OKLO REACTORS :
2 billion Years before Fermi !

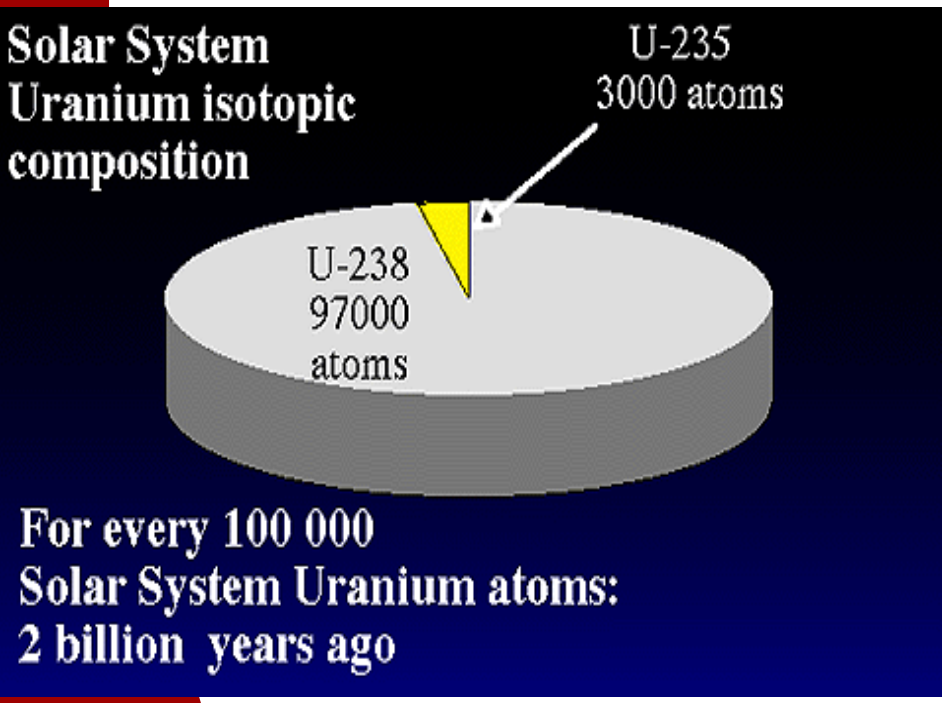
Bertrand BARRÉ, AREVA

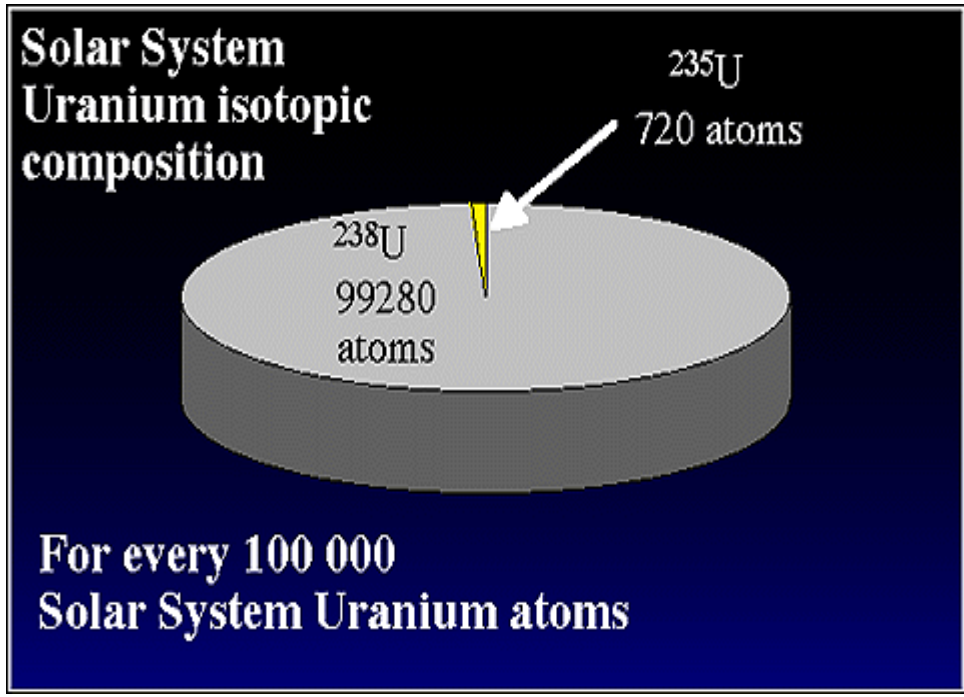
« The italian Navigator has landed in the New World »

And not even a photographer…

Then and Now

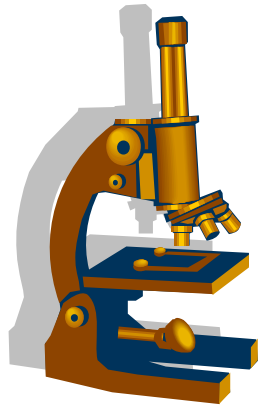
- *2000 million years ago*
- *Today*





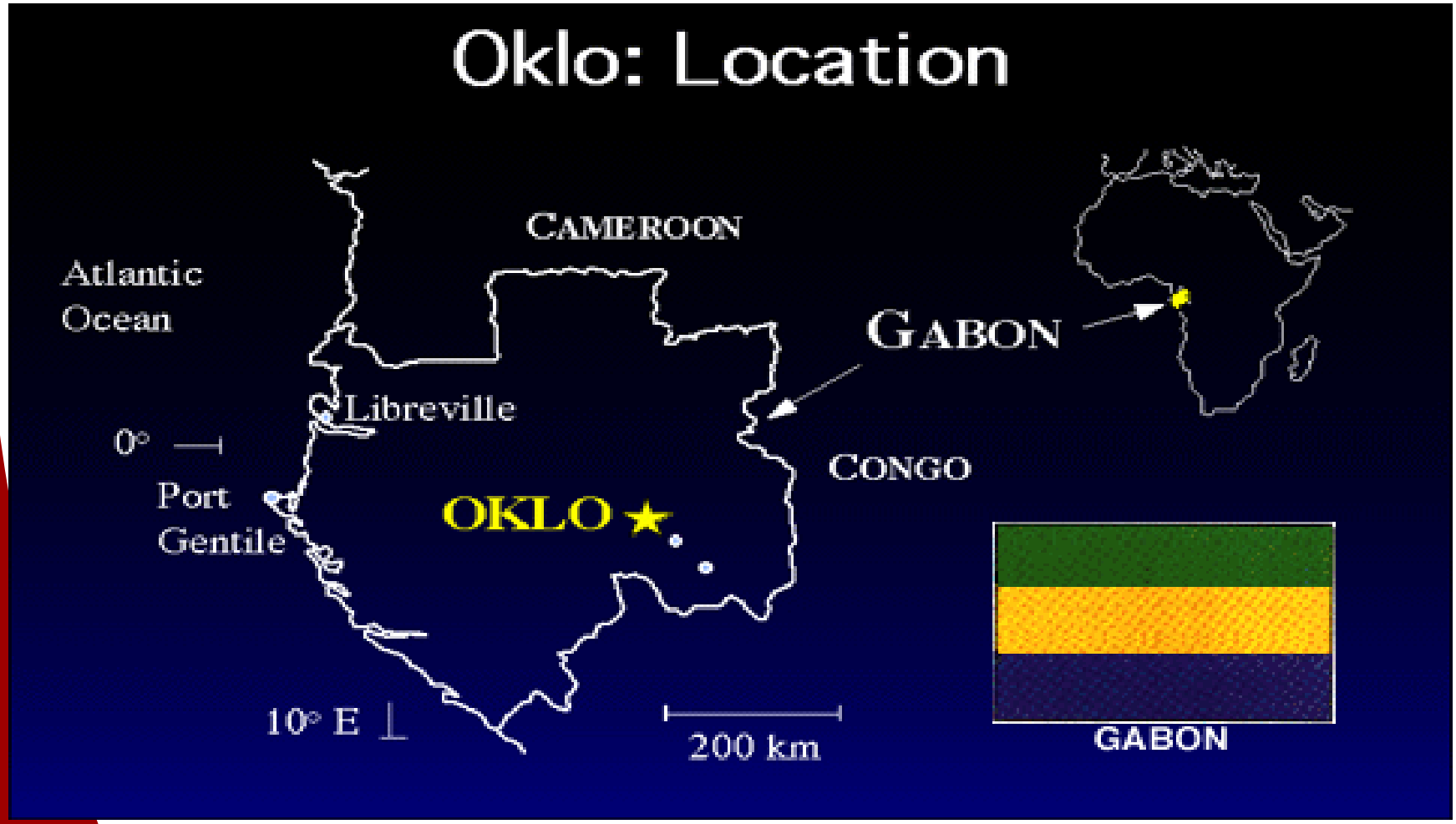
Detective Story

- *June 1972*
- *Pierrelatte Nuclear Fuel Enrichment plant was using ore from Gabon (deposits discovered in 60's)*
- *Shipment of U routine mass spec. measurements of $^{235}U/^{238}U$ ratio (0.7171% instead of 0.7202%), and no ^{236}U…*
- *Talk about paying attention to details!*



- *Pierrelatte > Malvesi > Gueugnon > Mounana > Oklo (north)*

Where is Oklo?



Franceville Basin

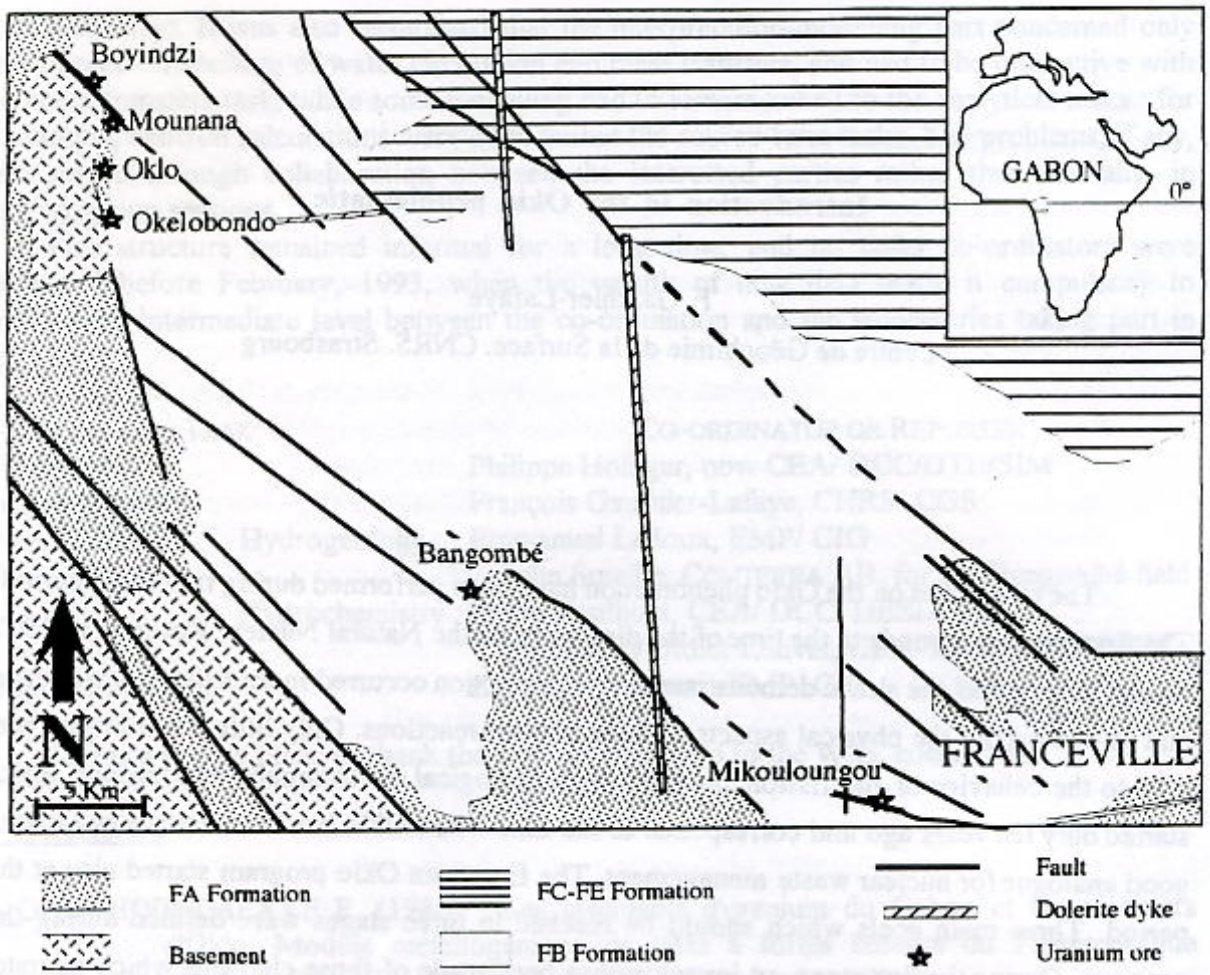
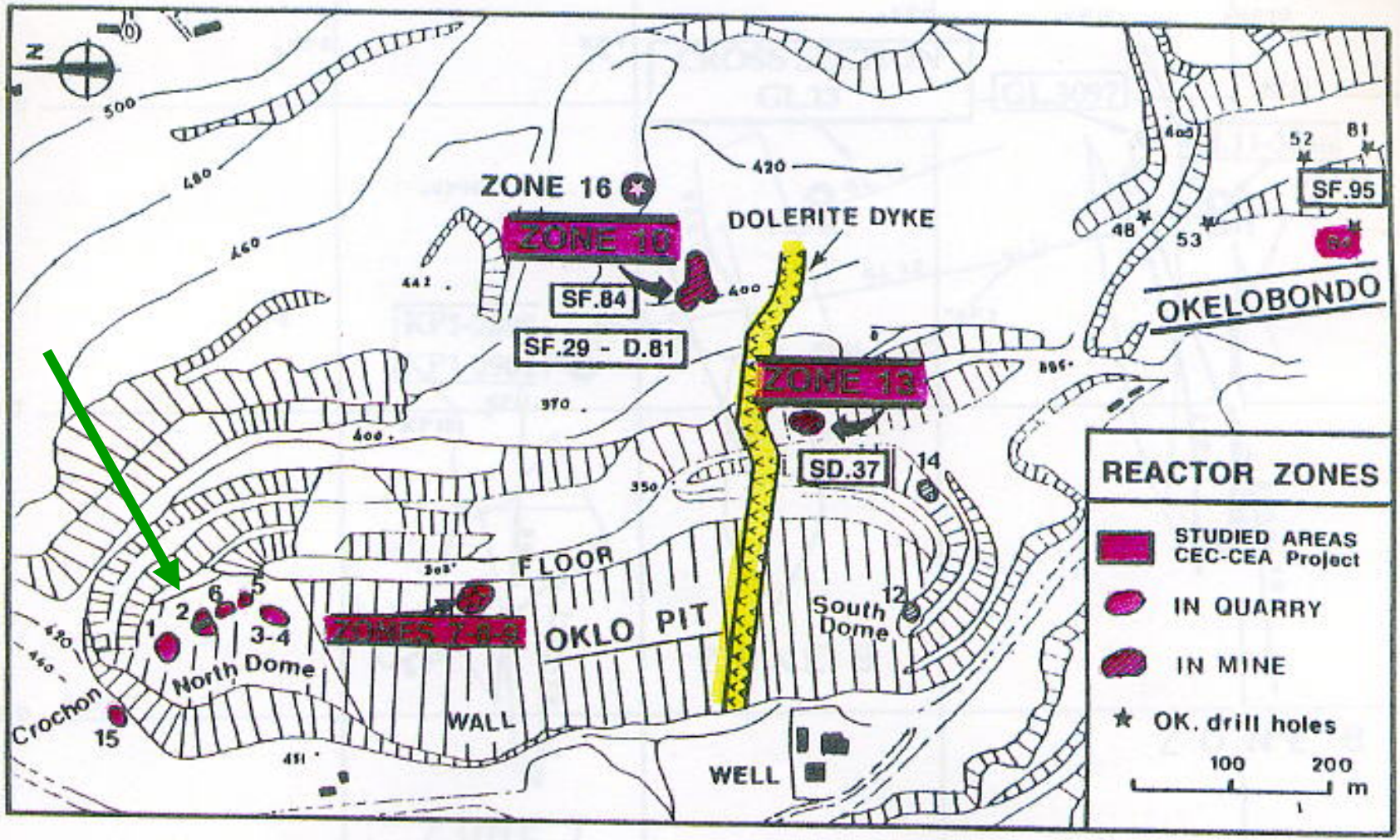


Figure 1

Geological map of the Franceville basin and location of the uranium deposits.



OKLO: LOCATION OF REACTOR ZONES

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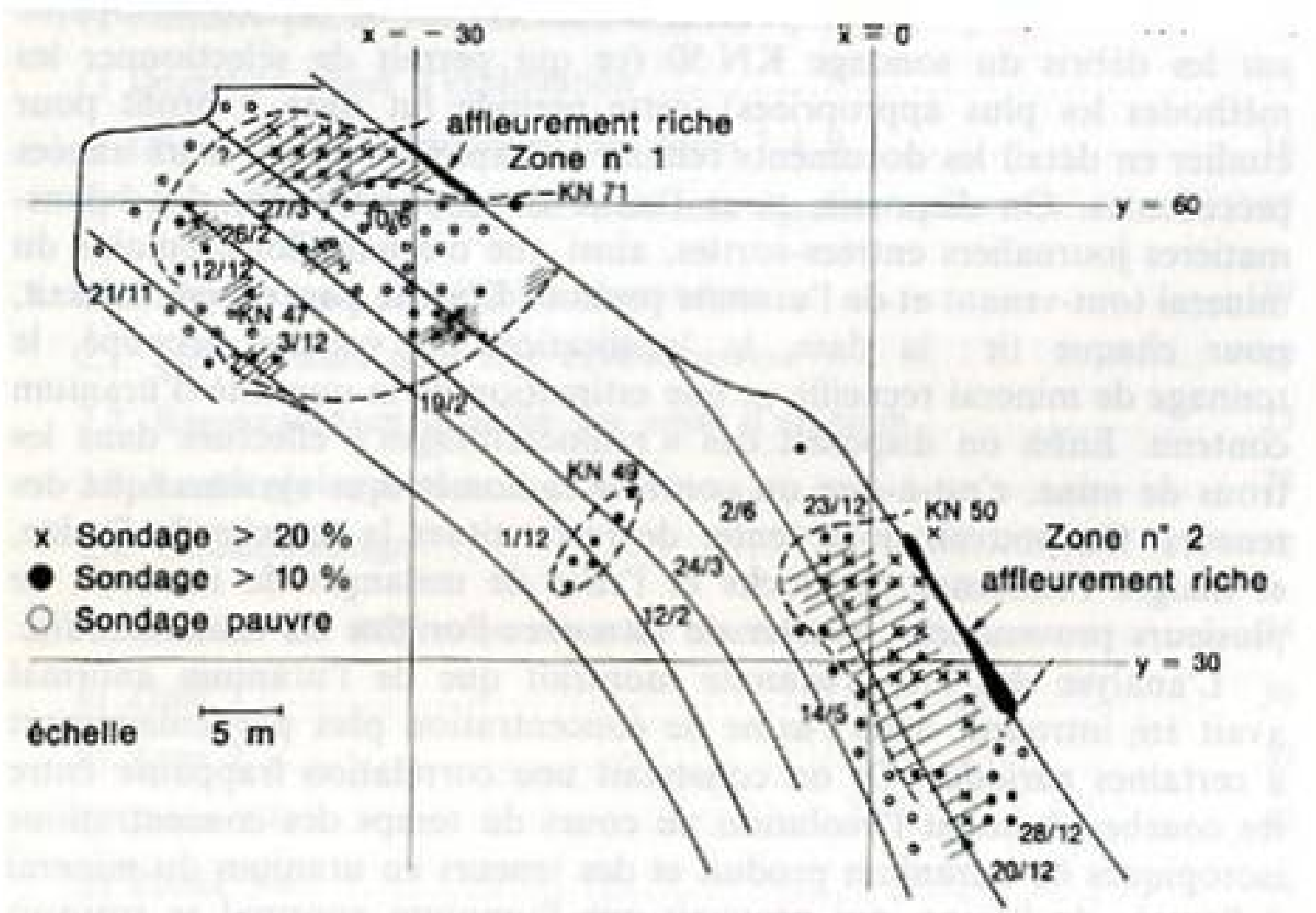
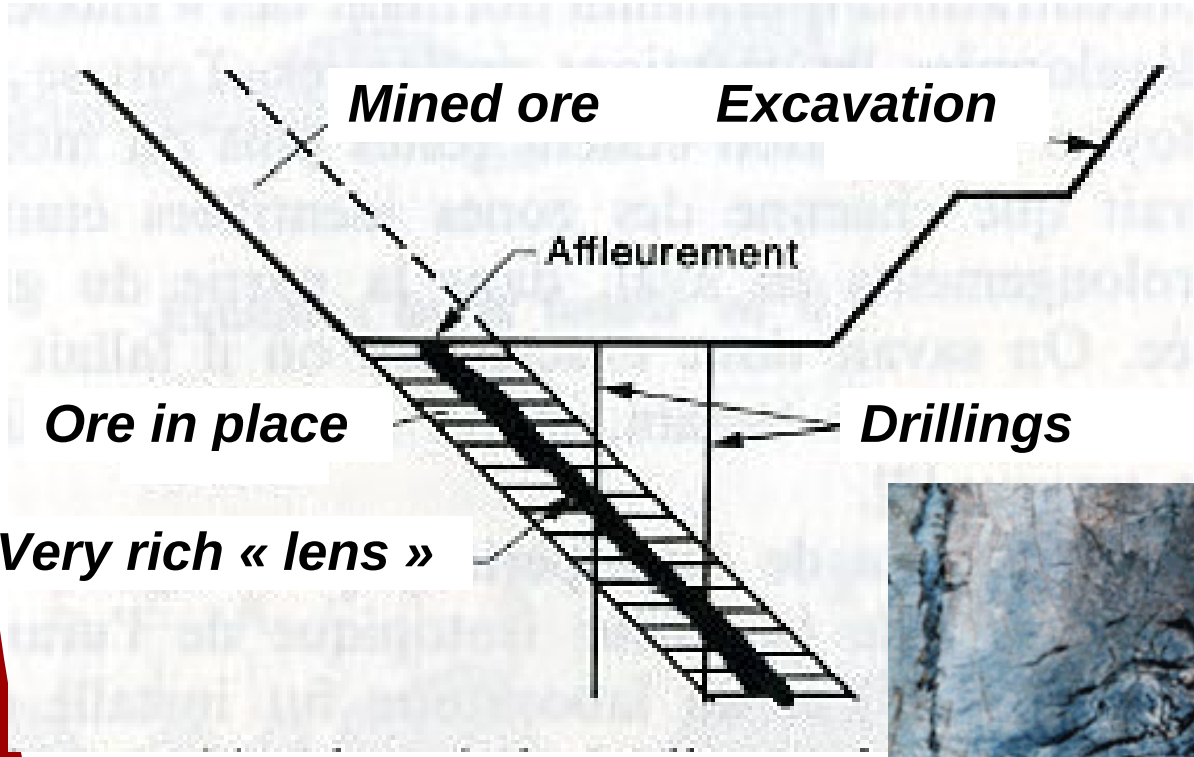
Oklo, Gabon (CEA 1974)

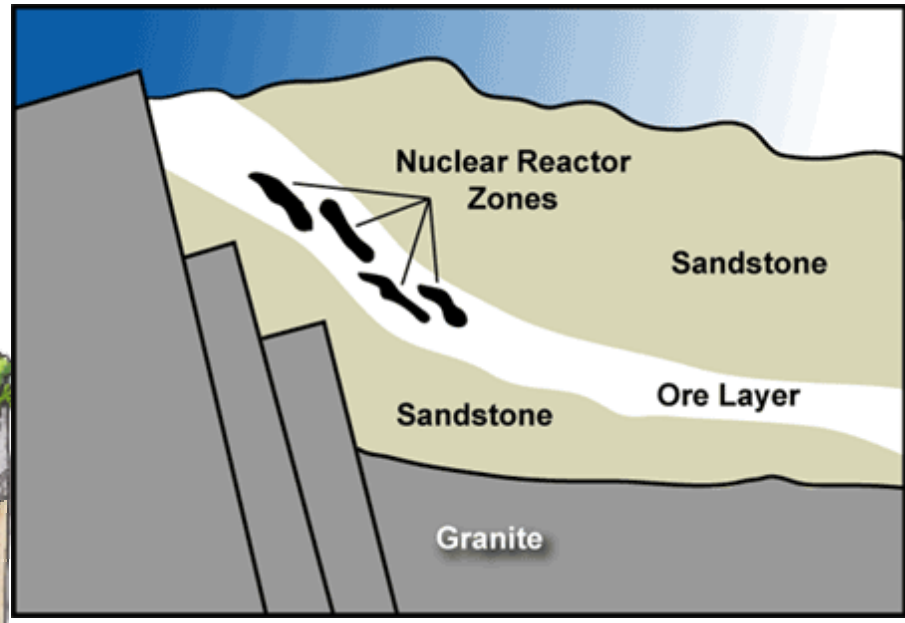
OKLO Mining Operations Nov1970-Dec1971

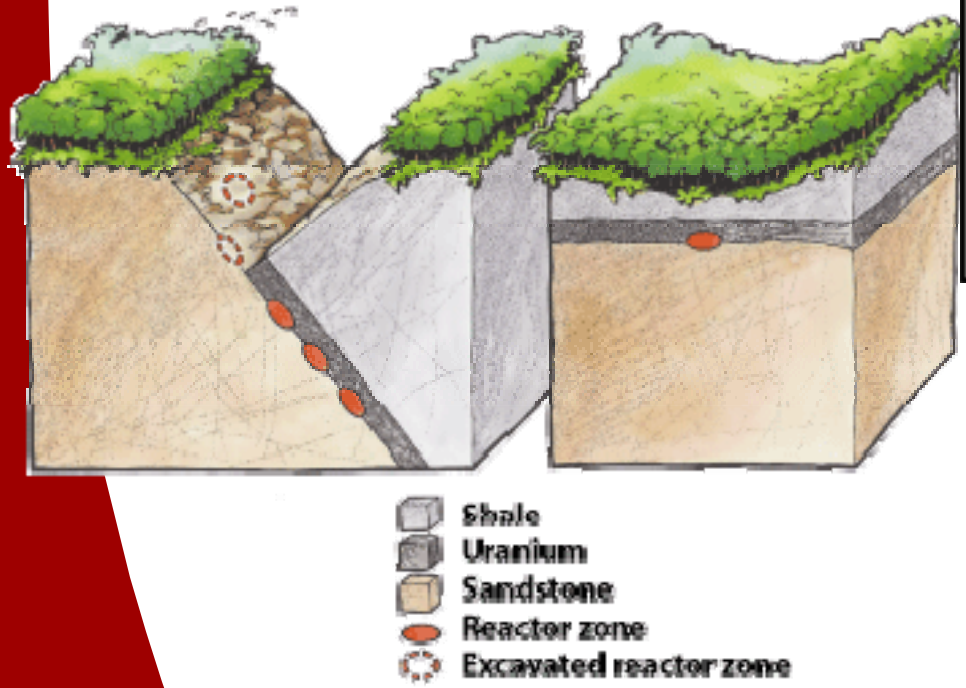


Open Pit Mining in Oklo



The OKLO Mine





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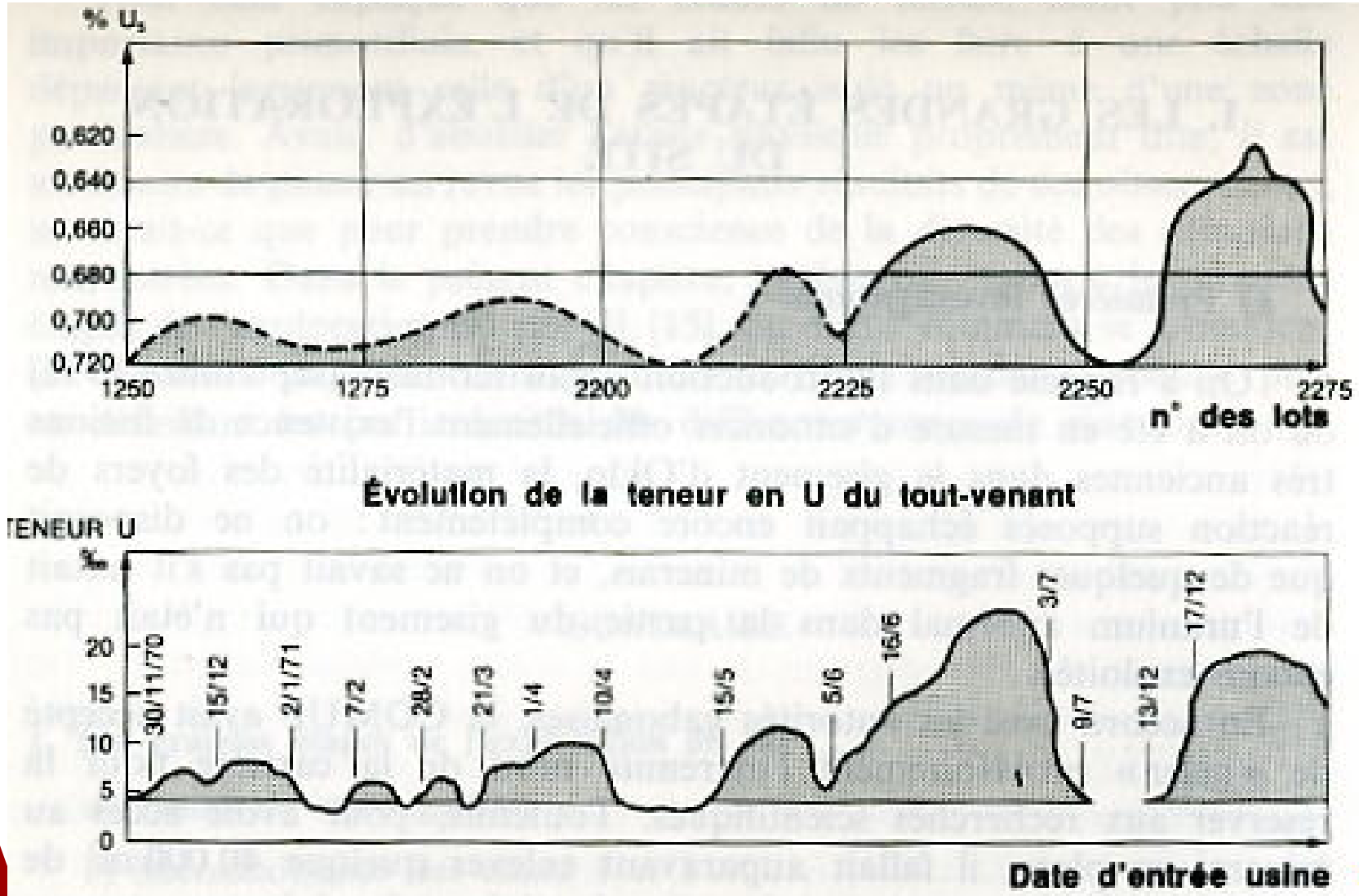
Mounana Plant Nov1970-Dec1971

U concentration in ore vs ^{235}U abundance



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Reminder…

- *^{235}U is desired form of Uranium for thermal fission*
- *Reactors (other than CANDU and Magnox) require enrichment :*

- *MTR (old) :93%*
- *MTR (new): 20%*
- *LWR : 3.2-4.5%*

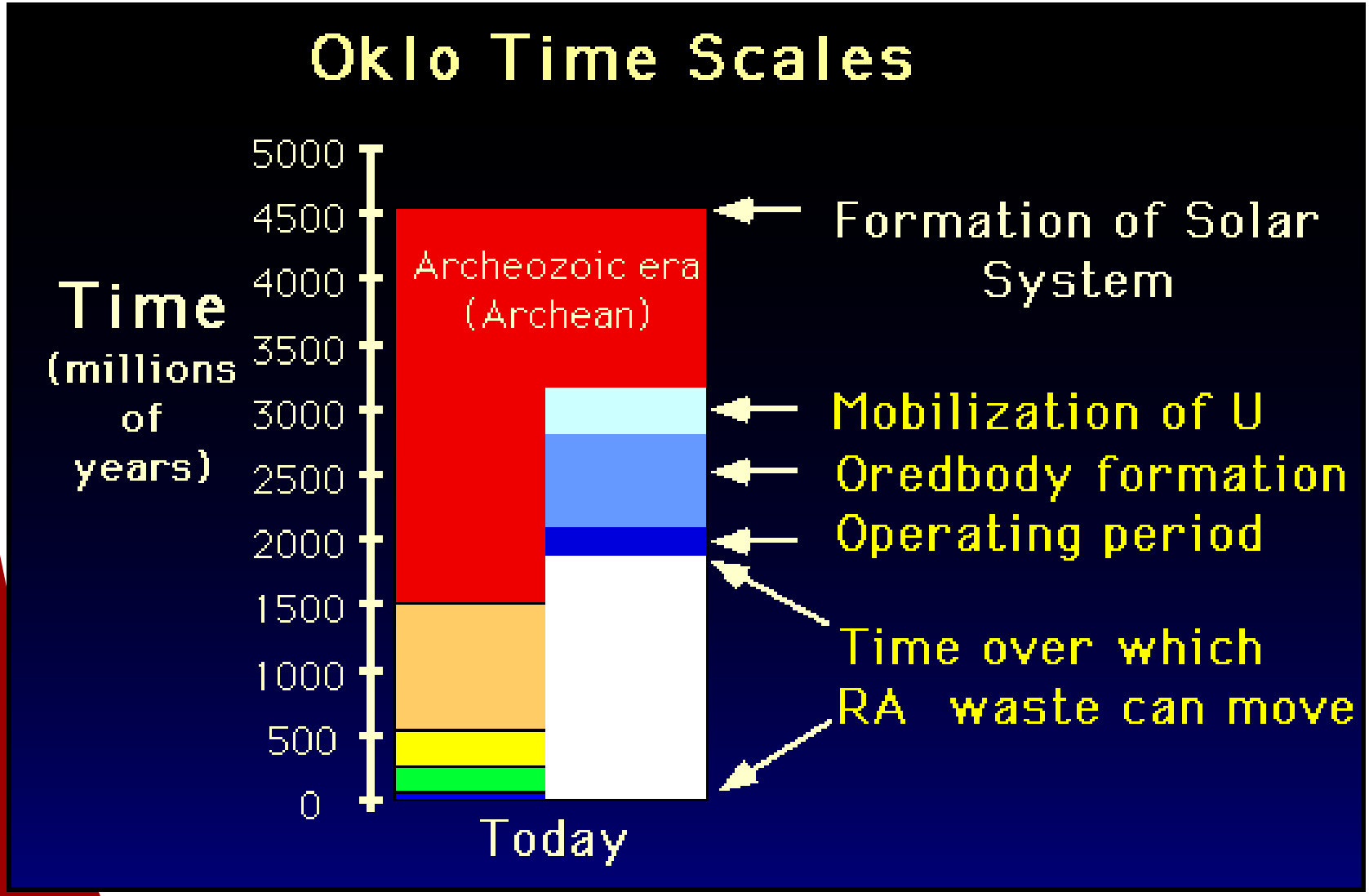
A Window in Time

- ***Before 2.2 billion years ago, no uranium deposit, because not enough oxygen in atmosphere and therefore water***
- ***After 1.4 billion years ago, ^{235}U abundance too low***

Remember…

The Americas separated from EurAsia and Africa less than 200 million years ago

Oklo Events… How'd it Happen?



- *Mobilization of Uranium:*
  - ***source of U for reactors came from tiny amounts scattered about Earth's crust.***
  - ***Major biological event:***
  - ***photosynthesis and atmospheric oxygen***
    - ***Water acquires its 'oxidizing nature', dissolve Uranium from crustal rocks into streams and rivers***

- *Uranium ore/reactor formation:*
  - ***Uranium was deposited thinly and low concentration over large area (by water)***
  - ***Thousands of meters of sand deposited on top***
  - ***Earth lifted (45o), rain percolated down, re-mobilized uranium, which eventually re-deposited in very high concentrations (up to 70% UO_2)***

Stratigraphy of Zones 5-6

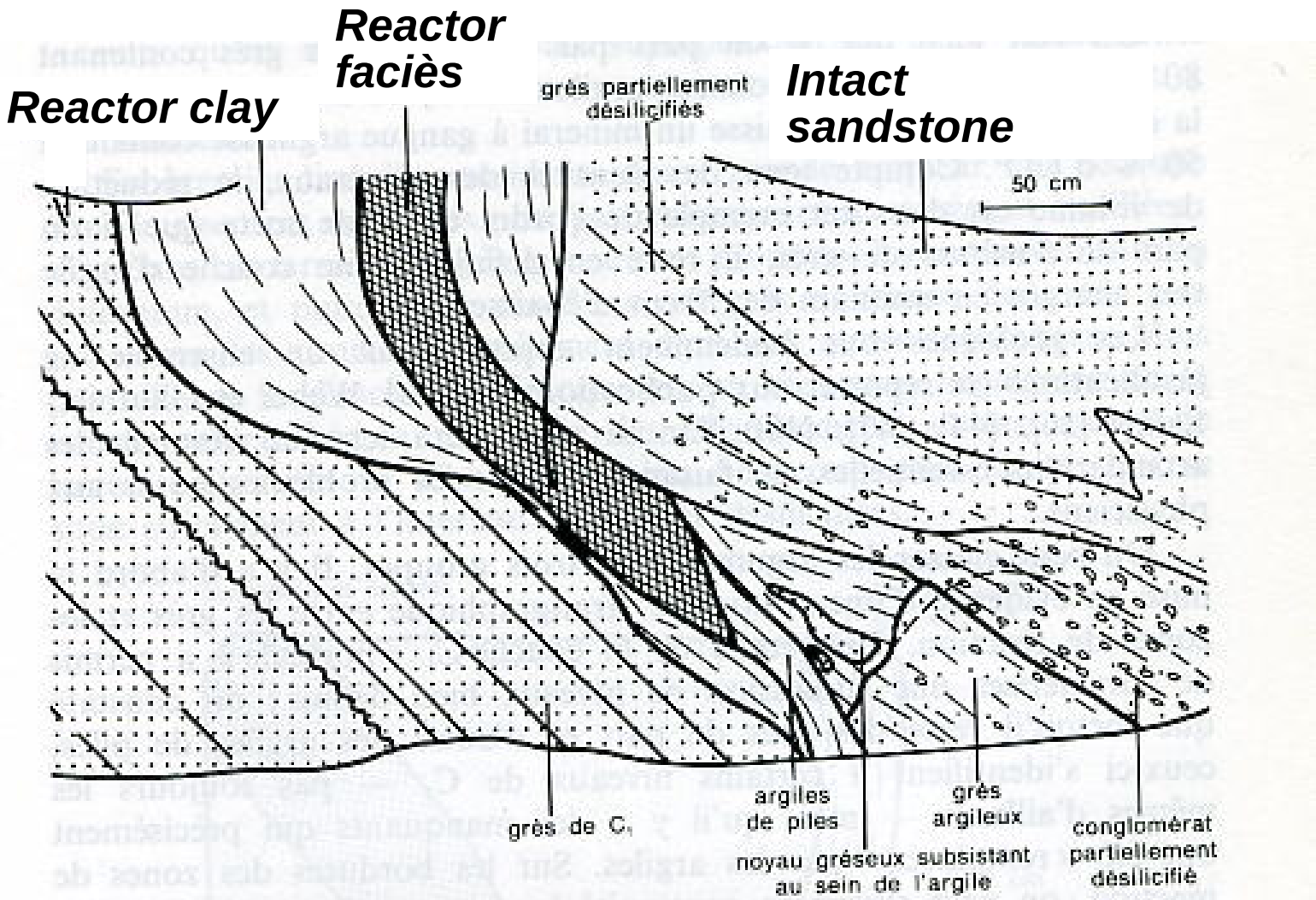


FIG. 2. — Front du 30/9/76 (zones 5-6) (d'après [16]. On observe toute une série de transitions entre le réacteur et le minerai gréseux.

Reactor Operation:

~1 million years (can tell by dating byproducts)

Waste Movement:

All radioactive waste products have decayed (2000million years to degrade)

Fossil Reactor # 15

Yellow is Uranium Oxide and white is recrystallized quartz

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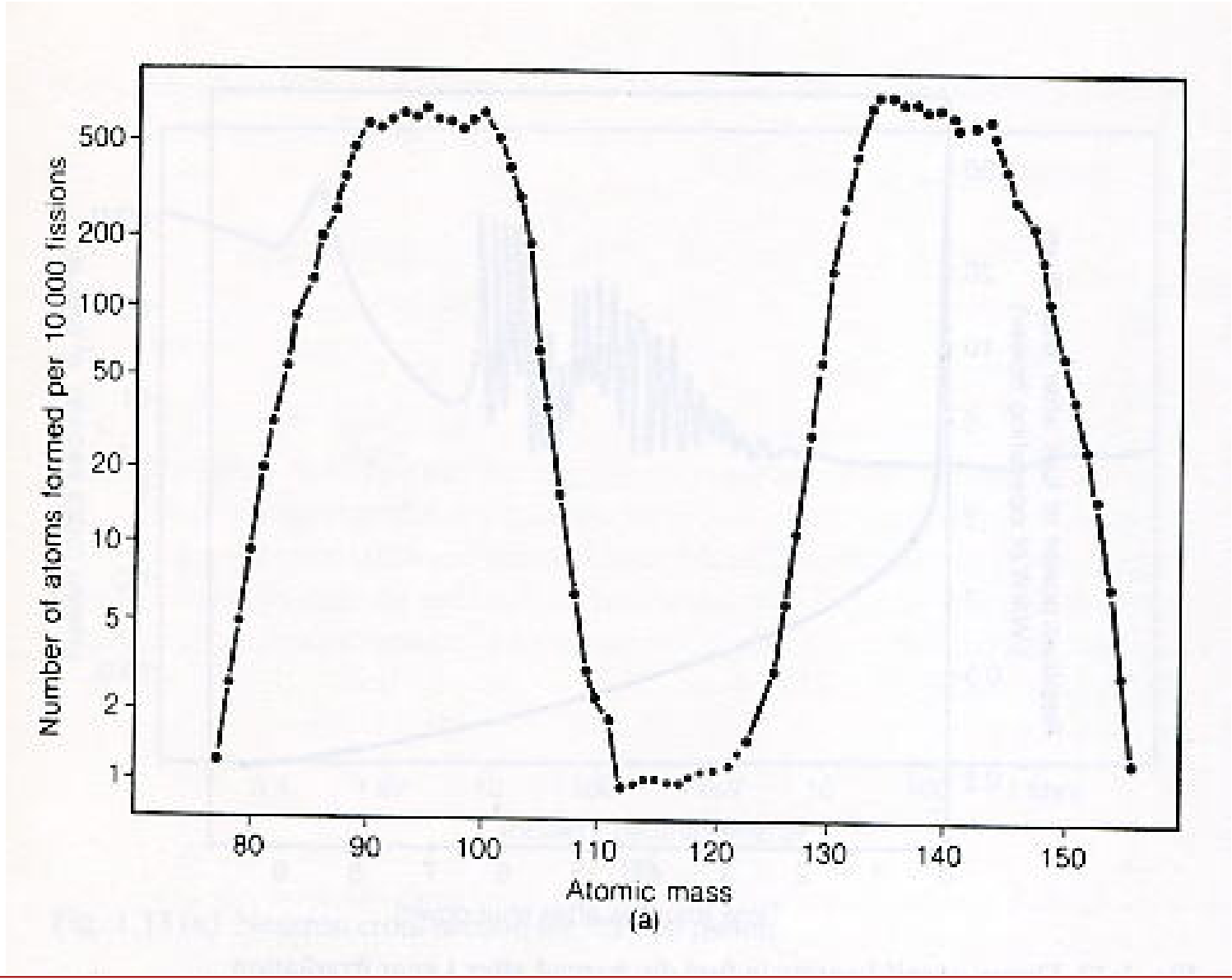
Calculating the Reactors

- ***Compare*** *Absolute Cumulative Fission Yields*
  - ***Oklo vs. modern nuclear reactors***
  - ***Oklo was fissioning both ^{238}U and ^{239}Pu as well as ^{235}U.***
    - ***But no ^{239}Pu present on the earth when Oklo formed***
    - ***Oklo Reactors have 'BRED' the ^{239}Pu***
    - ***^{236}U decayed in ^{232}Th***

Fission yields for ^{235}U, or « the camel's back »



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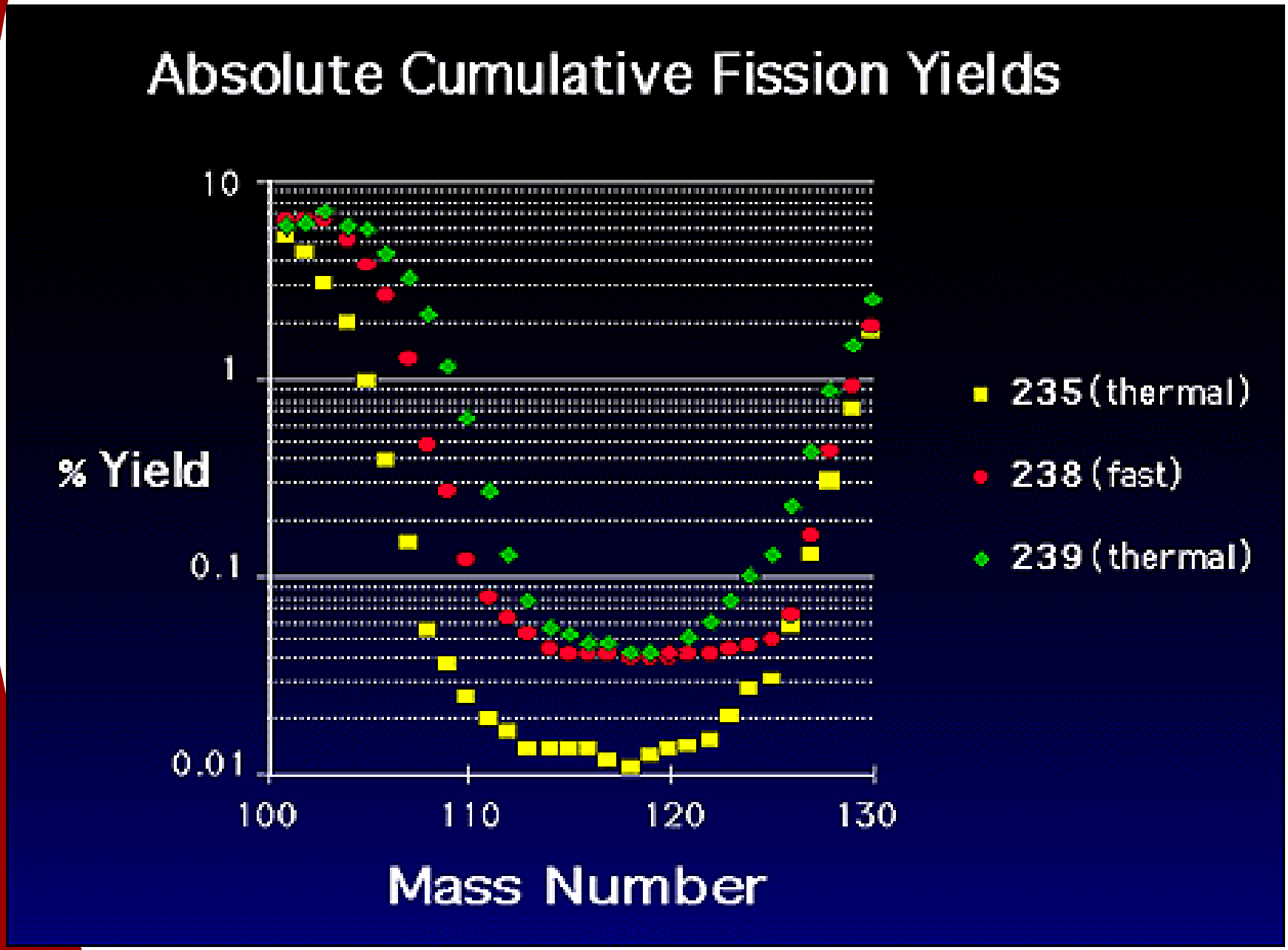
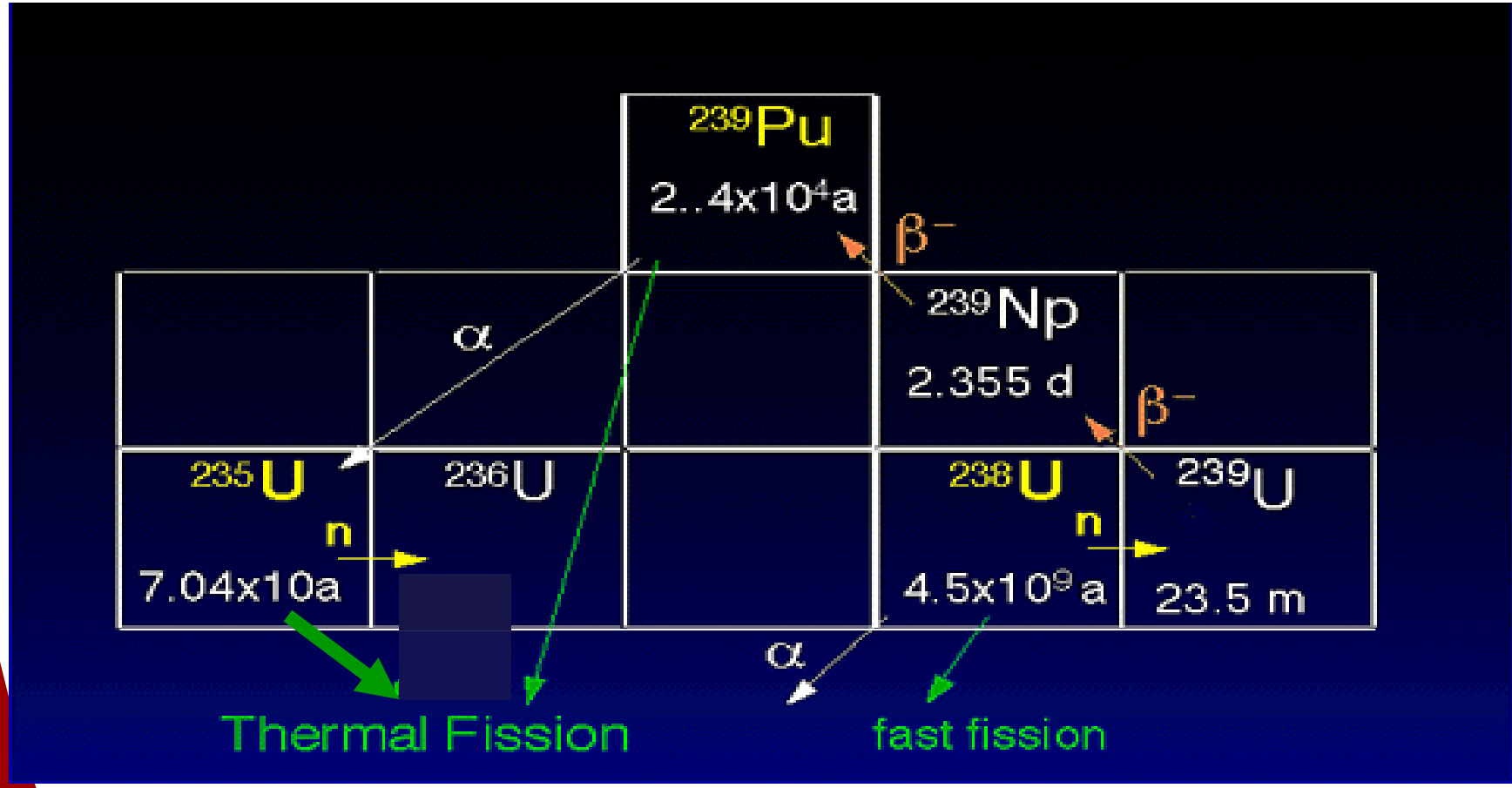

Absolute Cumulative Fission Yields
10
1
0.1
0.01
% Yield
100
110
120
130
Mass Number
235 (thermal)
238 (fast)
239 (thermal)

The main nuclear Reactions



Correlation between « enrichment » and U concentration in the Ore

% ^{235}U

% U in Ore

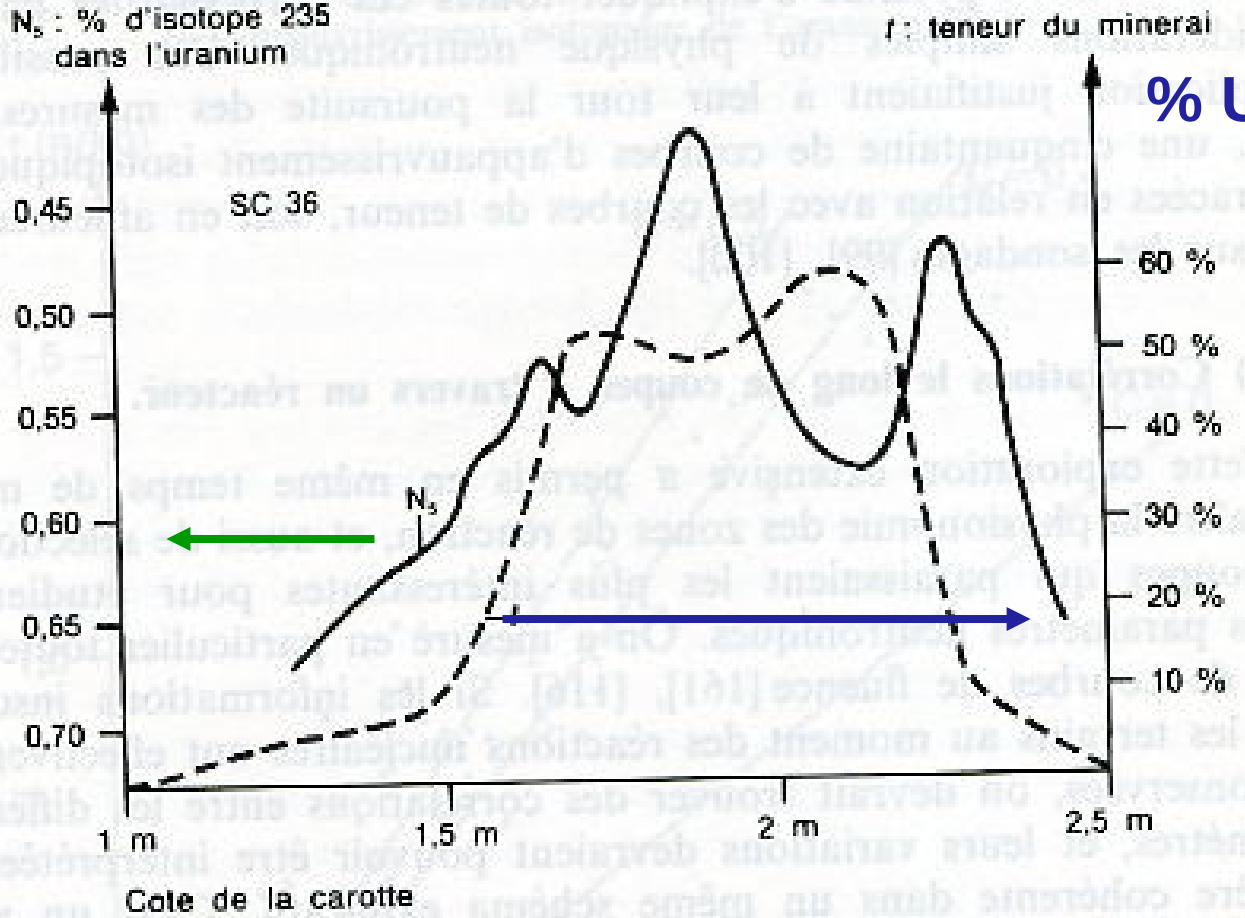


FIG. 7. — Exemple de « corrélation », le long d'un sondage, entre la teneur de l'uranium dans le minerai et son appauvrissement isotopique.

Average « Core » Temperature vs Fluence

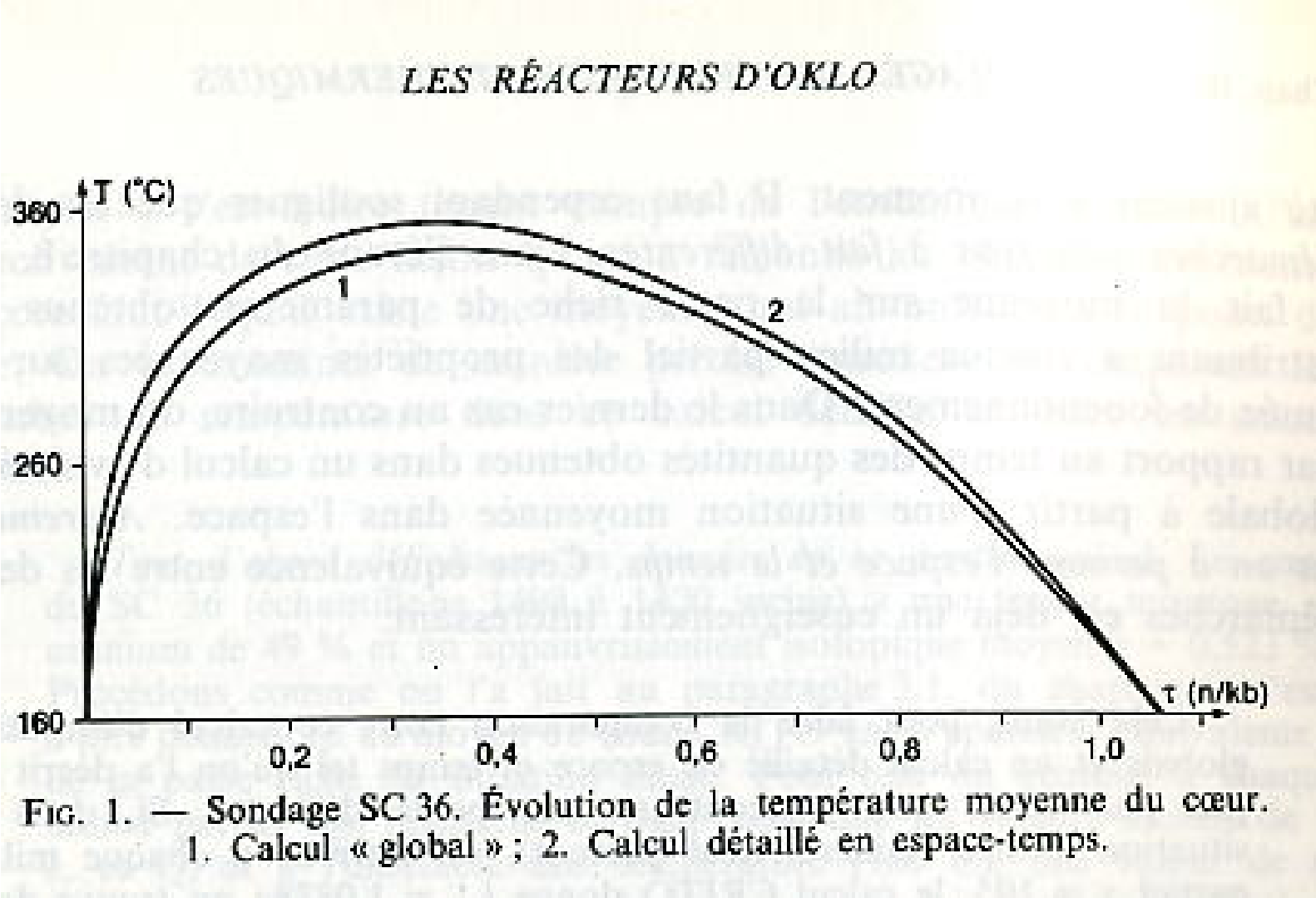


FIG. 1. — Sondage SC 36. Évolution de la température moyenne du cœur. 1. Calcul « global » ; 2. Calcul détaillé en espace-temps.

REACTOR 2

2 000 Kg of ^{235}U fissioned

5 500 Mw/y

REACTORS 7 to 9

480 Kg of ^{235}U fissioned

1 300 MW/y

REACTOR 10

650 Kg of ^{235}U fissioned

2 000 MW/y

Table 1

Amount of fissioned ^{235}U in various reactors.

Correlation between Reactor operation & Clay Formation

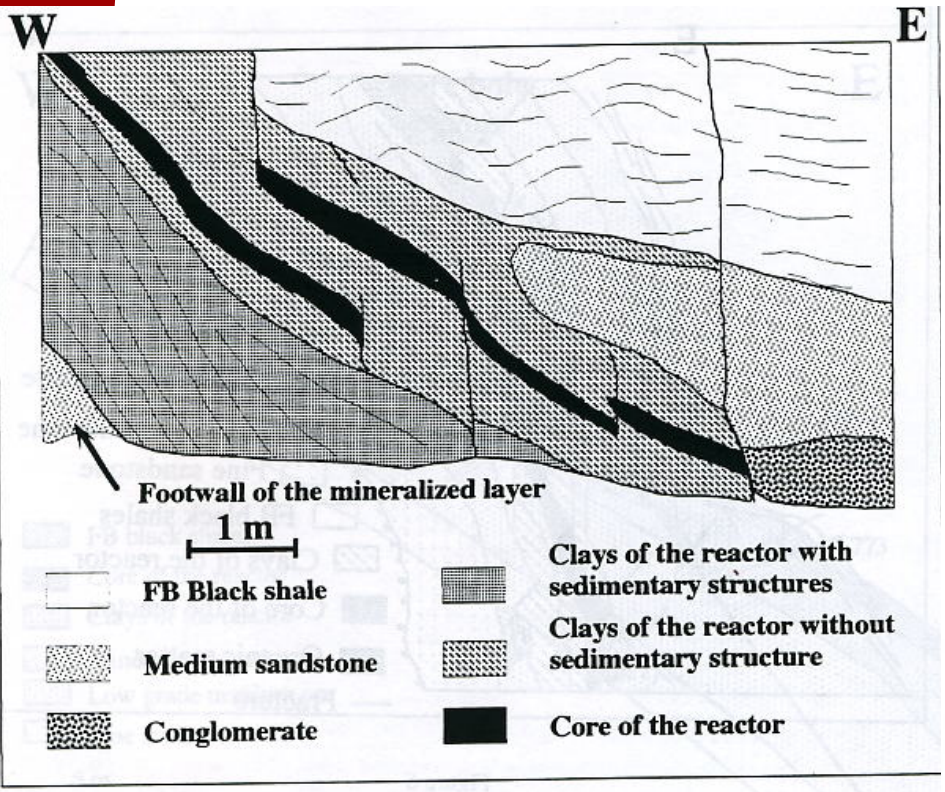


Figure 5

Outcrop of the bottom of the reactor 2.

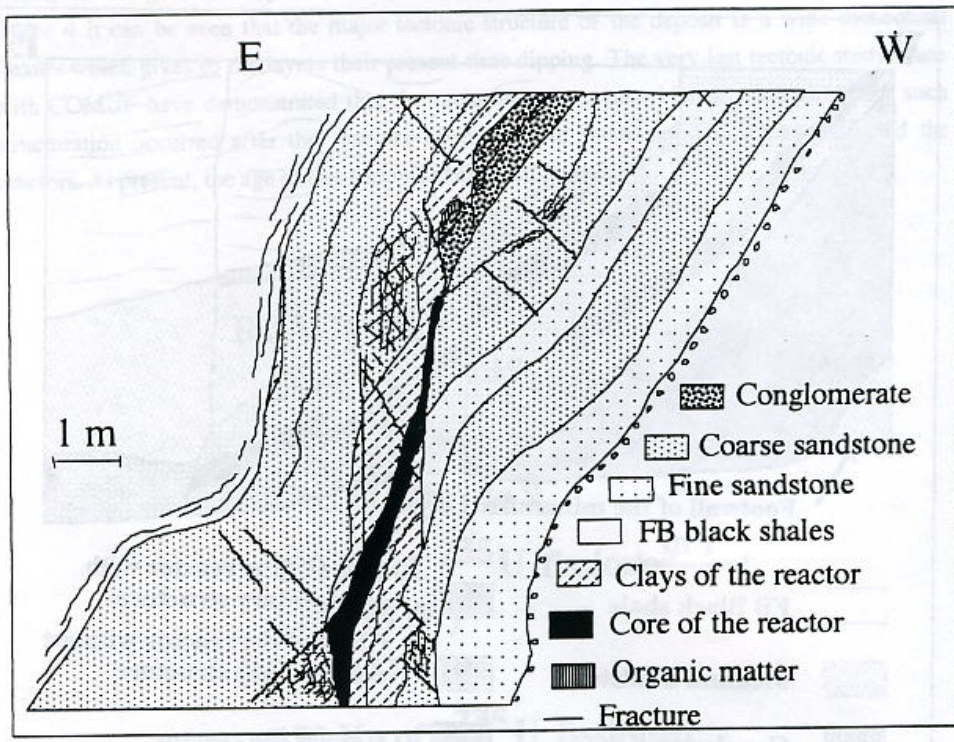


Figure 6

Cross section of the reactor 9.

OKLO as a Waste Disposal « Analogue » ?

Sciences

Oklo, réacteur nucléaire naturel

Physique Non seulement la fission nucléaire existait deux milliards d'années avant l'homme, mais, en plus, au Gabon, la nature a découvert le secret du stockage des déchets radioactifs.

« Berceau » géologique du réacteur naturel d'Oklo, au Gabon

« *Oklo fonctionnait comme un geyser.* » Le physicien américain Alexander

mesurant la proportion des neuf isotopes de xénon dans un minuscule fragment de matériau pré-

a pour effet de stopper la réaction en chaîne. La température retombe, la vapeur se recondense et donc les neutrons reprennent leur course. Au bout de deux heures trente, la réaction en chaîne se réenclenche. Et ainsi de suite...

Mais Meshik est bien davantage passionné par l'échantillon d'aluminophosphate (mélange de lanthane, cérium, strontium et calcium) qui a piégé le xénon et le krypton 85, produits de fission

Le Point

Nov 2004

Bure Underground Laboratory

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Bangombé :
Near Surface, best Analogue

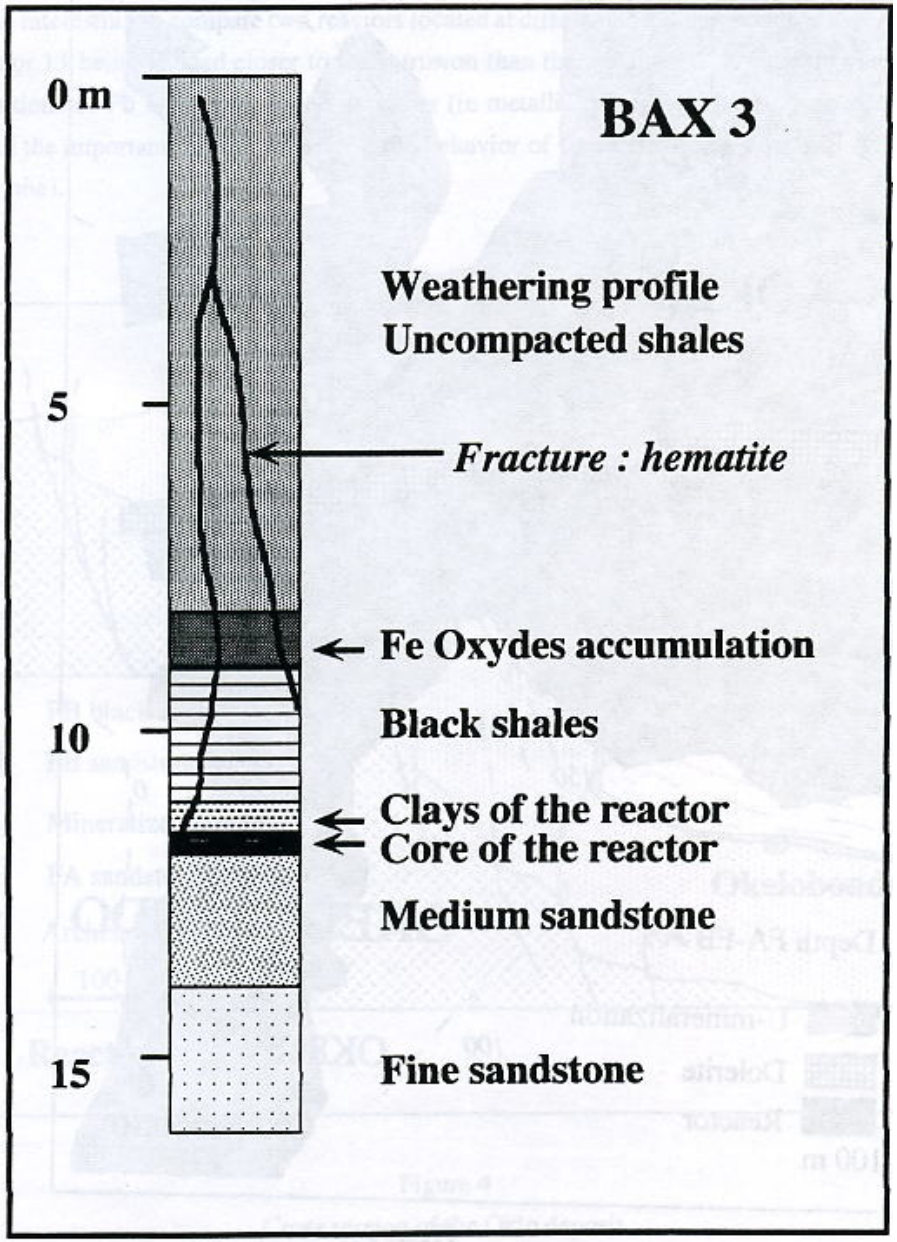
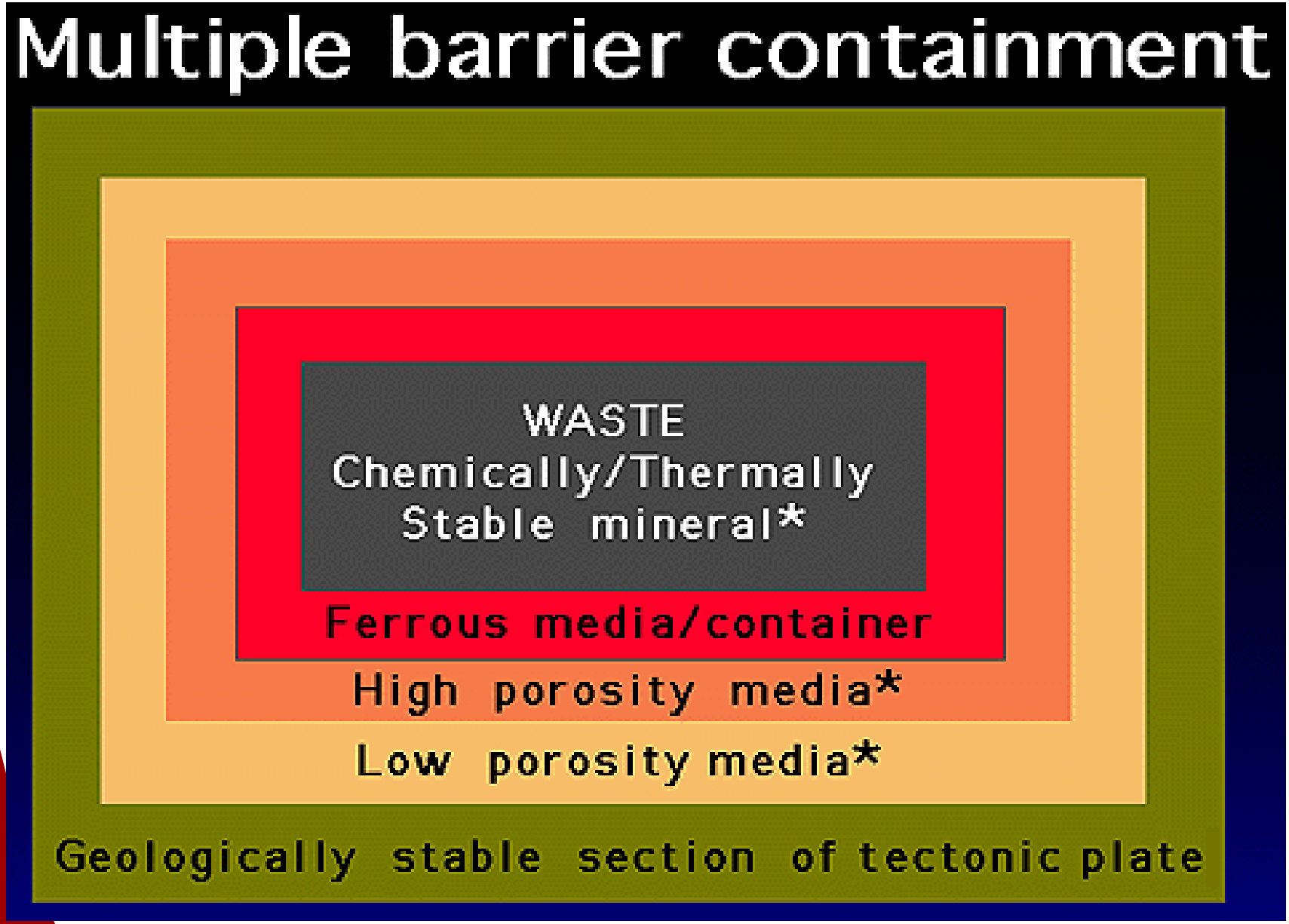


Figure 2
Stratigraphic Log of the bore-hole BAX3. Reactor of Bagombé

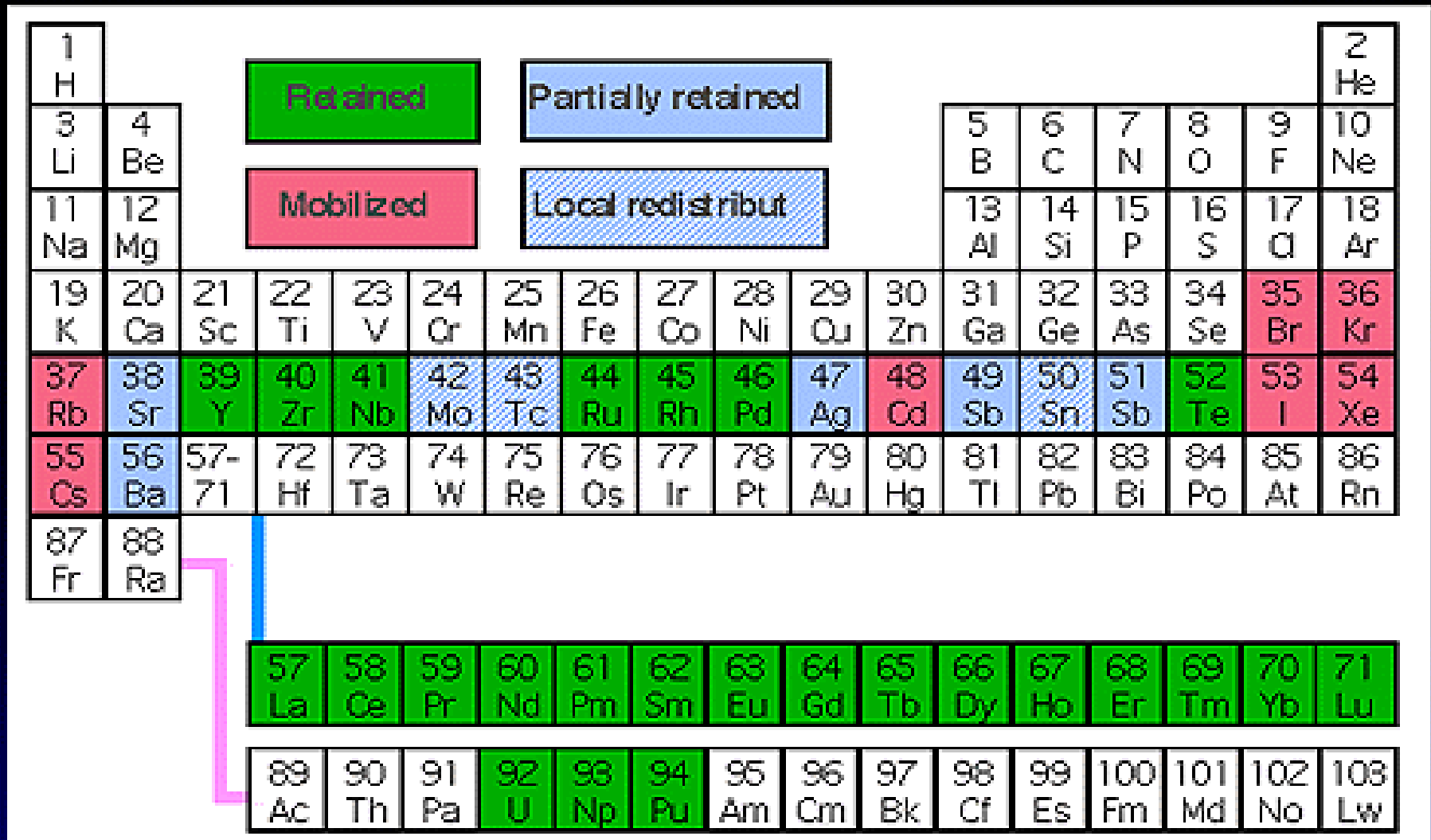
Oklo: The Natural Waste Disposal Experiment

- *Nature dealing with tonnes of concentrated radioactive waste near surface*
- *Large parts of reactor holding original waste still intact!*
  - *hope that nuclear fission waste may be stored in suitable geological repositories.*

Multiple barrier containment



Retention of Fission Products at OKLO



Summary

- *16 reactors 10 to 30 m wide & 1 m thick , 3 500 m deep.*
- *Operation : 100 000 to 1 million years*
- *Flux 10^{7} to 10^{8} $n.cm^{-2}.s^{-1}$*
- *Fluence 1.3 10^{21} $n.cm^{-2}$*
- *Temperature ~300°C (from ^{176}Lu)*
- *Water controlled. Water/U ~20 to 30% volume*
- *Total Energy produced 16 500 W.year*
- *Plutonium production ~3 t*

One of a Kind ??

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