

A reassessment of problems affecting stabilized layers in roads in South Africa

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TREMTI 2009 – ANTIGUA GUATEMALA – 11 - 13 Nov.



Background

- Significant research has been carried out in South Africa on the deterioration of stabilized materials since 1981
- The cause was undeniably attributed to carbonation of the stabilized materials (a design and/or construction problem)
- An alternative cause was presented at TREMTI in Paris in 2005

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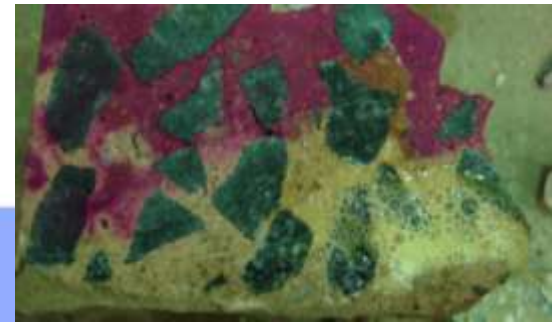


Background

- “Water-driven” reactions (material-related) and not carbonation
- Material problem gives the Contractor reason for an “unforeseen” claim
- This has caused serious problems and unnecessary claims
- This paper reviews the two processes to determine their likelihoods

CARBONATION

- Known factor in the deterioration of concrete
 - Loss of stabilizer → carbonates
 - Lowered pH
 - Destabilization of hydrated silicates
 - Can close surface voids
 - Slows down deterioration
- Greater effect on road stabilization



CARBONATION

- Chemical background
 - Affects both lime and cement
 - Fundamentally similar stabilization processes
 - Lime requires clay minerals (Si & Al)
 - Lime and cement both manufactured at high temperatures - $\text{CO}_3^{++} \rightarrow \text{O}(\text{H}^-) + \text{CO}_2$
 - OH^- inherently unstable \rightarrow Carbonates
 - pH 12.4 \rightarrow 8.3



REACTIONS WITH CLAY

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- Rapid
 - Ion exchange → flocculation → lower PI and ϕ
- Slow/long term
 - High pH
 - Increased solubility of Si and Al
 - $\text{Si} + \text{CH} + \text{H} \rightarrow \text{C}_3\text{S}_2\text{H}_3$
 - $\text{Al} + \text{CH} + \text{H} \rightarrow \text{C}_4\text{AH}_{13}$
- NB. Cement has all ingredients
 - Releases $\text{Ca}(\text{OH})_2$
 - $\text{C}_2\text{S} + \text{C}_3\text{S} + \text{H}_2\text{O} \rightarrow \text{C}_3\text{S}_2\text{H}_3 + \text{Ca}(\text{OH})_2$

CARBONATION

- Lime only stable when $P_{\text{CO}_2} < 3 \times 10^{-14}$ atm
- Normal environmental $P_{\text{CO}_2} = 3 \times 10^{-4}$ atm
- Absorbs CO_2
- Increase in volume (10 – 14%)
- Atmosphere has 0.035% CO_2
- Where does it come from
 - “Unlimited” volume
 - Measured 4 – 13% in pavement layers

CARBONATION

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- Requires humidity
- Most rapid between (40% & 70% RH)
- Not always detrimental
 - If $ITS < \sigma_T$ microcracking occurs
- Natural and common process



“WATER DRIVEN” REACTION THEORY

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- Poorly described in TREMTI 2005 (Botha et al)
 - Reaction with clay minerals
 - $\text{Ca}^{++} + 2(\text{OH})^- + \text{H}_2\text{O} \rightarrow 2\text{Na}^+ + 2(\text{OH})^-$
 - NaOH is soluble
 - Moves to beneath surface (hydrogenesis)
 - NaOH is hygroscopic and attracts water
 - Ion exchange reaction with remaining clays
 - $\text{Ca}^{++} + 2(\text{OH})^- + \text{H}_2\text{O} + 2\text{Na}^+ \rightarrow 2\text{Na}^+ + 2(\text{OH})^-$

“WATER DRIVEN” REACTIONS

- NaOH then attacks aluminosilicates and fine quartz, destroying cementitious bonds
- If more $\text{Ca}(\text{OH})_2$ is available then CSH and CSA forms destroying matrix by expansion
- $\text{Ca}(\text{OH})_2$ is depleted and pH drops
- High solubility of NaOH allows migration to between base and surfacing and thus pH is still high (sic)
- Essentially typical alkali-silica reaction sometimes occurring in concrete



“WATER DRIVEN” REACTIONS

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• Assumptions in theory

- That sufficient Na actually exists in the material to be displaced by Ca and form NaOH
- Must come from materials, cement (none in lime) or compaction water
- Earths rocks contain 0 – 3.5% sodium oxide and 0 – 20% calcium oxide
- Exchangeable Na in SA gravels < 6 meq/kg soil
- SA cements have < 0.3% Na oxide

“WATER DRIVEN” REACTIONS

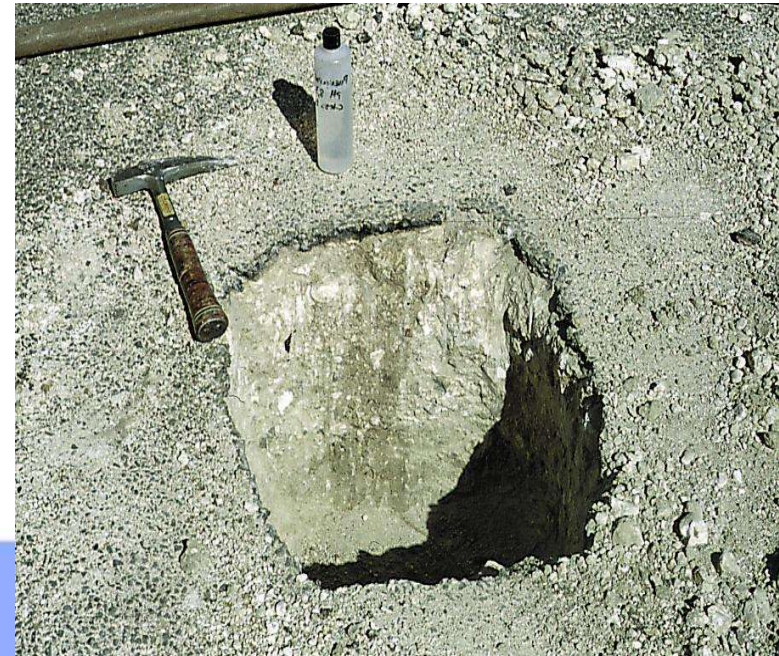
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- Assumptions in theory

- Presence of Na – actually very low
- Majority of problems encountered have been in calcium rich/saturated materials (calcretes and weathered dolerites)

- Other problems

- Principle is fundamentally flawed



“WATER DRIVEN” REACTIONS

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• Fundamental flaws

- 0.5N solution of NaOH is required to dissolve free silica in clay (in steam bath over 4 hours)
- Only amorphous silica and not quartz is dissolved (NaOH must also dissolve Al)
- NaOH from 5 meq/kg and 10% moisture = 0.05N solution (one tenth)
- NaOH attacks fines (mostly colloids or clay fraction)

“WATER DRIVEN” REACTIONS

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• Fundamental flaws (cont)

- Correctly assumes that Ca ions will displace exchangeable Na ions on clays
- These remain in solution and undergo hydrogenesis in sealed road
- Majority of problems on roads before sealing
- NaOH is probably more susceptible to carbonation than $\text{Ca}(\text{OH})_2$



“WATER DRIVEN” REACTIONS

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• Fundamental flaws (cont)

- NaOH will absorb water – already in solution !
- NaOH attacks alumino silicates and fine quartz destroying cementitious bonds – these aren't reaction products !
- Assumes increase in volume when new CSH form that destroys cementing matrix – not known or proved
- Repeated reference to calcium silica aluminates – not referred to in cement chemistry (or even clay mineralogy)

“WATER DRIVEN” REACTIONS

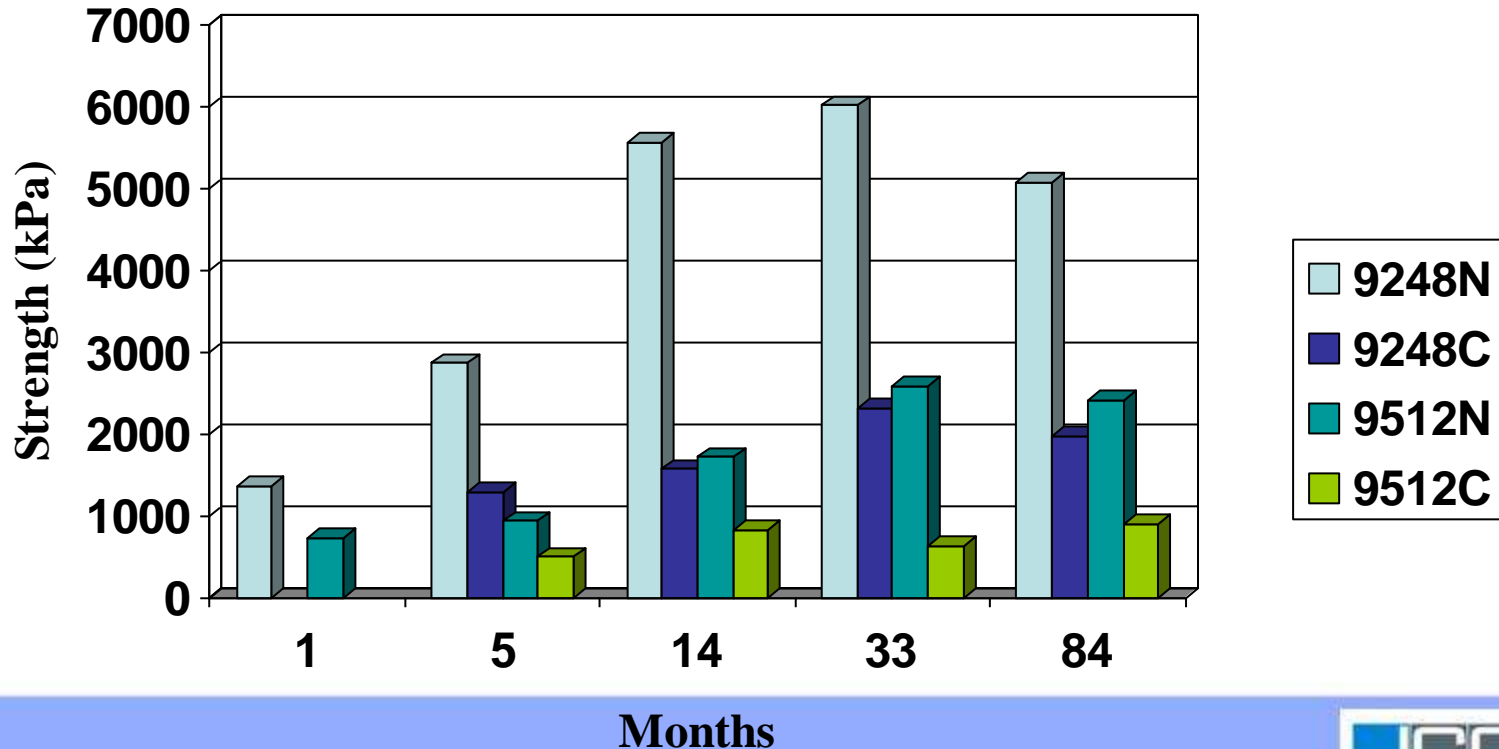
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• Fundamental flaws (cont)

- No reason why NaOH should attack clays preferentially to $\text{Ca}(\text{OH})_2$
- Alkali silica reaction requires metastable forms of silica – reports of clay reactions (as required for WDR) never substantiated
- “Reacted” layer must be dry and have high pH
- Botha et al state that carbonation is more strength gaining than reducing

TIME EFFECTS

- Attack on gels (during curing)



LABORATORY INVESTIGATIONS

- Field samples can be carbonated (accelerated) in the laboratory
- Standard test in SA

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CARBONATION



Block sample collected 31/01/02: sealed in two plastic bags on site. Stored in office until 31/05/02 – opened and block broken for ICC testing and pH assessment.



31/05/02 at 12h06 - 00 sprayed on freshly opened surface (pH = 13.29)



31/05/02 at 14h26 – first spray almost faded – second sprayed area slightly pink after 1 minute



31/05/02 at 15h00 – first spray almost faded – second sprayed area dark pink after 34 minutes



03/06/02 at 09h06 – both sprays fully faded



03/06/02 at 09h07 – sprayed – no red after 1 minute



03/06/02 at 09h22 – sprayed – no red after 16 minutes or any time thereafter

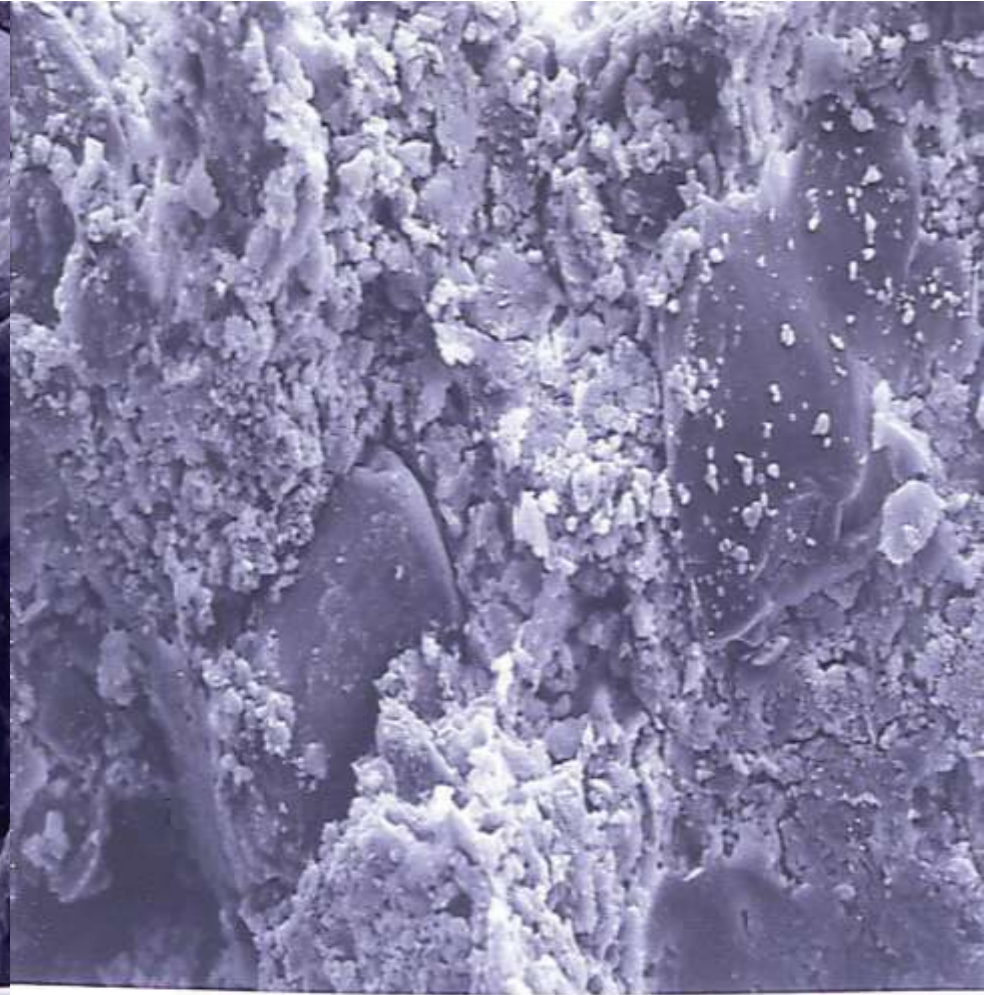
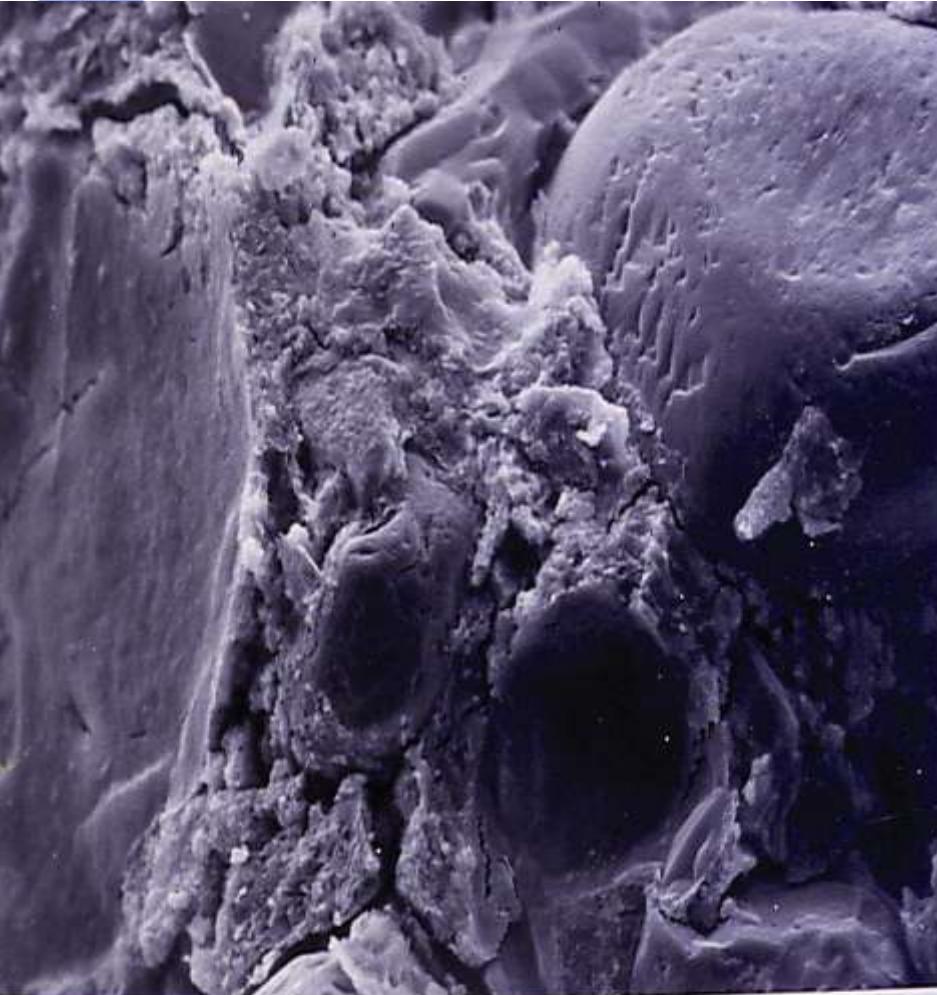




Carbonation of outside 10 mm of block after 70 hours of indoor exposure to atmospheric air (03/06/02 at 12h00). The ambient temperature during this period never exceeded 20°C. (ph = 11.6)

CARBONATION

13 Nov.





1 μ m

2 μ m

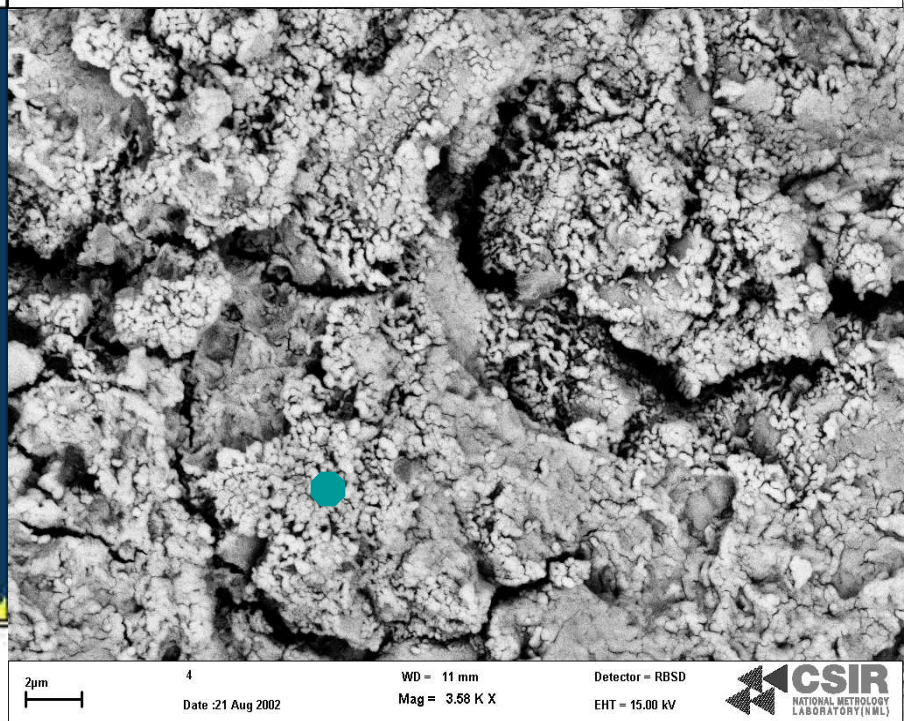
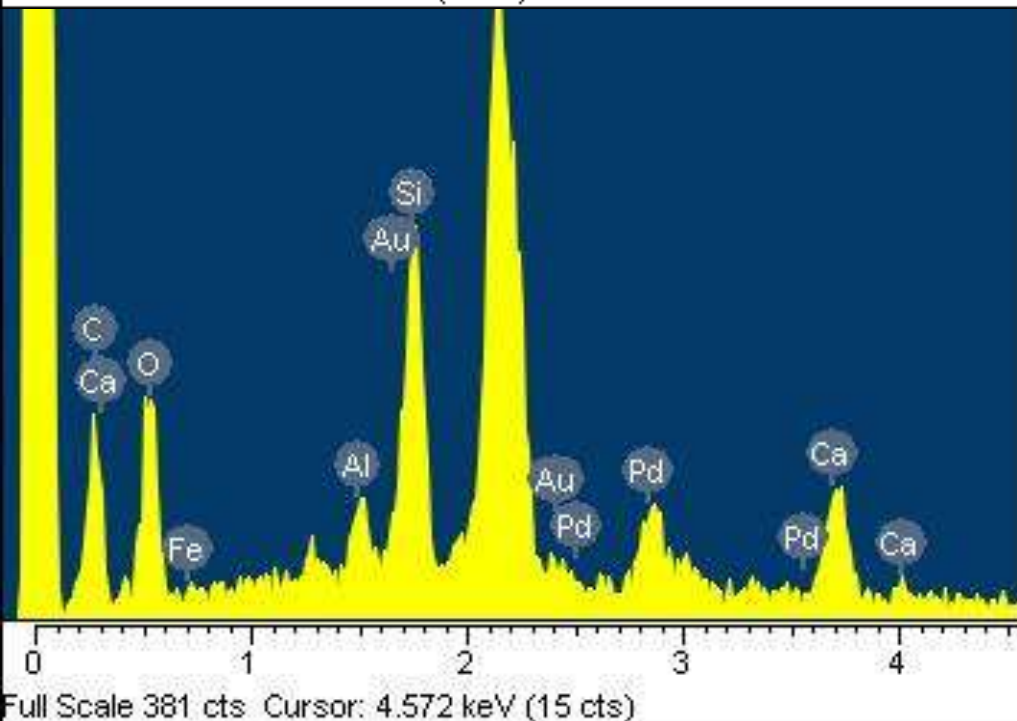
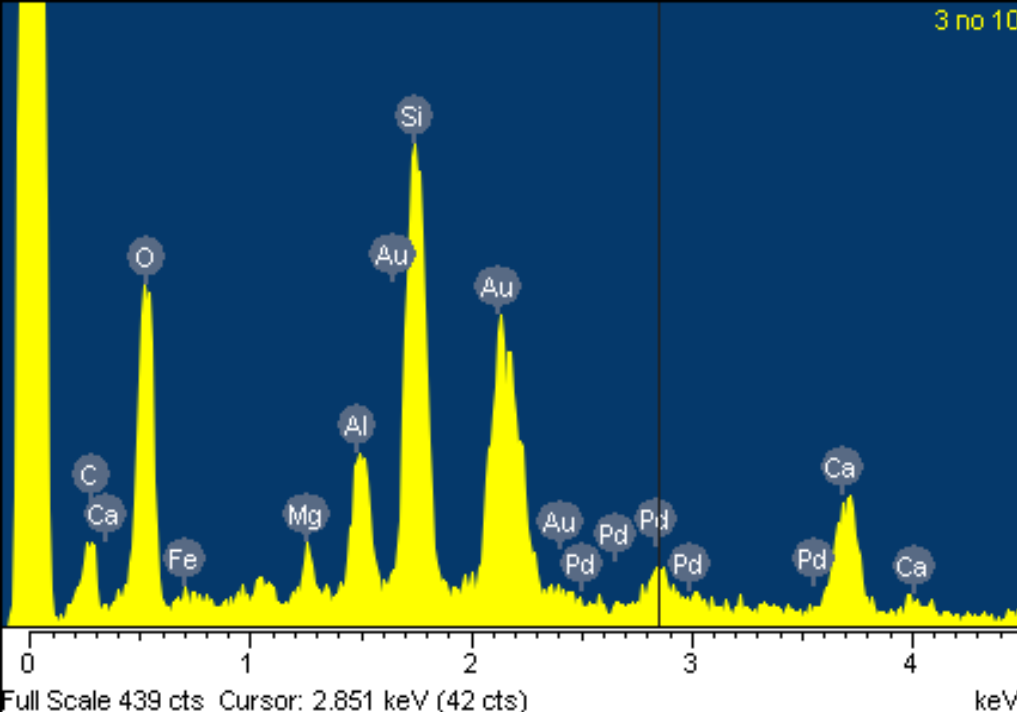
4

Date :21 Aug 2002

WD = 11 mm
Mag = 3.58 K X

Detector = RBSD
EHT = 15.00 kV





FIELD INVESTIGATIONS

- Carbonation
- Numerous investigations over past 28 years

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CARBONATION





TREMTI 2009

TREMTI
TREATMENT AND RECYCLING OF MATERIALS FOR TRANSPORT INFRASTRUCTURE



LABORATORY EVIDENCE

- Water driven reactions
 - Little evidence
 - Attempts to simulate reactions (using granitic material) have failed
 - Even added some dispersive clay
 - Repeated Botha tests
 - Only weak material was 90% density

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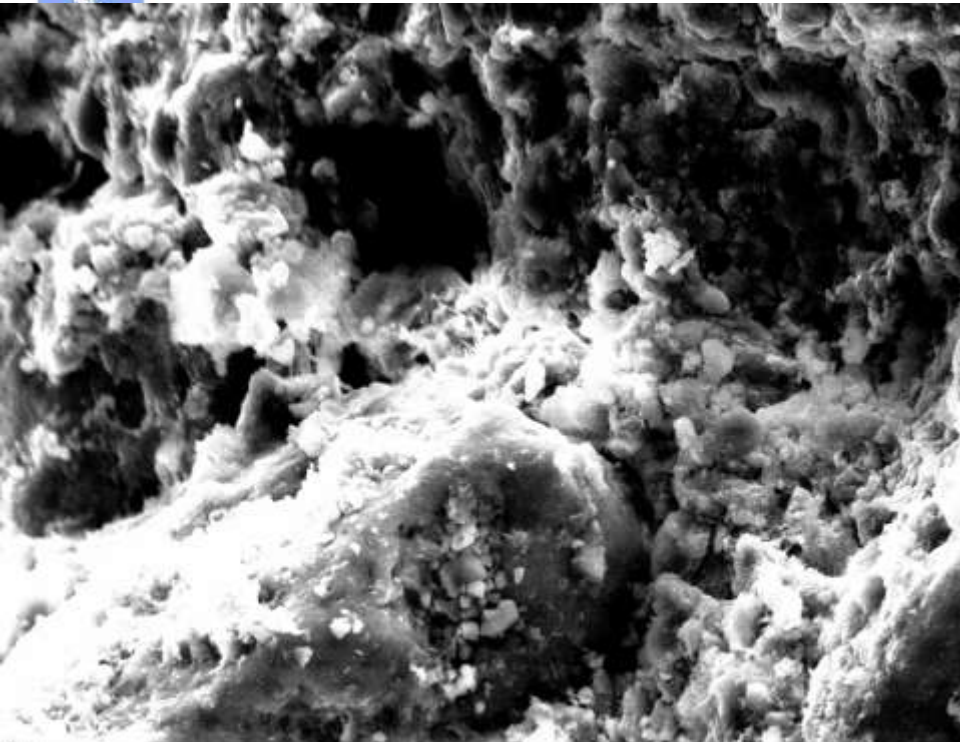
LABORATORY EVIDENCE

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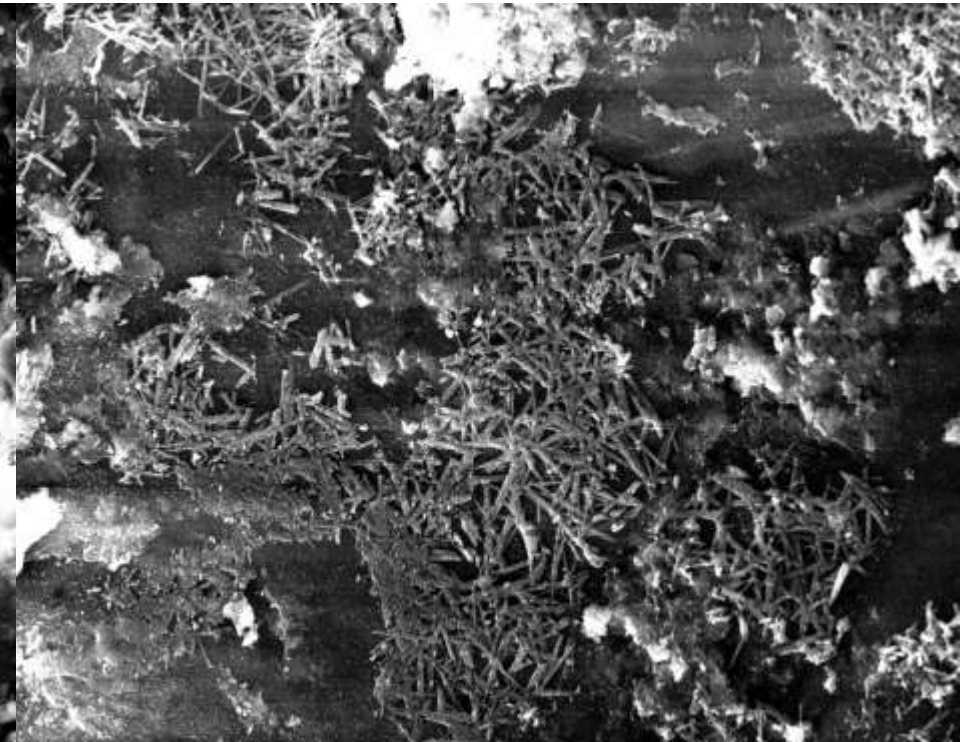


LABORATORY EVIDENCE

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CEM VS
Mag = 2.50 KX EHT = 20.00 kV WD = 12 mm Signal A = SE2



Lime
Mag = 2.53 KX EHT = 20.00 kV WD = 11 mm Signal A = SE2

FIELD EVIDENCE

- Water driven reactions
- All problems carefully checked for WDR in field
- Dry weak layer - high pH & no CO_3

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DISCUSSION & SUMMARY

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- Carbonation is a standard reaction
- WDR is not - requires sodium – source never proved
- Water is needed for hydration and has never been a problem – why suddenly ?
- WDR possible but unlikely !
- Process never proved scientifically