Micro-analytical evidence that natural limestones of Maadi and Turah are different from Khufu and Kafrè pyramid material

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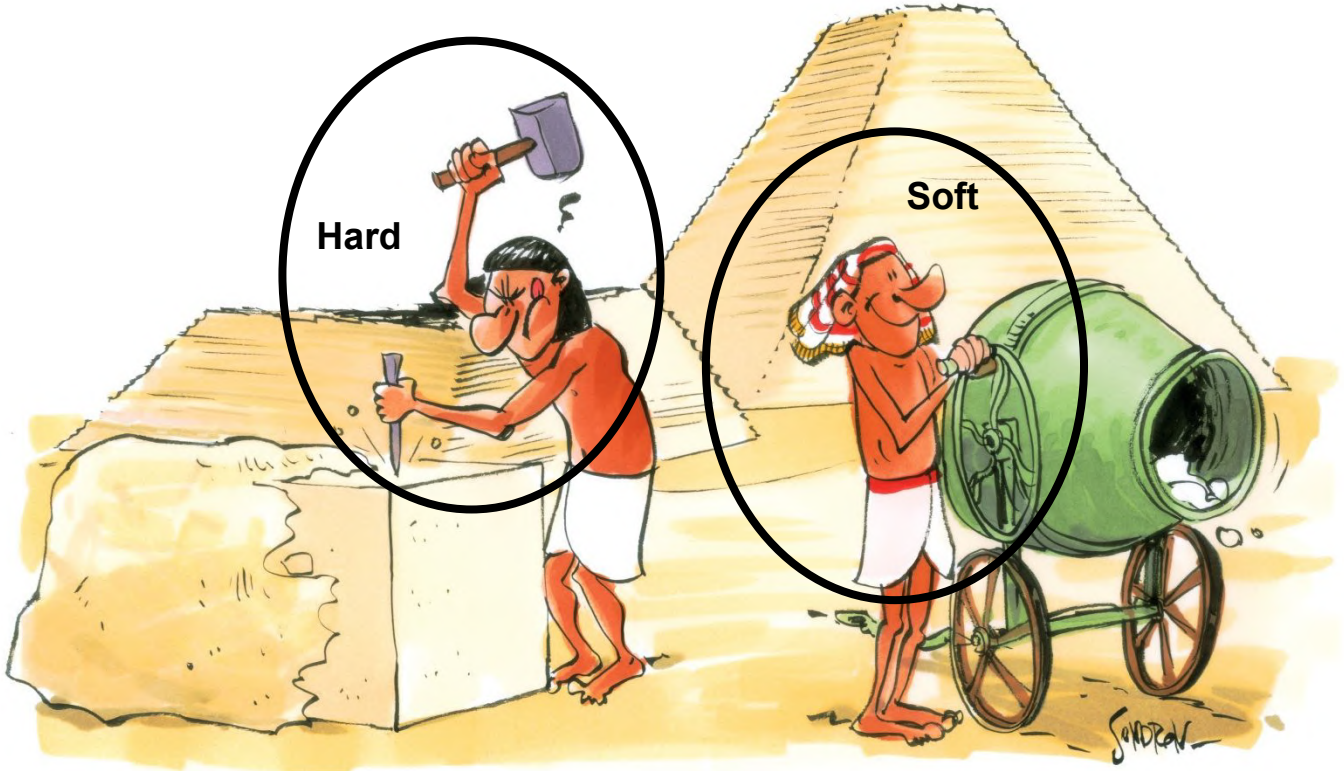
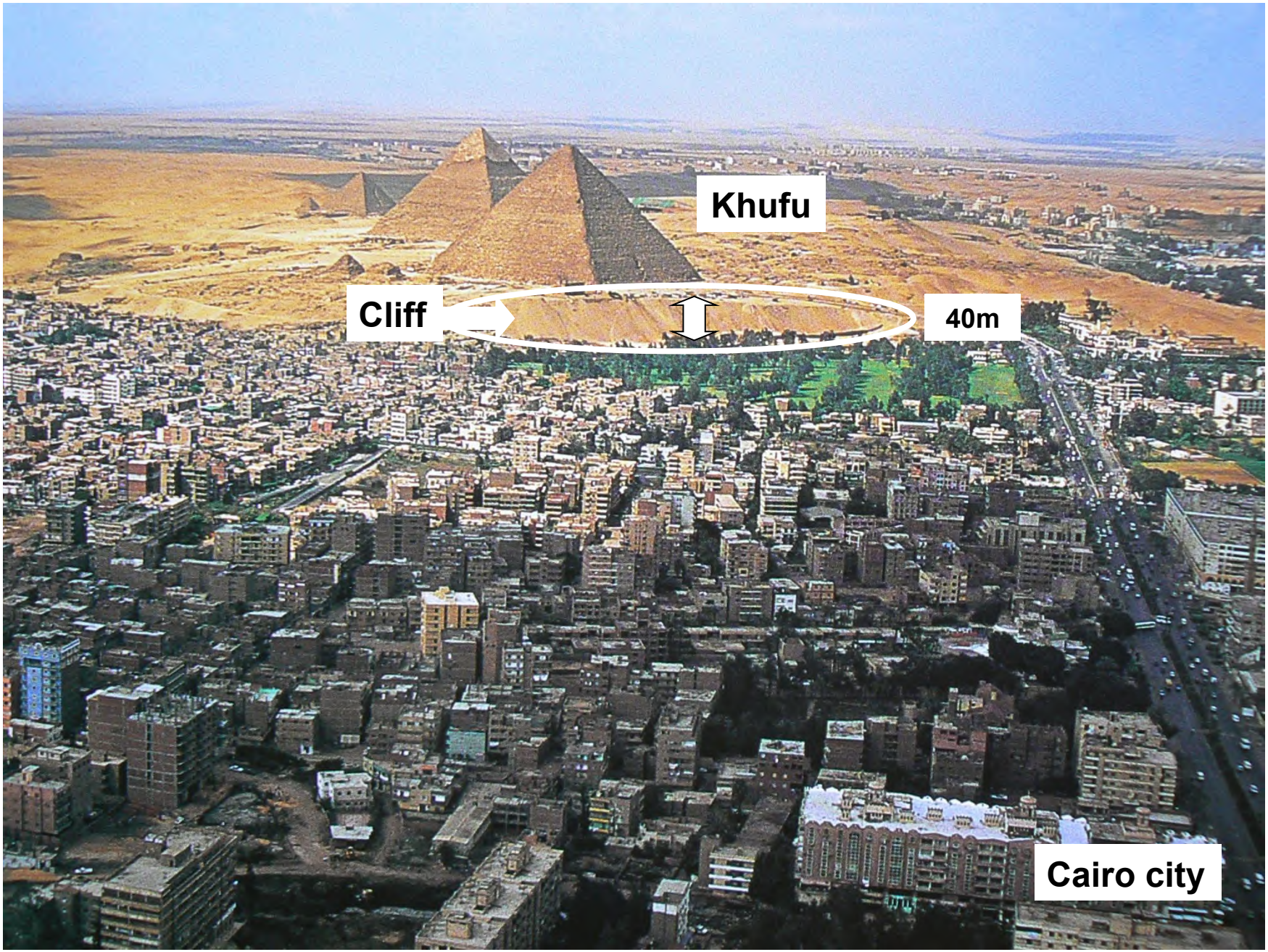
Geopolymer Camp 2013
Saint-Quentin

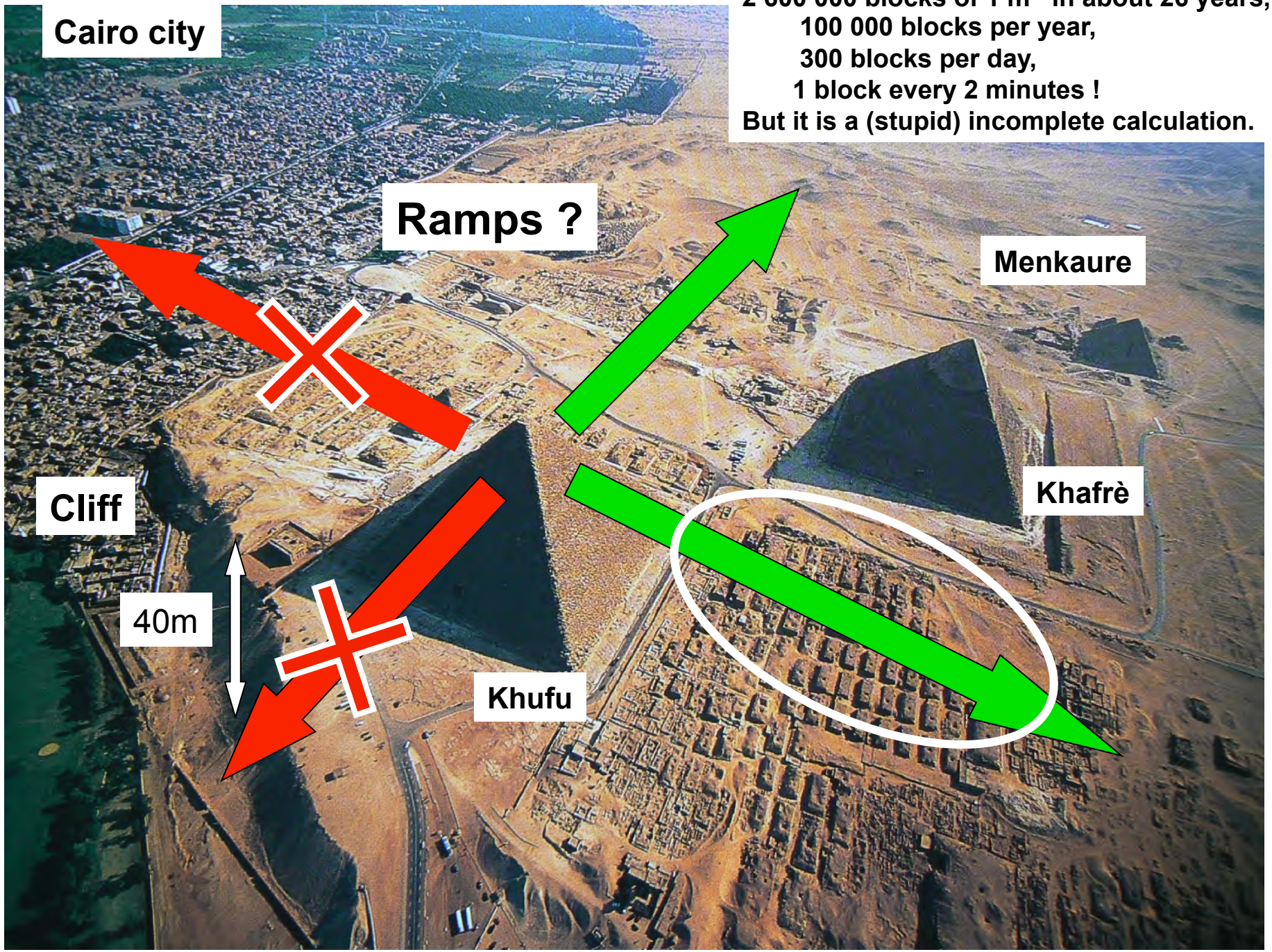
The pyramids of Giza:
visual and analytical evidences for moulded blocks.



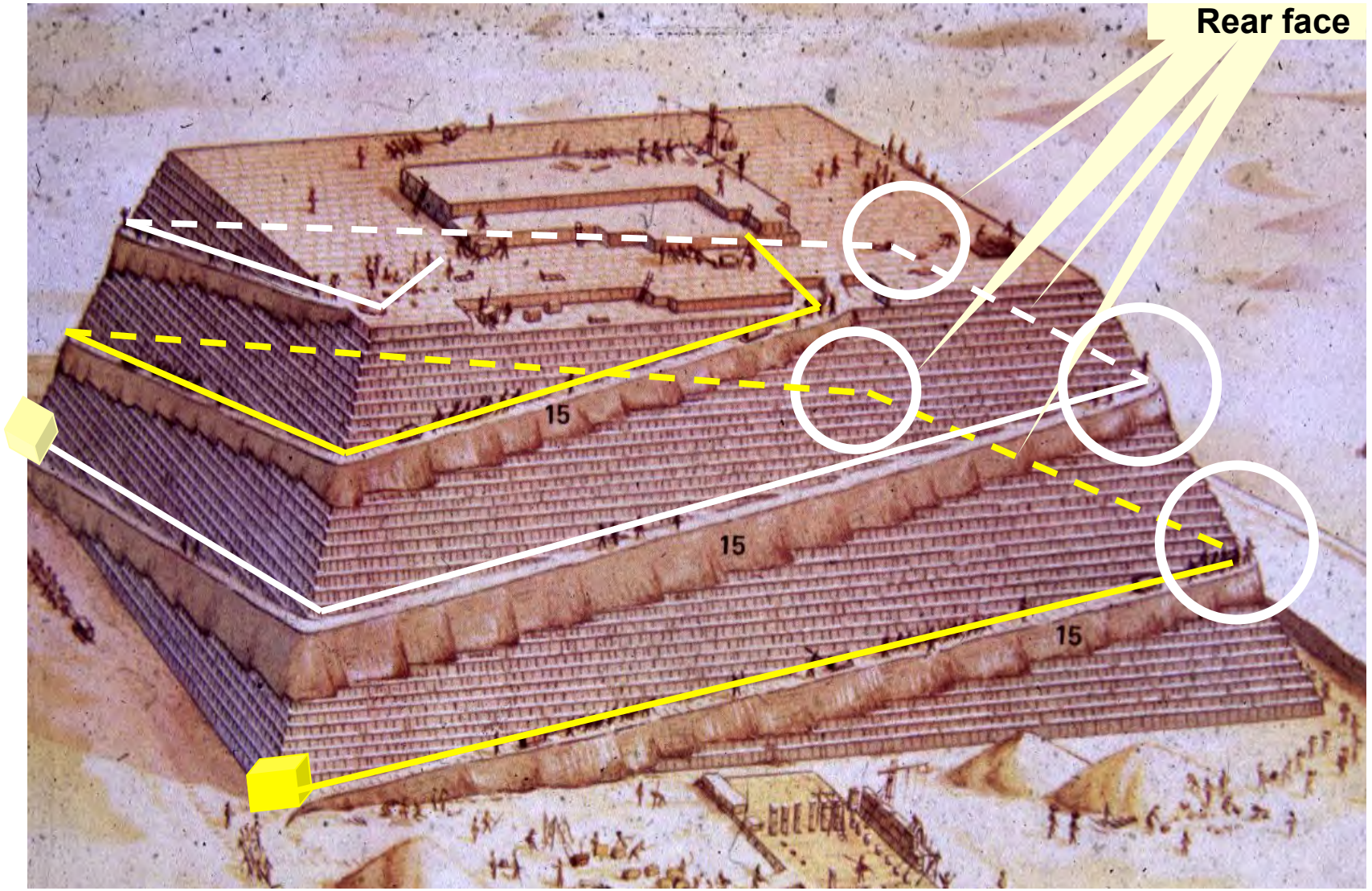
A proposal made in 1978 by J. Davidovits (chemist) and supported by G. Demortier since 1991.

J. Davidovits – Cheops with man-made stones – Third International Congress of Egyptology, Toronto, (1982)
J. Davidovits and Maggie Morris – The pyramids ; an enygma solved – Hippocrene Books-Madisson (1988)
Joël Bertho – La pyramide reconstituée – Editions Unic
G. Demortier – PIGE,PIXE and NMR study of the masonery of the pyramid of Cheops –NIMB226 (98-109)2004
G. Demortier – Revisiting the construction of the Egyptian pyramids – Europhysics News 40 (27-31) 2009


Khufu
Cliff
40m
Cairo city

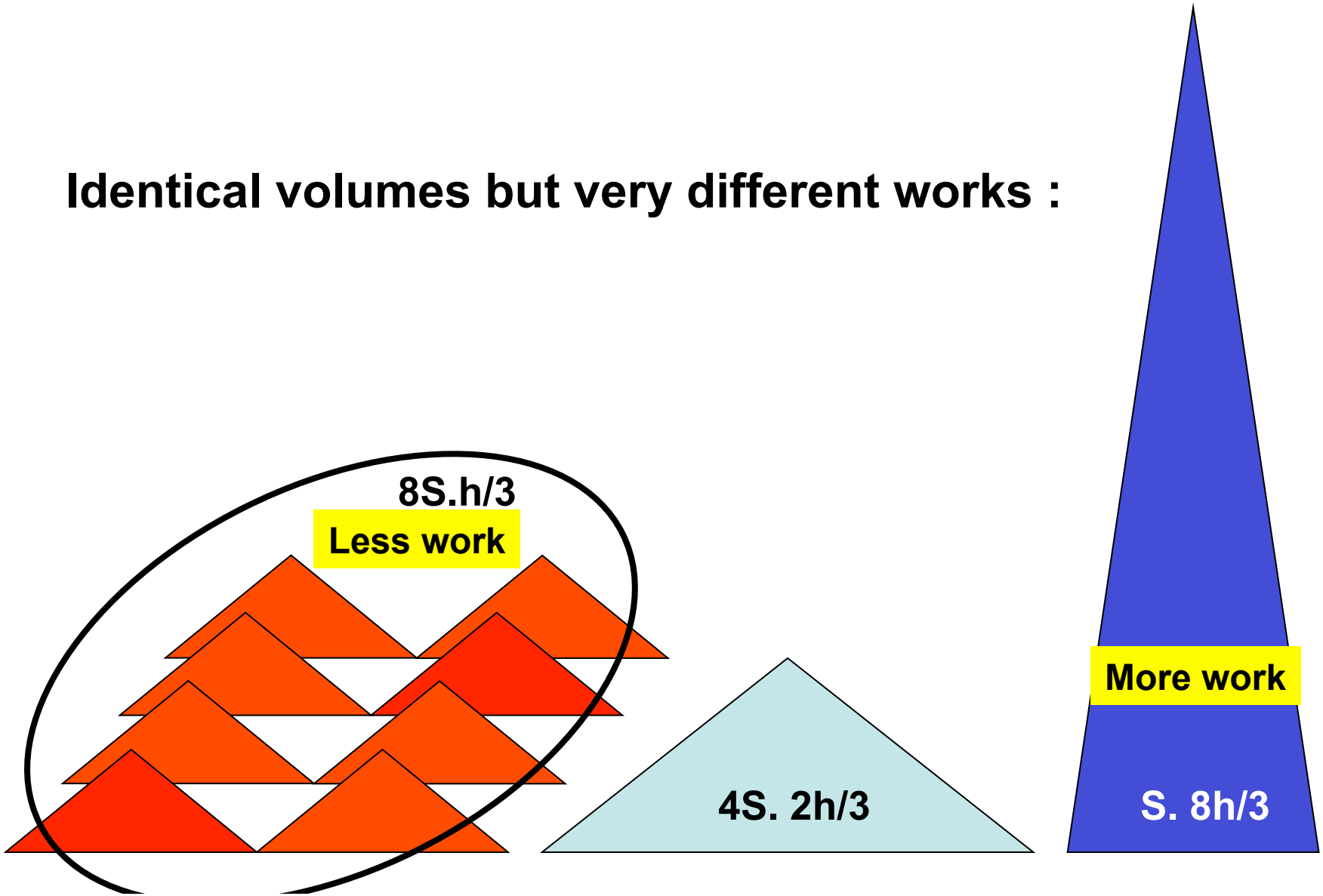


2 600 000 blocks of 1 m^3 in about 26 years,
100 000 blocks per year,
300 blocks per day,
1 block every 2 minutes !
But it is a (stupid) incomplete calculation.



Hypothetical lifting procedure for huge blocks

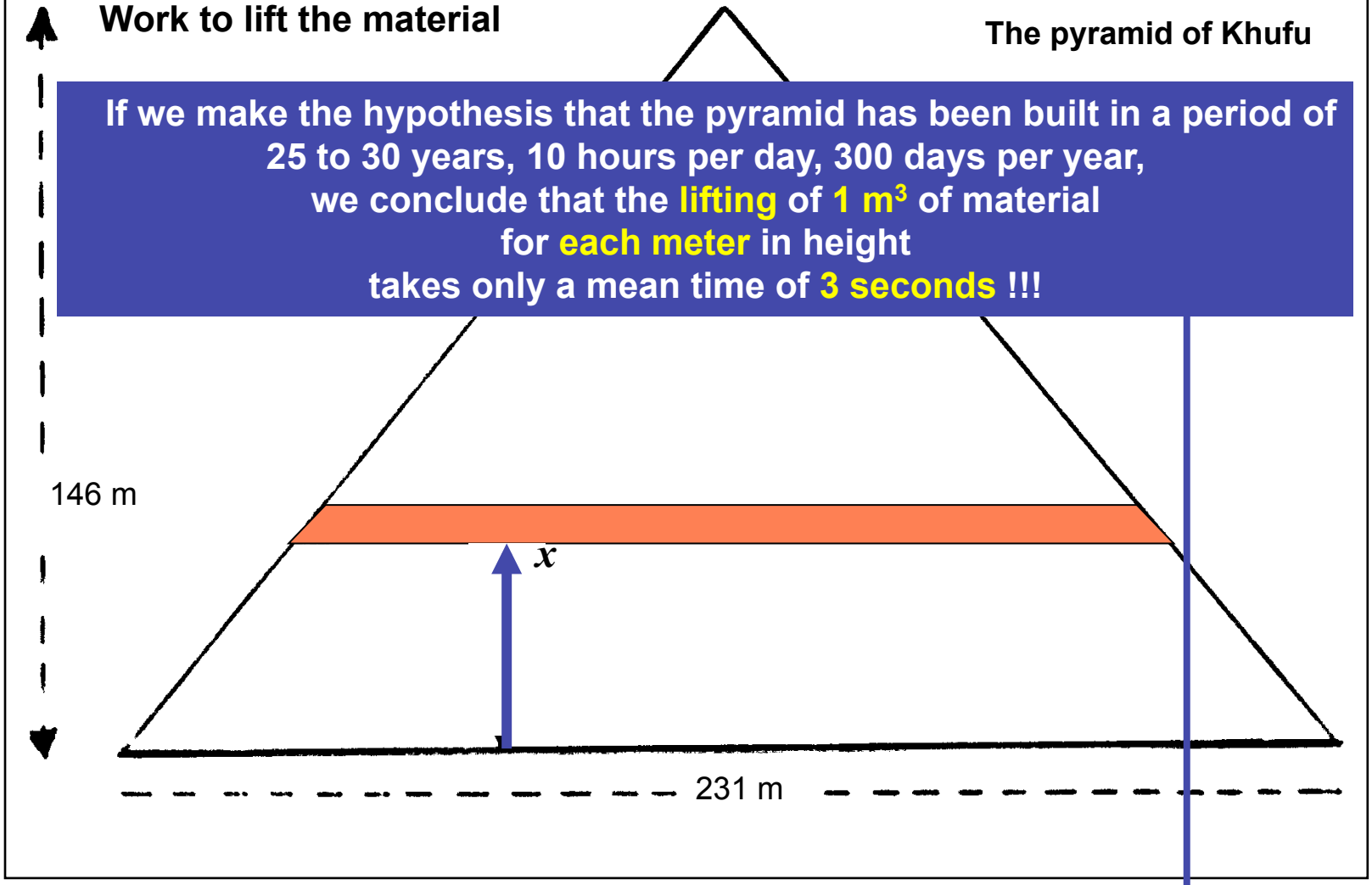
Identical volumes but very different works :



Work to lift the material

The pyramid of Khufu

If we make the hypothesis that the pyramid has been built in a period of 25 to 30 years, 10 hours per day, 300 days per year, we conclude that the lifting of 1 m^3 of material for each meter in height takes only a mean time of 3 seconds !!!



$$\rho \left(\frac{231}{146}\right)^2 \int_0^{146} (146-x)^2 \, x \, dx = \rho \; 95\,545\,218 \; m^3 \cdot m$$

Specific weight

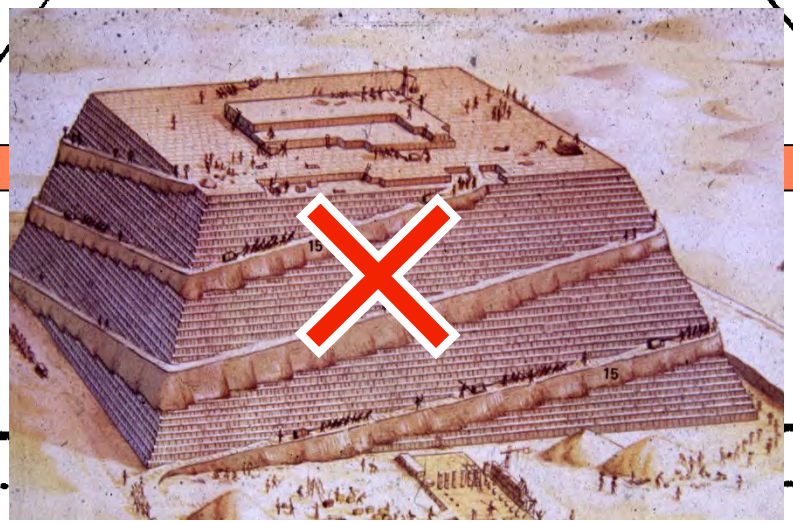
volume of a tier

heigth of the tier

Work to lift the material

The pyramid of Khufu

If we make the hypothesis that the pyramid has been built in a period of 25 to 30 years, 10 hours per day, 300 days per year, we conclude that the lifting of 1 m^3 of material for each meter in height takes only a mean time of 3 seconds !!!



146 m

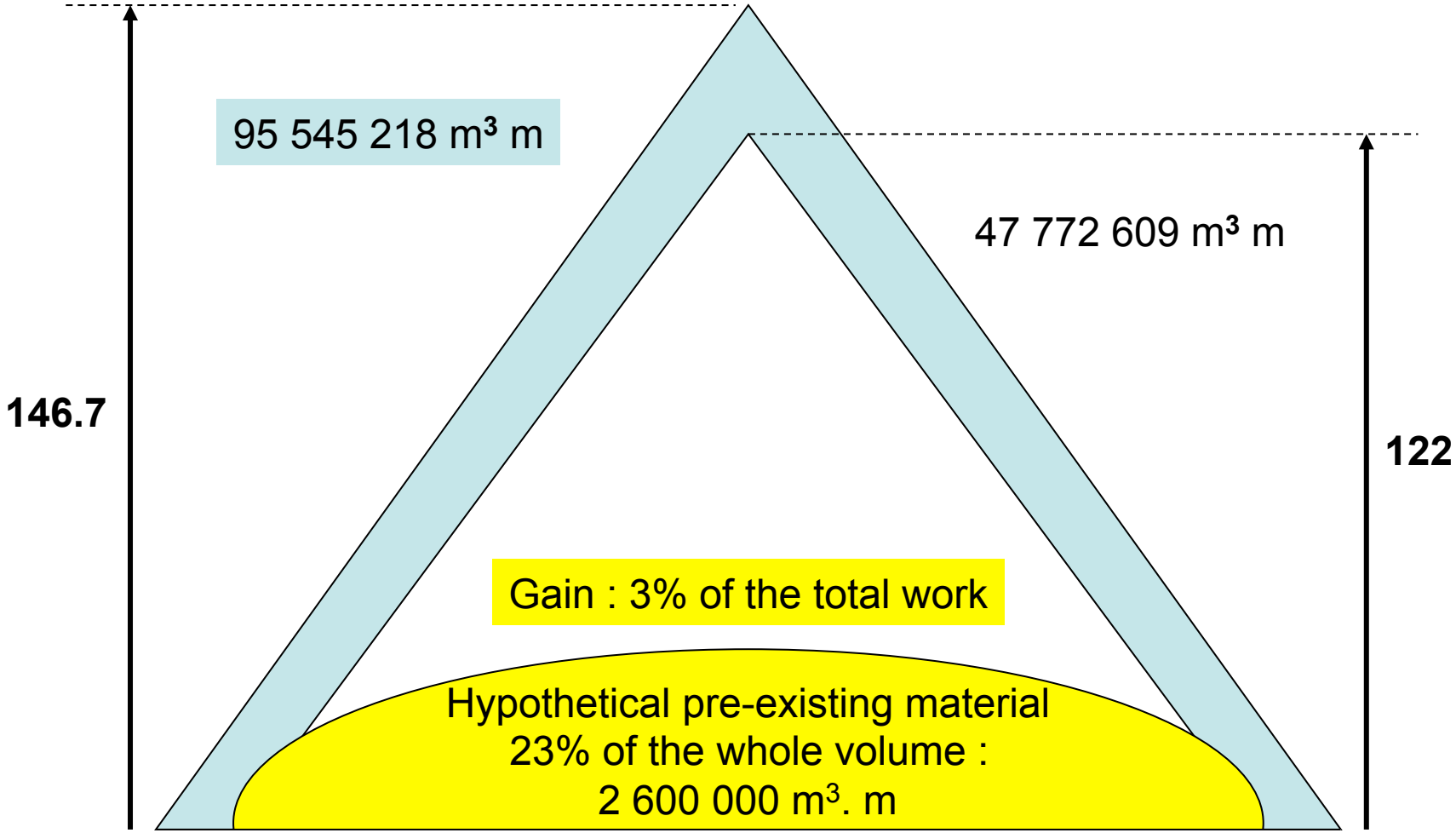
$$\rho \left(\frac{231}{146}\right)^2 \int_0^{146} (146-x)^2 \; x \; dx = \rho \; 95\,545\,218 \; m^3 \cdot m$$

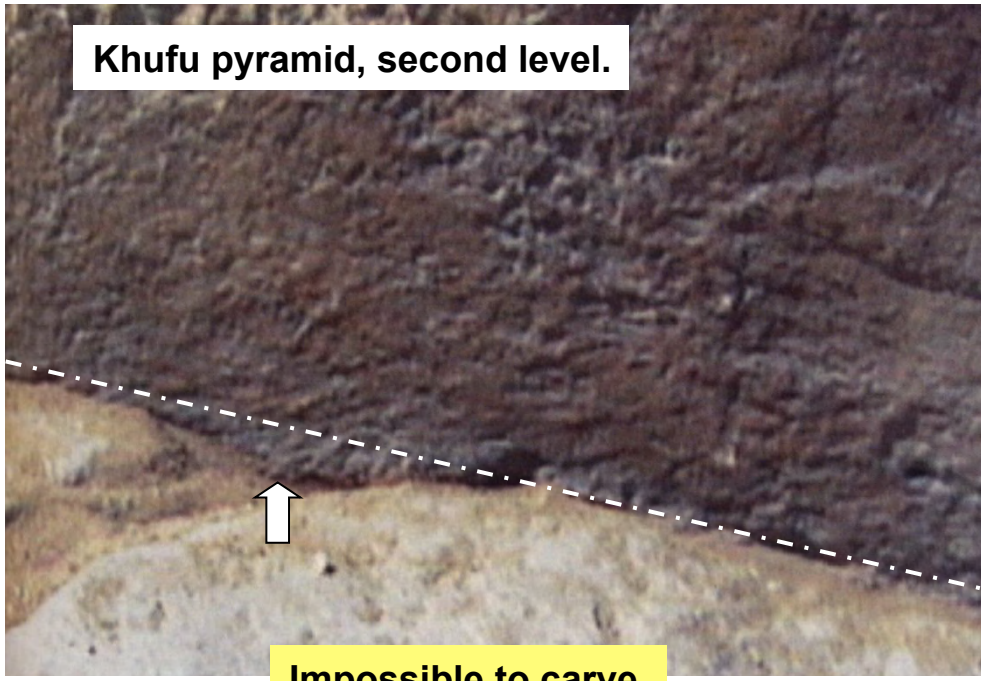
density

volume of a tier

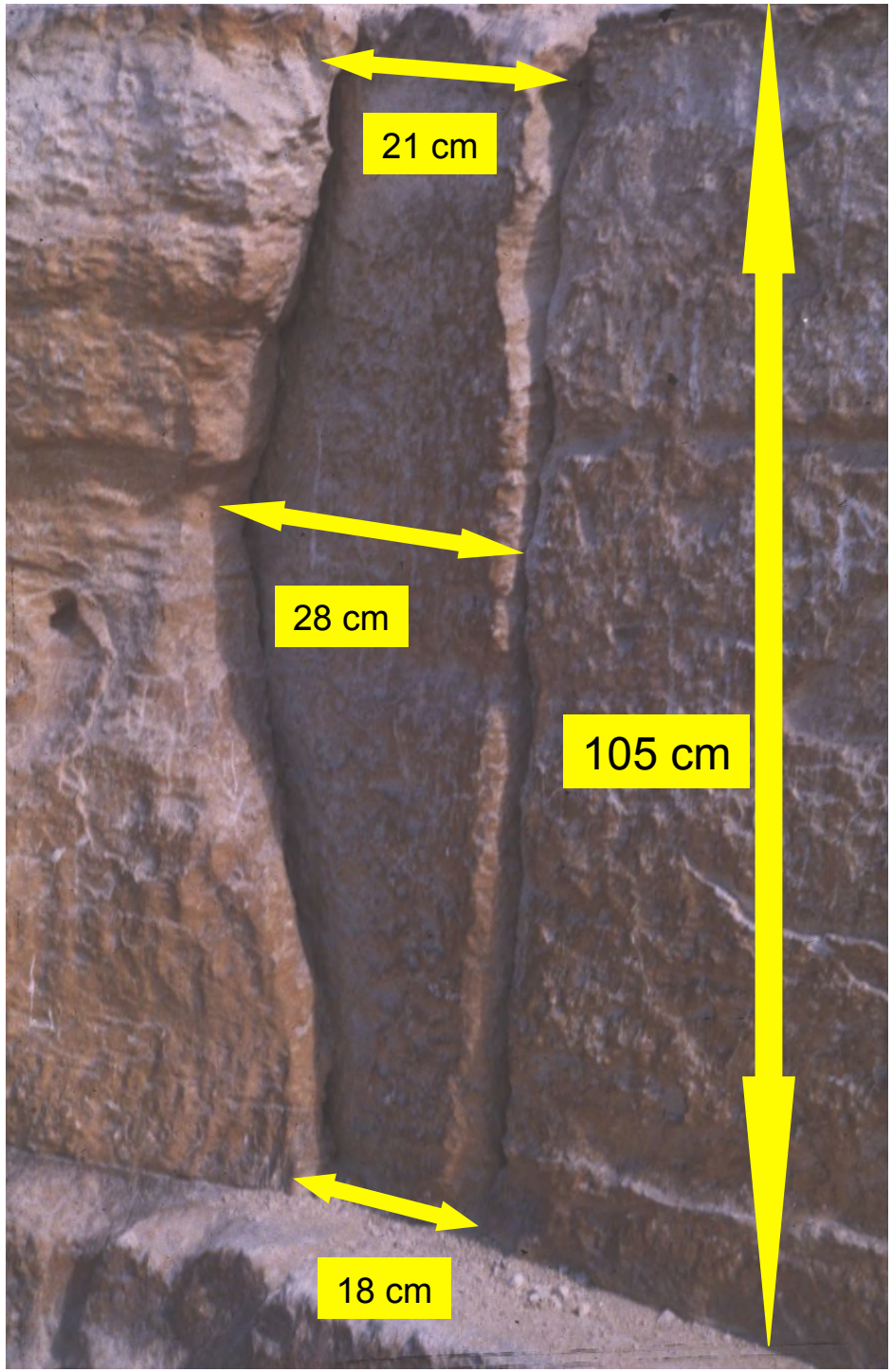
heigth of the tier

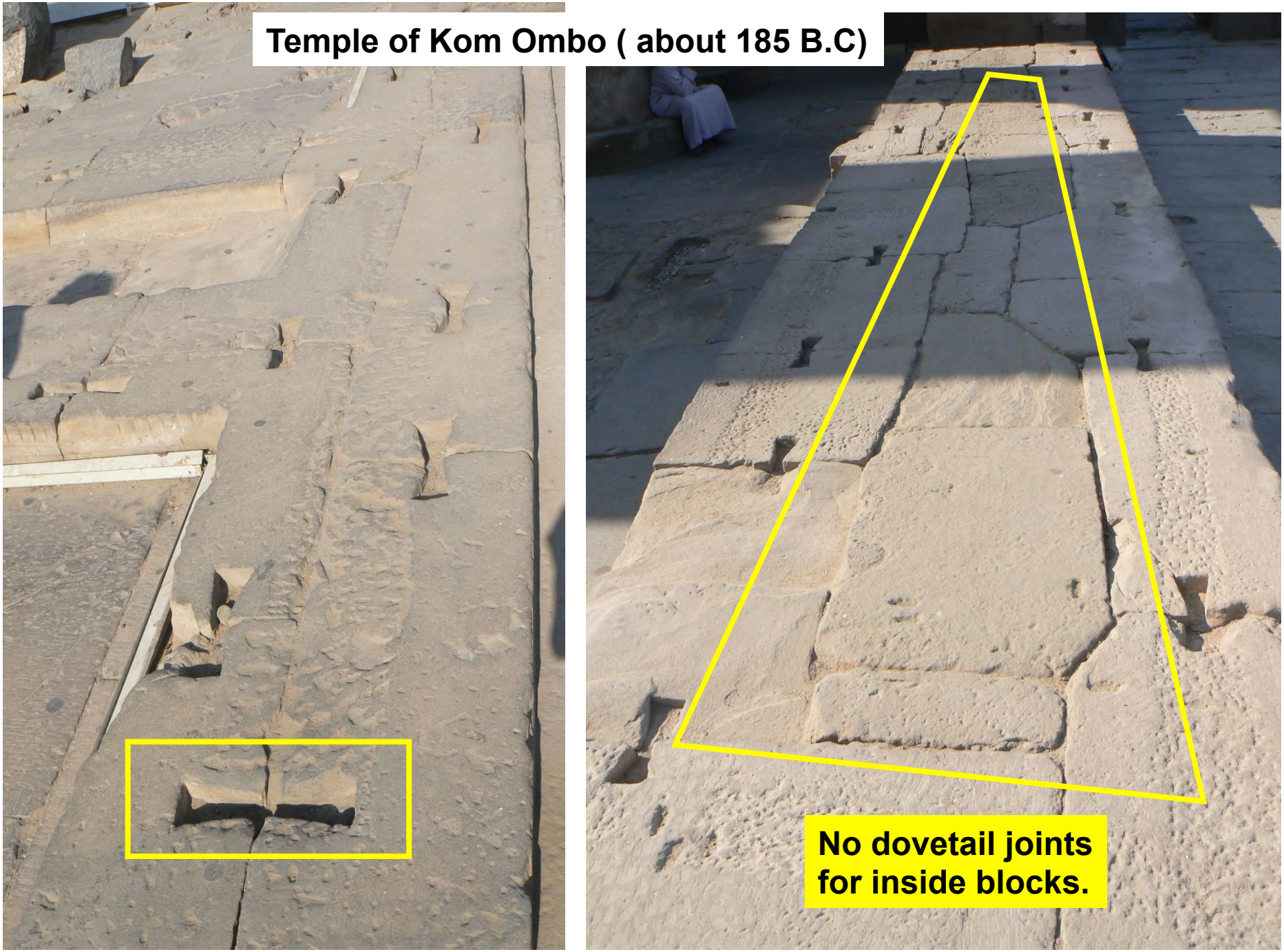
For pyramids with the same slope,
the volume increases with h^3
but the work increases with h^4.



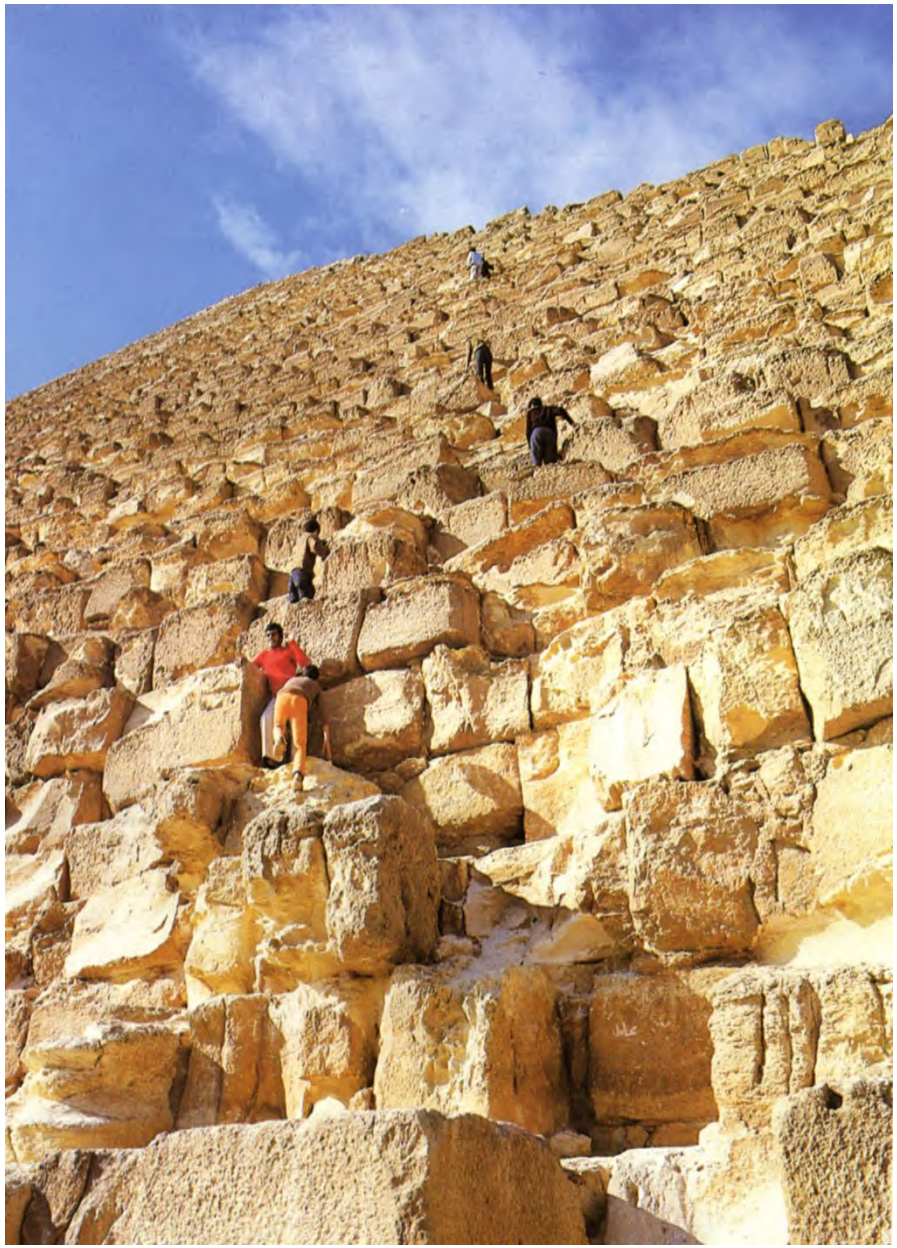

Khufu pyramid, second level.


Impossible to carve


21 cm
28 cm
105 cm
18 cm


Temple of Kom Ombo (about 185 B.C)
No dovetail joints
for inside blocks.

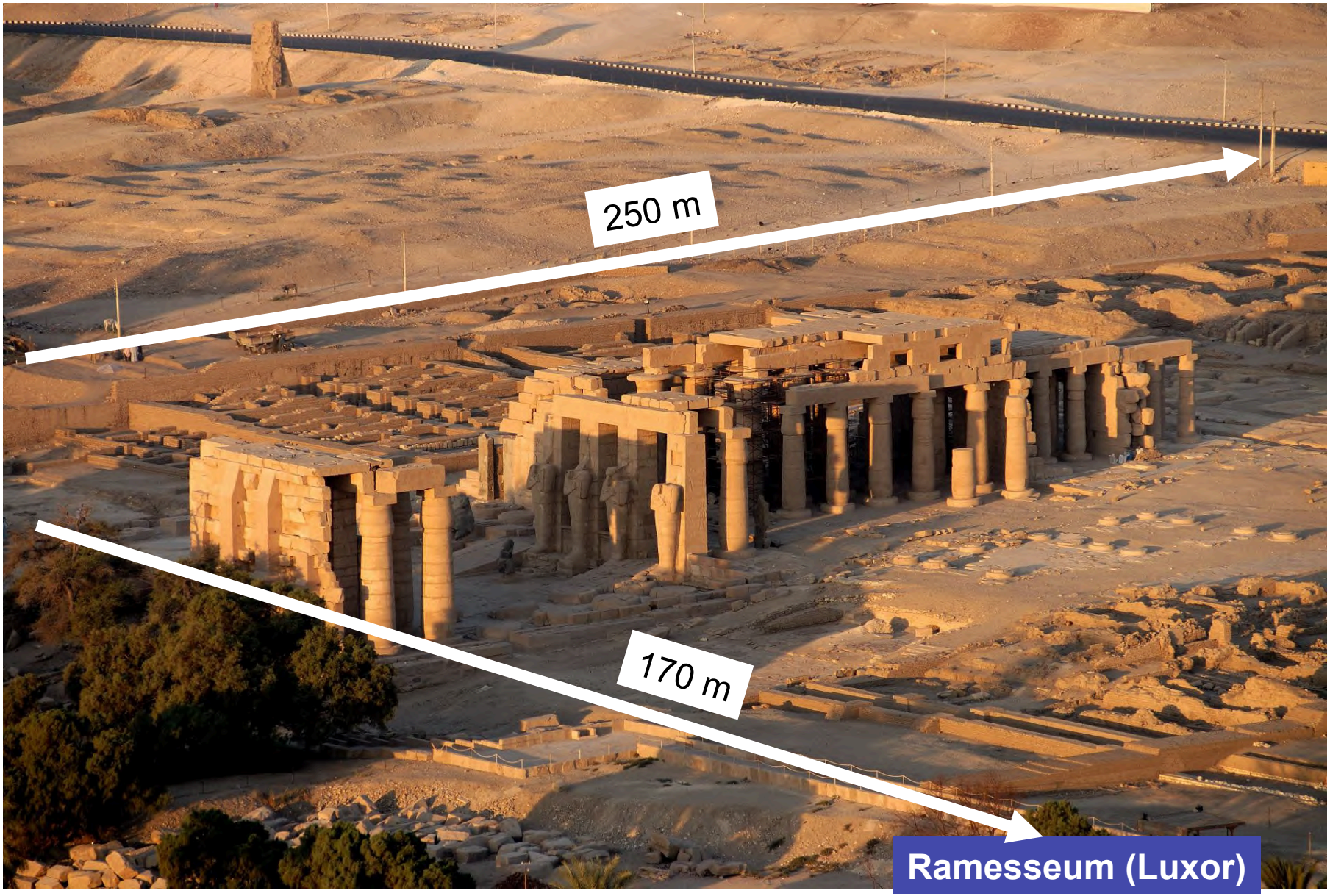
From the ground

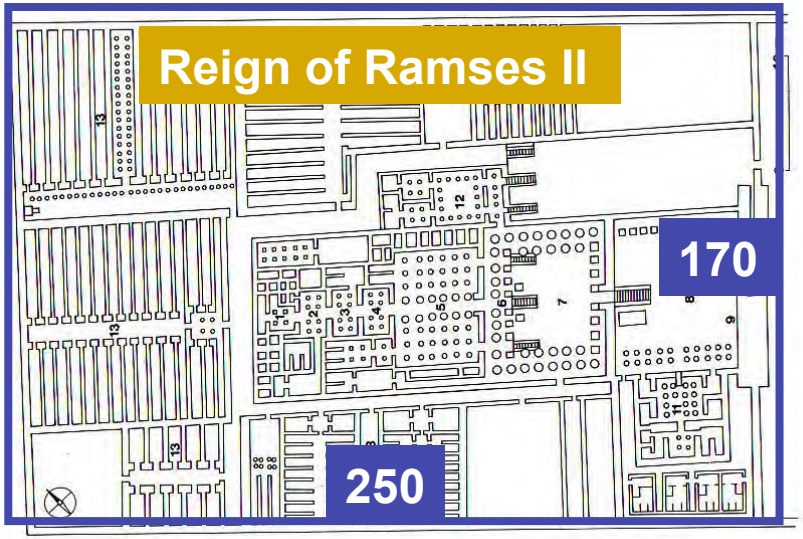


Irregular surfaces

From the sky

Construction during the New Kingdom, more than 1300 years after the Khufu period.





Ramesseum

3 300 years ago

Volume : 250 x 170 x 15 = 637 500 m^3

Lift 4 781 250 m^3 m

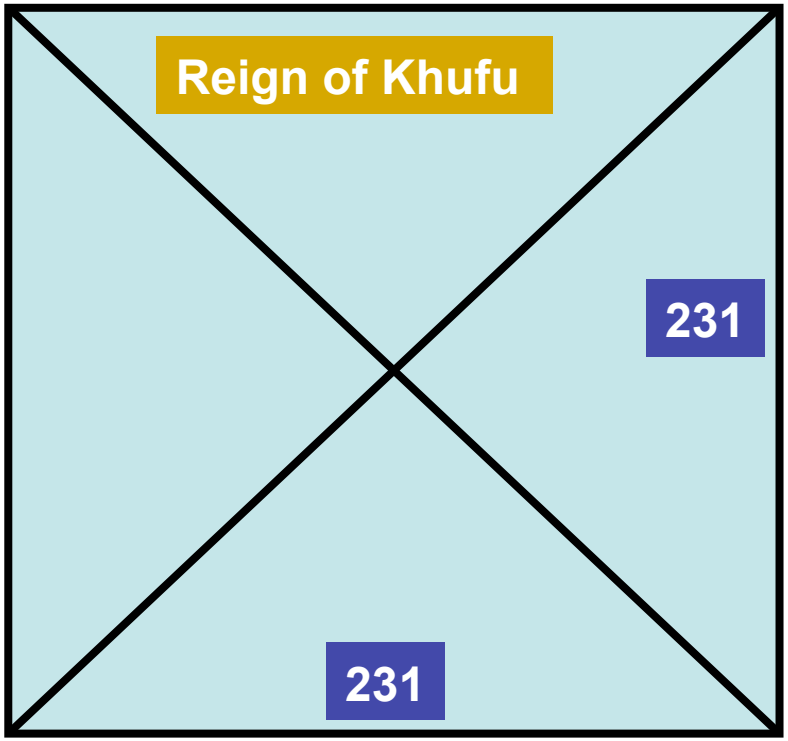
15

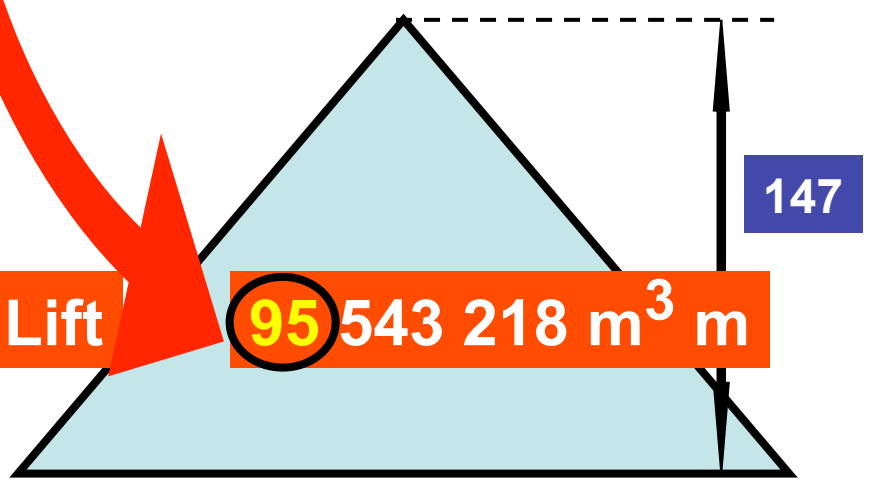
X 20

Pyramid of Khufu

4 500 years ago

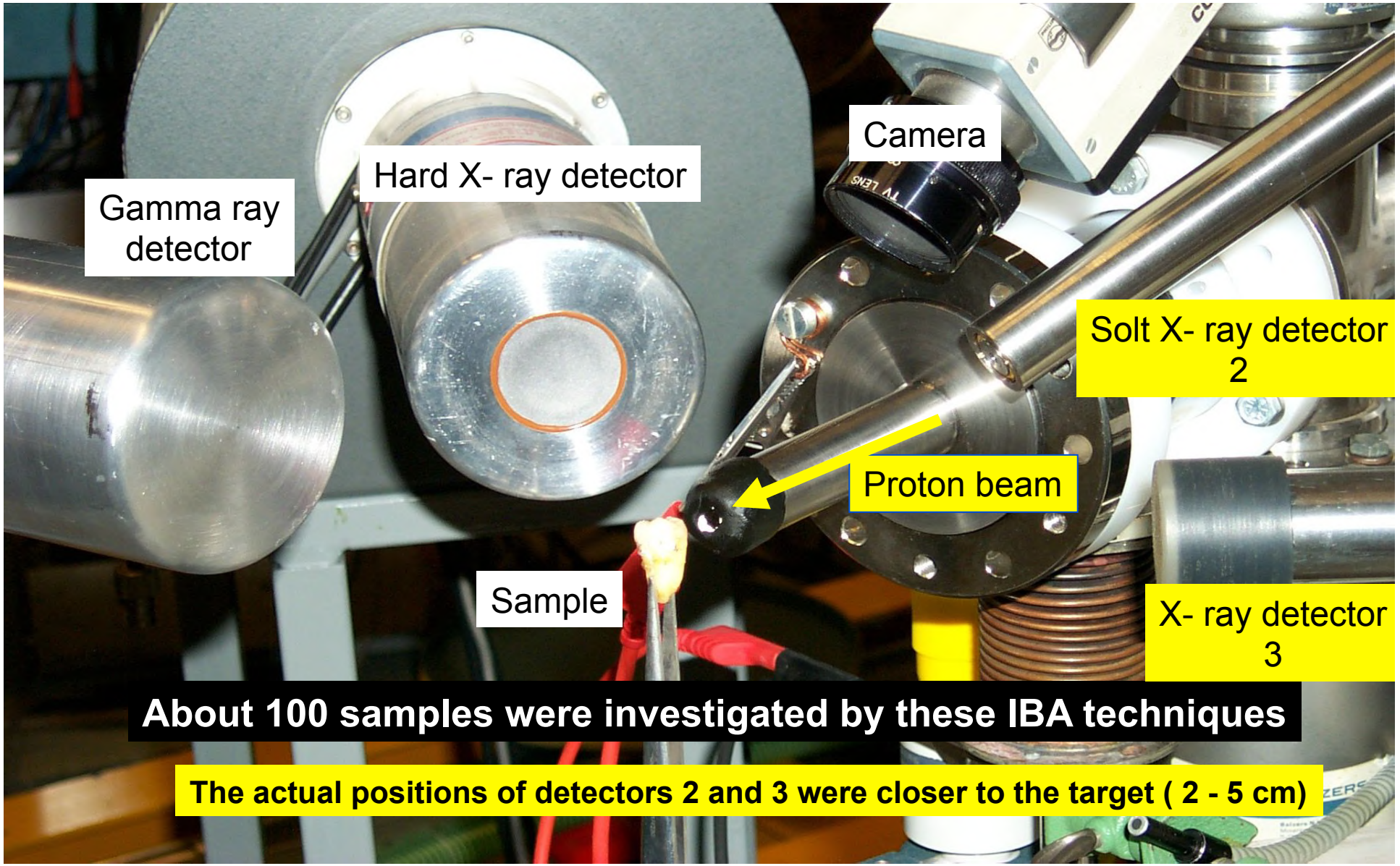
Volume : 231 x 231 x 146 / 3 = 2 596 902 m^3





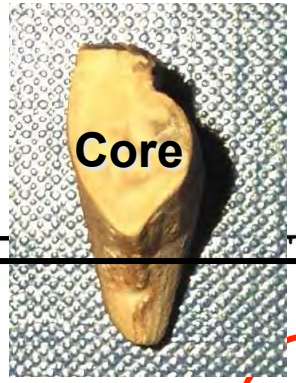
Analysis of the material

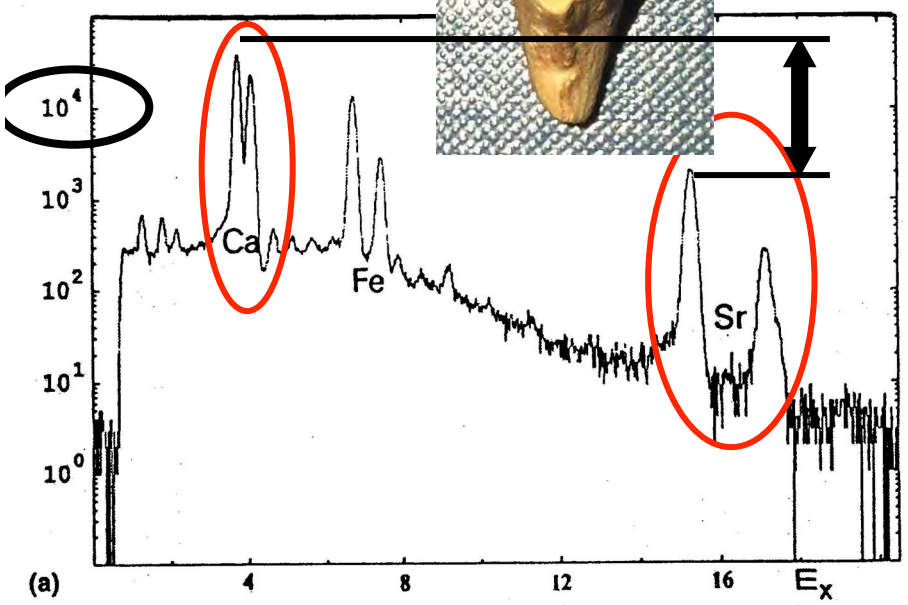
Irradiation facility for elemental analysis (PIXE and PIGE) with an external proton beam

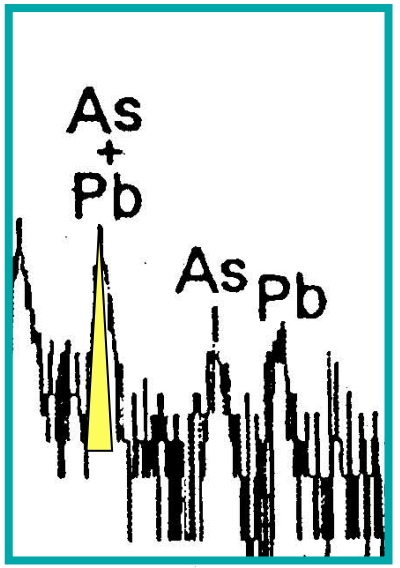


PIXE

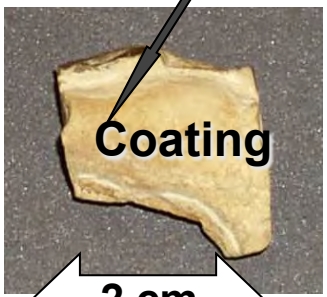
G. Demortier – PIGE, PIXE and NMR study of the masonry of the pyramid of Khufu – NIMB226 (98-109)2004

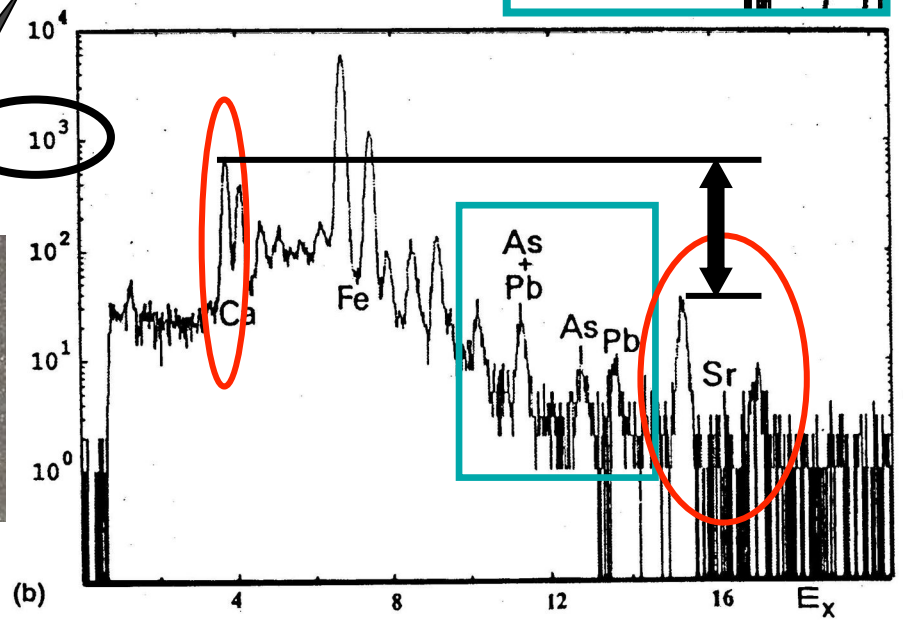






only 5% of Ca

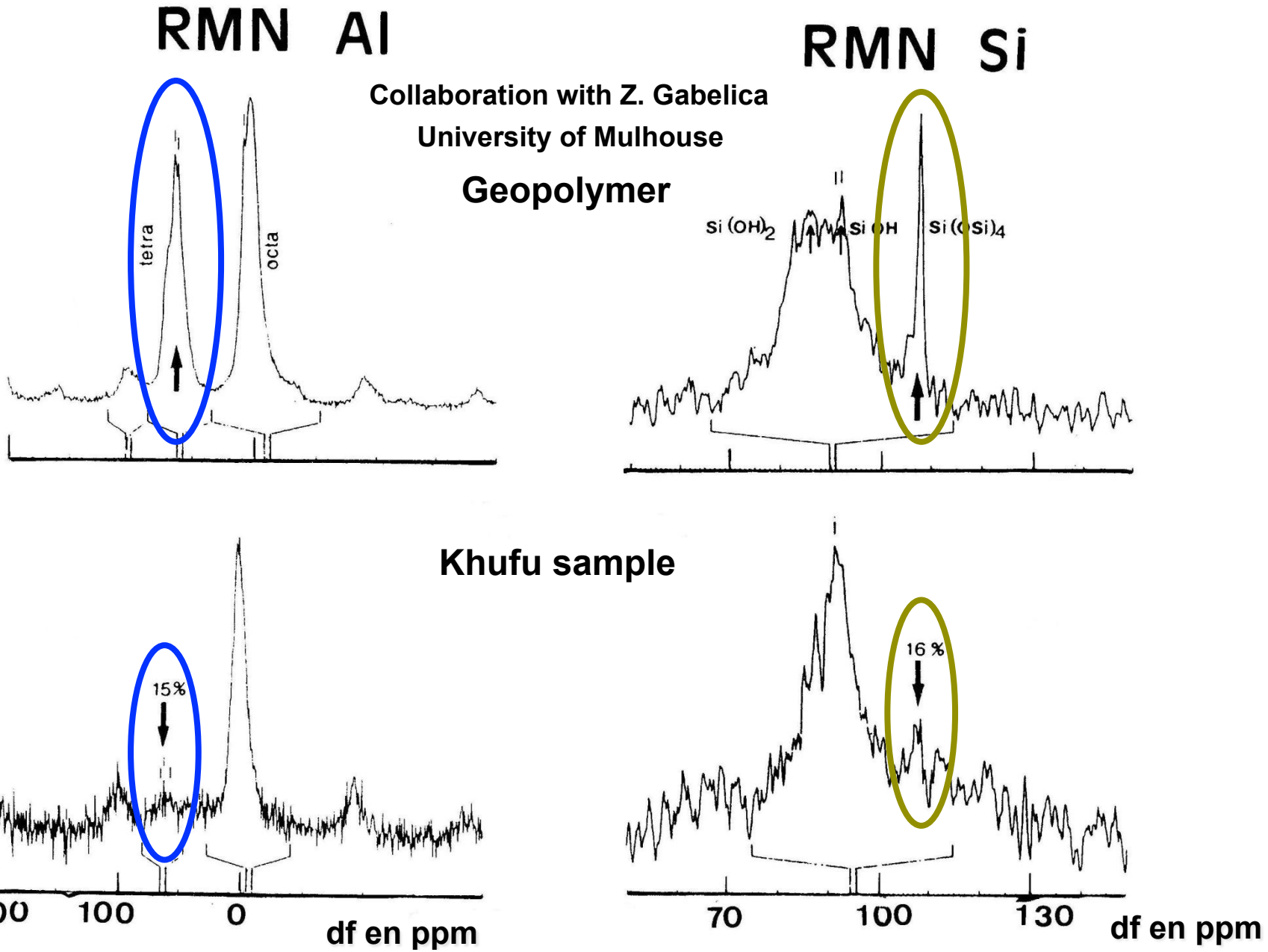




Relative concentrations Coating / Core

PIGE

F	Na	Mg	Al	Si
7.5	8.5	12	2	21

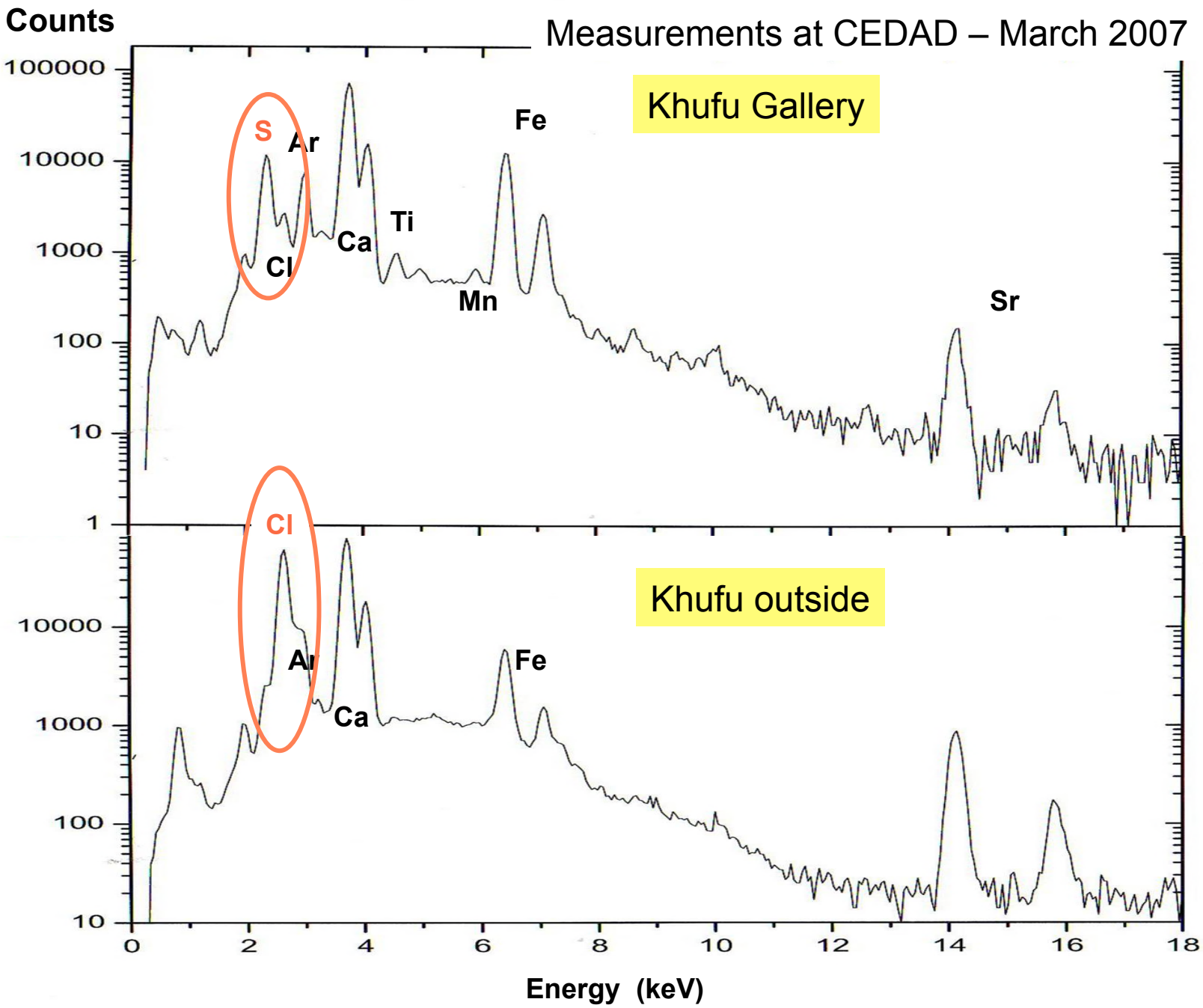


Collaboration with Z. Gabelica
University of Mulhouse

Geopolymer

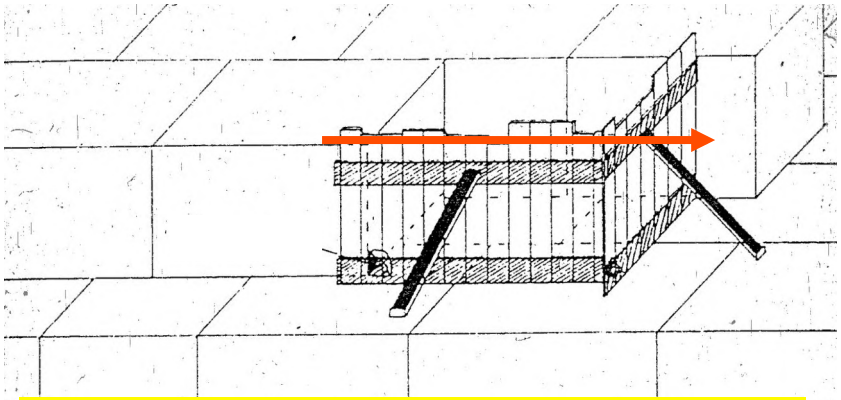
Khufu sample

How to distinguish natural stone from man made concrete ?


Counts
Measurements at CEDAD – March 2007
Khufu Gallery
Khufu outside
S
Ar
Cl
Ca
Ti
Mn
Fe
Sr
Cl
Ar
Ca
Fe
100000
10000
1000
100
10
1
10000
1000
100
10
0
2
4
6
8
10
12
14
16
18
Energy (keV)

Model of construction

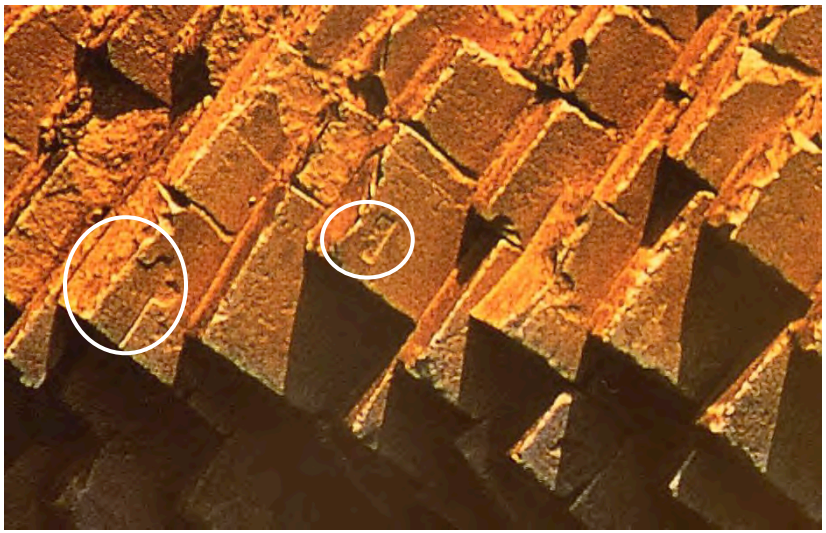
Mould model of Demortier
Guy (physicist) and Benoit (architect)



Herodotus description : When the base had been built, the rest of stones was raised by means of machines fabricated with **short** wooden pieces …

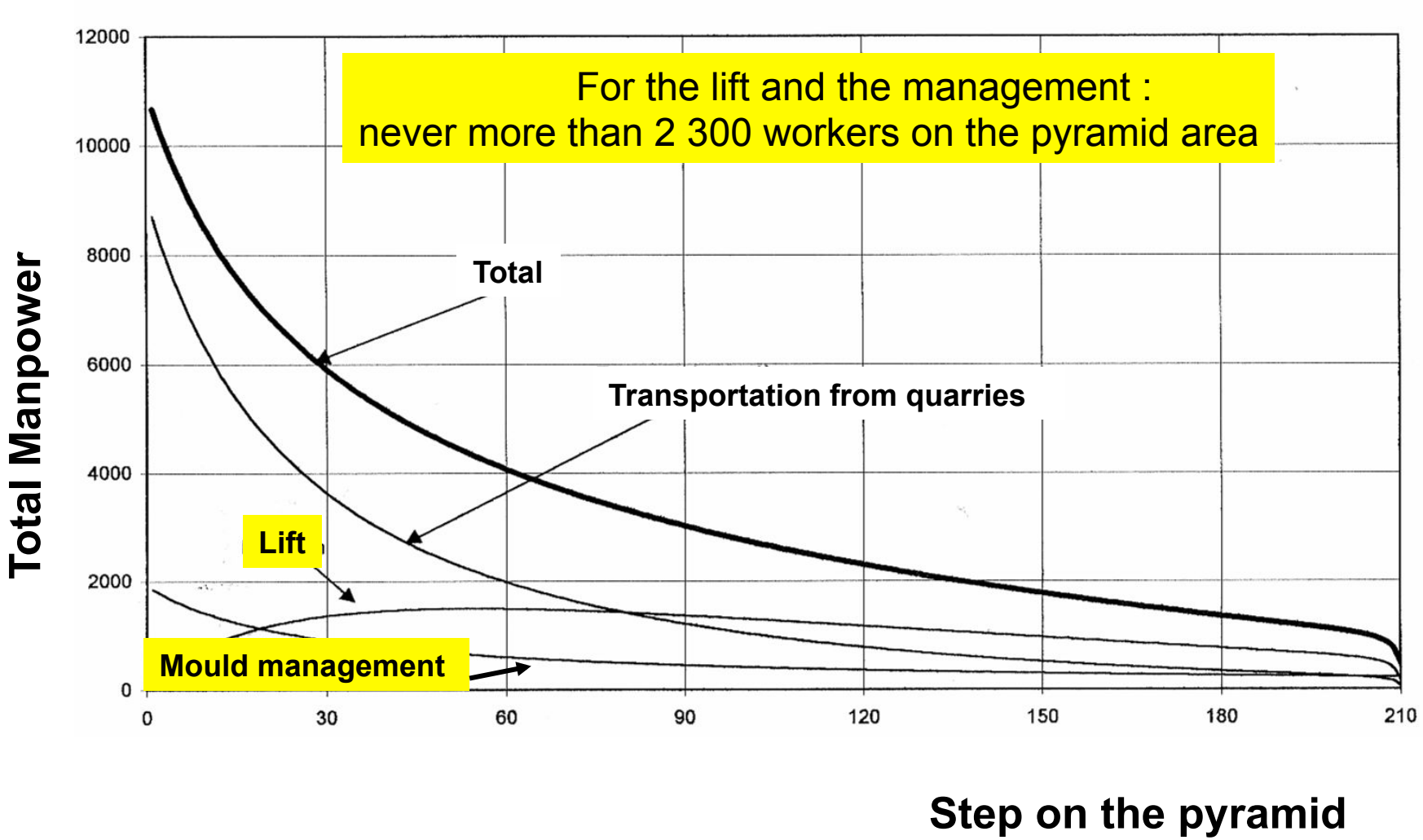
1. Daily, 6 workers transport 1m^3 of limestone fragments from quarries to the pyramid site.
2. One man stands on each level to lift, in one minute, 40 kg of material (limestone, water, natron, Nile silt,…) to the next higher step (maximum one meter high).
3. At the highest reached level one worker pours the material in a container (not the mould).
4. At this level 2 workers select the aggregates to make the appropriate mixture (right size and proportion) and pour the ingredients in the mould.

Top of Khufu's pyramid



Recent reproduction by the Davidovits group

Building site occupation



Fast checking :

30 years x 300 days then 9 000 working days
ou 90 000 hours.

These 90 000 hours concern only work
performed by 1000 workers in charge of the lifting of materials,
Therefore, these **90 000 000 hours** performed by 1000 workers
are used to lift **95 545 218 m^3** one **meter** upwards.

$$\left(\frac{231}{146}\right)^2 \cdot \int_0^{146} (146-x)^2 \, x \, dx \quad = \quad 95545218 \, m^3 m$$

Each worker lifts about 1 m^3 of material
per hour **from one step to the next one upwards.**
With a specific weight of 2 000 kg /m^3 :
2 000 kg /60 minutes = 33.33 kg per minute,

In addition 1300 other workers are present
on the whole surface of the construction for different tasks :
horizontal transportation, watch of waterproof of the moulds,
various additional maintenance, take a rest, exchange of task.

Additional measurements

2002

Guy Demortier Joseph Davidovits Michel Barsoum Gilles Hug

ABSTRACT

How the Great Pyramids of Giza were built has remained an enduring mystery. In the mid-1980s, Davidovits proposed that the pyramids were cast *in situ* using granular limestone aggregate and an alkali alumino-silicate-based binder. Hard evidence for this idea, however, remained elusive. Using primarily scanning and transmission electron microscopy, we compared a number of pyramid limestone samples with six different limestone samples from their vicinity. The pyramid samples contained microconstituents (μc's) with appreciable amounts of Si in combination with elements, such as Ca and Mg, in ratios that do not exist in any of the potential limestone sources. The intimate proximity of the μc's suggests that at some time these elements had been together in a solution. Furthermore, between the natural limestone aggregates, the μc's with chemistries reminiscent of calcite and dolomite—not known to hydrate in nature—were hydrated. The ubiquity of Si and the presence of submicron silica-based spheres in some of the micrographs strongly suggest that the solution was basic. Transmission electron microscope confirmed that some of these Si-containing μc's were either amorphous or nanocrystalline, which is consistent with a relatively rapid precipitation reaction. The sophistication and endurance of this ancient concrete technology is simply astounding.

ABSTRACT

J. Amer. Ceram. Soc. (Barsoum, Ganguly, Hug) December 1, 2006

The Boston Globe

On April 2, 2008, an announcement proves once again that the cement pyramid theory is not going away. Linn Hobbs and his class at **MIT University** are going to test the theory in another way, they'll be building a 'Mini Great Pyramid':

"In fact, the very idea has been so controversial that "you can't get research funding, and it's difficult to get a paper through peer review," says Linn Hobbs, professor of materials science and engineering and professor of nuclear science and engineering at MIT and coteacher of the pyramid-building class.

Students work with materials science and nuclear engineering professor Linn Hobbs to cover limestone blocks with mortar

Hobbs says that actually building a small-scale model of the pyramid using the materials and methods the Egyptians may have used is far more than just an educational exercise for the students. "Like any other investigation of ancient technologies, you can only get so far by speculating, and even only so far by looking at evidence.

The Boston Globe

Linn Hobbs working with his students

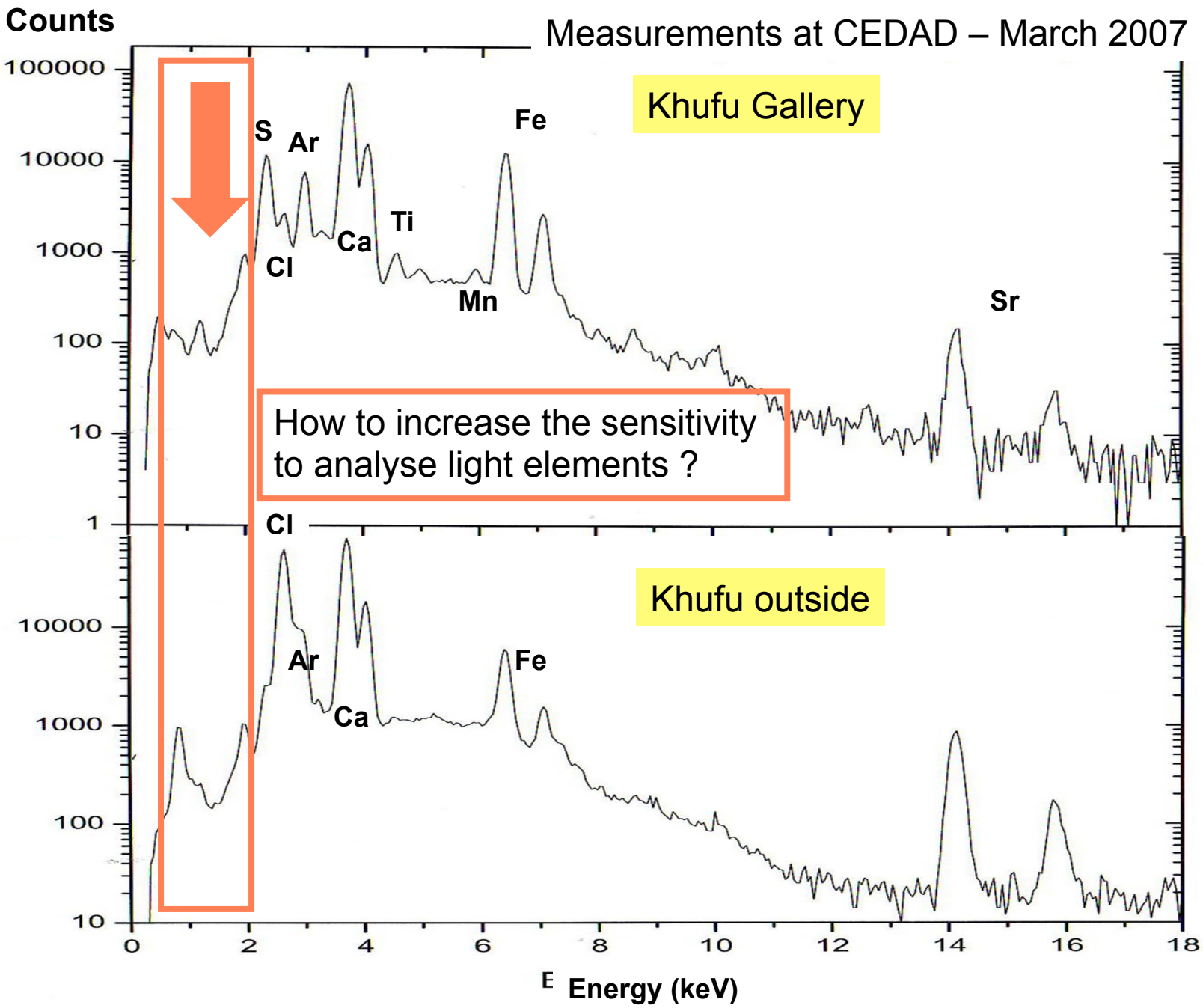
Next presentation

Dr. Igor Túnyi from Geophysical Institute SAS – Bratislava (Slovak Republic) and **Ibrahim A. El-hemaly** from National Research Institute of Astronomy and Geophysics – Cairo, Egypt **"Europhysics News",, (2012), Vol. 43, number 6**

Our paleomagnetic investigation of the two great Egyptian pyramids, Kufu and Khafre, is based on the assumption that if the blocks were made in situ by the geopolymer concrete technique described above, then their magnetic moments would all have been parallel, oriented approximately in the north-south direction. However, if the pyramids were constructed from blocks transported from the nearby quarries, having been rotated randomly during transport and construction, then the directions of their magnetic moments would be oriented randomly.

The aim of paleomagnetic investigation of the rock material of the great Egyptian pyramids, Khufu and Khafre, was to find out the directions of the magnetic polarization vectors of their building blocks. This is one of the possible ways to verify the hypothesis according to which the blocks were produced in situ by a concrete technique. The analysis of a limited set of paleomagnetic samples provided the following results. The paleodirections of three sampling locations (2 from Khafre and 1 from Khufu pyramid) exhibit the common north-south orientation, suggesting that they may have been produced in situ by a concrete technique. The block from one sampling location of the Khafre pyramid is of natural limestone and evidently comes from the adjacent quarry. It is likely that the block from one sampling position of the Khufu pyramid comes also from the same quarry. Finally, we conclude that even if the geopolymer concrete technique was used, the pyramids were constructed from a mixture of natural and artificial limestone blocks.

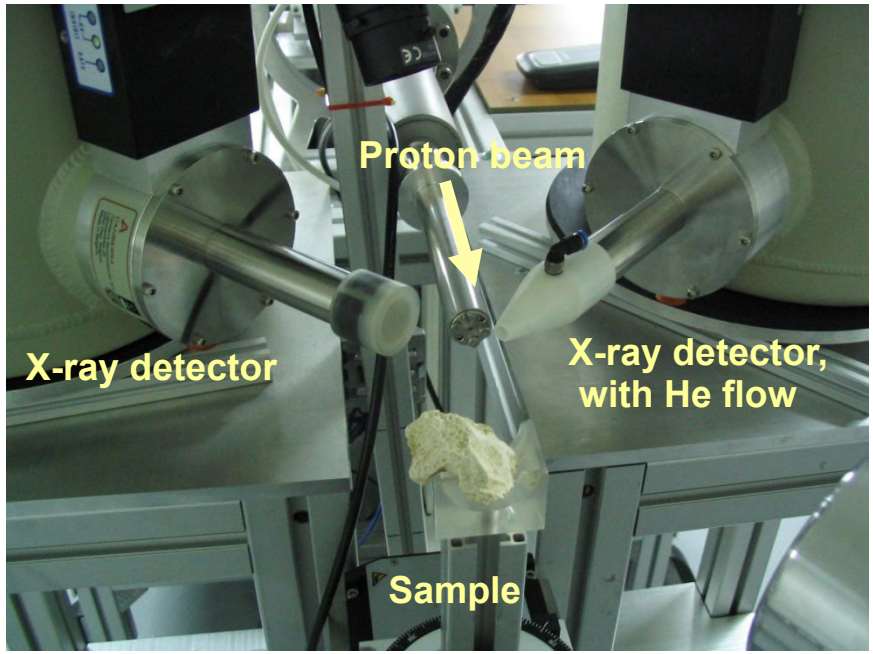
Is the material of the pyramids
similar to that of the limestone quarries ?


Counts
Measurements at CEDAD – March 2007
Khufu Gallery
S
Ar
Ca
Ti
Cl
Mn
Fe
Sr
How to increase the sensitivity
to analyse light elements ?
Cl
Khufu outside
Ar
Ca
Fe
100000
10000
1000
100
10
1
0
2
4
6
8
10
12
14
16
18
E Energy (keV)

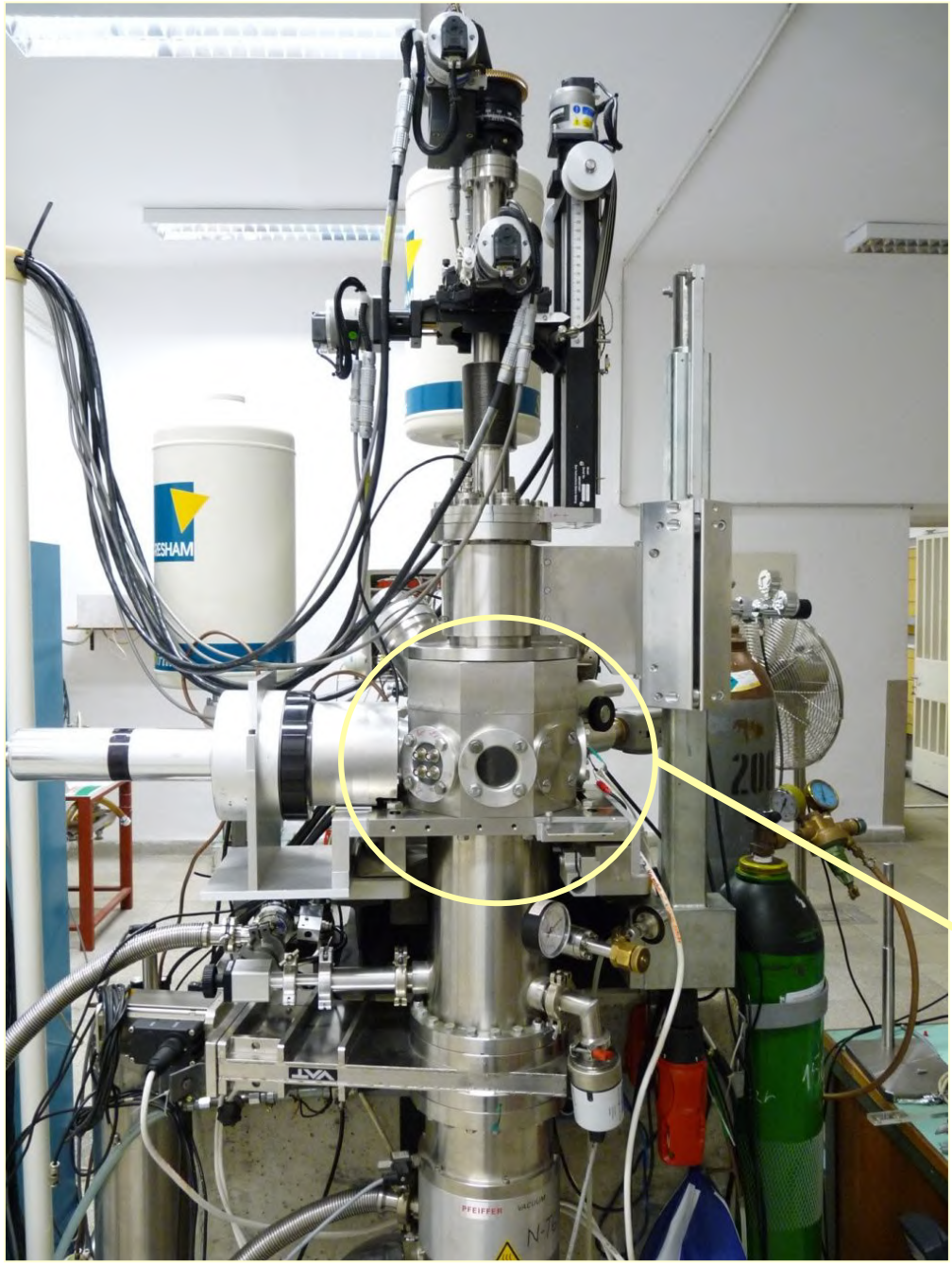
The limitation arises from the absorption of low energy X-rays of the ligth elements by the air **(or even helium)** present between the irradiated surface and the detector.

The solution is to irradiate the samples inside vacuum.

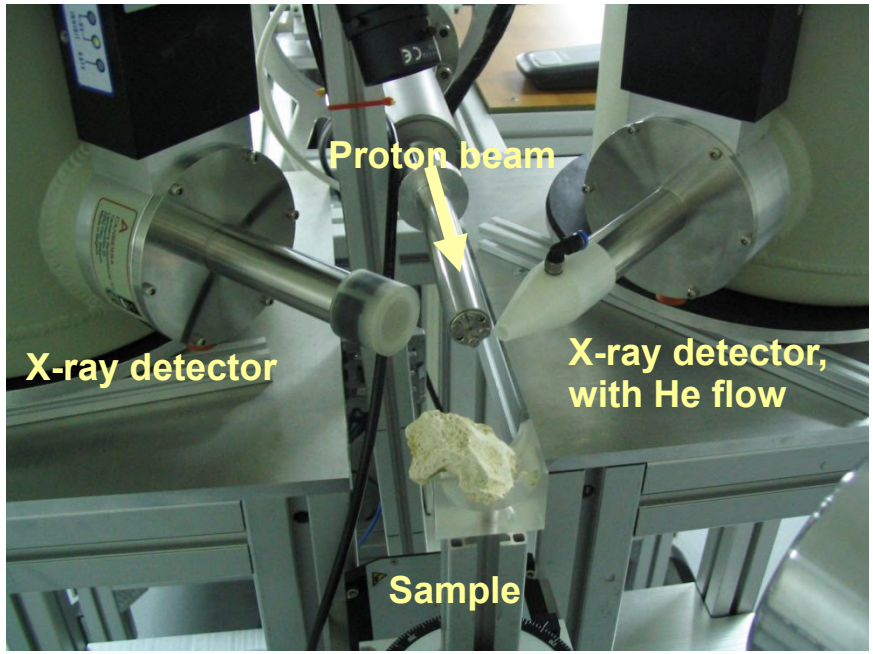
Set up for PIXE outside vacuum



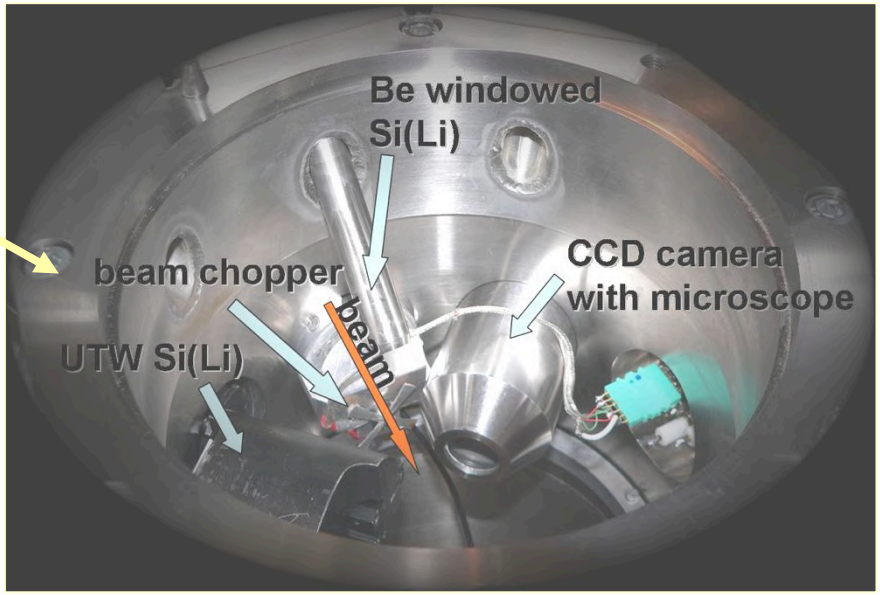
The nuclear microprobe of Atomki (Debrecen)



Set up for PIXE outside vacuum



Set up for micro- PIXE (in vacuum)



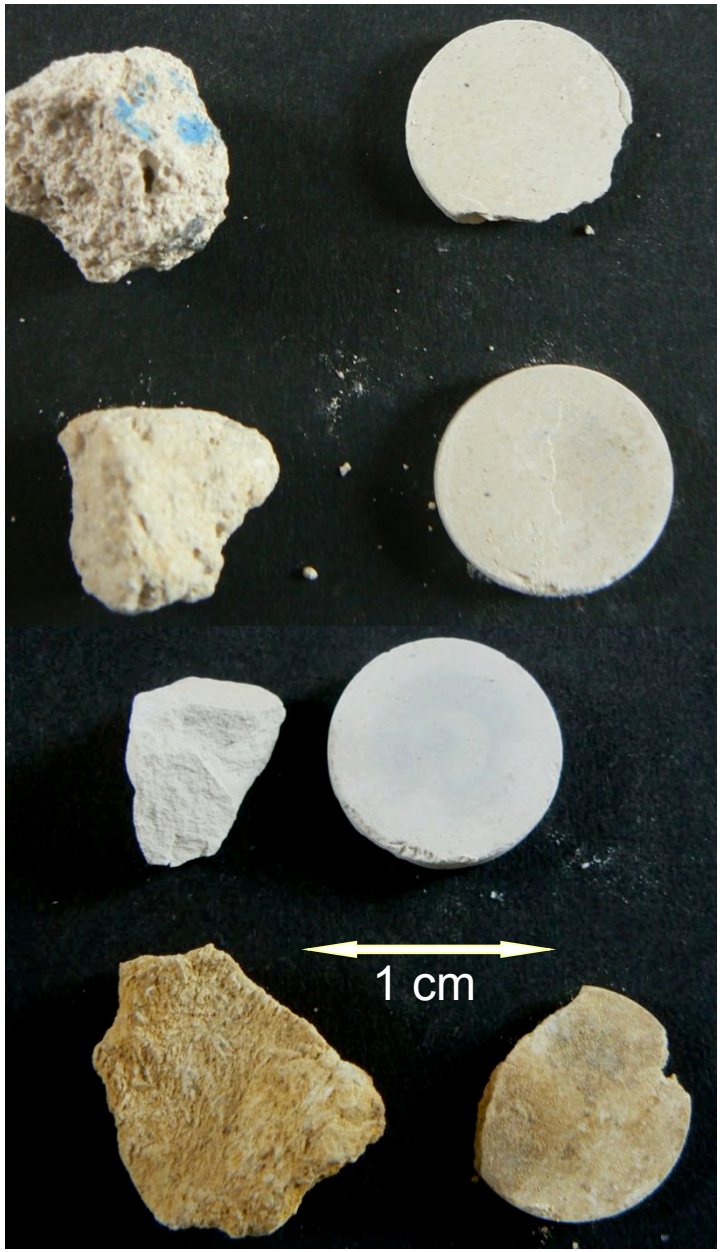
Microprobe features:

Incident proton energy ; 2.5MeV
Beam current : 100 pA
Beam spot : 3 μm

- Analysed elements:
  from 12(C) to 238 (U)
- K, L, M characteristic X-ray lines are used in the calculations.
- Peak shape correction, escape peak, pile-up, background subtraction
- Quantification method:
  - Fundamental parameters
  - Some standard(s) needed for calibration and test of spatial resolution (NIST610 glass CRM)
  - Accuracy:
    ~2-5%, (major) ~10-20 % (traces)

SAMPLES

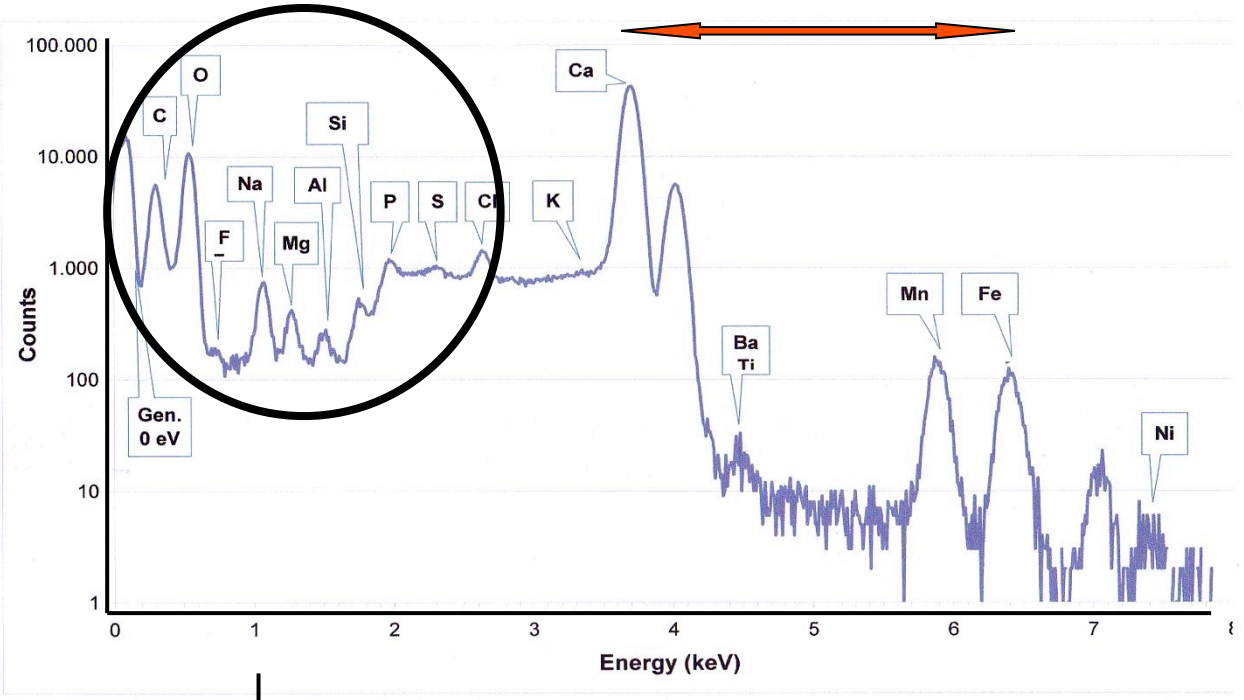
pebble pellet



Sample VTRS (Khufu outside block)

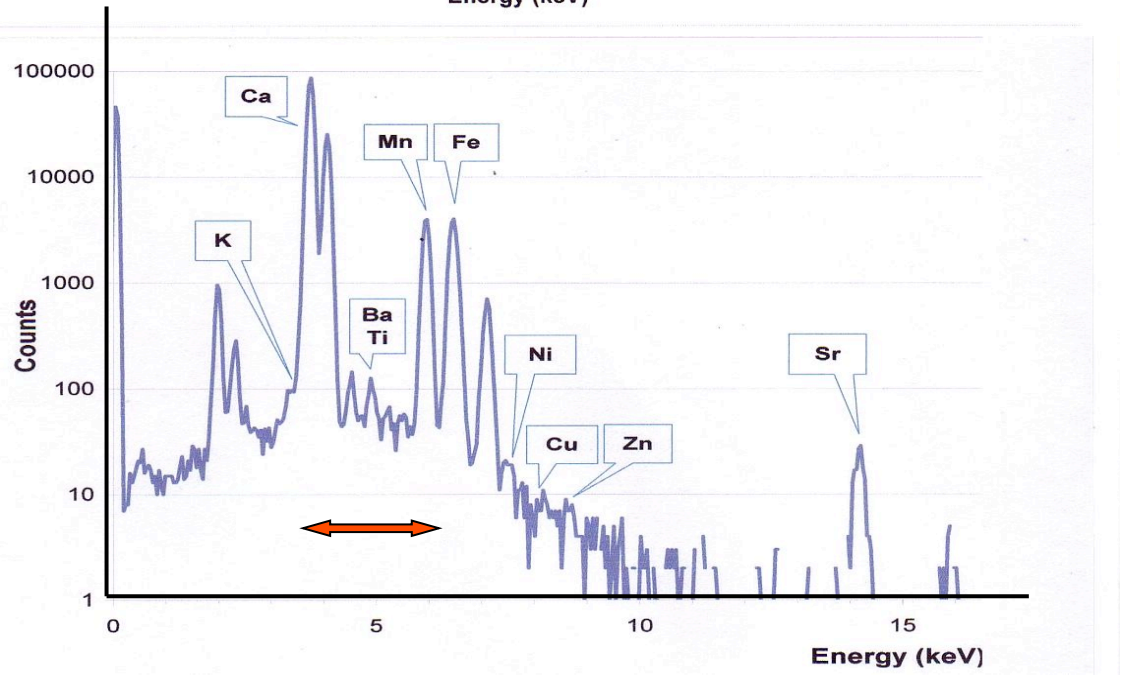
PIXE spectrum :
Low energy x-rays

Thin SUTWindow and permanent magnet, for the analysis of all the elements from C to Fe



PIXE spectrum :
Medium energy x-rays

Be window and kapton filter for the analysis of all the elements from Ca to Sr

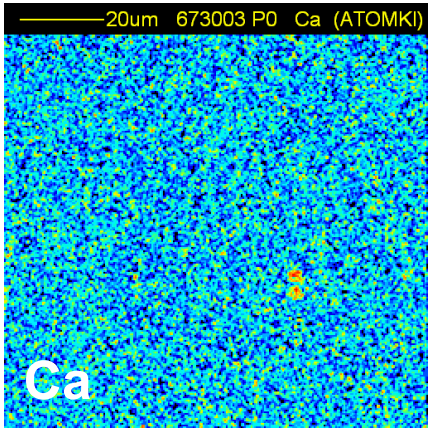


Both spectra are simultaneously collected and the data from the elements from Ca to Fe are compared for compatibility reasons

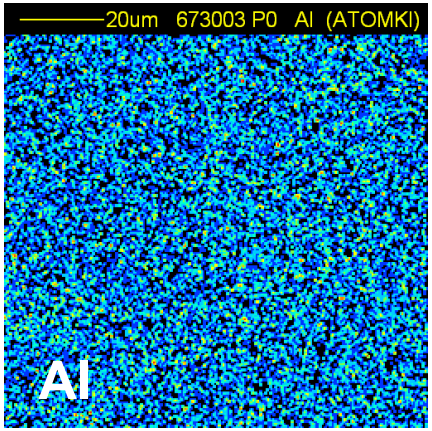
100 µm

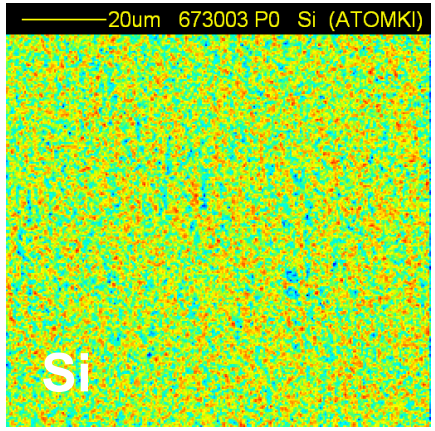
pellet

NIST 610

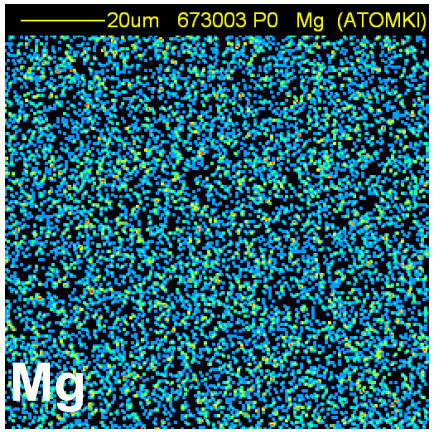


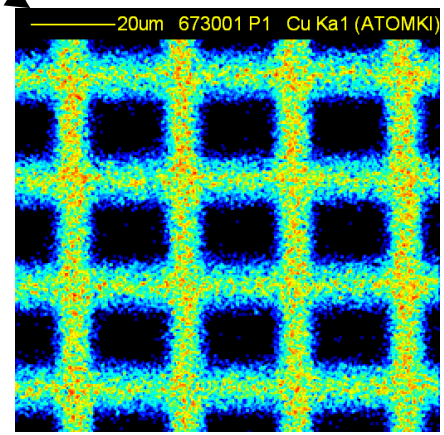
Copper grid to check the spatial resolution : about 2.5µm

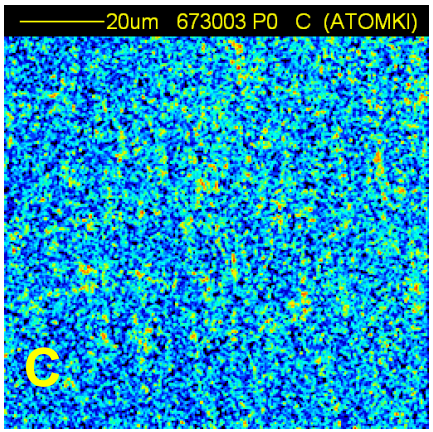


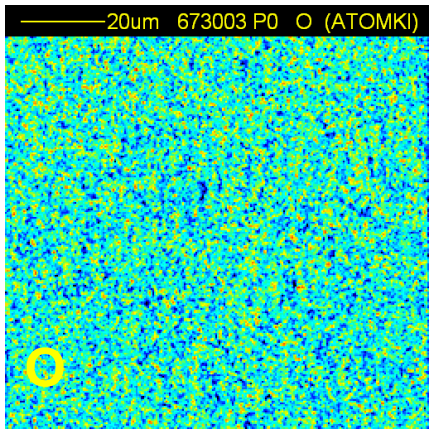


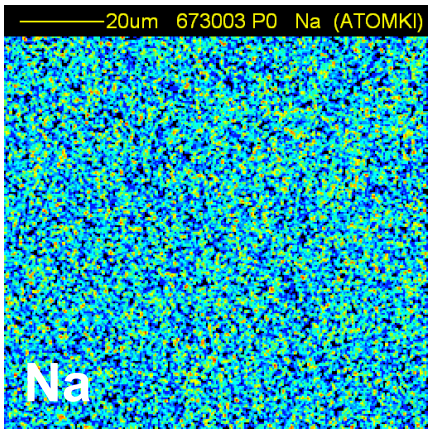
Glass reference material: (to check the homogeneity of the scanning with the microprobe)

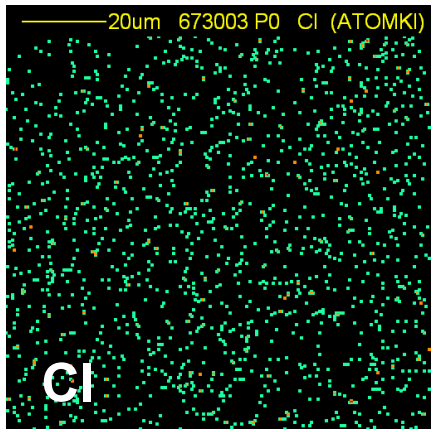


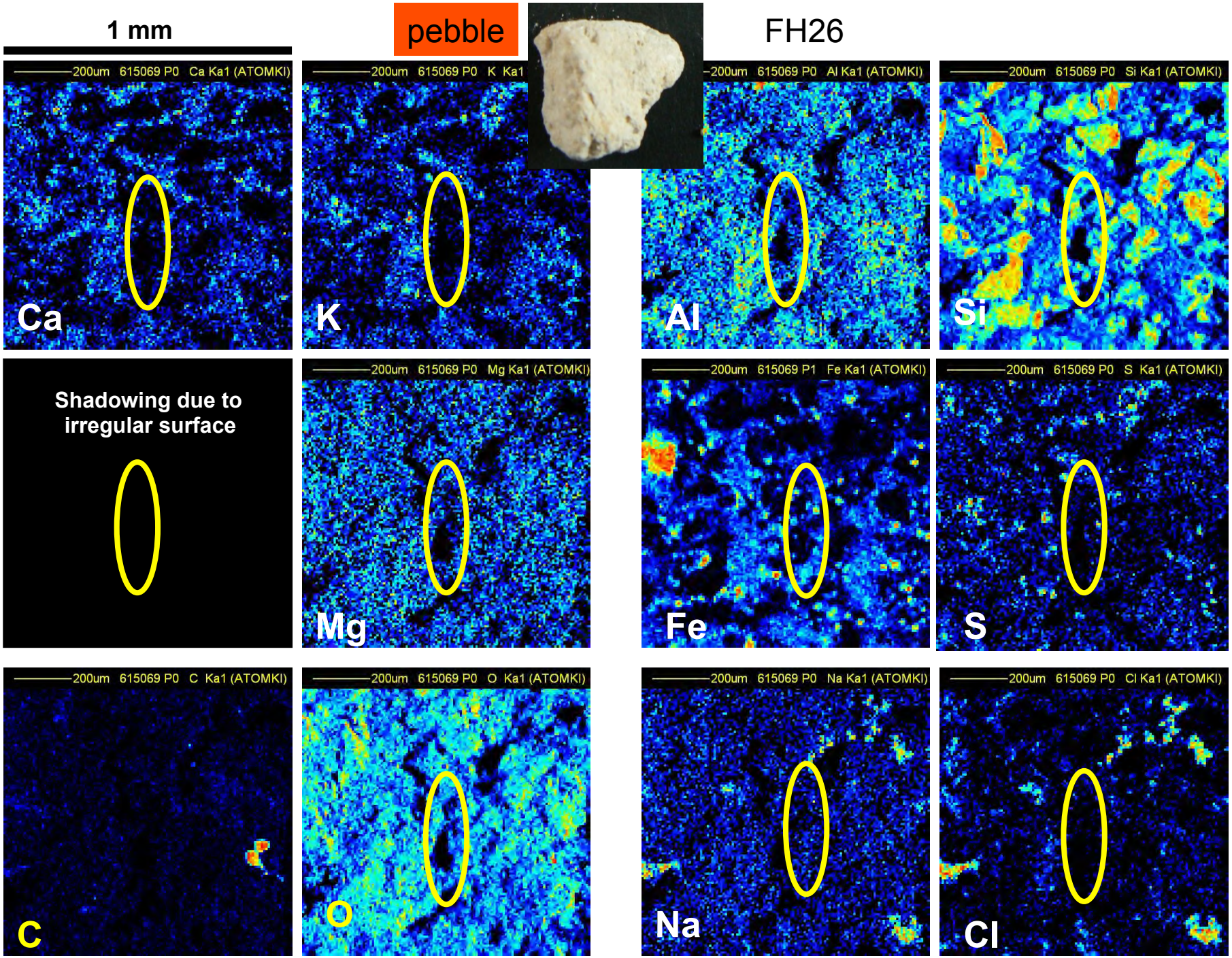








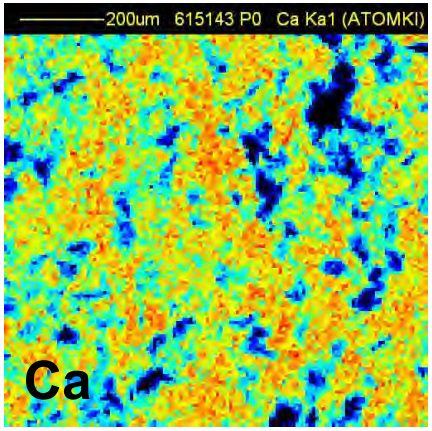


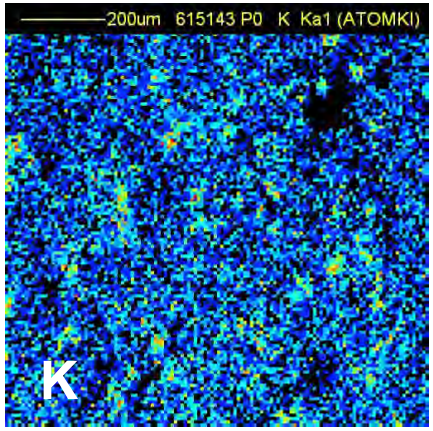

1 mm
pebble
FH26
200um 615069 P0 Ca Ka1 (ATOMKI)
Ca
200um 615069 P0 K Ka1
K
200um 615069 P0 Al Ka1 (ATOMKI)
Al
200um 615069 P0 Si Ka1 (ATOMKI)
Si
Shadowing due to irregular surface
200um 615069 P0 Mg Ka1 (ATOMKI)
Mg
200um 615069 P1 Fe Ka1 (ATOMKI)
Fe
200um 615069 P0 S Ka1 (ATOMKI)
S
200um 615069 P0 C Ka1 (ATOMKI)
C
200um 615069 P0 O Ka1 (ATOMKI)
O
200um 615069 P0 Na Ka1 (ATOMKI)
Na
200um 615069 P0 Cl Ka1 (ATOMKI)
Cl

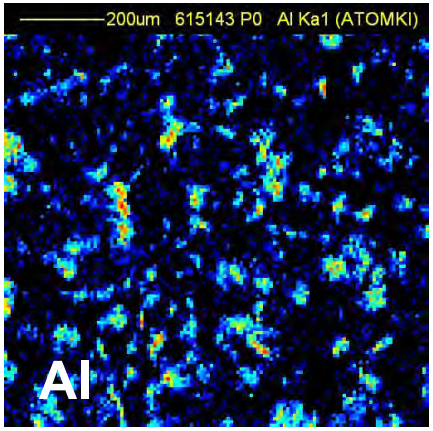
1 mm

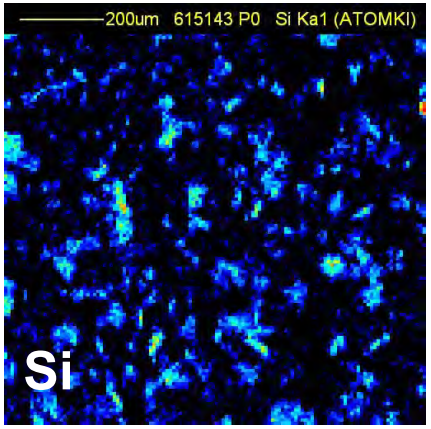
pellet

Limestone Hungary

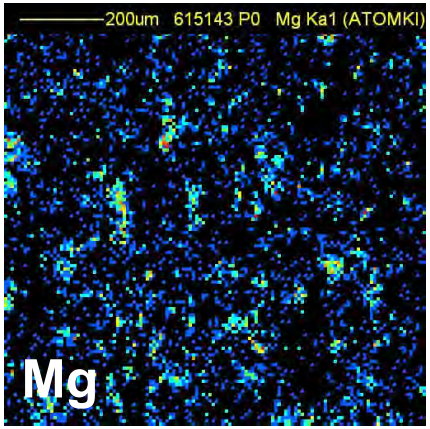


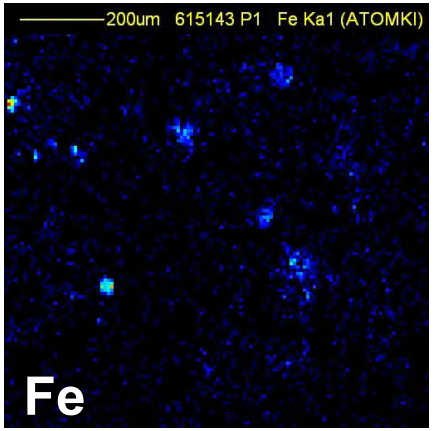


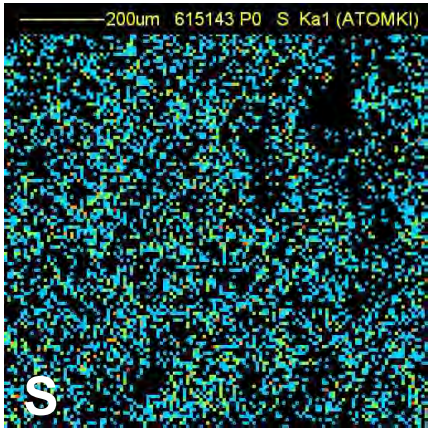


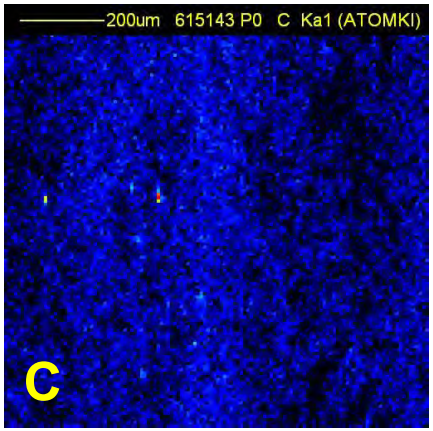


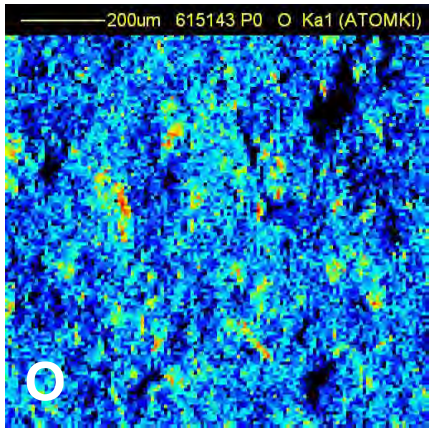
$CaCO_3$	86.05
Na	< 0.09
Cl	< 0.2
MgO	0.75
Al_2O_3	4.0
SiO_2	8.0
K_2O	0.9

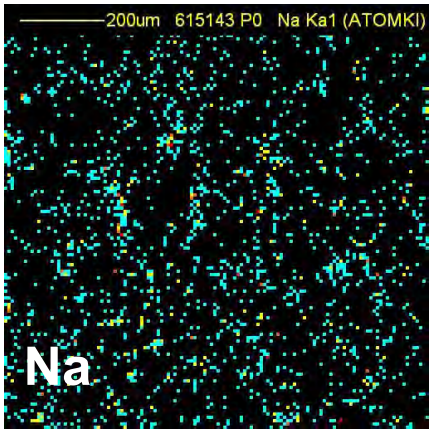


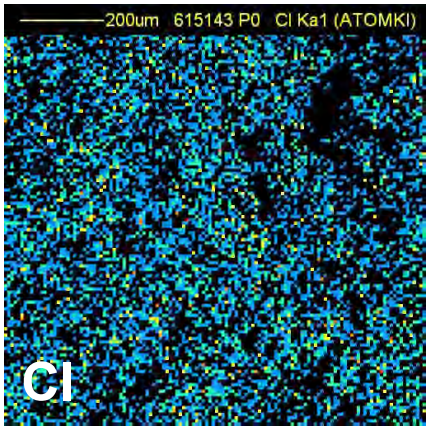


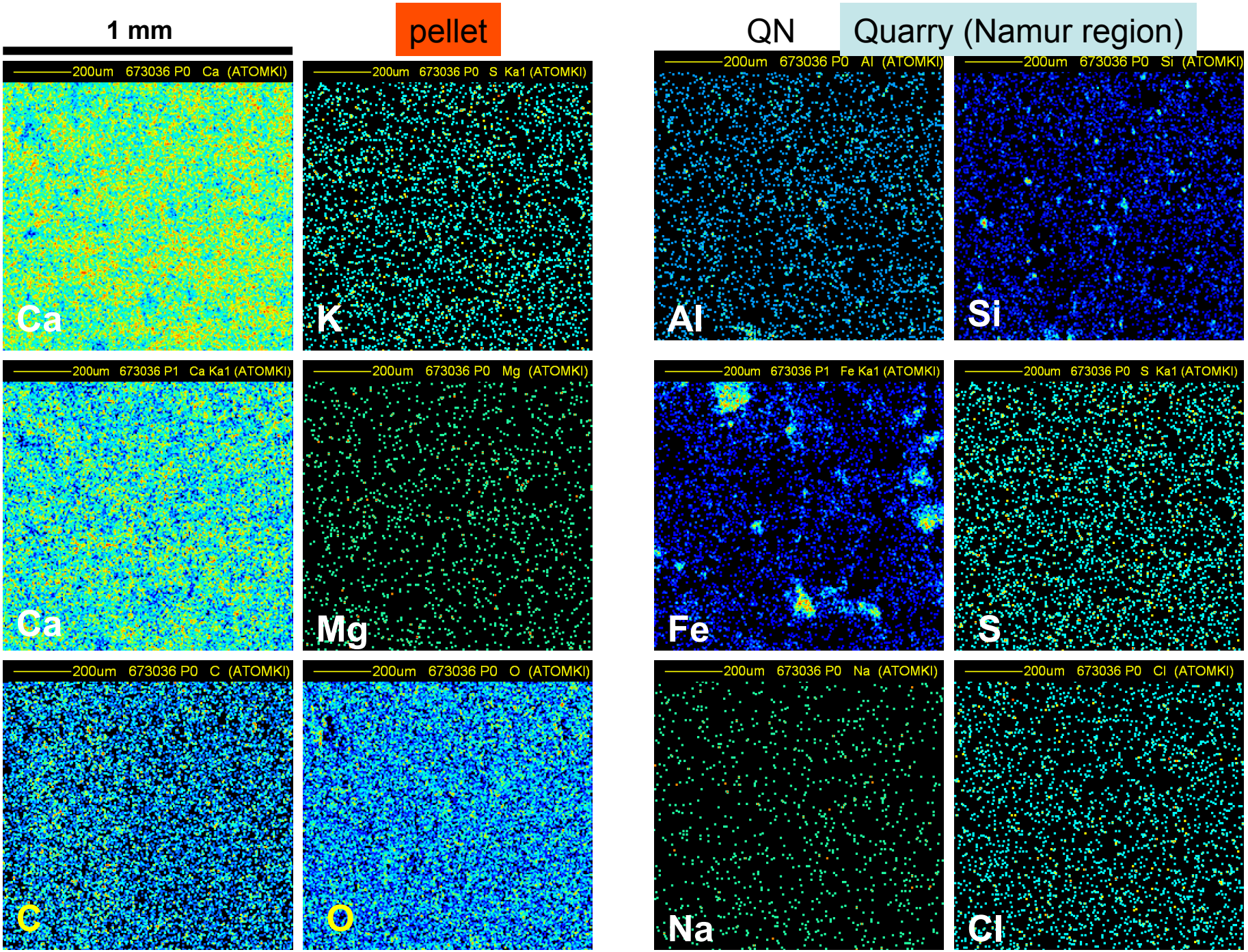


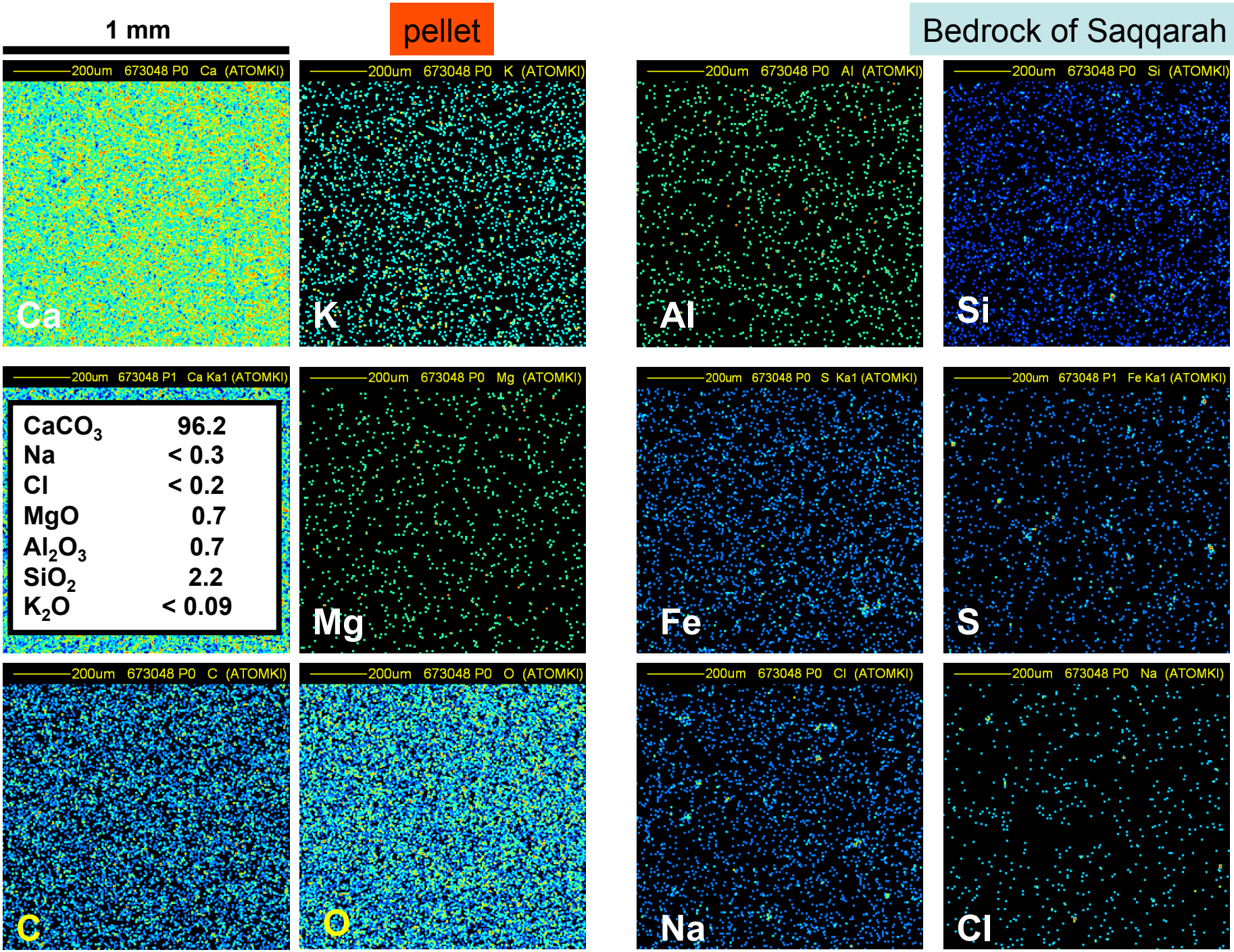


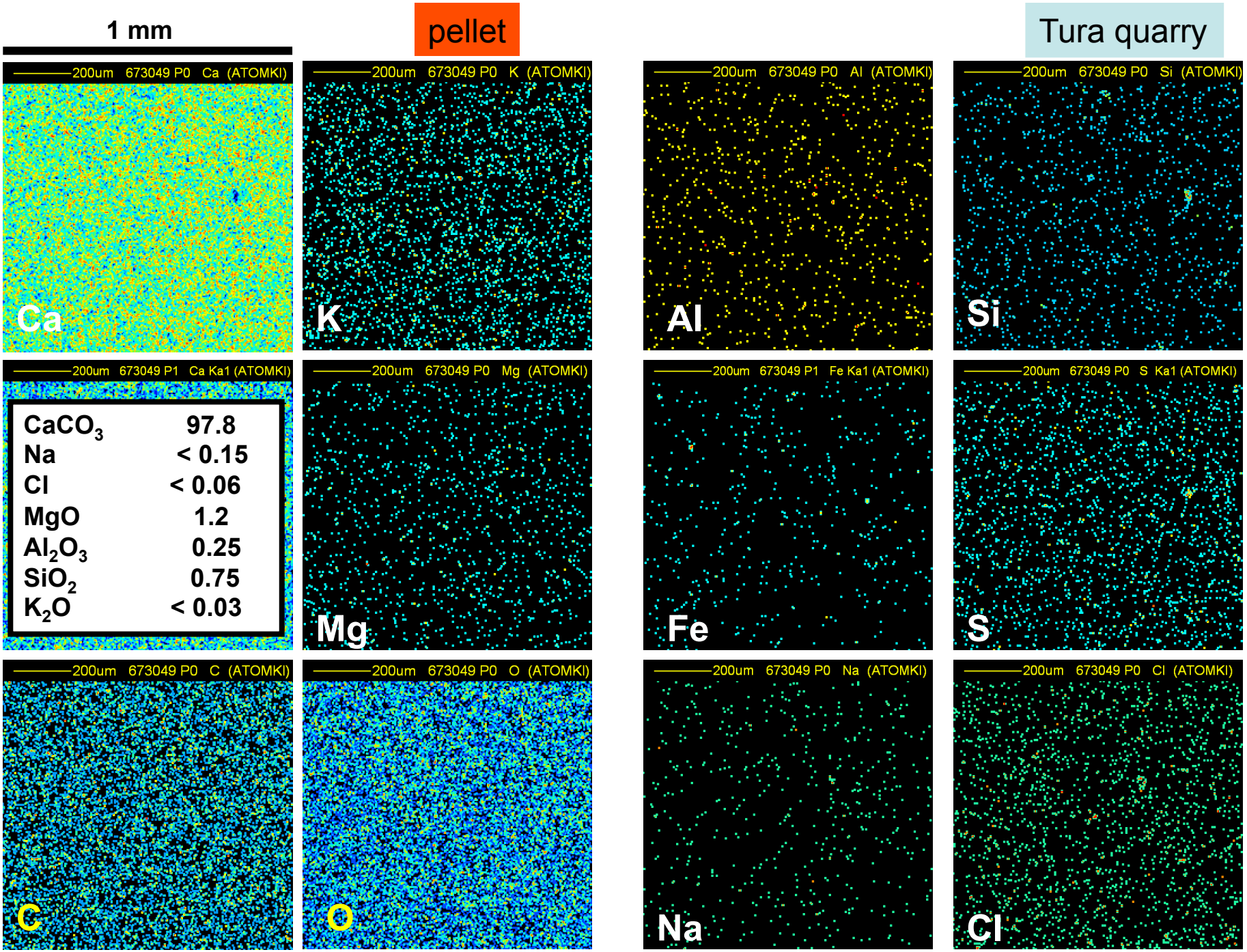


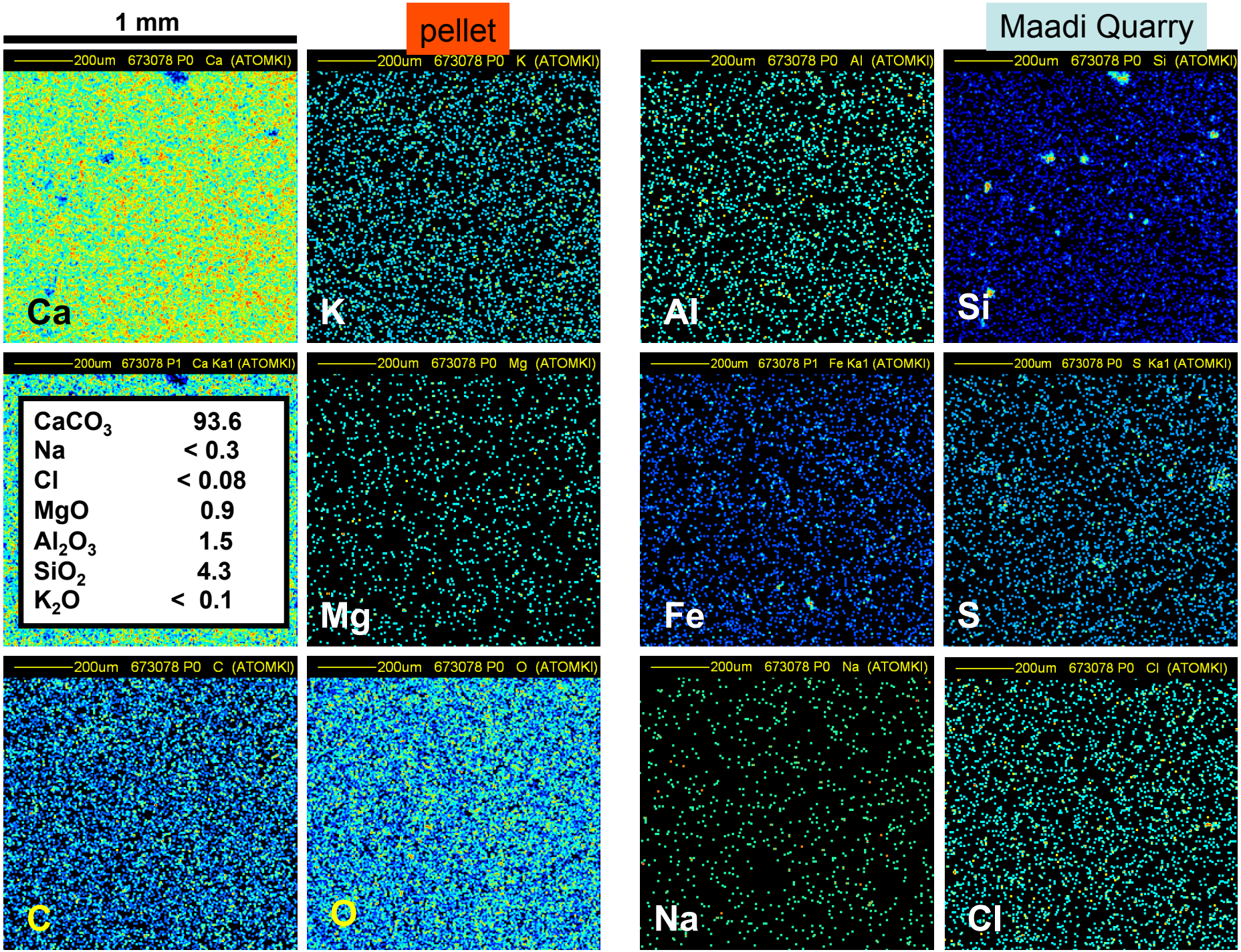





1 mm
pellet
QN
Quarry (Namur region)
200um 673036 P0 Ca (ATOMKI)
Ca
200um 673036 P0 S Ka1 (ATOMKI)
K
200um 673036 P0 Al (ATOMKI)
Al
200um 673036 P0 Si (ATOMKI)
Si
200um 673036 P1 Ca Ka1 (ATOMKI)
Ca
200um 673036 P0 Mg (ATOMKI)
Mg
200um 673036 P1 Fe Ka1 (ATOMKI)
Fe
200um 673036 P0 S Ka1 (ATOMKI)
S
200um 673036 P0 C (ATOMKI)
C
200um 673036 P0 O (ATOMKI)
O
200um 673036 P0 Na (ATOMKI)
Na
200um 673036 P0 Cl (ATOMKI)
Cl


1 mm
pellet
Bedrock of Saqqarah
200um 673048 P0 Ca (ATOMKI)
Ca
200um 673048 P0 K (ATOMKI)
K
200um 673048 P0 Al (ATOMKI)
Al
200um 673048 P0 Si (ATOMKI)
Si
200um 673048 P1 Ca Ka1 (ATOMKI)
CaCO3 96.2
Na < 0.3
Cl < 0.2
MgO 0.7
Al2O3 0.7
SiO2 2.2
K2O < 0.09
200um 673048 P0 Mg (ATOMKI)
Mg
200um 673048 P0 S Ka1 (ATOMKI)
Fe
200um 673048 P1 Fe Ka1 (ATOMKI)
S
200um 673048 P0 C (ATOMKI)
C
200um 673048 P0 O (ATOMKI)
O
200um 673048 P0 Cl (ATOMKI)
Na
200um 673048 P0 Na (ATOMKI)
Cl

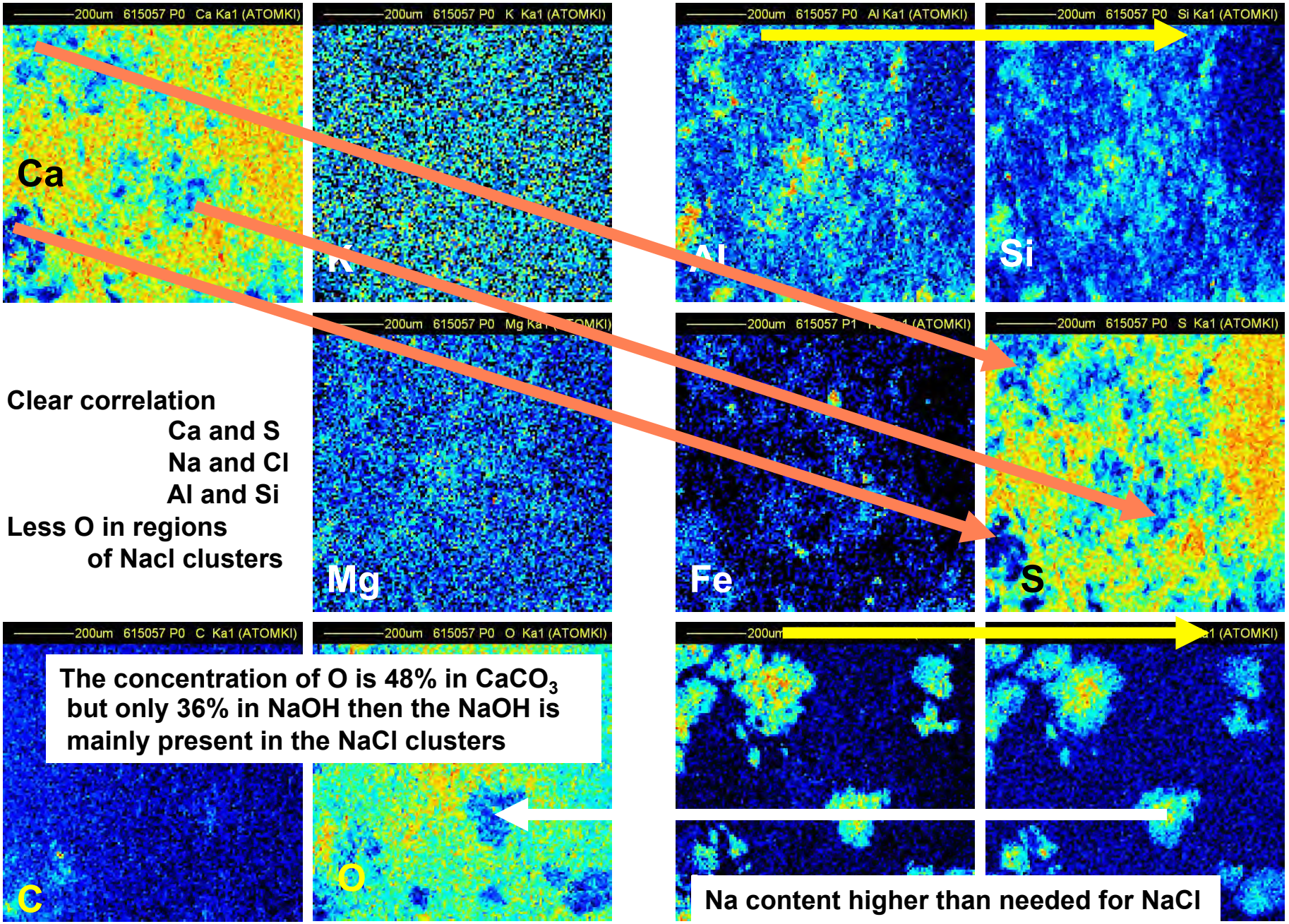

1 mm
pellet
Tura quarry
200um 673049 P0 Ca (ATOMKI)
Ca
200um 673049 P0 K (ATOMKI)
K
200um 673049 P0 Al (ATOMKI)
Al
200um 673049 P0 Si (ATOMKI)
Si
200um 673049 P1 Ca Ka1 (ATOMKI)
CaCO3 97.8
Na < 0.15
Cl < 0.06
MgO 1.2
Al2O3 0.25
SiO2 0.75
K2O < 0.03
200um 673049 P0 Mg (ATOMKI)
Mg
200um 673049 P1 Fe Ka1 (ATOMKI)
Fe
200um 673049 P0 S Ka1 (ATOMKI)
S
200um 673049 P0 C (ATOMKI)
C
200um 673049 P0 O (ATOMKI)
O
200um 673049 P0 Na (ATOMKI)
Na
200um 673049 P0 Cl (ATOMKI)
Cl


1 mm
pellet
Maadi Quarry
200um 673078 P0 Ca (ATOMKI)
Ca
200um 673078 P0 K (ATOMKI)
K
200um 673078 P0 Al (ATOMKI)
Al
200um 673078 P0 Si (ATOMKI)
Si
200um 673078 P1 Ca Ka1 (ATOMKI)
CaCO3 93.6
Na < 0.3
Cl < 0.08
MgO 0.9
Al2O3 1.5
SiO2 4.3
K2O < 0.1
200um 673078 P0 Mg (ATOMKI)
Mg
200um 673078 P1 Fe Ka1 (ATOMKI)
Fe
200um 673078 P0 S Ka1 (ATOMKI)
S
200um 673078 P0 C (ATOMKI)
C
200um 673078 P0 O (ATOMKI)
O
200um 673078 P0 Na (ATOMKI)
Na
200um 673078 P0 Cl (ATOMKI)
Cl

1 mm

pellet

X1 Khufu (outside second step)



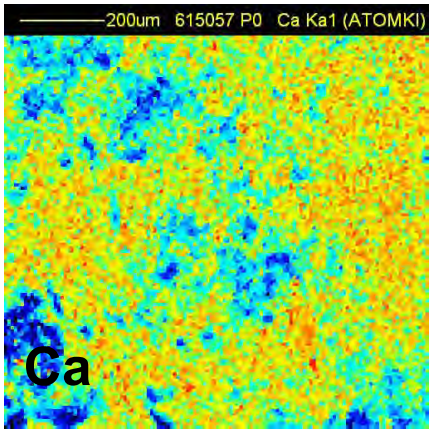
Clear correlation
Ca and S
Na and Cl
Al and Si
Less O in regions of Nacl clusters

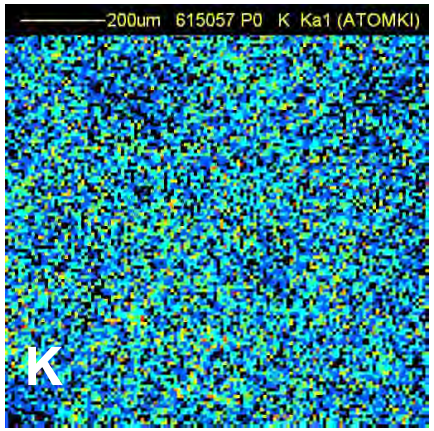
The concentration of O is 48% in $CaCO_3$ but only 36% in NaOH then the NaOH is mainly present in the NaCl clusters

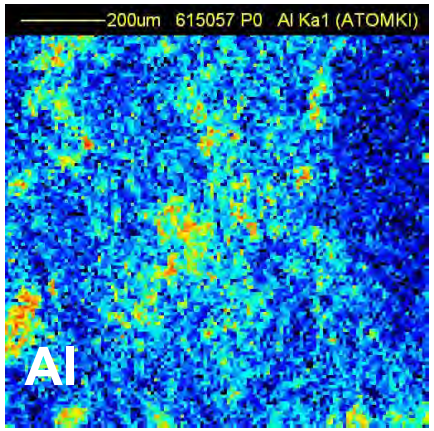
1 mm

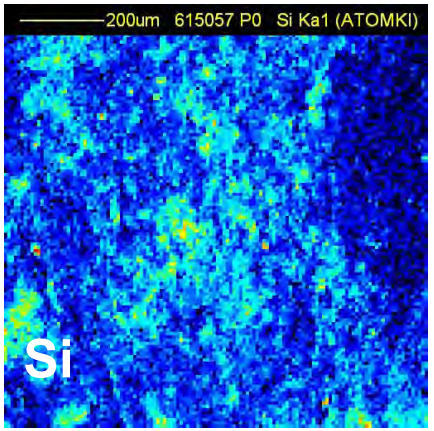
pellet

X1 Khufu (outside second step)

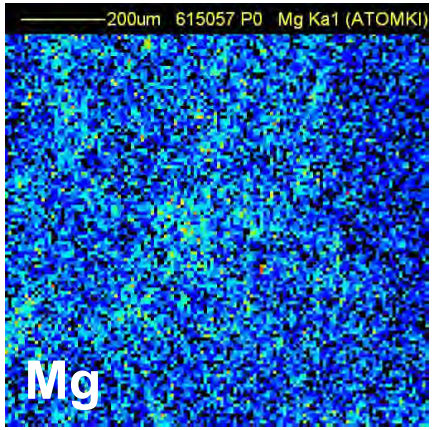


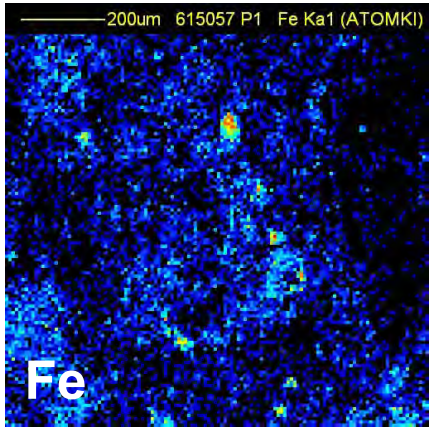


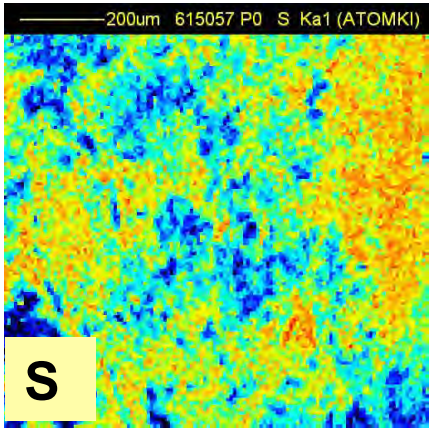


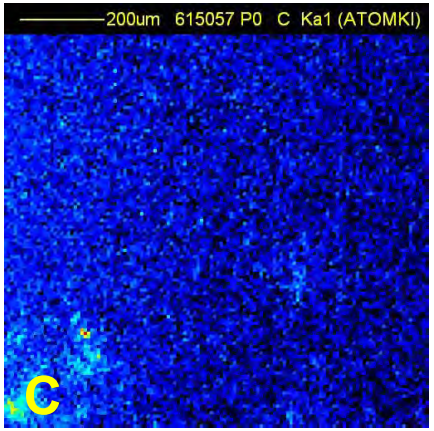


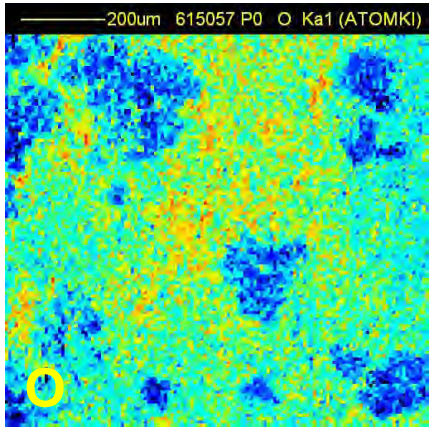
$CaCO_3$	2.5
NaCl	2.4
MgO	0.95
Al_2O_3	5.55
SiO_2	12.05
$CaSO_4.2H_2O$	73.45
K_2O	0.5
NaOH ??	2.6

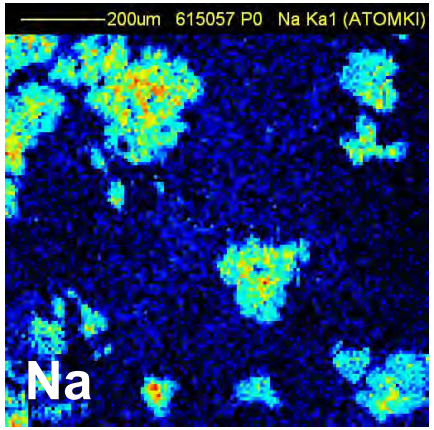


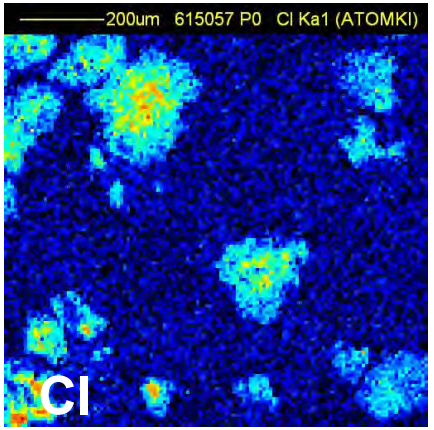










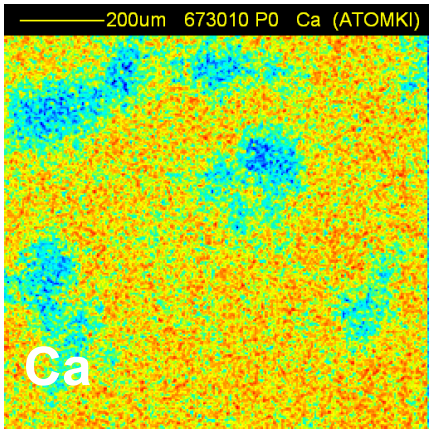


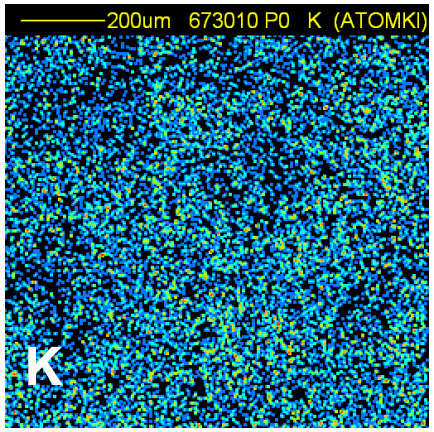
1 mm

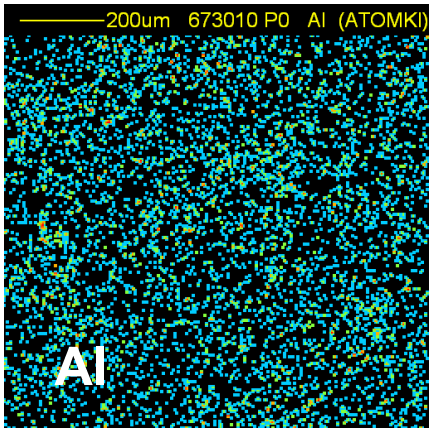
pellet

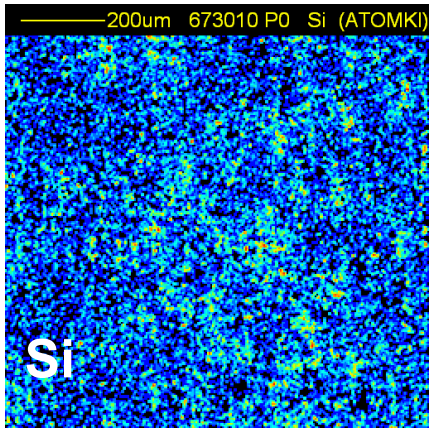
VTRS

Khufu (outside)

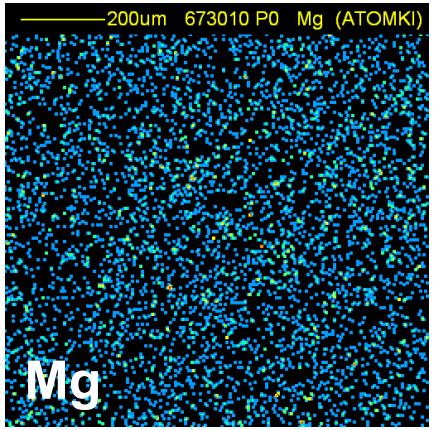


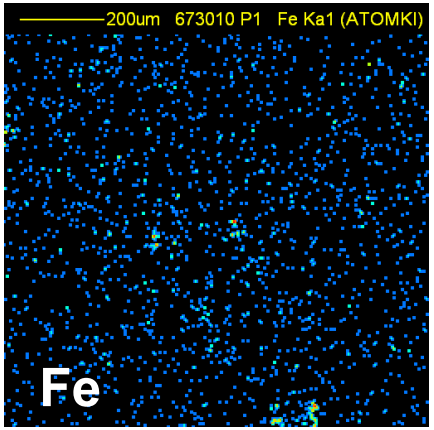


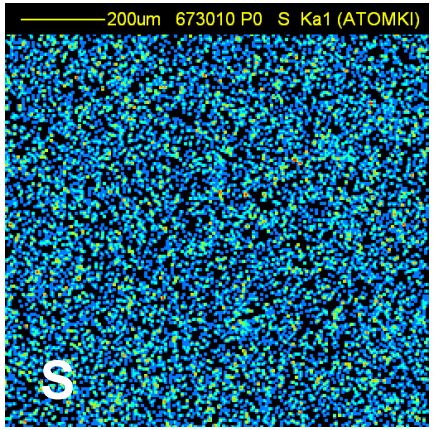


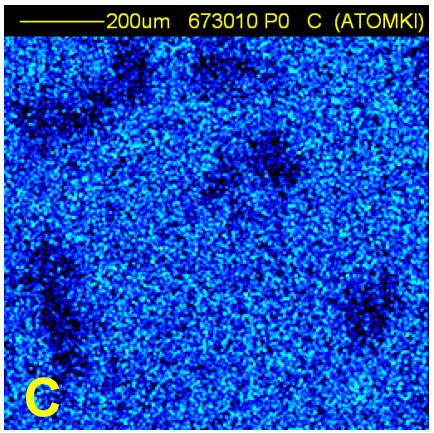


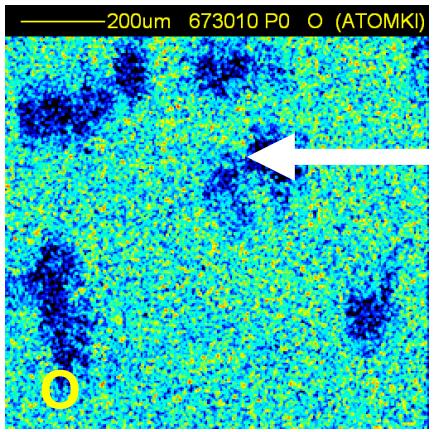
$CaCO_3$	88.0
NaCl	1.55
MgO	0.8
Al_2O_3	0.45
SiO_2	5.5
$CaSO_4.2H_2O$	0.35
K_2O	0.2
NaOH ??	3.15

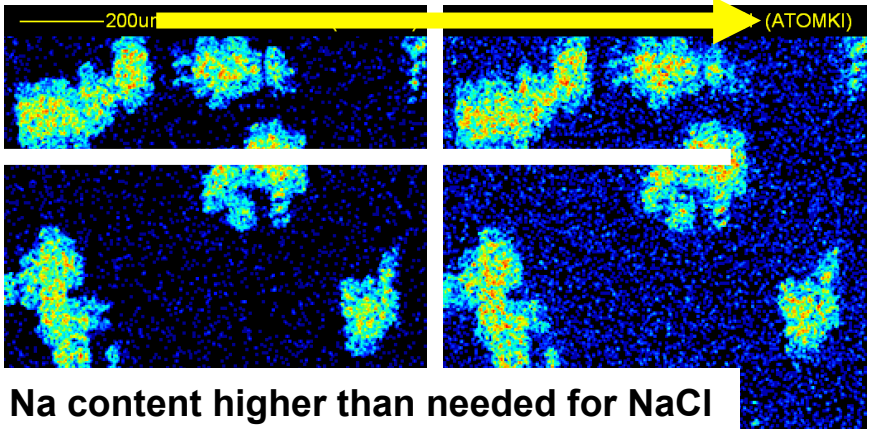












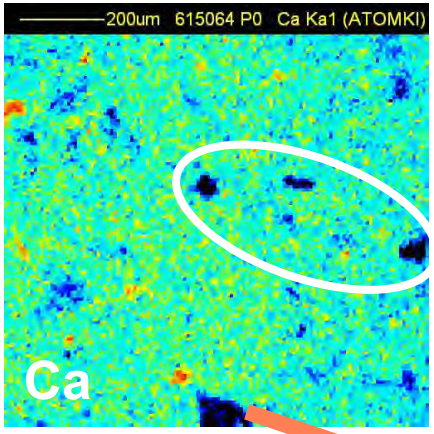
Na content higher than needed for NaCl

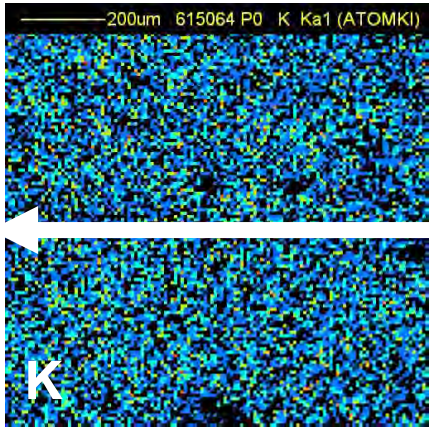
1 mm

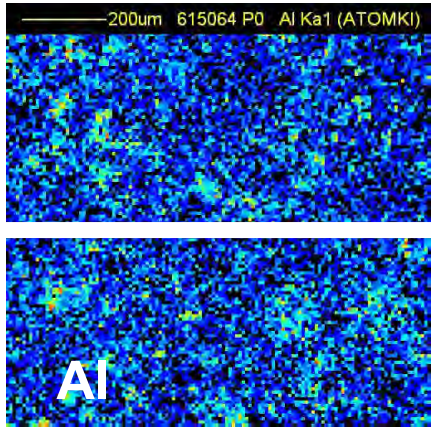
pellet

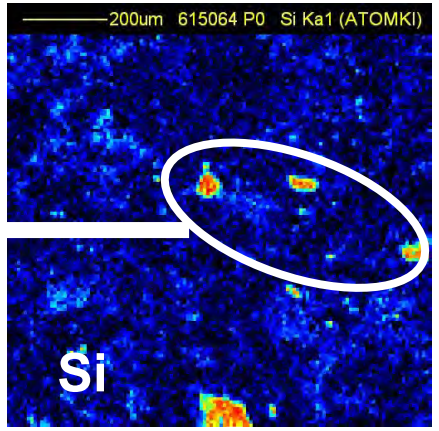
FH7

Khufu (inside great gallery)

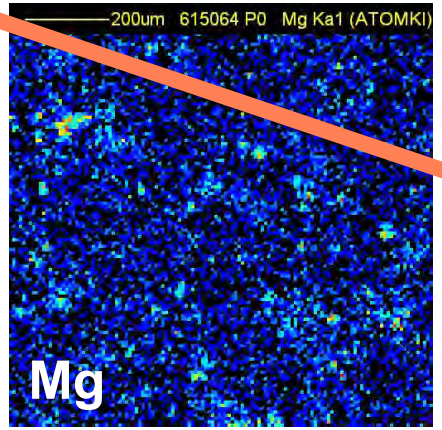


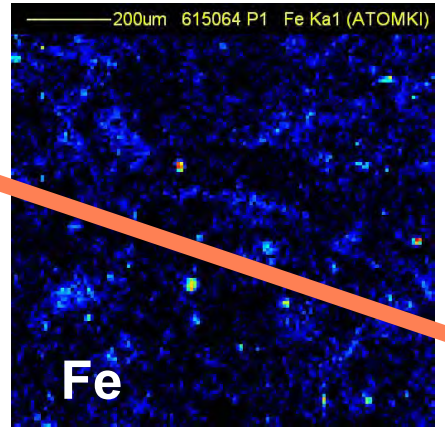


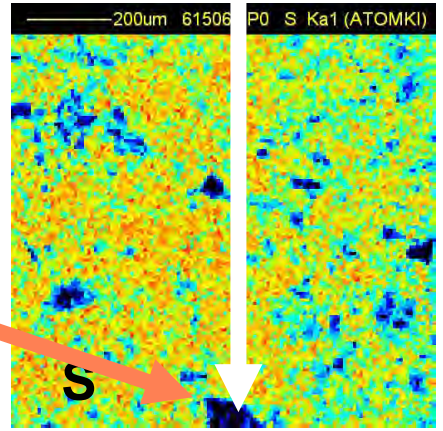


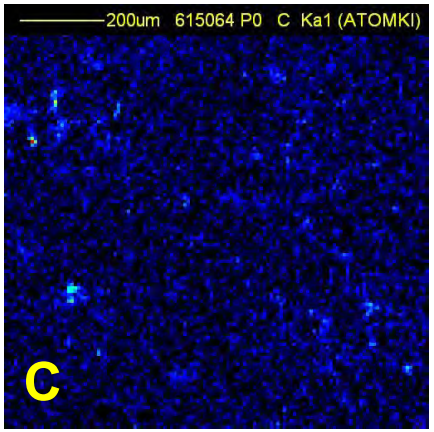


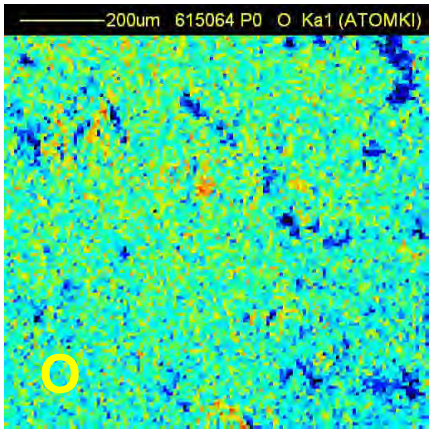
$CaCO_3$	7.6
NaCl	1.85
MgO	1.00
Al_2O_3	2.0
SiO_2	6.2
$CaSO_4.2H_2O$	79.7
K_2O	0.3
NaOH ??	1.5

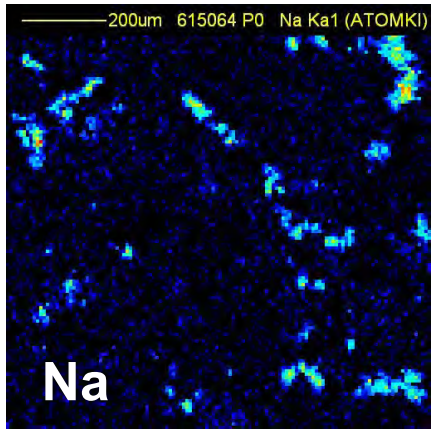


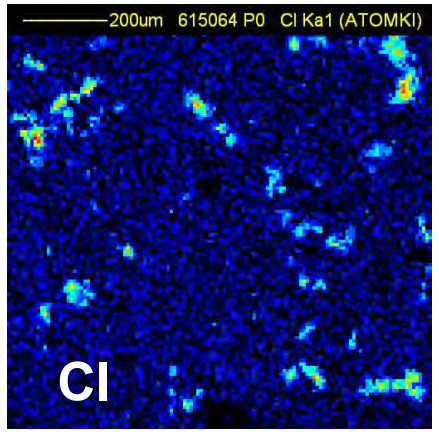








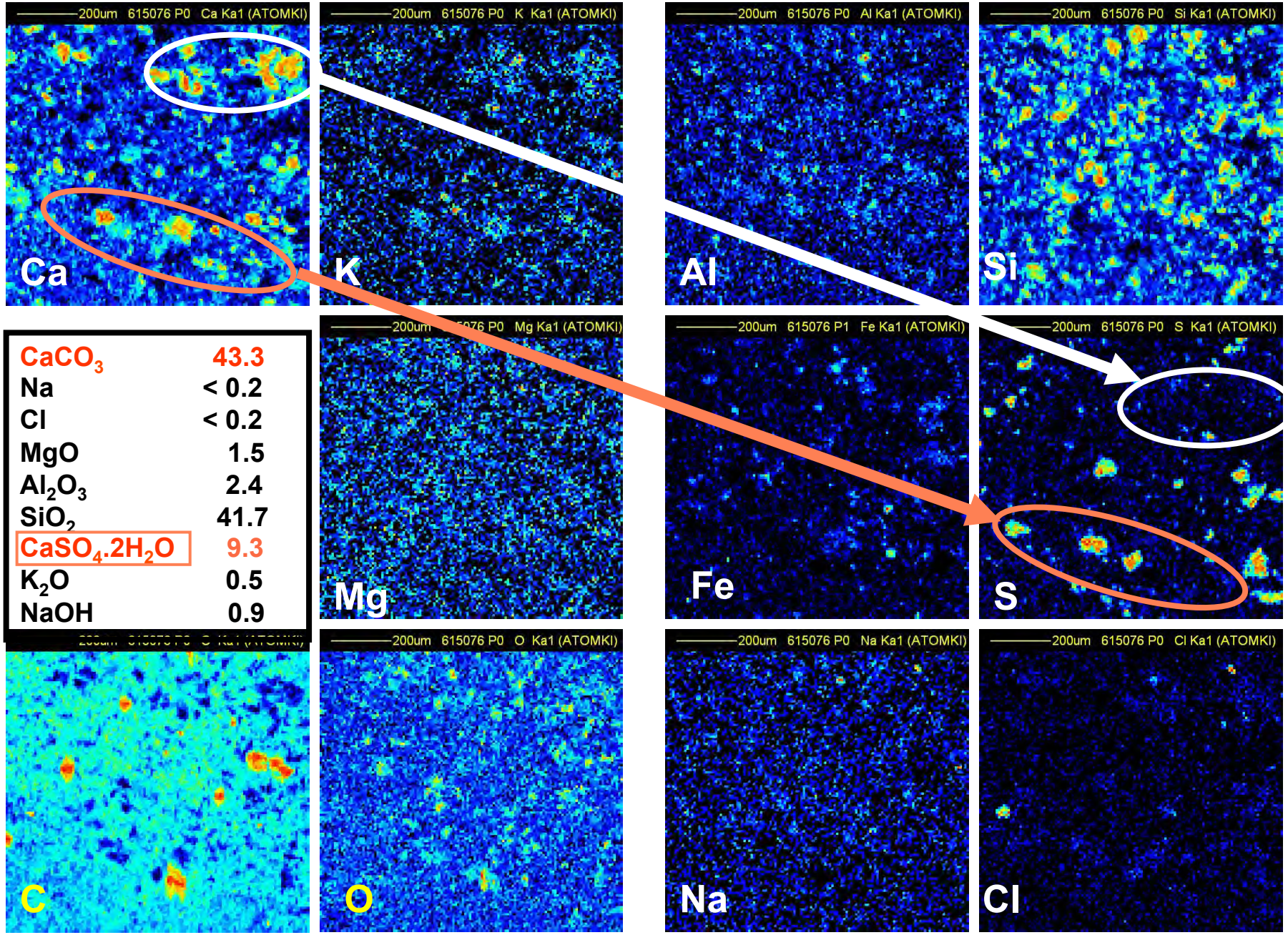




1 mm

pellet

FH22 Khufu (joining material great gallery)



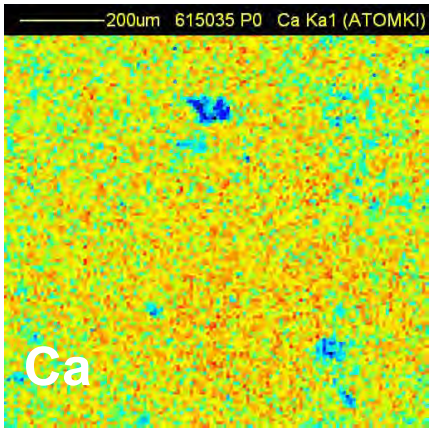
$CaCO_3$	43.3
Na	< 0.2
Cl	< 0.2
MgO	1.5
Al_2O_3	2.4
SiO_2	41.7
$CaSO_4.2H_2O$	9.3
K_2O	0.5
NaOH	0.9

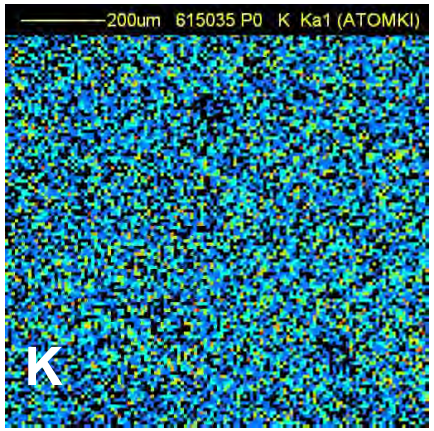
1 mm

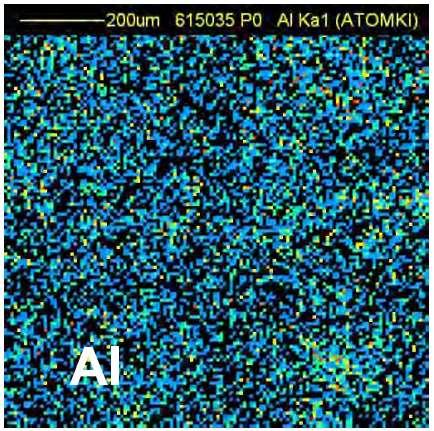
pellet

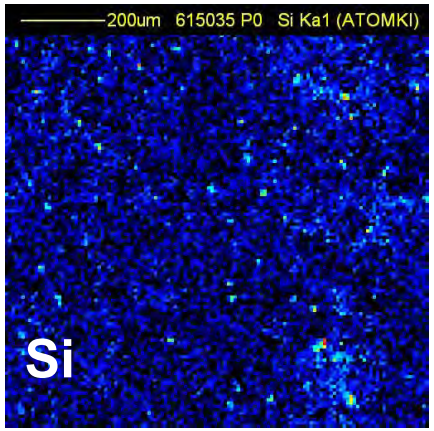
FH123

Khufu (inside great gallery)

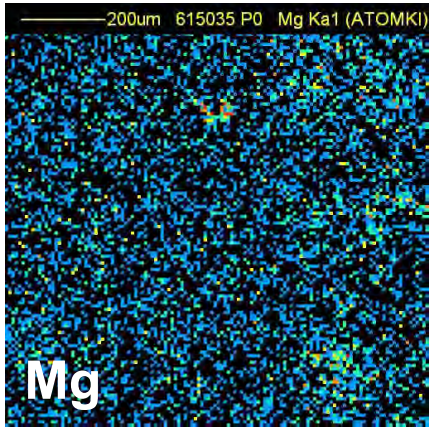


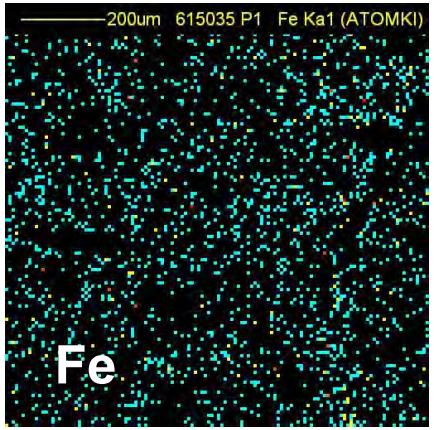


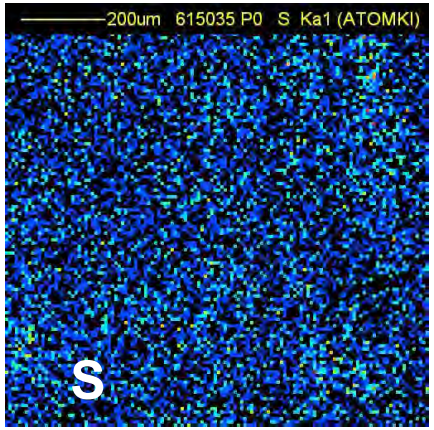


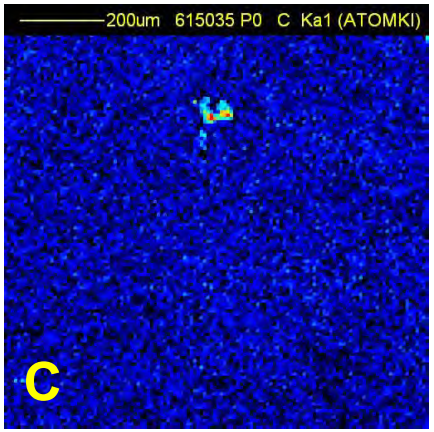


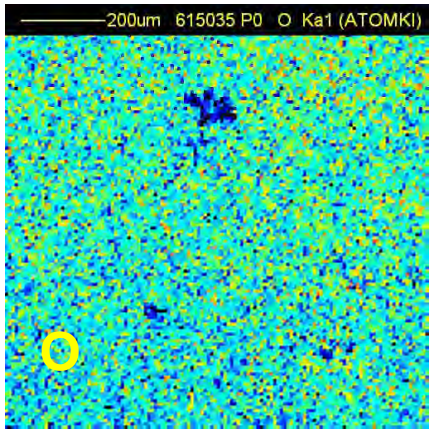
$CaCO_3$	87.9
NaCl	1.35
MgO	1.2
Al_2O_3	1.5
SiO_2	5.05
$CaSO_4.2H_2O$??	1.5
K_2O	0.1
NaOH ??	1.4

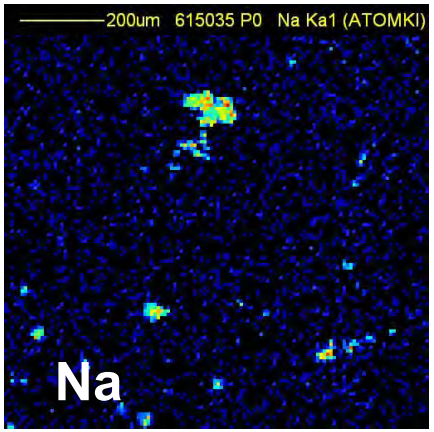


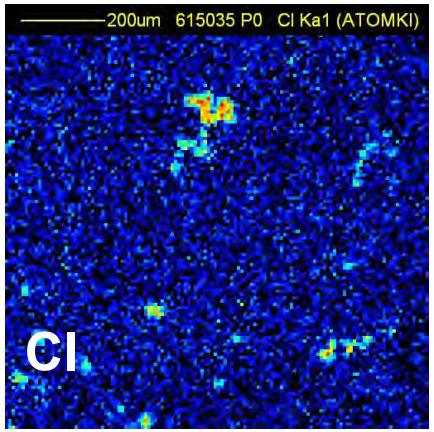


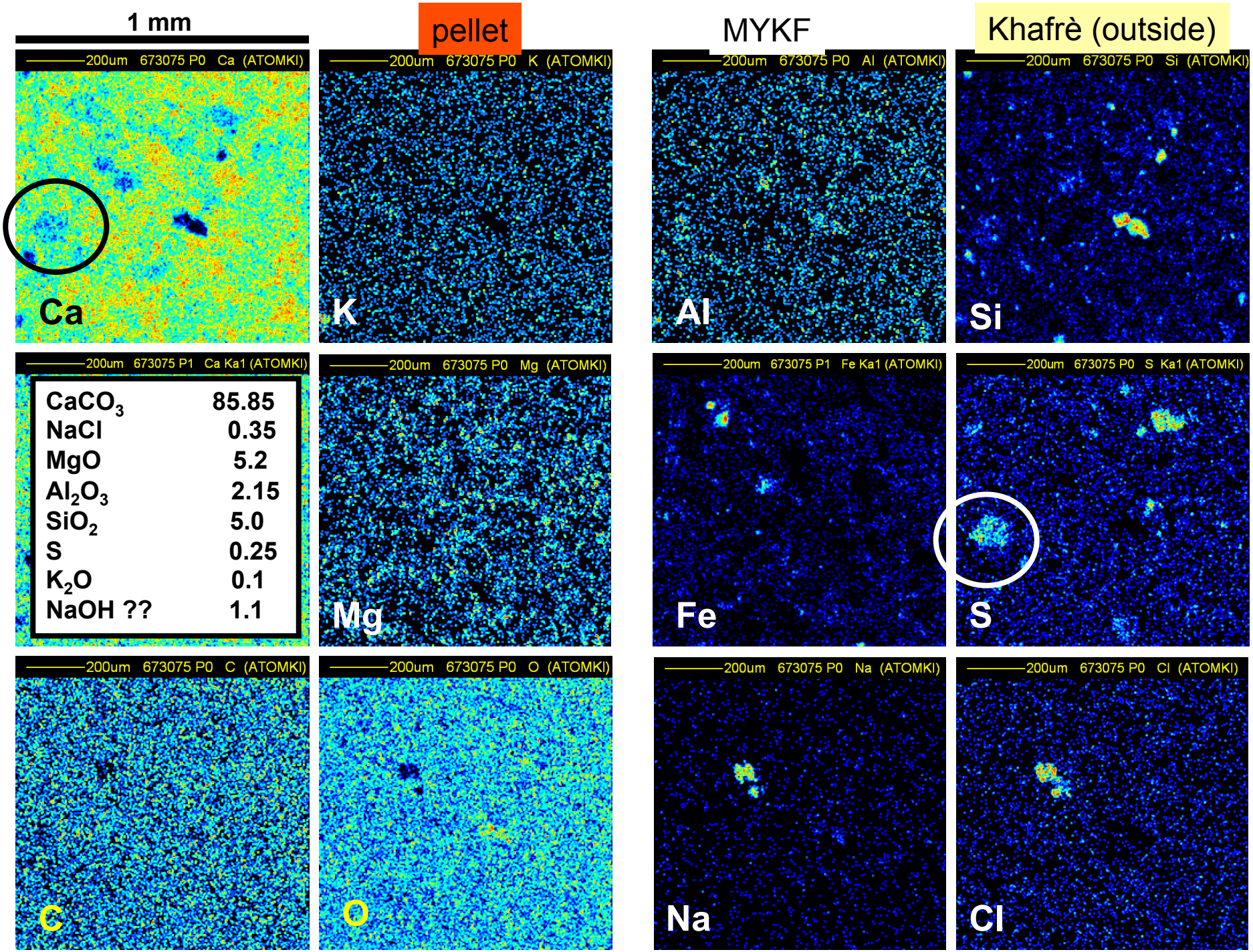








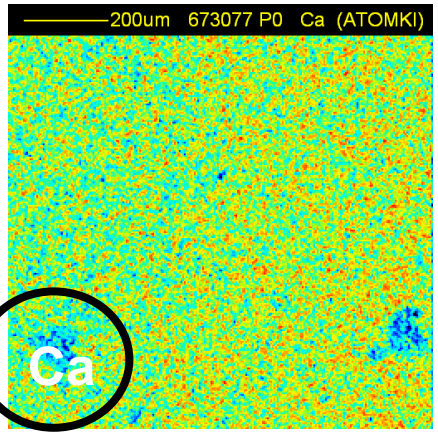


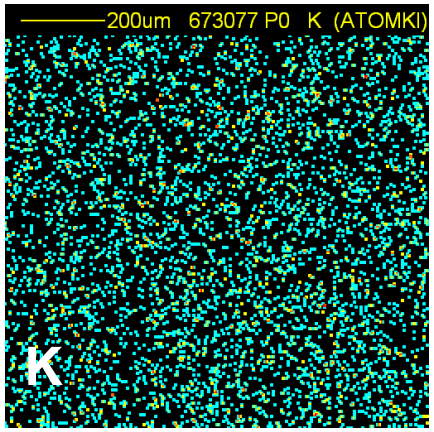

1 mm
pellet
MYKF
Khafrè (outside)
200um 673075 P0 Ca (ATOMKI)
Ca
200um 673075 P0 K (ATOMKI)
K
200um 673075 P0 Al (ATOMKI)
Al
200um 673075 P0 Si (ATOMKI)
Si
200um 673075 P1 Ca Ka1 (ATOMKI)
CaCO3 85.85
NaCl 0.35
MgO 5.2
Al2O3 2.15
SiO2 5.0
S 0.25
K2O 0.1
NaOH ?? 1.1
200um 673075 P0 Mg (ATOMKI)
Mg
200um 673075 P1 Fe Ka1 (ATOMKI)
Fe
200um 673075 P0 S Ka1 (ATOMKI)
S
200um 673075 P0 C (ATOMKI)
C
200um 673075 P0 O (ATOMKI)
O
200um 673075 P0 Na (ATOMKI)
Na
200um 673075 P0 Cl (ATOMKI)
Cl

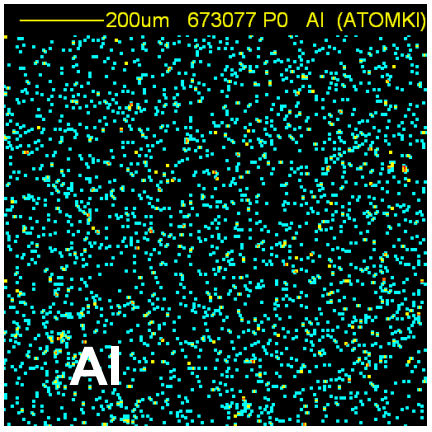
1 mm

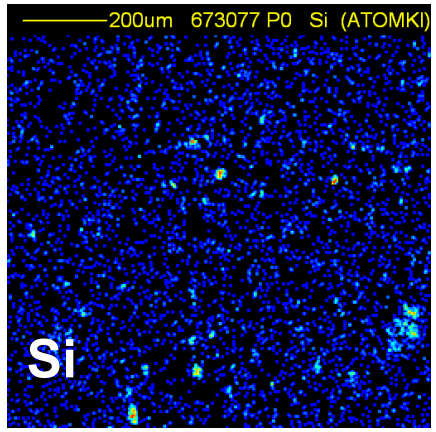
pellet

PIS Khufu (entrance in the pyramid)

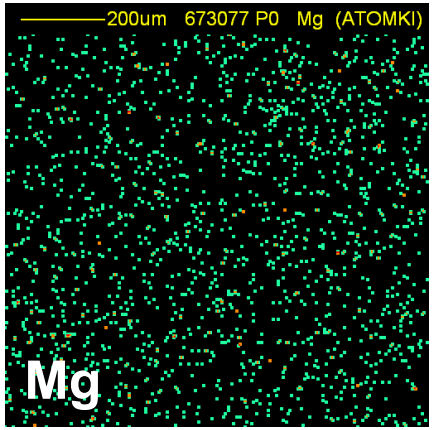


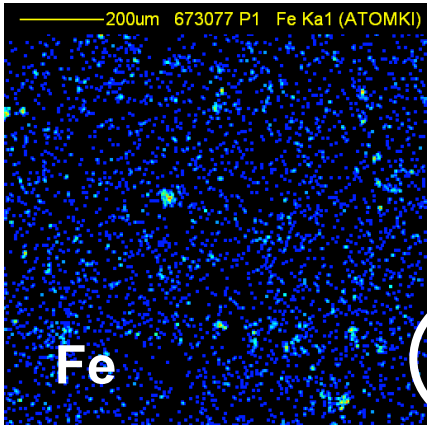


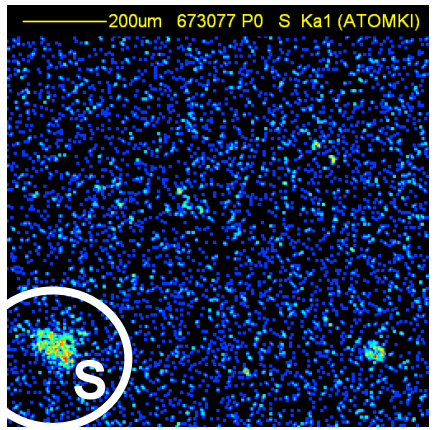


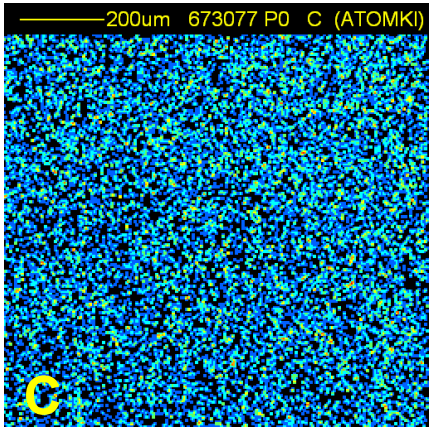


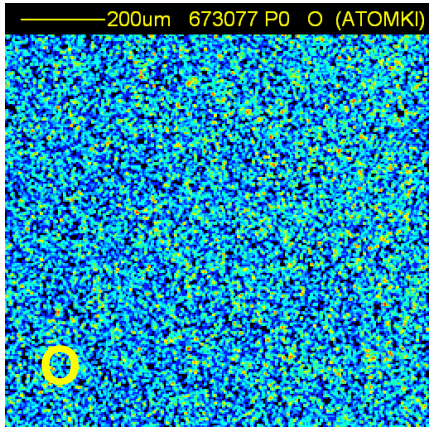
$CaCO_3$	94.35
Na	0.15
Cl	0.30
MgO	0.9
Al_2O_3	1.15
SiO_2	2.75
S	0.3
K_2O	0.1

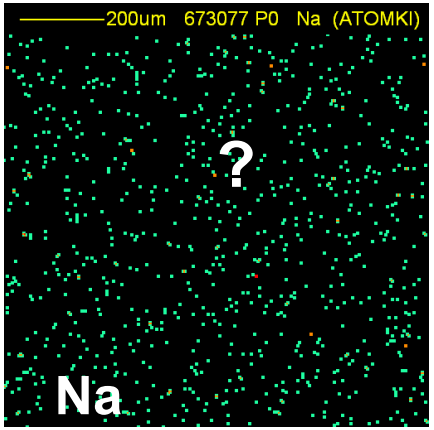


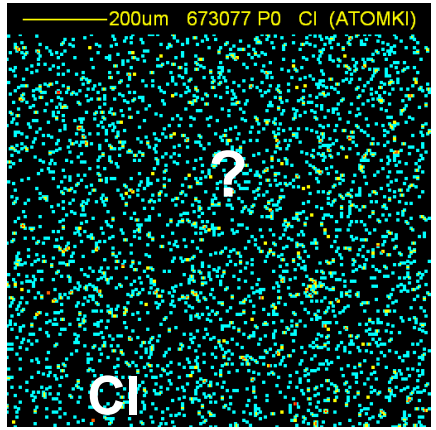








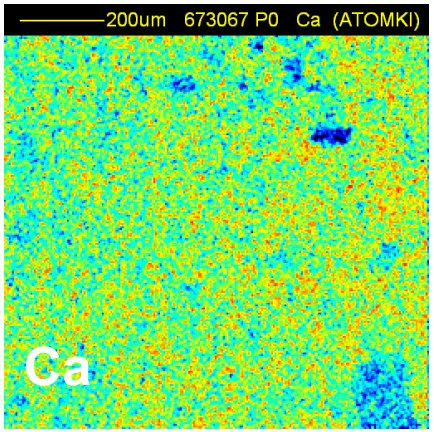


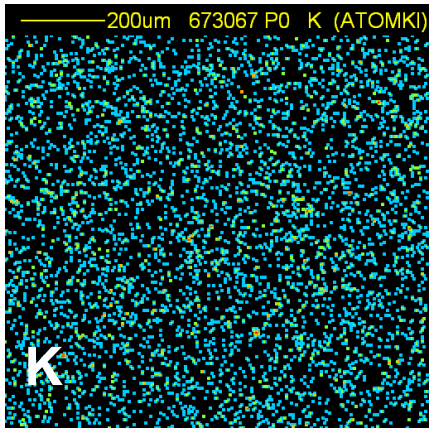


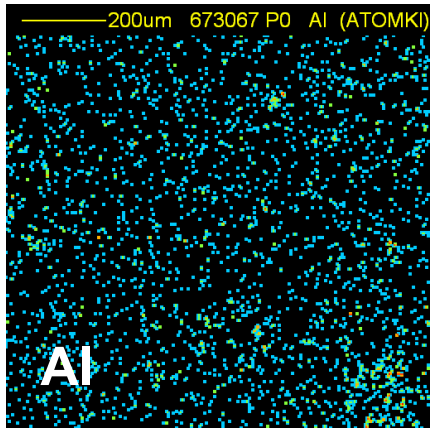
VT3

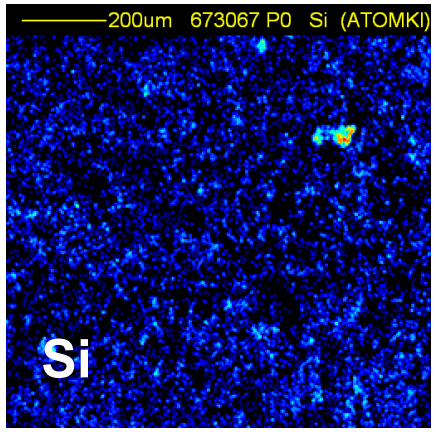
pellet

Khufu (outside)

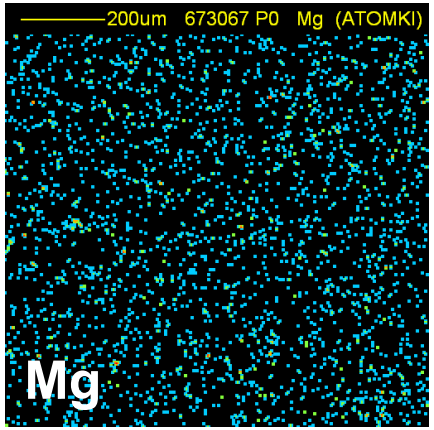


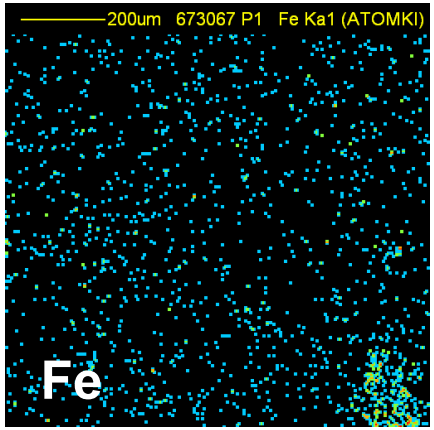


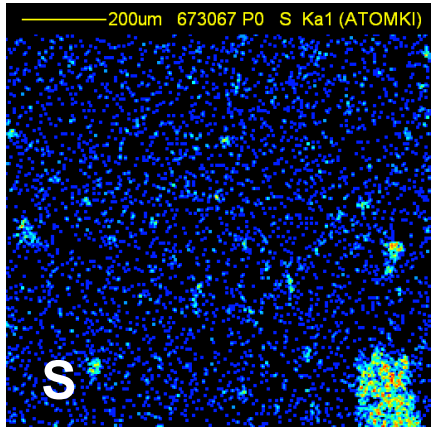


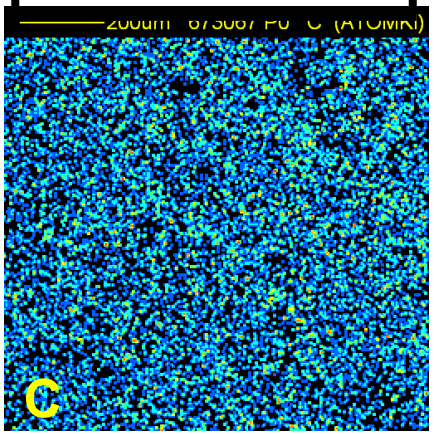


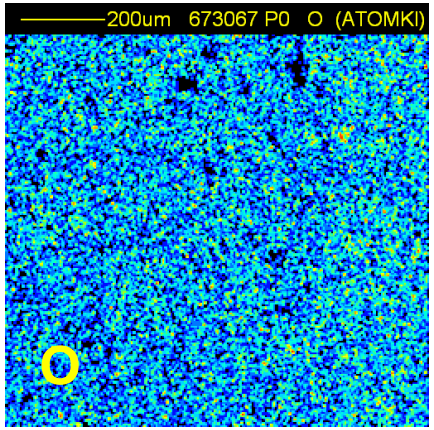
$CaCO_3$	84.95
NaCl	0.55
MgO	1.35
Al_2O_3	0.75
SiO_2	7.65
$CaSO_4.2H_2O$	2.35
K_2O	1.2
NaOH ??	0.95
FeS	0.25

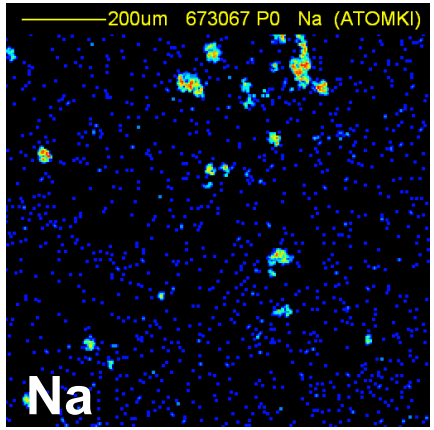


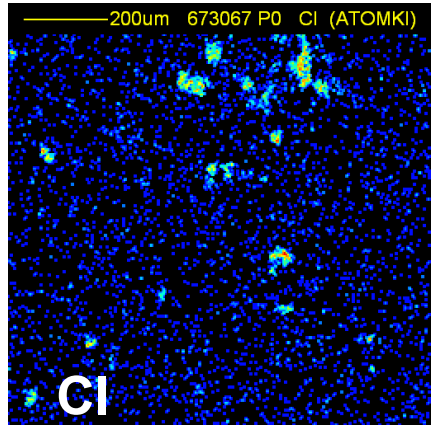




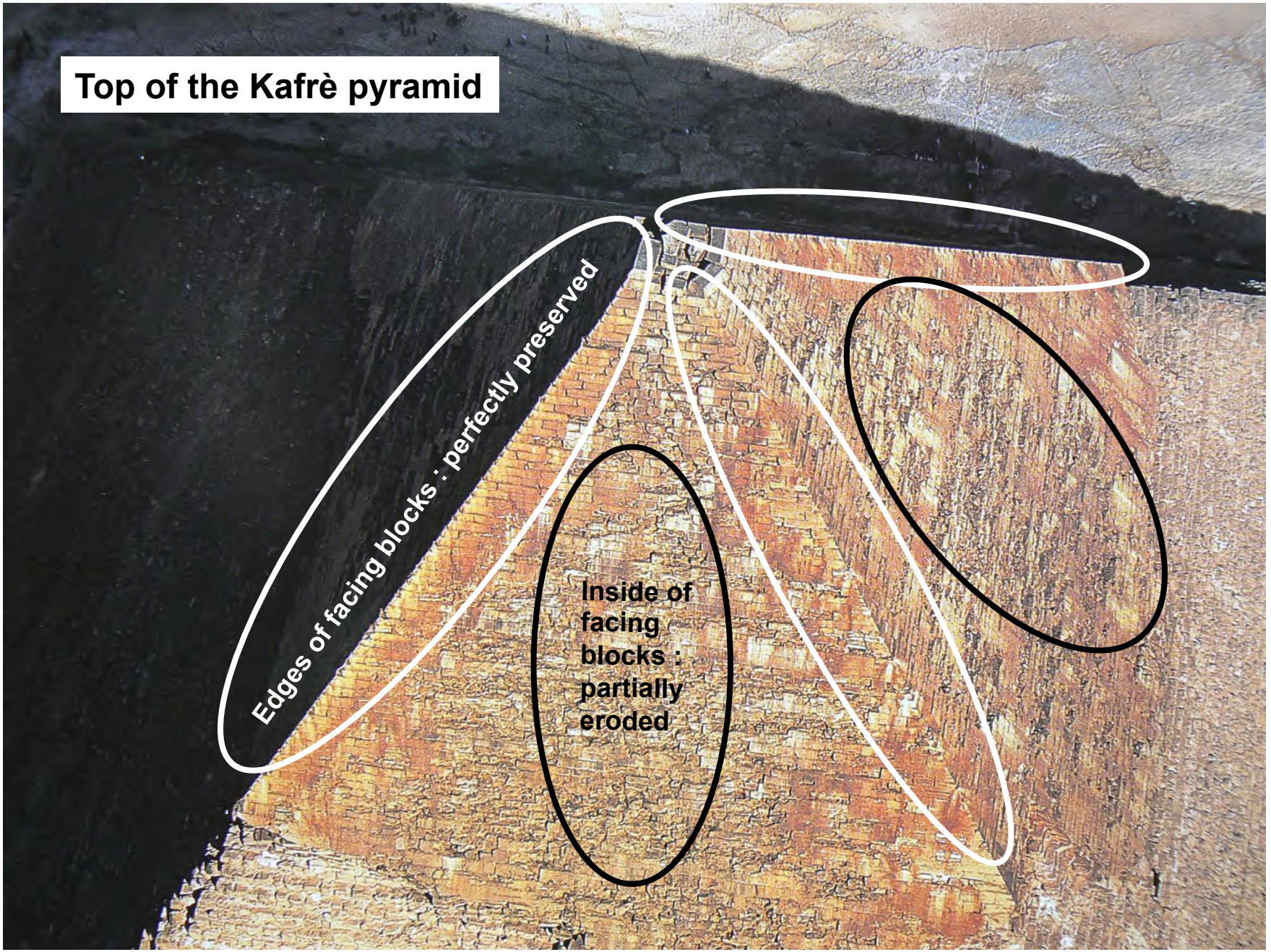




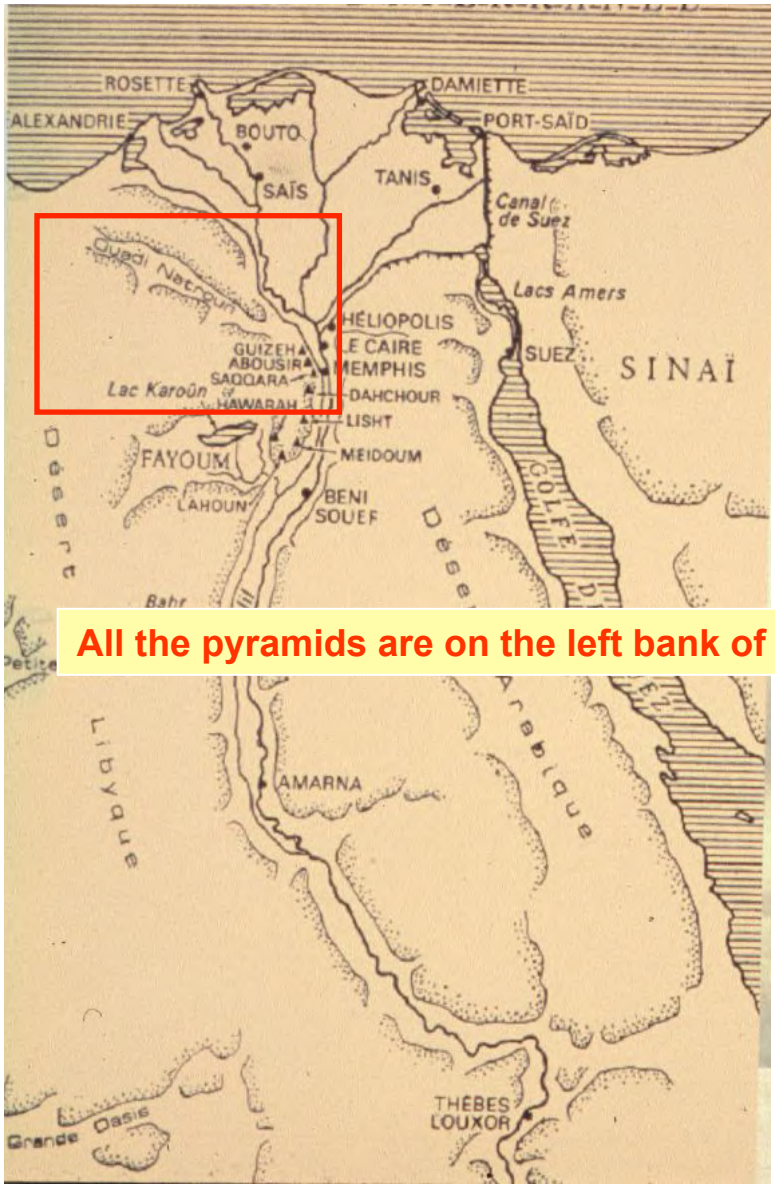


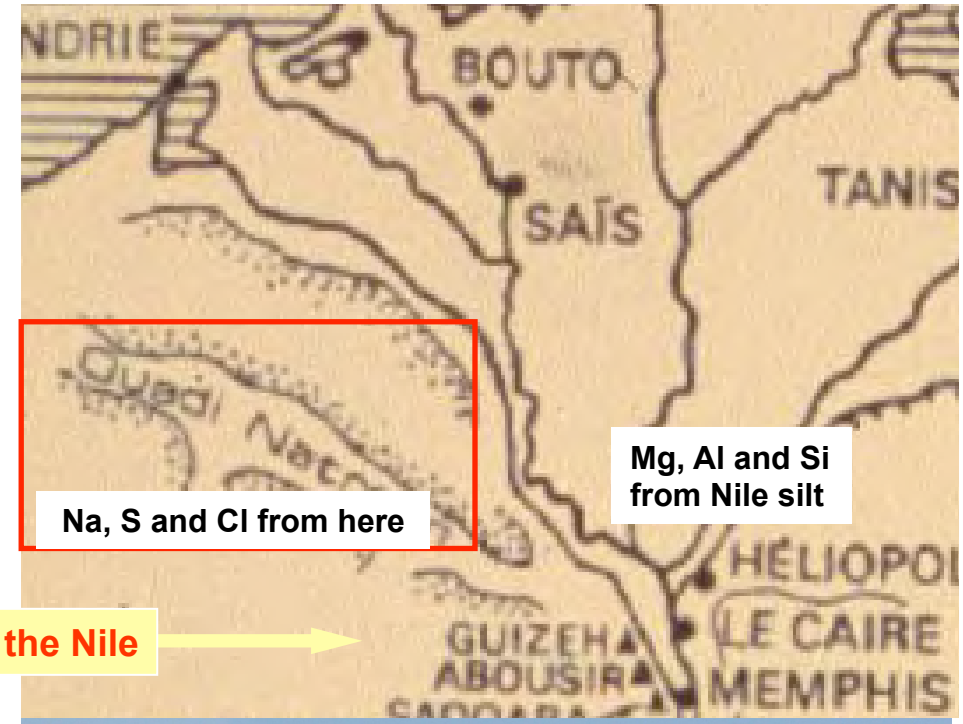


Additional facts


Top of the Kafrè pyramid
Edges of facing blocks : perfectly preserved
Inside of facing blocks : partially eroded

The region in the North of Giza **Ouadi Natrum**



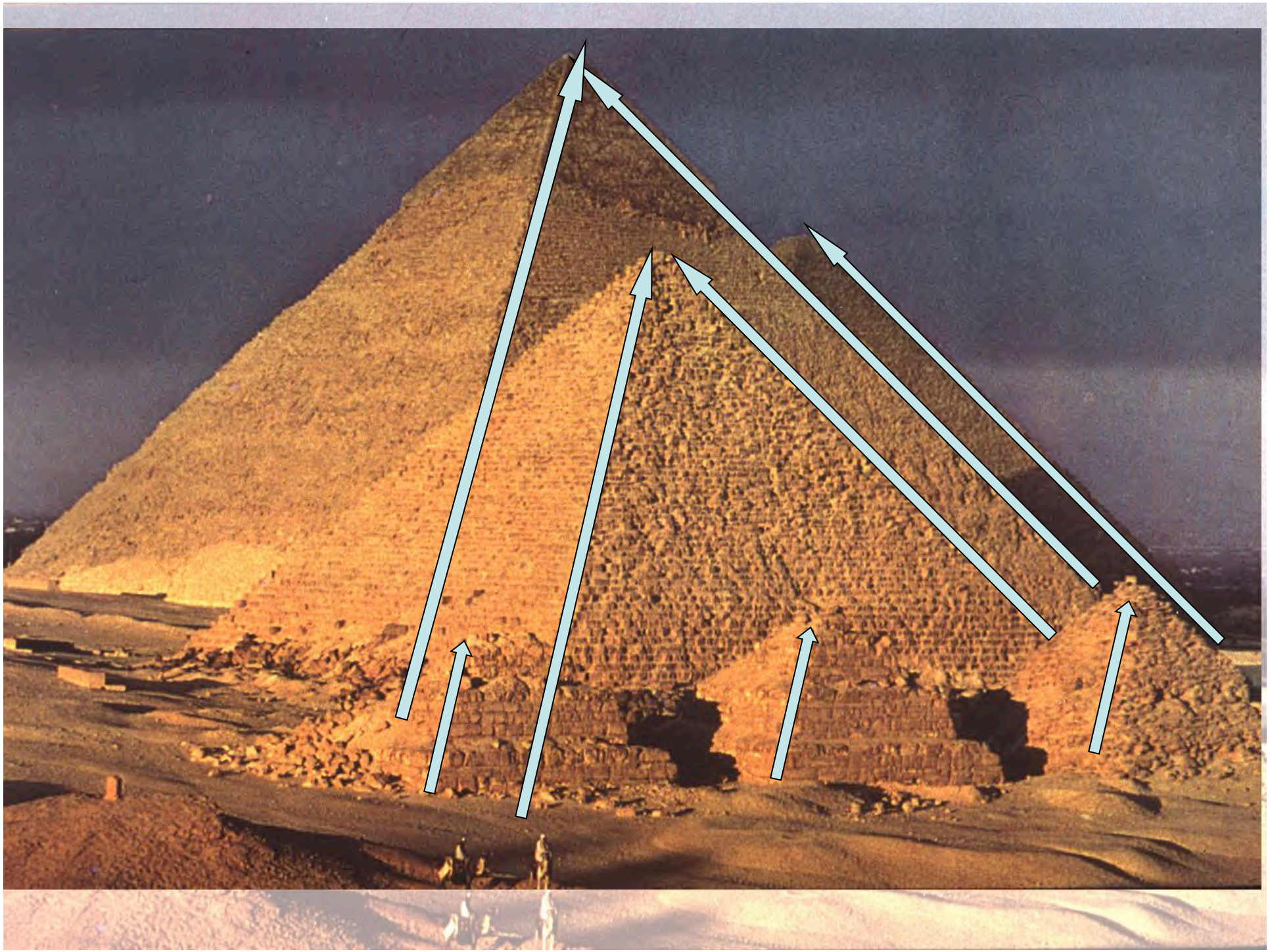


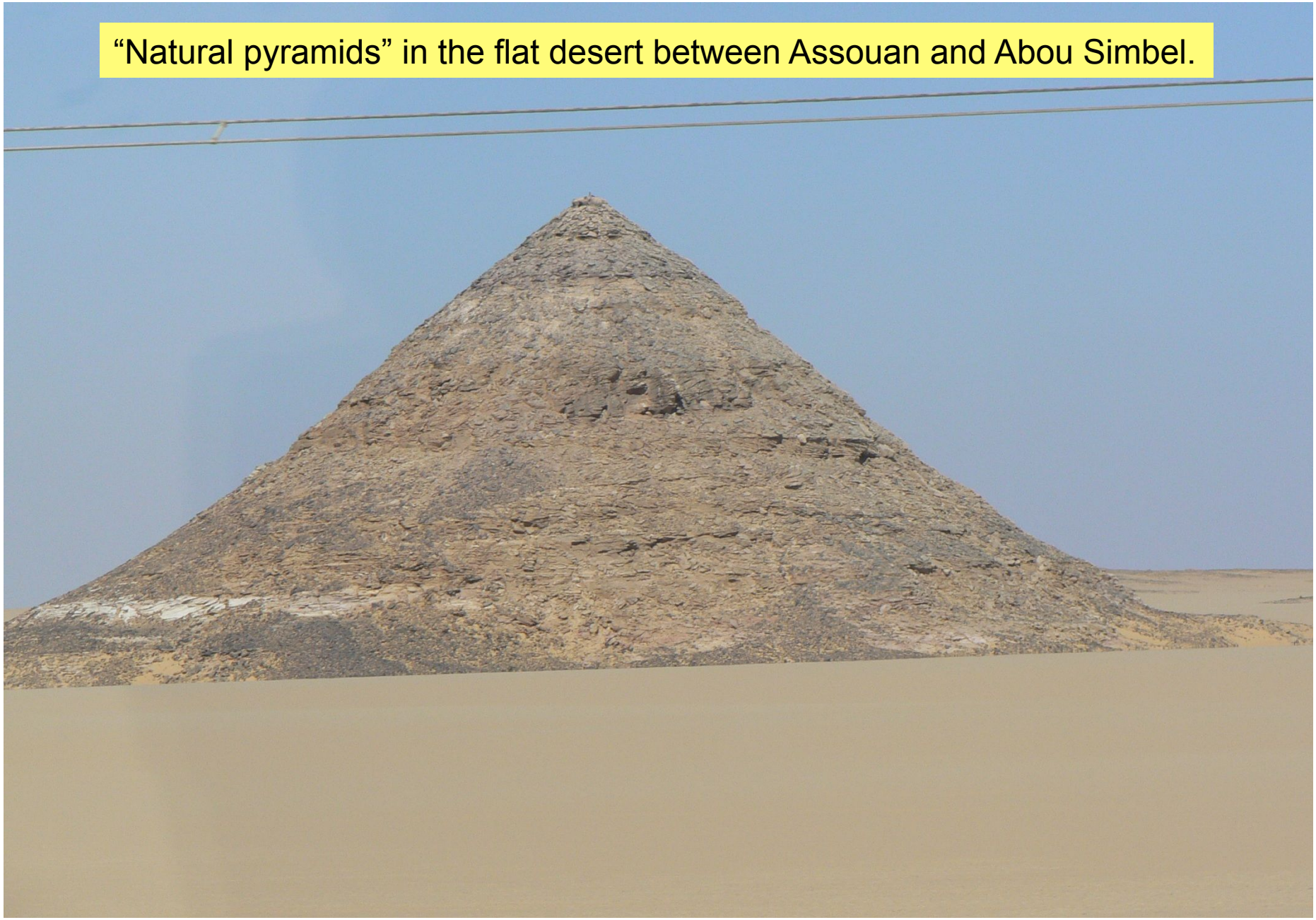
Na, S and Cl from here

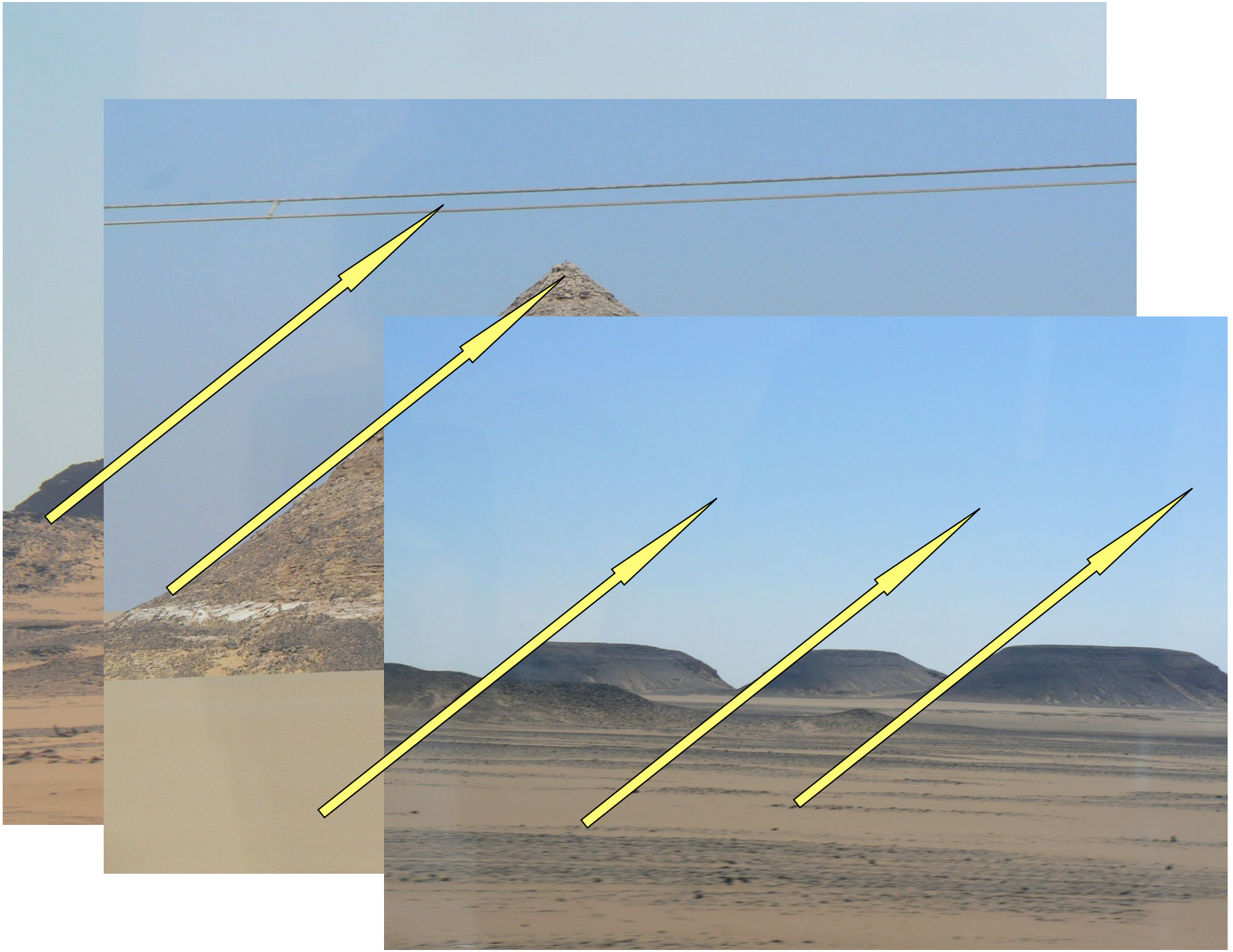
Mg, Al and Si from Nile silt

All the pyramids are on the left bank of the Nile

"Natural pyramid" in the flat desert between Assouan and Abou Simbel
Source of inspiration for the ancient architects ?




“Natural pyramids” in the flat desert between Assouan and Abou Simbel.



There are three steps in the revelation of truth:
in the first, it is ridiculed;
in the second resisted;
***in the third, it is considered self-evident*.**

Schopenhaur (1788-1860).

Conclusions

PIXE and micro-PIXE results indicate that the **structure** and the **composition** of the material of the pyramid blocks are different from the quarries samples

NMR confirmation of this difference

Main compositional differences concern the content in **Cl, Na and S**

Pyramid samples are structurally less homogeneous **(clusters)**

Future experiments

Dating of mortars (AMS dating possible at CEDAD - Lecce)

Dating of inclusions by photoluminescence.

Additional physical and chemical analyses on **freshly** sampled material (Na, Mg, Al, Si, S, Cl, K, Ti,…As…).

Careful study of the **slope** of various pyramids and comparison with “natural slope”.

Comparison of (not) **growing plants** on pyramids but well in the quarries.

Possible modern application

If the pyramids were actually made with the “concrete” technology… why do we not reproduce this material for long time storage of nuclear waste ?