

UNIVERSITEIT VAN PRETORIA  
UNIVERSITY OF PRETORIA  
YUNIBESITHI YA PRETORIA

## Faculty of Engineering, Built Environment and Information Technology

Fakulteit Ingenieurswese, Bou-omgewing en  
Inligtingtegnologie / Lefapha la Boetšenere,  
Tikologo ya Kago le Theknolotši ya Tshedimošo

# Nano-technology in road pavement engineering

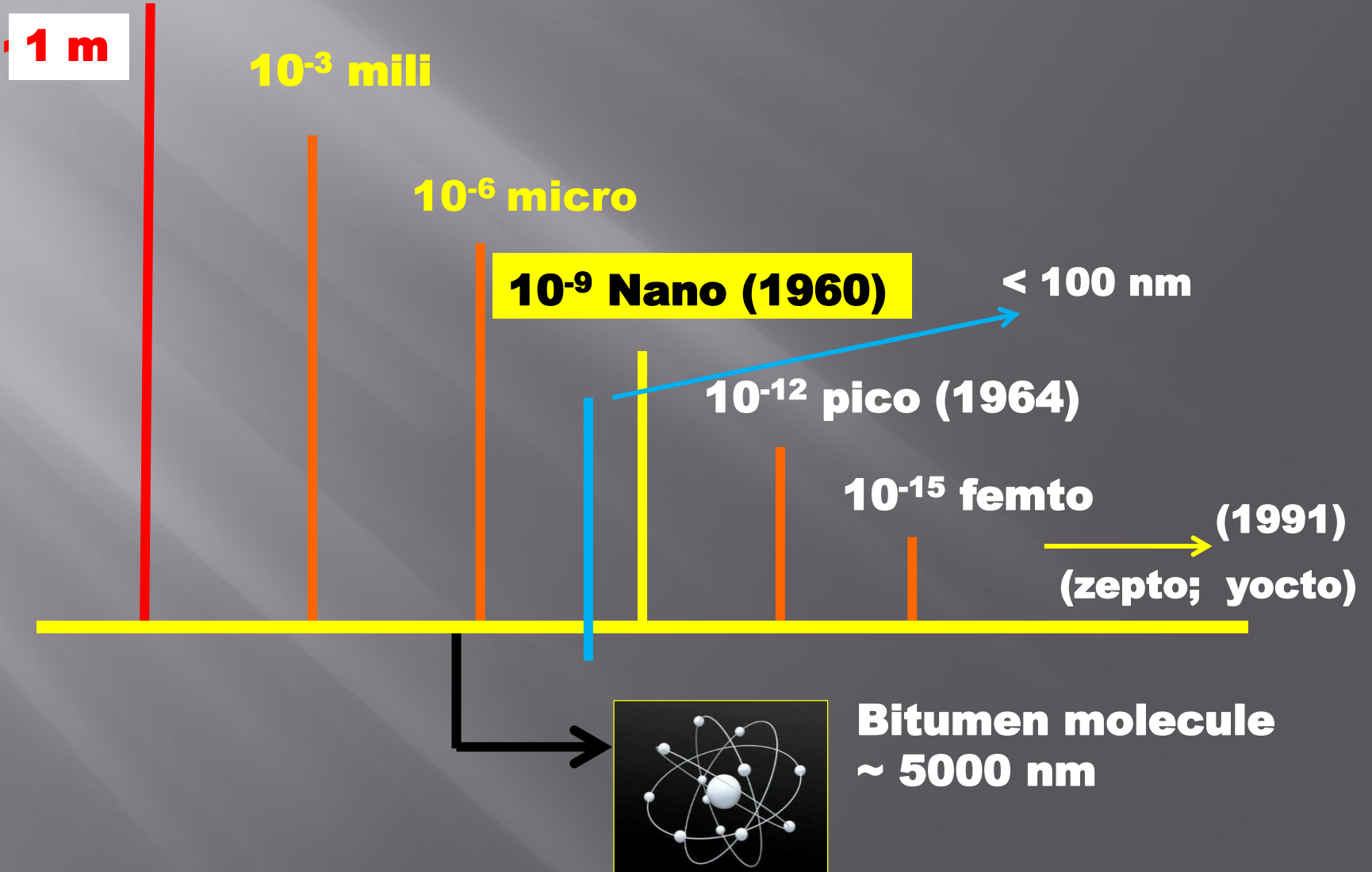
Prof Gerrit Jordaan, Pr. Eng., PhD  
Extraordinary Professor  
University of Pretoria



**“buzz” word**  
**Nano-technology**

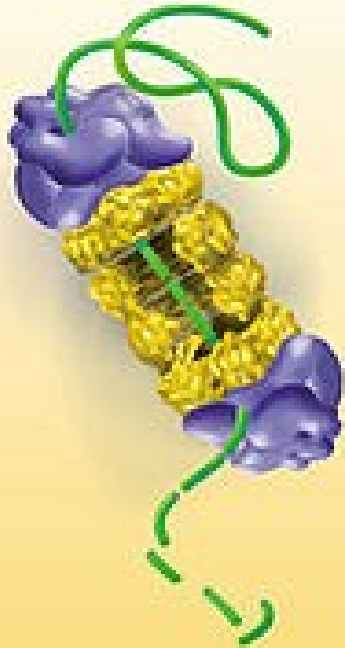


# Nano-technology ?

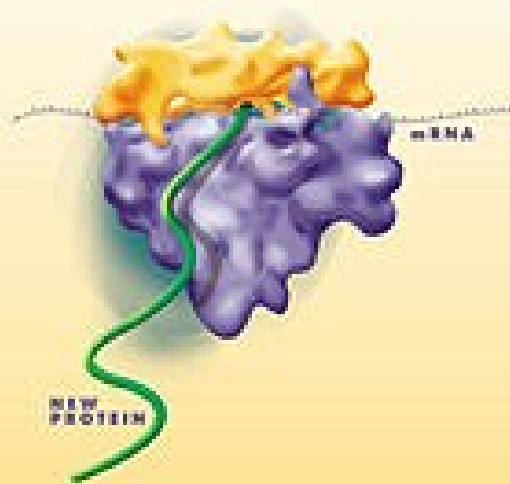


MOLECULAR MACHINES OF LIFE

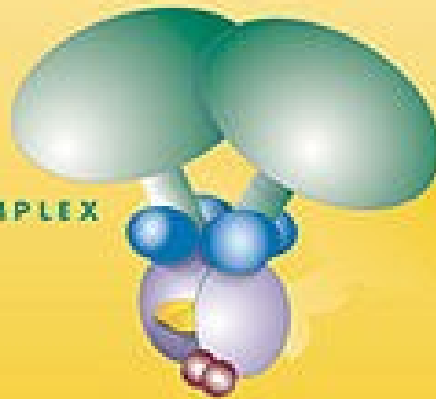
PROTEASOMES



RIBOSOME



DYNEIN COMPLEX



# Nano-technologies In medicine

- **robotics**
- **delivery systems**
- **designer medicines**

# Scientists accidentally discover how to turn carbon dioxide into fuel

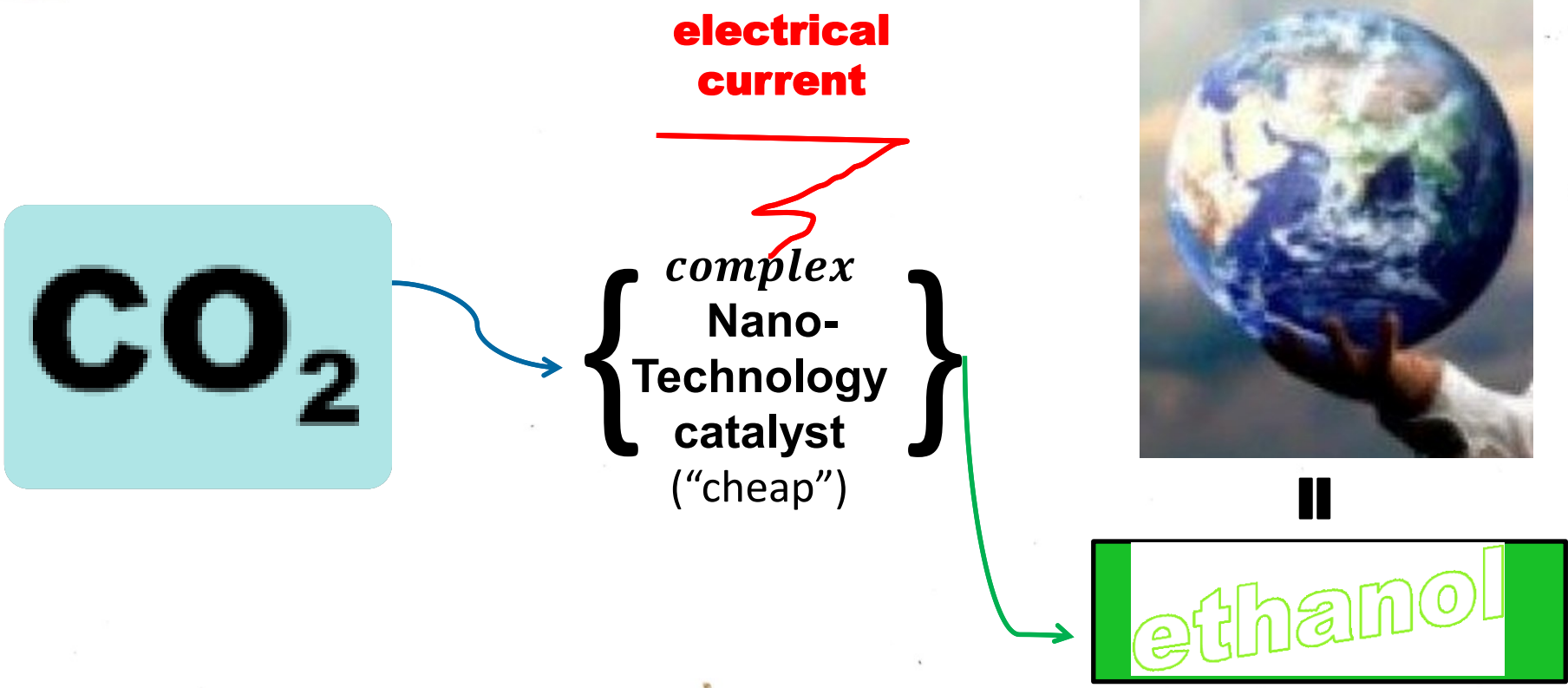
LONDON: Scientists have accidentally discovered a way to reverse the combustion process, turning carbon dioxide back into a fuel. Researchers at the Oak Ridge National Laboratory in the US used complex nanotechnology techniques to turn the dissolved gas into ethanol. Because the materials used are

relatively cheap, they believe the process could be used in industrial processes, including to store excess electricity generated by wind and solar power. The researchers had hoped the technique would turn carbon dioxide into methanol, but ethanol was produced instead. "We're taking carbon dioxide, a

waste product of combustion, and we're pushing that combustion reaction backwards with very high selectivity to a useful fuel," said Dr Adam Rondinone, lead author of a paper about the experiment in the journal ChemistrySelect. "You can use ethanol in the current vehicle fleet right now with no modifications. Carbon

dioxide is a problem. If we can use it, then we're preventing it from going into the atmosphere." The team made a catalyst from carbon, copper and nitrogen and an electric current was used to trigger a reaction. They had expected the process to be more complicated. "We discovered somewhat by accident

that this material worked," Rondinone said. "We were trying to study the first step of a proposed reaction when we realised that the catalyst was doing the entire reaction on its own. Ethanol was a surprise. It's extremely difficult to go straight from carbon dioxide to ethanol with a single catalyst." - The Independent



RED EARTH™

SAND STONE

and acrylic finish for interior & exterior

beach sand

7

FIRED EARTH

SAND STONE

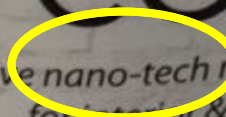
# ULTIMATE COAT

protective nano-tech mid-sheen pure acrylic  
for interior & exterior use

x2  
THE SPREAD RATE  
OF TEXTURED  
PAINT

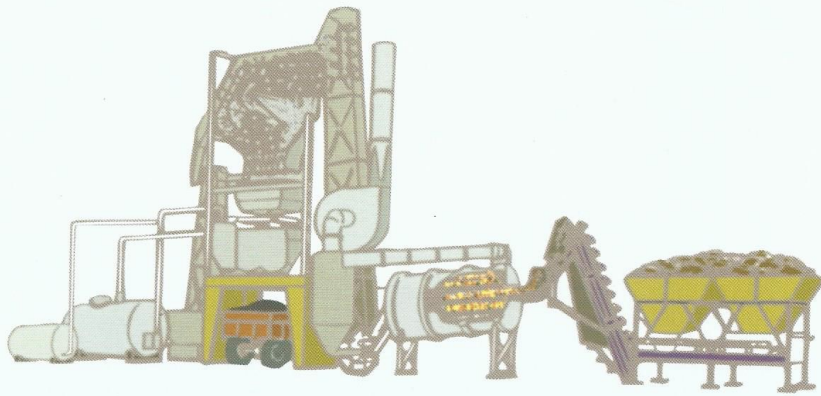
7+  
SEVEN YEAR  
GUARANTEE  
3  
THREE YEAR  
GUARANTEE

acme



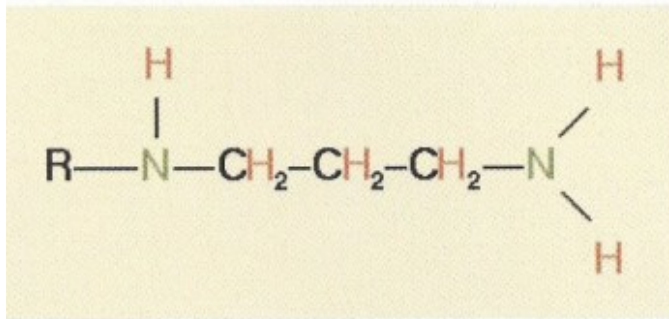
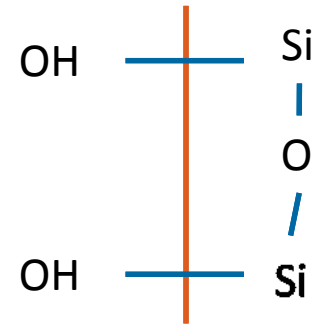
x2  
THE SPREAD RATE  
OF TEXTURED  
PAINT

FIRED EARTH

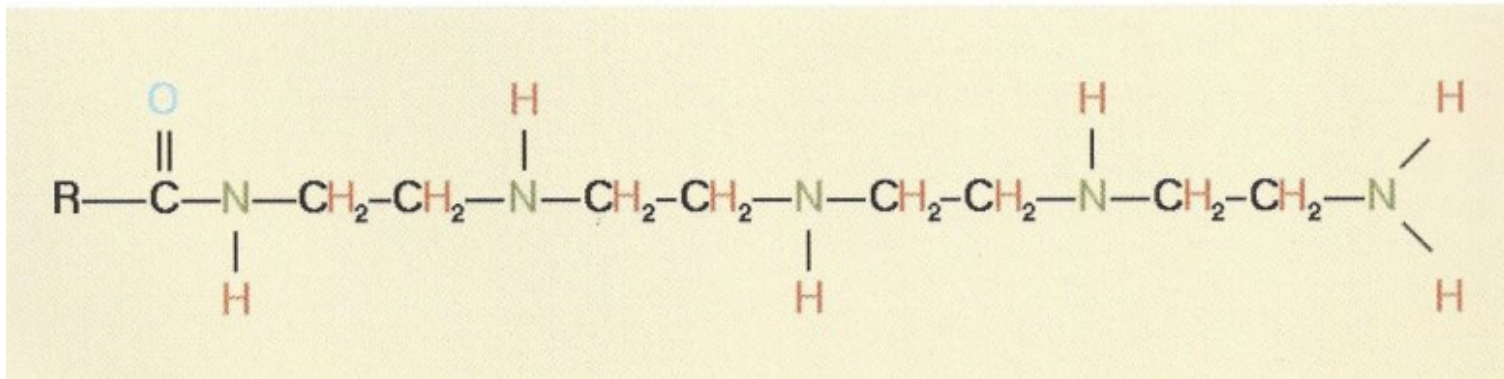


# Roads: 2003

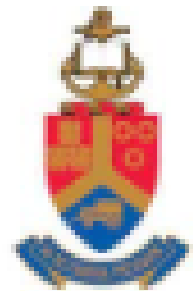
## ADHESION PROMOTERS TECHNICAL BULLETIN



Typical adhesion promoter molecules  
Left: Diamine type  
Below: Amidoamine type



JvdM Steyn, W., 2009, “**Potential Applications of Nanotechnology in Pavement Engineering**”,  
Journal of Transportation Engineering, ASCE, USA.



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PROVINCIAL GOVERNMENT  
REPUBLIC OF SOUTH AFRICA

**GPDRT - 2014**

**GPDRT -  
Rehabilitation road -  
D1884**



2014 11 11

# GPDRT - Rehabilitation - D1884

**G7 material**

**Design traffic loading:** 2.9 – 3.4 m E80s

**Distress C & M:** Primary – Sub-grade  
Secondary -150 mm base

**General approach:** in-situ stabilisation  
+ G1/G2 new base

**Required:** Improve 150 mm base quality



**2014**

# **recognised need to improve:**

## ➤ **Problem:**

- **excessive costs of road infrastructure (R 5 – 6 m /km)**

## ➤ **Solution:**

- **improve use of natural materials**
- **identify available / applicable technologies**
  - **e.g. nano-technologies!**



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**GPDRT - 2014**

**GPDRT Experimental  
section - D1884**

**Investigate cost –effective  
proven new technologies  
~ nano-technologies**

2014 11 11

A green Volkswagen Beetle is shown with a nano-coating applied to its surface. The car is parked outdoors, and the background is slightly blurred. The text is overlaid on the image.

**Available tested new technologies;**

**nano-technologies already tested with natural materials:**

- silanes (5 nm)**
- polymers (various) (60 – 80 nm)**

**Small particles – improved mixing properties !**

- unique properties !**
- proven material stabilising enhancements (with / without traditional stabilising agents)**

# Nano –technology =

**Bitumen molecule** ~ **5 000 nm**

**Nano - polymer** ~ **60 – 80 nm**

**Nano-silane** ~ **5 – 6 nm**

**(“waterproof”) – hydrophobic**

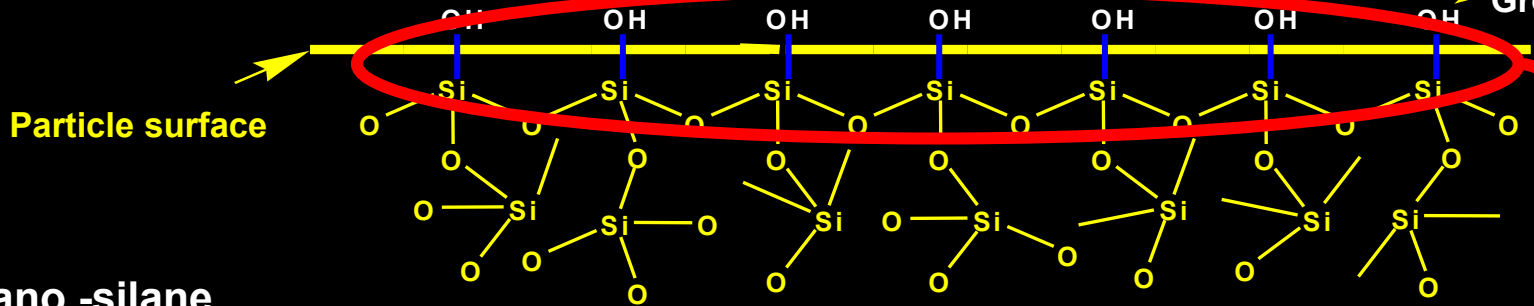
**Coverage:**

**1 litre = 99 litres**

# THE "free energy" ACTION

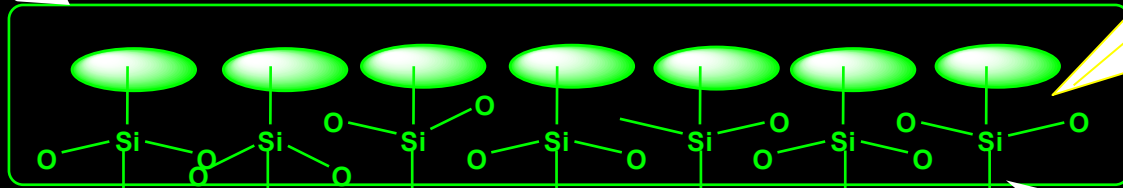
-OH groups make surface very hydrophilic (water loving)

Silanol Groups



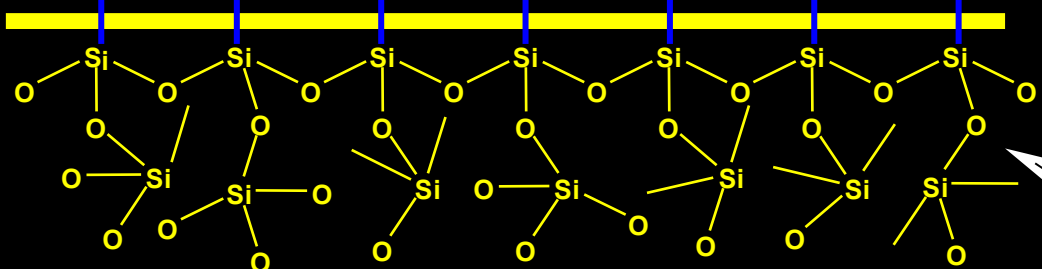
Aggregate / Soil / Clay / Sand surface silicate structure

Nano -silane  
creates  
molecular level  
hydrophobic  
zone  
(water  
repellent)



4 - 6  
nm Alkyl  
Siloxane  
surface

Particle surface



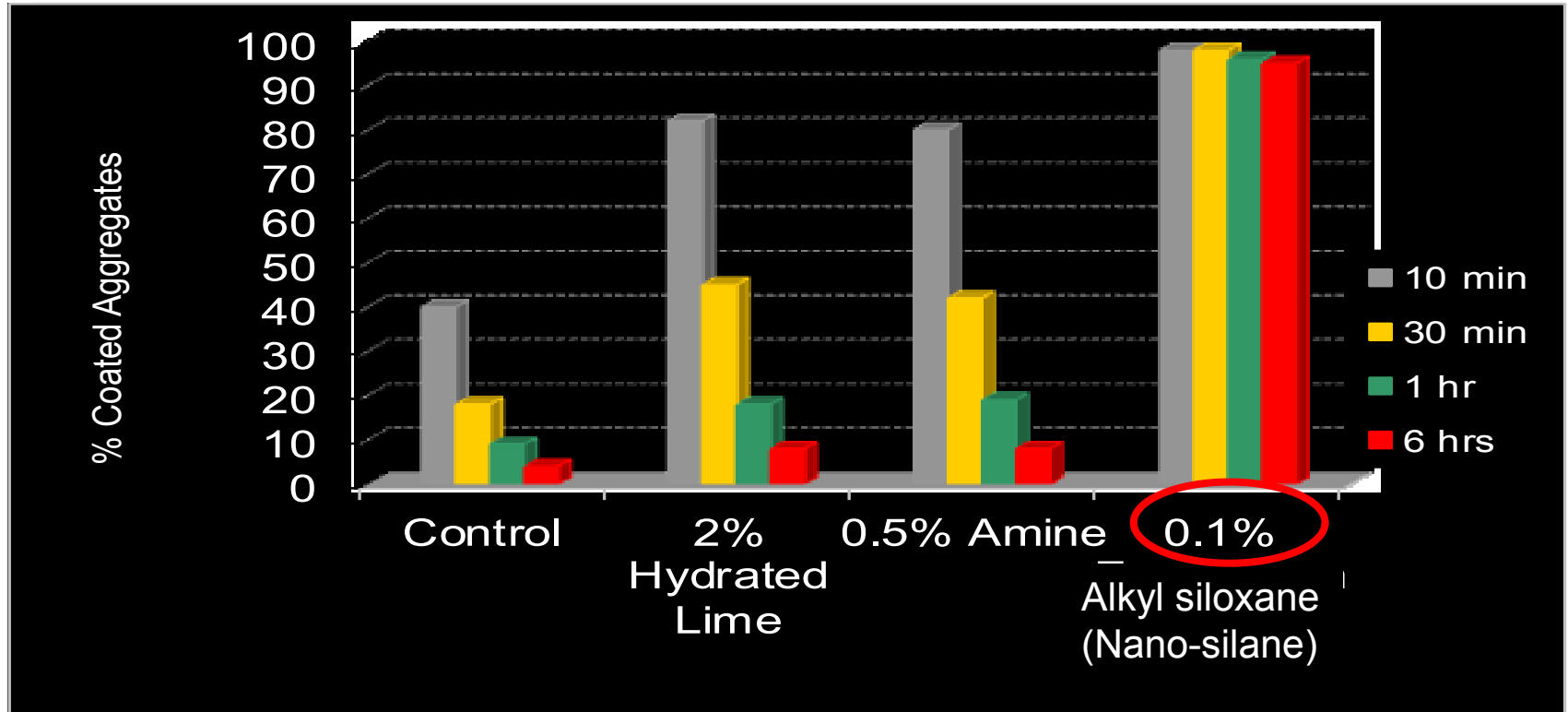
Internal  
Siloxane bonds

**Aggregate / Soil / Clay / Sand**

surface silicate structure after nano-silane reaction

# Bitumen adherence to aggregate

## BOIL TEST ASTM D3625 : EXTEND TO 6 HOURS



Basalt Aggregate (DBM) : 45% 20 mm, 10% 10 mm, 45% less than 6 mm with stone dust  
Asphalt Grade: AC-20 (VG-30, 60-70 penetration grade)

# Nano-mod bitumen-aggregate retention (4.5% Bit 100° C)

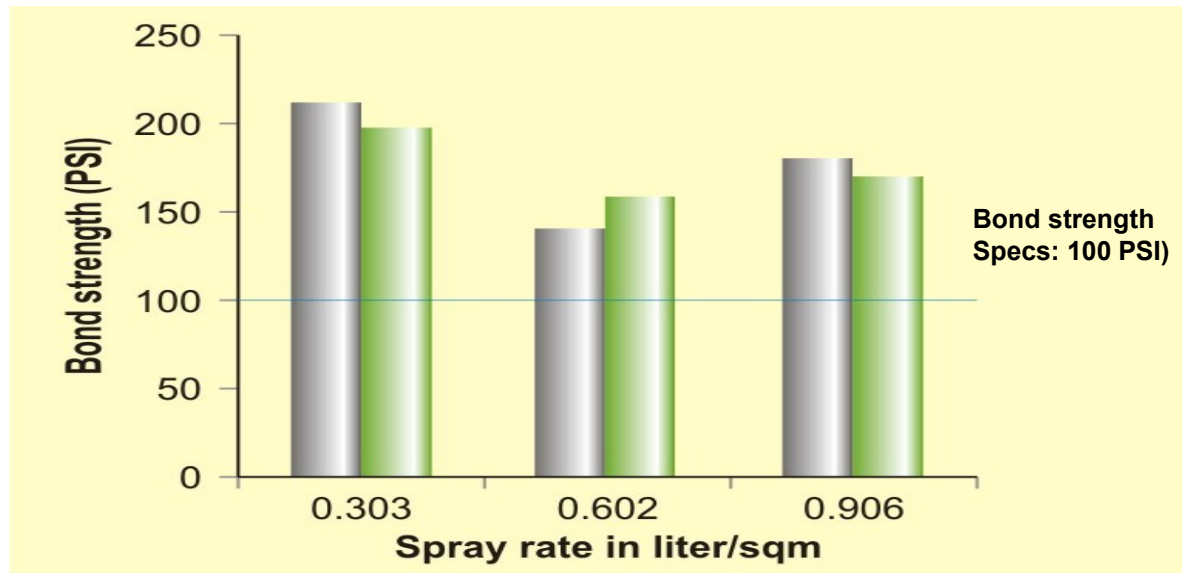
<b>Boil Test (ASTM D 3625)</b>	<b>Percentage of retained Coating</b>		
	<b>After 10 min</b>	<b>After 1 hr</b>	<b>After 3 hr</b>
<b>Neat mix</b>	<b>50%</b>	<b>30%</b>	<b>10%</b>
<b>Modified mix</b>	<b>100%</b>	<b>95%</b>	<b>95%</b>

(Much asphalt – Cape Town 2015 - 50/70 pen bit)

# Nano -Tak

## BOND STRENGTH OF NEW SURFACE - NCAT STUDY

- ✓ Maintains bond strength with lower residual bitumen content
- ✓ Bond strength values consistently above 150 PSI



- Control - Residual bitumen 30 %
- With Nanotac - Residual bitumen 10 %

# Paving down to 90°C

3% FT paraffin wax

**GPDRT  
N14/1**

02/06/2012

< 0 °C

02/06/2012 01:56





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**GPDRT - 2014**

**GPDRT rehabilitation  
- D1884**

**Investigate cost –effective  
proven new technologies  
~ nano-technologies**

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GRADING ANALYSES - % PASSING SIEVES (TMH1 1986 : METHOD A1 (a))		
SIEVE	63.0	100
ANALYSES	53.0	100
(mm)	37.5	87
	26.5	78
	19.0	74
	13.2	68
	4.75	59
	2.00	54
(TMH A1a)	0.425	32
	<b>0.075</b>	<b>17</b>
ATTERBERG LIMITS ANALYSIS (TMH1 1986 : METHOD A2 & A3 ; TMH1 1986;TMHA4 1974)		
ATTERBERG	LL%	24.1
LIMITS	<b>P.I.</b>	<b>2.5</b>
(TMH A2&A3)	LS%	1.2
	GM	2.00
CLASSIFI - CATION	H.R.B.*	A-1-b(0)
	<b>COLTO*</b>	<b>G7</b>
	<b>T.R.H. 14*</b>	<b>G7</b>
UNCONFINED COMPRESSIVE STRENGTH (TMH1 1986 : METHOD A7, A14 & A16T)		
MOD AASHTO	<b>OMC%</b>	<b>8.8</b>
(TMH A7)	MDD(KG/M <sup>3</sup> )	2126
	COMP MC %	8.0
C.B.R.	% SWELL	0.36
KPA	100%	33
U.C.S.	98%	29
(TMH A13T)	97%	27
	95%	23

### ITS - STRENGTH OF BRIQUETTES (DRY)

Binding Agent Content	0.7% GE-Nano20P	0.7% GE-Nano-20P
Cement Content		
Compaction effort (%)	100%	100%
ITS (kPa)	383	391

### UCS - STRENGTH OF BRIQUETTES (DRY)


Binding Agent Content	0.7% GE-20	0.7% GE-20
Cement Content		
Compaction effort (%)	100%	100%
UCS TMH1 A14 (kPa)	2269	2173

### ITS-STRENGTH OF BRIQUETTES (SOAKED)

Binding Agent Content	0.7% GE-20	0.7% GE-20
Cement Content		
Compaction effort (%)	100%	100%
ITS (kPa)	142	124

### UCS-STRENGTH OF BRIQUETTES (SOAKED)

Binding Agent Content	0.7% GE-20	0.7% GE-20
Cement Content		
Compaction effort (%)	100%	100%
UCS TMH1 A14 (kPa)	2139	2094
BSM Classification	BSM3	BSM3
Test Type	48 hour curing	48 hour curing

Test or Indicator		Design Equivalent Material Class		
		BSM1	BSM2	BSM3
TRAFFIC LOADING		> 6 MESA	< 6 MESA	<1 MESA
Nano-modified emulsions				
ITS (dry) (kPa)	150mm (d)	> 125	80 to 125	50 to 80
ITS (wet) (kPa)	150mm (d)	> 100	60 to 100	50 to 75
UCS (kPa)	All	1 500 to 3 000	700 to 1 500	450 to 700
Retained Cohesion ITS Wet/Dry (%)	All	> 70	> 65	> 60
GE-NANO (%)	Min.	0.5	0.5	0.3
	Max.	1.2	1.0	0.9

<sup>1</sup>CS – crushed stone, NG – natural gravel, GS – gravel soil, SSSC – sand, silty sand, silt, clay



**Nano –  
“water-  
proofing”  
Agent added**

**Normal  
Stabilising  
agent**

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123.mp4

**G7 Material**

**0.7% nano Modified  
Emulsion**

**Illustrating:**

**“water –proofing”  
Repellent of water**

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**Briquette – 3 days in water**



**No water  
“wetting”**



2014 11 11

# Thohoyandou - 5 December 2015





25 January 2016

2016 1 25



2016 1 25

PORCHE-VILLA  
HOTEL AND CONFERENCE CENTRE  
HOTEL  
WEDDING  
VENUE  
CONFERENCE  
CENTRE  
RESTAURANT



2016 1 25



2016 1 25



40

2016 1 25



2016 1 25



# Thohoyandou Nano-prime

- prime Saturday 30/01/2016
- Rain Sunday 31/01/2016
- Picture: Monday 01/02/2016

# D29 Pavement design 2015



# Pavement design D29

**Recommended design – (2003):**

**Design traffic loading ~ 0.5 MESA**

**B – Category road**

- **40 A / ~~30 A~~ / ~~S2~~**
- **150 G2 / ~~150 C3~~ / ~~150 C3~~**
- **250 C4 / ~~300 C4~~ / ~~300 C4~~**

- **Available materials –sufficient G6**

# Pavement design D29

## Recommended design – now NEW:

### • Available materials – sufficient G6

### C – G6 laboratory tests

	Cement Test Results -			GE- Nano -20P	
	2%	2.5%	3%	0.5%	0.7%
	7 days curing			48 hours curing	
UCS	1120	1340	1580	2440	2930
ITS	85	106	120	131	151

Save more than 1 million/km

# Pavement design D29

## Recommended design – now NEW:

### • Available materials – sufficient G6

### C – Category road (up to 3 MESA)

- Cape Seal (S1 + Slurry = long life)
- 150 (125) GE Nano 20 modified G6 (Equivalent C4 +)
  - (Nano prime)
- 150 (125) G6

Save more than 1 million/km

# K46 – William Nicol – Dual carriageway

**Design traffic loading : 7 – 10 MESA**

**Base: 150 mm 1.2% GE Nano**

**Sub-base: 150 mm G5 - 0.7% GE Nano**



25 3:16PM

# K46 – William Nicol – Dual carriageway

**Design traffic loading : 7 – 10 MESA**



25 3:16PM



25 3:32PM



25 5:58PM

A wide, unpaved road under construction. The road surface is a mix of dirt and sand, with visible tire tracks. On the left side, there are several large concrete pipes stacked. In the background, there are several vehicles, including a white pickup truck and a white SUV, and a group of workers in high-visibility vests. A tall utility pole is visible on the left. The sky is clear and blue.

# **Savings:**

**Material ~ 20 %**

**Time and effort:**

**no G1 (considerable effort)**

**no curing of 2 x C4 layers**

**ease of construction**

25 6:17PM

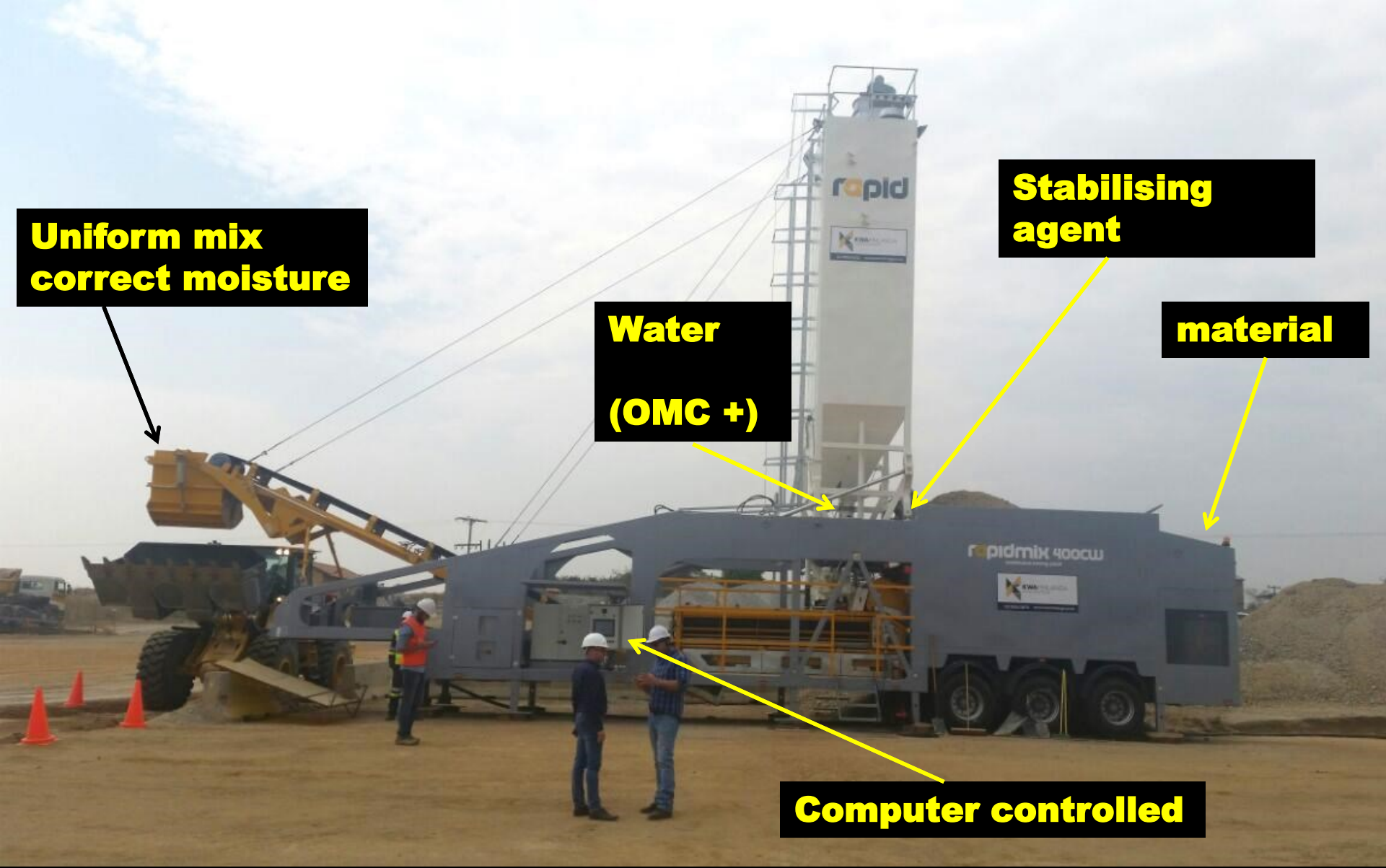
**Uniform mix  
correct moisture**

**Stabilising  
agent**

**Water  
(OMC +)**

**material**

**Computer controlled**



4

Gauteng Province:  
GPDRT:  
Johannesburg  
North:  
Road K46 –  
New dual-carriage  
high capacity road  
7 – 10 MESA



Limpopo Province:  
RAL  
Thohoyandou:  
Road D3718 –  
Rehabilitation of  
Township road  
~ 1.0 MESA

2

Gauteng Province:  
GPDRT:  
Heidelberg West:  
Road D1884 -  
Rehabilitation of  
rural road  
~ 3.0 MESA



1



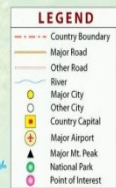
Swaziland  
SMPWT:  
North of Manzini:  
Road D29 – New  
road linking several  
villages  
~ 0.5 MESA

3

Map not to Scale

Copyright © 2012-13 www.mapsofworld.com  
(Updated on 23rd November, 2012)

Copyright © 2015 www.mapsofworld.com  
(Created on 30th December 2015)



# Implementation of nano-technologies

## advantages

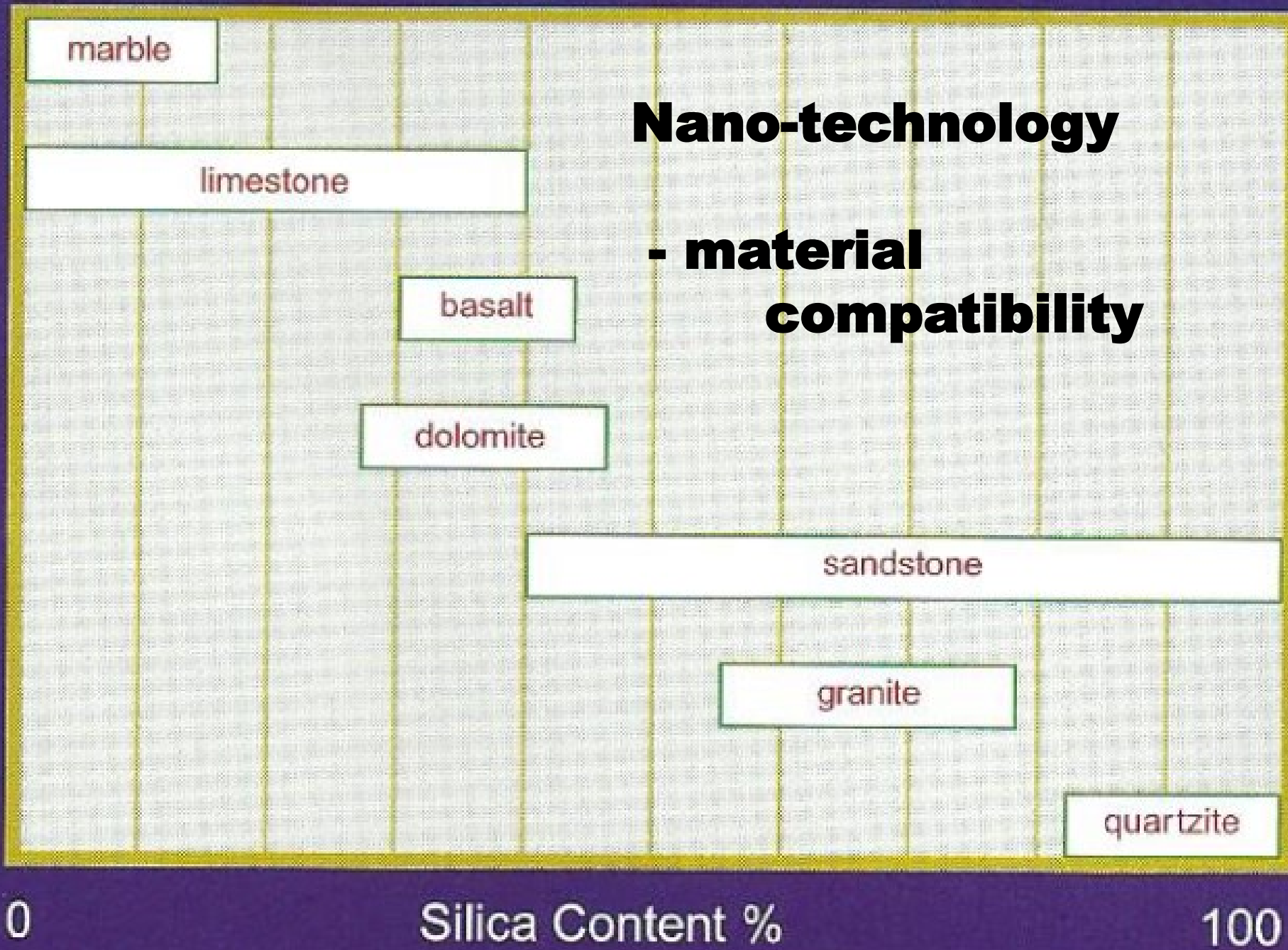
- **Cost factors**
- **Environmental factors**
- **Energy factors**

**“green roads”**

25 5:58PM

# Nano-technology

## - material compatibility



# Material indicators

- **Developed > 50 years old**
- **Empirically derived**
- **Good “indicators”**
- **Experience**

**mineralogy ?????**

2002 8 31

# Pavement design

Property	Cold regions	Warm regions
Climate	Temperate to cold	Arid, tropical, warm temperate ←
	Natural or crushed	Varies from rock to clay ←
Aggregate	Solid, strong rock	Sometimes porous, weakly cemented fines
Clay minerals	Mostly illite or montmorillonite	Wide variety, e.g. halloysite, attapulgite
Cement/bonding agent	None (usually)	Iron oxides, aluminium hydroxide, calcium carbonate, etc
Chemical reactivity	Inert	Reactive ←
Grading	Stable	Sensitivity to drying and working
Solubility	Insoluble	May be soluble
Weathering	Weathering or stable	Forming or weathering
Consistency limits	Stable	Sensitive to drying and mixing
Salinity	Non-saline	May be saline
Self-stabilisation	Non-self-stabilising	May be self-stabilising
Moisture	U	Extensive field ←

# Weinert (1980):

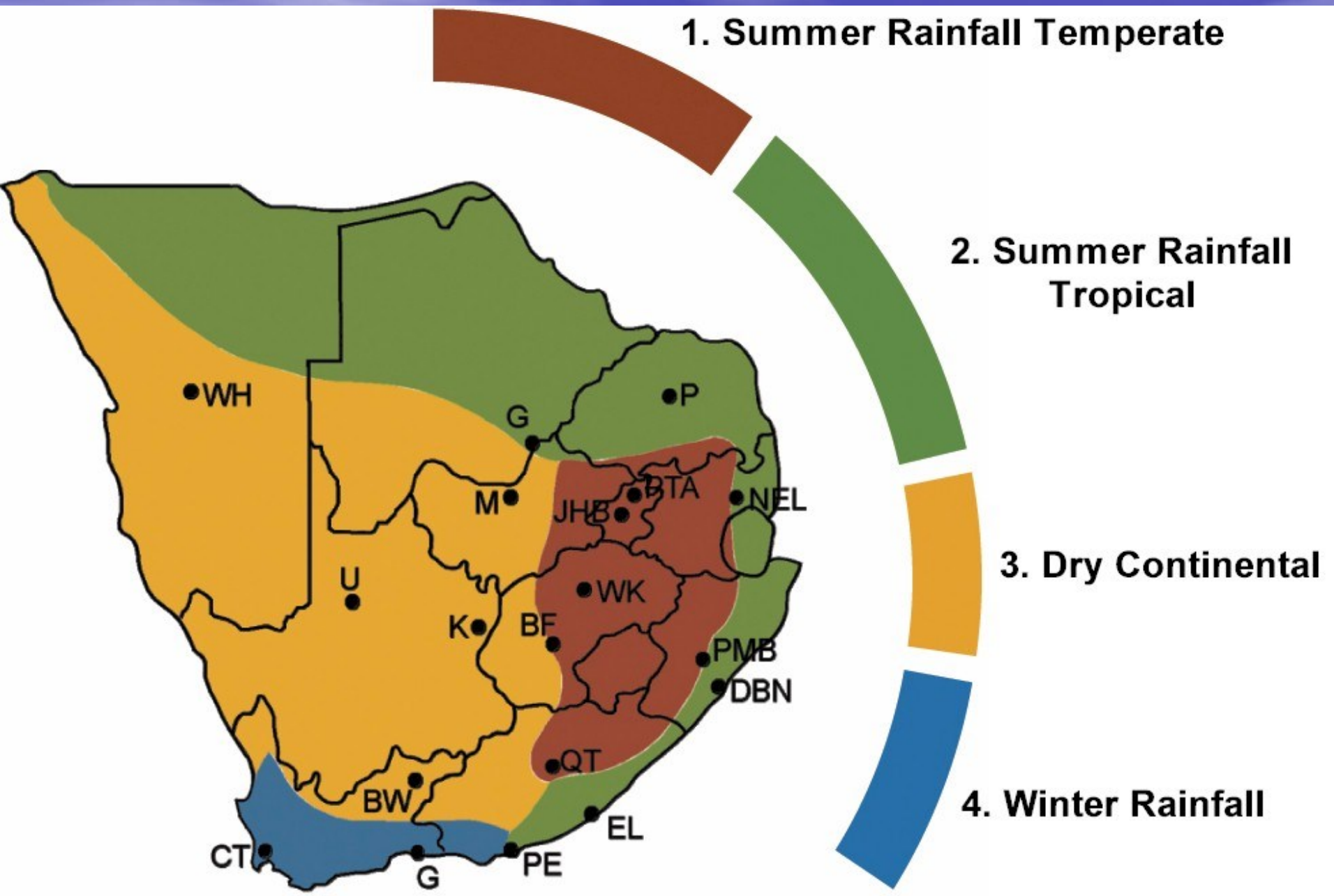
Southern Africa – “Unique”

Seasonal Rainfall  
High Temperatures

Weathering: Smectite / Mica



Figure 5.5 - Climatic N-value map of southern Africa<sup>7</sup>  
(currently does not cover the entire SADC region)



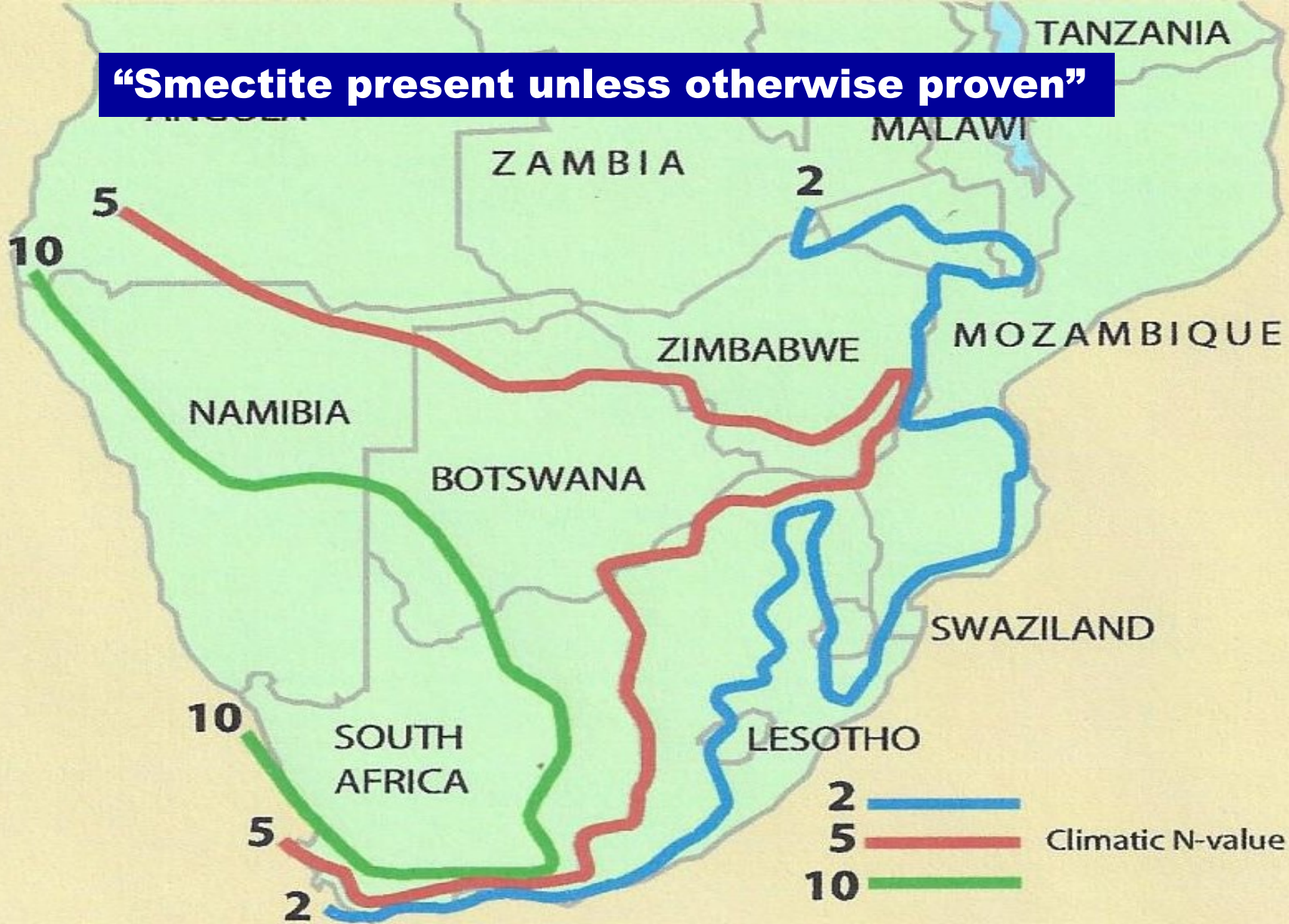
1. Summer Rainfall Temperate

2. Summer Rainfall Tropical

3. Dry Continental

4. Winter Rainfall

**“Smectite present unless otherwise proven”**



**Figure 5.5 - Climatic N-value map of southern Africa<sup>7</sup>**  
(currently does not cover the entire SADC region)



# Cost – effective approach: Use available materials !!!

**MUST** Consider basic Geology:  
southern Africa almost unique !

- **Basic rocks**
  - (crystalline rocks and argillaceous rocks)
- High temperatures
- Seasonal rainfall
  - Weathering = Smectite / Mica = !!!

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# Indicator testing (1930s/40s?)

## ▣ Marble Hall (example):

▪ PI (normal) – SP to 5 = material ✓

▪ PI (0.075) - 13 to 16

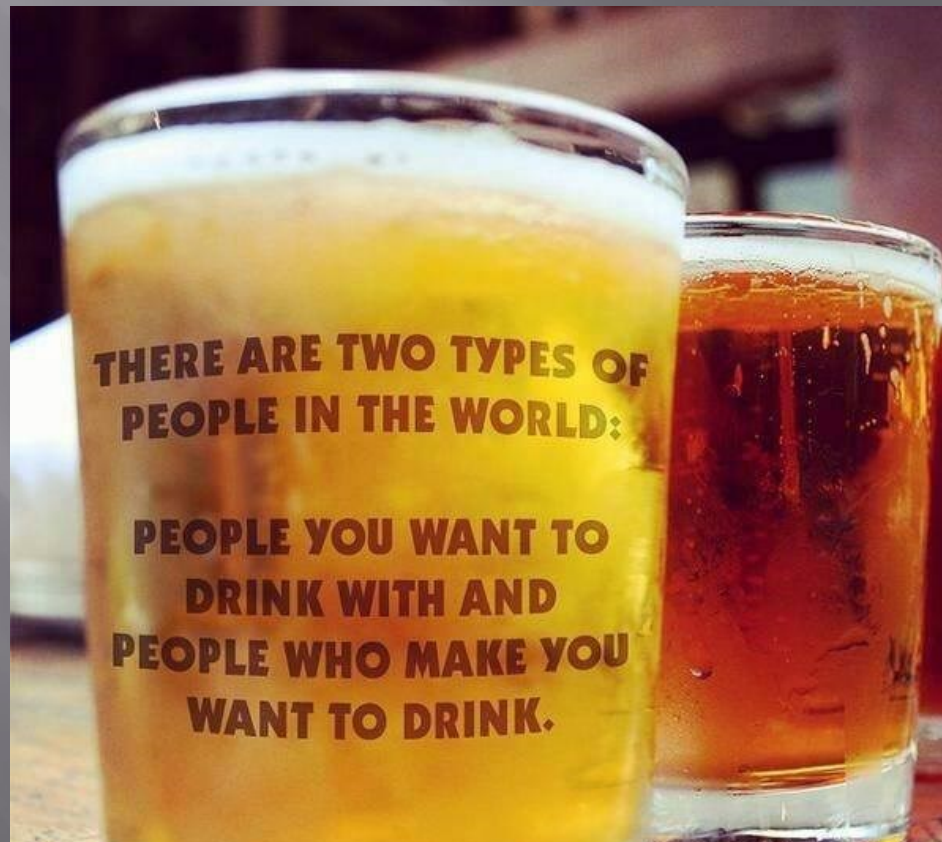
**Smectite !**

# Indicator testing (1930s/40s?)

(apologies Prof Savage 2016)

▣ **PI = 6** – what does it mean ?

Lets compare 2 “Establishments” – each selling 6 beers

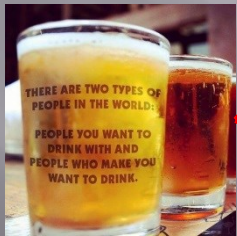


# Indicator testing (1930s/40s?)

(apologies Prof Savage 2016)

▣ **PI = 6 –what does it mean ?**

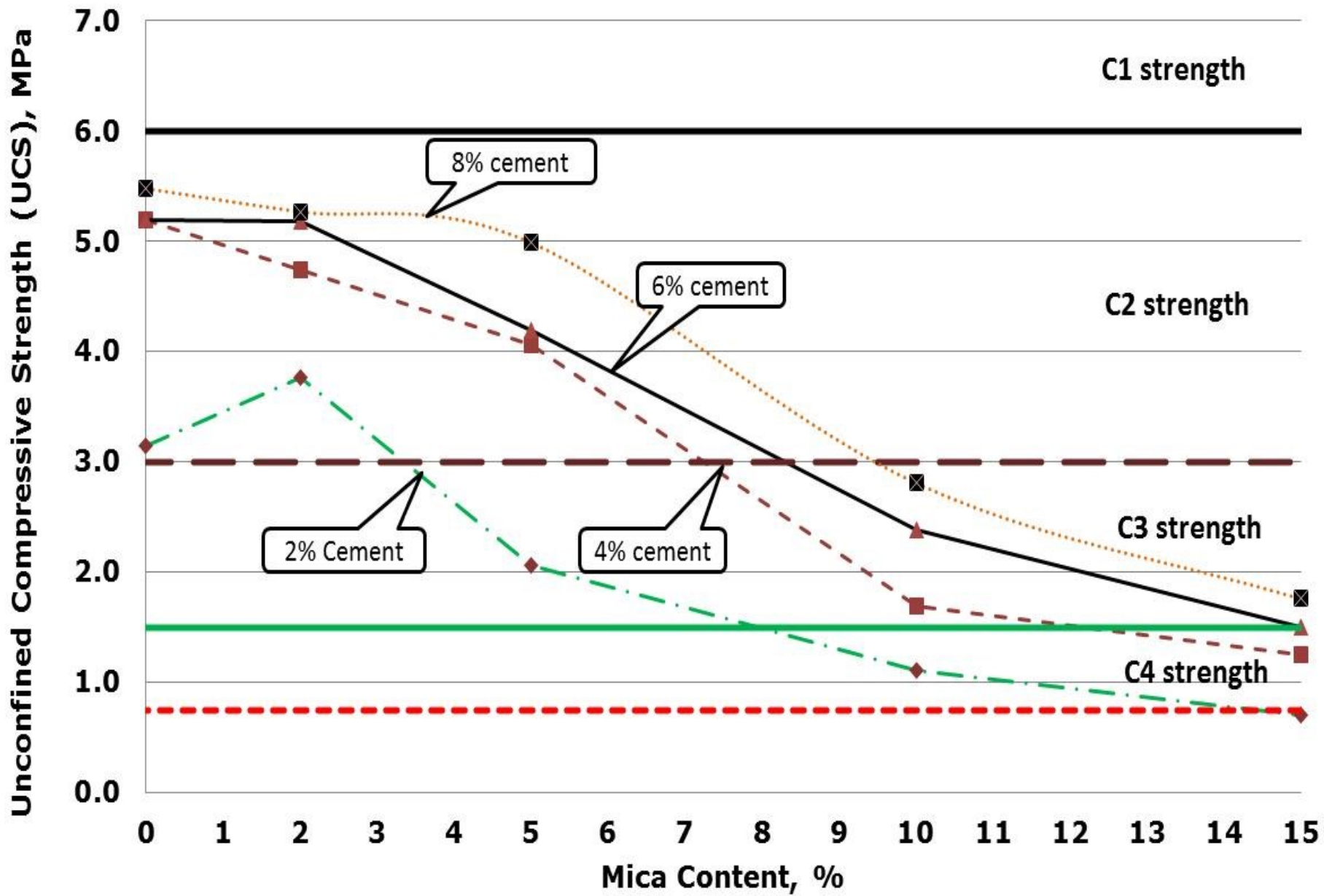
Equivalent of 2 “Establishments” selling 6 beers each

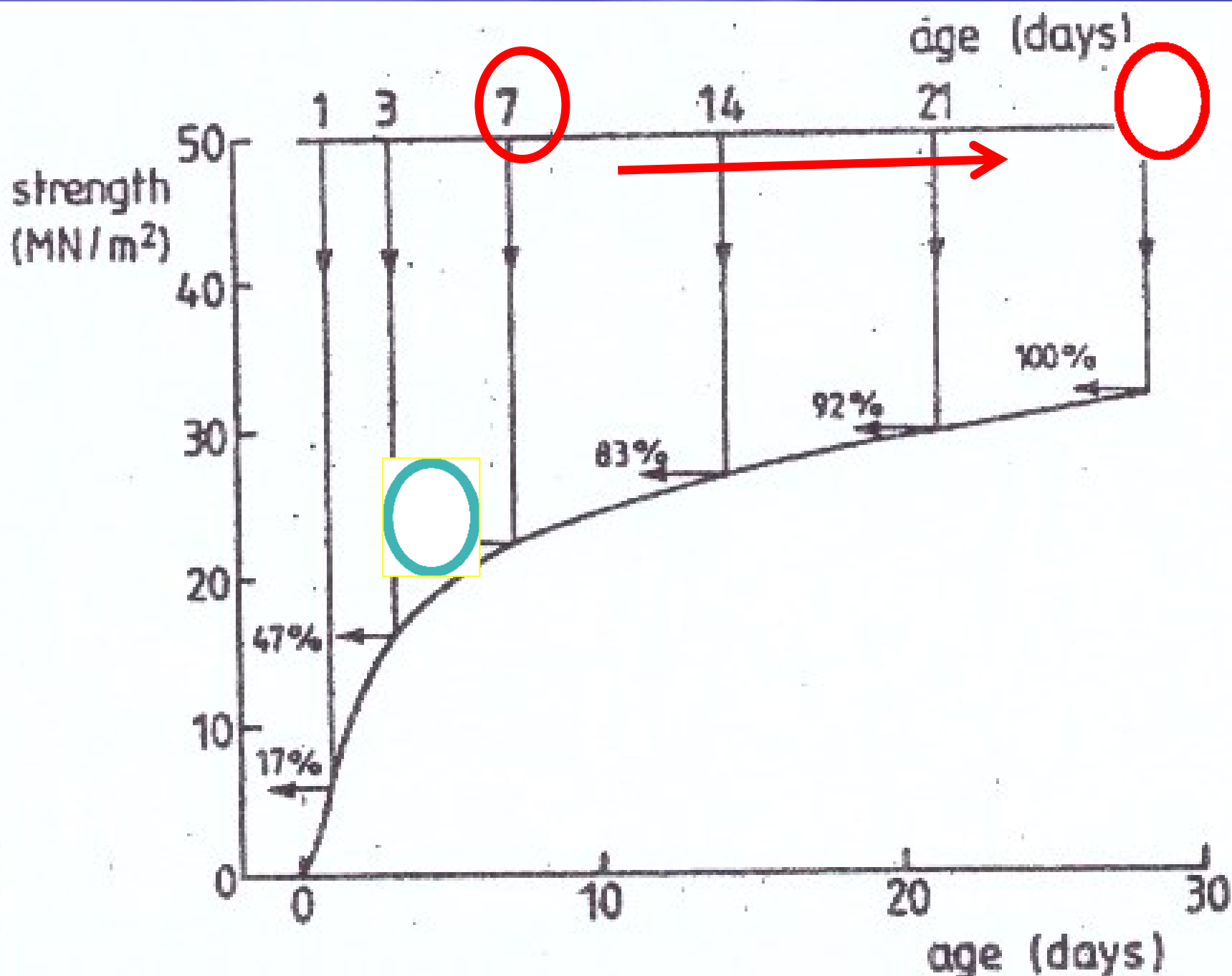


**1 illegal driver**



**6 legal drivers**

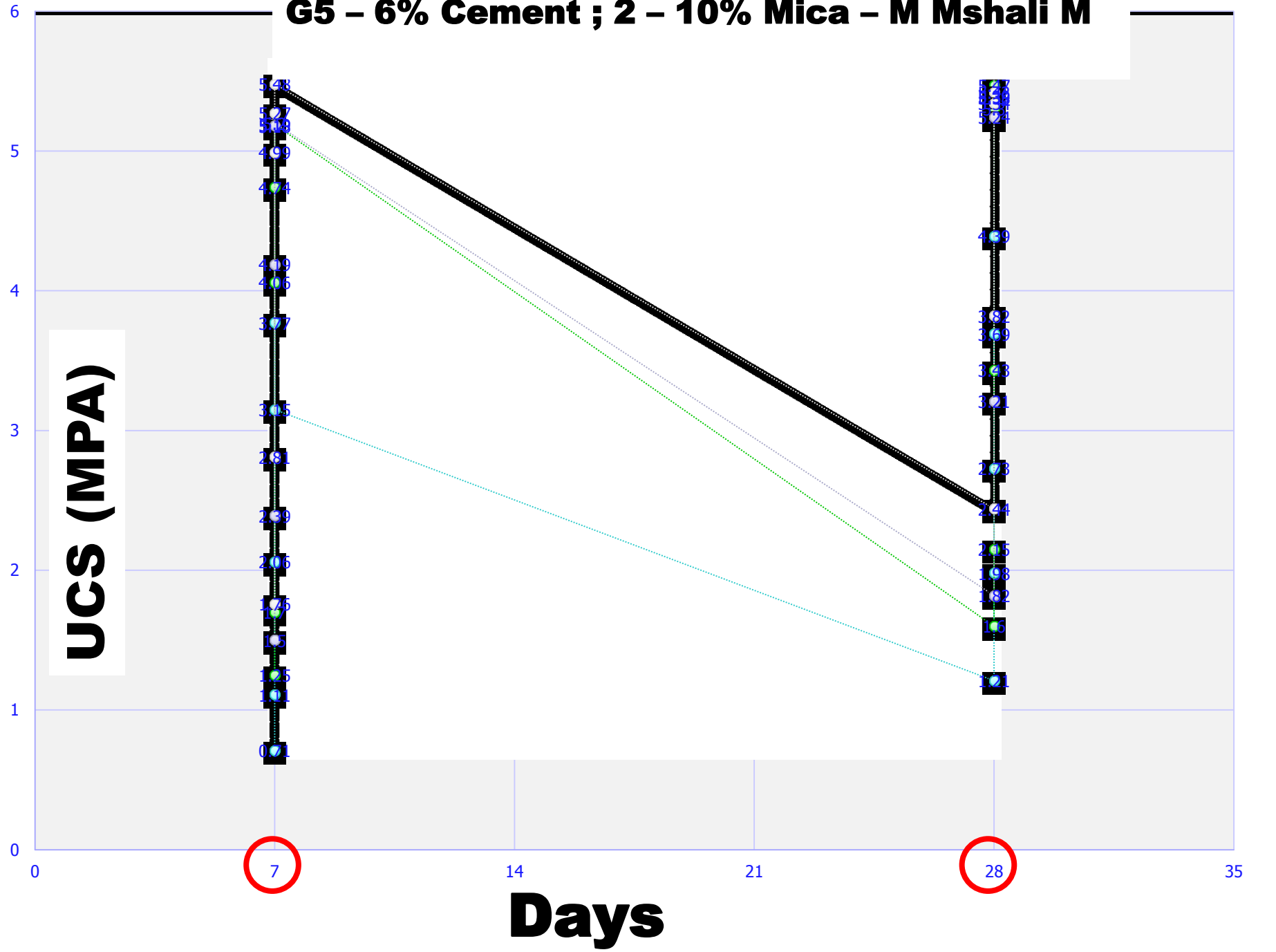




**Cement stabilisation – Normal prediction of UCS strength**

# G5 - 6% Cement ; 2 - 10% Mica - M Mshali M

**UCS (MPA)**



7

28

**Days**



**Road age – < 10 years**

**Smectite/Mica:  
Disintegration of  
cemented layer**

# THE PHILOSOPHY OF ENGINEERING

**Engineering**

Chemistry

science

Physics

Cost - effectiveness



109 5 19

# THE PHILOSOPHY OF PAVEMENT ENGINEERING

## Engineering

Chemistry

science

Physics

**Design catalogue**

GRANULAR BASES (KEY NOTATIONS)

PAVEMENT CLASS AND DESIGN BEARING CAPACITY (80 kN AXLES/ANE)

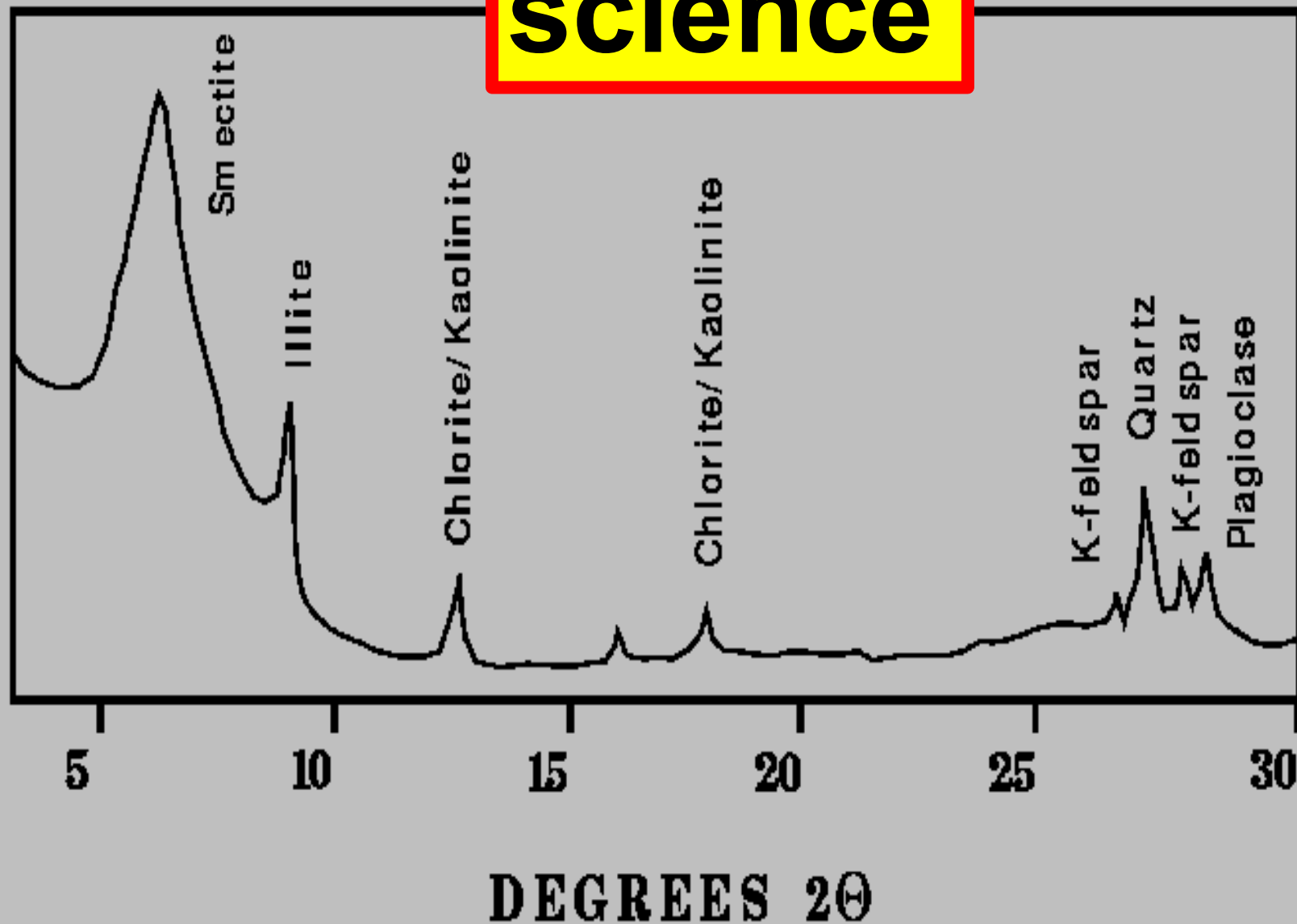
ROAD CATEGORY	PAVEMENT CLASS AND DESIGN BEARING CAPACITY (80 kN AXLES/ANE)										Foundation
	ES600	ES500	ES400	ES300	ES200	ES1	ES2	ES10	ES30	ES100	
	0.1-0.2x10 <sup>6</sup>	0.3-1.0x10 <sup>6</sup>	1.0-2.0x10 <sup>6</sup>	3.0-9.0x10 <sup>6</sup>	0.1-0.2x10 <sup>6</sup>	0.2-1.0x10 <sup>6</sup>	1.0-3.0x10 <sup>6</sup>	3.0-10x10 <sup>6</sup>	10-30x10 <sup>6</sup>	30-100x10 <sup>6</sup>	
A: Major interurban freeways and roads. (95 % approximate design reliability)							10A 125 G2 125 C3 10A 125 G2 125 C3	10A 125 G2 125 C3 10A 125 G2 125 C3	20A 150 G1 250 C3	20A 150 G1 200 C3	
B: Interurban collectors and major rural roads. (90 % approximate design reliability)						125 G4 125 C4 100 G4 125 G2	210A 125 G2 125 C4 210A 125 G2 125 C4	10A 150 G2 200 C1 10A 150 G2 200 C1			125 G2 125 C3 125 G2 125 C4
C: Lightly trafficked rural roads and strategic roads. (80 % approximate design reliability)				125 G5 125 C4	125 G5 125 C4	125 G4 125 C4 125 G5 125 C4	125 G5 125 C4 125 G5 125 C4	125 G5 125 C4			
D: Light pavement structures, rural access roads. (50 % approximate design reliability)	100 G1 100 G2	100 G5 125 G7	125 G4 125 G7	125 G4 125 G5	125 G4 125 G5	125 G4 125 G5 125 G4 125 G5	125 G4 125 G5 125 G4 125 G5				125 G4 125 G5

Symbol A denotes NG, AC, OR AS.  
 H, AP may be recommended as a surfacing measure for improved skid resistance when wet or to reduce water spray.  
 S denotes Double Surface Treatment; (AKK or combinations of AKK and Kurry).  
 G1 denotes Single Surface Treatment.  
 \* AKK is used, minimum C4 and G5 subbase thickness to 200mm.

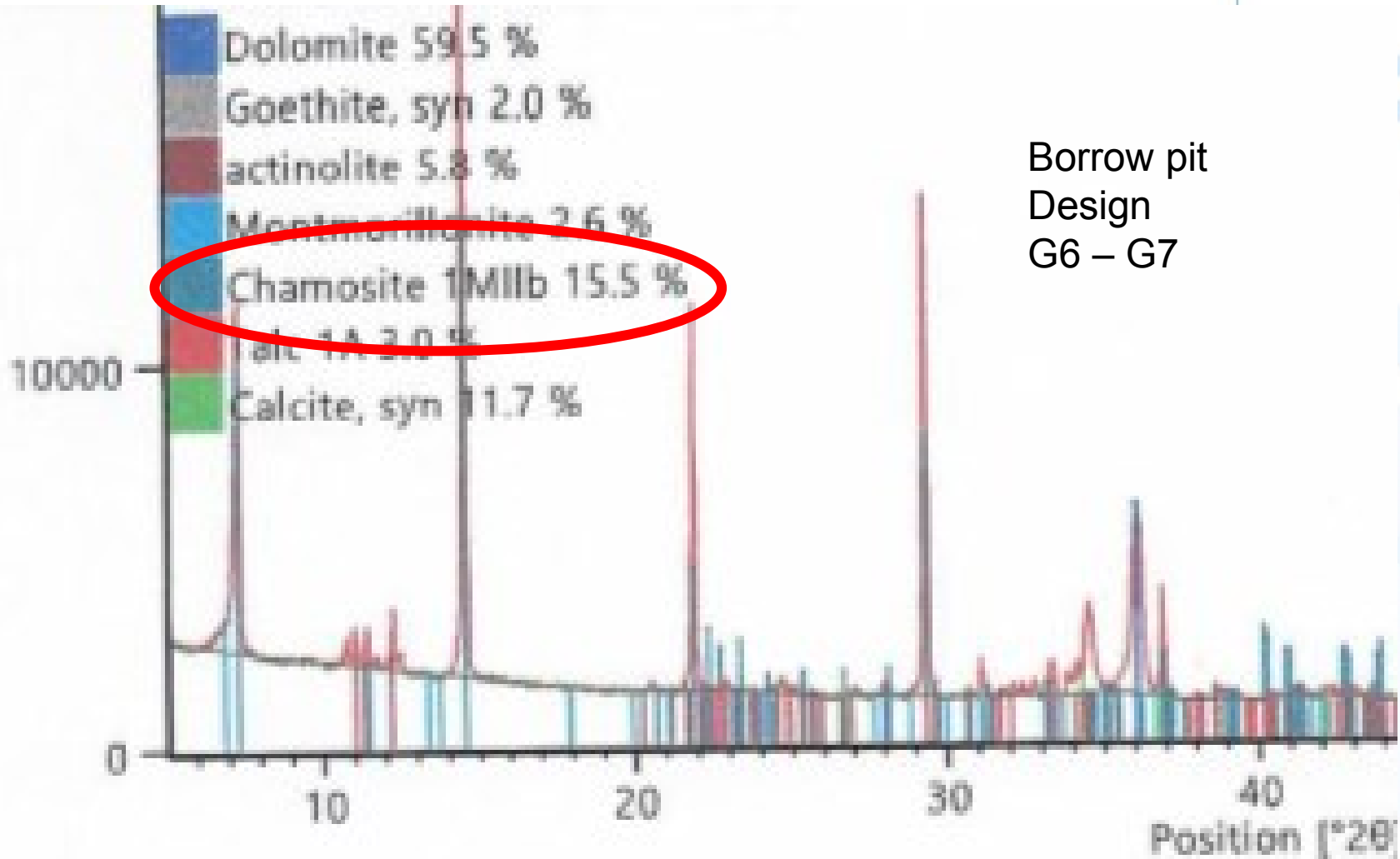
Most likely combinations of road category and design bearing capacity.

# TYPICAL LARGE SMECTITE - SMALL QUARTZ AND FELDSPAR PEAK SCAN

science



# Polokwane



# Polokwane

	S-5065	S-5065-75m
Chlorite	12.37	15.54
Quartz	0.84	3.46
Tremolite	8.55	10.66
Talc	76.21	57.44
Tobermorite	0.02	0.92
Plagioclase	0	5.77
Dolomite	0	4.67
Calcite	1.82	1.4
Hornblende	0.18	0.13

Alternative 1

	S-5225	S-5225_-75m
Chlorite	13.68	19.66
Quartz	4.49	5.87
Tremolite	1.39	7.84
Talc	47.91	29.34
Tobermorite	0.02	0.13
Plagioclase	0	1.76
Dolomite	15.27	6.97
Calcite	12.42	23.23
Hornblende	4.81	5.19

Alternative 2

# Thohoyandou

	Roadlab_S4347	Roadlab_S4347_-75m
Quartz	40.44	21.86
Plagioclase	48.25	20.9
Muscovite	trace	3.88
Actinolite	1.28	8.7
Smectite	6.75	39.24
Microcline	3.28	5.92

## Common design:

### Import:

150 mm Crushed stone base -  
from Louis Trichard / Lepahale (> 80 km)

### In-situ stabilisation

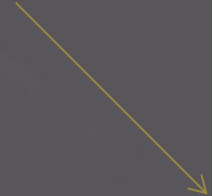
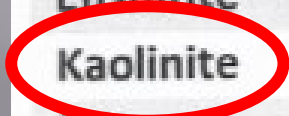
150 mm C4

KZN

“G5”

Weathered Material	S_2931	S_2931 -75 micron
Actinolite	10.35	3.57
Augite	2.93	1.11
Chlorite	1.84	4.28
Enstatite	3.19	0.27
Kaolinite	7.34	11.13
Microcline	6.34	3.62
Plagioclase	30.79	26.83
Quartz	4.48	6
Smectite 1	11.26	37.74
Smectite 2	9.61	3.61
Total	11.87	1.83

>50%



# Mozambique

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## “fine sand”

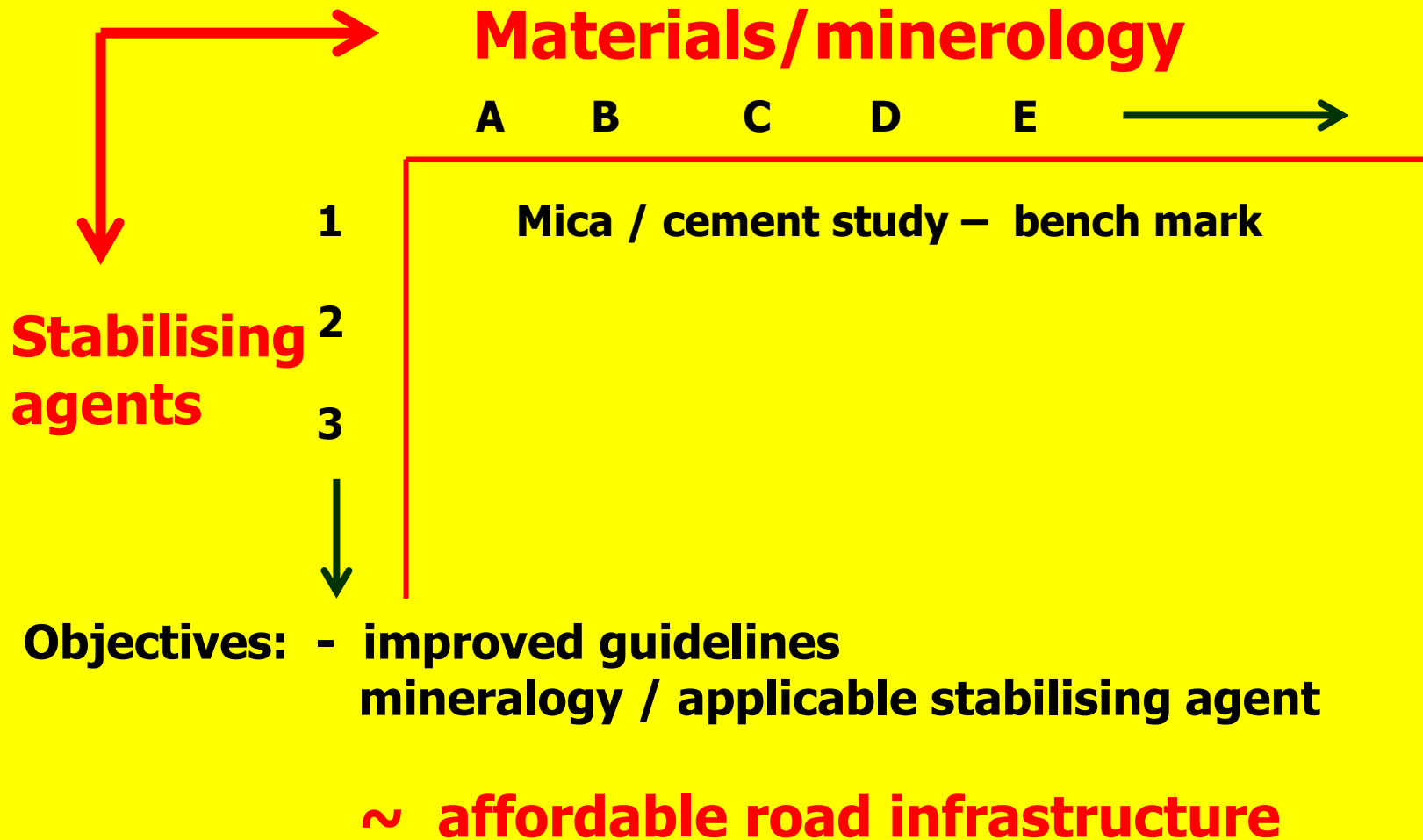
	S/2933	S/2933
	Yellowish fine Sand	-75 micron
Kaolinite		6.39
Microcline	2.31	14.09
Quartz	97.69	79.52

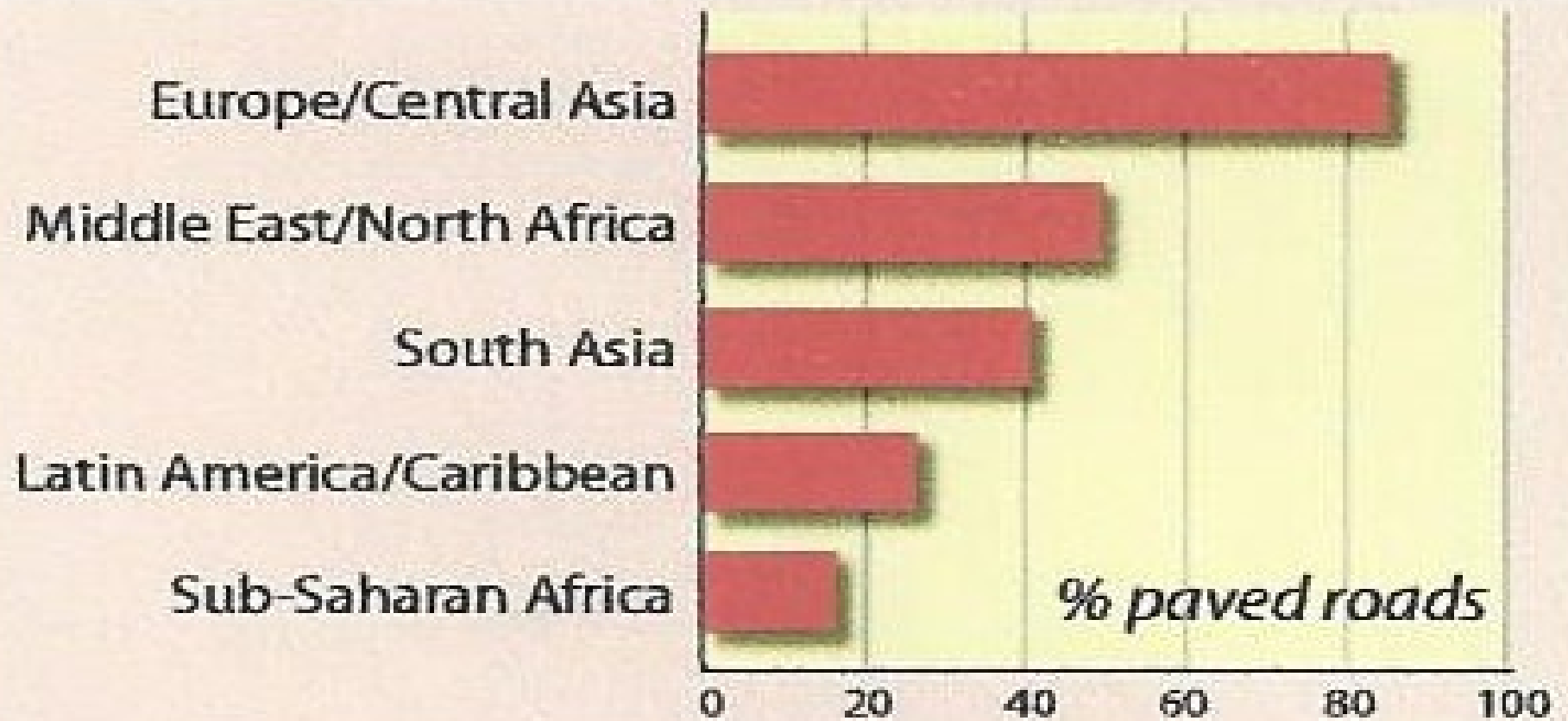
~ 98%

**Idea: Pre-treatment**

**Wet UCS > 1200 kPa**

# **Research : University of Pretoria**

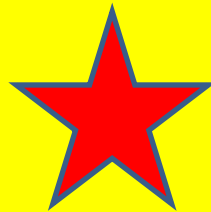




*Sub-Saharan Africa, including the SADC region, lags considerably behind Asia and Latin America in terms of road coverage and density<sup>3</sup>.*

# SA roads “practitioners”

- notoriously conservative  
“problem materials”



**mind shift required !**

**“New”**

**Proven technologies**

- seldom used – “risks”
- need support of authorities





# ATP – HVS: - CSIR

## Demonstration sections

- Low volume – (< 1 MESA)
- Medium traffic loading (WN) (< 10 MESA)
- High traffic loading (> 30 MESA)



25 6:17PM

# Pavement design

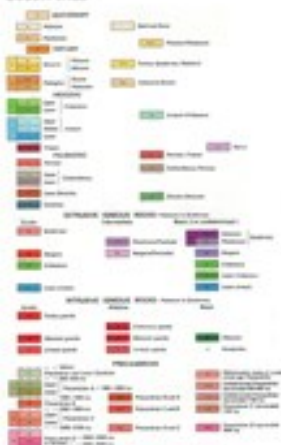
**Back to basics !**

**Need to consider basic available natural materials**  
**- Geology / mineralogy !**

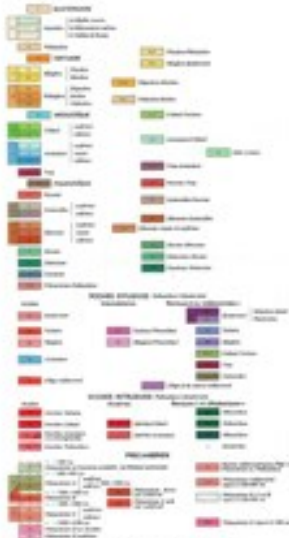
Atlas géologique du monde  
Geological World Atlas

Légende / Legend

South Africa



West Africa



East Africa



# Road structure (pavement) design

## Draft TRH4 (1996):

- Granular (G1 – G4) /  
+ (Cemented sub-base)
- Bituminous treated Base (BTB)
- Cement-Treated base (CTB)
- ???????

**Chapter 3  
Condition  
Assessment**

Uniform pavement sections:

- Sections requiring strengthening
- Cause & Mechanism of distress
- Pavement situation
- Applicable rehabilitation options/strategies

**Chapter 4  
Rehabilitation Design**

**Draft TRH12:  
Road  
Rehabilitation  
design**

**Rehab design  
phase:**

- Theoretical analysis
- **Material design**

Re-assess information  
and/or options and  
adjust or obtain more  
info if necessary

Consider identified  
rehabilitation  
options and  
strategies

Select applicable  
rehabilitation design  
methods

Enough information  
available to  
confidently design  
structural needs  
?

No

Yes

Apply design method(s)  
and  
design strengthening needs  
for various options

Established  
with confidence  
?

No

Yes

**Chapter 5**

**Life-cycle cost comparison**

A child wearing a dark jacket and goggles is riding a skateboard down a street. Another child is visible in the background, also on a skateboard. The scene is outdoors on a paved surface.

**Aim: Cost-effective design**

**Engineering = risk management**

**“define appropriate padding !”**