オクロ現象:　天然原子炉の謎

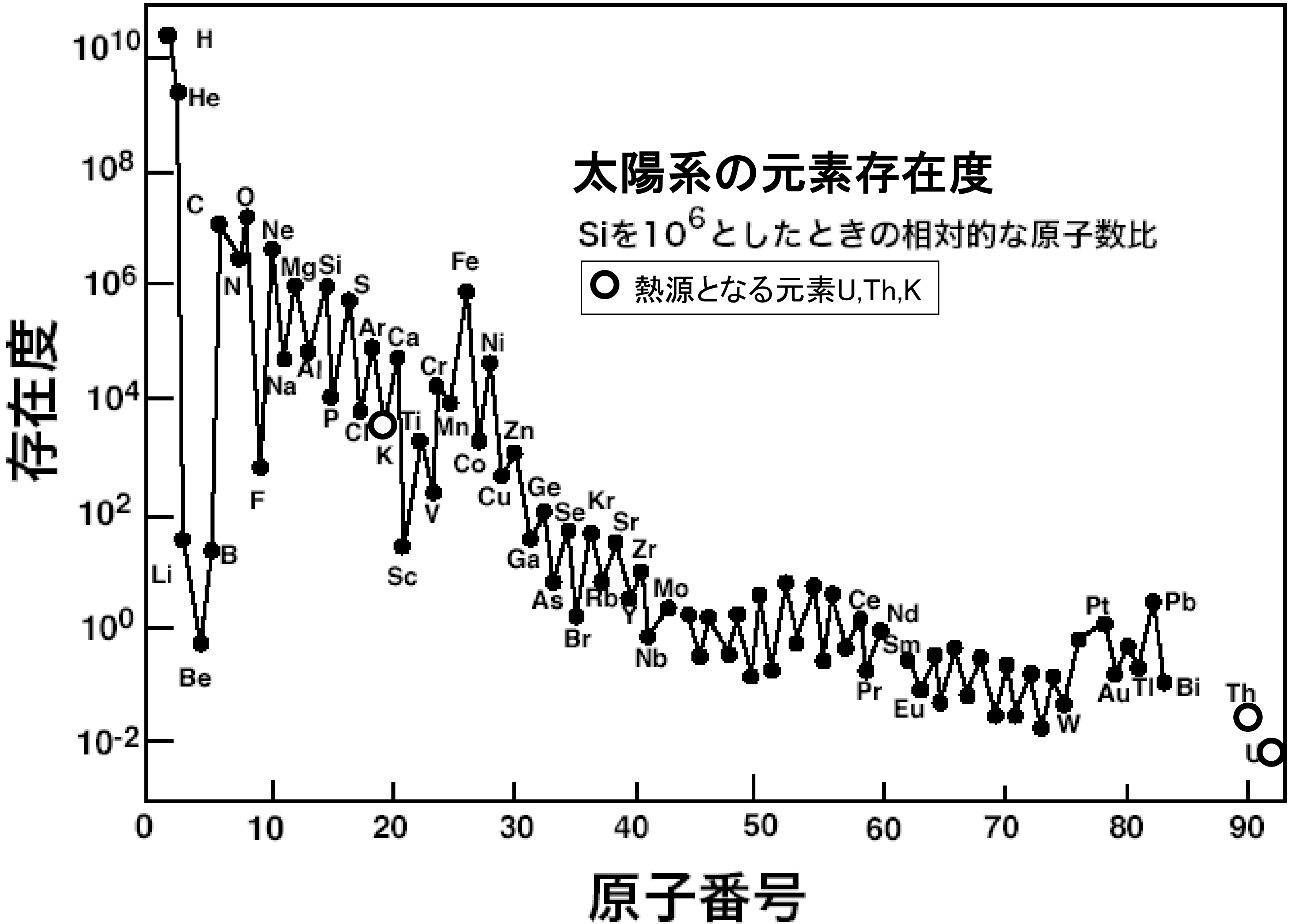
Oklo Phomenon

Nuclear Reactor in Nature

A "FOSSILIZED" NUCLEAR REACTOR

1.7 billion years ago

図 4.



地球の熱収支

太陽光として太陽から放出された光は、地球軌道付近で約**1.37kW/m²**（太陽定数）のエネルギーを持つ。

- 熱の散逸

  地球表面から宇宙空間の**80mW/m²**

  Q_{out} = 44 TW（全地球表面） ＝ $44X10^{12}$ W

- 熱の生成

  a) 地球形成期の熱（微惑星衝突＋核の分離の重力エネルギーの解放）

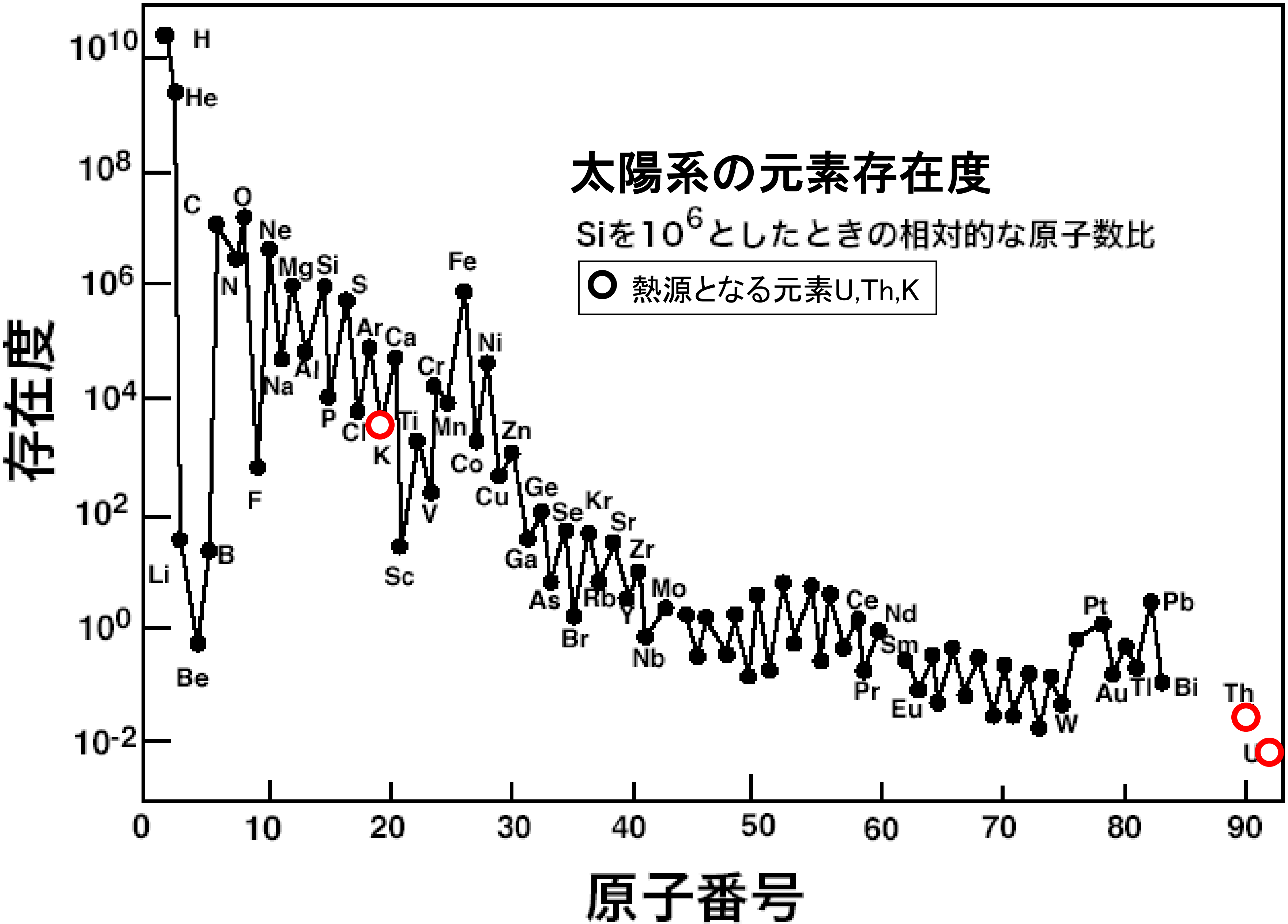
  b) 放射性熱源 ^{235}U, ^{238}U, ^{232}Th, ^{40}K：Q_R= 24 TW (コンドライトから推定）

  c) 核からマントルへの熱： Qc = 3-10 TW (ジオダイナモを駆動するのに必要な熱）

  内訳： 核の冷却 2-9 TW；
  内核の結晶化の潜熱 0.34 TW
  核の形成の重力エネルギー開放 0.66 TW

ユーリー比（Urey Ratio) = 地球内部の生成熱/地表からの熱散逸 ＝ Q_R/Q_{out}= 24/44~0.55

図 4.



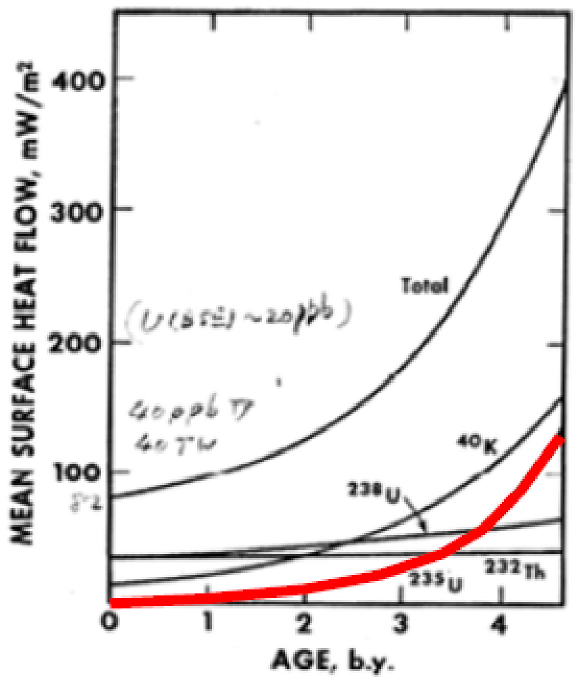
太陽系の元素存在度
Siを10^6としたときの相対的な原子数比
熱源となる元素U,Th,K
存在度
原子番号
H
He
Li
Be
B
C
N
O
F
Ne
Na
Mg
Al
Si
P
S
Cl
Ar
K
Ca
Sc
Ti
V
Cr
Mn
Fe
Co
Ni
Cu
Zn
Ga
Ge
As
Se
Br
Kr
Rb
Sr
Y
Zr
Nb
Mo
Ce
Pr
Nd
Sm
Eu
W
Pt
Au
Tl
Pb
Bi
Th
U

Geologically Useful Decay Schemes

Parent	Daughter	Half-life (years)
^{235}U	^{207}Pb	4.5×10^9
^{238}U	^{206}Pb	0.71×10^9
^{40}K	^{40}Ar	1.25×10^9
^{87}Rb	^{87}Sr	47×10^9
^{14}C	^{14}N	5730
^{232}Th	^{228}Ra	1.405×10^{10}

Geologically Useful Decay Schemes

146 *Basaltic Volcanism on the Terrestrial Planets*



9.4.1 Heat production in the Earth during geological time assuming that the present surface flux is in equilibrium with radiogenic heat production. In the lower part of the diagram the separate contributions of U, Th and K are shown. Present day values of Th/U = 3.7 and K/U = 10,000 are assumed.

Parent	Daughter	Half-life (years)
^{235}U	^{207}Pb	0.71×10^9
^{238}U	^{206}Pb	4.5×10^9
^{40}K	^{40}Ar	1.25×10^9
^{232}Th	^{228}Ra	1.405×10^{10}

3% similar to the man-made fission reactor more than 1.7 b.y. ago, and it decayed rapidly in later stage (0.72% at present).

17億年前の天然原子炉の謎:オクロ現象

原子炉の歴史:

１９４２年, シカゴ大学のエンリコフェルミ教授が原子炉が世界で最初に臨界状態に達す.

濃縮２３５Uの核分裂反応

軽水炉(減速材, 冷却材に水)

重水炉(減速材に重水)

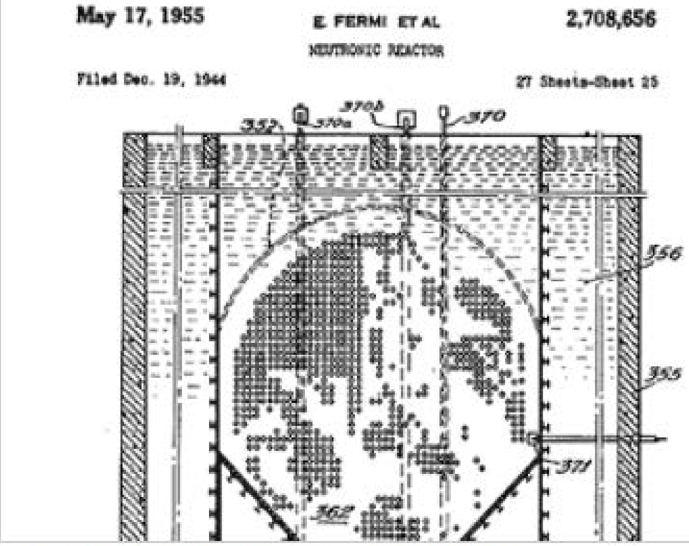
高速増殖炉(２３９Pu, 冷却材に金属ナトリウム)

２３５Uの半減期:７億年

２３９Puの半減期:２万４千年

1942

The First Man Made Fission Reactors



Part of Figure 38 from US Patent 2,708,656, 'Neutronic Reactor', awarded to Enrico Fermi and Leo Szilard.
[Source: Wikipedia CCL]

Enrico Fermi

Enrico Fermi, Italian-American physicist.
[Source: Wikipedia CCL]

Atomic Scientists, 20th Anniversary Reunion, 1962. The group who participated with Enrico Fermi in the December 2, 1942 experiment to create the world's first fission reactor.
[Source: Wikipedia GFDL]

福島第一原子力発電所

天然原子炉の謎

１９７２年９月 「天然の原子炉の発見」フランス原子力庁
オクロ鉱山の２３５Uの存在量が少ない.
235U:0.4~0.6%
通常は0.7%
約17億年前に核分裂連鎖反応が起こっていた.
この原子炉は１００万年程度の期間，熱を放出した.

黒田和夫アーカンソー大学教授が理論的に予測していた.

どうして，天然原子炉が形成されたのか.
酸素を含む大気ができ，酸化ウランが水に溶け，川の流れの中で沈殿，濃集した.

Paul K. Kuroda (1917-2001)

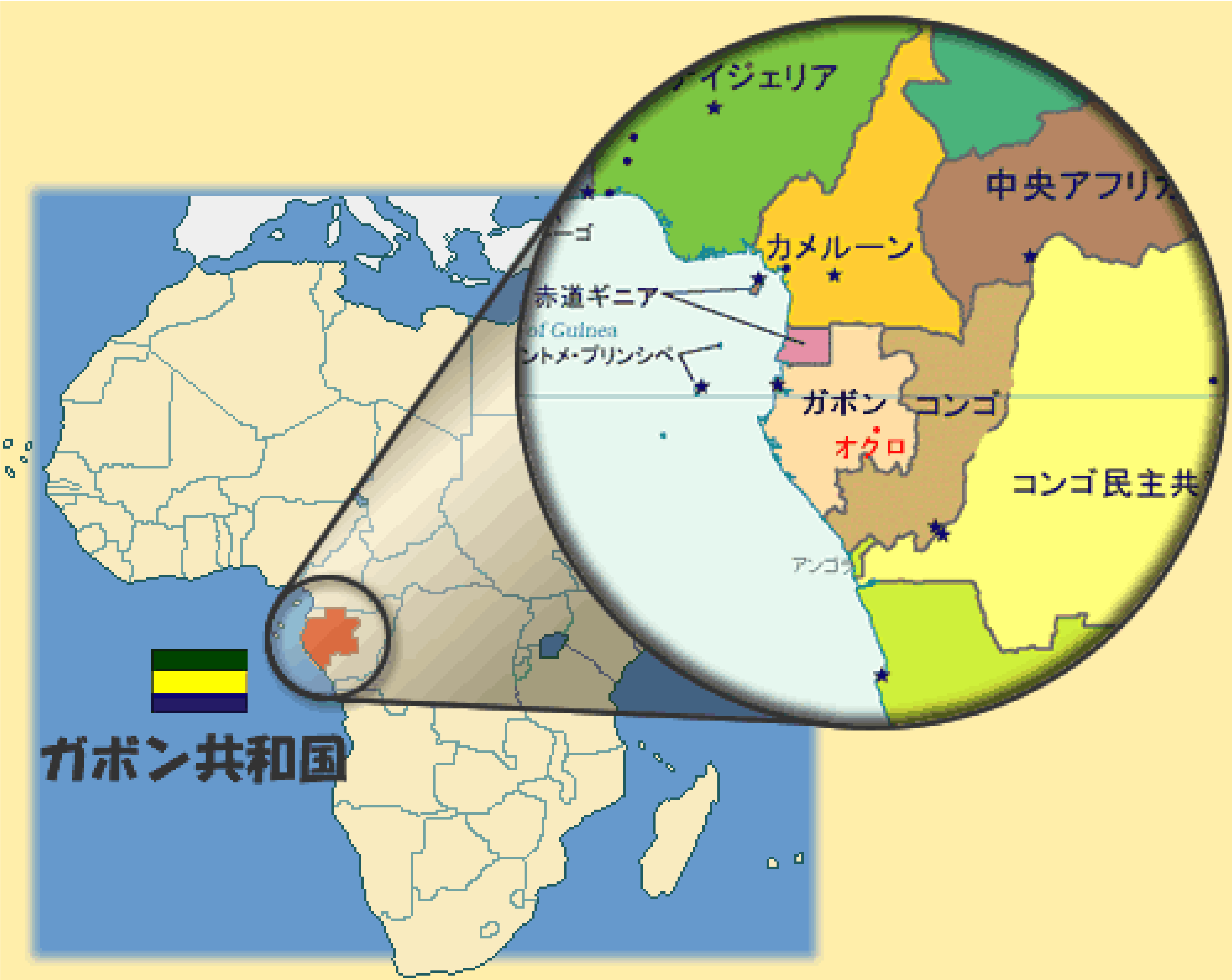
Kuroda, P. K., *J. Chem. Phys., 1956,* ***25,*** 781–782.

Following his move to Arkansas and his marriage to Louise, he became a US Citizen in 1955. At the University of Arkansas he trained 64 PhD students, several postdoctoral associates, and he befriended many undergraduate students. He became the first Edgar Wertheim Distinguished Professor of Chemistry in 1979, he officially retired from the University of Arkansas in 1987, but he remained active in research. He was the author or co-author of almost 400 publications.

Meteoritics & Planetary Science **36**, 1409-1410 (2001)

Paul K. Kuroda was born on 1 April 1917 in Fukuoka Prefecture, Japan, as Kazuo Kuroda, and died at his home in Las Vegas, Nevada on 16 April 2001. He received bachelors and doctoral degrees from the Imperial University of Tokyo where he studied under Professor Kenjiro Kimura.

- **Kuroda**, P. K. 1956. On the nuclear physical stability of the uranium minerals. Journal of Chemical Physics 25:781-1295.
- **Naudet**, R. 1974. Commissariat á l'Energie Atomique (France), Le Phénomène d'Oklo. Commissariat á l'energie Atomique, Bulletin d'Informations Scientifiques et Techniques 193(June):7-45.



ガボン共和国
イジェリア
中央アフリ
カメルーン
ーゴ
赤道ギニア
of Guinea
ントメ・プリンシペ
ガボン
コンゴ
オクロ
コンゴ民主共
アンゴラ

Oklo fossilized atomic reactor

R. Michel, ZSR, Leibniz Universität Hannov

（すでに知られていたNo.1～No.9に加えてA，B，C およびDが発見されている。）

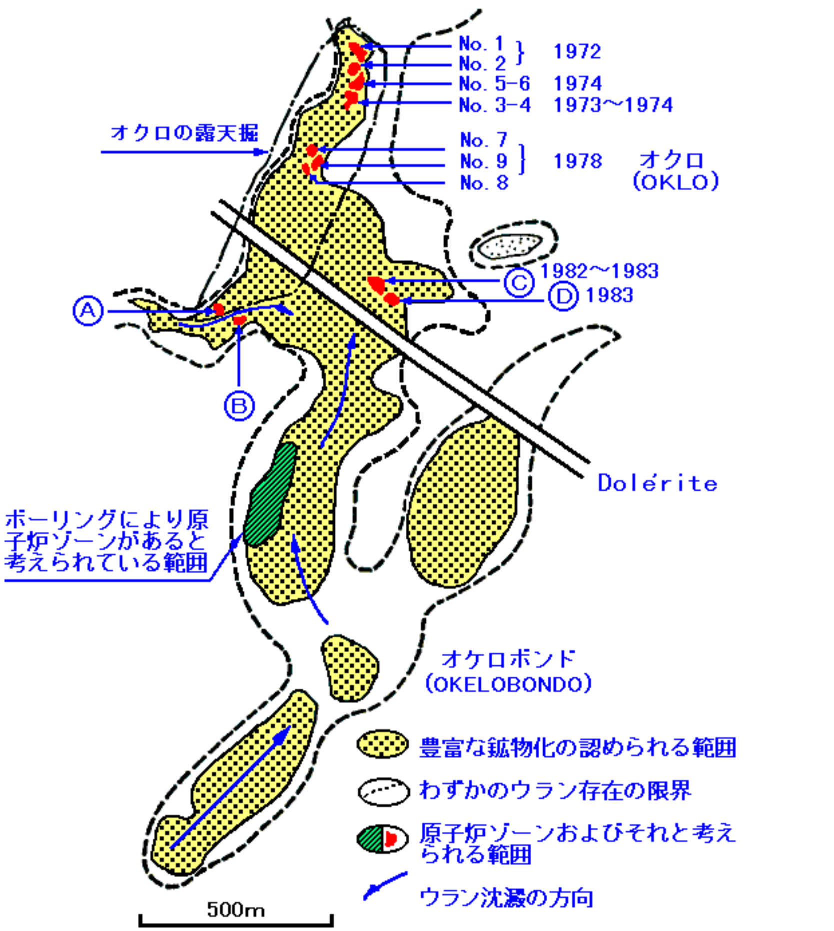
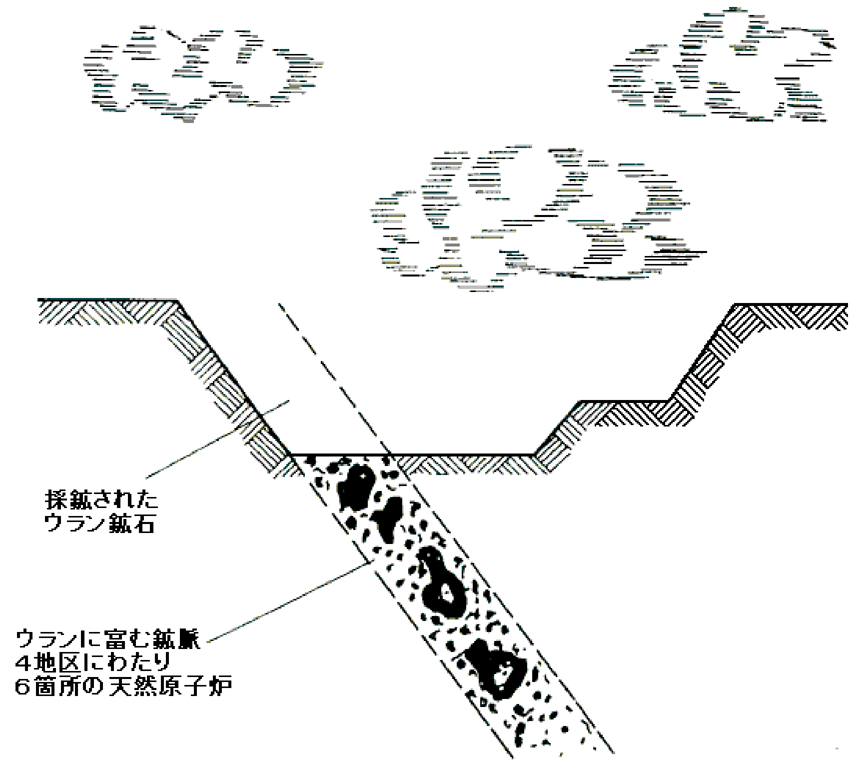


図２　オクロとオケロボンドのＵ鉱床における原子炉ゾーンの分布（１９８４年現在）

［資料提供］フランスビル・ウラン鉱山会社（ＣＯＭＵＦ）



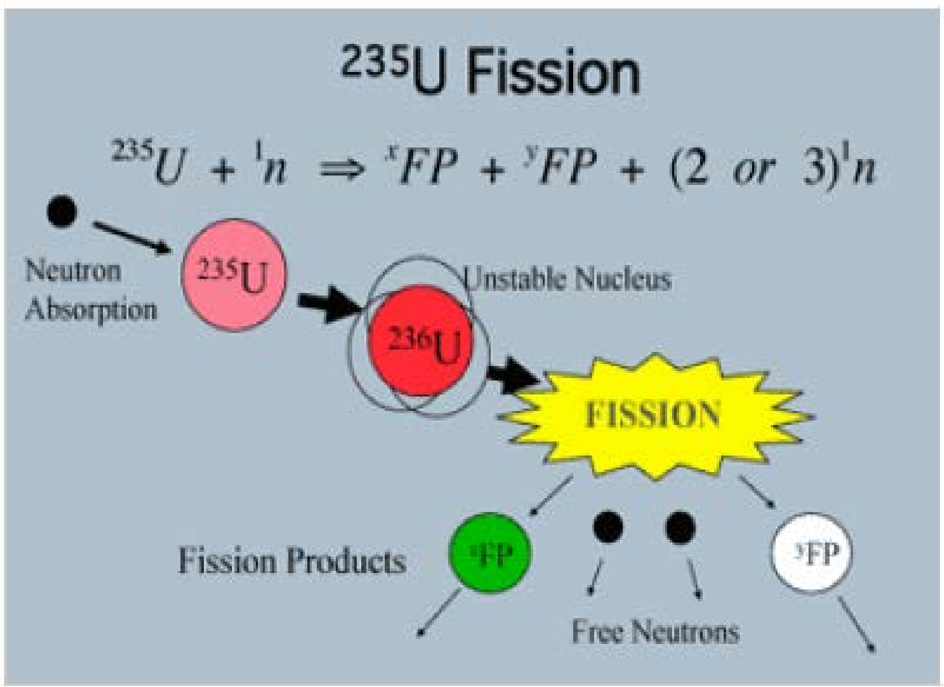
オクロ原子炉跡、ここには6ヵ所の天然原子炉炉心が4つの反応帯に分かれて存在する。

図３　オクロ原子炉跡

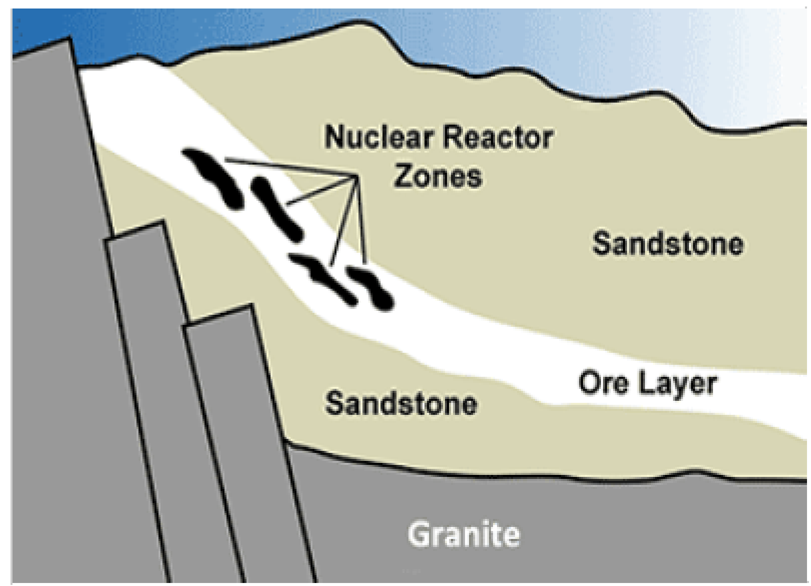
［出典］Ivan. G. Draganic ほか（松浦辰男ほか訳）：放射線と放射能、学会研究センター（1996．1），p149

A **natural nuclear fission reactor** is a uranium deposit where analysis of isotope ratios has shown that self-sustaining nuclear chain reactions have occurred. The existence of this phenomenon was discovered in 1972 at Oklo in Gabon, Africa, by French physicist Francis Pe

The Fission Process



Discovery of the Oklo Fission Reactors



The radioactive remains of a natural nuclear fission reaction that happened 1.7 billion years ago in Gabon, Africa, were held in place by the surrounding geology.
[Source: Wikipedia CCL]

The Oklo mining site

The outcrop of the ore from the deposit

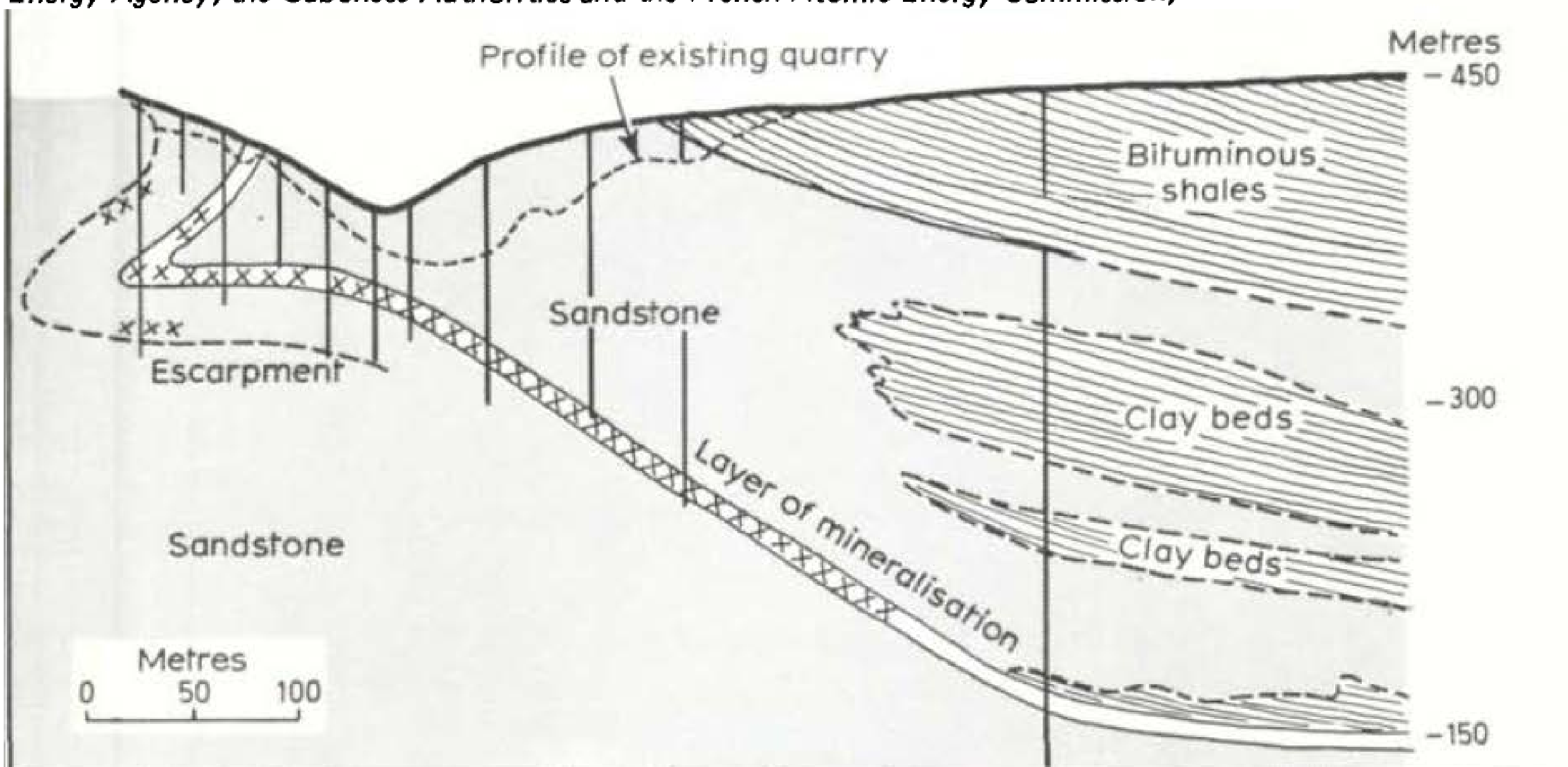

オクロ鉱山の天然原子炉

REPORT ON INTERNATIONAL SYMPOSIUM ON THE OKLO PHENOMENON
LIBREVILLE, GABON, JUNE 1975
The meeting was attended by 73 participants from 19 countries.

A "FOSSILIZED" NUCLEAR REACTOR

The Oklo Phenomenon

A scientific conference about the Oklo phenomenon took place in Gabon in West Africa on 23–27 June this year. The conference was arranged jointly by the International Atomic Energy Agency, the Gabonese Authorities and the French Atomic Energy Commission,



Scale drawing of the Oklo mine formation. Credit: New Scientist

How and Why the natural reactor formed?

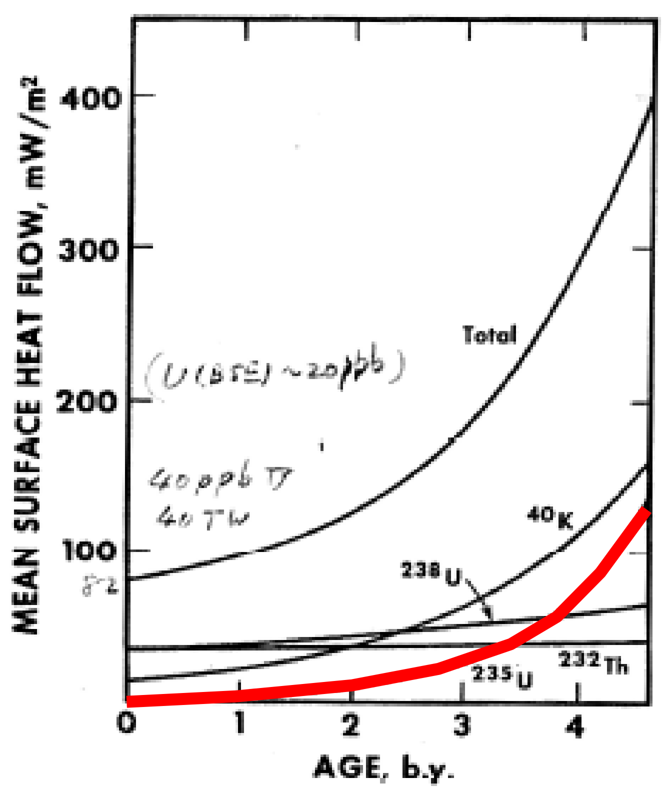
Why it formed 1.7 billion years ago

1. High concentration of ^{235}U: 3% similar to the man-made fission reactor, and it decayed rapidly in later stage (0.72% at present).

2. Development of the oxygen atmosphere in the Early Earth: Evidence from iron ore formations Oxidized uranium dissolved in ground water and precipitated to form U ore deposit.

Geologically Useful Decay Schemes

146 *Basaltic Volcanism on the Terrestrial Planets*



9.4.1 Heat production in the Earth during geological time assuming that the present surface flux is in equilibrium with radiogenic heat production. In the lower part of the diagram the separate contributions of U, Th and K are shown. Present day values of Th/U = 3.7 and K/U = 10,000 are assumed.

Parent	Daughter	Half-life (years)
^{235}U	^{207}Pb	0.71×10^{9}
^{238}U	^{206}Pb	4.5×10^{9}
^{40}K	^{40}Ar	1.25×10^{9}
^{232}Th	^{228}Ra	1.405×10^{10}

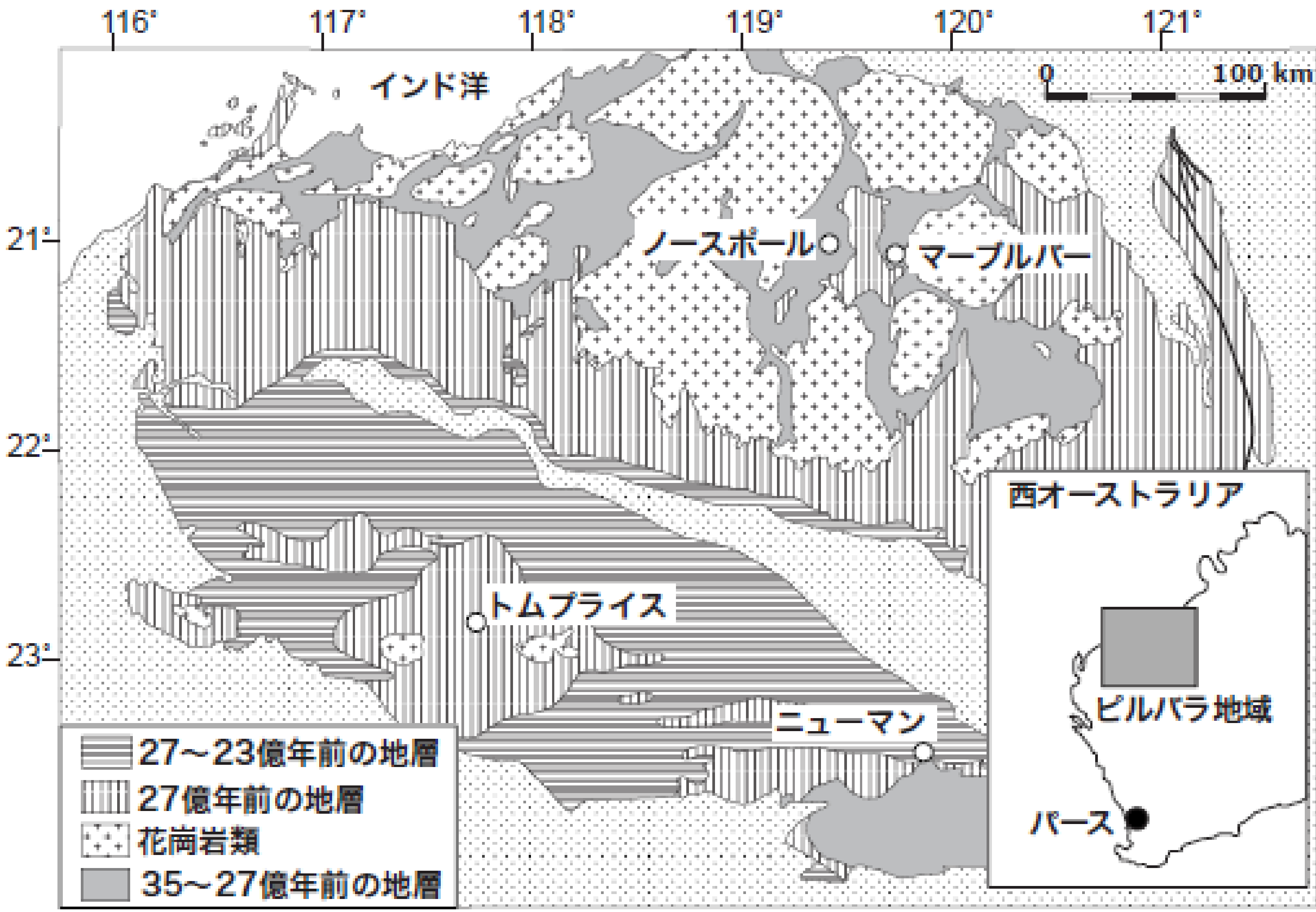
3% similar to the man-made fission reactor more than 1.7 b.y. ago, and it decayed rapidly in later stage (0.72% at present).

大気中の酸素の発生と縞状鉄鉱層

そして　オクロ現象

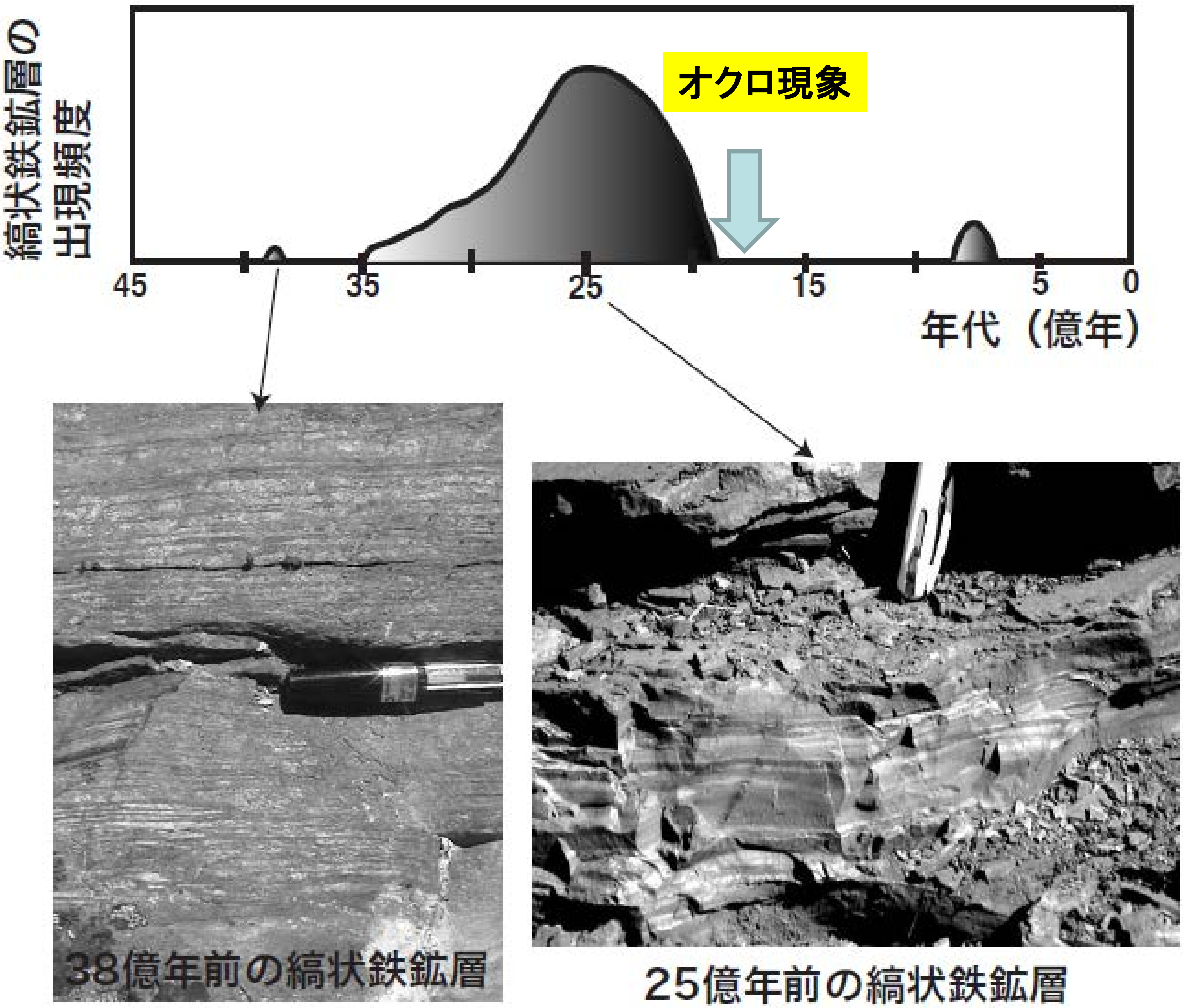
大気中の酸素の発生と縞状鉄鉱層

図67　ピルバラ地域の地質:　太古代の地質



シアノバクテリア？　光合成反応　特異な形態のグラファイト:化石？

図71　縞状鉄鉱層の形成と大気中の酸素の発生



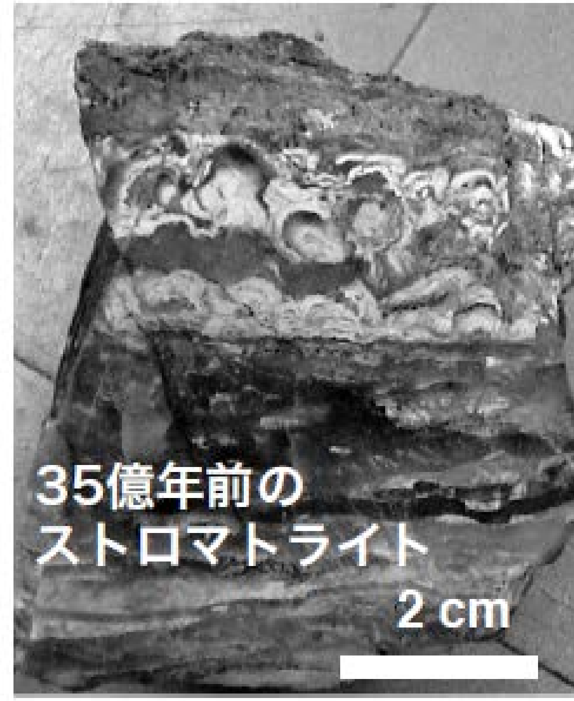
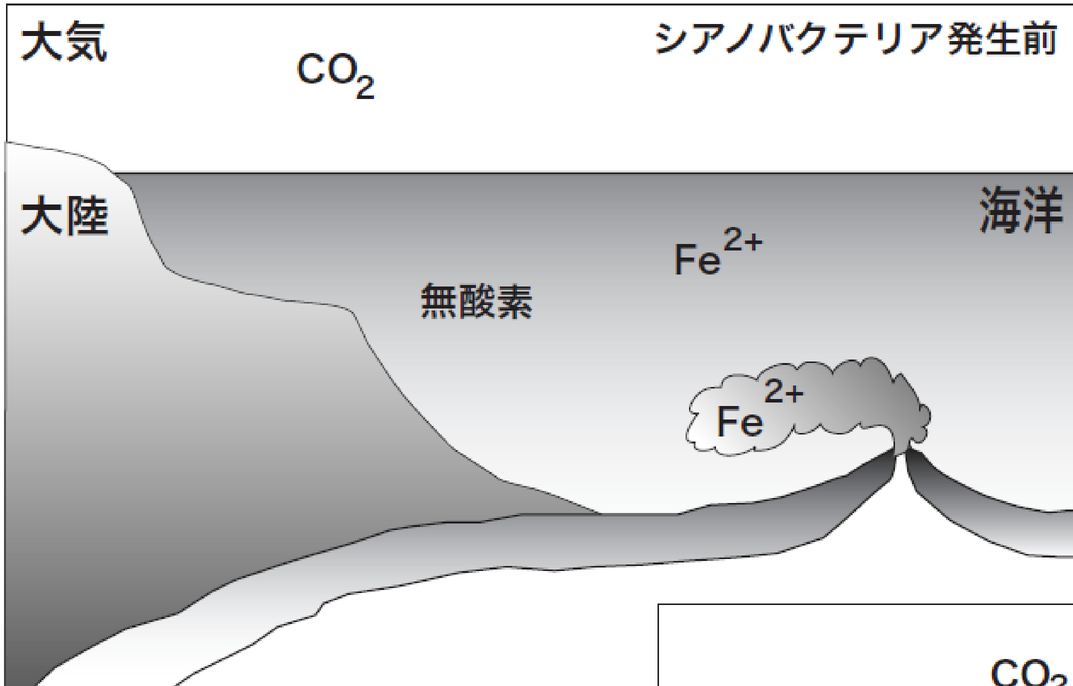


図69　ストロマトライトと酸素の発生

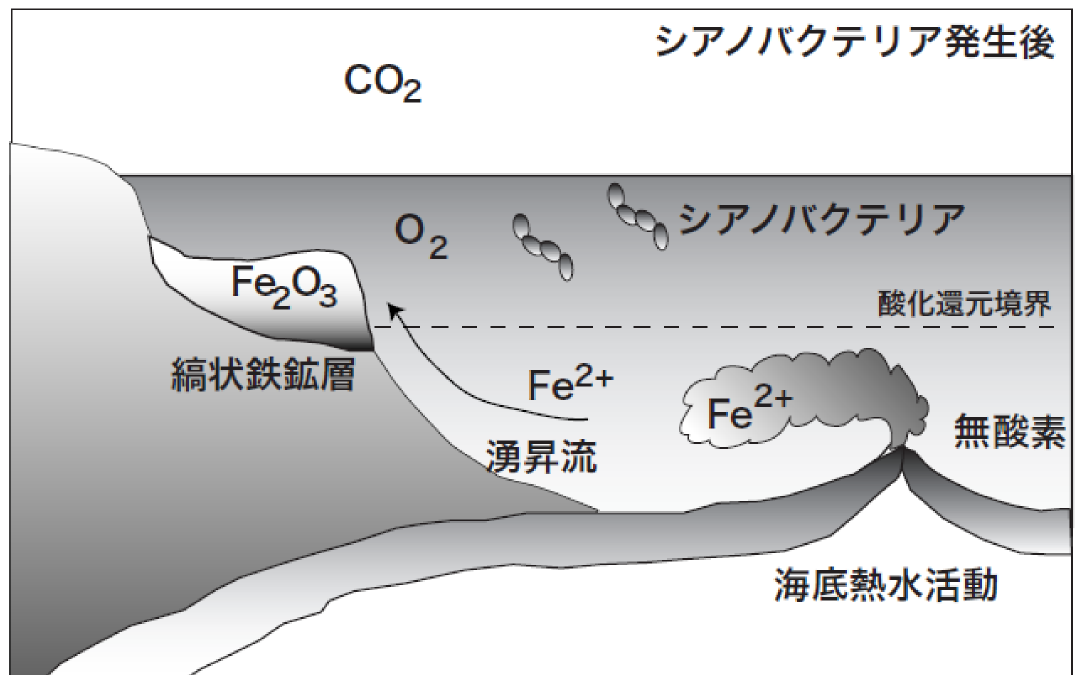
シアノバクテリアの活動の結果

$CaCO_3$の殻を作る。



酸素の発生と縞状鉄鉱層の形成

酸化によるFe2O3の沈殿



シアノバクテリア

$CO_2+H_2O \rightarrow CH_2O+O_2$

Summary

- Fossilized fission reactor was discovered in Oklo.

- It was formed 1.7 billion years ago and worked for one million years.

- It was formed because of 1) higher concentration of ^{235}U (~3%) in early Earth and 2) oxidization and dissolution of uranium in ground water and precipitation to form U-ore deposit.

- Oxygen atmosphere was generated by cyanobacteria by that time.

Thank you for your attention.

Message to take your home.
Remind the great activities in Nature!

考えてみよう･

オクロ現象[天然の原子炉）は、中央アフリカのオクロにしか発見されていない。

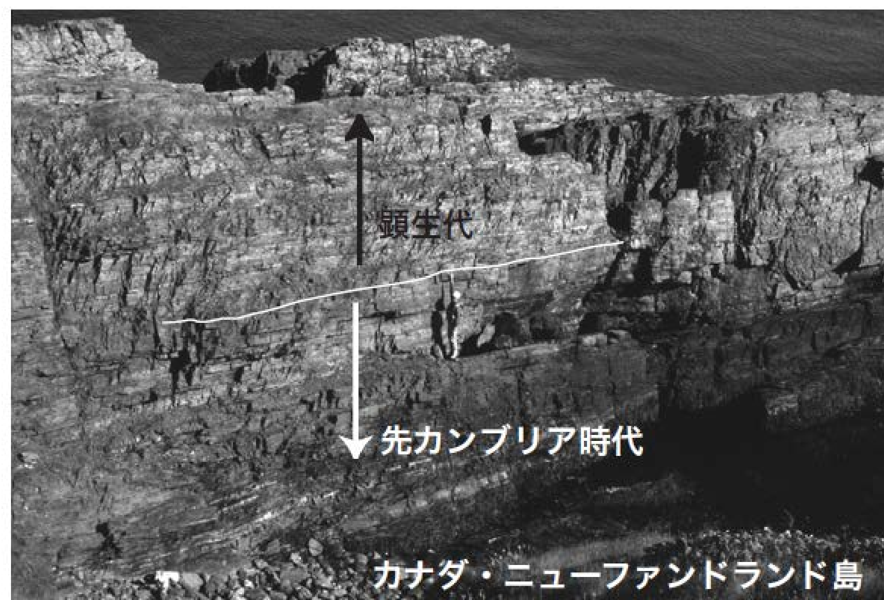
これを発見するには、どこを調査したらよいのであろうか？

図79　 生物の痕跡:生痕化石(生物の這い跡の化石)

図77　カンブリア紀の生命大爆発

5億4500万年前
プレカンブリア時代の終結

図78



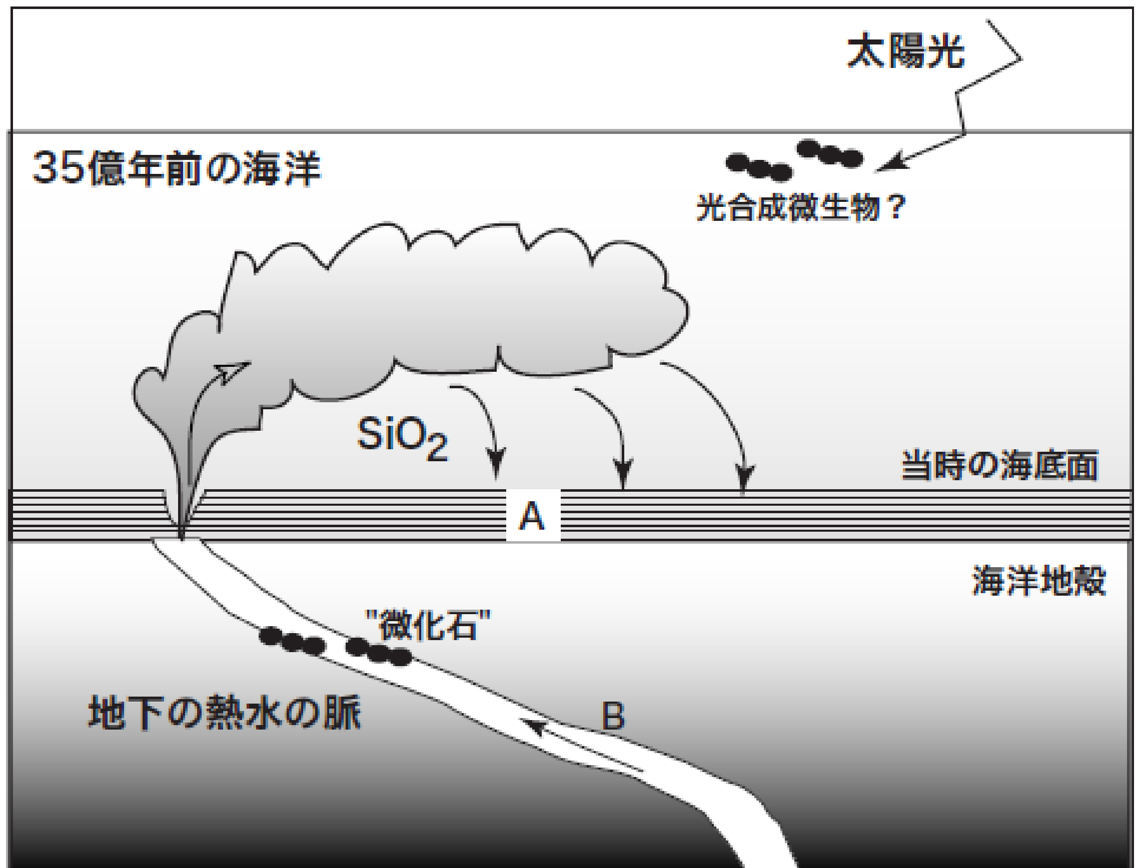


図68

微化石の存在

光合成微生物？


25億年前の縞状鉄鉱層
(オーストラリア)


縞状鉄鉱層から
鉄を採掘する鉱山(南アフリカ)

図72


2 m
27億年前の縞状鉄鉱層(カナダ)

図71　　縞状鉄鉱層の形成と大気中の酸素の発生