



Aggregates Containing Pyrrhotite

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Pyrrhotite Damage is a Slow Motion Disaster

- Not a photogenic disaster
- Damage occurs slowly
- Driving by houses – nothing looks out of place
- Houses slowly become unsafe
- Swelling concrete wracks the house and concrete foundation becomes unstable



What is Pyrrhotite?

- Pyrrhotite is an iron sulfide mineral
- Closely related to other iron sulfide minerals:
 - Pyrite
 - Marcasite
- All of these minerals have a desire to oxidize in the presence of oxygen and water



Pyrrhotite is an unusual mineral

- $\text{Fe}_{(1-x)}\text{S}$ where $x=0 \rightarrow 0.2$
- Typical combinations Fe_7S_8 , Fe_9S_{10} , $\text{Fe}_{10}\text{S}_{11}$, or $\text{Fe}_{11}\text{S}_{12}$
 - Pyrite is FeS_2
- May be “contaminated” with Copper, Nickel or Cobalt
- Has different crystalline structures
 - Has variable degrees of stability based on structure
- May or may not be magnetic
 - Is responsible for the weak magnetic fields observed by spacecraft orbiting Mars



Pyrrhotite Oxidation

- Exothermic reaction (releases heat)
- Has been blamed for starting mine fires when large quantities of pyrrhotite are first exposed to air and
- Iron sulfides in rock waste has been blamed for acidification of water runoff
- Iron sulfides can be used to make sulfuric acid



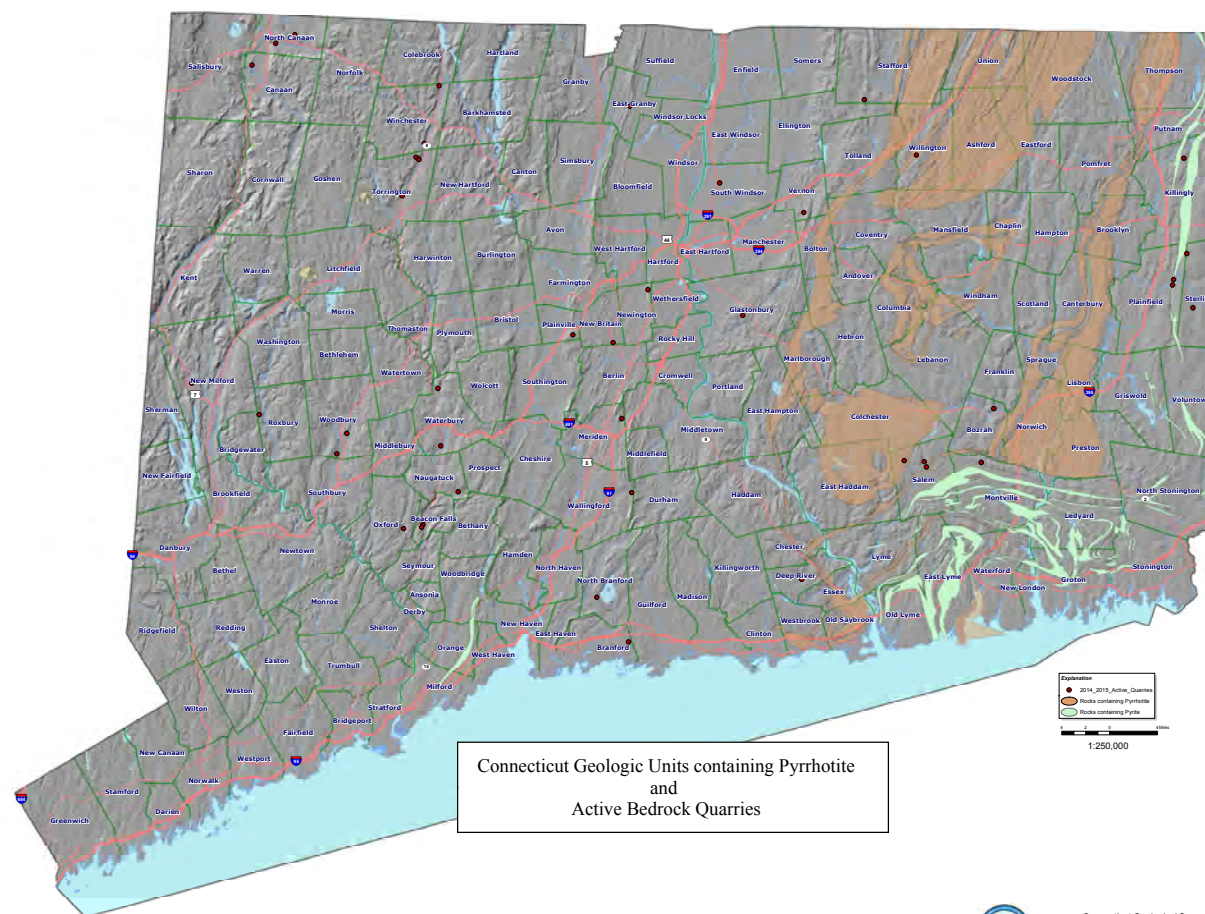
Products of Iron Sulfide oxidation in Concrete

- When iron sulfides oxidize it produces iron oxides and sulfuric acid
- Iron oxides occupy more space than original molecules
- Sulfuric acid attacks the concrete paste weakening it and it forms secondary expansive minerals such as ettringite
- Bottom line: the concrete is weakened with internal stresses growing from the swelling materials in the concrete

Why Does Pyrrhotite Matter?



Where is Pyrrhotite in Connecticut?



Bedrock Geological Map of Connecticut
Connecticut Geological and Natural History Survey
Natural Resources Atlas Series, 2 sheets, 1:125,000
(Rodgers, 1985)



Connecticut Geological Survey
Department of Energy and Environmental Protection
www.ct.gov/deep/geology





Connecticut Background History

- Residential poured Concrete foundations began to develop unusual cracking (spider/map) in the 1990's from 1980's placements
- After enough houses were identified with this cracking, the common thread was determined to be a single concrete supplier/quarry
- The cause of the cracking was unknown although the cracking resembled ASR
- A meeting was held with Connecticut officials from multiple departments in 2002-3 timeframe to discuss the problem
- Nothing came of the meeting



CT History Continued

- As time progressed, more and more affected homeowners came forward and in 2015 the Department of Consumer Protection and Attorney General Launched investigation into the cause of the cracking to determine if consumer protection laws were violated
- Concrete supplier continued to provide concrete using the same quarry materials until Companies signed a voluntary agreement to stop selling materials for residential concrete in May 2016
- Research by Wille and Zhong in 2016 showed pyrrhotite in the quarry aggregate is a factor in the concrete degradation
- Concrete supplier has maintained throughout that the problem is with the installation such as additional water added by installers



CT History Continued

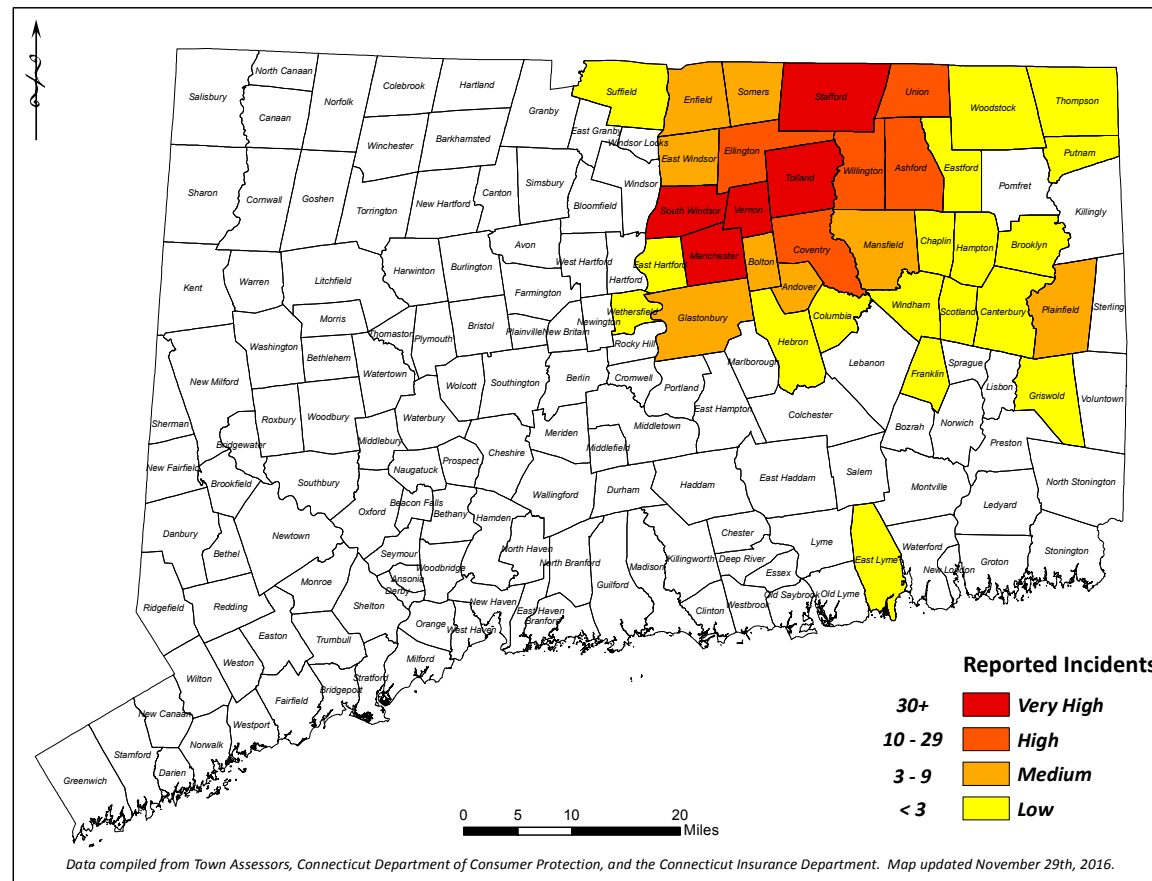
- Concrete supplier also produced septic tanks and other precast drainage products
- Septic tanks are also failing and being replaced
- 20 Bills were introduced during the 2017 Legislative Session and zero were passed
- CT still does not have a budget and some of the proposed legislation may be in budget bill when that is finalized



CT House Foundations

- Approximately 600 homeowners have registered with the Department of Consumer Protection as having the problem
- Currently, the only recognized remediation is to remove and replace the concrete foundation
- It is estimated that more than 34,000 CT residences contain concrete from this supplier
- No records from the supplier exist to determine exactly how many residences may be affected
 - 2016 CT law was enacted to require recording concrete supplier as part of Certificate of Occupancy
- Supplier also provided concrete across the border to Massachusetts

Map of affected Towns – Courtesy of Capital Region Council of Governments (11-29-2016)





CT Impacts

- Exact number of impacted houses is not known
- 10 Year Statute of Limitation on concrete foundations
- Generally taking more than 10 years to show damage
- Most homeowners insurance companies are denying coverage for this damage
- Concrete work is typically in the \$150,000 - \$200,000 per house (not including damage to hardscape, landscape, relocation, etc)
- Condominiums are also part of this problem and are much more complicated
- Currently there is no financial relief for homeowners



Impacts to CT

- CT real estate market in the region is significantly impacted
- Houses showing damage are virtually worthless
- Home buyers are requesting core testing and if any pyrrhotite is detected, buyers are either walking away or significantly negotiating the price downward
- Most towns are reducing the assessed values of houses showing damage
- Some towns are waiving building permit fees for repairing foundations



CT Pyrrhotite Problem is Growing

- Concrete placed from 1983 – most likely through 2015 impacted
- Commercial properties are now reporting problems
- Municipal buildings as well are reporting issues
 - Elementary school
 - Fire House
- First bridge (municipal) is potentially showing signs of the problem
- Rough estimates to repair all of the damage are in the \$billions

Concrete Without Ettringite Deposits or Cracking

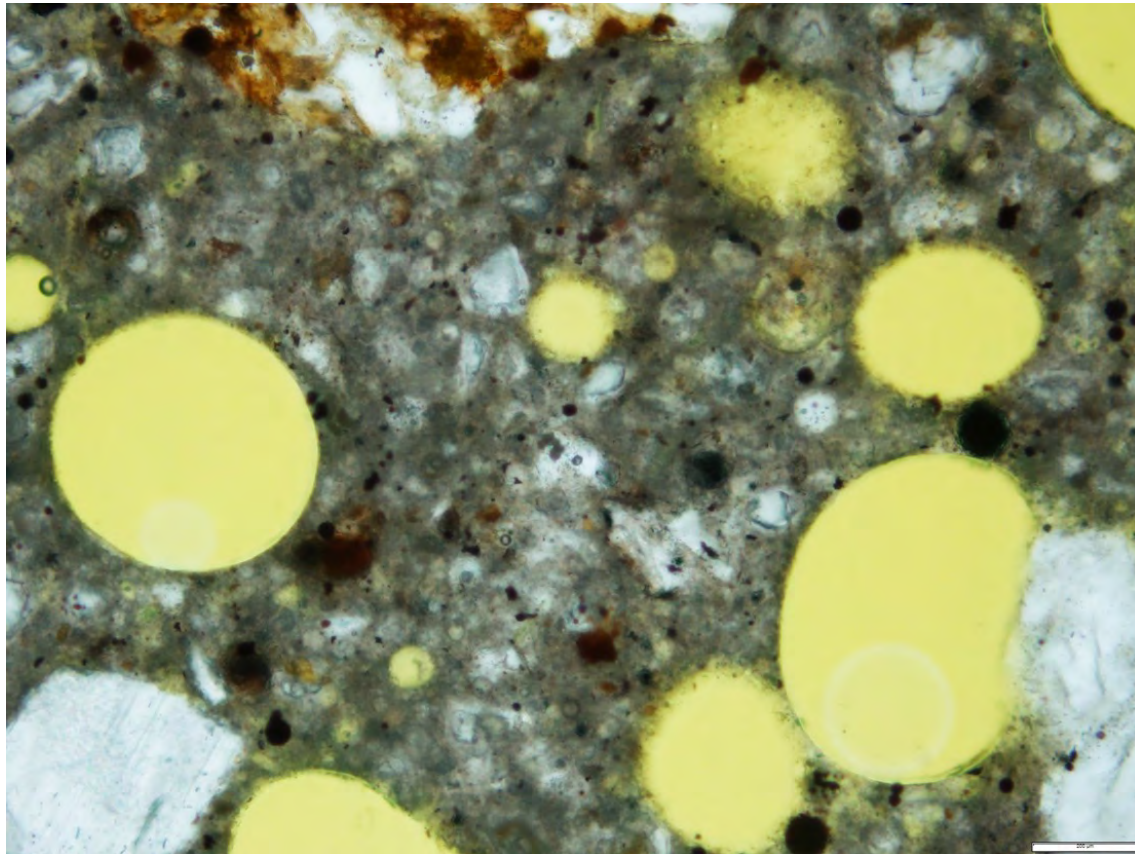


Image Courtesy of Advance Testing

Microscopic View of Pyrrhotite in Concrete

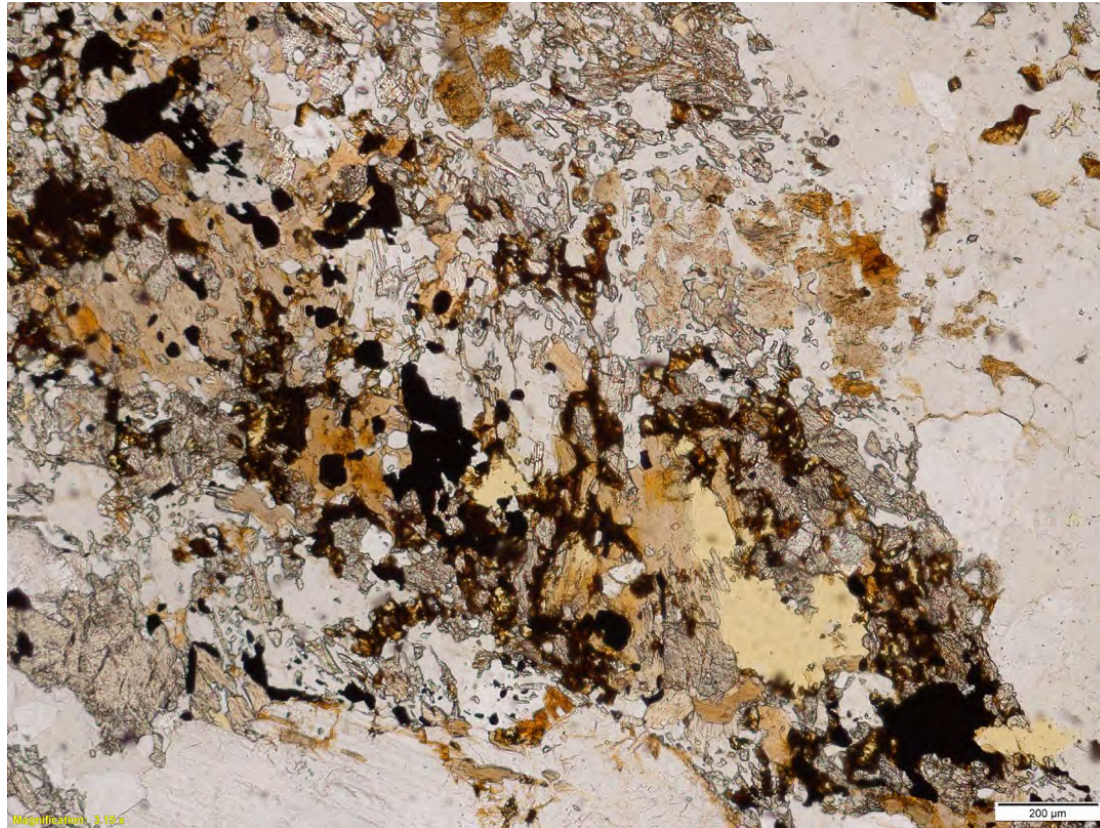


Image Courtesy of Advance Testing

Microscopic Damage from Pyrrhotite in Concrete

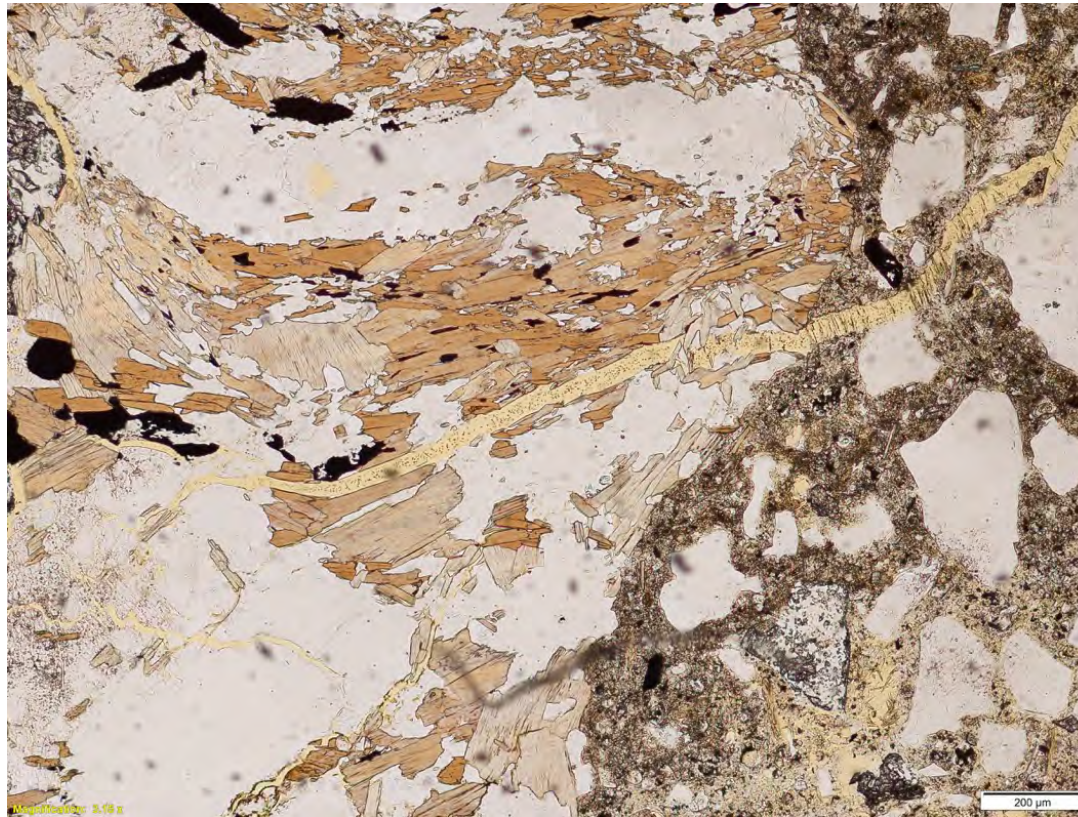


Image Courtesy of Advance Testing

Ettringite in Cracks

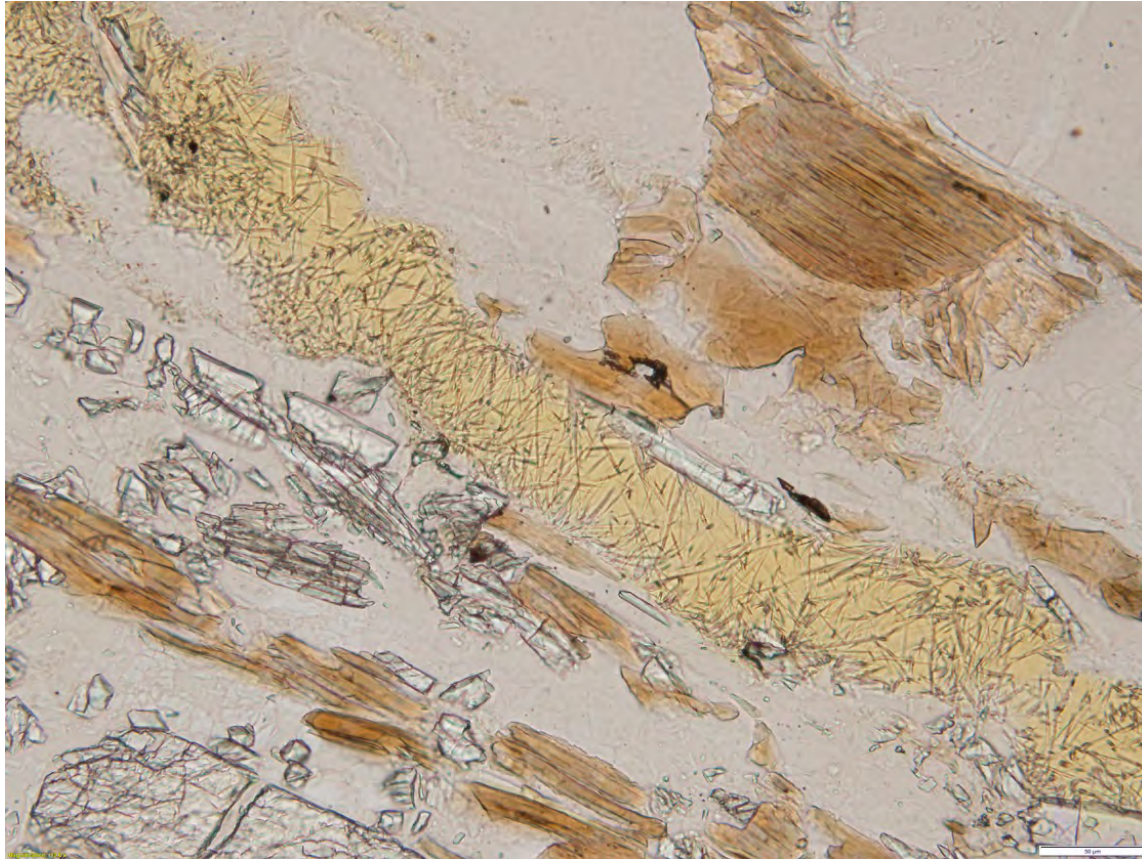


Image Courtesy of Advance Testing

Ettringite Formation in Concrete Void Space Caused By Pyrrhotite Oxidation

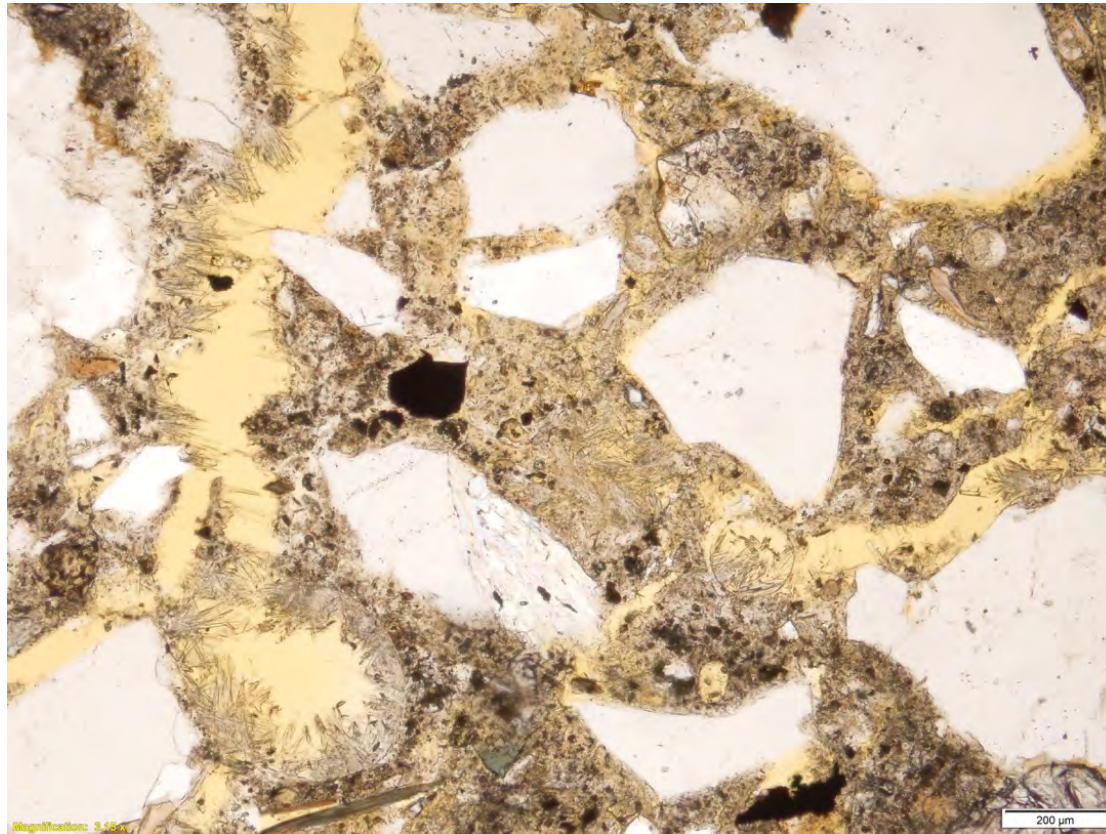


Image Courtesy of Advance Testing

Concrete Core without Pyrrhotite

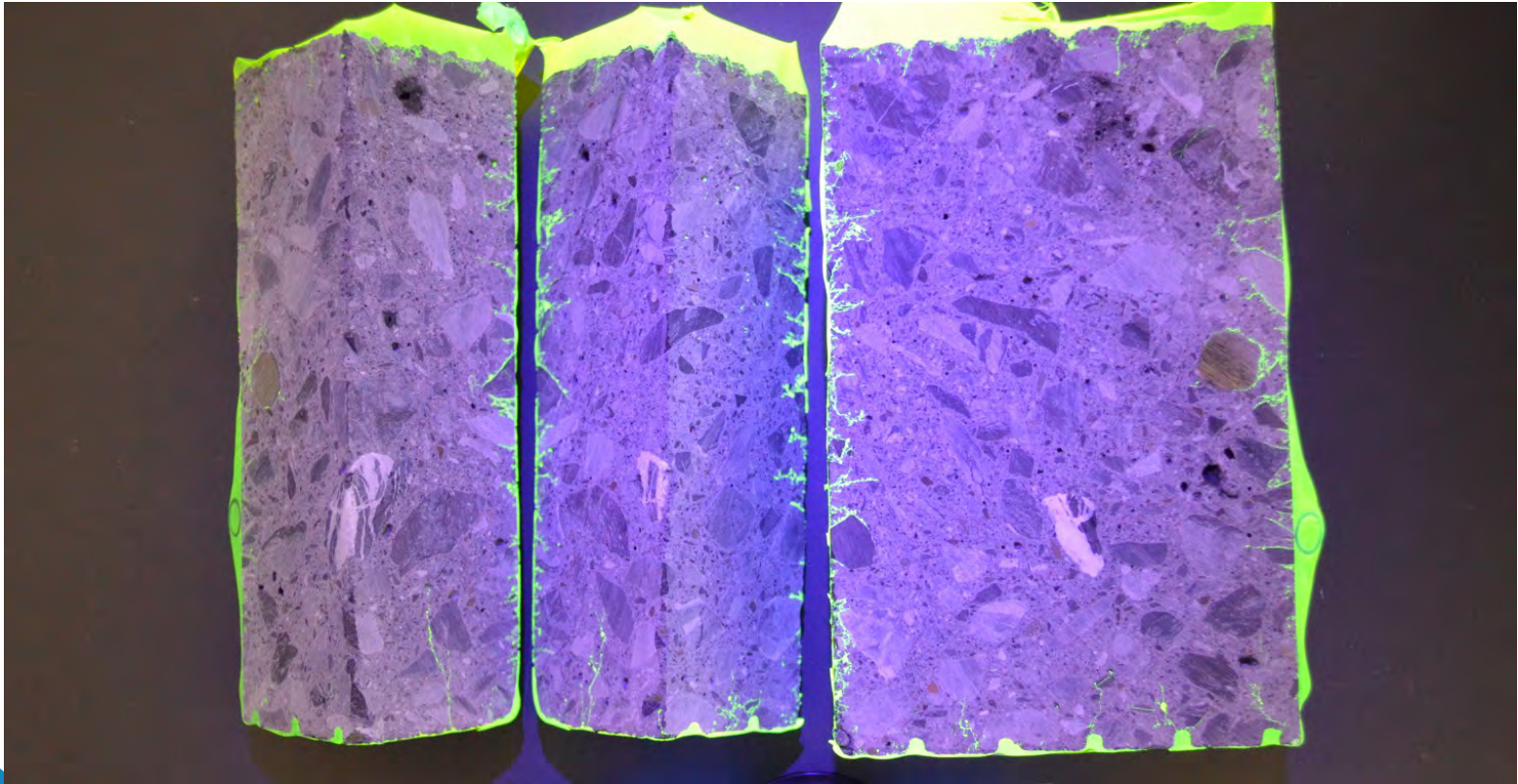


Image Courtesy of Advance Testing

Pyrrhotite in Impacts on Concrete

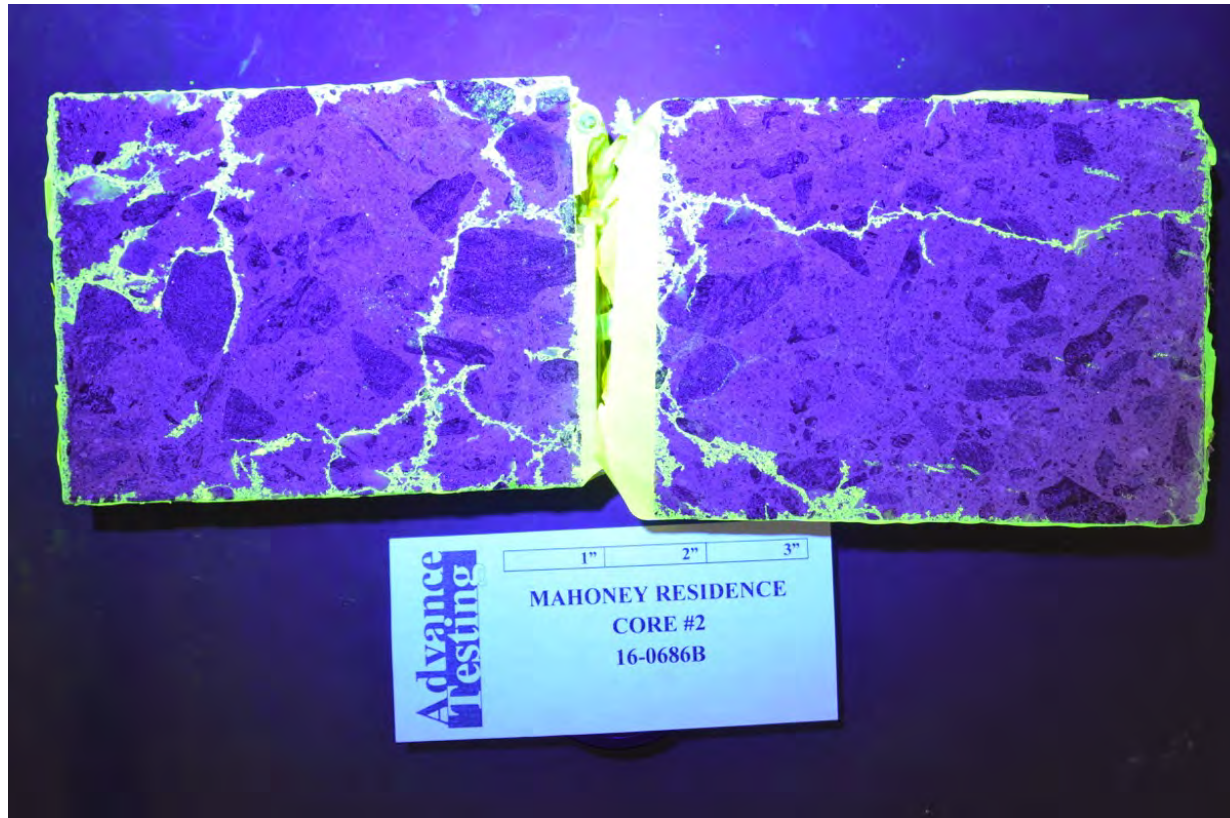


Image Courtesy of Advance Testing

Core With Large Piece of Pyrrhotite



Core with Visible Cracking From Aggregate Particle



Aggregate Rusting and Popping Out of Concrete



Damage to Concrete Foundations



Courtesy Wille and Zhong

Concrete Foundation Damage



Courtesy Wille and Zhong

Concrete Damage



Courtesy Wille and Zhong

Concrete Damage



Courtesy Wille and Zhong

Concrete Damage



Courtesy Wille and Zhong

Concrete Damage





Where Else Has This Problem Occurred?

- Three Rivers, Quebec - Using 0.23% by volume pyrrhotite threshold
- Oslo, Norway
- Spain
- Cornwall, England – Mundic Blocks
 - Houses built from 1900-1950's using blocks with mine waste as aggregate
 - (Mundic is an old Cornish word for iron pyrites)
 - Developed a risk based system for insurance and mortgage purposes



NYSDOT Aggregate Specifications

- Only specification found in the region regarding pyrrhotite
- Limited to 1% iron sulfides in aggregates



Is It Possible to Develop a Fast and Low Cost Test for Pyrrhotite in Lieu of Petrographic Analysis?

- Navy's SBIR Program is funding research to develop a handheld unit to test aggregate as well as in hardened concrete
- Spectroscopy shows promise for developing a test method
 - Including X-Ray Fluorescence and X-Ray Diffraction
- Critical step in determining an estimate number of affected houses based on data driven decisions



Failed Remediation Efforts

- Epoxy sealing of cracks
- Poured foundation inside of the original foundation
 - Swelling concrete destroyed new wall
- Piles driven under the foundation to support it
- Steel reinforcement with tiebars
- Plenty of ideas are out there from both well intentioned and not-so well intentioned people



There Are Many More Questions Than Answers

- Can a threshold level of pyrrhotite be established below which damage may not occur?
- How many samples need to be taken to properly characterize the pyrrhotite level in a foundation?
- Can steps be taken for foundations not showing damage to prevent any further damage?
- For structurally sound foundations with minor cracking, is it possible to remediate it without full foundation replacement?
- Are threshold values from Canada applicable to Connecticut?
- Are there other factors such as other minerals that affect the rate of damage to concrete?



Thank You - Questions