# The Effect of Fine Aggregate Properties on the Quality of Composite Materials

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**on Sustainable Development**
**in the Minerals Industry**
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**Greece**

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# INTRODUCTION

Aggregates are among the main constituents of composite building materials

- Concrete: occupy 60-80% by volume
- Mortar: aggregate : binder 3 : 1 (w/w)

Physico-mechanical properties of aggregates are very influential in terms of concrete and mortars durability

# INTRODUCTION

- Objective of this presentation:
  - Study the properties and therefore the suitability of crushed fine aggregates from Cyprus used in the production of cementitious composite materials
  - Correlate the soundness coefficient with other physicomechanical properties
  - Correlate the quality of fine aggregates to the quality of cement mortars and concretes

# MATERIALS

University of Cyprus

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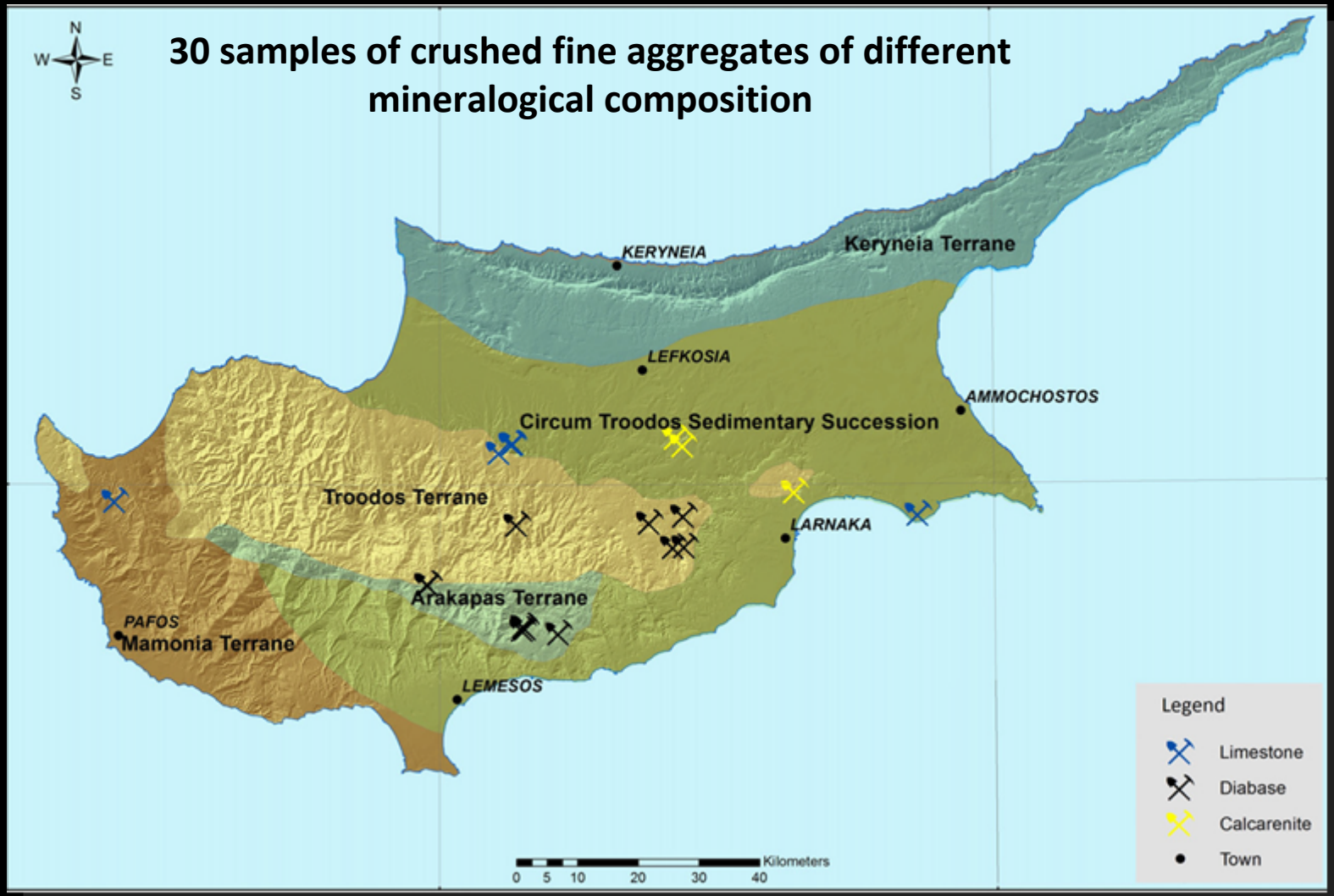
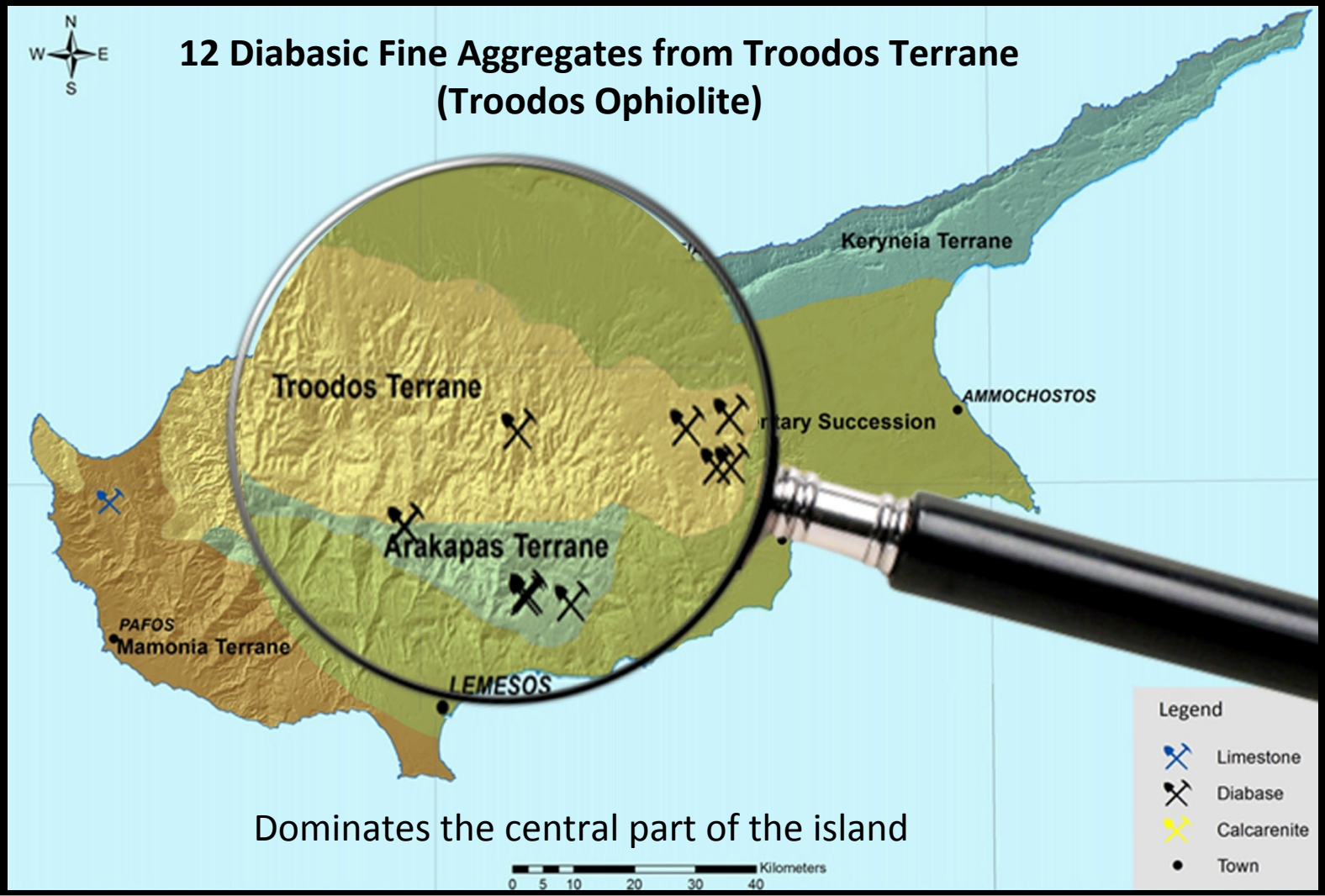
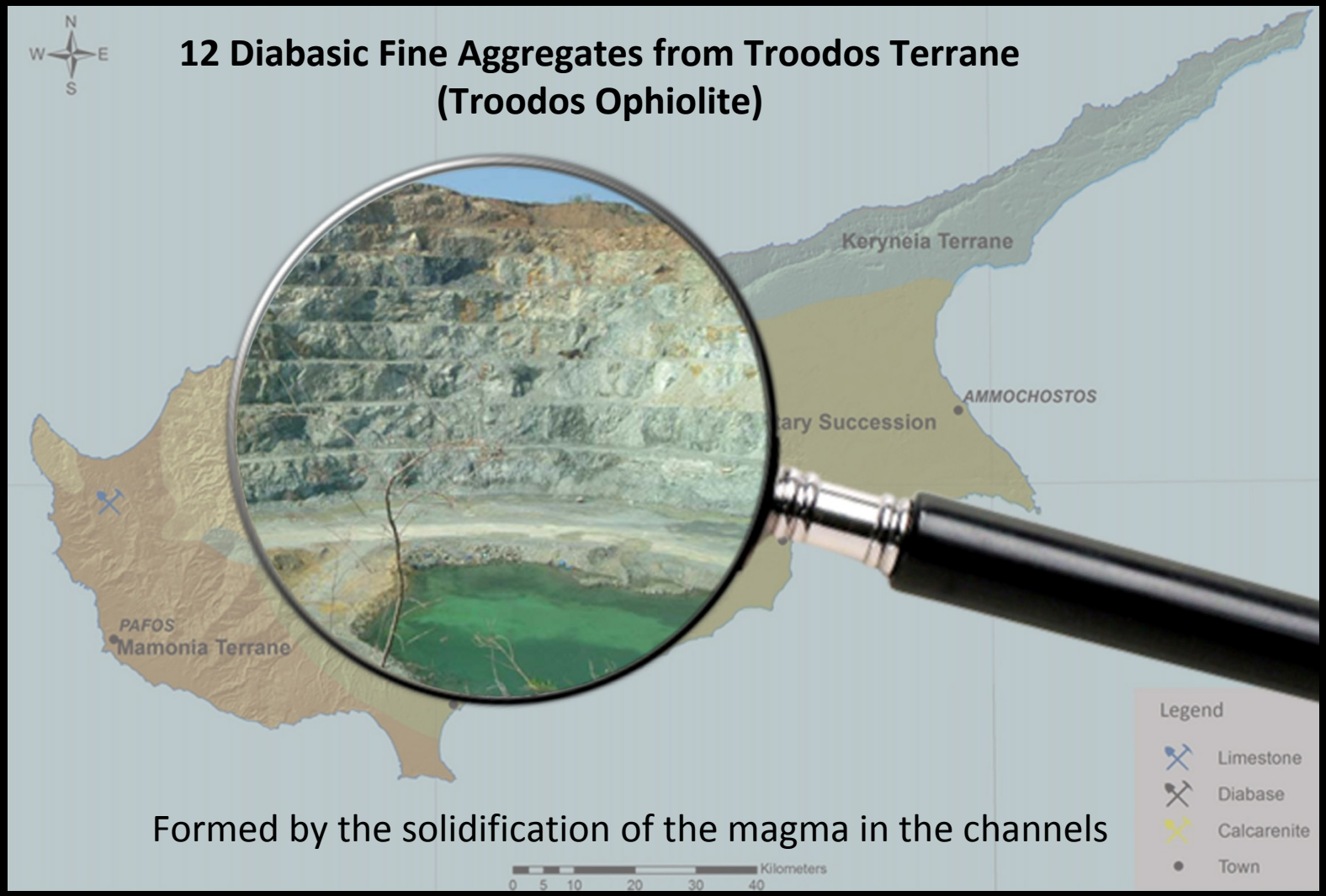

30 samples of crushed fine aggregates of different mineralogical composition
N
W
E
S
KERYNEIA
Keryneia Terrane
LEFKOSIA
AMMOCHOSTOS
Circum Troodos Sedimentary Succession
Troodos Terrane
LARNAKA
Arakapas Terrane
PAFOS
Mamonia Terrane
LEMESOS
Legend
Limestone
Diabase
Calcarenite
Town
Kilometers
0 5 10 20 30 40

# MATERIALS

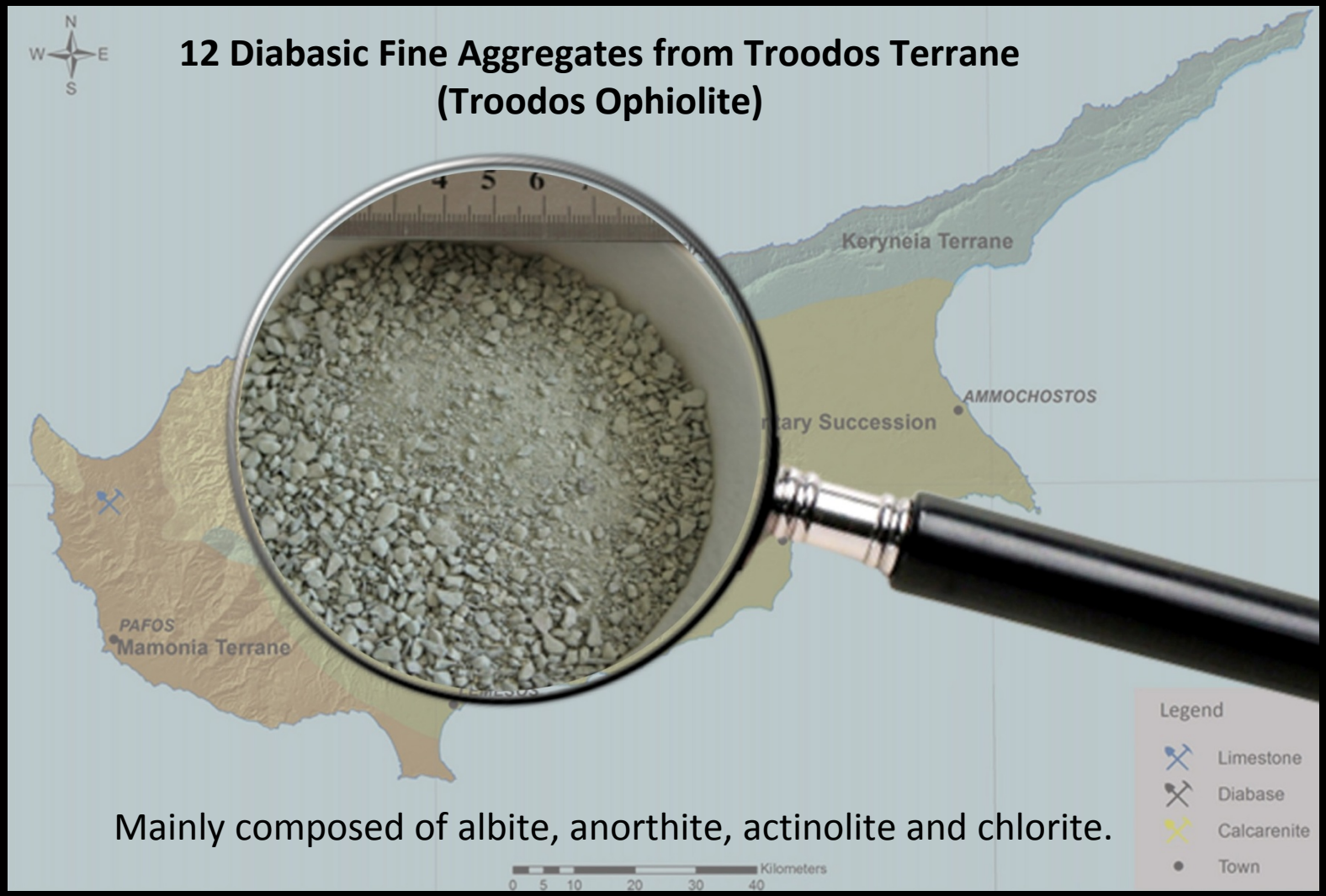



Dominates the central part of the island

# MATERIALS

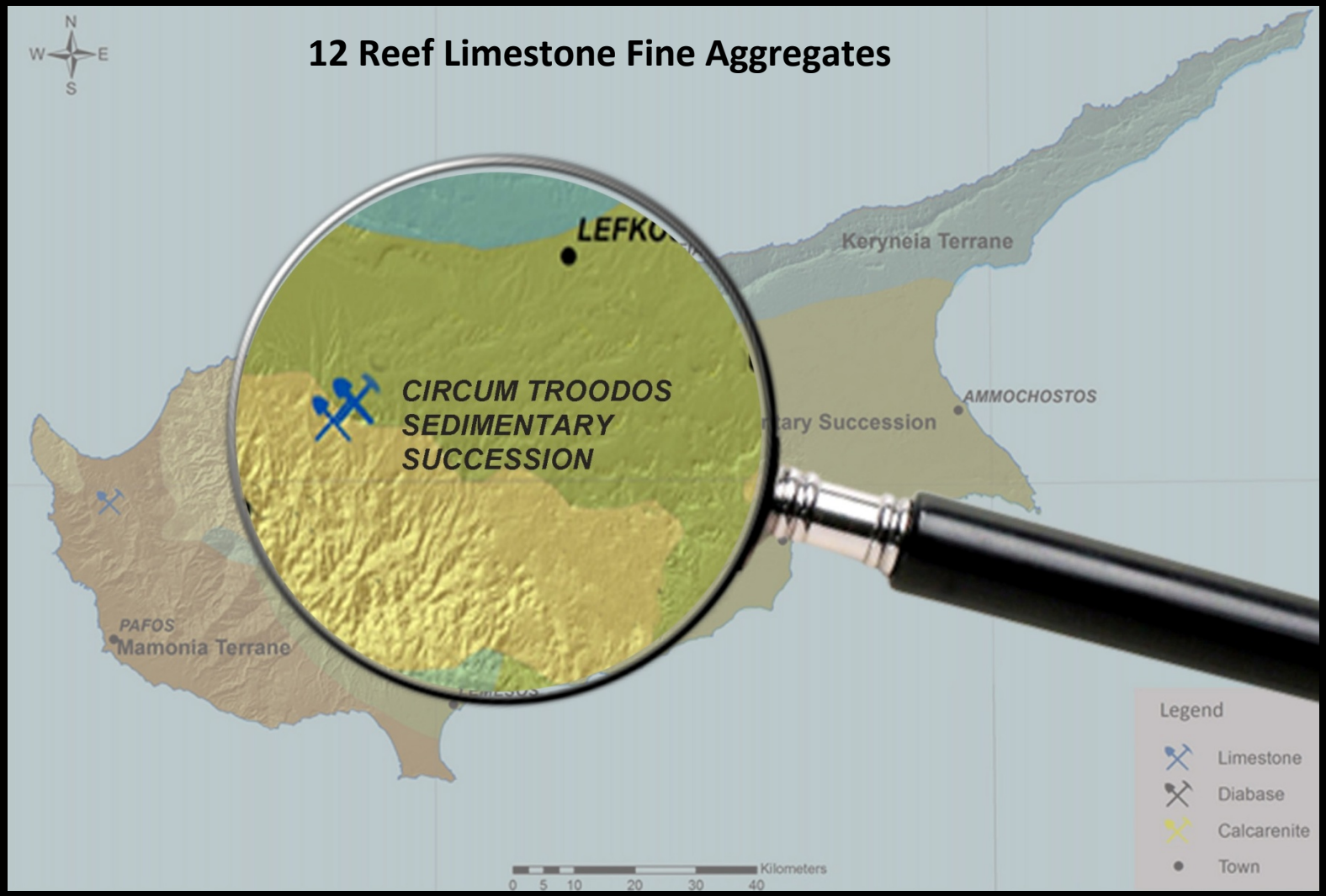

12 Diabasic Fine Aggregates from Troodos Terrane
(Troodos Ophiolite)
N
W
E
S
Keryneia Terrane
AMMOCHOSTOS
ary Succession
PAFOS
Mamonia Terrane
Legend
Limestone
Diabase
Calcarenite
Town
Kilometers
0 5 10 20 30 40
Formed by the solidification of the magma in the channels

# MATERIALS




Mainly composed of albite, anorthite, actinolite and chlorite.

# MATERIALS

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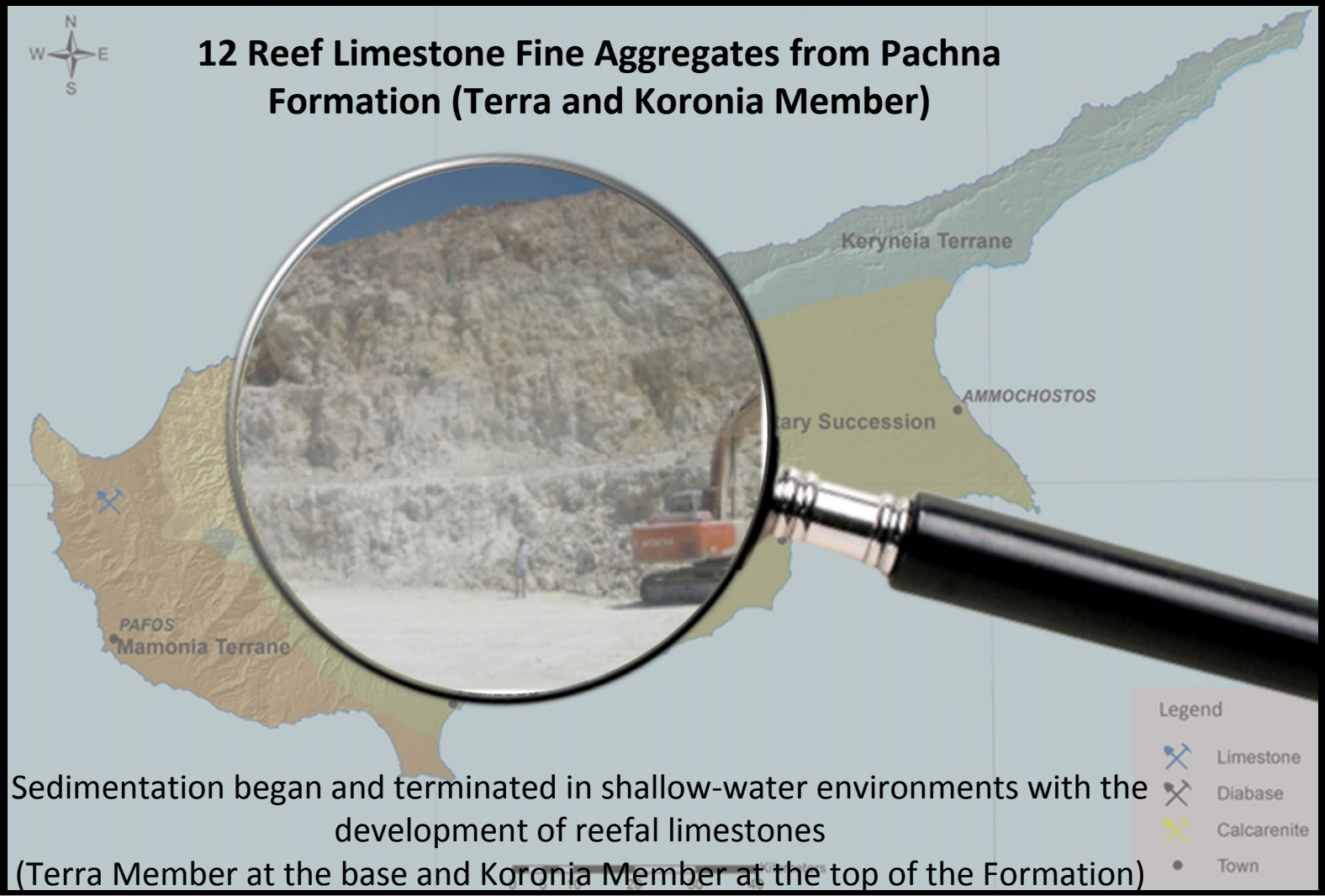
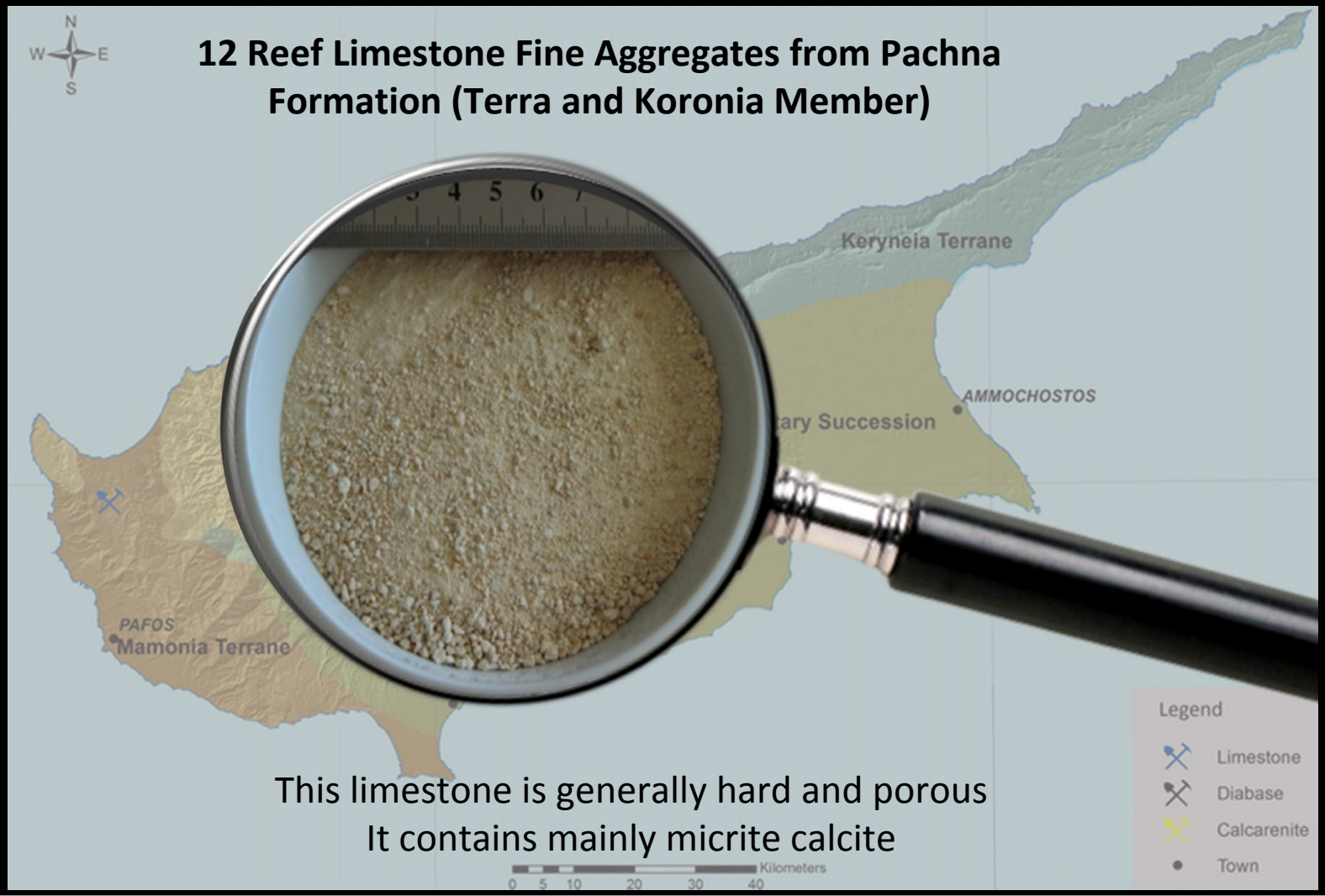
# MATERIALS

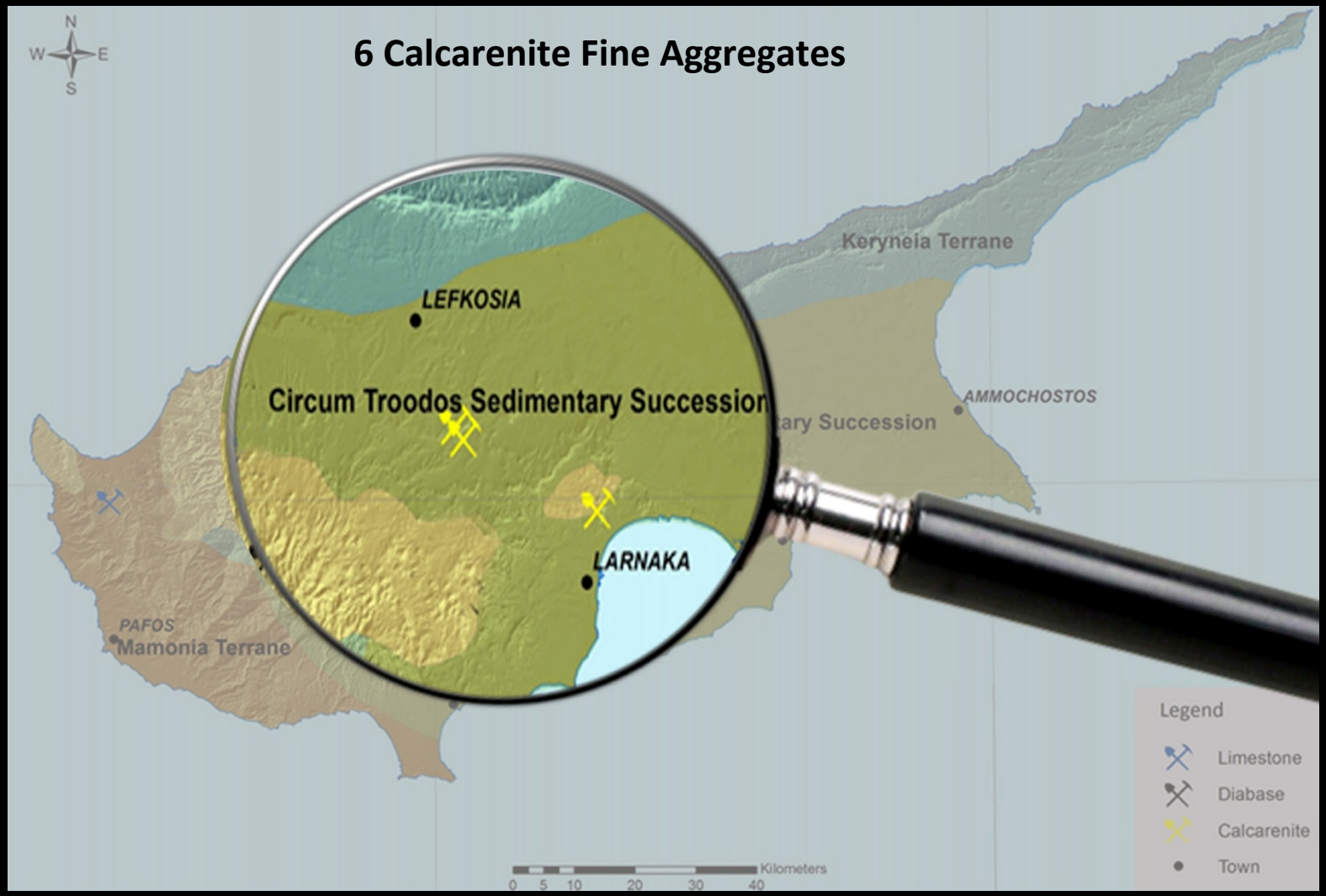



Sedimentation began and terminated in shallow-water environments with the development of reefal limestones
(Terra Member at the base and Koronia Member at the top of the Formation)

# MATERIALS


12 Reef Limestone Fine Aggregates from Pachna Formation (Terra and Koronia Member)
Keryneia Terrane
AMMOCHOSTOS
PAFOS
Mamonia Terrane
Legend
Limestone
Diabase
Calcarenite
Town
Kilometers
0 5 10 20 30 40
This limestone is generally hard and porous
It contains mainly micrite calcite

# MATERIALS


6 Calcarenite Fine Aggregates
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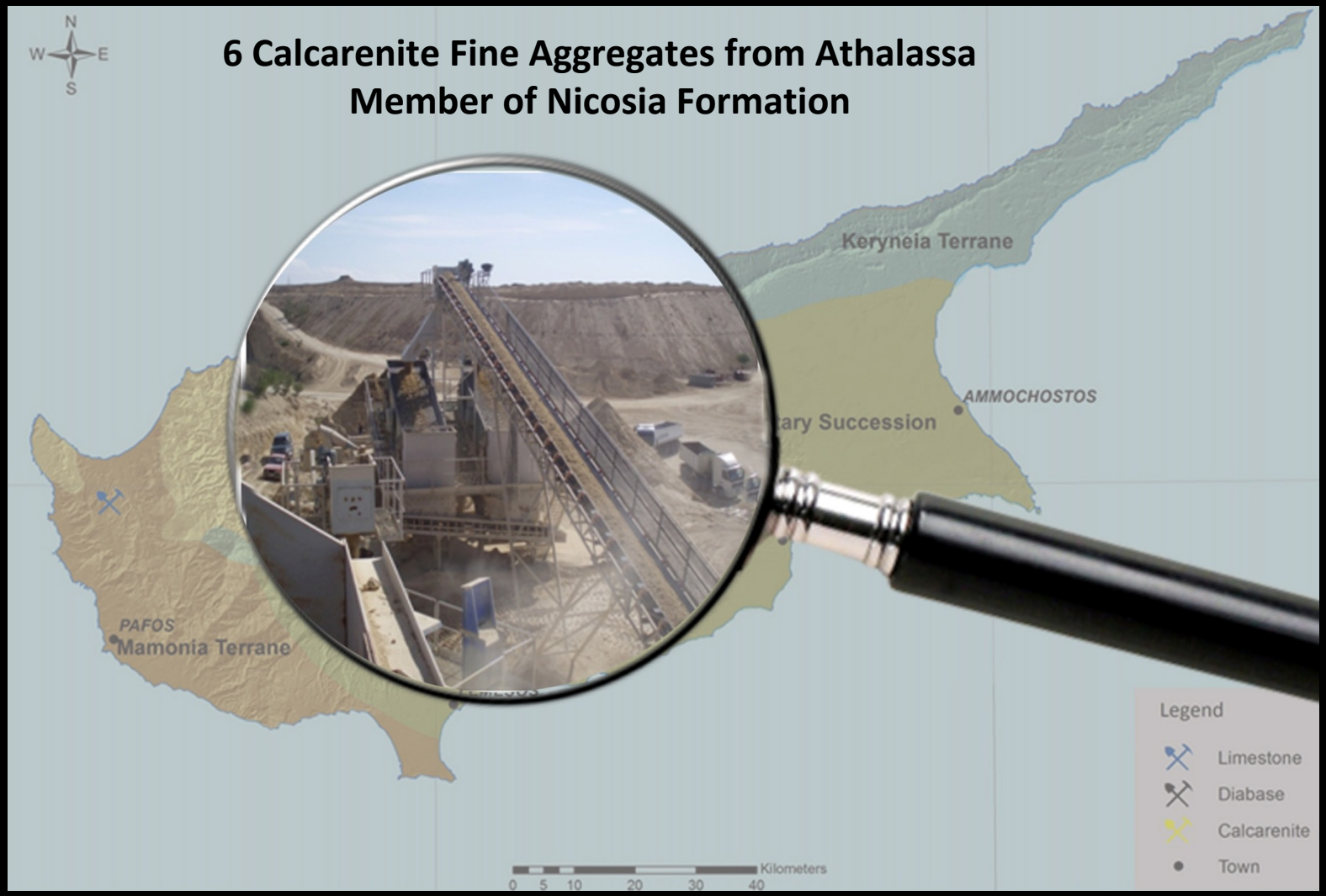
6 Calcarenite Fine Aggregates from Athalassa Member of Nicosia Formation
N
W
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Keryneia Terrane
AMMOCHOSTOS
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PAFOS
Mamonia Terrane
Legend
Limestone
Diabase
Calcarenite
Town
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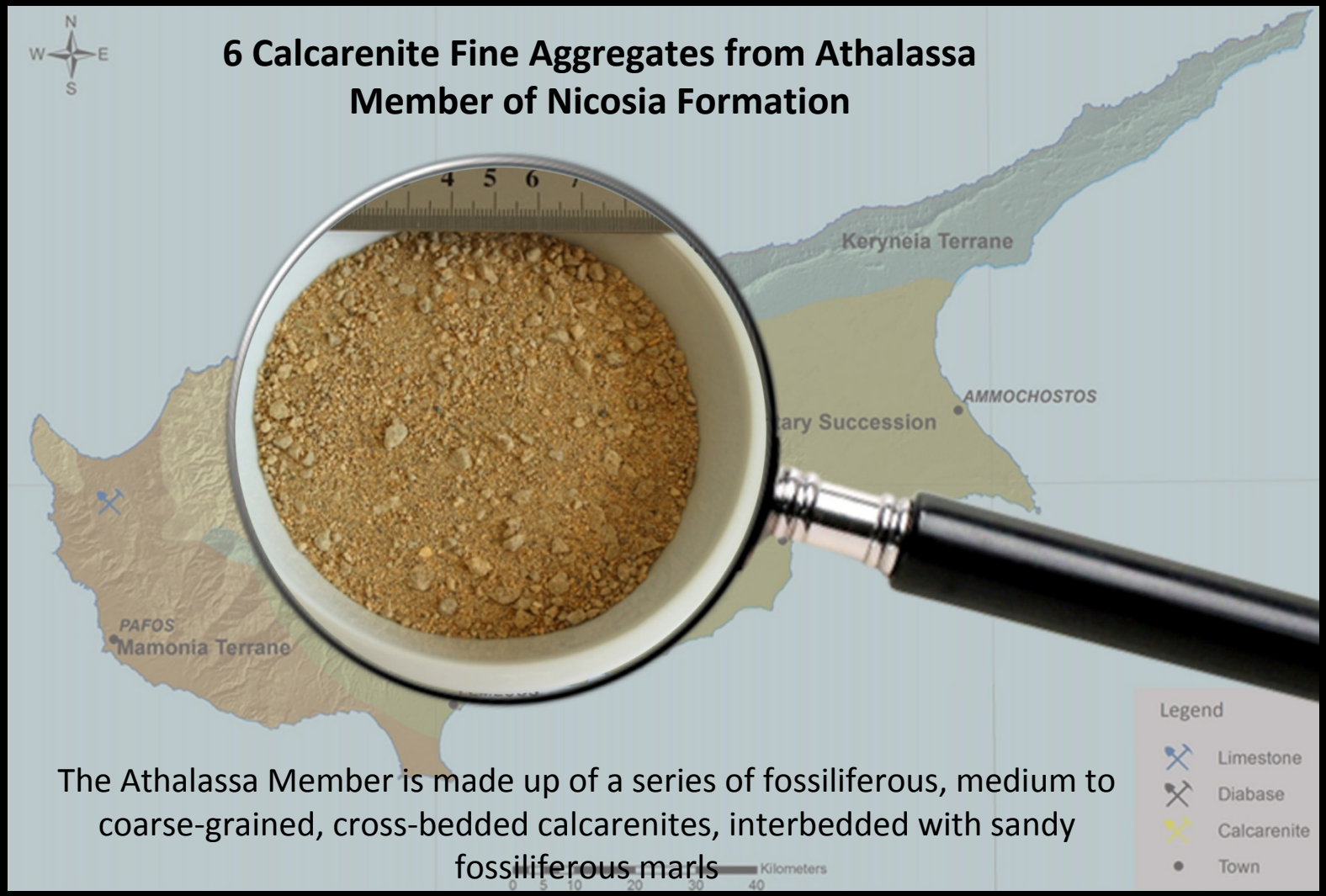



The Athalassa Member is made up of a series of fossiliferous, medium to coarse-grained, cross-bedded calcarenites, interbedded with sandy fossiliferous marls

# METHODOLOGY

The aggregate tests that were carried out in two different laboratories included:

- ***EN 1097-6***
  Tests for the mechanical and physical properties of aggregates – Part 6: Determination of particle density and **water absorption**

- ***EN 933-8***
  Tests for the geometrical properties of aggregates – Part 8: Assessment of fines – **Sand Equivalent test**

- ***EN 933-9***
  Tests for the geometrical properties of aggregates – Part 9: Assessment of fines – **Methylene blue test**

- ***EN 1367-2***
  Tests for thermal and weathering properties of aggregates. **Magnesium sulfate test**

- ***ASTM C88***
  Standard test method for soundness of aggregates by use of **sodium sulfate or magnesium sulfate**

- ***ASTM D7428***
  Standard test method for resistance of fine aggregate to degradation by abrasion in the **Micro-Deval** apparatus

# METHODOLOGY

***EN 1097-6***

**Tests for the mechanical and physical properties of aggregates – Part 6: Determination of particle density and water absorption**

- Determines the quantity of water that can be absorbed by aggregates
- It is useful for determining the required amount of water in concrete and mortar mix design

# METHODOLOGY

***EN 933-8***

**Tests for the geometrical properties of aggregates – Part 8: Assessment of fines – Sand Equivalent test**

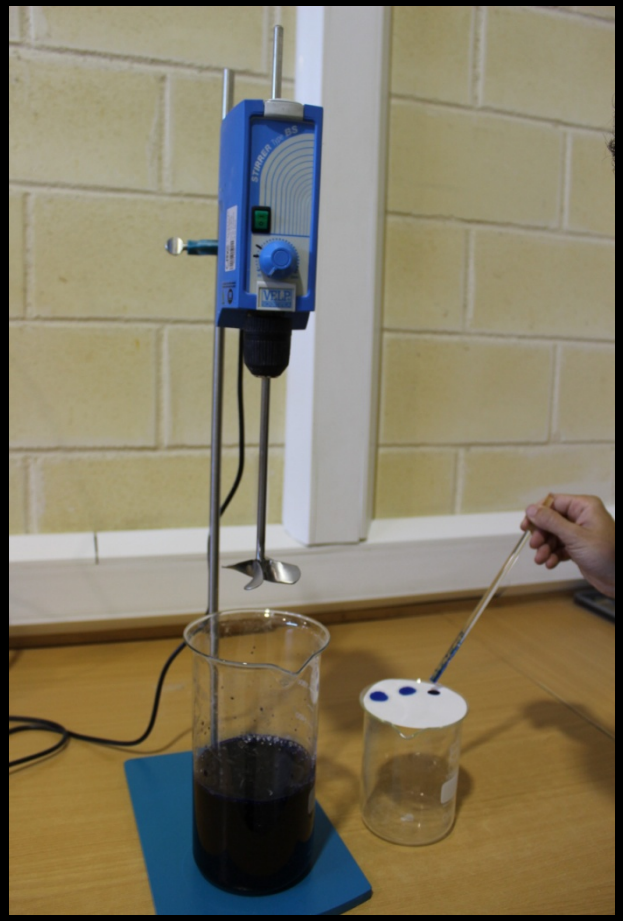
- Determination of the presence of fines (<63 μm)
- This test is not suitable for finding the active clay minerals

# METHODOLOGY

***EN 933-9***

**Tests for the geometrical properties of aggregates – Part 9: Assessment of fines – Methylene blue test**

- Verifies the activity of clay minerals
- Active clay minerals tend to swell, depending on their water content
- Swelling may have devastating consequences for both mortars and concrete



# METHODOLOGY

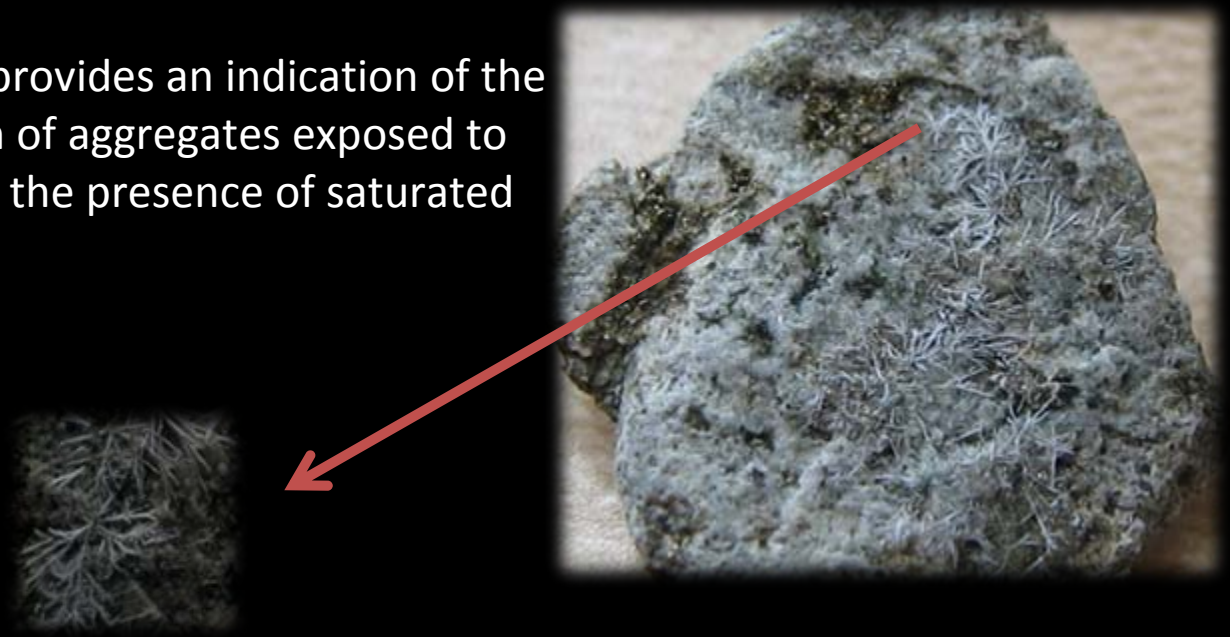
- ***EN 1367-2***

**Tests for thermal and weathering properties of aggregates. Magnesium sulfate test.**

- ***ASTM C88***

**Standard test method for soundness of aggregates by use of sodium sulfate or magnesium sulfate**

- The soundness test provides an indication of the chemical degradation of aggregates exposed to wetting and drying in the presence of saturated sulfate salt solutions



# METHODOLOGY

***ASTM D7428 - 08***

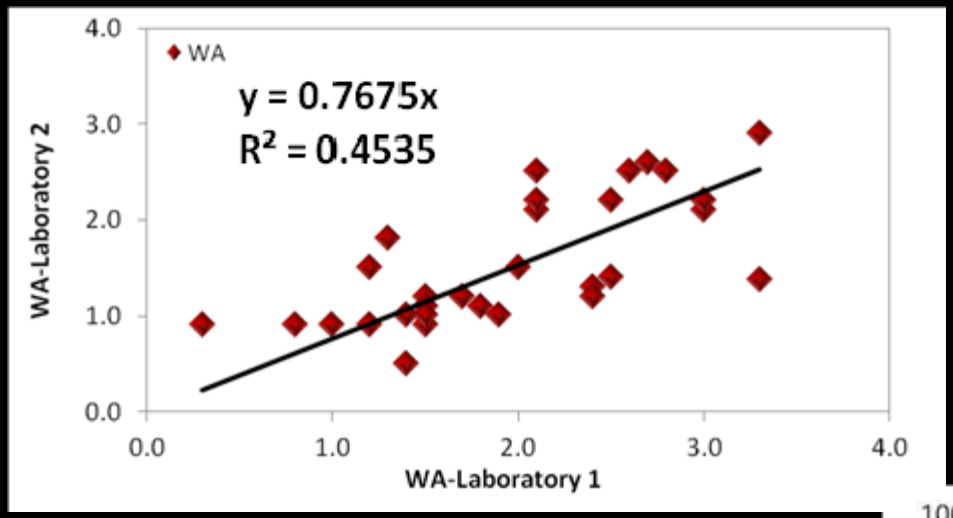
**Standard test method for resistance of fine aggregate to degradation by abrasion in the Micro-Deval apparatus**

- Determines the resistance of aggregates to a combination of actions, including friction and abrasive contact with steel balls, in the presence of water

- The Micro-Deval test is considered by many researchers to be of particular importance to the performance of the final product

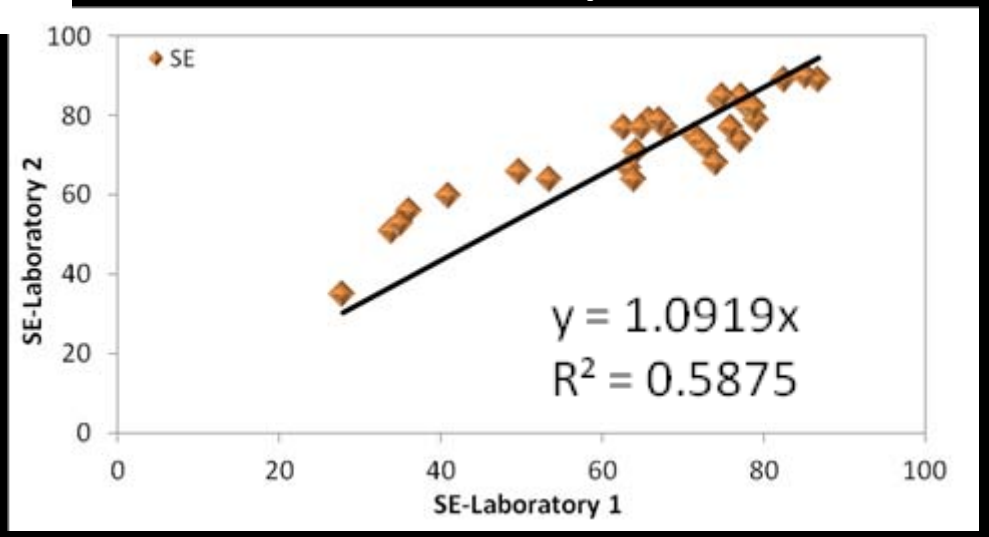
# RESULTS

## Interlaboratory correlations between the properties of fine aggregates



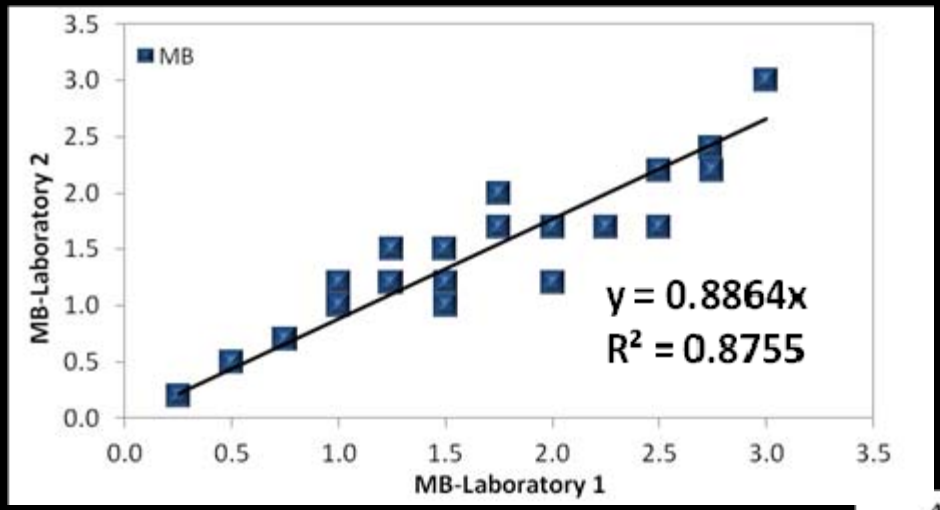

**Water Absorption**

**Sand Equivalent**



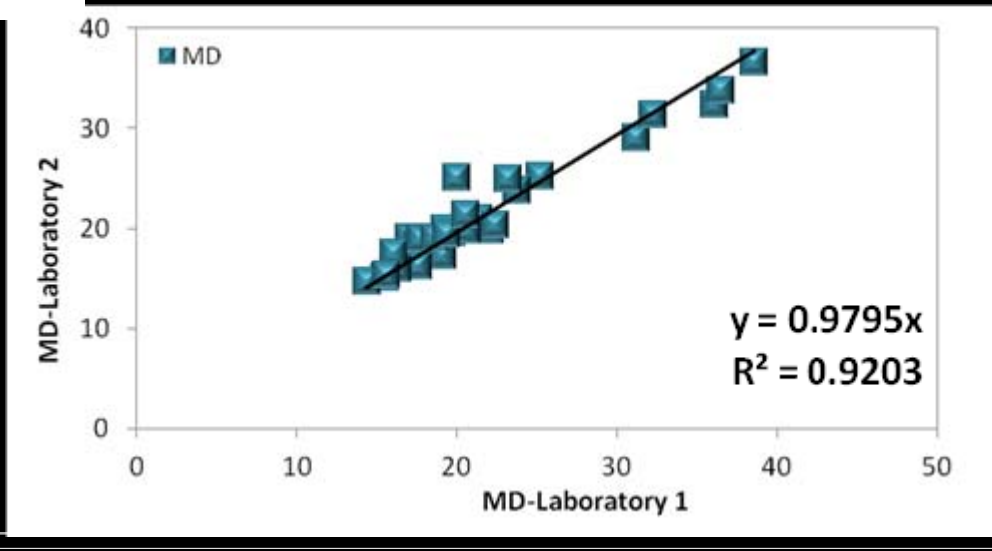
# RESULTS

## Interlaboratory correlations between the properties of fine aggregates




**Methylene Blue**

**Micro Deval**



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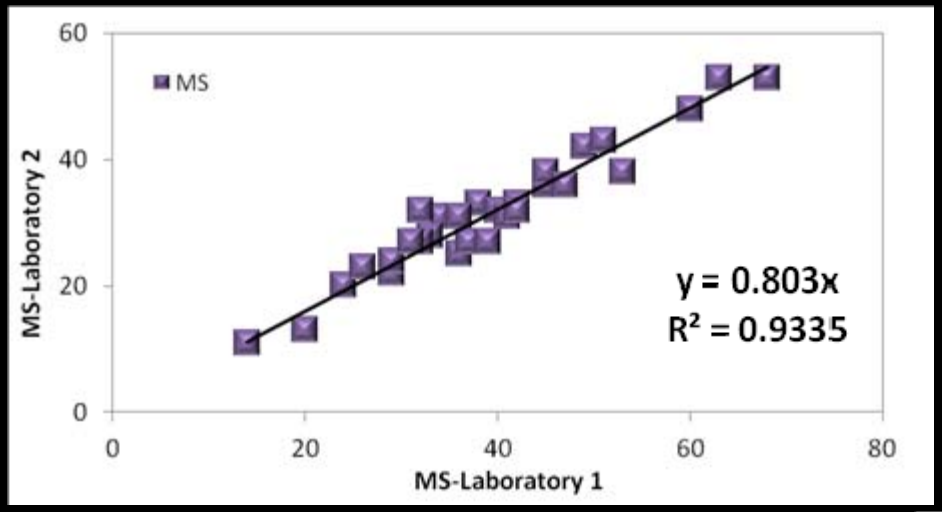
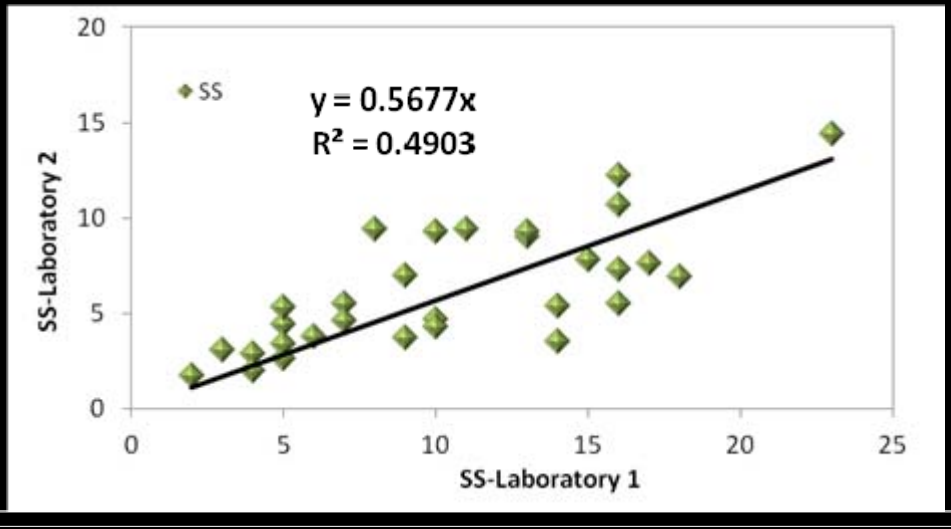


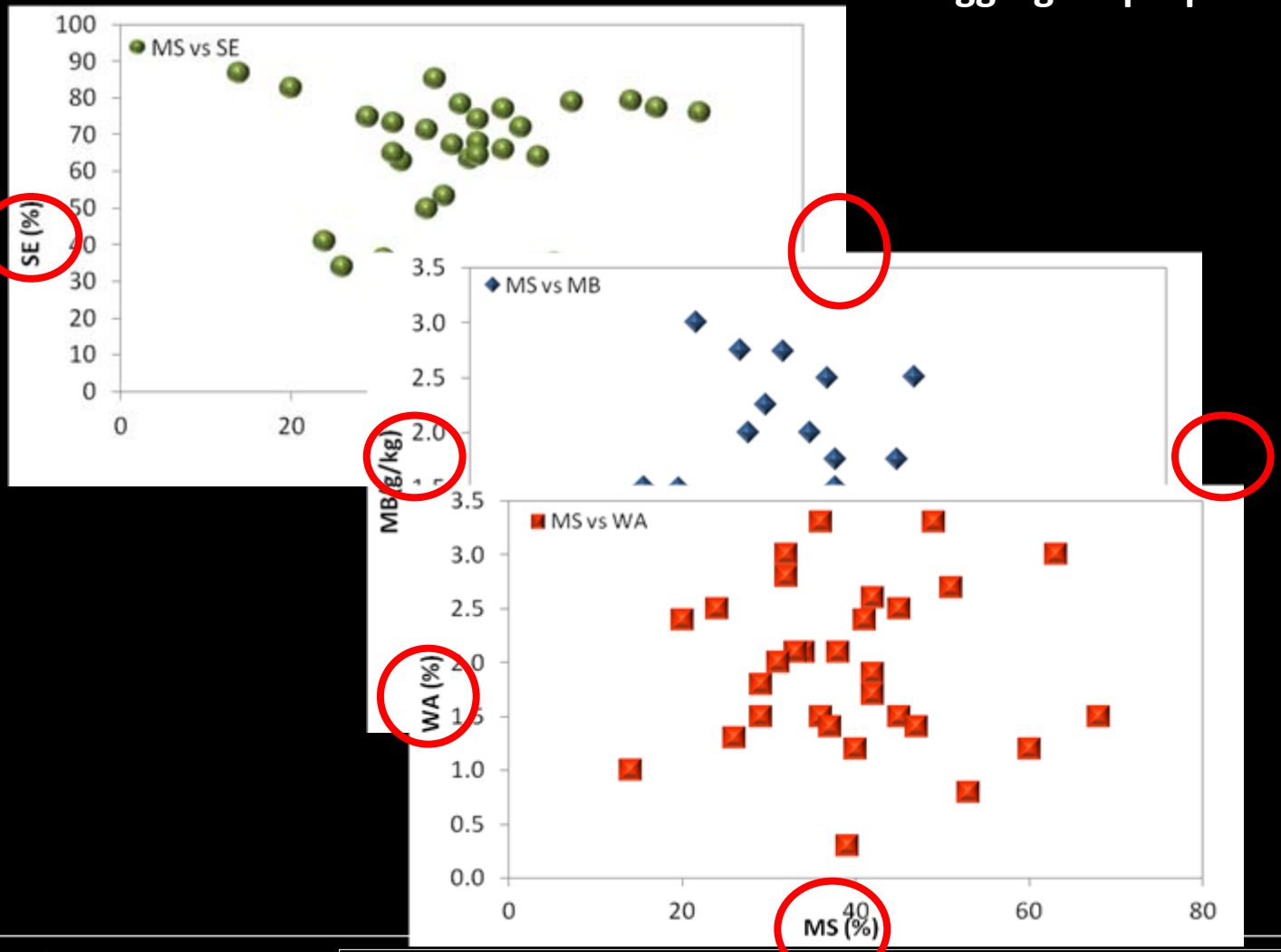

**Magnesium Sulfate**

**Sodium Sulfate**



# RESULTS

## Correlations between aggregate properties



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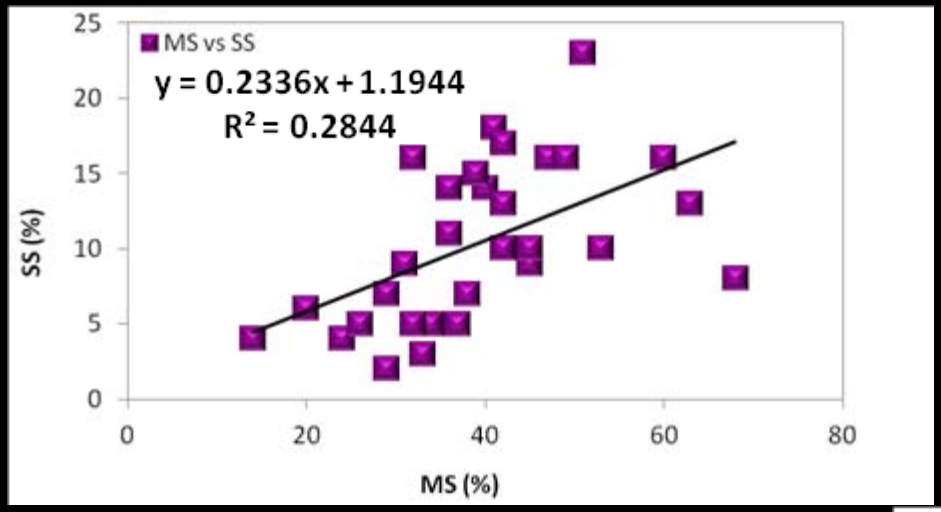


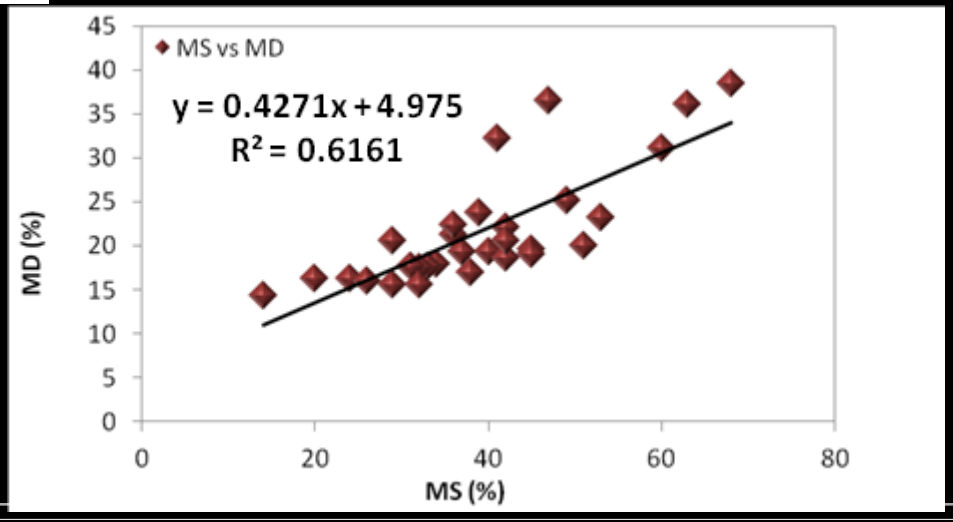

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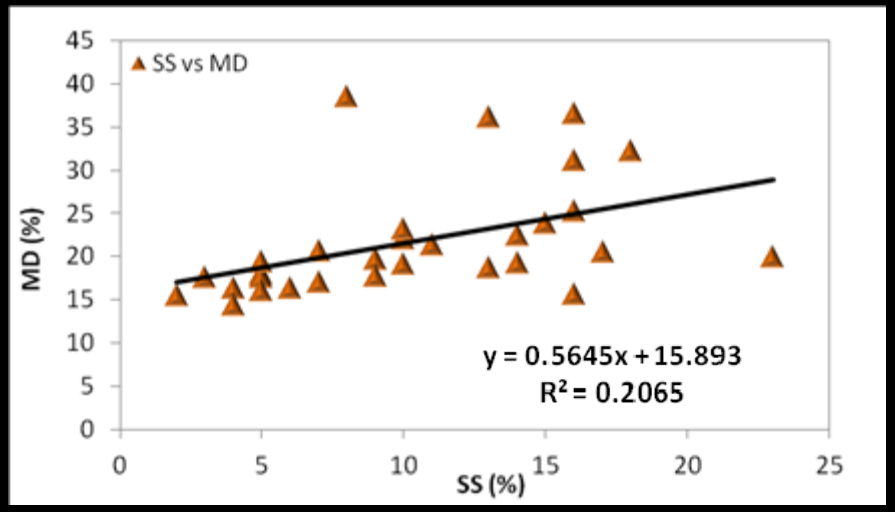


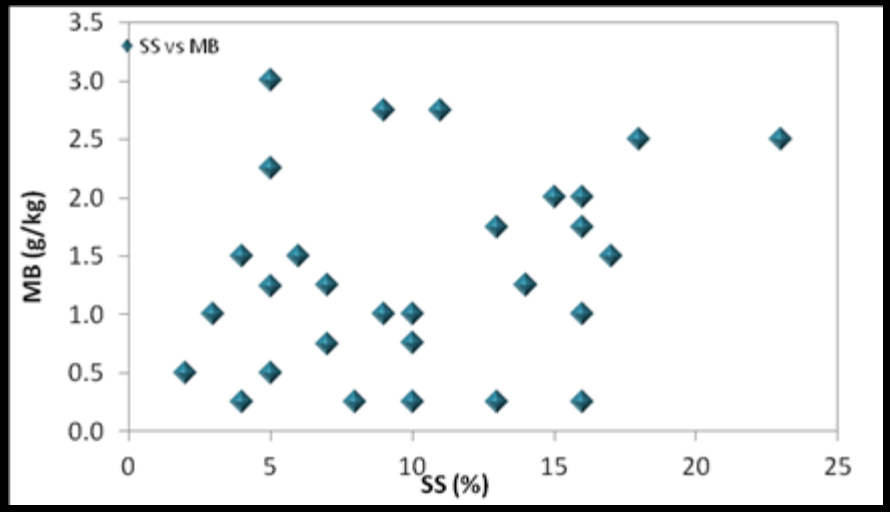


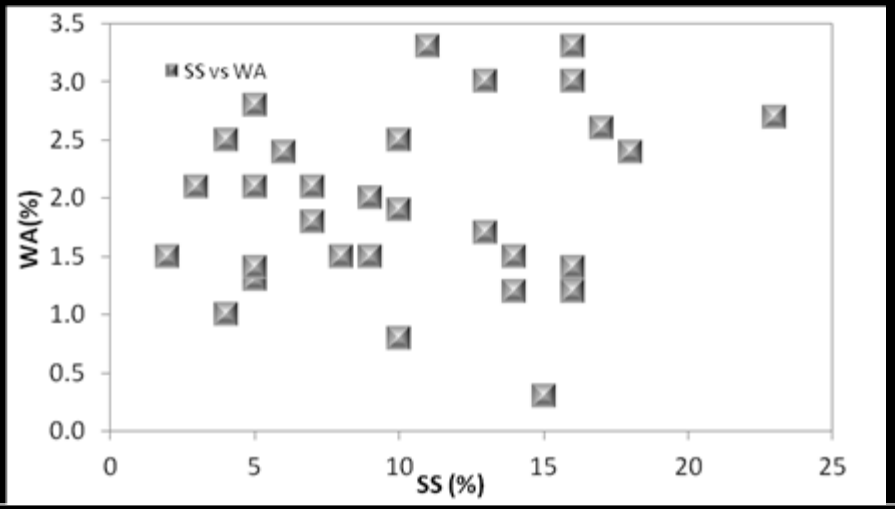


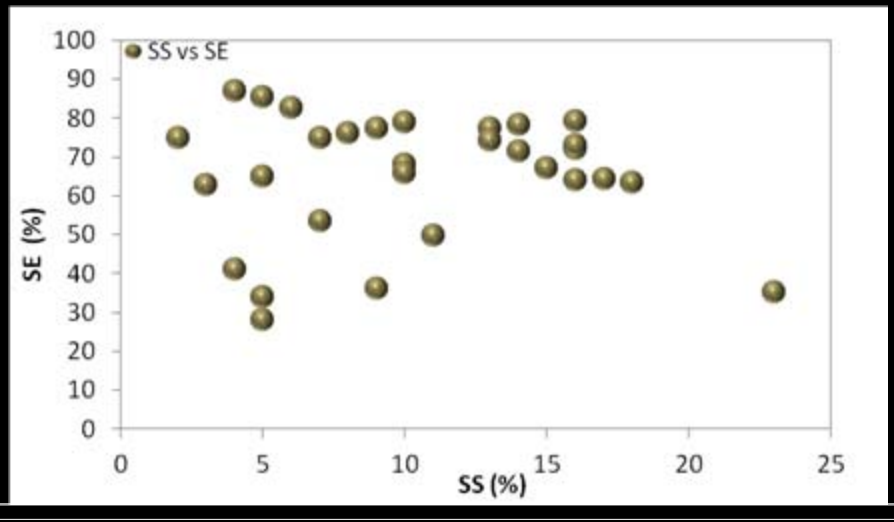


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# RESULTS

In order to study the effect of aggregate properties on the quality of mortar:

- Six series of cement mortars with aggregates of known physicomechanical properties were designed and cast in the laboratory
  - Three mixes (M1, M2, M3) with diabase aggregates (D1, D2, D3)
  - Two mixes (M4, M5) with reef limestone aggregates (L4, L5)
  - One mix (M6) with calcarenite aggregates (C6)

| Samples | Mortar | SE (%) | MB(%) | WA(%) | MS(% | SS(%) | MD(%) |
|---|---|---|---|---|---|---|---|
| D1 | M1 | 66 | 3.7 | 3.7 | 61 | 12 | 27.0 |
| D2 | M2 | 41 | 1.5 | 2.5 | 24 | 4 | 16.3 |
| D3 | M3 | 50 | 2.7 | 3.3 | 36 | 11 | 21.4 |
| L4 | M4 | 87 | 0.2 | 1.0 | 14 | 4 | 14.4 |
| L5 | M5 | 77 | 0.2 | 3.0 | 63 | 13 | 36.1 |
| C6 | M6 | 77 | 1.0 | 1.5 | 45 | 9 | 19.7 |

# RESULTS

In order to study the effect of aggregate properties on the quality of concrete:

- Five mixes with the same fine aggregates were designed and cast in the laboratory
  - Three mixes (C1, C2, C3) with diabase aggregates (D1, D2, D3)
  - Two mixes (C4, C5) with reef limestone aggregates (L4, L5)

| Samples | Concrete | SE (%) | MB(%) | WA(%) | MS(%) | SS(%) | MD(%) |
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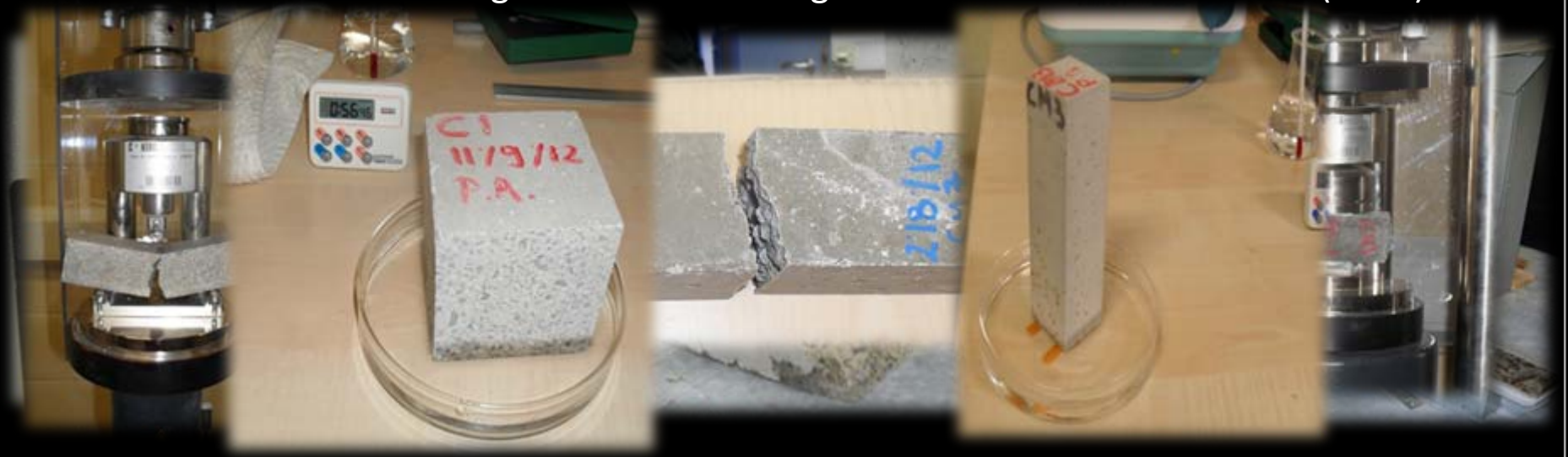
| L4 | C4 | 87 | 0.2 | 1.0 | 14 | 4 | 14.4 |
| L5 | C5 | 77 | 0.2 | 3.0 | 63 | 13 | 36.1 |

# RESULTS

The concretes and mortars were tested at certain time intervals (28, 56 and 90 days), in order to determine:

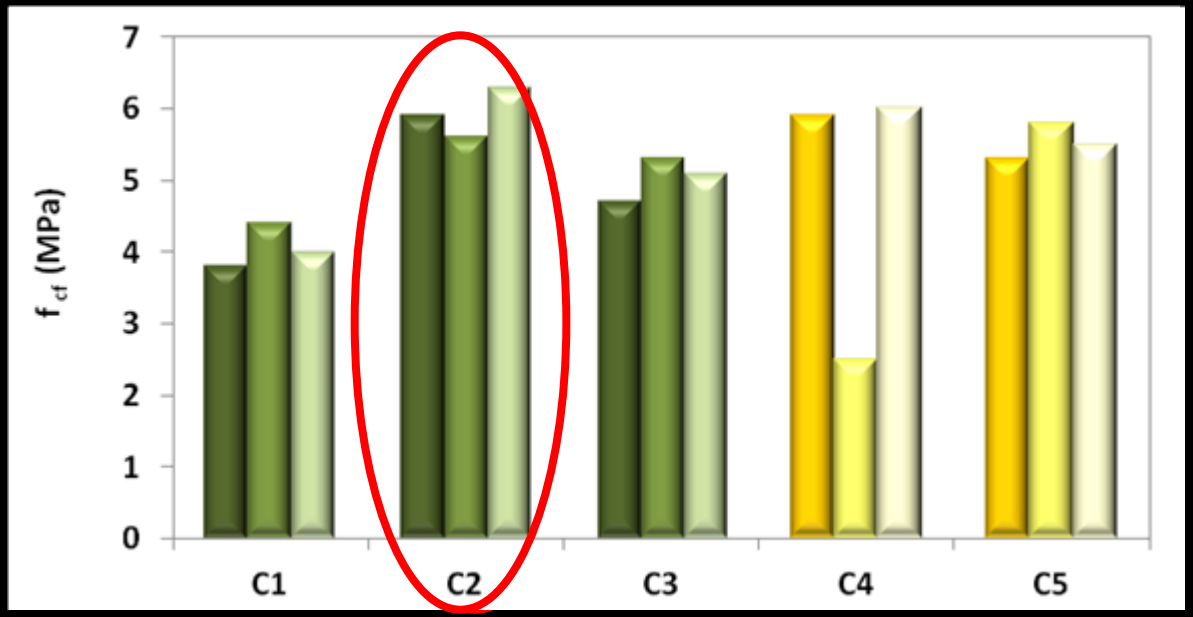
- their compressive and flexural strength
  - on concrete : according to the procedures outlined in EN 12390-3 and EN 12390-5 respectively
  - on cement mortars according to EN 1015-11

- their porosity and sorptivity
  - according to the methodologies described in Hall and Hoff (2012)



# RESULTS

•Concrete (C2) prepared with the better quality diabase aggregate (D2) shows higher compressive and flexural strengths than concretes (C1 and C3) prepared with the poor quality diabase aggregate (D1 and D3)

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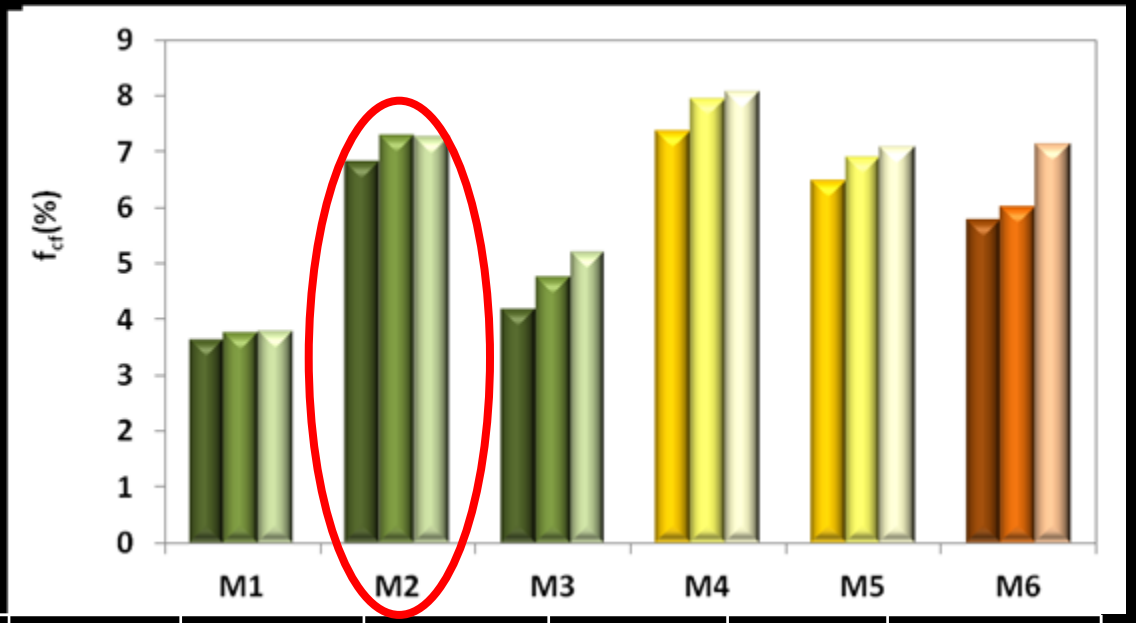
|---|---|---|---|---|---|---|---|---|
| D1 | M1 | C1 | 66 | 3.7 | 3.7 | 61 | 12 | 27.0 |
| D2 | M2 | C2 | 41 | 1.5 | 2.5 | 24 | 4 | 16.3 |
| D3 | M3 | C3 | 50 | 2.7 | 3.3 | 36 | 11 | 21.4 |

# RESULTS

•Mortar(M2) prepared with the better quality diabase aggregate (D2) shows higher compressive and flexural strengths than mortars (M1 and M3) prepared with the poor quality diabase aggregate (D1 and D3)

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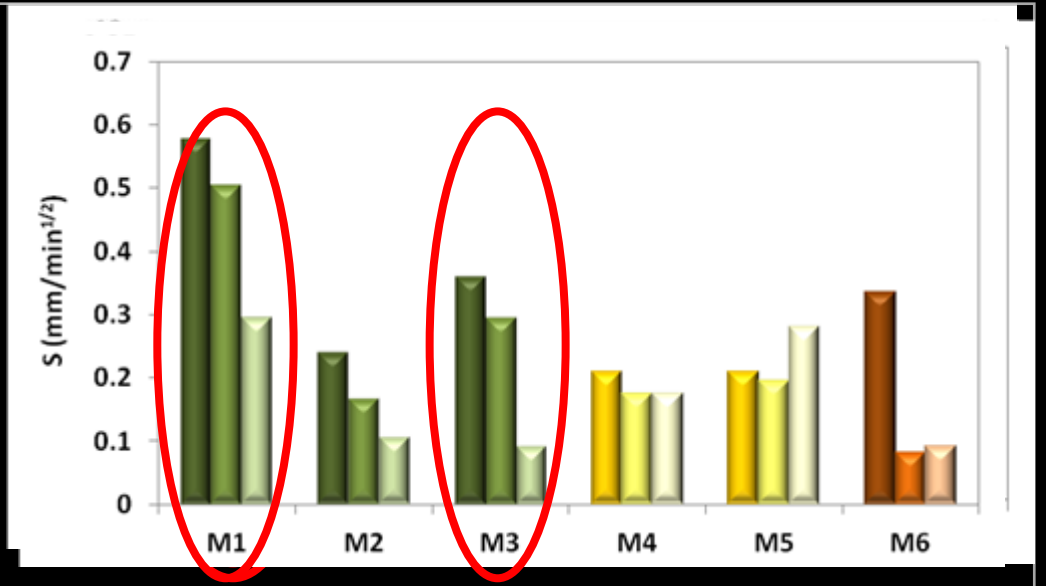
| D2 | M2 | C2 | 41 | 1.5 | 2.5 | 24 | 4 | 16.3 |
| D3 | M3 | C3 | 50 | 2.7 | 3.3 | 36 | 11 | 21.4 |

# RESULTS

- Similar results were obtained for the physical properties (porosity and sorptivity) on the concretes and mortars prepared with diabase aggregates

- The poor quality aggregates (D1 and D3) resulted in higher porosities and sorptivities

- These results are possibly attributed to the higher soundness coefficient and water absorption of the poor quality aggregates

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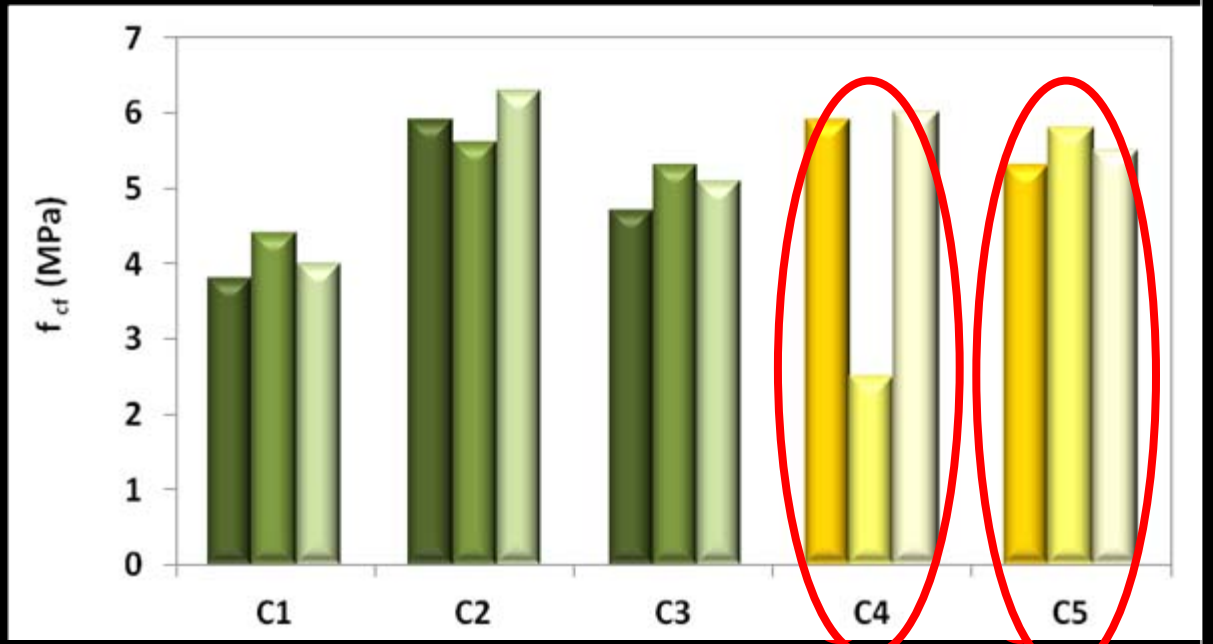
| D3 | M3 | C3 | 50 | 2.7 | 3.3 | 36 | 11 | 21.4 |

# RESULTS

•Concretes (C4 and C5) prepared with reef limestone aggregates

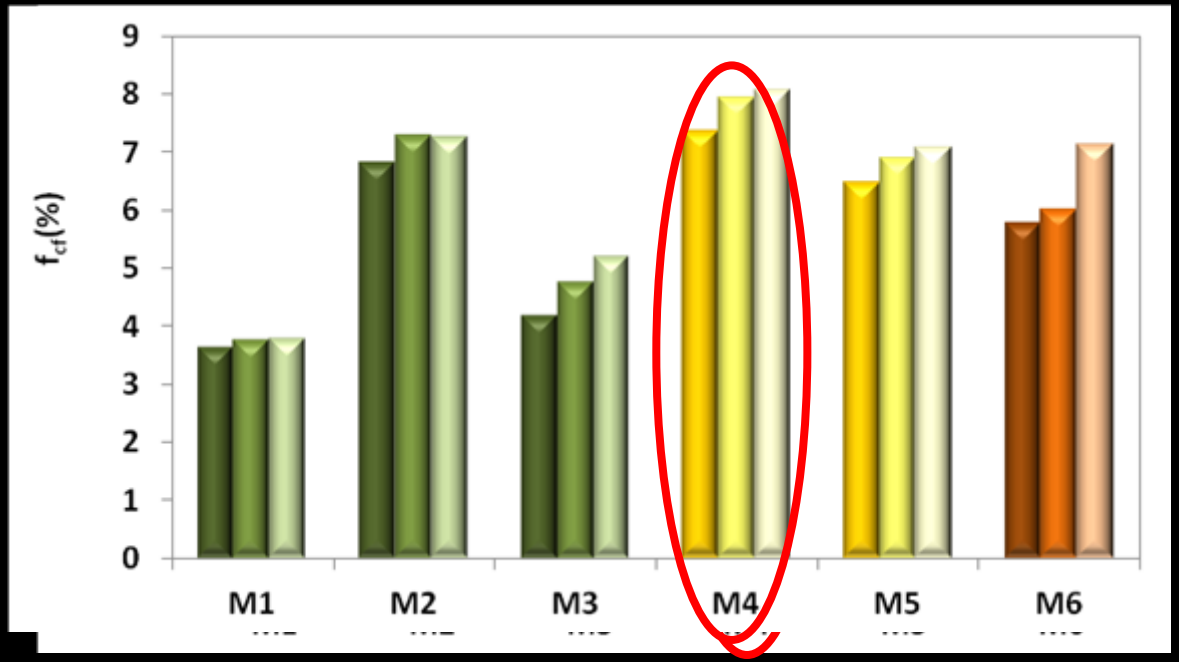
•no significant variations in compressive and flexural strength were observed, irrespective of the quality of aggregates used




| Samples | Concrete | SE (%) | MB(%) | WA(%) | MS(%) | SS(%) | MD(%) |
|---|---|---|---|---|---|---|---|
| L4 | C4 | 87 | 0.2 | 1.0 | 14 | 4 | 14.4 |
| L5 | C5 | 77 | 0.2 | 3.0 | 63 | 13 | 36.1 |
| C6 | C6 | 77 | 1.0 | 1.5 | 45 | 9 | 19.7 |

# RESULTS

- Mortars (M4) prepared with good quality (L4) reef limestone aggregates
  - show higher compressive and flexural strengths than mortars (M5) prepared with the poor quality reef limestone aggregates (L5)

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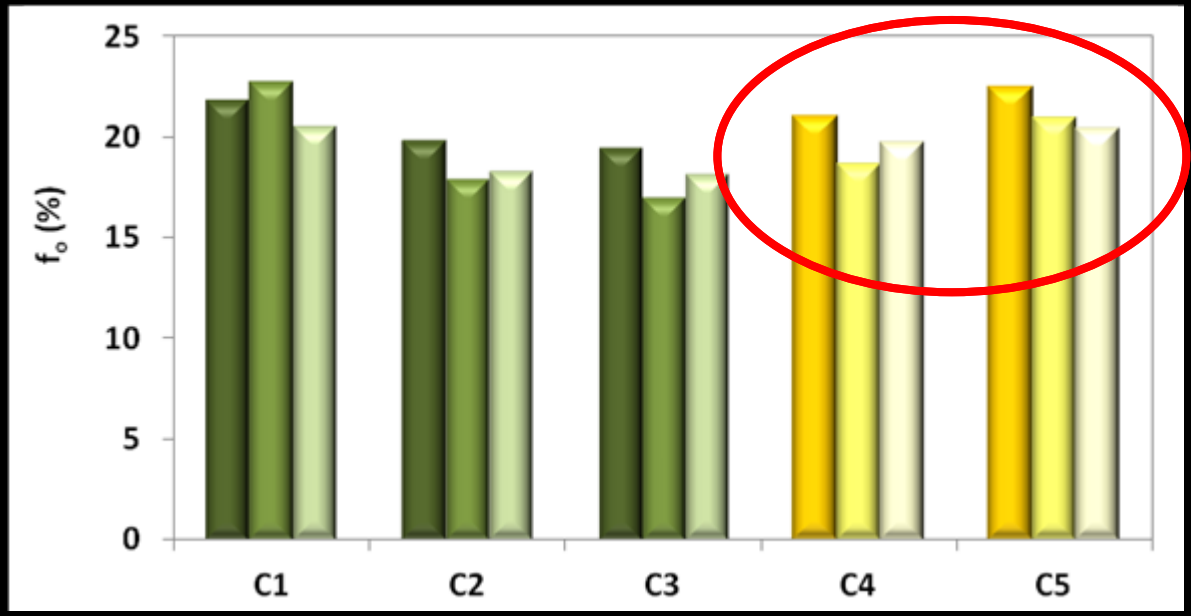
# RESULTS

Slight differences in the physical properties (porosity and sorptivity) of concrete were noted

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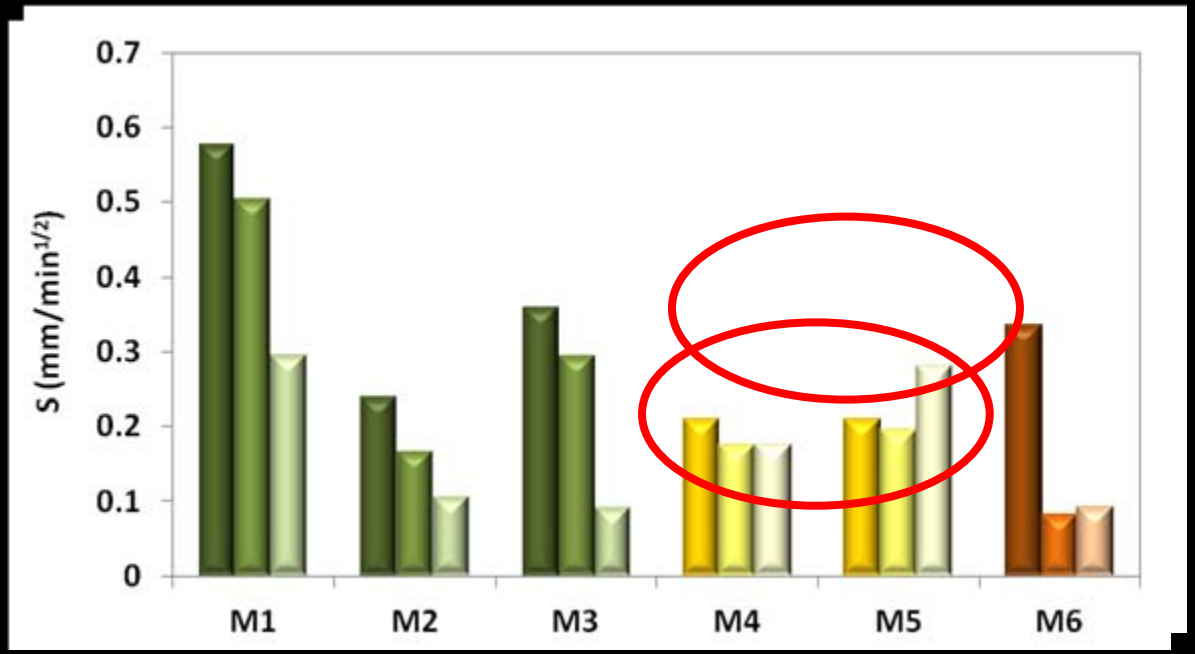
# RESULTS

Slight differences in the physical properties (porosity and sorptivity) of mortar were noted

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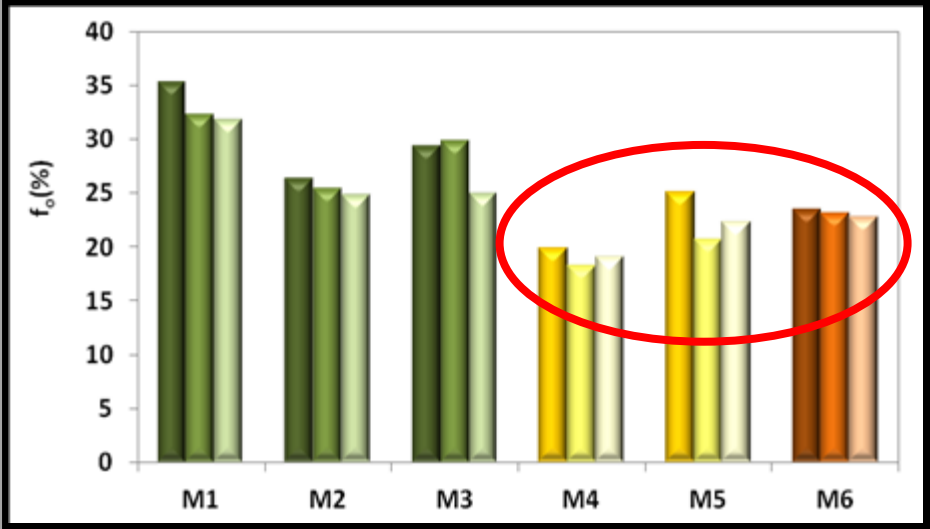
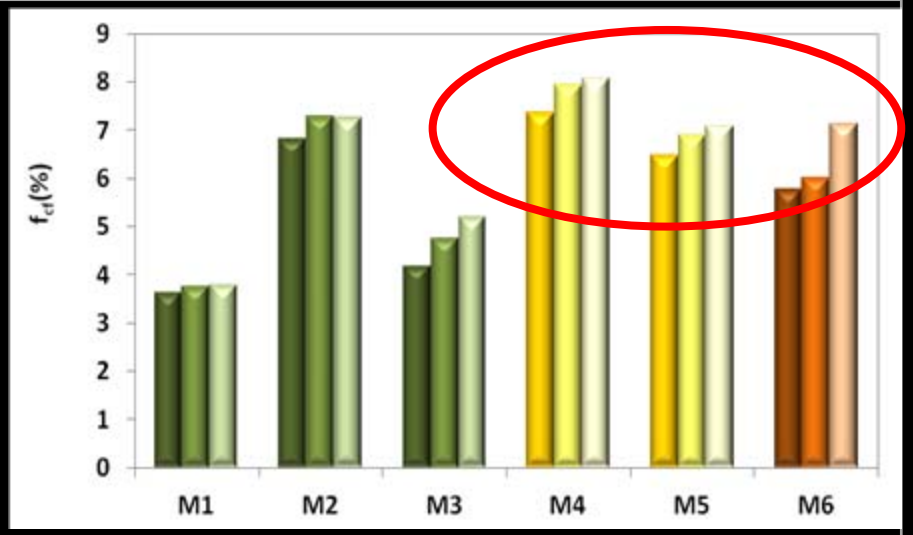
| C6 | M6 | 77 | 1.0 | 1.5 | 45 | 9 | 19.7 |

# RESULTS




•The mortar (M6) prepared with the calcarenite fine aggregate (C6) showed similar results to the mortars prepared with the reef limestone aggregates, despite the former being of a much finer gradation.

•This is likely attributed to the similar mineralogical composition of the calcarenite and reef limestone aggregates. In both types the dominant mineral present is calcite.

| Samples | Mortar | SE (%) | MB(%) | WA(%) | MS(%) | SS(%) | MD(%) |
|---|---|---|---|---|---|---|---|
| L4 | C4 | 87 | 0.2 | 1.0 | 14 | 4 | 14.4 |
| L5 | C5 | 77 | 0.2 | 3.0 | 63 | 13 | 36.1 |
| C6 | M6 | 77 | 1.0 | 1.5 | 45 | 9 | 19.7 |

# CONCLUSIONS

•Excellent interlaboratory correlations between the results of the magnesium sulfate, methylene blue and Micro-Deval tests; weaker correlations were observed for the water absorption, sand equivalent and sodium sulfate tests

•Good correlation between the results of the magnesium sulfate and Micro-Deval tests; a rather weak correlation was observed between the two soundness tests, while no other correlations between aggregates properties were noted

•The effect of aggregate quality on the quality of the end product was clearly evident in the case of mortars and concretes prepared with diabase aggregates

•A similar effect was also noted in some of the properties of reef limestone aggregate mortars and concretes

•These preliminary results show that a careful selection of aggregates is needed before designing a mortar and/or concrete mixture, as their durability may affect the performance of the end product in the long term

# Thank you for your attention

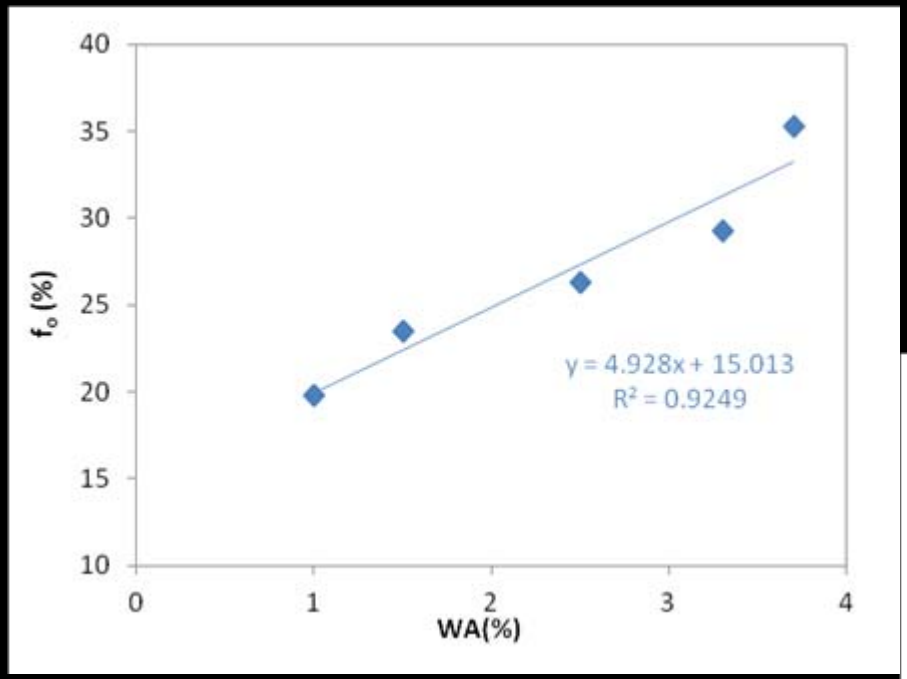
# Concrete – Mix Design

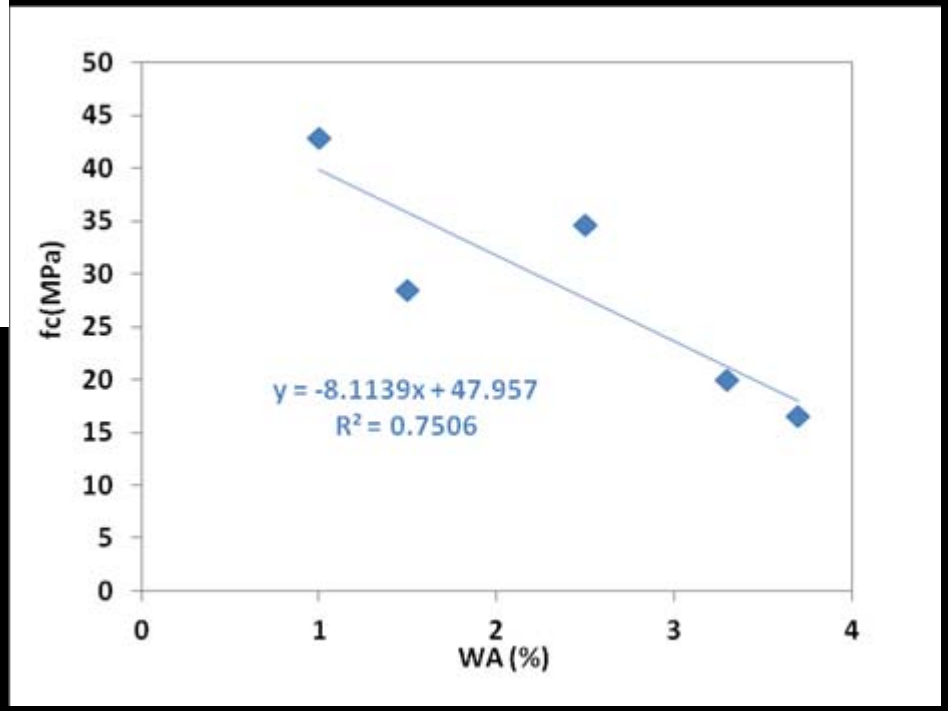
| | C1 | C2 | C3 | C4 | C5 |
|---|---|---|---|---|---|
| Cement (kg) | 24.02 | 24 | 24.5 | 24 | 24.9 |
| Aggregate 8/20 (kg) | 43.23 | 47 | 46 | 46 | 45.1 |
| Aggregate 4/10 (kg) | 21.66 | 23 | 23 | 23 | 22.6 |
| Aggregate (1) 0/4 (kg) | 32.02 | 30 | 31 | 26 | 26.8 |
| Aggregate (2) 0/4 (kg) | 31.48 | 30 | 31 | 26 | 28.2 |
| Water (kg) | 17.23 | 16.8 | 17.8 | 17.8 | 19.2 |
| w/c | 0.72 | 0.70 | 0.73 | 0.74 | 0.77 |
| Superplasticizer (ml) | - | 40 | 195 | - | - |
| Slump (mm) | 750 | 700 | 780 | 775 | 750 |

# Mortar – Mix Design

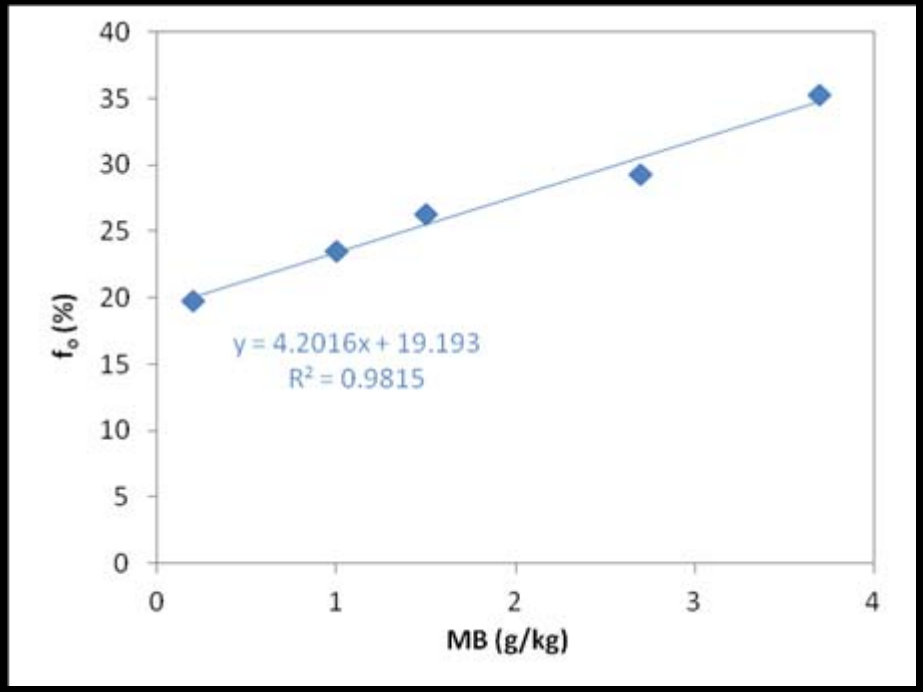
| | M1 | M2 | M3 | M4 | M5 | M6 |
|---|---|---|---|---|---|---|
| Cement (kg) | 3 | 3 | 3 | 3 | 3 | 3 |
| Aggregate 0/4 (kg) | 9 | 9 | 9 | 9 | 9 | 9 |
| Water (L) | 2.45 | 1.89 | 2.27 | 1.50 | 1.70 | 1.78 |
| Workability (mm) | 165 | 169 | 165 | 175 | 163 | 163 |

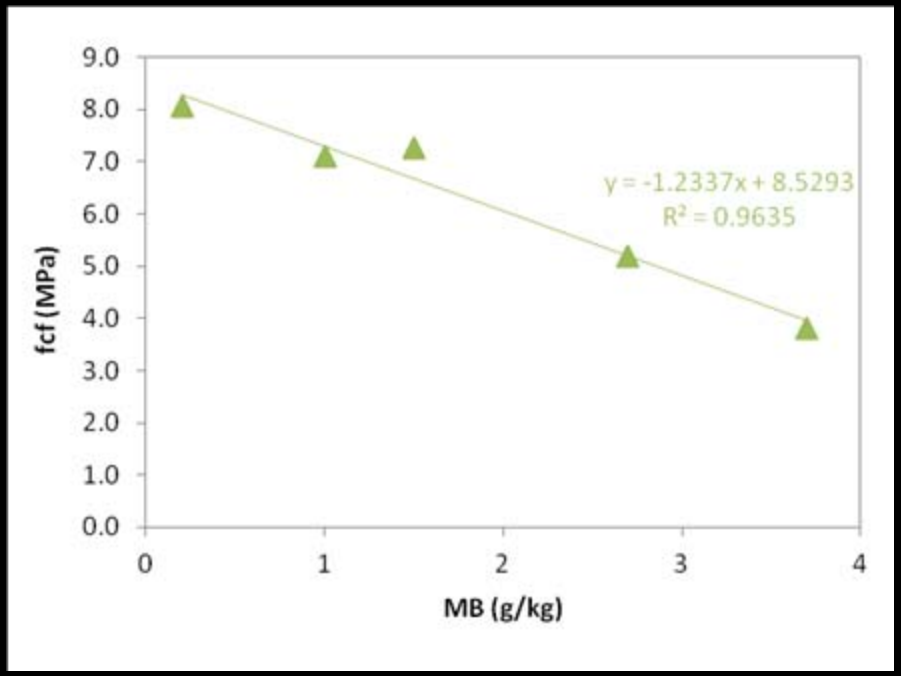
# RESULTS


40
35
30
25
20
15
10
0
1
2
3
4
$f_o$ (%)
WA(%)
y = 4.928x + 15.013
$R^2$ = 0.9249

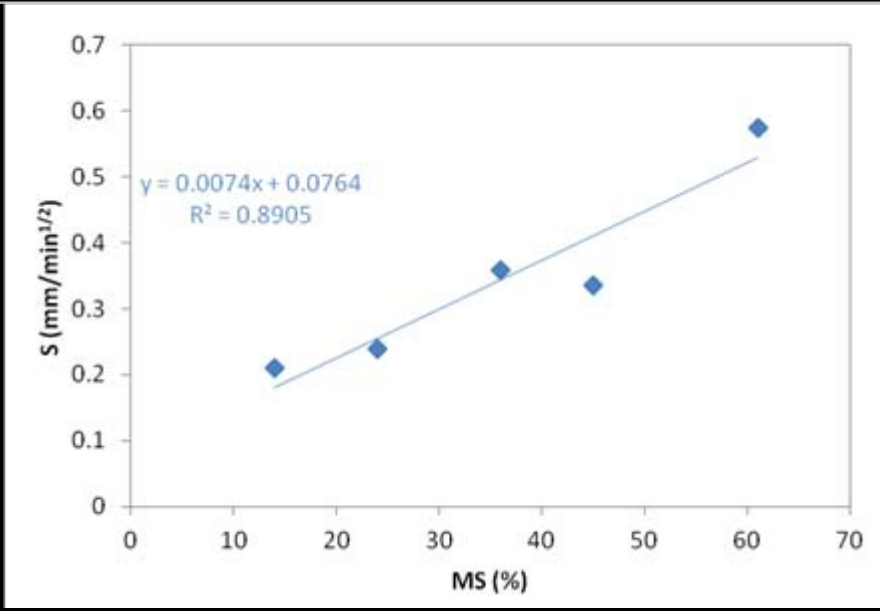

50
45
40
35
30
25
20
15
10
5
0
0
1
2
3
4
fc(MPa)
WA (%)
y = -8.1139x + 47.957
$R^2$ = 0.7506

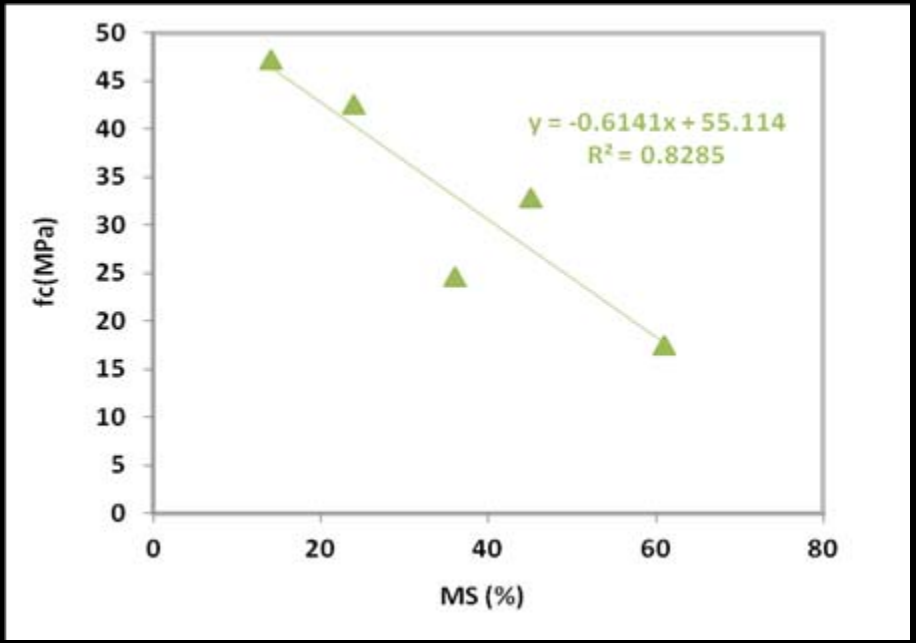
# RESULTS


40
35
30
25
20
15
10
5
0
0
1
2
3
4
$f_o$ (%)
MB (g/kg)
y = 4.2016x + 19.193
R² = 0.9815

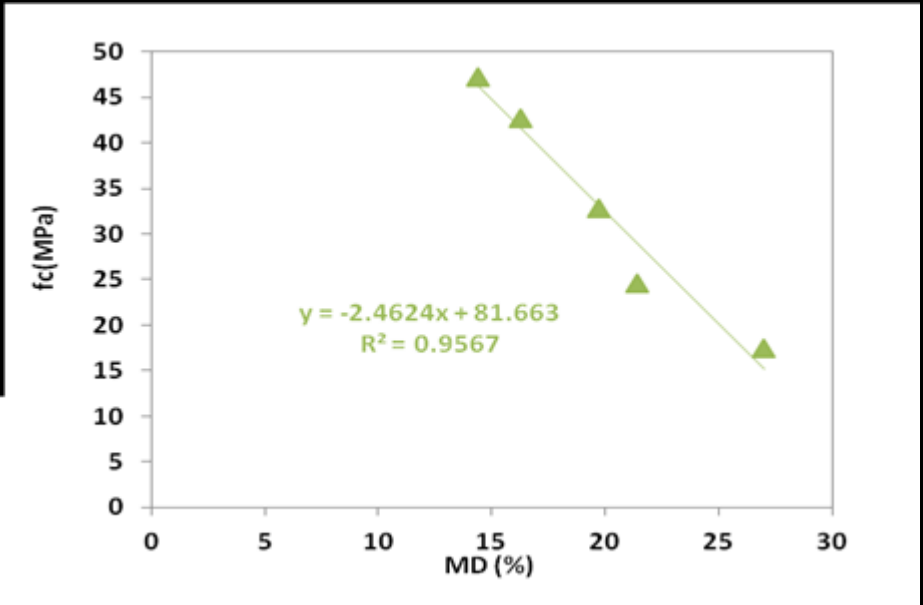

9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
1
2
3
4
fcf (MPa)
MB (g/kg)
y = -1.2337x + 8.5293
R² = 0.9635

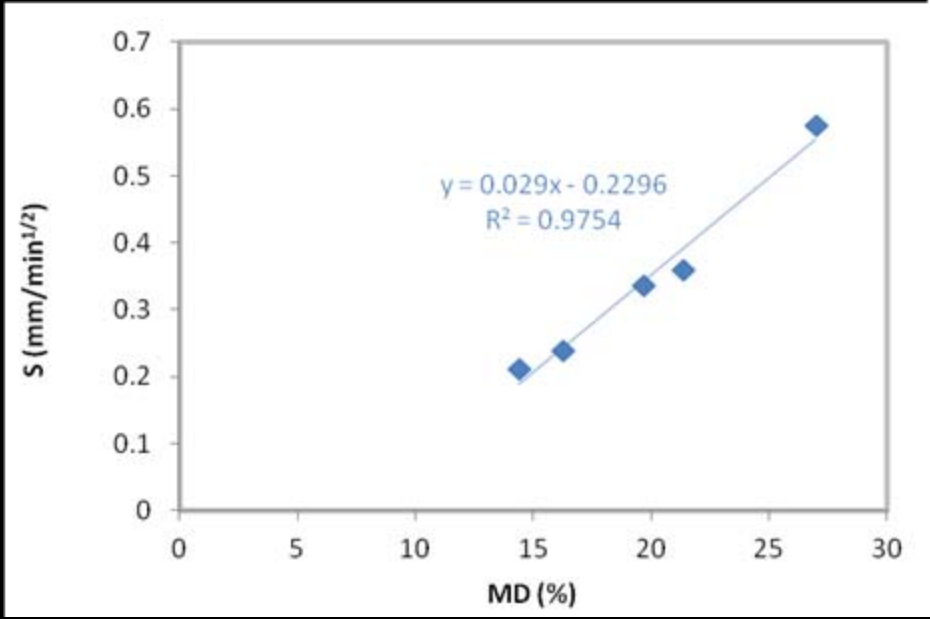
# RESULTS


y = 0.0074x + 0.0764
R² = 0.8905
S (mm/min^1/2)
MS (%)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
10
20
30
40
50
60
70


y = -0.6141x + 55.114
R² = 0.8285
fc(MPa)
MS (%)
0
5
10
15
20
25
30
35
40
45
50
0
20
40
60
80

# RESULTS


fc(MPa)
MD (%)
y = -2.4624x + 81.663
R² = 0.9567


S (mm/min^1/2)
MD (%)
y = 0.029x - 0.2296
R² = 0.9754