Early Earth and South Africa Geology

Yoshio Okamoto

Geoscience-English lecture
29th Nov. 2016
Tennoji High School At OKU

Why South Africa?

As a Geological wonderland

Oldest rocks: Canada, Greenland, Western Australia;
most accessible locality!

⇒In Japan, no rock of this era.

Economic Ores: Gold, Diamond, Platinum etc.

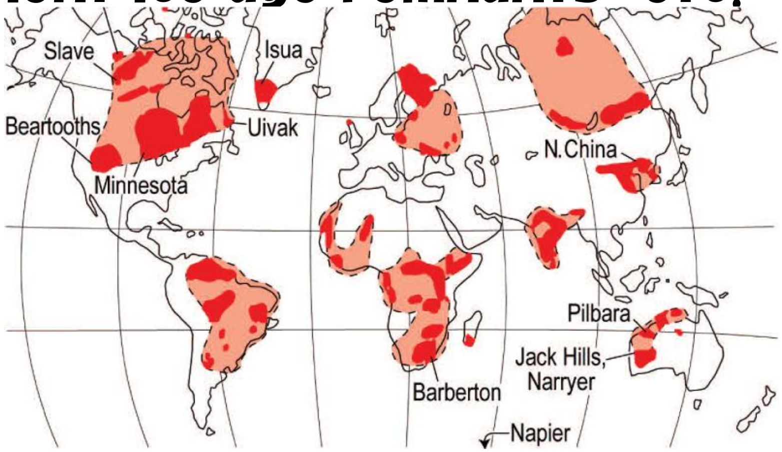
Gondwana homeland of continental drift

Oldest magma intrusion "Bushveld igneous intrusion"

Meteor impacts Crater

Banded Iron Formation(BIF)

Ancient ice age remnants etc.

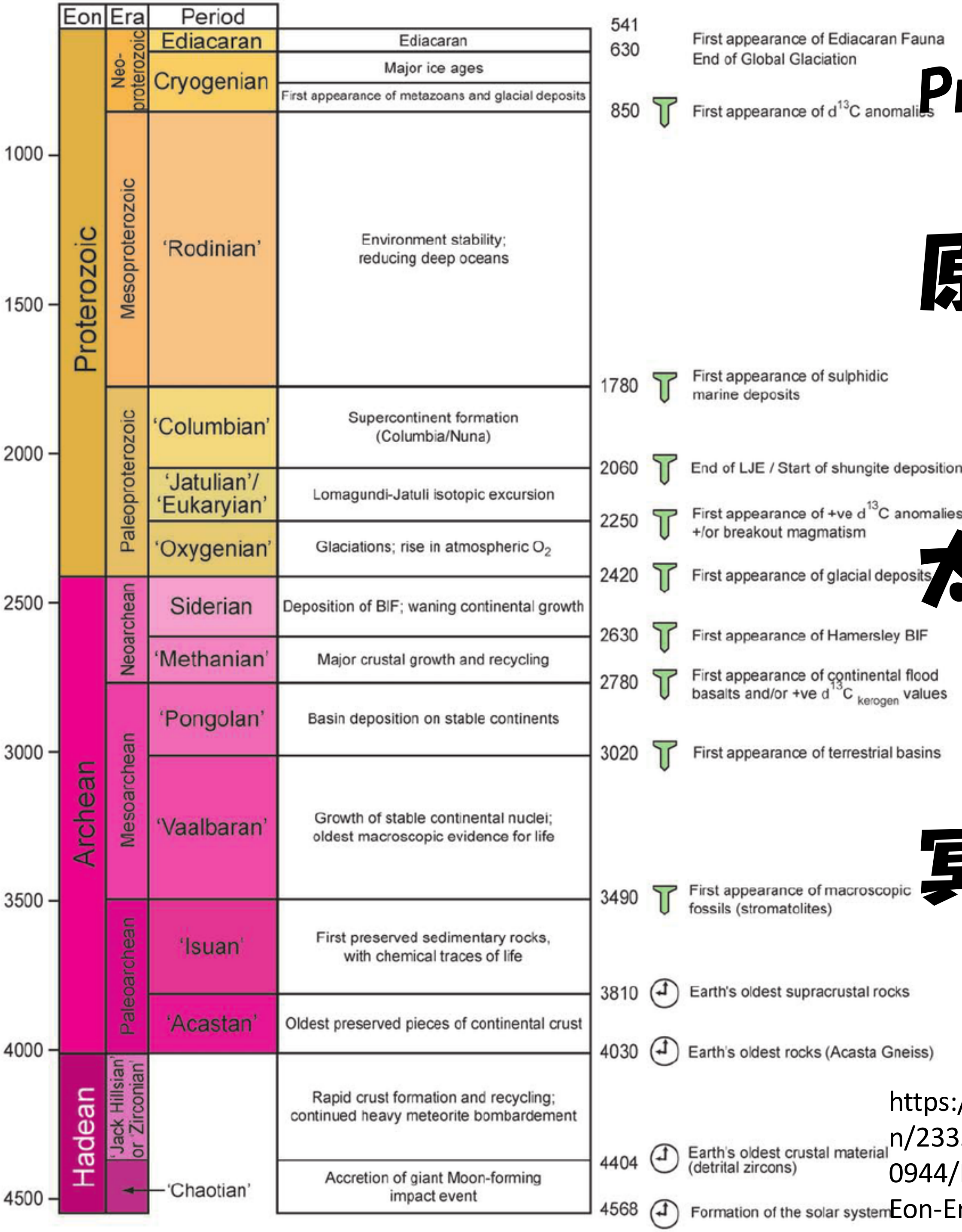


Global distribution of Archean rocks in modern continents. Known (red), suspected (pink). Areas with rocks or zircons older than 3.6 billion years are labelled by name.

http://www.earthsciences.hku.hk/shmuseum/earth_evo_03_archean_intro.php

Visited Area

Pre-Cambrian Time scale



原生代

太古代（始生代）

冥王代

https://www.researchgate.net/profile/James_Ogg/publication/233524897/figure/fig1/AS:300141383831555@1448570690944/Fig-1-The-Precambrian-chronometric-scheme-used-for-Eon-Era-and-SystemPeriod.png

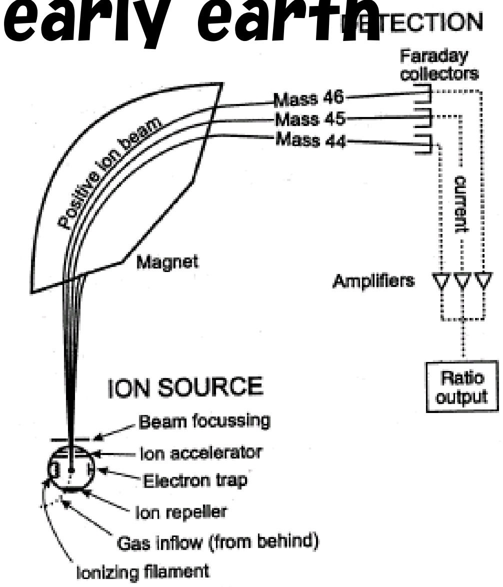
Why recently is the early earth so revealed.

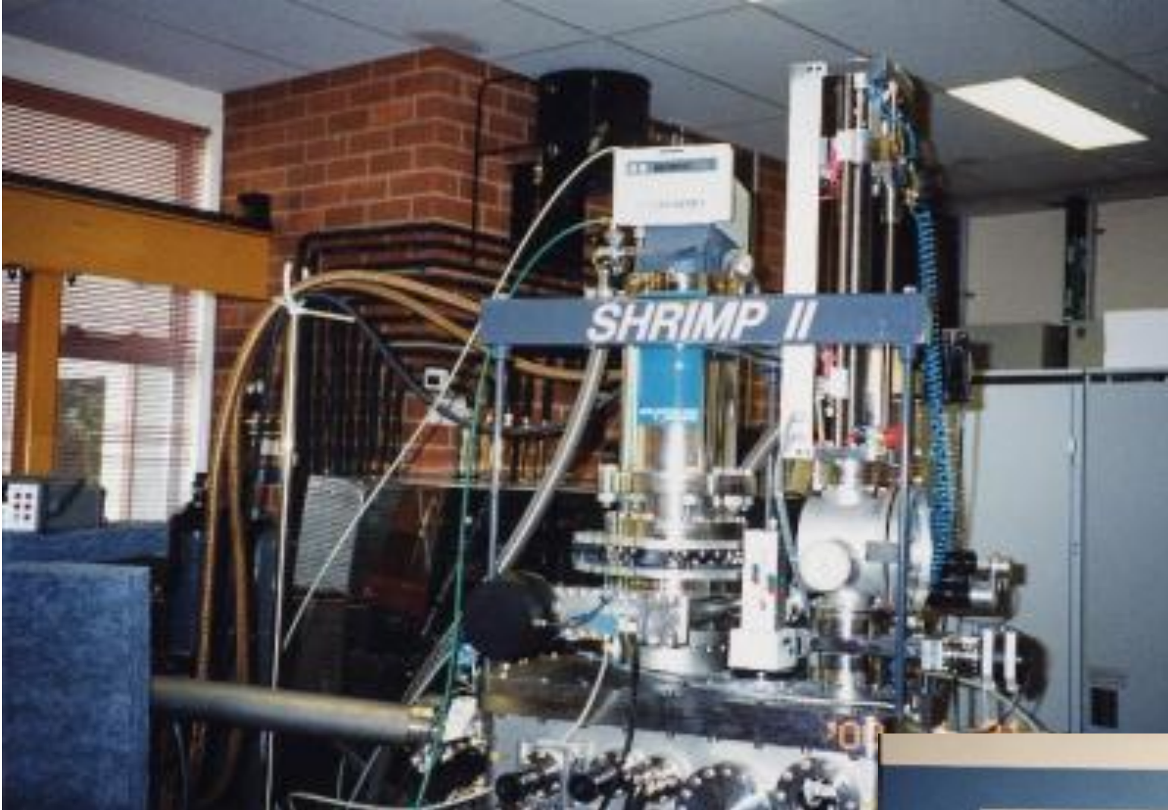
After 1990's: A radiometric dating tool is developed: "SHRIMP, Sensitive high-resolution ion microprobe" ->20μm Zircon

Also isotope ratio geochemical techniques are advanced: $^{146}Sm-^{142}Nd$: $^{182}Hf-^{182}W$: $^{142}Nd/^{144}Nd$, $^{182}W/^{184}W$ -> use for evolution of early earth crust and mantle system

<Applying Mass Spectrometry>

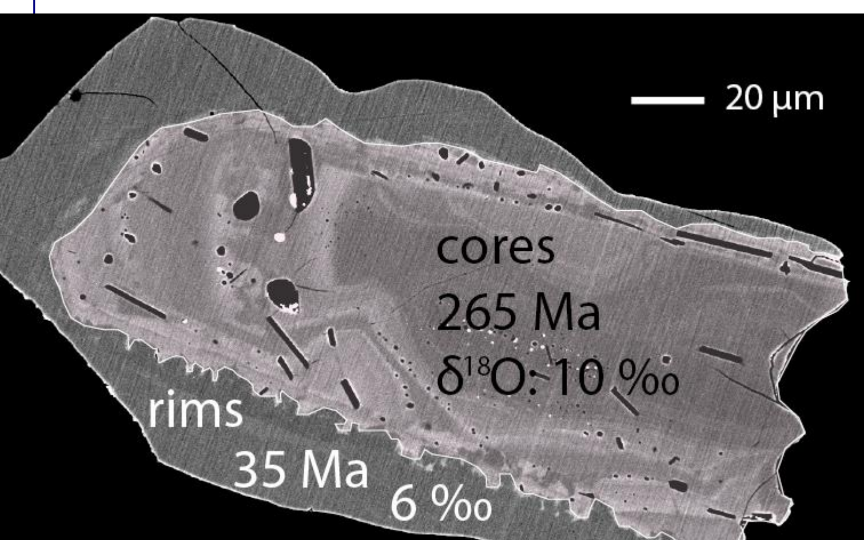
A new window is opened for the early earth!





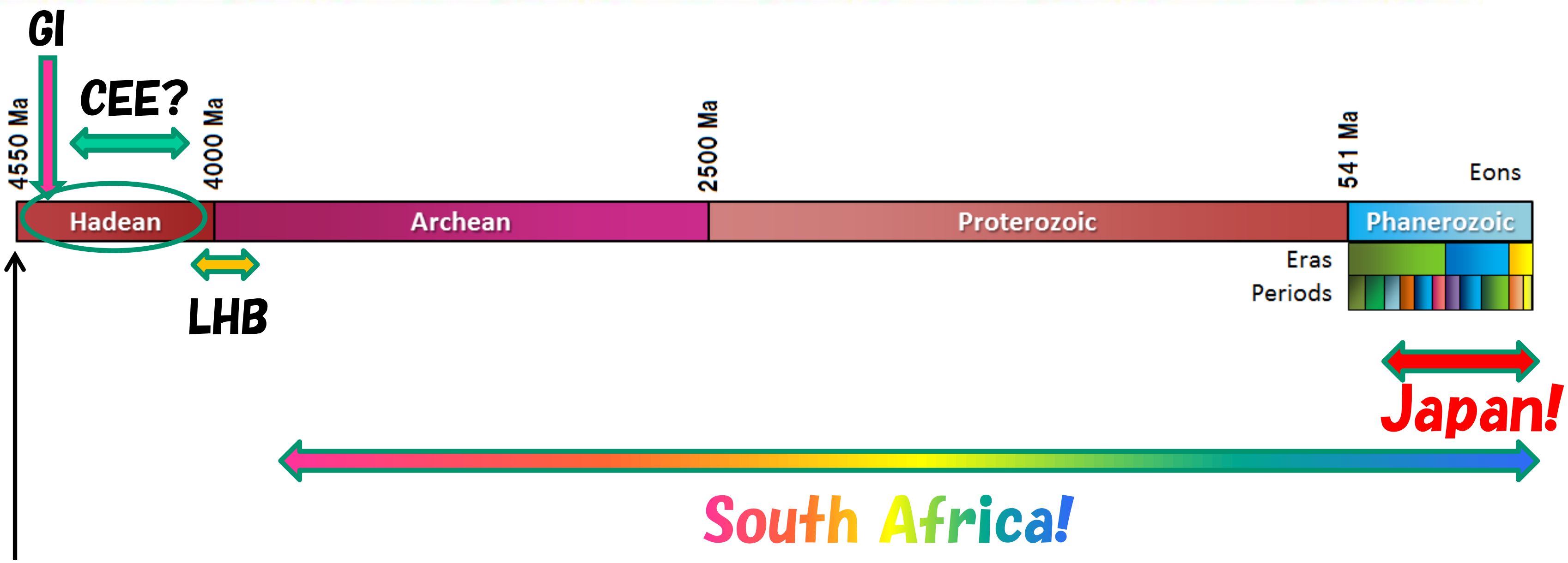
Photos by Prof. Fujioka

SHIRIMP II
at ANU (Australian National University) Geoscience Lab.



http://rses.anu.edu.au/highlights/view.php?article=394

Early Earth (Part 1) Hadean eon



Forming of Earth 4.6Ga

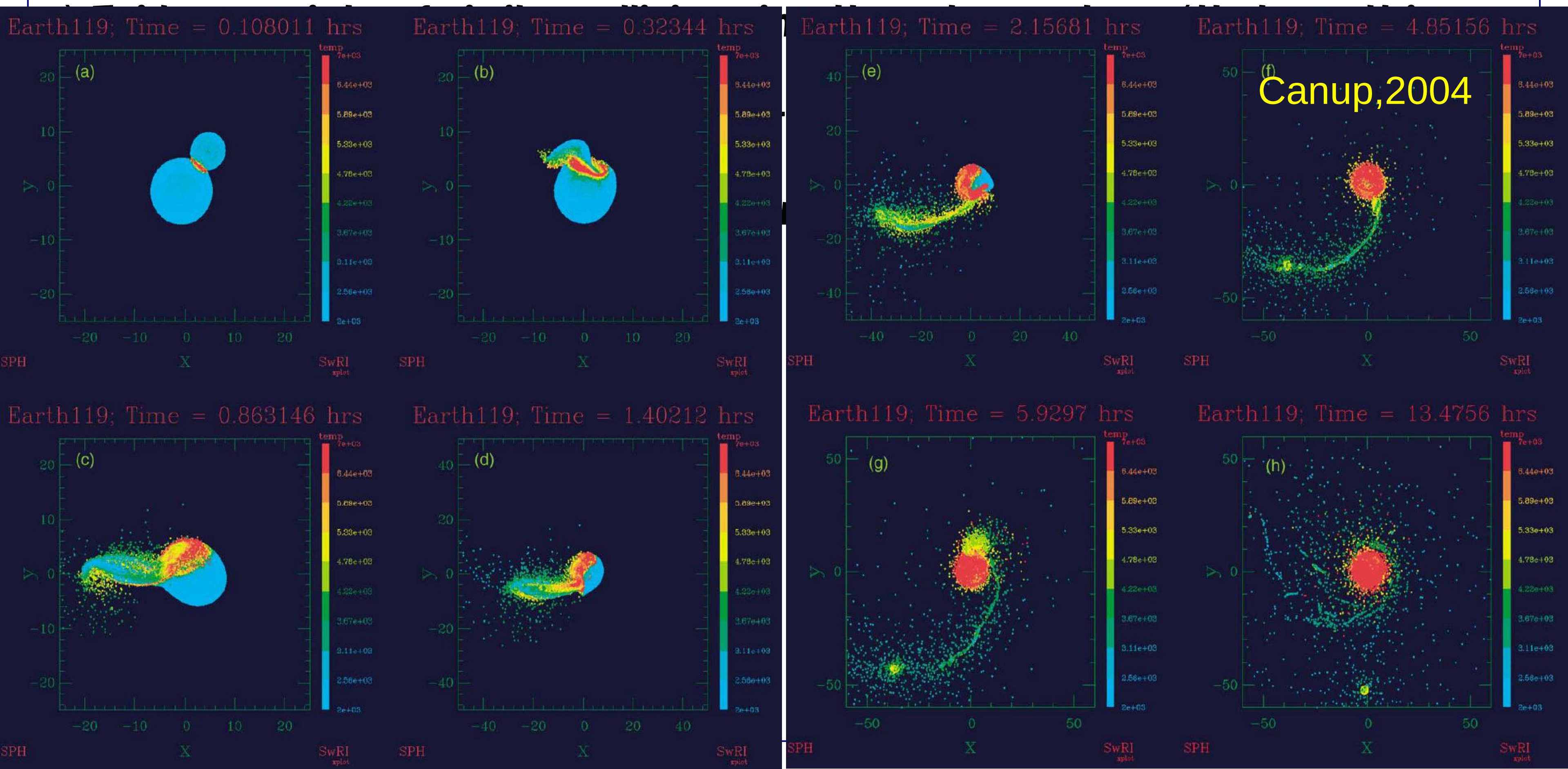
Giant Impact (the birth of Moon) 4.5Ga

Cool Early Earth 4.4-4.0 Ga

Late Heavy Bombardment (LHB) 3.9 Ga

Supporting evidence includes(wiki)

i) Earth's spin and the Moon's orbit have similar orientations.
ii) Moon samples indicate that the Moon once had a molten surface.
iii) The Moon has a relatively small iron core.
iv) The Moon has a lower density than Earth.



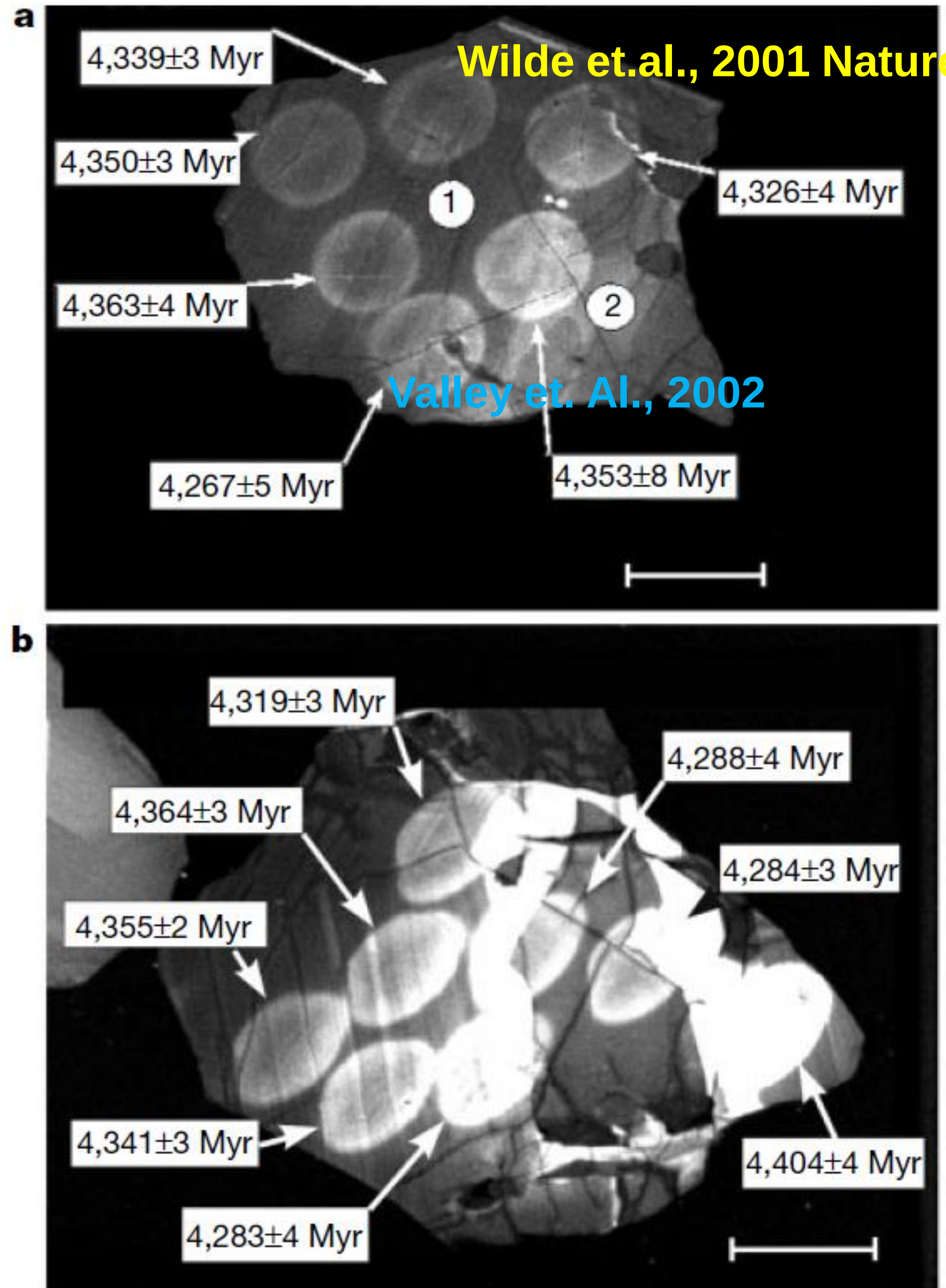
4.4Ga Zircon
by SHRIMPII

Oldest mineral
Granitic rocks

Why Zircon?

Resist against
weathering
U, Pb rich

Linewever & Norman, 2008



A cool early Earth

John W. Valley*
William H. Peck*
Elizabeth M. King*
Department of Geology and Geophysics, University of Wisconsin, Madison, Wisconsin 53706, USA
Simon A. Wilde
School of Applied Geology, Curtin University of Technology, GPO Box U1987, Perth, Australia

Sterilizing Impacts and life
"Panspermia Hypothesis"

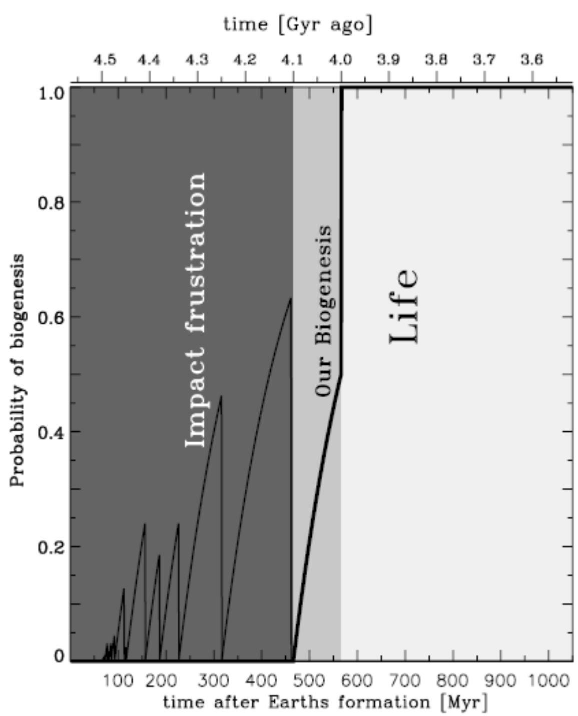


Fig. 2. After the sterilizing impact that formed the Moon about 90±20 Myr after the formation of the solar system (Halliday 2008), a heavy but decreasing and stochastic bombardment lasted for a few hundred million years probably frustrated the origin of life on Earth. Eventually, the molecular evolution that led to life as we know it, was able to squeeze through the thermal bottlenecks produced by impacts (however see Abraomov & Mojzsis 2008a,b). Figure from Davies & Lineweaver 2005.

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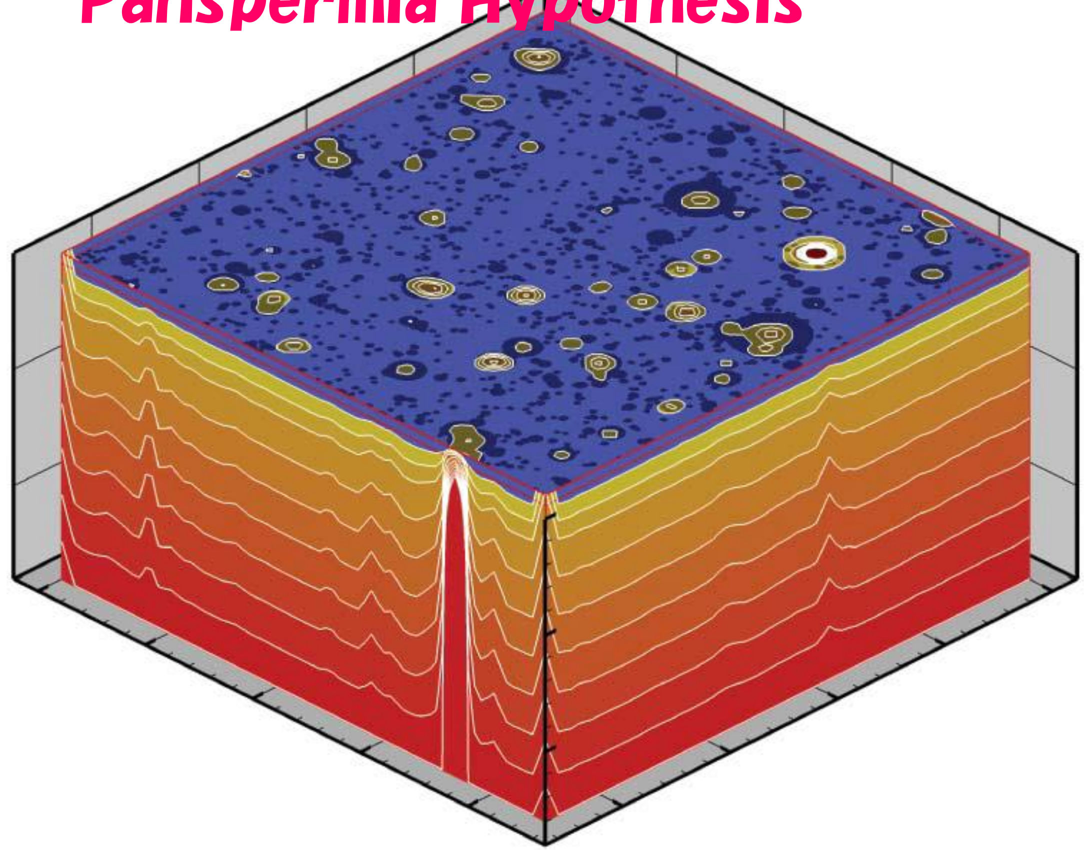


Hadean Earth (4.0 Ga)

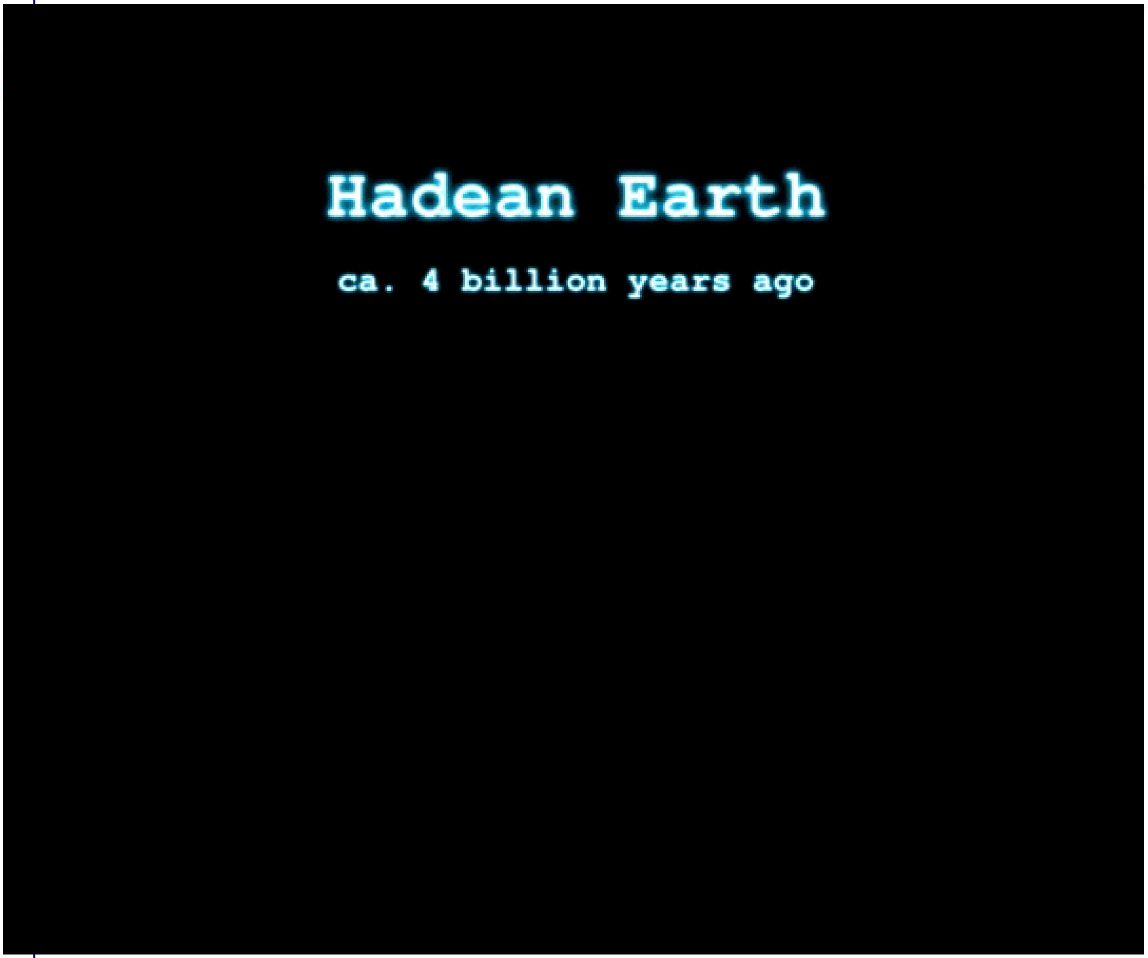


Figure 1. An artistic conception of the early Earth-Moon system. The Earth is pictured as surface pummeled by large impacts, resulting in extrusion of impact-generated deep-seated magma onto the surface. At the same time, distal portion of the surface could have retained liquid water. The Moon is pictured as a dry, heavily cratered body. The Moon is far less geologically active than the Earth and its older surface and rocks have been used to calibrate our bombardment.

Dr. Simone Marchi kindly allow me to use this gif-images

http://www.boulder.swri.edu/~marchi/

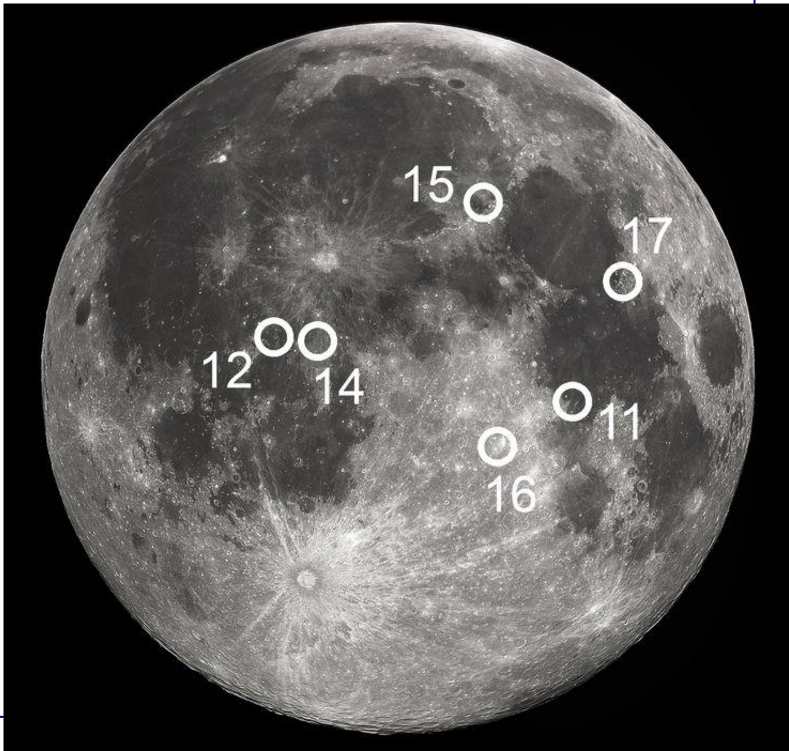
Late Heavy Bombardment (LHB)

<Evidence>

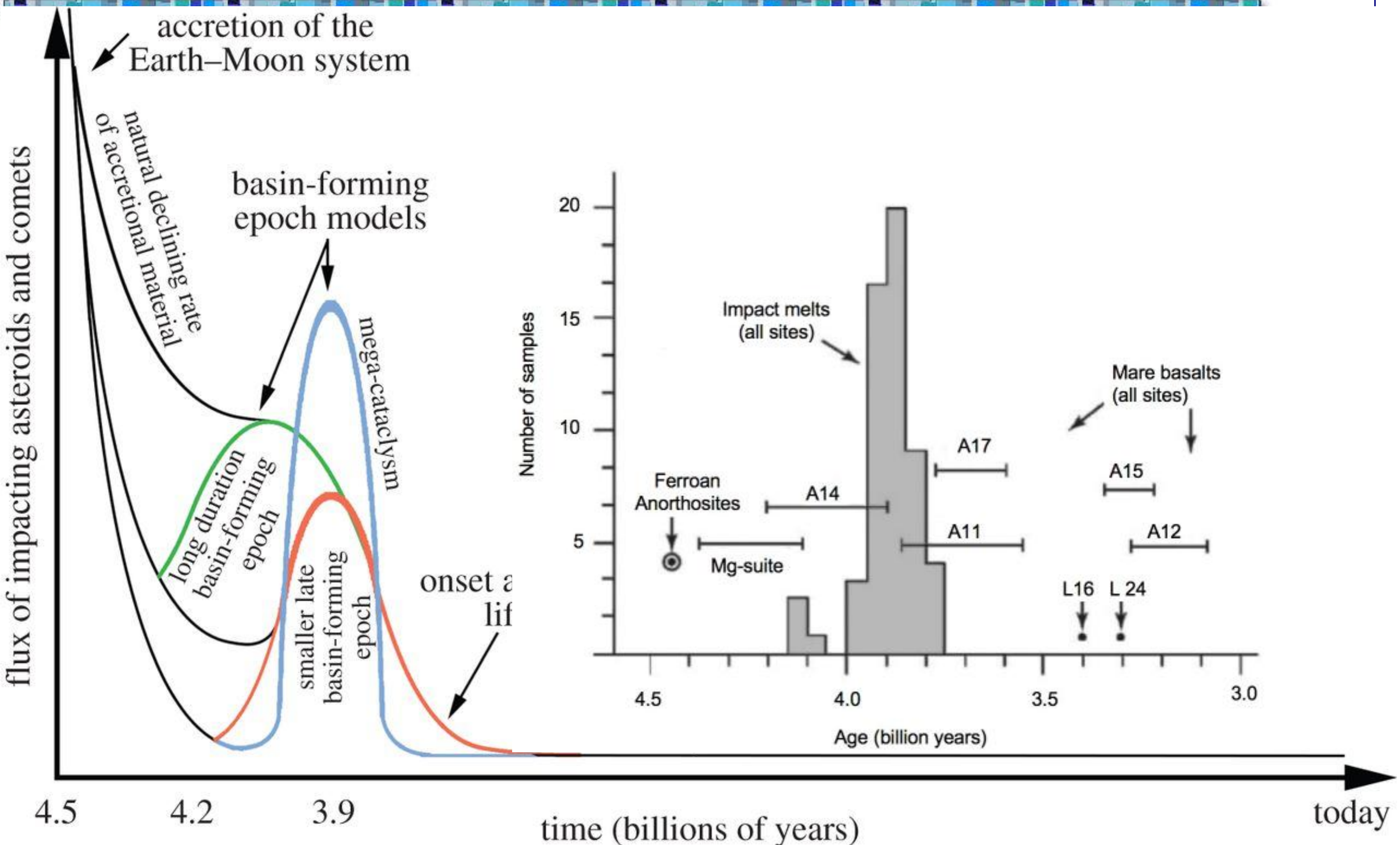
Moon rocks (Apollo mission):

The ages of impact melts collected at these sites clustered between about 3.8 and 4.1 Ga. The apparent clustering of ages of these led to postulation that the ages record an intense bombardment of the Moon. They called it the "lunar cataclysm" and proposed that it represented a dramatic increase in the rate of bombardment of the Moon around 3.9 Ga.

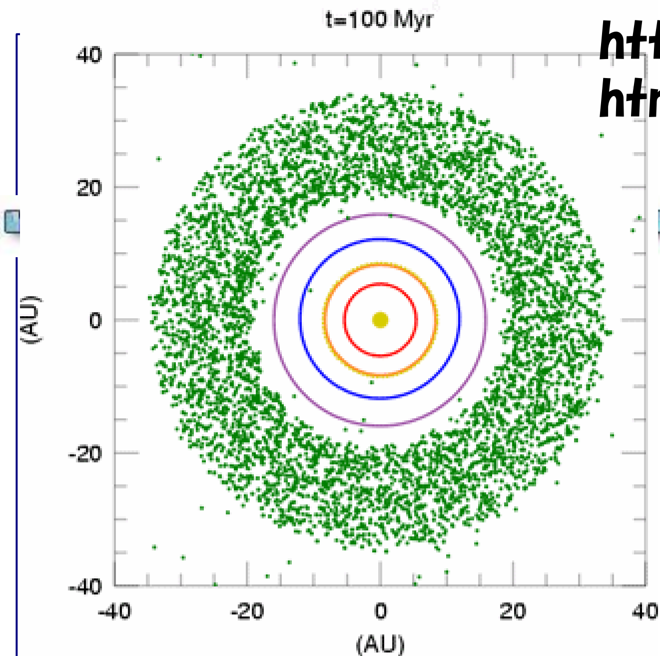
http://public.media.smithsonianmag.com/legacy_blog/age-histogram.jpg



Late Heavy Bombardment part2.



http://rsta.royalsocietypublishing.org/content/372/2024/20130315



(From Gomes, et al., 2005, Nature, v. 435, p. 466-469.)

http://www.psrd.hawaii.edu/Aug06/cataclysmDynamics.html

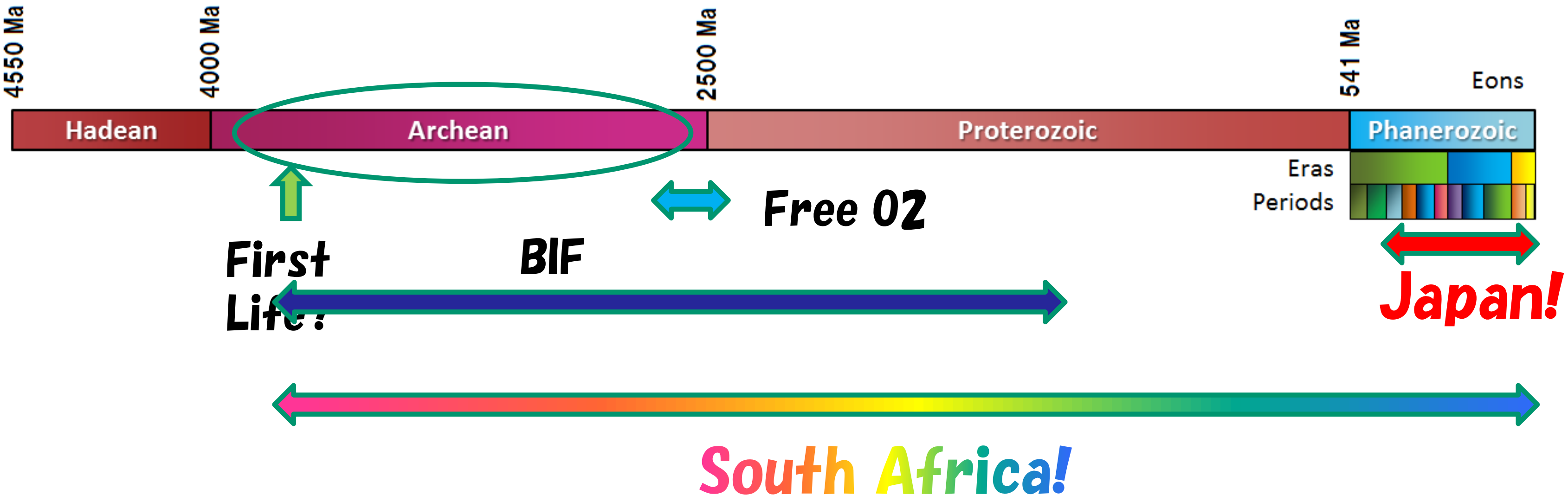
Simulation : "Nice model"
R.Gomes et.al, Nature2005
A migration of the giant planets

In this dynamical simulation of the late heavy bombardment, the Sun is in the center, the colored circular rings represent the orbits of the four giant planets, and the green dots represent the disk of planetesimals between 15.5 AU and 34 AU.

Each panel represents the state of the planetary system at a different time, starting at t=100 million years. Saturn and Jupiter migrate slowly, reaching 2:1 resonance. This scatters Neptune and Uranus. Their extreme migrations scatter planetesimals in a short time interval--a cataclysm.

The four panels below correspond to four different snapshots taken from the simulations. From left to right: The beginning of planetary migration (100 Myr), just before the beginning of the scattering (879 Myr), just after

Early Earth (Part 2) Archean eon

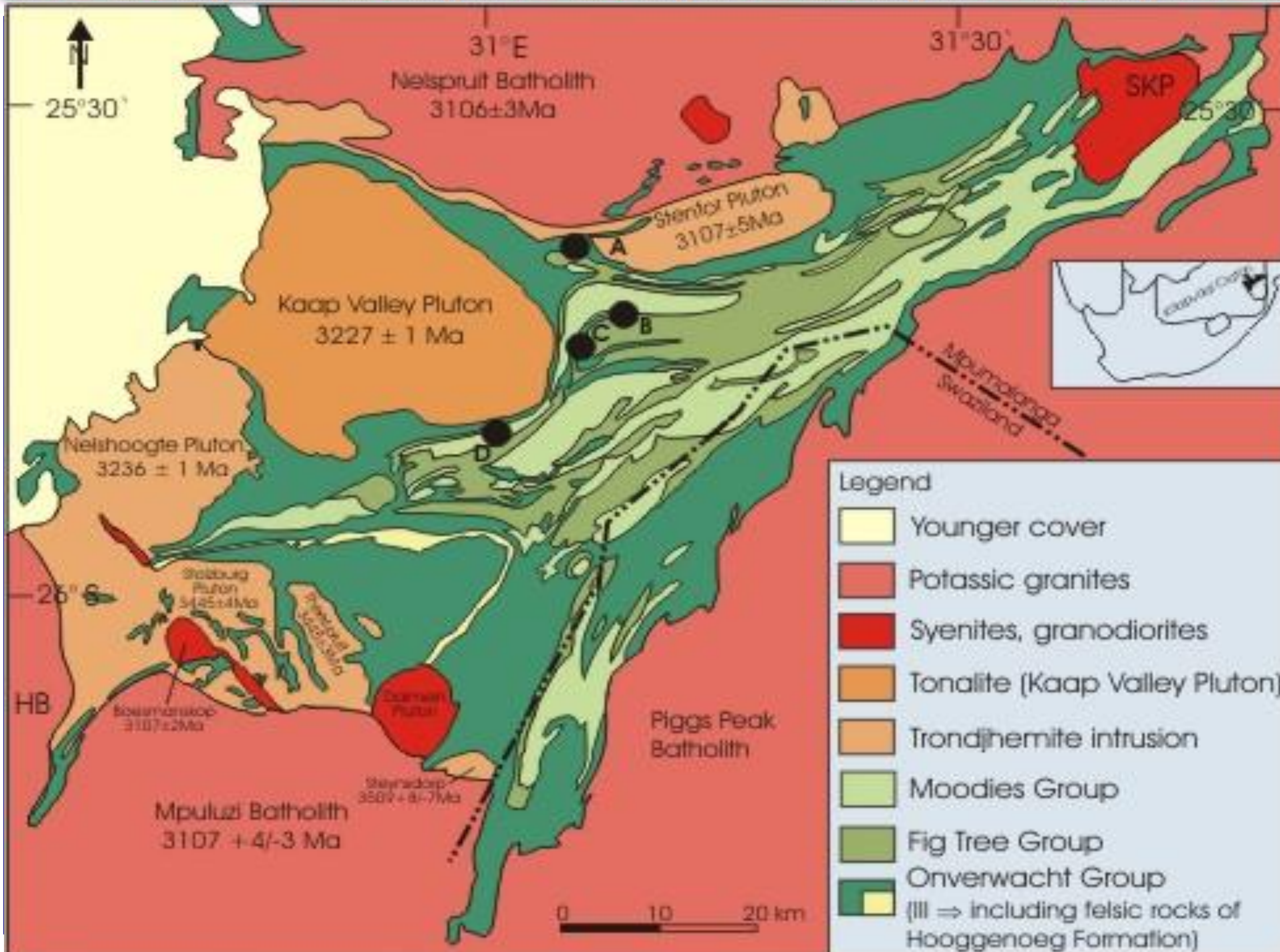


First life? 3.7-3.5 Ga

Banded Iron Formation (BIF) 3.8 to 1.9 Ga

Free Oxygen 2.5-2.4 Ga

Barberton Geological Map



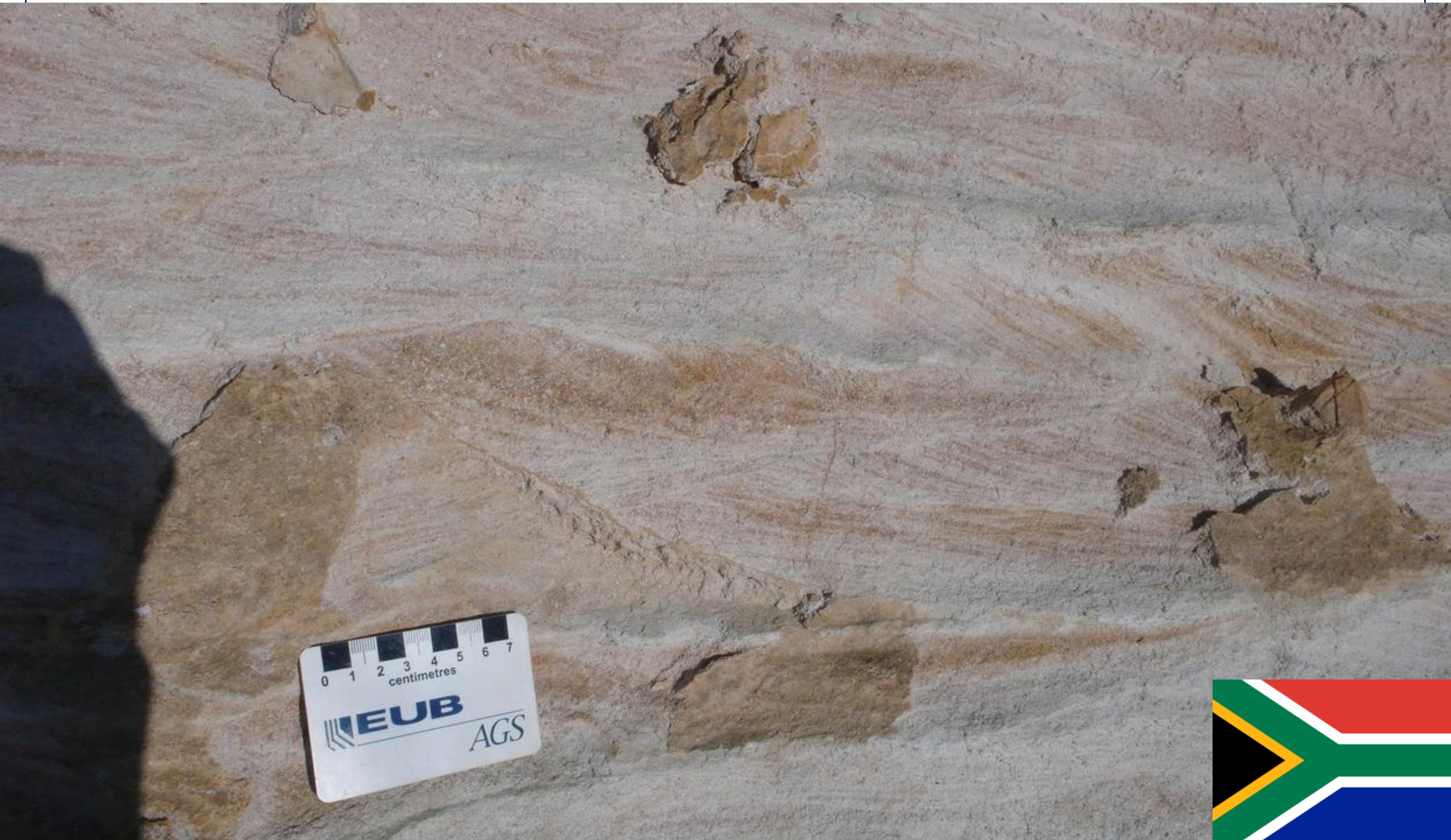
Members


Barberton

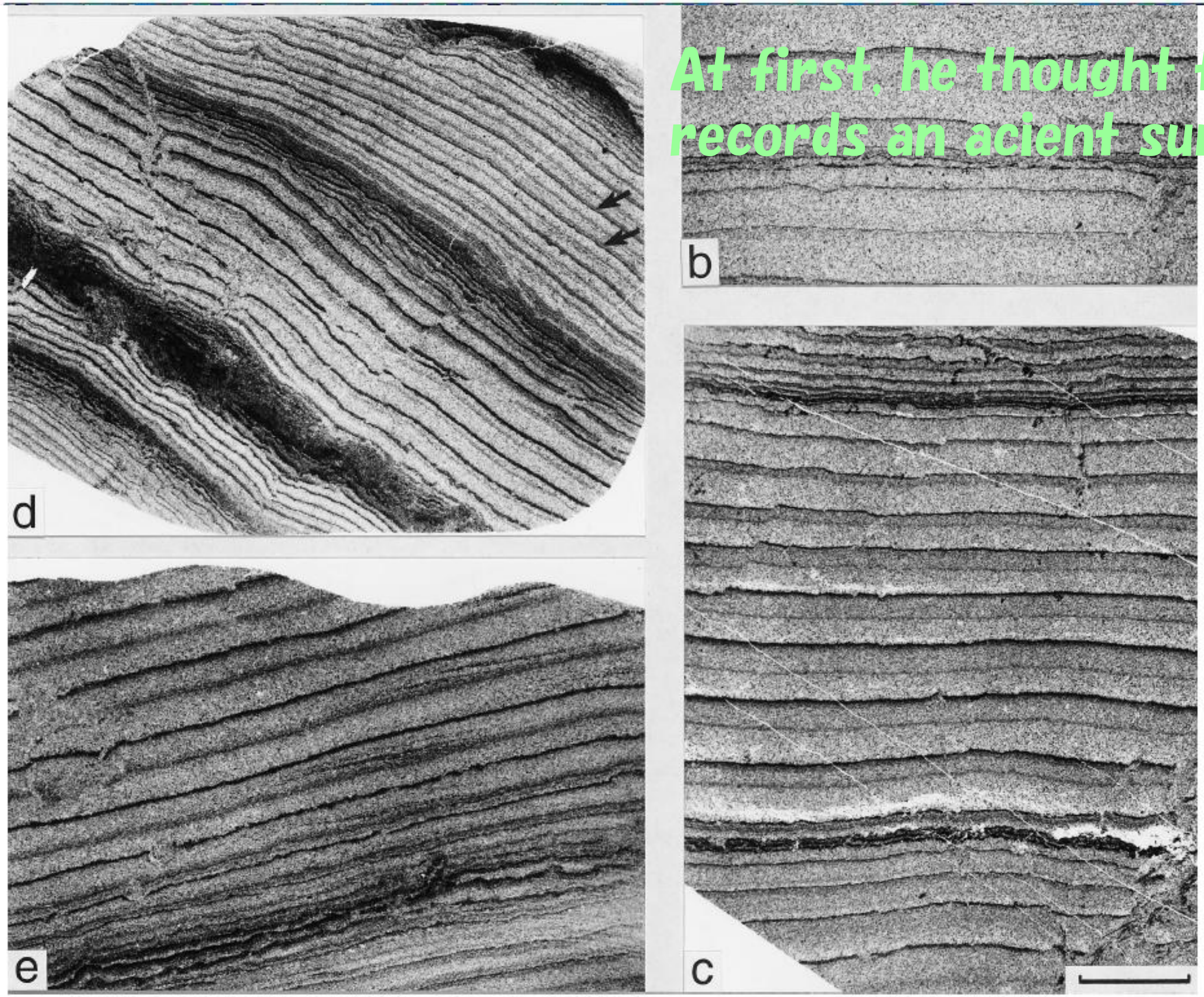
Moodies Group（3.2Gy） shallow marine tidal rhythmites

South Africa 2010

At Barberton



Williams 2000: Australia 0.6Ga



At first, he thought the lamina records an acient sunspot cycle

Williams 2000: Australia 0.6Ga

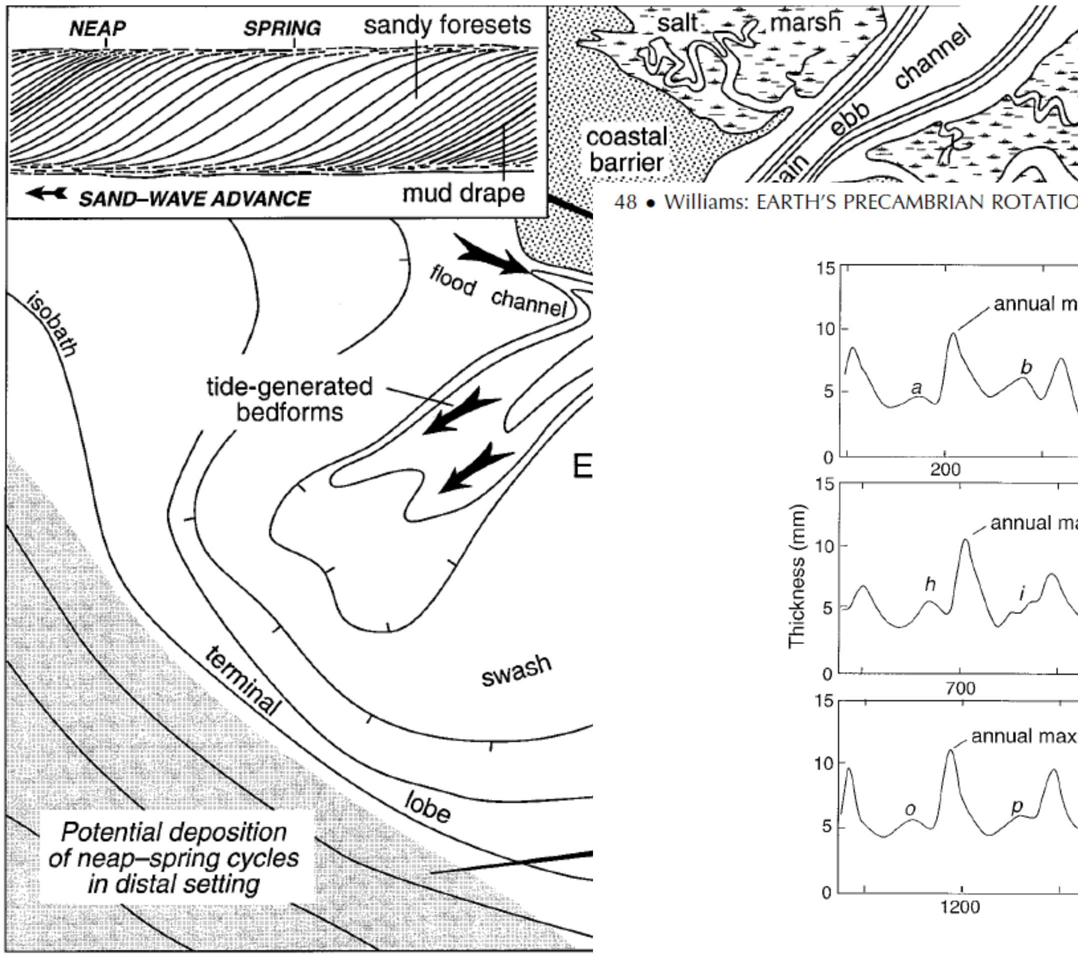


Figure 5. Envisaged environment of deposition for the E
a hypothetical ebb tidal delta adapted from *Imperato et al.* [1
tidal inlet, where fine-grained sediment is entrained by ebb t
via the main ebb channel to deeper water offshore. There t
cycles of thin, graded laminae mostly of sand and silt (show
the neap-spring cycles become progressively more abbreviat
into marine shelf mud. Where protected from wave acti
deposition and preservation of long rhythmite records. Ti
inset) are confined to proximal, nearshore tidal channels. M
the permission of the International Union of Geological S

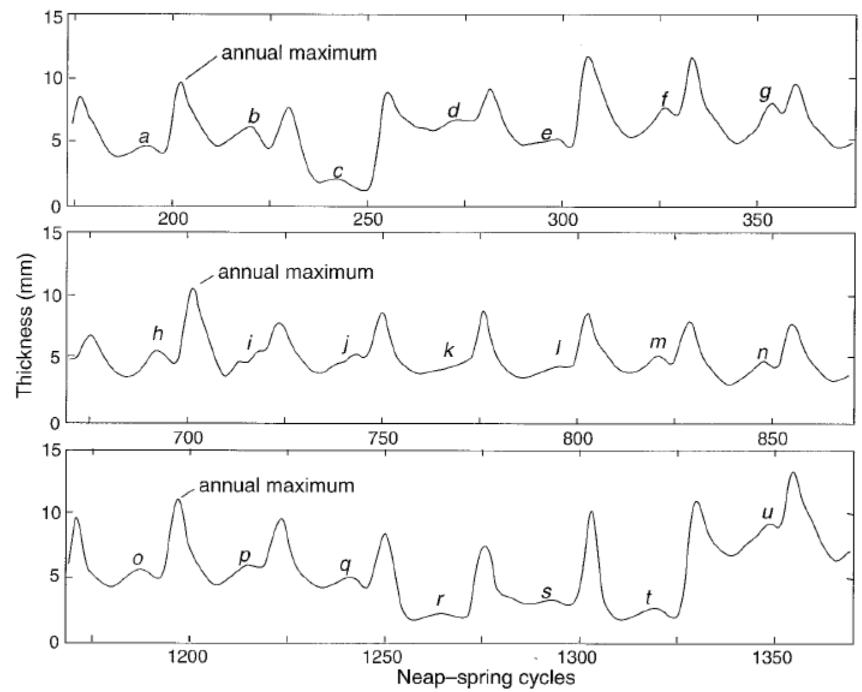
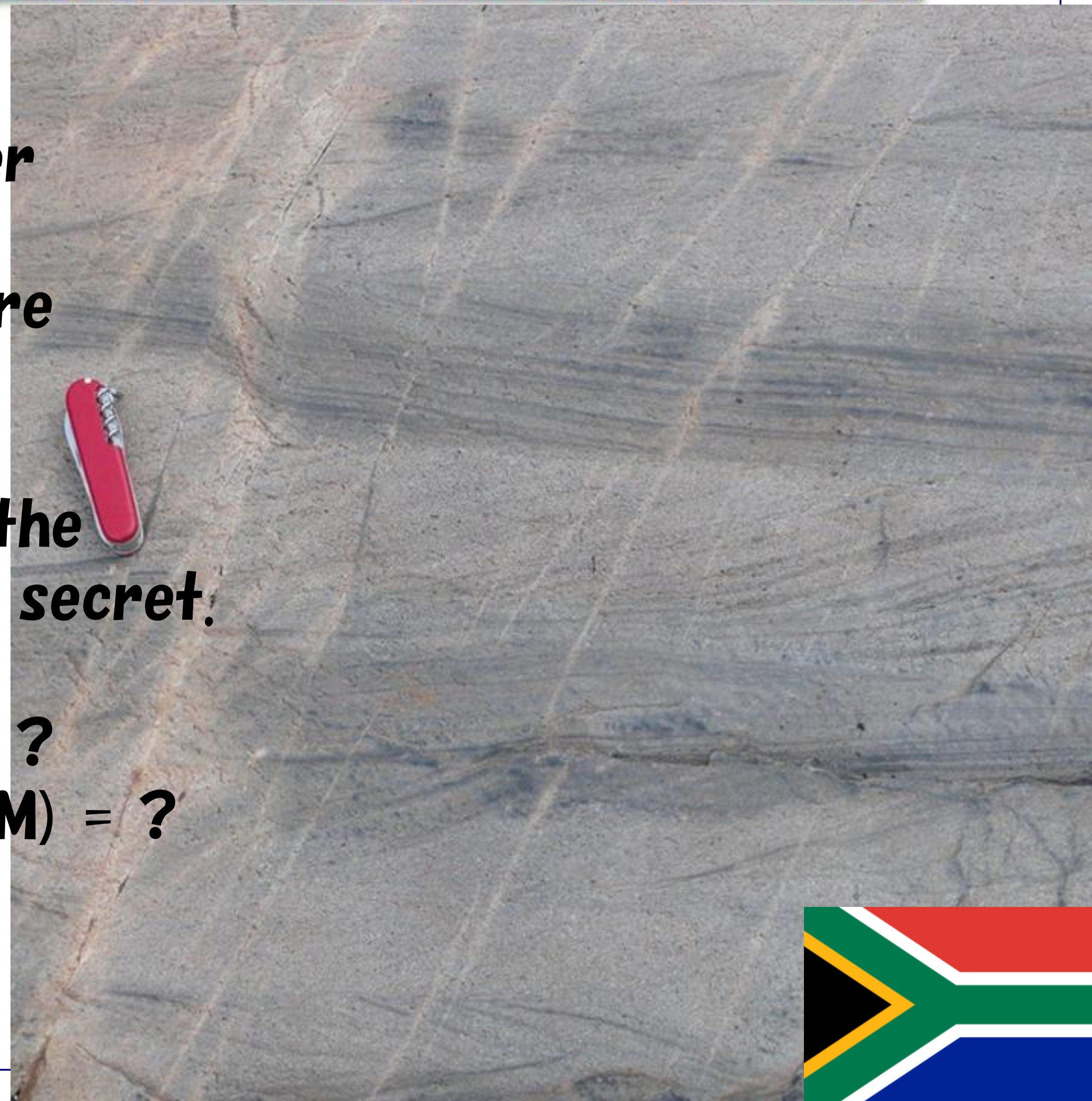


Figure 9. Three extracts from the Elatina paleotidal record of neap-spring cycle thickness (smoothed by a five-point filter weighted 1, 4, 6, 4, 1; neap-spring cycle number increases up the stratigraphic succession), showing 24 first-order peaks that are equated with the nontidal annual or seasonal maximum in sea level. The plots span the three intervals where the second-order peaks (peaks a–u), which are interpreted as reflecting the semiannual paleotidal cycle, show minimal height (peaks c–e, j–l, and q–t); the symmetry of the annual peaks tends to be greatest at these places. Over the 60-year record, a period of 19.5 ± 0.5 years is revealed by variation in the height of the semiannual peaks (see Figure 13a), as measured from the base of the preceding trough to the top of the peak or to the midpoint between rare twin peaks (peaks i and j). Neap-spring cycle thickness shows a gradual decrease for cycles 1200–1325 and abrupt increases at cycles 250 and 1325; these nonperiodic changes evidently reflect sedimentary processes on the tidal delta such as a gradual blocking of the main ebb channel followed by channel avulsion.

Verify the Giant Impact Theory

In the Archean eon,
Moon was more closer
to earth.
So, these periods were
shorter than today.
How to examine?
The tidal records in the
sediments reveal the secret.

length of day (LOD)= ?
Length of month (LOM) = ?



Moodies Group（3.2Gy）Analysis of tidal rhythmites

- 現在より早い月の公転(約18日!)
- 未知数は1月の長さ, 1日の長さ
- 月の軌道が円軌道に近い

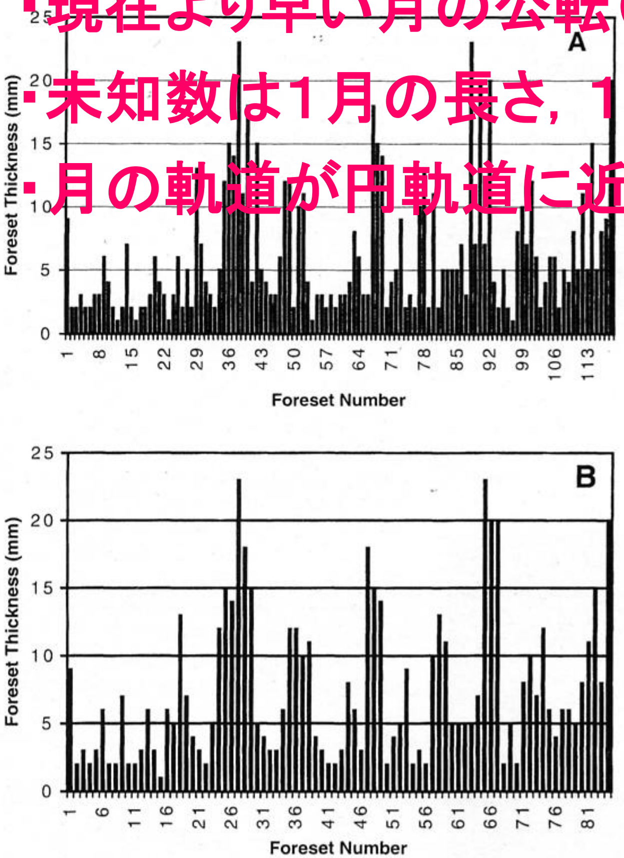


Figure 3. A: Traverse 2—all data. Histogram of sandstone foreset bundle thicknesses plotted against foreset number for traverse two through cross-bed set shown in Figure 2. Note variation in thickness of sandstone foresets and common presence of thick-thin pairs of foresets. B: Traverse 2—subordinates removed. Histogram of inferred dominant-tide foreset bundle thicknesses plotted against foreset number for traverse two through cross-bed set shown in Figure 2. Inferred subordinate flood-tide laminations were removed visually from data sets. Note that interpreted neap-spring-neap cycles are 9–10 days long and that alternate neap-spring-neap cycles are thicker and thinner, respectively.

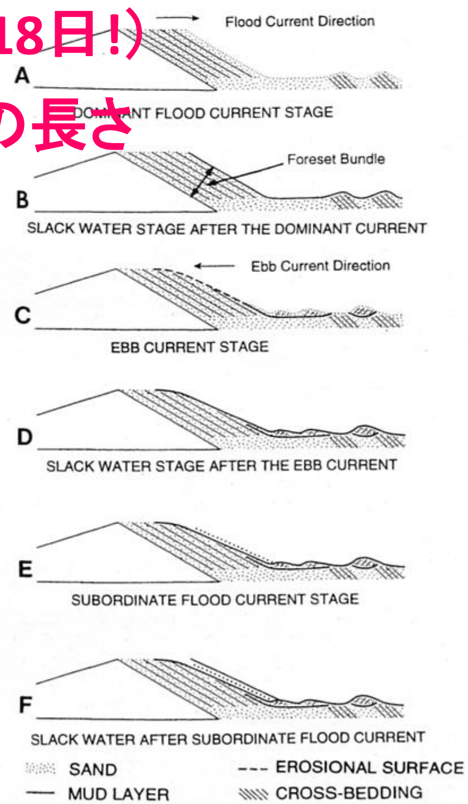


Figure 4. Migration of sand wave in tidal system characterized by strong flood current and weak ebb current (modified after Visser, 1980). Note that most sand is deposited on lee face of sand wave during dominant flood stage (A), whereas only thin sand layer is deposited on lee face during subordinate flood stage (E). Dominant and subordinate flood currents are typical of semidiurnal tidal systems. During ebb stage, sand deposition takes place only in trough of sand wave and is preserved in form of intrasets within toesets of cross-bed set (C). During stillstand associated with turning of tide, clay accumulates on lee face and within trough of sand wave and is preserved as mudstone drapes (B, D, F).

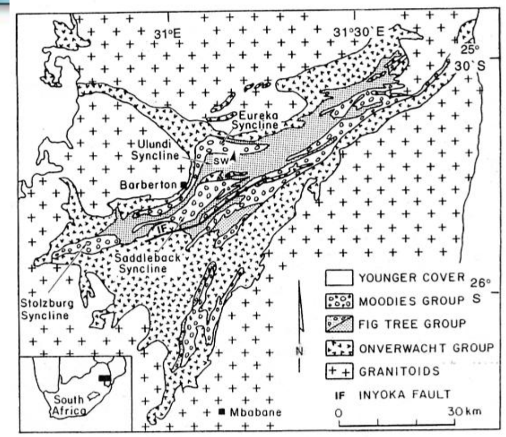


Figure 1. Simplified geological map of Barberton Greenstone Belt. Heavy arrowhead indicates location of sand-wave (sw) in Eureka syncline.

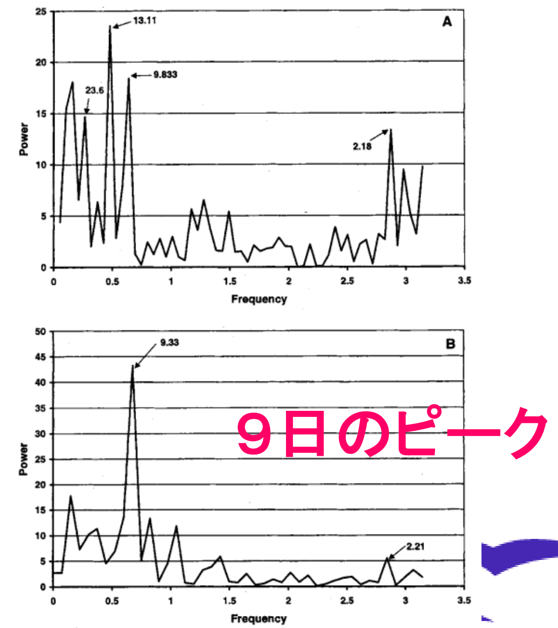
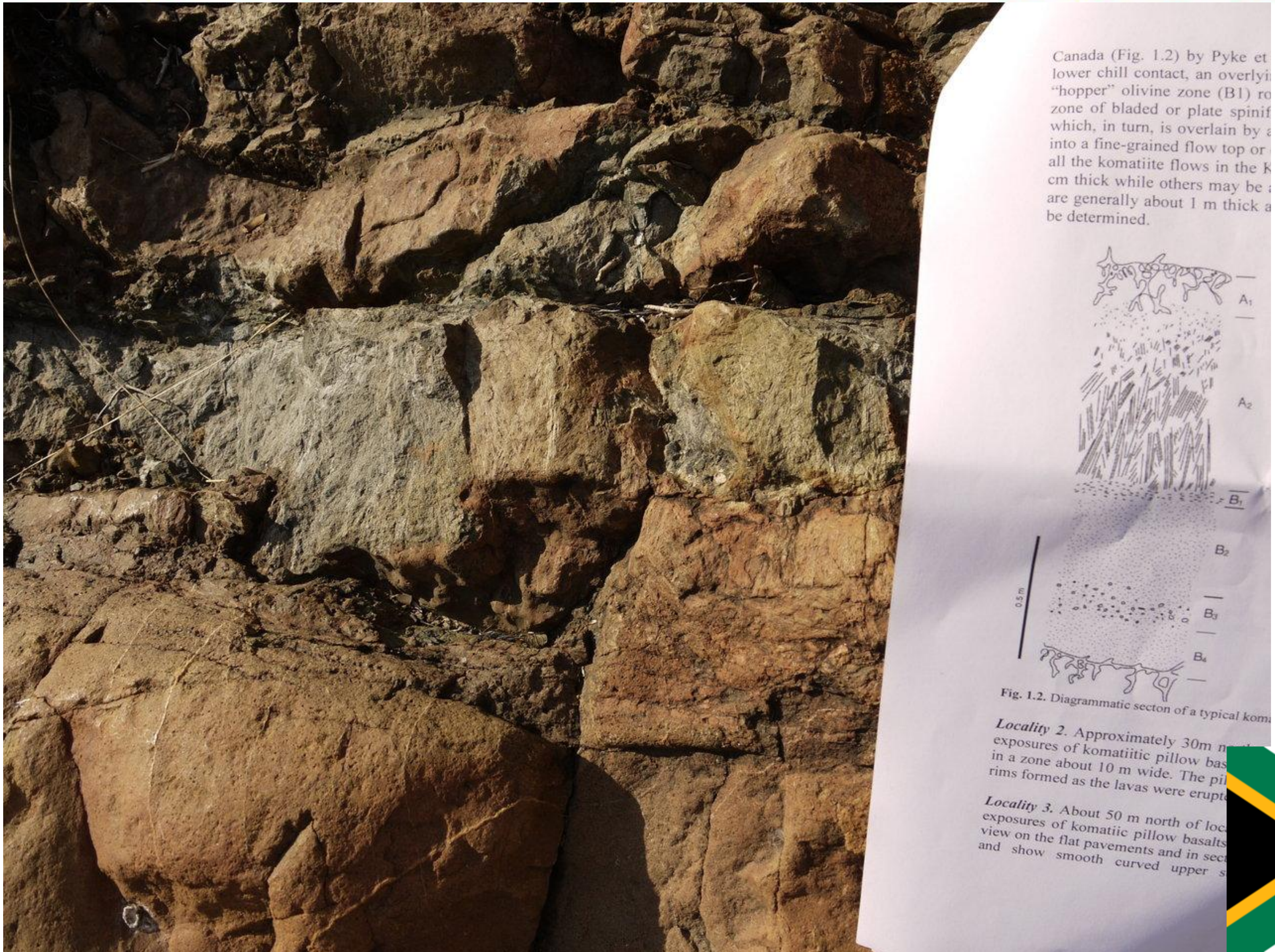


Figure 5. A: Traverse two—all data. Power spectral plot of foreset bundle thicknesses measured along traverse two (see Fig. 3A). B: Traverse two—subordinates removed. Power spectral plots of dominant flood-tide foreset bundle thicknesses along traverse two (see Fig. 3B).

GEOLOGY, September 2000

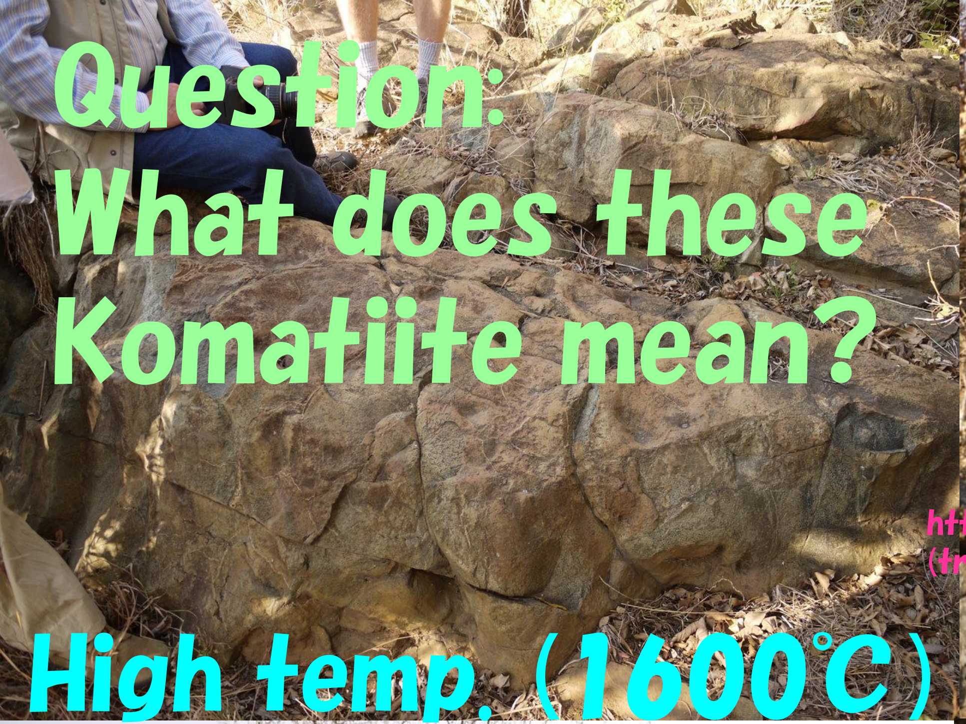
Eriksson,2000より

Komatiite: A Rock from a hot mantle!



Komatiitc basalt: Pillow Lava

Question:
What does these Komatiite mean?



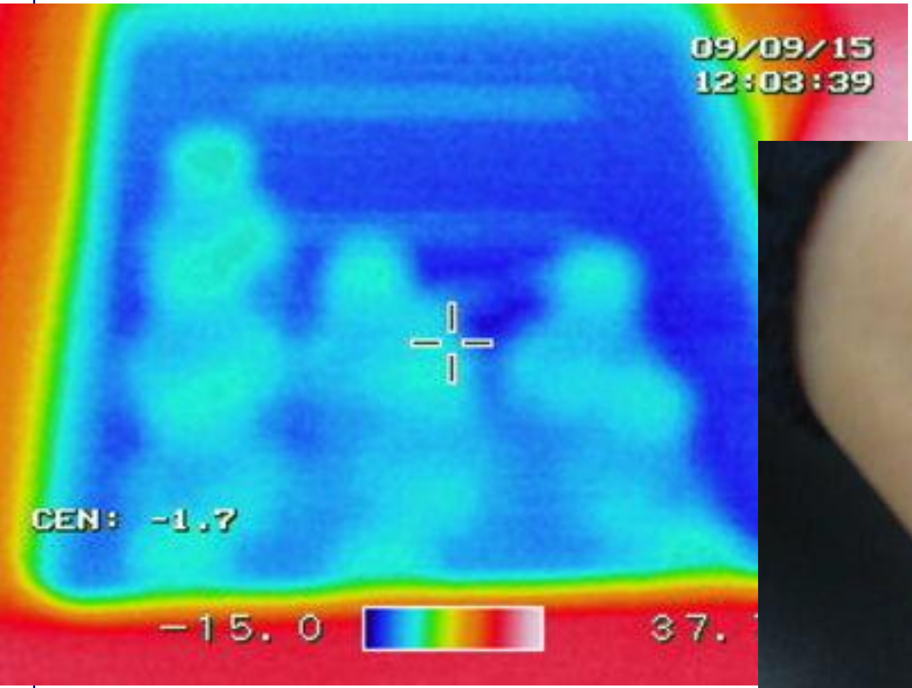
http://aginnovators.org.au/sites/default/files/Spinifex (triodia) grass in NT

High temp. (1600℃) of early mantle
Super Cooling: Spinifex texture

First Oceanic Crust!

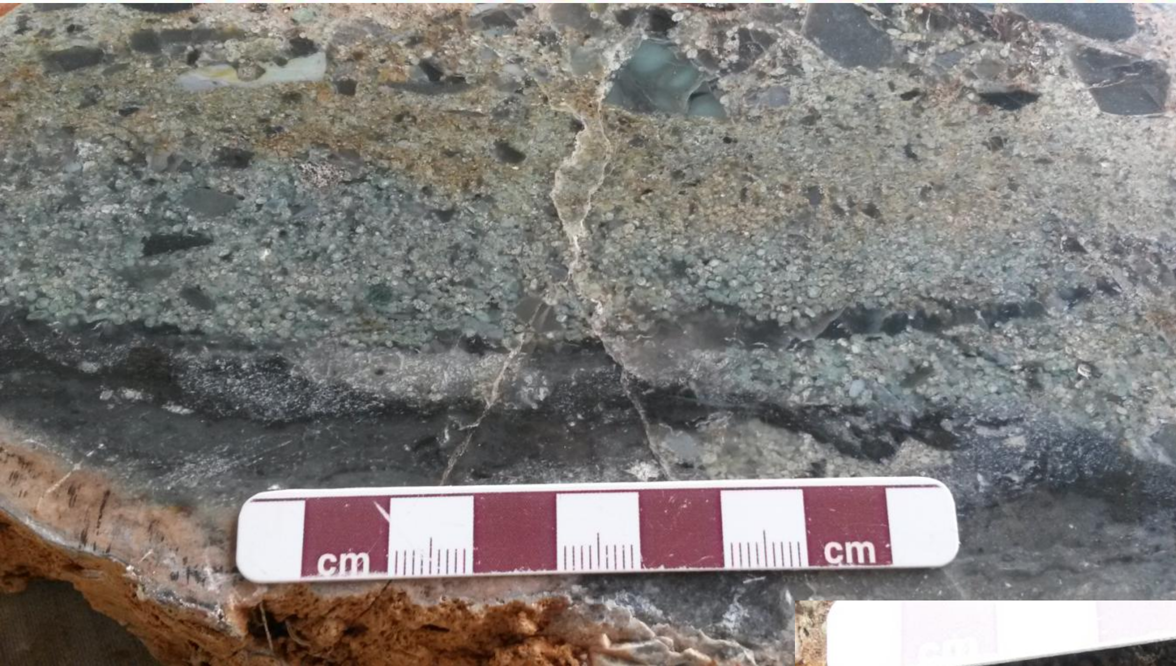
High temp. (1600℃) of early mantle

Super cooling -> Spinifex texture



Special thanks to
Prof. Konishi (OKU)

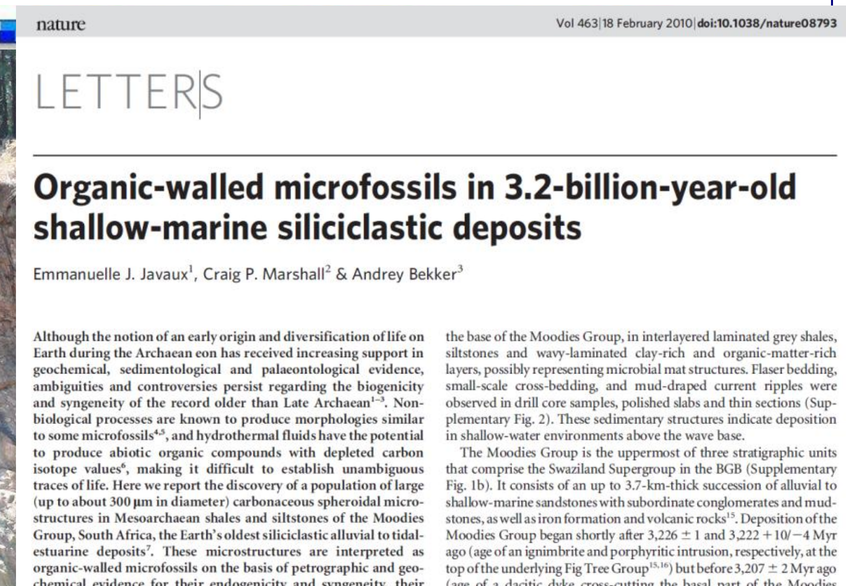
A Spherule sample at Barberton, South Africa (3.5-3.2Ga)



Pictures by Tony Ferrar
Dr. Dion's friend
He sent me these pictures.

- Sample from Fig Tree G (3.4 Ga Barberton)

A Bio-mat sample at Barberton, South Africa (3.2 Ga)



nature Vol 463 | 18 February 2010 | doi:10.1038/nature08793

LETTERS

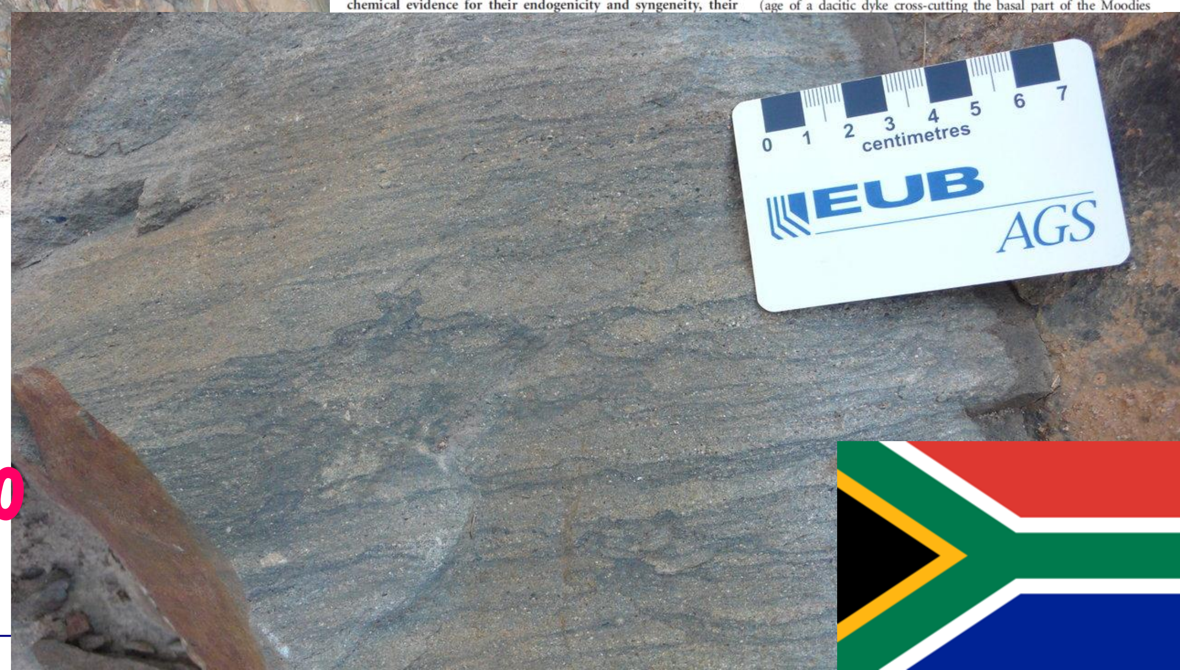
Organic-walled microfossils in 3.2-billion-year-old shallow-marine siliciclastic deposits

Emmanuelle J. Javaux[1], Craig P. Marshall[2] & Andrey Bekker[3]

Although the notion of an early origin and diversification of life on Earth during the Archaean eon has received increasing support in geochemical, sedimentological and palaeontological evidence, ambiguities and controversies persist regarding the biogenicity and syngeneity of the record older than Late Archaean[1–3]. Non-biological processes are known to produce morphologies similar to some microfossils[4,5], and hydrothermal fluids have the potential to produce abiotic organic compounds with depleted carbon isotope values[6], making it difficult to establish unambiguous traces of life. Here we report the discovery of a population of large (up to about 300 µm in diameter) carbonaceous spheroidal microstructures in Mesoarchaean shales and siltstones of the Moodies Group, South Africa, the Earth's oldest siliciclastic alluvial to tidal-estuarine deposits[7]. These microstructures are interpreted as organic-walled microfossils on the basis of petrographic and geochemical evidence for their endogenicity and syngeneity, their

the base of the Moodies Group, in interlayered laminated grey shales, siltstones and wavy-laminated clay-rich and organic-matter-rich layers, possibly representing microbial mat structures. Flaser bedding, small-scale cross-bedding, and mud-draped current ripples were observed in drill core samples, polished slabs and thin sections (Supplementary Fig. 2). These sedimentary structures indicate deposition in shallow-water environments above the wave base.

The Moodies Group is the uppermost of three stratigraphic units that comprise the Swaziland Supergroup in the BGB (Supplementary Fig. 1b). It consists of an up to 3.7-km-thick succession of alluvial to shallow-marine sandstones with subordinate conglomerates and mudstones, as well as iron formation and volcanic rocks[15]. Deposition of the Moodies Group began shortly after 3,226 ± 1 and 3,222 +10/−4 Myr ago (age of an ignimbrite and porphyritic intrusion, respectively, at the top of the underlying Fig Tree Group[15,16]) but before 3,207 ± 2 Myr ago (age of a dacitic dyke cross-cutting the basal part of the Moodies



Javaux et. al., Nature 2010

Banded iron Formation(Sample)

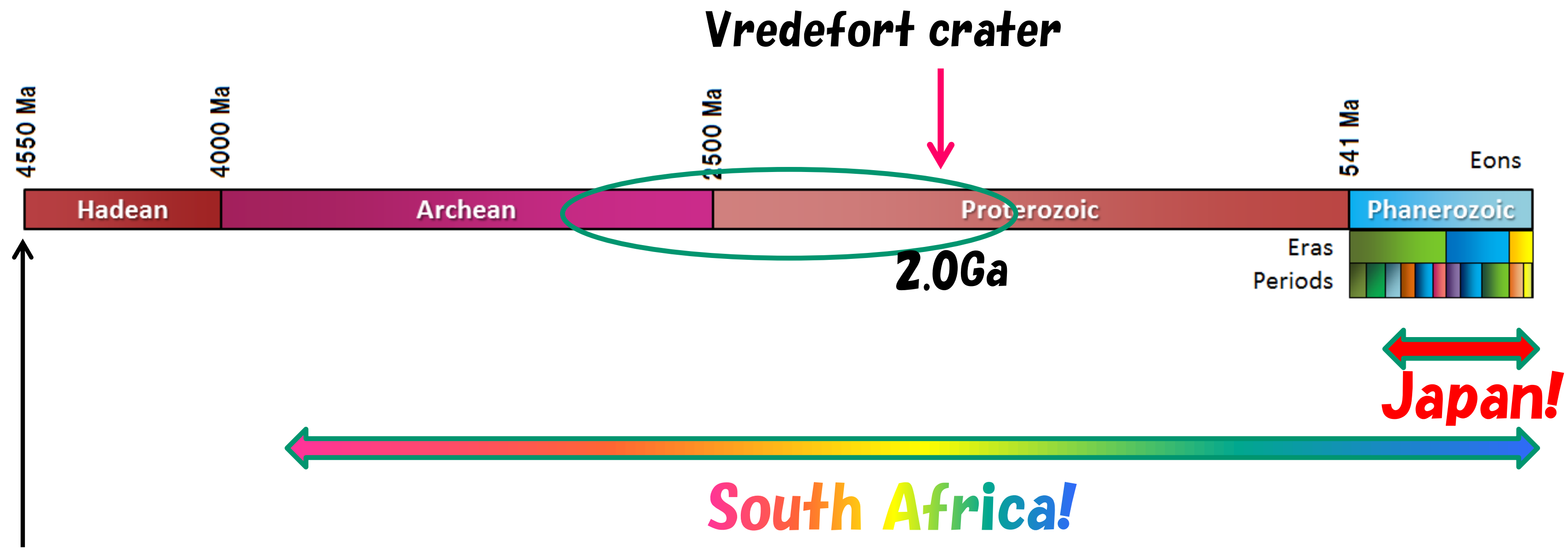
Oxygen in the Ocean
Photo-synthesis by Ciano bacteria

One scene, at the Kruger national park, South Africa

- We enjoyed the game drive in the Kruger National Park
- Our driver opened the both side doors to view and made us to take picture easily---.
- Unfortunately we came across a patrol car, we got stopped.
- Two young black police men walked to our car, One police man said to our driver Dr. Dion, " You commit a traffic violation. The rule prohibit driving car with the door open. Opening the door is very dangerous. Because the wild animals running into the car! ".
- Then we all asked to the police "Please forgive our violation. Could you just let him off this one time?"
- Of course their answer was "NO!" . Our driver had ticketed.
- However, at that time I was deeply moved this sight! -----.

Question:
Why was I deeply moved at that time?

Early Earth (Part 3) Archean to Proterozoic



Gold deposit 3.0Ga

Chromium and Platinum: Bushveld Igneous Complex (BIC) 2.0Ga

Vredefort impact crater 2.0Ga

Diamond Kimberlite 1.2-0.1 Ga

(Coal 0.25 Ga)