Swift Contract No. 93112

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May 29, 2015

Project B1503482

Mr. Jared DeMaster
Minnesota Dept. of Natural Resources
- Southern Regional Office
21371 State Highway 15
New Ulm, MN 56073

Re: Petrographic Examination of Hardened Concrete
Sloped Stone Embankment of Old Park Road
Blue Mounds State Park
Luverne, Minnesota

Dear Mr. DeMaster:

Purpose

The purpose of this investigation is to document the composition and condition of concrete sample taken from the sloped shoulder of an excavated park road.

Background

A fragment of hardened cementitious material was received on May 18, 2015 from Mr. Jared DeMaster of the Minnesota Department of Natural Resources, New Ulm, Minnesota. Mr. DeMaster stated that the sample was taken from the excavated remains of a sloped stone embankment along the sides of an old road in the Blue Mounds State Park in Luverne, Minnesota. Figures 1 through 6 provide documentation of the fragment in as-received condition. Copies of old drawings and a few photographs of the excavation site were also provided by the DNR.

Petrographic examination and chemical analysis (ASTM C1324) was originally requested on the provided sample (initially thought to be mortar) to document the physical condition and mineralogical and microscopical properties of the material and to determine the proportions of mineral constituents. However, based on initial examination of the provided sample, chemical analysis was not performed and the sample was subjected only to petrographic examination (ASTM C856).

Procedures

Petrographic examination of the concrete sample was conducted in general accordance with ASTM C856, “Standard Practice for Petrographic Examination of Hardened Concrete.” Visual examination was conducted on the as-received sample, as well as saw-cut, polished, and broken surfaces of the sample. This examination was conducted with the aid of a stereomicroscope at magnifications up to 45x.

Thin sections were produced from various depths in the sample and examined using a Nikon Optiphot-Pol petrographic (polarized light) microscope at magnifications up to 400x. The petrographic examination was performed in our laboratory in Spring Green, Wisconsin.

Results

The following salient findings are based on the petrographic examination of the concrete sample. Details of the examination are also given in the attached petrographic data report.

1. The sample consists of well graded natural gravel coarse aggregate and natural sand fine aggregate uniformly dispersed in a non-air-entrained paste of portland cement. No hydrated lime, natural cement, fly ash or other mineral admixtures or additives were noted in the concrete. Figures 3 through 8 further document some of the physical and microscopical features of the concrete.

2. Air content in the concrete is low, estimated in the range of 0.5 to 1.5 percent. The concrete does not appear to be air entrained (Figure 4).

3. Base on observed properties and microscopical features of the cement paste, the concrete appears to have been placed with a fairly low water-cement ratio (w/c). However, due to the apparent old age of the concrete, no numeric estimation of w/c is given.

4. Microscopical examination of the cement paste reveals the presence of numerous relics of residual (unhydrated and hydrated) cement clinker particles (Figures 7 and 8), confirming the use of Portland cement. Some of these clinker relics appear to be fairly large, up to 150 µm, and consistent with coarser-ground portland cement commonly available prior to the 1950's.

5. The concrete fragment is hard, dense, and in physically good condition, although it appears that the concrete has likely separated from the large stones in the embankment, allowing carbonation of the concrete along all of its outer sides.

6. Despite the apparent old age of the concrete, carbonation of the cement paste is fairly shallow and typically only a few millimeters deep along the weathered top surface and surfaces previously in contact with the rip-rap stones (Figure 3b). The shallow carbonation is further indication of the dense nature, low permeability, and moderately low w/c of the concrete.

7. Constituents of the coarse and fine aggregate used in the concrete appear to be mostly hard, dense, and durable, with exception to the presence of a small amount of diatomaceous shale associated with the fine aggregate (Figures 4 and 6). These shale particles exhibit some internal microcracking, but few of the microcracks appear to extend into the surrounding concrete.

Discussion and Conclusion

Findings of the petrographic examination reveals the provided material is best described as concrete or a "coarse cement grout" and was likely used to set large stones as part of a stabilized embankment of the old road. Base on the overall composition of the material, it is not a cementitious mortar, as defined in ASTM C270, "Standard Specification for Mortar for Unit Masonry." Therefore, chemical analysis was not performed and mix proportions were not determined. To determine the proportions of the concrete mix, the concrete could be analyzed in accordance with ASTM C1084, "Standard Test Method for Portland-Cement Content in Hardened Hydraulic Cement Concrete."

Characteristics of the concrete suggest it is fairly old. However, the analysis does not reveal the actual age of the concrete or whether it was from original construction. It should also be noted that materials and techniques used in production of historic concrete may have been different from those available for modern concrete and matching the physical properties of historical concrete may be difficult. Although the examined concrete was not air entrained, yet remarkably survived, new or repair concretes should be designed to be durable in harsh outdoor conditions.

General Remarks

Findings of this evaluation are based solely on examination and analysis of the provided sample and may not necessarily represent the materials and condition of materials elsewhere in the same structure.

In performing its services, Braun Intertec used that degree of care and skill ordinarily exercised under similar circumstances by reputable members of its profession currently practicing in the same locality. No warranty, express or implied, is made.

Samples will be retained for 30 days from the date of this report unless additional instructions for longer sample retention are provided

If you have any questions or concerns, please do not hesitate to contact Ron Sturm at 612.280.6505.

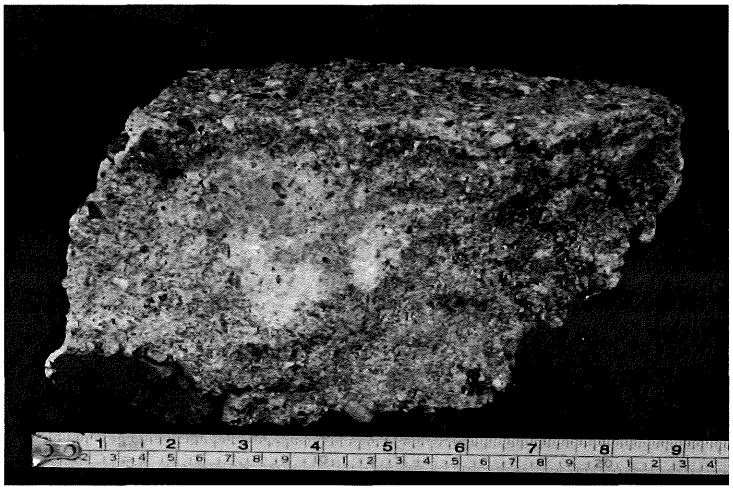
Sincerely,

BRAUN INTERTEC CORPORATION

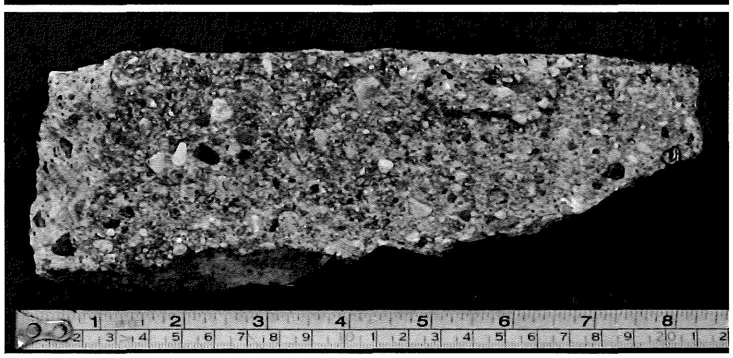
Ronald D. Sturm
Senior Petrographer

Alfred J. Gardiner
Principal, Laboratory Director
Manager Concrete Consulting

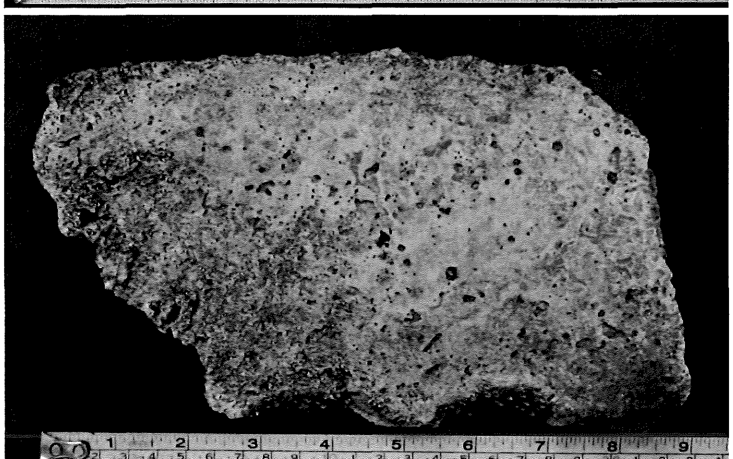
Attachments:
Figures
Petrographic Examination Report



1a. Formed and broken side.

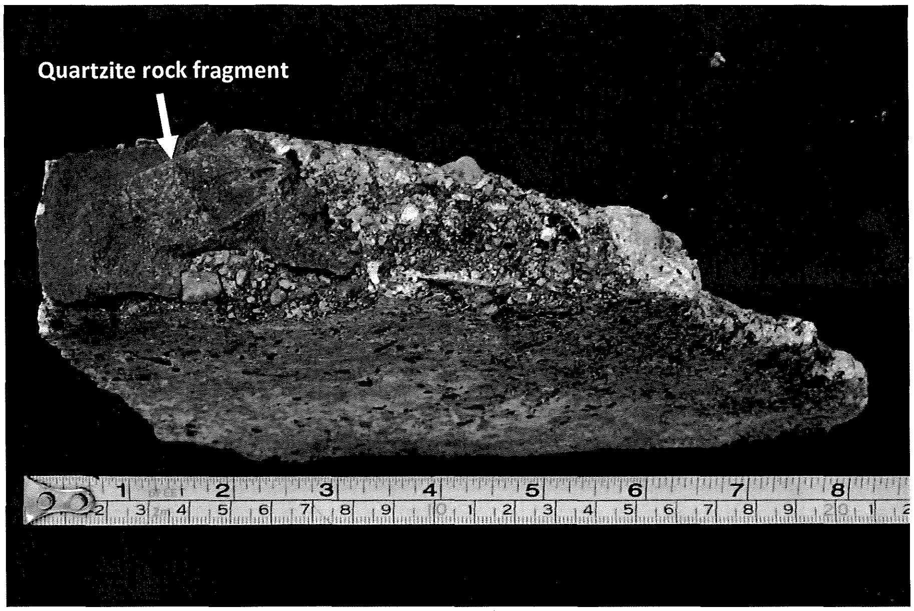


1b. Outer side.

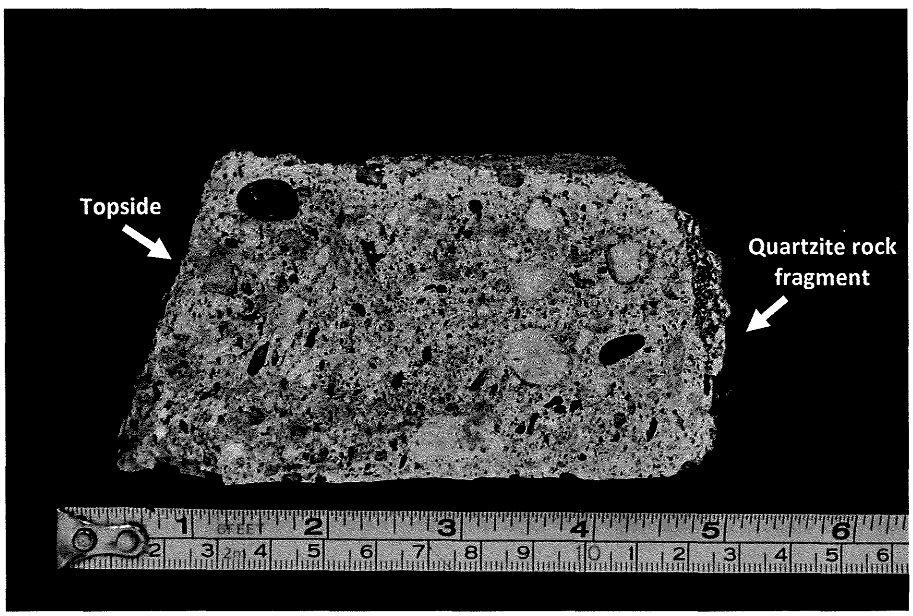


1c. Formed side.

Figure 1. **Broad, outer sides of the Blue Mounds sample, as received for examination. Note the fragment exhibits a weathered, outer surface (1b) and a slanted, formed side (1c). The other side (1a) exhibits both formed and fracture surfaces.**

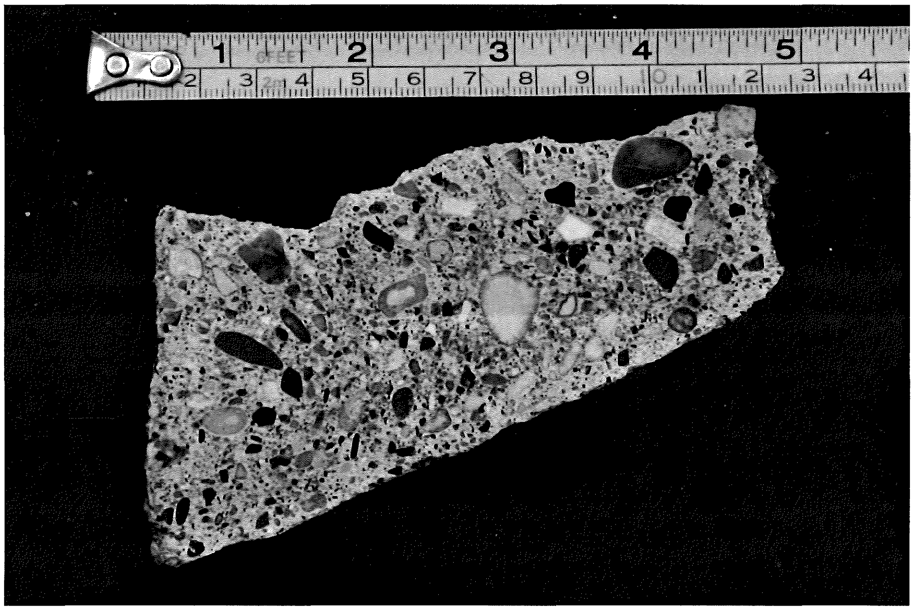


2a. Inner side.



2b. Broken end.

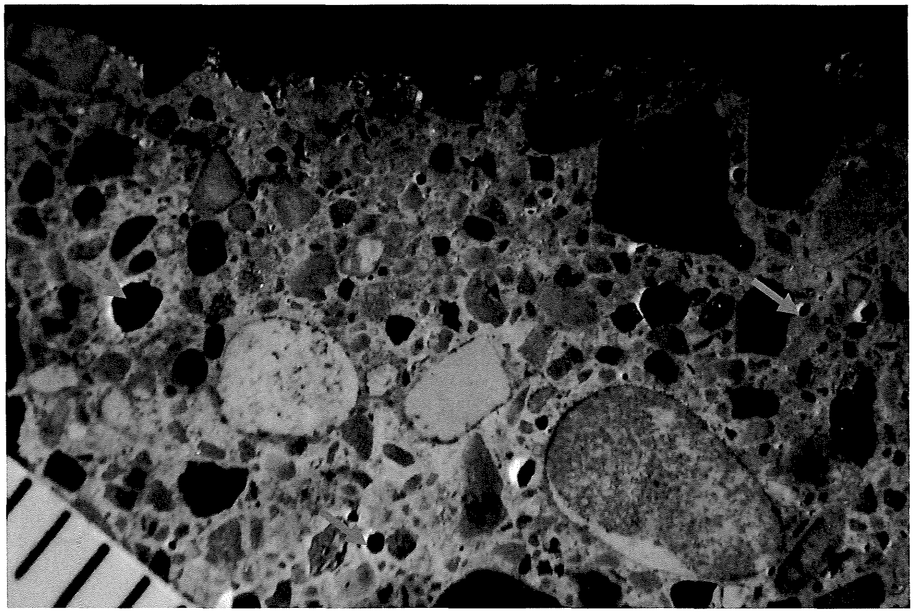
Figure 2 Additional views of the Blue Mounds sample, as received. Note the bottom side exhibits a large rock (quartzite) fragment. Also note the cross sections of coarse aggregate-size gravel particles in the concrete (2b).



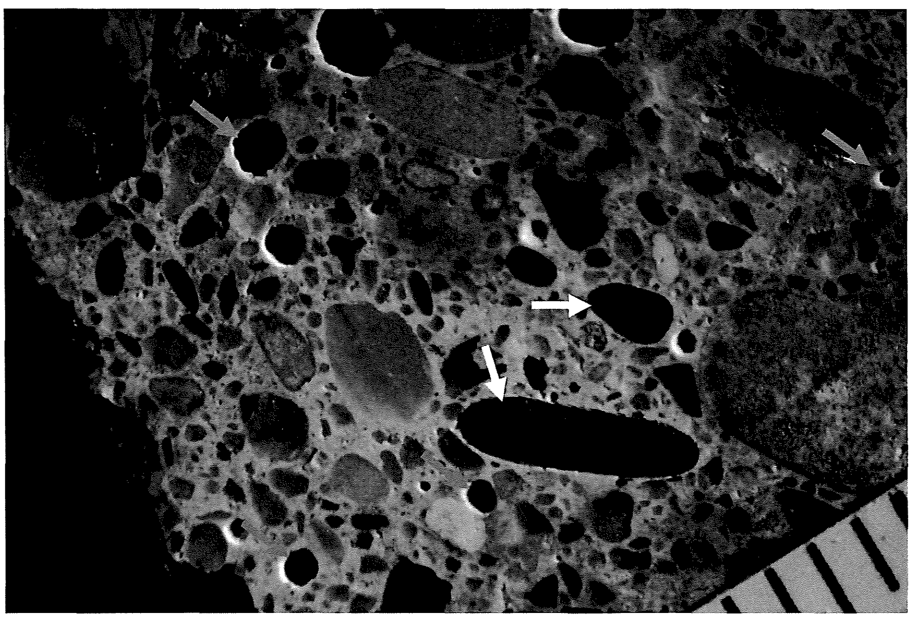
3a. Polished cross section 1.

3b. Stained cross section 2.

Figure 3 Polished and stained cross sections of the Blue Mounds concrete sample shows the general appearance and condition of the concrete as well as the patterns and depth of paste carbonation along the outer sides of the fragment. The surface in the lower image was treated with pH-indicator (phenolphthalein) solution that imparts a magenta stain to high-pH, non-carbonated cement paste, but does not stain reduced-pH, carbonated paste. Also note the presence of coarse aggregate in the concrete.

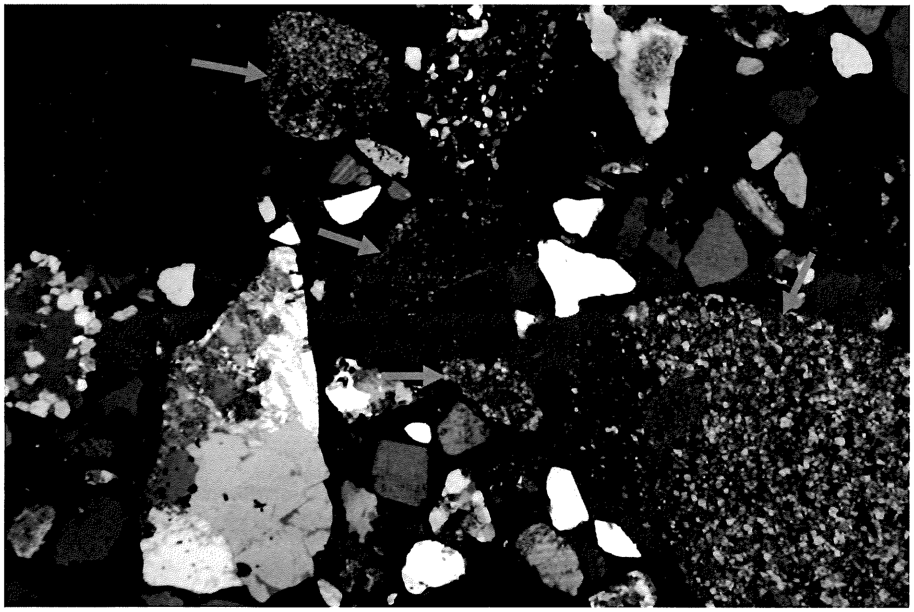


4a. Concrete adjacent to weathered outer side.

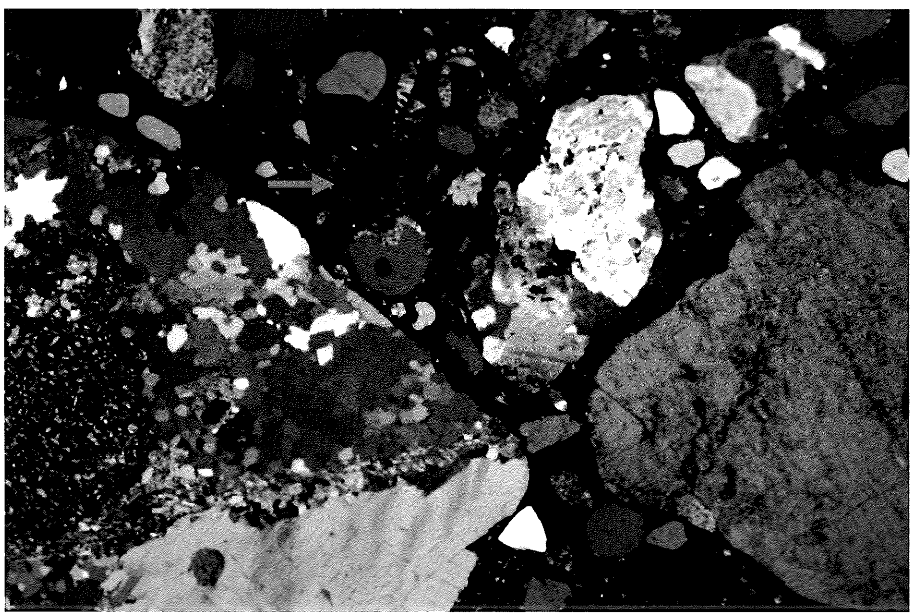


4b. Concrete adjacent to formed side.

Figure 4 Magnified views of the polished cross sections of Blue Mounds sample further document the general appearance and condition of the non-air-entrained concrete. Examples of sparse air voids are marked with red arrows. Also note two sand aggregate grains on shale (yellow arrows). Scales are marked in millimeter increments.



5a.



5b.

Figure 5 Photomicrographs of representative areas of the Blue Mounds sample in thin section show visible characteristics of the aggregate, including presence of both siliceous and carbonate rock types. Red arrows mark carbonate rock grains. All other grains shown are siliceous in mineralogy. Each area is viewed under cross-polarized light. Length of each field (LOF), left to right, is approximately 6 mm (0.25 in.).

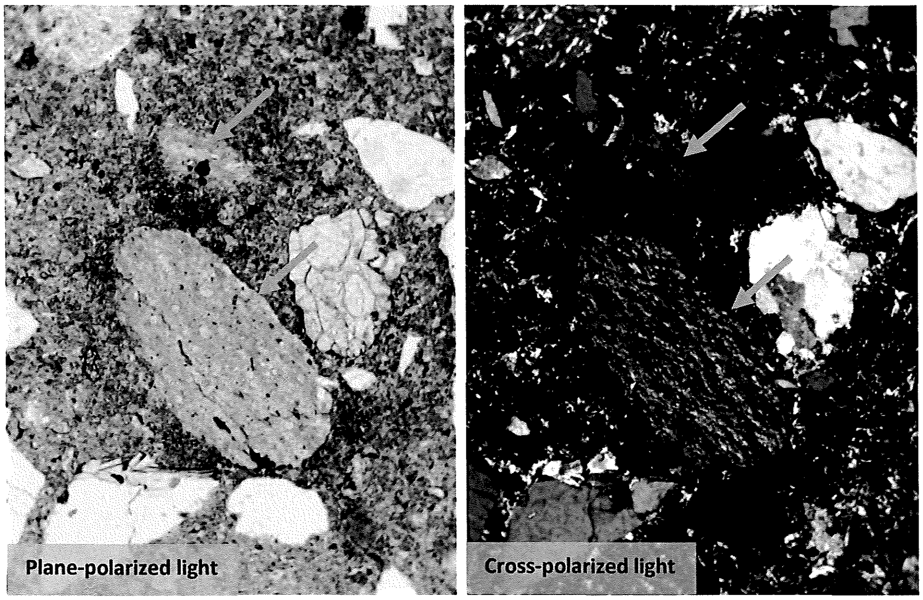


Figure 6 **Thin-section photomicrographs show two fine aggregate particles of diatomaceous shale (marked with arrows) in the concrete. Length of field, top to bottom, is 1.2 mm (0.05 in.).**

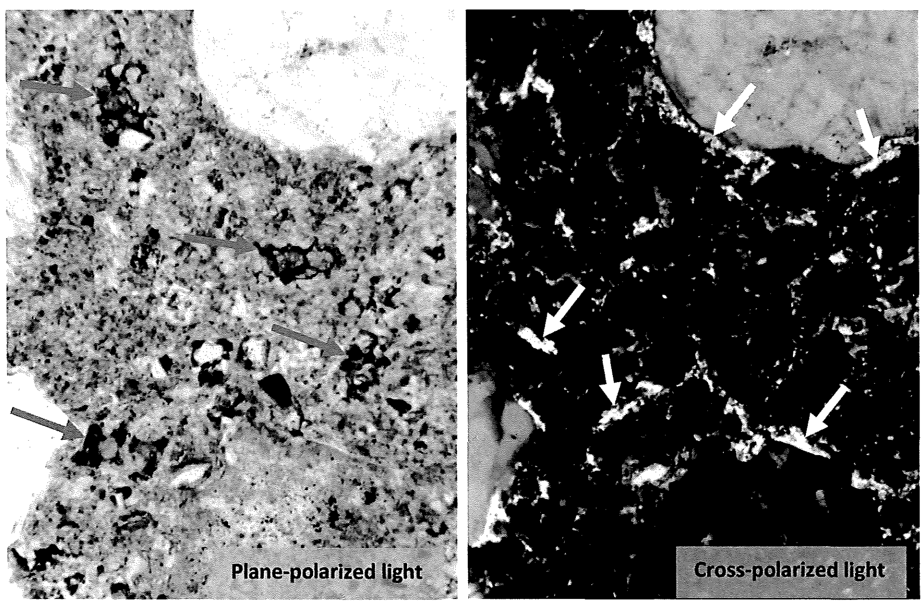
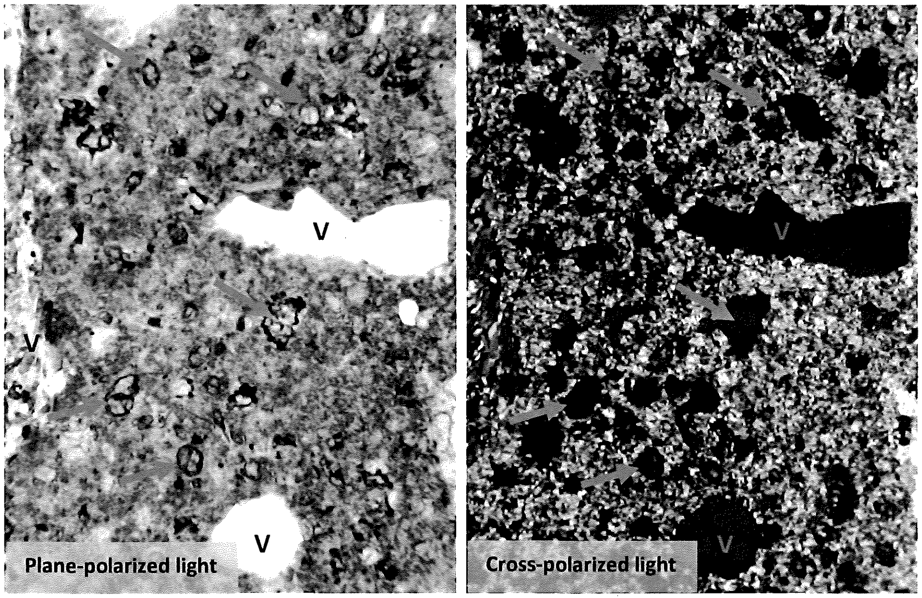
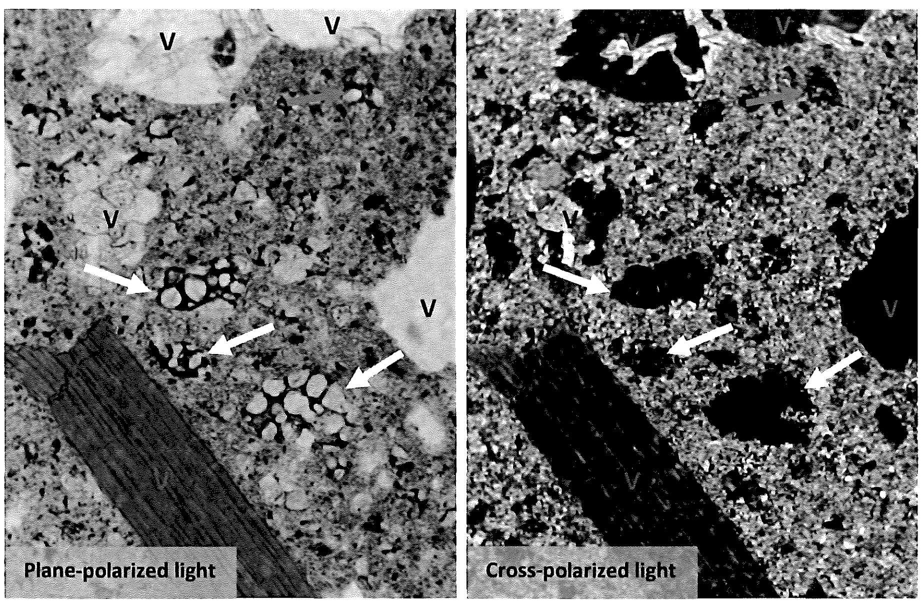


Figure 7 **Thin-section photomicrographs show residual portland cement clinker (red arrows) and portlandite crystals (yellows arrows) in a non-carbonation portion of the Blue Mounds sample. Portlandite (calcium hydroxide) is a hydration product of portland cement. Other than portland cement, no pozzolanic or mineral additives were observed in the cement paste. Length of each field (LOF), top to bottom, is approximately 0.6 mm (0.025 in.).**



8a.



8b.

Figure 8 Thin-section photomicrographs further document the presence of residual unhydrated (red arrows) and in-situ hydrated (yellow arrows) portland cement clinker particles in carbonated paste of the Blue Mounds sample. The brighter, speckled appearance of the paste in the right-hand images is due to formation of secondary carbonate minerals associated with paste carbonation. Examples of aggregate grains are marked “A.” Length of field, top to bottom, in each image is approximately 0.6 mm (0.024 in.).

Petrographic Examination of Hardened Concrete - ASTM: C 856

Client:
Minnesota Dept. of Natural Resources
New Ulm, Minnesota

Project Description:
Blue Mounds State Park
Stone embankment of Old Park Road

Sample Information — Sample: *Blue Mounds*

Sample Location: Sloped embankment along side of Old Park Road, Blue Mounds State Park.

Placement Date: Not reported.

Reported Distress Observed: None reported. Composition assessment.

General Observations

Sample Dimensions and Description:

Analysis was performed on an intact fragment of concrete weighing 2.18 kg (4.79 lb.). The fragment measures up 16.5 cm (6.5 in.) x 11.5 cm (4.5 in.) across and up to 22.0 cm (8.7 in.) long. The fragment exhibits the following outer surface characteristics:

- Outer Face/Top - A flat, weathered top surface that exposes many fine aggregate in low to moderate relief.
- Side 1 - A broad, slanted, flat side that was apparently formed against a flat surface (possibly stone). The surface also exhibits several small entrapped air voids and some light-colored surface deposits.
- Side 2 - A broad rough and irregular formed and locally fractured face. The formed portion of the face is compacted to slightly under-compacted and exhibit numerous small entrapped air voids and does not bisect exposed aggregate. The fractured portion is rougher and extends around and through aggregate particles.
- Inner End/Bottom - A rough and irregular surface of concrete exposing a partially embedded, large quartzite rock fragment.
- Broken End - One end of the sample exhibits a rough, fracture surface oriented perpendicular to the aforementioned surfaces. The fracture passes mostly through aggregate particles.

With exception to some effects of weathering, wear and shallow erosion along the outer/top surface, none of these surfaces exhibit evidence of significant or apparent distress or deterioration.

General Physical Conditions:
Aside from surface features described above, the sample was received intact and in fairly good condition with no large cracks or joints and only sparse small consolidation voids in the body of the concrete. A few fine aggregate particles of shale exhibits some internal microcracking, otherwise, the constituents of the aggregate appear in good condition. A few random microcracks are observed elsewhere in the concrete with no apparent source or distress mechanism.

Reinforcement: None present in sample.

Aggregate

Coarse: Natural gravel composed of a variety of sedimentary, igneous, and metamorphic rock types, including: limestone and dolomite, granite and meta-granite, diorite and gabbro, greywacke and sandstone, and small amounts of chert, and other rocks. Aggregate particles are rounded to sub-angular and exhibit smooth to rough surfaces. The coarse aggregate visually appears fairly well graded to an observed top size of 13 mm (0.5 in.) and uniformly distributed in the concrete.

Fine: Natural sand grains composed mainly of quartz, feldspar, and granitic rocks, with lesser amounts of chert, quartzite, limestone, shale, and other rocks and minerals. Aggregate particles are rounded to angular and exhibit smooth to rough surfaces. The sand appears fairly well graded and well distributed in the concrete.

Paste

Depth of Carbonation	Variable and mostly shallow along all existing sides: 1 to 3 mm (0.04 to 0.12 in.) along the weathered top surface; 1 to 3 mm (0.04 to 0.12 in.) along the flatter, formed side; 2 to 5 mm (0.08 to 0.20 in.) along the more irregular formed side and the bottom end. Figure 3b further documents the profile and pattern of carbonation.
Air Content	Estimated 0.5 to 1.5 percent. The body of concrete exhibits only sparse small, spherical voids, less than 1 mm, in the cement paste suggesting the concrete is not air entrained. Porosity of the concrete is locally higher in under-consolidated, poorly compacted concrete along the formed sides.
Paste Color:	Buff to beige throughout the sample.
Paste Hardness	Moderately hard throughout the sample.
Paste Absorbency	Moderate to moderately low throughout the sample.
Paste-Aggregate Bond	Moderately tight; surfaces of freshly fractured concrete pass mostly through coarse aggregate and equally through and around fine aggregate.

Residual Cement	Estimated trace to 5 percent residual (unhydrated and partially hydrated) portland cement clinker, by volume of paste, with greatest amounts observed near the top surface. Relics of suspected in-situ hydrated cement clinker are common in the paste throughout the sample.
Supplementary Cementitious Materials	None apparent.
Calcium Hydroxide	Estimated 5 to 10 percent of small to large-size portlandite crystals in the body of the sample, away from carbonated areas. None in carbonated paste near-surface paste.
Water-Cement Ratio (w/c):	Estimated moderate, based on observed physical properties and microscopical features of the concrete and cementitious paste.
Microcracking	Aside from the cracking and microcracking within some shale aggregate particles, random microcracks are observed but generally sparse in the cement paste in the body of the concrete.
Secondary Deposits	Small, acicular crystals of ettringite, a calcium sulfo-aluminate hydrate commonly associated with hydrated portland cement, line or partially fill a few small voids in the cement paste. Amounts of ettringite are judged to be small and the deposits are believed to be innocuous and void-filling in nature. Some off-white deposits of calcium carbonate are observed along the slanted, flat side of the sample.
Miscellaneous	A large fragment of rock, up to 8 cm (3 in.) long, and composed of pink quartzite, is embedded in the concrete along the bottom edge.

Examination By:

Ronald D. Sturm
Senior Petrographer