



CONSTRUCTION MATERIALS CONSULTANTS, INC.

## Investigation of Failure of Anchoring Grout & Associated Distress in Concrete



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**TABLE OF CONTENTS**

Executive Summary.....3

Introduction .....4

    Background Information .....4

    Product Information.....4

    Field Photographs.....4

    Purpose Of Present Investigation .....5

Methodologies .....5

Sample.....8

    Photographs, Identifications, Integrity, And Dimensions .....8

Petrographic Examinations .....8

    Fine Aggregate.....8

    Paste Microstructures From Optical Microscopy .....9

    Paste Compositions & Microstructures From Sem-Eds.....16

    Air .....17

X-Ray Diffraction .....17

Total Sulfate Content.....18

Discussions .....18

    Anchoring Grouts – Properties & Types, And Problems .....18

    Anchoring Grouts – Problems.....20

    Anchoring Grouts – Excess Calcium Sulfates & Mechanisms Of Post-Hardening Expansions And Distress.....21

    Anchoring Grouts – Mix Proportioning & Curing.....22

    Anchoring Grouts – Astm Specifications & Tests.....23

    Anchoring Grouts – Pitfalls Of Using Gypsum-Based Grout In A Moist Outdoor Environment.....24

    Atmospheric Carbonation Of Gypsum – The Loss Of Structural Integrity Of The Gypsum Microstructure .....24

    Comparison Of Present Grout With ‘Anchor All’ .....24

Conclusions .....25

References .....26

Appendix .....A-1

Abbreviations:

PPL: Plane-polarized light mode in a petrographic microscope;  
XPL: Crossed-polarized light mode in a petrographic microscope;  
SEM-EDS: Scanning electron microscopy and x-ray every-dispersive spectroscopy.



## EXECUTIVE SUMMARY

Performance and durability of a cementitious anchoring grout in a moist outdoor environment with continuous or intermittent exposures of moisture can increase noticeably if a gypsum-based grout formulation is avoided, and substituted by a dominantly hydraulic cement-based formulation, especially when the application procedures deviate from manufacturer's recommendations. Due to extreme moisture sensitivity of gypsum, a gypsum-based formulation can easily distress when exposed to moisture during service, either simply by wetting and drying of the grout i.e. by softening and expansion, and/or by causing potentially deleterious expansive chemical reactions with the aluminate components within the grout and/or within the surrounding concrete.

The examined distressed anchoring grout showed a gypsum-based formulation, and its application in a moist outdoor environment, where not only the grout was exposed to moisture during service, e.g., received in a damp condition, but also was installed probably with an excessive amount of water i.e. beyond the manufacturer's recommended dosage of 1-part water to 7-part dry grout powder by weight (if the grout applied was indeed the reported specified grout 'Anchor All' from Dayton Superior), thus providing 'excess water' within the system even before exposure to an external source of moisture, e.g., rainwater. As a result, the grout has undergone significant expansion after hardening, from softening by excess water as well as further softening from moisture during service causing severe disintegration of the grout, and, cracking and spalling of the surrounding concrete. As a result, contrary to the advertised compressive strength of at least 7500-psi in 28 days for 'Anchor All,' the present sample of grout, in its soft powdery condition, has no strength at all.

Mineralogy and microstructure of the grout shows quartz sand in a gypsum-based binder formulation containing a minor amount of Portland cement, approximately 50-50 to 75-25 by weight sand-to-total binder formulation, where the former is broadly similar to the composition of the specified 'Anchor All,' but the latter indicates an over-sanded nature, probably from segregation of sand from an over-watered mass. The matrix in the distressed grout contains gypsum, ettringite, and hydrates of calcium aluminate, sulfoaluminate, and silicate as the primary products of hydration of the original gypsum and Portland cement components, as well as abundant secondary calcium carbonate (calcite,  $\text{CaCO}_3$ ) intermixed with gypsum. Secondary calcite, however, cannot be produced from carbonation of a minor Portland cement component in the binder but indicates a much larger phenomenon of carbonation of the gypsum skeleton to calcite as dissolution of gypsum in the presence of moisture during service followed by precipitation of calcite - with a severe loss of strength. SEM-EDS analyses showed calcite, gypsum, and ettringite as the three main minerals in the binder, as well as areas of pastes that are characterized by Si > Ca, Al (no S), Si-Al, Ca-Si-S, and Ca-Al-S compositions from hydrations of various phases of the original cement component in the binder, as well as of calcium-sulfate-aluminate reactions to form ettringite. Bulk sulfate (as  $\text{SO}_4$ ) content in the distressed grout powder is 8.37 percent, which is typical of many gypsum grouts. The basic gypsum-based microstructure of the grout was not only destroyed by the presence of 'excess' moisture during and after installation, but also by atmospheric carbonation of gypsum to calcite (having no cementitious property) during service - with a further loss of strength, and possible depassivation and corrosion of metal anchors by carbonation-induced reduction in pH of grout down to 9.3.

Unfortunately, the best method to mitigate the existing problem is to remove the distressed material and reinstall the anchoring grout with a more durable and acceptable (preferably a non-gypsum-based) material with a proven service-record in the moist outdoor environment, and installed by strictly following the manufacturer's application guidelines. Access of moisture to the grout during service must also be restricted.



## INTRODUCTION

Reported herein are the results of detailed laboratory studies of an anchoring grout sample from the field received from ABC of ABC Condominium Association, Inc. The grout sample was, reportedly, collected from the base of two adjacent railing posts that have shown extensive cracking and spalling of concrete around the railing posts, as well as severe disintegration of grout and its soft, pliable nature when the spalled concrete was removed and the underlying grout was collected.

### Background Information

The following background information was received with the grout in a letter from Mr. ABC. Also provided with the sample was a video of sample collection process in the field, from which field photos provided herein were retrieved.

“The issue with this condominium is the cantilevered balconies. The community had the railing replaced 3-5 years ago with an anodized style seen in the video. After the initial installation, there was an issue with the spacing between the ballasts that didn’t meet code. Those railings were then removed and replaced with railings of correct code requirements. As you can see, the material in which the railings were set is soft, pliable and unstable. In speaking with the manufacturer on site, the railings require a pourable concrete material with a setting strength of 4000-6000 psi for adequate adherence. That is clearly not the case here.

The reason for the testing is to compare the material used to set the railings with that of the manufacturer’s specifications.”

### Product Information

The product, reportedly, used to anchor the railings is ‘Anchor All’ manufactured by Dayton Superior. The Appendix section of this report provides the technical and safety data sheets of this product. The product is, reportedly, a mixture of quartz, calcium sulfate, and Portland cement, having a set time of 15-20 minutes, an expansion of 0.1 percent, and compressive strengths of 1000-psi in 1-hour, 4500-psi in 24 hours, 6000-psi in 7 days, and 7500-psi in 28 days.

### Field Photographs

Field photographs retrieved from the video of sample collection process show severe cracking and spalling of concrete at the base of the railing posts as well as severe disintegration of the anchoring grout as seen in the following photos (as well as in Figure A1 in the Appendix).



Figure 1: Photographs showing severe cracking and spalling of concrete and disintegration of anchoring grout.

### Purpose of Present Investigation

Based on the background information provided, the purposes of the present investigation are to determine:

- The composition, quality, and overall condition of grout, and whether or not the grout represents the specified 'Anchor All' product, and was applied following the manufacturer's recommendations;
- Binder composition of the grout, and if it confirms the manufacturer's specified composition;
- Evidence of any physical or chemical deterioration of grout; and,
- Based on detailed laboratory investigation, investigation of all possible reasons to explain the observed and reported distress of grout and associated concrete.

### METHODOLOGIES

Common methodologies for evaluation of performance and durability of an anchoring grout system in the field include the following procedures, most of which are also applicable for evaluation of failure of such systems during service:

- Review of technical and safety data sheets to investigate possible compositions of binder, advertised intended application exposures (interior-only vs. both interior and exterior), setting time, water requirements, curing requirements, application methods, and manufacturer's test results (e.g., compressive strengths and expansion).
- Total sulfate contents – For evaluation of the presence of free calcium sulfate in the dry grout or hydrated in-place grout, which is the most common cause of distress when grout is exposed to moisture during service. For anchoring grouts, the binder usually constitutes about half of the material by mass, so the sulfate contents for the material are about half of those for the binder alone. Materials with low sulfate content ( $<1.5\% \text{SO}_3$ ) are



acceptable; materials with high sulfate content ( $> 15\% \text{SO}_3$ ) are unacceptable; and materials with moderate sulfate contents need to be evaluated further by the following methods.

- Mortar Bar Expansion - Particularly for evaluating performance of a grout in a moist environment. A modified ASTM C 157 test is appropriate to determine the 14-day and 28-day expansions of mortar bars prepared by following the manufacturer's recommended proportions (there is currently no ASTM test for expansion specific to rapid-hardening grout for use in moist exterior environments). Usually, if the measured expansion after 14 days is no more than 500 microstrain, the free calcium sulfate content of the grout is not likely to promote deleterious expansions during service (Papas 2014).
- Petrographic Examinations, *a la* ASTM C 856, of the dry powder to characterize if the binder system is Portland-cement only, or gypsum-only, or Portland cement/gypsum blend, or Portland cement/calcium aluminate cement blend, as well as to determine the constituents in the binder that can cause deleterious expansions during service in a moist outdoor environment. Petrography is routinely used to evaluate failure of hardened grout in service, as the present study, to evaluate the binder components and diagnose materials and microstructures that are indicative of grout failures.
- X-ray Diffraction – To determine the presence or absence of free calcium sulfate (e.g., gypsum) and/or sulfate-related distress compounds (e.g., ettringite) in the hydrated material, both of which are generally detectable by XRD when the binder  $\text{SO}_3$  content is 1% or more.

For the present distressed grout:

- Figures A3a through A3c in the Appendix provide the Technical and Safety Data Sheets for 'Anchor All' from the manufacturer, Dayton Superior.
- Total Sulfate Content was determined by Combustion-IR method of Leco. The procedure followed is described in ASTM E 1019. A Portland cement standard with a known sulfate ( $\text{SO}_3$ ) content was used for calibration.
- Mortar bar expansion test was done on the dry grout power, and not on the distressed hydrated grout from field. The safety data sheet of 'Anchor All' indicates a 0.1 percent expansion of the product (Figure A3c in the Appendix); however, the test method followed to derive the expansion value could not be found. The specified expansion, however, is well within the acceptable limit for any free calcium sulfate to not promote undue deleterious expansion after hardening.
- Petrographic examination was done by using the following procedures (details of sample preparation can be found in Jana 2006):
  - ✓ Visual examinations of the distressed grout, as received, as well as photographing and documenting the appearance and condition of the grout when received;
  - ✓ Low-power stereomicroscopical examinations of grout;
  - ✓ Examinations of oil immersion mounts in a Nikon Eclipse E600 POL petrographic microscope for mineralogical compositions;



- ✓ Examinations of blue dye-mixed epoxy-impregnated large area (50 mm × 75 mm) thin section of grout in a Nikon Eclipse E600 POL petrographic microscope for detailed compositional and microstructural analyses; the purpose of impregnating a representative portion of the dried grout sample with a low viscosity blue dye-mixed epoxy is to highlight the void spaces, cracks, and porous areas in the hardened grout;
  - ✓ Collecting numerous photomicrographs of thin section of grout to provide detailed mineralogical and microstructural information of grout, which are presented in Figures 3 through 14, as well as in Figures A4 through A14 in the Appendix; and,
  - ✓ Scanning electron microscopy and X-ray microanalyses of various areas of paste to determine the overall compositions and detailed microstructures of various binder phases in the paste, which are presented in Figures A17 through A25 in the Appendix.
- X-ray diffraction analysis (XRD) was done to determine the proportions of sand and binder, and to detect the presence of gypsum and ettringite in grout. XRD was carried out in a Siemens D5000 Powder diffractometer employing a long line focus Cu X-ray tube, divergent and anti-scatter slits fixed at 1 mm, a receiving slit (0.6 mm), diffracted and incident beam Soller slits (0.04 rad), a curved graphite diffracted beam monochromator, and a sealed proportional counter. Generator settings used were 45 kV and 30mA. XRD was done on:
    - ✓ A finely pulverized bulk grout sample wet-ground in a McCrone Micronizing mill with 200-proof ethanol to pass US 325 sieve (44- $\mu\text{m}$ ) i.e. to determine the mass fractions of sand and binder,
    - ✓ Gently disintegrating the grout in a mortar and pestle to separate sand from paste, followed by sieve analyses through US 200 sieve (74- $\mu\text{m}$ ) to collect the fraction passing the sieve openings (i.e. enriched in the binder), followed by pulverization of the finer fraction in a McCrone Micronizing mill with 200-proof ethanol to pass US 325 sieve (44- $\mu\text{m}$ ) to determine the mineralogical composition of the paste.
    - ✓ Finally, a portion of the binder-rich fraction (i.e. passing US No. 200 sieve) was digested in dilute hydrochloride acid to dissolve out the carbonate component, and the residue was then scanned for detecting the sulfate phases in the paste (e.g., gypsum, ettringite).

Each prepared sample was placed in a 1-in. diameter circular sample holder and excited with the copper radiation of 1.54 angstroms. Tests were performed at a 2-theta range from 4° to 64° with a step of 0.02° and a dwell time of one second. The resulting diffraction patterns were collected by using DataScan 4 software of Materials Data, Inc. (MDI), analyzed by using Jade 9.0 software of MDI with ICDD PDF-4 (Minerals 2014) diffraction data, and, phase identification plus quantitative analyses were carried out with MDI's Search/Match and Easy Quant modules, respectively. Results are provided in Figures A30 and A31 of the Appendix.

The entire sample (shown in Figure 2) was separated into three fractions by coning and quartering. One fraction was used for preparation of sample for optical and scanning electron microscopy. The second fraction was used for X-ray diffraction. Finally, the third fraction was used for determination of total sulfate content. The fraction

selected for microscopy was oven dried at 40°C to remove dampness (without dissociating gypsum), then encapsulated with a blue dye-mixed low viscosity epoxy to improve the overall integrity for subsequent preparation of thin section (less than 30-µm in thickness). The XRD fraction was further split into two – one used for mineral contents of bulk grout by grinding (under 200-proof ethanol) in a micronizing mill to pass US 325 sieve (finer than 44-µm), and the second fraction was gently disintegrated to separate sand from binder, sieved through US 200 sieve to screen out sand, and then the fraction passing the sieve (finer than 74-µm) was further hand ground in an agate mortar and pestle to prepare for XRD analysis of the binder-fraction. Finally, the fraction for sulfate content was ground to pass US No. 50 sieve.

**SAMPLE**

**Photographs, Identifications, Integrity, and Dimensions**

Figure 2 (and Figure A2 in the Appendix) show the soft, light gray, powdery nature of sample from severe disintegration of grout. The sample, as received was damp, indicating the presence of moisture during service.



Figure 2: The powdery nature from severe disintegration of the grout, as received. The left photo shows the sample after placing in a petri dish, the right photo shows blue dye-mixed low-viscosity epoxy-impregnated thin section of grout prepared for petrographic examinations, and the middle image shows the sample at a higher magnification in a low-power stereomicroscope.

**PETROGRAPHIC EXAMINATIONS**

**Fine Aggregate**

Fine aggregate is quartz sand having a nominal maximum size 0.5 mm or less, as seen in the following photomicrographs of thin section of grout in Figure 3. Particles are clear, subangular to angular, dense, hard, equidimensional to elongated, unaltered, uncoated, uncracked, and well-graded. There is no evidence of alkali-aggregate reaction of fine aggregate particles. Fine aggregate particles have been sound during their service.

The observed quartz sand is consistent with the reported use of quartz in the safety data sheet of ‘Anchor All.’

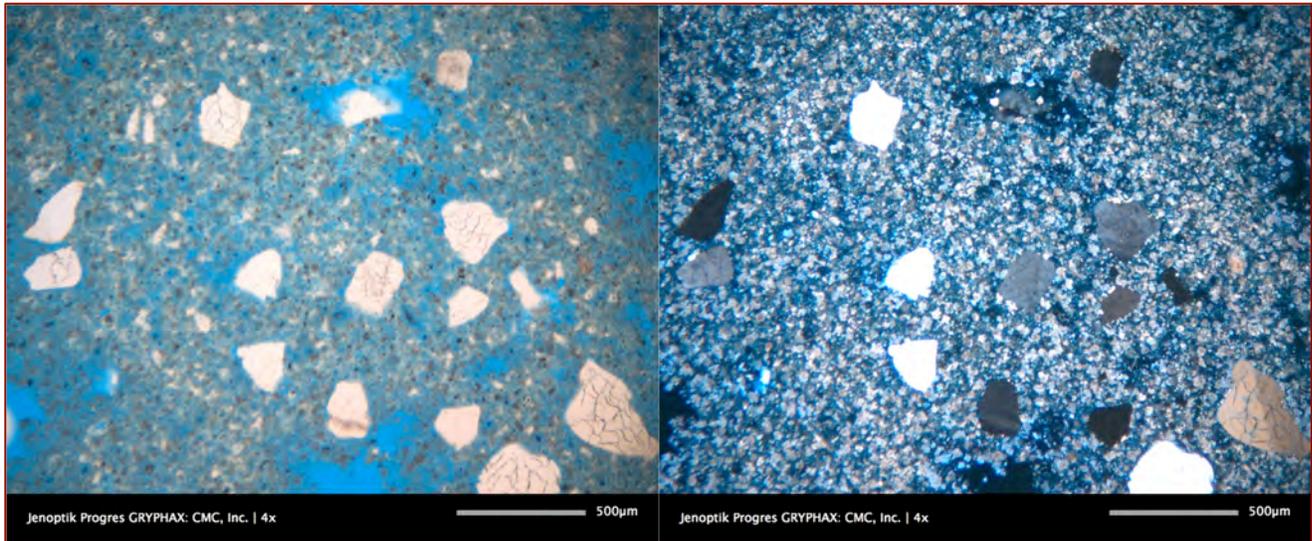


Figure 3: Photomicrographs of blue dye-mixed epoxy-impregnated thin section of the grout showing quartz sand fine aggregate particles.

#### Paste Microstructures From Optical Microscopy

Paste is soft, gray, powdery, and shows abundant very fine-grained gypsum intermixed with calcium carbonate, in the overwhelming matrix within which are patchy areas representing hydration products of a hydraulic cement component from the binder. Figure 4 shows such a patchy appearance from a mixed gypsum plus hydraulic cement binder (where the former occupies a much larger volume than the latter).

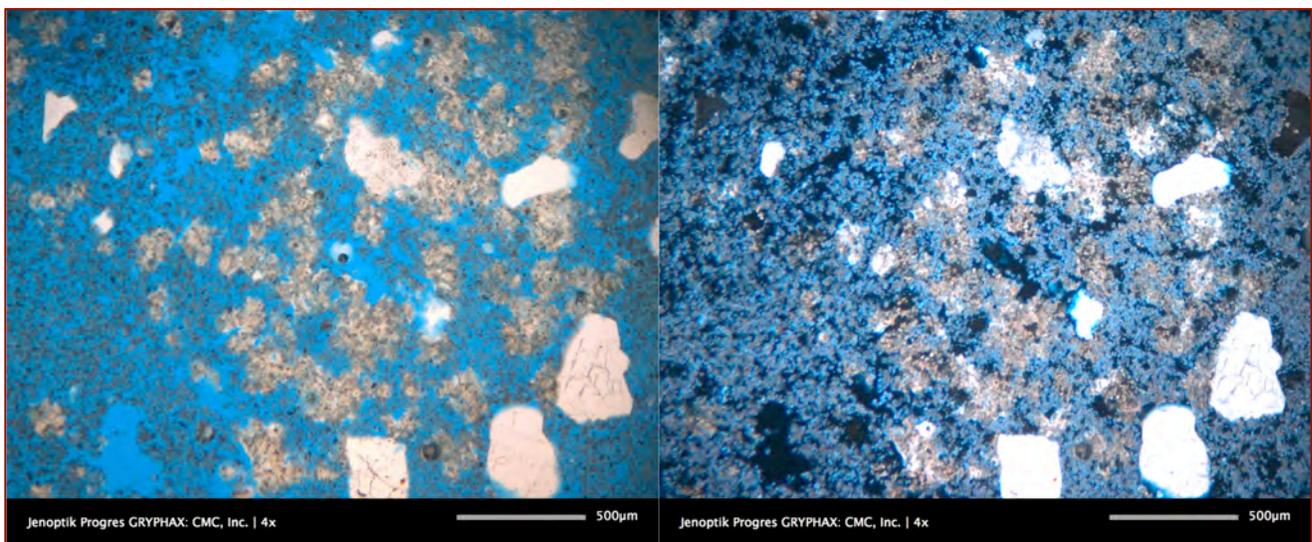


Figure 4: Photomicrographs of blue dye-mixed epoxy-impregnated thin section of the grout showing patchy nature of the paste consisting of dominant porous areas of paste that are represented by blue tones from absorption of dye and smaller portions of patches where dye did not absorb due to denser areas.

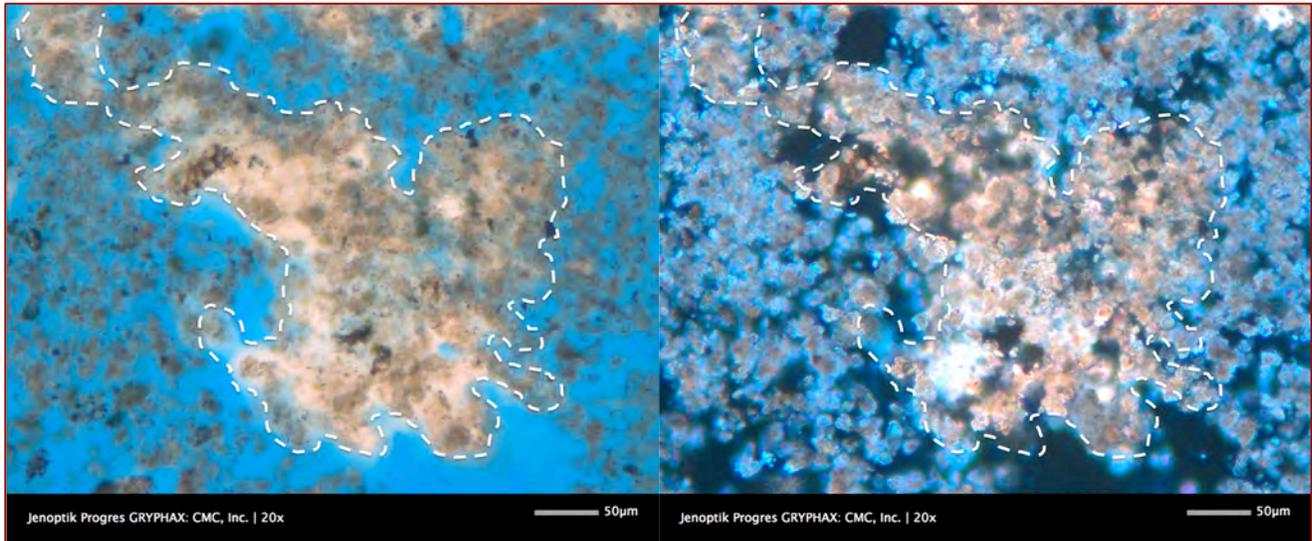


Figure 5: Photomicrographs of blue dye-mixed epoxy-impregnated thin section of the grout showing patchy nature of the paste consisting of dominant porous areas of paste that are represented by blue tones from greater absorptions of dye, and, smaller portions or patches where dye was not absorbed due to denser areas.

Occasional coarse subhedral crystals of gypsum in paste indicates secondary crystallization or re-crystallization of gypsum during drying after a wetting event in the hardened state, as shown below:

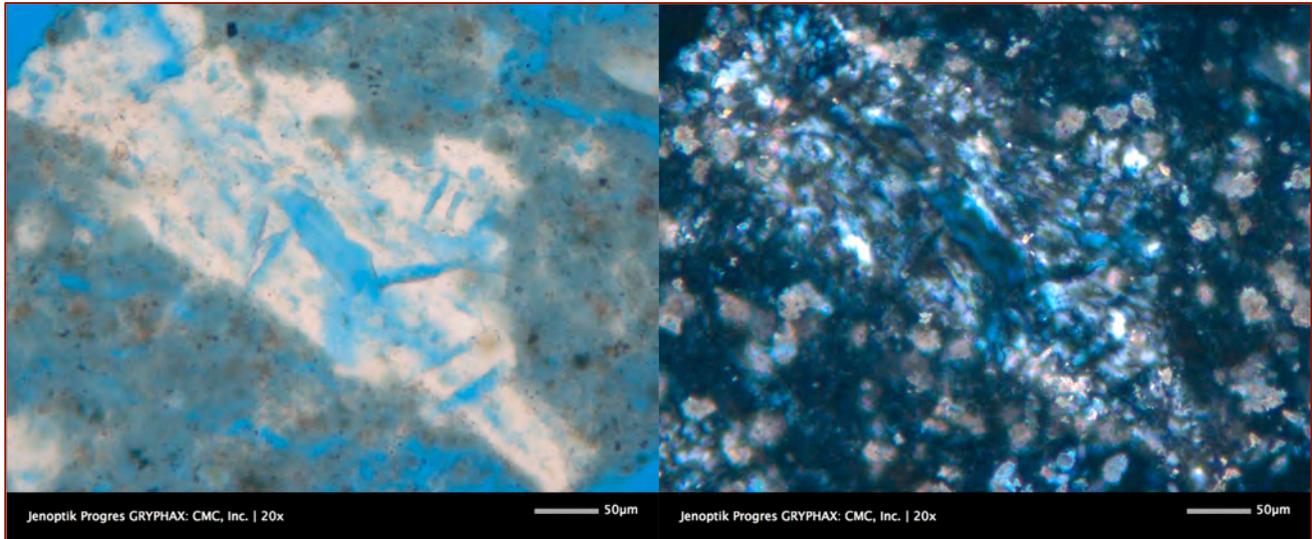


Figure 6: Photomicrographs of blue dye-mixed epoxy-impregnated thin section of the grout showing coarse subhedral secondary gypsum recrystallization from drying of grout after a period of wetting.

The basic mineralogical compositions of paste shows: (a) gypsum, ettringite, and hydrates of calcium aluminate, sulfoaluminate, and silicate as the products of hydration of the original binder components of gypsum and Portland cement in the grout, as well as (b) secondary products of coarser gypsum crystals, and calcium carbonation, which were formed by dissolution of primary hydration products and precipitation of gypsum or atmospheric carbonation of gypsum to calcite (through dissolution of gypsum in the presence of moisture during service followed by atmospheric carbonation and precipitation as calcite).

Excessive water in the mix has produced shrinkage microcracking, which is not anticipated in a nonshrink grout:

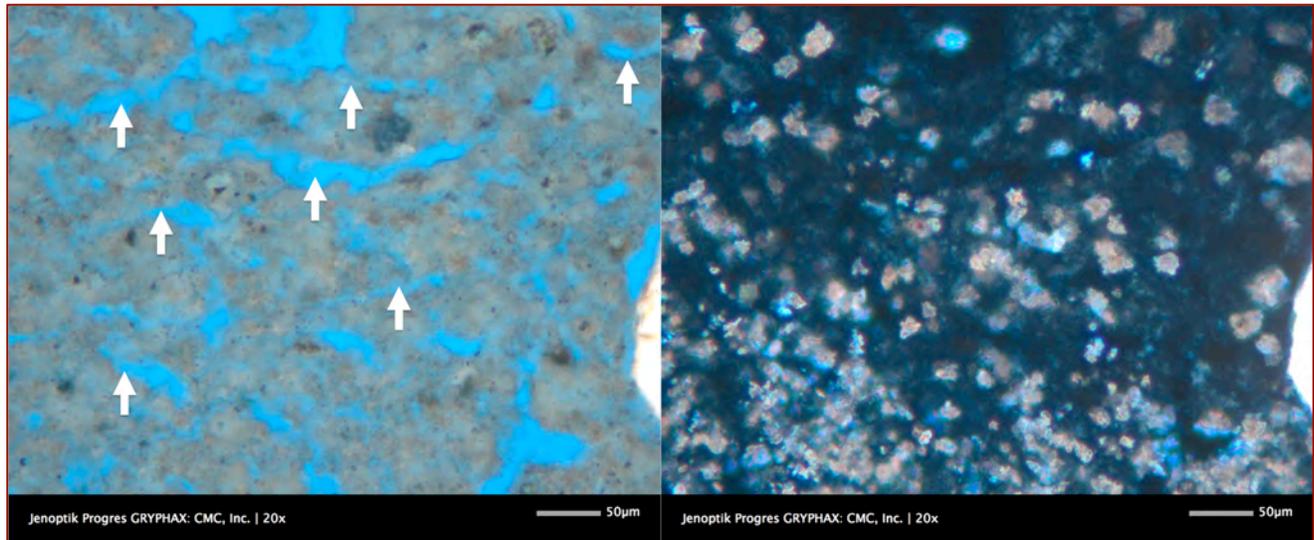


Figure 7: Photomicrographs of blue dye-mixed epoxy-impregnated thin section of the grout showing parallel shrinkage microcracks in the paste, many of which are marked with arrows.

General microstructure of paste shows an overwhelming matrix of intermixed calcium carbonate occurring as small blots of high birefringence masses intermixed with not so discernable masses of gypsum and ettringite, as shown in Figures 7, 8, and 9. Such an abundance of calcium carbonate indicates atmospheric carbonation of the original gypsum hydration products in the presence of moisture and atmospheric carbon dioxide, since such a high abundance of calcium carbonate cannot be formed from carbonation of hydrated products of a small amount of Portland cement added to the gypsum-based grout. The anhedral shapes of secondary calcium carbonate masses in Figures 8 and 9 as opposed to clear euhedral shapes of calcite fines indicate their secondary formation after dissolution of gypsum, carbonation, and precipitation as secondary calcite precipitates, by e.g., the following reactions:

- Dissolution of atmospheric carbon dioxide in a moist alkaline environment of grout (at pHs ~ 12 atmospheric  $\text{CO}_2$  is readily absorbed in moisture) and formation of carbonic acid:  $\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3$  which dissociates into  $2\text{H}^+ + \text{CO}_3^{2-}$ ;
- $\text{CO}_3^{2-}$  then reacts with gypsum  $\text{CO}_3^{2-} + \text{CaSO}_4 \cdot 2\text{H}_2\text{O} = \text{CaCO}_3$  (secondary calcite precipitates) +  $\text{SO}_4^{2-} + 2\text{H}_2\text{O}$
- Calcite has a lower solubility product than gypsum ( $\text{pK}_s \sim 8.4$  for calcite versus  $\text{pK}_s \sim 4.6$  for gypsum at  $25^\circ\text{C}$  and calcite is much less soluble than gypsum under the alkaline condition of the grout.

Many field and laboratory studies on the effects of carbonation of gypsum in industrial flue gas desulfurization (FGD) plants show similar formation of calcite at the expense of gypsum during weathering (where ettringite is more stable to carbonation than gypsum, Robl et al. 2007, Wang 2009).

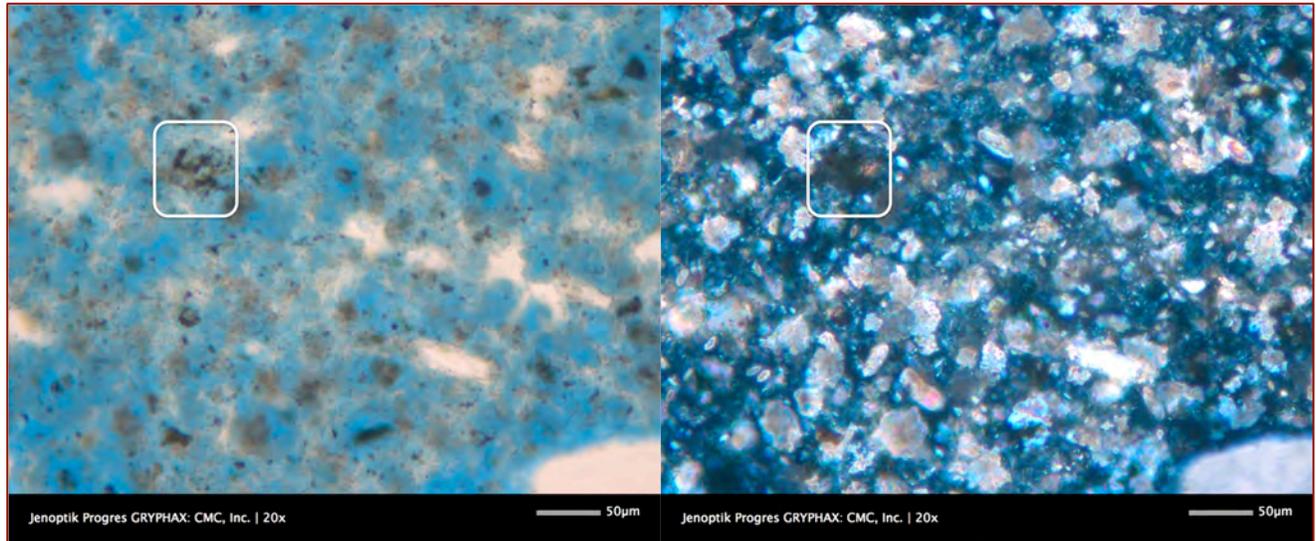


Figure 8: Photomicrographs of blue dye-mixed epoxy-impregnated thin section of the grout showing an overwhelming matrix of high birefringent masses of secondary calcium carbonate and low birefringent masses of gypsum (plus some ettringite), and a few residual (or relict) hydraulic cement particles that appeared to be of Portland cement mineralogy and microstructure showing residual belite and interstitial dark ferrite (boxed).

Another set of photomicrographs show the residual Portland cement particle in a better detail:

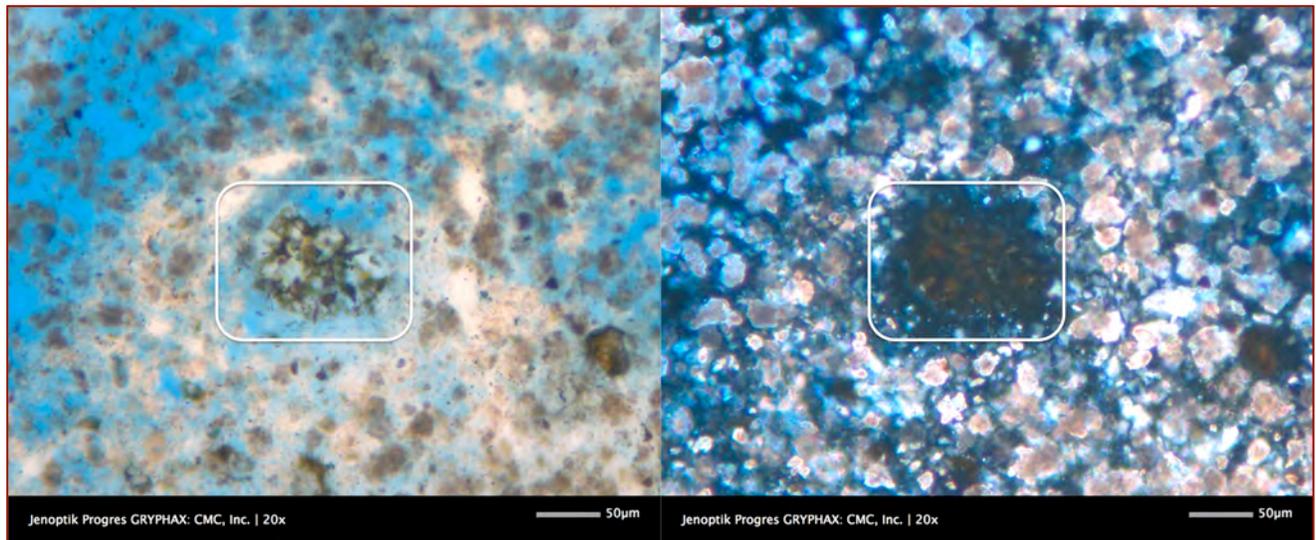


Figure 9: Photomicrographs of blue dye-mixed epoxy-impregnated thin section of the grout showing an overwhelming matrix of high birefringent masses of secondary calcium carbonate precipitates and low birefringent masses of gypsum (plus some ettringite), and a few residual (or relict) hydraulic cement particles that appeared to be of Portland cement mineralogy and microstructure showing residual belite and interstitial dark ferrite (boxed).

Residual cement particles are scattered throughout the matrix, as shown in another set below. Their low abundance is due to excessive water in the system as well as of using a gypsum-based grout containing a minor amount of Portland cement.

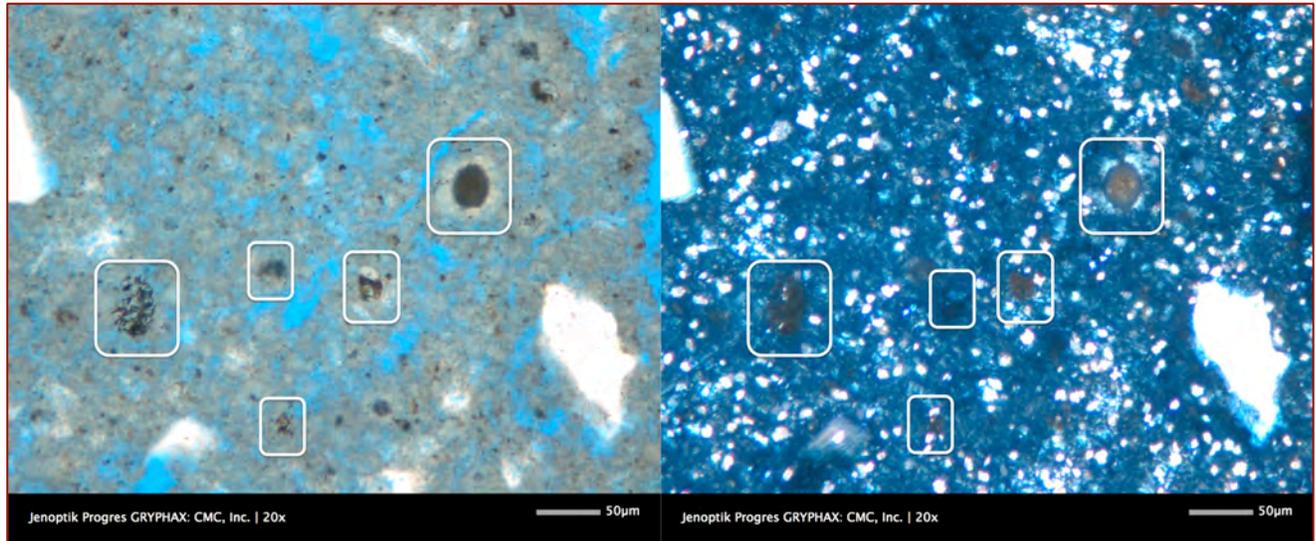


Figure 10: Photomicrographs of blue dye-mixed epoxy-impregnated thin section of the grout showing a few residual cement particles (marked with boxes).

The gypsum binder in the paste is noticed in portions that are not invaded by the high birefringent calcium carbonate masses, such as the one shown below, where gypsum occurs as low birefringent (first order gray to white) fibrous masses.

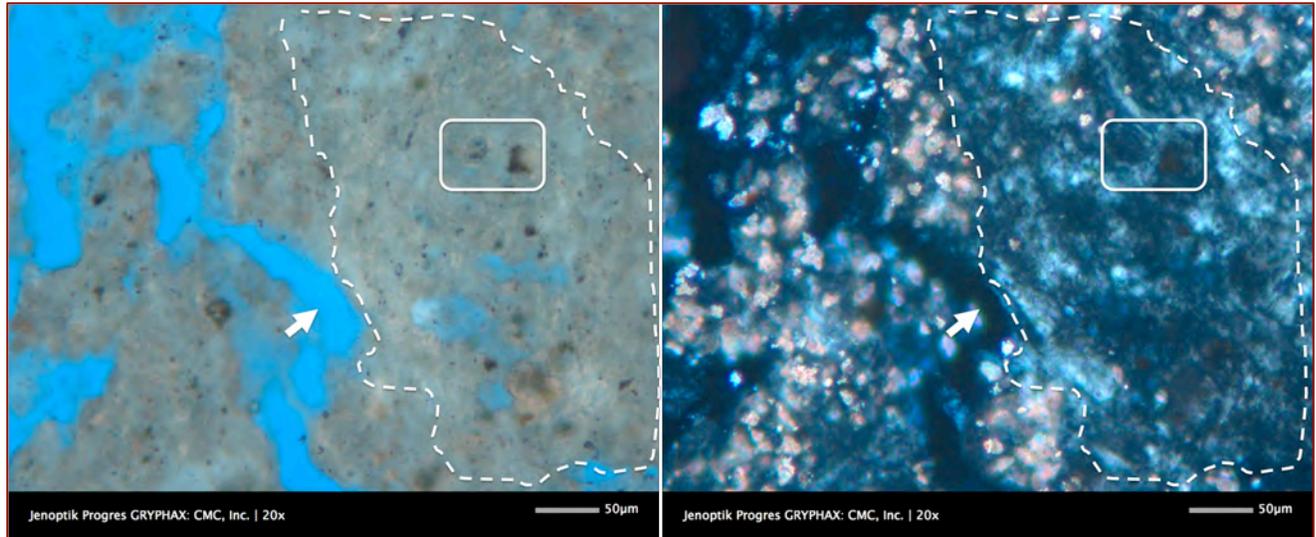


Figure 11: Photomicrographs of blue dye-mixed epoxy-impregnated thin section of the grout showing an area enriched in gypsum and lack of calcium carbonate masses (within the dashed line). Within the boxed area in the gypsum-rich area are a few residual cement particles. The area on right outside the gypsum-rich mass is the typical matrix consisting of both secondary calcium carbonate, and hydrates of sulfate, sulfoaluminate, etc.

Leaching of water-soluble components due to the presence of excess moisture in the system is anticipated, which is evidenced by isotropic nature of leached areas in crossed-polarized light despite an apparent appearance of dense areas due to the lack of absorption of blue dye. The following set of photomicrographs show a leached area marked with dashed line that shows the presence of a microcrack that has acted as a channel for leaching out of

masses. Notice the calcium carbonate masses are still present in the leached area, as well as some gypsum crystals with weak birefringence.

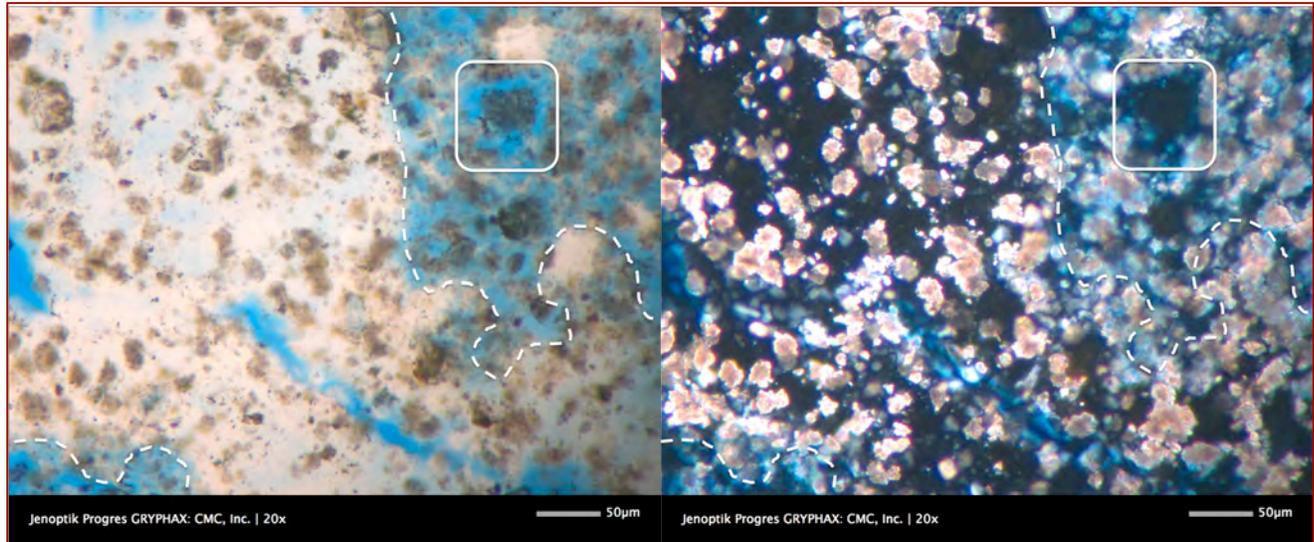


Figure 12: Photomicrographs of blue dye-mixed epoxy-impregnated thin section of the grout showing an area having an isotropic nature in XPL (within the dashed lines), which contains birefringent calcium carbonate masses, and a microcrack (highlighted by dye) that has acted as a channel to remove some water-soluble gypsum.

At high magnifications, some fibrous ettringite deposits are found formed topochemically on the surfaces of residual aluminate phases in residual cement particles.

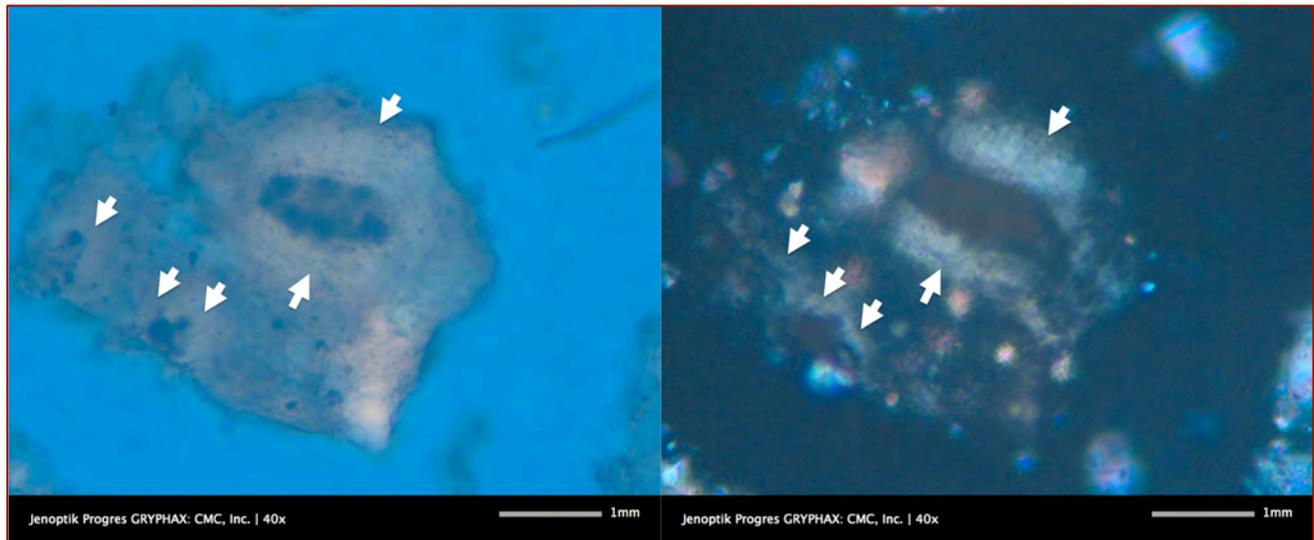


Figure 13: Photomicrographs of blue dye-mixed epoxy-impregnated thin section of the grout showing topochemical formation of fibrous ettringite deposits (arrows) on the surfaces of residual aluminate phases in the cement particles.

The following set of photomicrographs also shows such topochemical formation of ettringite having first order white to grey birefringence on the surfaces of residual cement particles.

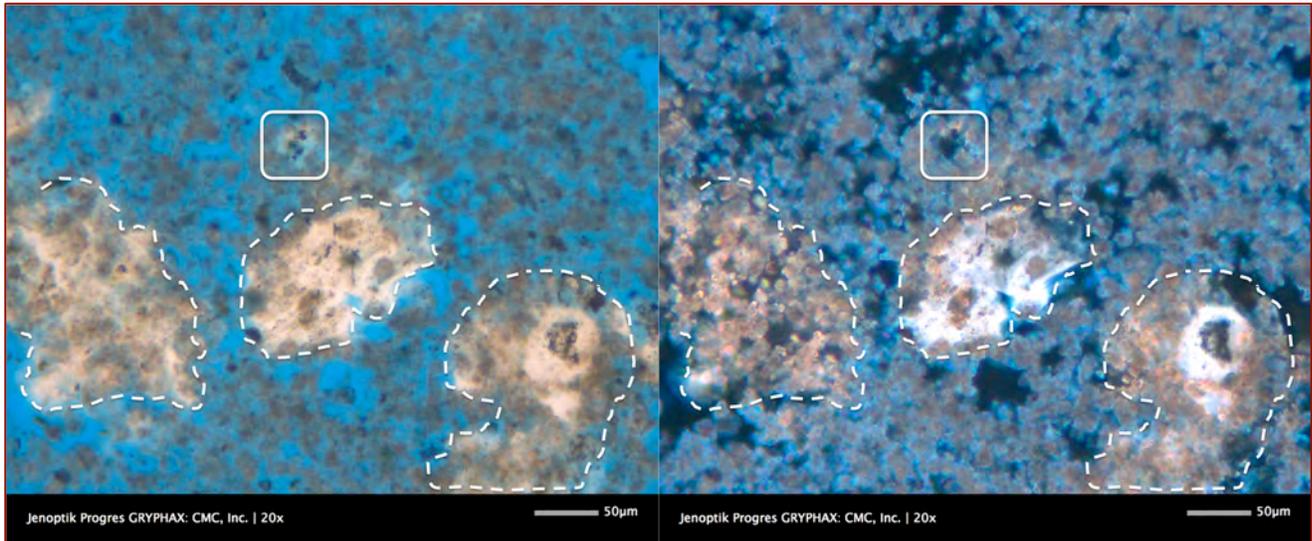


Figure 14: Photomicrographs of blue dye-mixed epoxy-impregnated thin section of the grout showing topochemical formation of fibrous ettringite deposits (mostly in the right two areas within dashed lines) on the surfaces of residual aluminate phases in the cement particles.

Therefore, in summary, various microstructures of paste show the following features:

- Distribution of quartz sand in the matrix consisting dominantly of calcite and gypsum (Figures 3 and 4);
- Patchy areas of matrix that were once the locations of cement particles during hydration (Figures 4 and 5);
- Coarse, subhedral secondary (recrystallized) gypsum crystals from wetting and drying of grout (Figure 6);
- Shrinkage microcracks in paste from excessive moisture, which are not anticipated in a nonshrink grout (Figure 7);
- An overwhelming matrix of high birefringent masses of anhedral calcium carbonate precipitates and low birefringent crystals of gypsum, and a few residual (or relict) hydraulic cement particles that appeared to be of Portland cement mineralogy and microstructure showing residual belite and interstitial dark ferrite (Figure 8);
- A few scattered areas of residual and relict cement particles that are indicative of the presence of a minor cement component in the gypsum-based binder of grout (Figures 9 and 10);
- Abundant secondary calcite precipitates indicating atmospheric carbonation of the main gypsum skeleton of the basic microstructure of gypsum-based grout, where calcite was not formed by solid-state or topochemical reaction but by dissolution of gypsum in the presence of moisture, and precipitation of calcite due to atmospheric carbonation of gypsum (Figures 7 and 8);
- Gypsum-rich areas of paste that are not invaded by calcium carbonate masses (Figure 11);
- Leaching of water-soluble components from matrix by moisture and microcracks (Figure 12); and,
- Topochemical formation of fibrous ettringite on the surfaces of residual aluminate phases of residual cement particles, which are indicative of hydration of calcium sulfoaluminate components of binder and formation of ettringite as the primary ettringite hydration products of binder (Figures 13 and 14).



### Paste Compositions & Microstructures From SEM-EDS

SEM-EDS studies of paste show many further details of compositions and microstructures of various phases in the paste as well as of original and hydrated mineral components of binder. Figures A17 through A25 show many such details of compositions and microstructures of paste that are summarized here:

- Distribution of ettringite deposits in various areas of paste having characteristic fibrous habit and shrinkage microcracks that are shown mainly in Figures A17, A18, and A24 in secondary electron images with x-ray elemental analyses, and, in the elemental map of ettringite areas in Figure A19 occurring as isolated patches in paste as well as along aggregate-paste interfaces, having characteristically high calcium, aluminum, and sulfur.
- Distribution of calcite grains in various areas of paste having characteristically very high calcium compared to all other elements, which are shown in Figures A20, A22, and A24 in secondary electron images with x-ray elemental analyses. Consistent with observations from optical microscopy, SEM-EDS studies also show secondary precipitation of calcium carbonate crystals by atmospheric carbonation of gypsum in the presence of moisture and atmospheric carbon dioxide.
- Distribution of gypsum in various areas of paste having characteristically high calcium and sulfur compared to all other elements, which are shown in Figures A20, A22, and A24 in secondary electron images with x-ray elemental analyses.
- Other than ettringite, calcite, and gypsum, no other minerals are detected in the paste, which is consistent with the results from optical microscope and XRD studies (shown below).
- The major aspect of SEM-EDS, however, is to determine the overall composition of paste away from these above binder minerals, i.e. to determine the nature of hydration products of binder.
- Figures A17, A18, A20, and A22 (SED images with EDS analyses) show areas of paste that are devoid of sulfur and enriched in silica compared to calcium and alumina [ $Si > (Ca > \text{ or } < Al)$ ]. These areas represent products of hydration from the Portland cement component where not only calcium silicate, as would be anticipated from direct hydration of calcium silicates of Portland cement but also has noticeably detectable aluminum, indicating hydration of an aluminate component as well, a component, which was also responsible for formation of ettringite from the original gypsum component of the binder.
- X-ray elemental map of paste in Figure A21 shows small isolated patchy areas in paste that are enriched in silica and alumina ( $Si > Al$ ) but depleted in calcium and sulfur. These patches indicate contributions from aluminosilicate component of binder, possibly present as interstitial phases in the cement or perhaps of a separate component. Such aluminosilicate components are known as effective glue to polymerize a paste. Their abundance, however, is in small isolated patches, possibly due to the presence of excess water in the system; otherwise such areas are judged to be a contributor to the strength development of paste.

- X-ray elemental map of paste in Figure A23 shows high sulfate areas that are also rich in calcium, but depleted in aluminum (indicating the presence of gypsum but not intermixed with ettringite for lack of aluminum). Outside the gypsum areas, paste is overwhelmingly rich in calcium, aluminum, and sulfur, from the presence of ettringite.
- X-ray elemental map of paste in Figure A25 shows a paste area that is enriched in calcium, silica, and sulfur but depleted in aluminum.

### Air

The grout is non-air-entrained due to the lack of any intentionally introduced entrained air.

### X-RAY DIFFRACTION

X-ray diffraction of bulk grout (Figure A15 in the Appendix) shows quartz as the dominant mineral from the quartz sand, as expected, and calcite as the next subordinate mineral from carbonation of binder components (mostly from atmospheric carbonation of the main gypsum component of the binder), gypsum from the excess calcium sulfate in the distressed grout, which is present as both the gypsum from hydration of binders as well as coarse secondary precipitates of gypsum, and ettringite (calcium sulfoaluminate hydrate,  $3\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot 3\text{CaSO}_4\cdot 31\text{H}_2\text{O}$ ) from the reactions between the sulfate and aluminate components in the grout, mostly as the primary product of hydration of the binder, as well as some as secondary ettringite precipitates. Other possible phases that could not be detected in the present XRD study are other hydrates of calcium aluminate, sulfoaluminate and silicate (probably due to low crystallinity or occurrence in gel-like masses, and/or low abundance).

XRD of the binder-fraction passing the US 200 sieve (i.e. finer than  $74\text{-}\mu\text{m}$ , Figure A16 in the Appendix) showed lesser quartz than that detected in the bulk sample for mechanical separation, but clear discernable peaks of three main minerals present in the paste - calcite, gypsum, and ettringite.

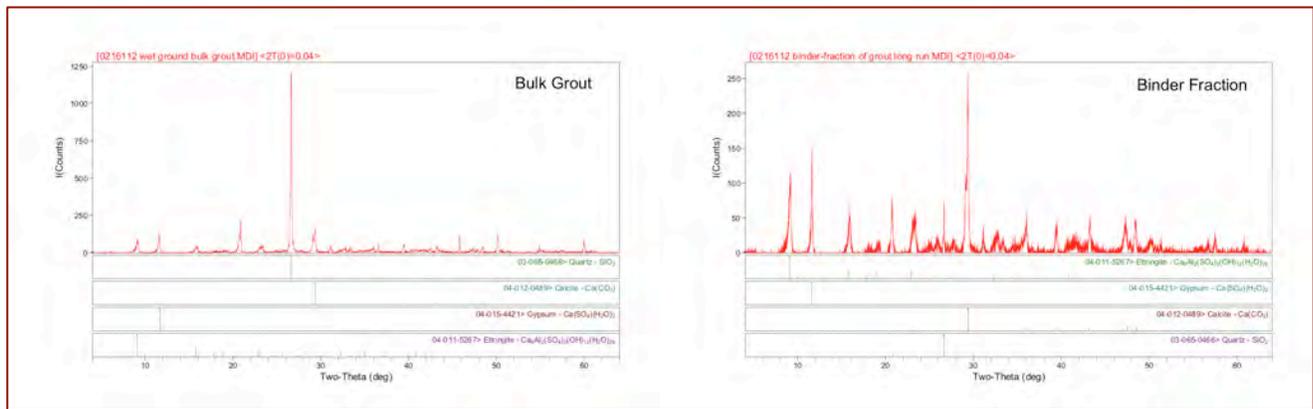


Figure 15: XRD patterns showing various phases in the bulk grout sample at left and in the binder-fraction at right [after separating sand from the binder by passing gently disintegrated grout through US No. 200 sieve ( $74\text{-}\mu\text{m}$ ) and analyzing the fraction that has passed the sieve (finer than  $74\text{-}\mu\text{m}$ )].

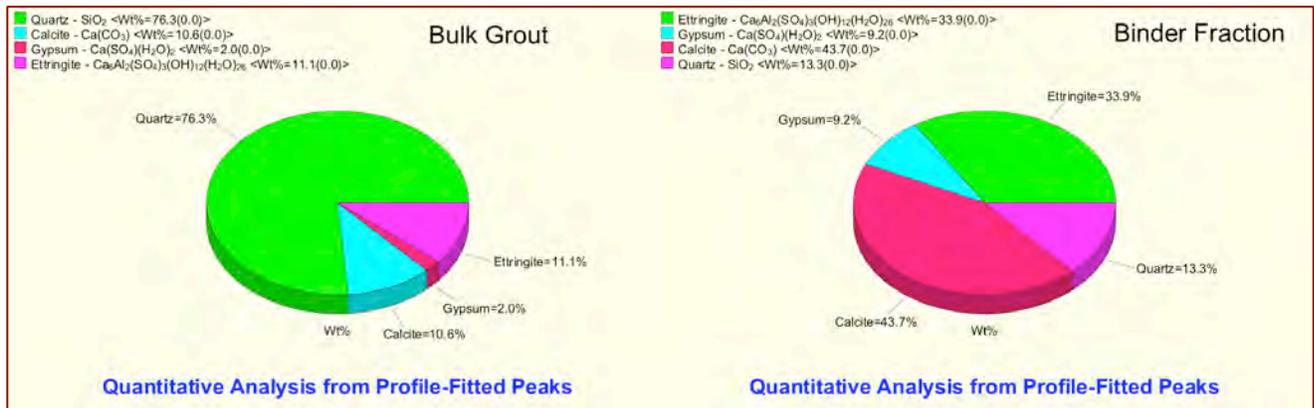


Figure 16: Pie-graphs showing semi-quantitative proportions of various phases in the bulk grout sample at left and in the binder-fraction at right [after separating sand from the binder by passing gently disintegrated grout through US No. 200 sieve (74-µm) and analyzing the fraction that has passed the sieve (finer than 74-µm)].

Bulk mineralogy of grout shows 75-25 by weight of quartz sand to binder minerals, which is also found to be 50-50 in a separate batch of sample in a second XRD run. Clearly, sand distribution in the grout is not uniform, which could be due to some segregation of sand from an over-watered mixture. Etringite formation in the hardened state due to sulfate-aluminate reactions in the presence of moisture during service causes expansion and cracking of grout and the surrounding medium. Detection of both gypsum and calcite in the XRD indicates adequate presence of both sulfate and carbonate, respectively, which is consistent with optical microscopy and SEM-EDS studies.

### TOTAL SULFATE CONTENT

Sulfate content as SO<sub>3</sub> in the bulk grout is determined to be 8.37 percent by mass of grout. This sulfate content is typical of many gypsum grouts.

### DISCUSSIONS

#### Anchoring Grouts – Properties & Types, and Problems

Properties that are vital for use of a proprietary prepackaged anchoring grout in railing posts are:

- Non-shrink behavior when set and hardened (hence also called nonshrink, or, shrinkage-compensating grout), which is achieved by an expansion at the plastic state (*pre-hardening expansion*) to fill available open or void spaces around railing post to provide successful anchorage and load-transfer from the railing to the surrounding concrete. Pre-hardening expansion reduces or eliminates subsequent shrinkage during hardening that a traditional Portland-cement-only grout system undergoes. Usually, the mechanism that provides the early expansion at the plastic state and thus the nonshrink behavior, if continues after hardening, contributes to the *post-setting/hardening expansions* with the failure of the grout system and/or the surrounding medium.



- Quick setting and high early strength, in order to reduce the time that posts are needed to be supported. Traditional Portland-cement-only grouts provide slow setting and strength gain, hence are commonly replaced by many newer-generations of proprietary grout products offering very fast setting and high early strengths (e.g., the current 'Anchor All' grout of Dayton Superior that achieves an advertised 4500 psi strength within 24 hours when mixed, used, and applied according to the manufacturer's recommendations).

*The present examined grout is reported to be a product called 'Anchor All' from Dayton Superior, which shares both of the above-mentioned properties of a nonshrink anchoring grout system. In its technical data sheet, it is described as: "Fast setting, shrinkage compensated anchoring cement. Pourable and fast setting. Anchor All provides a durable high strength anchor for interior and exterior applications." It is advertised to set in 15-20 minutes with controlled expansion mechanically locks in to fill voids, advertised to use for both interior and exterior applications, with compressive strength (ASTM C 109) developing as fast as 1000 psi in 1-hr., 4500 psi in 24-hr., 6000 psi in 7 days and 7500 psi in 28 days. Advertised mixture composition in the product safety data sheet indicates 25-50% quartz, 25-50% calcium sulfate, and 10-25% Portland cement.*

The newer generations of nonshrink anchoring grouts are broadly classified into:

- Polymer Grouts (e.g., nonshrink epoxy grouts) that contain a filler and a polymer binder, or, a Polymer-Modified Grout, where a cementitious system is further densified with an impregnated polymer, or,
- Cementitious Grouts.

*The present examined grout belongs to the category of cementitious grouts.*

Cementitious grouts can have one of the following three primary types of binders that are traditionally used for repair materials, or, anchoring:

- Portland cement-based repair grouts, where Portland cement constitutes the dominant binder component. Due to the requirements of shrinkage-compensation, quick setting, and high early strength during anchoring applications, Portland-cement-only grout systems, as mentioned, are less common than the following two types. A Type III Portland cement, being more finely ground than Type I/II can provide high early strength, hence a better choice in a cement-grout.
- Gypsum-based, which provide fast, early set, which may contain gypsum as the sole binder component, or gypsum with a minor amount of Portland cement (usually less than 10 percent cement to provide some passivation of embedded metals, which, however, can also cause formation of deleteriously expansive compounds like ettringite, a calcium sulfoaluminate hydrate, after initial hardening, if exposed to moisture during service, resulting in cracking of the grout itself and/or of the surrounding medium),
- Blended Portland cement and Calcium Aluminate Cement-based, or expansive calcium sulfoaluminate cement system, where sulfate-aluminate reactions during setting provide the necessary nonshrink behavior,



which, however, can also contribute to the distress if this reaction continues after setting i.e. during service in the continued presence of moisture.

*The present examined grout belongs to the second category of gypsum-based cementitious grout, which is determined to contain gypsum as the major binder component, along with calcite fines and a minor amount of hydraulic cement.*

Both gypsum-based grouts and Portland cement/calcium aluminate cement-based grouts offer the necessary shrinkage compensation characteristic of a nonshrink grout. Many proprietary grout products contain other shrinkage compensation additives, such as:

- A shrinkage-compensating (expansive) cement, e.g., a Type K sulfoaluminate-type expansive cement, or a Type M expansive cement, which is a mixed Portland cement plus calcium aluminate cement plus calcium sulfate, or, a Type S expansive cement, which is a very high  $C_3A$ , as high as 20%  $C_3A$  Portland cement containing a stoichiometrically high amount of calcium sulfate - all of which undergo an expansive formation of ettringite during hydration thus provide the shrinkage-compensation (expansion) during the early hardening period after setting, and all are specified in ASTM C 845.
- A shrinkage-compensating/reducing chemical (e.g., organic, water-soluble) admixture (SRAs, however, are not covered in ASTM C 494 specifications for chemical admixtures), which operates by interfering with the surface chemistry of the air/water interface within the capillary pores, reducing surface tension of water in the capillary pores (which is the prime factor for drying shrinkage of Portland cement-based systems), and consequently reducing the shrinkage as water evaporates from within the grout or concrete.
- Oxidizing iron aggregate, or metallic powders (aluminum).

### Anchoring Grouts – Problems

Three common types of problems of many anchoring grout systems related to *post-hardening expansions* are:

- Volume instability when exposed to moisture after hardening i.e. during service, resulting in expansion or degradation of the product itself,
- Migration into and reaction with the surrounding concrete, again, in the presence of moisture during service that causes dissolution of potentially deleterious water-soluble components from the grouts to the concrete, resulting in the formation of expansive chemical compounds and deterioration of concrete as cracking and spalling; and,
- Lack of passivation of embedded metal, particularly aluminum causing corrosion of metal.

*Based on detailed petrographic examinations, the present grout is judged to have experienced at least both of the first two types of distress, and, possibly also of the third type that can be verified from field survey. Additionally,*



*from the soft, powdery, severely disintegrated appearance of the grout in the field, during retrieval, and subsequent laboratory examination, as well as from the microstructure of the grout (e.g., very soft, porous microstructure having evidence of excess water in the mix), the grout is determined to have been prepared with an excess amount of water, i.e. far more water was judged to have been added than the advertised proportion of 1-part water to 7-part powder by weight, mentioned under the water requirements section of the technical data sheet of Anchor All. Excess water left from mixing and setting, have caused softening, subsequent recrystallization during drying, expansion, and disintegration of the grout, as well as deleterious expansive reactions with the aluminate components either within the grout (i.e. from the minor amount of added hydraulic cement) and/or from the surrounding concrete. From such evidence of excess water in the mix, the grout is judged not to have been mixed as per the manufacturer's recommendation let alone to provide strength anywhere near the advertised strength of 4500 psi within 24 hours, or 6000 psi in 7 days.*

#### **Anchoring Grouts – Excess Calcium Sulfates & Mechanisms of Post-Hardening Expansions and Distress**

The primary cause for post-hardening expansion and associated distress of the grout and/or of the surrounding concrete is the presence of: (i) free calcium sulfate in the hardened grout, and (ii) moisture during service.

- After the rapid-setting/hardening grout has set, free calcium sulfate, if present dissolves if exposed to moisture during service, and then precipitates out as calcium sulfate again, when the material dries. After precipitation, the calcium sulfate is more loosely packed and occupies more space than the original free calcium sulfate, resulting in a friable deposit that expands within the material. This phenomenon is similar when a drywall, which is mostly calcium sulfate, gets wet and then dries out, forming an expanded, flaky residue.
- Also, when calcium sulfate is dissolved in water, it can migrate into the surrounding concrete, where it can react with the aluminates in the cement, resulting in deleterious expansions from sulfate-aluminate reactions and formation of secondary ettringite deposits.

*As mentioned, both of the above mechanisms are judged to have played roles in causing disintegration of the present grout. However, moisture is judged not only provided from the environment during service but more so from mixing of the original dry grout powder with an excess amount of water.*

For Portland-cement-only grouts, calcium sulfate originally present in the Portland cement (usually less than 3% by mass of cement when  $C_3A$  content of cement is 8% or less, or, less than 3.5% by mass of cement when  $C_3A$  content is greater than 8%) for set-controlling purposes (to control the flash set of  $C_3A$  in cement) is consumed during initial hydration of cement in the plastic state. If, however, 'excess' calcium sulfate is present after hydration that can, when exposed to moisture during service, cause several distress mechanisms in grout and/or surrounding concrete. That 'excess' calcium sulfate can: (a) readily dissolve in the moisture during service, and when the system dries out, it can recrystallize, thus occupying more volume than before it was wetted, thus



causing disintegration of the grout. Additionally: (b) excess calcium sulfate in the hardened grout can migrate out to the surrounding concrete to form deleteriously expansive materials by sulfate-aluminate reactions, leading to cracking and spalling of concrete.

*The present grout does not belong to the above category.*

For gypsum-based grouts that, by definition, contain abundant free calcium sulfate at the hardened state, the system, though fast-setting, is extremely vulnerable to moisture during service, for the same reasons as mentioned for the fate of excess calcium sulfate in the Portland-cement-only grouts during service in a moist environment. Gypsum can: (a) expand during wetting (ready dissolution in water) and drying (recrystallization to larger masses); (b) gypsum can participate in deleterious expansive reaction with aluminates in Portland cement, if the grout formulation contains a minor cement additive, or with the hydrates of aluminate in the Portland cement in the surrounding concrete; (c) gypsum can cause expansive corrosion of aluminum posts, anchors, and clips that they may be in contact with when exposed to moisture during service; and (d) gypsum in a confined space can absorb a lot of moisture in the moist outdoor condition and expand during freezing at the moist state.

*For the present grout, all four above mechanisms may have played roles in causing severe softening and disintegration of the grout as well as cracking and spalling of the surrounding concrete.*

For blended cement systems containing Portland cement and calcium aluminate cement, or an expansive (e.g., calcium sulfoaluminate) cement, pre-hardening expansion is achieved by sulfate-aluminate reactions and abundant primary ettringite formation from hydration of such systems, which provide the necessary expansion at the plastic state. Both Portland cement and calcium aluminate cement contain calcium sulfate for set-controlling purposes (3-3.5% maximum  $\text{SO}_3$  for Portland cement and 2.5-15%  $\text{SO}_3$  for calcium aluminate cement), where the former has a much tighter control on chemistry and a well-established ASTM standard (C 150) than the latter (which has no ASTM standard or a control of  $\text{SO}_3$  content). Hence sulfate content in calcium aluminate cement can vary between products and formulations depending on the desired performance in a particular application. Hence two different products having the same  $\text{SO}_3$  content may behave differently i.e. one could be expansive when exposed to moisture, while the other may not. Due to such uncontrolled, inconsistent calcium sulfate contents, it is difficult to know if a given batch will be durable prior to use. The binder in these newer-generation of grouts can also contain fly ash, limestone fines, silica fume, and other additives.

*The present grout does not belong to this category.*

### **Anchoring Grouts – Mix Proportioning & Curing**

In addition to the type of the binder present, a control on the amount of mix water added and adequate moist curing are critical. Sufficient mix water is needed for calcium sulfate to react at the plastic state, but 'excess' water



can cause physical and/or chemical segregation, e.g., of aggregates at the bottom from binder at the top and/or different layers of compounds, respectively. It is crucial to follow manufacturer's recommended amount of mix water. For blended cement systems, adequate moist curing is important since inadequate curing may cause reversal of chemical reactions changing the resulting chemical compounds to more expansive and lower-strength compounds (Papas 2014).

*The present grout showed gross deviation from the manufacturer's recommended dosage of 1-part water to 7-part powder by weight, which has caused the powdery nature and severe disintegration of the grout.*

### Anchoring Grouts – ASTM Specifications & Tests

Presently, there is no ASTM standard that specifically addresses rapid-hardening grouts, particularly for use in an exterior environment where the hardened material will be exposed to moisture in service, *such as the case for the present grout*. The ASTM standards commonly associated with the repair and anchorage grout systems are:

- ASTM C 928, "Standard Specification for Packaged, Dry, Rapid-Hardening Cementitious Materials for Concrete Repairs," which covers packaged, dry, cementitious mortar or concrete materials for rapid repairs to hardened hydraulic-cement concrete pavements and structures i.e. elements that could be exposed to moist exterior environments during service.
- ASTM C 1107, "Standard Specification for Packaged, Dry, Hydraulic Cement Grout (Nonshrink)" is the specification that is often cited by manufacturers of prepackaged grouts, where the specification covers as stated in the scope "packaged dry, hydraulic cement material (nonshrink) intended for use under applied load (such as to support a structure, a machine, and the like) where a change in height below the initial placement heights is to be avoided." Many anchoring grout systems advertised to meet C 1107, however, are not consistent with intended use mentioned in the scope of C 1107.

Both standards require length change measurements at specific ages, but do not necessarily simulate the conditions that an anchoring grout may face during service. For example, ASTM C 928 uses mortar bars cured in both air and water but the length change is measured only at a single age of 28 days, which does not provide sufficient information to predict expansion potential of an anchoring grout. ASTM C 1107 uses a cylindrical specimen that is stored restrained for 56 days, which may simulate semi-restrained condition of anchoring grout but does not simulate the conditions that a repair grout in a deteriorated concrete would be exposed to after removal of the forms.

Two ASTM Tests followed by manufacturers of many nonshrink cementitious grouts are:

- ASTM C 827, "Standard Test Method for Change in Height at Early Ages of Cylindrical Specimens from Cementitious Mixtures;" and,



- ASTM C 1090, “Standard Test Method for Measuring Change in Height of Cylindrical Specimens for Hydraulic-Cement Grout.”

ASTM C 827 evaluates vertical height change of nonshrink grout at the plastic state prior to hardening, where up to 90% of shrinkage can occur following the initial expansion; therefore, C 827 has been used widely as the starting point for specification of nonshrink grout. ASTM C 1107 sets the maximum height change requirements in the plastic state to be 4.0% when tested in accordance with C 827, but C 1107 does not set a minimum requirement for height change in the plastic state. Therefore, a grout can exhibit shrinkage in the plastic state and still meet the requirements of C 1107. Typical values of height change of nonshrink grouts tested *in accordance with* C 827 and conforming to C 1107 are from 1% minimum to 4% maximum.

### Anchoring Grouts – Pitfalls of using Gypsum-based Grout in a Moist Outdoor Environment

Due to extreme moisture-sensitivity of gypsum-based grouts, perhaps it would have been better to avoid using this present grout system in the moist outdoor environment as the field photos have shown. Field photos show cracking and spalling of concrete and severe disintegration of anchoring grout; sample when received in our laboratory showed severe fragmentation and damp condition indicative of the presence of moisture during service. The best method to mitigate the existing problem is to remove the distressed material and reinstall the anchoring grout with acceptable material by following the manufacturer’s application guidelines.

### Atmospheric Carbonation of Gypsum – The Loss of Structural Integrity of the Gypsum Microstructure

Abundant secondary calcite precipitates intermixed with gypsum throughout the matrix of the grout indicates dissolution of gypsum in the presence of moisture during service, followed by atmospheric carbonation of gypsum during service and precipitation of secondary calcite. Since calcite has no cementitious property, the result is the complete loss of the structural integrity of basic gypsum skeletal microstructure of the grout. Severe carbonation has reduced the inherent pH of the grout down to 9.3, which can destabilize any oxide film around metal anchors to cause corrosion of metal and associated distress.

### Comparison of Present Grout with ‘Anchor All’

Based on the overall gypsum-based composition of the binder having a minor amount of Portland cement, and the presence of quartz sand, the present grout appeared to be compositionally similar to ‘Anchor All,’ which is also a gypsum-based grout containing a minor amount of Portland cement, and quartz sand. However, the present grout shows abundant calcium carbonate in the matrix intermixed with gypsum that cannot be formed from carbonation of cement hydration products unless a separate carbonate component (e.g., calcite fines) was added with the grout powder, or perhaps a different grout was used that contained calcite fines with gypsum as two binder components (and minor amount of Portland cement). The safety data sheet of ‘Anchor All’ (Figure A3b in



the Appendix) does not indicate the presence of calcium carbonate; hence its presence in the present grout sample cannot be indicative of use of just 'Anchor All' and no separate carbonate additives.

The most plausible explanation, as mentioned, is atmospheric carbonation of the gypsum microstructure, which is consistent with the anhedral shapes of secondary calcite precipitates, and is also common in many weathered and carbonated gypsum products in flue gas desulfurization (FGD) plants.

## CONCLUSIONS

The examined distressed anchoring grout showed a gypsum-based formulation, and its application in a moist outdoor environment, where not only the grout was exposed to moisture during service, e.g., received in a damp condition, but also was installed probably with an excessive amount of water i.e. beyond the manufacturer's recommended dosage of 1-part water to 7-part dry grout powder by weight (if the grout applied is indeed the reported specified grout 'Anchor All' from Dayton Superior), thus providing 'excess water' within the system even before an exposure to an external source of moisture, e.g., rainwater. As a result, the grout has undergone significant expansion after hardening, from softening by excess water as well as further softening from moisture during service causing severe disintegration of the grout, and, cracking and spalling of the surrounding concrete.

Mineralogy and microstructure of the grout shows quartz sand in a gypsum-based binder formulation containing a minor amount of Portland cement, approximately 50-50 to 75-25 by weight sand-to-total binder formulation, where the former is broadly similar to the composition of the specified 'Anchor All,' but the latter indicates an over-sanded nature, probably from segregation of sand from an over-watered mass. The matrix in the distressed grout contains gypsum, ettringite, and hydrates of calcium aluminate, sulfoaluminate, and silicate as the primary products of hydration of the original gypsum and Portland cement components, as well as abundant secondary calcium carbonate (calcite,  $\text{CaCO}_3$ ) intermixed with gypsum. Secondary calcite, however, cannot be produced from carbonation of a minor Portland cement component in the binder but indicates a much larger phenomenon of carbonation of the gypsum skeleton to calcite as dissolution of gypsum in the presence of moisture during service followed by precipitation of calcite - with a severe loss of strength. SEM-EDS analyses showed calcite, gypsum, and ettringite as the three main minerals in the binder, as well as areas of pastes that are characterized by Si > Ca, Al (no S), Si-Al, Ca-Si-S, and Ca-Al-S compositions from hydrations of various phases of the original cement component in the binder, as well as of calcium-sulfate-aluminate reactions to form ettringite. Bulk sulfate (as  $\text{SO}_3$ ) content in the distressed grout powder is 8.37 percent, which is typical of many gypsum grouts. The basic gypsum-based microstructure of the grout was not only destroyed by the presence of 'excess' moisture during and after installation, but also by carbonation of gypsum to calcite during service with further loss of strength.

In summary – (a) use of a gypsum-based grout in a moisture, outdoor environment where the grout during service was exposed to moisture, and hence softened and expanded, (b) installation of grout with more than



recommended water to leave enough excess water and its telltale microstructural evidence in the distressed grout, (c) atmospheric carbonation of gypsum and loss of structural integrity of the basic gypsum microstructure by formation of abundant secondary calcite precipitates having no cementitious property, and (d) possible corrosion of embedded metal anchors by carbonation-induced reduction in pH of grout down to 9.3 – are the main reasons for the loss of strength and integrity of grout, as well as expansive reactions to cause cracking and spalling of the surrounding medium.

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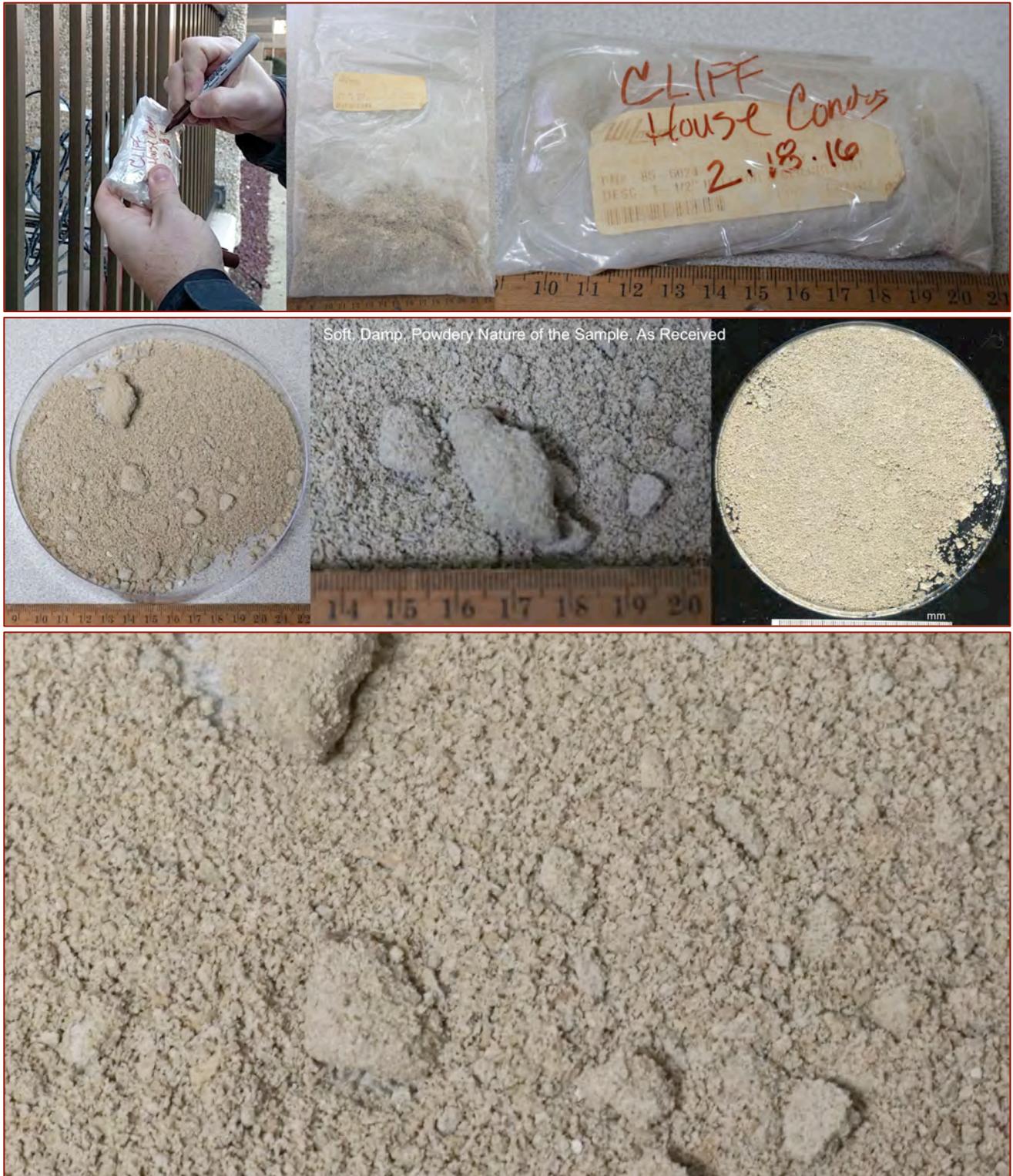
The above conclusions are based solely on the information and samples provided at the time of this investigation. The conclusion may expand or modify upon receipt of further information, field evidence, or samples. Samples will be discarded two weeks after submission of the report unless otherwise requested in writing. 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.



# APPENDIX



**Figure A1:** Cracking, spalling, and disintegration of concrete at the base of two railings, as well as severe disintegration of anchoring grout that has been exposed from severe cracking and spalling. Notice cracks are long, continuous and extended from one railing base to the neighboring ones. Cracks are wide and indicative of an expansion of the underlying grout material, including expansion and disintegration of the anchoring grout itself. Notice how readily the anchoring grout is disintegrated during sample collection with a screwdriver. The top row shows collection of anchoring grout sample from one railing and the bottom row shows sample collection from the adjacent railing. Grout samples from both railings were collected in a plastic bag (shown in Figure A2) that was received in our laboratory.



**Figure A2:** Shown is the anchoring grout sample collected from the field and received in our laboratory in a double plastic bag. Notice the severe fragmentation and powdery nature of the material. Sample was damp when received.





**Anchor All**  
Anchoring Cement

**TECHNICAL DATA SHEET**

**DESCRIPTION**  
Fast setting, shrinking compensated anchoring cement. Pourable and fast setting, Anchor All provides a durable high strength anchor for interior and exterior applications.

**USE**  
Use for anchoring bolts, rails, posts and dowels into concrete where a non-shrink, rapid-setting anchoring cement is required.

**FEATURES**

- Sets in 15-20 minutes
- Controlled expansion mechanically locks in
- Pourable; fills voids and crevices
- Use interior or exterior

**PROPERTIES**

Compressive Strength (ASTM C-109):  
 1 hour 1000 psi (6.9 MPa)  
 24 hours 4500 psi (31 MPa)  
 7 days 6000 psi (41.3 MPa)  
 28 days 7,500 psi (51.7 MPa)

Setting Time (neat) 15-20 minutes

**Note:**  
The data shown is typical for controlled laboratory conditions. Reasonable variation from these results can be expected due to interlaboratory precision and bias. When testing the field mixed material, other factors such as variations in mixing, water content, temperature and curing conditions should be considered.

**Estimating Guide**  
Yield: 0.43 cu. ft. (0.012 cu. M)/50 lb. (22.67 kg)

**Packaging**

PRODUCT CODE	PACKAGE	SIZE	
		lbs	kg
143407	Pail	50	22.67

**APPLICATION**

**Surface Preparation:**  
The concrete surface must be sound and free of all foreign material, including oil, grease, dust, laitance, or other surface contaminants. Anchors should have a washer for greater pull out strengths and the washers should be sized to fit within the drilled hole, but not touch edges or bottom of the holes to allow material to flow around the washer and lock anchor into place. Fill the hole with water and scrub sides and bottom with stiff brush just prior to placing. Remove all standing water, but ensure the substrate is damp prior to application of Anchor All.

**Water Requirements:**  
Mixing ratio: 6.75 pints (3.19 L) /50 lbs. (22.67 kg) of powder or 1:7 water to powder by weight.

**Mixing:**  
Mix with low speed drill and paddle mixer in a suitable container. DO NOT mix more than three minutes. Mix only what can be used in five to ten minutes. Add water first, and then add the powder. DO NOT over mix or retemper. By using less water than noted (never use more water), this material can be varied to produce a stiff to pourable consistency.

**Placement:**  
Ensure all standing water has been removed from the hole. Place anchor in prepared hole then fill with the properly mixed Anchor All. For horizontal applications, pour the flowable mixture in the hole. For vertical applications, mix to a stiff, not sag consistency and tamp the material in place ensuring no voids exist. Provide support for the anchor if needed. Do not disturb anchor until such time as the Anchor All has developed sufficient strength. Adjusting or disturbing the anchor too soon can result in cracking.

**CLEAN UP**  
Use clean water. Hardened material will require mechanical removal methods.

**CURING**  
Adequate curing is important, especially during windy, hot and dry conditions. A wet burlap cure or Dayton Superior water based curing compound or a cure & seal is recommended.

**LIMITATIONS**

**FOR PROFESSIONAL USE ONLY**  
Not for use for anchoring aluminum  
DO NOT place at temperatures below 40°F(5°C) or if the temperature is expected to fall below 40°F(5°C) in the next twenty-four hour period.  
DO NOT place when temperature exceeds 90°F (32.2°C).  
Do not re-temper after initial mixing.  
Do not add other cements or additives.  
Setting time will slow during cooler weather and speed up during hot weather.  
Prepackaged material segregates while in the bag, thus when mixing less than a full bag it is recommended to first agitate the bag to assure it is blended prior to sampling.

**PRECAUTIONS**

**READ SDS PRIOR TO USING PRODUCT**

- Keep material and containers away from high heat, open flames, sparks or other sources of ignition
- Use with adequate ventilation
- Wear protective clothing, gloves and eye protection (goggles, safety glasses and/or face shield)
- Keep out of the reach of children

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14

Concrete Repair

**Figure A3a:** The anchoring grout is, reportedly, ‘Anchor All’ from Dayton Superior. Shown here is an excerpt of the technical data sheet of ‘Anchor All.’



### Safety Data Sheet acc. to OSHA HCS

Printing date 01/17/2015 Reviewed on 01/17/2015

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**Trade name: Anchor All**

(Contd. of page 1)

- **Classification system:**
- **NFPA ratings (scale 0 - 4)**



Health = 1  
Fire = 0  
Reactivity = 0

- **HMIS-ratings (scale 0 - 4)**

HEALTH	1	Health = 1
FIRE	0	Fire = 0
PHYSICAL HAZARD	0	Reactivity = 0

- **Other hazards**
- **Results of PBT and vPvB assessment**
- **PBT: Not applicable.**
- **vPvB: Not applicable.**

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**3 Composition/information on ingredients**

- **Chemical characterization: Mixtures**
- **Description: Mixture of the substances listed below with nonhazardous additions.**
- **Dangerous components:**

14808-60-7	Quartz (SiO <sub>2</sub> )	25-50%
26499-65-0	Calcium sulfate	25-50%
65997-15-1	Cement, portland, chemicals	10-25%

- **Additional information: For the wording of the listed risk phrases refer to section 16.**

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**4 First-aid measures**

- **Description of first aid measures**
- **After inhalation:**  
Supply fresh air and to be sure call for a doctor.  
In case of unconsciousness place patient stably in side position for transportation.
- **After skin contact:** If skin irritation continues, consult a doctor.
- **After eye contact:** Rinse opened eye for several minutes under running water. Then consult a doctor.
- **After swallowing:** Seek medical treatment.
- **Most important symptoms and effects, both acute and delayed** No further relevant information available.
- **Indication of any immediate medical attention and special treatment needed** No further relevant information available.

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**5 Fire-fighting measures**

- **Extinguishing media**
- **Suitable extinguishing agents:**  
CO<sub>2</sub>, extinguishing powder or water spray. Fight larger fires with water spray or alcohol resistant foam.
- **Special hazards arising from the substance or mixture** No further relevant information available.

(Contd. on page 3)

**Figure A3b:** Portion of the Safety Data Sheet of 'Anchor All' showing its mixture ingredients.





TECHNICAL DATA SHEET

## ANCHOR ALL

**DESCRIPTION**  
A fast-setting, non-shrink cement with controlled expansion. Pourable and fast setting, Anchor All provides a durable high strength anchor for interior and exterior applications.

**USE**  
Use for anchoring bolts, rails, posts and dowels into concrete where a non-shrink, rapid-setting anchoring cement is required. Also used for grouting columns and other structural materials interior or exterior.

**BENEFITS**

- ☒ Sets in 15-20 minutes
- ☒ Controlled expansion mechanically locks in
- ☒ Pourable; fills voids and crevices
- ☒ Non-staining
- ☒ Ideal for exterior areas exposed to water runoff

**ARCHITECTURAL SPECIFICATIONS**  
Non-shrink, Anchoring Cement: For grouting plates, bolts, bars and cables a pourable, fast-setting, non-shrink cement material shall be used. Approved product: Conspec Anchor All or approved equivalent.

**APPLICATION PROPERTIES**

Compressive Strength (ASTM C-109)	
1 hour	1000 psi (6.9 MPa)
24 hours	4500 psi (31 MPa)
7 days	6500 psi (44.8 MPa)
28 days	10,000 psi (68.9 MPa)
Expansion	.1%
Setting Time (neat)	15-20 minutes

**APPLICATION**  
Areas receiving Anchor All should be a minimum depth of 1/2"(1.3 cm), saw cut at a 90° angle. DO NOT featheredge. Surface must be free of all loose and foreign material such as oils, grease, curing compounds, etc. Dampen surface with water just prior to placing. Remove all standing water.

Mix by hand or with low speed drill in a suitable container. DO NOT mix more than three minutes. Mix only what can be used in five to ten minutes. Add water first, then powder.

DO NOT over mix or retemper. Mixing ratio: 6.75 pints per 50 lbs. of powder or 1:7 water to powder by weight. This can be varied to produce a stiff to pourable consistency.

**PACKAGING**  
50 lb. bag (22.7 KG)

**LIMITATIONS/PRECAUTIONS**  
DO NOT place at temperatures below 40°F(5°C) or if the temperature is expected to fall below 40°F(5°C) in the next twenty-four hour period. DO NOT place when temperature exceeds 90°F(32.2°C).

Caution. Contains Portland Cement and sand. Cement will cause irritation. Avoid contact. Use of a dust respirator, safety goggles and rubber gloves are recommended. Avoid prolonged contact with clothing. In case of contact with eyes, immediately flush with water for at least 15 minutes. Get prompt medical attention. DO NOT wear contact lenses when working with this product. DO NOT take internally. Keep out of reach of children.

Avoid hazards by following all precautions found in the Material Safety Data Sheets (MSDS), product labels and technical literature. Please read this information prior to using the product.

**RECEIVING**  
All bagged products should be checked for dryness prior to signing shipping papers.

**STORAGE**  
Conspec Anchor All should be stored in a cool, dry interior area. At no time should material be exposed to high moisture, rain or snow conditions.

**TECHNICAL SERVICES**  
Complete technical and specification services are available from the manufacturer and their authorized representatives and distributors.

**FILING SYSTEM**  
Additional literature and the Material Safety Data Sheet can be obtained from Conspec upon request.

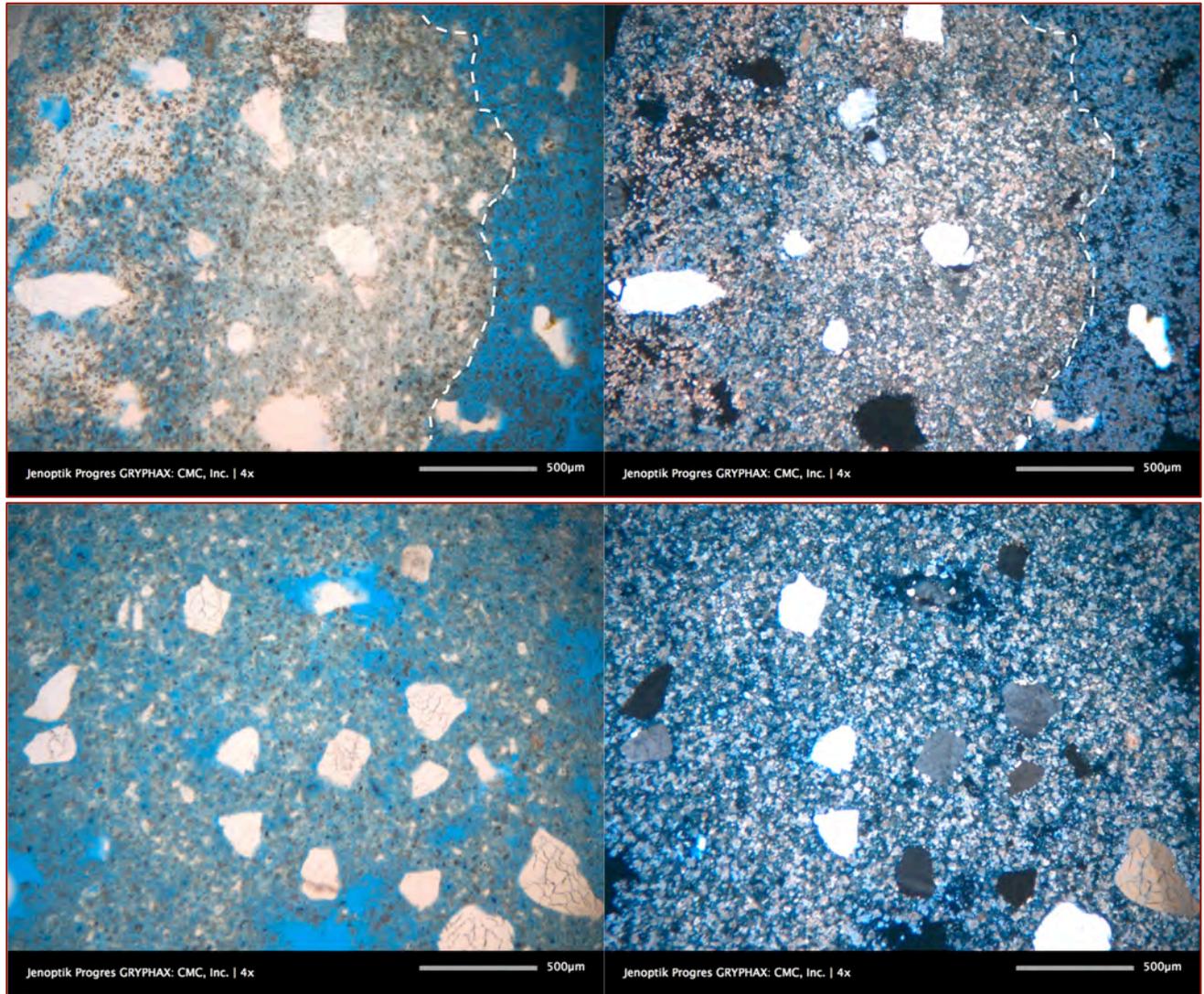
Refer to [www.daytonsuperior.com](http://www.daytonsuperior.com) for latest Technical Data Sheet and MSDS  
1125 Byers Road, Miamisburg OH 45342  
Customer Service: (888) 977-9600  
Technical Assistance: (866) 329-8724

• For Commercial/Industrial Use Only • Page 1 of 2

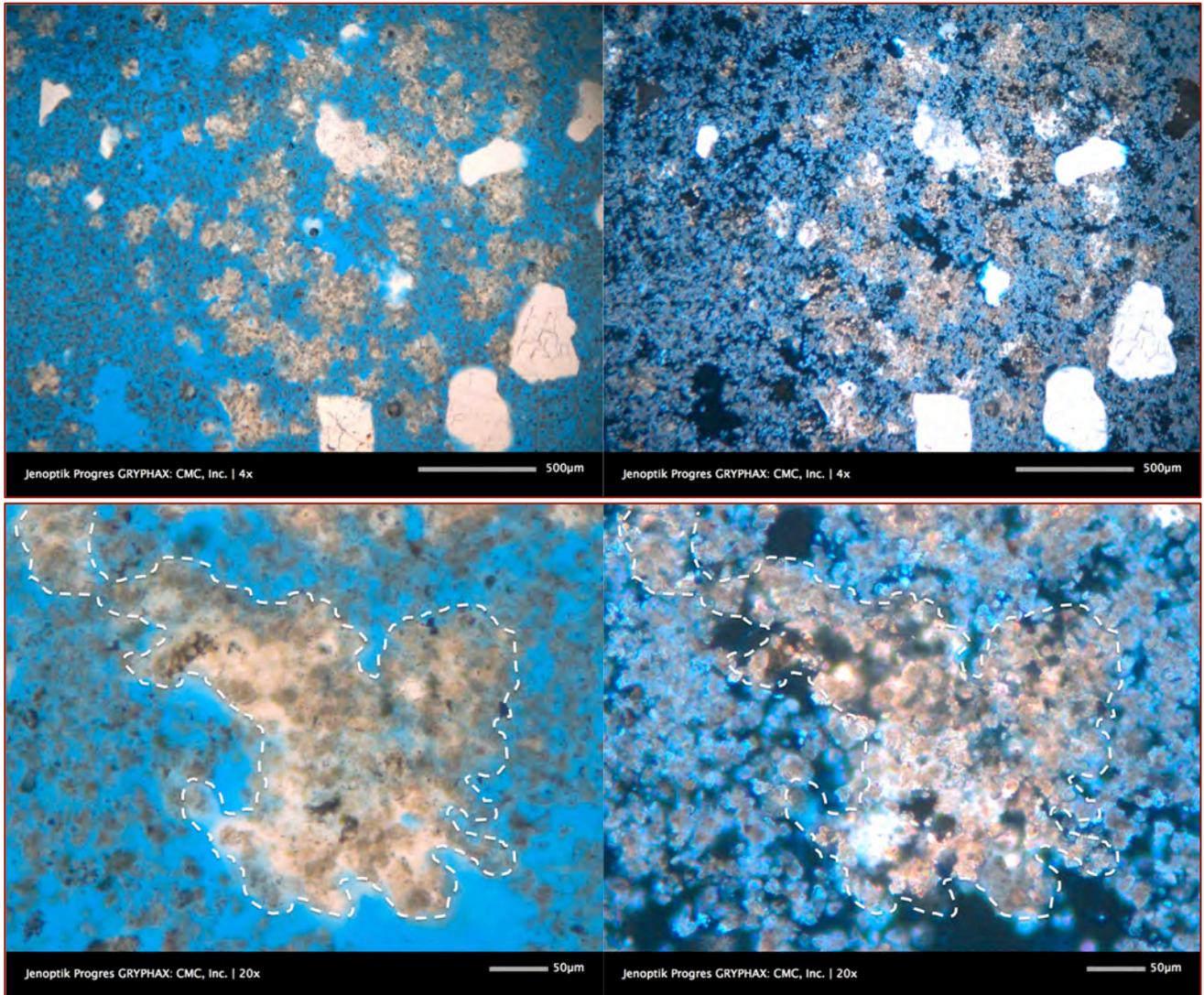
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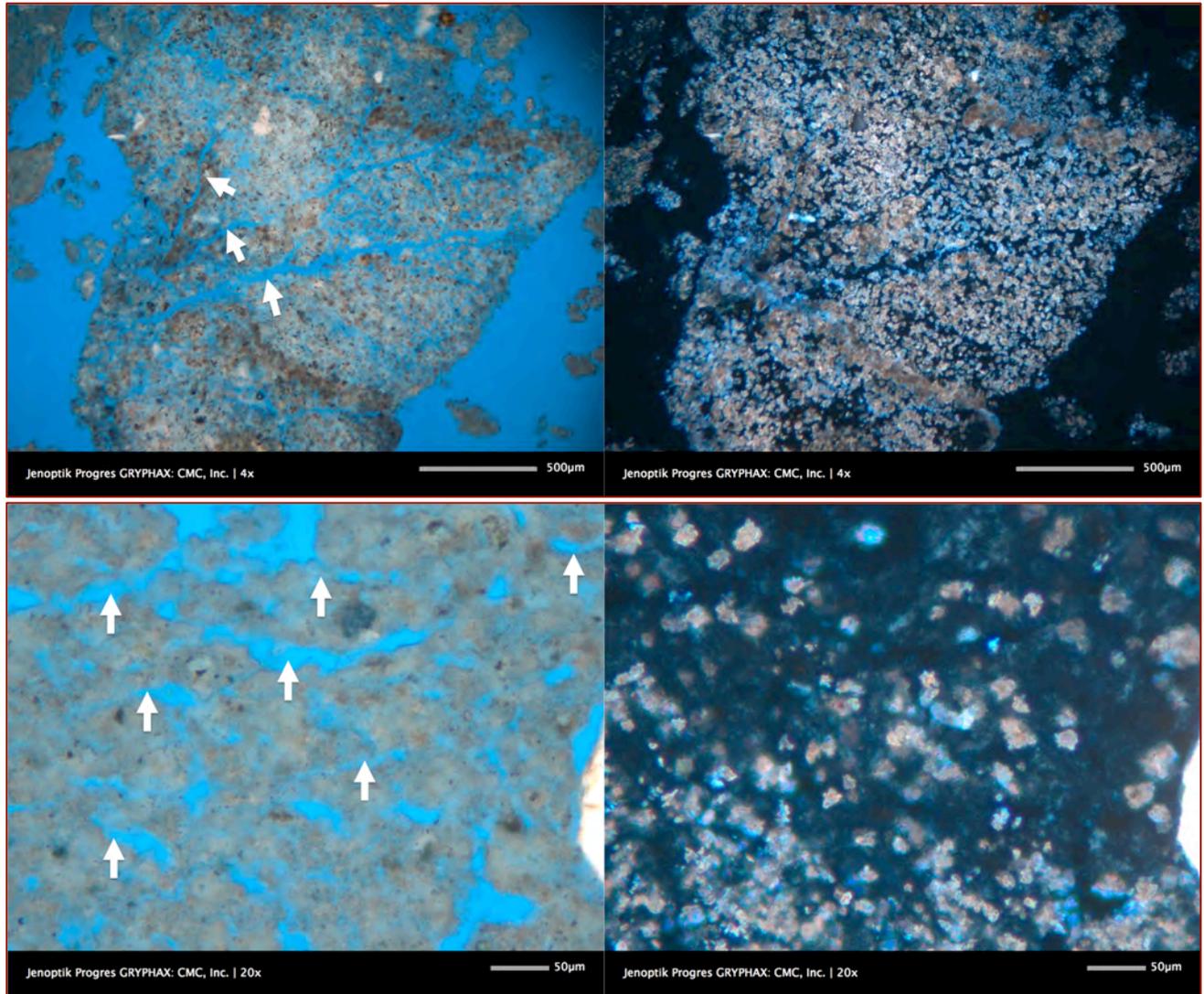
Figure A3c: Technical Data Sheet of 'Anchor All' showing 0.1 percent expansion.



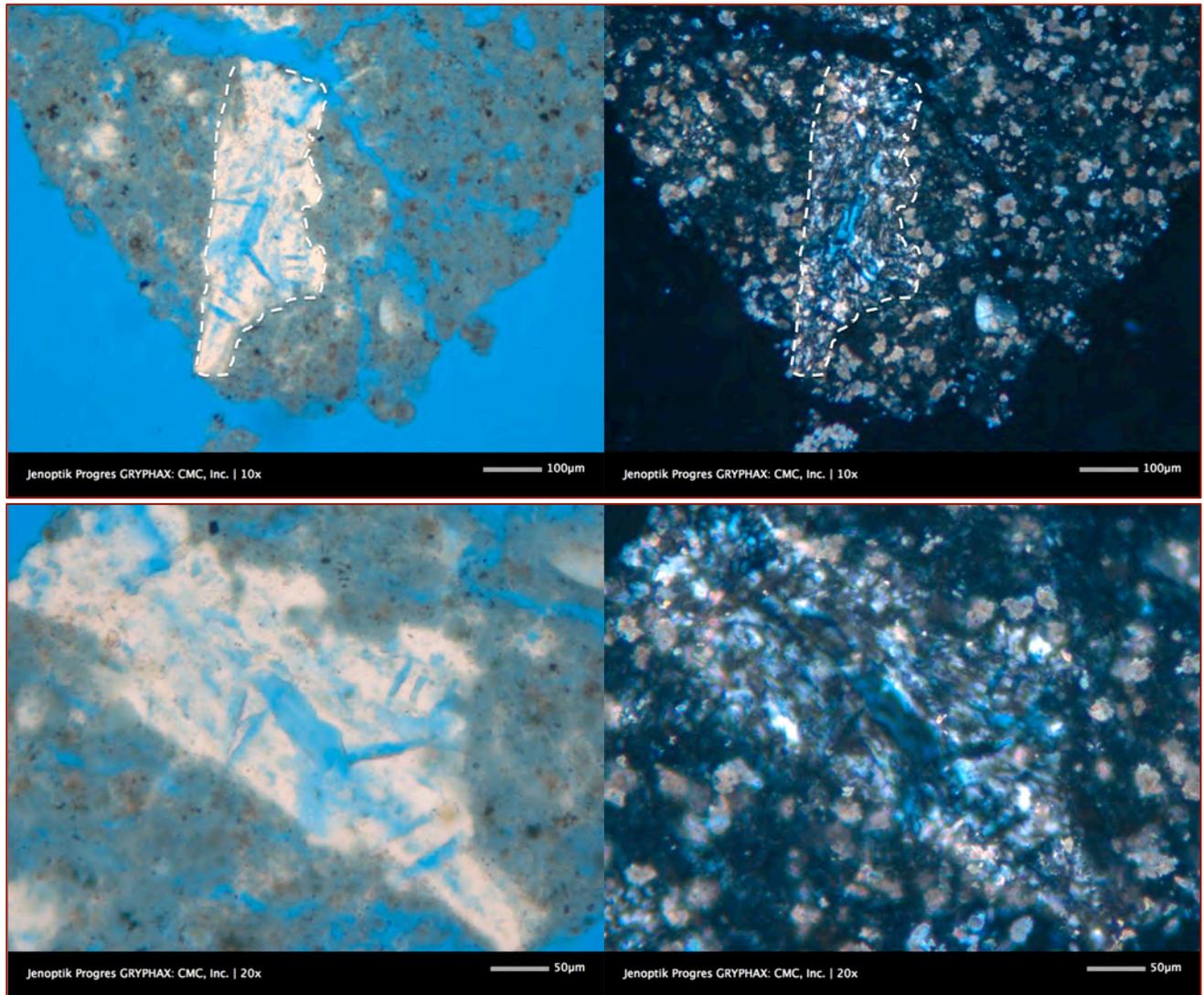
**Figure A4:** Photomicrographs of thin section of grout showing quartz sand scattered in an overwhelming porous matrix of calcium carbonate and gypsum.



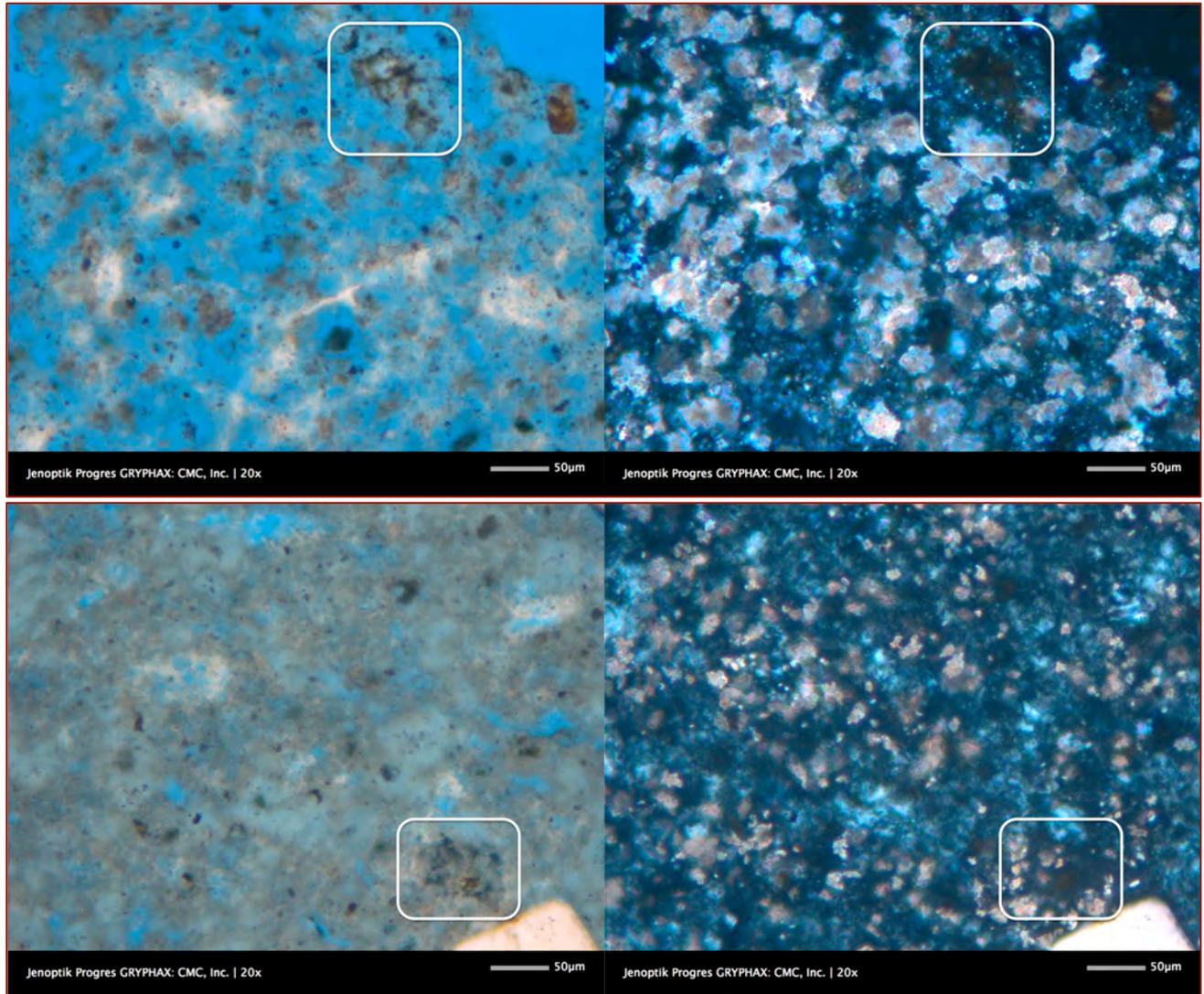
**Figure A5:** Photomicrographs of thin section of grout showing patchy areas of relatively denser paste that are scattered in an overwhelming porous matrix of calcium carbonate and gypsum.



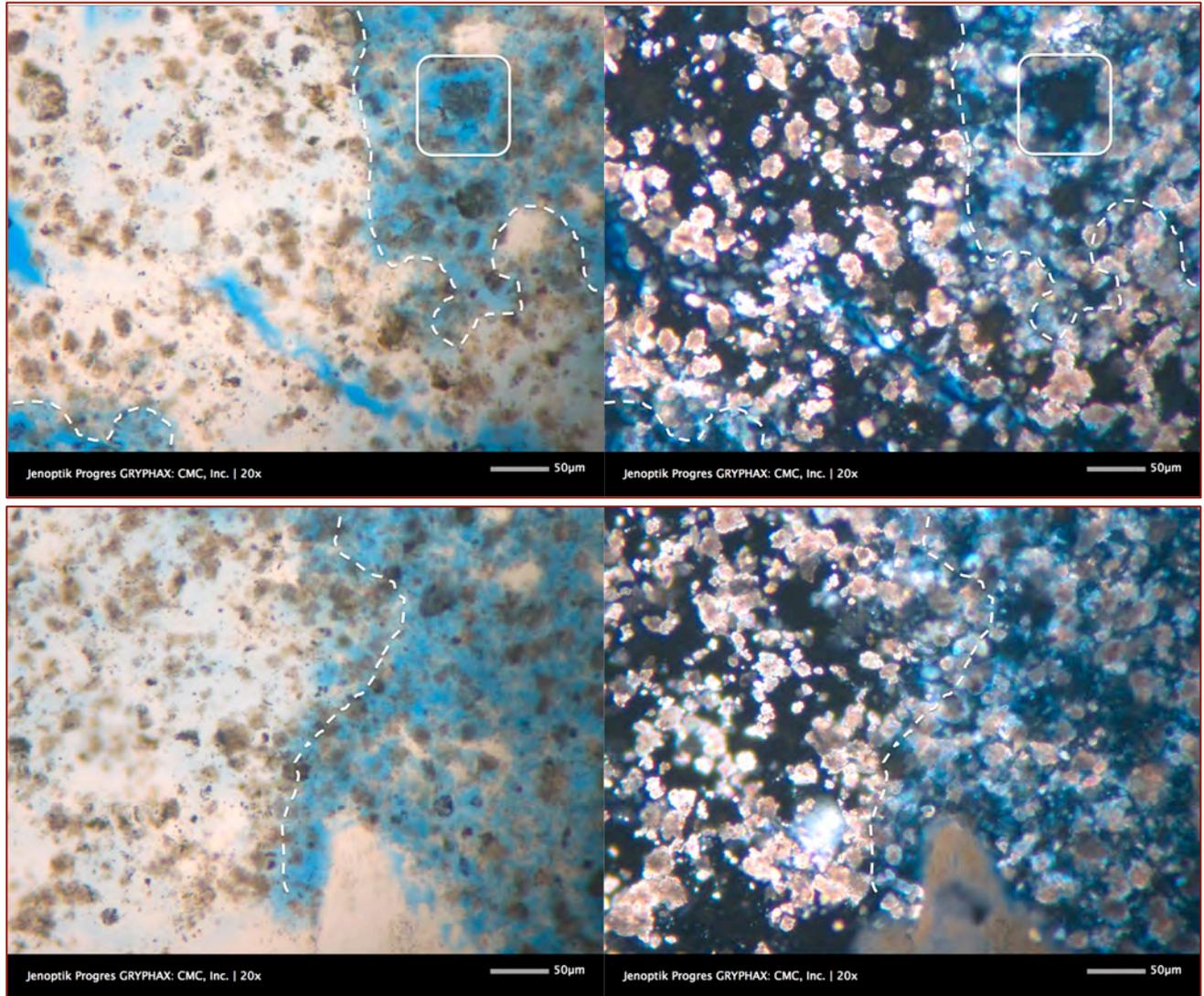
**Figure A6:** Photomicrographs of thin section of grout showing shrinkage microcracks from excessive moisture in the paste that are not anticipated in a nonshrink grout.



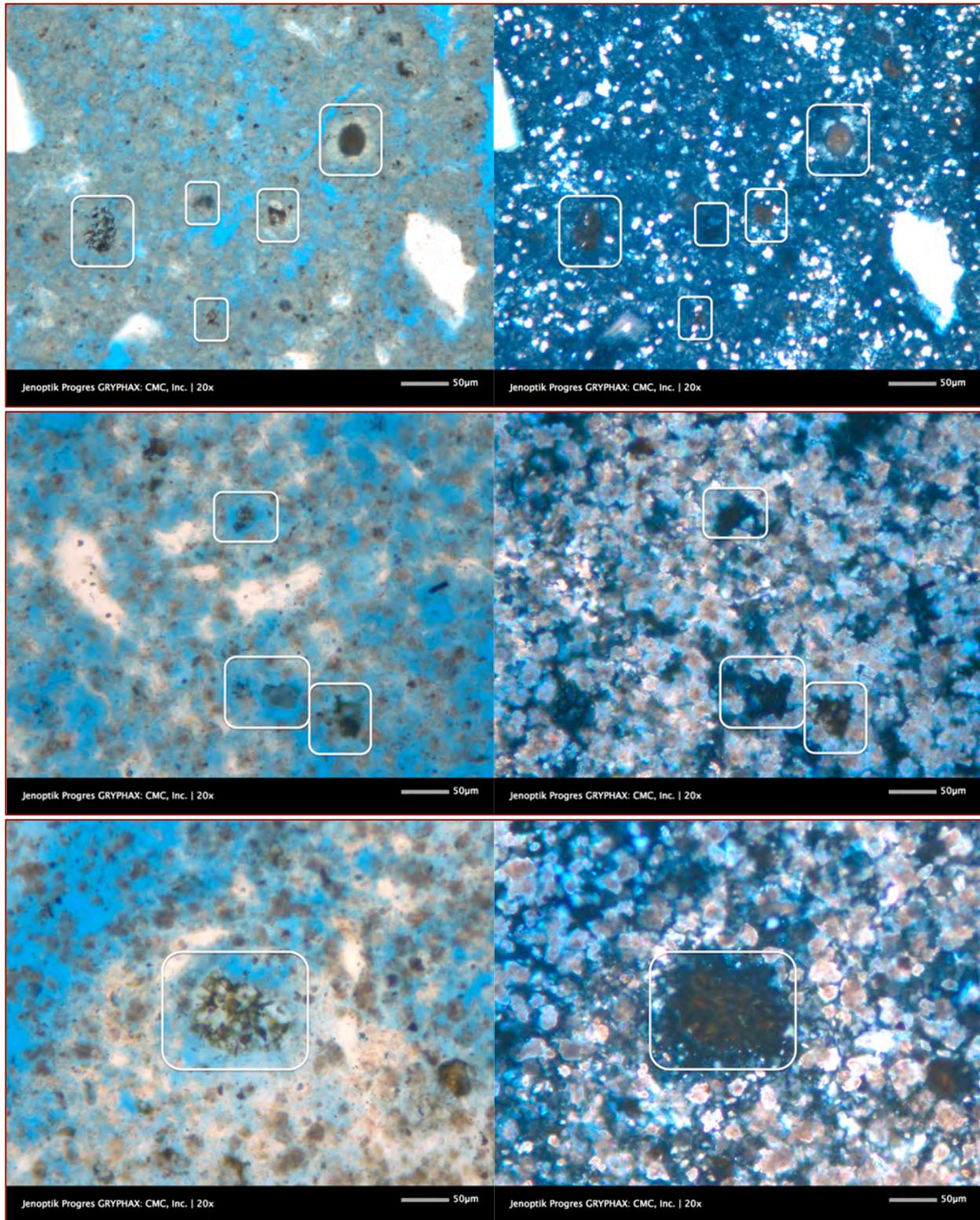
**Figure A7:** Photomicrographs of thin section of grout showing large subhedral secondary (recrystallized) gypsum that were formed from wetting and drying of grout.



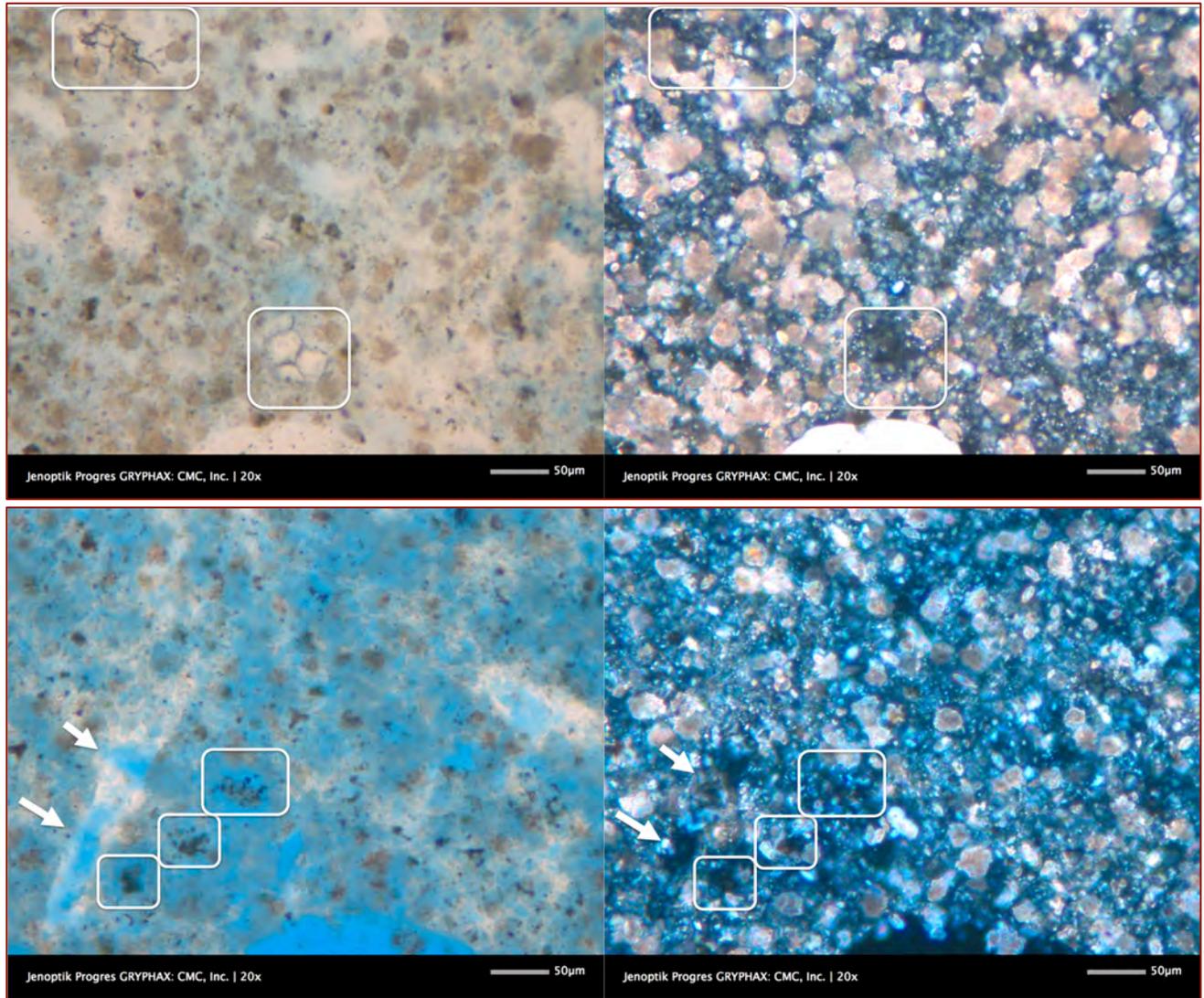
**Figure A8:** Photomicrographs of thin section of grout showing the dominant matrix consisting of overwhelming mixtures of calcium carbonate and gypsum and a few scattered residual and relict cement particles (boxed).



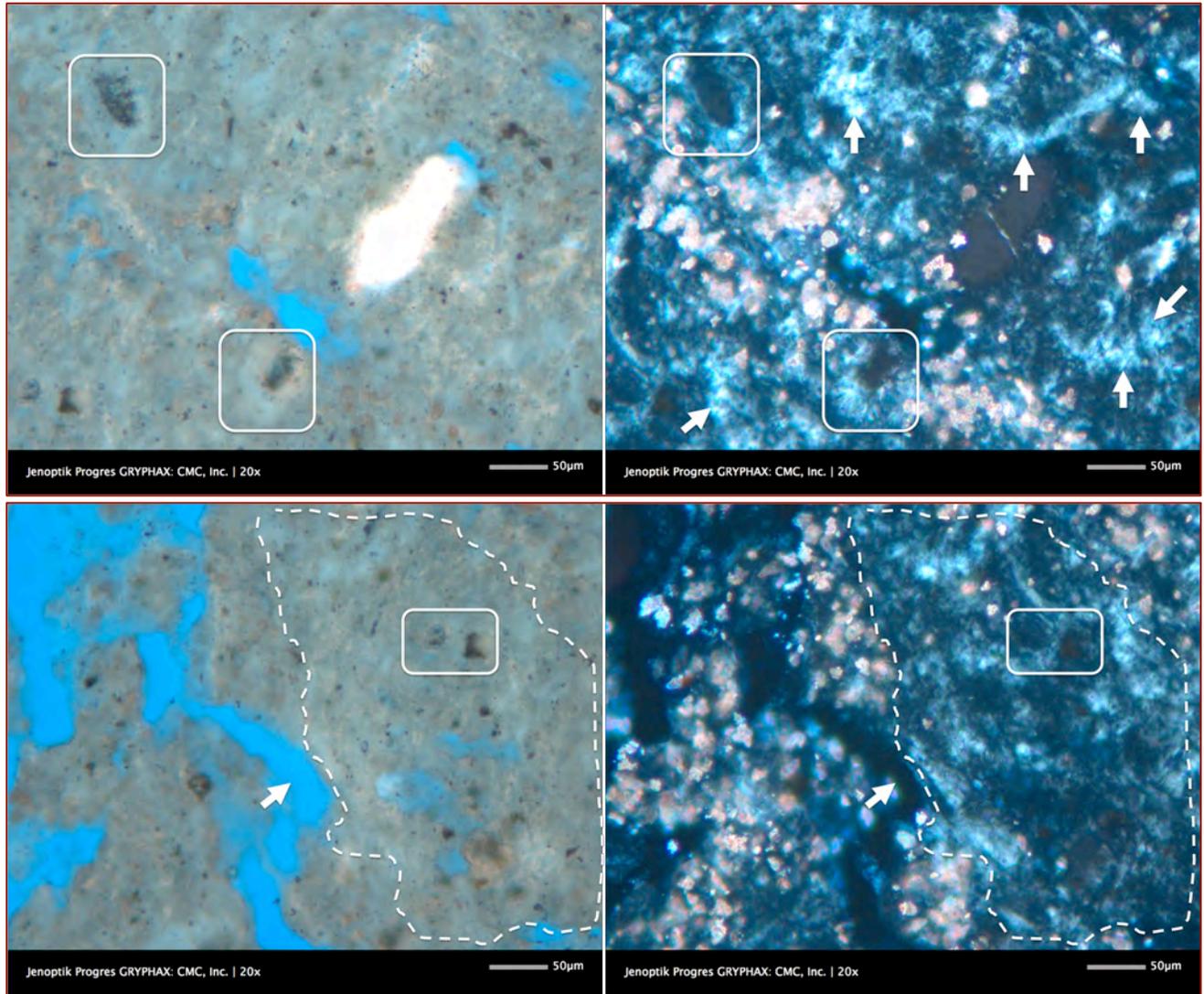
**Figure A9:** Photomicrographs of thin section of grout showing leaching of water-soluble masses creating an isotropic appearance of areas in XPL (separated by dashed lines from the non-leached porous areas).



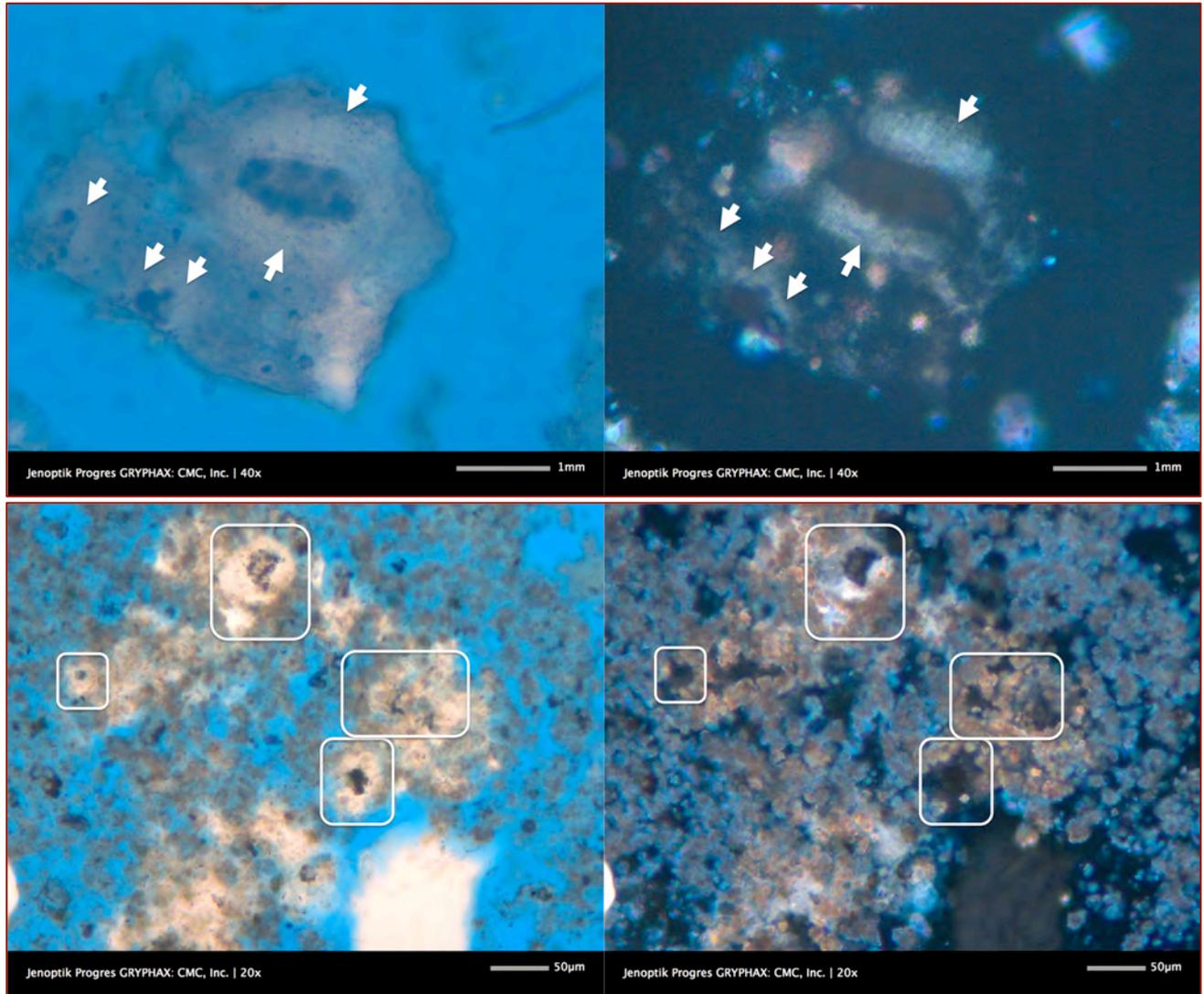
**Figure A10:** Photomicrographs of thin section of grout showing a few scattered residual and relict cement particles (boxed) that are indicative of the presence of a minor cement component in the gypsum-based grout.



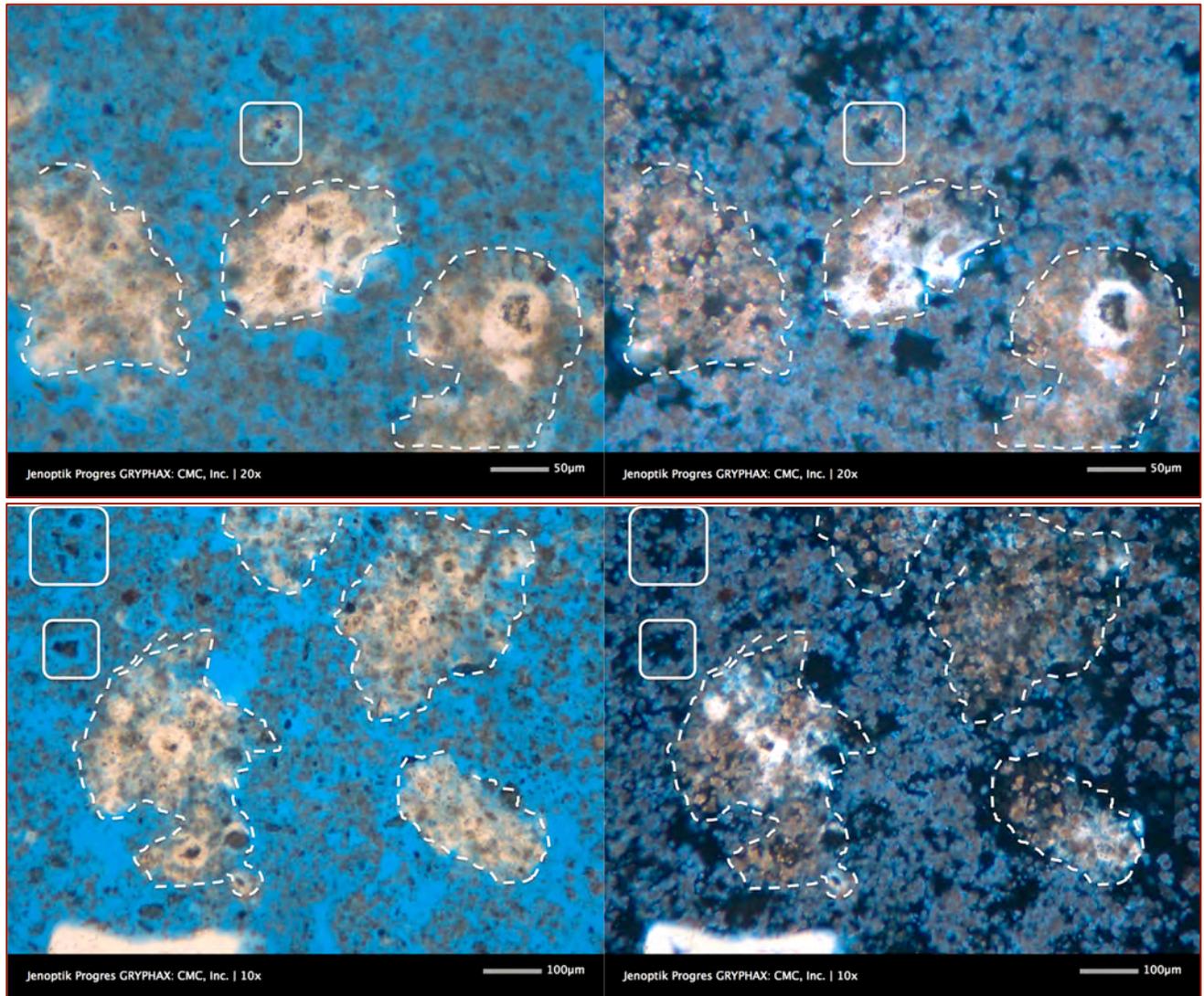
**Figure A11:** Photomicrographs of thin section of grout showing a few scattered residual and relict cement particles (boxed) that are indicative of the presence of a minor cement component in the gypsum-based grout.



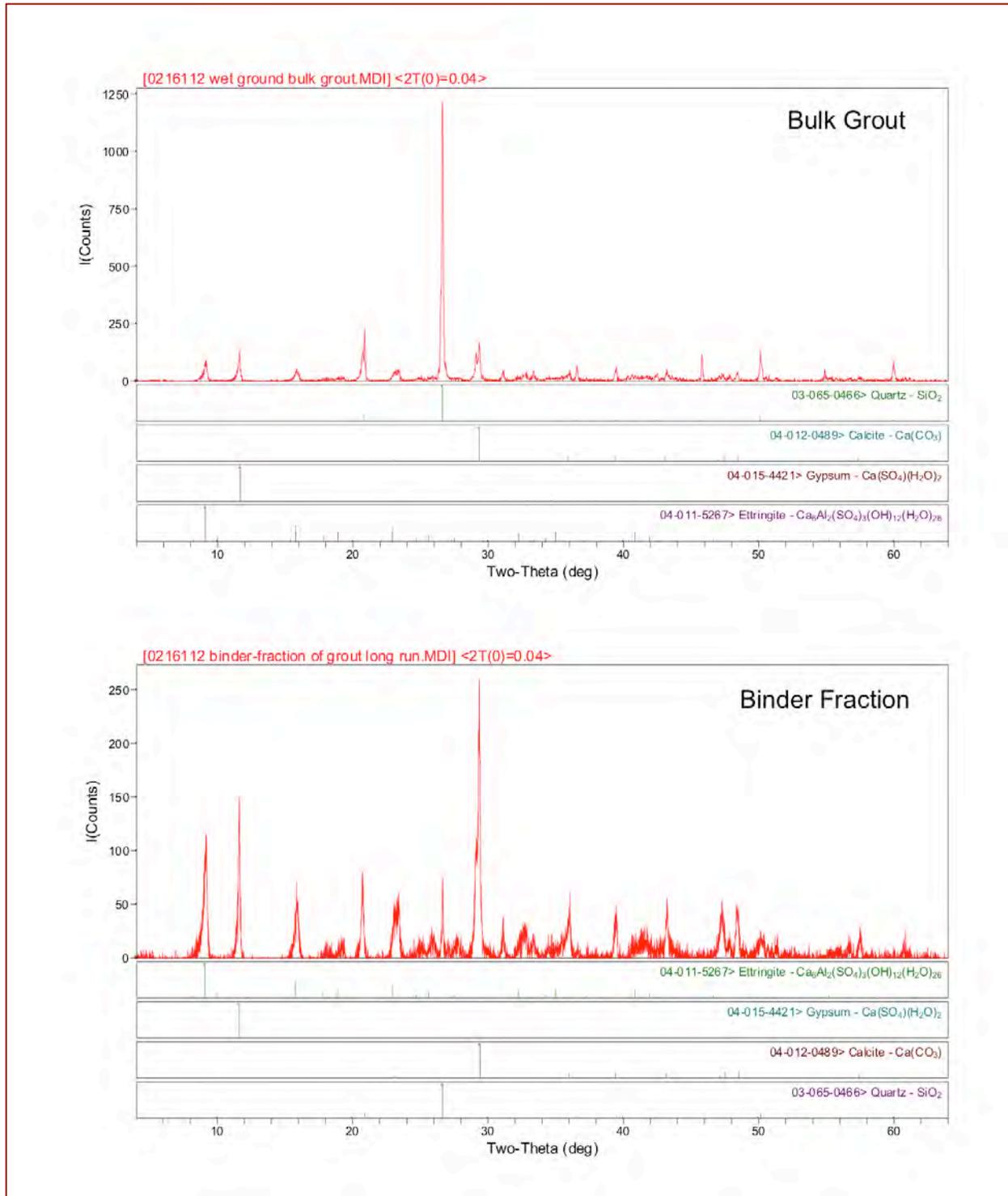
**Figure A12:** Photomicrographs of thin section of grout showing gypsum-rich areas in paste that are not mixed with calcium carbonate masses.



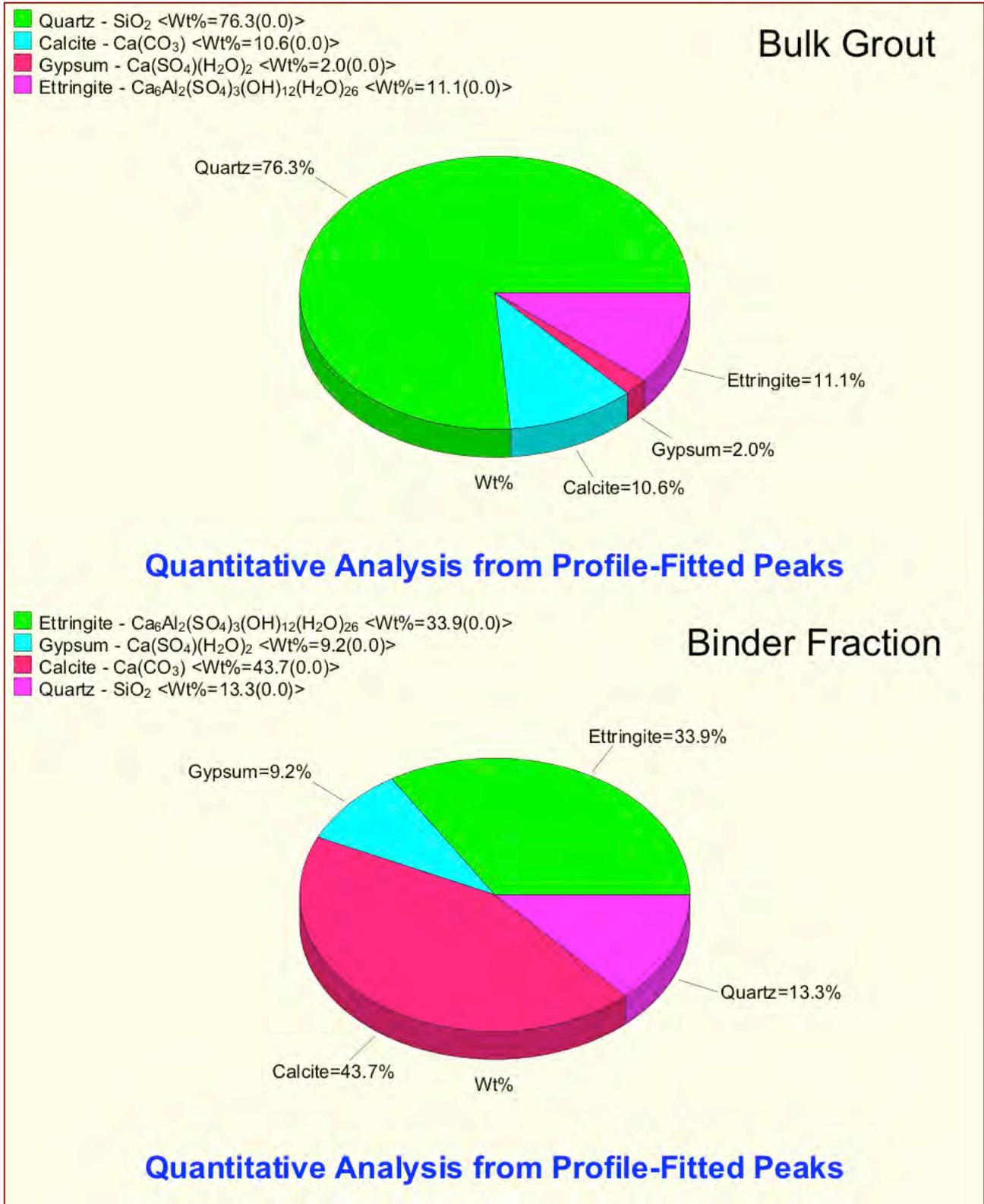
**Figure A13:** Photomicrographs of thin section of grout showing topochemical formation of fibrous ettringite on the surfaces of residual aluminate phases within the residual cement particles.



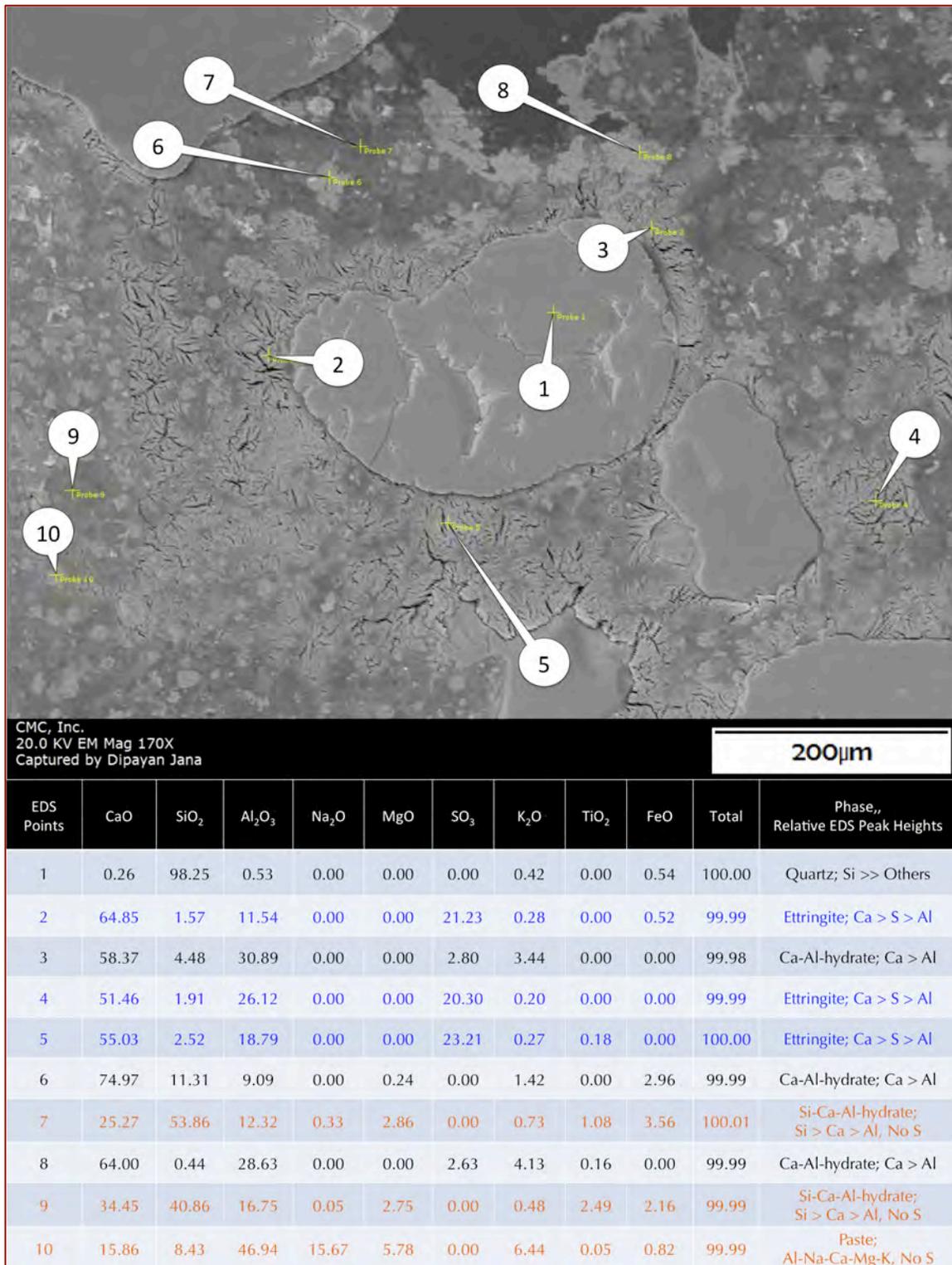
**Figure A14:** Photomicrographs of thin section of grout showing topochemical formation of fibrous ettringite on the surfaces of residual aluminate phases within the residual cement particles.



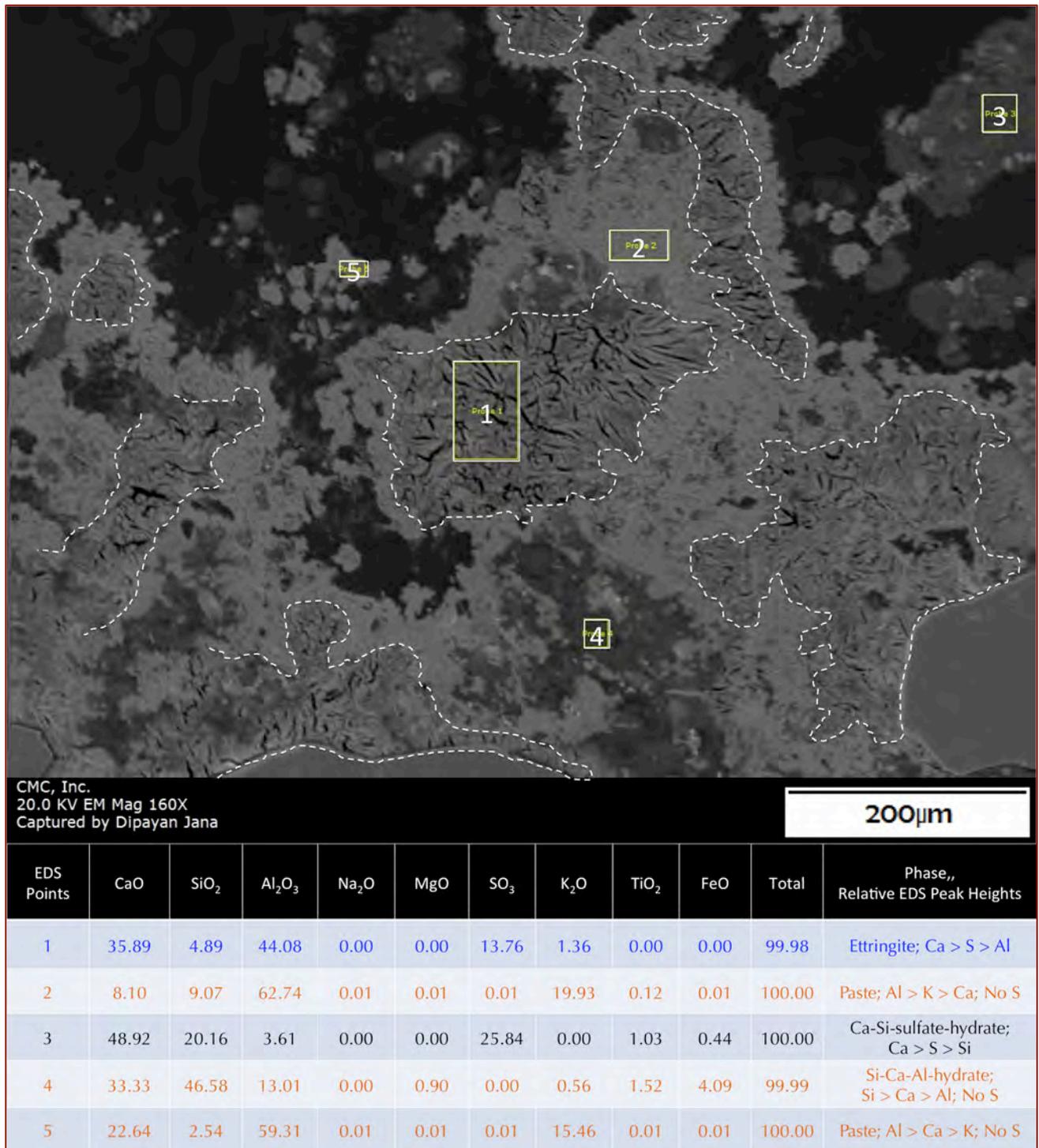
**Figure A15:** X-ray diffraction patterns of bulk grout (top) and binder fraction after screening out quartz sand (bottom) showing gypsum, ettringite, and calcite as the three predominant minerals in the paste. Notice the noticeable drop in count rates in the binder fraction, despite doubling the scan-time, due to the absence of the major mineral, quartz, which was responsible for the high-count rate in the bulk grout.



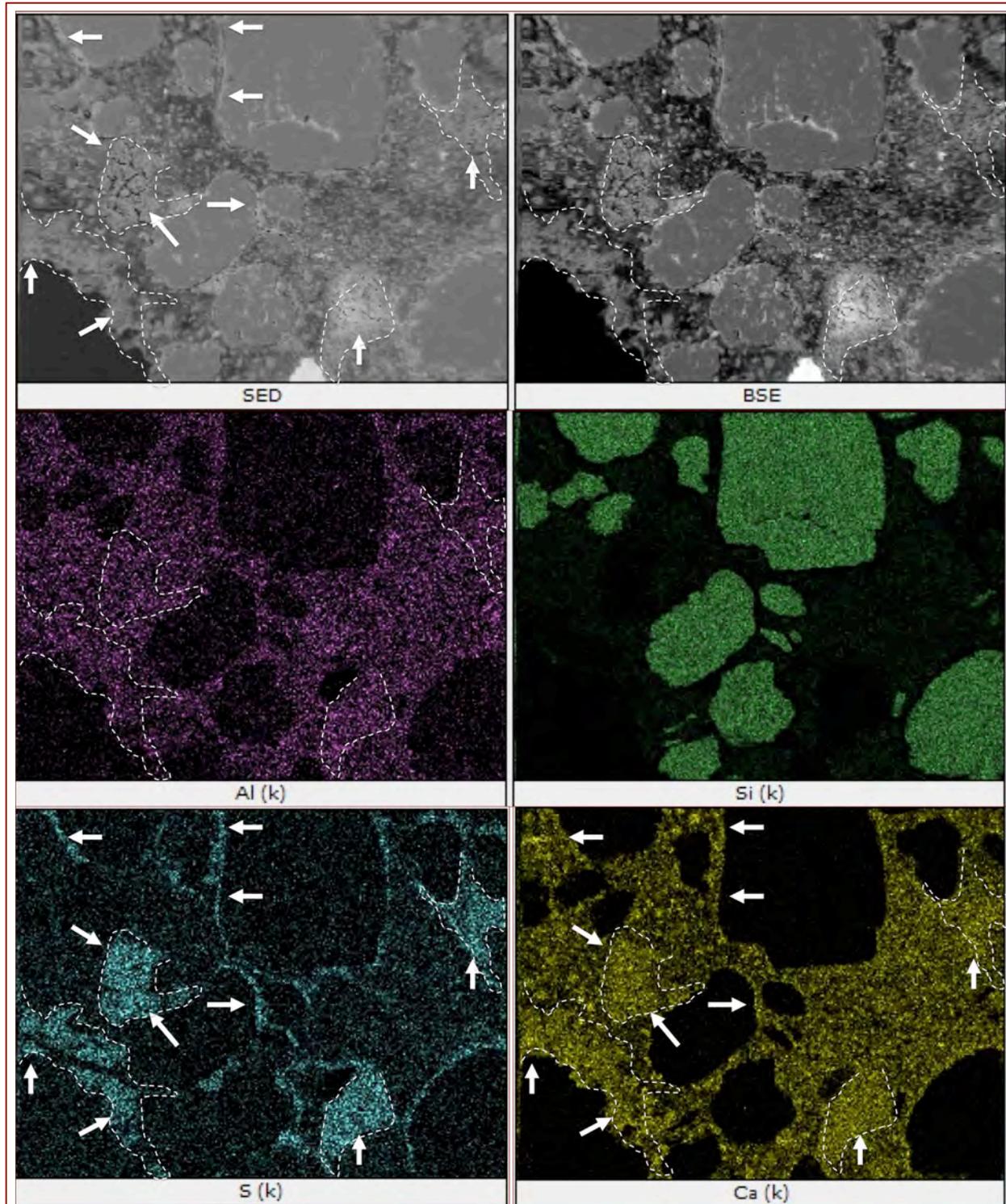
**Figure A16:** Semi-quantitative proportions of various minerals in the bulk grout (top) and binder fraction after screening out quartz sand (bottom) showing gypsum, ettringite, and calcite as the three predominant minerals in the paste.



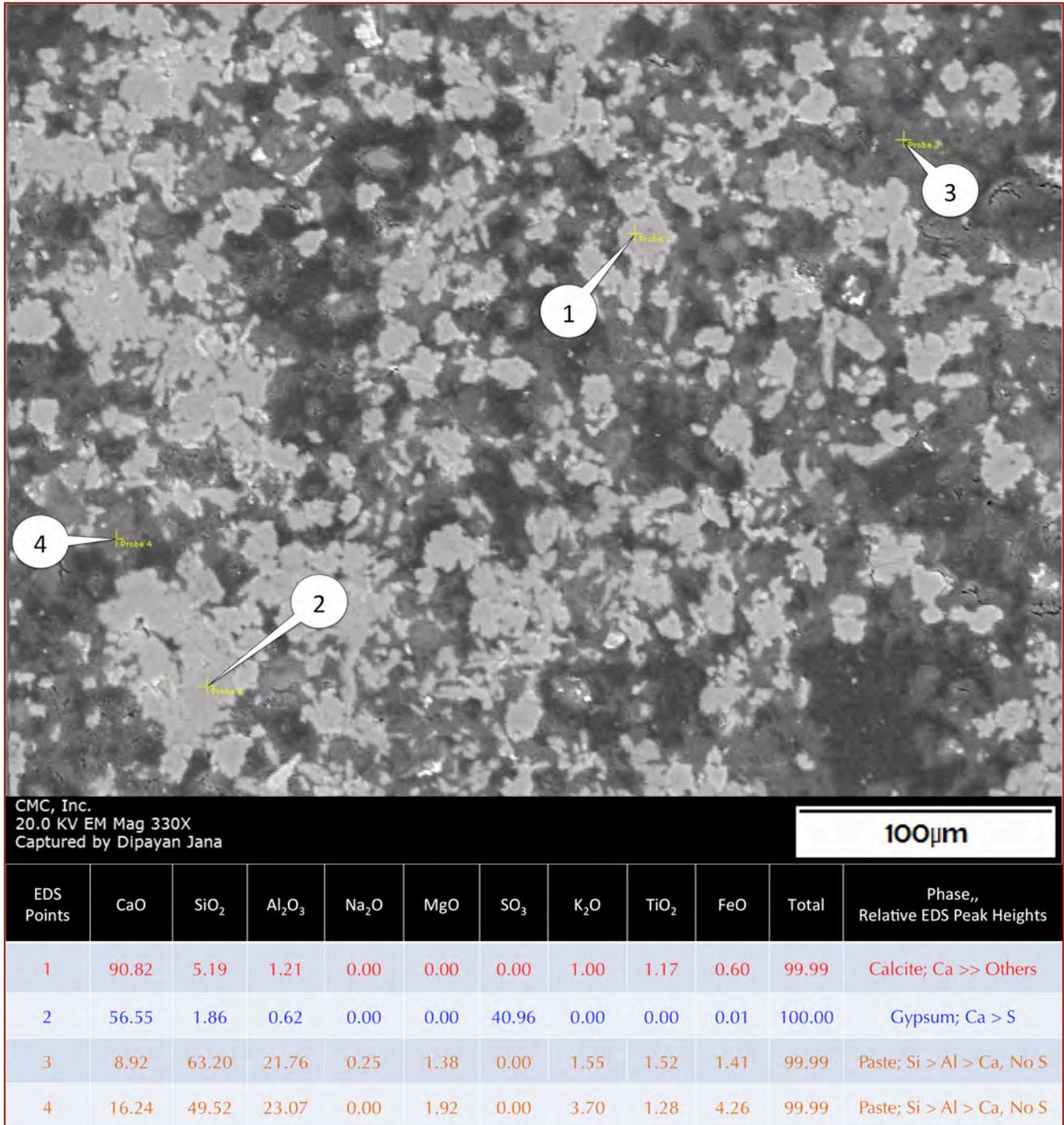
**Figure A17:** Secondary electron image and x-ray elemental analyses of various marked areas around paste showing the presence of: (a) quartz sand; (b) ettringite deposits, having its characteristic fibrous habit and shrinkage microstructure, in blue, measured in Probe Nos. 2, 4, and 5; (c) Paste areas having no sulfate, in orange, measured in Probe Nos. 7, 9, and 10; and (d) calcium aluminate hydrates, in black, in Probe Nos. 3, 6, and 8.



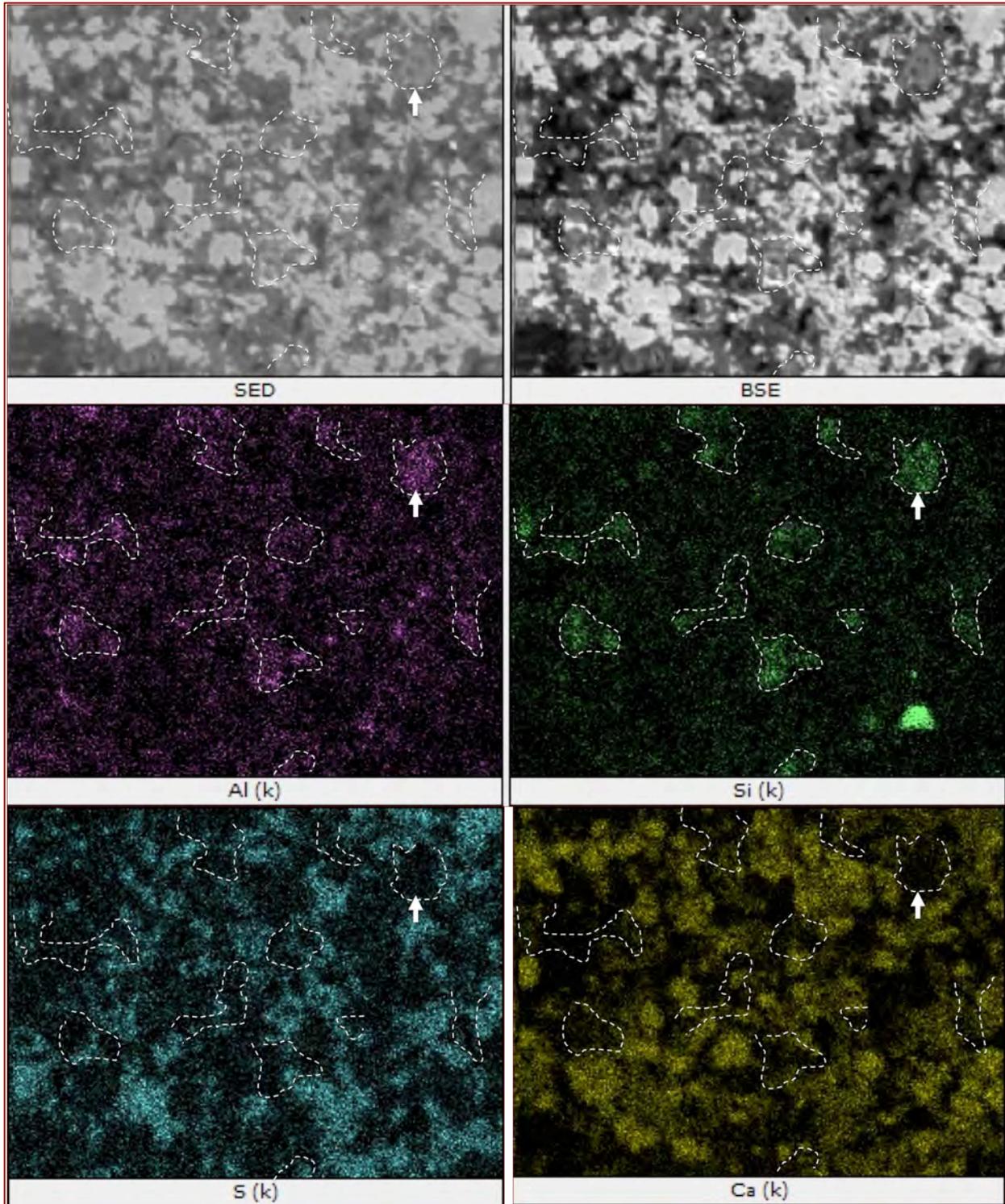
**Figure A18:** Secondary electron image and x-ray elemental analyses of various marked areas around paste showing the presence of: (a) profuse ettringite deposits, having its characteristic fibrous habit and shrinkage microstructure, marked within dashed lines, and measured in Probe No. 1; (b) Paste areas having no sulfate, in orange, measured in Probe Nos. 2, 4, and 5; and (c) calcium silica-sulfate-hydrates, in black, in Probe No. 3.



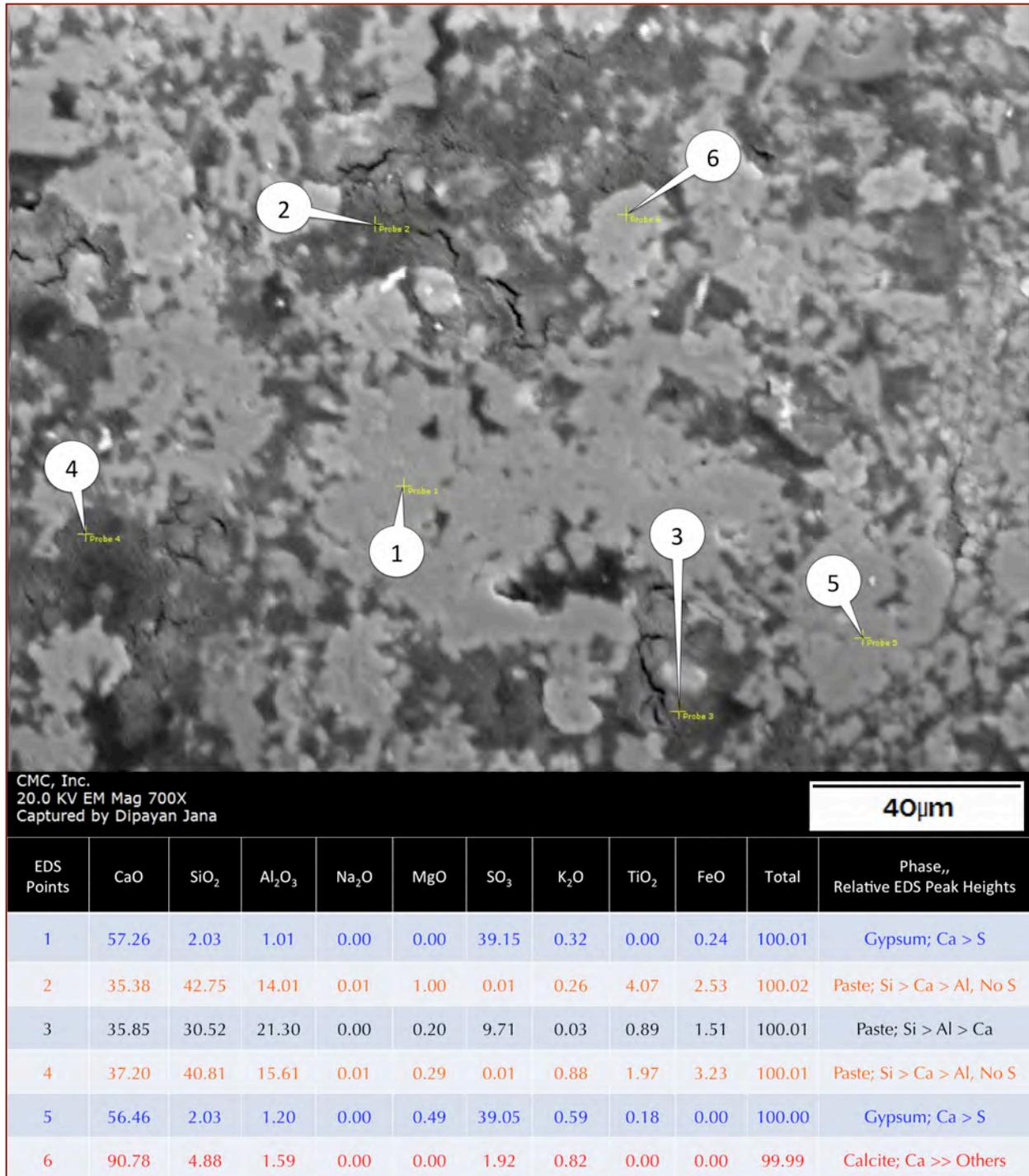
**Figure A19:** Secondary (SED) and backscatter electron image (BSE) at the top row and corresponding X-ray elemental map of four major elements - aluminum (Al), silicon (Si), sulfur (S), and calcium (Ca) showing high sulfate areas within dashed lines as well as with arrows that are also rich in calcium, and aluminum (indicating the presence of gypsum and/or ettringite). Quartz sand particles are highlighted in silicon map. Paste is overwhelmingly rich in calcium and aluminum, besides sulfate-rich areas.



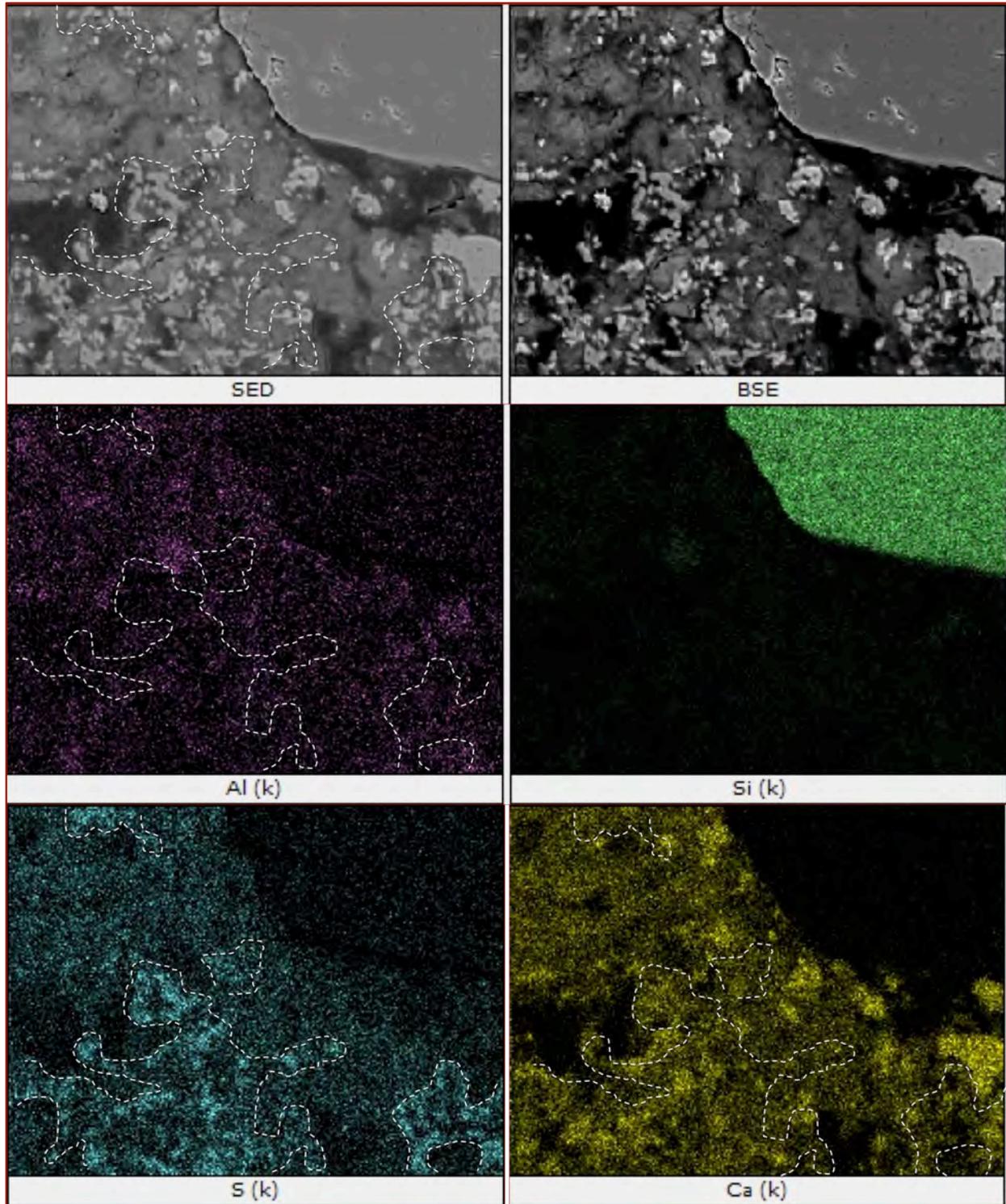
**Figure A20:** Secondary electron image and x-ray elemental analyses of various marked areas around paste showing the presence of: (a) calcite, measured in Probe No. 1; (b) gypsum, in blue, measured in Probe No. 2; and (c) Paste areas having no sulfate, in orange, measured in Probe Nos. 3 and 4.



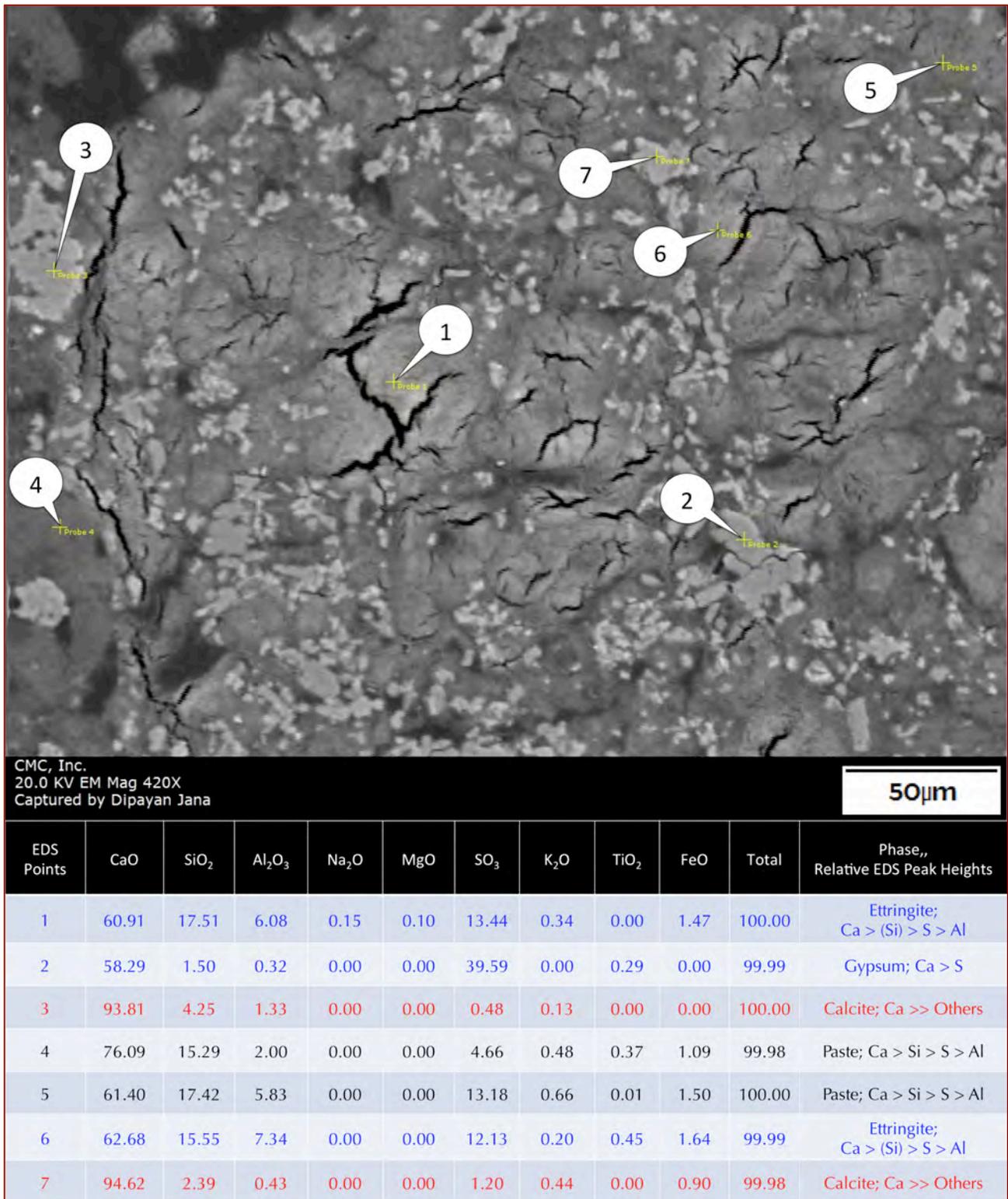
**Figure A21:** Secondary (SED) and backscatter electron image (BSE) at the top row and corresponding X-ray elemental map of four major elements - aluminum (Al), silicon (Si), sulfur (S), and calcium (Ca) showing patches of high silica (beside very bright quartz grain at the bottom right in silicon map) areas in paste within the dashed lines that are also rich in aluminum but depleted in sulfur and calcium.



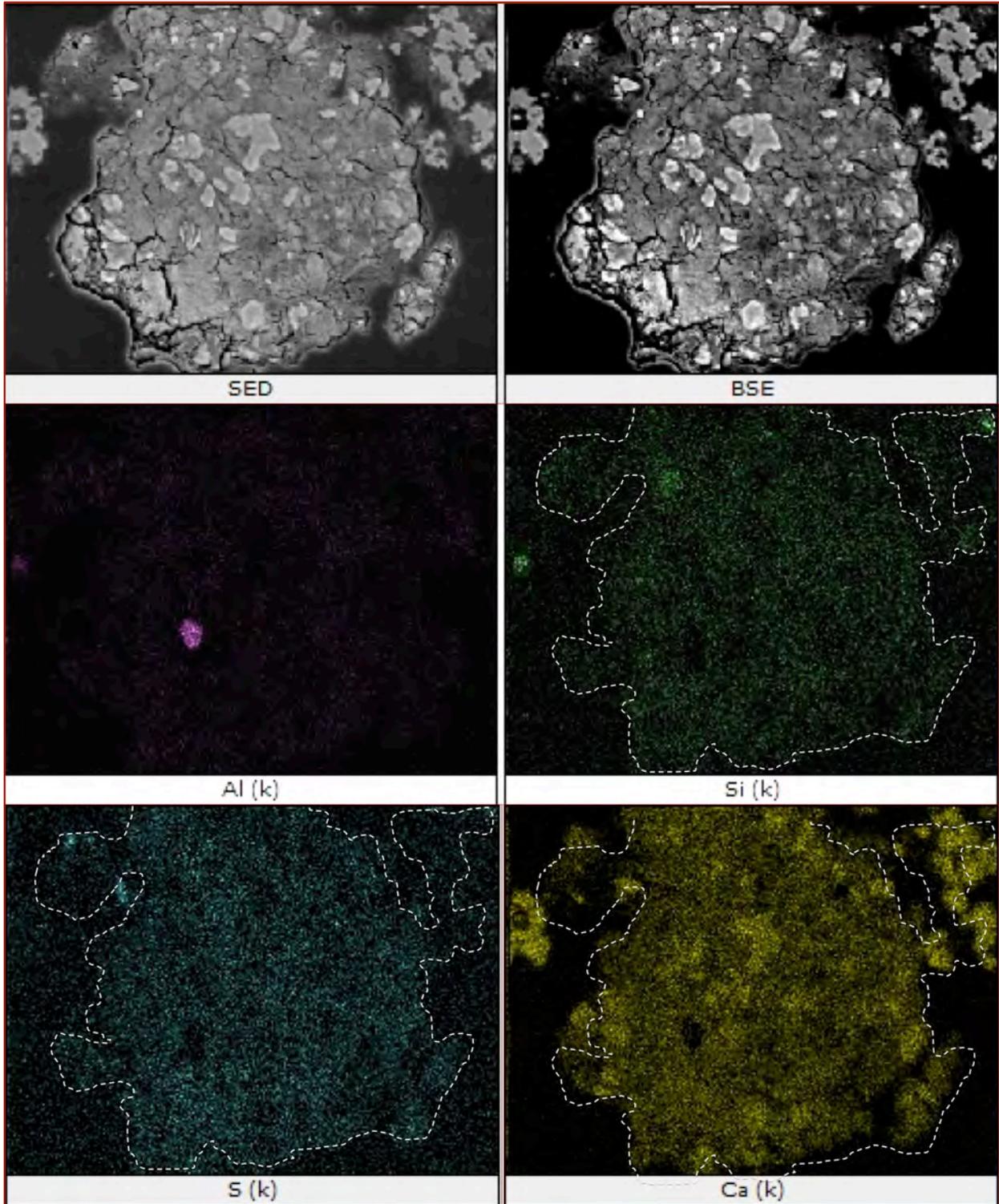
**Figure A22:** Secondary electron image and x-ray elemental analyses of various marked areas around paste showing the presence of: (a) gypsum, in blue, measured in Probe Nos. 1 and 5; (b) calcite, in red, measured in Probe No. 6; and (c) Paste areas having no sulfate, in orange, measured in Probe Nos. 2 and 4. Probe No. 3 shows an area in paste having silica, alumina, and calcium in decreasing orders of abundances.



**Figure A23:** Secondary (SED) and backscatter electron image (BSE) at the top row and corresponding X-ray elemental map of four major elements - aluminum (Al), silicon (Si), sulfur (S), and calcium (Ca) showing high sulfate areas within dashed lines that are also rich in calcium, but depleted in aluminum (indicating the presence of gypsum but not intermixed with ettringite for lack of aluminum). A quartz sand particle is highlighted at the top right corner in the silicon map. Paste is overwhelmingly rich in calcium, aluminum, and sulfur i.e. outside the dashed sulfate-rich (gypsum-based) areas.



**Figure A24:** Secondary electron image and x-ray elemental analyses of various marked areas around paste showing the presence of: (a) gypsum and ettringite, in blue, measured in Probe Nos. 1, 2, and 6; (b) calcite, in red, measured in Probe Nos. 3 and 6; Probe Nos. 4 and 5 show paste areas having calcium, silica, sulfur, and alumina in decreasing orders of abundances.



**Figure A25:** Secondary (SED) and backscatter electron image (BSE) at the top row and corresponding X-ray elemental map of four major elements - aluminum (Al), silicon (Si), sulfur (S), and calcium (Ca) showing an overall paste area within the dashed line that is rich in calcium, silica, and sulfur, and a few grains of calcite.



# END OF REPORT<sup>1</sup>

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