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ICRI 2022 Spring Convention

Petrographic Analysis of Precipitation-Damaged Freshly Placed Concrete

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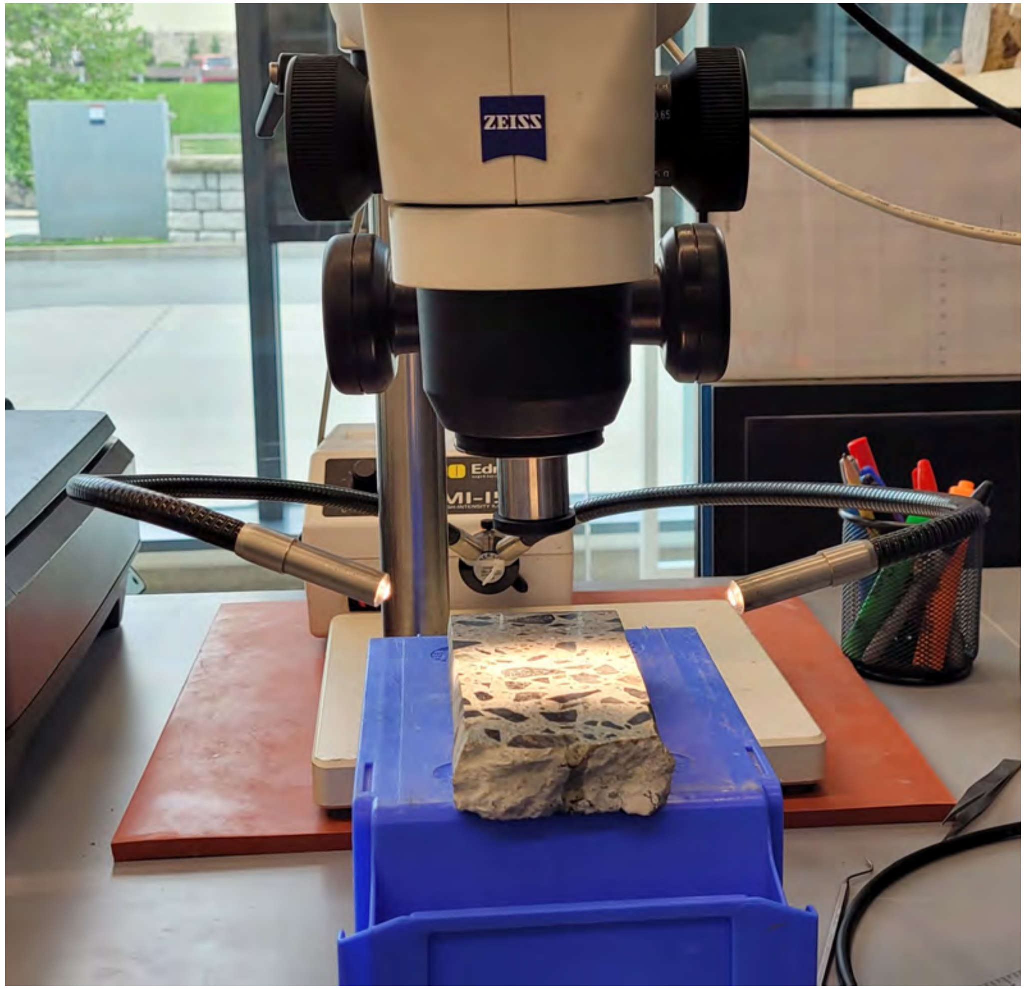
Overview

- Introduction to concrete petrography.
  - Our methods to petrographically analyze concrete.
- Case studies – evaluation/repair of slabs subjected to snow melt falling from above during placement:
  - Case study 1 – slab was hard-troweled while wet.
  - Case study 2 – slab was hard-troweled after excess water was removed

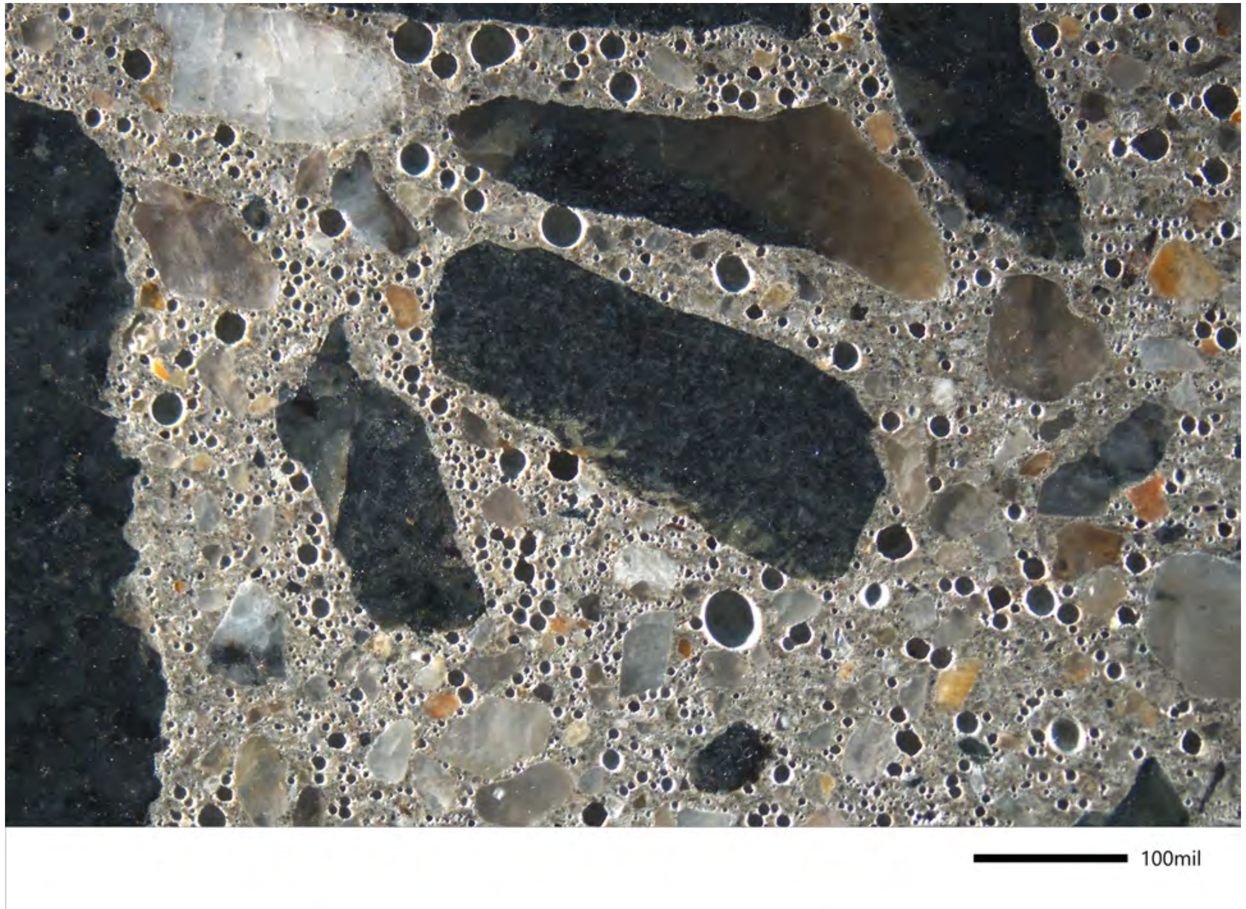
Concrete Petrography



Polished "thick" section

"Ultrathin" section

Polished "Thick" Sections



- "Big picture" condition assessment
- Provides valuable information about aggregate composition and distribution, macroscopic cracking, air void system, etc.

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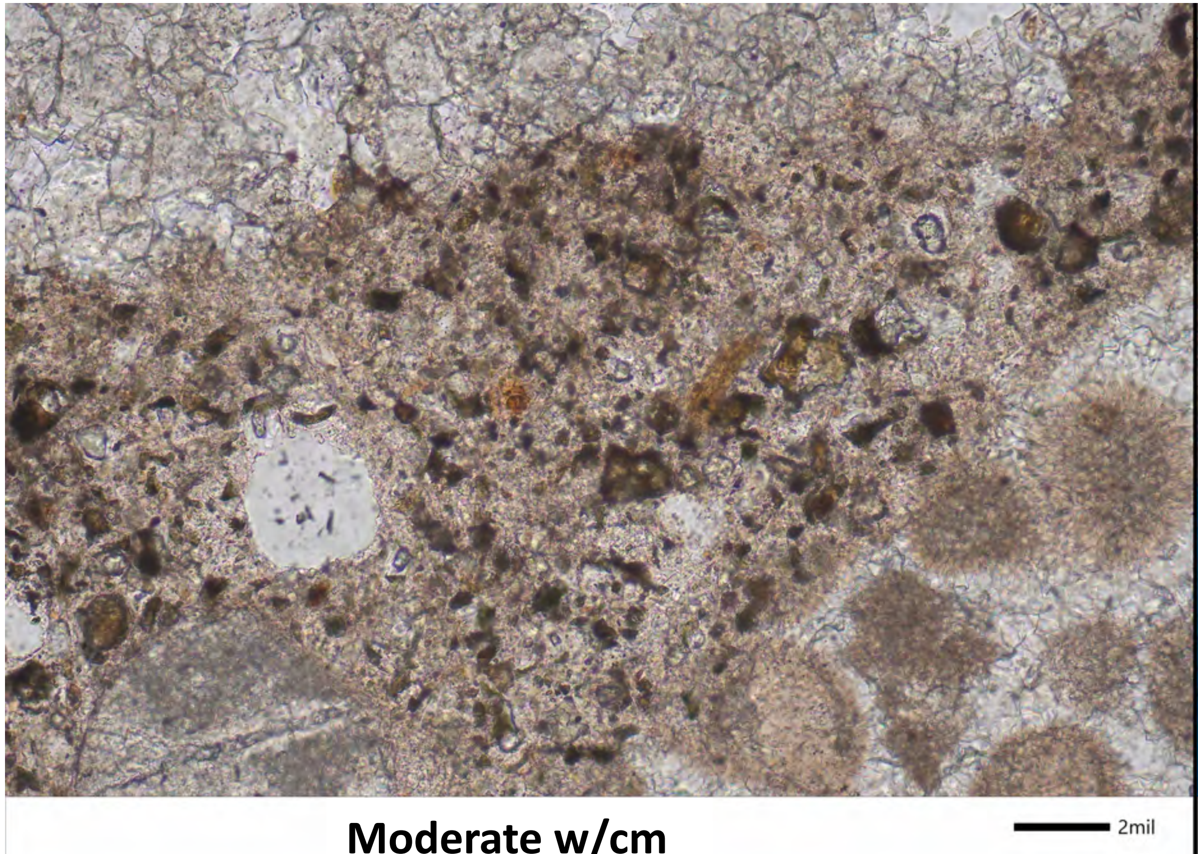
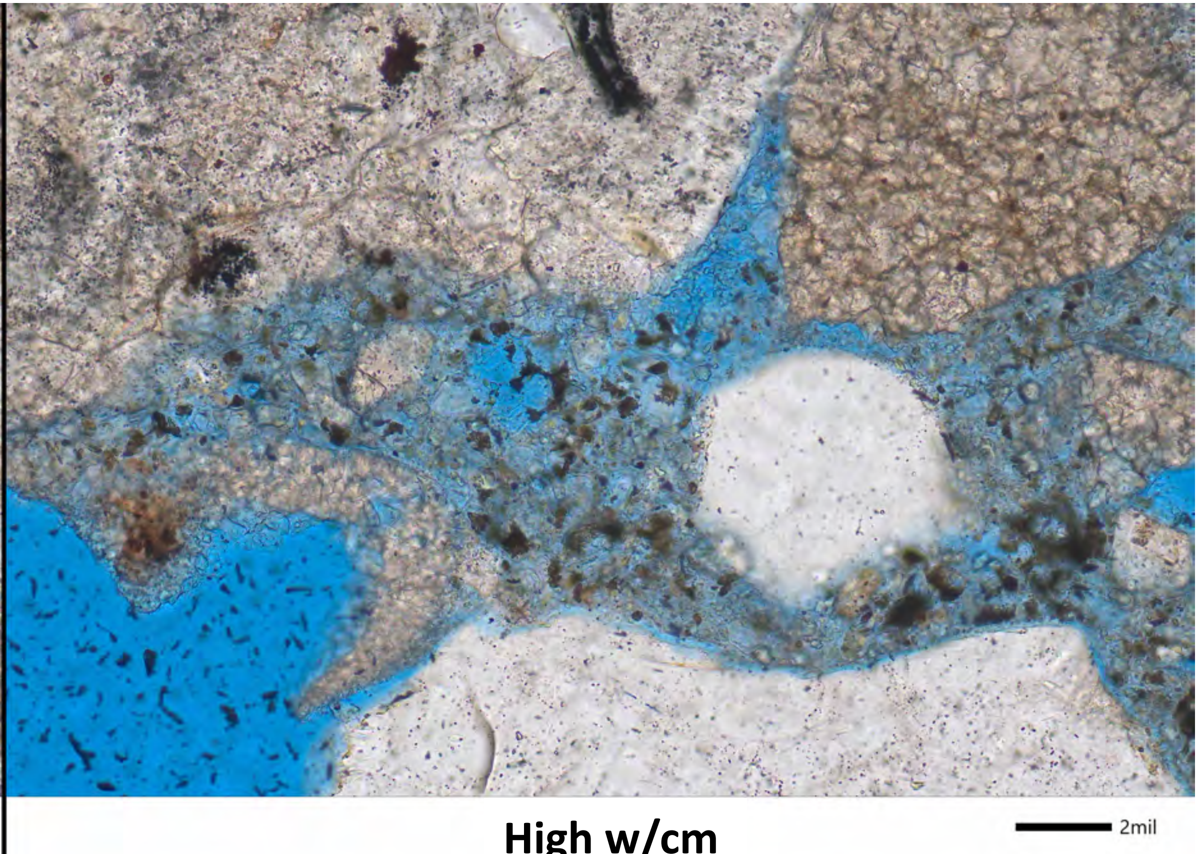
Blue-dye epoxy-injected ultrathin sections



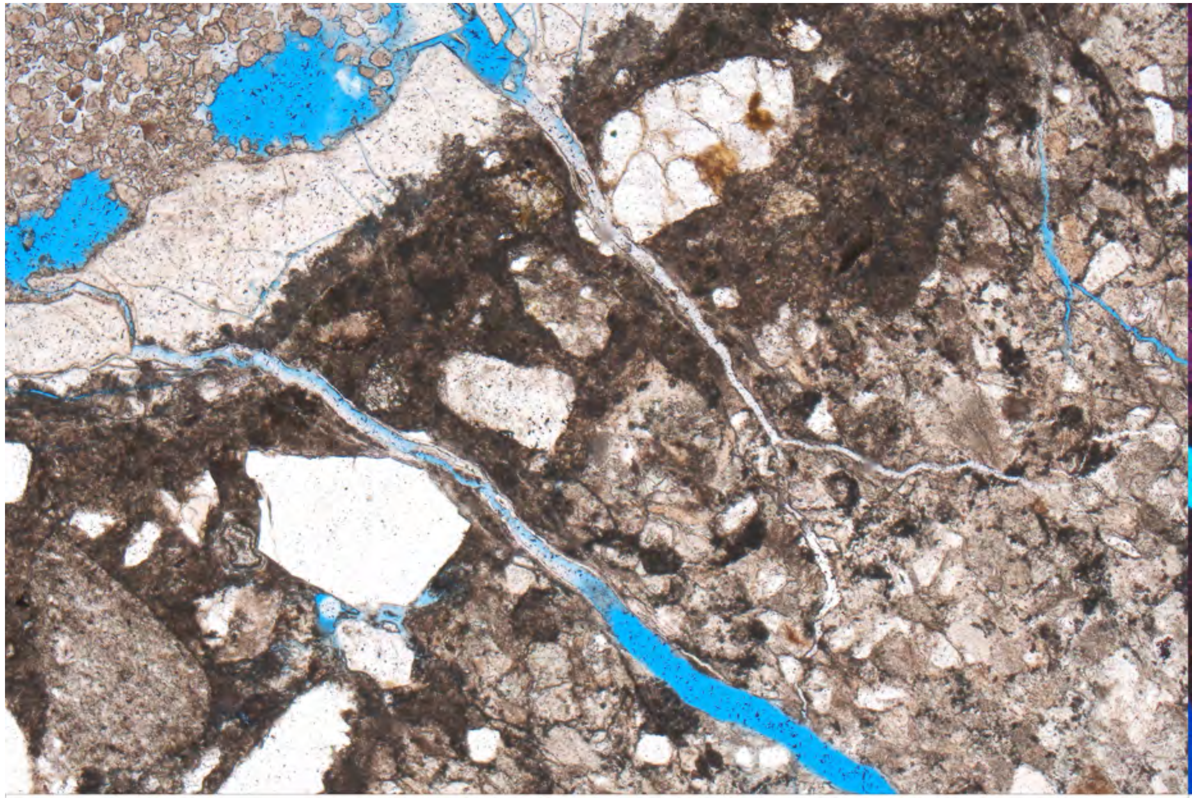
Moderate w/cm



High w/cm

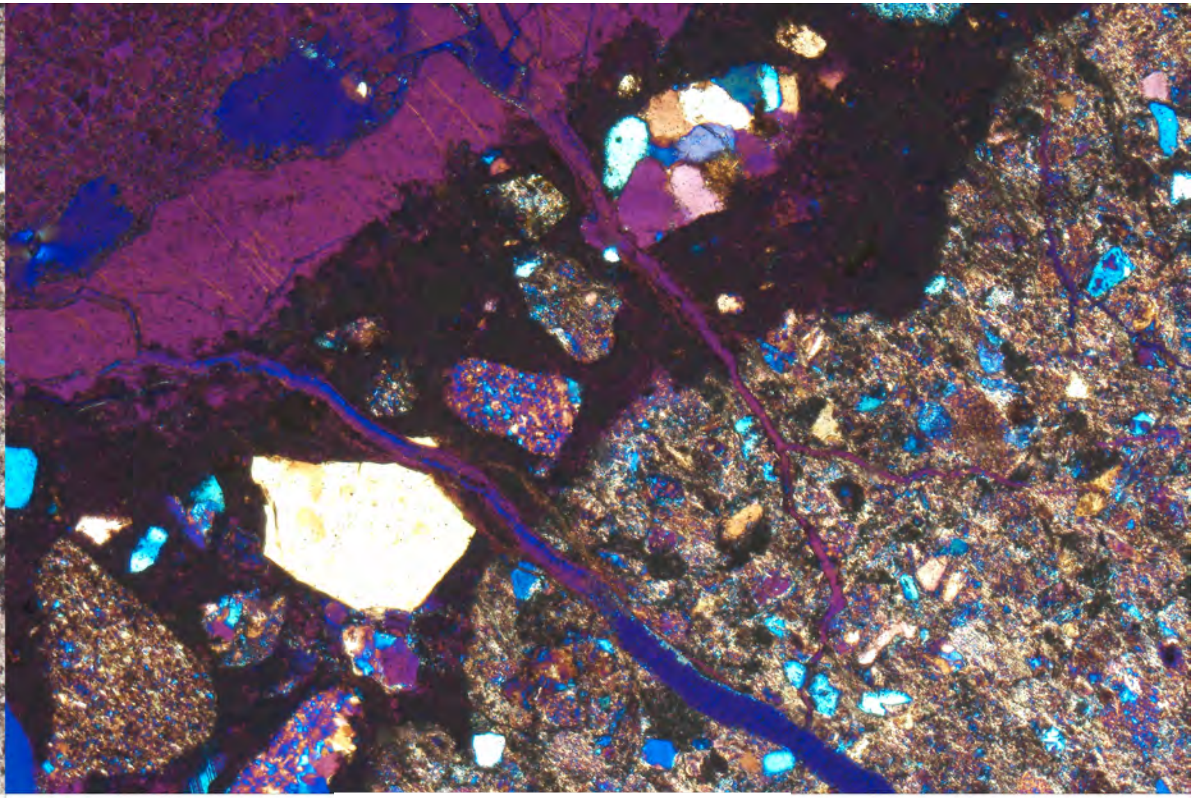
- Detailed assessment; high magnification
- Composition of the cementitious paste, estimate w/cm (see photos above), detailed examination of microcracks, determine potential causes of distress.

Blue-dye epoxy-injected ultrathin sections



10mil

Plane Polarized Light



10mil

Cross Polarized Light with Full Waveplate

- Detailed assessment; high magnification
- Composition of the cementitious paste, estimate w/cm (see photos above), detailed examination of microcracks, determine potential causes of distress.

Case Study 1 – Background

- First level cast-in-place concrete slab on metal deck
  - Placed in February 2021.
  - Mix design – 5,000 psi, 0.40 w/cm, 6.5% air content, normal weight.
  - Concrete cylinder QC testing indicated 28-day strength >5,000.

Case Study 1

- Exposed to water dripping from melting snow on metal decks above during placing and finishing
- Pitting, scaling, etc. observed mid-February during site inspection.

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Case Study 1 – 3rd Party Onsite Testing and Sample Extraction

- Observations prompted rebound hammer testing; indicated overall decrease in concrete strength.
  - Weak upper surface layer?
- Someone decided cores were in order
- 2-3/4 in. cores extracted; well below nominal (5000 psi) strength
  -

Compressive Strength (Sixty-three days; psi)		
Core 1	Core 2	Core 3
3,480	2,650	2,750
2,760	3,120	2,750

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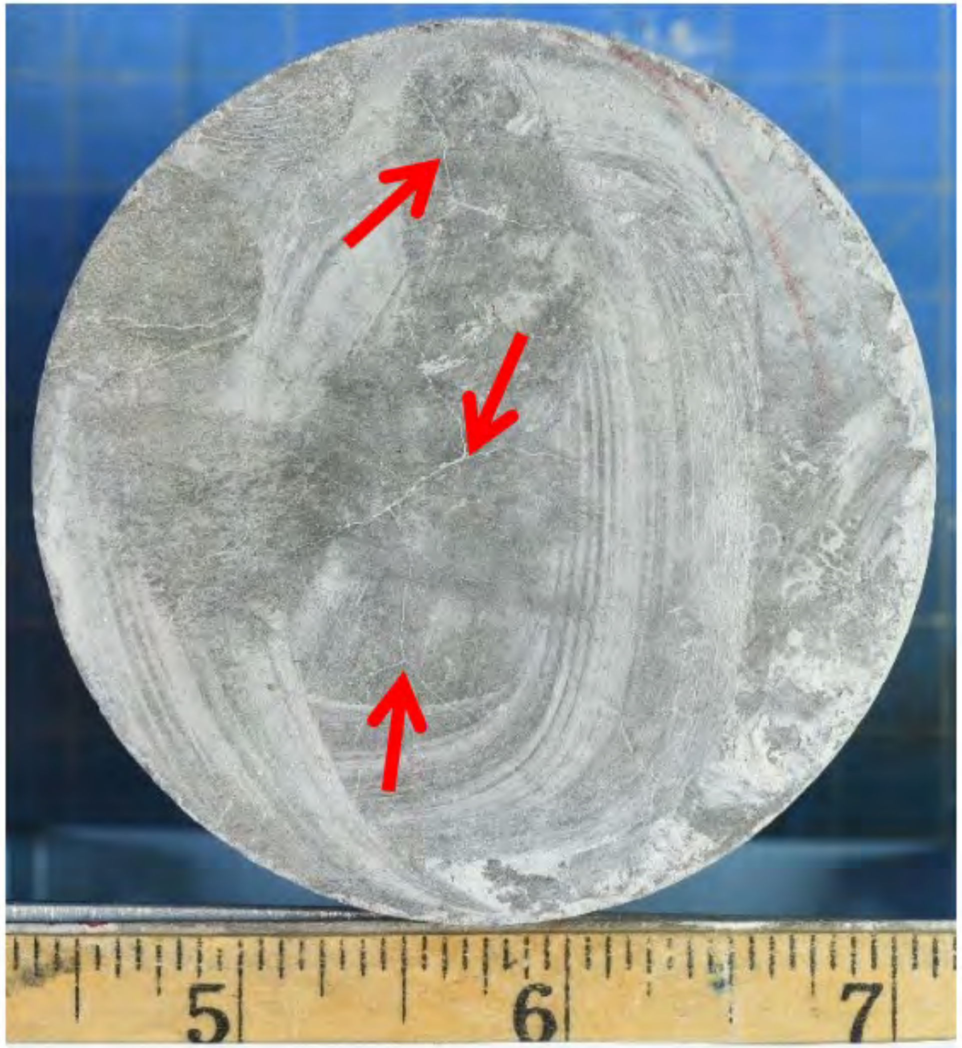
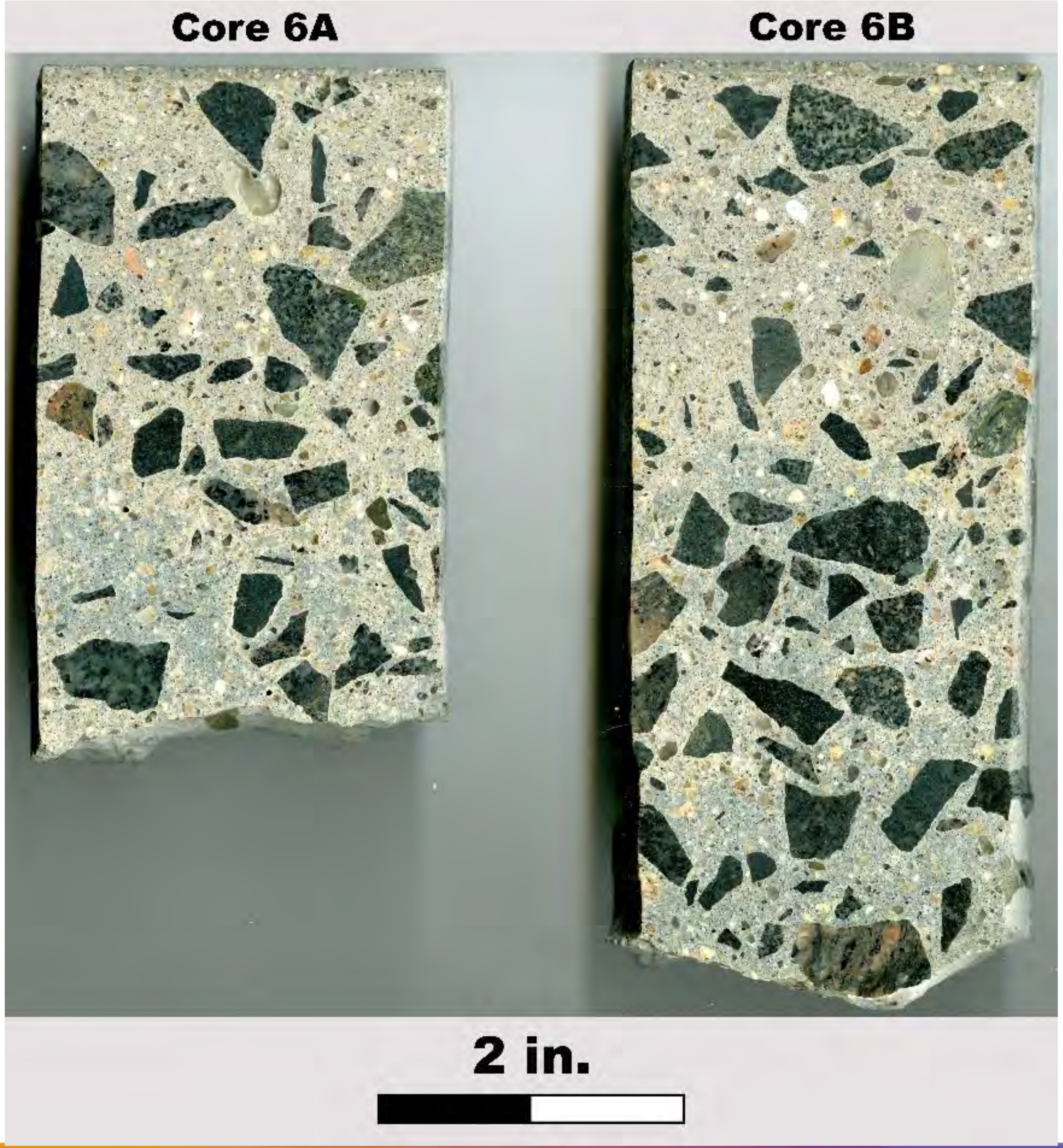
Case Study 1 – Questions to answer

- We were engaged to petrographically analyze two concrete cores to address the following:
  - Extent of incorporation of snowmelt.
  - Cause of low concrete core compressive strength. Possibly related to snowmelt?

Case Study 1 – Finished Surface



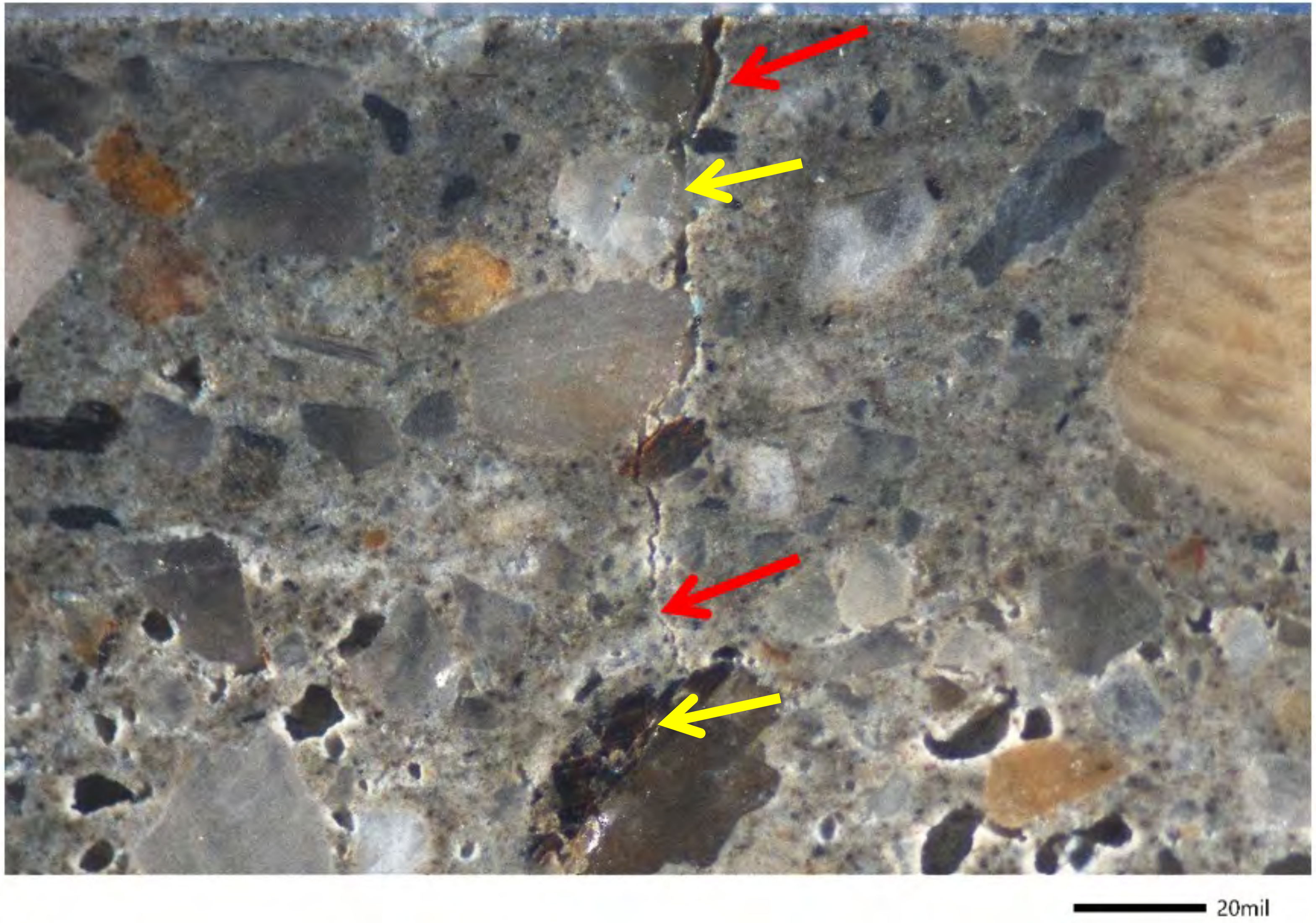
- Hard-troweled surface
- Microcracks (red arrows) observed on the finished surface.



Case Study 1 – Polished Sections

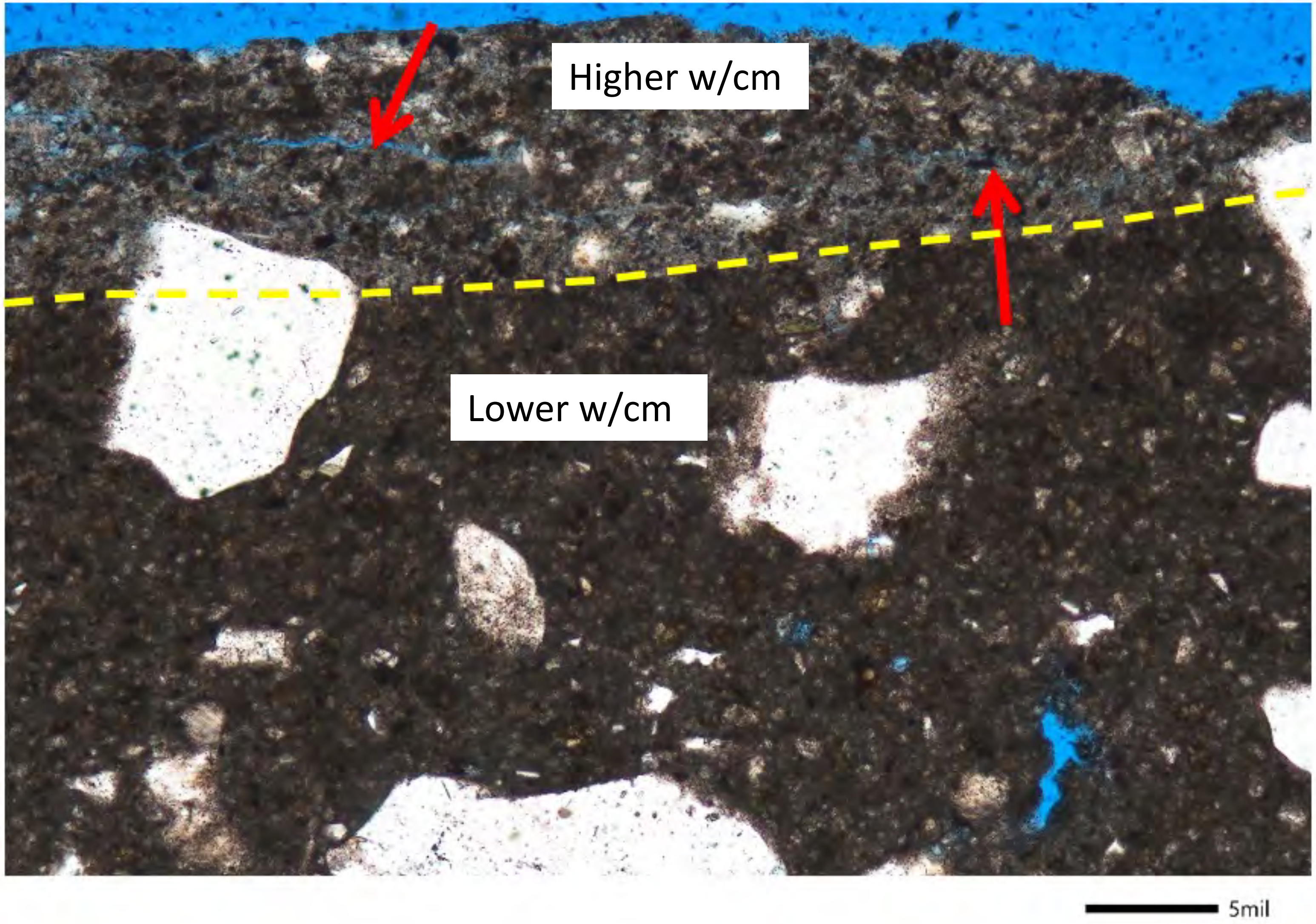
- Mottled light-medium gray beige and green coloration
  - Typical of slag-cement concrete.
- Upper ~1/8 in. darker gray color
  - Typical of a hard-troweled finish.

Case Study 1 – Perpendicular Microcracks



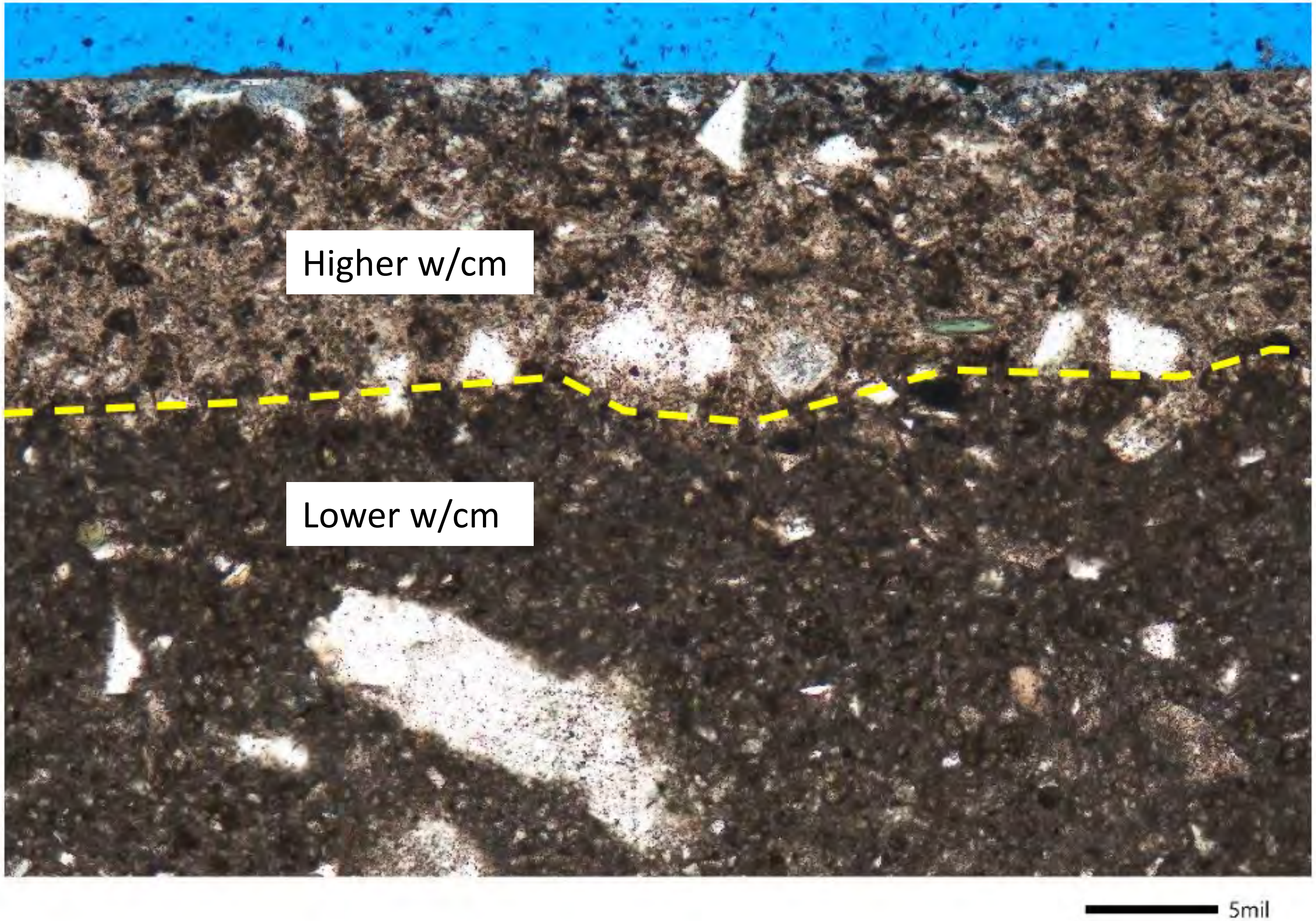
- Microcracks perpendicular to finished (top) surface extend ~1/4 in. into concrete from finished surface.
- Break through aggregate (yellow arrows) and paste (red arrows) and taper with depth
- Typical of early-age drying shrinkage cracks (common in most concrete).

Case Study 1 – Incorporation of Snowmelt



- Higher w-cm in uppermost (<20 mils) concrete (above yellow dashed line; lighter colored paste)
  - Likely a result of incorporated snowmelt.
- Horizontal microcracks (red arrows) in this higher w-cm zone.

Case Study 1 – Incorporation of Snowmelt



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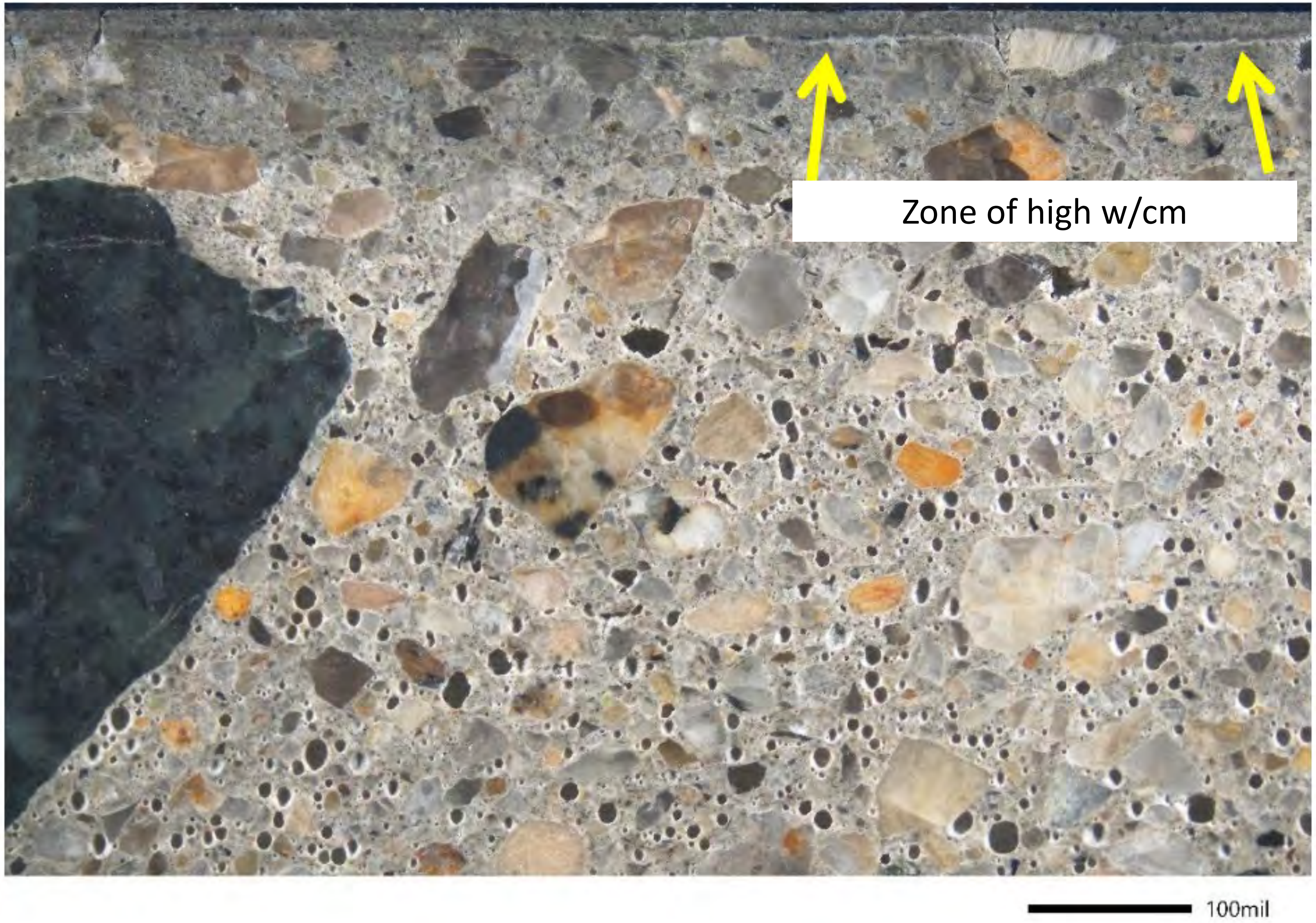
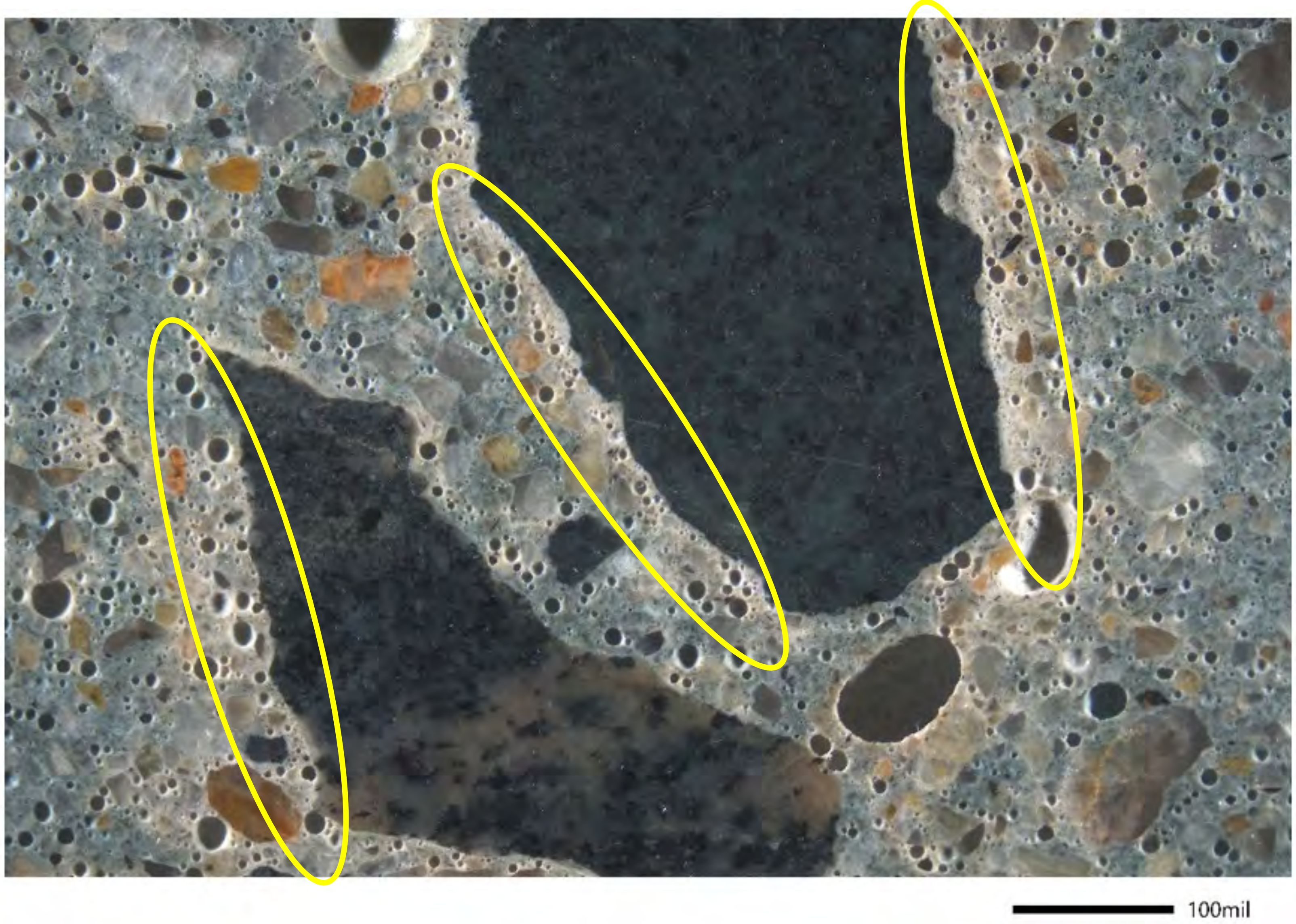
Case Study 1 – Incorporation of Snowmelt



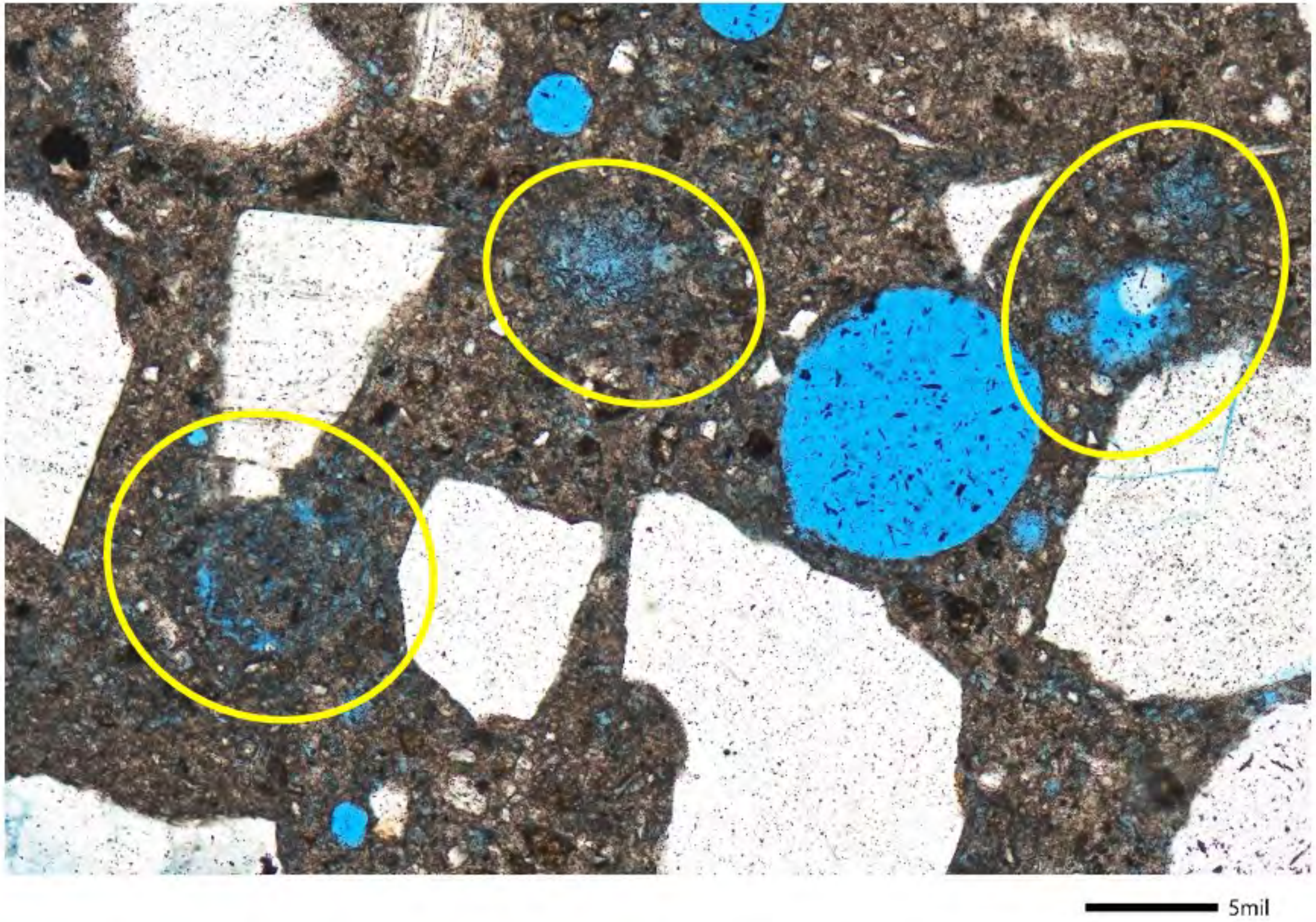
- Zone of high w/cm (yellow arrows) within densified zone (darker gray paste).
  - Likely caused by incorporation of snowmelt during finishing.

Case Study 1 – Uneven Air Void Distribution



- Clustered air voids adjacent to aggregate particles (yellow ovals) – typical of retempered concrete
- Air void analyses results measured 8% to 8.6% for air content
  - 6.5% mix design

Case Study 1 – Variable W/CM



- Pockets of high w-cm (yellow ovals; stronger saturation of blue epoxy) in paste structure at depth
- "Typical" w/cm was estimated between 0.40 to 0.45
  - 0.40 mix design

Case Study 1 – Petrography Summary

- Overall weaker upper ~1/8 in. of concrete – upper 10-20 mils higher w/cm, microcracking, and zones of high w/cm within the densified zone.
  - Explains surface deterioration (pitting, scaling, etc.) and low rebound hammer results.
  - Evidence for incorporation of snowmelt in the uppermost portion of concrete.

- Evidence of retempering and subsequent incomplete mixing of retempering water and overall higher than specified air content.
  - Retempering can result in higher air content, clustering of air voids, and variable w/cm.
  - Slight increase in air content (+2%), minor clustering of air voids at aggregate interfaces, and variable w/cm <u>partially</u> explains lower strength results.

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Case Study 1 – Sample Extraction

- Recommended additional cores to address the apparent low strength of the concrete.
  - Small (2-3/4 in. diameter) original cores
  - Limited number of original cores
  - Unknown original core treatment
- Prior to testing, we cut out the uppermost ¼ in. of each core to remove the weak layer of concrete.

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Case Study 1 – Compressive Strength Results

Specimen ID	L/D	L/D Factor	Maximum Load (lbf.)	Compressive Strength (psi)
1A	1.40	0.95	59835	6980
1B	1.37	0.94	57640	6650
1C	1.34	0.94	55294	6380
2A	1.12	0.90	55847	6170
2B	1.34	0.94	54448	6290
2C	1.29	0.93	55261	6310
3A	1.25	0.93	47771	5460
3B	1.23	0.92	54162	6120
3C	1.25	0.93	56169	6390
4A	1.02	0.87	50553	5400
4B	1.21	0.92	42325	4780
4C	1.22	0.92	54992	6210
5A	1.19	0.92	59700	6740
5B	1.27	0.93	54572	6230
5C	1.29	0.93	32633	3730
6A	1.36	0.94	48794	5630
6B*				
6C	1.22	0.92	48805	5510
7A	1.28	0.93	49370	5640
7B	1.34	0.94	45129	5190
7C	1.33	0.94	48029	5540
8A	1.24	0.93	55490	6340
8B*				
8C	1.26	0.93	50939	5800
9A	1.11	0.90	45932	5080
9B	1.15	0.91	45901	5130
9C	1.22	0.92	41655	4710
10A	1.31	0.94	44020	5080
10B	1.06	0.88	48223	5180
10C	1.12	0.90	45463	5010
11A	1.07	0.89	58689	6410
11B	1.05	0.88	51619	5560
11C	1.42	0.95	54295	6330

*Untested – lower than 1:1 L/D ratio (6B)

*Untested – lower than 1:1 L/D ratio (8B)

- Extracted 11 sets of 3 cores (33 total) throughout the slab
  - 3-1/4 in. diameter cores
  - Resampled areas previously tested for comparison.
- All eleven sets average above 85% nominal strength
- One core (5C) below 75% nominal
  - >3 three standard deviations below the 5,740 psi average; likely an outlier.

Case Study 1 – Structural Adequacy Assessment

- 5,740 psi average core strength > 5,000 psi nominal
- Without outlier, all cores met requirements:
  - Average of three cores is at least 85% of nominal (4,250 psi)*
  - No single core is less than 75% of nominal strength (3,750 psi)*
  - (Section 26.12.6.1 (e) of *ACI 318 – Building Code Requirements for Structural Concrete)*

* Note this is really applicable only for sets of 3 cores, but that's for another day – see Bartlett and Lawler, 2011

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Case Study 1 – Structural Adequacy Summary

- The newly-extracted cores indicated that the concrete is structurally adequate and meets the stipulations of Section 26.12.6.1 (e) of ACI 318-19
  - Considering outlier of Core 5C
  - All parties involved satisfied with the results

- Difference between previous and compressive testing?
  - The newly-extracted cores (3-1/4 in.) are larger than previously extracted cores (2-3/4 in.). Smaller cores are known to produce lower strength results.
  - Previous testing may not have removed the uppermost weaker layer, which would provide a preexisting plane of weakness and would not be representative of the overall slab strength.

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Case Study 1 – Conclusions

- Concrete exhibits adequate strength development
  - Petrography identified retempering, but it was not detrimental to the overall strength.

- Incorporation of (detrimental) snowmelt restricted to the uppermost portion of concrete (~1/4 in.).
  - Revealed by petrographic analysis.
  - Uppermost weaker portion of concrete could be removed by abrasion/shotblasting.

Case Study 1 – Lessons Learned

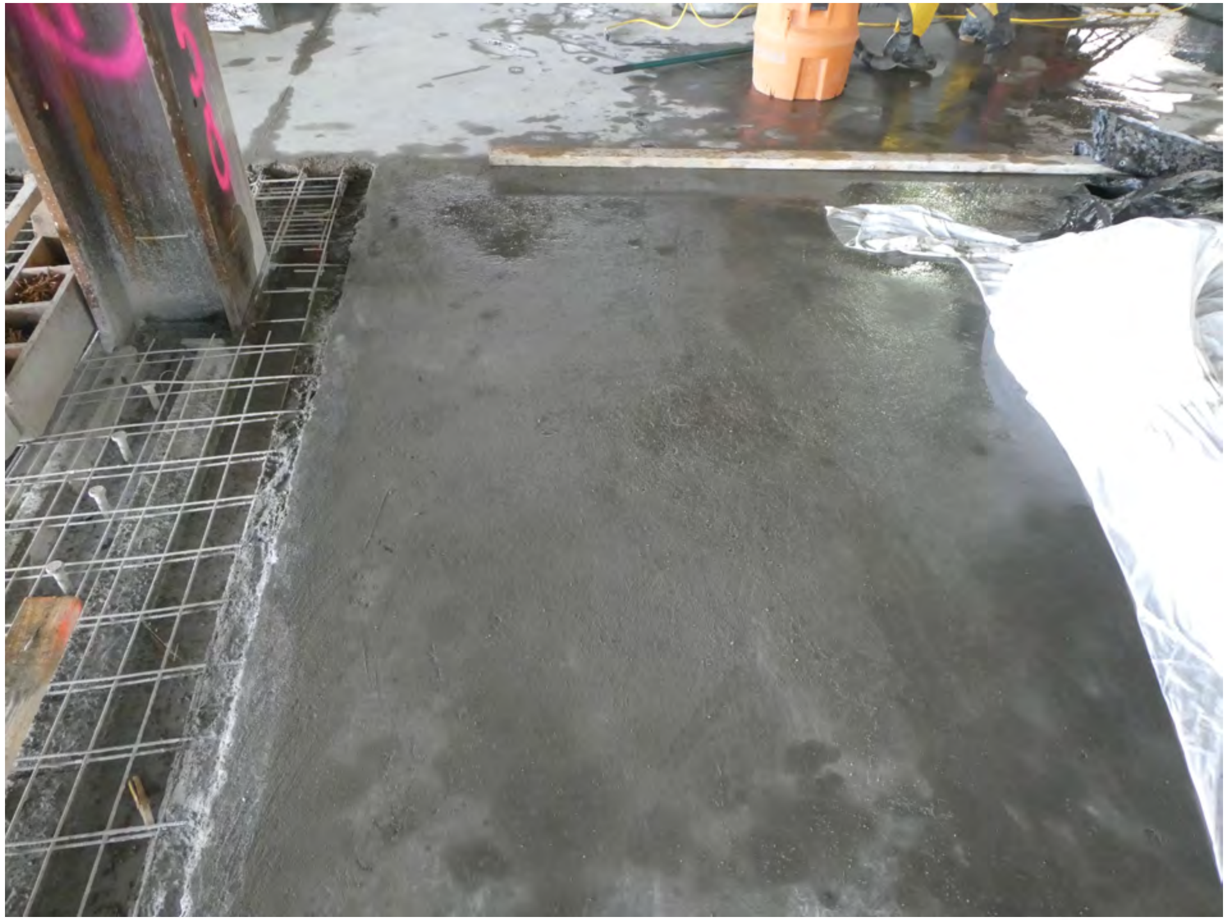
- Stop finishing activities until the precipitation/excess water is dealt with.

- Think before you core and test
  - QC cylinders indicated adequate strength.
  - Rebound hammer low, but weak upper surface…
  - Surface deterioration observed, but no indication of “deep” water incorporation.
  - Consider petrography for a detailed analysis prior to testing in compression.

- If coring for compressive testing, extract the largest diameter cores possible
  - Know what and why you’re testing and use this as a last resort.

Case Study 2 - Background

- Cast-in-place concrete slab on metal deck; 4000 psi , 0.45 w/cm, lightweight.
- Snow on roof deck melted and fell ~30 feet onto the slab, eroding parts of the surface.
- Contractor stopped finishing operations (hard troweling), waited for it to stop, removed excess water, and completed finishing operations.
- The Owner directed the Contractor to demolish and replace the worst areas and investigate the remaining portions.



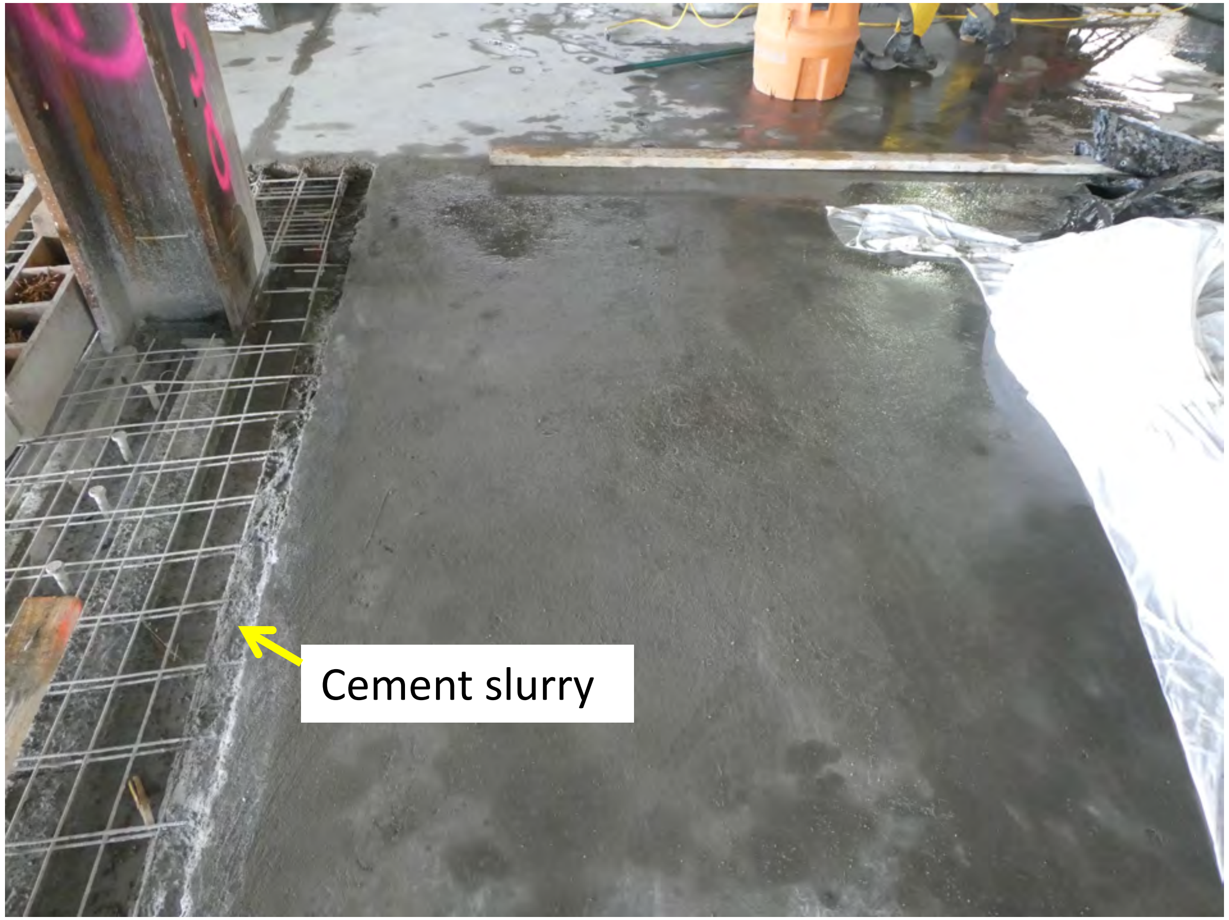
Case Study 2 – Questions to answer

- We were engaged to investigate the concrete slab and petrographically analyze extracted concrete cores to determine:
  - Depth of the incorporation of excess water.
  - Geographic extent of water-affected areas – is it localized, or did excess water detrimentally affect the entire slab?

Case Study 2 – Heavily Water-Affected Zone

- Photo taken shortly after the snow melt event.
- Concrete in this area (right side of photo; covered in curing blankets) was later removed.

Case Study 2 – Heavily Water-Affected Zone

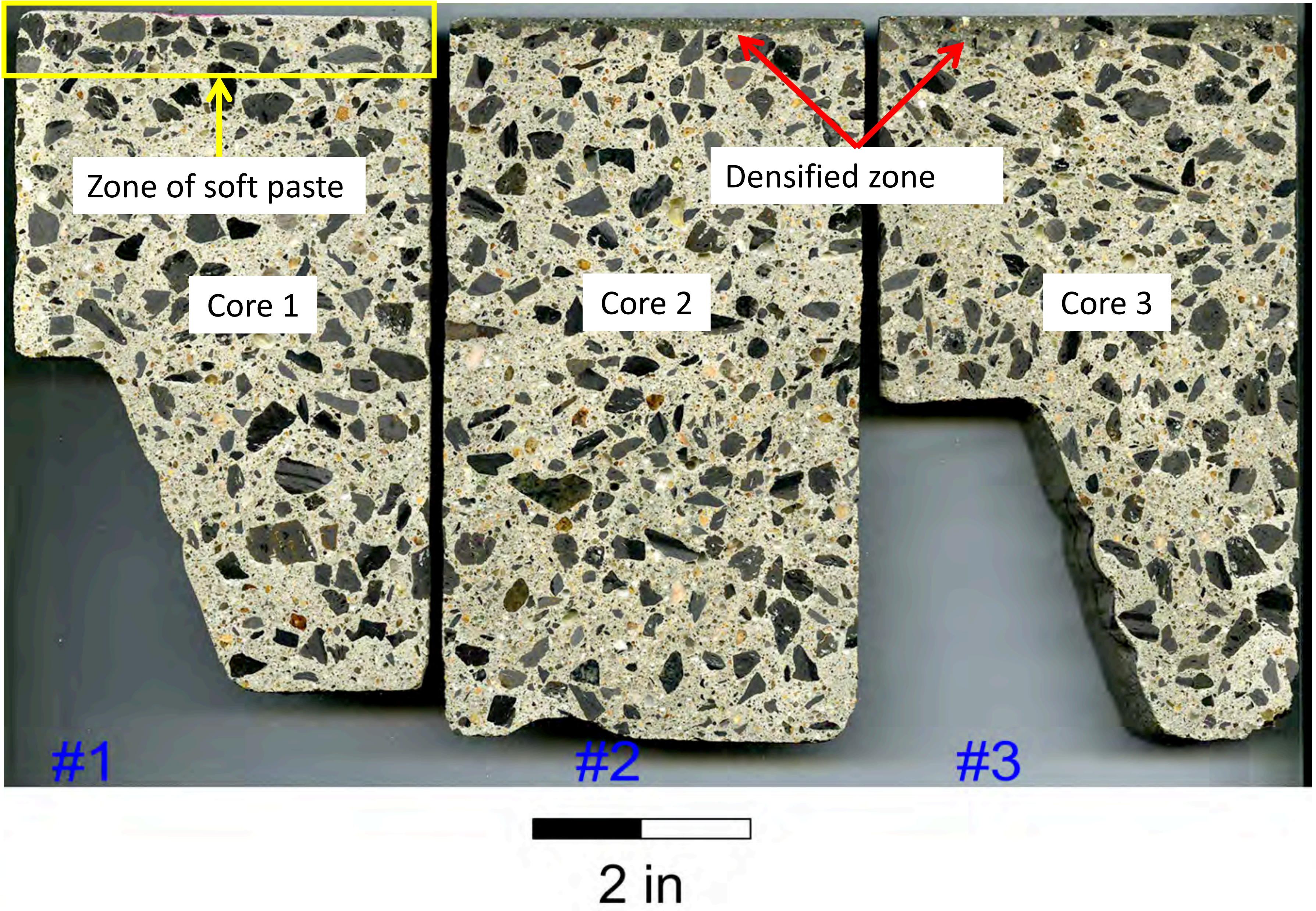


- Surface roughness, cement slurry, and exposed welded wire reinforcement (WWR). Rebound hammer results were generally low in this area, compared to other areas.

Case Study 2 – Heavily Water-Affected Zone

- The most water-affected portion of the slab was removed.
- Three cores were extracted prior to demolition (next slide).

Case Study 2 – Heavily Water-Affected Zone



- Core 1 exhibits evidence of "soft" paste (outlined in yellow box) in uppermost ~1/4 in.
  - Likely related to minor intrusion and mixing of excess water in the near-surface region.
- Upper portion of Cores 2 and 3 exhibit a densified layer (red arrows).
  - Typical of a hard-troweled finish.

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Case Study 2 – Areas Away from Heavily Water-Affected Zone

- Area that was subject to minor amounts of snowmelt.

Case Study 2 – Areas Away from Heavily Water-Affected Zone

- Minor surface imperfections (yellow circles). Rebound hammer results were generally consistent in these areas and greater than in the heavily water-affected zone.

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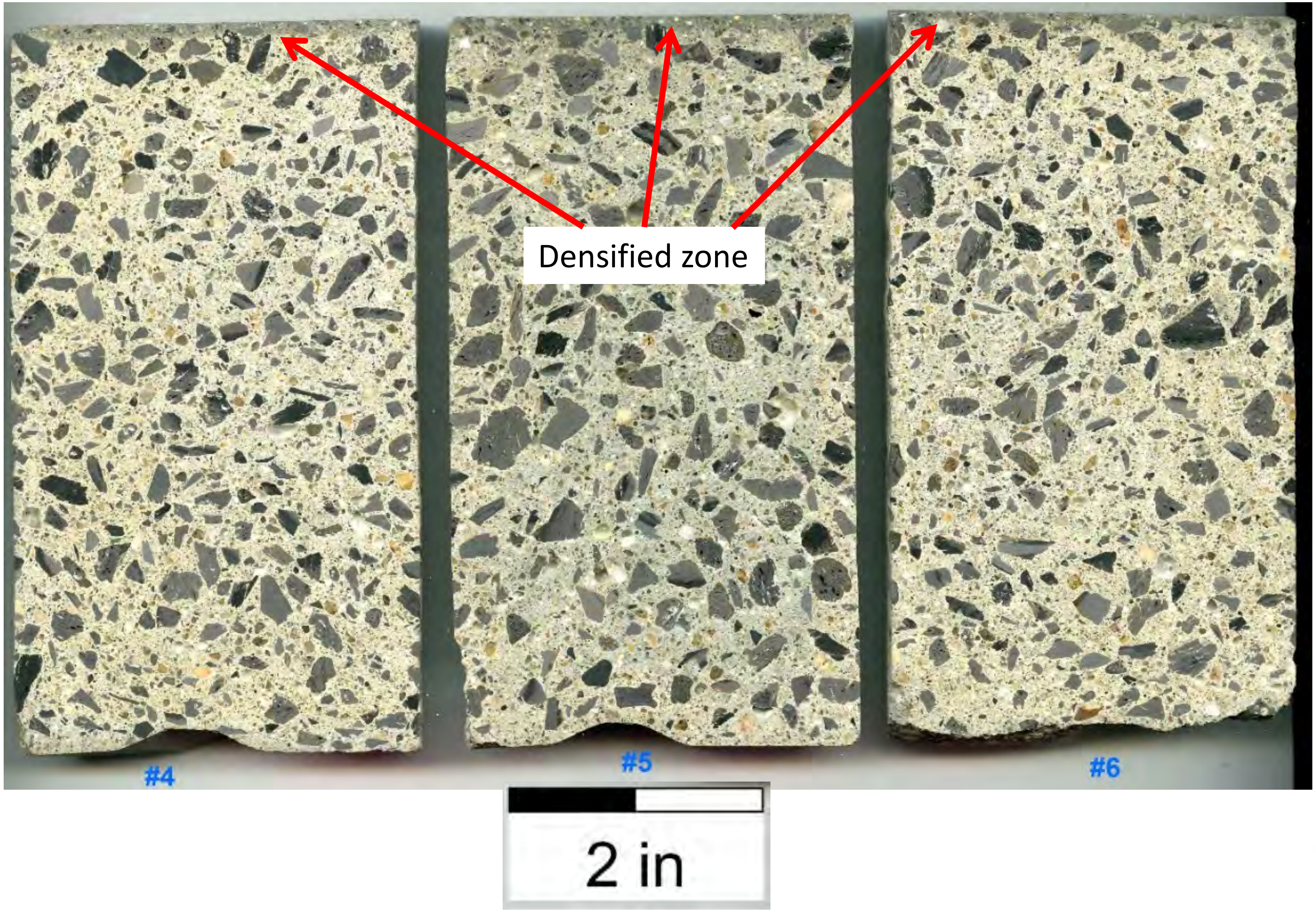
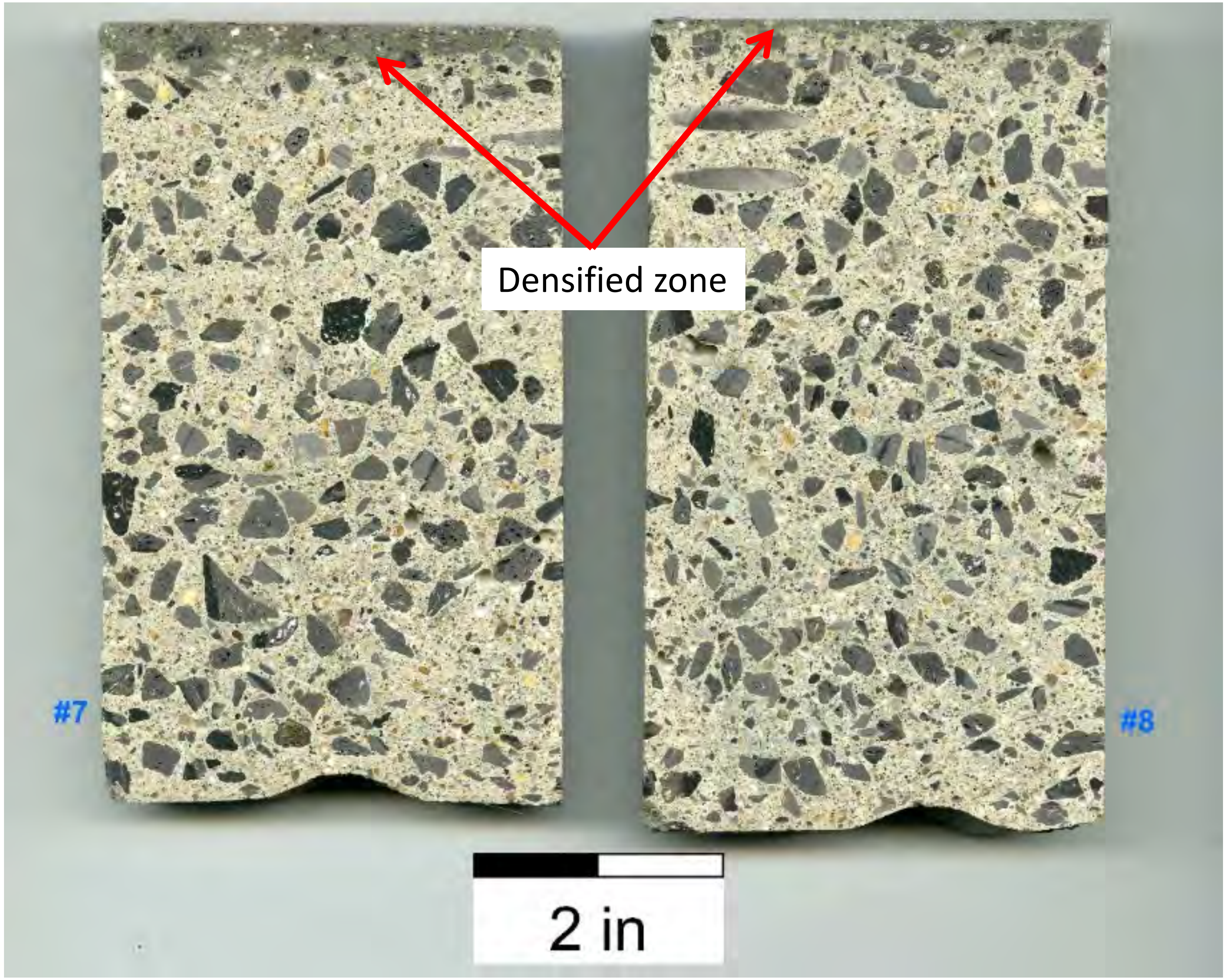
Case Study 2 – Areas Away from Heavily Water-Affected Zone



- Upper portion of all cores exhibit a densified layer (red arrows).
  - Typical of a hard-troweled finish.
- No evidence for incorporation of snowmelt.

Case Study 2 – Areas Away from Heavily Water-Affected Zone



- Upper portion of cores exhibit a densified layer.
  - Typical of a hard-troweled finish.
- No evidence for incorporation of snowmelt.

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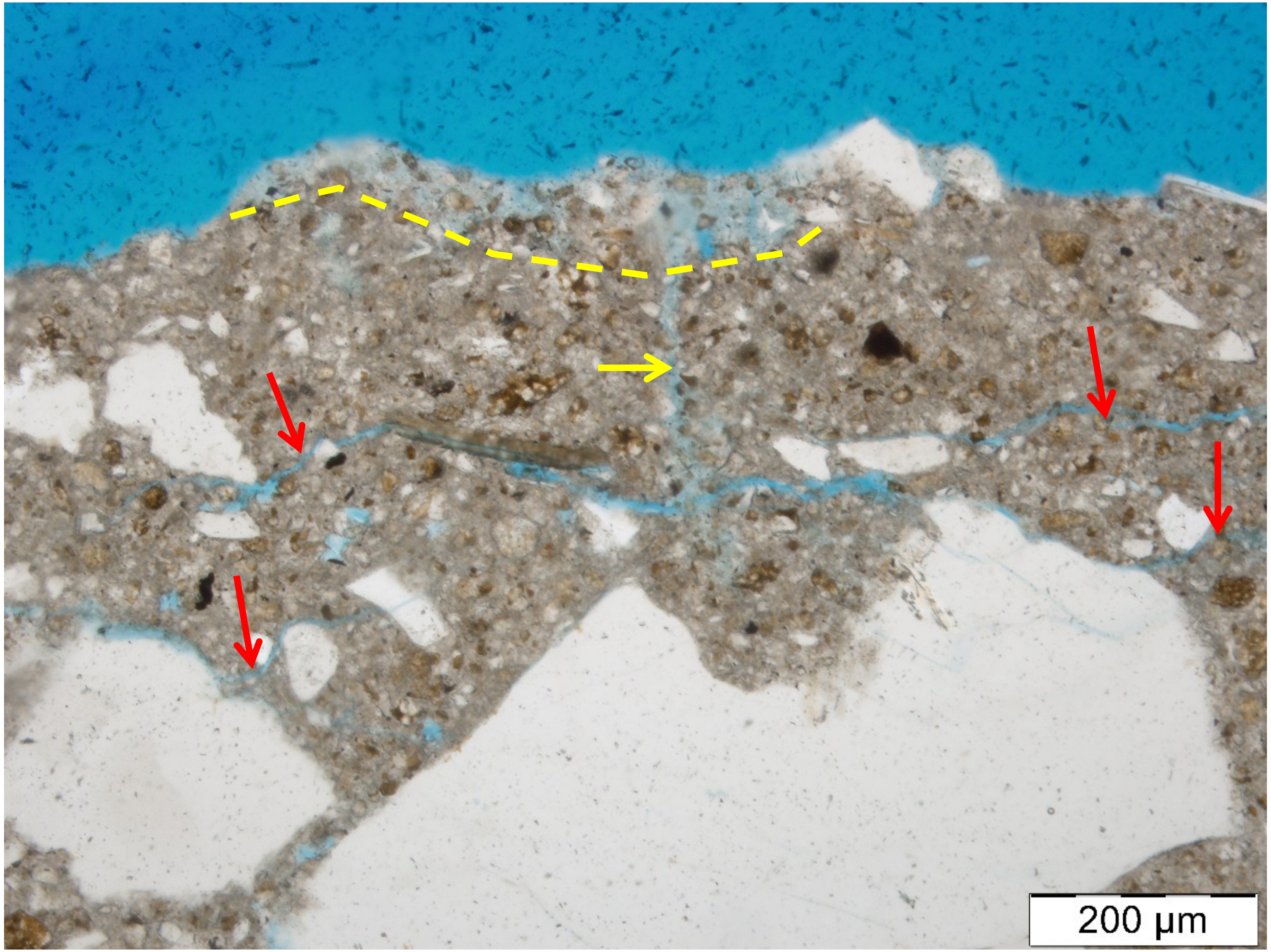
Case Study 2 – Areas Away from Heavily Water-Affected Zone



- Minor early-age plastic tear microcracks (red arrows) in the uppermost portion of each core.
  - Likely a result of the hard-trowel finishing.
- Bleed water channel (yellow arrow) that connects to a thin uppermost porous zone (above yellow dashed line).
  - Indicates some bleed water was incorporated into the densified layer.
  - No evidence of snowmelt incorporation.

Case Study 2 –Summary

- In the area subjected to a high volume of snowmelt, we observed evidence of excess water incorporation in one core to a depth of ~1/4 in.
  - The slab in this entire area was later removed.
  - This weak zone could have been removed via the planned shot blasting.

- The remaining portion (areas subject to minor amounts of snowmelt) of the concrete slab did not exhibit evidence of snowmelt incorporation.
  - Hard, densified layer in the uppermost ~1/8 in. of each core.
  - Minor plastic tear cracks and some bleed water incorporation in the uppermost densified layer, which may explain the few surface imperfections observed onsite.
    - The minor surface imperfections were addressed via the planned shot blasting.

Case Study 2 – Lessons Learned

- By stopping finishing activities, the effect of the snowmelt was confined to the near-surface (~1/4 in. depth) in one small region.
- After removal of the excess water, finishing activities achieved a densified, hard-troweled surface throughout the rest of the areas.
- The planned shot blasting may have addressed the upper weak surface in the heavily water-affected area.
- The planned shot blasting removed the minor surface imperfections in the remaining portion of the slab.

Concluding Remarks

- Stop finishing activities until the precipitation/excess water is dealt with.
- Even when exposed to a high volume of water, the incorporation of excess water is confined to the near-surface region of concrete.
- Concrete petrography is an invaluable tool to determine the extent of incorporation of snowmelt/rain and to inform potential removal/replacement/repair.

Questions?

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