WJE

MEMORANDUM | August 17, 2023

I-20 / I-26 / I-126 Corridor Improvement (Carolina Crossroads)

Asset IDs 7272, 7586, and 7937 - Laboratory Studies of Concrete Cores

WJE PROJECT NO. 2023.1990

PREPARED BY Hugh Hou, Senior Associate, JTC-I
Corrie Piehowski, Associate II, JTC-I

Laboratory studies were conducted on concrete cores extracted from deck slabs of three bridges from the I-20 and I-26 corridors in Columbia, South Carolina. The bridges were constructed in the 1970s and 1980s. WJE has conducted evaluations of the three bridges to aid in developing recommendations regarding the extent and scope of bridge deck rehabilitation for each structure. Laboratory studies, including petrographic examination, depth of carbonation testing, chloride ion content analysis, and compressive strength testing, were conducted to aid in the evaluation of the bridge decks.

SAMPLES

Fifty-three concrete cores were received by WJE's Janney Technical Center laboratory in Northbrook, Illinois between July 13 and July 18, 2023. The cores were extracted from three different bridges, or "assets", by WJE staff, and labeled with core number and asset number. Asset 7272 represents Bush River Road over I-20; Asset 7586 represents St. Andrews Road over I-26; and Asset 7937 represents Bush River Road over I-26. Cores will be referred to by their asset number and core number, as cores were numbered sequentially starting from 1 from each asset. All cores were extracted from the top surface of the decks, represented partial depth segments of the bridge decks, and were 3-5/8 inches in diameter. Sets of cores were selected for various laboratory testing listed above based on their extraction location and condition.

Nine cores consisting of three cores from each of the three bridges were selected for petrographic studies and examined in greater detail. A summary of these nine cores, including length, extraction location, cracking, and presence of reinforcing steel, is provided in Table 1. Images of these cores in their as-received condition are shown in Figure 1 through Figure 10. Photographs of all remaining cores were also taken and saved in the project folder.

The cores selected for petrographic examination will be described in detail for the remainder of this memorandum. Results of compressive strength testing are listed in a separate report. Results of chloride ion content analysis are listed in a separate report.

Table 1. Characteristics of As-received Cores for Petrographic Examination

Sample ID	Nominal Length (in.)	Extraction Location	Top Surface Condition	Cracking	Reinforcement	Other Notes
7272-C2	4-1/4	7272	Severe erosion	Minor surficial vertical cracking	Impression of No. 2 wire along bottom surface	Orange discolored paste along top surface, irregular boundary, up to 1 inch
7272-C5	5-3/4	7272	Severe erosion	Horizontal fracture 3/4 to 1-7/8 inches below top surface, extending mainly around aggregate	None	A few large consolidation voids along perimeter
7272-C13 *	2-1/2 to 3-1/4	7272	Moderate erosion	Surface-perpendicular crack 10 mils wide, extending mainly around coarse aggregate	Impression of rebar, maybe No. 5, 2 inch cover	Orange paste (carbonation) along crack
7586-C4	5-3/4	7586	Mild erosion	Minor vertical cracking	None	--
7586-C10 *	4	7586	Severe erosion	None	None	Slight orange paste discoloration along top, likely carbonation
7586-C13	4-1/2	7586	Severe erosion	None	None	A few large consolidation voids along perimeter
7937-C6	5	7937	Moderate erosion	Minor vertical cracking	None	--
7937-C11	5-1/2	7937	Mild erosion	None	(3) No. 2 wires, cover depth of 3, 3-1/4, and 5-3/8 inches from top	A few large consolidation voids along perimeter
7937-C16 *	4	7937	Minimal erosion	None	None	A suspected sealer exhibited shiny appearance on top surface

Notes: “Minimal erosion” refers to no exposed aggregate, well-defined tines; “Mild erosion” refers to few to some exposed coarse aggregate and well-defined tines; “Moderate erosion" refers to exposed coarse aggregate with somewhat visible tines; and “Severe erosion" refers to exposed coarse aggregate and eroded tines

**Cores 7272-C13, 7586-C10, and 7937-C16 were selected for full petrographic examination including polarized-light thin-section examinations, while the remaining cores were examined using stereomicroscope on their lapped sections for comparison.*

PETROGRAPHIC EXAMINATION

Cores 7272-C13, 7586-C10, and 7937-C16 were selected for full petrographic examination including polarized-light thin-section examinations, while the remaining cores were examined using stereomicroscope on their lapped sections for comparison.

Methods

Petrographic examinations were conducted on the above-listed cores in accordance with the methods and procedures outlined in ASTM C856, *Standard Practice for Petrographic Examination of Hardened Concrete*. All nine cores were cut in half longitudinally perpendicular to the top surface using a water-cooled continuous-rim diamond saw blade. The surface of one of the resulting saw-cut sections of each core was sprayed with a pH indicating phenolphthalein solution to determine the depth of carbonation of the paste. A representative image of one of the sprayed faces are shown in Figure 11. The other resulting surface from each core was lapped to achieve a fine matte finish suitable for examination with a stereomicroscope. Lapped surfaces and freshly fractured surfaces were examined using a stereomicroscope (5 to 63 times magnification) equipped with a digital camera and a calibrated reticle for measurements. The appearance of lapped sections is shown in Figure 12 through Figure 30. A thin section was prepared from the top region of Cores 7272-C13, 7586-C10, and 7937-C16 to assess the compositional and textural characteristics of the concrete and refine estimation of water to cementitious materials ratio (w/cm). Thin sections were examined using a petrographic (polarized-light) microscope at magnifications ranging from 50X to 400X. Thin-section photomicrographs are shown in Figure 31 through Figure 33.

The water-to-cement ratio (w/c) was estimated based on the paste features, including but not limited to paste color, hardness, porosity/water absorptivity, residual cementitious materials, hydration products, and paste-aggregate bond.

Various units of measurement are used in this report. For convenience, the following conversions are provided for reference: 1 mm = 1000 μm = 39 mil = 0.039 inch; 1 mil = 0.001 inch = 25 μm.

Concrete Characteristics

Concretes from the same asset exhibit overall similar appearance and contain similar composition of aggregate and cement (Figure 12). Variations in paste color, estimated w/c, air contents, and aggregate gradations were observed between the assets.

Concretes represented by all nine cores contain crushed granite and diorite igneous rock coarse aggregate (or their low-metamorphosed equivalents, 1/2 to 3/4 inch top size) and similar siliceous sand dispersed in air-entrained or marginally air entrained portland cement paste. No supplementary cementitious materials such as slag cement or fly ash were observed. No evidence of materials-related distress involving paste and aggregate such as alkali-silica reaction (ASR) was observed, nor was delayed ettringite formation (DEF). Apart from the surficial erosion/weathering, no deterioration or significant material alteration was observed in any of the cores. Minor vertical cracking was observed, most notably in Core 7272-C13 in which a vertical crack of 10 mils wide extended up to 2 inches deep from the top surface (Figure 4, Figure 12, and Figure 17). The crack extended mainly around aggregate particles and appeared to be related to restraint volumetric variations due to drying shrinkage or thermal fluctuations.

Finer and shorter vertical cracks were observed in other examined cores. These cracks appeared overall similar to the crack in Core 7272-C13 in characteristics and origin and typically extended no more than 1 inch deep from the top surface.

Other major findings are described below. Unless stated otherwise, the following descriptions pertain to all nine cores examined petrographically.

- The concrete is well consolidated overall with an few scattered entrapped voids. Paste is moderately hard with a Mohs hardness near 2.5. Hardness was highest in Asset 7937 and lowest in Asset 7586.
- Estimated w/c was 0.43 to 0.48. The w/c of Asset 7937 concrete was likely near the lower end value of the estimated range (0.43) and that of Asset 7586 was likely near the higher end value of the estimated range (0.48). The estimated w/c of Asset 7272 lied within the range.
- The cement is suspected to be a sulfate-resistant portland cement. Abundant amounts of ferrite were observed, considered as a feature of sulfate-resistant portland cement.
- No significant amounts cement-sized limestone fines were observed.
- Estimated air content was 5 to 7 percent in Asset 7272, 2 to 4 percent in Asset 7586, and 3 to 5 percent in Asset 7937. Concrete of Asset 7586 did not appear to be air-entrained.
- Volume of coarse aggregate appeared to be low in the cores from Assets 7586 and 7937. Fine aggregate volume appeared to be high in all 9 cores (no point-count analysis was conducted on any of the cores to confirm their volumetric proportions).
- The fine aggregate is suspected to be manufactured from rocks similar to the coarse aggregate.
- Minor secondary deposits of ettringite lined many air voids, consistent with exposure to moisture.
- Embedded steel reinforcement or impression of steel reinforcement does not contain significant corrosion products or paste stains.

DEPTH OF CARBONATION TESTING

Each of the nine examined cores was cut perpendicular to the top surface of the core. The freshly sawn surfaces were allowed to dry then immediately sprayed with a pH indicating phenolphthalein solution, which imparts a bright pink color on uncarbonated paste and remains colorless on carbonated paste. The results of depth of carbonation testing are listed in Table 2. A representative image of one of the cores after being sprayed with phenolphthalein solution is shown in Figure 11. Carbonation is also observable as an orange discoloration of the paste in the top region (Figure 12 through Figure 30), and confirmed by thin-section examinations.

Table 2. Measured Depth of Carbonation

Sample ID	Typical Depth of Carbonation, inch
7272-C2	1/8
7272-C5	1/8
7272-C13	1/4
7586-C4	1/16
7586-C10	1/16
7586-C13	1/8
7937-C6	1/16

Sample ID	Typical Depth of Carbonation, inch
7937-C11	1/16
7937-C16	1/16

Carbonation depth was slightly deeper in near-surface areas with coarse aggregate particles or along vertical cracking. Core 7272-C13 contained a crack along the top surface that propagated approximately 2 inches below the surface. Carbonation was deeper along the crack and carbonated paste extended up to 1/8 inch from the sides of the crack. Overall, the depth of carbonation was considered minor for concrete placed in the 1970s and 1980s.

SUMMARY

Laboratory studies, including petrographic examinations, compressive strength testing, and chloride ion content analysis, have been conducted on concrete cores extracted from various locations of three bridges, or Assets, in Columbia, South Carolina.

Concretes represented by the examined nine cores appeared dense, well consolidated, and of good quality overall. No evidence of distress caused by deleterious chemical reactions such as ASR was observed. No evidence of DEF or cyclic freeze-thaw was observed.

Concretes of the three assets are composed of crushed igneous rock coarse aggregate and likely manufactured siliceous sand fine aggregate dispersed in portland cement paste with varying estimated air contents among the three assets. Estimated w/c varied marginally between the assets but was overall within the range of 0.43 to 0.48. Depth of carbonation ranged from 1/16 to 1/4 inch among the nine cores, and was considered minor. Minor vertical cracking was observed and appeared to be related to restraint volumetric movements due to drying shrinkage or thermal fluctuations.

FIGURES

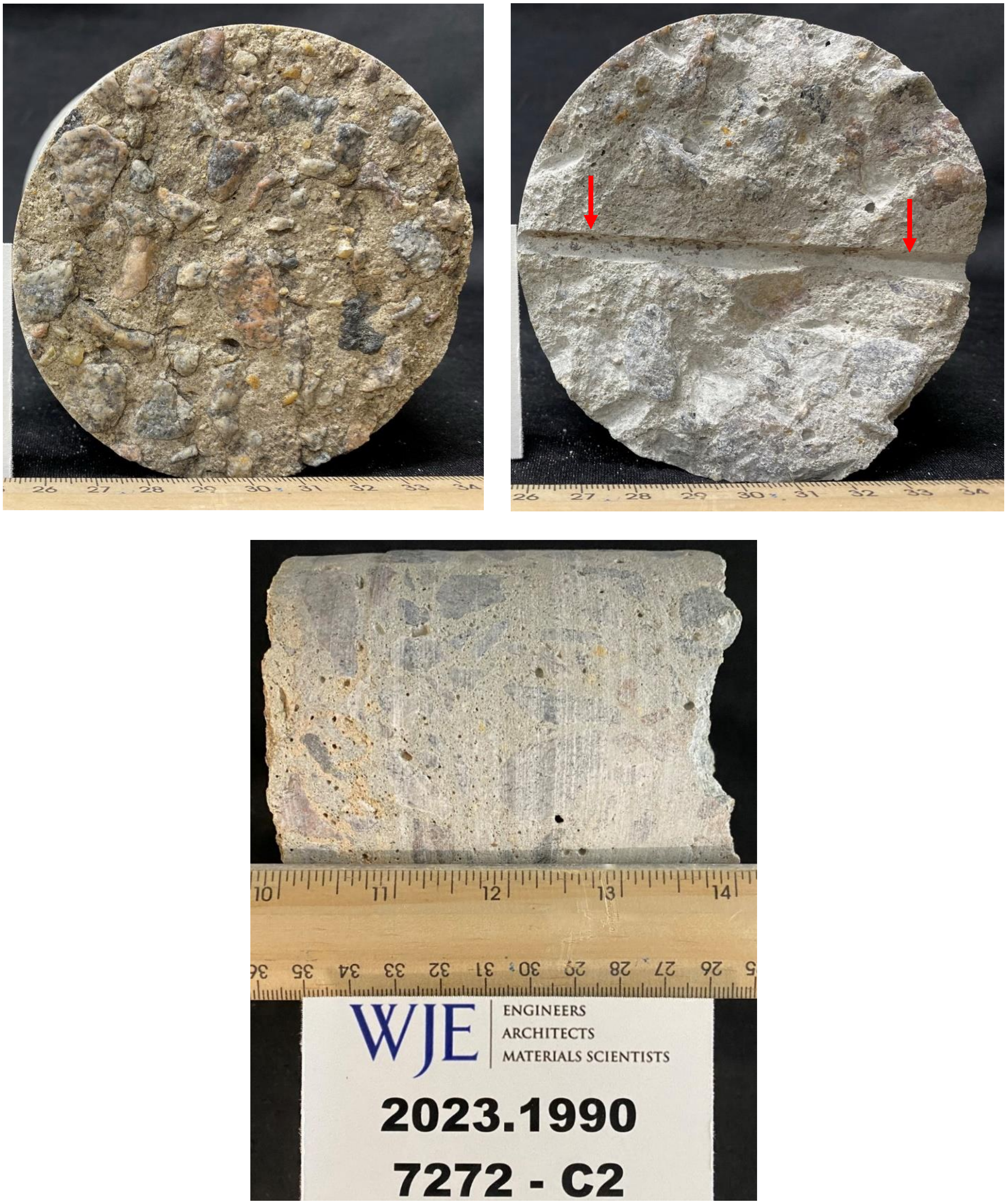


Figure 1. 7272-C2. As-received, with the top surface in the top left image, bottom surface in the top right, and a longitudinal view of the core with the top surface to the left in the bottom image. Red arrows indicate impressions of steel wire on the bottom of the core. Note orangish, discolored paste along the top surface region, likely due to carbonation and weathering.

Figure 2. 7272-C5. As-received, with the top surface in the top left image, bottom surface in the top right, and a longitudinal view of the core with the top surface to the left in the bottom image. Red arrows indicate a surface-parallel to surface-oblique fracture.

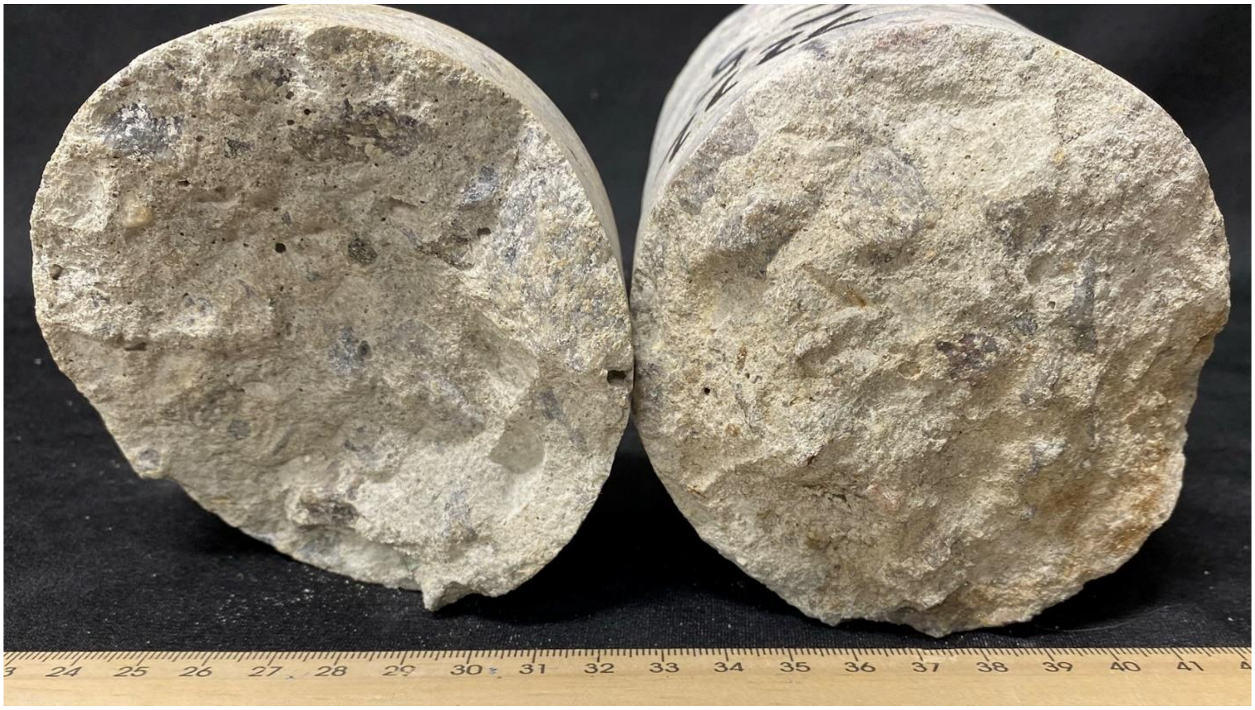


Figure 3. 7272-C5. Opposing fracture faces within the core. There are no impressions of rebar along the fracture. The fracture propagates around and through coarse aggregate.

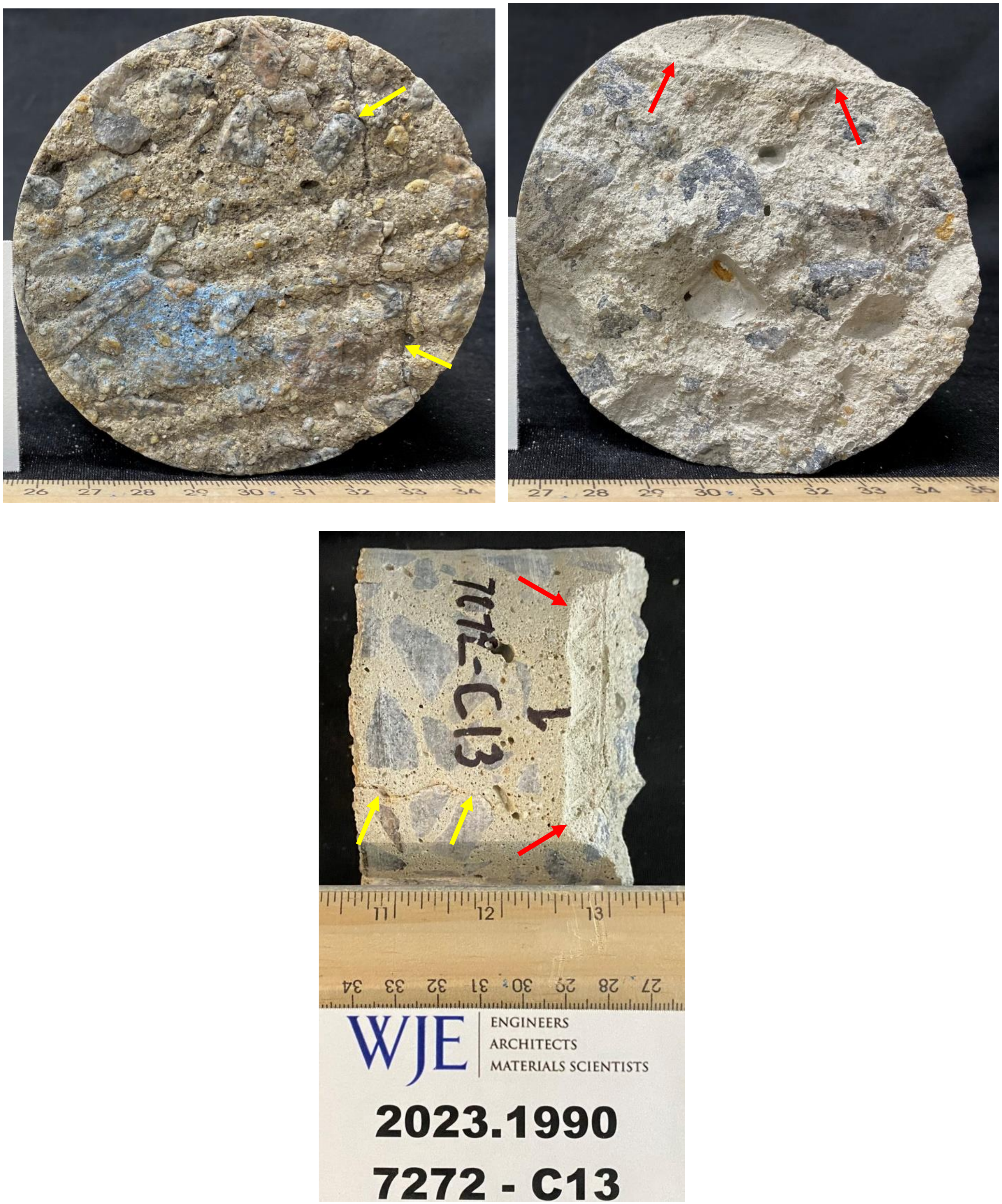


Figure 4. 7272-C13. As-received, with the top surface in the top left image, bottom surface in the top right, and a longitudinal view of the core with the top surface to the left in the bottom image. Red arrows indicate impressions of a rebar on the bottom of the core. Yellow arrows indicate a crack propagating from the top surface

Figure 5. 7586-C4. As-received, with the top surface in the top left image, bottom surface in the top right, and a longitudinal view of the core with the top surface to the left in the bottom image. Note the well-preserved tines on the top surface.

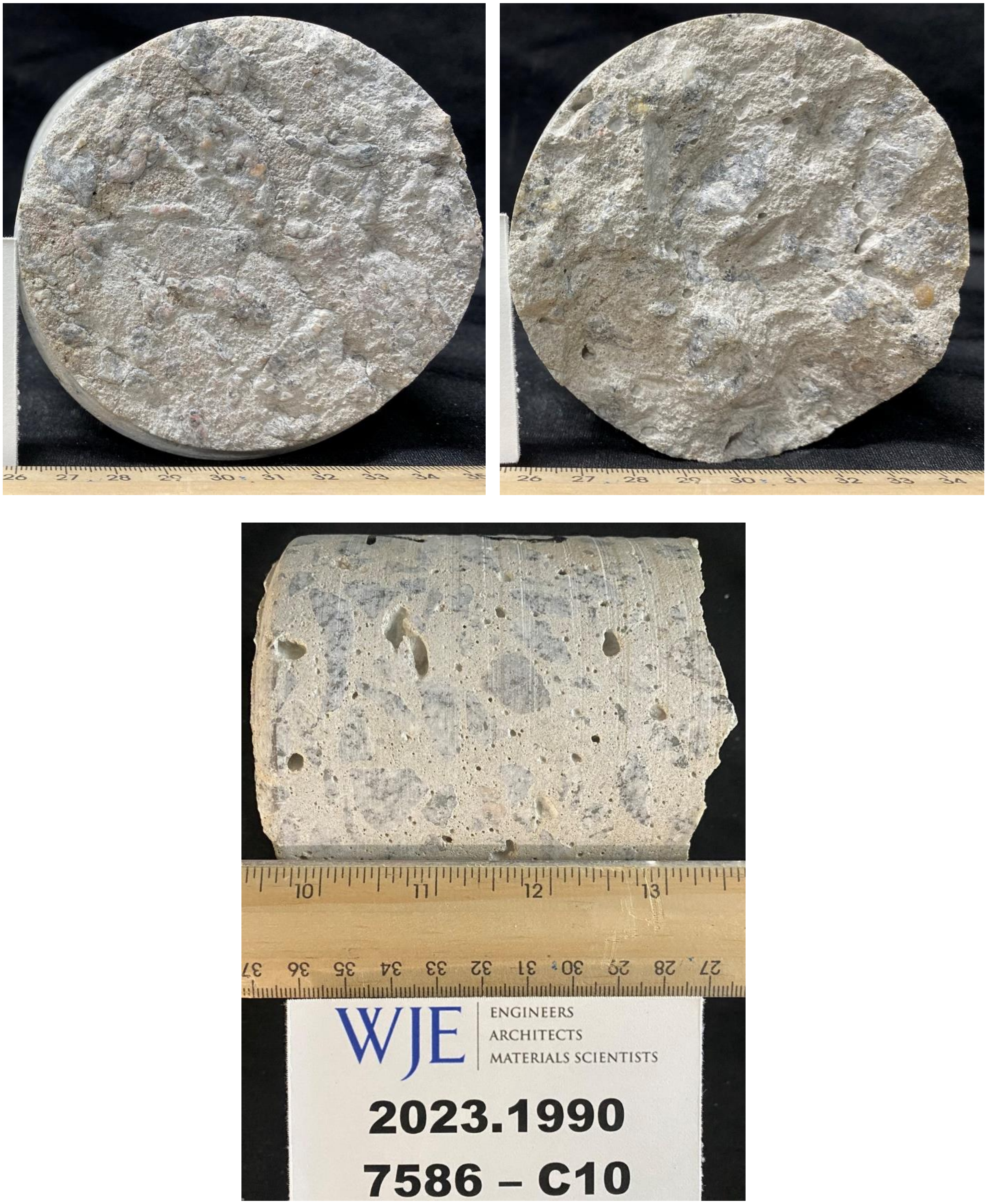


Figure 6. 7586-C10. As-received, with the top surface in the top left image, bottom surface in the top right, and a longitudinal view of the core with the top surface to the left in the bottom image. Note the severely eroded top surface.

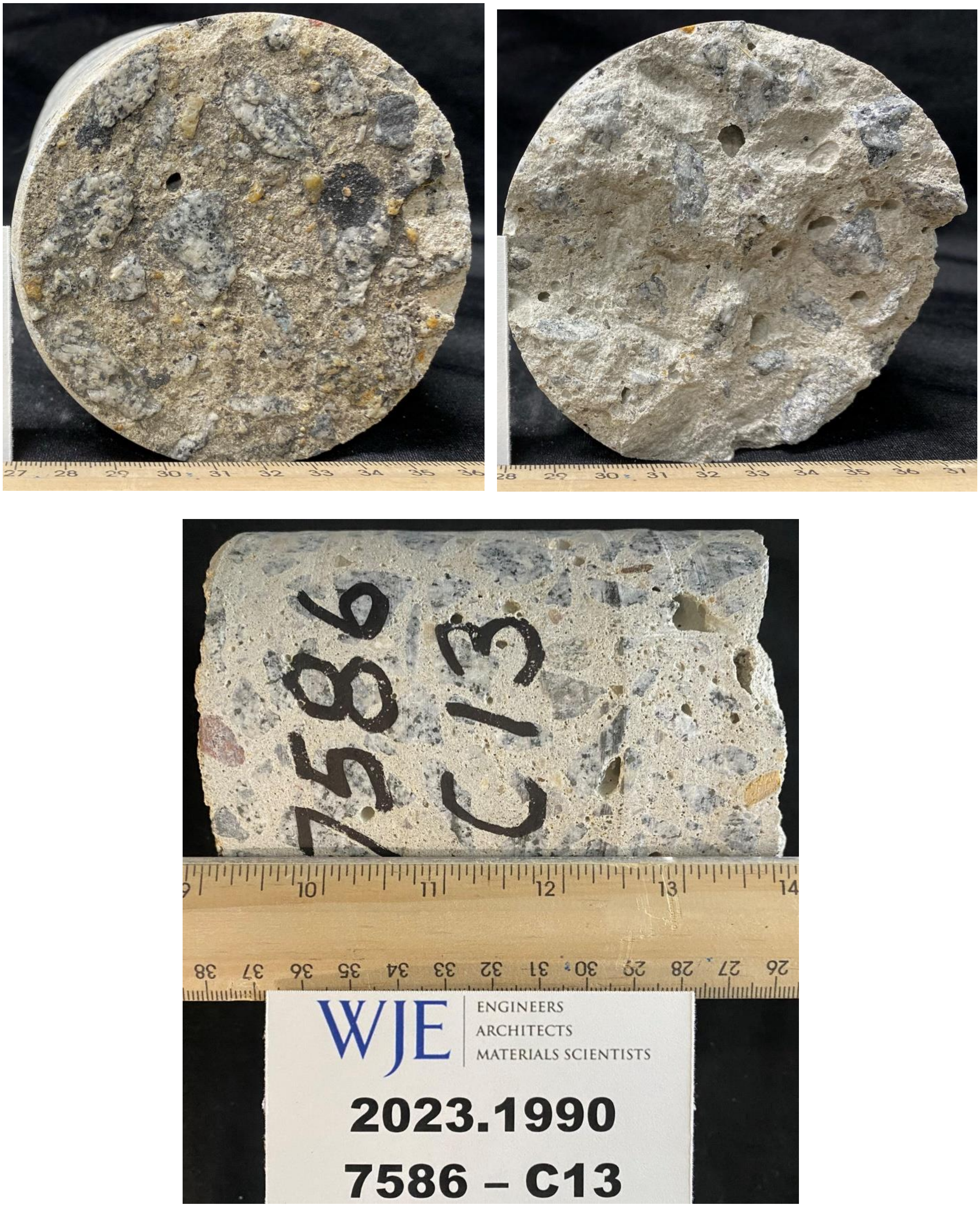


Figure 7. 7586-C13. As-received, with the top surface in the top left image, bottom surface in the top right, and a longitudinal view of the core with the top surface to the left in the bottom image. Note the eroded top surface.

Figure 8. 7937-C6. As-received, with the top surface in the top left image, bottom surface in the top right, and a longitudinal view of the core with the top surface to the left in the bottom image. The core barrel appears to have slipped during coring, causing a strange shape along the core edges (red arrows) that is not a feature of the concrete.

Figure 9. 7937-C11. As-received, with the top surface in the top left image, bottom surface in the top right, and a longitudinal view of the core with the top surface to the left in the bottom image. Red arrows indicate steel wires on the side and bottom of the core.

Figure 10. 7937-C16. As-received, with the top surface in the top left image, bottom surface in the top right, and a longitudinal view of the core with the top surface to the left in the bottom image. Note the very well-preserved tines and slightly glossy or shiny appearance on the top surface.

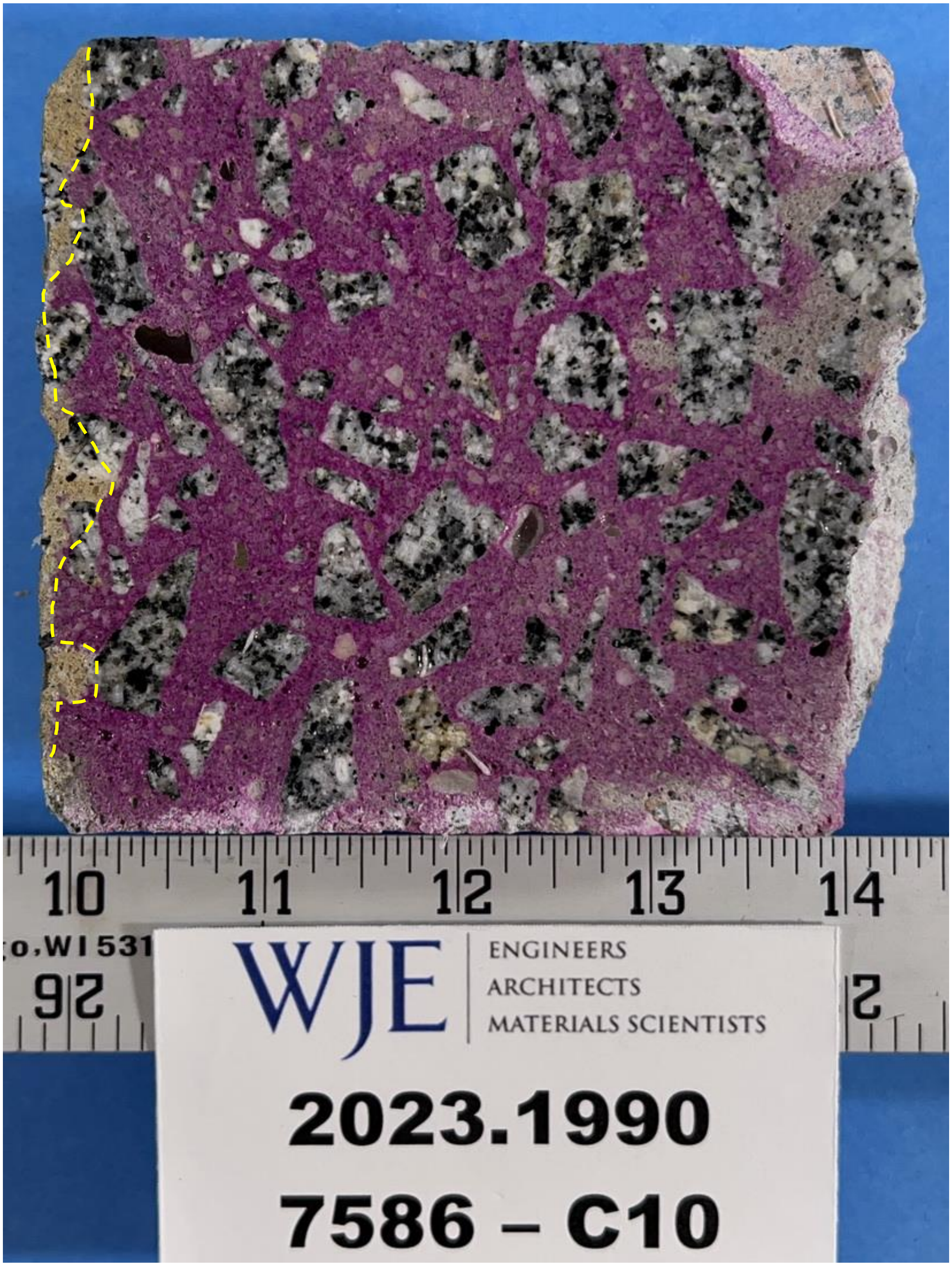


Figure 11. Core 7586-C10. Cut face shortly after being sprayed with phenolphthalein solution. Top surface to the left of the image. Note a thin layer (average of 1/16 inch, but locally up to 1/2 inch) of carbonated paste along the top surface, to the left of the yellow dashed line.

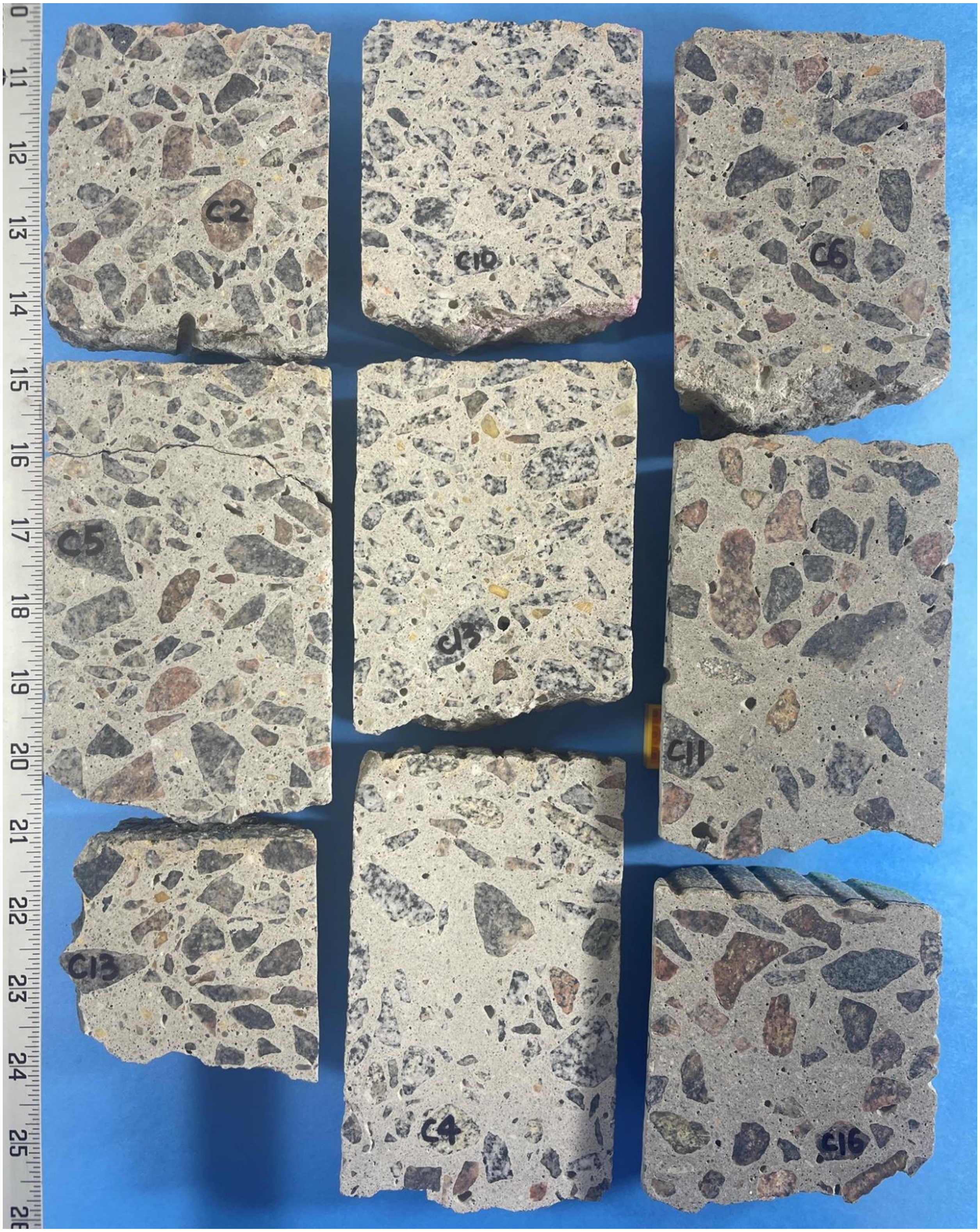


Figure 12. Lapped cross sections of the 9 cores from the three bridges. Left: Cores 2, 5 and 13 of Asset 7272; Middle: Cores 10, 13 and 4 of Asset 7586; Right: Cores 6, 11 and 16 of Asset 7937.

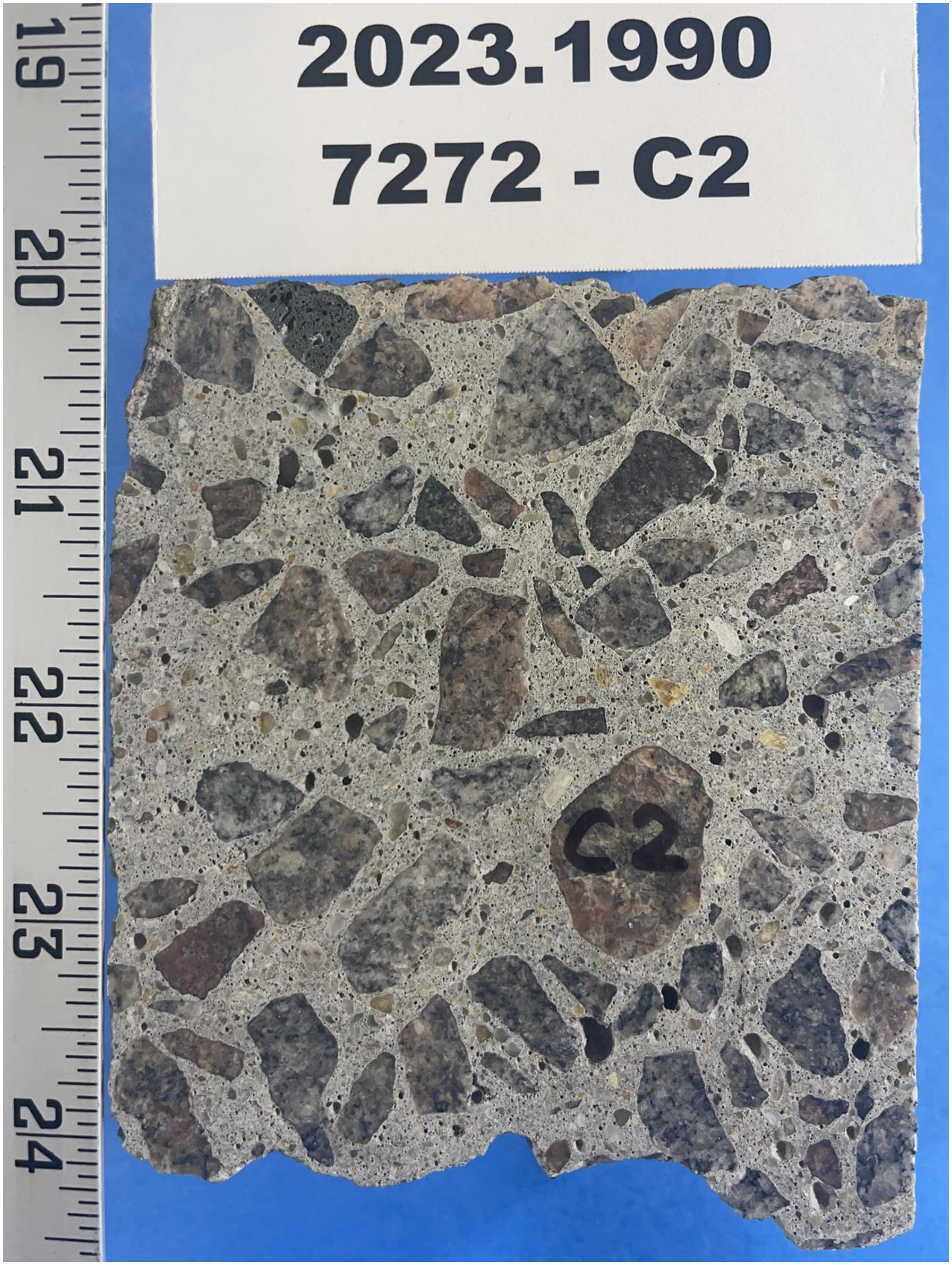


Figure 13. 7272-C2. Lapped longitudinal section, with the top surface towards the top of the image. Note the uneven top surface and loss of tines.

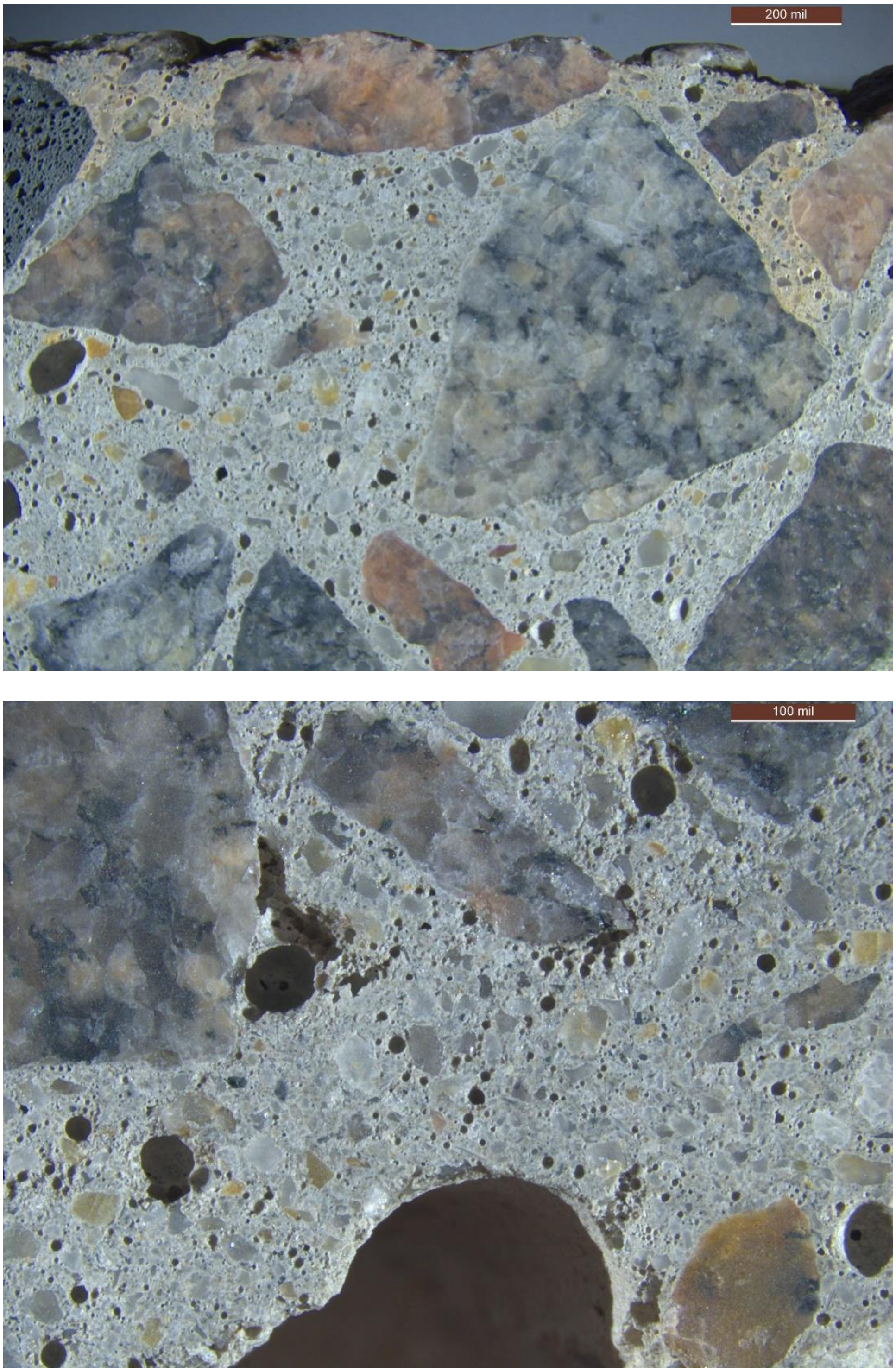


Figure 14. 7272-C2. Closeup views of the top region (top photo) and bottom region (bottom photo) of the core show paste, air voids, and aggregate of the concrete.

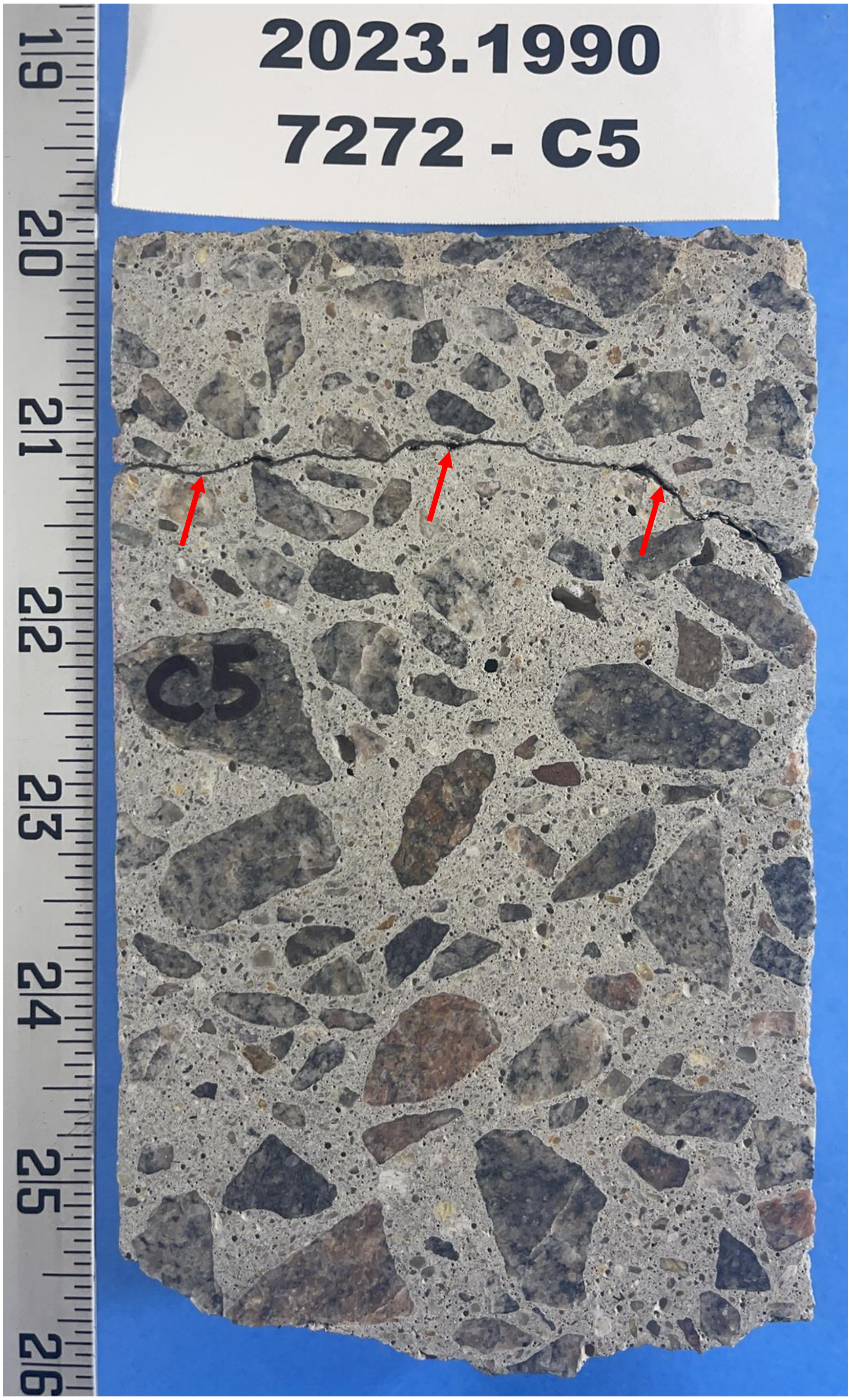


Figure 15. 7272-C5. Lapped longitudinal section, with the top surface towards the top of the image. Note the uneven top surface and loss of tines. Red arrows indicate a fracture below the surface.

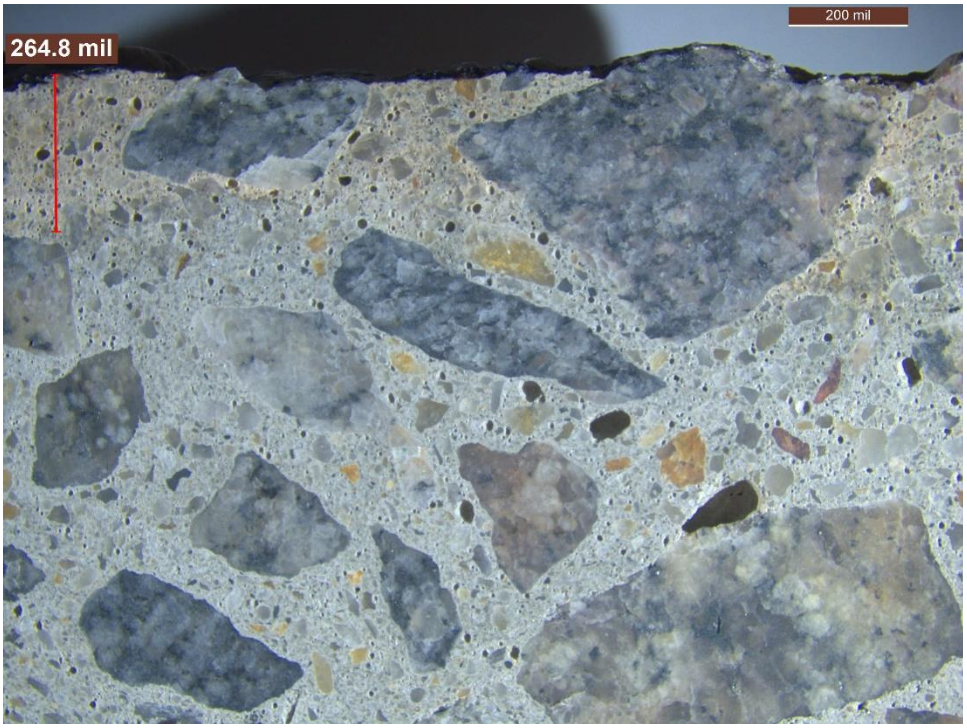
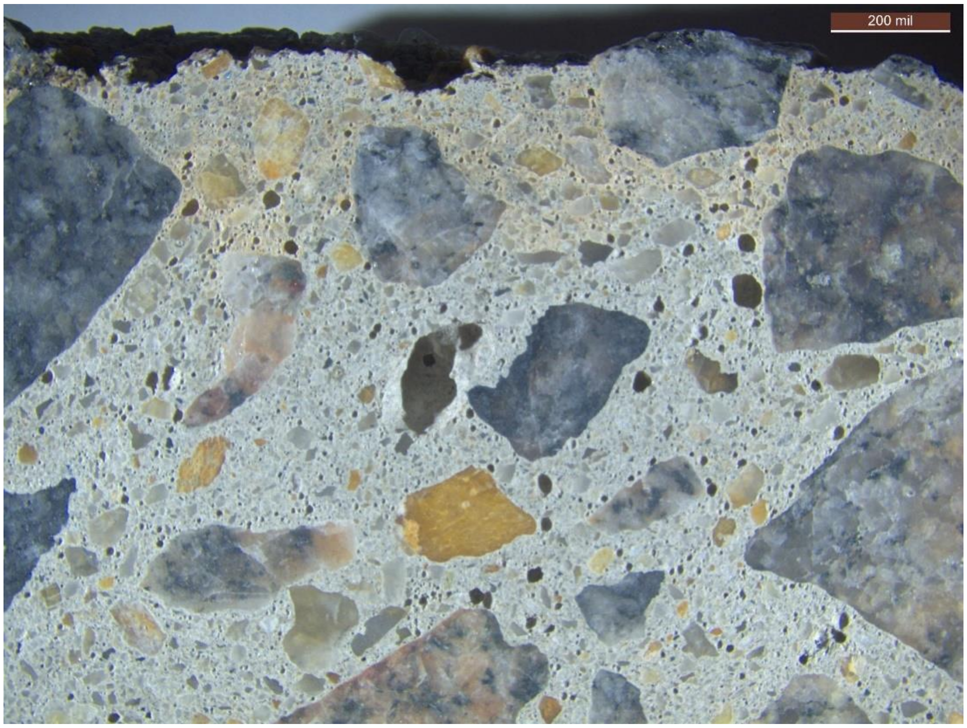


Figure 16. 7272-C5. Closeup views of the top region (top photo) and approximately 1 inch deep near the fracture (bottom photo) of the core show paste, air voids, and aggregate of the concrete. Carbonation-related discoloration is measured roughly 1/4 inch thick (264.8 mils).

Figure 17. 7272-C13. Lapped longitudinal section, with the top surface towards the top of the image. Note the uneven top surface and loss of tines. The core originally contained a vertical crack that opened during sample preparation, represented by the fractured left surface of the core (red arrows).



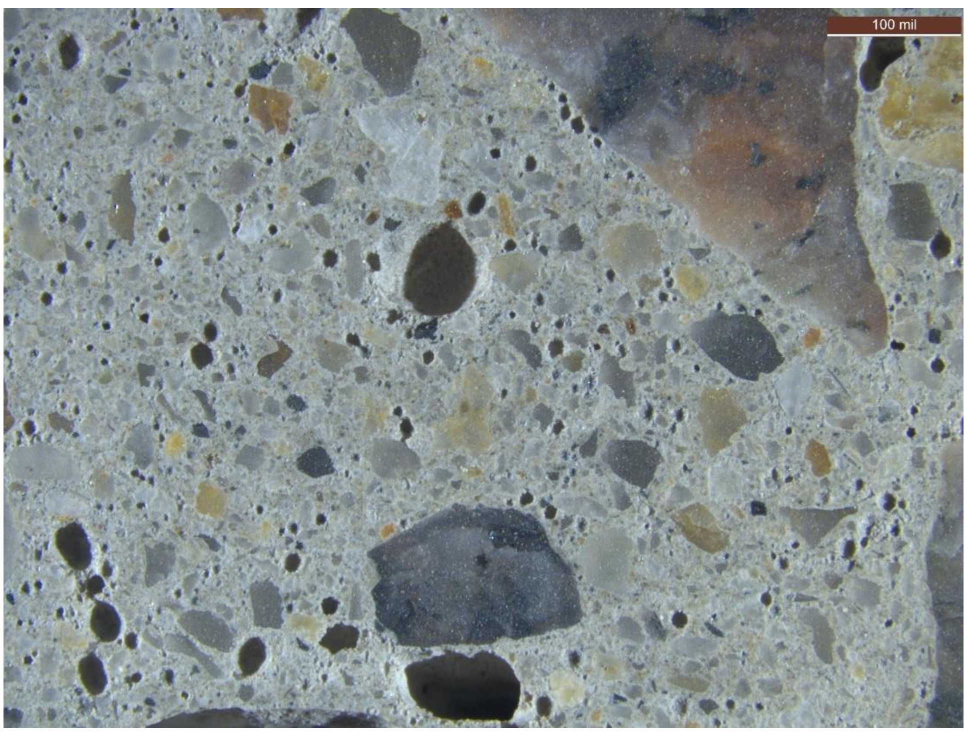


Figure 18. 7272-C13. Closeup views of the top region (top photo) and bottom region (bottom photo) of the core show paste, air voids, and aggregate of the concrete.

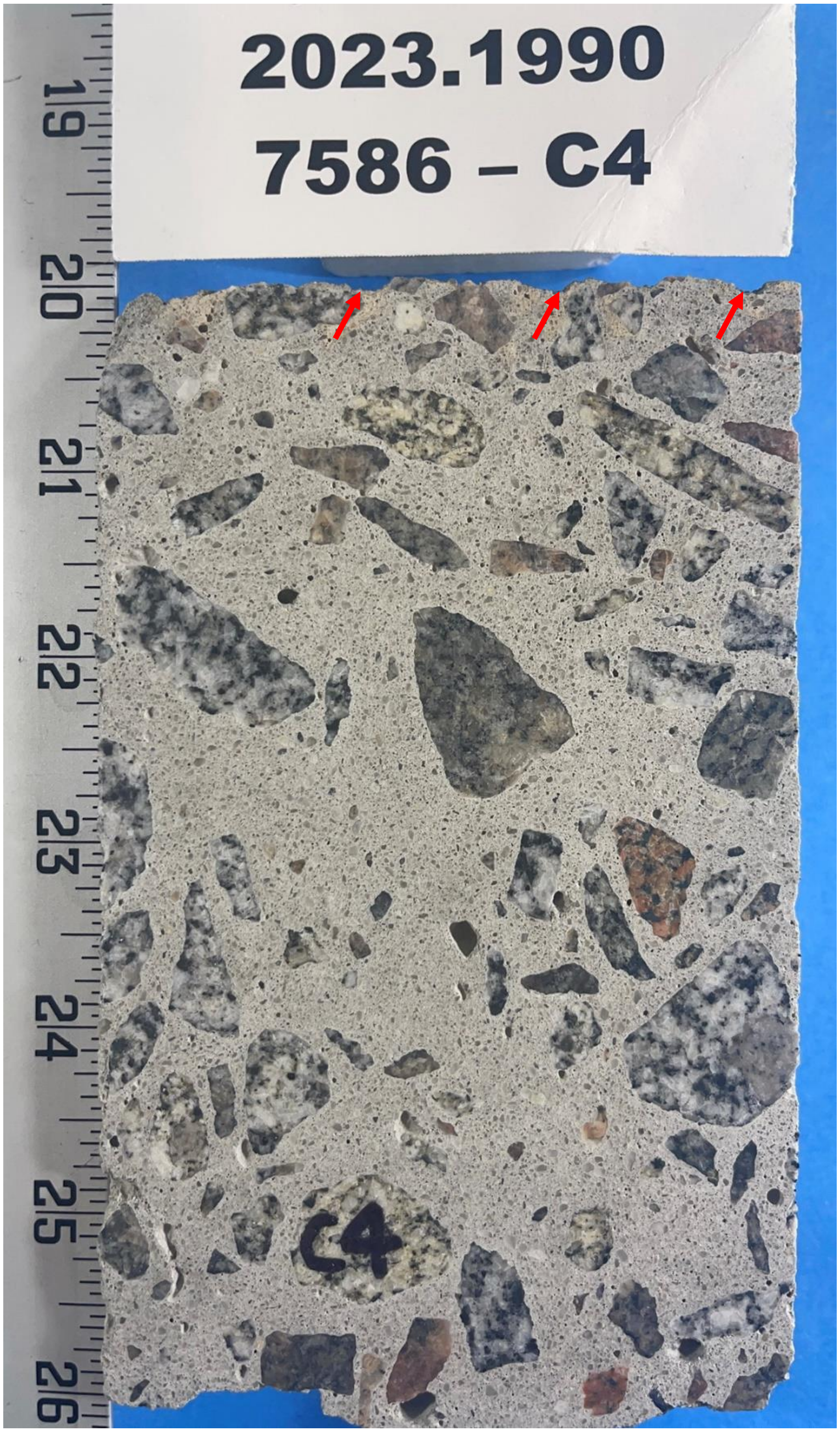


Figure 19. 7586-C4. Lapped longitudinal section, with the top surface towards the top of the image. Note the uneven top surface and somewhat preserved tines, indicated with red arrows. The aggregate in cores from Asset 7586 is different than that from 7272.

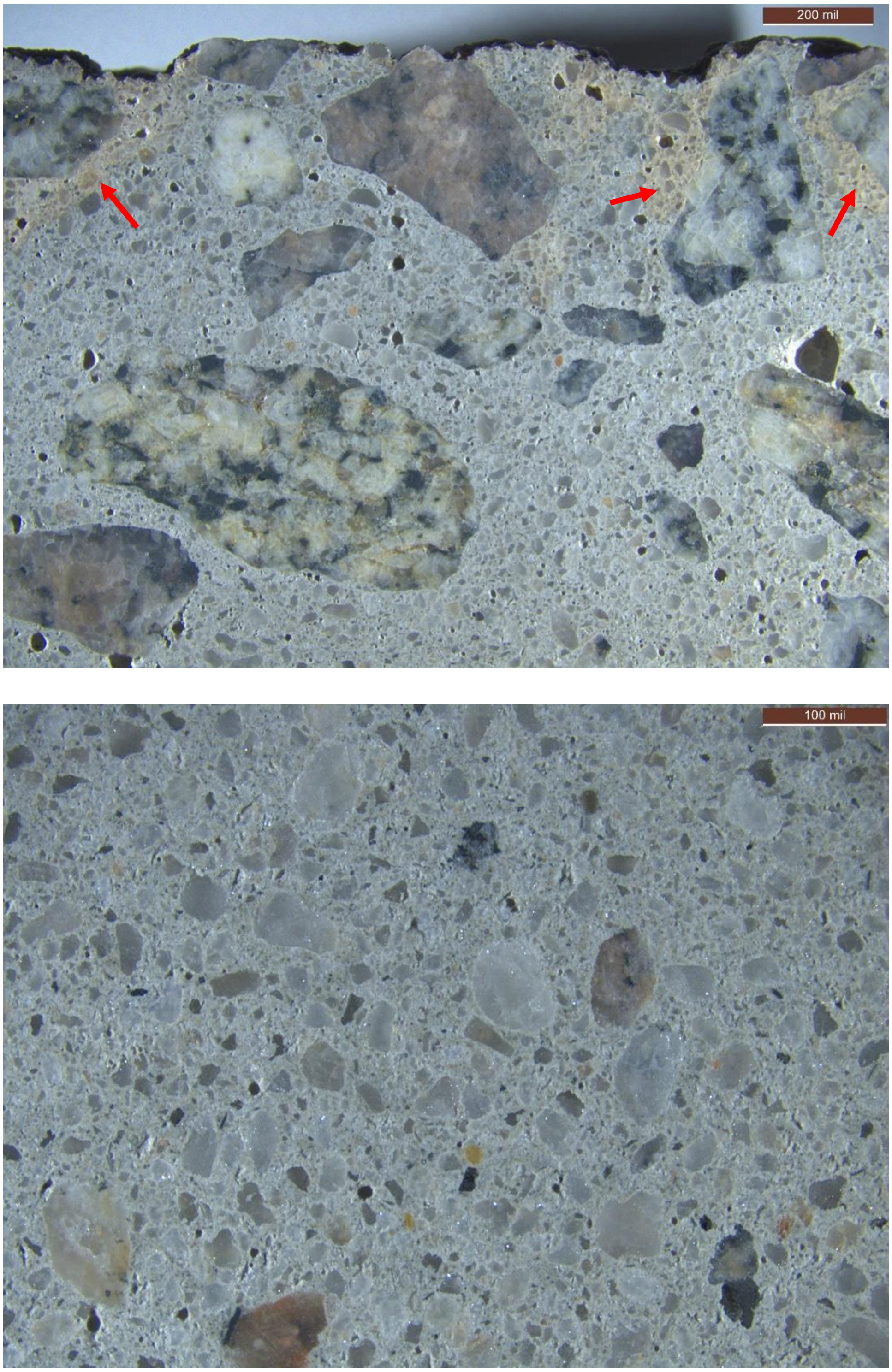


Figure 20. 7586-C4. Closeup views of the top region (top photo) and bottom region (bottom photo) of the core show paste, air voids, and aggregate of the concrete. Arrows indicate localized discoloration likely due to carbonation.

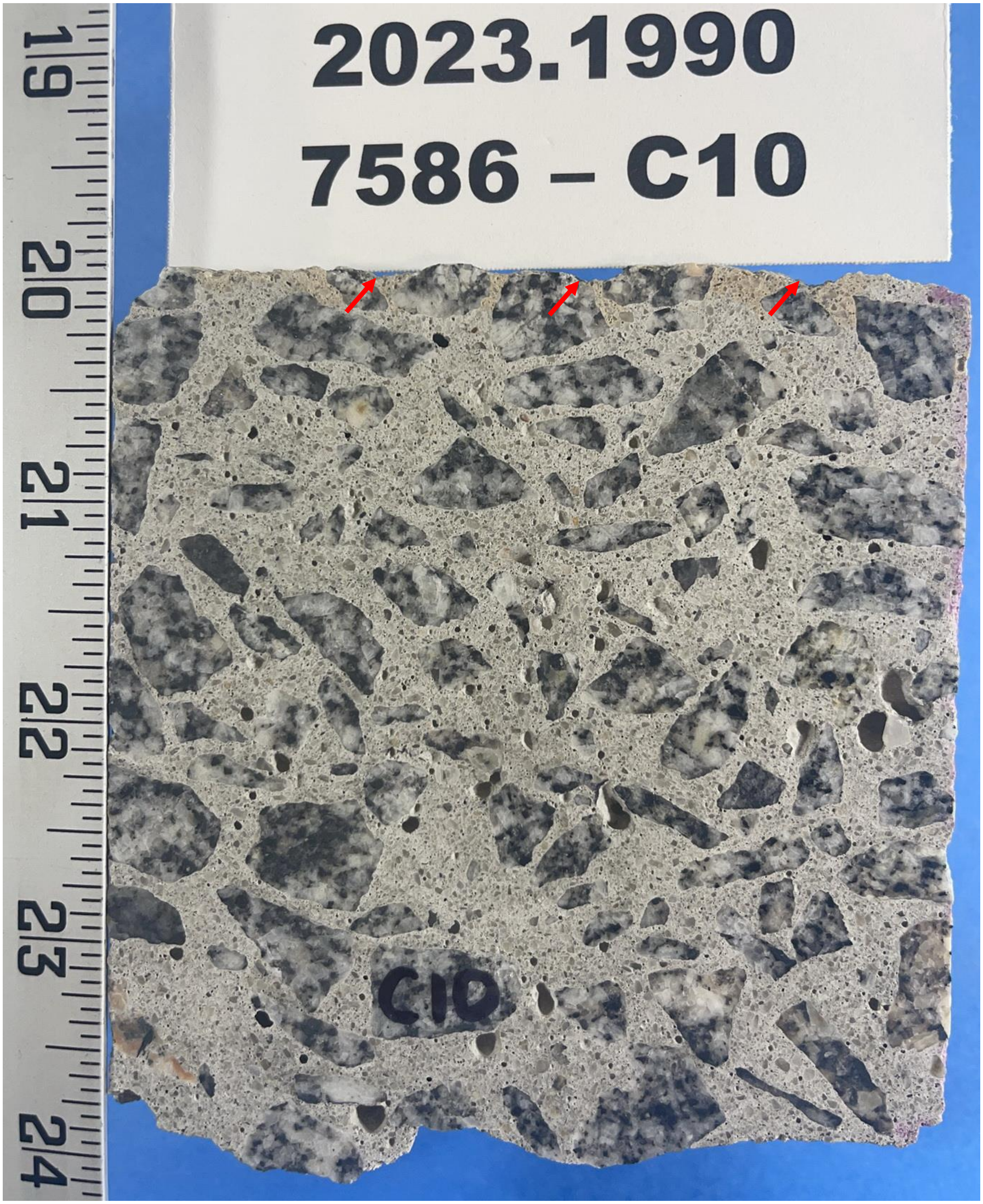


Figure 21. 7586-C10. Lapped longitudinal section, with the top surface towards the top of the image. Note the uneven top surface and somewhat preserved tines, indicated with red arrows. The aggregate in cores from Asset 7586 is different than that from 7272.

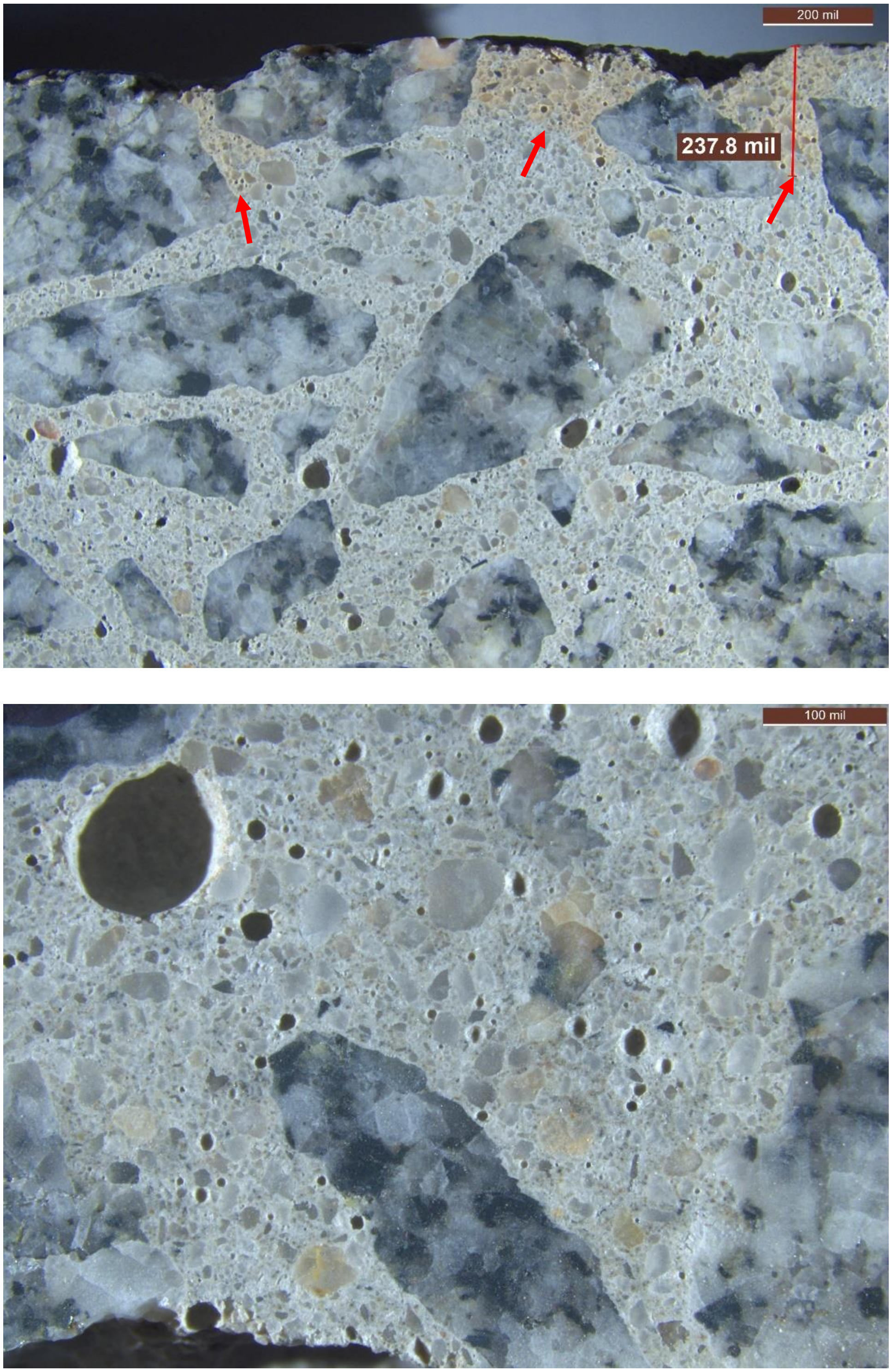


Figure 22. 7586-C10. Closeup views of the top region (top photo) and bottom region (bottom photo) of the core show paste, air voids, and aggregate of the concrete. Arrows indicate localized discoloration likely due to carbonation that measures roughly 1/4 inch.

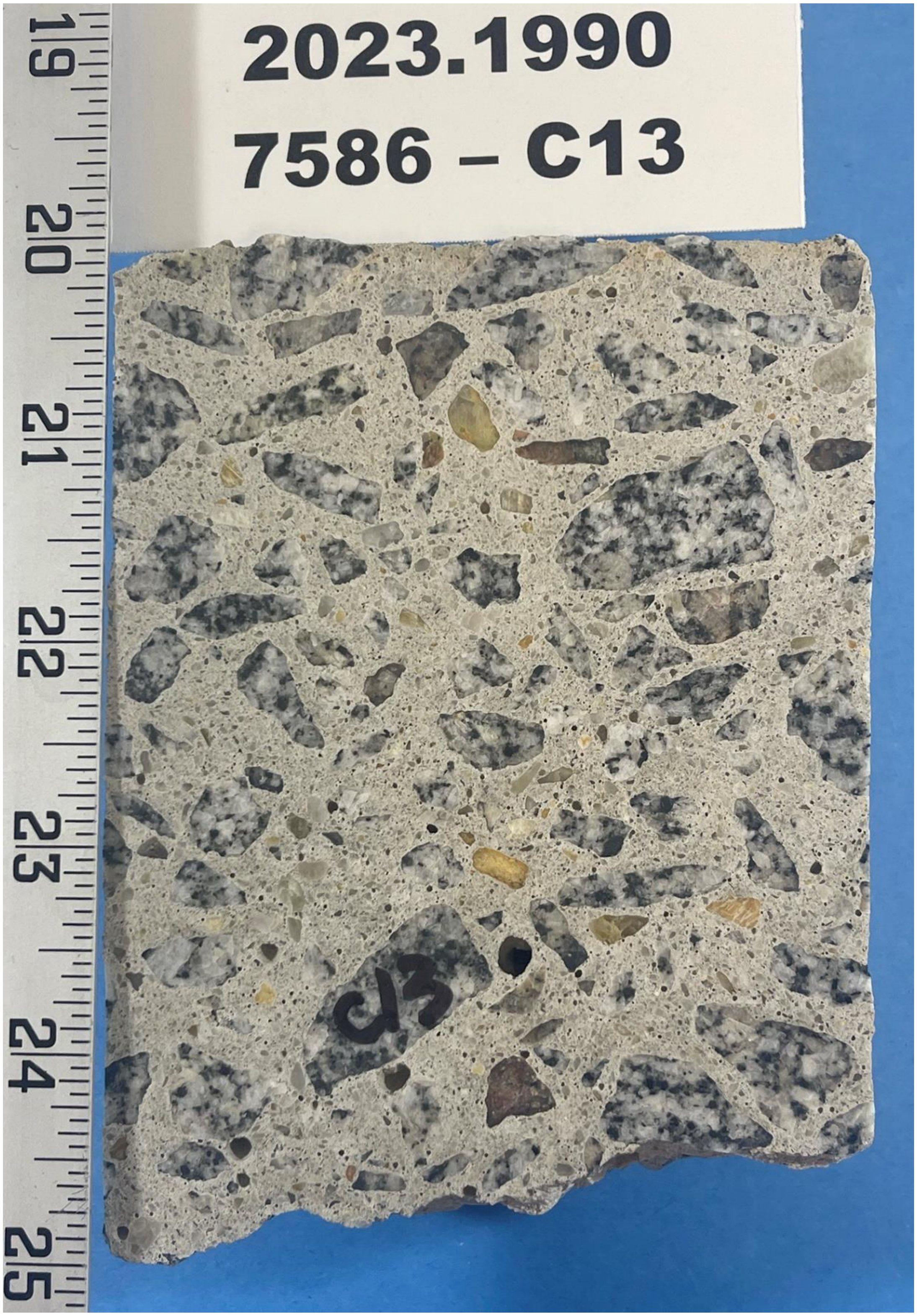
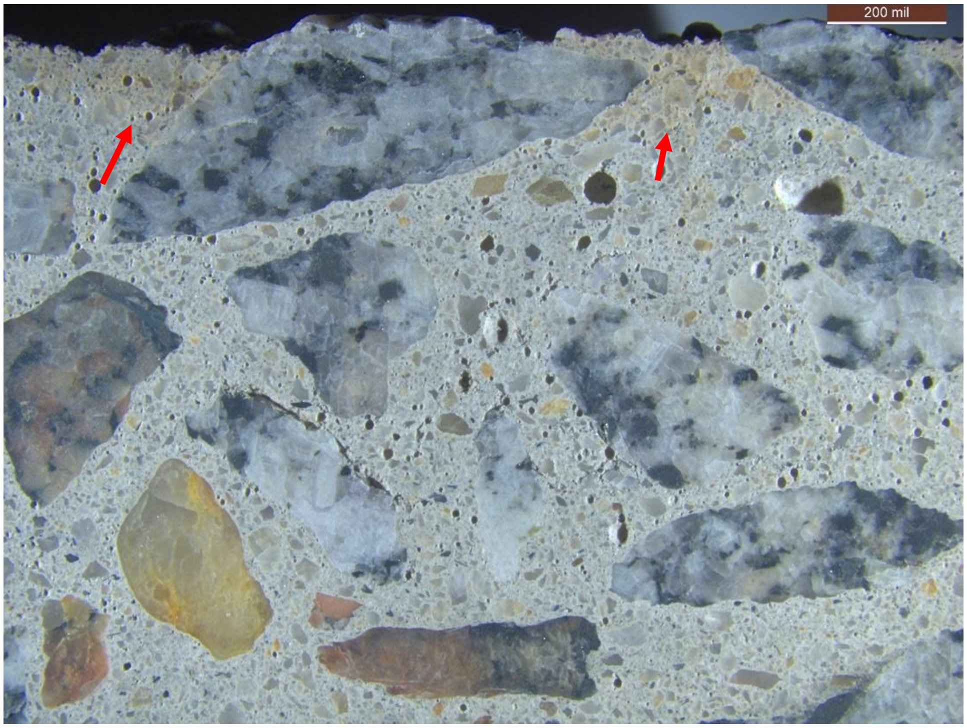


Figure 23. 7586-C13. Lapped longitudinal section, with the top surface towards the top of the image. Note the uneven top surface and loss of tines. The aggregate in cores from Asset 7586 is different than that from 7272.



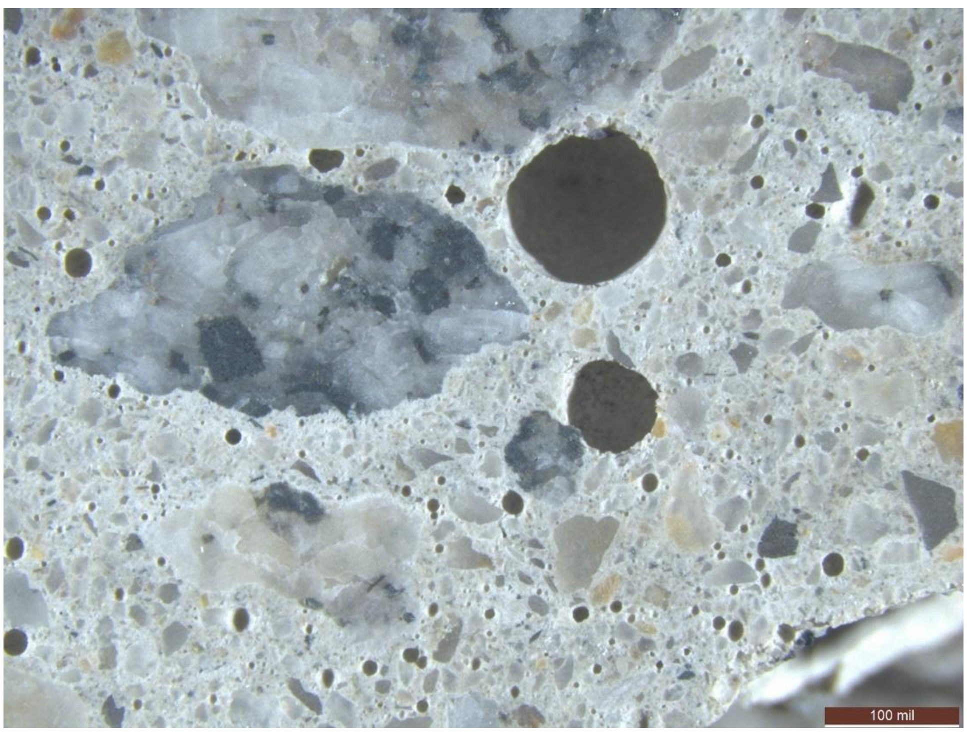


Figure 24. 7586-C13. Closeup views of the top region (top photo) and bottom region (bottom photo) of the core show paste, air voids, and aggregate of the concrete. Arrows indicate discoloration likely due to carbonation.

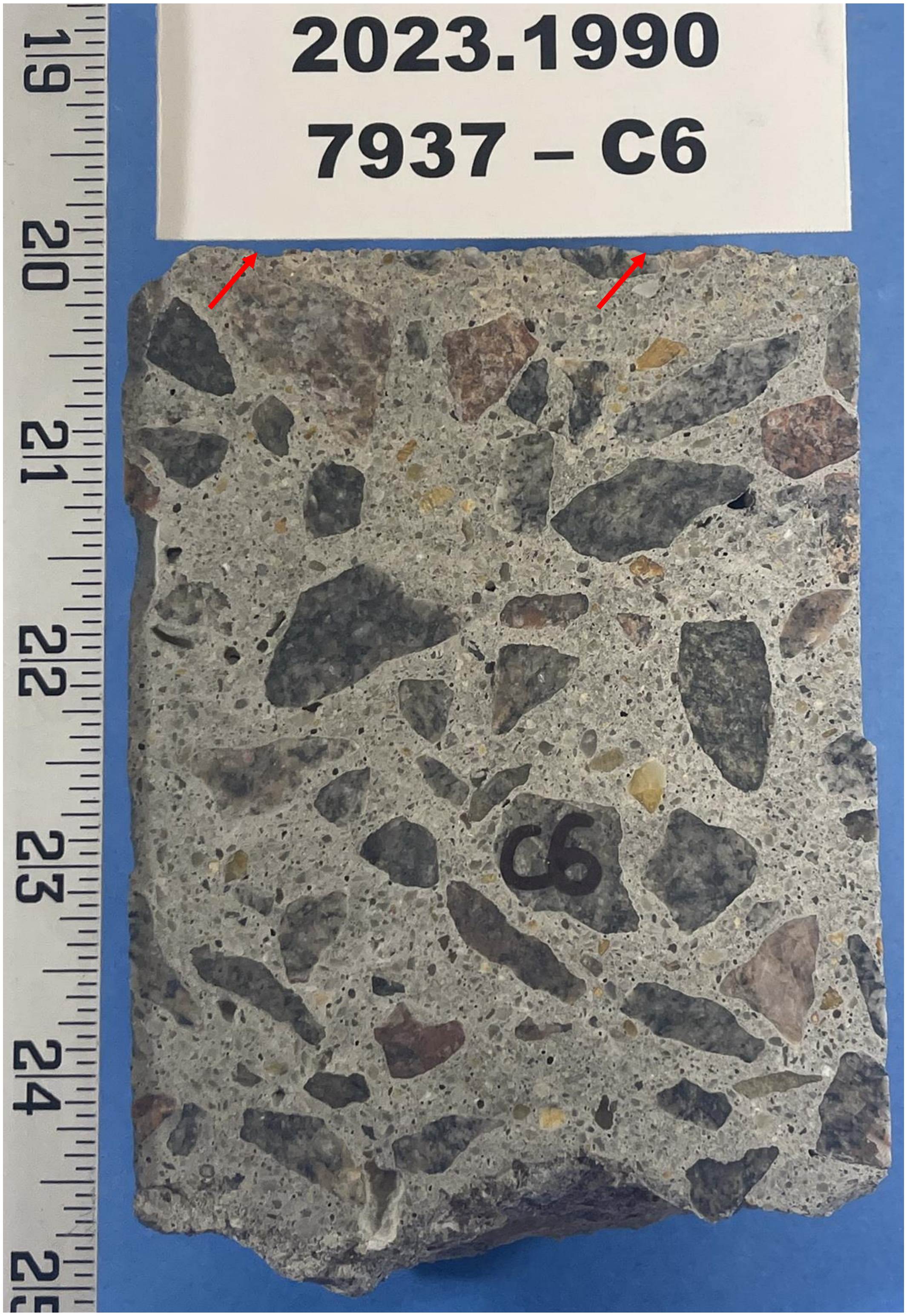
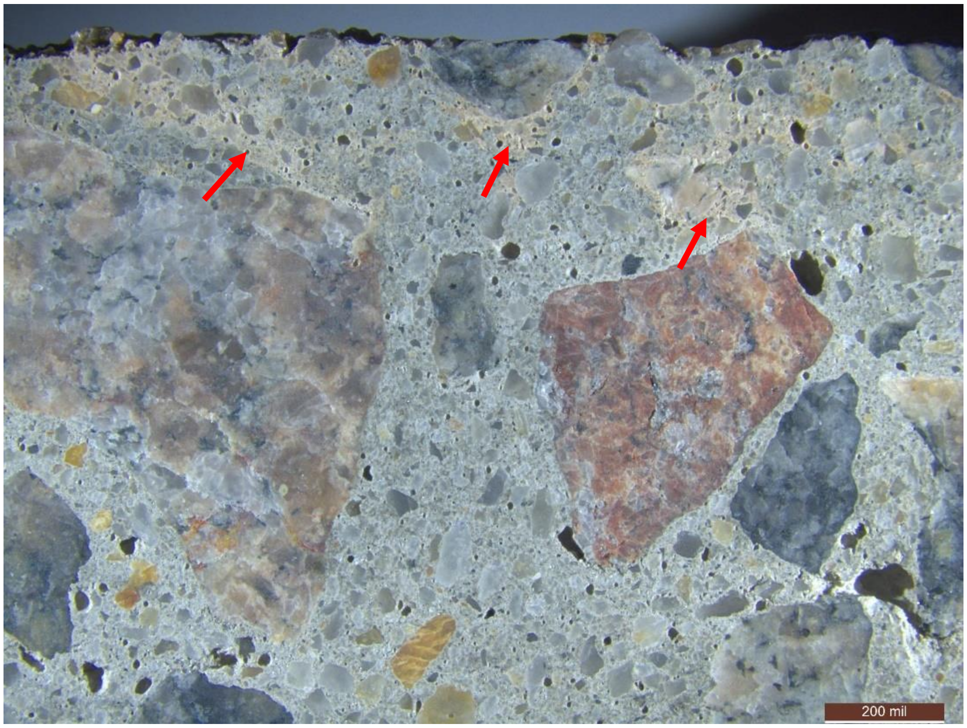


Figure 25. 7937-C6. Lapped longitudinal section, with the top surface towards the top of the image. Note the uneven top surface and somewhat preserved tines, indicated with red arrows. The aggregate in cores from Asset 7937 is similar to that from 7272.



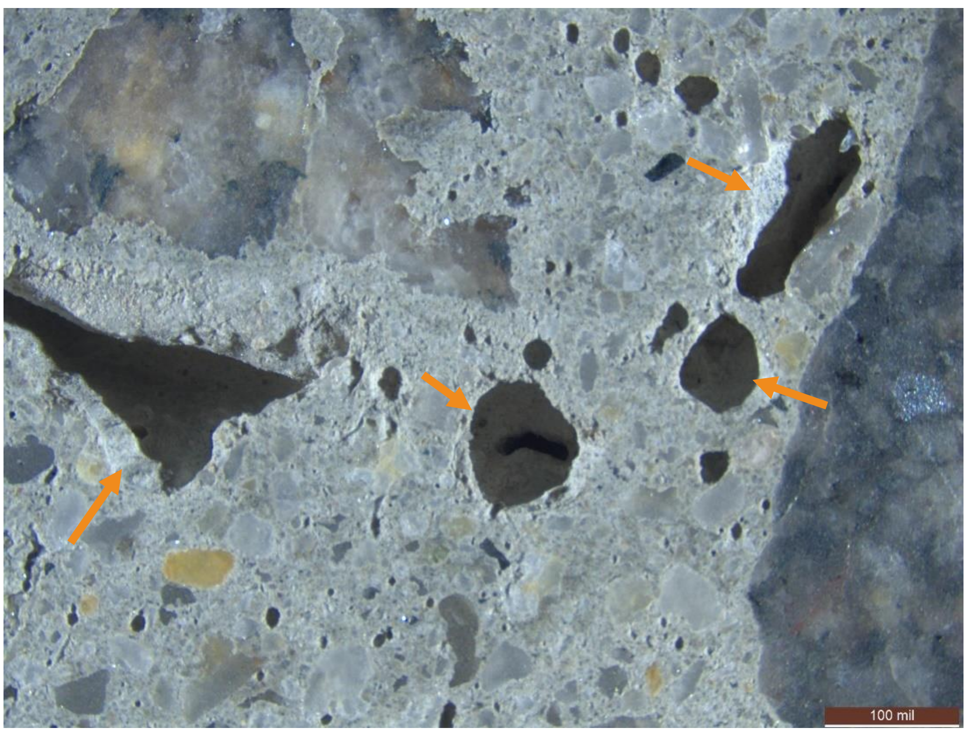


Figure 26. 7937-C6. Closeup views of the top region (top photo) and a region roughly 2 inch deep (bottom photo) of the core show paste, air voids, and aggregate of the concrete. Red arrows indicate localized discoloration likely due to carbonation. A few entrapped air voids were observed in the bottom photo (orange arrows).

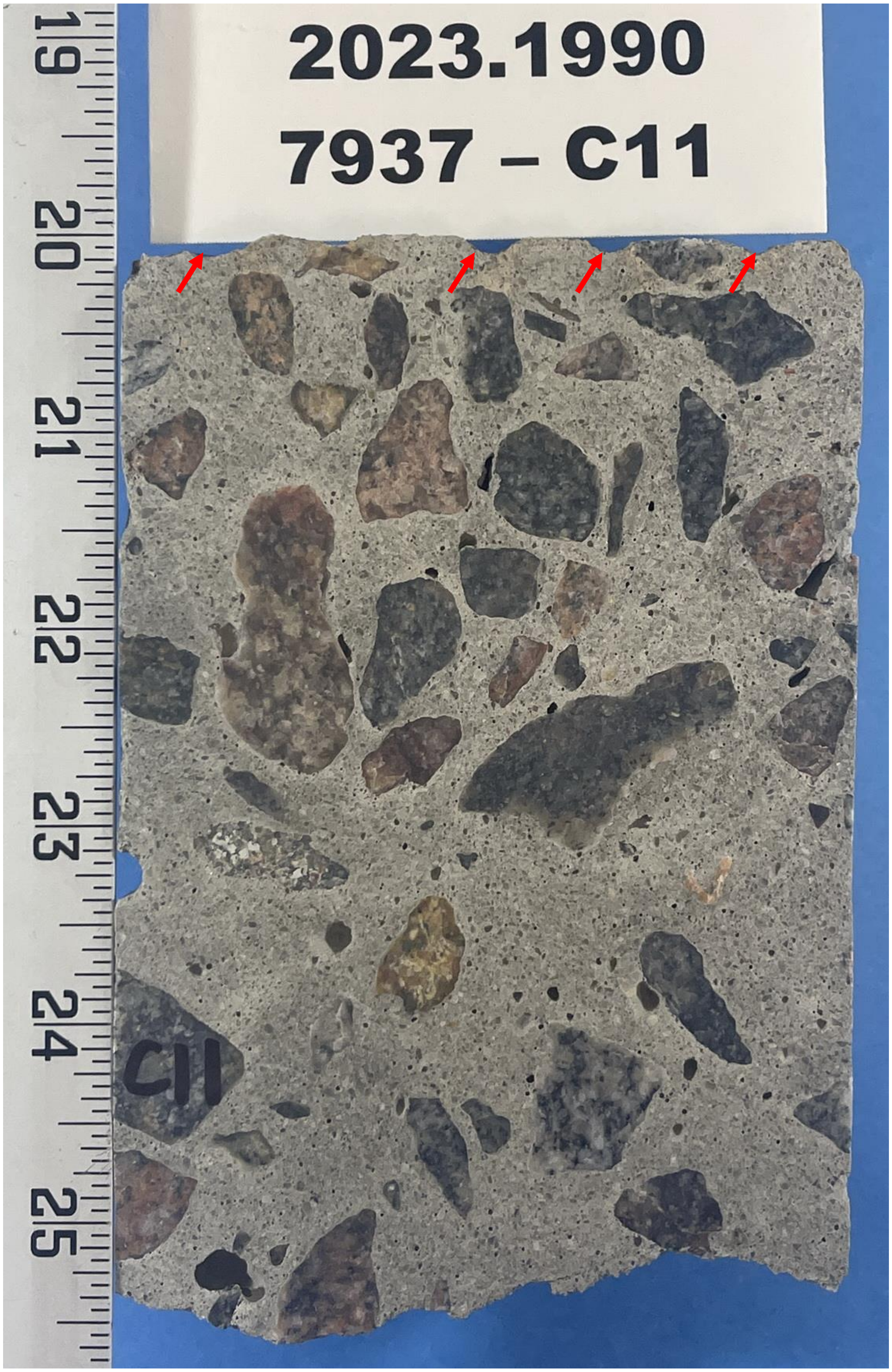
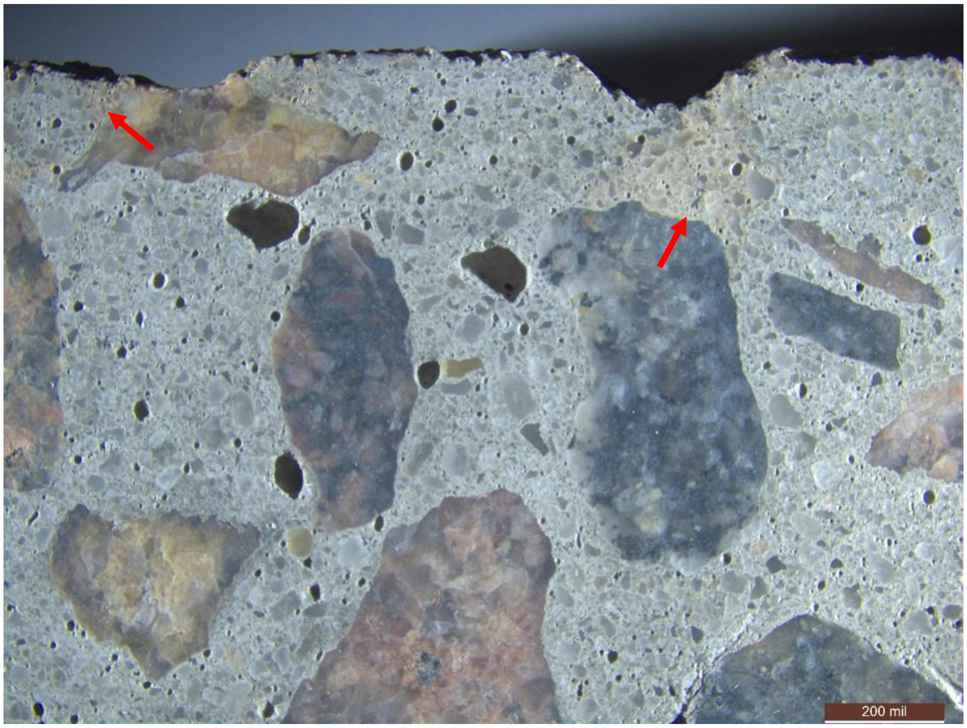


Figure 27. 7937-C11. Lapped longitudinal section, with the top surface towards the top of the image. Note the relatively well-preserved tines, indicated with red arrows. The aggregate in cores from Asset 7937 is similar to that from 7272.



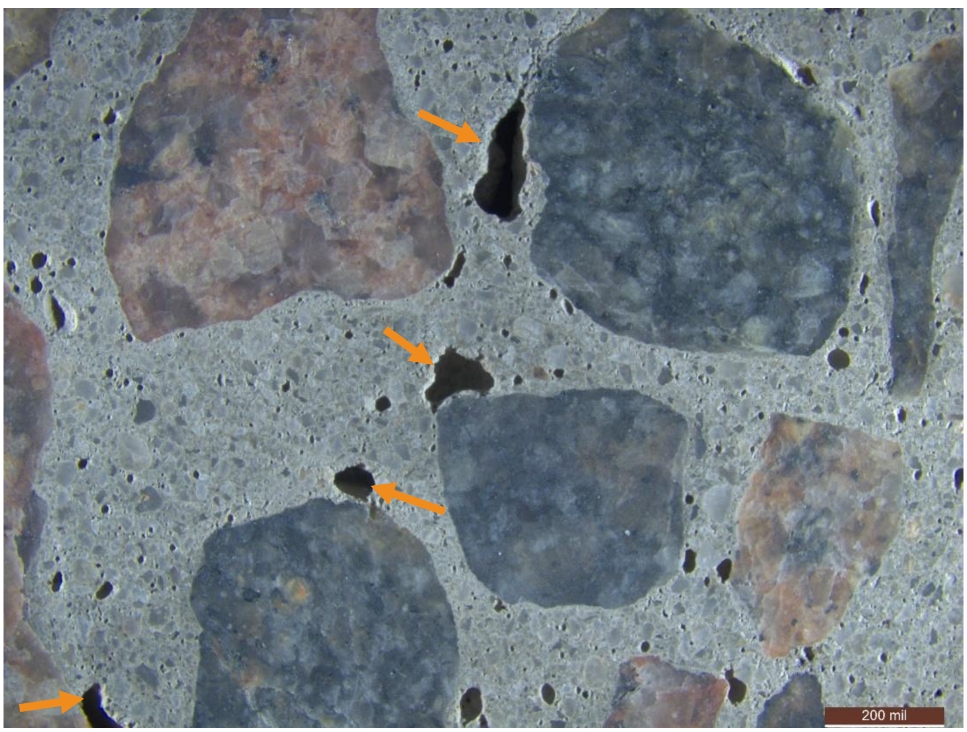


Figure 28. 7937-C11. Closeup views of the top region (top photo) and a region roughly 1.5 inch deep (bottom photo) of the core show paste, air voids, and aggregate of the concrete. Red arrows indicate localized discoloration likely due to carbonation. A few entrapped air voids were observed in the bottom photo (orange arrows).

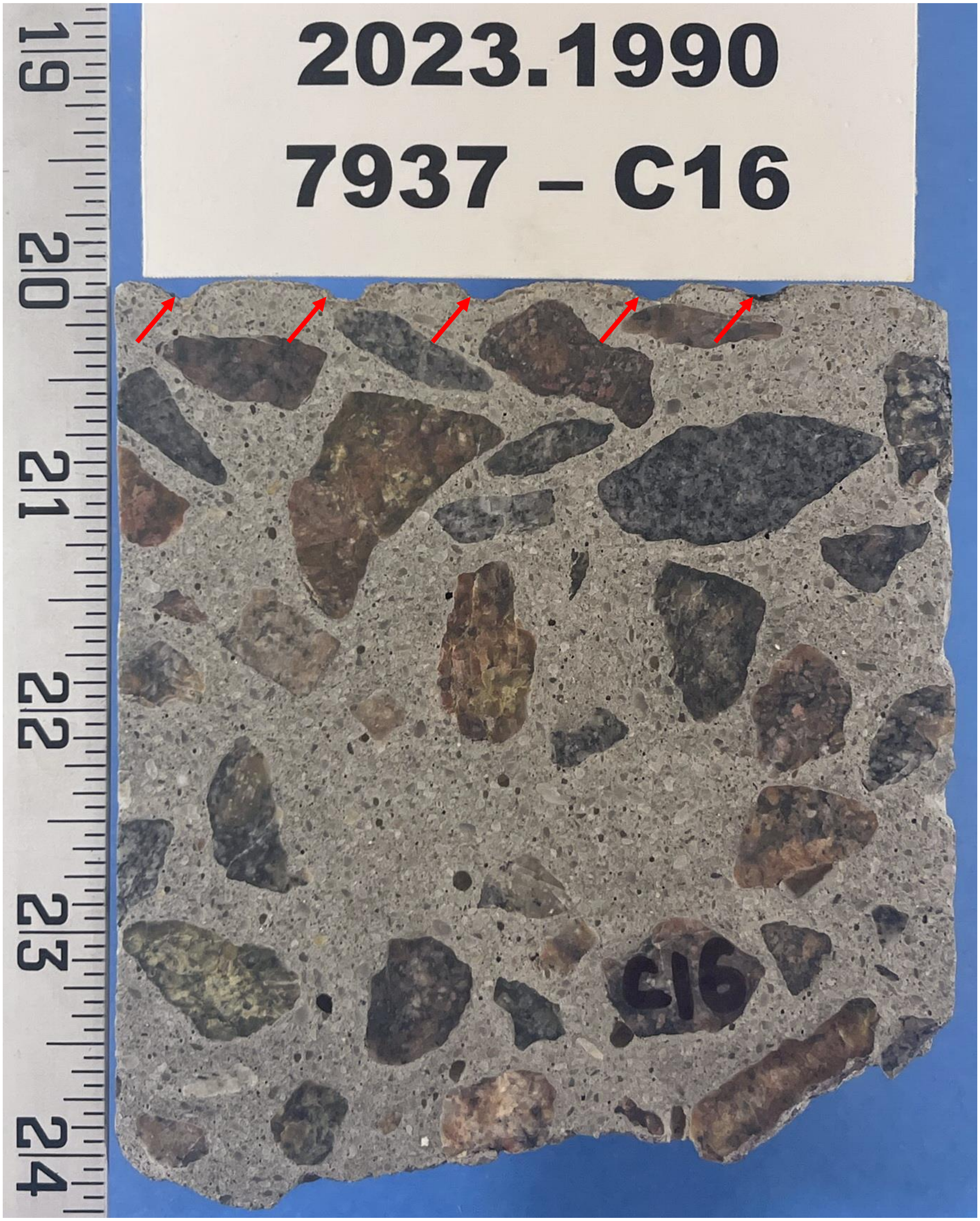


Figure 29. 7937-C16. Lapped longitudinal section, with the top surface towards the top of the image. Note the relatively well-preserved tines, indicated with red arrows. The aggregate in cores from Asset 7937 is similar to that from 7272.

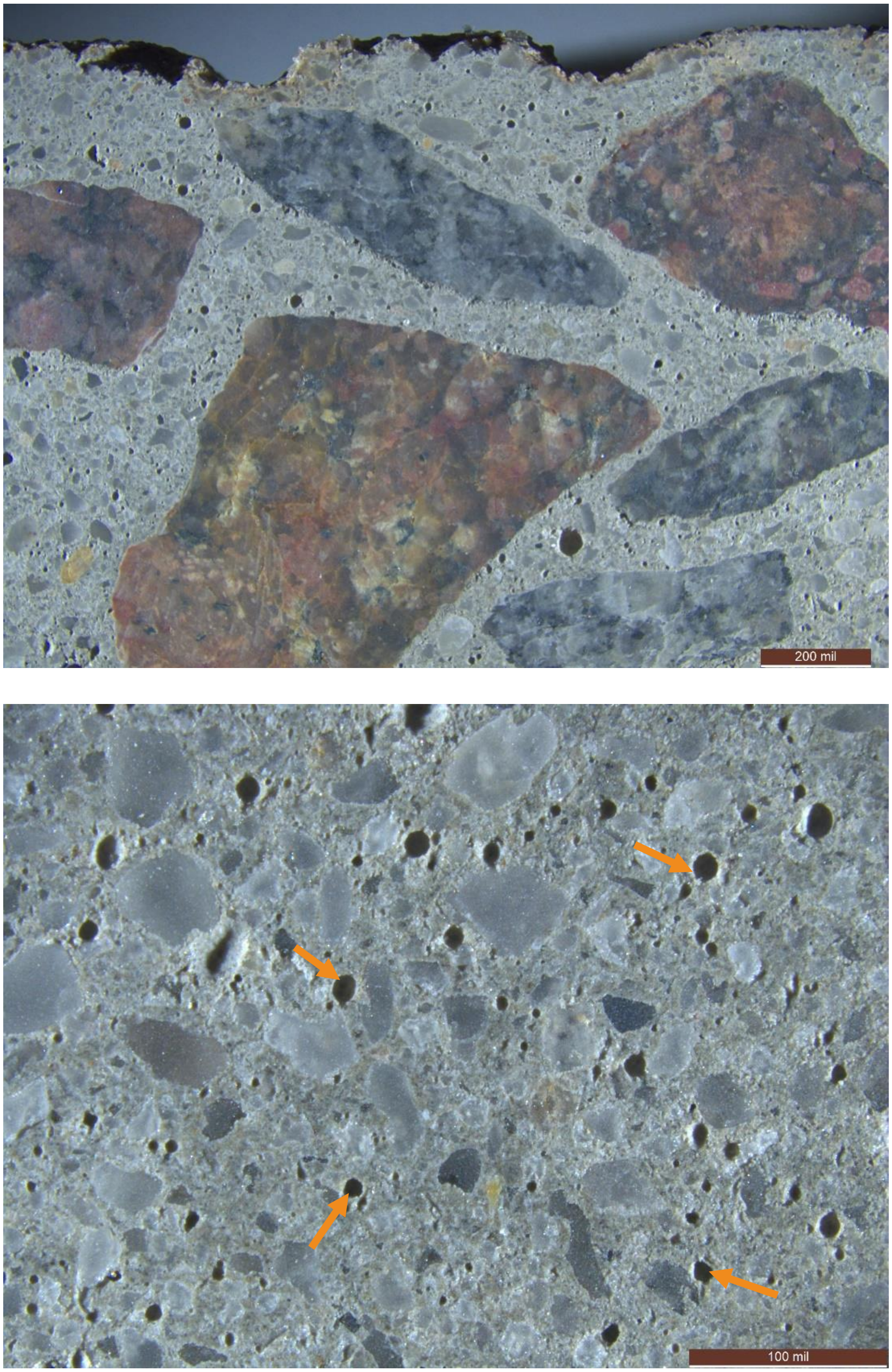


Figure 30. 7937-C16. Closeup views of the top region (top photo) and a region roughly 2.5 inch deep (bottom photo) of the core show paste, air voids, and aggregate of the concrete. Orange arrows indicate air voids.

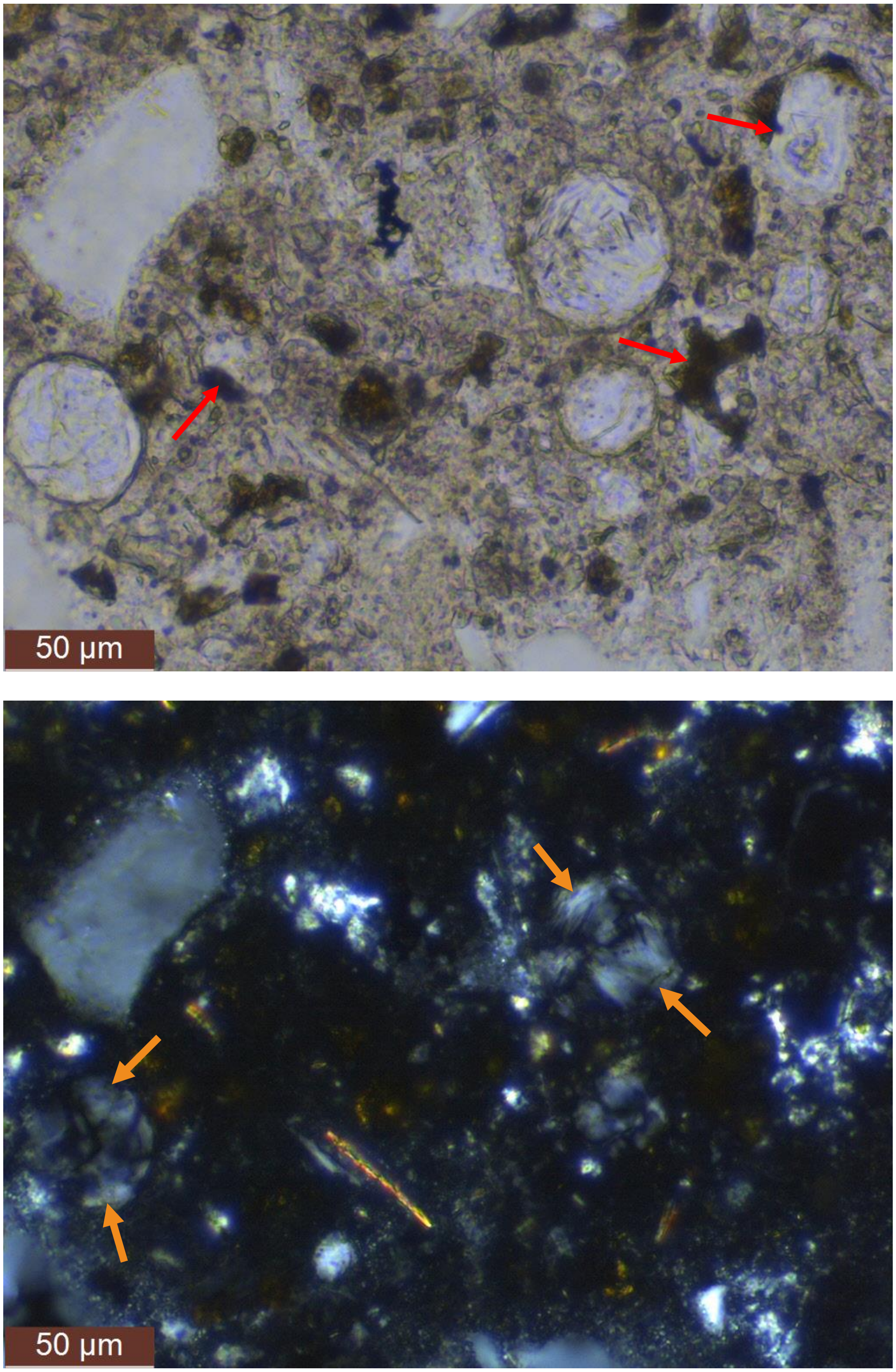


Figure 31. 7272 C-13. Thin section images. Red arrows indicate portland cement particles; orange arrows indicate ettringite line air voids. Top image: plane-polarized light. Bottom: cross-polarized light.

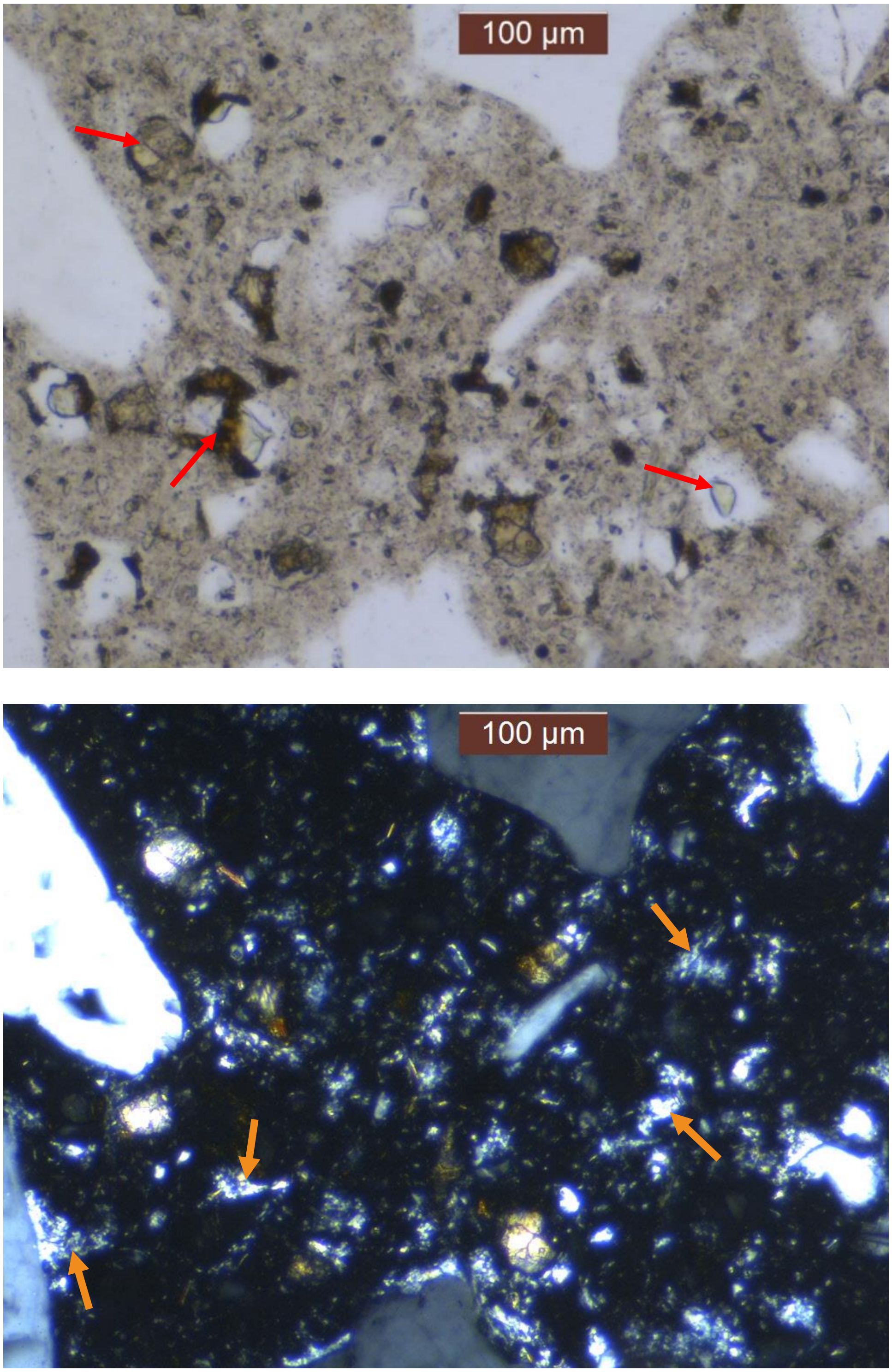
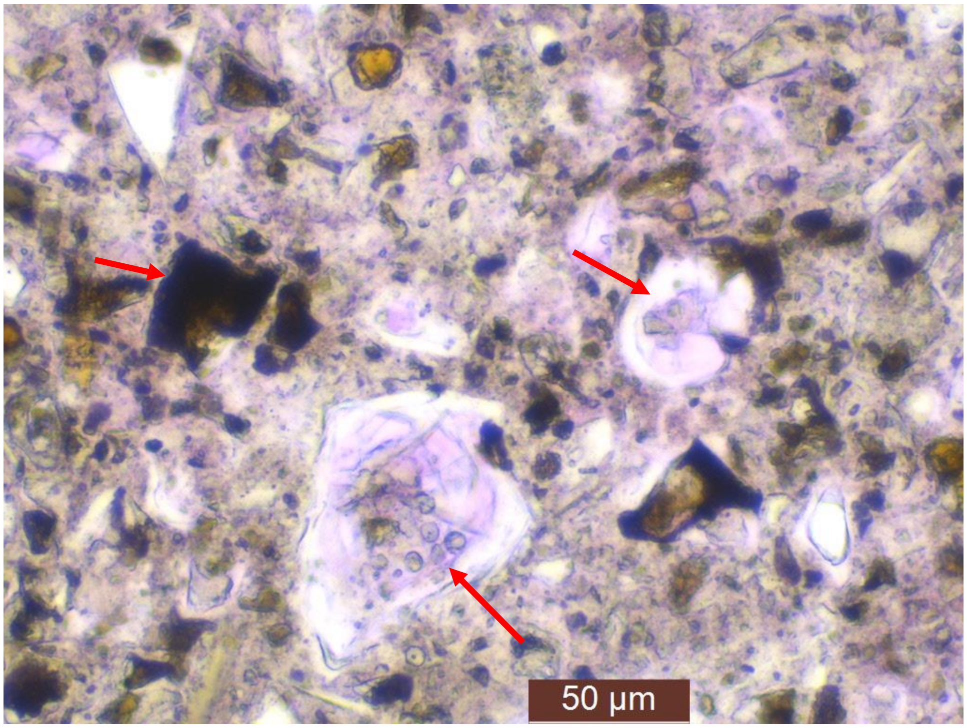


Figure 32. 7586 C-10. Thin section images. Red arrows indicate portland cement particles; orange arrows indicate calcium hydroxide crystals. Top image: plane-polarized light. Bottom: cross-polarized light.



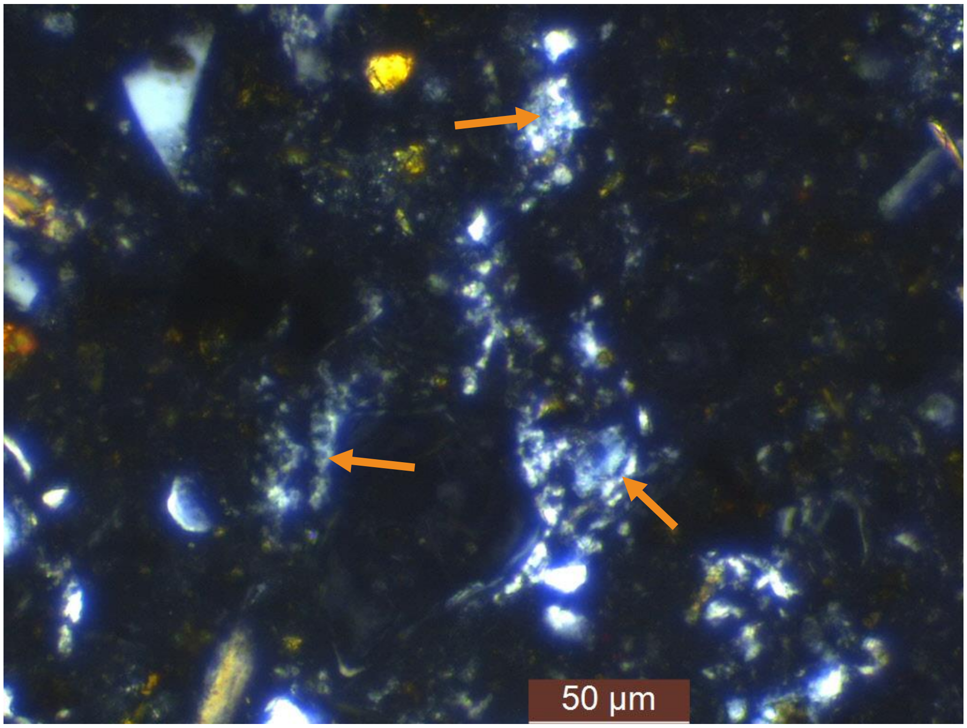


Figure 33. 7937 C-16. Thin section images. Red arrows indicate portland cement particles; orange arrows indicate calcium hydroxide crystals. Top image: plane-polarized light. Bottom: cross-polarized light.