REPORT ON THE MAJOR STONE TYPES
OF THE
IOWA STATE CAPITOL BUILDING
DES MOINES, IOWA

by

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I. REVIEW OF THE HISTORY OF THE STONE TYPES

A review of historical documentation related to the construction of the Iowa State Capitol Building in Des Moines has led to the identification of 5 primary building stones. These are granite, limestones from Johnson and Madison Counties in Iowa, and sandstones from Ste. Genevieve and Carroll Counties in Missouri.

Granite

Little Information could be found on the granite used as the basal (subsurface) foundation stone for the exterior walls and terraces of the capitol.

Winterset Stone

The interior foundation and cellar walls of the Iowa Capitol were constructed from a limestone called Winterset Stone from "Madison County near Winterset." The limestone exposed in the Winterset area is Pennsylvanian, Missourian age. Tilton and Bain (1896) describe the lower Missourian exposed in this area as Bethany Falls Formation, but subdivide the unit into four limestone beds. In ascending order these beds are the basal Fragmental Limestone Bed (probably what we call Hertha Fm. today), the Earlham Beds (today known as the Bethany Falls Member of the Swope Formation), the Winterset Beds (now called the Winterset Member of the Dennis Formation and the Fusulina Beds (probably the unit now called the Block Member of the Cherryvale Formation). Historical documents suggest that the stone used in the capitol building may have come from the Winterset Beds or Earlham Beds, both of which were quarried for dimension stone "near Winterset" or from the Earlham Beds (Bethany Falls Mbr.) near Earlham in northern Madison County. The later option is suggested by Tilton and Bain (1896, p. 526); "When the State Capitol was being built at Des Moines the limestone around Earlham was opened up at a number of points." Stone from the Winterset Beds (Winterset Mbr.), quarried at the Bevington Quarry (T. 79N., R. 28W., sec. 22), was used in construction of the Madison County Court House and in 1881 was tested as a building stone by the Rock Island Arsenal with the following results:

Crushing Strength - 4588 lbs/in^2
Specific Gravity - 2.73 g/cm^3
Ration of Absorption - .042603

Our examination of this stone, in place in the basement of the capitol building, revealed that while the stone is not exposed to the moisture and temperature variations of the outdoor environment, it is nevertheless poorly cemented and crumbly on its surface.

Old Capitol Quarry Stone

The stone which rests on the granite and forms the external foundation of the State Capitol Building is the "Old Capitol Quarry Stone" or State Quarry Limestone Formation from Johnson County, Iowa. Calvin (1896, p. 97) states, "The beds of the State Quarry stage are capable of furnishing building stone that in point of durability and ease of cutting is unexcelled . . . The rock resists the action of the weather admirably." The quarries which produced this stone are located in Penn Township (T. 80N., R. 6W.), Johnson County, Iowa. This stone was commercially dimensioned for the old Iowa Territorial Capitol in Iowa City and the new capitol building in Des Moines, as well as for heavy monument bases, bridge piers, curbstones, crossing stones, and common building stone. The finer grained ledges are said to have provided, "the best grades of cutting stone."

The State Quarry Formation is an Upper Devonian skeletal grainstone (Dunham, 1962) which was apparently formed in tidal channels which were developed contemporaneously with progressive restriction of water circulation during deposition of the Upper Coralville Member of the Cedar Valley Formation. A 5 foot thick bed near the center of the formation produced the stone used in the State Capitol. This rock is a calcite cemented skeletal packstone with most skeletal grains consisting of mollusk, echinoderm and brachiopod fragments. The quarried stone was delivered to Des Moines at a cost of \$1.50 per ft^3. Records indicate that 44,308 ft^3 (3500 tons) of State Quarry was delivered to Des Moines at a total cost of about \$67,000.

<u>Ste. Genevieve Stone</u>

The stone used most extensively in the construction of the State Capitol Building was the Ste. Genevieve or Brown Stone. This stone was quarried from the Aux Vases Formation (of Mississippian, Chesterian age) in Ste. Genevieve County, Missouri. It is principally a straw to tan colored, fine to medium grained, moderately sorted sandstone. The unit displays massive cross-bedding and local silica cementation near the center of the unit, the portion that was exploited for dimension stone. The rock used in the Capitol Building probably came from either the Richardson or the Bogy Quarry (T. 37N., R. 9W.) about 4 miles south of the town of Ste. Genevieve. Stone from these quarries was also used in the abutments of the Eads Bridge, in the Equitable Building, and in the McLean Building all in St. Louis.

Historical documents dated 15 June, 1874, mention the awarding of a contract to the St. Genevieve Sandstone and Granite Company of St. Louis for the main body of stone. The documentation describes the stone as follows:

> "The St. Genevieve stone is a yellow-brown sandstone described as beautiful and durable, hardening to the weather, and from extensive quarries; a close fine-grained stone with the cement binder being nearly pure silica; strong for a sandstone, a little hard to cut; of a uniform and pleasing color; and in Architect Piquenard's words, the strongest and most durable sandstone he had seen."

A total of 114,500 ft^3 of the Ste. Genevieve stone was delivered to Des Moines at a cost of \$1.13 per ft^3. This totaled about 9000 tons and a total cost of just under \$130,000.

Written observations of the present condition of the Ste. Genevieve Stone, apparently by the State-contracted consultant Bussard/Dikis Associates Ltd. of Des Moines, (1981?) identified surface erosion of the stone, to an approximate depth of 1/32 inch with localized, small, pyritic cemented spots standing in relief, contour scaling to irregular but apparently minor depths on stone railings, piers, and exterior stairs, and minor delamination. The consultants attribute this degradation primarily to the effects of the freezing of moisture absorbed by the stone and the leaching of salts from the stone and mortar and the crystalizing of these salts in pores near the surface of the stone.

Carroll County Stone

The Carroll County or "Blue Stone" was quarried at the White Rock Quarry near the town of Miami Station in southeastern Carroll County, Missouri. The stone was taken from the Warrensburg Member of the Middle Formation of Pennsylvanian, Pleasanton age. The stone was described by

Buckley and Buehler (1904), as light-gray to blue-gray, locally cross-bedded sandstone with films of carbonaceous material commonly present in bedding planes. Their microscopic examination of the stone revealed a dominance of small roundish to sub-angular quartz grains in a calcareous and ferruginous cement. They also identified subordinate amounts of calcite, mica, chlorite, iron oxide, bitumen feldspar, clay and coal.

The rock that was quarried near Miami Station was almost surely a westward extension of the Moberly Channel (Hinds and Green, 1915), a well defined alluvial channel that runs in a westerly direction from the town of Madison in Monroe County, Missouri, to the valley of the Chariton River south of Salisbury in Chariton County, a distance of about 40 miles. The quarry location near Miami Station is in line with this trend and about 15 miles west of the Salisbury exposures. From Miami Station the deposits are continuous for about a mile in a southwesterly direction to the town of White Rock. These Warrensburg-Moberly sands form bluffs on the north bank of the present Missouri River and it is in these deposits that the quarries were developed from which the stone for the Capitol was extracted. From White Rock, the Moberly Channel probably continued in a westerly direction to near the town Dover in Lafayette County where it joined the Warrensburg Channel, a north-trending alluvial channel with a similar history. In the intervening areas, the rock was removed during the excavation of the Missouri River valley.

The Moberly Channel had an apparent average width of less than 3 miles (Hinds and Greene, 1915) with a maximum recorded thickness of about 200 feet. This great depth in proportion to its width is described as "perhaps the most striking features of the channels" and suggests that the channel must have been confined by very steep-sided valley walls in many places. The Moberly River descended from northeastern Missouri, apparently off a northern extension of the Ozark Uplift. The conditions that created the valley were apparently short-lived, for the deep valley and the lack of lateral drainage is comparable to the youthful Red River of the North (Hinds and Green, 1915, p. 93). The Pleasanton age tentatively assigned to the deposits is based on the youngest unit cut by the channel.

Near the White Rock Quarry site the Moberly Channel is jointed by the Rockford Channel, draining from the north, approximately following the trend of the modern day Chariton River. The Rockford Channel continues into Appanoose County, Iowa, where it is filled with rocks of the Chariton Conglomerate. It is believed that the Chariton Conglomerates are the age equivalent of the Warrensburg Sandstone and were probably part of the larger Moberly drainage network (Miller, 1901). Similar channels in Guthrie, Boone and other counties in Iowa, may also be genetically related to the Moberly Channel.

The rock quarried by the Carroll County Sandstone Company at the White Rock Quarry was described by Buckley and Buehler (1904) as presenting two distinct zones. The variegated light buff colored upper 30 feet (the variegated color due to disseminated particles of iron oxide and pyrite), was quarried primarily for use as bridge abutments and other projects where uniform coloration was not required. The lower 80 feet of the rock "being uniform in color and texture" was used "extensively for caps, sills, monument bases and dressed building stone" as in the Iowa Capitol Building. When first quarried, the stone was apparently rather soft but "hardened with seasoning."

Buckley and Buehler described an old quarry face that had been exposed for 25 years that showed little or no effects of weathering; there was "no evidence of alteration in the stone." In addition to the Iowa Capitol Building the stone found miscellaneous uses in St. Louis, Kansas City, Ottumwa, Atlantic and Bloomfield.

Laboratory tests performed on the rock (Buckley and Buehler, 1904, p. 270) provided the following results:

Crushing strength	7477.6 lbs. per sq. in. on beds.
	9203. lbs. per sq. in. on edge.
Transverse strength	1321.76 lbs. per sq. in.
Specific Gravity	2.637
Porosity	14.31 per cent
Ratio of absorption	6.33
Weight per cubic foot	141.3 lbs.

Crushing strength of sample subjected to freezing test 8670.5 pounds per square inch.

The authors noted that despite the stone's moderately high porosity, it did not loose strength as a result of the freezing test. This characteristic will be expanded upon, in the conclusions and recommendations section of this report.

Historical documents dated 15 June, 1874 announce the awarding of a contract for trimming stone to be used in the Iowa State Capitol Building to J. A. Gains and Company for stone from Carroll County, Missouri near Miami Station, Missouri. The stone is described as having been "used in building for 35 years; the cement binder being carbonate of lime, not so strong as the St. Genevieve, but much easier to cut." The stone is stated to have been "proven by long actual experience to stand very well all the influences of the weather, the Carroll County stone being second only to the St. Genevieve stone," (from Report of the Architect Number Six, 1875). The report also states that by using this stone "for mouldings, carvings, and other ornimental work we have saved a large percentage (money) in the cutting." A total of 7640 tons of the Carroll County stone was delivered to Des Moines for the construction at $.95 per ft^3, for a total cost of about $98,000.

In the 1903 report to the Iowa State Capitol Commission the Superintendent of Repairs; Mr. J. R. Crawshaw, states that:

> "I find the exterior of the building, especially the blue, or Carroll County stone, is going very rapidly. I have had most of this stone on the roof repaired, and in doing so it has been necessary, in some places, to cut much of it away in order to get a solid surface. In some instances this work has required changes in the contour of the mouldings, but the mouldings thus altered still harmonize with those already in place.
>
> I have repaired the main cornice as a corner had already fallen away, and another corner in a very critical condition had to be secured and made good. Owing to the great difficulty of reaching some of this work and the danger attending its prosecution, the cost has been greater to prepare a safe place from which to work, than to do the actual work itself."

This report was produced only 19 years after the completion of the Capitol's walls in 1879.

At some date after this report a surface binder was applied to the stone to help preserve it. No details of this restoration are known.

Later observations by consultants Bussard/Dikis Associates Ltd. (1981?) included considerable erosion of Blue Stone, even though it had been coated with a surface binder. They described delamination problems as "in epidemic proportions both as scaling in surface sheets as well as loss of substantial portions of soffit ornaments."

PART II. PETROGRAPHIC REPORT ON THE STONE TYPES

Samples from four of the five stone types composing the State Capitol Building in Des Moines, Iowa were collected November 3, 1981 by Iowa Geological Survey staff and prepared for petrographic investigation in hopes of determining the controlling factors upon weathering and disaggregation of certain stones, in particular the Carroll County "Blue Stone." Table 1 identifies the six samples that were collected from the interior and exposed exterior portions of the building.

Table 1. Stone Types Sampled

Stone Type	Interior	Exterior
Carroll Co. Stone (Blue Stone)	x	x
Ste. Genevieve		x
State Quarry	x	x
Winterset		x

One or more petrographic thin sections were prepared from each sample. Standard preparation techniques were employed. Sample chips were vacuum impregnated with blue dyed epoxy before grinding and epoxy mounting onto glass slides. Where the sample contained enough porosity and permeability, blue dyed epoxy penetrated and hardened. Ground sections were stained for carbonates according to Dickson (1966) and cover slipped with Canadian Balsam. Through hand specimen and petrographic observations, each sample was described and classified texturally and mineralogically. The classification of Dott (1964) was used for the sandstones, and that of Dunham (1962) for the carbonate rocks. Modal analyses of 200 points each were performed for all samples except the Winterset limestone. Particular attention was directed toward documenting any alteration of framework grains, matrix and cement between interior and exterior samples. One dispersive X-ray analysis was conducted on the Carroll Co. Stone.

Winterset Stone

Two samples of this structurally sound stone were collected. No modal analyses were performed. The stone is a high calcium skeletal grainstone to packstone. Skeletal debris includes fragments of echinoderms, foraminifera, brachiopods and trilobites. Many grains have undergone recrystallization to the extent that they are not identifiable. Most grains have micrite coatings and many intraparticle pores have been infilled by micrite. Many unidentifiable grains have micritic exteriors grading to sparry interiors.

The stone contains little porosity due to pore filling calcite cements. Most grains are surrounded by fine equant to bladed spar which grades into anhedral blocky calcite spar that occupies almost all original pore space.

State Quarry Limestone

The State Quarry Limestone samples are high calcium skeletal grainstones cemented with blocky calcite spar and microspar. Table 4 is a simple modal analysis representing both interior and exterior samples.

Table 4. Modal Analysis, State Quarry Limestone

Skeletal Grains		38%
Calcite Cement		51%
Porosity		11%
	TOTAL	100%

Both interior and exterior samples are sound. As Table 4 indicates the samples are very similar. Skeletal grains consist of fragments of mollusks, brachiopods and echinoderms. Cement consists of interparticle clear, blocky calcite spar and neomorphic calcite microspar. The microspar is the weakest and most susceptable constituent of the stone to weathering. But both stones appear to be in good shape structurally.

Ste. Genevieve Sandstone

The Ste. Genevieve sandstone is a moderately sorted fine to medium grained silica cemented feldspathic arenite. The mineral constituents and their percentages are listed in Table 3.

Table 3. Modal Analysis, Ste. Genevieve Sandstone

MINERALS		EXTERIOR
Quartz		76.5%
Feldspar		4.5%
Rock Fragments		1.5%
Mica		.5%
Heavy Minerals and Opaques		1.0%
Clay Matrix and Cement		4.0%
Porosity		12.0%
	TOTAL	100.0%

Detailed discussion of the mineralogy and texture of this stone is not warranted here for the stone retains its structural integrity and no major problems affect its function. The stones principal cementing agents are quartz and feldspar overgrowths and meniscus cements which bond the primarily quartz detrital fraction. Pore lining clays which are most likely illites are a minor cement. The stone has approximately 12 percent porosity and moderate permeability as evidenced by the penetration of the vacuum impregnated blue dyed epoxy.

Carroll Co. Stone

Classification

The Carroll Co. Stone is a texturally and mineralogically immature sandstone. It can be classified as a very fine to medium grained micaceous feldspathic wackestone rich in authigenic clay minerals and calcite cement. The color is a light bluish grey with the exterior weathered samples exhibiting disseminated brownish-orange iron oxide staining.

Mineralogy and Texture

Table 2 partially summarizes the observations and modal analyses for the interior and exterior samples.

Table 2. Modal analyses, Carroll Co. Stone

MINERALS	INTERIOR (Unweathered)	EXTERIOR (Weathered)
Quartz	44.0%	43.0%
Feldspar	3.0%	7.0%
Rock Fragments	3.5%	4.0%
Detrital Micas	3.5%	1.5%
Unidentifiable Sericitized Grains	3.5%	4.5%
Opaques (hematite)	--	1.5%
Heavy Minerals	Tr	Tr
Clay Matrix	20.0%	28.0%
Calcite Cement	10.0%	9.0%
Porosity	12.5%	1.5%
TOTAL	100.0%	100.0%

a) Quartz is present as subangular to subround monocrystalline and polycrystalline grains. Quartz overgrowths are common.

b) Feldspar varieties include orthoclase, microcline and plagioclase. Most grains are angular to subangular and are sericitized and vacuolized to varying degrees. Feldspars also exhibit early clear overgrowths. Many feldspars, particularly in the exterior samples, have developed secondary intragranular porosity. This is very evident where the blue dyed epoxy has penetrated the intragranular pores.

c) Rock fragments consist chiefly of metamorphic shist grains rich in muscovite. These grains have been partially deformed by compaction. Polycrystalline quartz grains of metamorphic origin were not counted as rock fragments but included as quartz.

d) Detrital mica is present as fresh and altered muscovite. The larger grains are fresh and are easily visible in hand specimen. Many grains have undergone compactional deformation.

e) Unidentified sericitized grains are subangular to subround and are recognizable as detrital grains primarily by their shape. Most were probably feldspars or rock fragments originally.

f) Opaque minerals present consist only of amorphous hematite in the exterior sample. It occurs as scattered dark brown specks and under high intensity transmitted light as a distinctive brownish tinge through areas of authigenic chlorite that exhibit secondary porosity development.

g) Heavy minerals include detrital zircon grains and tourmaline and rutile inclusions in quartz grains.

h) Clay matrix of detrital and authigenic origin is a very important volumetric and structural constituent of the Carroll Co. sandstones. Dispersive X-ray analysis of a powder mount has identified with certainty the presence of the clay minerals illite and kaolinite. The powder mount analysis and petrographic observations suggest the presence of iron-rich chlorite and/or iron-rich smectite, but further, more sophisticated analytical techniques need to be employed to identify them with certainty. These techiques include SEM imaging, microprobe analysis, and oriented X-ray scans. Despite the uncertainty of the exact clay mineralogy, observations of textural relationships show that the clays occur as partial pore linings, pseudomorphic replacements and pore fillings. These clays serve the dual function of plugging original pore space and acting as a matrix cement to give the sandstone its cohesiveness. Of paramount importance to the integrity of the stone is the binding effect of the clay minerals, in particular pore lining and filling clays. As observed petrographically it is apparent that recent oxidation and dissolution of finely crystalline authigenic clay cements is pervasive in the samples from the exposed exterior of the building. The matrix cement clays in the weathered sample have degraded through oxidation and dissolution into a network of filamentous porosity and amorphous iron oxide stain. The vacuum impregnated blue dyed epoxy has penetrated these intercrystalline dissolution sites and imparted a definite blue color to the weathered exterior sample. The interior unweathered sample's modal analysis shows a higher porosity than the exterior sample, but this is due to unimpregnated clay washout and plucking during the grinding process in thin section preparation. The secondary porosity capable of permitting impregnation of the epoxy and infiltration of other fluids has not developed in the interior samples. Although the modal analysis shows only minor porosity for the exposed sample it is this porosity coupled with permeability that allows water to penetrate and oxidize the clay cements and redistribute their constituent iron molecules as amorphous and disseminated iron oxides. This dissolution appears to be the underlying degrading mechanism affecting the blue stone. Once the rock has developed this secondary porosity and permeability through dissolution of its cementing agents, water penetration, freezing-thawing, wetting-drying and clay expansion and contraction further degrade its structural integrity.

i) Calcite is also a cementing mineral in the stone. It appears to be a later cement than clay and filled most remaining pore space including some intragranular feldspar porosity. Dissolution of calcite cement is not readily apparent although one might suspect that acidic rainfall could dissolve portions of it and thereby affect the integrity of the second most important cement.

j) Porosity is rather low in both interior and exterior samples but it exists along with sufficient permeability in the weathered stone to allow easy fluid infiltration. The high porosity figure of 12.5% for the interior sample is as previously discussed an artificially produced porosity due to the wash out of clay minerals during the grinding process in thin section preparation.

PART III. CONCLUSIONS AND RECOMMENDATIONS

After examining the condition of the major stones of the Iowa State Capitol Building in Des Moines, reviewing the history of individual stone types and their uses in the construction, and after petrographic examination of thin sections of exterior (weathered) and interior (unweathered) samples of each of the major stone types, a series of conclusions and recommendations have been compiled. These conclusions and recommendations should not be considered definitive in all cases, since on several key points more work will be required to confirm preliminary conclusions. These areas will be identified, and potential, more definitive tests, will be outlined.

I. Granite

Little information about the granite blocks which form the subsurface external foundation wall was available to the authors. Visual examination of this stone on the building showed it to be fresh in appearance and apparently structurally sound. No samples of this stone were obtained for petrographic analysis.

II. Winterset Stone

The Winterset stone appears to have been used exclusively in the construction of interior foundation and cellar walls. None was found with external exposure. The stone is a high calcium skeletal grainstone to packstone, the skeletal components including fragmental echinoderms, foraminifera, brachiopods and trilobites. The rock displays little porosity due to pervasive pore filling calcite cementation. The stone was obtained from quarries near Winterset and also, probably, quarries near Earlham in Madison County, Iowa. It was extracted from the Bethany Falls Mbr. (Swope Fm.) and Winterset Mbr. (Dennis Fm.) of Missourian (Pennsylvanian) age.

A cursory examination of the stone in places revealed minor softening of a thin rind on exposed surfaces, but petrographic examination of samples of the stone did not identify any major increase in porosity or change in the state of mineral alteration beyond this thin zone. The stone appears to be structurally sound and no additional studies of it are recommended.

III. Old Capitol Quarry Stone

Old Capitol Quarry Stone was used in the construction of the exterior walls of the basement story of the Capitol Building. This rock is a high calcium skeletal grainstone, with skeletal components dominantly composed of brachiopod fragments with some echinoderm pieces noted. It was quarried north of Iowa City from a series of quarries developed in rocks of the State Quarry Formation (Upper Devonian age) first opened to produce stone for the Iowa Territorial Capitol Building in Iowa City.

Visual examination of the stone on the State Capitol Building revealed no appreciable weathering or loss of structural integrity. Under petrographic examination samples of the rock collected from exterior (weathered) and interior (unweathered) exposures appeared to be similar, with no increase in porosity or permeability noted and no difference in cementation identified. The rock appears to be sound and no additional studies of it are recommended.

IV. Ste. Genevieve (Brown) Stone

The Ste. Genevieve or Brown Stone was used in construction of the major portions of the exterior walls, stone railings and piers of the State Capitol Building. The stone is a moderately sorted fine to medium grained silica cemented feldspathic arenite. It was quarried south of Ste. Genevieve, Missouri from beds of the Aux Vases Fm. of Chesterian (Mississippian) age. The rock had been extensively quarried and utilized as a building stone for several decades prior to its selection for use on the State Capitol Building. It was selected because of its durability and the beauty and uniform nature of its light brown color.

Examination of the stone in place on the building revealed some minor surface erosion of the flat wall stone and rather more extensive scaling of carved exterior railings. This erosion is probably due to the action of freeze-thaw cycles on water abosrbed into the moderately permeable surface of the stone. Although deterioration of this stone is not extensive, and the stone appears to be structurally sound, further study and eventual sealing of the stone is recommended.

V. Carroll County (Blue) Stone

The Carroll County or Blue Stone was used for the trimmings and moulded parts of the State Capitol Building. The stone is a texturally and mineralogically immature very fine to medium grained micaceous feldspathic wackestone rich in authigenic clay minerals and calcite cement. The stone was quarried from beds of the Warrensburg Fm. of Pleasanton (Pennsylvanian) age near Miami Station in Carroll County, Missouri. It was chosen for use on the Capitol Building because of its uniform color and the pleasing effect of its color contrast with the Ste. Genevieve Stone, its uniform texture, ease of carving, and low cost. It had been used extensively in building, especially ornamental work, for 35 years and had not been observed to deteriorate. We can offer no explanation of why this stone had not deteriorated in previous ornamental work as it has on the State Capitol Building.

Examination of the Blue Stone on the State Capitol Building showed it to be in an advanced state of decay. Considerable erosion and delamination was observed. Details on many carved pieces had been lost due to the falling away of pieces of the stone. Pieces as large as 30 pounds have reportedly fallen from the building. Petrographic examination of external (weathered) and internal (unweathered) samples showed extensive alteration of the exposed samples. Clay minerals which are the primary cementing agent in the rock have undergone extensive secondary oxidation and dissolution on exposed surfaces. This dissolution has removed portions of the clay matrix cement and dramatically increased the stone's porosity and permeability (see discussion - Part II section h). With the increase in permeabiltiy, water is afforded an opportunity to move into the rock where the combination of shrinking and swelling of clay minerals and freezing and thawing of the water further complicates the problem and deteriorates the stone. No evidence was found to corroborate the suggestions by consultants Bussard/Dikis Associates LTD that surfate ions in rain water were combining with the calcium carbonate to form gypsum. No gypsum, secondary or primary, was observed in the thin sections. Traces of gypsum detected during X-ray analysis of are thought to have originated in the mortar.

The unexposed (unweathered) samples displayed very low permeabilities as documented by Buckley and Buehler (1904) in noting that test samples of the stone did not see any reduction of crushing strength as a result of the freezing test, apparently because water was not able to enter the stone. Further evidence of this low initial permeability is seen in the inability of the blue epoxy (with which vacuum impregnation of the stone was attempted) to move into the unexposed sample. The permeability was, however, dramatically increased on the stone that was exposed to the external environment. A report by the superintendent of repairs, submitted in 1903, 19 years after the stone was implaced, documented extensive weathering of the exposed stone at that time.

In order to completely understand the mechanisms responsible for the decay of the Carroll County Stone additional analyses of the rock is recommended. Scanning Electron microscopy, X-ray analysis of oriented clay mounts, and microprobe work are needed in order to be more definitive in identification and distribution of clay minerals in the stone. This work, on both weathered and unweathered specimens, would provide additional information on the mechanisms responsible for the deterioration of the stone.

Available information suggests that the additional surface coating of the remaining Carroll County Stone would not be effective in preventing its continued deterioration unless structural support were provided for each piece. Removal and replacement of the stone with artificial or more durable natural stone appears to be the only practical solution to the problems and dangers presented by this deteriorating stone.

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Mankato Stone

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