UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD
ENGINEERING & THE BUILT ENVIRONMENT

Concrete Materials & Structural Integrity Research Unit
CoMSIRU

LC³ Project at UCT

Development of low-clinker concrete: Partial replacement of cement with calcined clay and limestone, based on selected African raw materials

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Outline

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2. Why Africa needs LC^3 cement
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6. Methodology
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Background

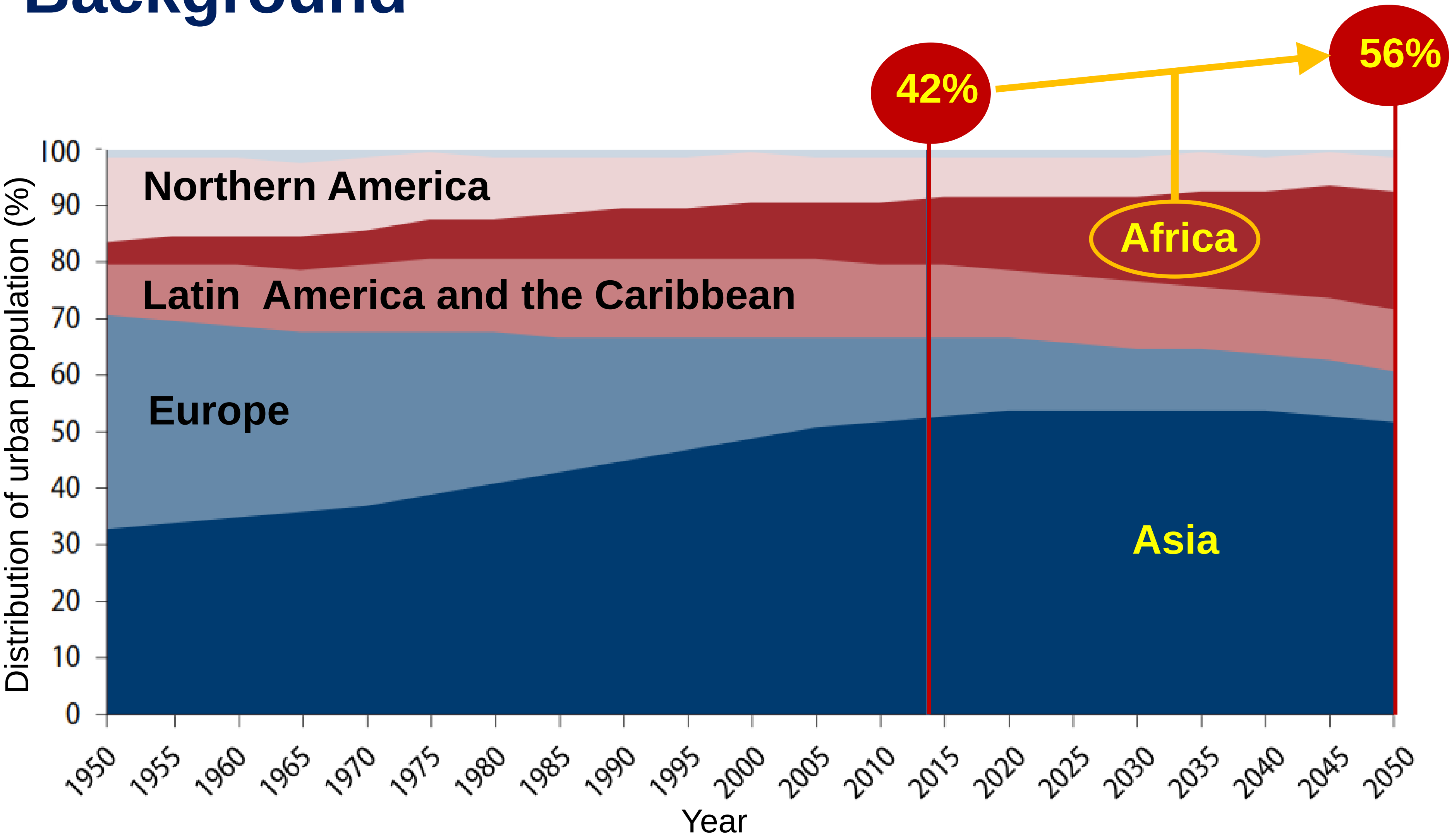
Production of Portland cement

- Generates 800 - 900 kg of CO_2 per ton of clinker
  - 40% - Fossil fuel combustion
  - 60% - Decomposition of limestone
- Contributes about 8% of global anthropogenic CO_2 emissions

Blended cement

- A promising option for lowering costs and environmental impact of concrete
- Clinker content in the cement is partially replaced by Supplementary Cementitious Materials (SCMs).

Background



Distribution of urban population – Global trend

(UN report 2014, *World Urbanization Prospects)*

Why Africa needs LC^3 cement

- **Slag and fly ash** - Limited in most of the African countries

- **Sources of raw materials** - almost unlimited

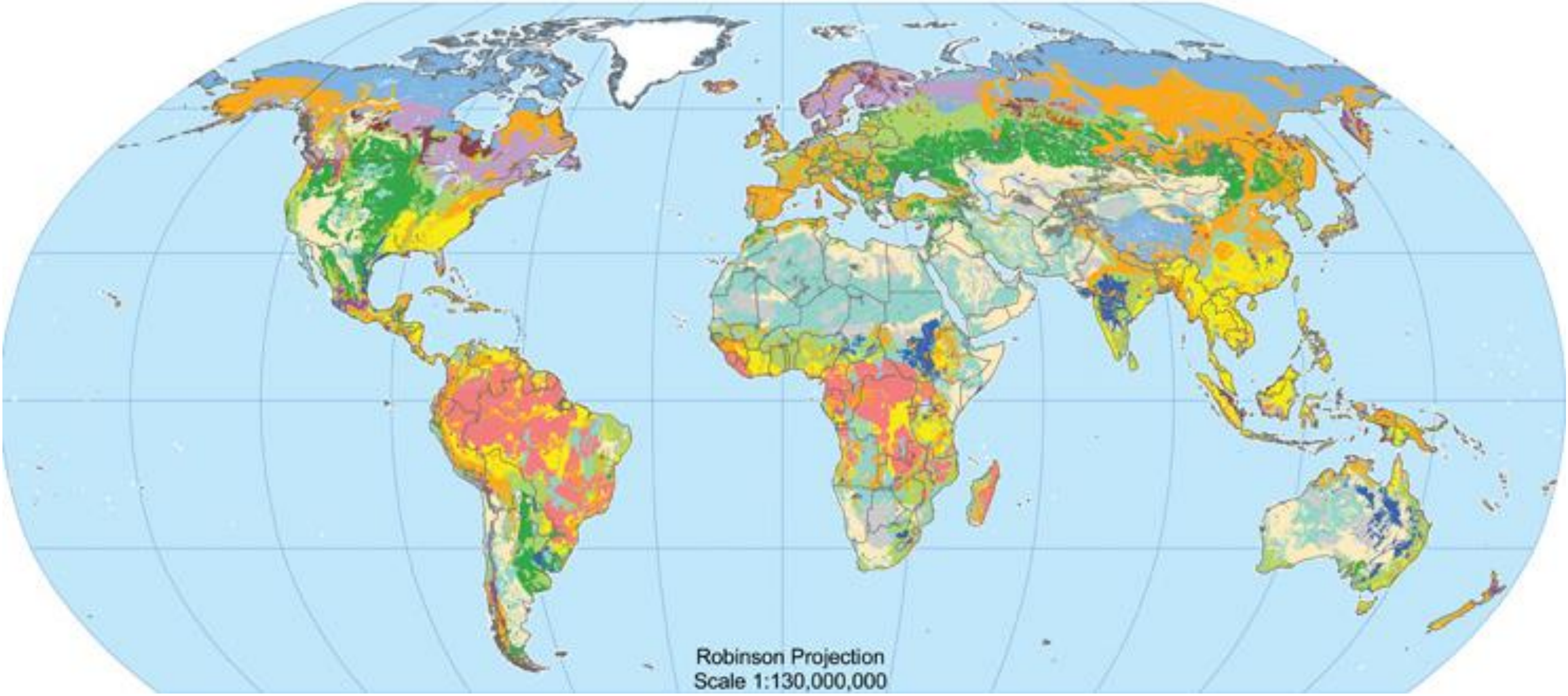
- **Energy saving**
  - Calcination temperature of kaolinite clay ≈ 50% of Limestone

- **Calcined clay + Limestone + Portland cement**
  - Strong chemical synergistic effect

- **Can reduce a great amount of CO_2 emissions (≈ 30%)**

$$\underbrace{AS_2H_2}_{\text{Kaolinite}} \xrightarrow[\text{Heat}]{800°C} \underbrace{AS_2}_{\text{Metakaolin}} + \mathbf{2H}$$

Why Africa needs LC³ cement



All contain kaolinite mineral

World Soil Map (United States Department of Agriculture 2005)

Objective

To use a performance-based approach in the development of low-clinker concrete while maintaining the required properties of workability, compressive strength and durability for marine concrete structures.

- Defining and assessing the required performance measures of the concrete mixes for optimal performance.
- Optimizing system chemistry and mineralogy to achieve synergistic effects with all constituents.

Key research questions

1. What are the required performance levels of the low-clinker concrete mixes for marine concrete structures?

2. What proportion of calcined clay and limestone (at a given amount of clinker) will produce the ‘optimum’ properties for marine concrete?

3. What is the limiting percentage of clinker that can be replaced by calcined kaolinite clay / limestone ratio while maintaining the required performance of concrete?

Scope and Limitations

- **Cementitious materials**

(1) Cement } From AfriSam (CEM II/A-L)

(2) Limestone - Kulubrite 5 (≈ 97% $CaCO_3$) } From Idwala carbonates

(3) Kaolinite clay }
(i) At least 2 samples from South Africa
(ii) At least 2 samples from Tanzania

- Chemical admixture – to enhance rheology and assist in packing of materials

Methodology (3 Phases)

Phase I **Materials Characterization**	Physical properties	Chemical and Mineralogical properties
	• Kaolinite clays – before and after calcination	

Phase II **Design of Concrete Mixes**	**Reference mixes** • 100% CEM II/A-L • 70% CEM II/A-L + 30% Fly ash • 50% CEM II/A-L + 50% Slag
	Clinker replacement (40 to 60%) • Mixture design: 3-factors approach
	Two water/binder ratios: 0.40 and 0.55

Methodology (3 Phases)

<table>
<tr><td rowspan="3">Phase IIIA
Concrete Properties</td><td>Tests for Early properties</td><td>Tests for Hardened properties</td></tr>
<tr><td>• Setting time
• Free shrinkage
• Restrained shrinkage (ring)</td><td>• Compressive strength
• Durability index
• Bulk diffusion
• Accel. Carbonation</td></tr>
<tr><td colspan="2">• Concrete resistivity (lab and site)</td></tr>
</table>

<table>
<tr><td rowspan="2">Phase IIIB
Micro-structural Analysis</td><td>Internal properties of concrete specimens (1,3, 7, 28 and 90 days)</td></tr>
<tr><td>• TGA & XRD - Detect and quantify phases in concrete
• SEM - Arrangement of component phases
• 3D Computed tomography - Pore-size distribution</td></tr>
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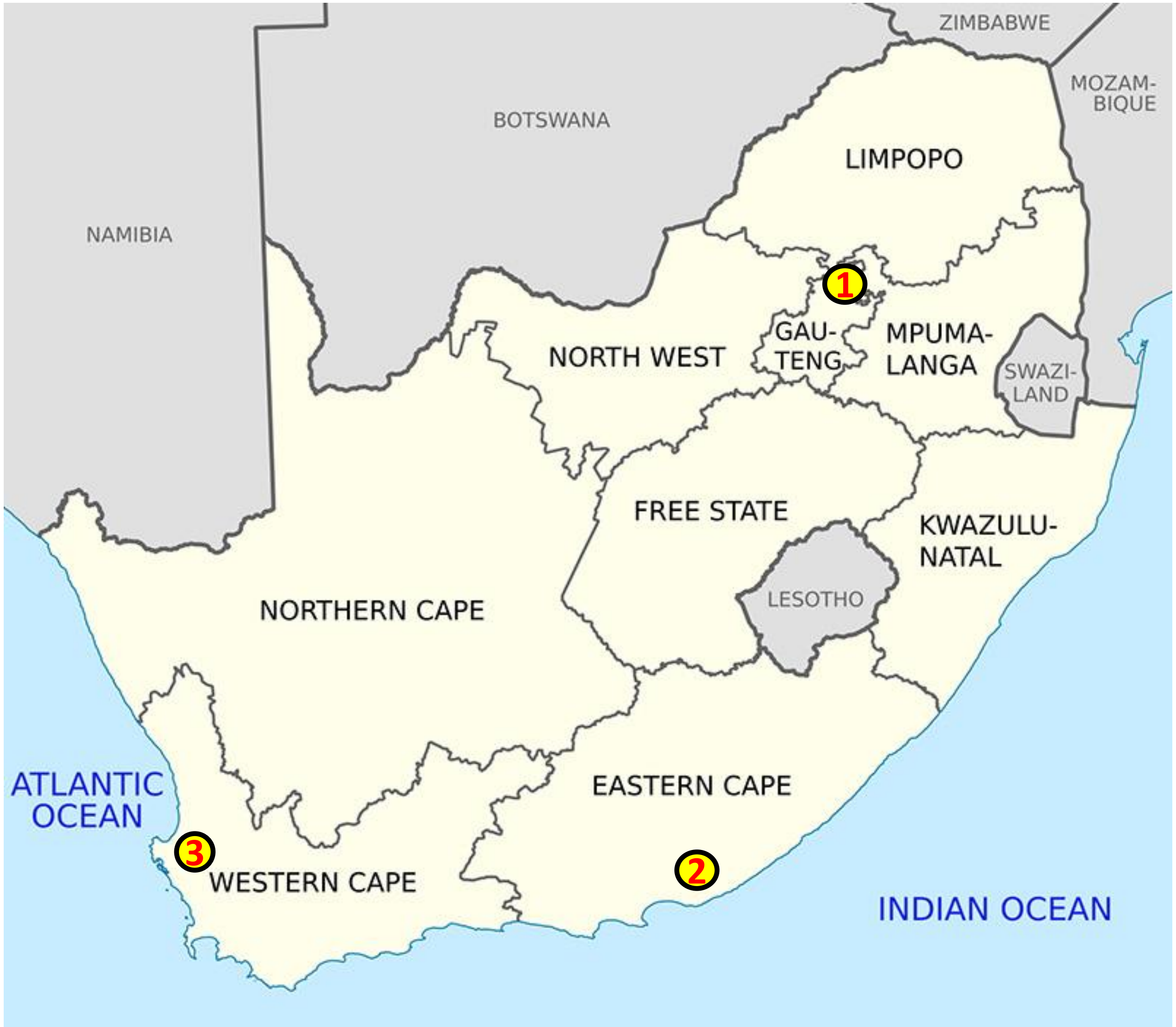
Selected kaolinite clay deposits in South Africa



1. Bronkhorstspruit **(B-Clay)** (35 Million tons)
2. Grahamstown **(G-Clay)** (60 Million tons)
3. Hopefield **(H-Clay)** (500 Million tons)

(Hosterman, Patterson & Good 1978; Cole, Ngcofe & Halenyane 2014; Hagemann, S)

Kaolinite clay deposits in Tanzania

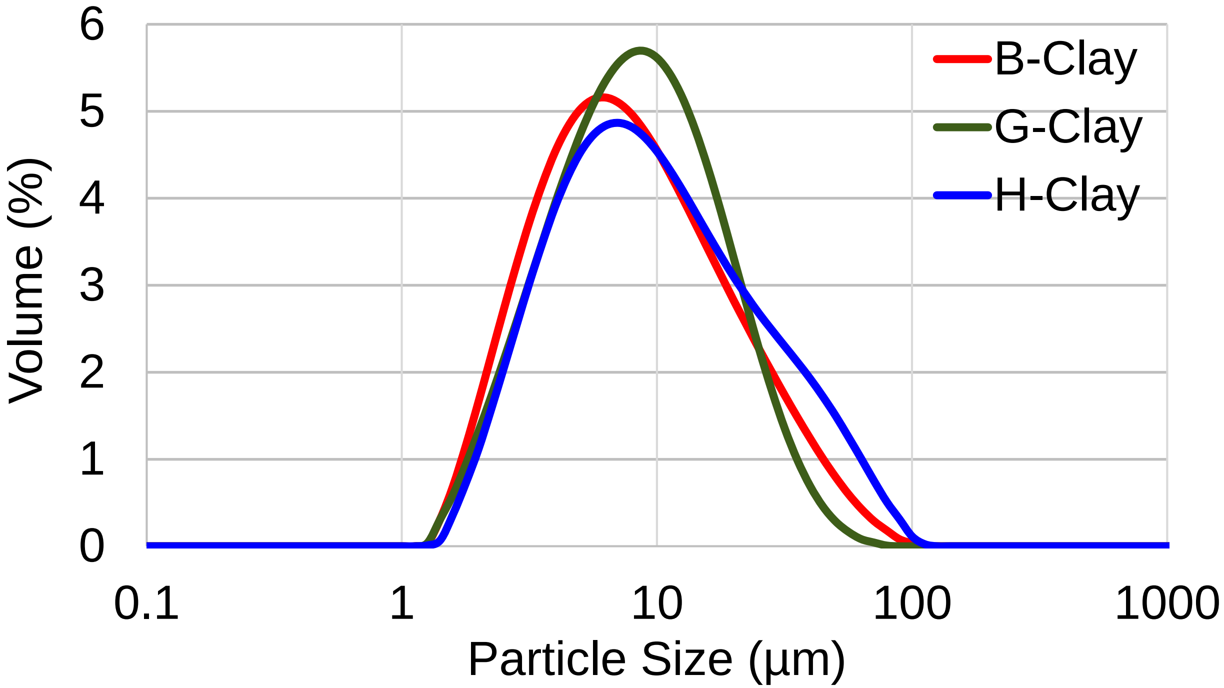
1. Pugu – Kisarawe
   (2 Billion tons)
   - Pugu 'Hard' **(PH-Clay)**
   - Pugu 'Soft' **(PS-Clay)**
2. Matamba – Makete
   (56 Million tons)
3. Malangali – Mufindi
   (?)

HeidelbergCement clay
(HC – Clay)

(Ministry of Energy and Minerals – Tanzania, 2008)

Uncalcined samples of clay

Uncalcined samples of clay



Sample	D_{10}	D_{50}	D_{90}
B-Clay	2.4	6.9	28.0
G-Clay	2.9	7.8	20.7
H-Clay	3.0	8.6	33.9

Chemical Composition (Uncalcined clays)

XRF Analysis

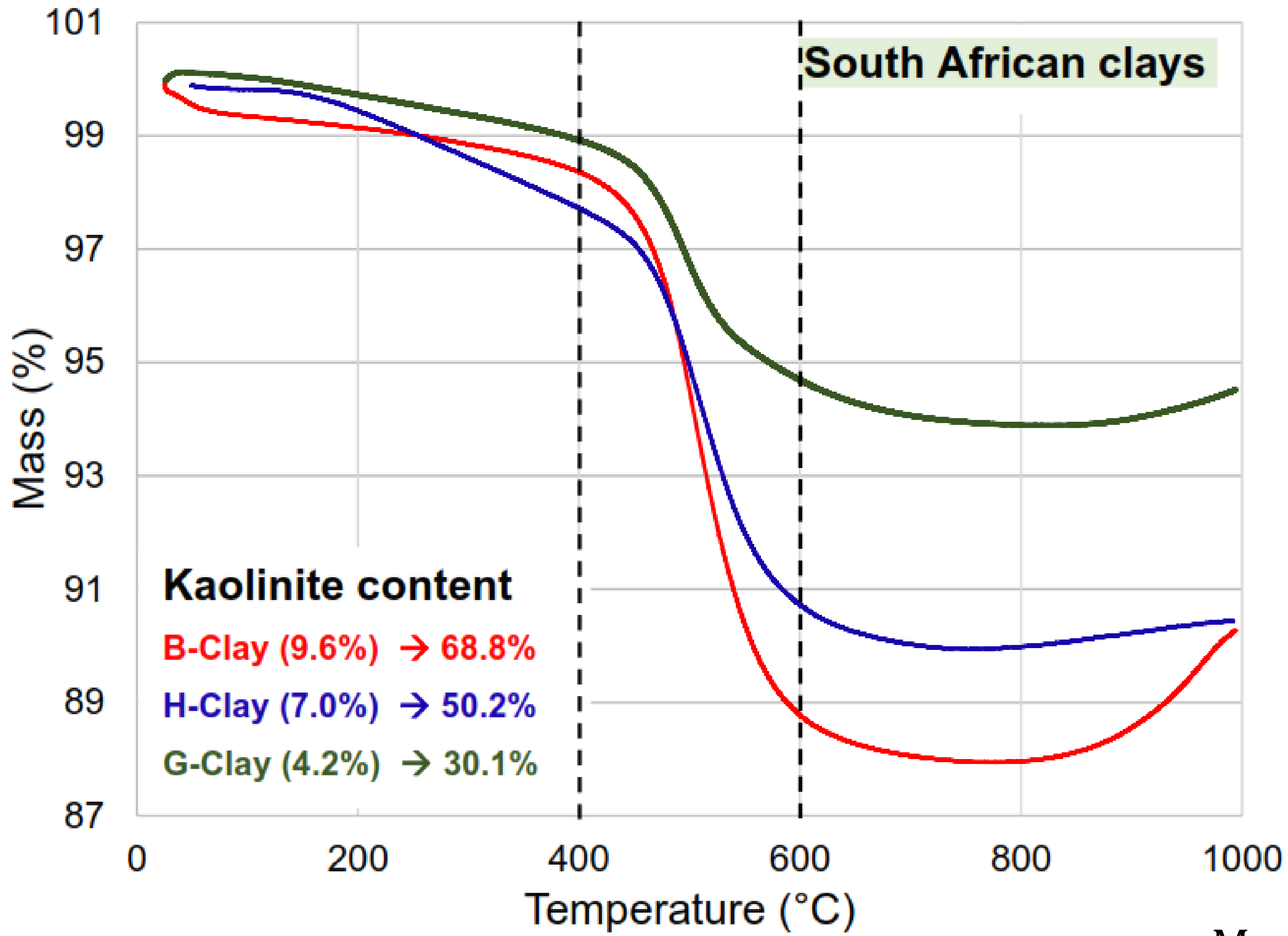
Oxides (wt.%)	South African clays			Tanzanian clays		
	B-Clay	H-Clay	G-Clay	PH-Clay	PS-Clay	HC-Clay
SiO_2	**51.52**	**62.63**	**68.53**	**68.32**	**70.11**	**63.86**
Al_2O_3	**31.59**	**20.95**	**20.58**	**20.07**	**19.79**	**18.59**
Fe_2O_3	1.14	1.60	0.52	0.63	0.65	7.12
CaO	1.64	0.03	0.00	0.03	<0.01	0.27
Na_2O	0.25	1.21	0.38	0.62	0.37	0.24
K_2O	0.35	2.35	2.74	0.08	0.20	0.50
LOI	**11.00**	**8.25**	**5.15**	**8.25**	**7.61**	**7.27**

Chemical Composition (Uncalcined clays)

XRF Analysis

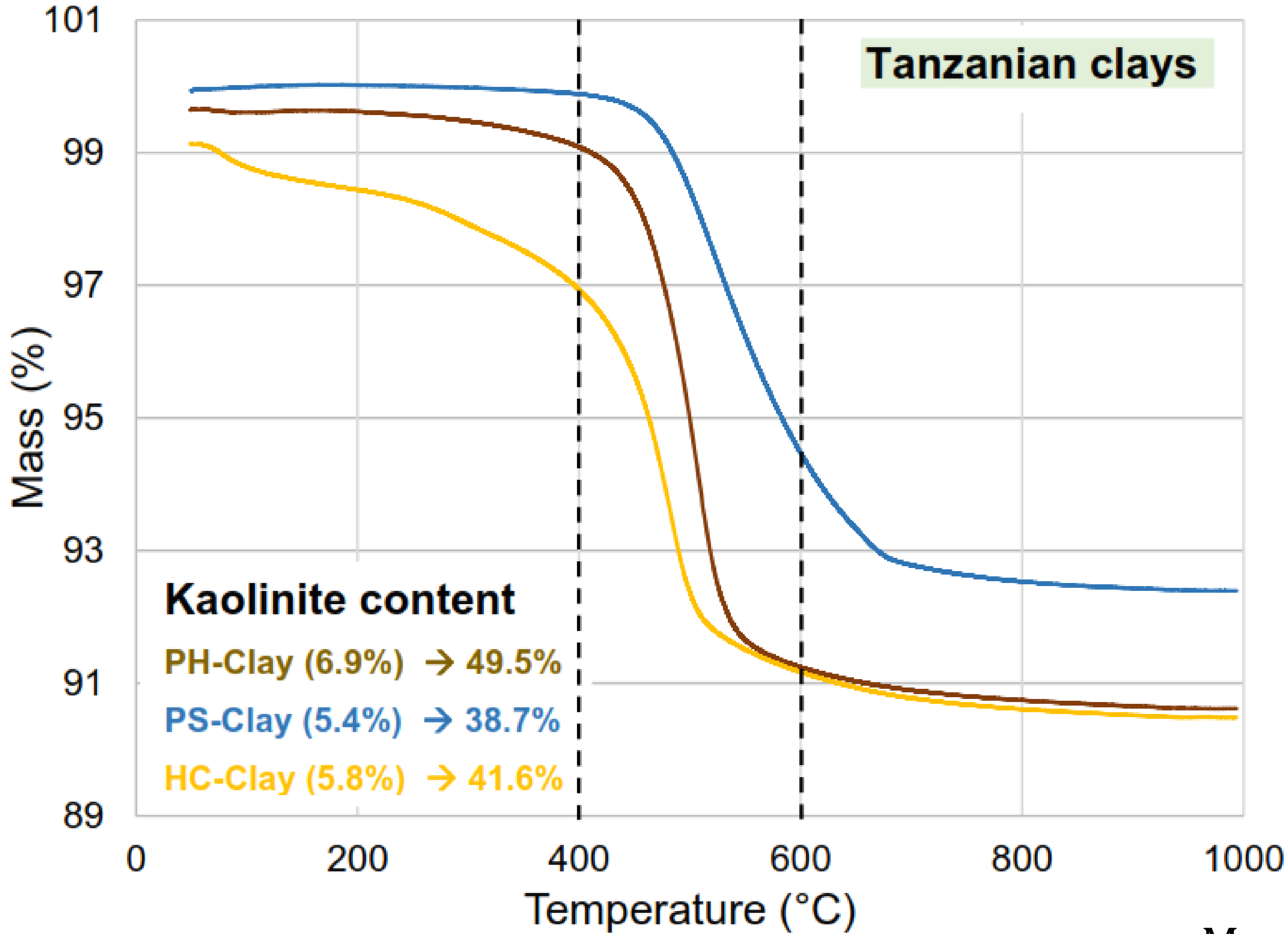
Suitable Clay (Scrivener, K)	Al_2O_3 > 18%	Al_2O_3/SiO_2 > 0.3	LOI > 7%	Comment
B-Clay	31.59%	0.61	11.00%	OK
H-Clay	20.95%	0.33	8.25%	OK
G-Clay	20.58%	0.30	5.15%	Marginal
PH-Clay	20.07%	0.30	8.25%	OK
PS-Clay	19.79%	0.30	7.61%	OK
HC-Clay	18.59%	0.30	7.27%	OK

Thermo-gravimetric Analysis (TGA)



$$AS_2H_2 \rightarrow AS_2 + 2H \Rightarrow \text{Kaolinite content (K)} = \underbrace{\Delta\text{Mass}}_{400-600°C} \times \frac{M_{Kaolinite}}{2M_{water}}$$

Thermo-gravimetric Analysis (TGA)



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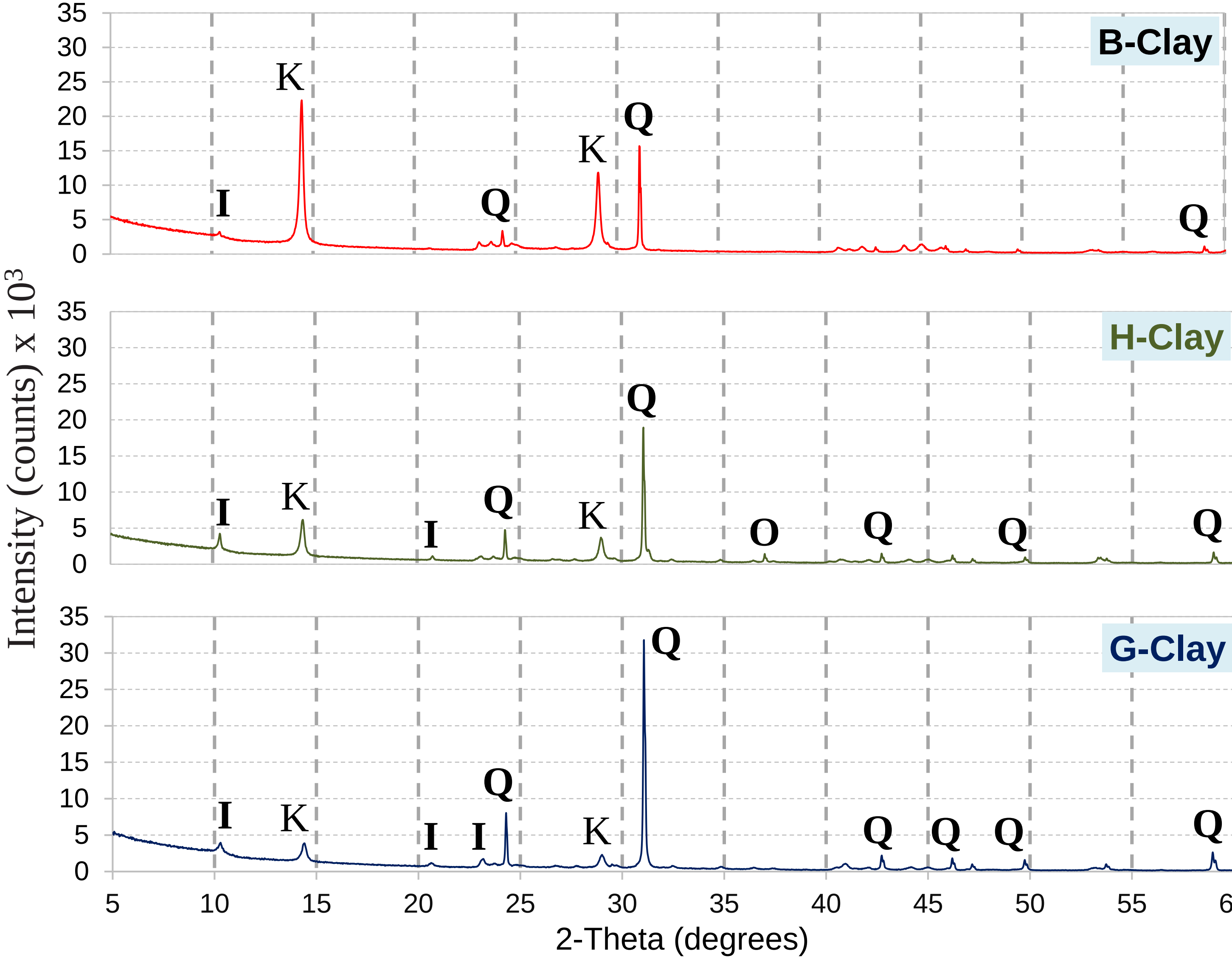
Mineralogical Composition of uncalcined samples

XRD Analysis and Phase quantification



South African clays

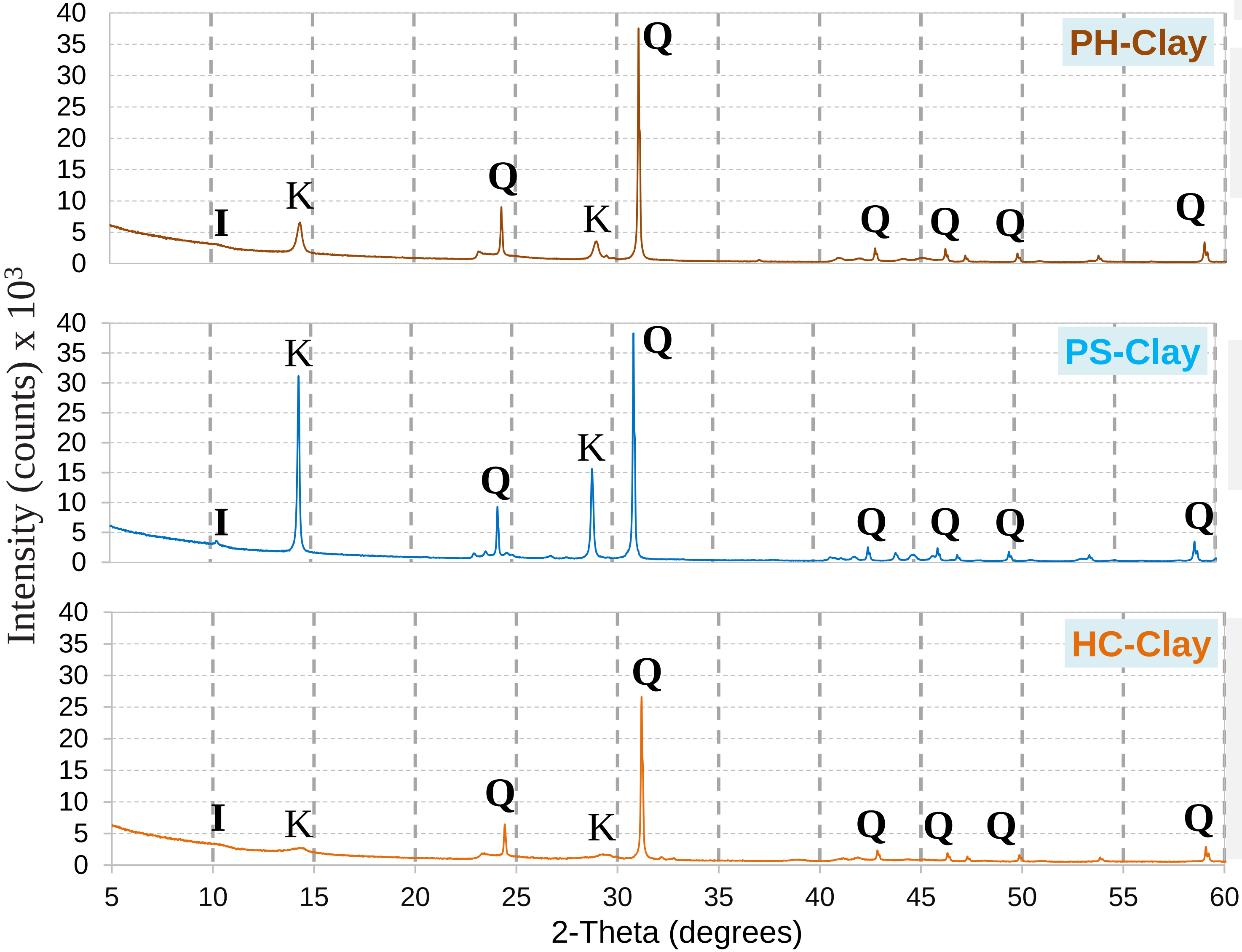
Quartz (Q)	18.3%
Illite (I)	8.0%
Kaolinite (K)	**72.6%**

Quartz (Q)	35.0%
Illite (I)	20.0%
Olivine (O)	<1.0%
Kaolinite (K)	**44.0%**

Quartz (Q)	45.9%
Illite (I)	29.2%
Kaolinite (K)	**24.9%**

Mineralogical Composition of uncalcined samples

XRD Analysis and Phase quantification



Tanzania clays

PH-Clay

Quartz (Q)	47.7%
Illite (I)	3.1%
Kaolinite (K)	**49.2%**

PS-Clay

Quartz (Q)	50.1%
Illite (I)	1.2%
Kaolinite (K)	**48.7%**

HC-Clay

Quartz (Q)	37.0%
Illite (I)	2.6%
Haematite	6.9%
Kaolinite (K)	**40.6%**

Reactivity results (R^3 Bound water test)

Calcined sample	Temperature °C	Bound water (105 °C – 350 °C)	
		Average (%)	SD
B-Clay	850	6.43	0.37
	800	6.99	0.30
	750	6.86	0.22
H-Clay	850	5.46	0.10
	800	6.13	0.11
	750	6.05	0.12
G-Clay	850	3.80	0.06
	800	4.02	0.12
	750	4.19	0.13
PH-Clay	850	4.08	0.01
	800	5.17	0.02
PS-Clay	850	4.59	0.11
	800	5.04	0.12
HC-Clay	850	4.67	0.15
	800	4.94	0.13

Conclusion

- All clays composed mainly of quartz, illite and kaolinite
- Good agreement: XRF versus QXRD and TGA results
- Kaolinite content (> 40%) is an important indicator for clay suitability
  - B-Clay has about 68 - 73% kaolinite content √
  - H-Clay has about 44 - 50% kaolinite content √
  - G-Clay has about 25 - 30% kaolinite content ✕
  - PH-Clay has about 48% kaolinite content √
  - PS-Clay has about 38 - 48% kaolinite content √
  - HC-Clay has about 41% kaolinite content √

Thank You

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