently north and west exposure in general results directly or indirectly in the greatest damage, as might be suspected because of the prevailing storm winds coming from those directions. Apparently also the rain and wind in sweeping in and around the projecting parts and over the roof produce a concentration of decay in some parts of the building more than in others. This is often not on northward or westward facing portions, but apparently on surfaces that are out of the wind. (Fig. 5) It would appear that such concentration is in places where there is much wetting and drying. Vertical faces that are freely washed have not suffered as much. Blue stone in the higher parts of the building, as about the domes and on the roof, has been somewhat more affected than that lower down.

Cause of the Decay of the Blue Stone and of the Distribution of the Decay

The chief factor in the decay of the blue stone is apparently the loss of the calcite cement, through the action of CO_2 and the SO_2 carried down by the rain. Parts so exposed that moisture might most readily be absorbed are the most affected. With increase in pore space the solution of cement is accelerated. The porosity thus increases to a point where freezing of water becomes effective in

Fig. 5. View from below, of south side of urn at northwest corner of southeast dome, showing decay of blue stone in an apparently sheltered position.

breaking the rock, generally along lamination planes. Vertical, and thus freely washed, surfaces of blue stone in the walls, and those protected by gutters do not decay, at least to any depth or so immediately, from this cause.

Some parts of the blue stone, such as the lower parts of the bottom rails of balustrades and the bases of urns, become scaley and friable. It is believed that these parts, some of them apparently in sheltered places, decay partly because of the repeated crystallization in their pores of the soluble constituents. They are so exposed that they suffer much wetting and drying, and are not freely washed. Repeated crystallization in this manner is well known to cause decay of porous rocks.

Pitted surfaces on the blue stone are caused apparently by the breaking loose of the casts of plant fragments, stems particularly, which are surrounded by thin films of carbon or clay. Such casts can not be strongly cemented to the surrounding rock. Solution of a small amount of cement and frost action about the periphery of the casts seem to account for the development of the pits. In crushing decayed rock these plant stems break out rather readily.

More weathering in the upper part is to be expected inasmuch as more rain would fall directly on these parts, and the action of CO_2 and SO_2 would be more effective. Furthermore, a freely washed vertical surface would be at an advantage, while one that the water might collect upon or in, or run down and drip from would be more likely to lose its cement. It is noted that balustrade railings decay at the bottom rather than at the top, due to the water remaining there longer, more recrystallization in the pores, subsequent frost action, and gravitative pull. The same is true to some degree of the under surfaces of overhanging or projecting parts of such things as pediments, cornices and architraves.

The situation of the capitol building with regard to the sources of atmospheric pollution through coal smoke undoubtedly bears not only on the amount but also somewhat on the distribution of the weathering. The heating plant is located only a short distance to the north and so whenever the wind is from that general direction the capitol building, the upper part particularly, suffers accordingly. Winds from the northwest, west, southwest and south also carry much smoke, though the sources are more distant, and the effect less.

MINOR WEATHERING OF AUX VASES SANDSTONE

The weathering undergone thus far by the Aux Vases sandstone in the masonry portion of the superstructure is trifling compared with that of the other sandstone. Exfoliation, whatever its causes, has affected it to a very limited extent, but is apparently not likely to become a serious matter.

On some surfaces this rock is apparently acquiring a surface skin. In places such surfaces are blistered and scaled, a feature which may continue to develop on them. Surface skins of this type are formed apparently by the precipitation of soluble material at or near the surface as the rock dries out. The exact manner of formation of blisters, although it is associated with skin formation, is not known, but in the course of such blistering an outside scale separates from the rock. This subsequently is broken through and the rock behind it is found to be quite friable, evidently owing to the stresses set up by repeated crystalization and solution of soluble constitutents. It renders the rock unattractive in appearance, but does not indicate great failure or damage.

In a rather few places the Aux Vases sandstone has been found to be so friable that some of it has been chipped away during repair work. Such places are generally below or have adjoining them some of the blue stone, and this deterioration is believed to be associated with that fact, the soluble material having been derived from the blue stone. (Fig. 6)

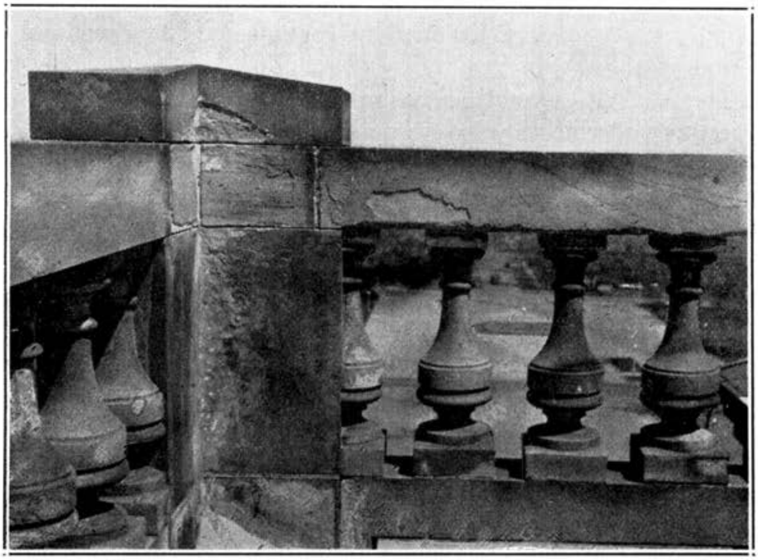

Fig. 6. Balustrade at northeast corner of east wing. The Aux Vases block in the corner beneath the rail has been affected by the bringing in of soluble salts from the blue stone above.

It is known through studies in England [10] that where a limestone or a calcareous sandstone and a non-calcareous sandstone are in contact, decay of the surface may take place in the latter through the carrying into it and the subsequent action of $CaCO_3$ and other salts from the more soluble rock. Soluble materials from mortars may have the same effect. The Aux Vases sandstone may thus in the course of time be more affected, since $CaCO_3$ and more particularly $CaSO_4$ from the deteriorating Carroll Co. stone, will be carried into it, and result in surface crumbling and in the formation of crusts and blisters.

Conclusions

The blue stone from Carroll Co., Mo., is suffering severe decay, particularly in the decorations and in exposed places. Its principal source of weakness is the calcite cement. Other factors entering in are the presence of plant fragments, the use of the rock in

[10] R. J. Shaffer. The Weathering of Natural Building Stones, Department of Scientific and Industrial Research (Great Britain) Building Research Special Report No. 18: 22-24. 1932.

unsuitable places, and the presence of a smoke polluted atmosphere.

The deterioration proceeds largely through loss of calcite cement, accelerated as the rock becomes more and more porous. Frost action plays a large part after the rock has become thus weakened. The repeated crystallization of soluble substances in the pores of the rock is an important factor in some parts. The decay of this stone may be expected to continue and to constitute a serious problem.

The Aux Vases sandstone has proven a durable stone. Whatever effects weathering may have upon it they will not render it unattractive nor weaken it for a long time to come. Care should be exercised however to keep lime rocks and mortars away from it. As long as there is blue stone in a position where soluble material from it may be drawn into the Aux Vases the latter will show the effect in scaling and blistering.

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