CONSTRUCTION MATERIALS CONSULTANTS, INC.

Petrographic Examinations of Two Concrete Cores From A Wastewater Tank

Arroyo Pump Station
Arroyo, Puerto Rico

July 15, 2020
CMC 0720133

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EXECUTIVE SUMMARY

The following study is a continuation of a prior study of two concrete cores collected from a column and a wall of a wastewater tank at Arroyo Pump Station located in Arroyo, Puerto Rico. The study was reported in CMC 1213245 dated January 3, 2014 for Project No. L3125-13. The present report provides further results of detailed petrographic examinations of two additional concrete cores collected from the east wall reportedly without any wastewater influence, and one in the south entrance channel that receives fluctuations of sewer water levels. The purposes of the present investigation, as before, are to determine the conditions, compositions, and qualities of the concretes in the cores, diagnose evidence of any chemical and/or physical deterioration of concretes in the cores, and if so, determine the depths or extents of such deteriorations. The cores were analyzed by detailed petrographic examinations *a la* ASTM C 856 "Standard Practice for Petrographic Examination of Hardened Concrete."

Based on detailed petrographic examinations, concretes in both cores are determined to be compositionally similar, i.e. made using the same or similar coarse and fine aggregates and cementitious materials (i.e. probably derived from the same or similar concrete mixes). Concrete from the east wall is determined to be *air-entrained* which is similar to two previously examined cores, whereas concrete from the south entrance channel is found to be non-air-entrained.

Both cores, as the previous ones contain crushed gravel coarse aggregates having nominal maximum sizes of $^{3}/_{4}$ in. Coarse aggregate particles are well-graded, well-distributed, subangular to subrounded, and have been sound during their service in the concretes. Particles contain both volcanic igneous rocks (basalt and trachyte), and, sedimentary rocks (siltstone, sandstone, mudstone), which are compositionally similar in both cores. There is no evidence of alkali-silica aggregate reaction of coarse aggregate particles detected in the concretes in either core, which is despite the presence of some potentially reactive particles, e.g., trachyte. This finding is consistent with lack of reactivity of crushed gravel particles found in the two previously examined cores.

Fine aggregate contains a mixture of basaltic and natural siliceous-calcareous sand having nominal maximum sizes of $^{3}/_{8}$ in. and containing major amounts of basalt, and moderate amounts of shale, feldspar, quartz, limestone, siltstone, mafic minerals, and ferruginous rocks. Fine aggregate particles are compositionally similar to the ones found in two previous cores, well-graded, well-distributed, and have been sound during their service in the concretes. There is no evidence of alkali-aggregate reaction of fine aggregates detected in the concretes.

Both coarse and fine aggregates are glued together by hardened Portland cement pastes having similar Portland cement contents in both cores, estimated to be $5^{1}/_{2}$ to 6 bags per cubic yard. There is no evidence of use of any other pozzolanic or cementitious materials (e.g., fly ash, slag, etc.) in the concretes, Portland cement was the only cementitious material used in the concretes. These finding are consistent with the ones observed during examinations of wall and column cores in the previous study. Water-cement ratios of the pastes are uniform throughout the bodies in both cores, which are similar and estimated to be 0.40 to 0.45; which values are similar to the ones found for previously tested cores from wall and column.

Previously studied wall core showed a thin mortar coating (~3 mm) containing calcareous-siliceous sand aggregates, and Portland cement as the sole cementitious material, having a *w/c* of 0.40 to 0.45, which was non-air-entrained, and completely carbonated. Depths of carbonation of pastes from exposed ends were only 3 to 4 mm in the column core and 1 to 2 mm in the wall core, which are shallow and indicative of sound, good, well-consolidated concretes in the cores where penetration of atmospheric carbon dioxide was minimal.

The present two cores from east wall and south entrance did not show any mortar coating. However, evidence of fluctuation of wastewater level in the south core is seen as bands or zones of variable alteration of paste, which is confined within the top 5 to 6 mm of the exposed end, beyond which the concrete is sound, unaltered, and serviceable. East wall core does not show any such alterations, which is consistent with its reported retrieval from an area that does not have wastewater influence.

The interior bodies of both cores have uniform and similar light gray colors and sound appearances of concretes; the interior bodies of both cores are free of any deleterious cracking or microcracking that is indicative of the absence of any potentially deleterious chemical or physical reactions of concretes; the interior concretes in both cores are found to be sound and free of any deteriorations. This is consistent with the findings in the previously examined wall and column cores.

The overall qualities and conditions of concretes in the main bodies of both cores are judged to be sound with no evidence of any physical or chemical deterioration. The interior concretes are dense, well-consolidated, and should be serviceable in their intended environment.

INTRODUCTION

Reported herein are the results of continuation of a prior study of two concrete cores collected from a column and a wall of a wastewater tank at Arroyo Pump Station located in Arroyo, Puerto Rico. The present report provides further results of detailed petrographic examinations of two additional concrete cores, one collected from the east wall reportedly without any wastewater influence, and one in the south entrance channel that receives fluctuations of sewer water levels.

BACKGROUND INFORMATION

This study is a continuation of a prior study of Column and Wall cores reported in CMC 1213245 dated January 3, 2014.

As mentioned, in addition to cores from the column and wall which were tested before, two additional cores were provided this time from the east wall and south entrance where concrete in the east wall core was not exposed to wastewater whereas the south entrance core has concrete that receives fluctuations of sewer water levels.

Reported corrosion potential tests showed no signs of corrosion of reinforcing steel in concrete. Concrete is reportedly segregated in several areas due to the fumes of the wastewater.

To determine an appropriate repair strategy, overall condition of the concrete is needed to be evaluated. Therefore, the present petrographic examinations of the cores were done.

PURPOSES OF PRESENT INVESTIGATION

The purposes of the present investigation are to determine: (a) the conditions, compositions, and qualities of the concretes in the cores; and (b) evidence of any chemical and/or physical deterioration of concretes in the cores, and if so, the depths or extents of such deteriorations.

METHODOLOGIES

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 samples include:

i. Visual examinations of samples, as received, with particular reference of any visible cracking near the exposed surfaces;

ii. Low-power stereo-microscopical examinations of as-received, saw-cut and freshly fractured sections, and lapped cross sections of samples 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 concretes in a petrographic microscope for detailed compositional and microstructural analyses;

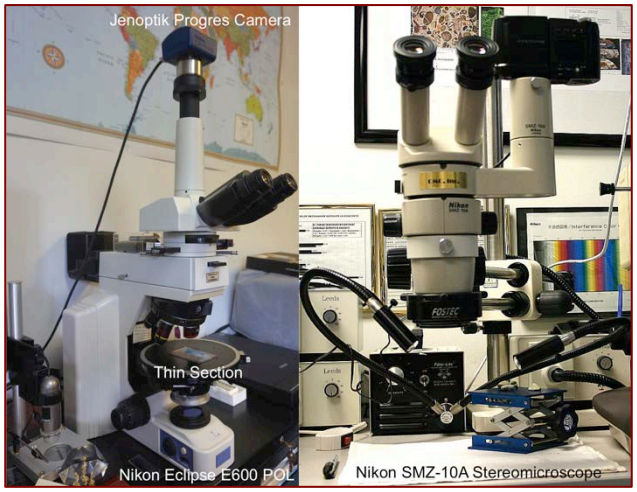

Figure 1: Nikon Eclipse E600 POL petrographic microscope and Nikon SMZ-10A stereomicroscope used for examinations of thin sections and lapped sections of concrete cores, respectively.

v. Determination of depth of carbonation and other alterations of paste from the surfaces in contact with the elements in wastewater;

vi. Photographing the samples, as received and at various stages of preparation with digital camera and scanner;

vii. Micrographs of lapped sections and thin sections of samples taken with stereomicroscope and petrographic microscope, respectively, to provide detailed compositional and mineralogical information of concrete.

viii. A Jenoptik Progres GRYPHAX camera attached to a Nikon Eclipse 600 POL petrographic microscope (equipped with reflected, transmitted, polarized and fluorescent-light facilities), a Jenoptik Progres C14 camera attached to an Olympus SZH reflected and transmitted-light stereomicroscope, and an OMAX digital camera attached to a Nikon SMZ-10A low-power stereomicroscope were used together for detailed optical microscopical examinations and associated digital photomicrography (Figure 1).

SAMPLES

PHOTOGRAPHS, IDENTIFICATION, INTEGRITY, AND DIMENSIONS

Figures 2 to 5 show the two concrete cores as received from East Wall and South Entrance.

Sample ID	Diameter	Length	Exterior Surface	Interior Surface	Cracking	Embedded Items	Integrity
South	2 in. (50 mm)	$7^{1}/_{2}$ in (190 mm)	Exposed fine aggregate, weathered dark gray	Fresh fractured	Cracked 95 mm from Exterior surface	None	Broken, Dry, Ring
East	2 in. (50 mm)	$5^{3}/_{4}$ in (150 mm)	Weathered, dark gray, exposed fine aggregate	Fresh fractured	None	None	Intact, Dry, Ring

Table 1: Dimensions and conditions of the two cores, as received.

Figure 2: Shown are the side cylindrical surfaces of the core from East Wall, as received. Both photos of the same core show overall dense and well-consolidated nature of concrete and the absence of any coarse voids or visible cracks in the wall at this core location.

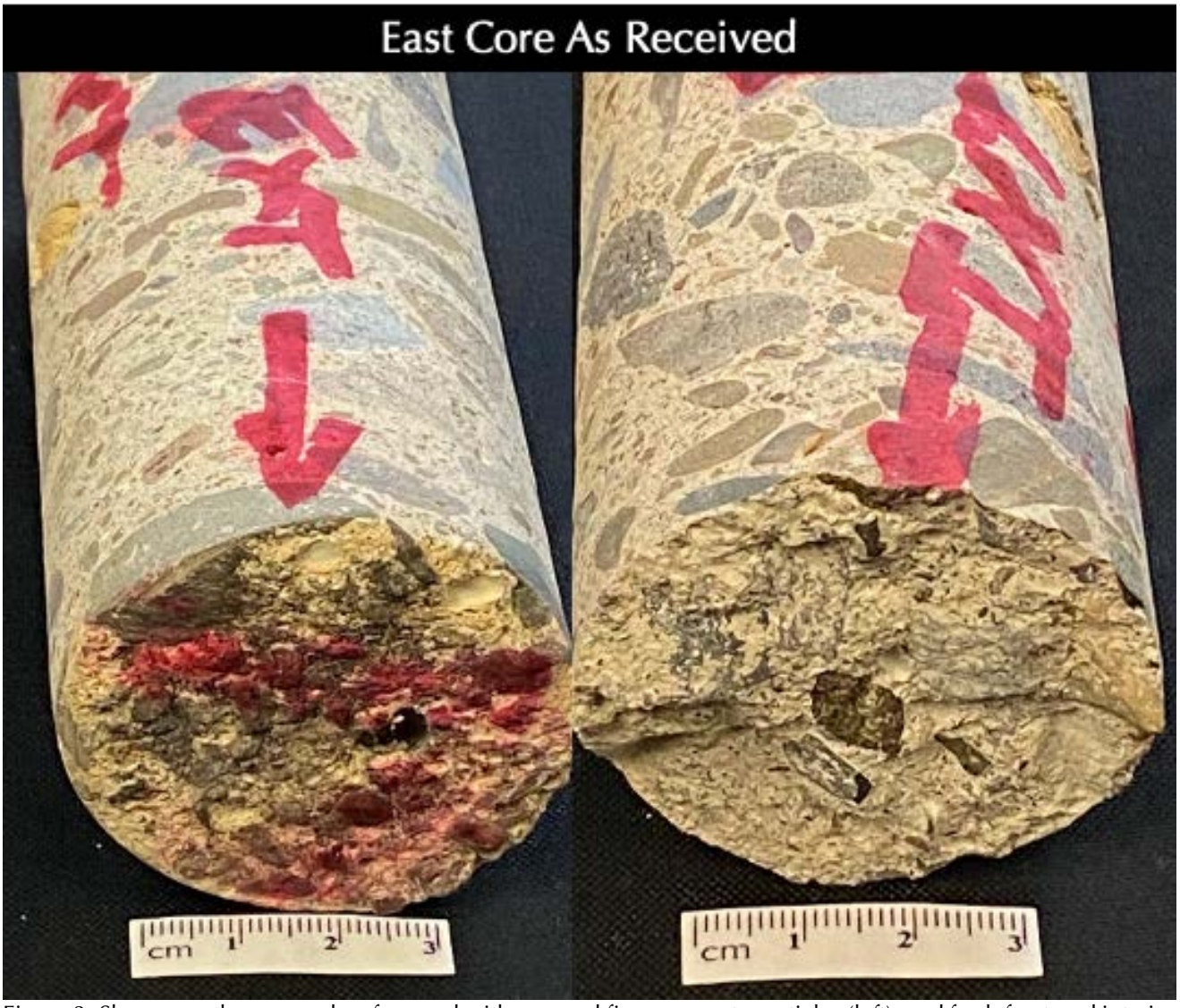

Figure 3: Shown are the exposed surface end with exposed fine aggregate particles (left), and fresh fractured interior surface (right) of the core from East Wall, as received. Notice some dark discoloration at the exposed end as well as exposures of aggregate particles, which are unrelated to any influence of wastewater since the core was reportedly retrieved from an area without any wastewater contamination.

Figure 4: Shown are the side cylindrical surfaces of the core from the South Entrance Channel, as received. Both photos of the same core show overall dense and well-consolidated nature of concrete and the absence of any coarse voids. The crack at the middle is judged to have formed during the coring operations and/or during transport.

Figure 5: Shown are the exposed surface end with exposed fine aggregate particles (left), and fresh fractured interior surface (right) of core from the South Entrance Channel, as received. The exposed surface is the result of intermittent exposure of reported fluctuations of wastewater levels.

PETROGRAPHIC EXAMINATIONS

LAPPED CROSS SECTIONS

Figure 6: Lapped cross sections of the core from the East Wall showing: (a) good grading and well-distribution of the aggregate particles; and (b) the overall sound, dense, well-consolidated nature of the concrete in the body of the core. The concrete contains crushed gravel coarse aggregate particles, which are consistent with the coarse aggregate found in the previous studies of wall and column cores.

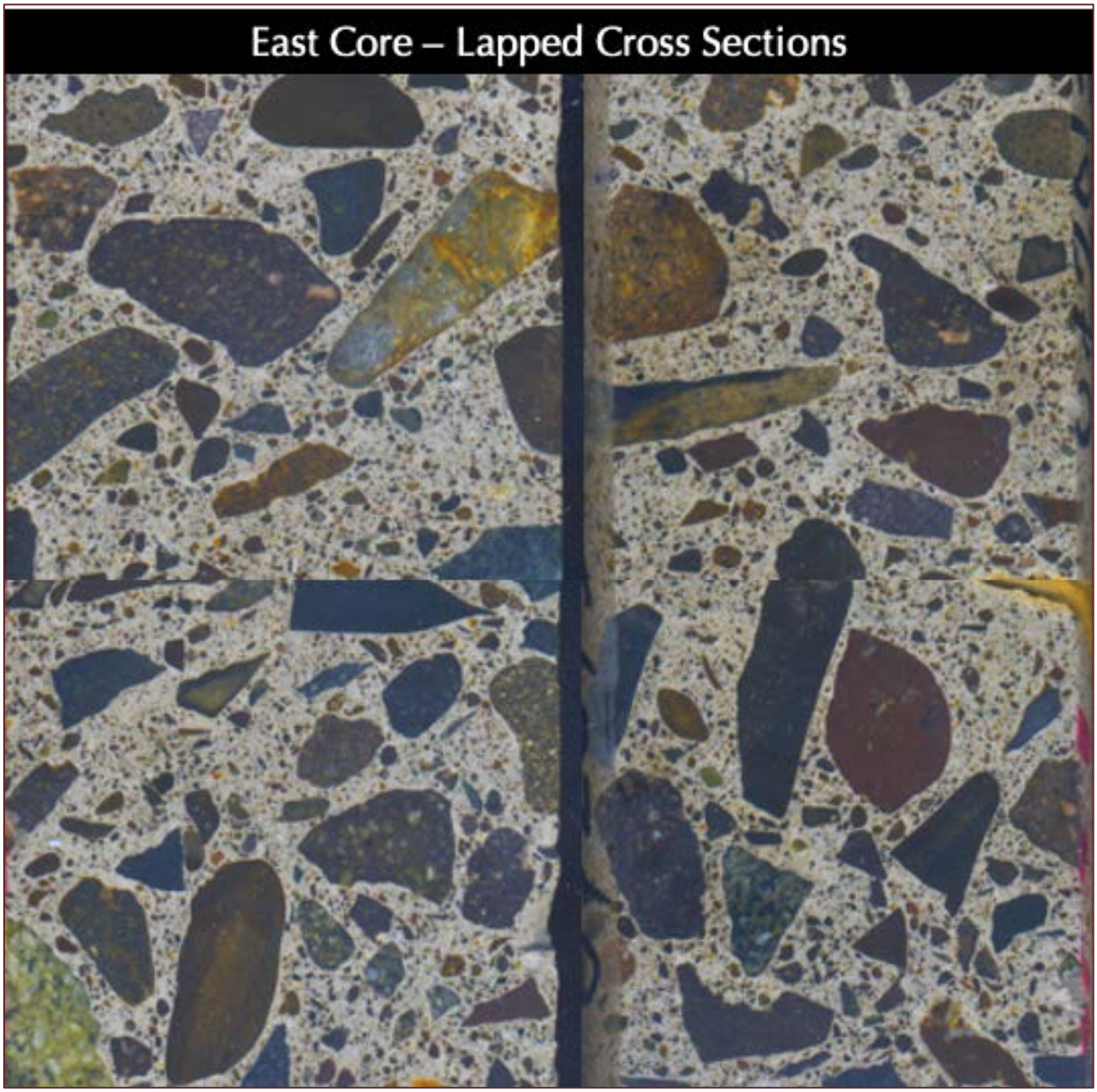

Figure 7: Lapped cross sections of the core from the East Wall showing: (a) good grading and well-distribution of the aggregate particles; and (b) the overall sound, dense, well-consolidated nature of the concrete in the body of the core. Particles have nominal maximum sizes of $^{3}/_{4}$ in. Particles contain both volcanic igneous rocks (basalt and trachyte), and, sedimentary rocks (siltstone, sandstone, mudstone), which are compositionally similar in both cores; there is no evidence of alkali-silica aggregate reaction of coarse aggregate particles detected in the concretes in either core; despite potential reactivity of trachyte there is no evidence of any such reaction of trachyte particles in the coarse aggregates in concretes.

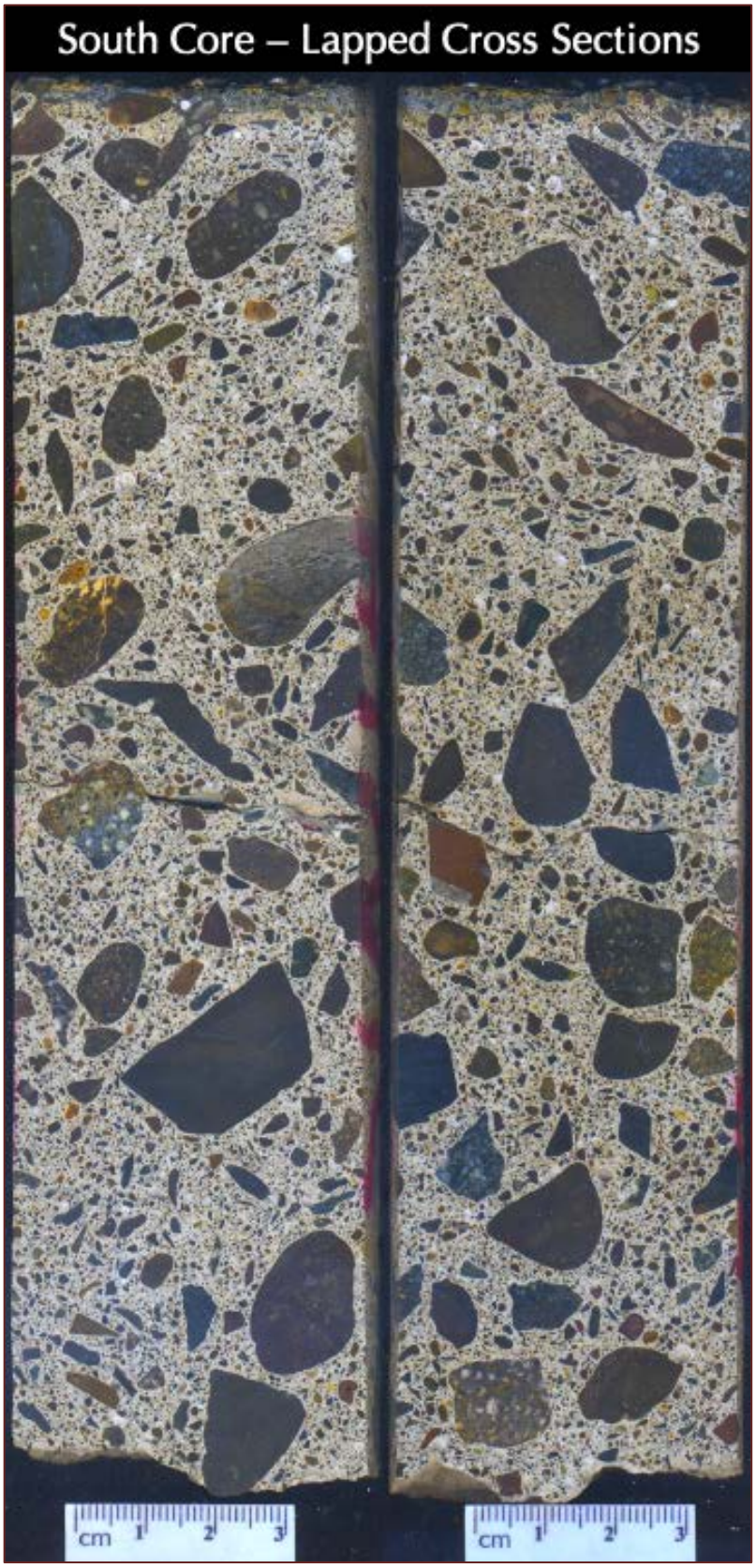

Figure 8: Lapped cross sections of the core from the South Entrance showing: (a) good grading and well-distribution of the aggregate particles; and (b) the overall sound, dense, well-consolidated nature of the concrete in the body of the core.

Figure 9: Lapped cross sections of the core from the south entrance showing: (a) good grading and well-distribution of the aggregate particles; and (b) the overall sound, dense, well-consolidated nature of the concrete in the body of the core. Particles have nominal maximum sizes of $^{3}/_{4}$ in. Particles contain both volcanic igneous rocks (basalt and trachyte), and, sedimentary rocks (siltstone, sandstone, mudstone), which are compositionally similar in both cores; there is no evidence of alkali-silica aggregate reaction of coarse aggregate particles detected in the concretes in either core; despite potential reactivity of trachyte there is no evidence of any such reaction of trachyte particles in the coarse aggregates in concretes.

Figure 10: Lapped cross sections of two previously tested cores from the column and wall which shows overall compositional similarities with the present two cores from East Wall and South Entrance. However, the previous two cores had a thin mortar coating on their exposed ends. No such coatings are found in the present cores.

MICROGRAPHS OF LAPPED CROSS SECTIONS

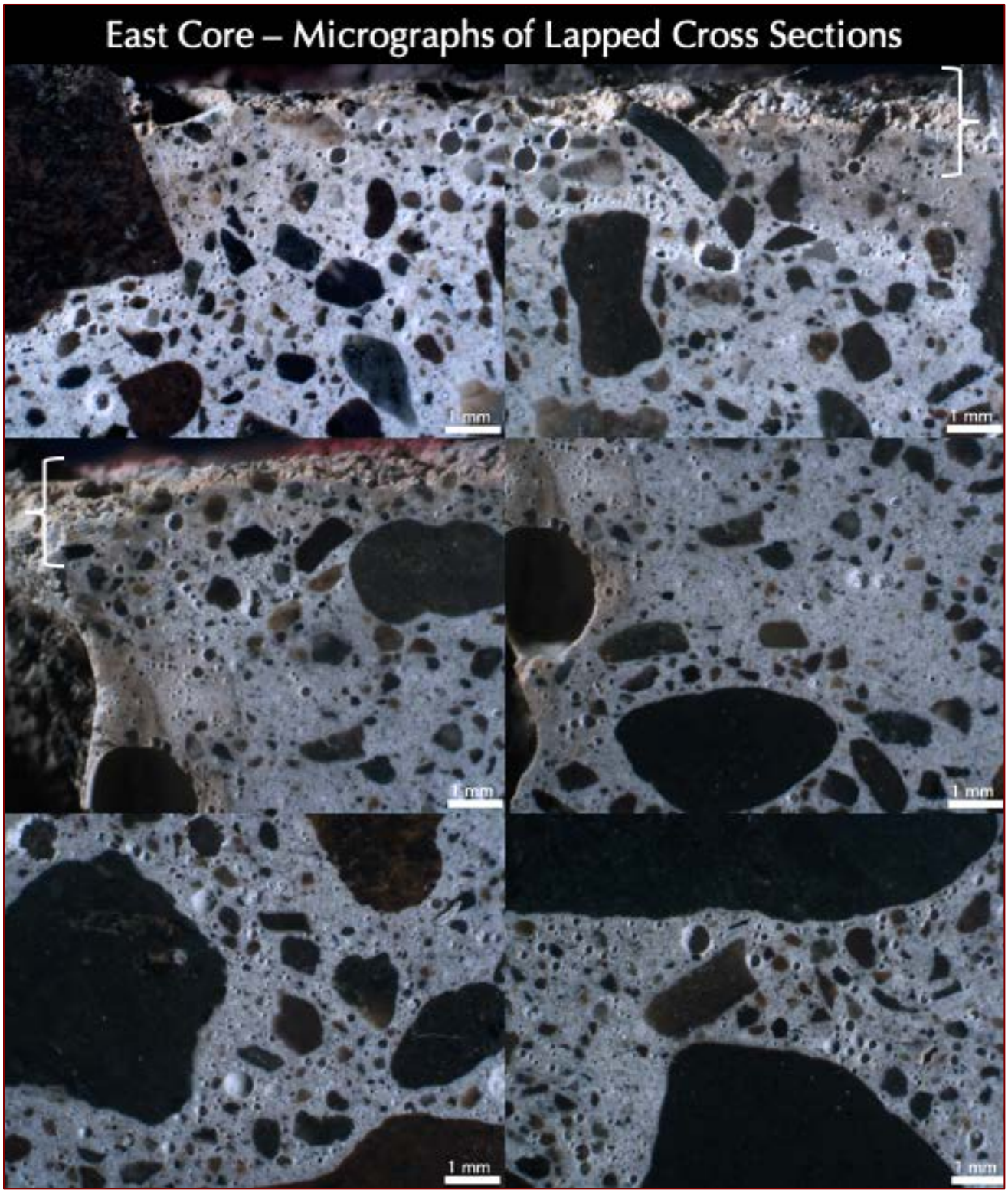

Figure 11: Micrographs of lapped cross section of the core from East Wall showing: (a) shallow carbonation and surface alteration to a depth of 1 to 2 mm in the top row photos; (b) the air-entrained nature of the concrete (all photos); and (c) the overall sound, dense, well-consolidated nature of the concrete in the core (all photos).

Figure 12: Micrographs of lapped cross section of the core from East Wall showing: (a) the air-entrained nature of the concrete (all photos); and (b) the overall sound, dense, well-consolidated nature of the concrete in the core (all photos).

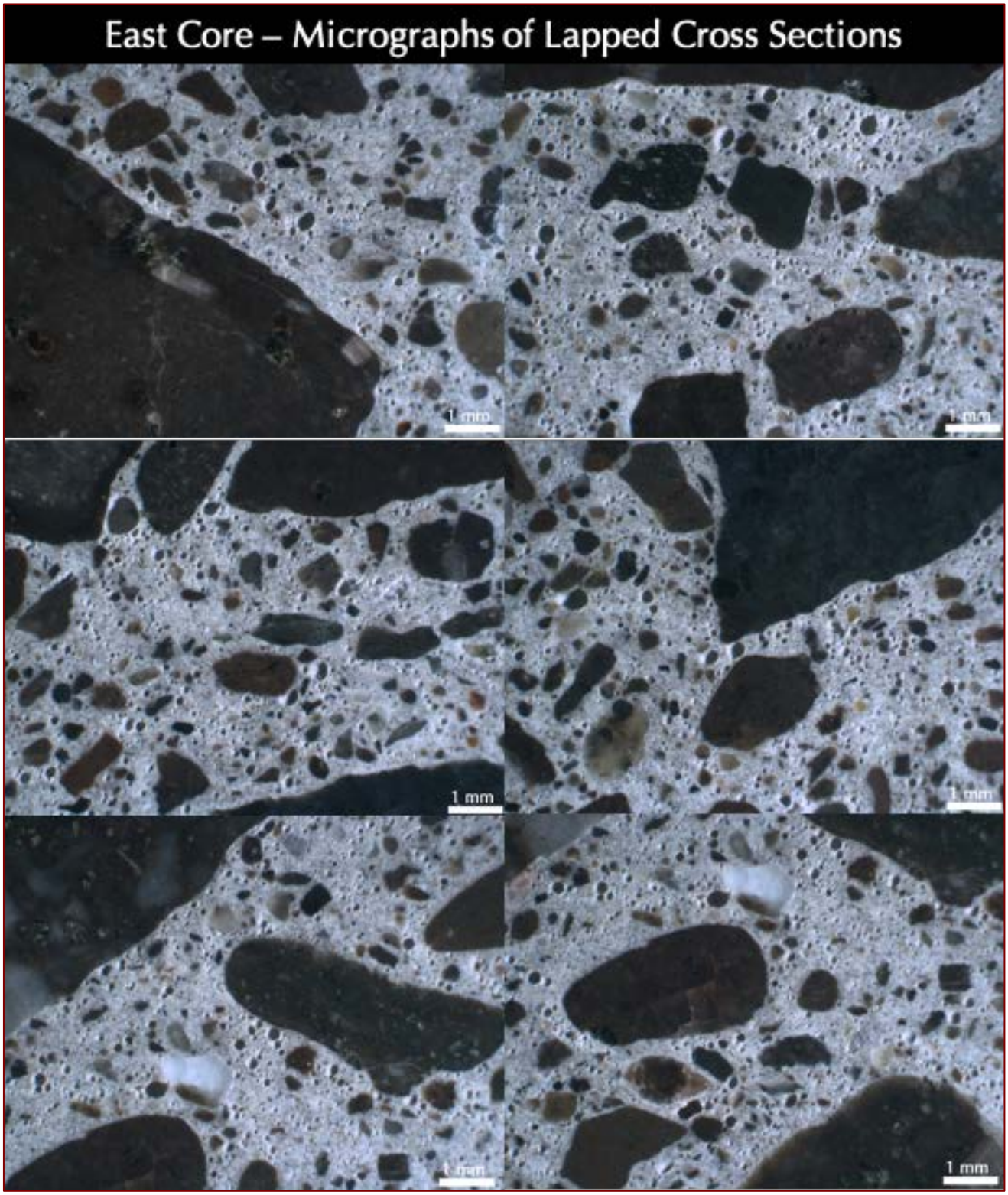

Figure 13: Micrographs of lapped cross section of the core from East Wall showing: (a) the air-entrained nature of the concrete (all photos); and (b) the overall sound, dense, well-consolidated nature of the concrete in the core (all photos).

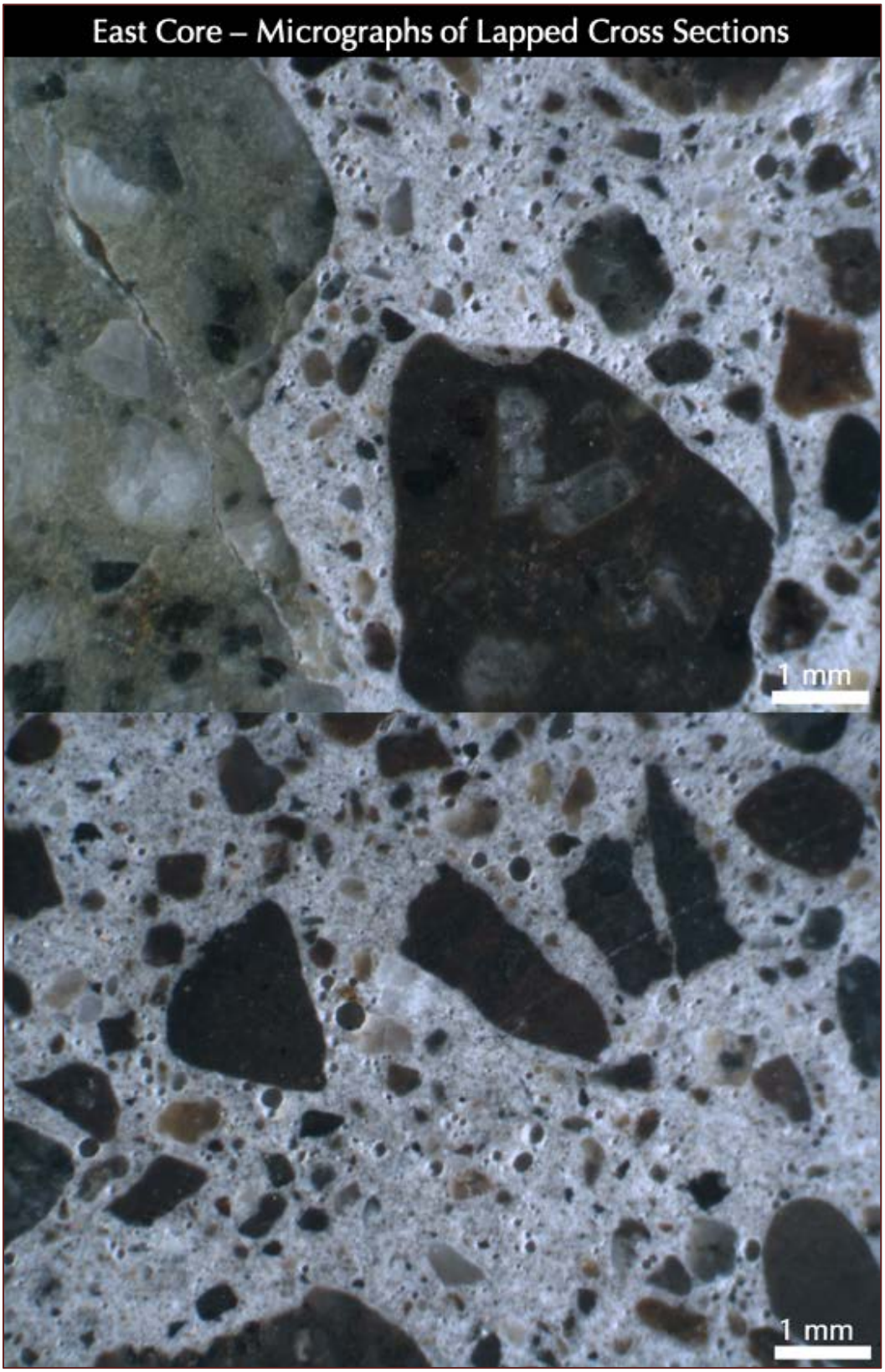

Figure 14: Micrographs of lapped cross section of the core from East Wall showing: (a) the air-entrained nature of the concrete (all photos); and (b) the overall sound, dense, well-consolidated nature of the concrete in the core (all photos).

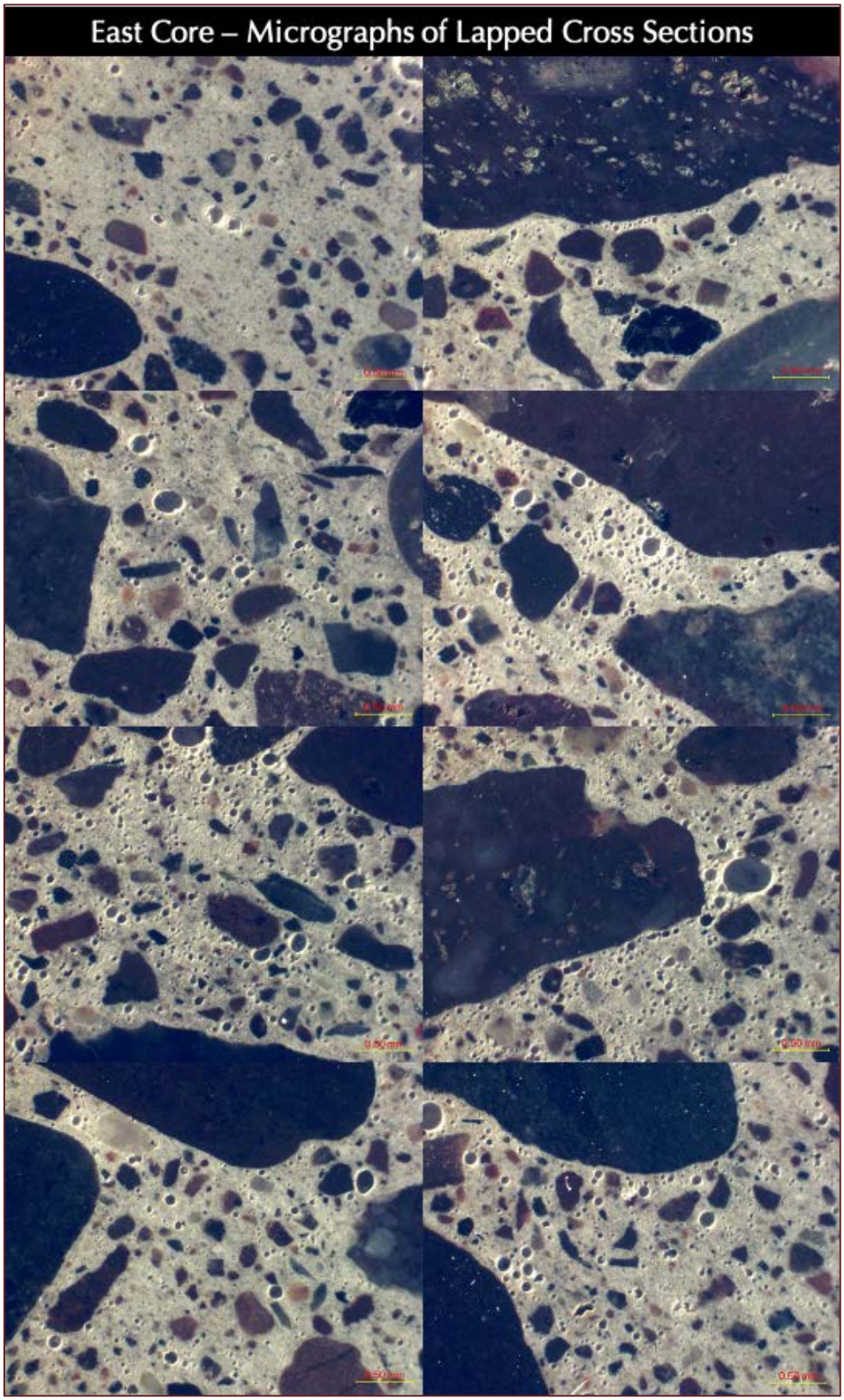

Figure 15: Micrographs of lapped cross section of the core from East Wall showing: (a) the air-entrained nature of the concrete (all photos); and (b) the overall sound, dense, well-consolidated nature of the concrete in the core (all photos).

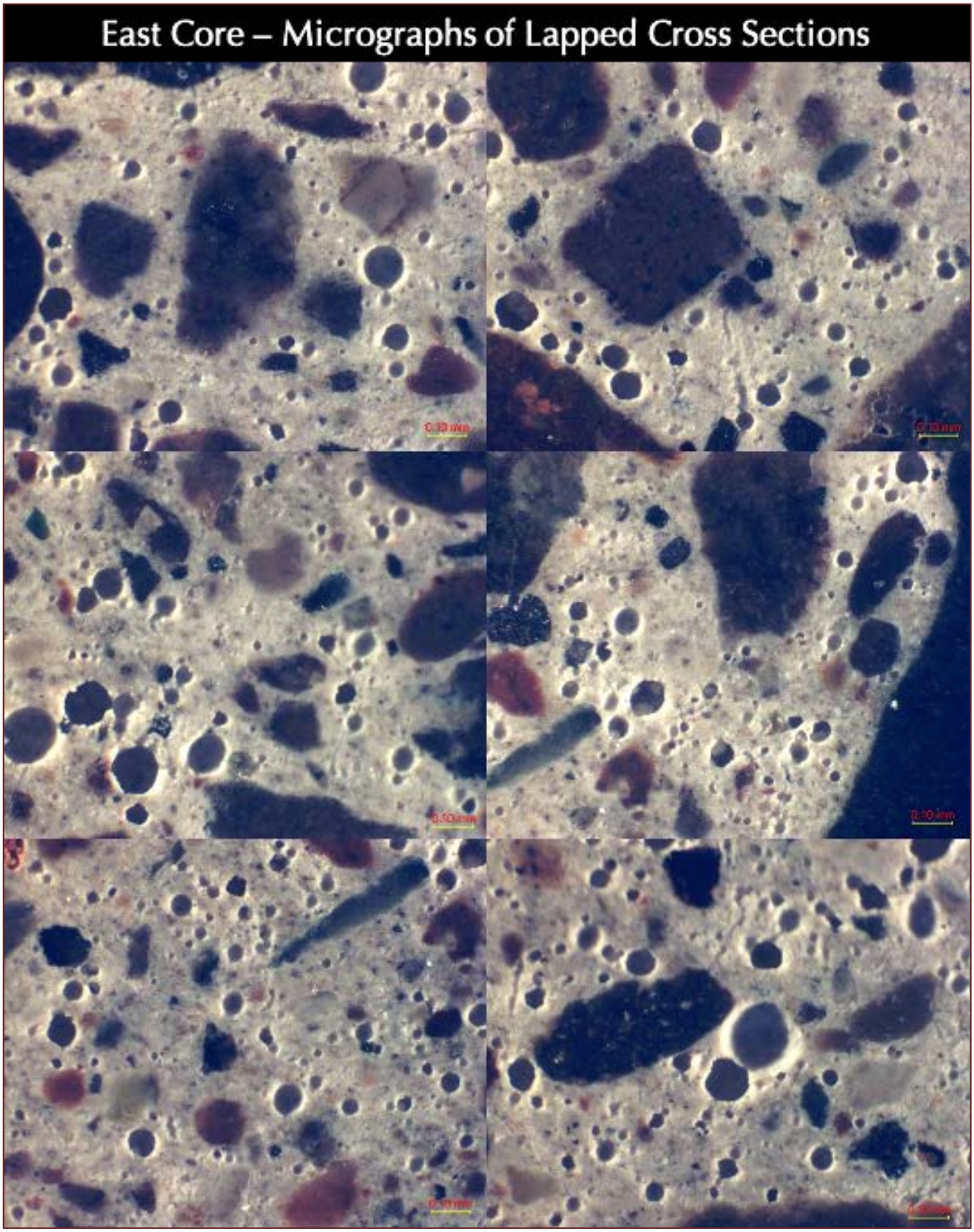

Figure 16: Micrographs of lapped cross section of the core from East Wall showing: (a) the air-entrained nature of the concrete (all photos); and (b) the overall sound, dense, well-consolidated nature of the concrete in the core (all photos).

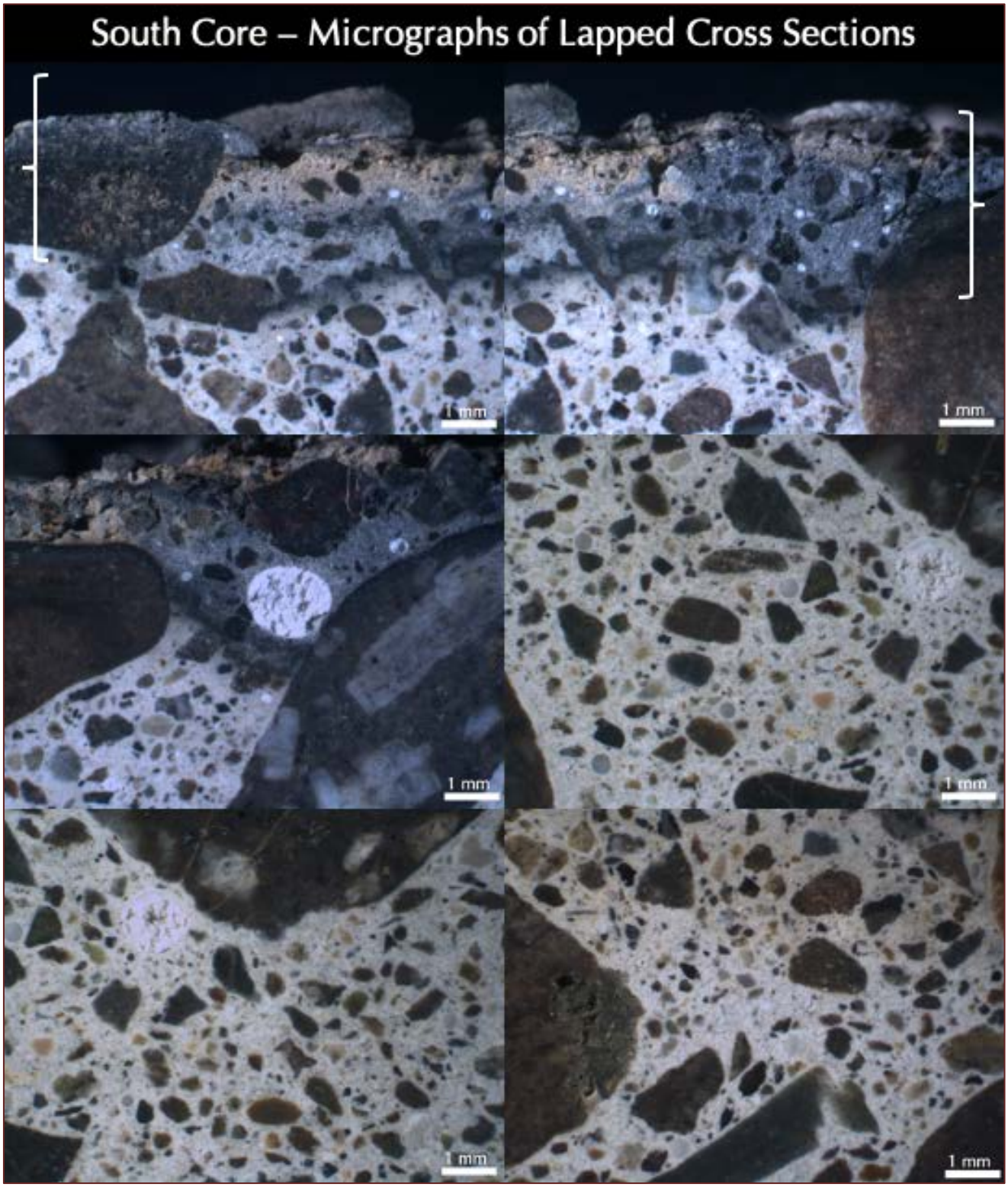

Figure 17: Micrographs of lapped cross section of the core from South Entrance showing: (a) parallel zones of alterations of paste at the top 3 to 5 mm of the exposed end due to the reported fluctuations of wastewater level; altered zones are shown in the top row and middle left photo where many air voids are seen to be filled with white secondary ettringite deposits (arrows) from interactions of fluctuating wastewater; (b) the absence of any spherical entrained air hence the non-air-entrained nature of the concrete (all photos); and (c) the overall sound, dense, well-consolidated nature of the concrete in the core (all photos).

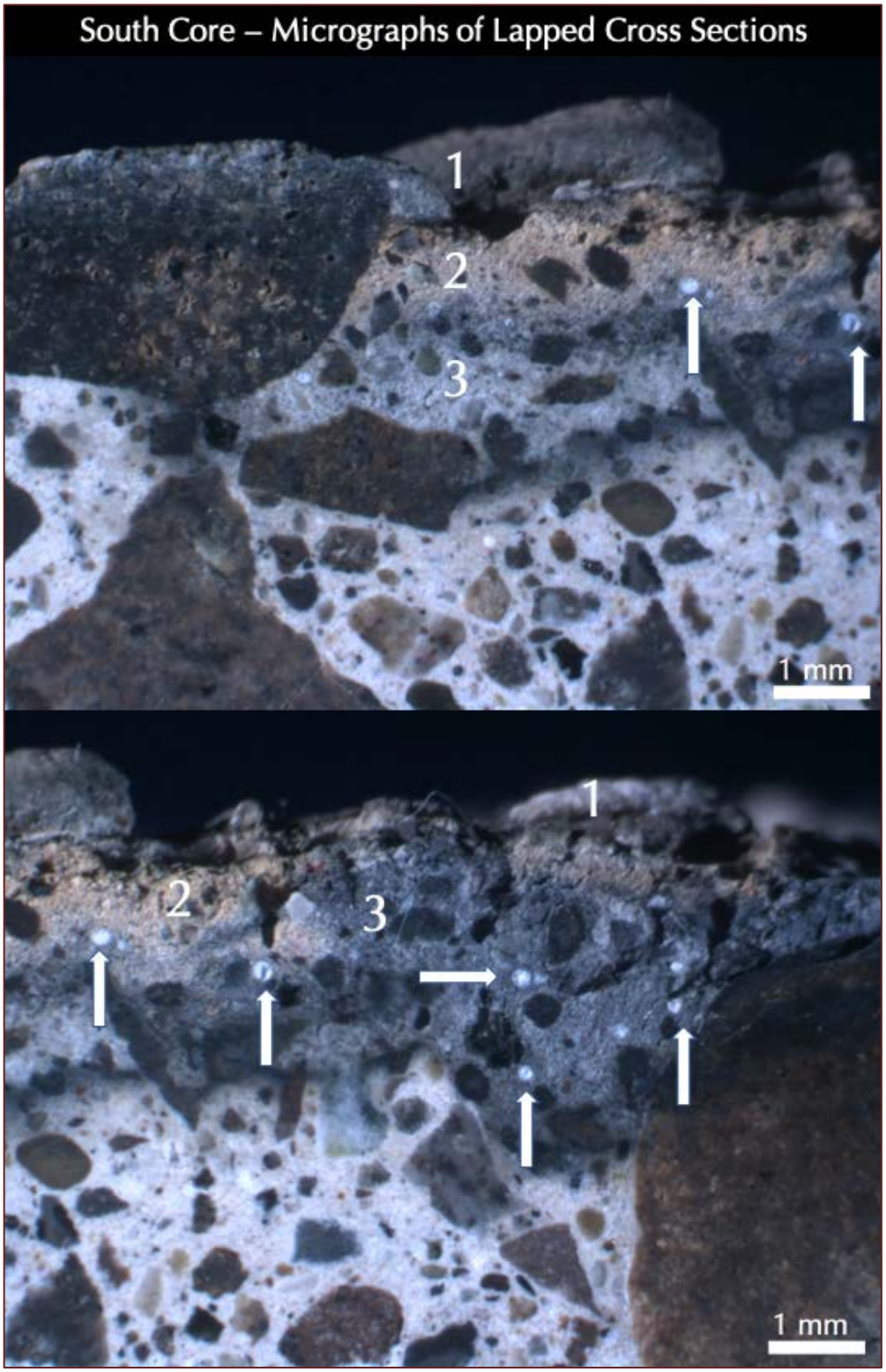

Figure 18: Micrographs of lapped cross section of the core from South Entrance showing: (a) parallel zones of alterations of paste at the top 3 to 5 mm of the exposed end due to the reported fluctuations of wastewater level; altered zones are indicated by numbers 1, 2, and 3 in the photos, and many air voids are seen to be filled with white secondary ettringite deposits (arrows) from interactions of fluctuating wastewater; (b) the absence of any spherical entrained air hence the non-air-entrained nature of the concrete (all photos); and (c) the overall sound, dense, well-consolidated nature of the concrete in the core (all photos).

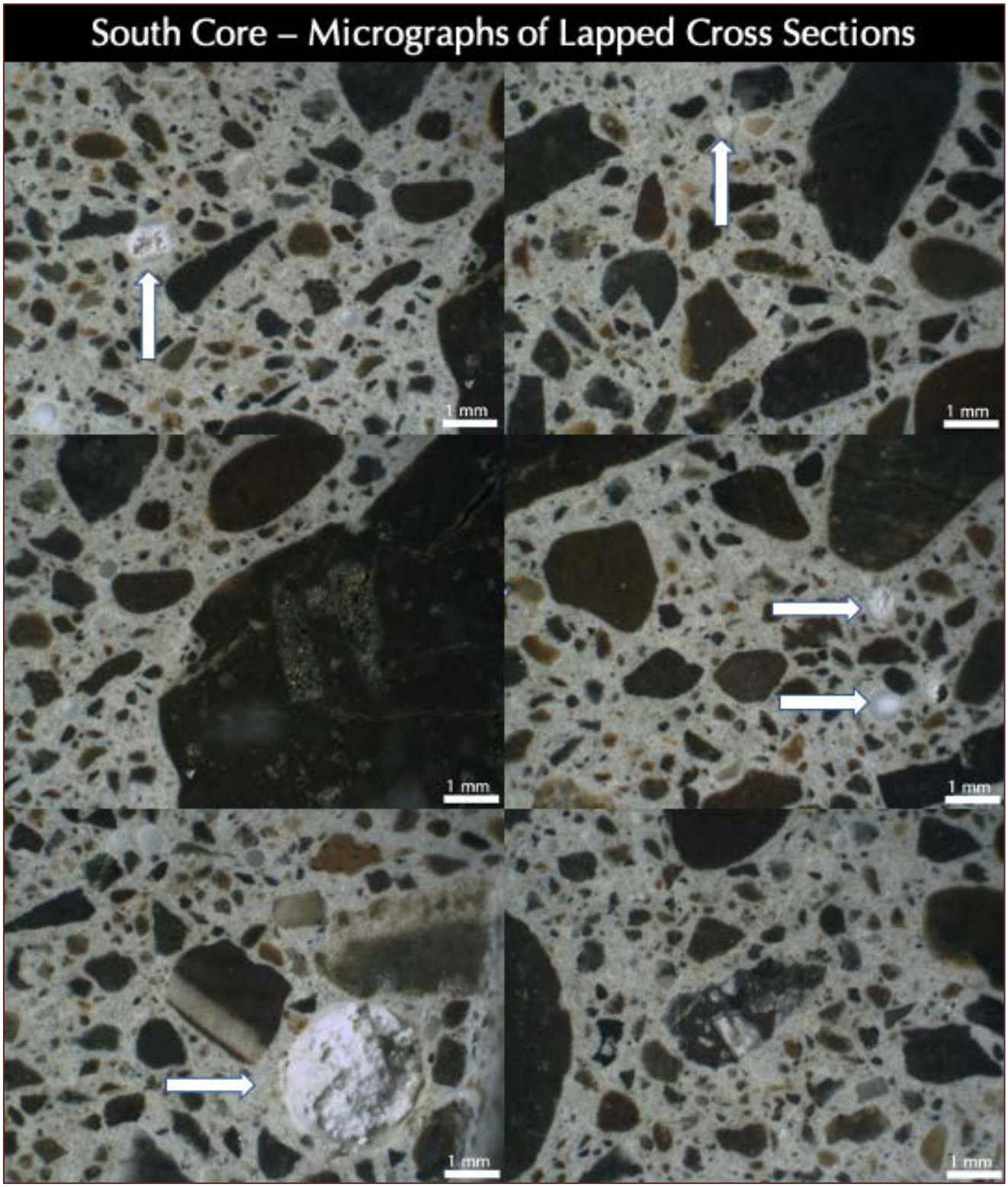

Figure 19: Micrographs of lapped cross section of the core from South Entrance showing: (a) many air voids filled with white secondary ettringite deposits (arrows) from interactions of fluctuating wastewater; (b) the absence of any spherical entrained air hence the non-air-entrained nature of the concrete (all photos); and (c) the overall sound, dense, well-consolidated nature of the concrete in the core (all photos).

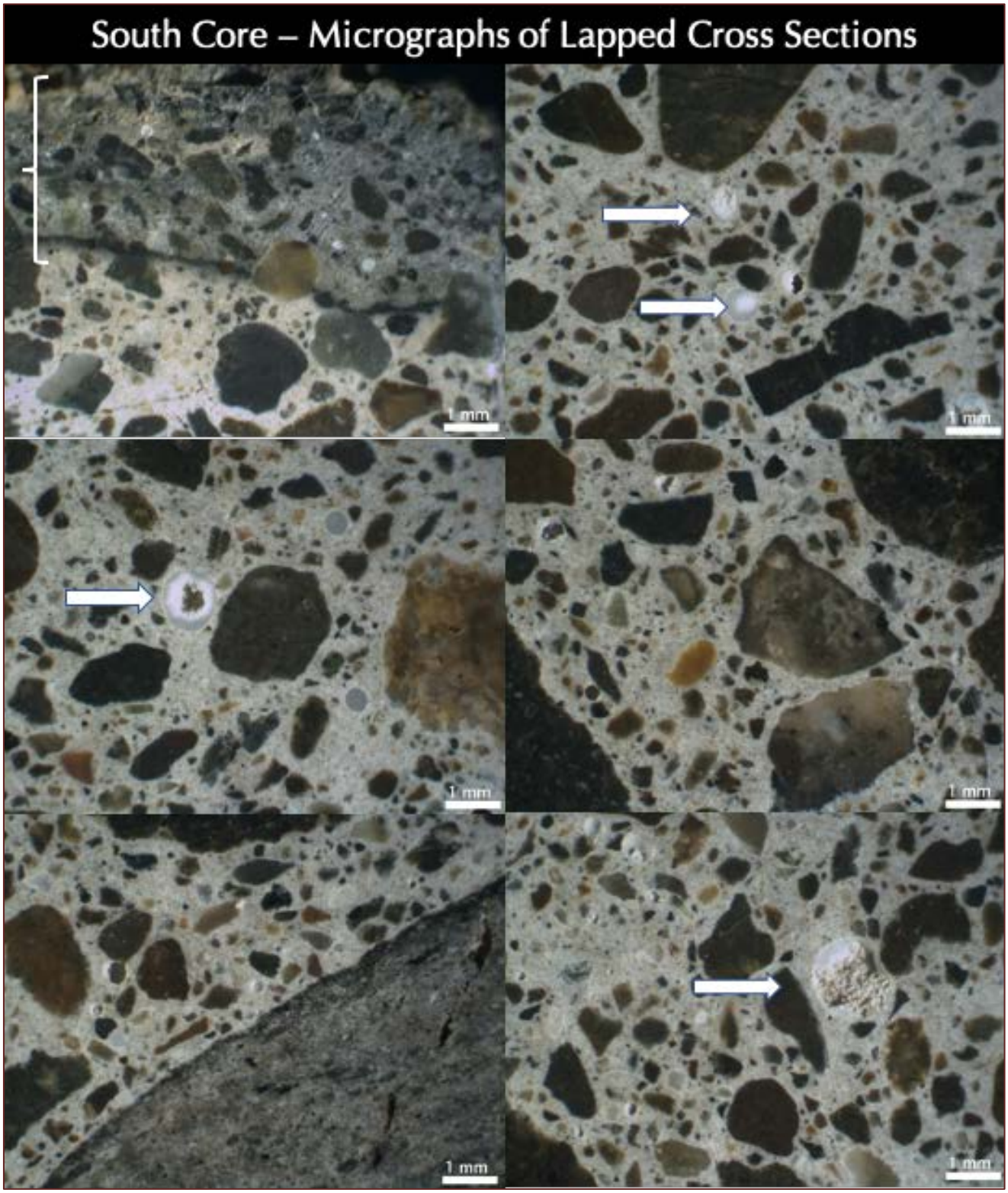

Figure 20: Micrographs of lapped cross section of the core from South Entrance showing: (a) alterations of paste at the top 3 to 5 mm of the exposed end due to the reported fluctuations of wastewater level shown in the top left photo, (b) many air voids are seen filled with white secondary ettringite deposits (arrows) from interactions of fluctuating wastewater; (c) the absence of any spherical entrained air hence the non-air-entrained nature of the concrete (all photos); and (d) the overall sound, dense, well-consolidated nature of the concrete in the core (all photos).

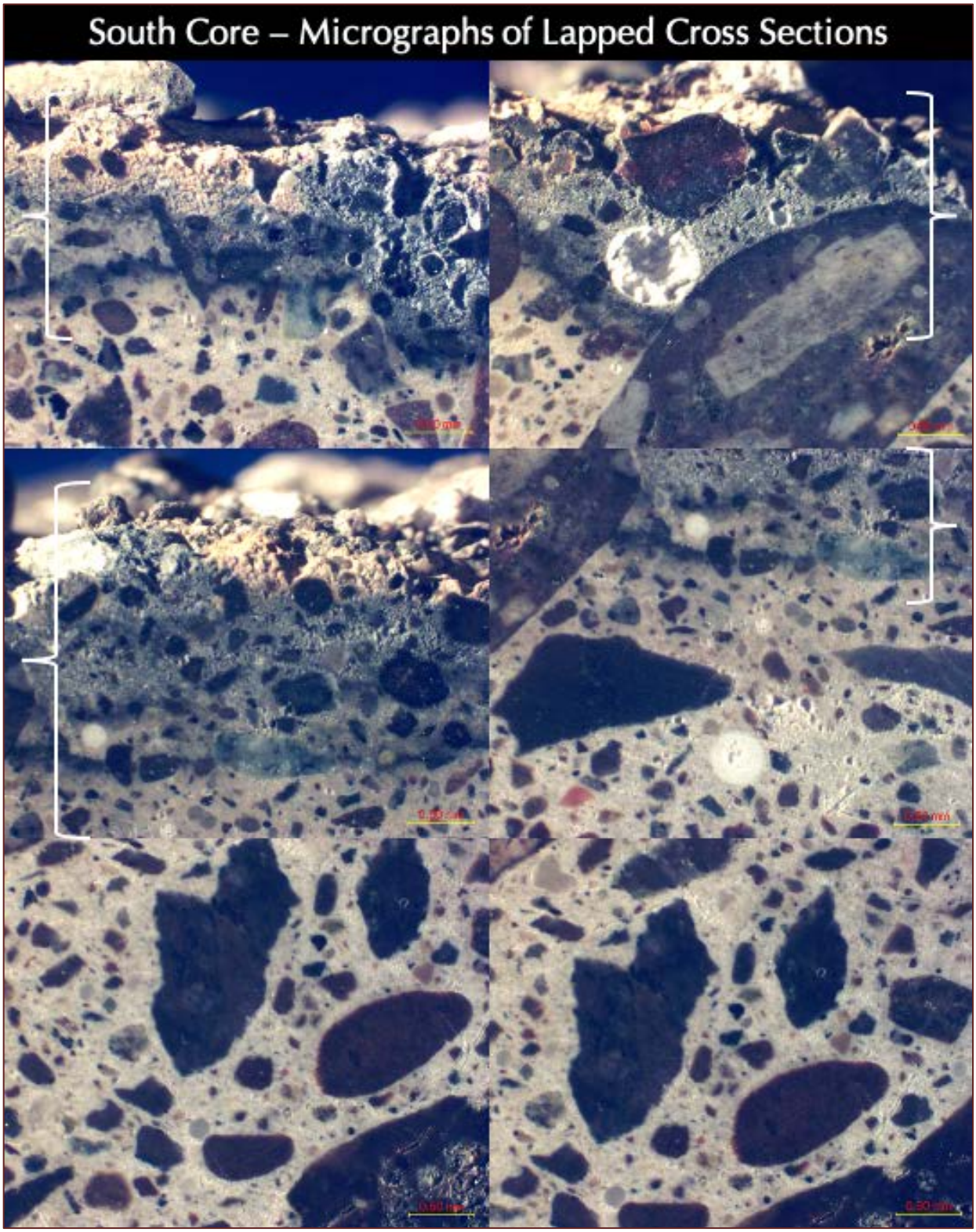

Figure 21: Micrographs of lapped cross section of the core from South Entrance showing: (a) parallel zones of alterations of paste at the top 3 to 5 mm of the exposed end due to the reported fluctuations of wastewater level; altered zones are shown in the top and middle row photos where many air voids are seen to be filled with white secondary ettringite deposits from interactions of fluctuating wastewater; (b) the absence of any spherical entrained air hence the non-air-entrained nature of the concrete (all photos); and (c) the overall sound, dense, well-consolidated nature of the concrete in the core (all photos).

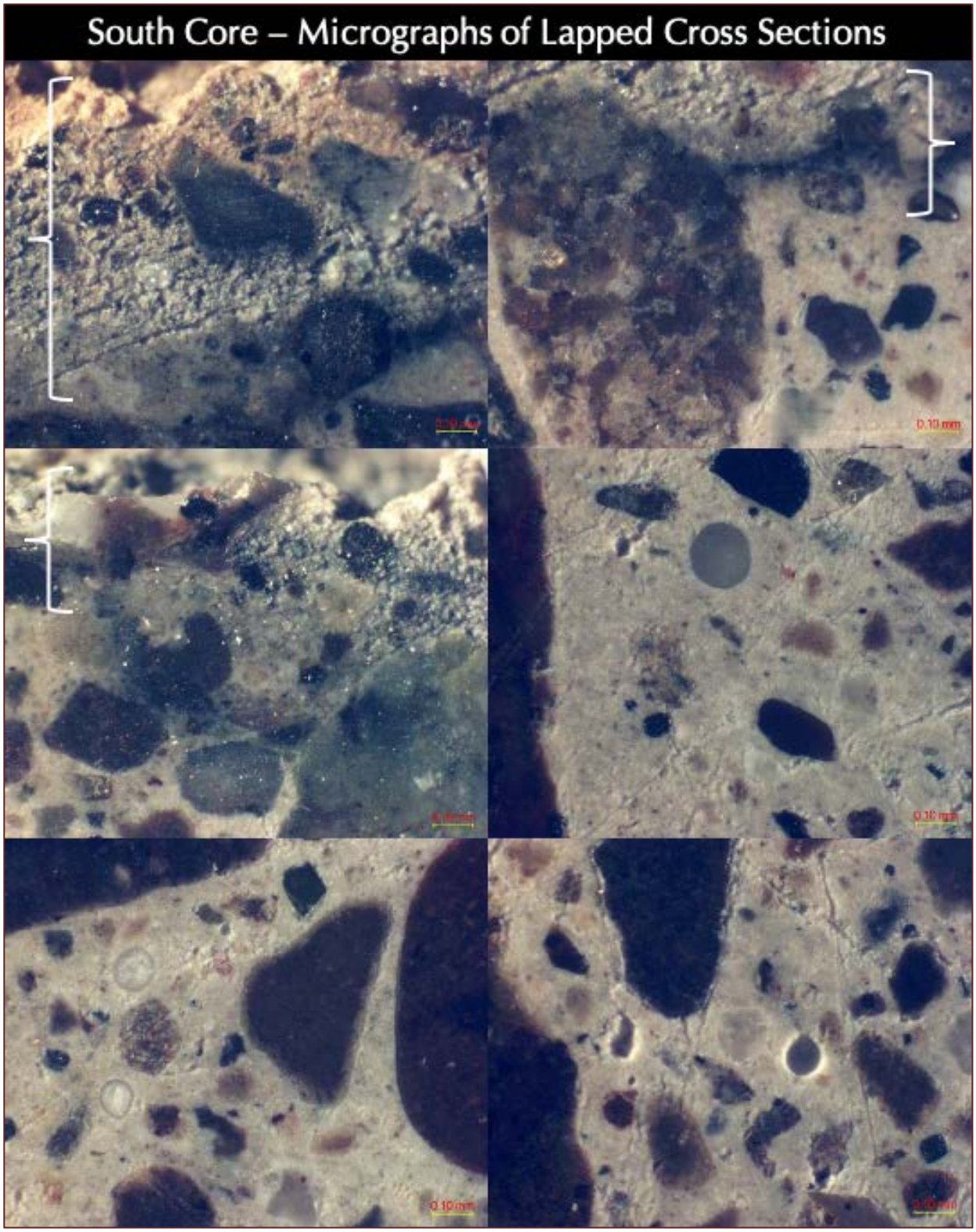

Figure 22: Micrographs of lapped cross section of the core from South Entrance showing: (a) parallel zones of alterations of paste at the top 3 to 5 mm of the exposed end due to the reported fluctuations of wastewater level; altered zones are shown in the top row and middle left photo where many air voids are seen to be filled with white secondary ettringite deposits from interactions of fluctuating wastewater; (b) the absence of any spherical entrained air hence the non-air-entrained nature of the concrete (all photos); and (c) the overall sound, dense, well-consolidated nature of the concrete in the core (all photos).

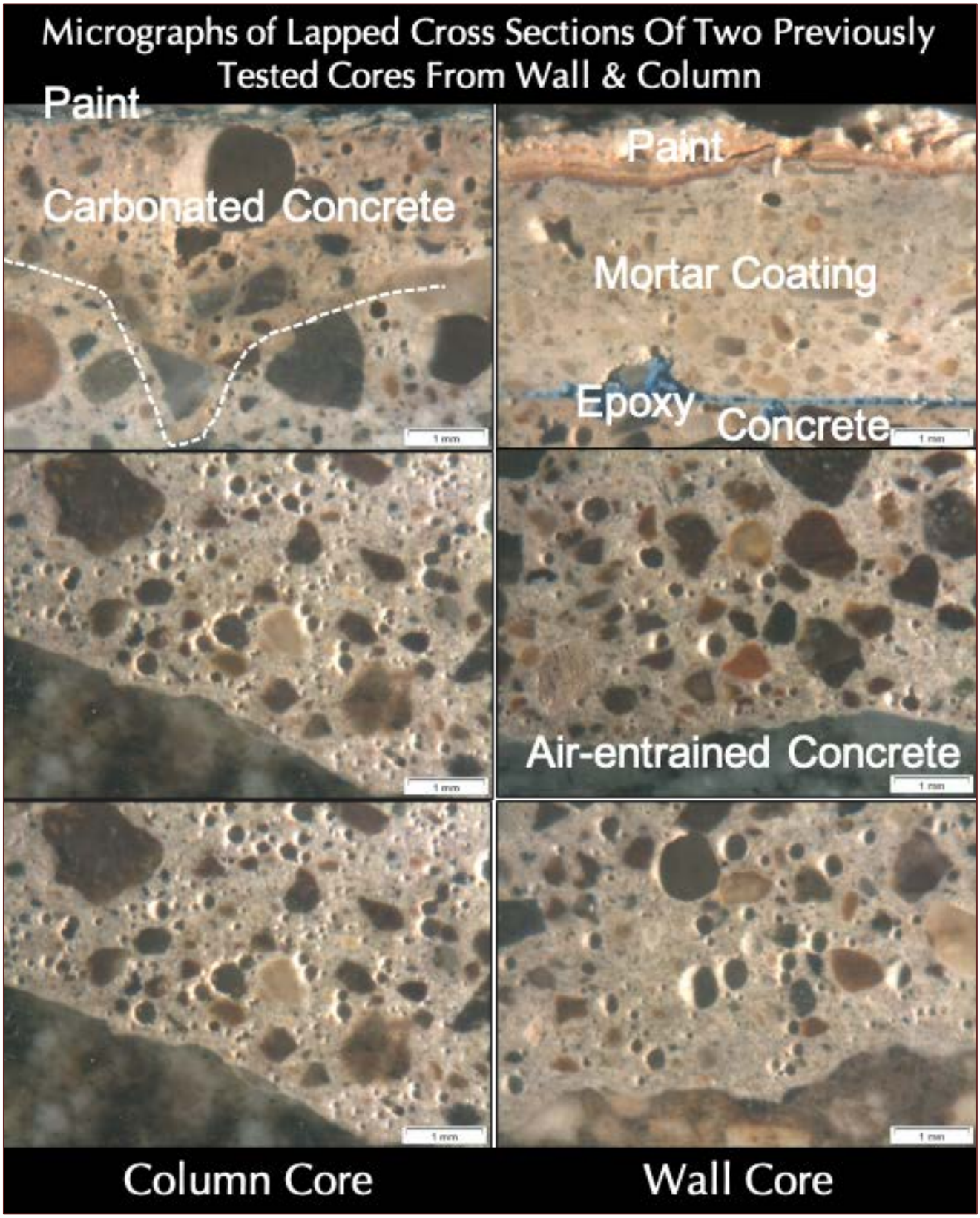

Figure 23: Micrographs of lapped cross sections of two previously tested cores from Wall and Column that show overall air-entrained natures of concrete and the presence of paint and protective mortar coating over concrete, no such coatings are found in the present two cores from East Wall and South Entrance.

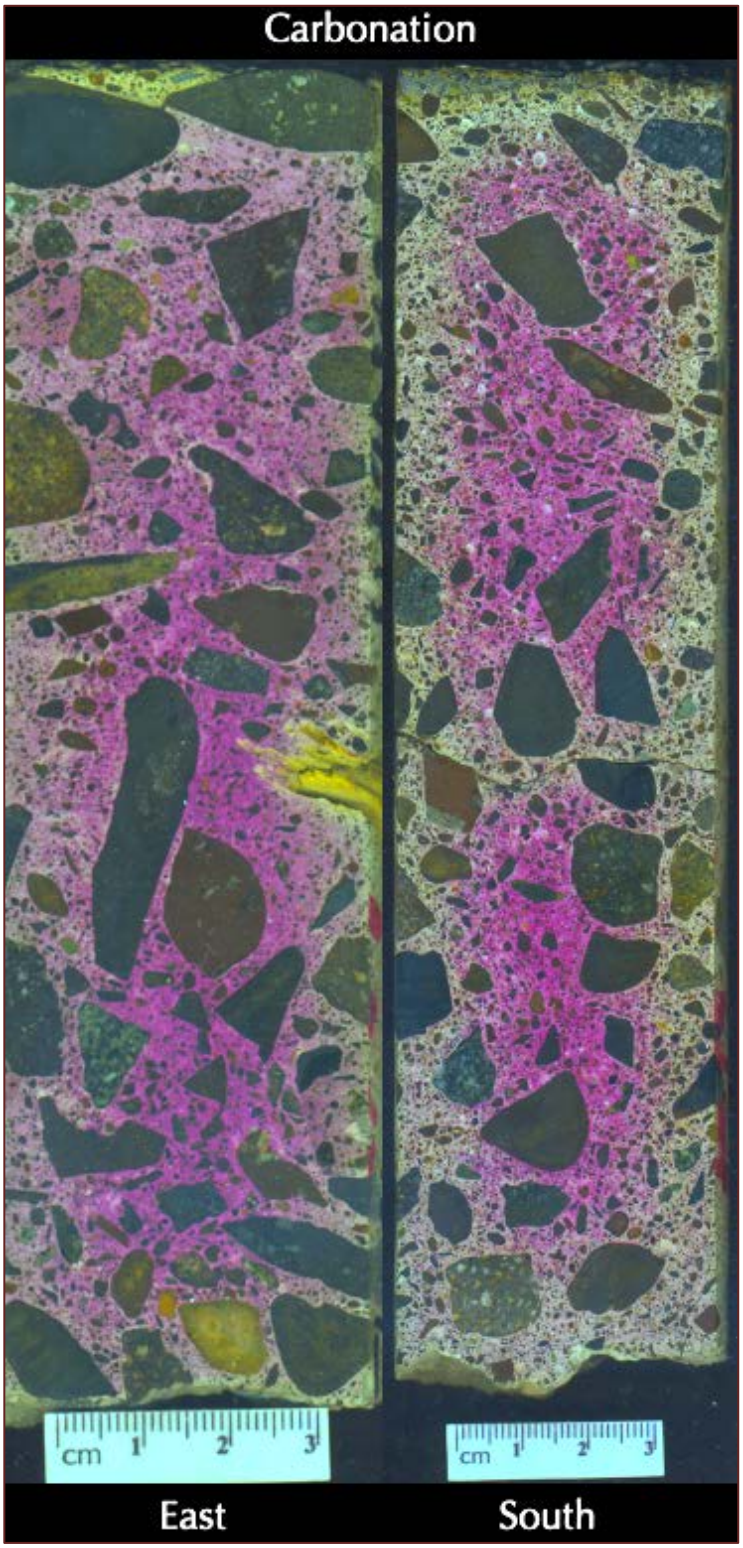

Figure 24: Lapped cross sections of two cores from East Wall and South Entrance after treatment with phenolphthalein alcoholic solutions for determination of the depth of carbonation of concrete where the carbonated portion remained normal gray color tone of paste whereas non-carbonated concrete turns to pink discoloration. Both cores show shallow carbonation at the exposed ends but non-carbonated interiors.

THIN SECTIONS

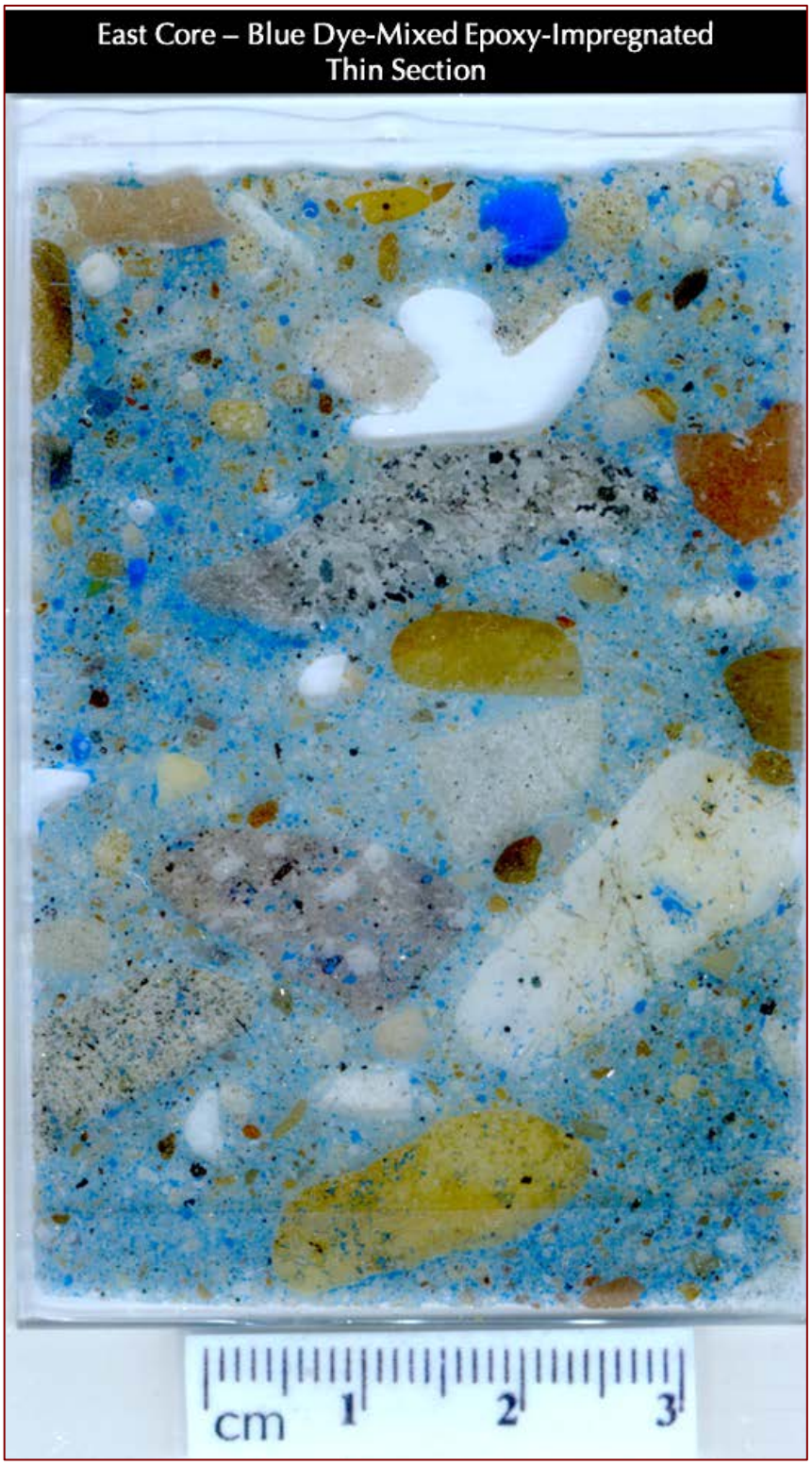

Figure 25: Blue dye-mixed epoxy-impregnated thin section of core from East Wall showing crushed gravel coarse aggregate and fine aggregate, surface alteration at the top, and air-entrained nature of concrete where air voids are highlighted by blue epoxy.

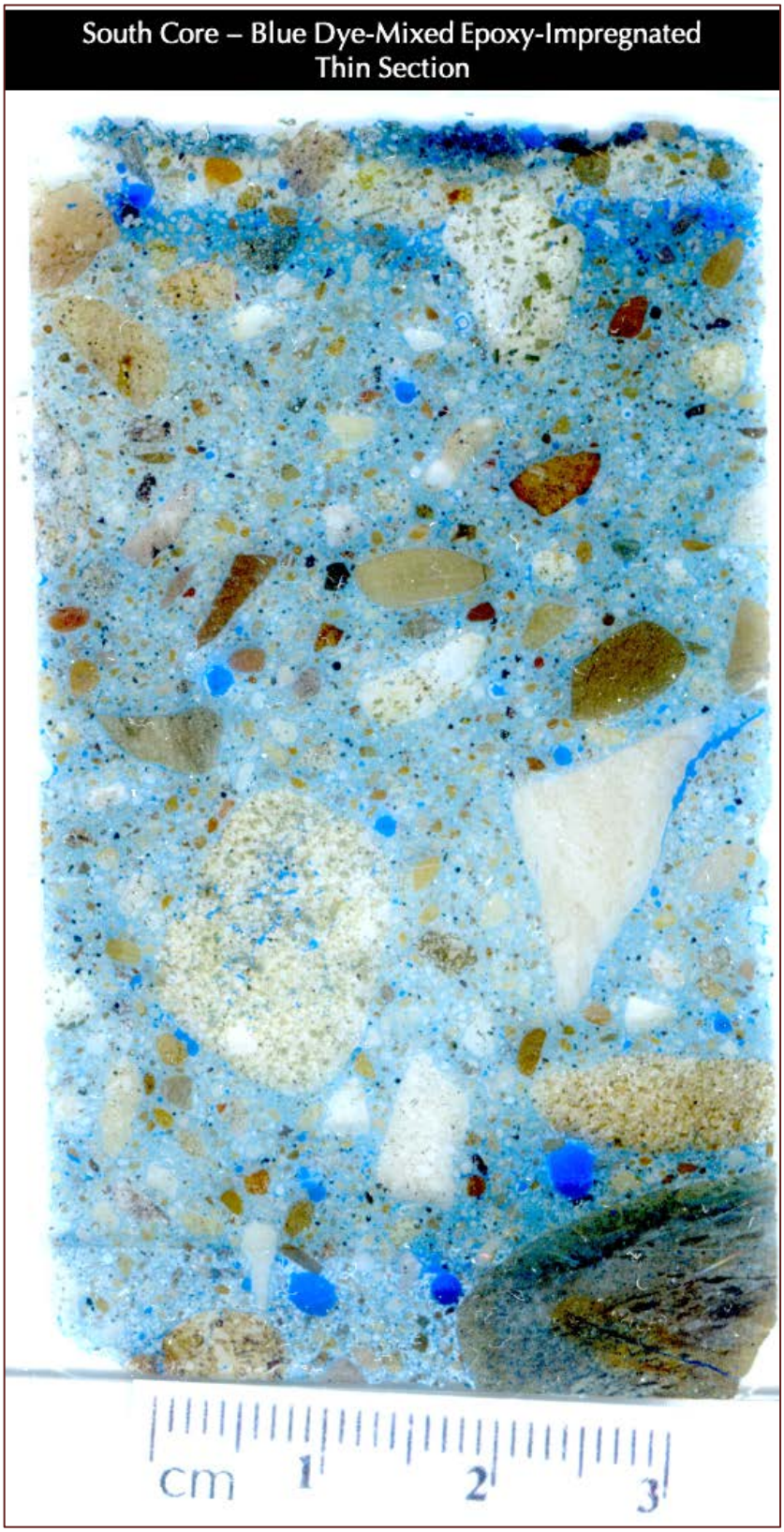

Figure 26: Blue dye-mixed epoxy-impregnated thin section of core from the South Entrance showing zoned alterations of exposed surface end at the top due to intermittent interactions with the fluctuating wastewater level, crushed gravel coarse aggregate and fine aggregate, non-air-entrained nature of concrete where some coarse entrapped air voids are highlighted by blue epoxy.

MICROGRAPHS OF THIN SECTIONS

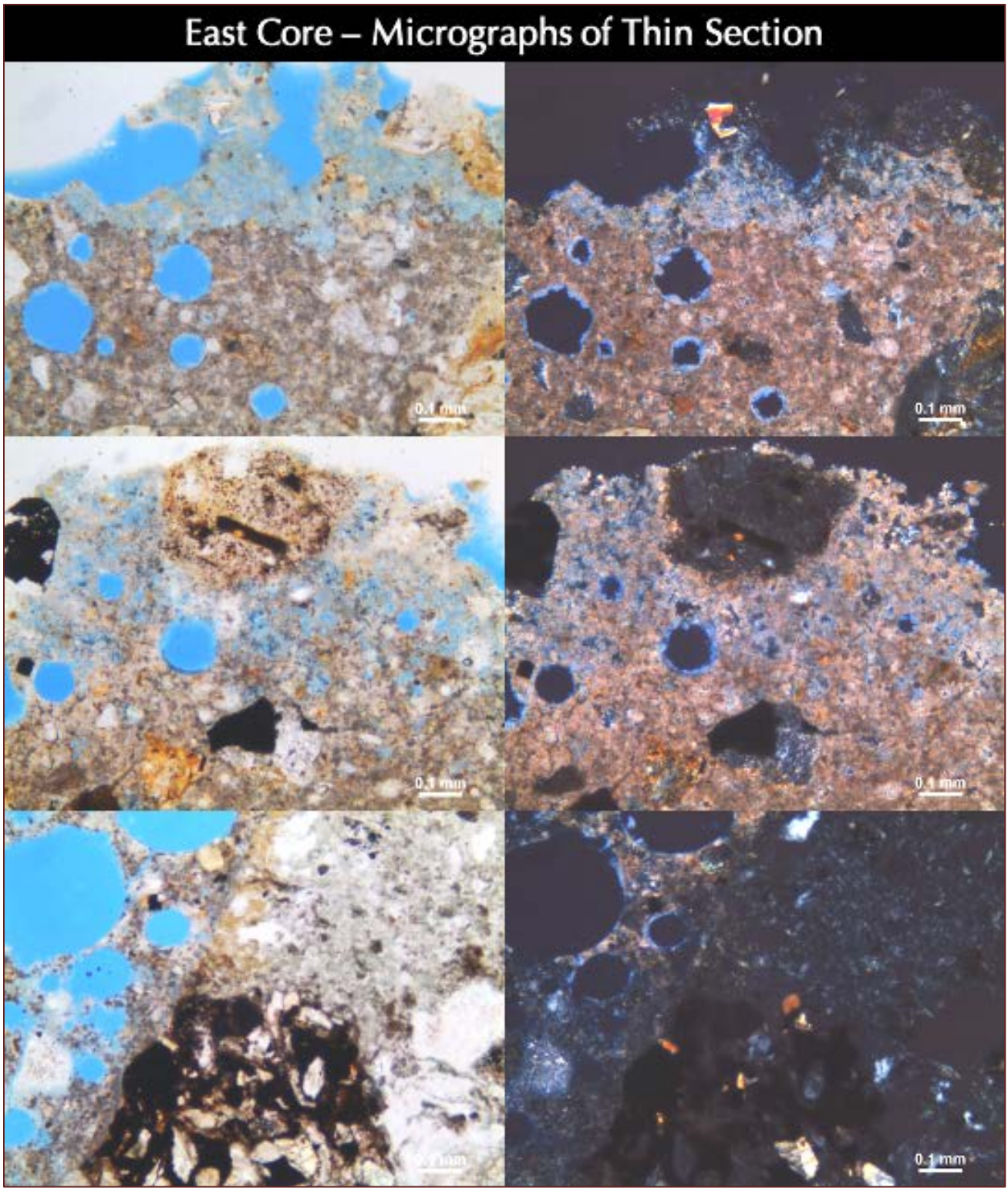

Figure 27: Micrographs of thin section of core from the East Wall showing some leaching of paste and carbonation at the top exposed end despite the reported absence of any wastewater influence.

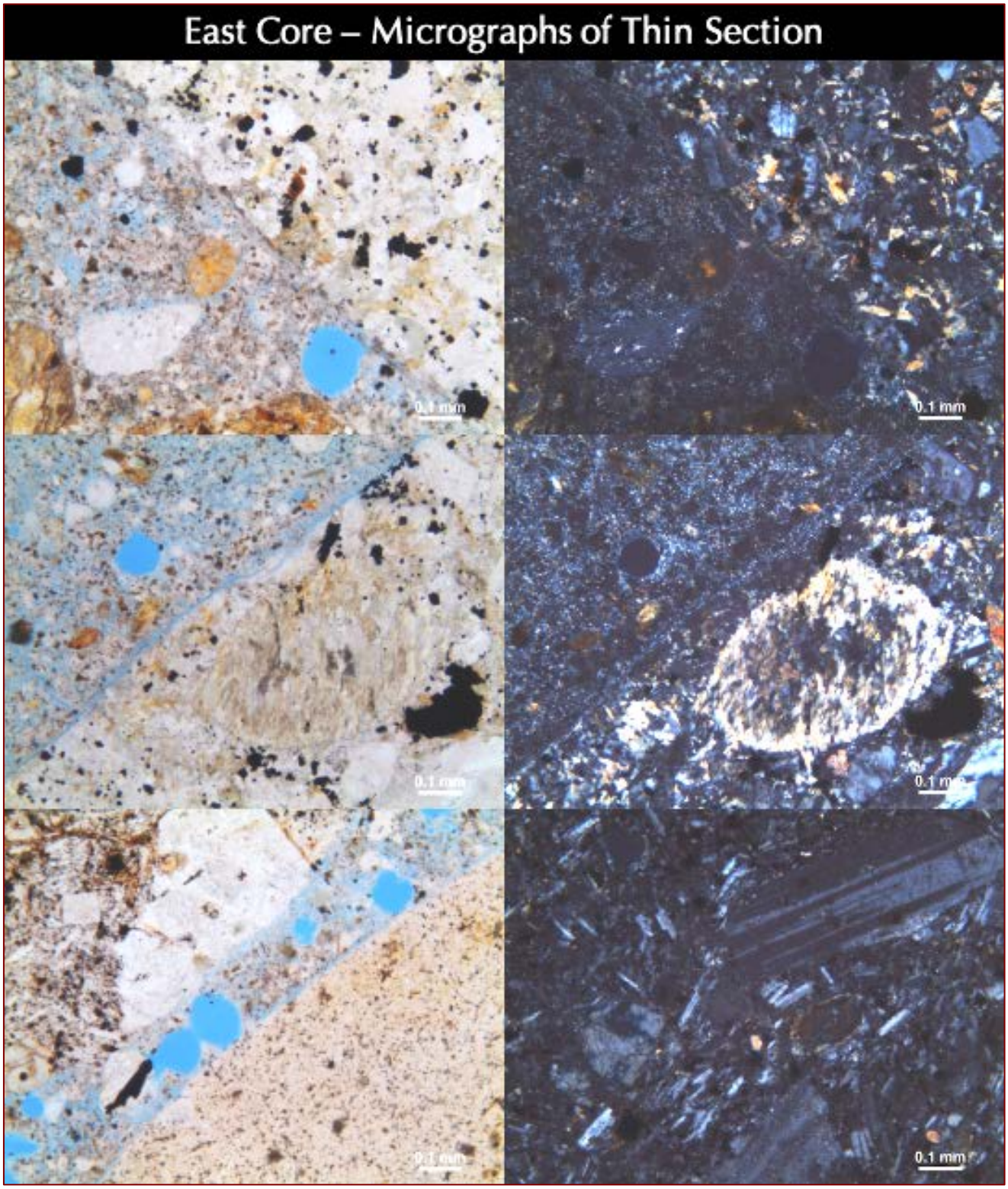

Figure 28: Micrographs of thin section of core from the East Wall showing crushed volcanic gravel coarse aggregate particles from andesite to trachyte and mortar fraction of concrete.

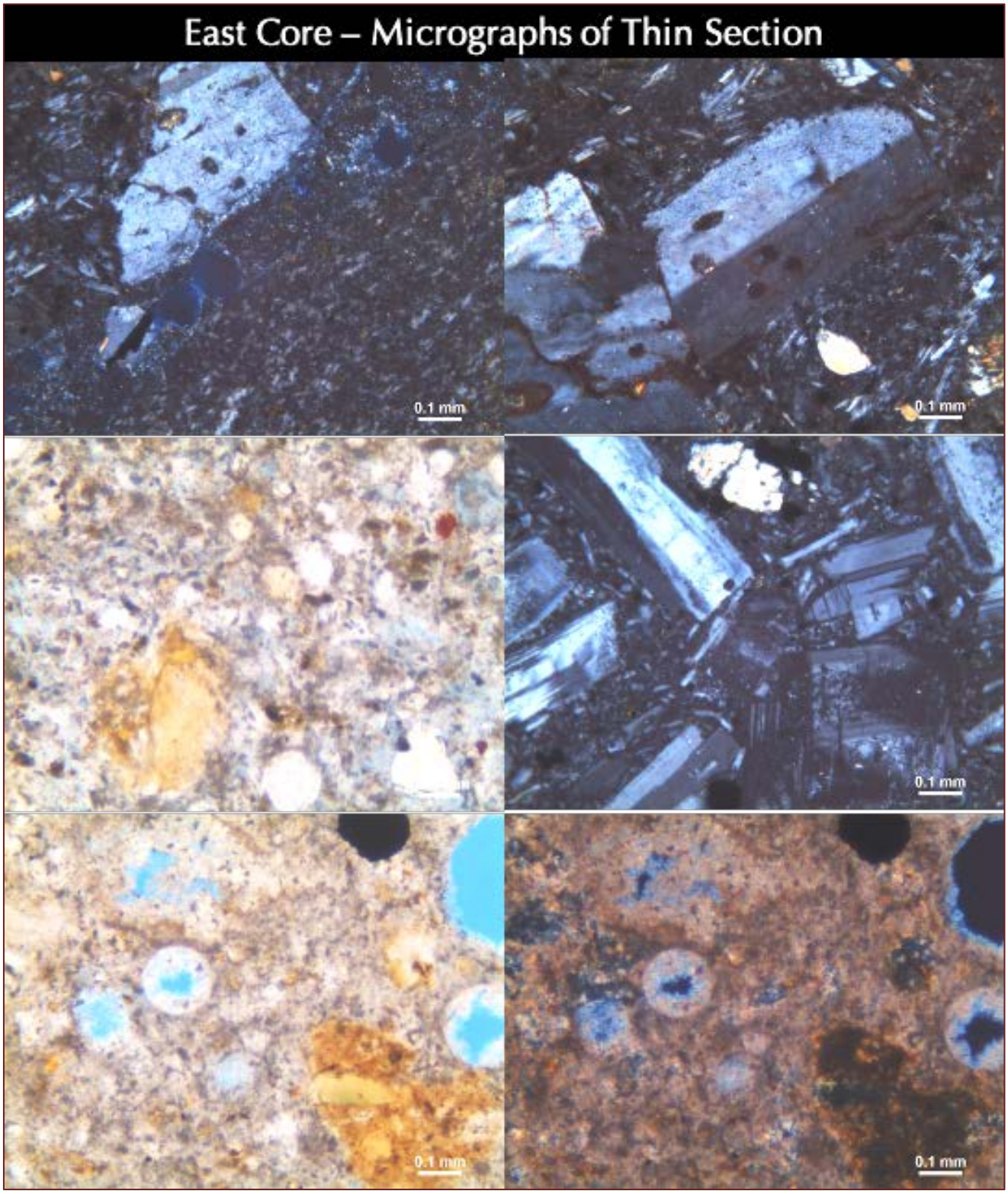

Figure 29: Micrographs of thin section of core from the East Wall showing crushed volcanic gravel coarse aggregate particles from andesite to trachyte and mortar fraction of concrete. The bottom photos show secondary ettringite deposits filling some air voids within the carbonated zone of exposed surface region of concrete.

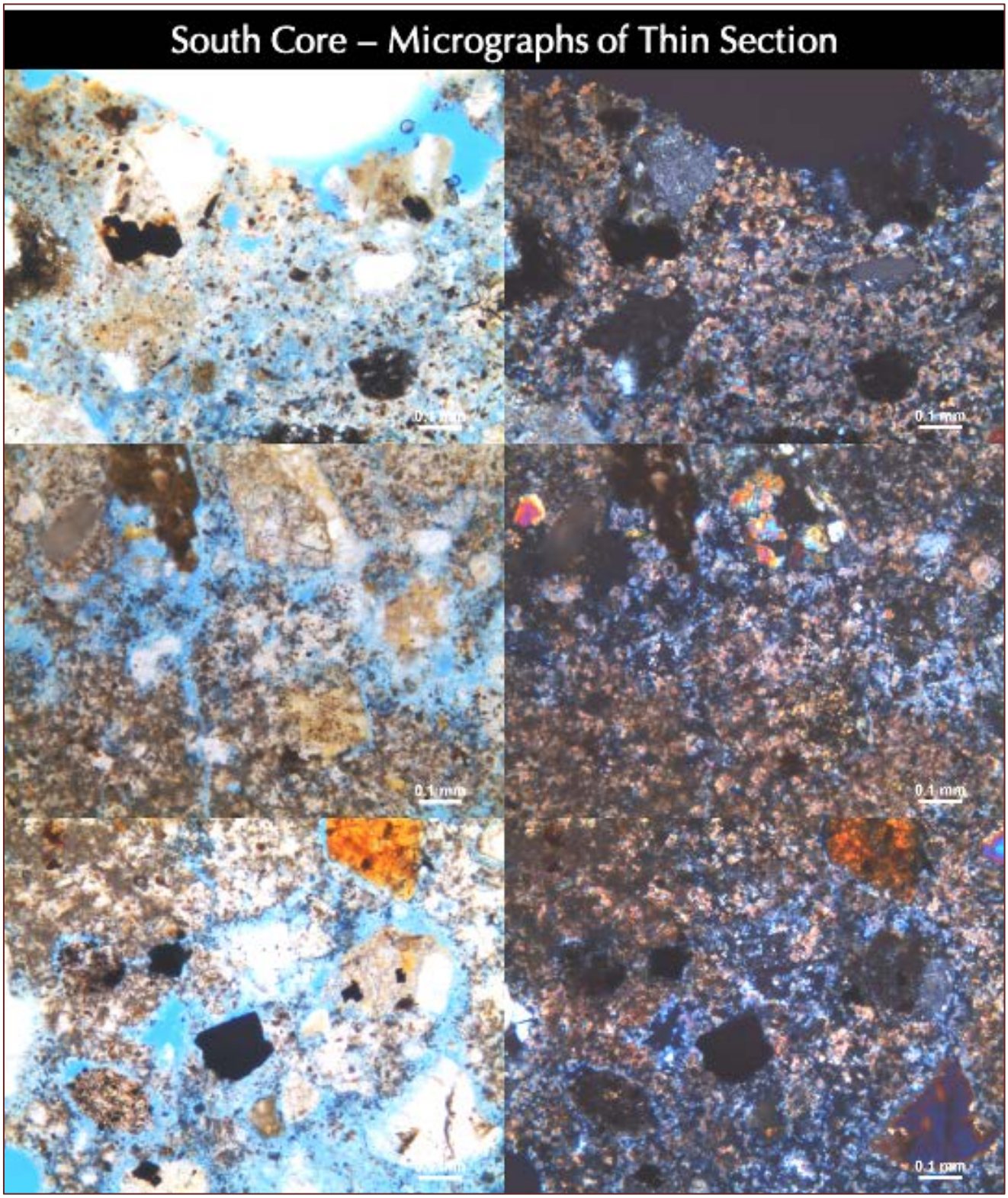

Figure 30: Micrographs of thin section of core from South Entrance showing various leaching and carbonation of paste at the exposed end from intermitted wastewater exposures.

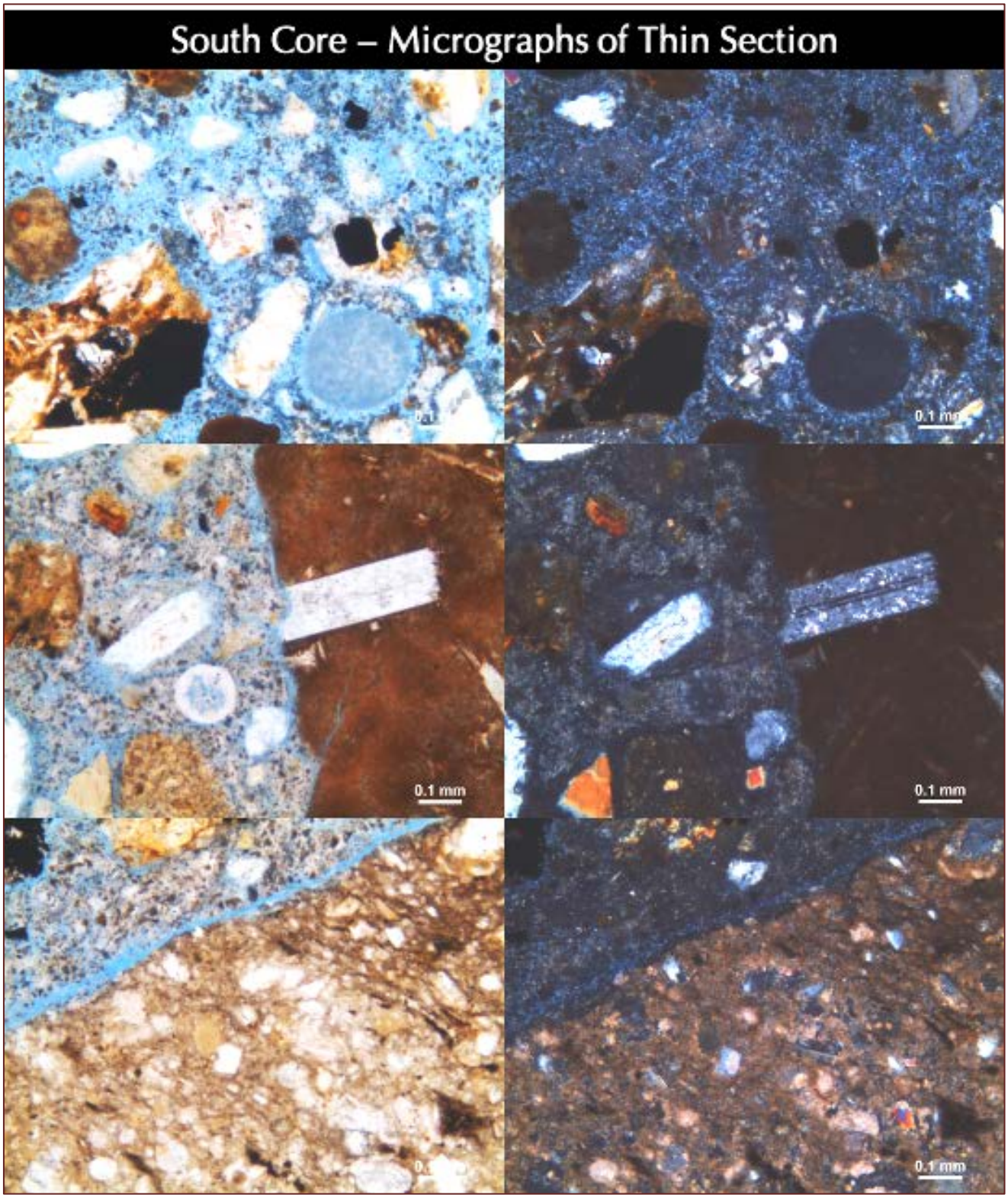

Figure 31: Micrographs of thin section of core from South Entrance showing various leaching and carbonation of paste at the exposed end from intermitted wastewater exposures. Bottom photos show an argillaceous limestone particle in coarse aggregate whereas the middle row shows an andesite particle in coarse aggregate having an euhedral feldspar phenocryst in a dark brown ferruginous glass groundmass.

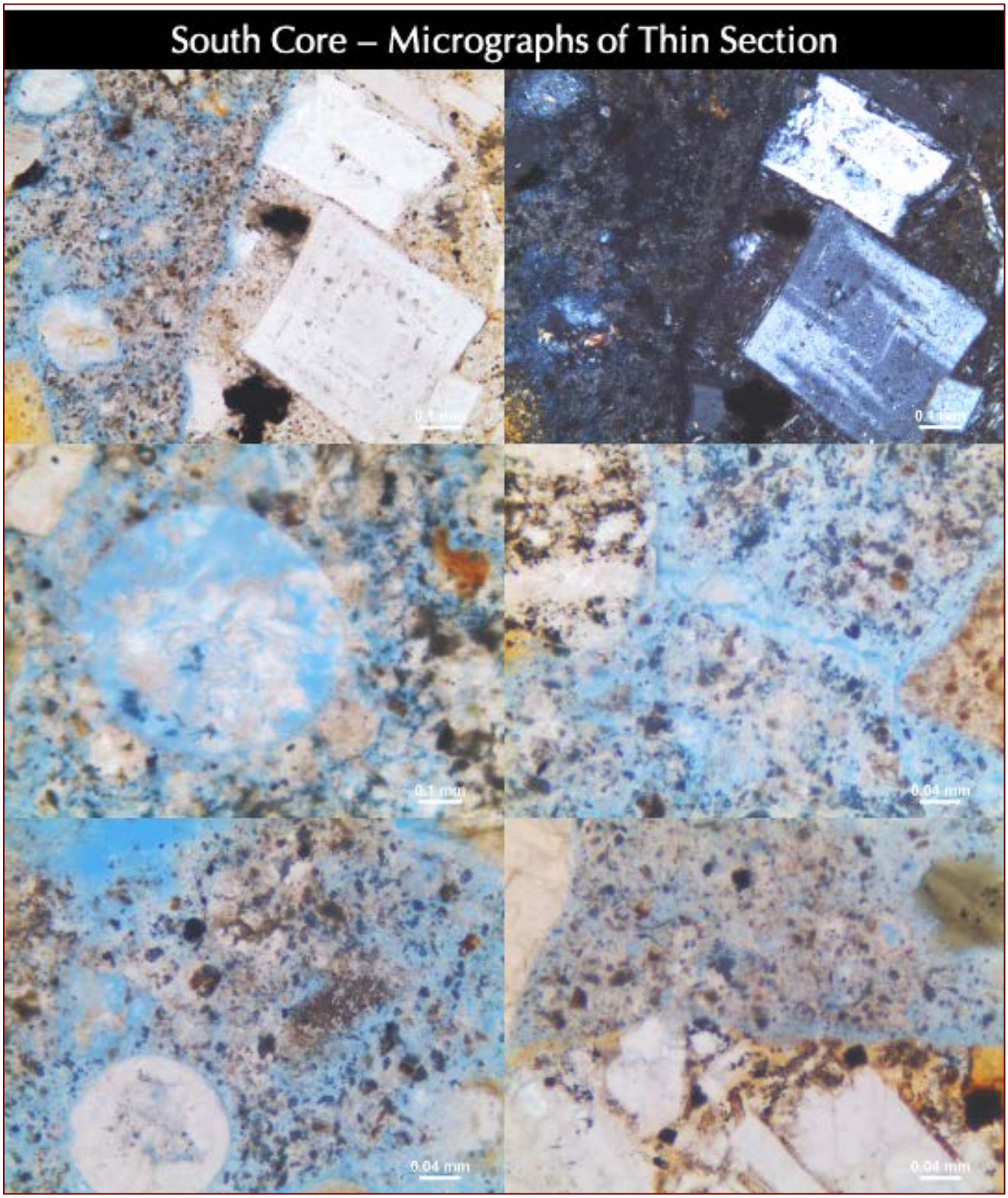

Figure 32: Micrographs of thin section of core from South Entrance showing various alterations of paste near the exposed end from intermitted wastewater exposures, fibrous and acicular secondary ettringite deposits filling air voids, euhedral square and rectangular blocky, zoned feldspar phenocrysts in a glassy groundmass of an andesite particle in coarse aggregate in the top row.

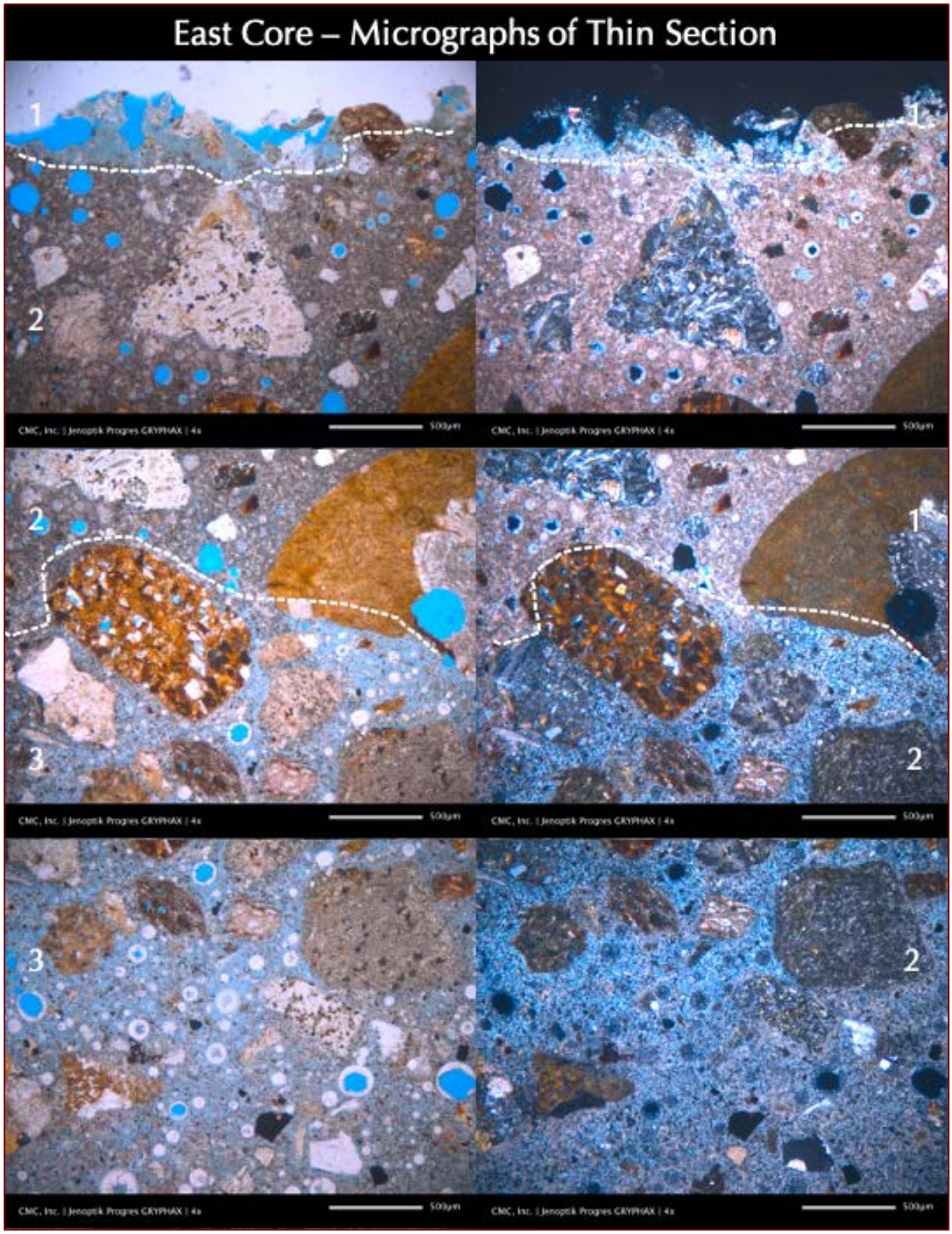

Figure 33: Micrographs of thin section of core from the East Wall showing microstructures of altered zones of paste at the exposed end from leaching of paste at the very top (marked as 1), to carbonation beneath the leached zone (marked as 2), to a porous zone beneath denser carbonated zone where many air voids are lined with secondary ettringite deposits (marked as 3).

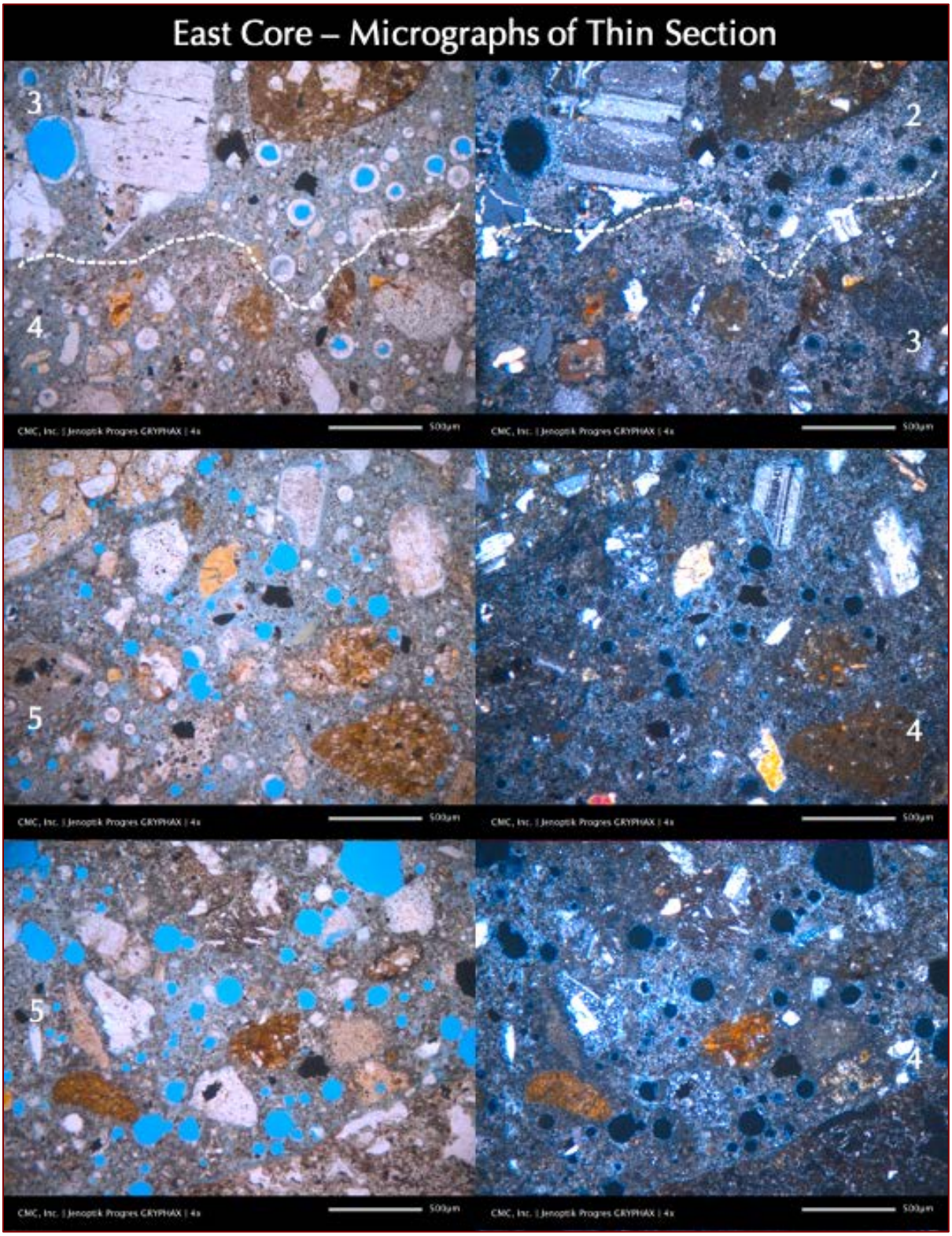

Figure 34: Continuations of micrographs of thin section of core from the East Wall showing microstructures of altered zones of paste at the exposed end from the porous zone beneath denser carbonated zone in the last figure where many air voids are lined with secondary ettringite deposits (marked as 3) to a relatively denser zone with fewer voids (marked as 4) to another zone beneath with lots of spherical entrained air voids (marked as 5).

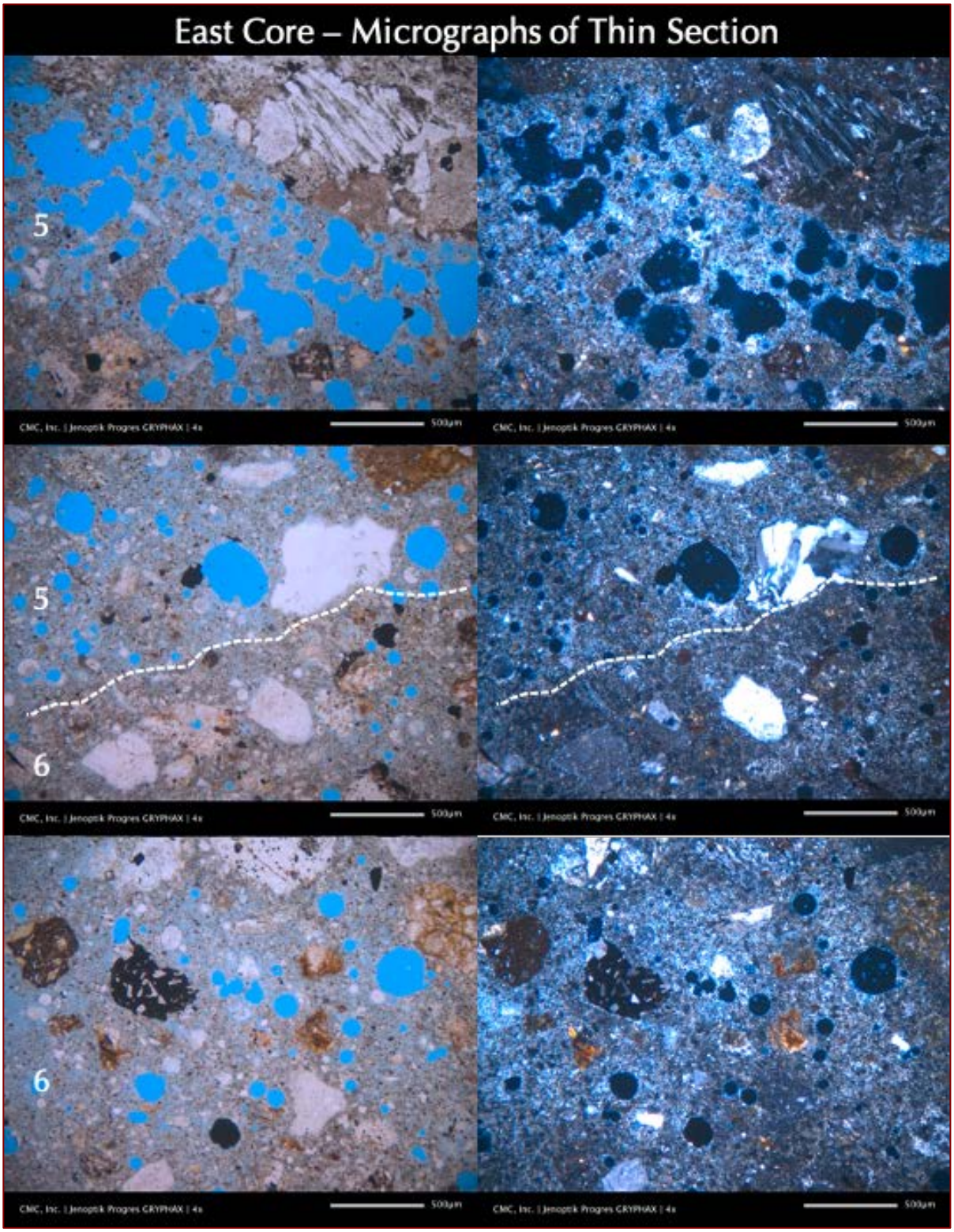

Figure 35: Continuations of micrographs of thin section of core from the East Wall showing microstructures of altered zones of paste at the exposed end from the zone with lots of spherical entrained air voids shown in the last figure (marked as 5) to a relatively denser zone again (marked as 6).

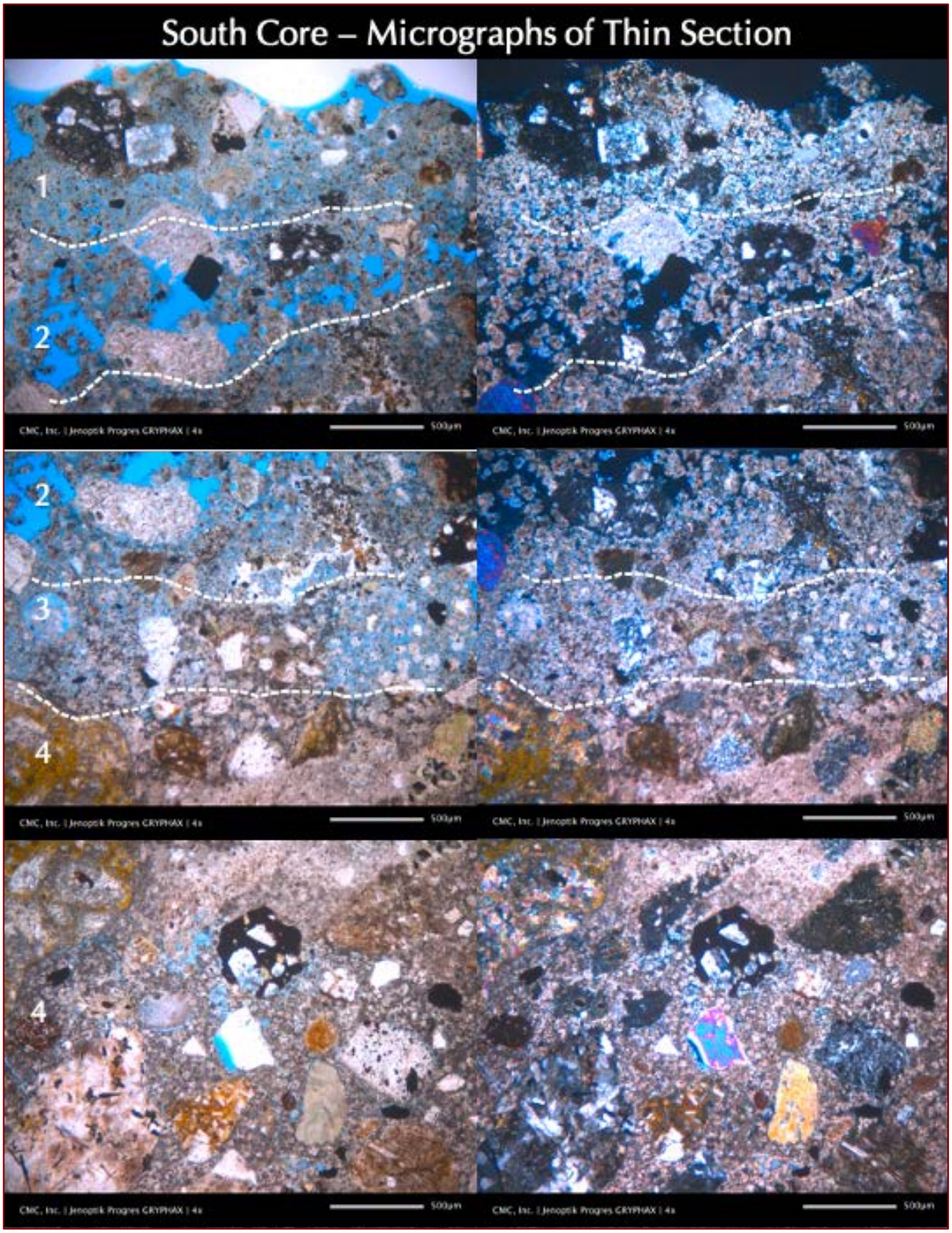

Figure 36: Micrographs of thin section of core from the South Entrance showing microstructures of altered zones of paste at the exposed end from leaching of paste at the very top (marked as 1), to a zone having lots of entrapped voids and secondary carbonates due to extensive leaching (marked as 2), to carbonation beneath the leached zone where paste is relatively denser than above (marked as 3), to a further denser and carbonated zone (marked as 4).

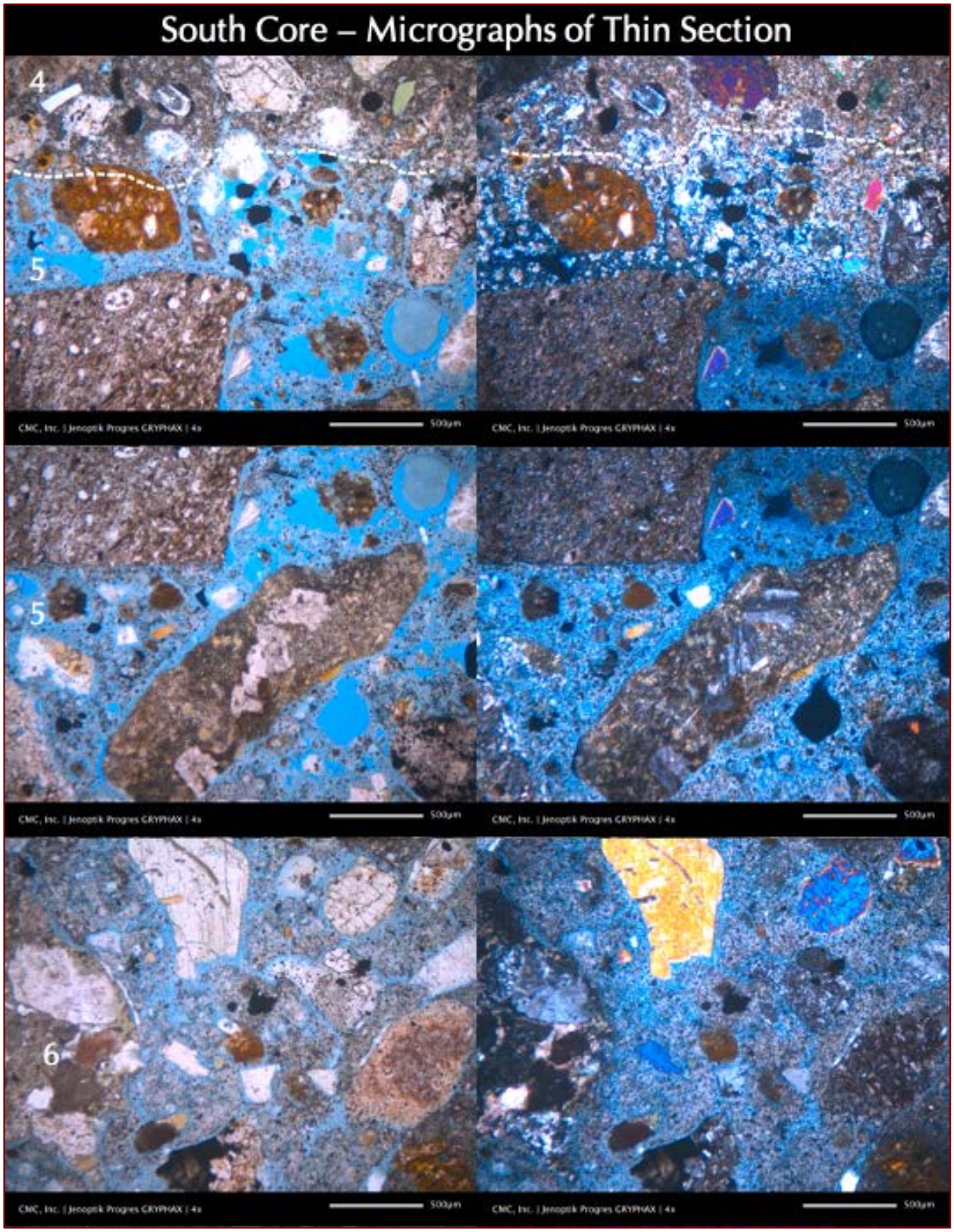

Figure 37: Continuations of micrographs of thin section of core from the South Entrance showing microstructures of altered zones of paste at the exposed end from the dense, carbonated zone shown in the last figure (marked as 4) to a very porous and leached zone again (marked as 5) beneath the denser zone where most of the cement hydration products are leached out by fluctuating wastewater, which is eventually transferred to a relatively denser but still leached and carbonated zone (marked as 6).

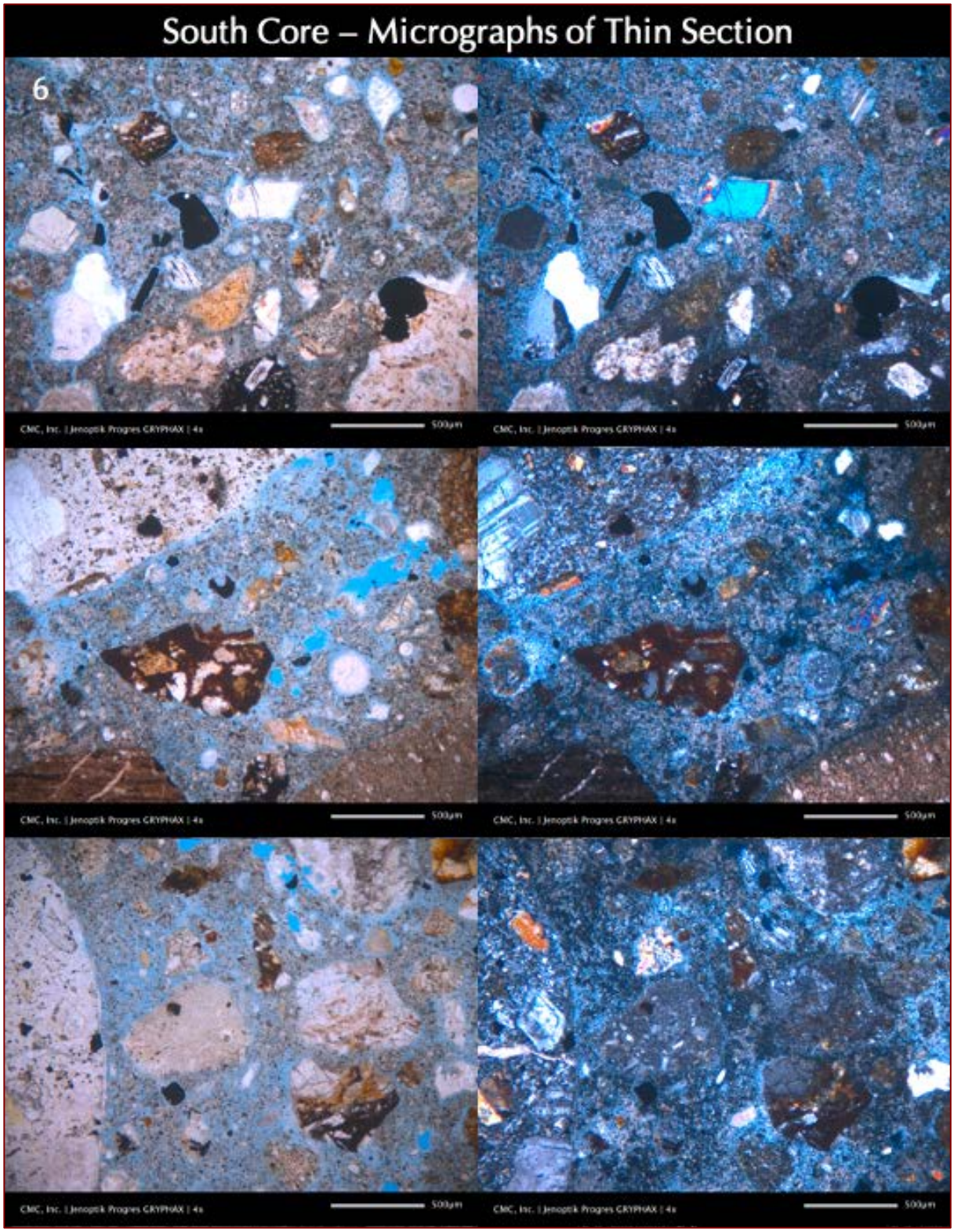

Figure 38: Continuations of micrographs of thin section of core from the South Entrance showing microstructures of altered zones of paste at the exposed end from the leached and carbonated zone in the previous figure (marked as 6) which has many fine hair-line shrinkage microcracks to a relatively normal paste seen from the altered surface region to the interior body of core.

COARSE AGGREGATES

Coarse aggregates are compositionally similar crushed gravels of siltstone, sandstone, mudstone, basalt, and trachyte. Having nominal maximums sizes of 3/4 in. (19 mm). Particles are dark gray to black, medium brown, variably dense and hard, subangular to subrounded, equidimensional to elongated, unaltered, uncoated, and uncracked. Particles are well-distributed throughout the lengths of the cores and well-graded. There is no evidence of any potentially deleterious physical or chemical deterioration of coarse aggregate particles found in the cores during service.

FINE AGGREGATES

Fine aggregates are compositionally similar mixtures of basaltic and natural siliceous-calcareous sands in both cores having nominal maximum sizes of 3/8 in. (9.5 mm) containing major amounts of basalt and moderate amounts of shale, feldspar, quartz, limestone, siltstone, mafic minerals, and ferruginous rocks. Particles are subangular to subrounded, dense, hard, variably colored from colorless to light gray to brown to pink, well-graded and well-distributed. There is no evidence of alkali-aggregate reaction of fine aggregate particles. Fine aggregate particles have been sound during their service.

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

Properties and Compositions of Aggregates	East Wall	South Entrance
Coarse Aggregates		
Types	Crushed gravels	
Nominal maximum size (in.)	3/4 in. (19 mm)	3/4 in. (19 mm)
Rock Types	Siltstone, sandstone, mudstone, basalt, and trachyte	
Angularity, Density, Hardness, Color, Texture, Sphericity	Particles are dark gray to black, medium brown, variably dense and hard, subangular to subrounded, equidimensional to elongated	
Cracking, Alteration, Coating	Unaltered, uncoated, uncracked	
Grading & Distribution	Particles are well-graded and well-distributed	
Soundness	Sound; no evidence of any cracking	
Alkali-Aggregate Reactivity	None	None
Fine Aggregates		
Types	Mixtures of basaltic and natural siliceous-calcareous sands	
Nominal maximum size	3/8 in. (9.5 mm)	3/8 in. (9.5 mm)
Rock Types	Major amounts of basalt, and moderate amounts of shale, feldspar, quartz, limestone, siltstone, mafic minerals, and ferruginous rocks	
Cracking, Alteration, Coating	Particles are variably colored (colorless, light gray, brown, pink), subangular to subrounded, dense, hard, equidimensional to elongated	
Grading & Distribution	Well-graded and Well-distributed	
Soundness	Sound	

Properties and Compositions of Aggregates	East Wall	South Entrance
Alkali-Aggregate Reactivity	None	None

Table 2: Properties of coarse and fine aggregates of concretes.

PASTE

Pastes in the cores are gray, hard, and dense. Freshly fractured surfaces have subvitreous lusters and subconchoidal textures. Residual and relict Portland cement particles are present in the sound interior bodies 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 pastes are indicative of Portland cement contents similar in both cores and estimated to be approximately 5½ to 6 bags per cubic yard; and water-cement ratios uniform throughout the bodies of the cores and estimated to be 0.40 to 0.45. There is no evidence of deleterious secondary deposits in either core. Carbonation of pastes extended to nominal depths of 3 to 4 mm in both cores. Bonds between the coarse and fine aggregate particles and pastes are tight. There is no evidence of any deleterious micro or macro cracking of concrete in the sound interior bodies of the cores.

Properties and Compositions of Paste	East Wall	South Entrance
Color, Hardness, Porosity, Luster	gray, hard, and dense, 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	
Pozzolans, Slag, etc.	None	
Water-cementitious materials ratio (*w/cm*), estimated	0.40 to 0.45, uniform throughout the sound interior bodies of cores	
Cementitious materials contents, estimated (equivalent to bags of Portland cement per cubic yard)	5½ to 6	5½ to 6
Secondary Deposits	None	
Depth of Carbonation, mm	Carbonation of pastes extended to nominal depths of 3 to 4 mm in both cores.	
Microcracking	There is no evidence of any deleterious micro or macro cracking of concrete in the sound interior bodies of the cores	
Aggregate-paste Bond	Tight in the sound interior concretes	
Bleeding, Tempering	None	
Chemical deterioration	None in the interior concretes	

Table 3: Properties and composition of hardened cement pastes.

There is no evidence of deleterious secondary deposits in either core. Carbonation of pastes extended to nominal depths of 3 to 4 mm in both cores. Bonds between the coarse and fine aggregate particles and pastes are tight.

There is no evidence of any deleterious micro or macro cracking of concrete in the sound interior bodies of the cores.

AIR

Air occurs as: (a) very fine (less than 100 microns) to fine (less than 500 microns), discrete, spherical and near-spherical voids having sizes up to 1 mm; and (b) coarse, near-spherical and irregularly shaped voids having sizes up to 4 mm. The former voids are characteristic of entrained air and the latter voids are characteristic of entrapped air. Concrete in the East Wall core is air-entrained, having an estimated air content of 5 to 6 percent. However, the concrete from South Entrance is non-air-entrained having an estimated air content of 1 to 2 percent.

Air	East	South
Estimated Air Content	5 to 6 percent	1 to 2 percent
Air Entrainment	Air-entrained	Air-entrained
Air-Void System	Good	Poor
Micrographs showing air void systems	Figures 11 to 16	Figures 17 to 22

Table 4: Air contents and air entrainments in the cores.

DISCUSSIONS

The overall qualities and conditions of concretes in the main bodies of both cores are judged to be sound with no evidence of any physical or chemical deterioration. The interior concretes are dense, well-consolidated, and should be serviceable in their intended environment.

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.

✪ ✪ ✪ END OF TEXT ✪ ✪ ✪

The above conclusions are based solely on the information and samples provided at the time of this investigation. The conclusion may expand or modify upon receipt of further information, field evidence, or samples. Samples will be disposed after submission of the report as requested. All reports are the confidential property of clients, and information contained herein may not be published or reproduced pending our written approval. Neither CMC nor its employees assume any obligation or liability for damages, including, but not limited to, consequential damages arising out of, or, in conjunction with the use, or inability to use this resulting information.

END OF REPORT[1]

[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.