CONSTRUCTION MATERIALS CONSULTANTS, INC.

Petrographic Examinations Of Two Concrete Cores From An 80-Year-Old Hotel In A Marine Environment

Normandie Hotel
San Juan, Puerto Rico

November 11, 2021
CMC 1021170

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EXECUTIVE SUMMARY

Reported herein are the results of detailed petrographic examination of two concrete cores (C-11p, and C-17p) retrieved from a ground-level column, and east wall at the ground level, respectively, of the historic (circa 1940's) Normandie Hotel in San Juan, Puerto Rico. The purposes of the investigation are to determine the overall condition, composition, and quality of concrete in the two cores, and evidence of any chemical and/or physical deterioration of concrete. The cores were analyzed by detailed petrographic examinations according to the procedures of ASTM C 856.

Based on petrographic studies, coarse aggregates are determined to be compositionally similar #57 crushed limestone consisting of fossiliferous limestone (biomicrite and biosparite with finer-grained micritic and coarser-grained sparry calcite cement matrix, respectively), and fine-grained (micritic) limestone having nominal maximum sizes of 1 in. (25 mm) in Core C-11p, and 3/4 in. (19 mm) in Core C-17p. Particles are angular, dense, hard, medium gray, equidimensional to elongated, uncoated, unaltered, and uncracked. Coarse aggregate particles are well-distributed in both cores, but poorly graded in both cores due to the deficiency of some finer and intermediate sizes. Overall proportions of crushed limestone are lower than the optimum amounts needed to minimize the interstitial mortar fractions. There are no evidence of alkali-aggregate reactions of coarse aggregate particles, which are present in sound and serviceable conditions.

Fine aggregates in both cores are mixtures of (a) major amounts of crushed limestone, (b) subordinate amounts of seashell fragments (mollusks, echinoderms, etc.), and (c) noticeably finer fractions of crushed siliceous particles (major amounts of quartz, and subordinate amounts of quartzite, feldspar, chert, etc.) where the proportions of crushed limestone particles in fine aggregate are higher in Core C-11p than in Core C-17p. The finest silicate fractions of fine aggregate are present at a greater abundance in Core C-17p than in C-11p. Such minor but noticeable variations in relative proportions of crushed limestone and finer size silicate particles in both cores indicate a slight variation in the compositions of fine aggregates used at the locations of both cores even though the crushed limestone coarse aggregate was identical in the concretes placed at those core locations. Fine aggregate particles have nominal maximum sizes of 3/8 in. (9.5 mm). Particles are angular, moderately dense, moderately hard, off-white to light gray, well-graded and well-distributed. There is no evidence of alkali-aggregate reaction of fine aggregate particles found in the cores. Fine aggregate particles have been sound during their service.

Paste is light gray, moderately hard to moderately soft in Core-11p, and, moderately soft to soft in Core-17p. Freshly fractured surfaces have subvitreous lusters and subconchoidal textures. Residual and relict Portland cement particles are detected and estimated to constitute 6 to 8 percent of the paste volumes. The calcium hydroxide component of cement hydration occurs as small, platy, patchy units in the sound interior bodies and is estimated to constitute 8 to 10 percent of the paste volume. Hydration of Portland cement is normal. The textural and compositional features of the paste are indicative of Portland cement contents estimated to be approximately 6 to 6 1/2 bags per cubic yard; and water-cement ratios (*w/c*) uniform throughout the bodies of the cores and estimated to be similar in both cores in the range of 0.55 to 0.60. There is no evidence of any potentially deleterious secondary deposits found in the cores.

Carbonation of paste has extended to depths of 10 mm in Core C-11p, and, as deep as 40 mm in Core C-17p. Interior concrete beyond those depths also show sporadic patchy carbonation especially in Core C-11p, which are indicative of inherent porous and permeable nature of concrete to atmospheric carbon dioxide and other potentially deleterious agents.

As a result, the protective coats detected on the exposed ends of both cores, though installed only after the concrete at both core locations were carbonated to those depths, are beneficial to prevent further migration of those agents after the installation of protective coats. Bonds between the coarse and fine aggregate particles and paste are moderately tight to weak at some places due to inherent soft, porous natures of paste from the use of high *w/c* mixes.

In both cores, air occurs as a few coarse, near-spherical and irregularly shaped entrapped voids having sizes >1 to 2 mm. Concretes in both cores are non-air-entrained, having air contents estimated to be 3 to 4 percent.

As mentioned, both cores showed the presence of multiple layers of protective coats, from paint coats in Core C-11p to a thick mortar coat sandwiched between thin multi-layered polymer coats in Core C-17p, which are determined to be 4 to 5 mm in total nominal thickness in Core C-11p, and 16 to 17 mm in total thickness in Core C-17p. These coats were applied after the concrete was carbonated to as deep as 40 mm at the location of Core C-17p.

Therefore, concrete in the two examined cores was compositionally similar and apparently prepared with a high *w/c* mix consisting of crushed limestone coarse aggregate, mixed crushed limestone, seashell, and finer siliceous fragments of fine aggregate, Portland cement estimated to be 6 to $6^1/_2$ bags per cubic yard, and mix water at estimated water-cement ratios of 0.55 to 0.60. Such high *w/c* in concrete is potentially detrimental to long-term performance and serviceability in a marine environment since the aggressive agents in the environment from chloride to atmospheric carbon dioxide can penetrate deep into a porous and permeable concrete from the use of high *w/c* mix.

Despite the determined soft, porous, high *w/c* of paste with deep carbonation, there is, however, no evidence of any physical or chemical deterioration of concrete detected in the cores. Both crushed limestone coarse aggregate and fine aggregate are present in sound conditions without any potentially deleterious reactions.

Due to the overall soft, porous, high *w/c* natures of paste, atmospheric carbonation has extended as deep as 40 mm at the location of Core C-17p, and from severe carbonation at the top 10 mm of exposed end to patchy carbonation throughout the retrieved depth in Core C-11p. Such deep carbonation from inherent porous and permeable high *w/c* concrete can initiate *carbonation-induced corrosion of reinforcing steel in concrete* in the presence of oxygen and moisture. There is, however, no evidence of any reinforcing steel detected in any core, or evidence of corrosion of steel in concrete.

Due to the suspected high chloride environment, water-soluble chloride contents should be determined from the exposed ends to the interior of the cores to determine the depth of penetration of chloride. Chloride, especially in a carbonated concrete can easily initiate *chloride-induced corrosion of steel* in the presence of oxygen and moisture. In a marine environment this is important especially if a portion of mix water had incorporated the saline marine water, which would promote corrosion of steel in concrete. Therefore, additional chloride content analyses at exposed and interior depths of the cores are recommended.

Due to the determined soft, porous, high *w/c* nature of the paste in both cores and thus overall permeable nature of paste to penetration of potentially deleterious agents from the marine environment, having those multi-layered protective coats were not only beneficial but are actually essential for long-term durability and serviceability of concrete.

INTRODUCTION

Reported herein are the results of detailed petrographic examination of two concrete cores, reportedly retrieved from an interior slab of Normandie Hotel in San Juan, Puerto Rico, which was reportedly construction in the 1940's.

BACKGROUND INFORMATION

The Normandie Hotel is a historic building located in the Isleta de San Juan, in San Juan, Puerto Rico, which was opened on October 10, 1942 as a hotel, but as of 2021 remains unused and abandoned. Its design was inspired by the French transatlantic passenger ship SS Normandie in addition to featuring the same art deco design as the ocean liner that inspired it, and the hotel's original roof sign was one of the two signs that adorned the top deck of the SS Normandie, but were removed from it during an early refitting. It is an example of what came to be known as the Streamline Modern architecture style.

PURPOSES OF PRESENT INVESTIGATION

The purposes of the present investigation are to determine: (a) the overall condition, composition, and quality of concrete in the two cores provided; and (b) evidence of any chemical and/or physical deterioration of concrete, and if so, the depths or extent of such deterioration.

SAMPLES

PHOTOGRAPHS, IDENTIFICATION, INTEGRITY, AND DIMENSIONS

Table 1 and Figures 1 to 7 show the concrete cores as received from the hotel.

Sample ID	Diameter	Length	Exterior Surface	Interior Surface	Cracking	Embedded Items	Integrity
C-11p Column 21 Ground Level	2^{3}/8 in. (70 mm)	9 in (225 mm)	Smooth, approx. 3 mm thick off-white coat well-bonded to concrete	Fresh fractured (pinkish-discoloration due to field test of carbonation with phenolphthalein)	None	No reinforcing steel, wire mesh, or other embedded items	Intact, Dry, Ring
C-17p Wall (East) Axes 11/12 Ground Level	2^{3}/8 in. (70 mm)	8^{3}/4 in (250 mm)	Smooth, < 1 mm light gray paint coat partially peeled from 15 mm thick mortar coat, which is well-bonded to concrete	Fresh fractured (pinkish-discoloration due to field test of carbonation with phenolphthalein)	None, 40 mm thick carbonated concrete beneath the mortar coat, followed by rest 170 mm interior non-carbonated concrete	No reinforcing steel, wire mesh, or other embedded items	Intact, Dry, Ring

Table 1: Dimension and condition of the cores, as received.

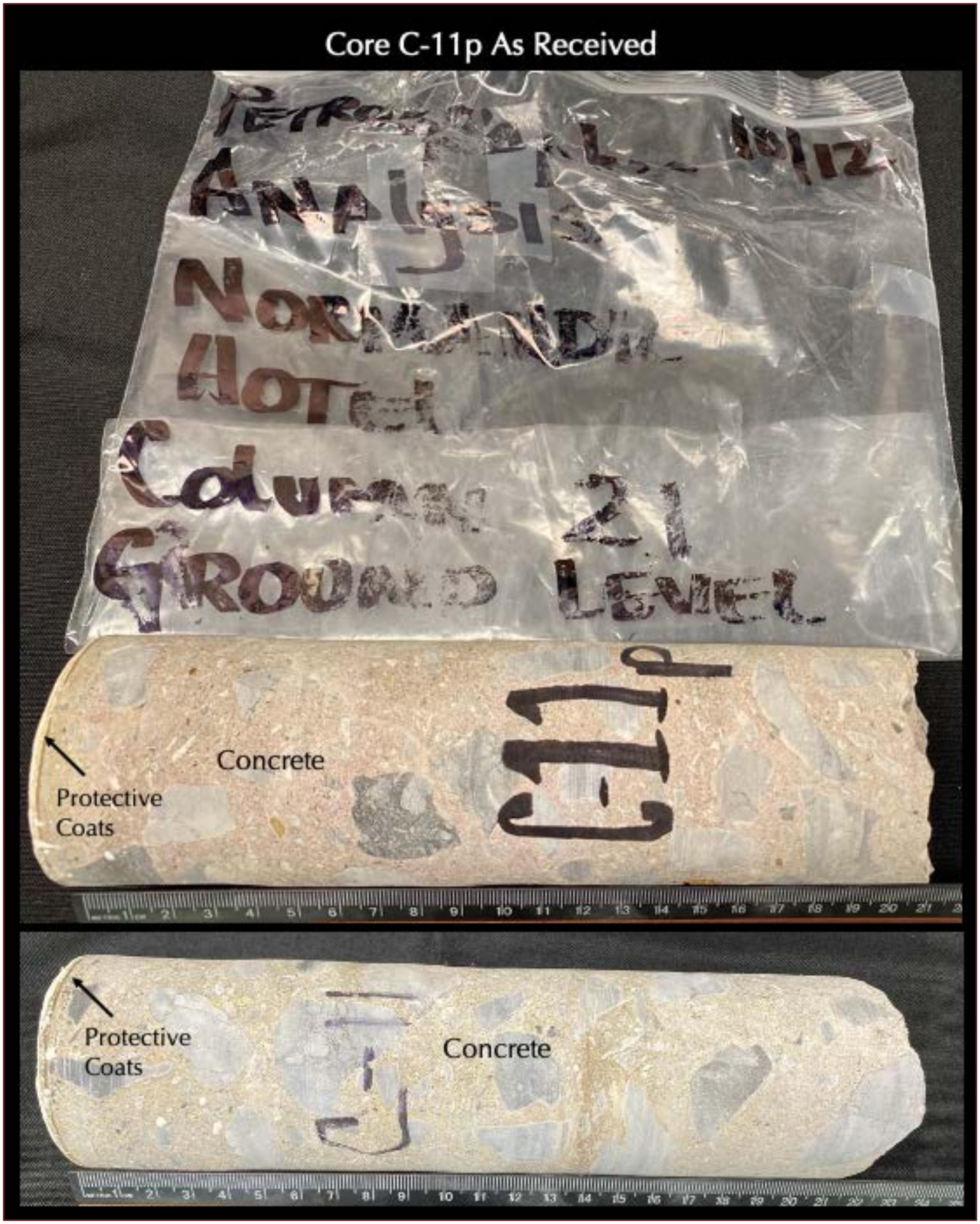


Figure 1: Core C-11p from Column 21, Ground Level, as received showing an off-white protective paint coat and a few more layers of a protective coating system, which is well-bonded to the underlying concrete body.

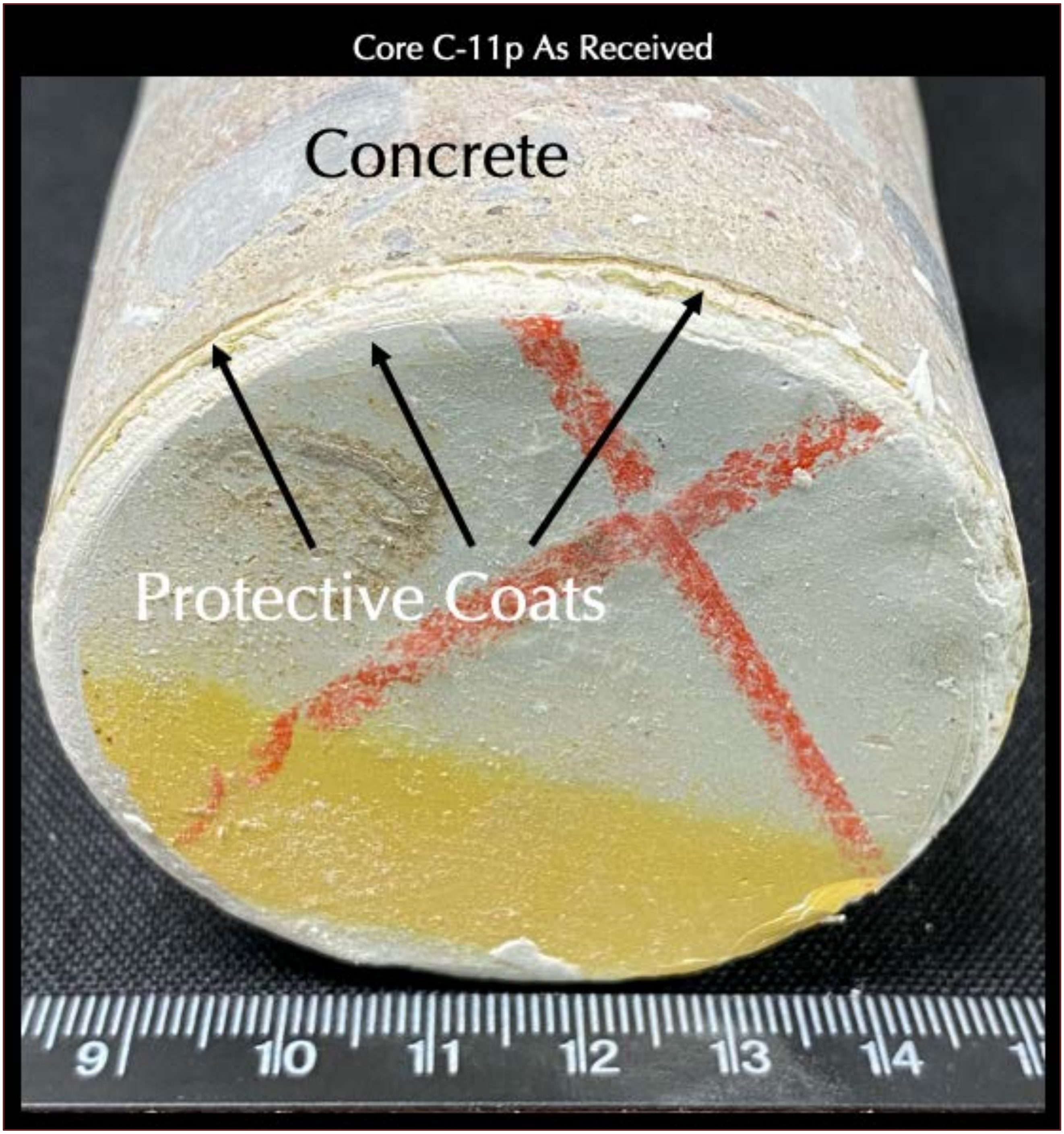
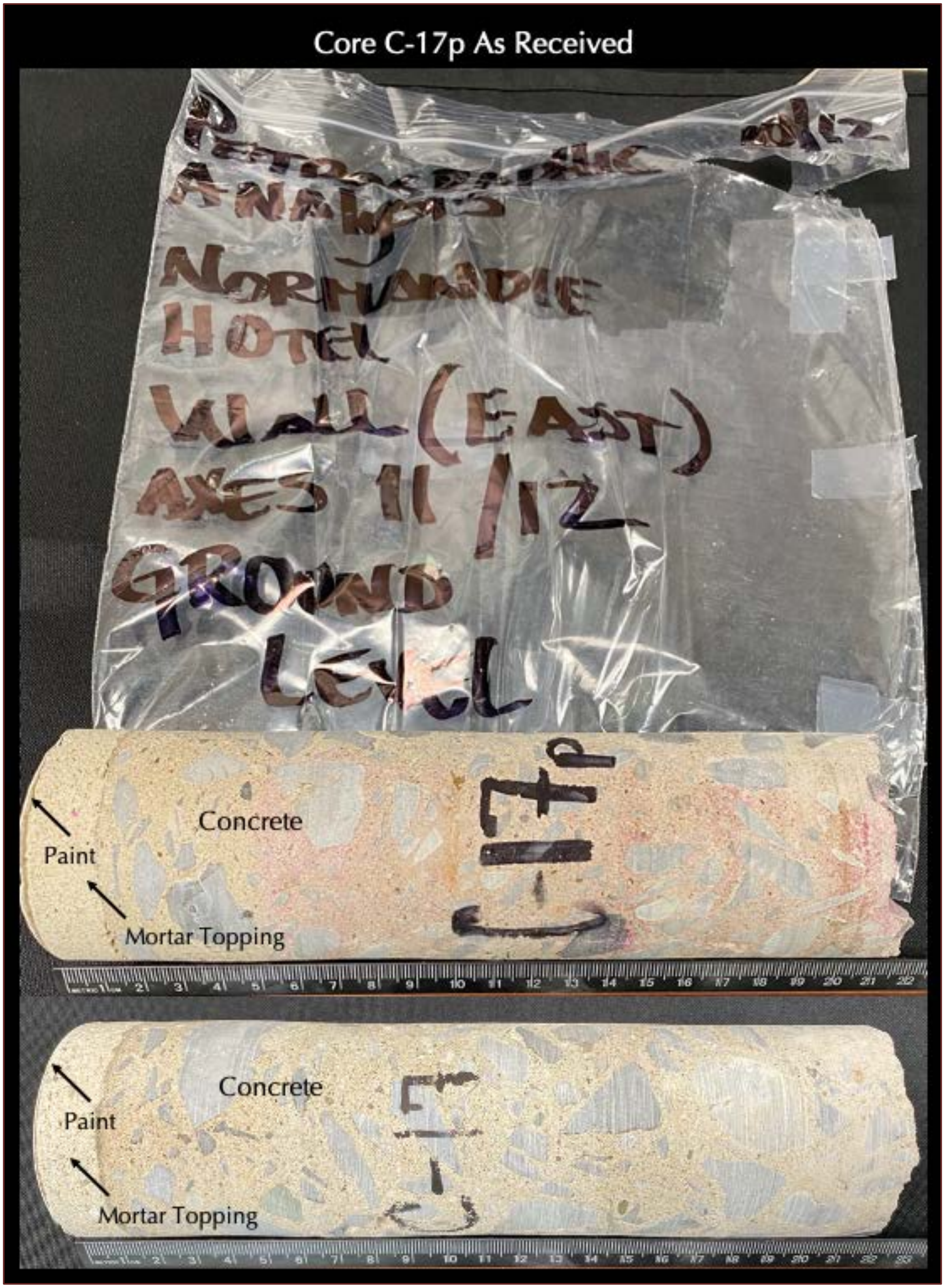


Figure 2: Core C-11p from Column 21, Ground Level, as received showing an off-white protective paint coat and a few more layers of a protective coating system, which is well-bonded to the underlying concrete body.

Figure 3: Fresh fractured interior opposite end of Core C-11p with a pinkish-discoloration due to field test of carbonation with phenolphthalein alcoholic solution.



Core C-17p As Received

Figure 4: Core C-17p from East Wall, Ground Level, as received showing an off-white protective paint coat, an underlying thick mortar coat, and a few more layers of a protective coating system, which are all well-bonded to each other and eventually to the underlying main concrete body. Notice pinkish-discoloration of interior non-carbonated concrete body beyond approximately 40 mm thick carbonated concrete where pinkish-discoloration appeared after a field test of concrete carbonation with phenolphthalein alcoholic solution.

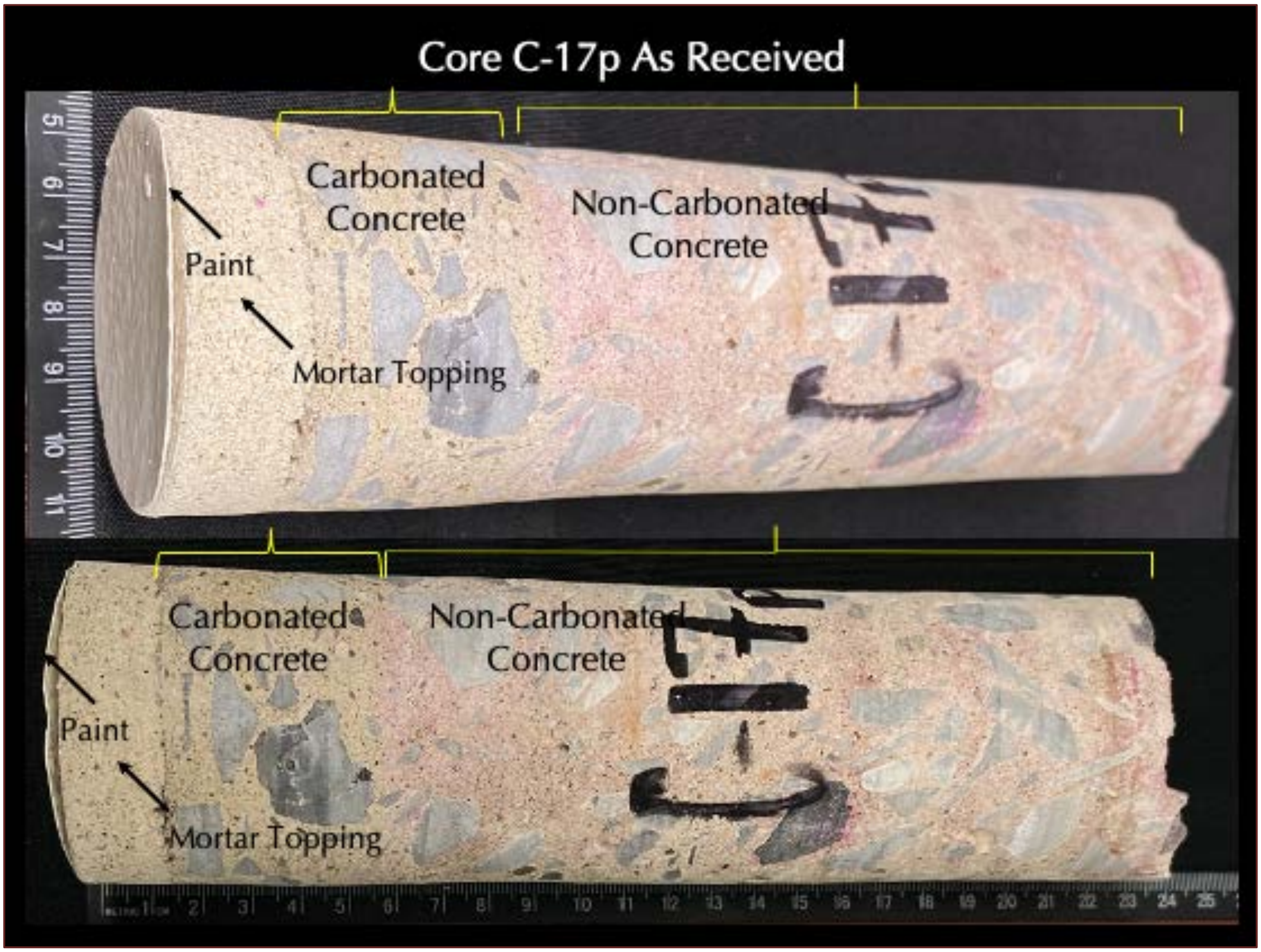


Figure 5: Core C-17p from East Wall, Ground Level, as received showing an off-white protective paint coat, an underlying thick mortar coat, and a few more layers of a protective coating system, which are all well-bonded to each other and eventually to the underlying main concrete body. Notice pinkish-discoloration of interior non-carbonated concrete body beyond approximately 40 mm thick carbonated concrete where pinkish-discoloration appeared after a field test of concrete carbonation with phenolphthalein alcoholic solution.

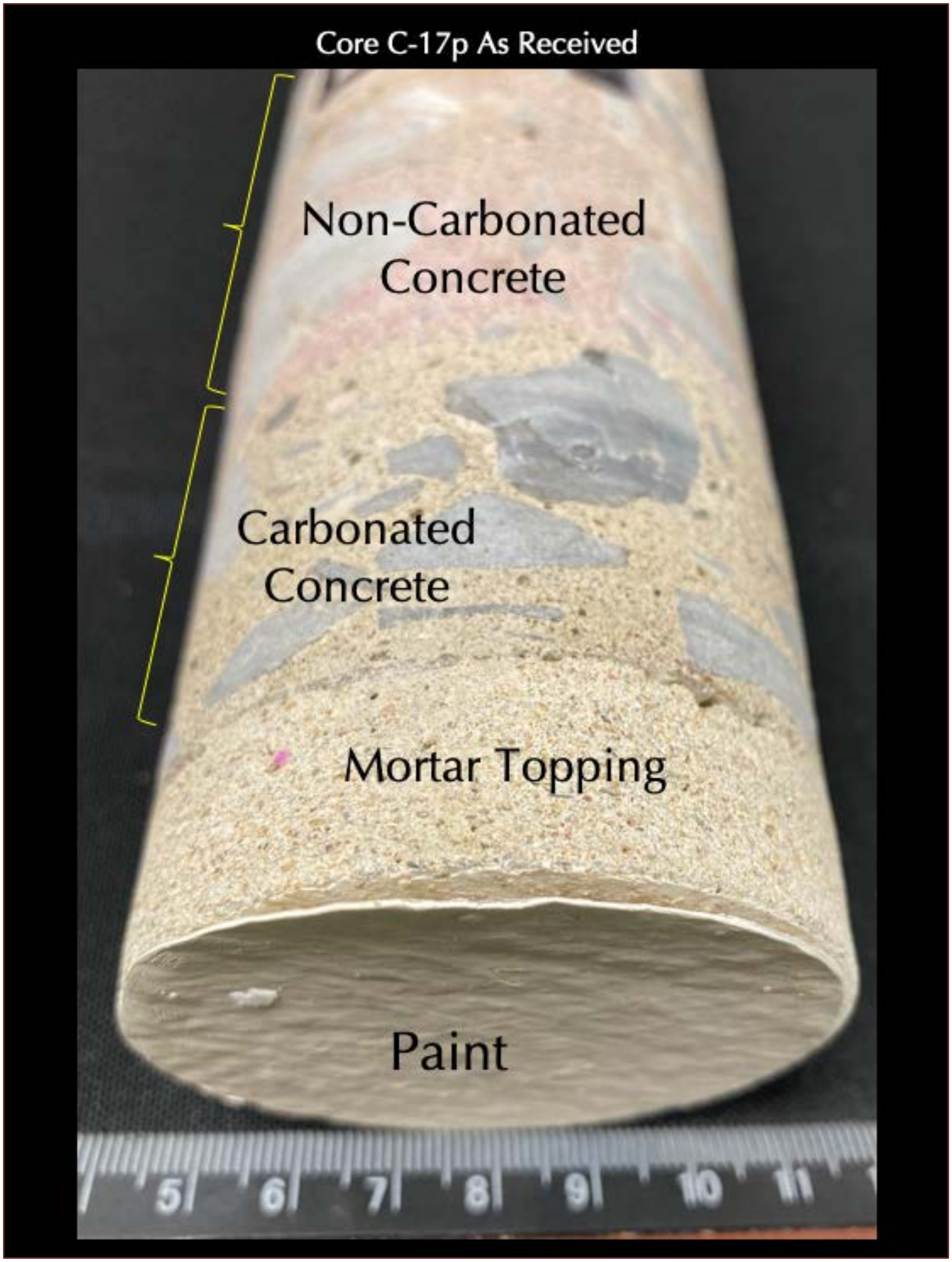


Figure 6: Core C-17p from East Wall, Ground Level, as received showing an off-white protective paint coat, an underlying thick mortar coat, and a few more layers of a protective coating system, which are all well-bonded to each other and eventually to the underlying main concrete body. Notice pinkish-discoloration of interior non-carbonated concrete body beyond approximately 40 mm thick carbonated concrete where pinkish-discoloration appeared after a field test of concrete carbonation with phenolphthalein alcoholic solution.

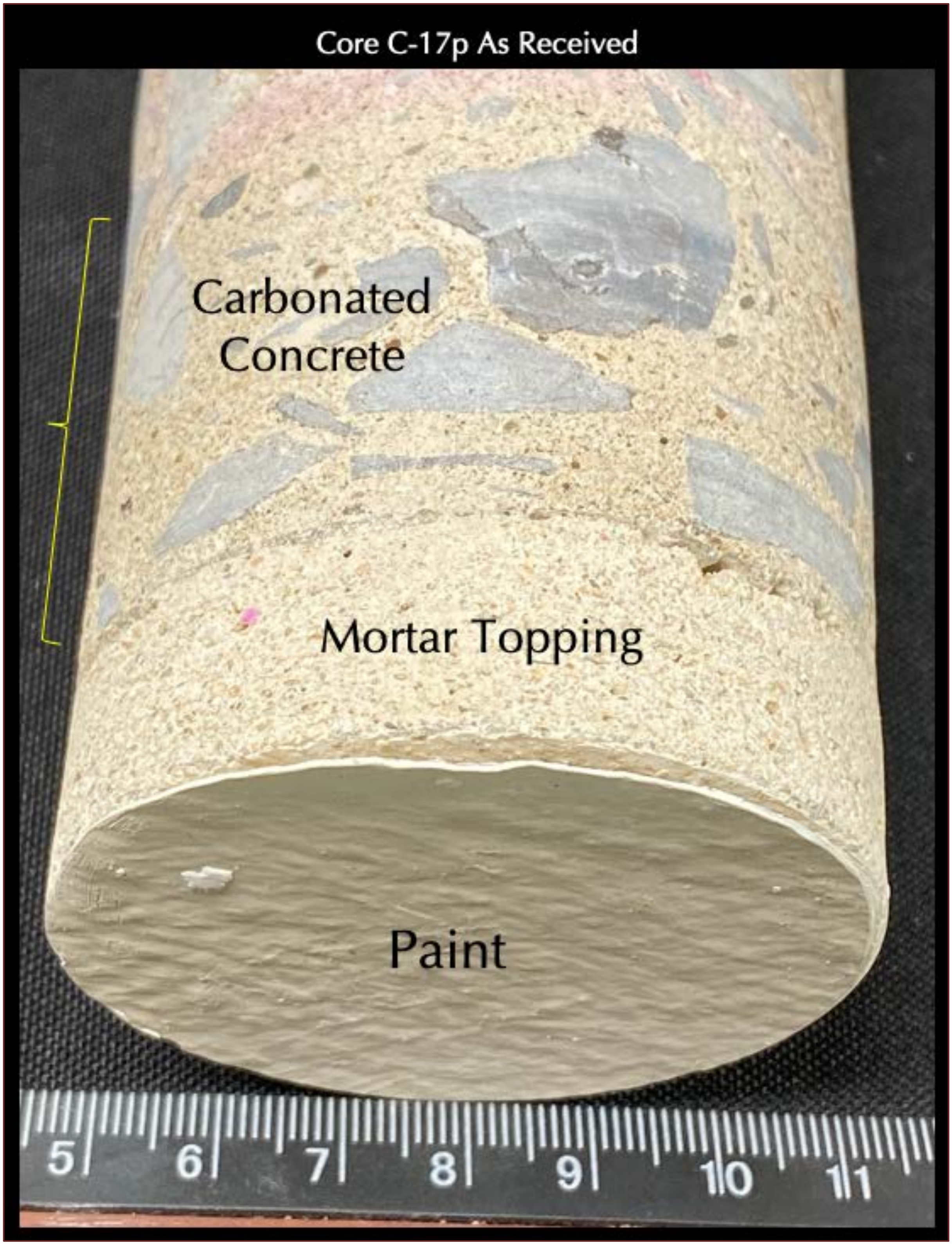


Figure 7: Core C-17p from East Wall, Ground Level, as received showing an off-white protective paint coat, an underlying thick mortar coat, and a few more layers of a protective coating system, which are all well-bonded to each other and eventually to the underlying main concrete body. Notice pinkish-discoloration of interior non-carbonated concrete body beyond approximately 40 mm thick carbonated concrete where pinkish-discoloration appeared after a field test of concrete carbonation with phenolphthalein alcoholic solution.

METHODOLOGIES

PETROGRAPHIC EXAMINATIONS

The concrete cores were examined by detailed petrographic (microscopical) examinations by following the methods of ASTM C 856 "Standard Practice for Petrographic Examination of Hardened Concrete." Details of concrete petrography, and sample preparation techniques for petrographic examinations of concrete are provided in Jana (2006).

Briefly, the steps followed during petrographic examination of the cores include:

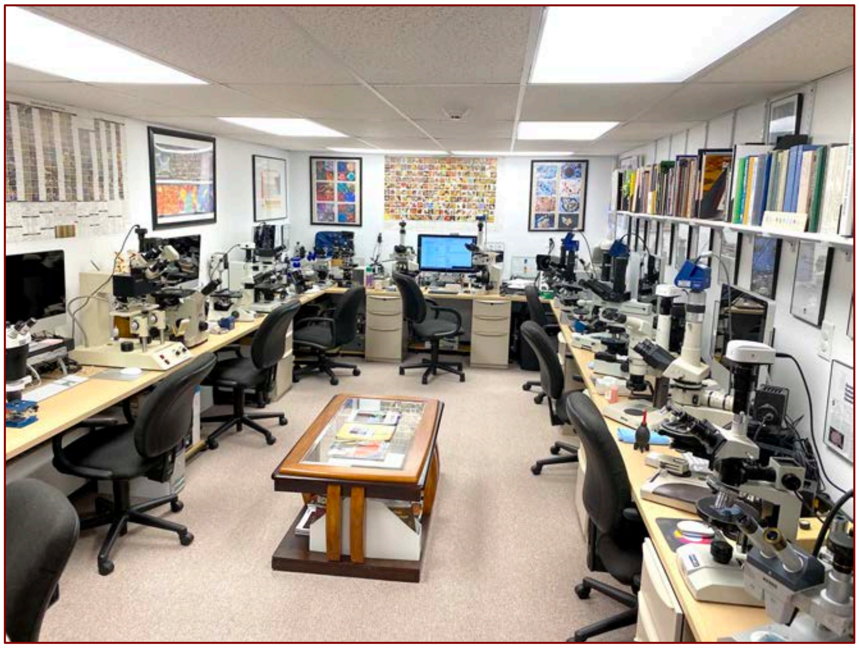


Figure 8: Optical microscopy laboratory in CMC that houses various stereo-microscopes, and petrographic microscopes used in this study.

i. Visual examinations of cores, as received, with particular reference of any visible cracking near the exposed surface;
ii. Low-power stereo-microscopical examinations of as-received, saw-cut and freshly fractured sections, and lapped cross sections of cores for evaluation of textures, and compositions, and diagnosis of any distress;
iii. Examinations of oil immersion mounts in a petrographic microscope for mineralogical compositions of specific areas of interest;
iv. Examinations of blue dye-mixed (to highlight open spaces, cracks, voids, etc.) epoxy-impregnated large area (50 mm × 75 mm) thin sections of concrete in a petrographic microscope for detailed compositional and microstructural analyses;
v. Determination of depths of carbonation and other alterations of paste from the exposed surface end;
vi. Photographing the cores, as received and at various stages of preparation with digital camera and scanner;
vii. Micrographs of lapped sections and thin sections of cores taken with stereomicroscope and petrographic microscope, respectively, to provide detailed compositional and mineralogical information of concrete.
viii. Figure 8 shows the optical microscopy laboratory that houses various microscopes used for this study.

PETROGRAPHIC EXAMINATIONS

LAPPED CROSS SECTIONS

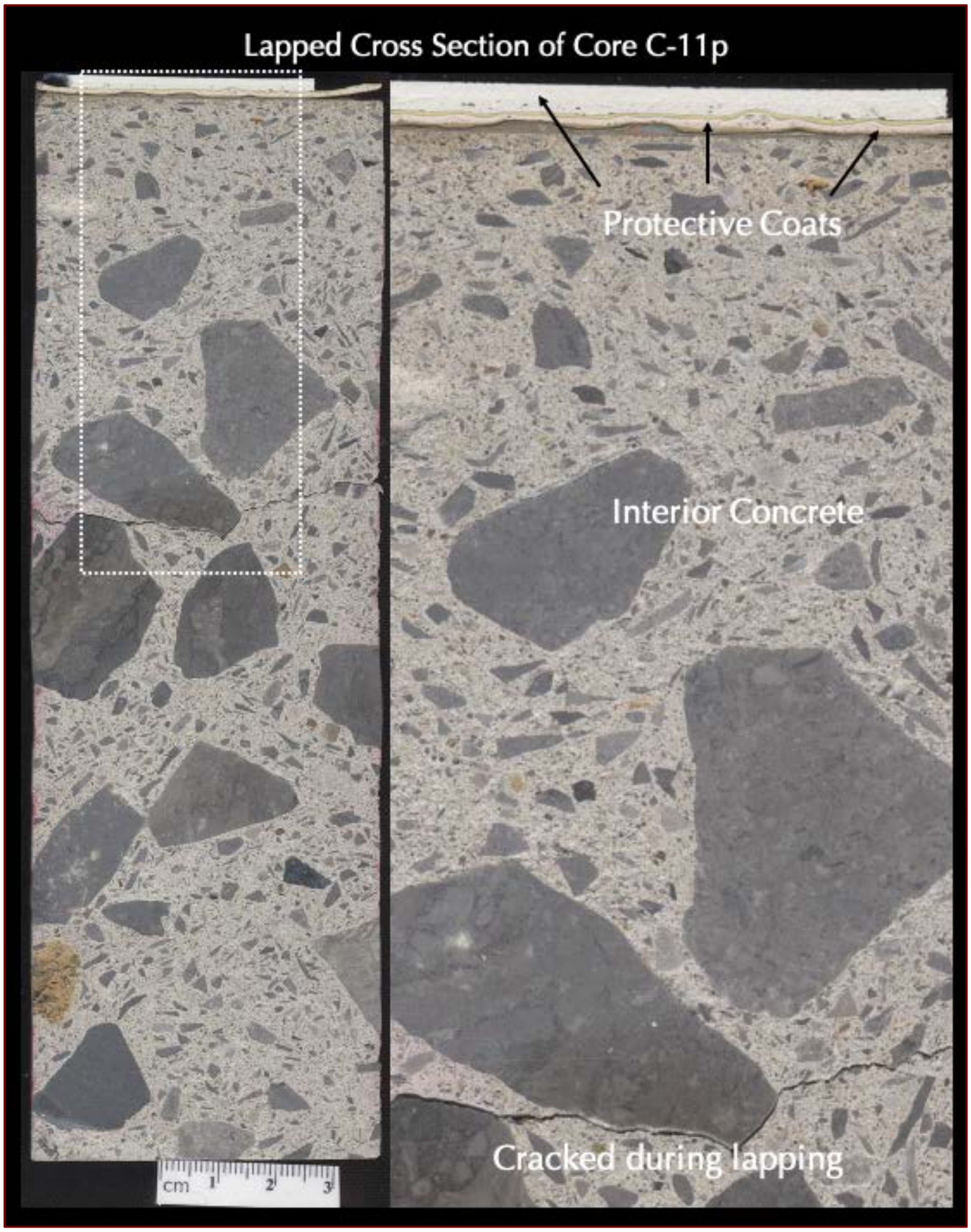


Figure 9: Lapped cross section at left and an enlarged view of the boxed area of lapped cross section at the right of Core C-11p. Notice the overall dense and well-consolidated nature of concrete in both sections containing dense, dark gray, crushed limestone coarse aggregate, where the coarse particles are poorly graded due to the deficiency of some intermediate and finer size fractions. The fine aggregate is a mixture of crushed limestone, marine shell fragments, and finer-size crushed siliceous fragments (quartz, feldspar, chert, quartzite, siltstone, etc.), which are well-graded and well-distributed throughout the depth of the core. Notice a series of protective coats applied on the exposed side of concrete to protect the concrete from penetration of potentially deleterious agents (chloride, carbon dioxide, moisture, etc.) from the marine environment.

Figure 10: Lapped cross section at left and an enlarged view of the boxed area of lapped cross section at the right of Core C-17p. Notice the overall dense and well-consolidated nature of concrete in both sections containing dense, dark gray, crushed limestone coarse aggregate, where the coarse particles are poorly graded due to the deficiency of some intermediate and finer size fractions. The fine aggregate is a mixture of crushed limestone, marine shell fragments, and finer-size crushed siliceous fragments (quartz, feldspar, chert, quartzite, siltstone, etc.), which are well-graded and well-distributed throughout the depth of the core. Notice a series of protective coats sandwiched between a thick mortar coat, all applied on the exposed side of concrete to protect the concrete from penetration of potentially deleterious agents (chloride, carbon dioxide, moisture, etc.) from the marine environment.

DEPTHS OF CARBONATION ON SAW-CUT CROSS SECTIONS

Figure 11: Saw-cut cross sections of Core C-11p (left) and C-17p (right) after treatment with phenolphthalein alcoholic solutions to show significantly deeper depth of carbonation of concrete in Core C-17p at right, which is measured to be approximately 40 mm after which the remaining 170 mm of concrete is non-carbonated and discolored to pink tone. Core C-11p, on the other hand, shows only a shallow depth of carbonation at the exposed surface region measured to be approximately 10 mm, after which the remainder of the concrete shows sporadic patchy carbonation due to inherent porous and permeable nature of concrete to atmospheric carbon dioxide. Boxed areas in both cross sections show interior non-carbonated or less carbonated concrete that have turned pink compared to carbonated surface regions that remained light gray after treatment with phenolphthalein solutions.

MICROGRAPHS OF LAPPED CROSS SECTIONS

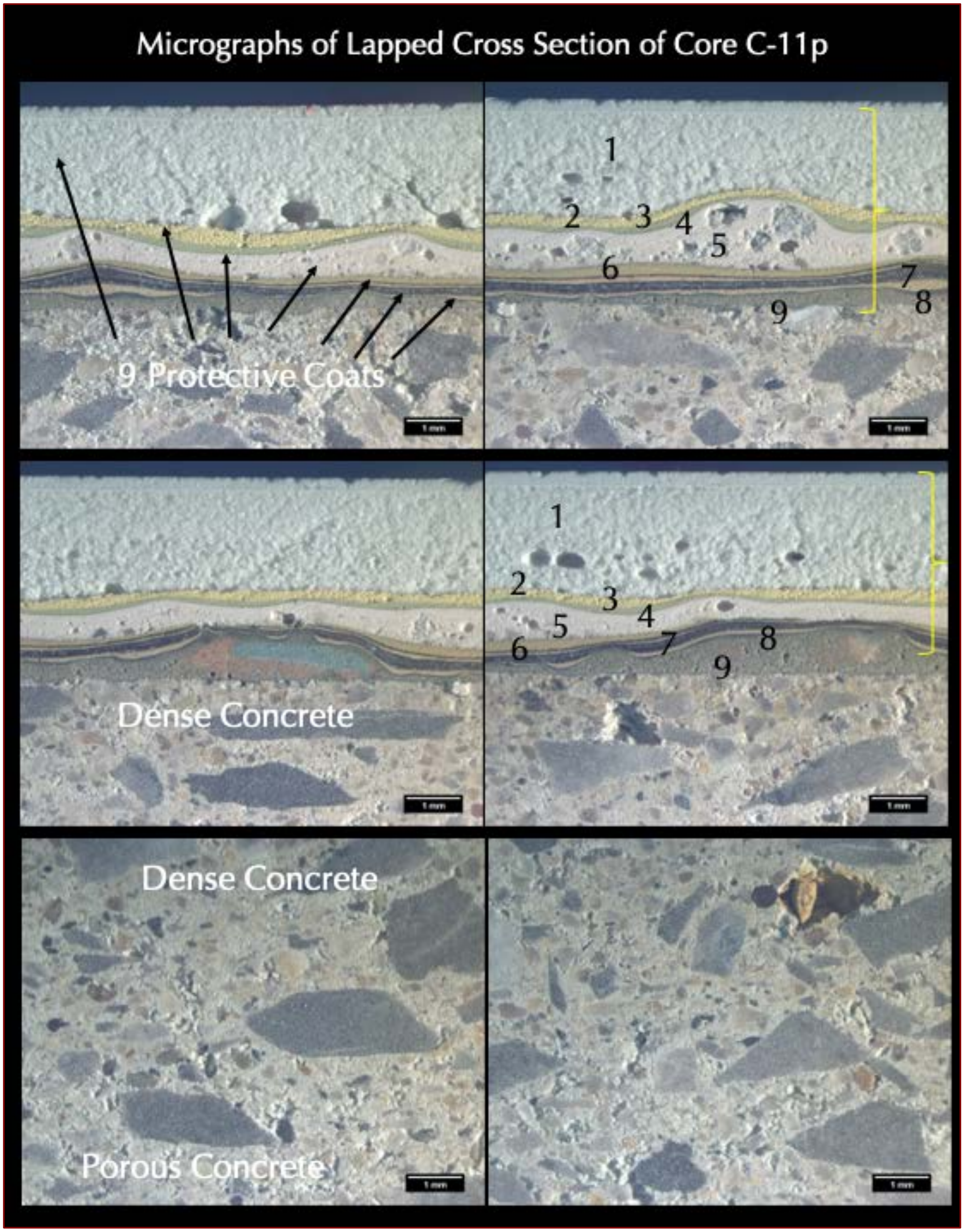


Figure 12: Micrographs of lapped cross section of Core C-11p showing: (a) multiple layers of protective coating system, which is measured to be approximately 4 to 5 mm total, consisting of at least 9 detectable layers that are all well-bonded to each other, and, eventually to the interior concrete; (b) the non-air-entrained nature of the concrete (all photos) due to the lack of any spherical entrained air voids except seeing only a few coarse entrapped voids; (c) crushed limestone coarse aggregate and crushed limestone and seashell fragments in fine aggregate; and (d) the overall sound, but soft, porous, well-consolidated nature of the concrete in the core (all photos).

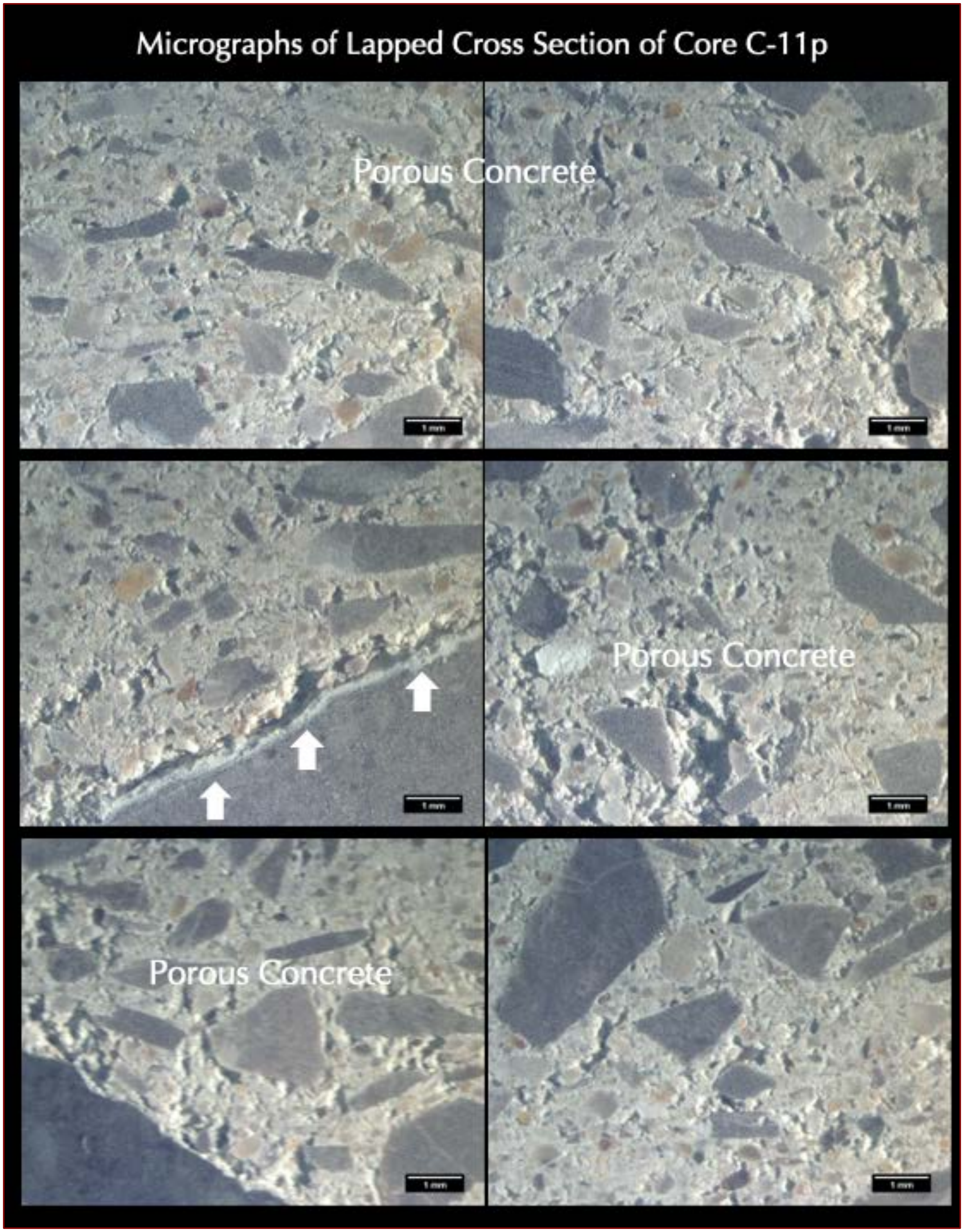


Figure 13: Micrographs of lapped cross section of Core C-11p showing: (a) the non-air-entrained nature of the concrete (all photos) due to the lack of any spherical entrained air voids except seeing only a few coarse entrapped voids; (b) crushed limestone coarse aggregate and crushed limestone and seashell fragments in fine aggregate; and (c) the overall sound, but soft, porous, well-consolidated nature of the concrete in the core (all photos).

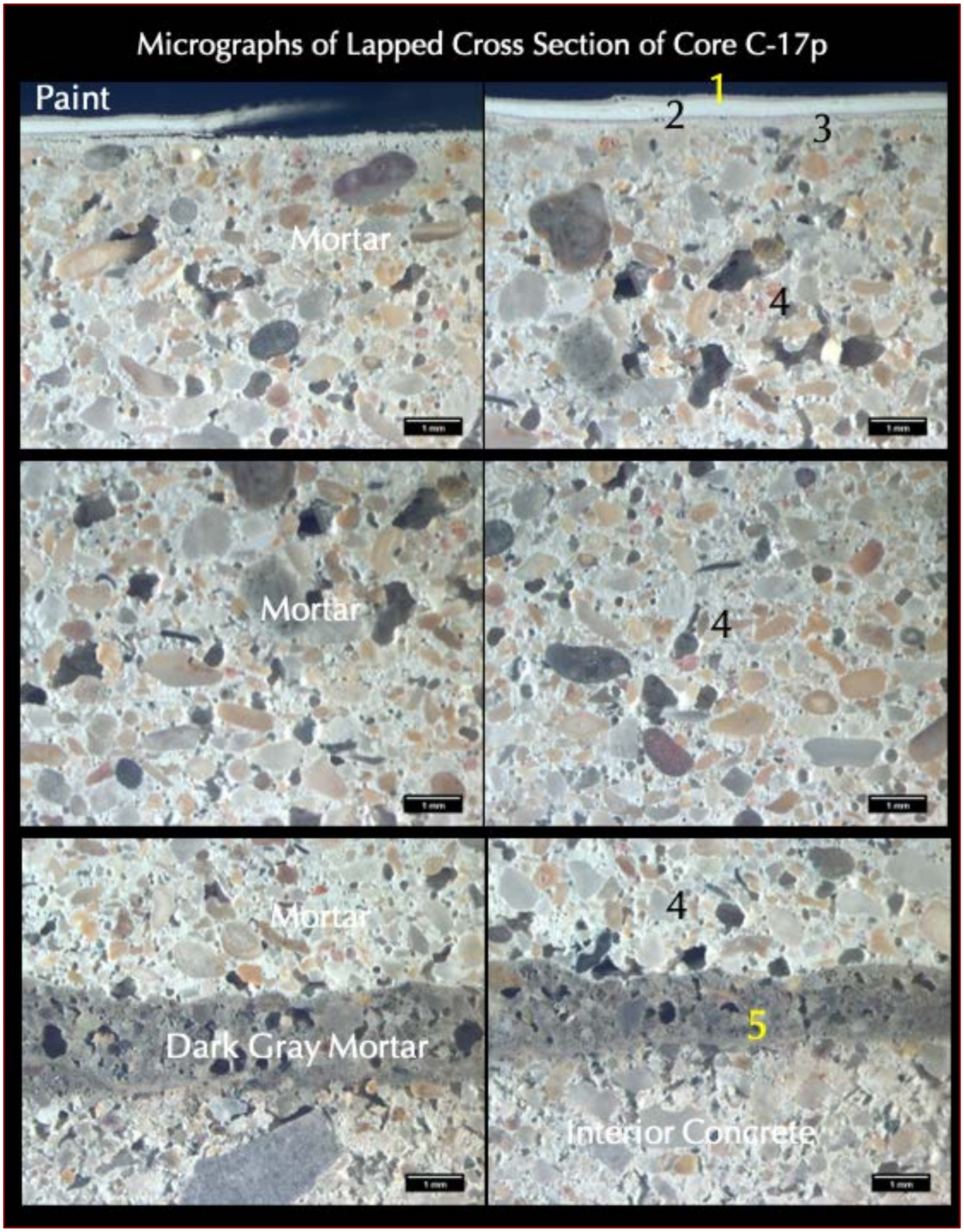


Figure 14: Micrographs of lapped cross section of Core C-17p showing: (a) multiple layers of protective coating system, which is measured to be approximately 16 to 17 mm total, consisting of at least 5 detectable layers, where a 15 mm thick mortar layer is sandwiched between thinner coats, where individual coats are all well-bonded to each other, and, eventually to the interior concrete; (b) overall air-entrained nature of the mortar coat consisting of many fine, discrete, uniformly distributed spherical (< 1 mm size) entrained air voids and a few coarse, near-spherical and irregularly-shaped entrapped voids (all photos), (c) but the non-air-entrained nature of the concrete (shown in the next Figure) due to the lack of any spherical entrained air voids, except seeing only a few coarse entrapped voids; (d) rounded mostly elliptical carbonate sand particles well-dispersed in well-consolidated off-white to light gray paste in the mortar coat (all photos); (e) crushed limestone coarse aggregate and crushed limestone and seashell fragments in fine aggregate (next Figure); and (d) the overall sound, but soft, porous, well-consolidated nature of the concrete in the core (next photos).

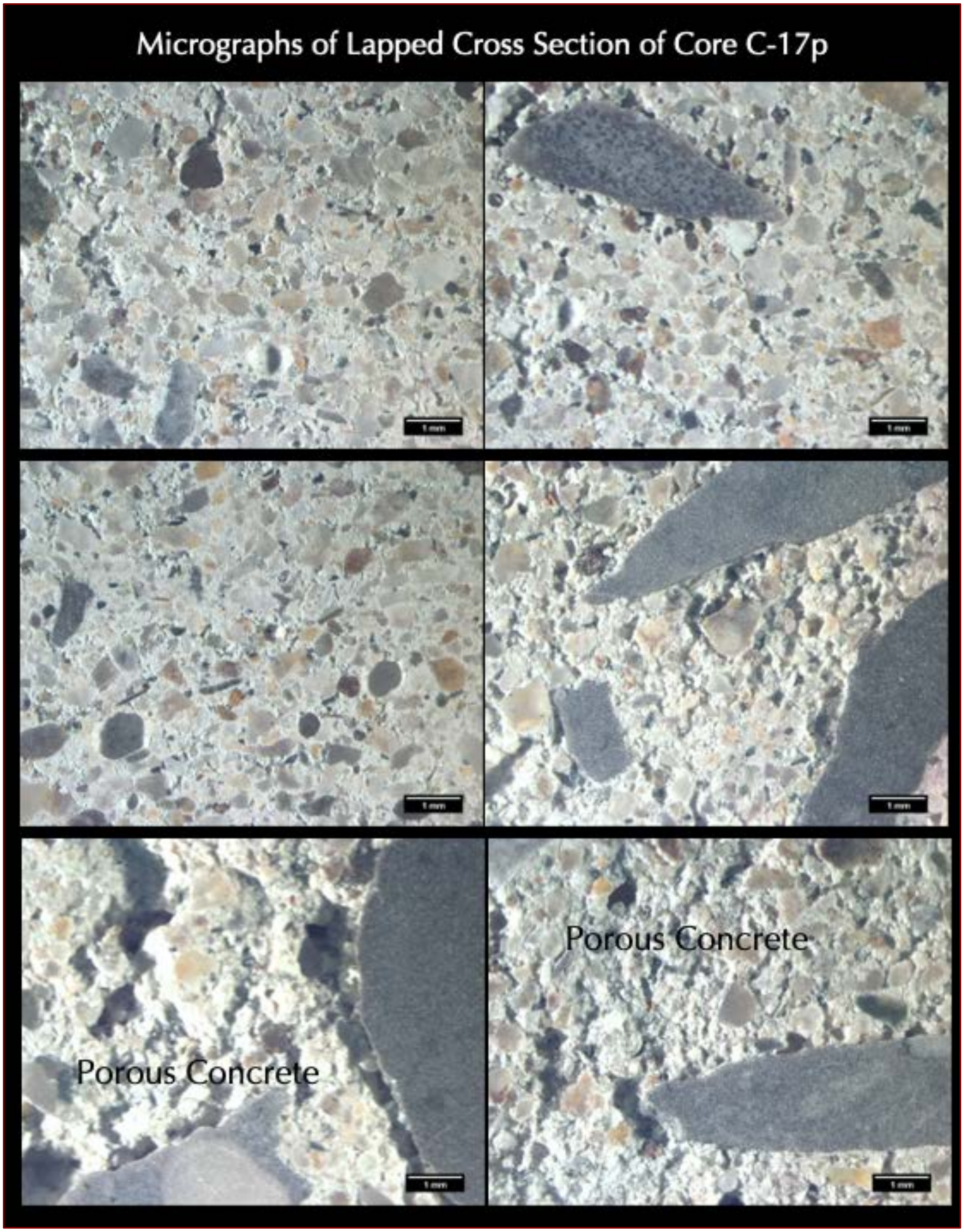


Figure 15: Micrographs of lapped cross section of Core C-17p showing: (a) overall air-entrained nature of the mortar coat consisting of many fine, discrete, uniformly distributed spherical (< 1 mm size) entrained air voids and a few coarse, near-spherical and irregularly-shaped entrapped voids (top two rows of photos), (b) but the non-air-entrained nature of the concrete (bottom row) due to the lack of any spherical entrained air voids, except seeing only a few coarse entrapped voids; (c) rounded mostly elliptical carbonate sand particles well-dispersed in well-consolidated off-white to light gray paste in the mortar coat (top two rows); (e) crushed limestone coarse aggregate and crushed limestone and seashell fragments in fine aggregate (bottom row); and (d) the overall sound, but soft, porous, well-consolidated nature of the concrete in the core (bottom row).

THIN SECTIONS

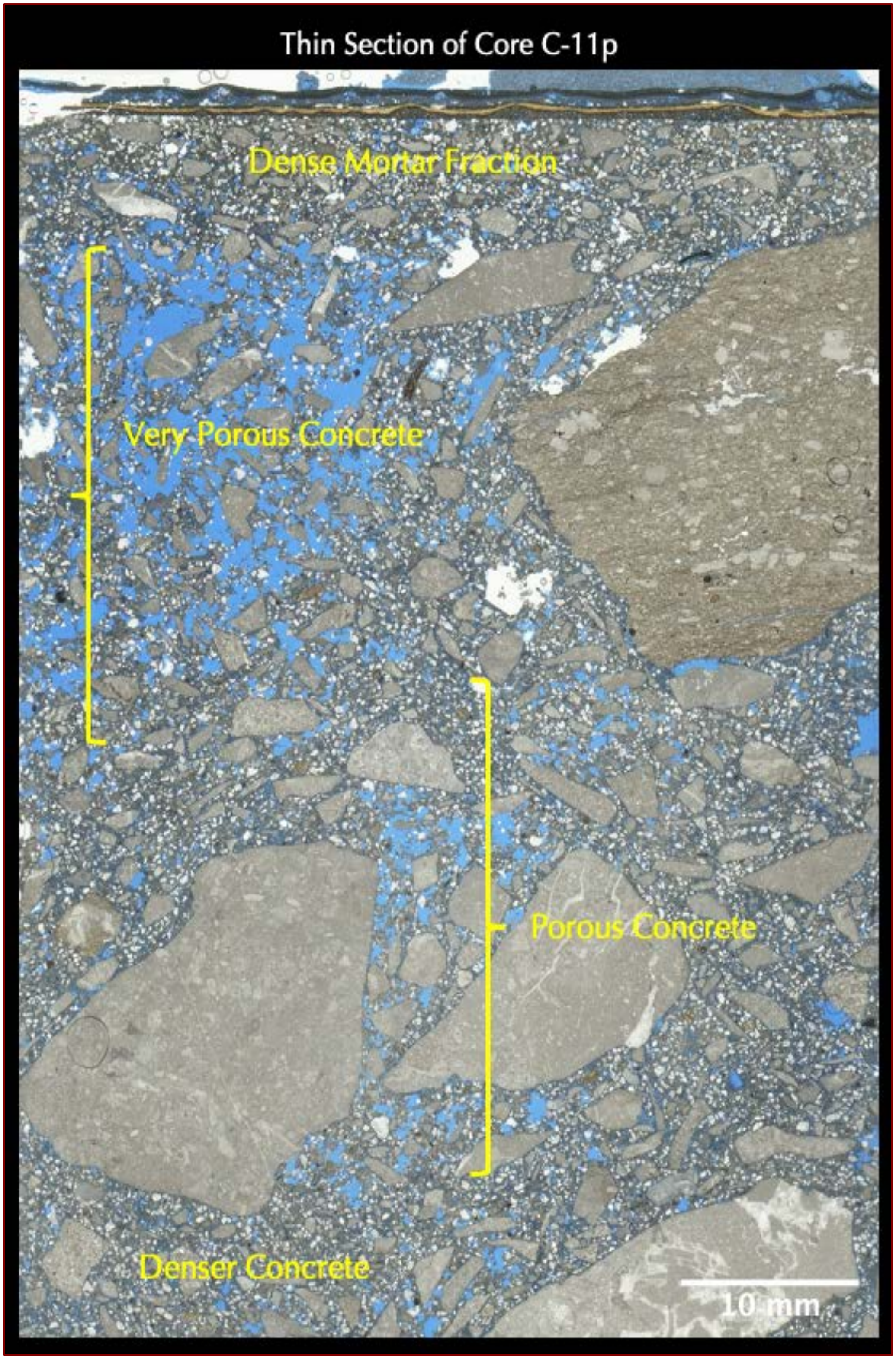


Figure 16: Blue dye-mixed epoxy-impregnated thin section of Core C-11p showing:

(a) Protective coats at the top exposed end of core;

(b) Variably dense and porous regions of concrete highlighted by blue epoxy;

(c) Crushed limestone coarse aggregate and mixture of crushed limestone, seashell fragments, and very fine crushed quartz particles in fine aggregate; and,

(d) The non-air-entrained nature of concrete where air voids are highlighted by blue epoxy.

The image was taken with a flatbed film scanner with a polarizing filter placed on the thin section during scan to highlight voids and porous regions in plane polarized light view.

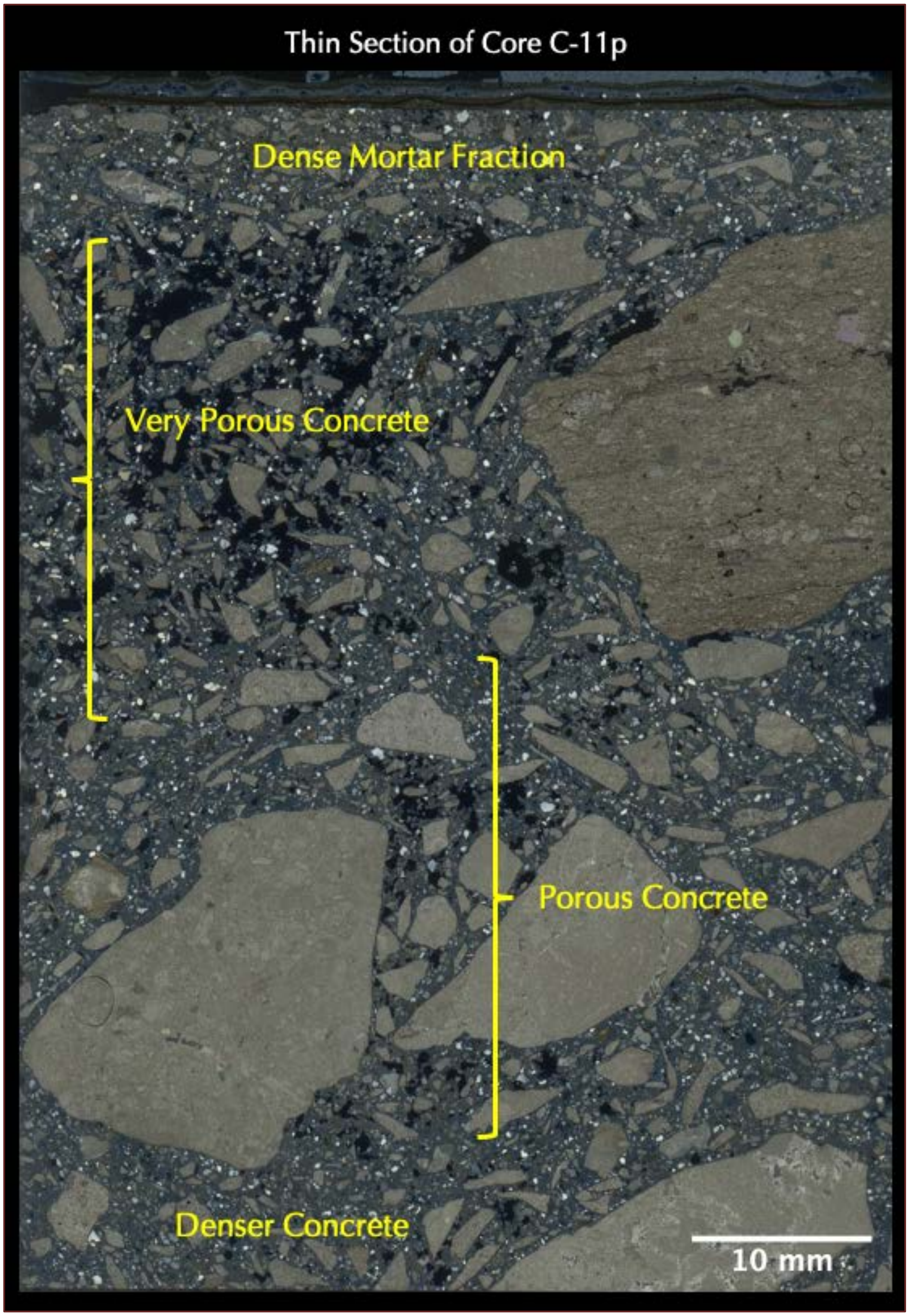


Figure 17: Blue dye-mixed epoxy-impregnated thin section of Core C-11p showing:

(a) Protective coats at the top exposed end of core;

(b) Variably dense and porous regions of concrete highlighted by blue epoxy;

(c) Crushed limestone coarse aggregate and a mixture of crushed limestone, seashell fragments, and very fine crushed quartz particles in fine aggregate; and,

(d) The non-air-entrained nature of concrete.

The image was taken with a flatbed film scanner with two perpendicular polarizing filters placed on the thin section during scan to highlight the limestone coarse aggregate, calcareous fine aggregate, and very fine siliceous particles in cross polarized light view.

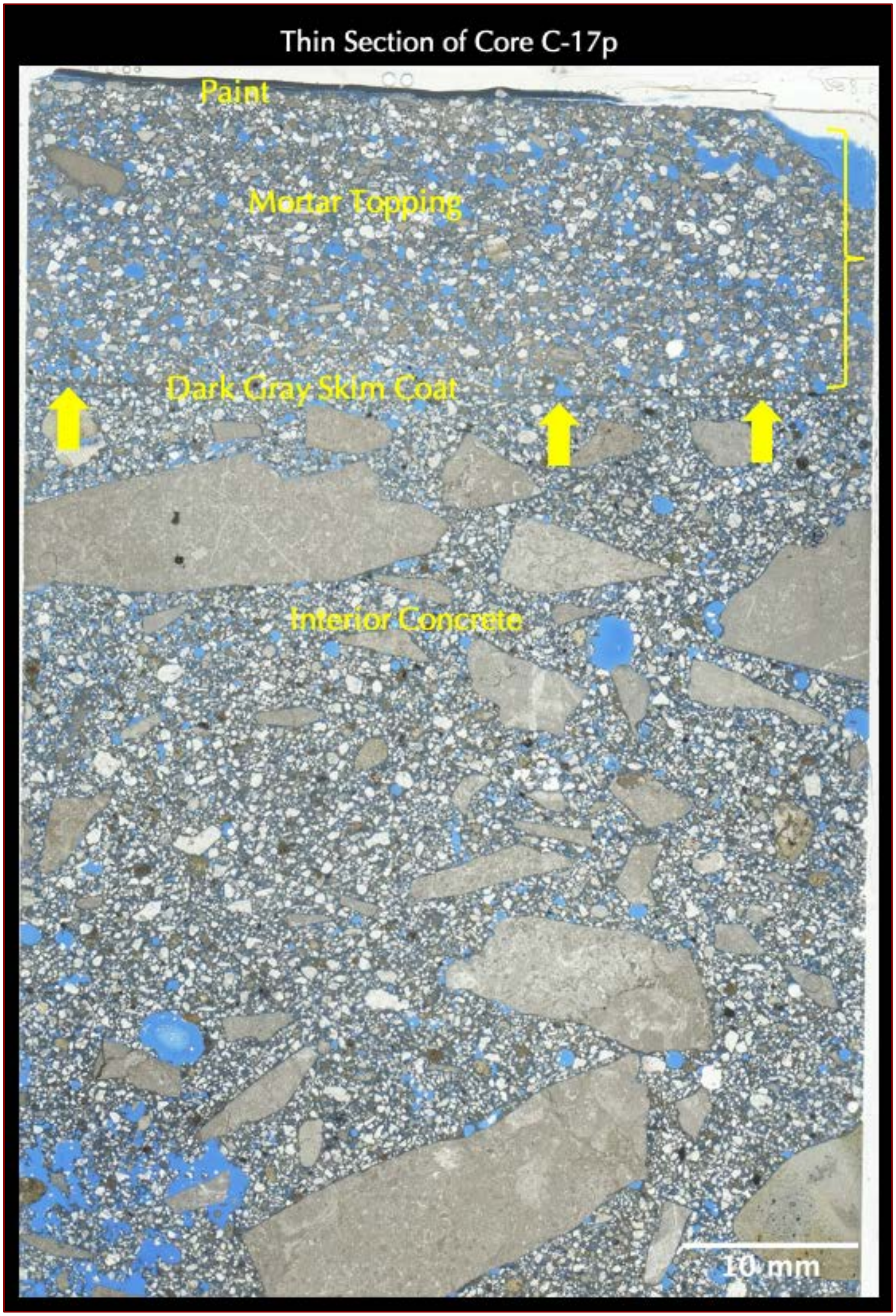


Figure 18: Blue dye-mixed epoxy-impregnated thin section of Core C-17p showing:

(a) Protective coats at the top exposed end of core, where a thick mortar coat is sandwiched between other thinner coats;

(b) Variably dense and porous regions of concrete highlighted by blue epoxy;

(c) Crushed limestone coarse aggregate and a mixture of crushed limestone, seashell fragments, and very fine crushed quartz particles in fine aggregate; and,

(d) The non-air-entrained nature of concrete where air voids are highlighted by blue epoxy.

The image was taken with a flatbed film scanner with a polarizing filter placed on the thin section during scan to highlight voids and porous regions in plane polarized light view.

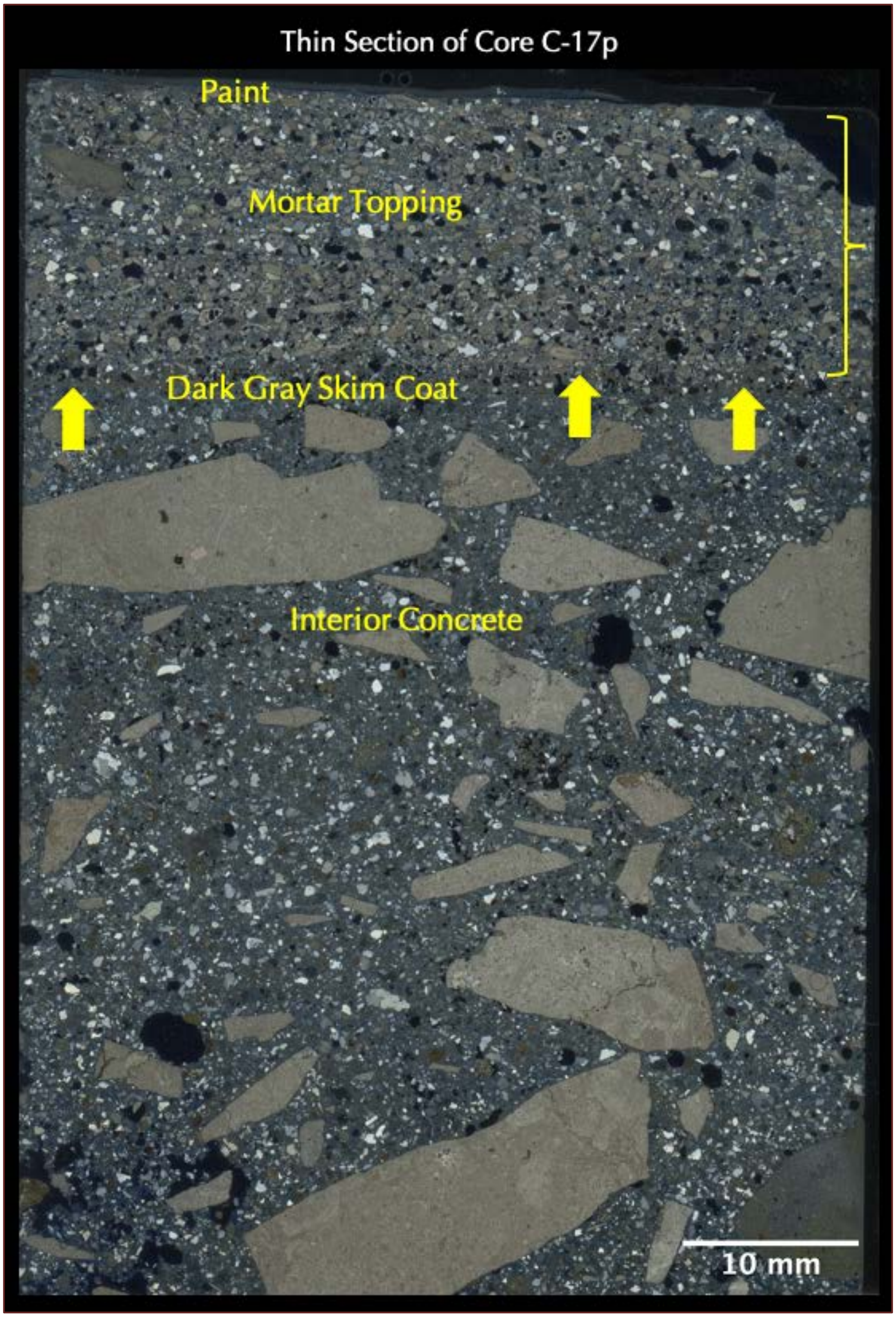


Figure 19: Blue dye-mixed epoxy-impregnated thin section of Core C-17p showing:

(a) Protective coats at the top exposed end of core where a thick mortar coat is sandwiched between other thinner coats;

(b) Variably dense and porous regions of concrete highlighted by blue epoxy;

(c) Crushed limestone coarse aggregate and a mixture of crushed limestone, seashell fragments, and very fine crushed quartz particles in fine aggregate;

(d) The non-air-entrained nature of concrete.

The image was taken with a flatbed film scanner with two perpendicular polarizing filters placed on the thin section during scan to highlight the limestone coarse aggregate, calcareous fine aggregate, and very fine siliceous particles in cross polarized light view.

Notice a higher proportion of crushed fine siliceous particles in this Core compared to Core C-11p.

MICROGRAPHS OF THIN SECTIONS

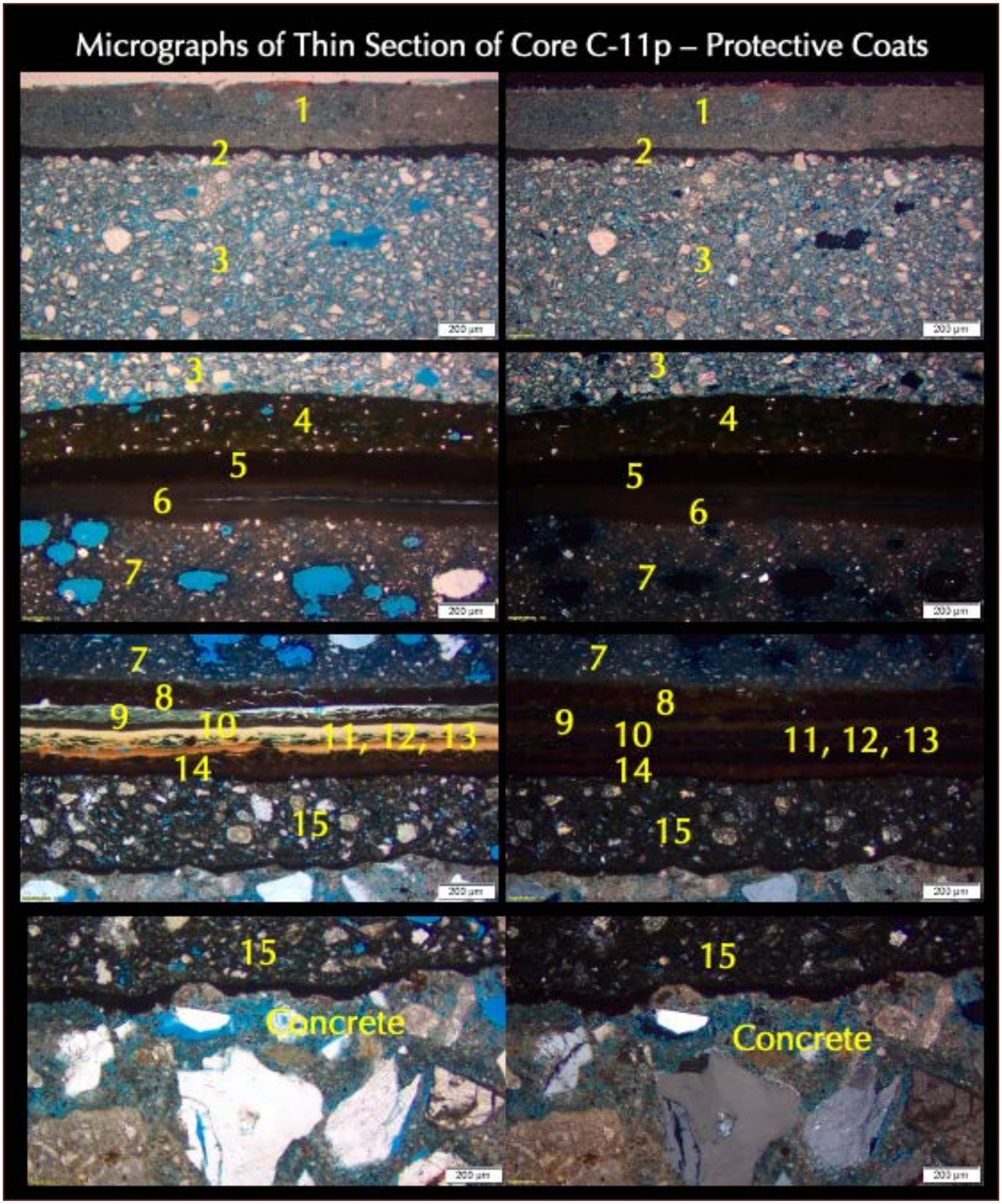


Figure 20: Micrographs of thin section of Core C-11p showing as many as 15 distinct protective coats applied on the exposed surface of concrete that consist of both polymeric (e.g., paint) and crystalline layers, marked as #1 through 15, which are all well-bonded to each other and as a whole well-bonded to underlying concrete.

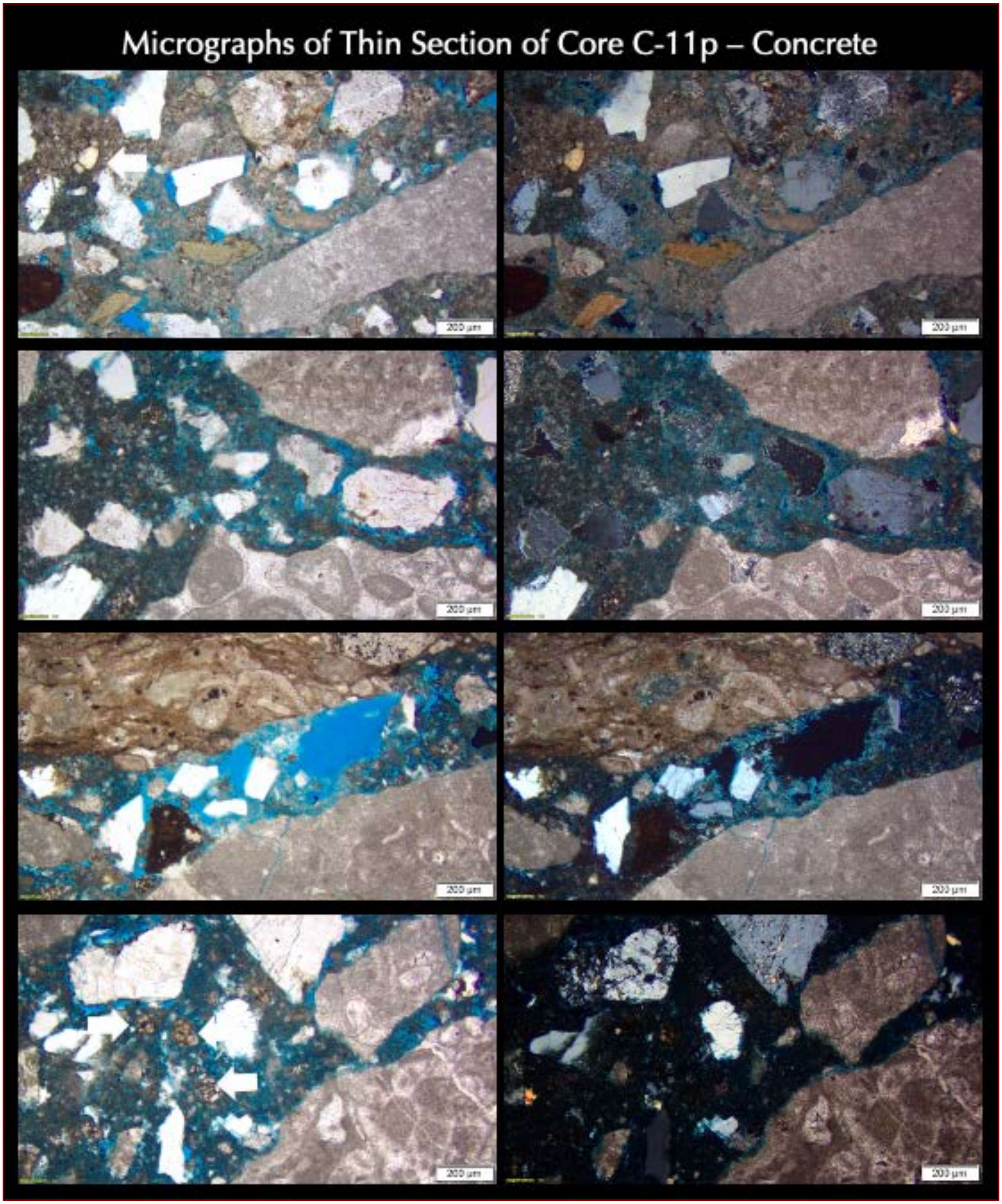


Figure 21: Micrographs of thin section of Core C-11p showing: (a) crushed limestone (biomicrite, biosparite, micrite) coarse aggregate and a mixture of crushed limestone, seashell fragments, and very fine crushed quartz particles in fine aggregate; (b) variably dense Portland cement paste containing many residual Portland cement particles scattered over variably porous and carbonated paste of cement hydration products; and (c) the non-air-entrained nature of concrete where air voids are highlighted by blue epoxy in the left column plane polarized light photos.

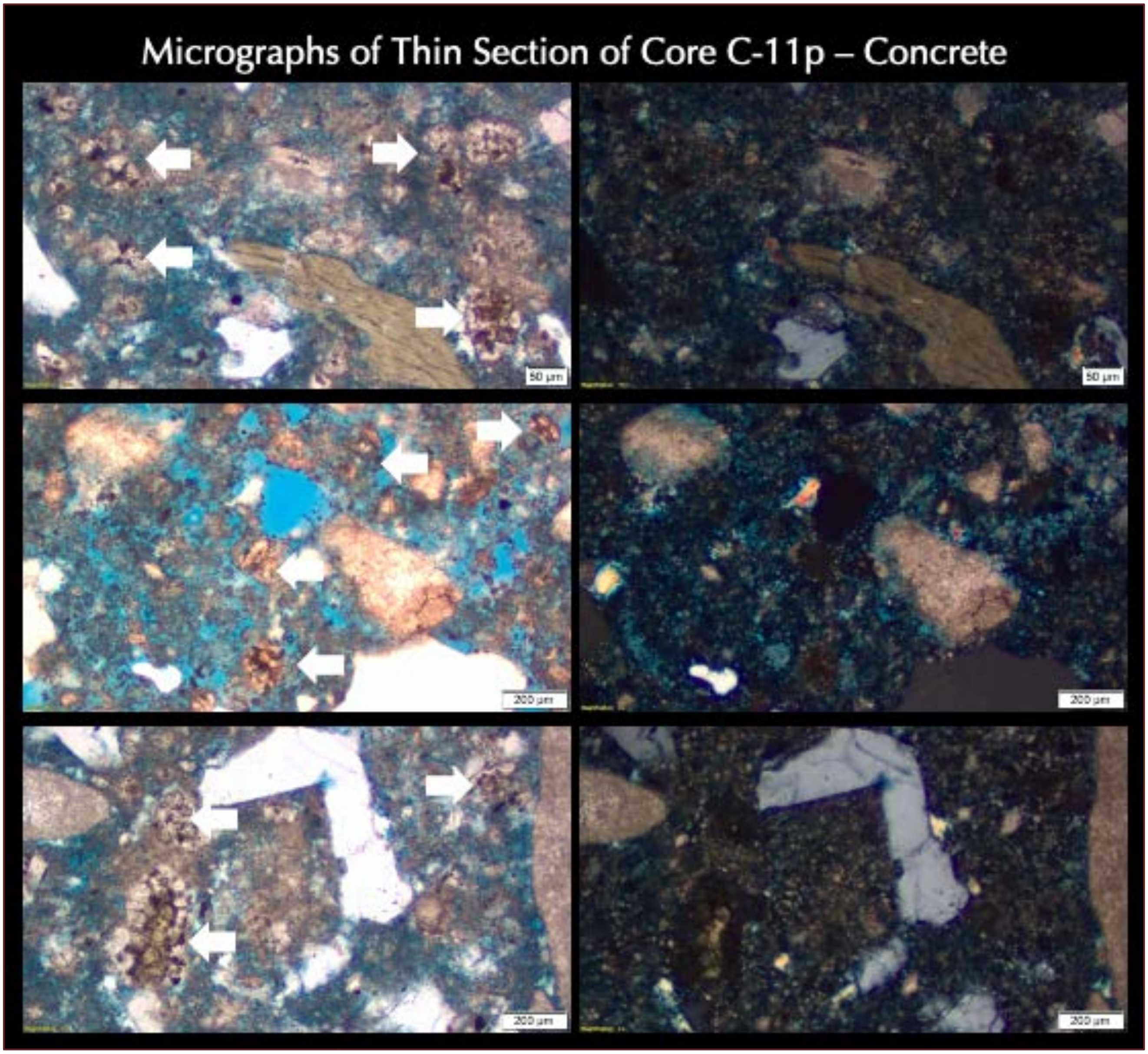


Figure 22: Micrographs of thin section of Core C-11p showing variably dense and porous Portland cement paste containing many residual Portland cement particles (many are indicated by arrows in left column) scattered over variably porous and carbonated paste of cement hydration products.

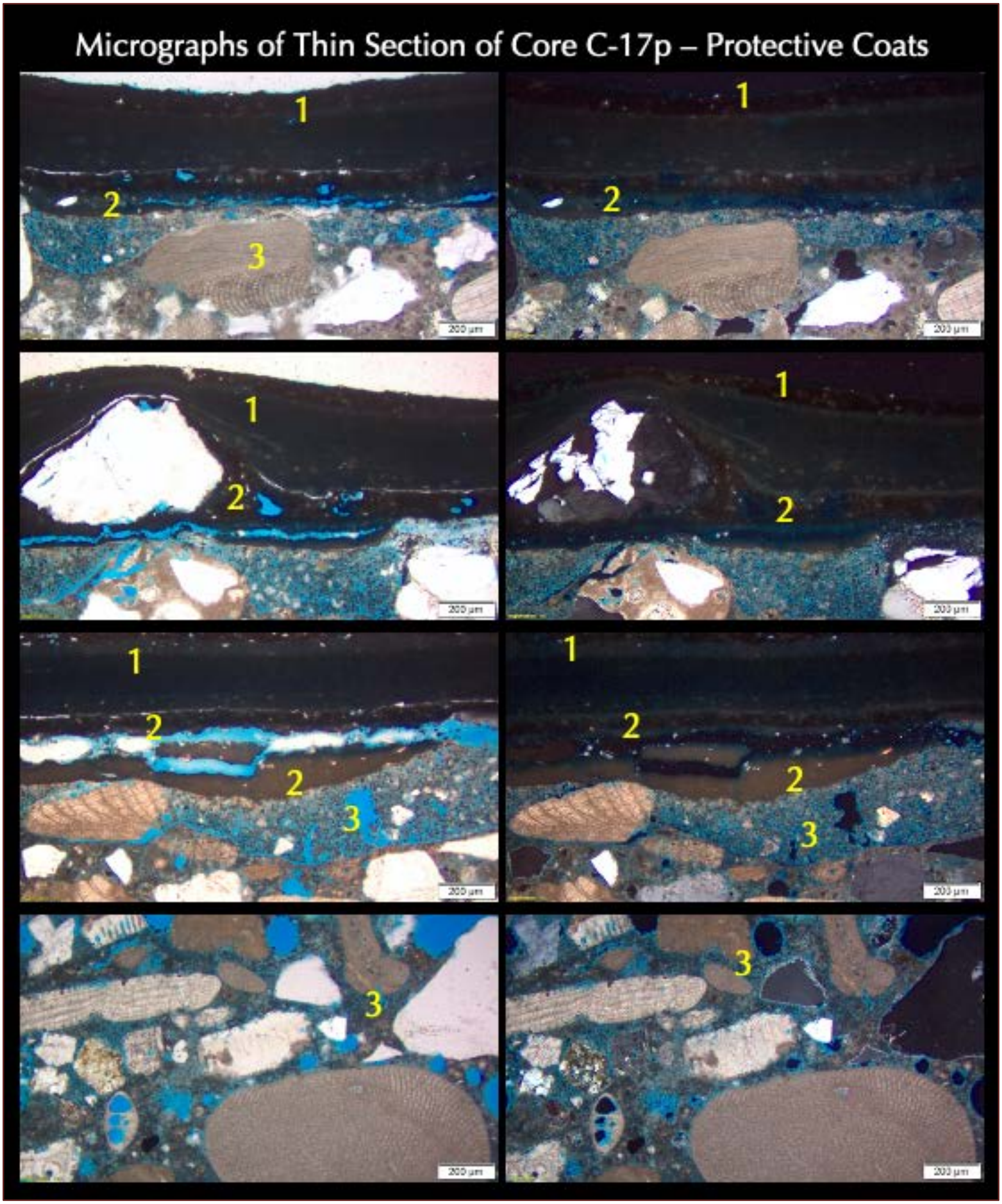

Micrographs of Thin Section of Core C-17p – Protective Coats

Figure 23: Micrographs of thin section of Core C-17p showing as many as 6 distinct protective coats applied on the exposed surface of concrete that consist of both polymeric (e.g., paint) and crystalline layers, marked as #1 through 6, which are all well-bonded to each other and as a whole well-bonded to the underlying concrete.

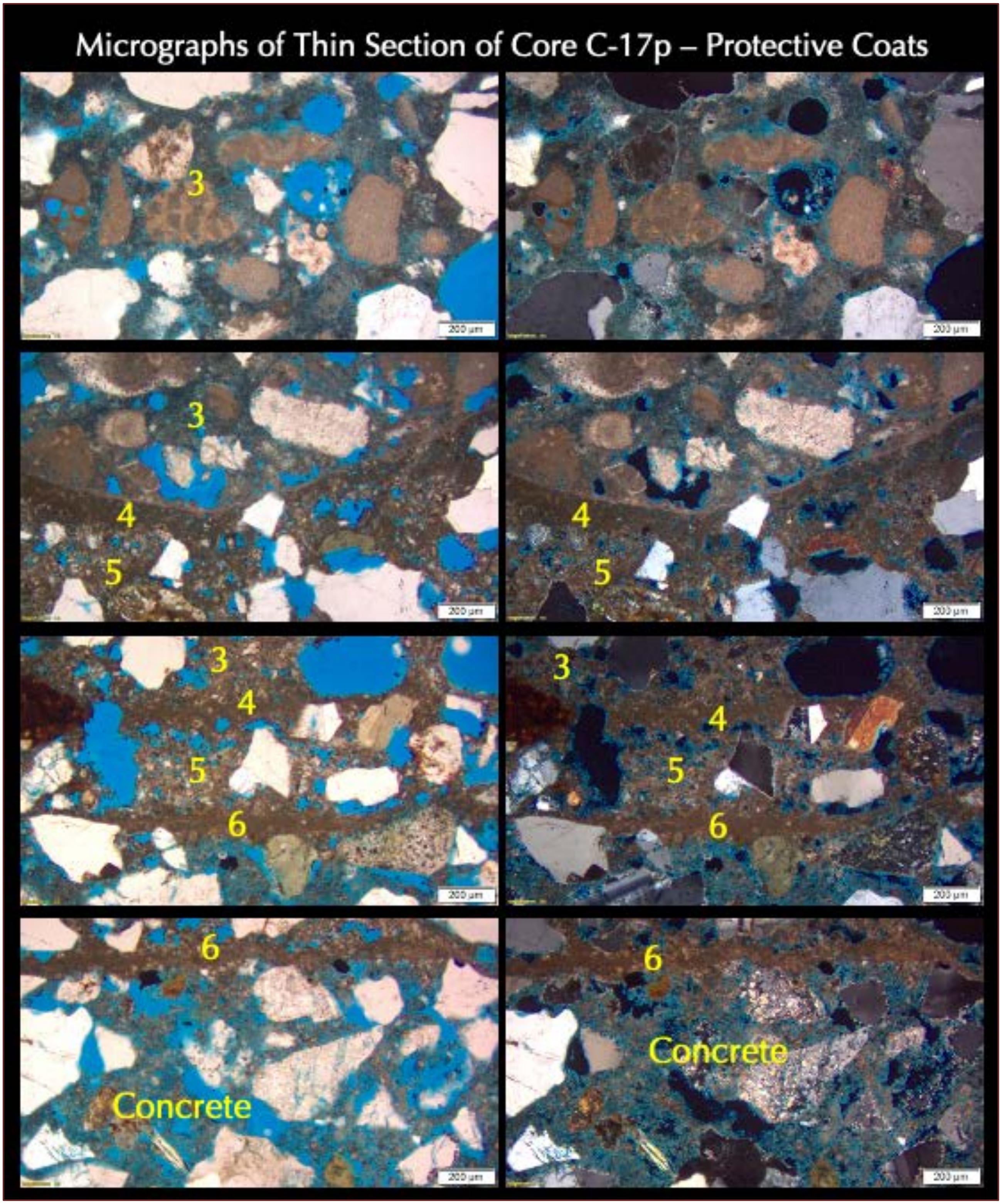

Micrographs of Thin Section of Core C-17p – Protective Coats

Figure 24: Micrographs of thin section of Core C-17p showing as many as 6 distinct protective coats applied on the exposed surface of concrete that consist of both polymeric (e.g., paint) and crystalline layers, marked as #1 through 6, which are all well-bonded to each other and as a whole well-bonded to the underlying concrete.

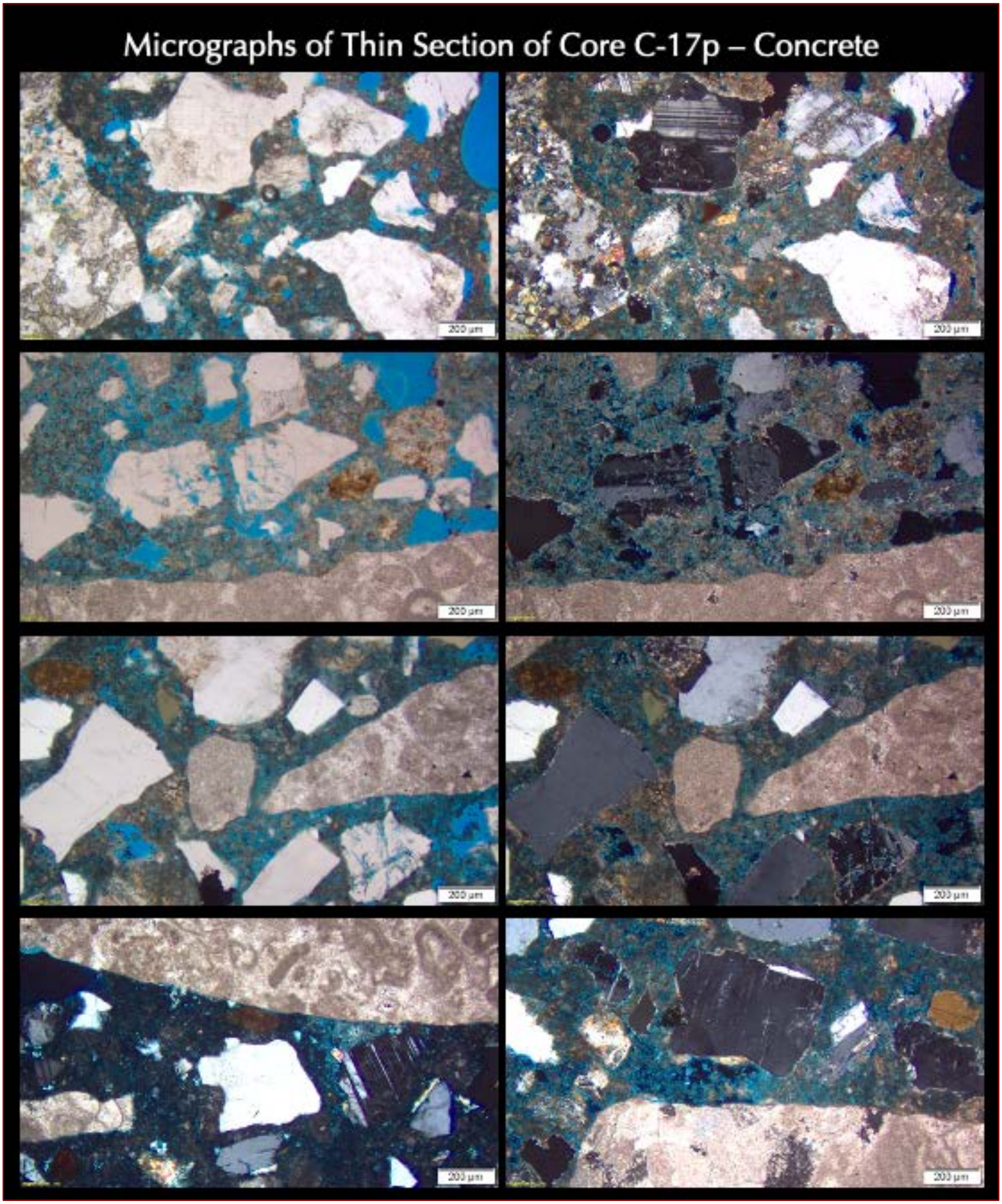


Figure 25: Micrographs of thin section of Core C-17p showing: (a) crushed limestone (biomicrite, biosparite, micrite) coarse aggregate and a mixture of crushed limestone, seashell fragments, and very fine crushed quartz particles in fine aggregate; (b) variably dense Portland cement paste containing many residual Portland cement particles scattered over variably porous and carbonated paste of cement hydration products; and (c) the non-air-entrained nature of concrete where air voids are highlighted by blue epoxy in the left column plane polarized light photos.

COARSE AGGREGATES

Coarse aggregates are compositionally similar crushed limestone in both cores consisting of fossiliferous limestone (biomicrite and biosparite with finer-grained micritic and coarser-grained sparry calcite cement matrix, respectively), and fine-grained (micritic) limestone having nominal maximum sizes of 1 in. (25 mm) in Core C-11p, and $^{3}/_{4}$ in. (19 mm) in Core C-17p. Particles are angular, dense, hard, medium gray, equidimensional to elongated, uncoated, unaltered, and uncracked. Coarse aggregate particles are well-distributed in both cores, but poorly graded in both cores due to the deficiency of some finer and intermediate sizes. Overall proportions of crushed limestone coarse aggregates are lower than the optimum to increase the mortar fractions. There are no evidence of alkali-aggregate reactions of coarse aggregate particles, which are present in sound conditions.

FINE AGGREGATES

Fine aggregates are mixtures of crushed limestone, seashell fragments, and noticeably finer fractions of crushed siliceous particles (quartz, quartzite, feldspar, chert, etc.) in both cores, where the proportions of crushed limestone particles in fine aggregate are higher in Core C-11p than in Core C-17p. The finest silicate fractions of fine aggregate are present at greater abundance in Core C-17p than in C-11p. Such variations in relative proportions of crushed limestone and finer silicate particles in both cores indicate a slight variation in the compositions of fine aggregates used at the locations of both cores even though the crushed limestone coarse aggregate was identical in the concretes placed at those core locations. Fine aggregate particles have nominal maximum sizes of $^{3}/_{8}$ in. (9.5 mm). Particles are angular, moderately dense, moderately hard, off-white to light gray, well-graded and well-distributed. There is no evidence of alkali-aggregate reaction of fine aggregate particles found in the cores. Fine aggregate particles have been sound during their service in both cores.

The following Table summarizes properties of coarse and fine aggregates determined from the cores:

Properties and Compositions of Aggregates	C-11p	C-17p
Coarse Aggregates		
Types	Crushed Limestone	Crushed Limestone
Nominal maximum size (in.)	1 in. (25 mm)	$^{3}/_{4}$ in. (19 mm)
Rock Types	Fossiliferous limestone (biomicrite and biosparite with finer-grained micritic and coarser-grained sparry calcite cement matrix, respectively), and fine-grained (micritic) limestone	
Angularity, Density, Hardness, Color, Texture, Sphericity	Particles are angular, dense, hard, medium gray, equidimensional to elongated	
Cracking, Alteration, Coating	Uncoated, unaltered, and uncracked	
Grading & Distribution	Particles are poorly graded, but well-distributed	
Soundness	Sound; no evidence of any cracking	
Alkali-Aggregate Reactivity	None	

Properties and Compositions of Aggregates	C-11p	C-17p
Fine Aggregates		
Types	Mixtures of crushed limestone, seashell fragments, and noticeably finer fractions of crushed siliceous particles (quartz, quartzite, feldspar, chert, etc.)	
Nominal maximum size	$^{3}/_{8}$ in. (9.5 mm)	
Rock Types	Crushed limestone, seashell fragments, and noticeably finer fractions of crushed siliceous particles	
Cracking, Alteration, Coating	Particles are angular, moderately dense, moderately hard, off-white to light gray, equidimensional to elongated	
Grading & Distribution	Well-graded and Well-distributed	
Soundness	Sound	
Alkali-Aggregate Reactivity	None	

Table 2: Properties of coarse and fine aggregates in two concrete cores.

PASTE

Paste is light gray, moderately hard to moderately soft in Core-11p, and moderately soft to soft in Core-17p. Freshly fractured surfaces have subvitreous lusters and subconchoidal textures. Residual and relict Portland cement particles are present and estimated to constitute 6 to 8 percent of the paste volumes. The calcium hydroxide component of cement hydration occurs as small, platy, patchy units in the sound interior bodies and is estimated to constitute 8 to 10 percent of the paste volume. Hydration of Portland cement is normal. The textural and compositional features of the paste are indicative of Portland cement contents estimated to be approximately 6 to $6^{1}/_{2}$ bags per cubic yard; and water-cement ratios uniform throughout the bodies of the cores and estimated to be 0.55 to 0.60. There is no evidence of any potentially deleterious secondary deposits found in the cores. Carbonation of paste has extended to depths of 10 mm in Core C-11p, and as deep as 40 mm in Core C-17p, however, interior concrete beyond those depths also show sporadic patchy carbonation especially in Core C-11p, which are indicative of inherent porous and permeable nature of concrete to atmospheric carbon dioxide and other potentially deleterious agents. As a result, the protective coats detected on the exposed ends of both cores, though installed only after the concrete at both core locations were carbonated to those depths, are beneficial to prevent further migration of those agents after the installation of protective coats. Bonds between the coarse and fine aggregate particles and paste are moderately tight to weak at some places due to inherent soft porous natures of paste from use of high water-cement ratio mixes.

Properties and Compositions of Paste	C-11p	C-17p
Color, Hardness, Porosity, Luster	Light gray, moderately hard to moderately soft, freshly fractured surfaces have subvitreous lusters and subconchoidal textures	Light gray, moderately soft to soft, freshly fractured surfaces have subvitreous lusters and subconchoidal textures
Residual Portland Cement Particles	Normal, 6 to 8 percent by paste volume in the sound interior concretes	
Calcium hydroxide from cement hydration	Normal, 8 to 10 percent by paste volume in the sound interior concretes	

Properties and Compositions of Paste	C-11p	C-17p
Pozzolans, Slag, etc.	None	None
Water-cement ratio (*w/c*), estimated	0.55 to 0.60, uniform	0.55 to 0.60, uniform
Portland cement contents, estimated	6 to 6$^1/_2$	6 to 6$^1/_2$
Secondary Deposits	None	None
Depth of Carbonation, mm	10 mm and patchy thereafter	40 mm
Microcracking	Shrinkage microcracks	Shrinkage microcracks
Aggregate-paste Bond	Moderately tight to weak	Moderately tight to weak
Bleeding, Tempering	None	None
Chemical deterioration	None except through-depth patchy carbonation prior to the installation of protective coats	None except deep carbonation prior to the installation of protective coats

Table 3: Properties and composition of hardened cement paste.

AIR

In both cores, air occurs as a few coarse, near-spherical and irregularly shaped entrapped voids having sizes >1 to 2 mm. Concretes in both cores are non-air-entrained, having air contents estimated to be 3 to 4 percent.

PROTECTIVE COATS

Both cores showed the presence of multiple layers of protective coats, which are determined to be 4 to 5 mm total in Core C-11p, and 16 to 17 mm total in Core C-17p. These coats were applied after the concrete was carbonated to as deep as 40 mm at the location of Core C-17p. Figures 12, 14, 20, 23, and 24 show the coats in detail.

DISCUSSIONS

POOR QUALITY OF CONCRETE

Concrete in the two examined cores reportedly retrieved from Normandie Hotel situated in the vicinity of marine environment in San Juan, Puerto Rico, was apparently prepared with a high water-cement ratio mix consisting of crushed limestone coarse aggregate, mixed crushed limestone, seashell, and finer siliceous fragments of fine aggregate, Portland cement estimated to be 6 to 6$^1/_2$ bags per cubic yard, and water at estimated water-cement ratios of 0.55 to 0.60. Such high *w/c* in concrete is potentially detrimental to long-term performance and serviceability in a marine environment since the aggressive agents in the environment from chloride to atmospheric carbon dioxide can penetrate deep into a porous and permeable concrete from the use of high *w/c* mix.

SOUND CONDITION OF CONCRETE

Despite the determined soft, porous, high water-cement ratio of paste with deep carbonation, there is, however, no evidence of any physical or chemical deterioration of concrete detected in the cores. Both crushed limestone coarse aggregate and fine aggregate are present in sound conditions without any potentially deleterious reactions.

POTENTIAL FOR CARBONATION-INDUCED CORROSION OF STEEL

Due to the overall soft, porous, high water-cement ratio natures of paste, atmospheric carbonation has extended as deep as 40 mm at the location of Core C-17p, and from severe carbonation at the top 10 mm of exposed end to patchy carbonation throughout the retrieved depth in Core C-11p. Such deep carbonation from inherent porous and permeable high water-cement ratio concrete can initiate corrosion of reinforcing steel in concrete in the presence of oxygen and moisture. There is, however, no evidence of any reinforcing steel detected in either core, or evidence of corrosion of steel in concrete.

POTENTIAL FOR CHLORIDE-INDUCED CORROSION OF STEEL

Due to the suspected high chloride environment, water-soluble chloride contents should be determined from the exposed ends to the interior of the cores to determine the depth of penetration of chloride. Chloride, especially in a carbonated concrete can easily initiate corrosion of steel in the presence of oxygen and moisture. Therefore, additional chloride content analyses at the exposed end and interior depths of the cores are recommended.

BENEFICIAL ASPECTS OF THE OBSERVED MULTI-LAYER PROTECTIVE COATS

Due to the determined soft, porous, high water-cement ratio nature of the paste in both cores and thus overall permeable nature of paste to migration of potentially deleterious agents from the marine environment, having those multi-layered protective coats are beneficial for long-term durability and serviceability of concrete.

REFERENCES

ASTM C 856 "Standard Practice for Petrographic Examination of Hardened Concrete," Vol. 4.02, ASTM International, West Conshohocken, PA, 2016.

Jana, D., "Sample Preparation Techniques in Petrographic Examinations of Construction Materials: A State-of-the-art Review," *Proceedings of the 28th Conference on Cement Microscopy*, International Cement Microcopy Association, Denver, Colorado, pp. 23-70, 2006.

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END OF REPORT[1]

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[1] The CMC logo is made using a lapped polished section of a 1930's concrete from an underground tunnel in the U.S. Capitol.