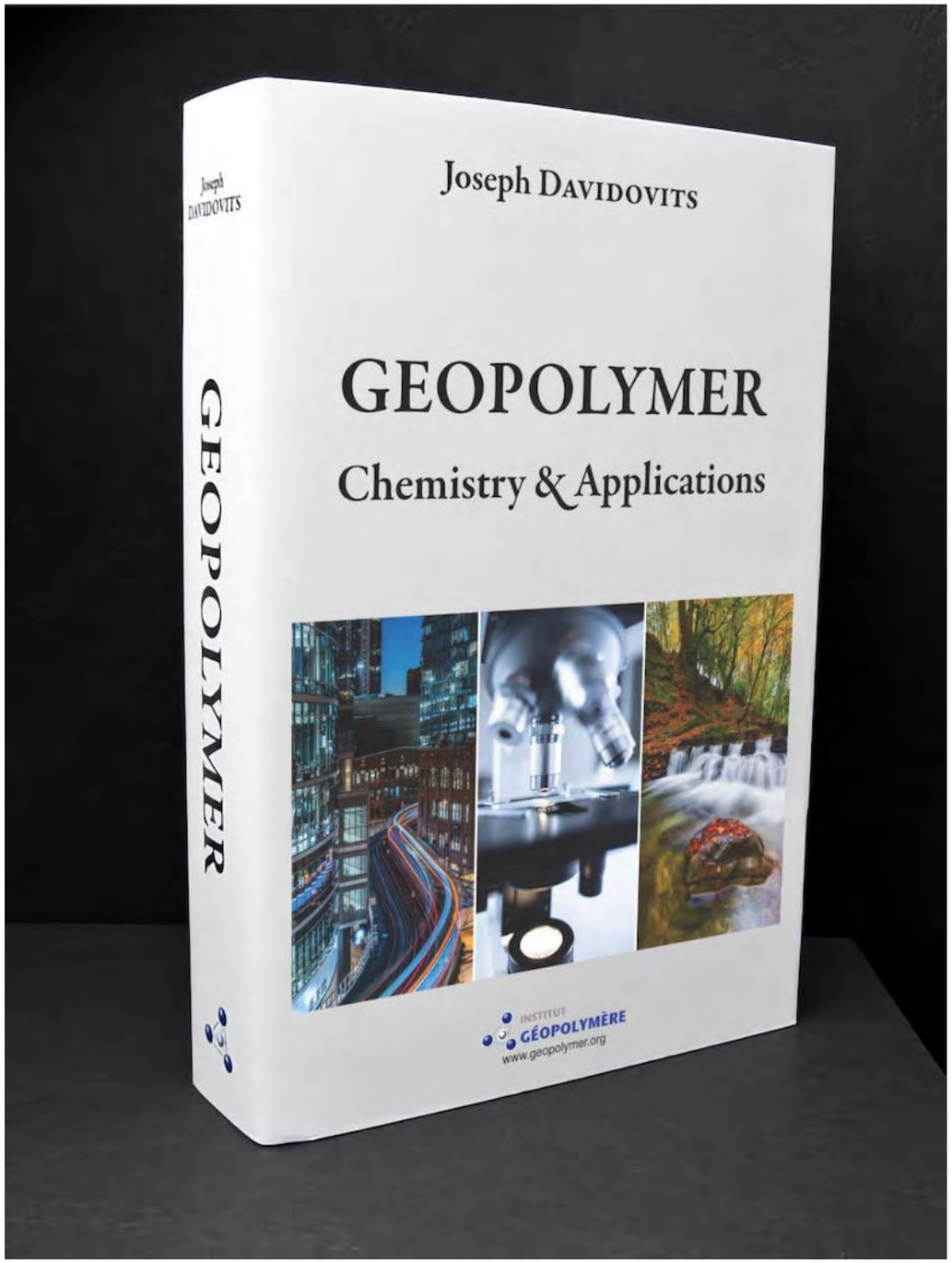
# Ferro-sialate geopolymer
## *Chapter 12*



# Definition

***Ferro-sialate geopolymer*** designates a binder or cement of the type poly (ferro-silico-aluminate), which has part of the Al atoms substituted by Fe atoms.

The Fe atoms are in structural tetrahedral Fe[IV] or pentahedral Fe[V] position in the ferro-sialate sequence

[Fe-O-Si-O-Al-O].

# Geological raw-materials:
# red iron-rich rocks or lateritic-clays.

- formed in weathered basic rocks (mafic) :
  basalt and gabbro.
- or in weathered acidic rocks :
  sandstone, granite or gneiss.

Ferro-sialate [Fe-O-Si-O-Al-O]-based geopolymer binder, results from a geopolymerisation of geological elements rich in iron oxides ($Fe^{3+}$ exclusively) and ferro-kaolinite.

*Goethite* FeO(OH) + $Fe_2O_3$ *Hematite* + $Fe_3O_4$ *Magnetite*, ranging up to 40 % by weight of the rock.

# Geological raw-materials:

# red iron-rich rocks

1) formed in weathered basic rocks (mafic)
basalt and gabbro.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**Lateritic rock (not clay) resulting from the weathering of basalt:**

12% quartz,
45% kaolinite,
30% hematite, 3% goethite,
10% other elements
(anatase + ilménite+ olivine).

- calcined at 750°C during 3 hours,
- ground to 10-25 microns.

# Geological raw-materials:

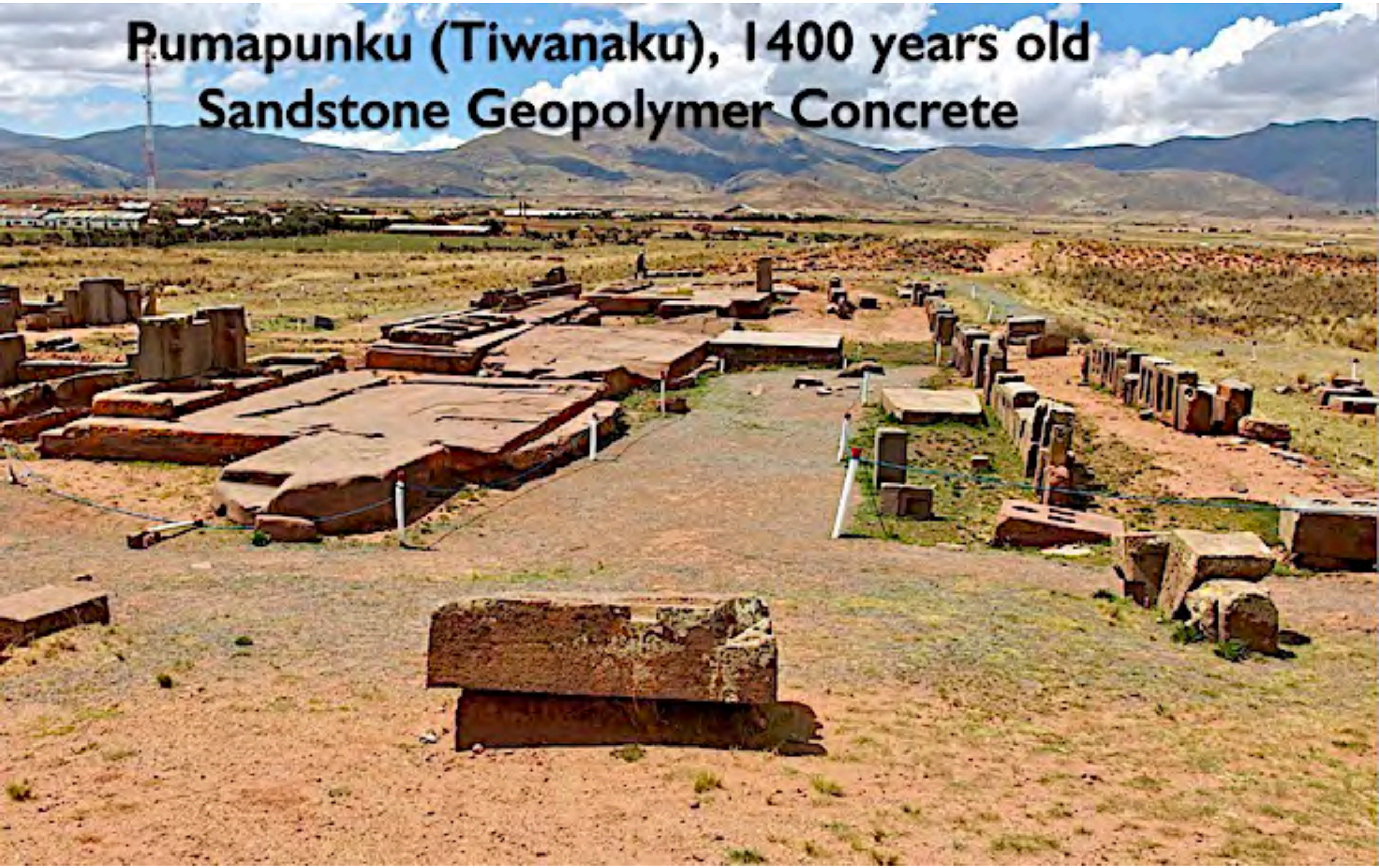
# red iron-rich rocks

II) formed in weathered acidic rocks :

sandstone, granite or gneiss,

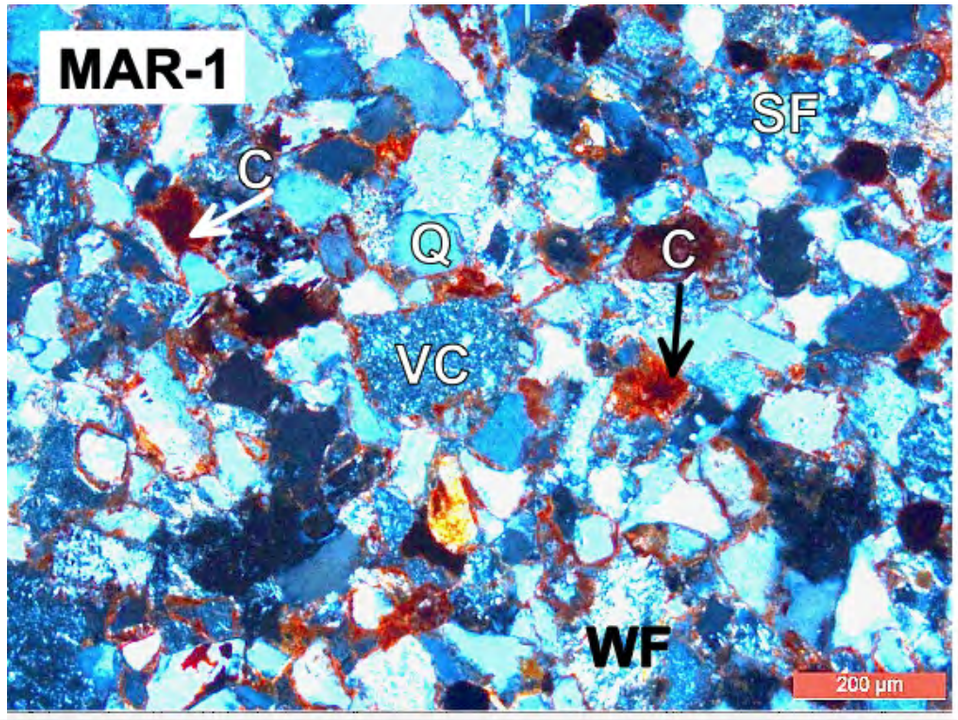
# South American Andes, Altiplano Tiwanaku and *Gate of the Sun* and Pumapunku megaliths.

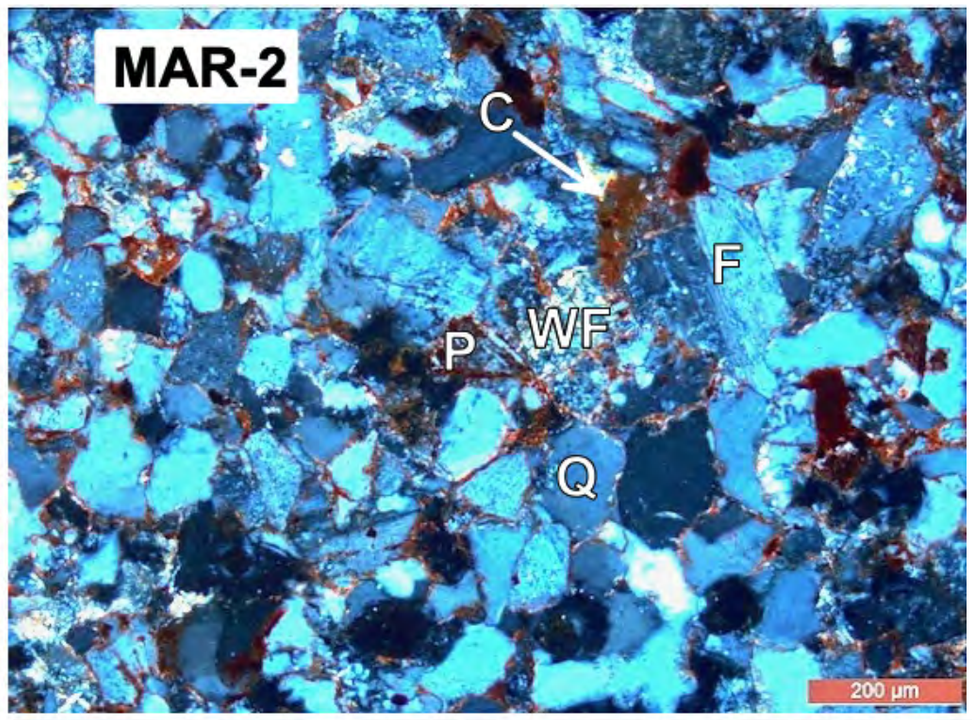
# (Na,K,Ca)-(ferro-sialate)-based geopolymer cement



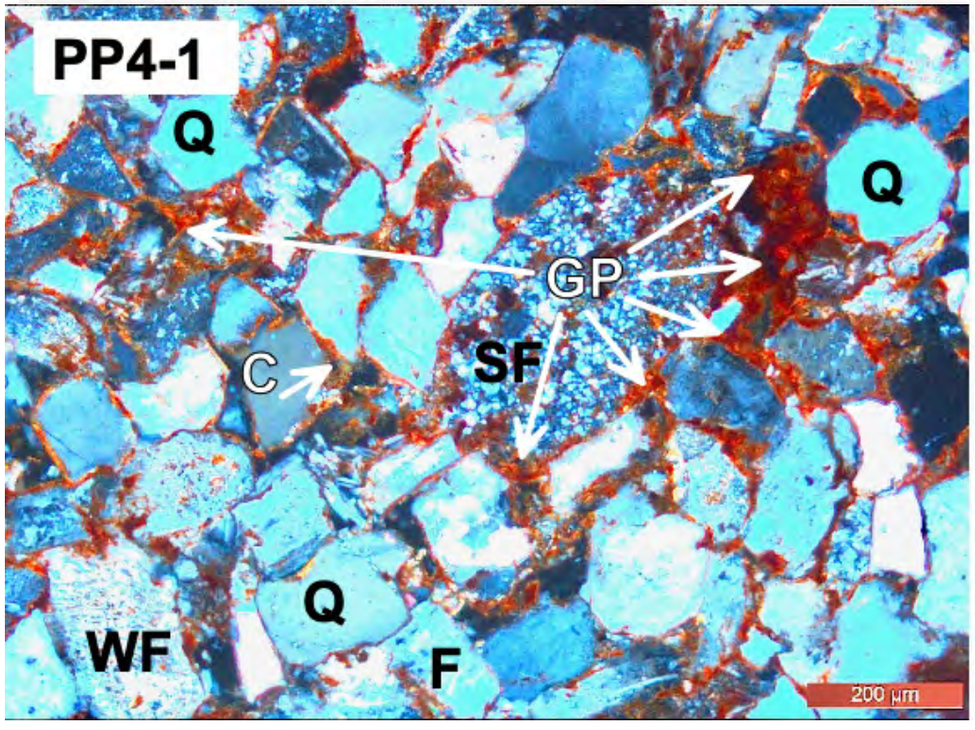
# Kallamarka, Bolivia

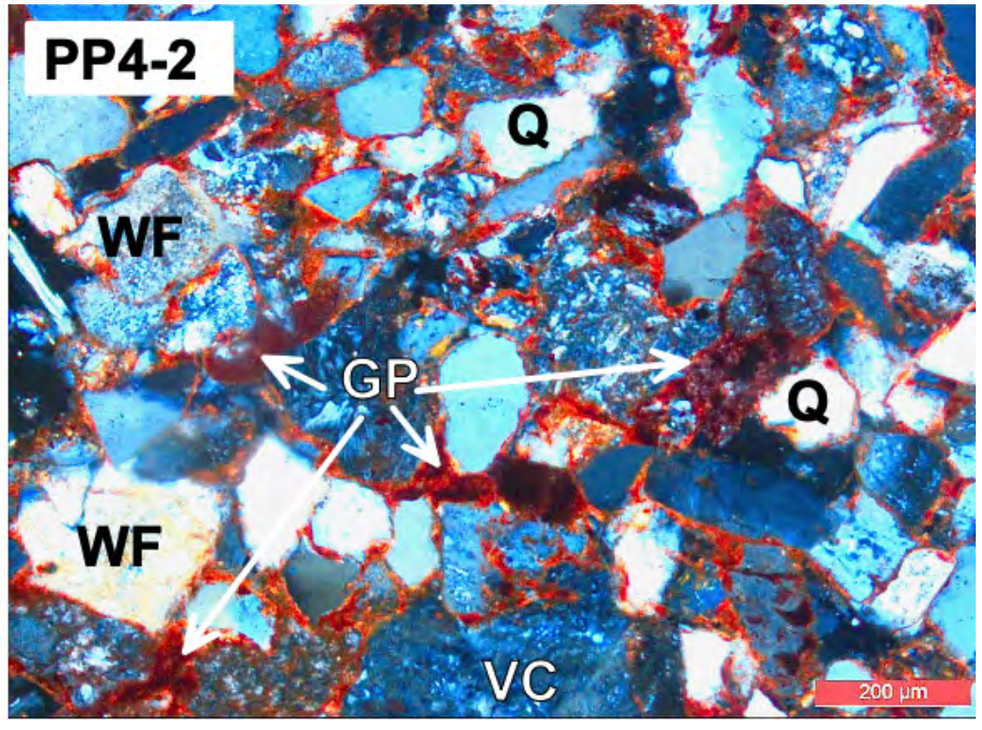

Geological site Kallamarka



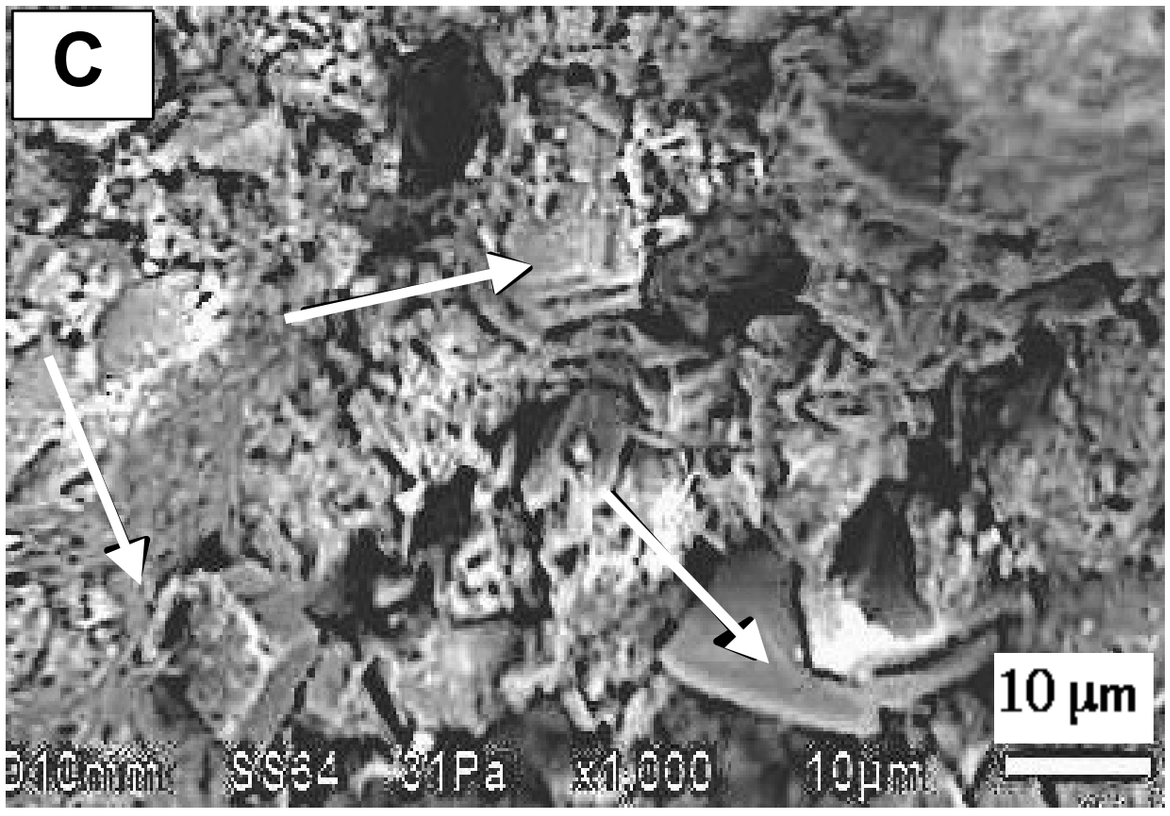



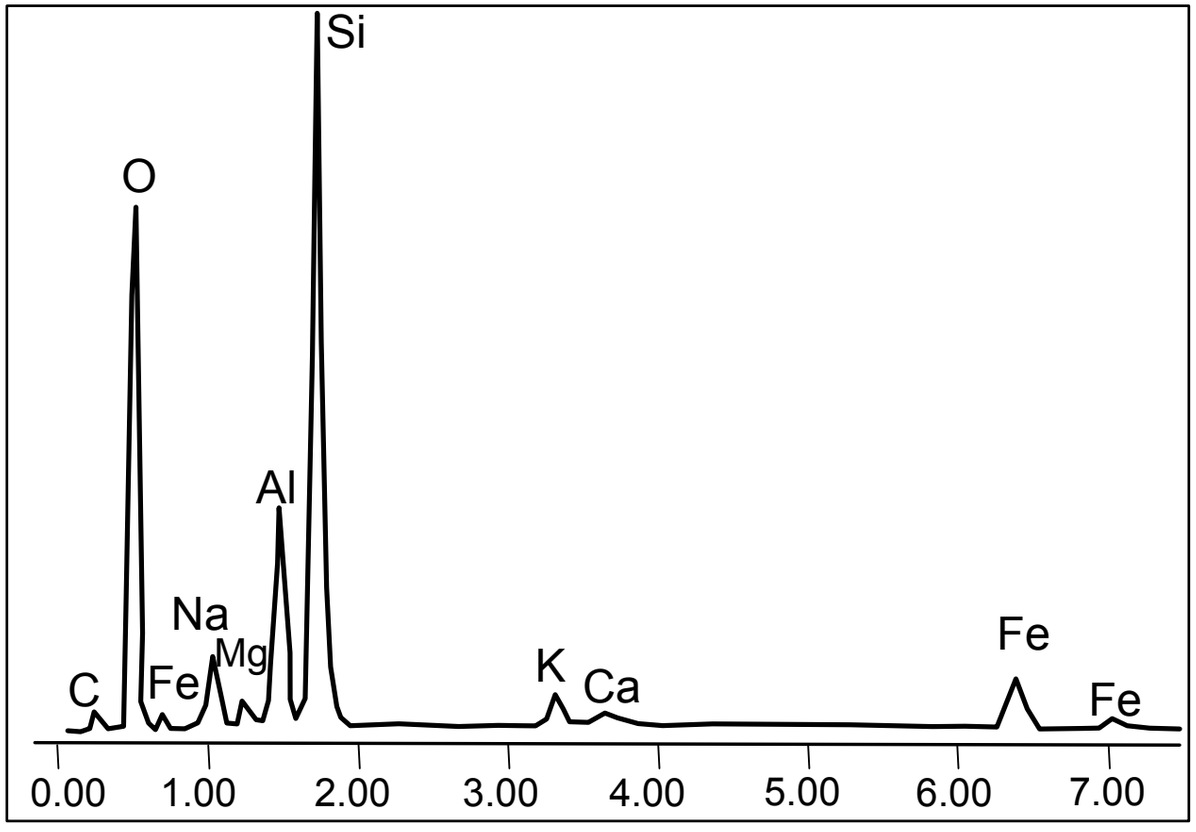

Pumapunku monument



# Pumapunku PP4 matrix




Ferro-sialate matrix between quartz and feldspar grains, with regular geometrical structures (arrows). EDS spectrum of the structures,

# Geological raw-materials

## Substitution by iron in kaolinite, P.J. Malden and R.E. Meads, *Nature* 215 (1967) 844-846.

**letters to nature**

*Nature* **215**, 844 - 846 (19 August 1967); doi:10.1038/215844b0

**Substitution by Iron in Kaolinite**

P. J. MALDEN & R. E. MEADS

Research Laboratories, English Clays, Lovering, Pochin and Co., Ltd., St Austell, Cornwall.
Department of Physics, University of Exeter.

**KAOLINITE often occurs in admixture with other minerals (for example, micas and iron oxides) in which iron is a legitimate constituent. Because of the difficulties of detection and separation, it has always been doubtful whether iron actually substitutes in the kaolinite lattice. We provide here evidence for substitution of irori(III) in the octahedral**

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**References**

1. Weaver, C., W
2. Kündig, W., Bö

# Geological raw-materials

This substitution occurs only when Fe is the

***trivalent $Fe^{3+}$***

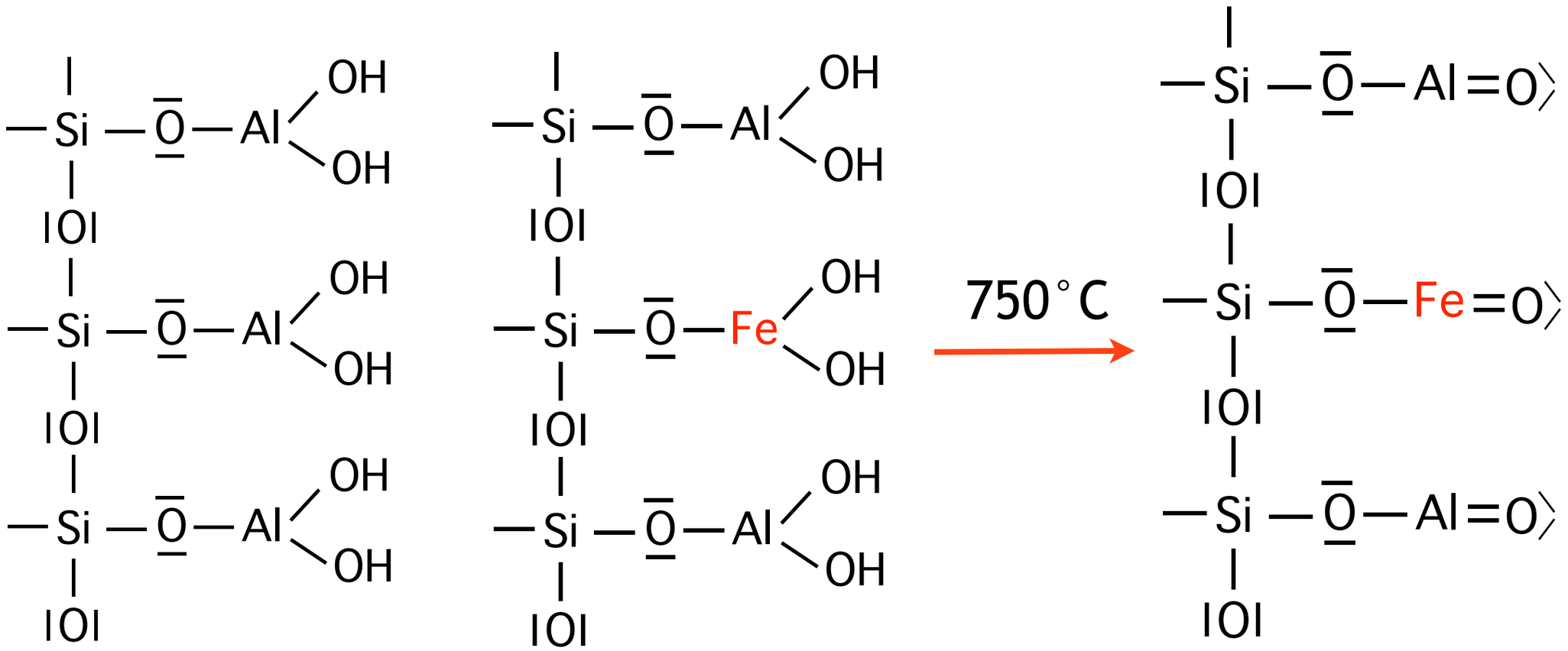
This substitution can reach 25% of the Al atoms, transforming the sequence

≡Si-O-$Al(OH)_2$ of kaolinite into ≡Si-O-$Fe(OH)_2$.

It is however impossible to separate the substituted kaolinite from that not-substituted.

This explains why, we designate the mixture of substituted kaolinite + not-substituted kaolinite by the generic term

***“ferro-kaolinite”.***




*kaolinite*

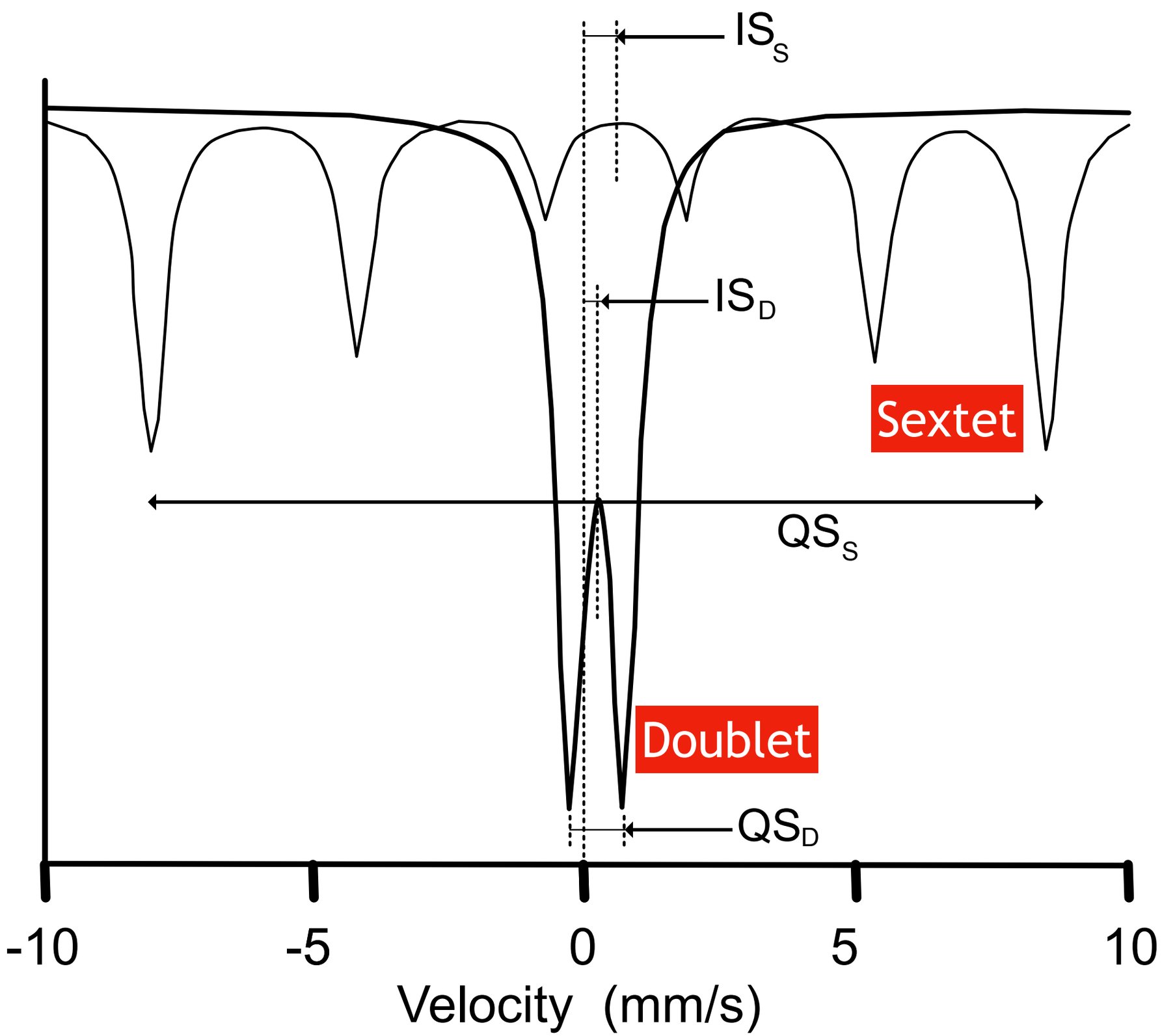
*ferro-kaolinite*
*25% Fe/Al*
*substitution*

*ferro-metakaolinite ?*
*Fe-MK-750*

~~NMR spectroscopy~~

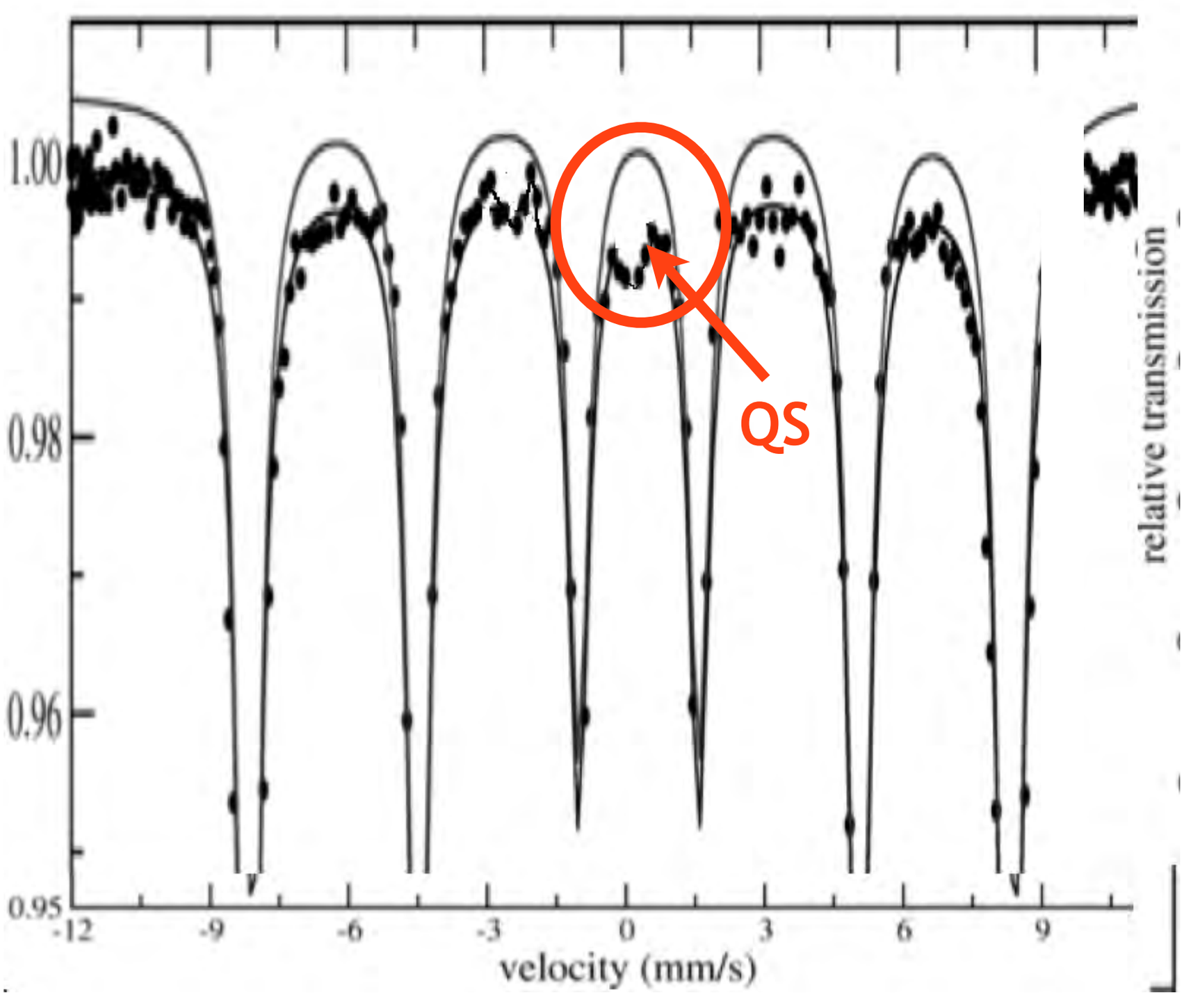
Mössbauer spectroscopy

# $^{57}$Fe Mössbauer Spectroscopy



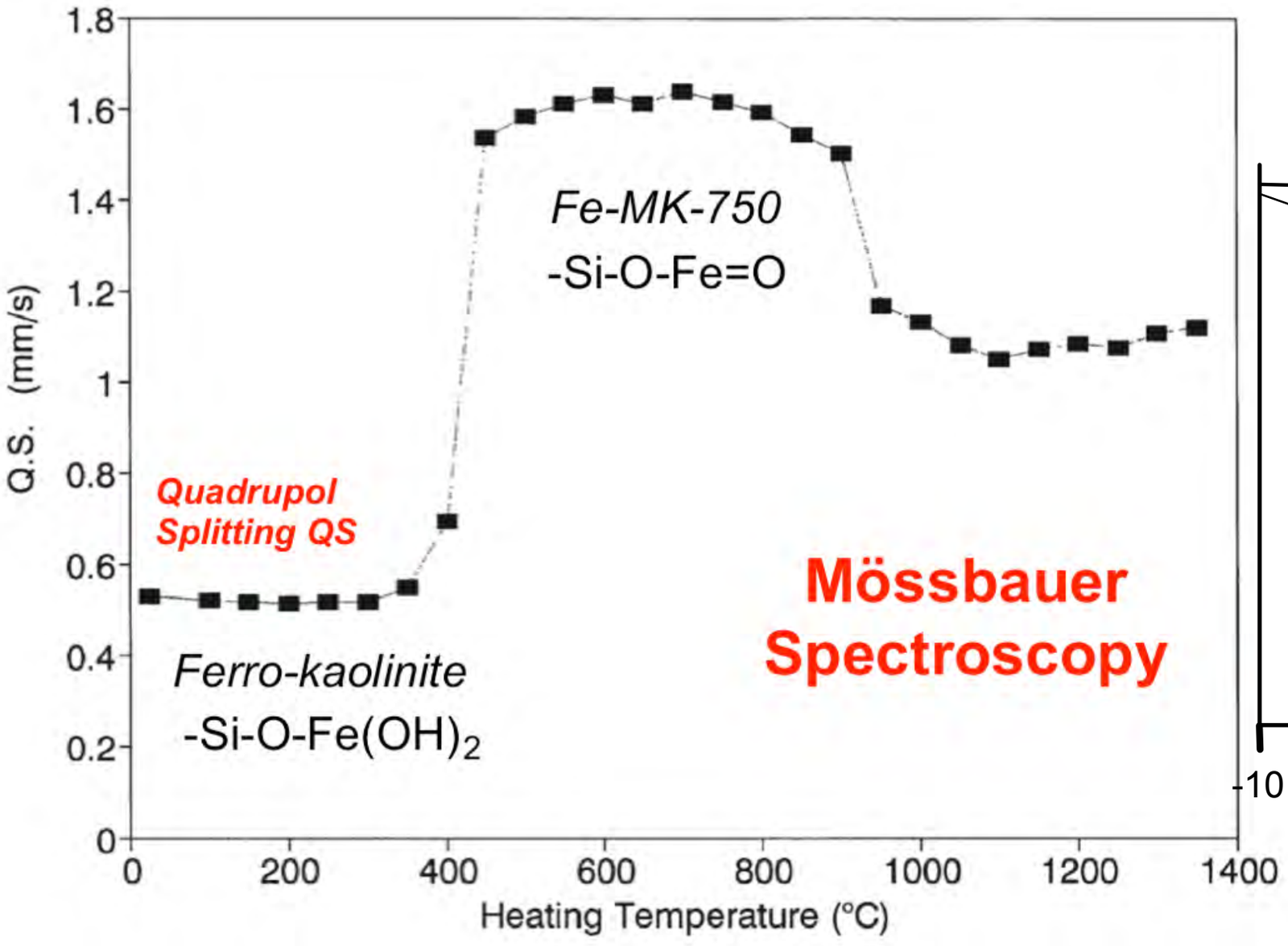
# Mössbauer Spectroscopy (ferro-sialate)-geopolymer

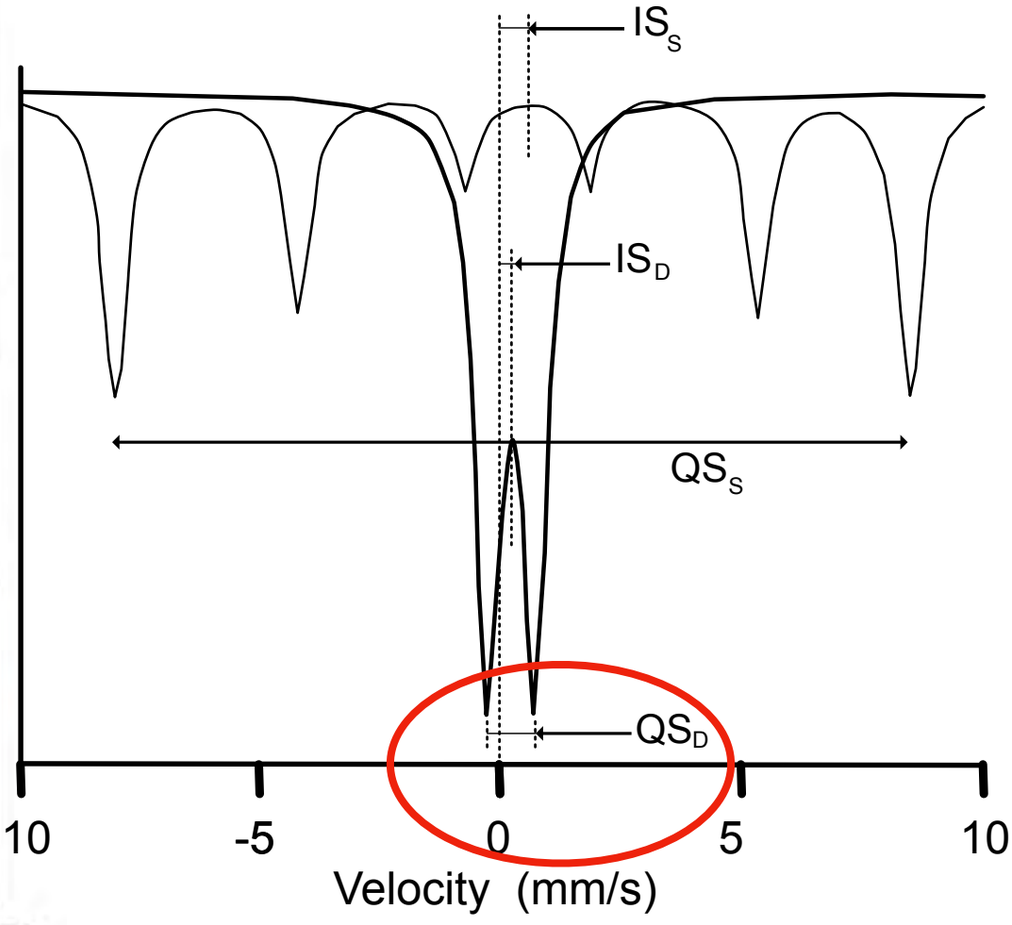
adapted from K. C. Gomes et al., *Materials Science Forum (2010)*



# Transformation of ferro-kaolinite into Fe-MK-750

adapted from E. Murad and U. Wagner, *Hyperfine Interactions 117* (1998)



# How to calculate substitution Fe / Al

**Pumapunku ferro-sialate geopolymer matrix**

| SEM/EDS | atom % | Oxide | Oxide % |
|---|---|---|---|
| Na | 7.63 | $Na_2O$ | 8.17 |
| Mg | 1.87 | MgO | 1.24 |
| Al | 15.43 | $Al_2O_3$ | 23.16 |
| Si | 59.12 | $SiO_2$ | 50.33 |
| K | 3.7 | $K_2O$ | 3.54 |
| Ca | 0.6 | CaO | 0.33 |
| Fe | 11.65 | $Fe_2O_3$ | 13.22 |
| | 100 | | 100 |

substituted Fe at. % : 3.86 (max. 25% of Al) in ferro-sialate geopolymer with Si/(Al,Fe) = 3 and rest 7.79 $Fe_2O_3$ hematite as filler.

# Geopolymer Ferrosialate

## Ratio K/Al=1 and K/Fe=0.2
## Si/Al=2 for a rigid 3D macromolecular structure

$$100\text{ g of liquid silicate} \times a\ \%\ K_2O \text{ in liquid} \times 101.96\text{ g/mol } Al_2O_3$$

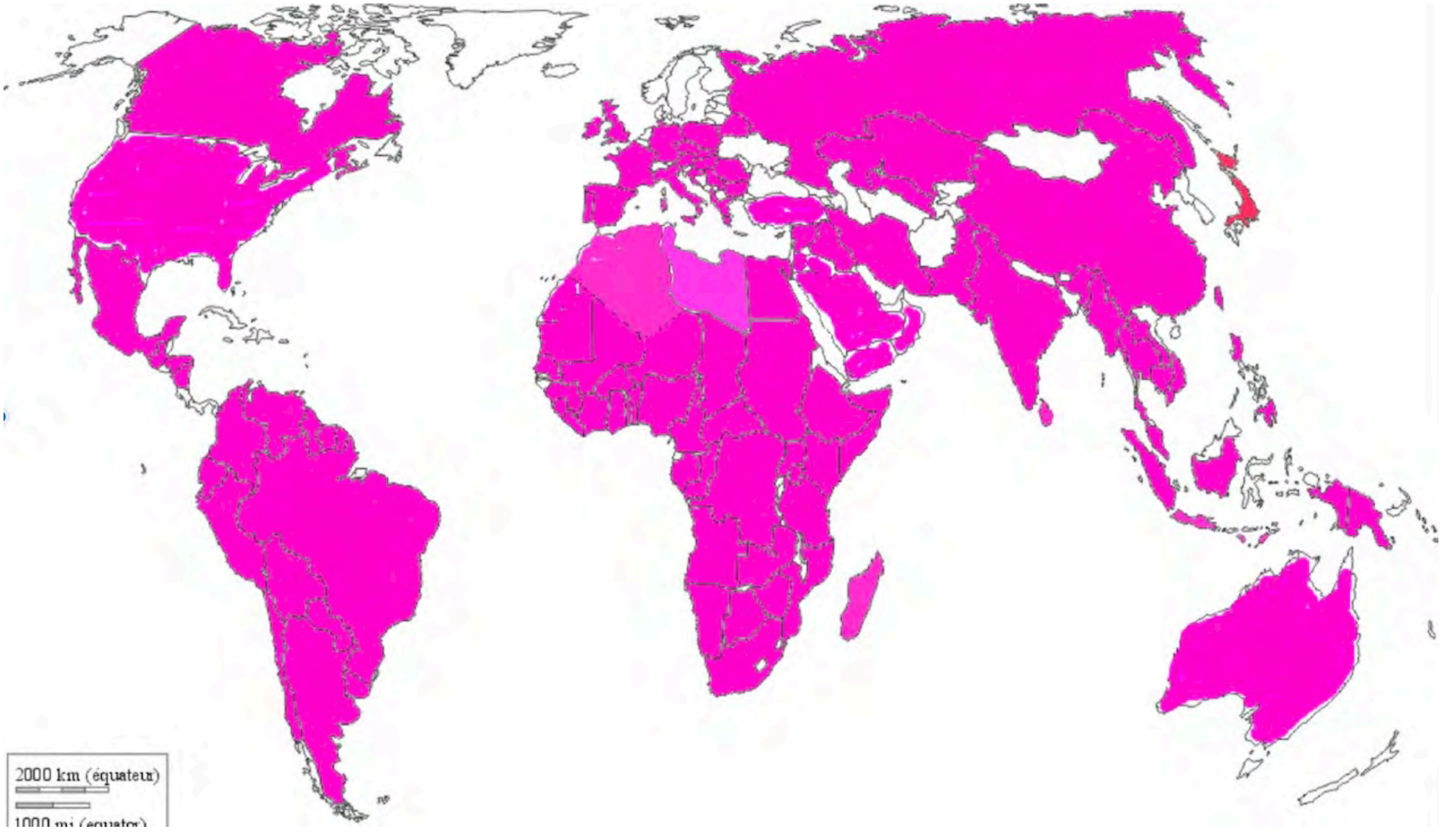
$$94.196\text{ g/mol } K_2O \times \left(\left(\frac{101.96\text{ g/mol } Al_2O_3}{156.58\text{ g/mol } Fe_2O_3} \times \frac{b\ \%\ Fe_2O_3}{5}\right) + c\ \%\ Al_2O_3\right)$$

adding the equivalent $Al_2O_3$

$Fe_2O_3$ = Hematite not Goethite

Result: for 100 g of silicate, add xx g of ferro-metakaolinite

# World-wide availability of raw material for ferro-sialate geopolymer cement



# Ferro-sialate geopolymer

*Joseph Davidovits*