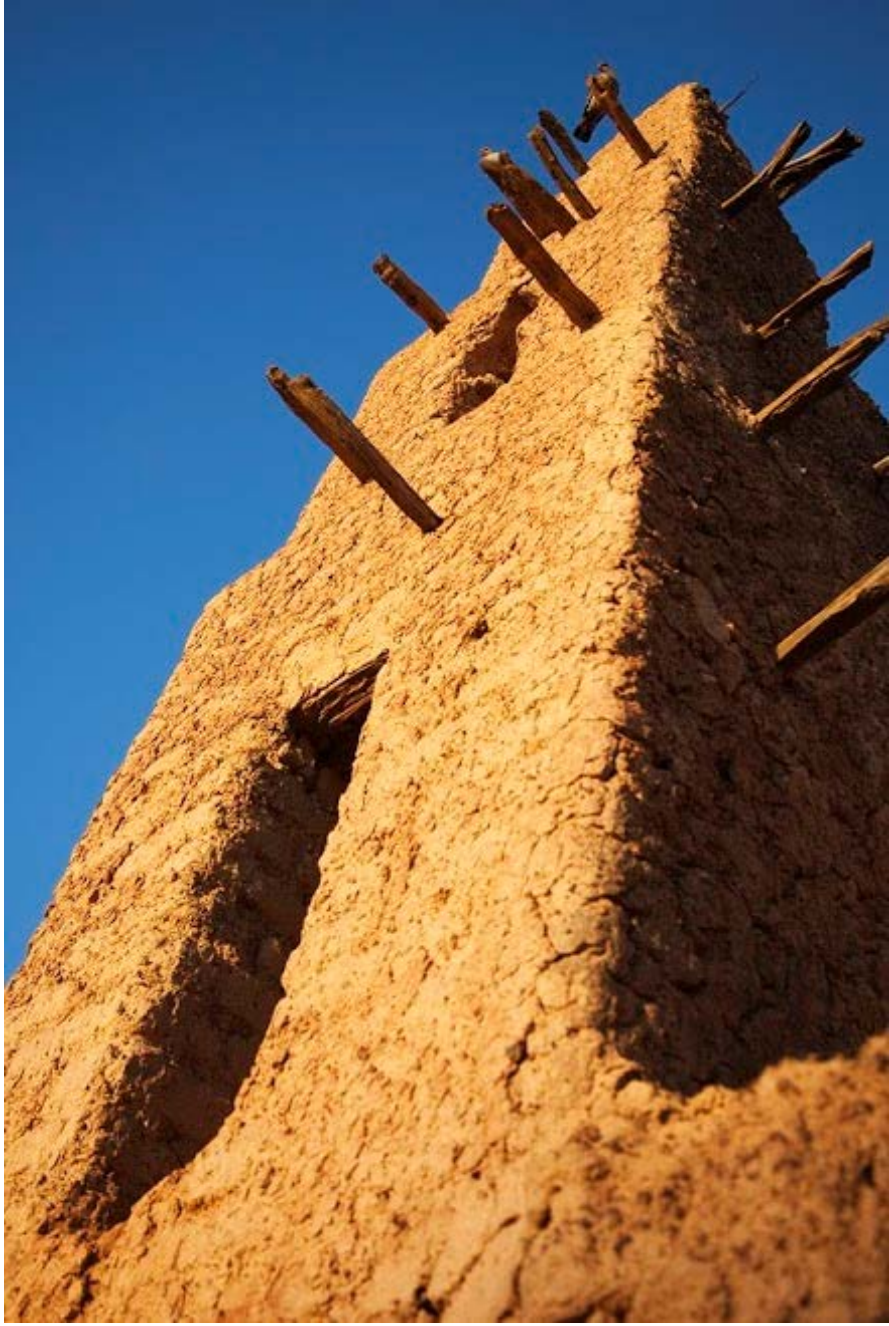
WAXI- West African Exploration Initiative

IXOA- L'Initiative d'Exploration Ouest Africaine

Lessons learned from multi-scale studies of crustal K-Th distribution

Baratoux*[1,2], D., Jessell[2,3], M.W. , Fall[4], M., Ndiaye[4], P.M., Vanderhaeghe[2], O., Baratoux[1,2], L., McFarlane[5], H., Boamah[6], K., André-Mayer[7], A.S.,

[1]IFAN Ch. Anta Diop, Dakar, Senegal.
[2]Géosciences Environnement Toulouse, UMR 5563, CNRS, IRD & University of Toulouse.
[3]Center for Exploration Tagerting, The University of Western Australia.
[4]University Cheikh Anta Diop, Geology Department, Dakar, Senegal
[5]Monash University, School of Earth, Atmosphere and Environment
[6]Geological Survey Department of Ghana
[7]Georessources Laboratory, University of Lorraine.



The Metallogenesis, Tectonics & Surface Evolution of the West African Craton - Conference.
17 & 18 September 2015, King Fahd Palace, Dakar, Sénégal

Why K, Th and U ?

These three elements are tracers of magmatic and secondary processes

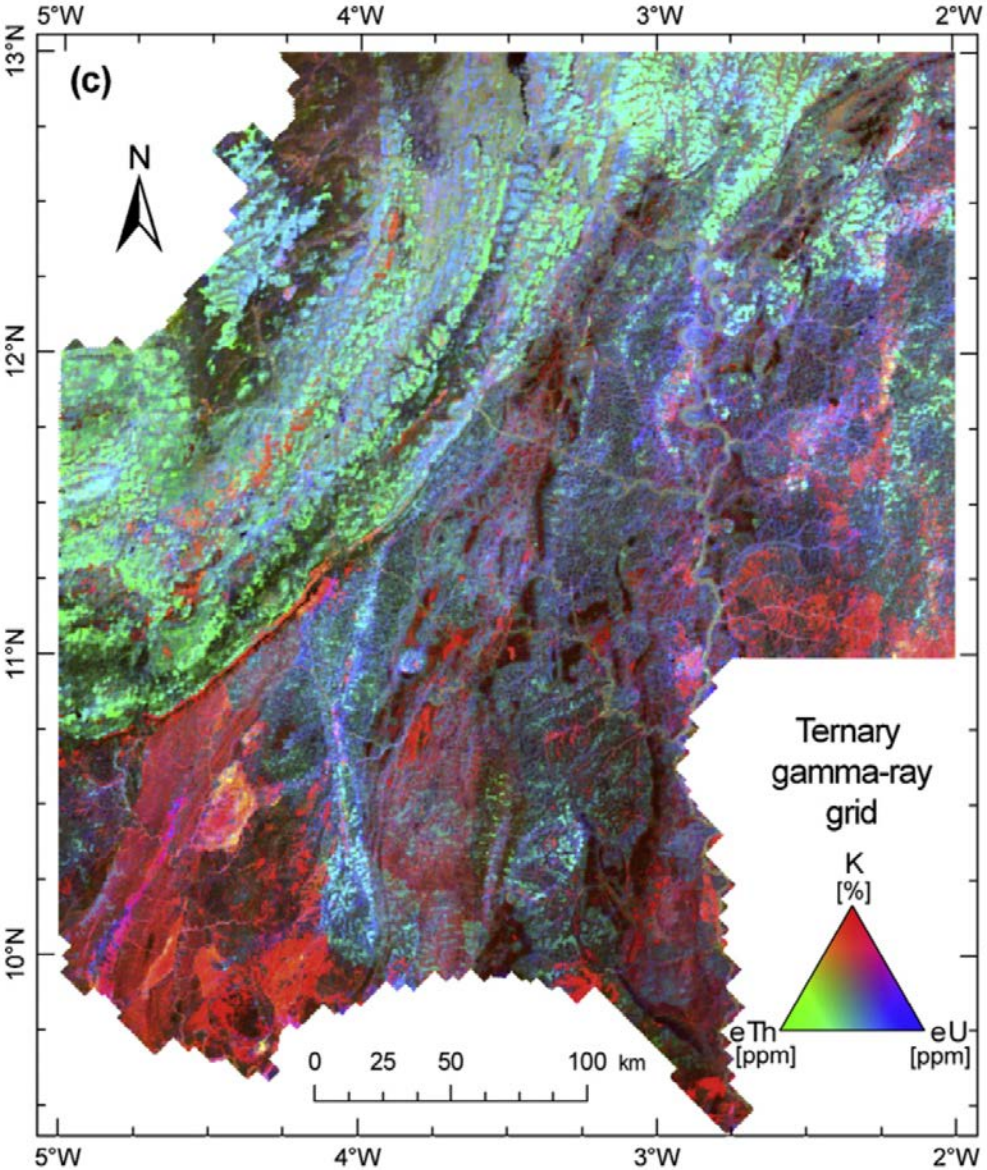
- There are incompatible – they concentrate in melt during fractional crystallization

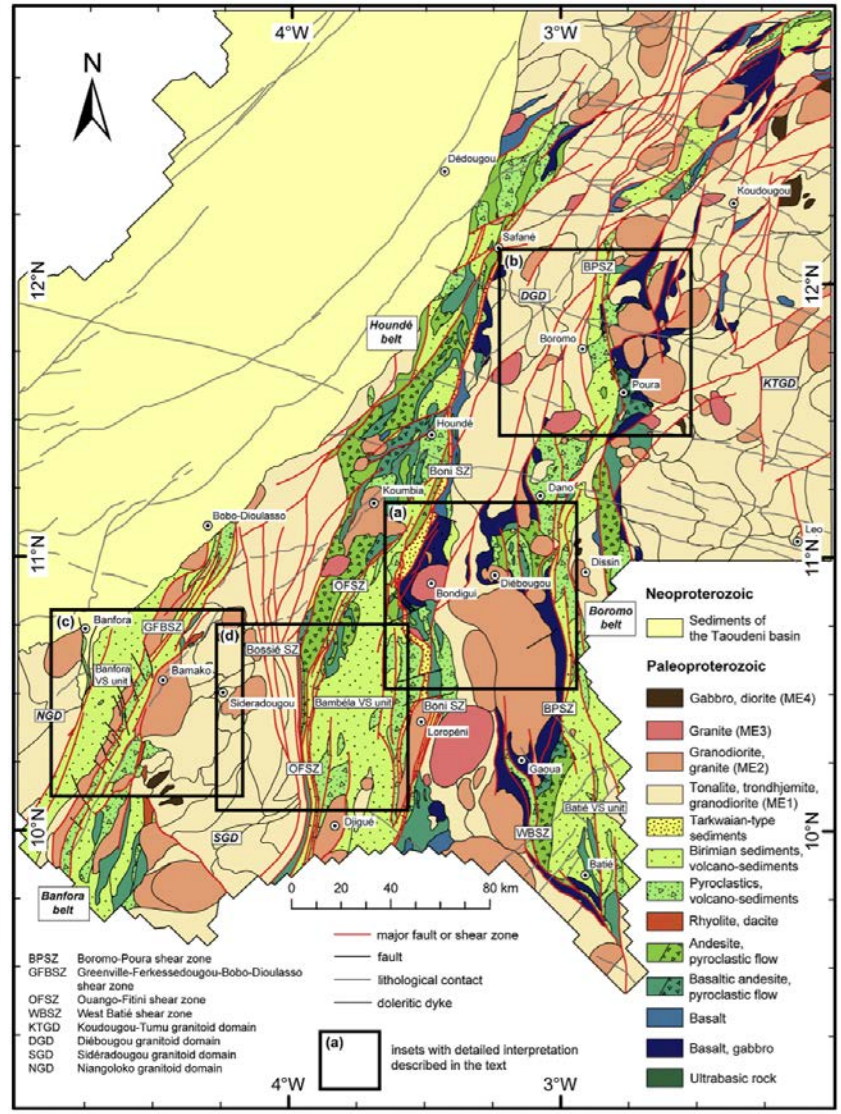
- Different behavior with respect to fluid/transport
- K is soluble/mobile
- Th is insoluble (except in very acid conditions)
- U^{4+} is insoluble, U^{6+} is soluble

^{40}K, ^{232}Th and ^{235}U are naturally radioactive and their disintegration or disintegration chain produces gamma rays
It is possible to produce map of their surface concentration

Use of airborne support to support geological mapping when outcrops are scarce (as in WA)

Radiometric surveys on Earth for Geological mapping





Metelka et al. 2011 – Precambrian Research

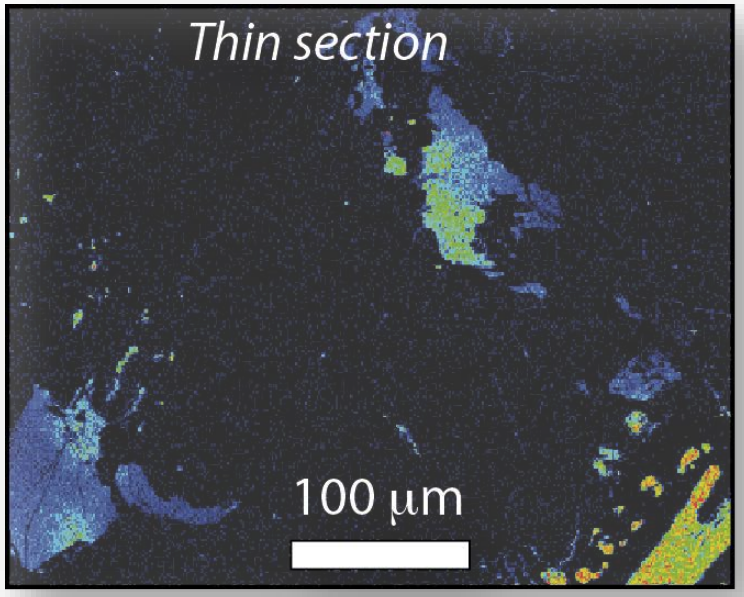
Quantitative interpretation or airborne surveys

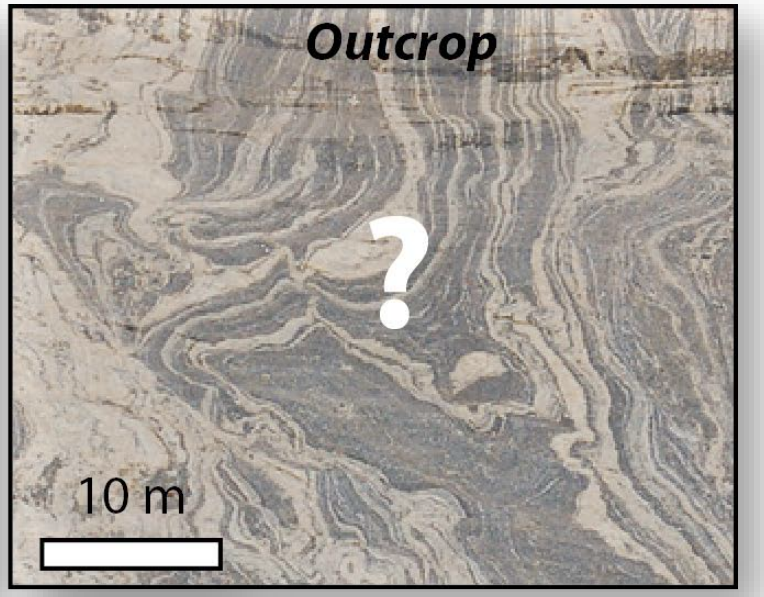
What is link between geochemical analyses of rock, regolith or soil samples and concentrations inferred from airborne radiometric survey ?

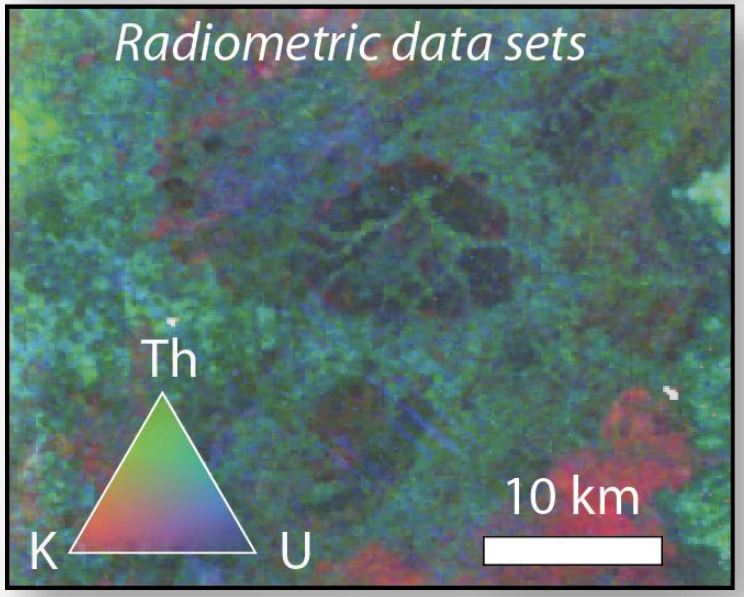
A problem of scale

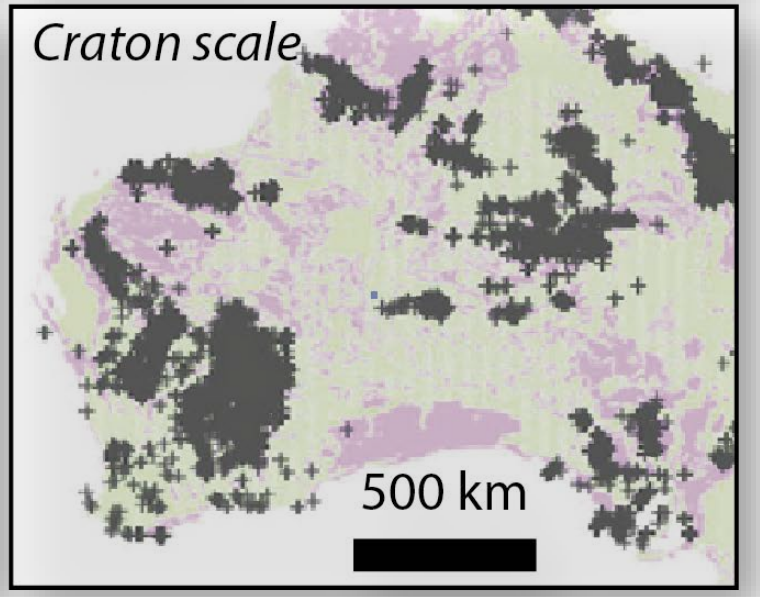
Geochemical analyses – samples of about 100 g
Airborne surveys – average concentrations in about 10^8 kg
(for a 100 m x 100 m pixel size)
9 orders of magnitude difference

What is the distribution of K – Th at various scales?

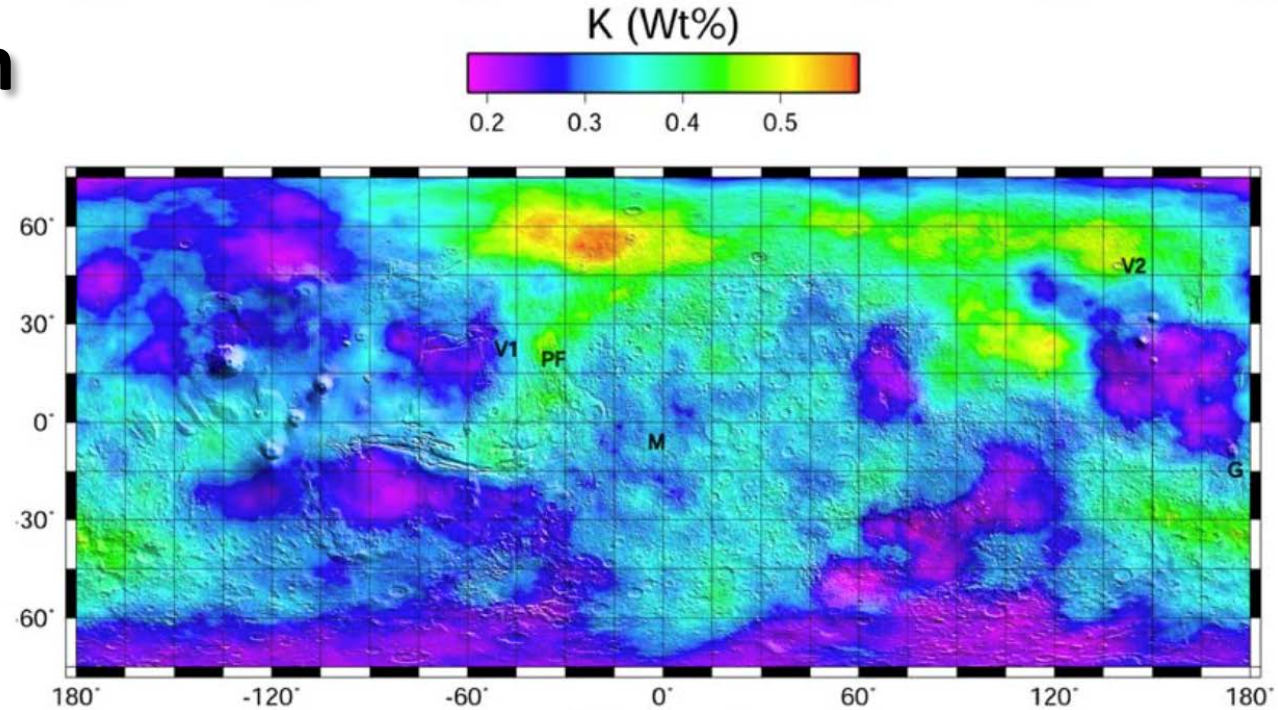




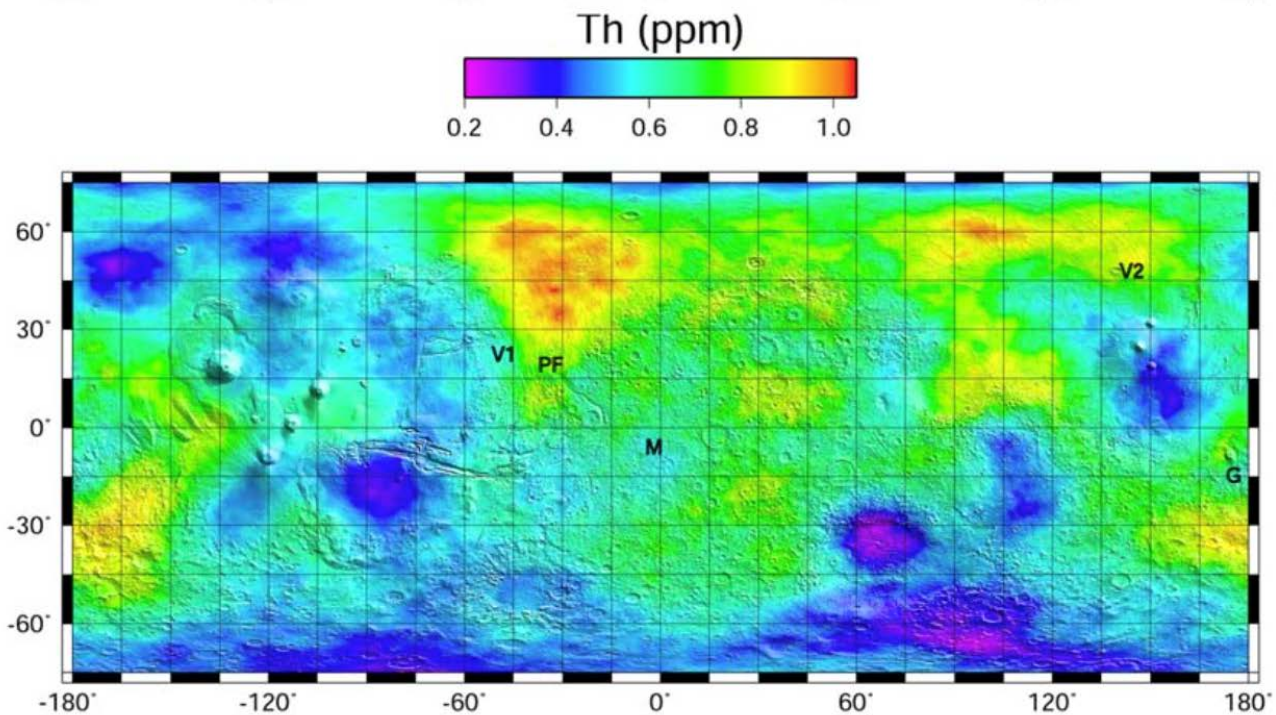




Maps at 400 km resolution



Geochemical mapping on Mars



Taylor et al. 2006 – Journal of Geophysical Research (Planets)

Distribution of chemical elements in Nature

Do the geochemical distributions of trace elements obey a scaling law?

The lognormal distribution of the elements[1]

(A fundamental law of geochemistry and its subsidiary)

L. H. AHRENS

Department of Geology and Geophysics, Massachusetts Institute of Technology[2]

(*Received* 3 *November* 1953)

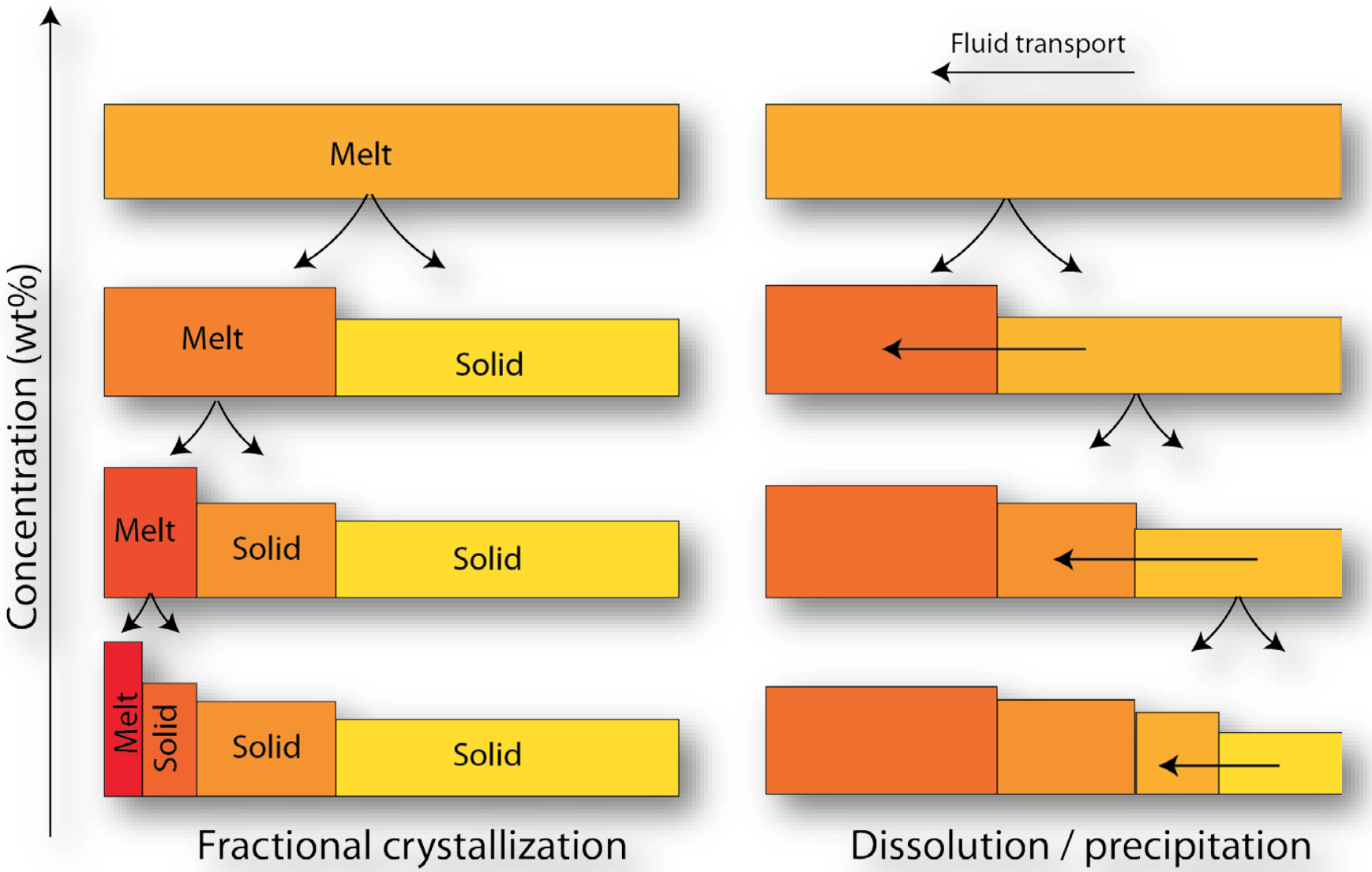
Ahrens 1954

Revisiting an old question with new data

Fundamental Geochemical Processes

- Differentiation
  - *Rayleigh distillation*
  - *Chromatographic infiltration-precipitation*
- Mixing

Distribution of chemical elements in Nature

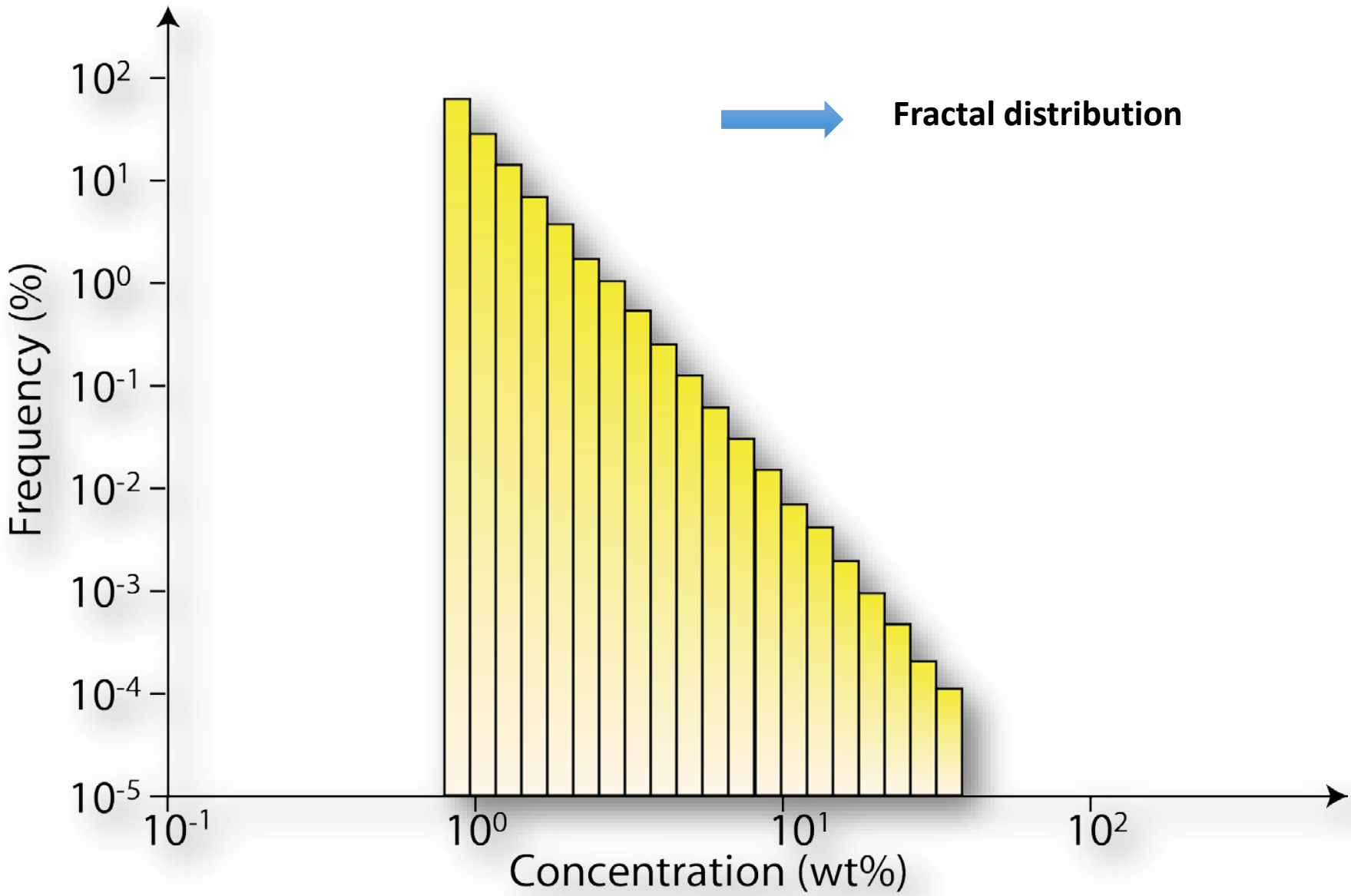


At each step, only the enriched segment is refractionated

At each step, only the residual segment is refractionated

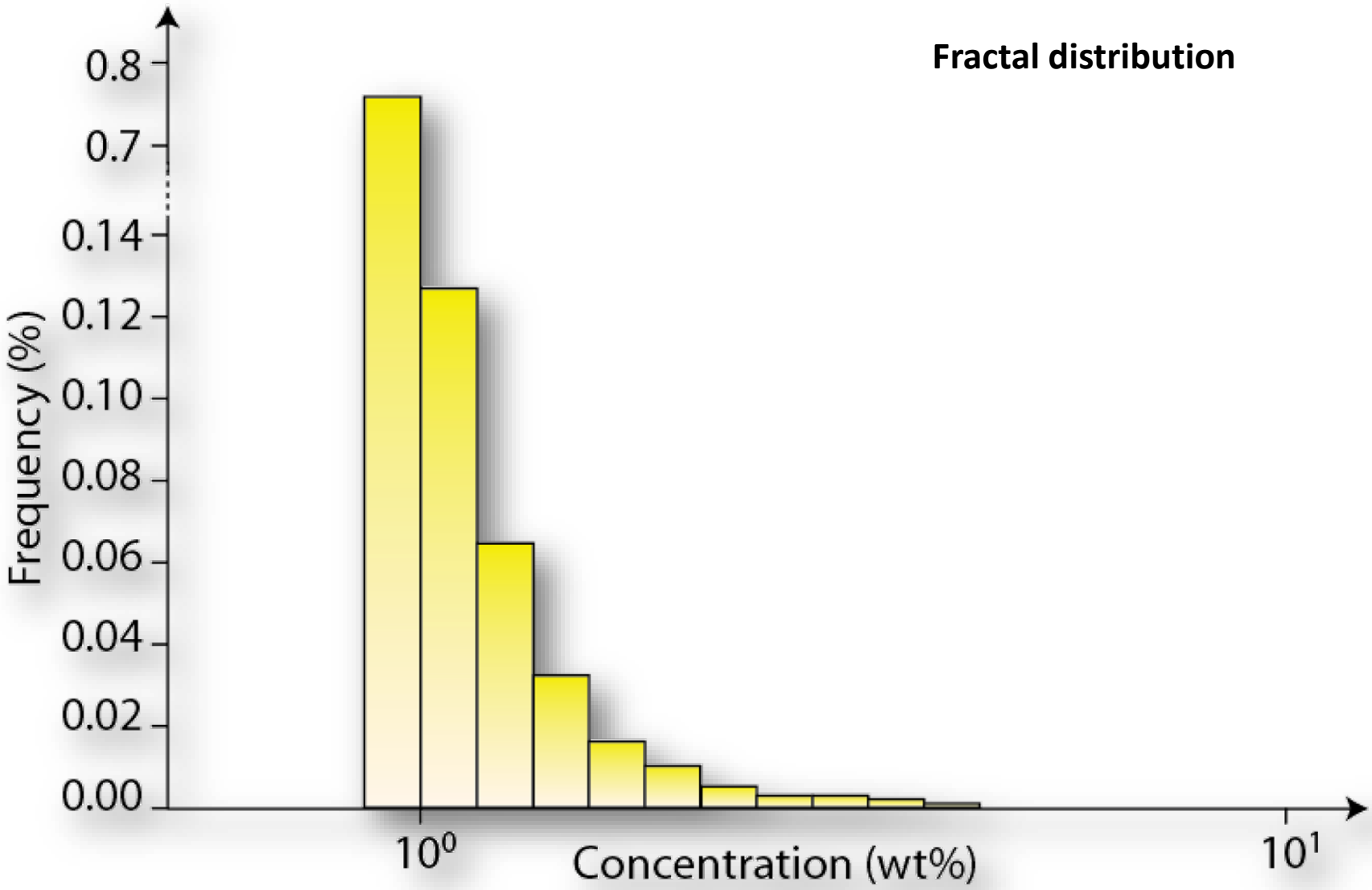
Sketches inspired from Allegre and Lewin 1995

Distribution of chemical elements in Nature



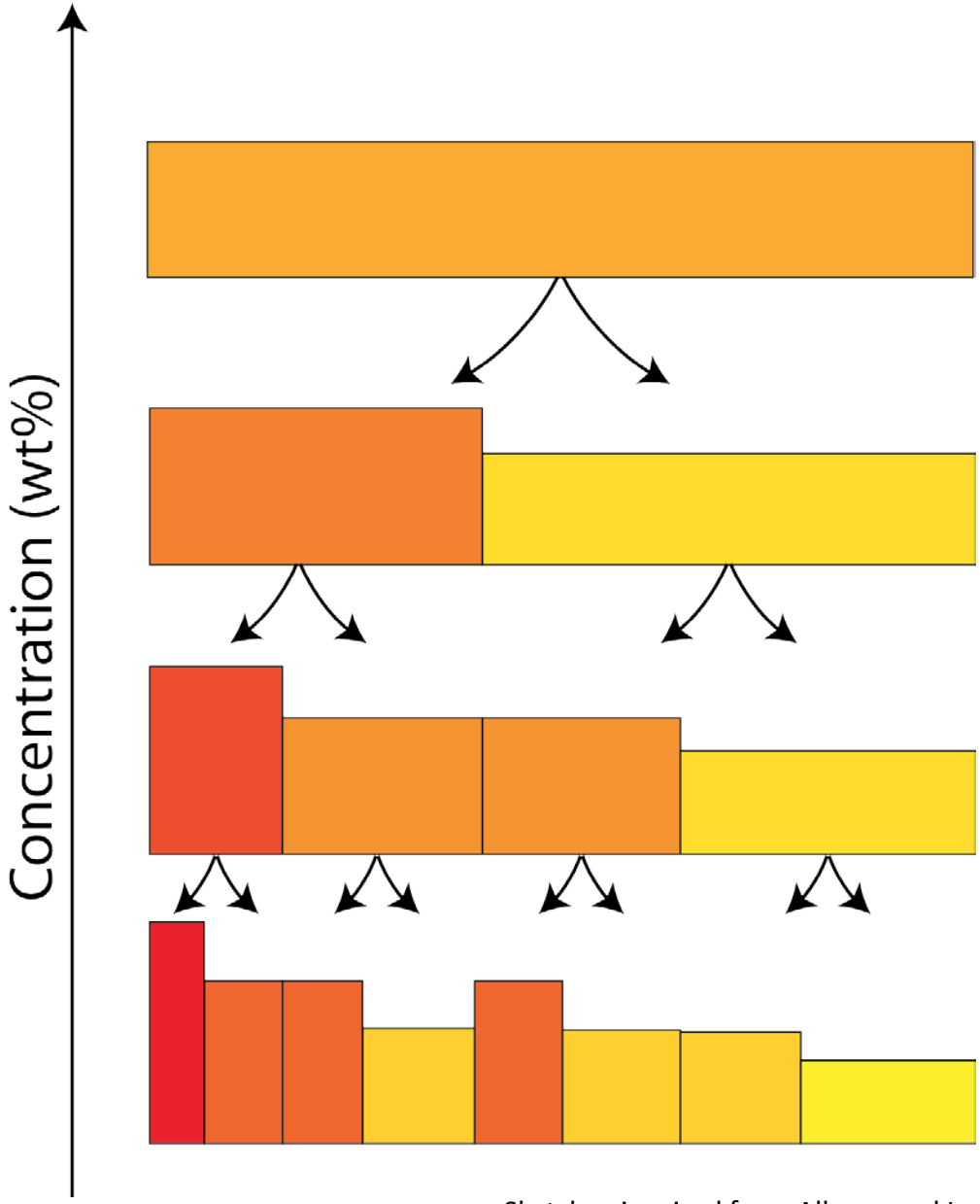
Sketches inspired from Allegre and Lewin 1995

Distribution of chemical elements in Nature



Sketches inspired from Allegre and Lewin 1995

Distribution of chemical elements in Nature

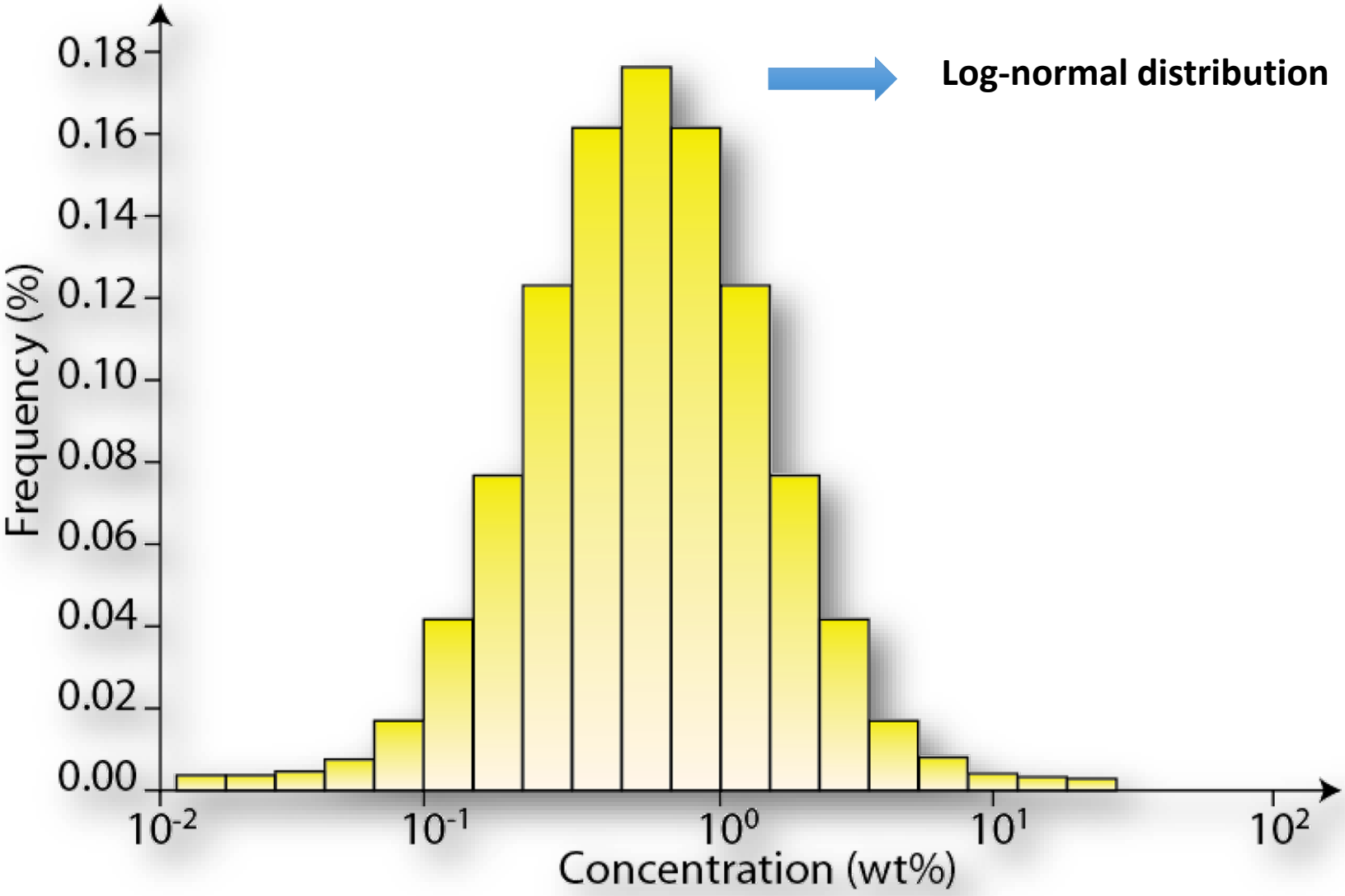


Repeated episodes of differentiation / fluid circulation affecting all segments

At each step, all segment are refractionated

Sketches inspired from Allegre and Lewin 1995

Distribution of chemical elements in Nature



Sketches inspired from Allegre and Lewin 1995

Distribution of chemical elements in Nature

Fundamental Geochemical Processes

- Differentiation

  Rayleigh distillation
  Chromatographic infiltration-precipitation
  => fractal distribution

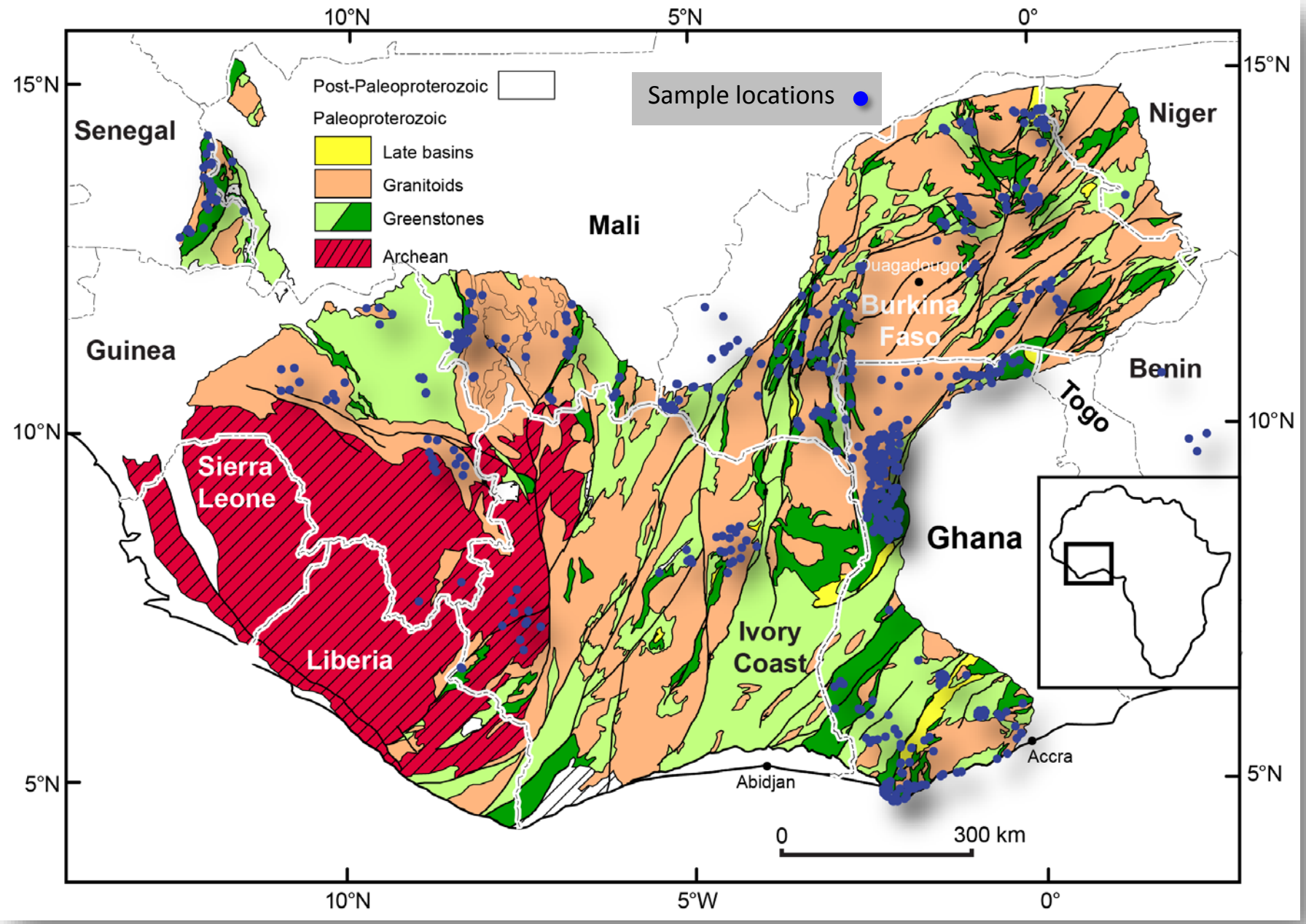
- Multiple episodes of differentiation

  => log-normal distributions

- Mixing

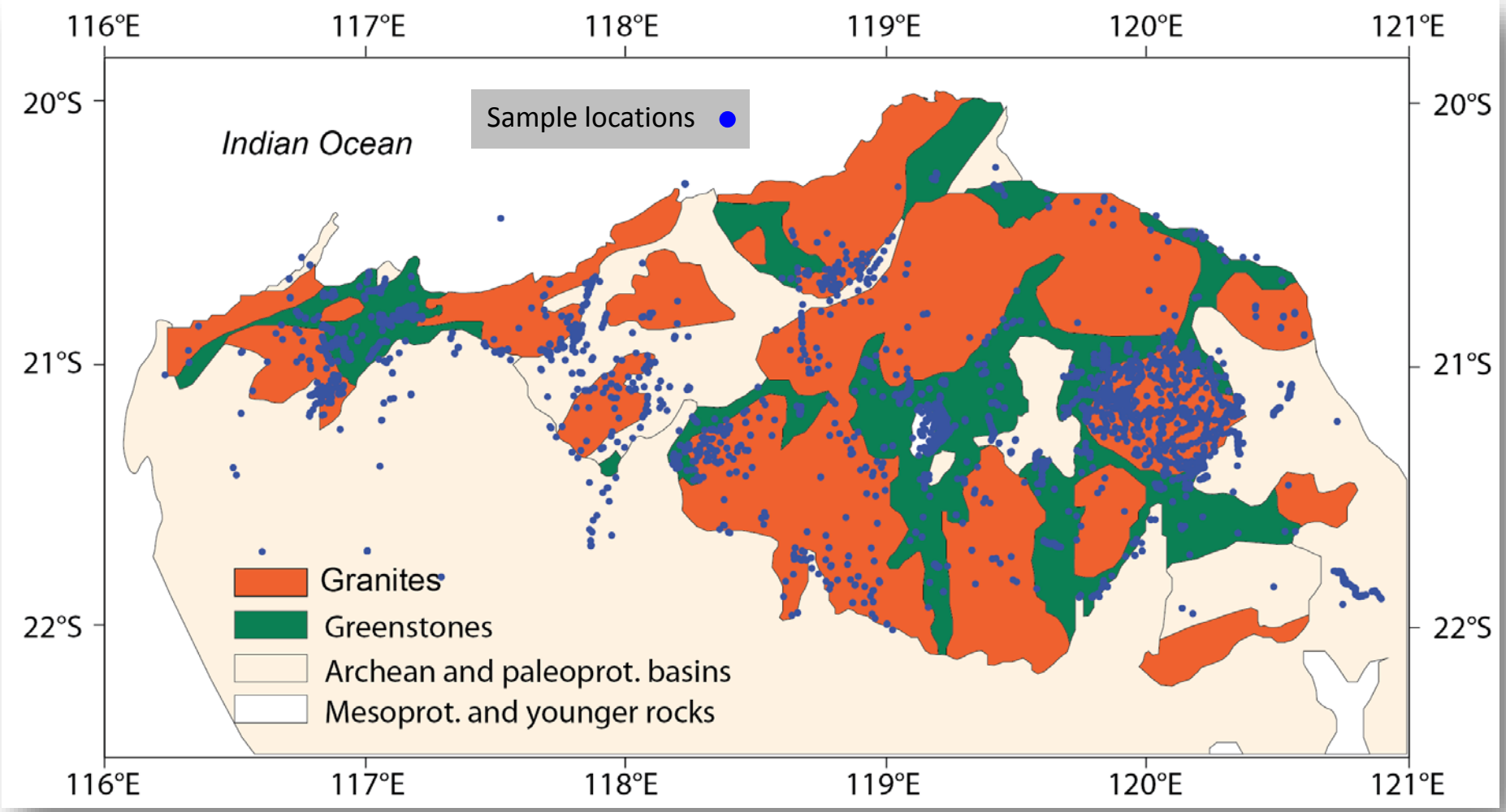
  => normal distributions

WAXI Geochemical database

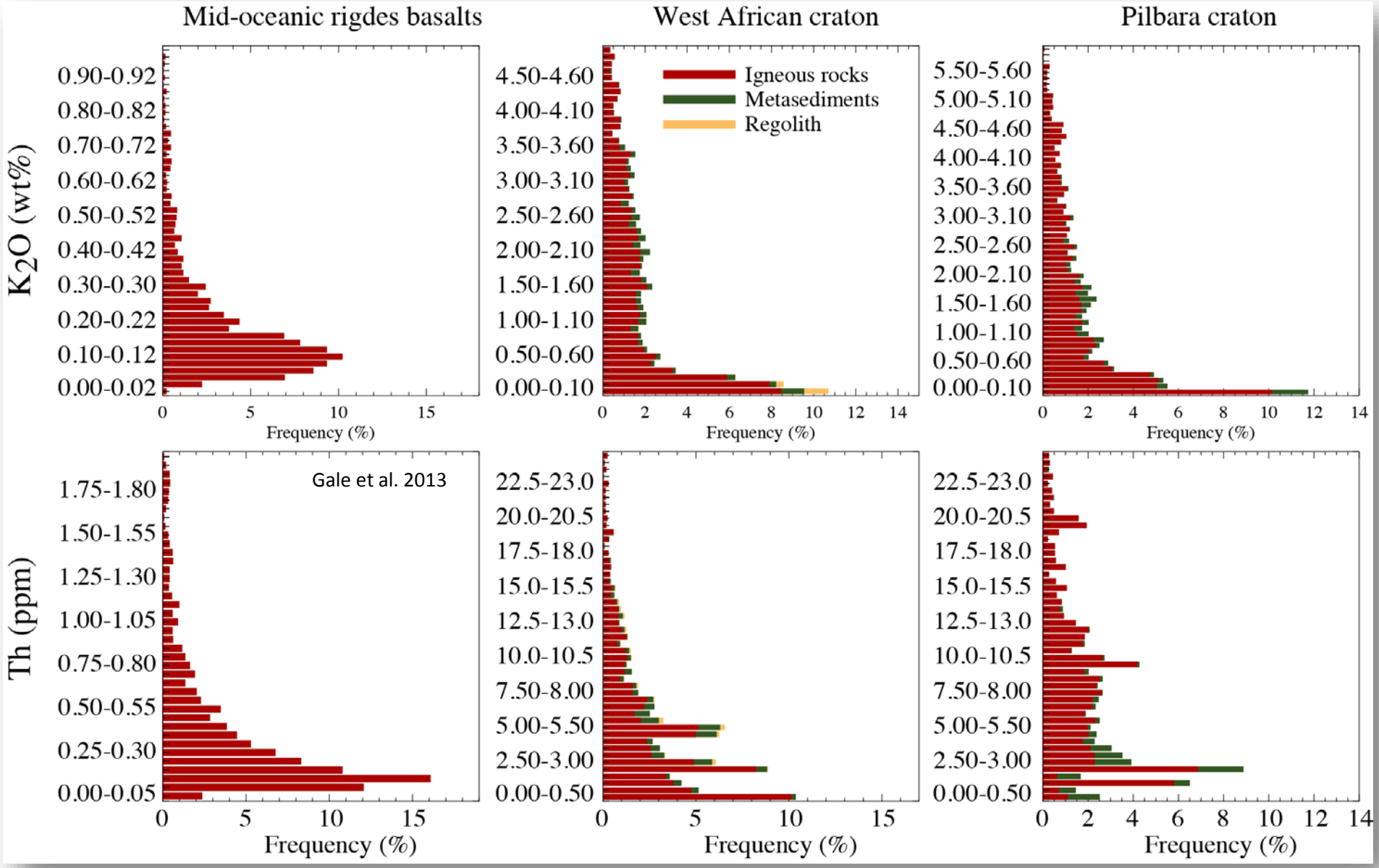


OZCHEM Geochemical database

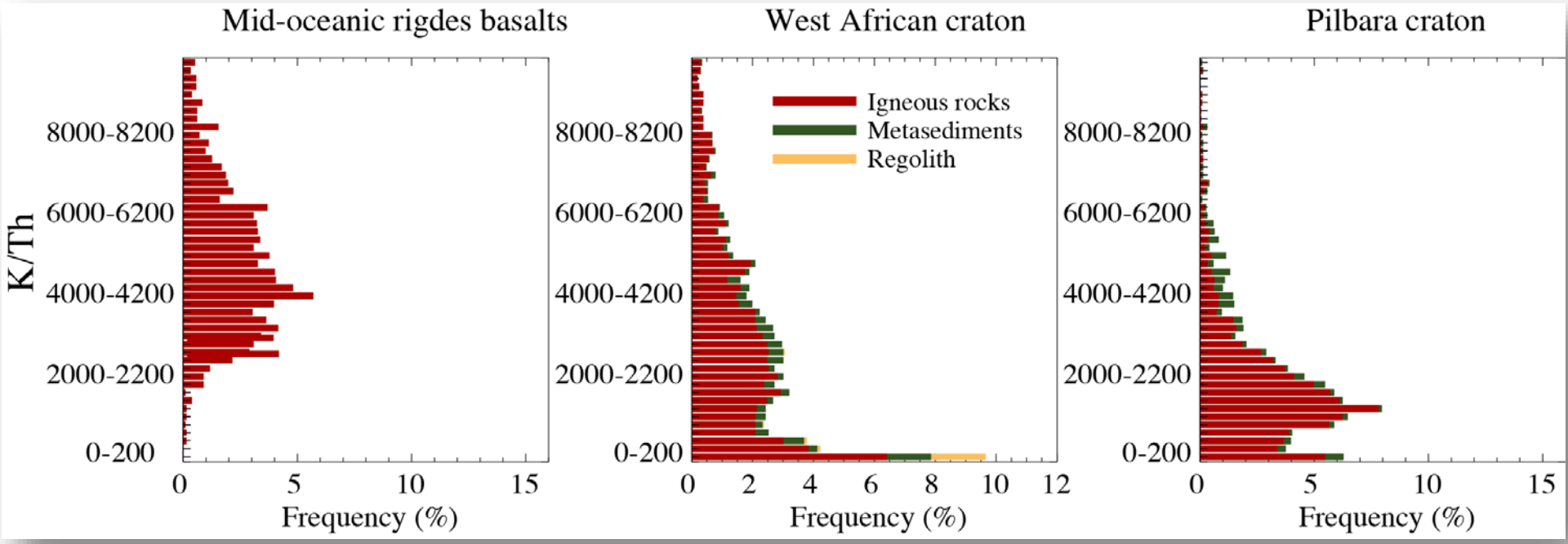
Northern Pilbara Craton



Distributions of K_2O and Th concentrations in nature

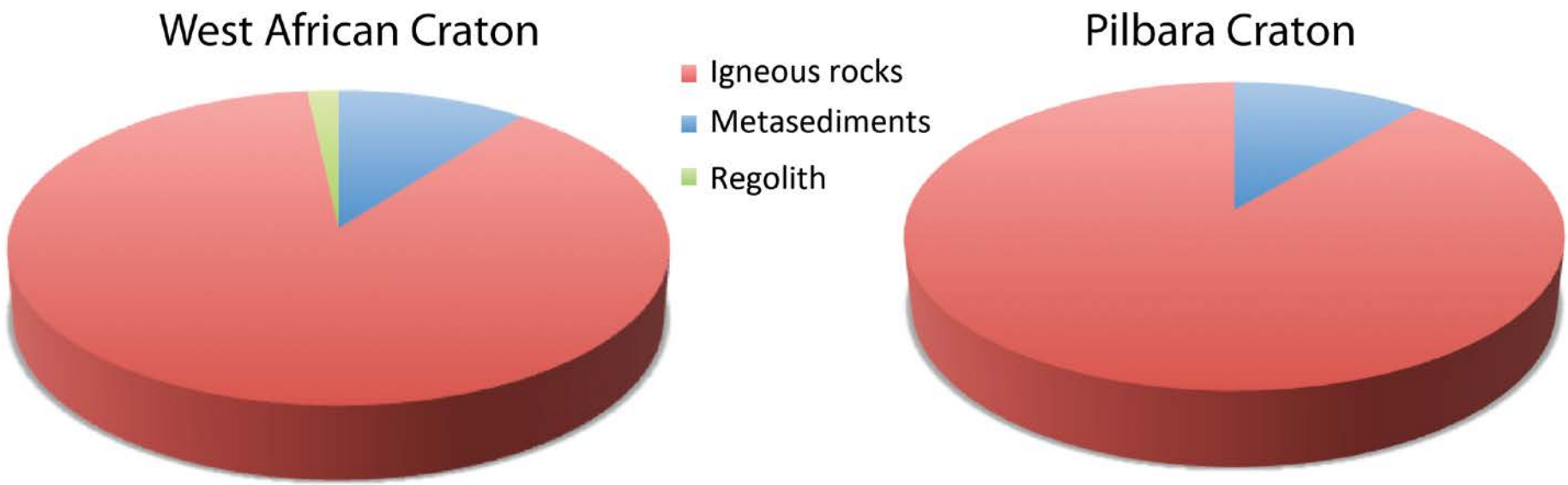


Distributions of K/Th ratio



How biased are the geochemical databases ?

How does this affect the K – Th distributions ?



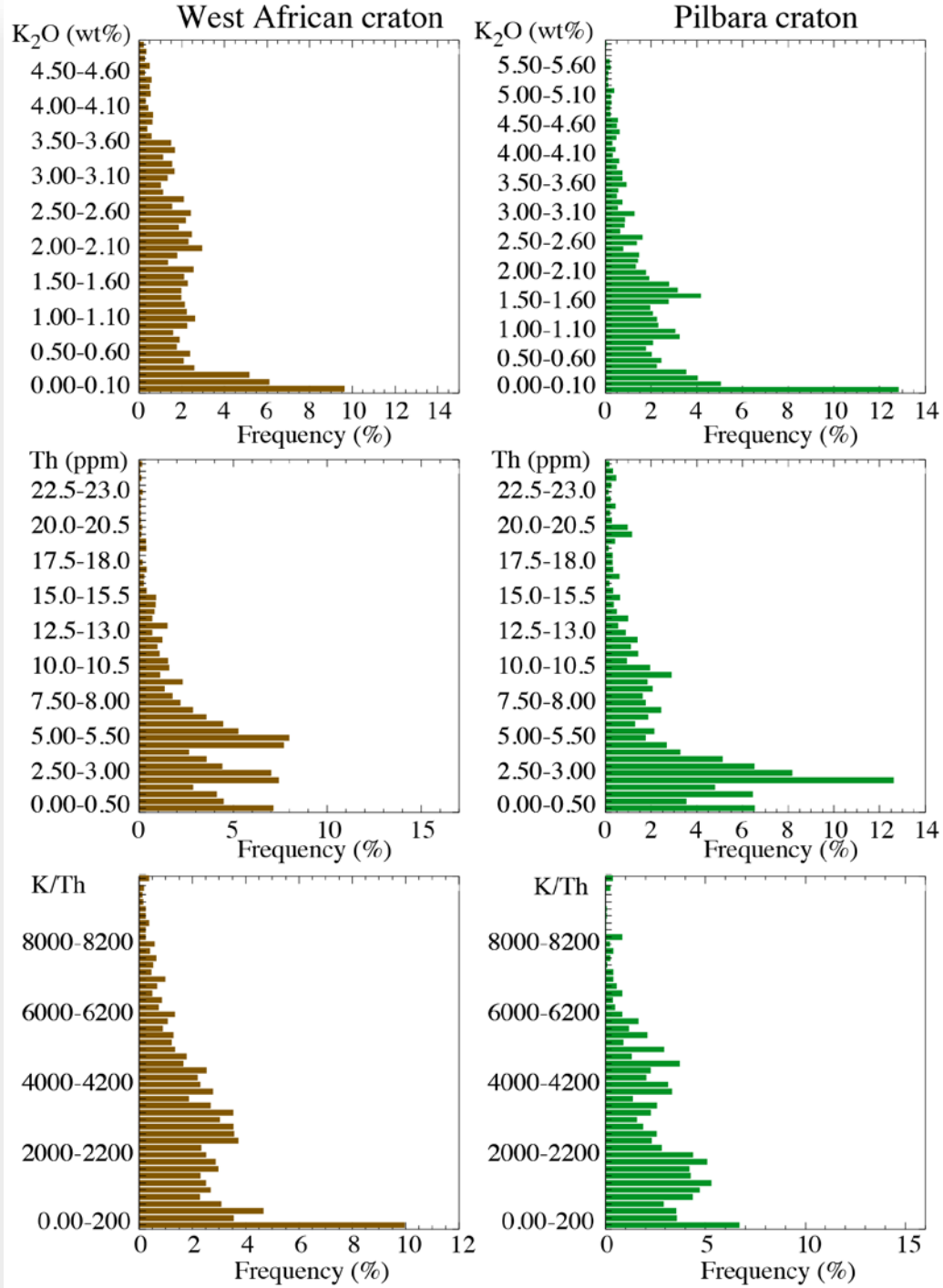
How does this affect the K-Th distributions ?

Simulated distributions for the West African Craton and Northern Pilbara Craton

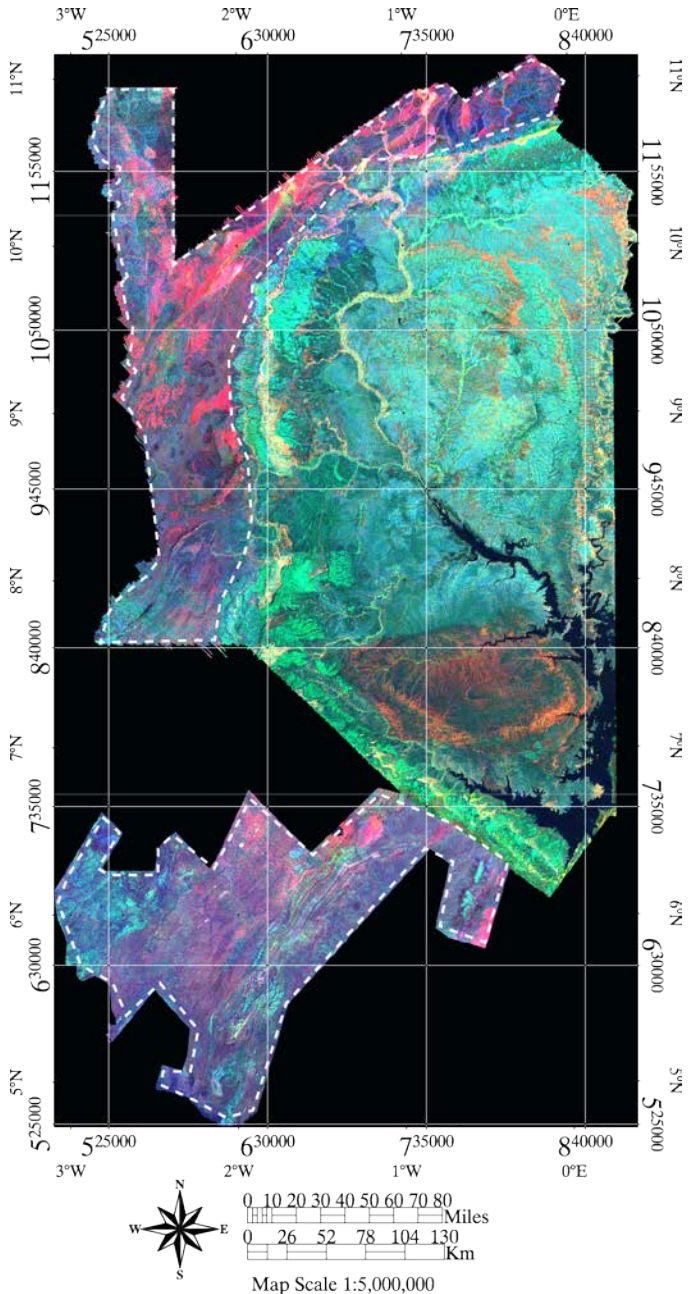
50% igneous rocks and 50% sediments/metasediments

The distribution retains their characteristics (right-skewed)

Long-standing debate about existence of log-normal distributions (Ahrens 1954, Allègre and Lewin 1995)

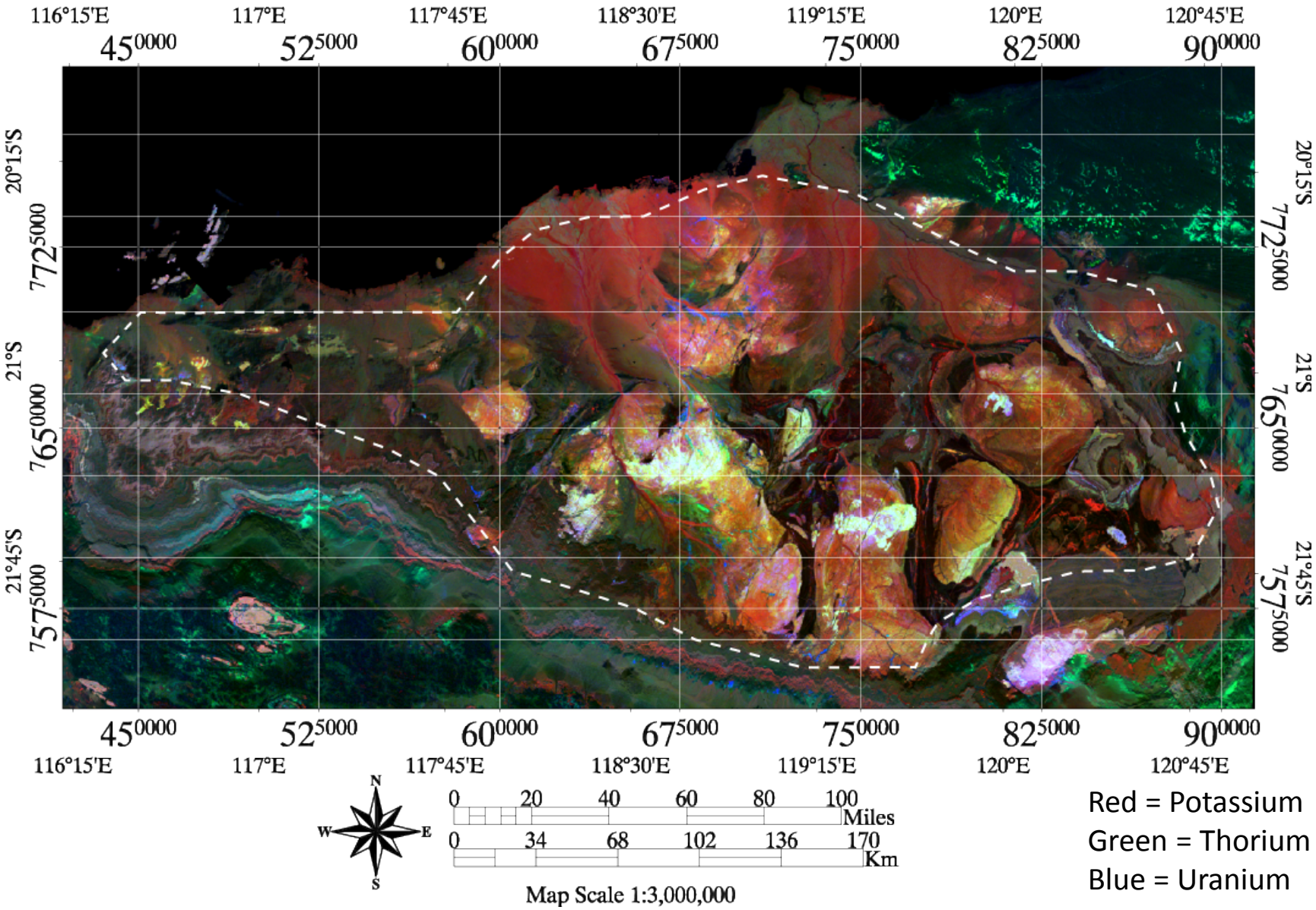


Radiometric data – Geological survey of Ghana



Red = Potassium
Green = Thorium
Blue = Uranium

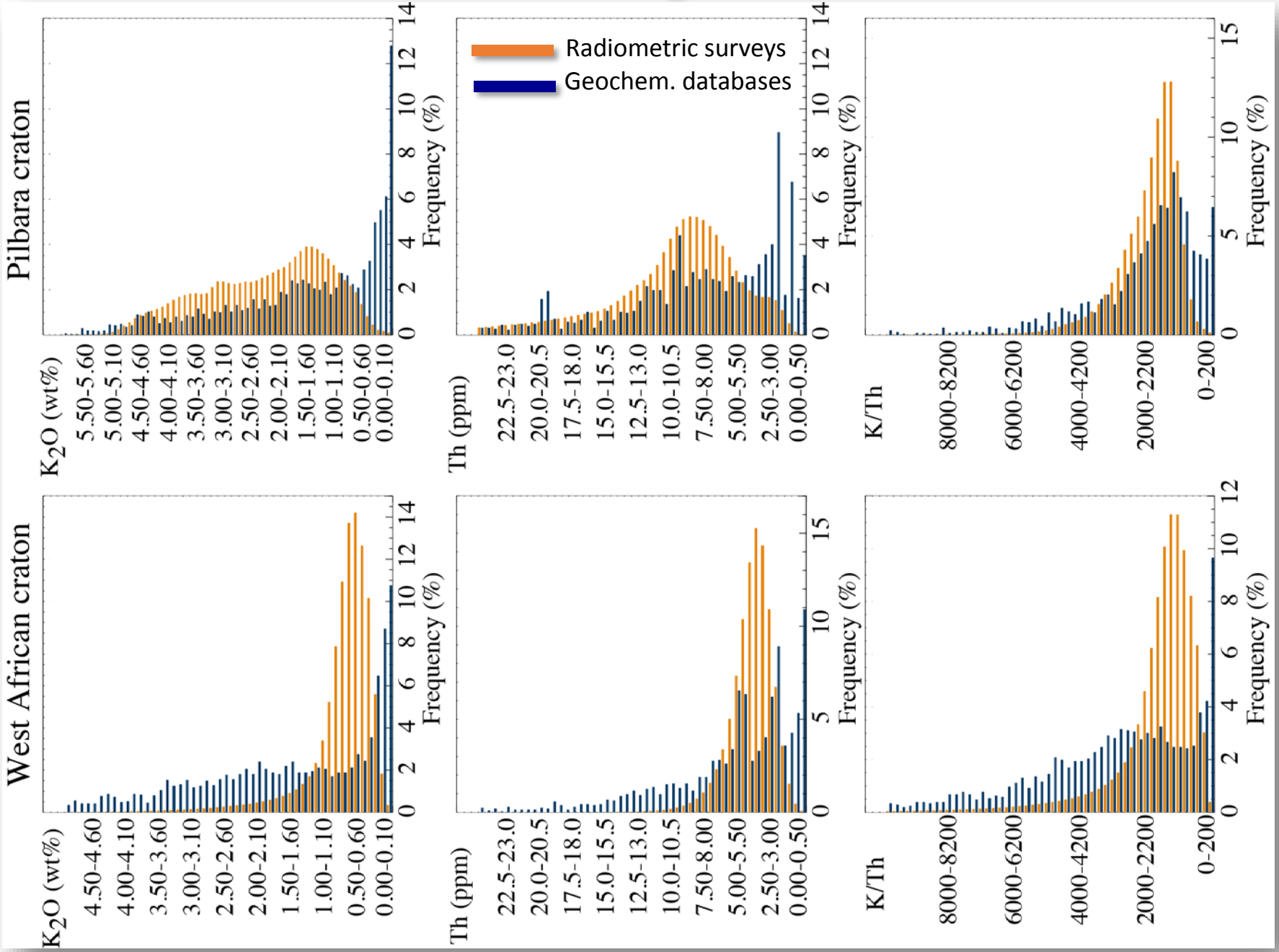
Radiometric map of Australia



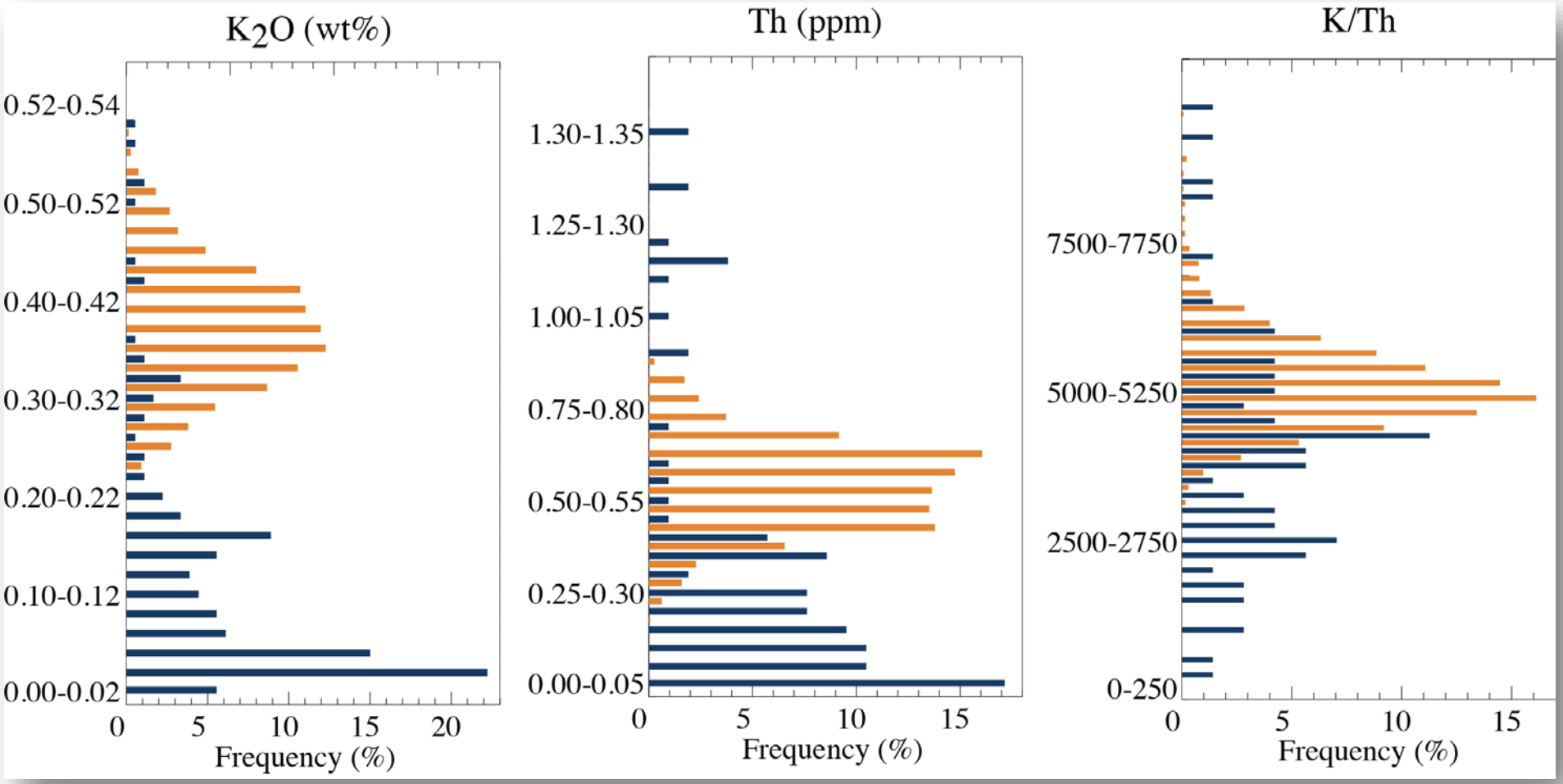
Red = Potassium
Green = Thorium
Blue = Uranium

Radiometric map of the Pilbara craton, W. Australia (Minty, B., Richardson, M., Wilford, J.)

Radiometric data versus geochemical databases



Martian meteorites versus surface geochemistry



GRS – Geochemical maps

Geochemical analyses - Martian meteorites

Baratoux et al. submitted

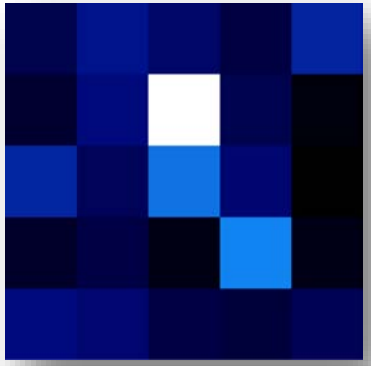
A same explanation for Earth and Mars ?

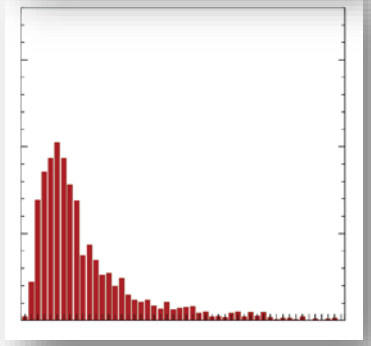
A simple illustration of the central limit theorem

Central limit theorem states that (given certain conditions), the arithmetic mean of a sufficiently large number of iterates of independent random variables, will be approximately normally distributed, regardless of the underlying distribution

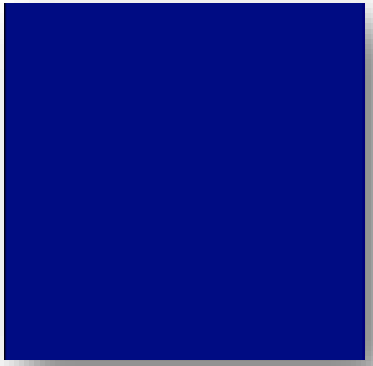
Simulations of the averaging process inherent to remote-sensing data

One pixel = average of sub-pixel values that correspond to the reference distribution



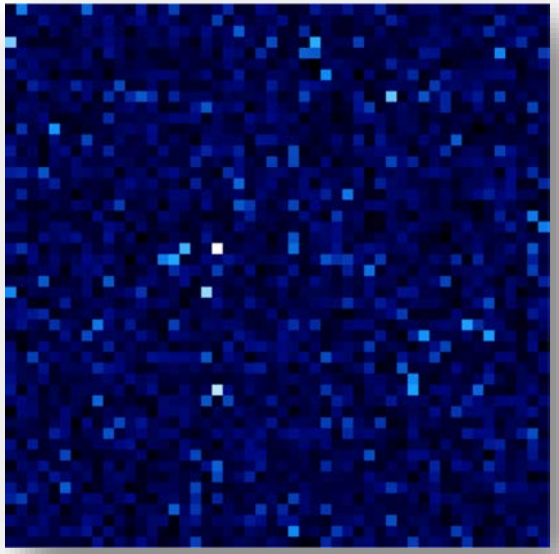


Step A



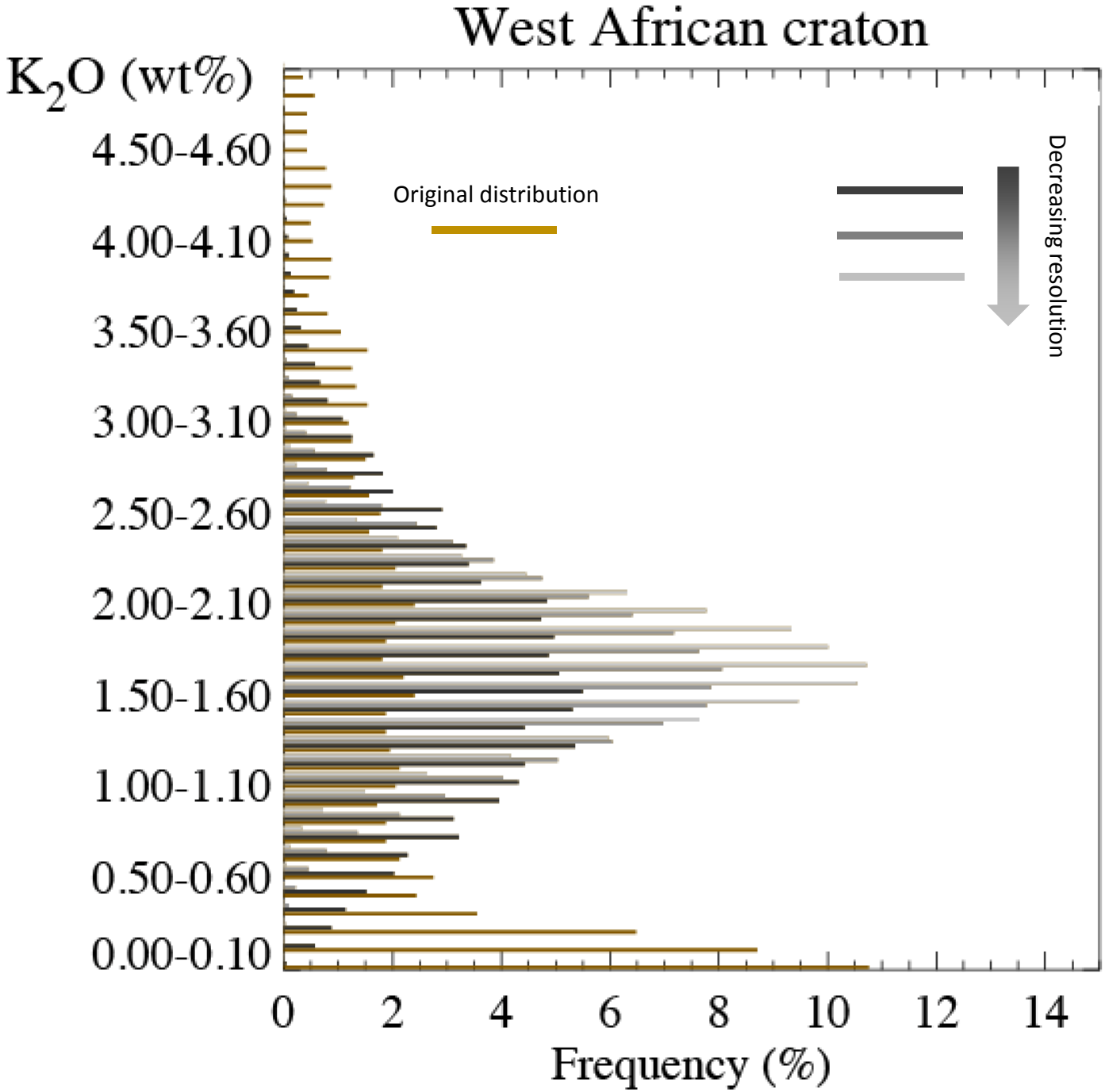
Repeat step A for each pixel

Step B



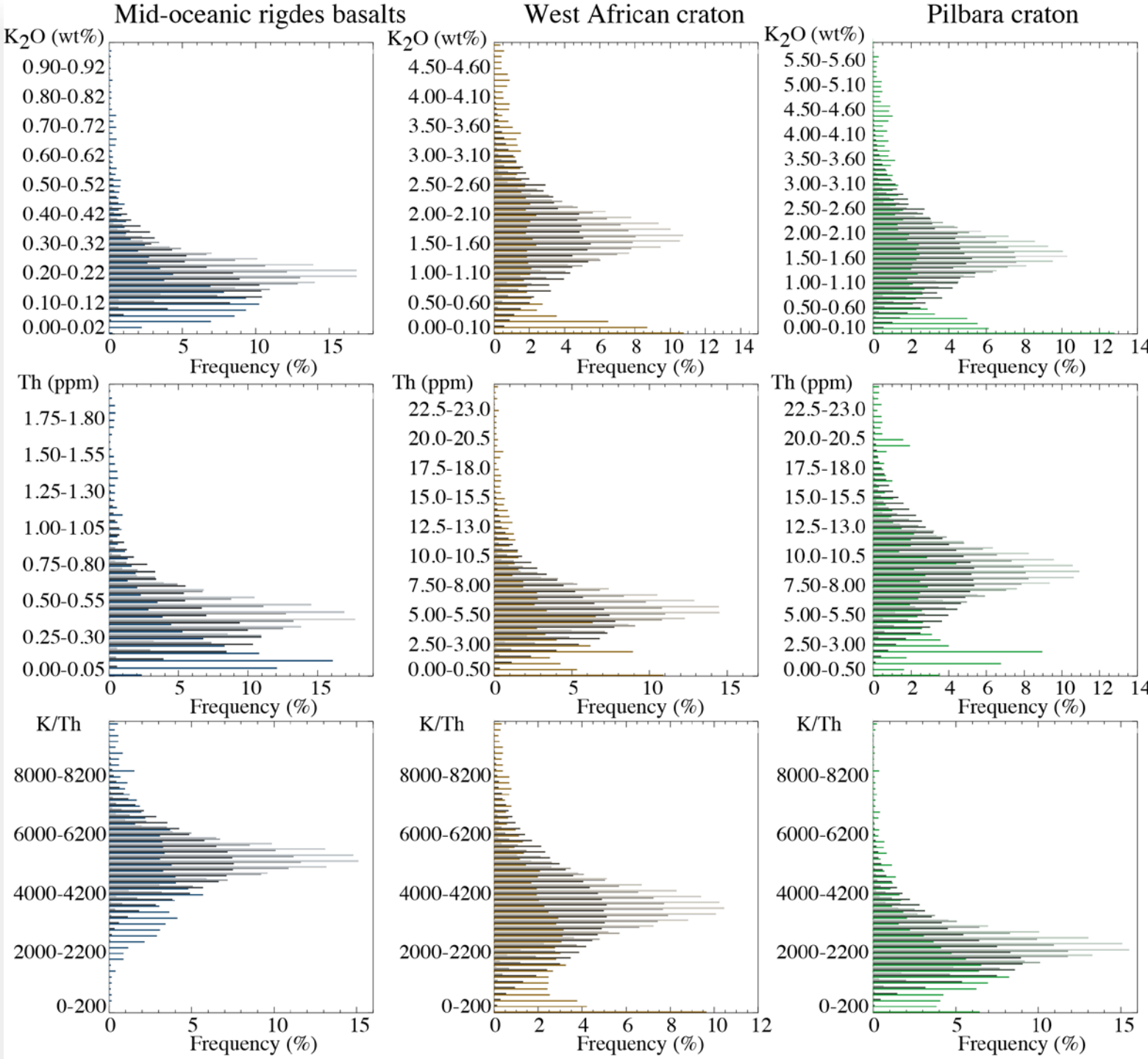
Simulated remote sensing data

Hypothesis : K_2O and Th concentrations are not spatially correlated

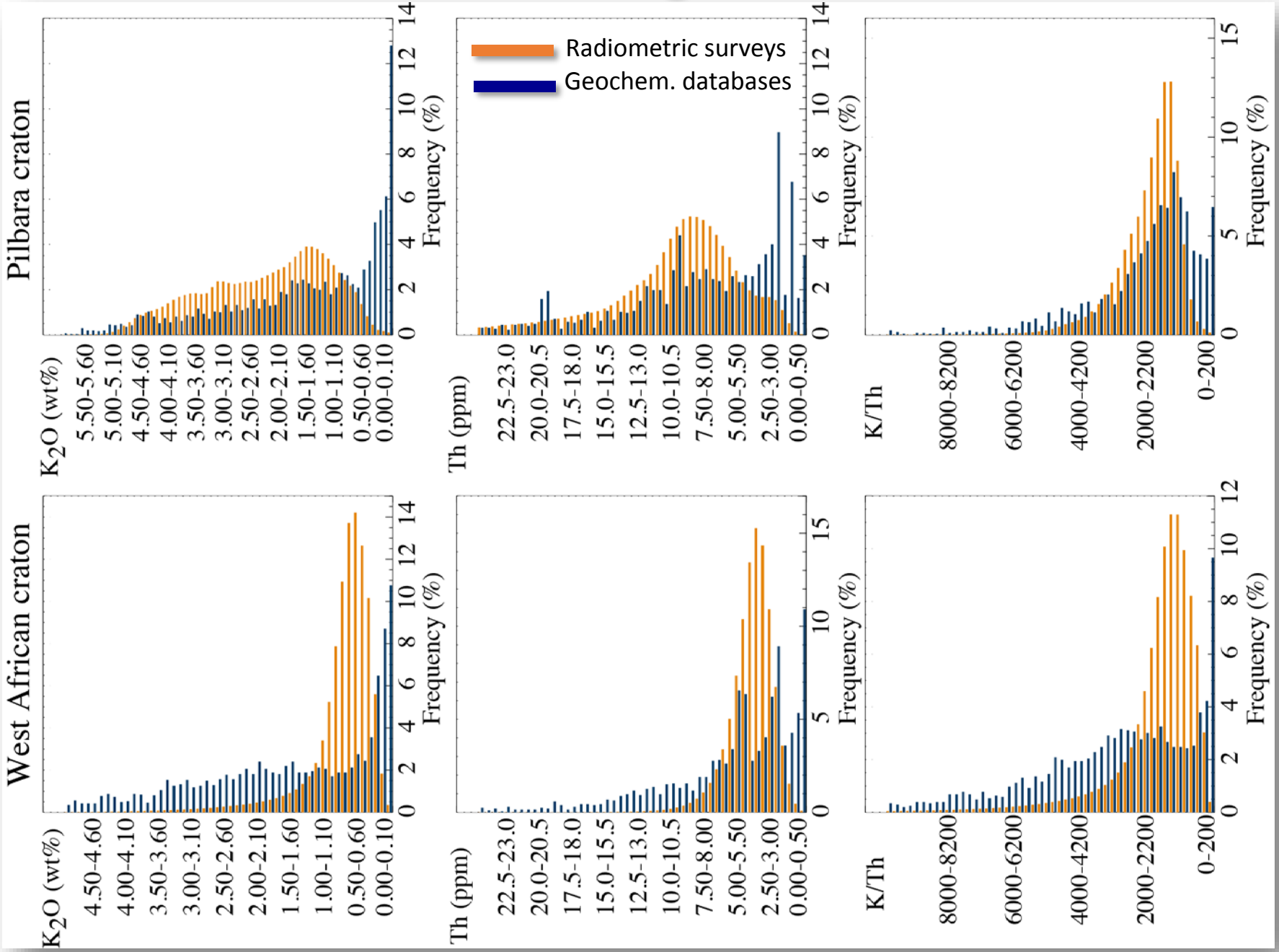

West African craton
K2O (wt%)
4.50-4.60
4.00-4.10
3.50-3.60
3.00-3.10
2.50-2.60
2.00-2.10
1.50-1.60
1.00-1.10
0.50-0.60
0.00-0.10
Original distribution
Decreasing resolution
0
2
4
6
8
10
12
14
Frequency (%)

Blue/brown/green = original distribution

Dark to light grey = Decreasing resolution (res /4, /9, /16)



Radiometric data versus geochemical databases



Conclusions and perspectives

Sub-pixel distribution of K-Th concentrations are important to interpret airborne radiometric surveys.

The most frequent value with a pixel is likely to be different from the average rock or soil concentration.

Work in progress

Characterization of the sub-pixel organization of K, Th and U concentrations. Regular grids acquired with a portable field spectrometer at 5 m spacing in mineralized and non-mineralized paleoprotorezoic units in the Eastern Senegal.

West Africa helps to understand Mars !

GRS Geochemical maps and distribution of K-Th concentrations in crustal material adds another piece of evidence for the existence of disseminated differentiated rocks on Mars

WAXI - West African Exploration Initiative

IXOA - L'Initiative d'Exploration Ouest Africaine

Project Broker & Coordinator

AMIRA INTERNATIONAL
Delivering solutions through collaboration

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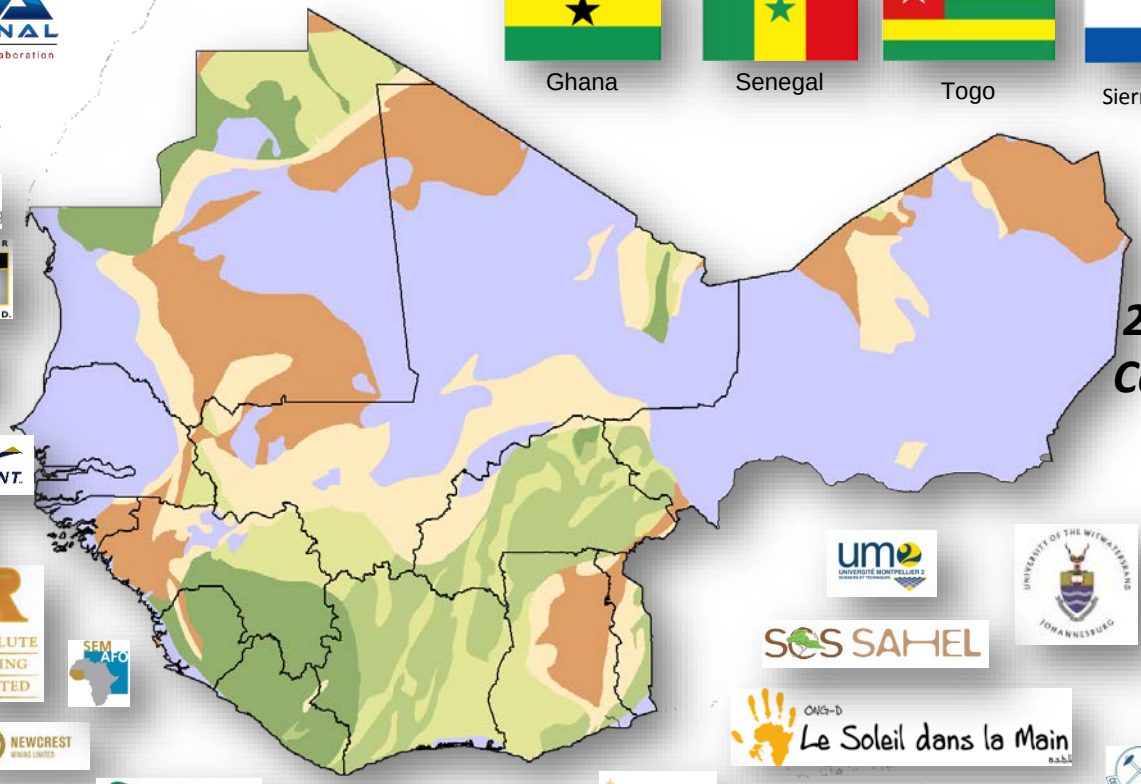

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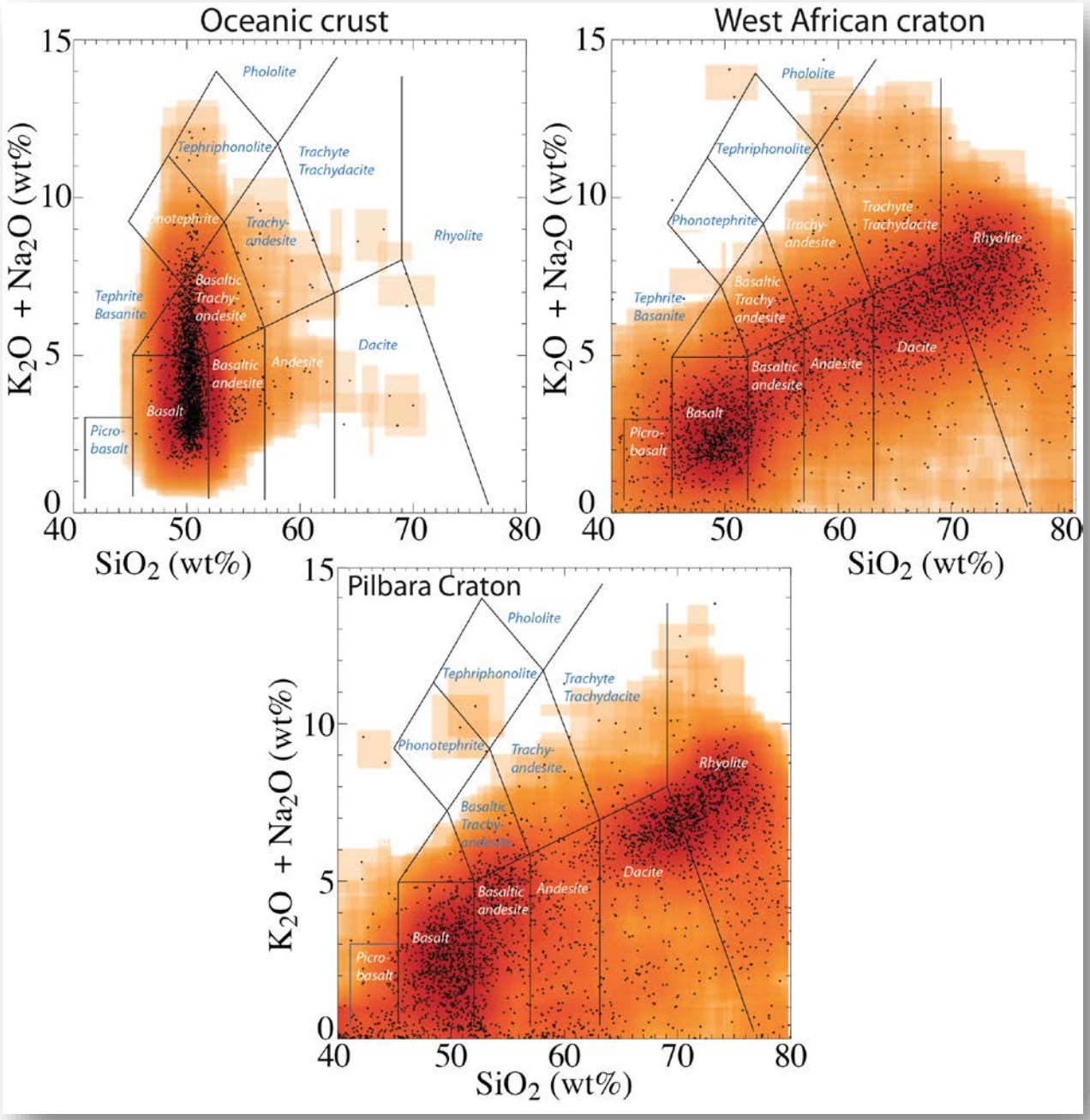
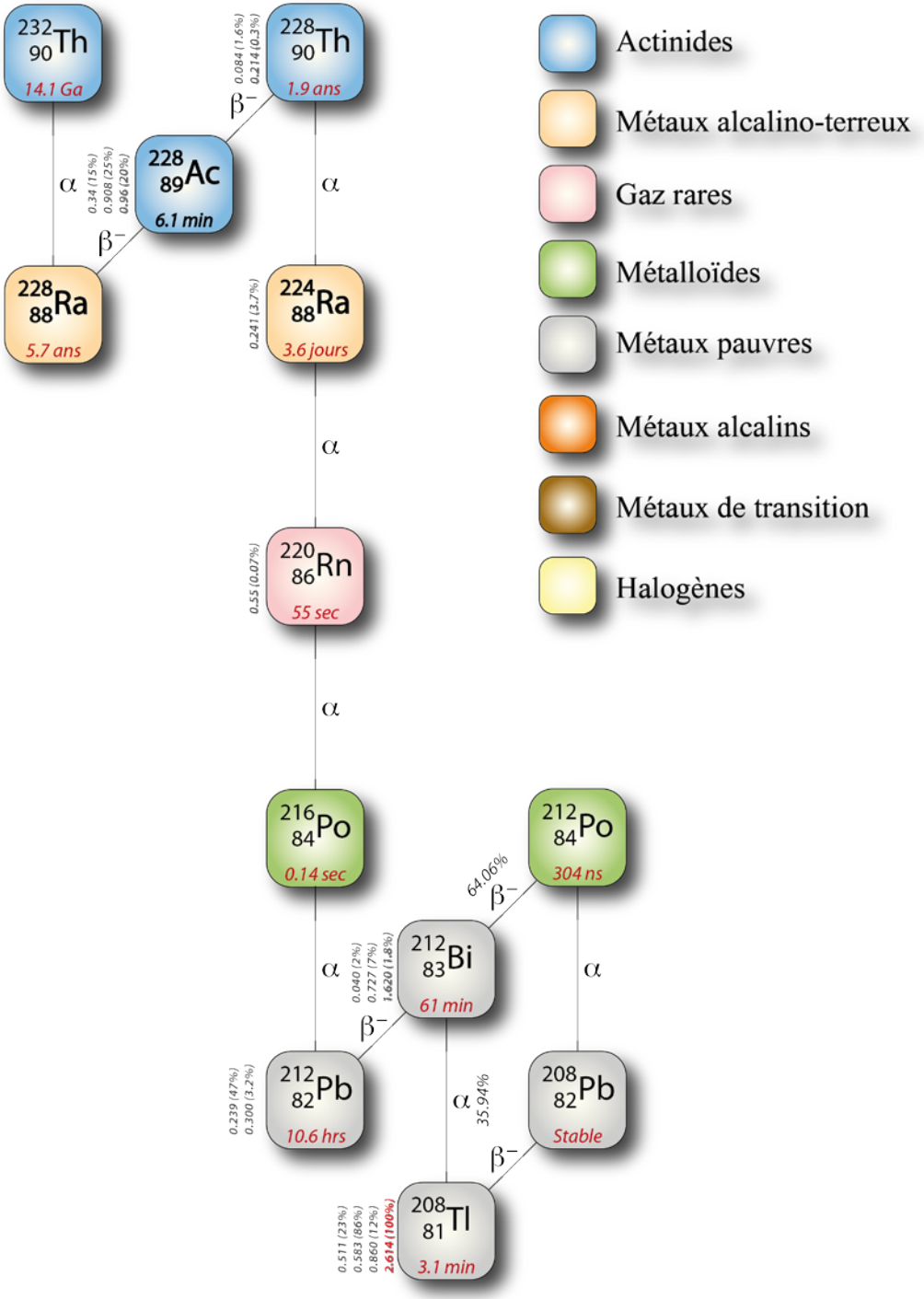
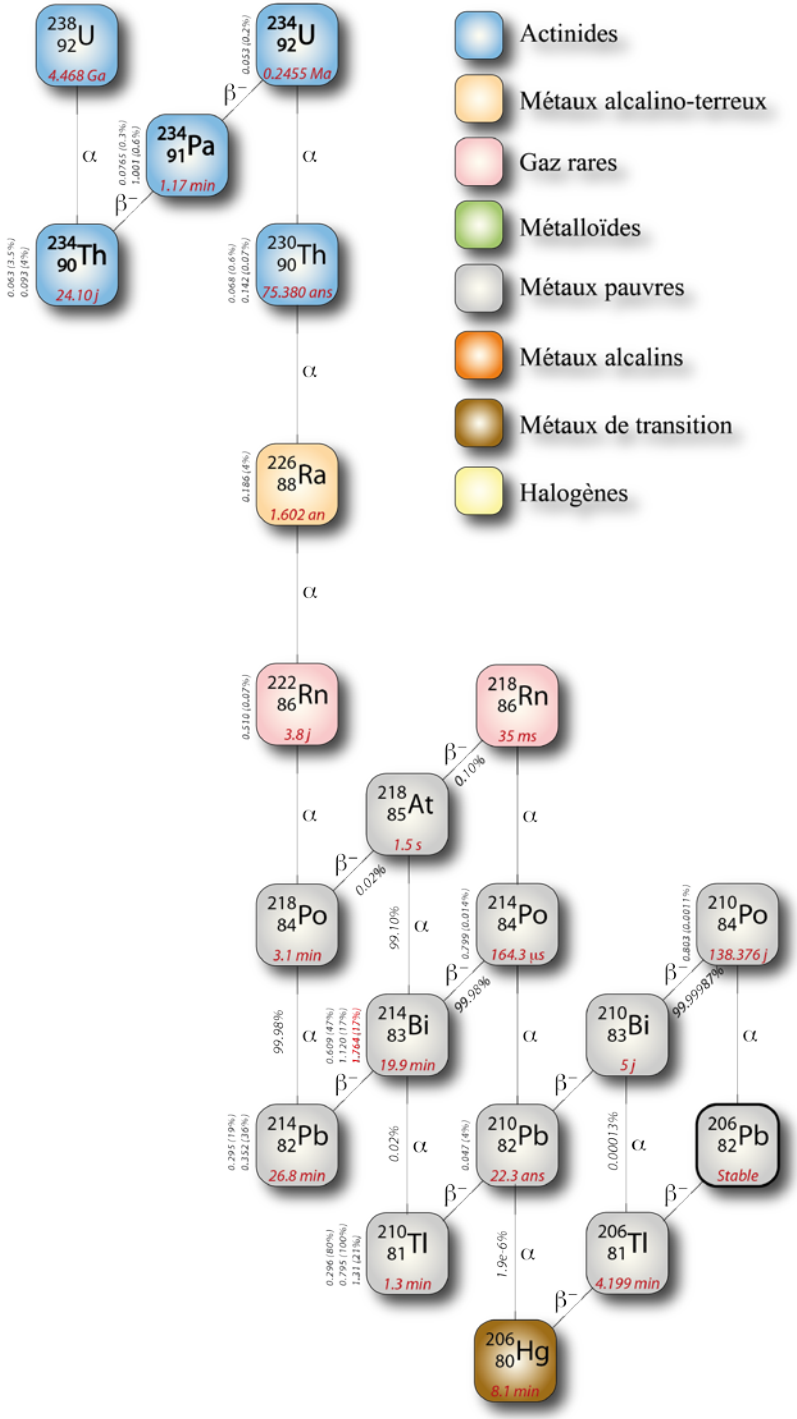
Any sampling bias for the igneous rocks ?



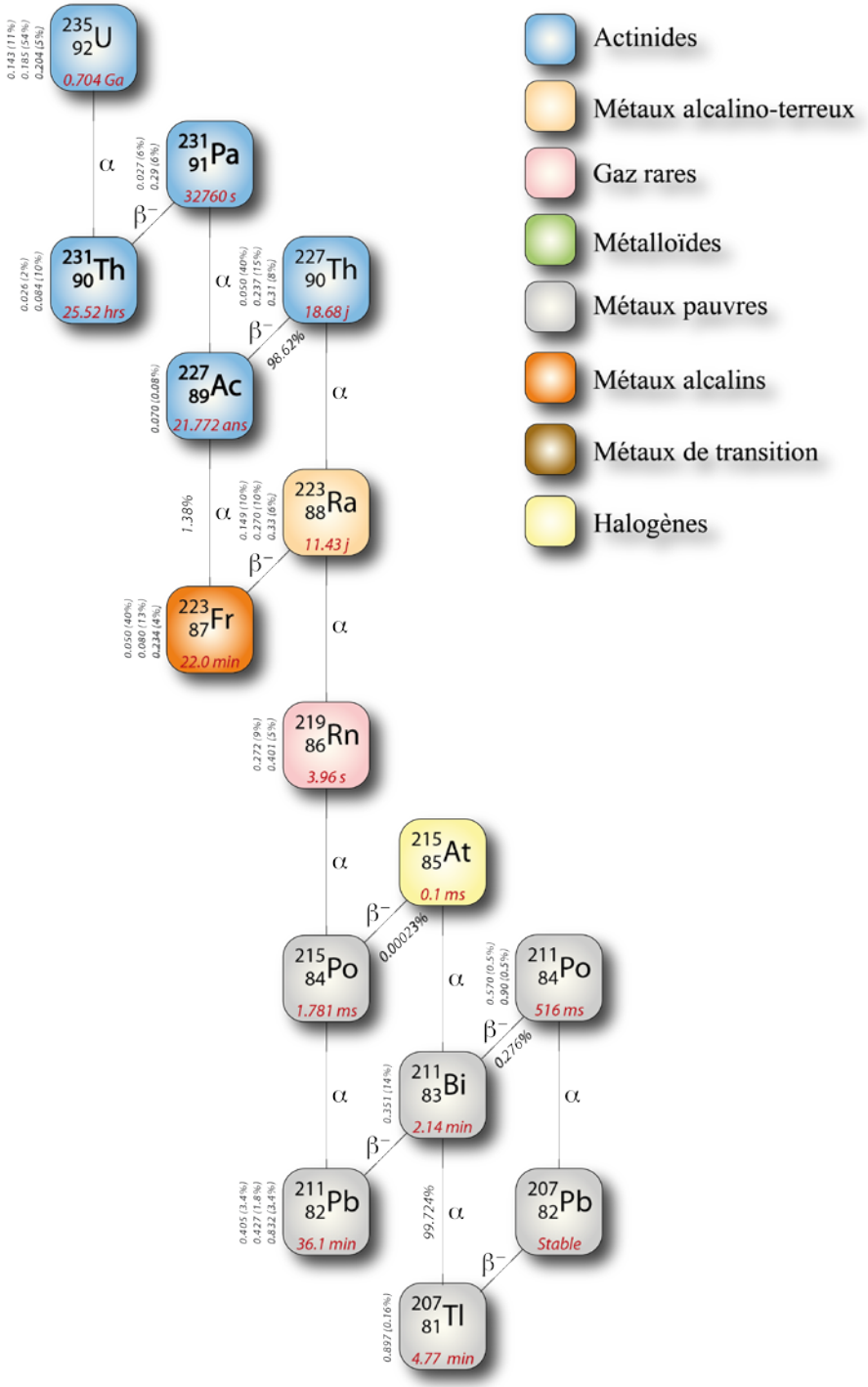
Chaîne de désintégration du ^{232}Th



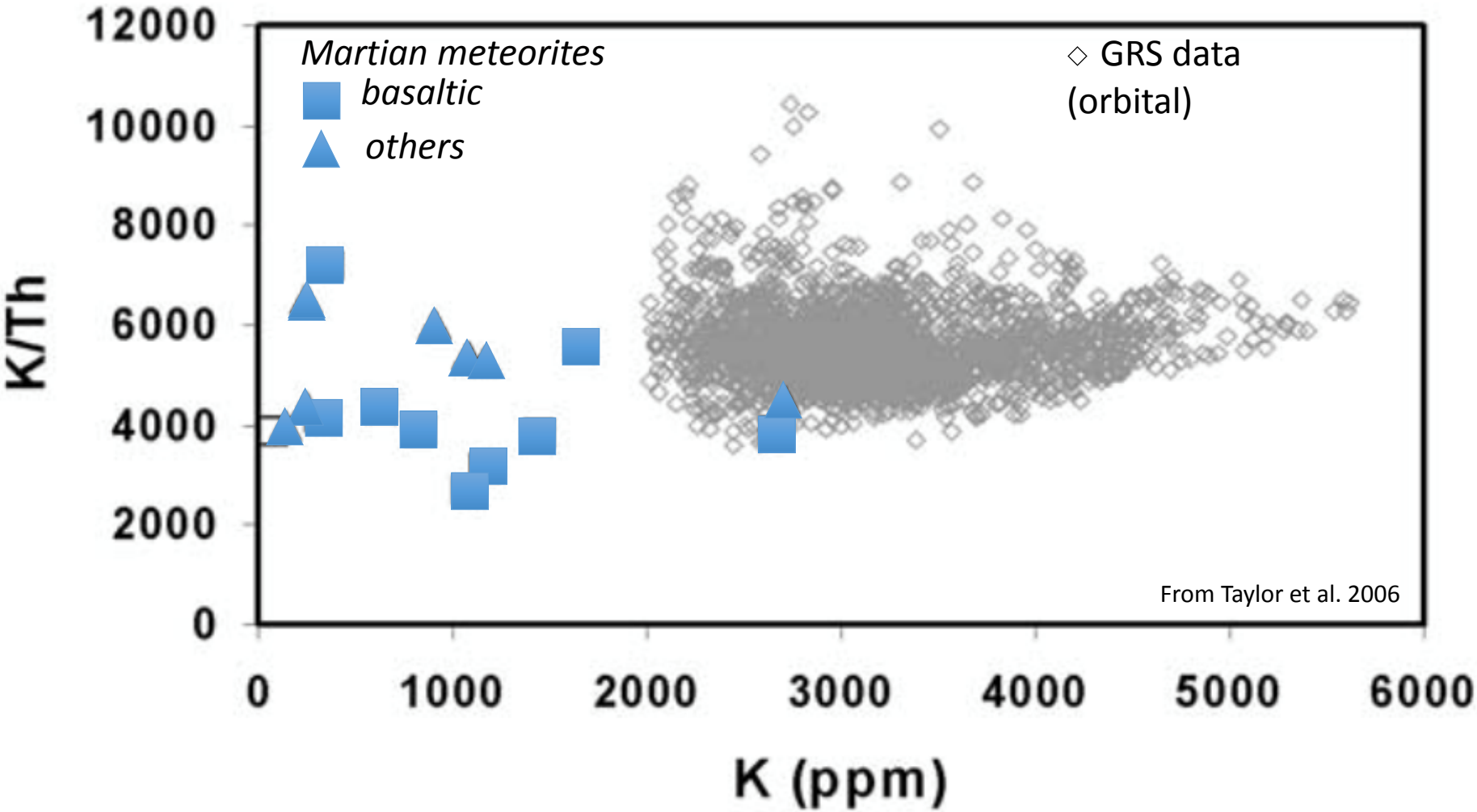
Chaîne de désintégration du ^{238}U



Chaîne de désintégration du ^{235}U



Martian meteorites versus surface geochemistry



? *"Martian meteorites are not representative of the Martian surface" Taylor et al. 2006*

Disseminated differentiated igneous rocks on Mars
Several pieces of evidence

✓ Unexpected magmatic diversity and the widespread presence of silica- and feldspar-rich materials in the vicinity of the landing site at Gale crater

Sautter et al. 2015. In situ evidence for continental crust on early Mars. Nature Geoscience

✓ Identification of feldspar-rich rocks from visible/NIR and infrared spectroscopy

Bandfield, J. L. 2006. Extended surface exposures of granitoid composition in Syrtis Major Mars. Geophys. Res. Lett.

Carter, J. & Poulet, F. 2013. Ancient plutonic processes on Mars inferred from the detection of possible anorthosite terrains. Nature Geoscience.

Wray, J. et al. 2013. Prolonged magmatic activity on Mars inferred from the detection of felsic rocks. Nature Geoscience.

✓ Evidence for the existence of a (mostly) buried felsic crustal component from the comparison of the density of Martian basalts with average crustal density inferred from the field of gravity of Mars.

Baratoux, D., H. et al. 2014. Petrological constraints on the density of the Martian crust, J. Geophys. Res. Planets.

✓ **GRS K/Th distributions and K/Th distributions from terrestrial crustal material**
Evidence for disseminated K_2O-rich and Th-Rich differentiated rocks

What can we learn from terrestrial data ?

		Radiometric data	Geochemical database
Continental crust	**West African Craton**	● Ghana Geological Survey Department archives	● West African Exploration Initiative (WAXI) Geochem. database
	Pilbara, Western Australia Craton	● Minty, B., et al. New Radiometric Map of Australia, 2014.	● OZCHEM National Whole Rock Geochemistry Dataset
Oceanic crust	**Mid-oceanic ridges**		● Gale et al. 2013 – Geochemistry, Geophysics, Geosystems. The mean composition of ocean ridge basalts.