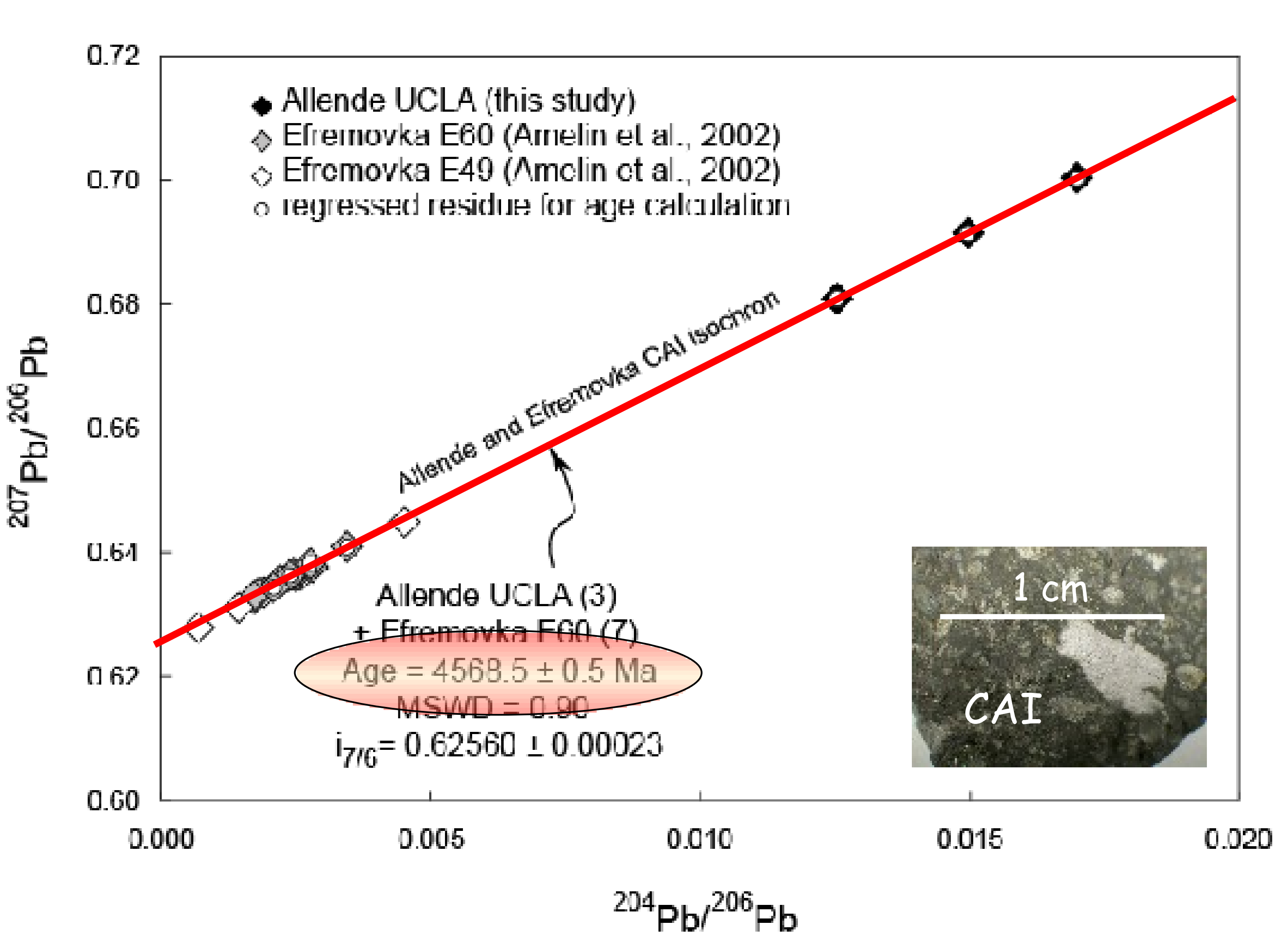
L'âge de la première croûte continentale et le début de la tectonique des plaques

Tout a commencé il y à 4568,5 Ma!



Bouvier et al. (2007)

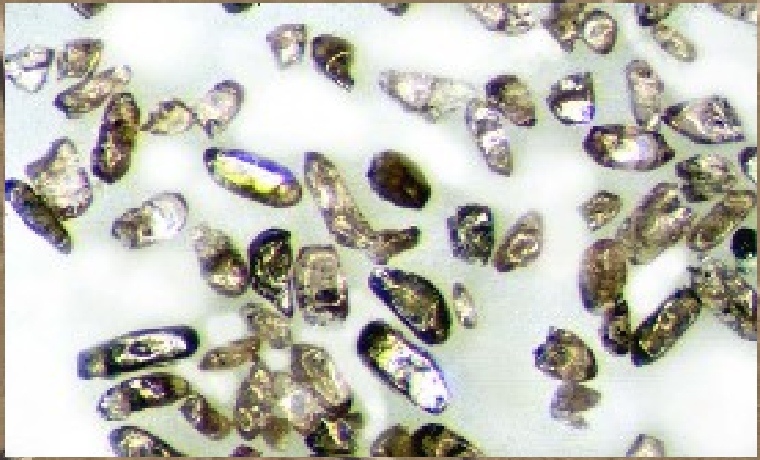
La nébuleuse
L'accrétion
Corps pla
Différenciation
nétaire
Bombardement
Dynamos/cha
Dégazage/atmosphère
© 2002 Don Dixon / cosmographica.com
Primordial
SOUP
Primordial
SOUP
continents
BASALTS
CONTINENTAL
FLOOD
BASALTS
670 km
Tectonique des plaques
PLAGIOCLASE
FELDSPAR
PYROXENE
AND OLIVINE
Océan magmatique

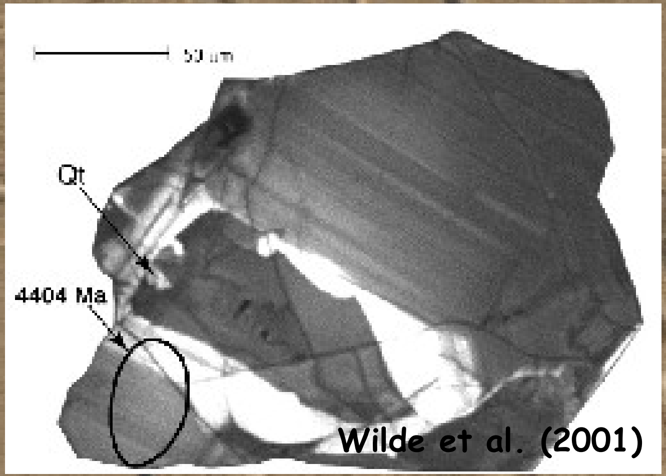
Un des grandes questions sur l'évolution de la Terre:

A quel moment sont apparus les premiers continents?

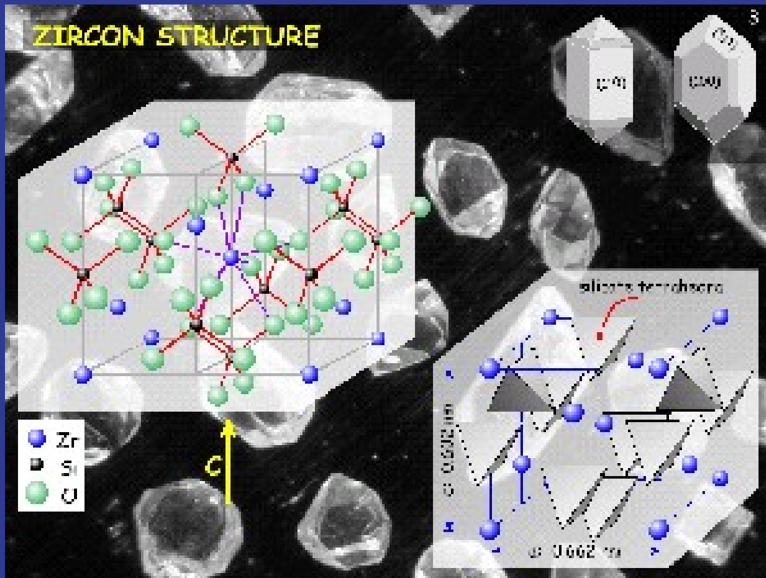
L’outil idéal: les zircons….

….petits, mais résistants, à l’heure et gèle l’Hf!





$ZrSiO_4$



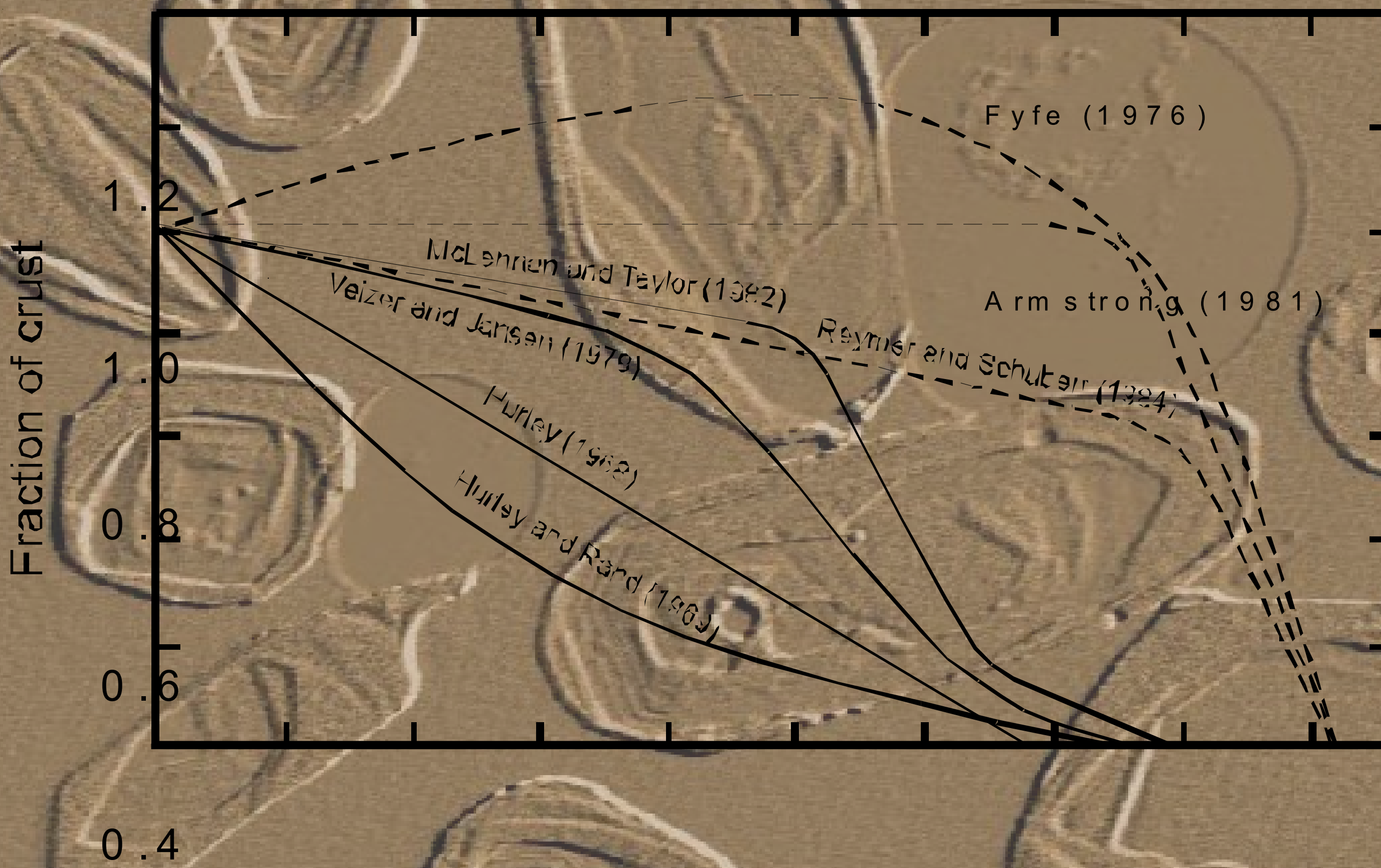
$^{91}_{40}Zr$

abundance: (silicate Earth) ~10 ppm

valence state: +4

ionic radius: 0.92Å

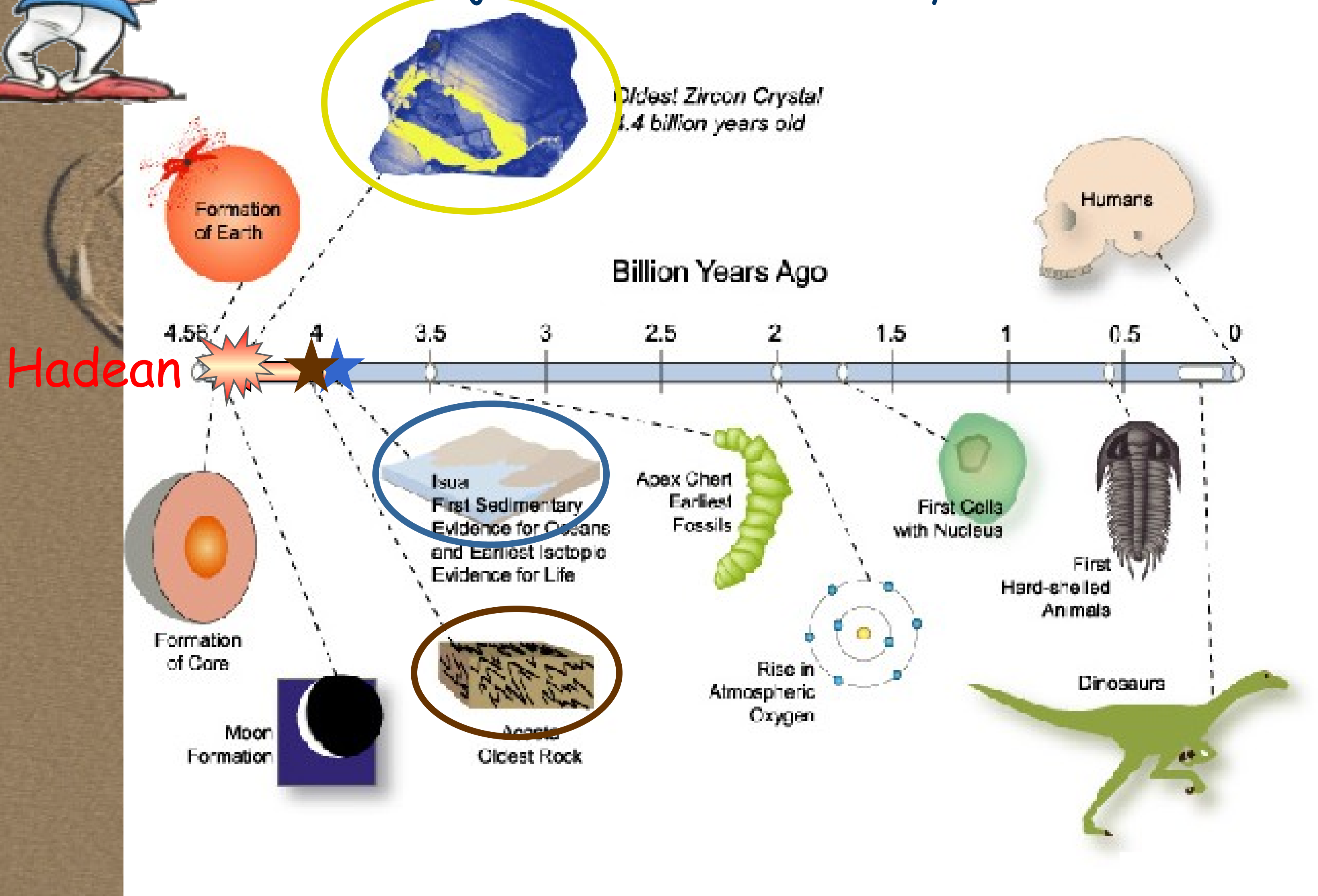
Continental crust growth models



From Taylor and McLennan (1985)

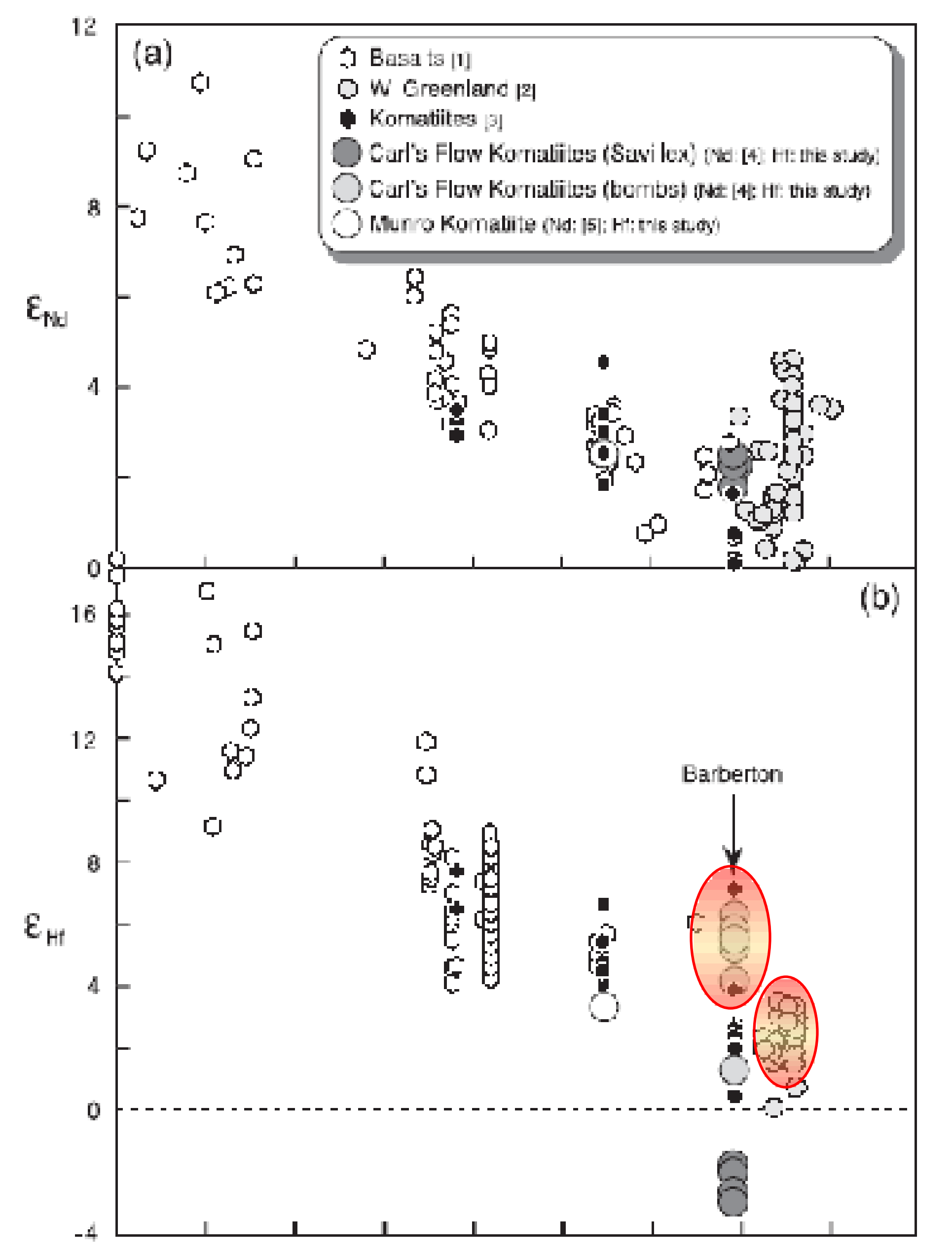
How old is "old"?

Timeline of major events in the history of the Earth



$\varepsilon_{Nd}(0) \sim +11$

$\varepsilon_{Hf}(0) \sim +18$



Missing from Early Archean rock record

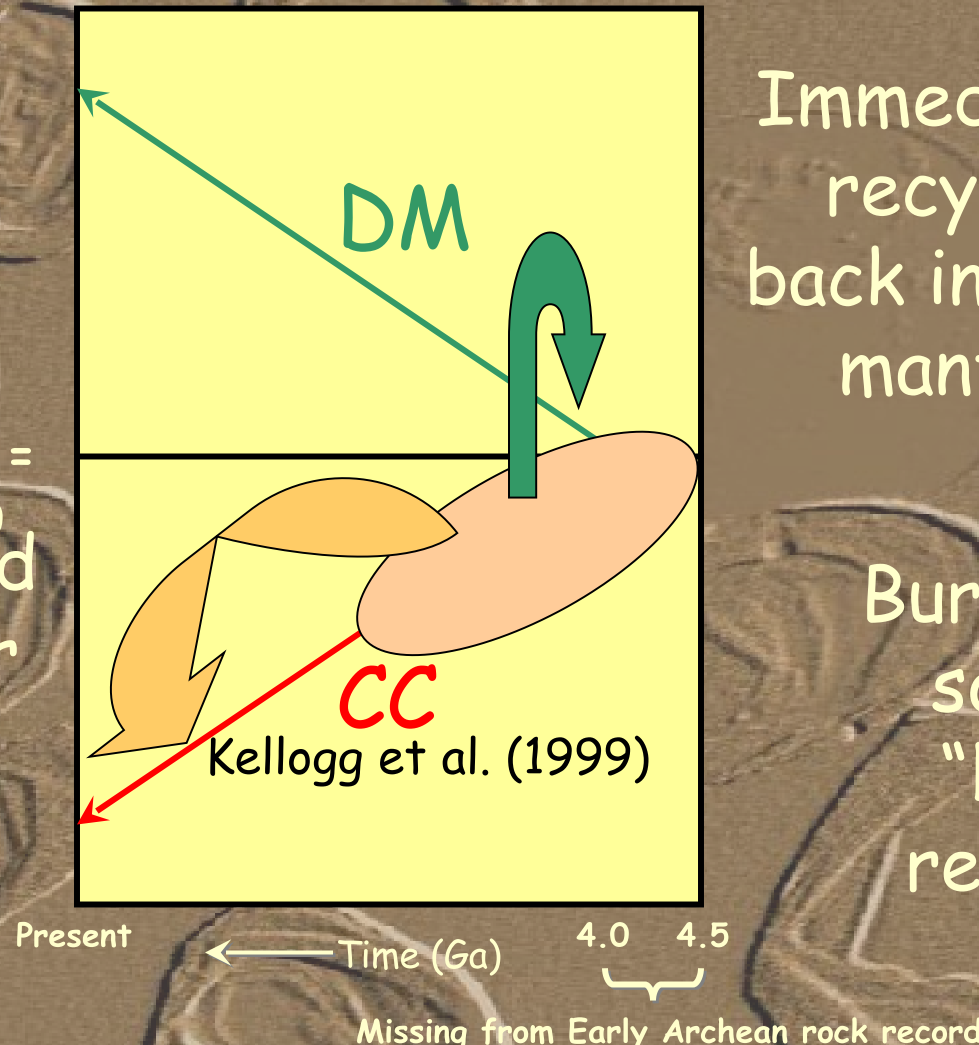
Blichert-Toft et al. (1999, 2004)

Where is the Hadean crust?

It never existed in the first place.....

$ =
0

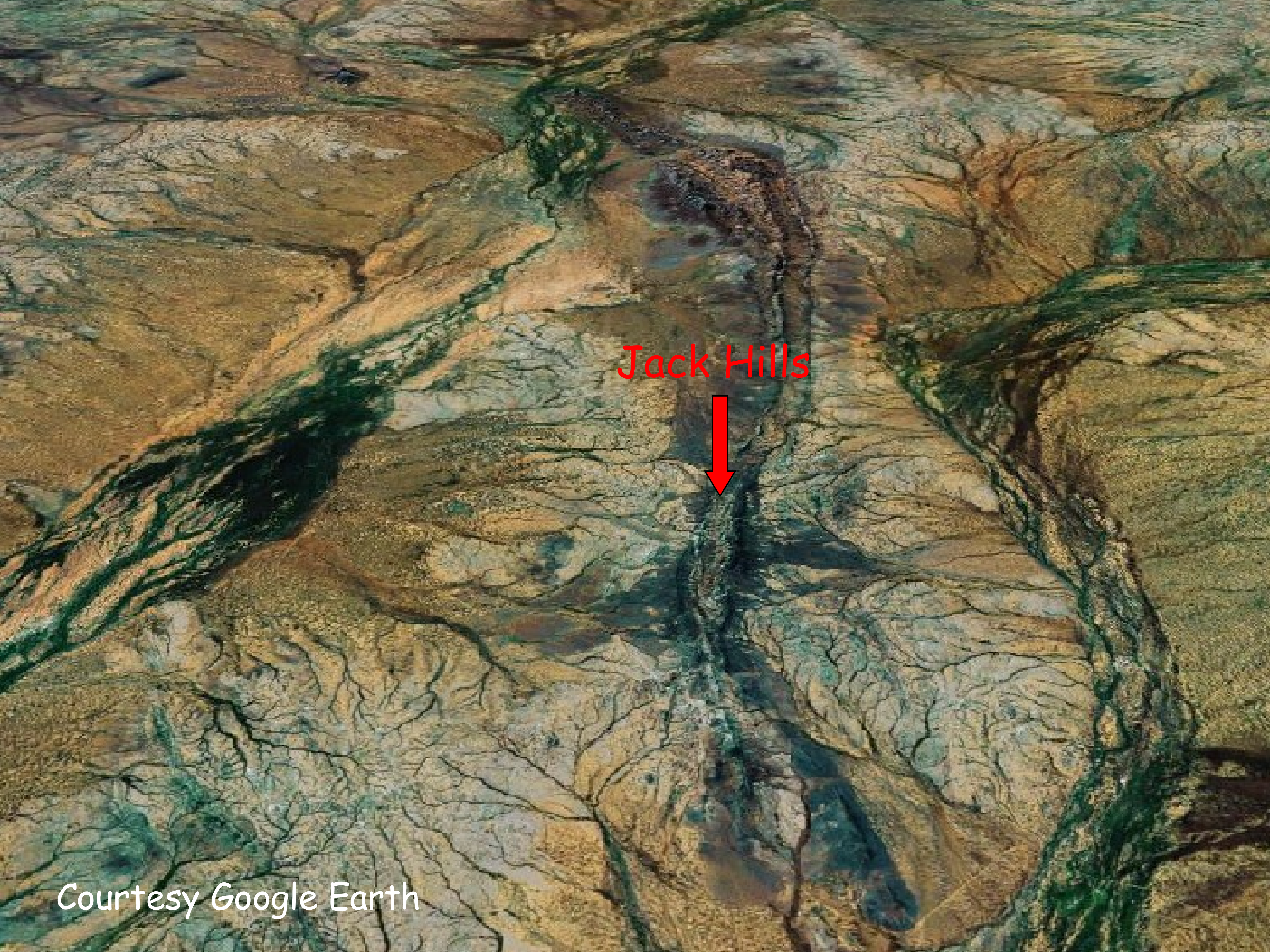
Incorporated into younger crust?



Immediately recycled back into the mantle?

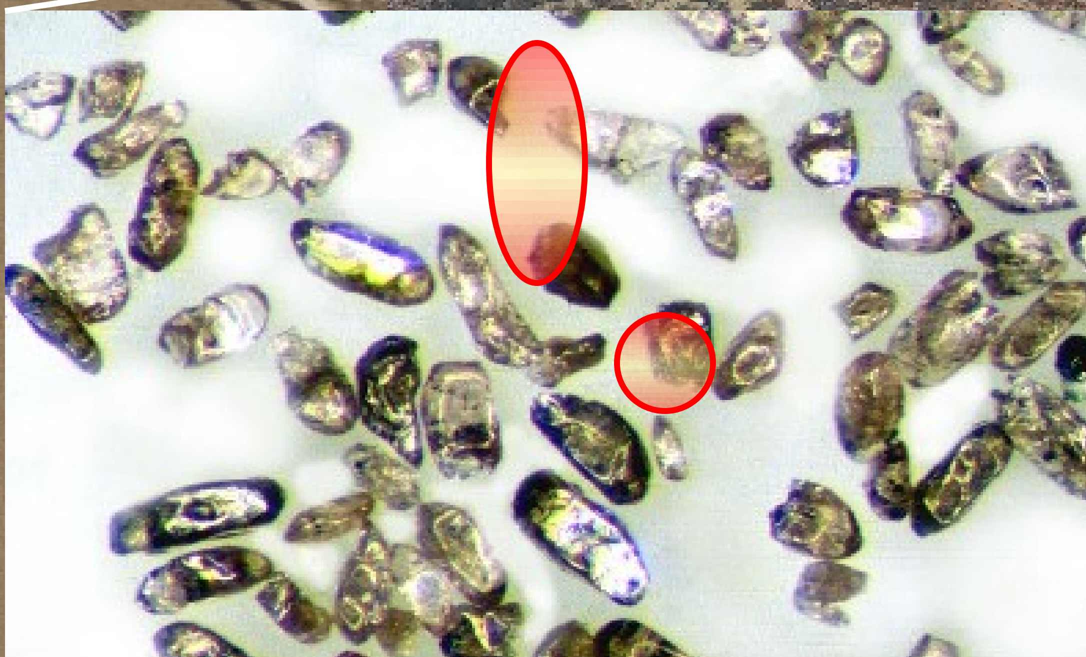
Buried in the so-called "hidden" reservoir?

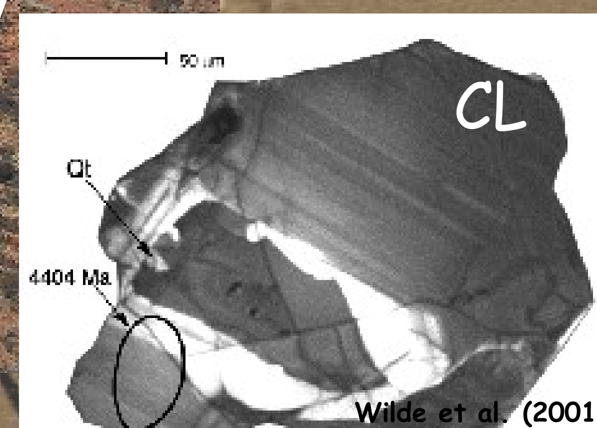
Les collines de Jack Hills, l'Australie de l'Ouest


Jack Hills
Courtesy Google Earth

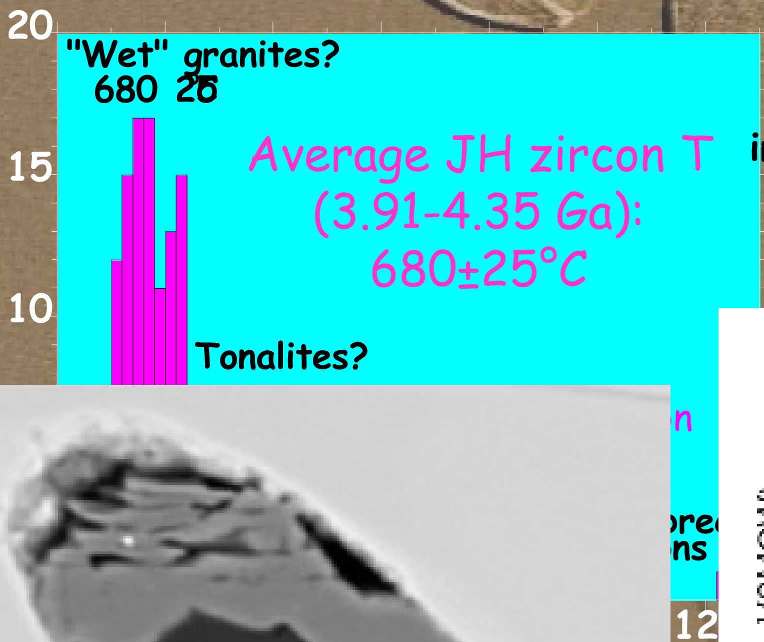
A window on the missing years of Earth history

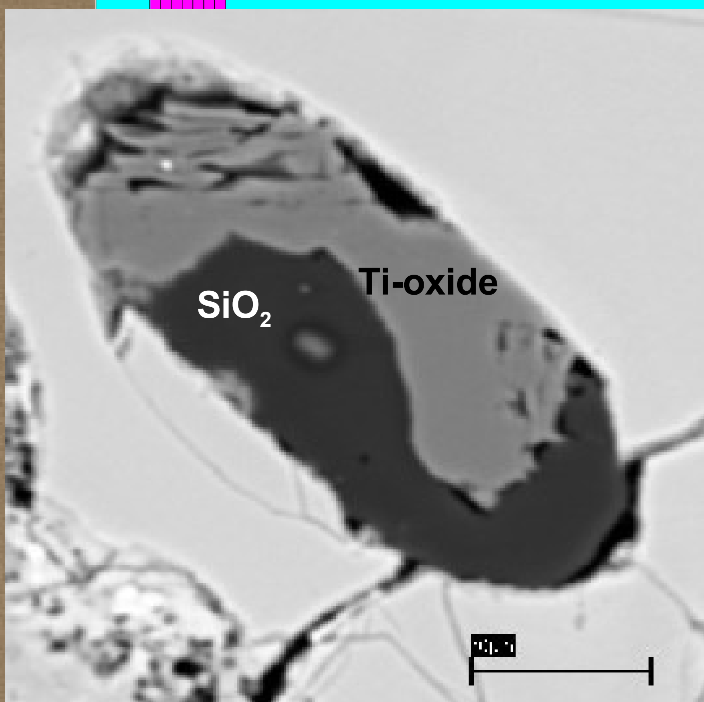
Ancient detrital zircon locality

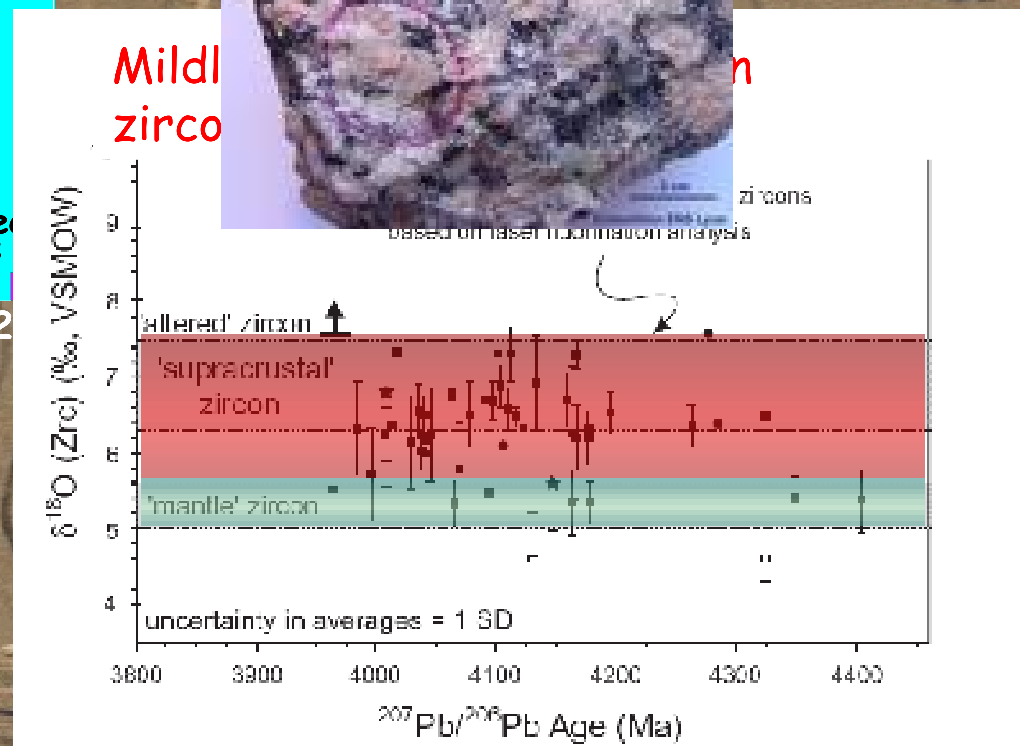




What do we know about the host rock of the detrital Jack Hills zircons?



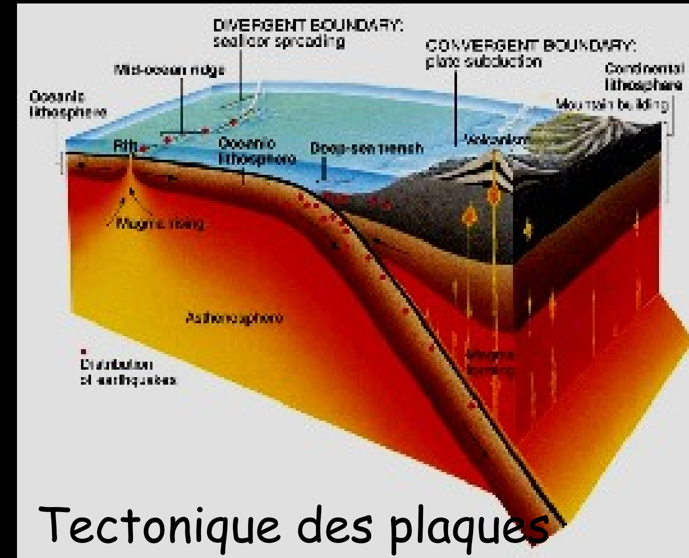




Maas et al. (1992); Cavosie et al. (2005); Trail et al. (2006); Harrison et al. (2007)

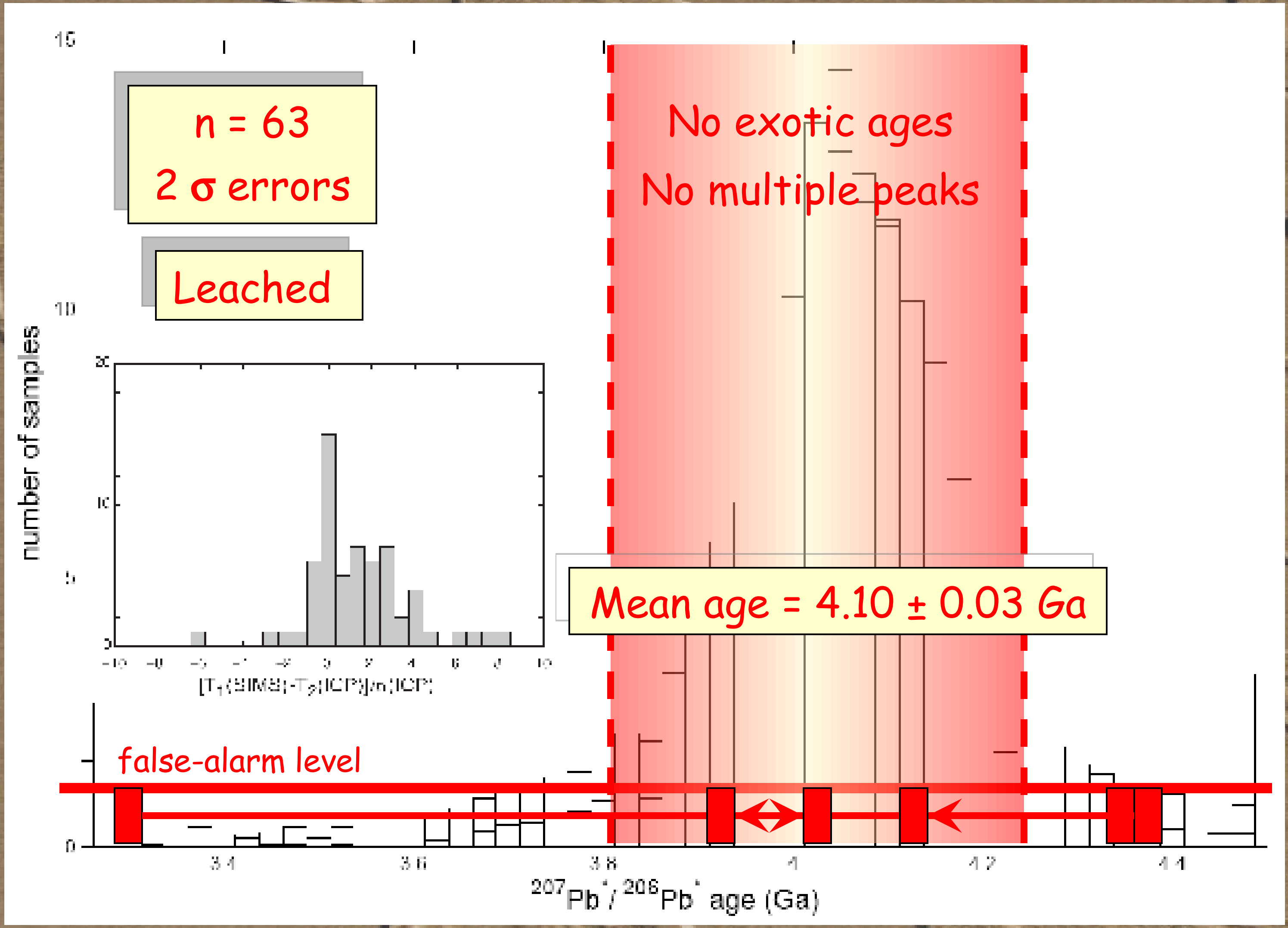
Pending issues:

- Multiplicity *vs* single event
- Age of event(s)
- Nature, formation, and age of protocrust
- Implications for plate tectonics

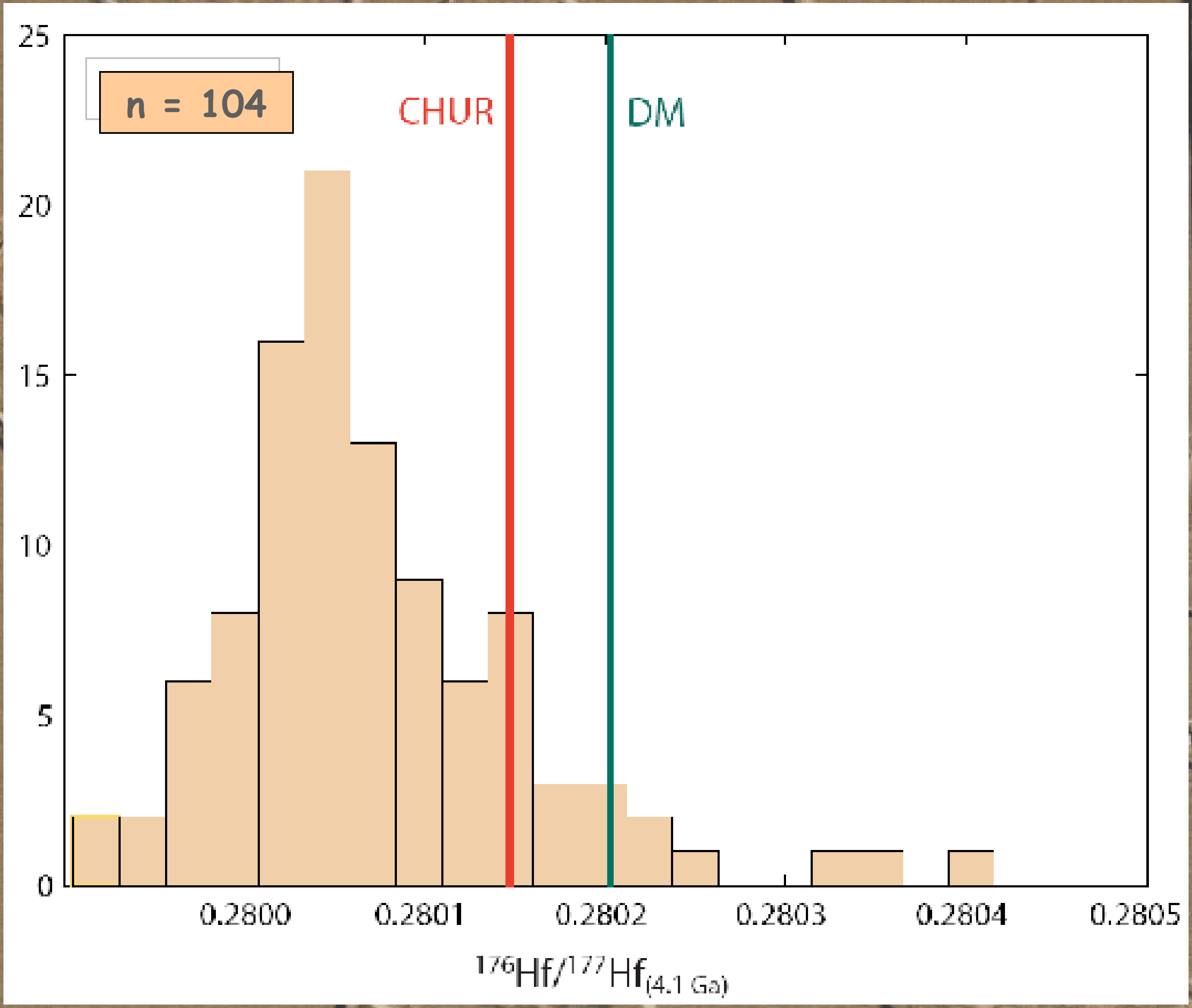


La géodynamique terrestre moderne transporte des nutriments (NO_3, PO_4, SiO_2) et accueille l'activité biologique.....

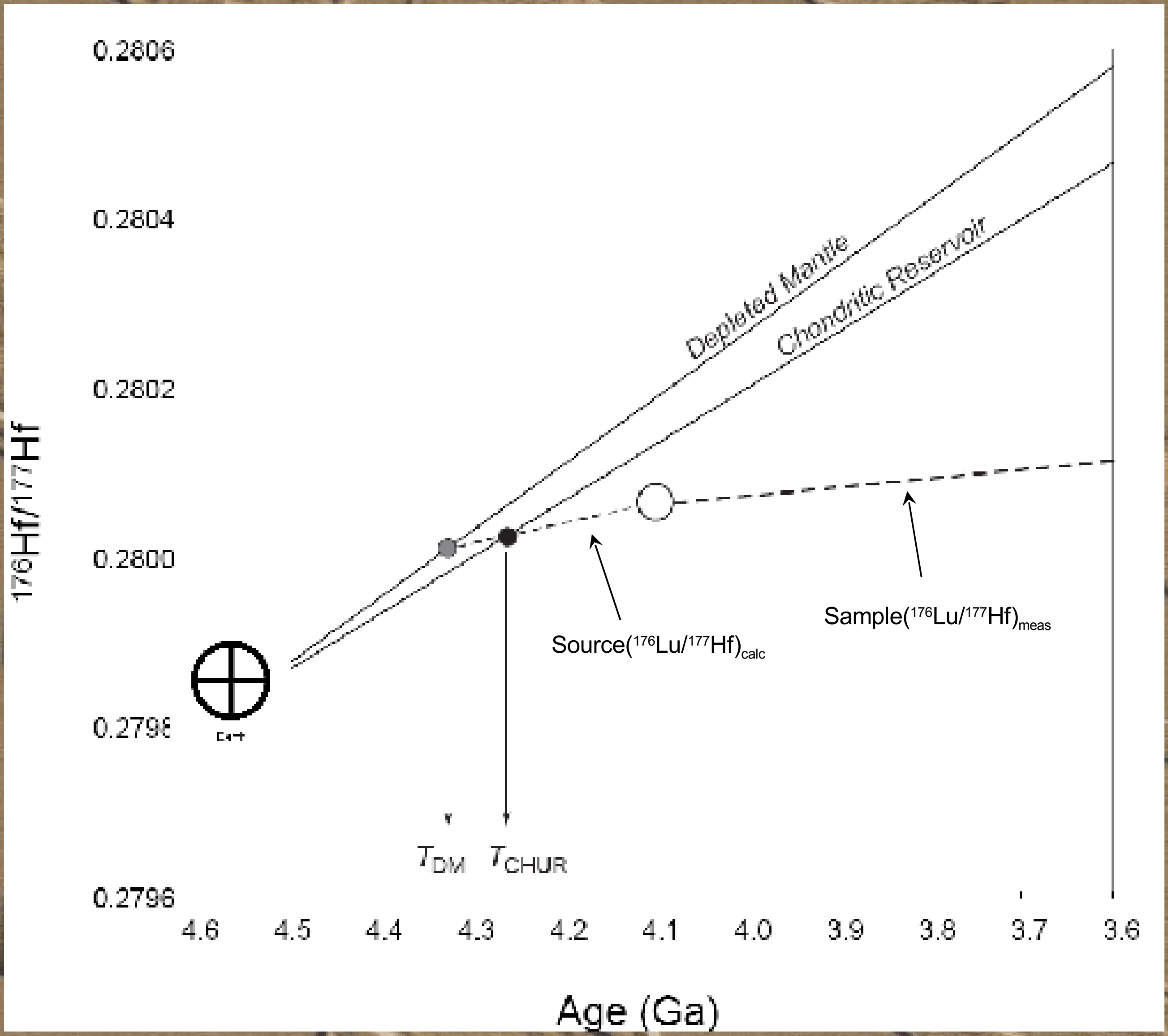
L'âge des plus vieux zircons terrestres = l'âge des granites de Jack Hills



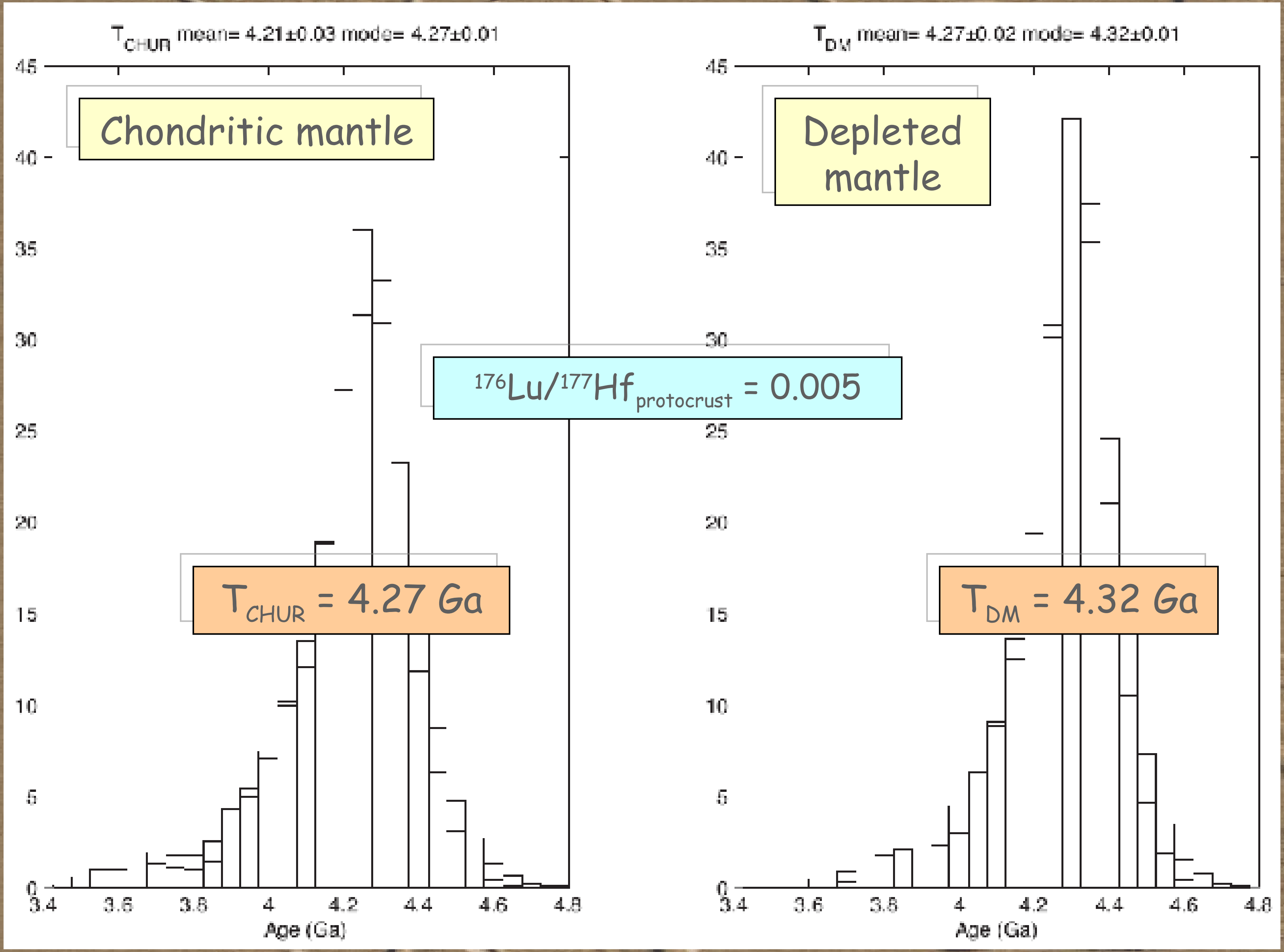
Initial Hf isotopic composition of Jack Hills zircons

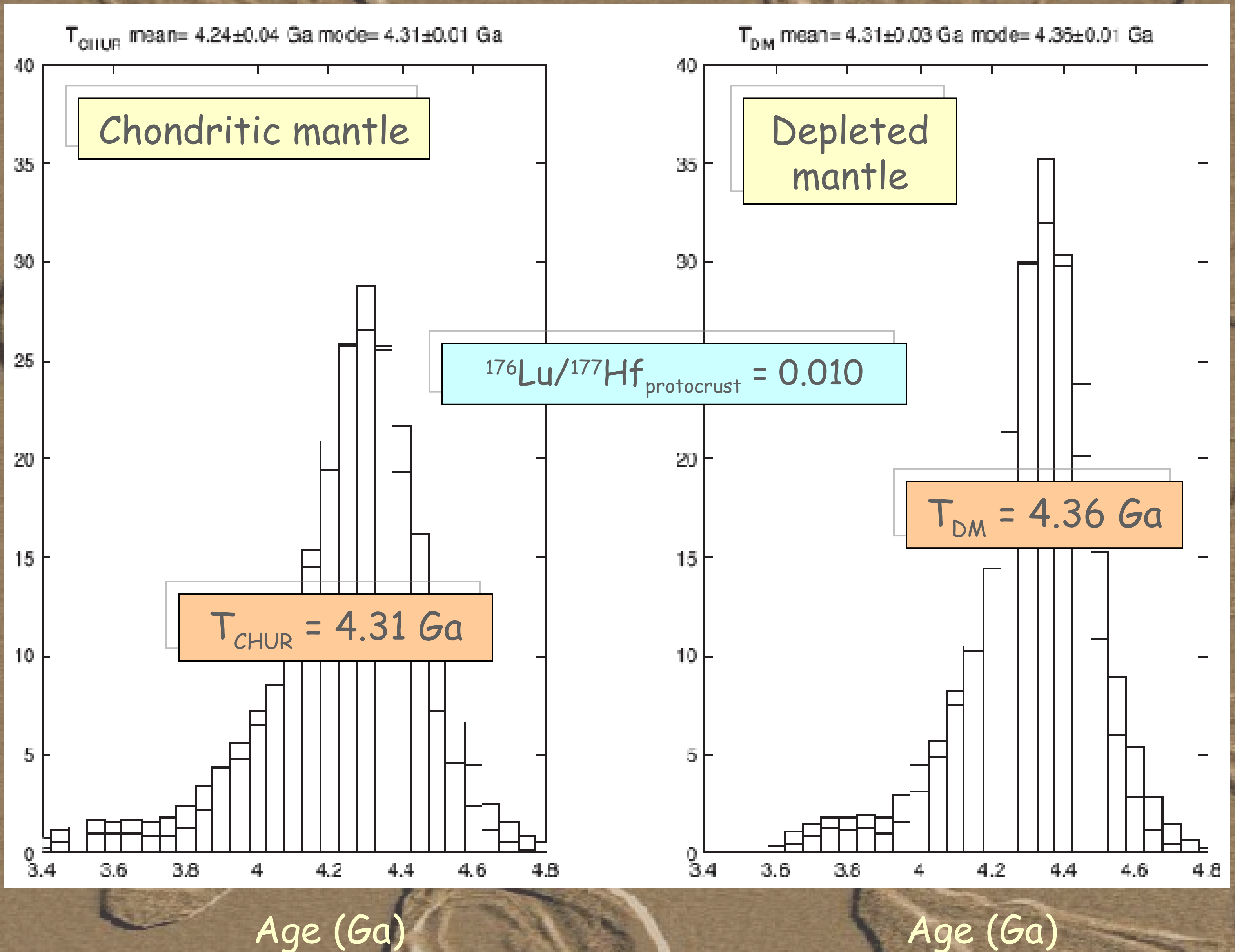


Rappel: Les âges modèles

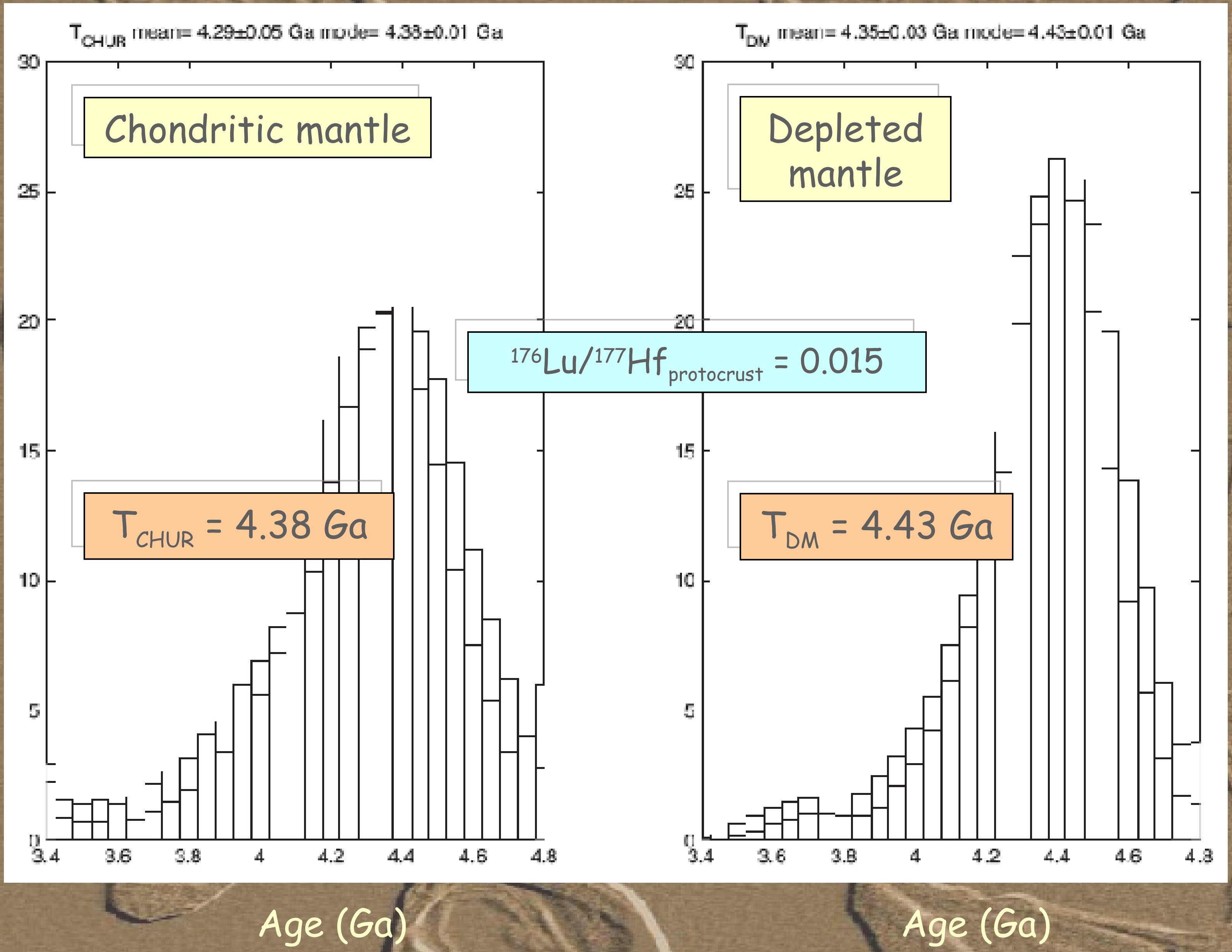


L'âge ^{176}Lu-^{176}Hf des plus vieux continents *parents* des granites de Jack Hills

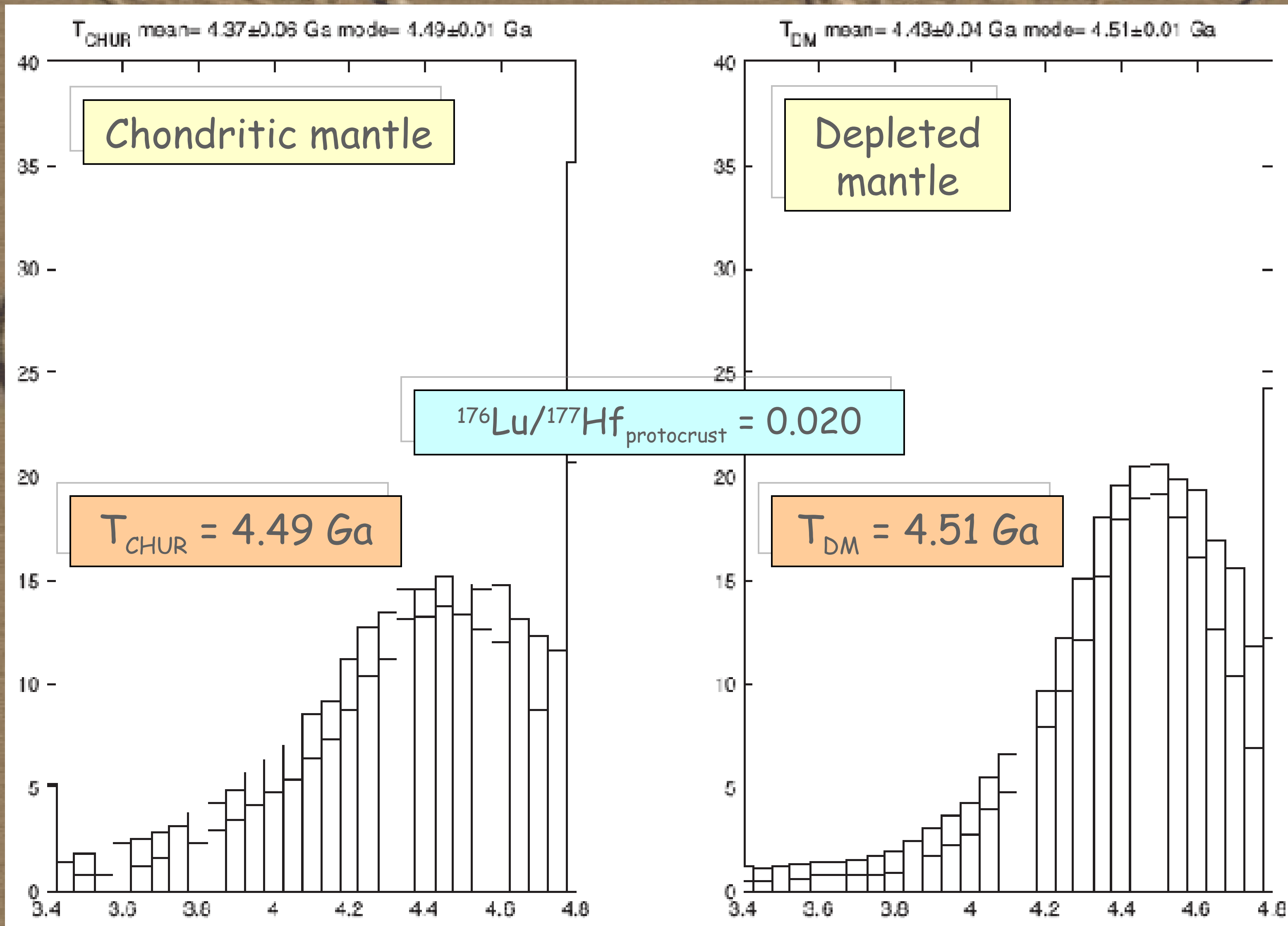




T_CHUR mean= 4.24±0.04 Ga mode= 4.31±0.01 Ga
Chondritic mantle
T_CHUR = 4.31 Ga
T_DM mean= 4.31±0.03 Ga mode= 4.36±0.01 Ga
Depleted mantle
T_DM = 4.36 Ga
176Lu/177Hf protocrust = 0.010
Age (Ga)
Age (Ga)

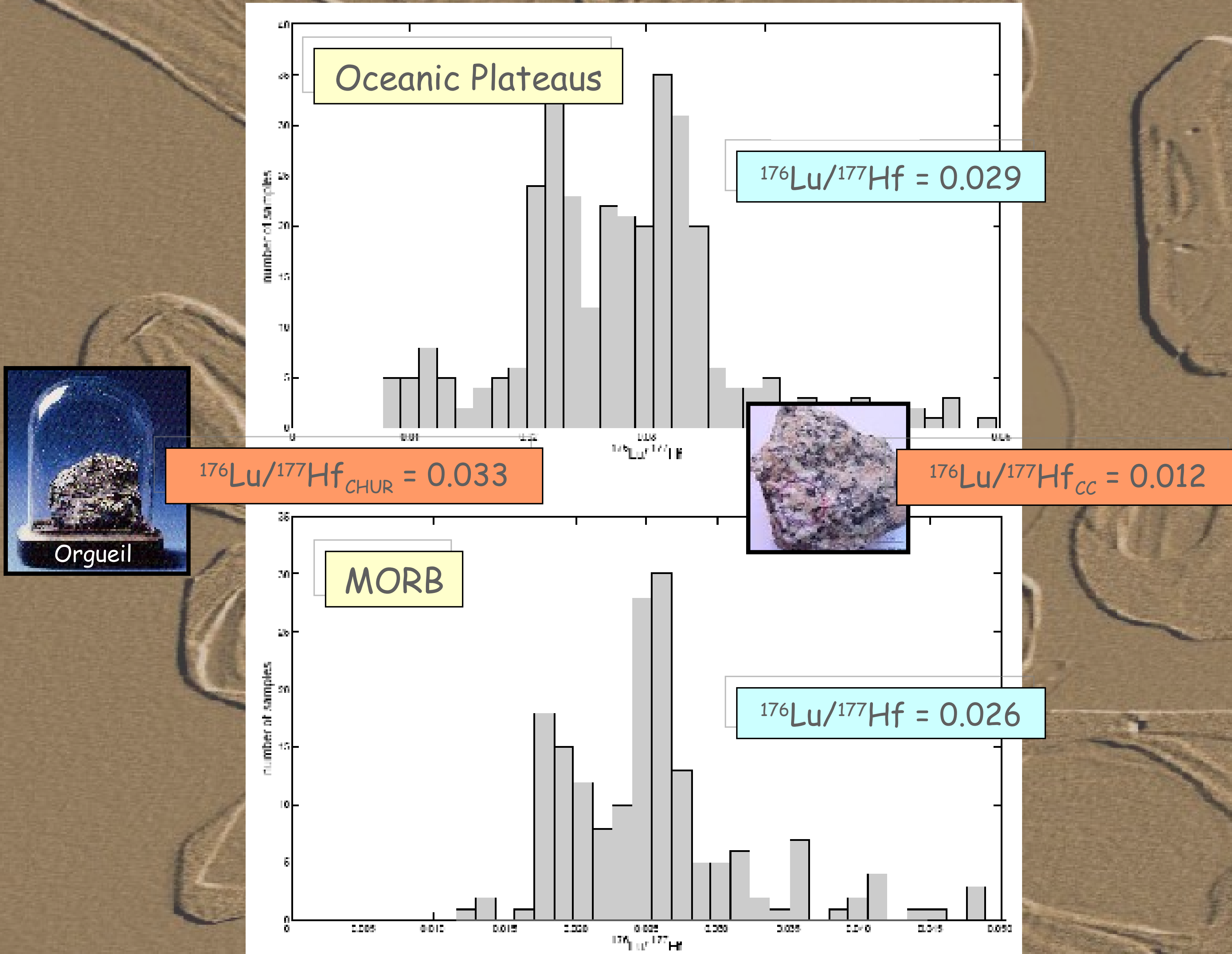


T CHUR mean= 4.29±0.05 Ga mode= 4.38±0.01 Ga
T DM mean= 4.35±0.03 Ga mode= 4.43±0.01 Ga
Chondritic mantle
Depleted mantle
176Lu/177Hf protocrust = 0.015
T CHUR = 4.38 Ga
T DM = 4.43 Ga
Age (Ga)
Age (Ga)



T_{CHUR} mean= 4.37±0.06 Ga mode= 4.49±0.01 Ga
Chondritic mantle
T_{CHUR} = 4.49 Ga
T_{DM} mean= 4.43±0.04 Ga mode= 4.51±0.01 Ga
Depleted mantle
T_{DM} = 4.51 Ga
$^{176}Lu/^{177}Hf_{protocrust}$ = 0.020
0
5
10
15
20
25
30
35
40
3.4
3.6
3.8
4
4.2
4.4
4.6
4.8

Age (Ga) Age (Ga)



Oceanic Plateaus
^{176}Lu/^{177}Hf = 0.029
number of samples
^{176}Lu/^{177}Hf$_{CHUR}$ = 0.033
Orgueil
^{176}Lu/^{177}Hf$_{CC}$ = 0.012
MORB
^{176}Lu/^{177}Hf = 0.026
number of samples

First-order observations:

- $^{176}Lu/^{177}Hf \geq 0.015$, as in crust made of basalt, produces flat histograms with many unacceptable ages > 4.56 Ga
- 'Granitic' $^{176}Lu/^{177}Hf = 0.005\text{-}0.010$ produces well-defined peaks centered around maxima at 4.31 (T_{CHUR}) and 4.36 (T_{DM}) Ga with all ages < 4.56 Ga

Les premiers continents apparaissent alors ~200 Ma après la formation de la Terre

Pending issues:

- Multiplicity *vs* single event
- Age of event(s)
- Nature, formation, and age of protocrust
- Implications for plate tectonics

Because granites are the hallmark of modern plate tectonics, the Jack Hills zircon bulk Pb ages suggest this process was active in its present form by at least 4.1 Ga

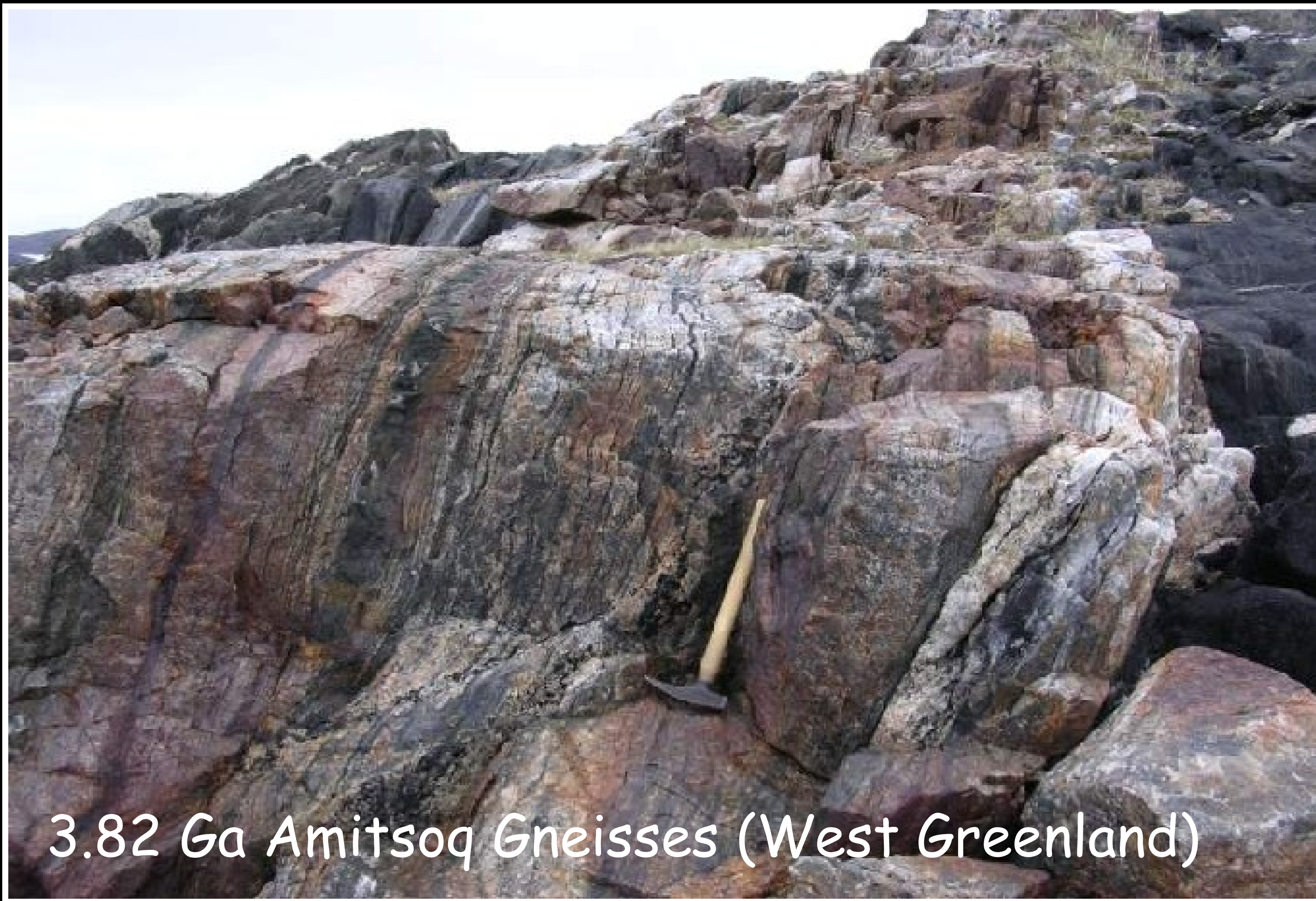
Demonstrating it started even earlier requires independent evidence that the ~4.35 Ga source rock of the Jack Hills granites was *also* granitic

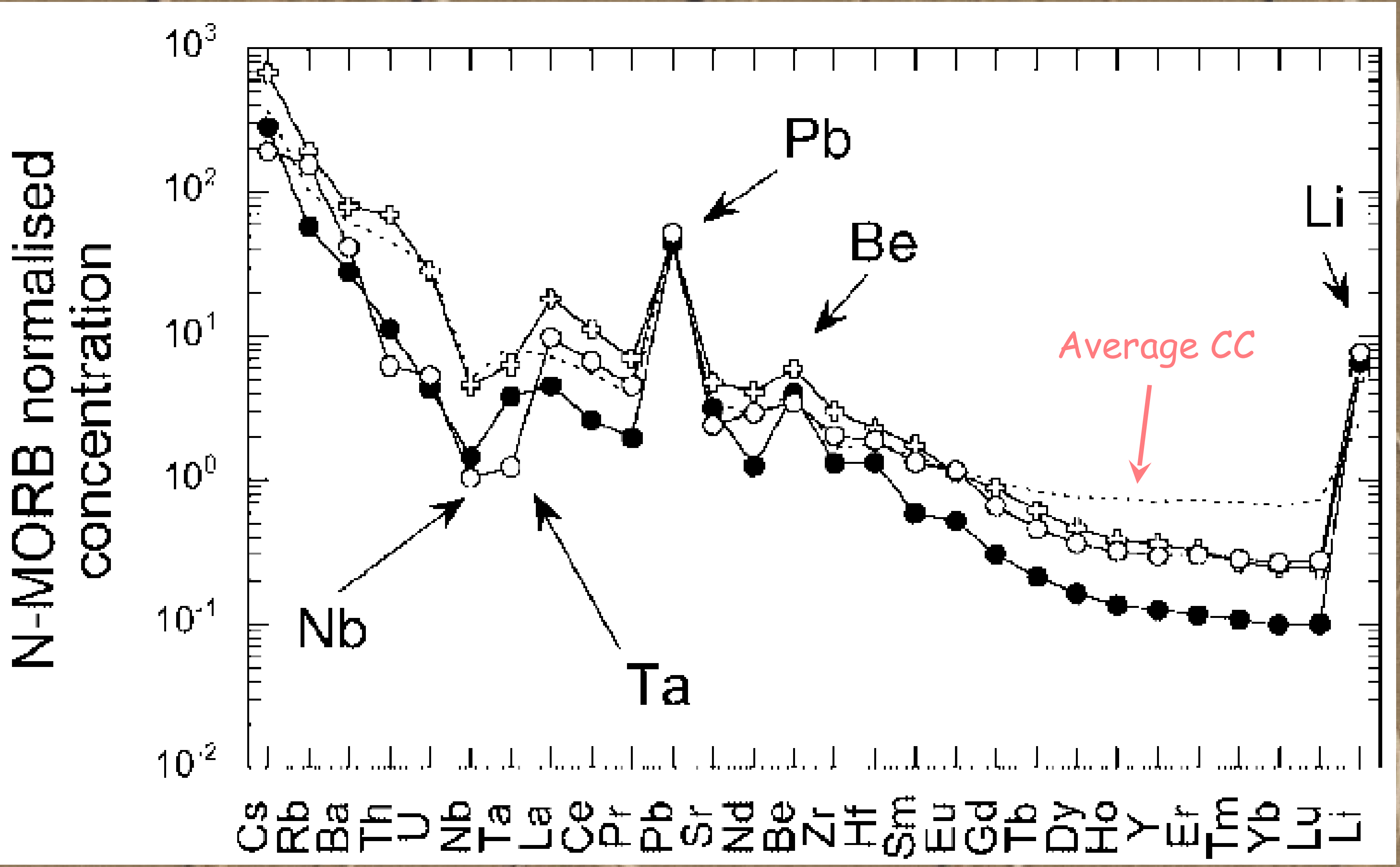
This *could* be given the

- heavy oxygen
- unradiogenic Hf
- low Lu/Hf

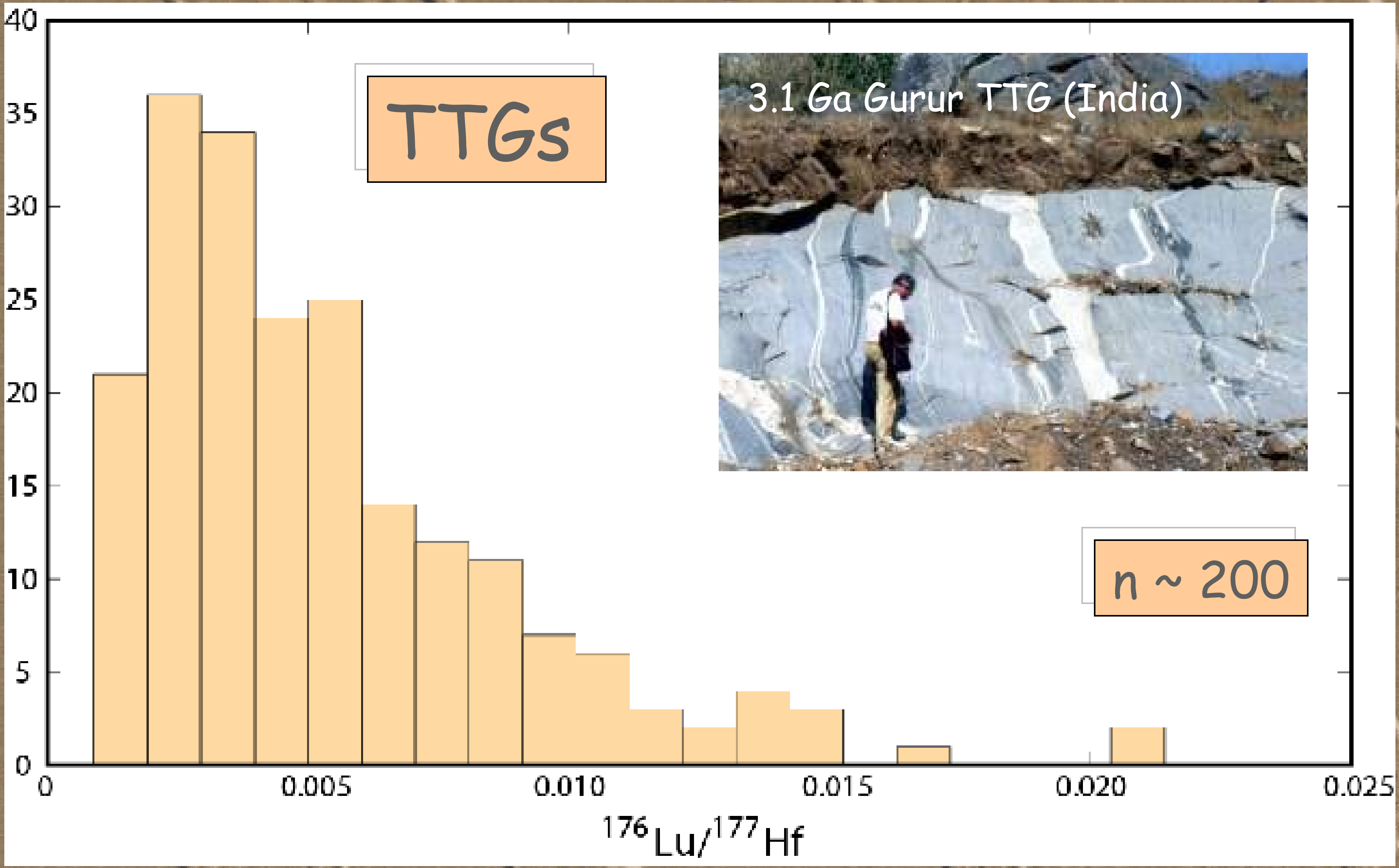
BUT……..Lu/Hf way too low!!!

Only Archean TTGs have such inordinately low Lu/Hf



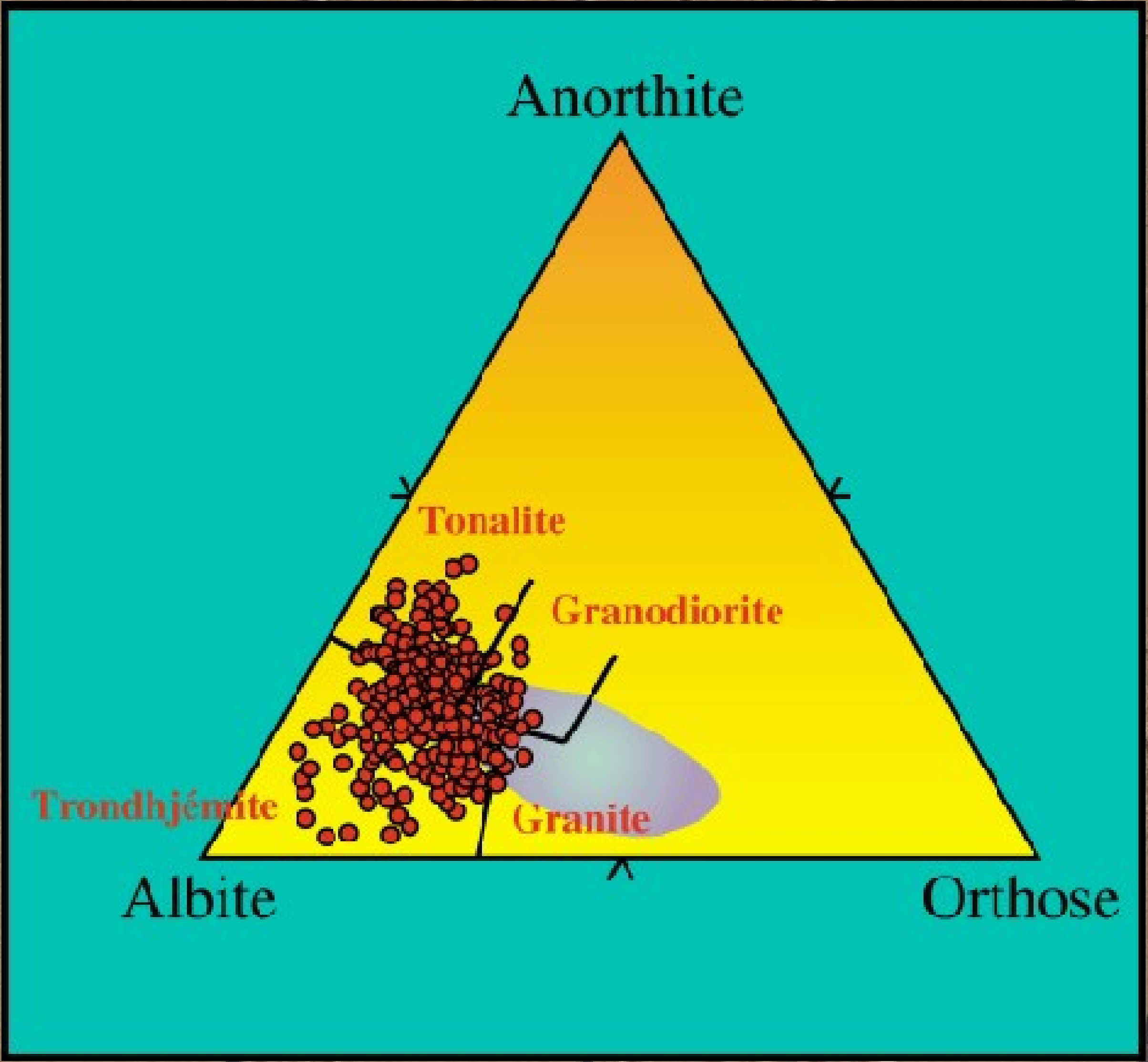


Kamber et al. (2002)



Hervé Martin (unpublished TTG data compilation)

Primitive continental crust

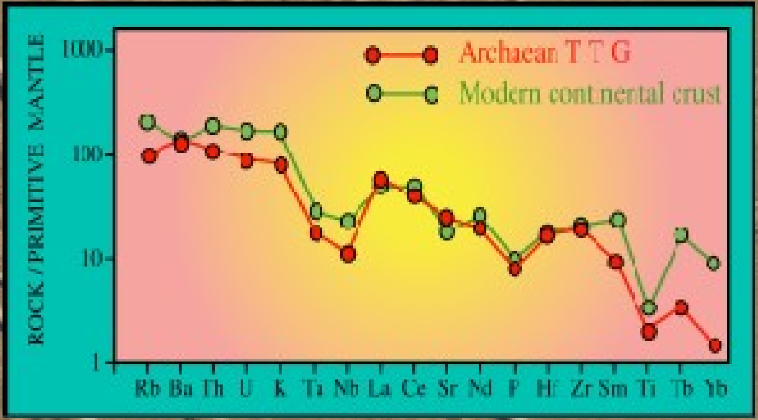


TTGs are calc-alkaline but Na-rich:
Tonalitic
Trondhjemitic
Granodioritic

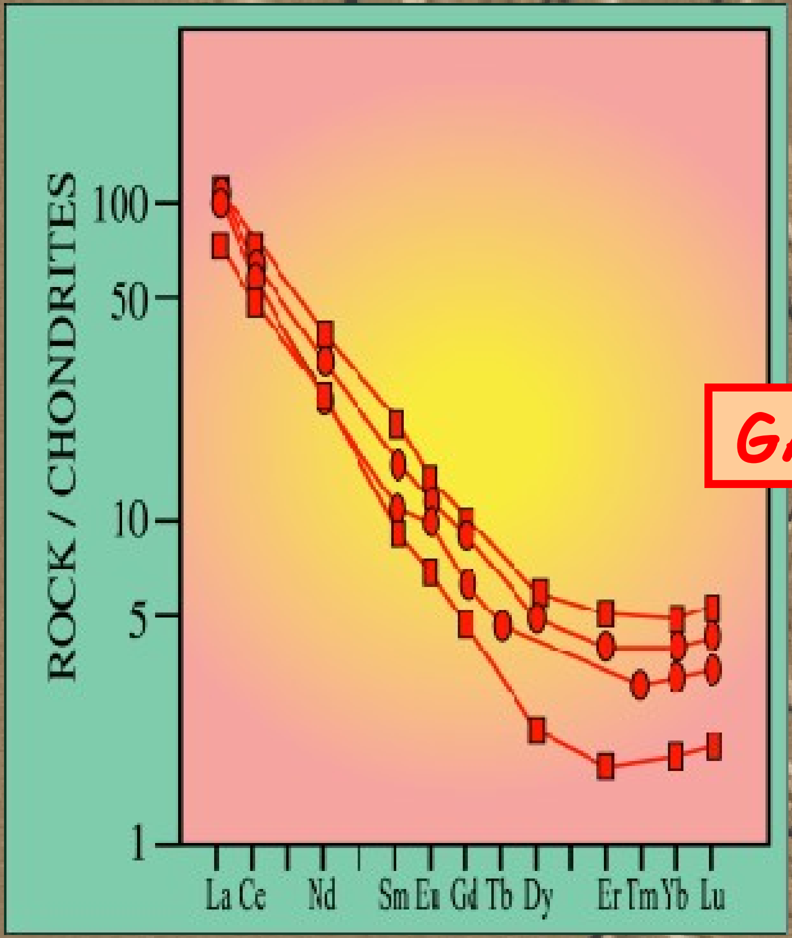
Modern continental crust is "classic" calc-alkaline = K-rich:
Granodioritic
to Granitic

Courtesy Hervé Martin

Courtesy Hervé Martin

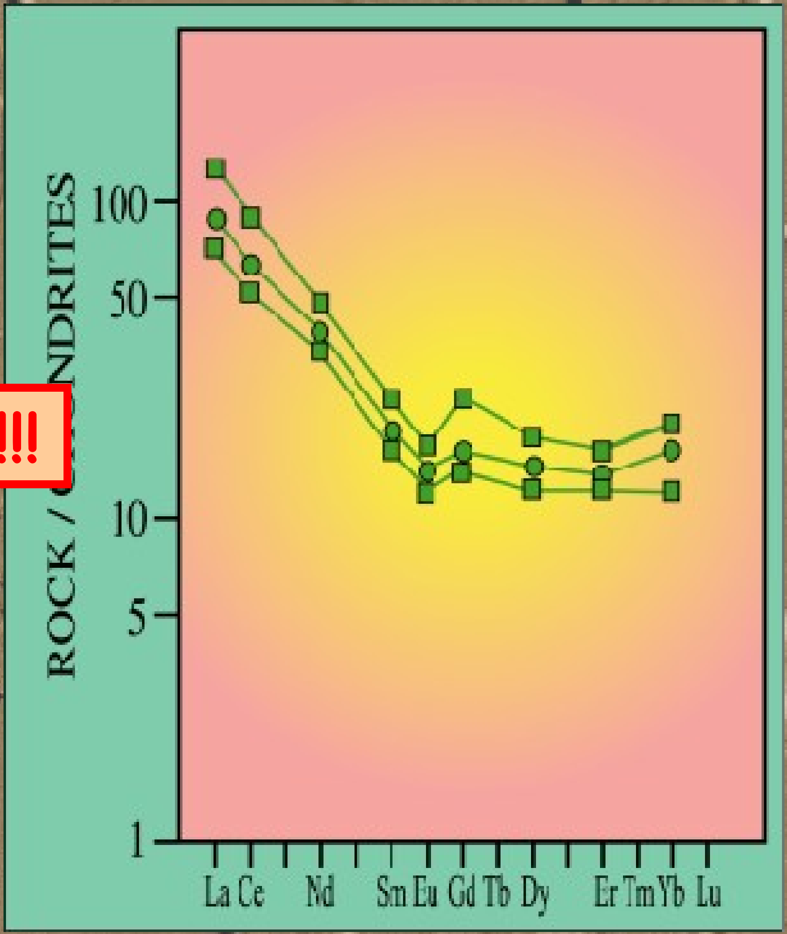


TTGs

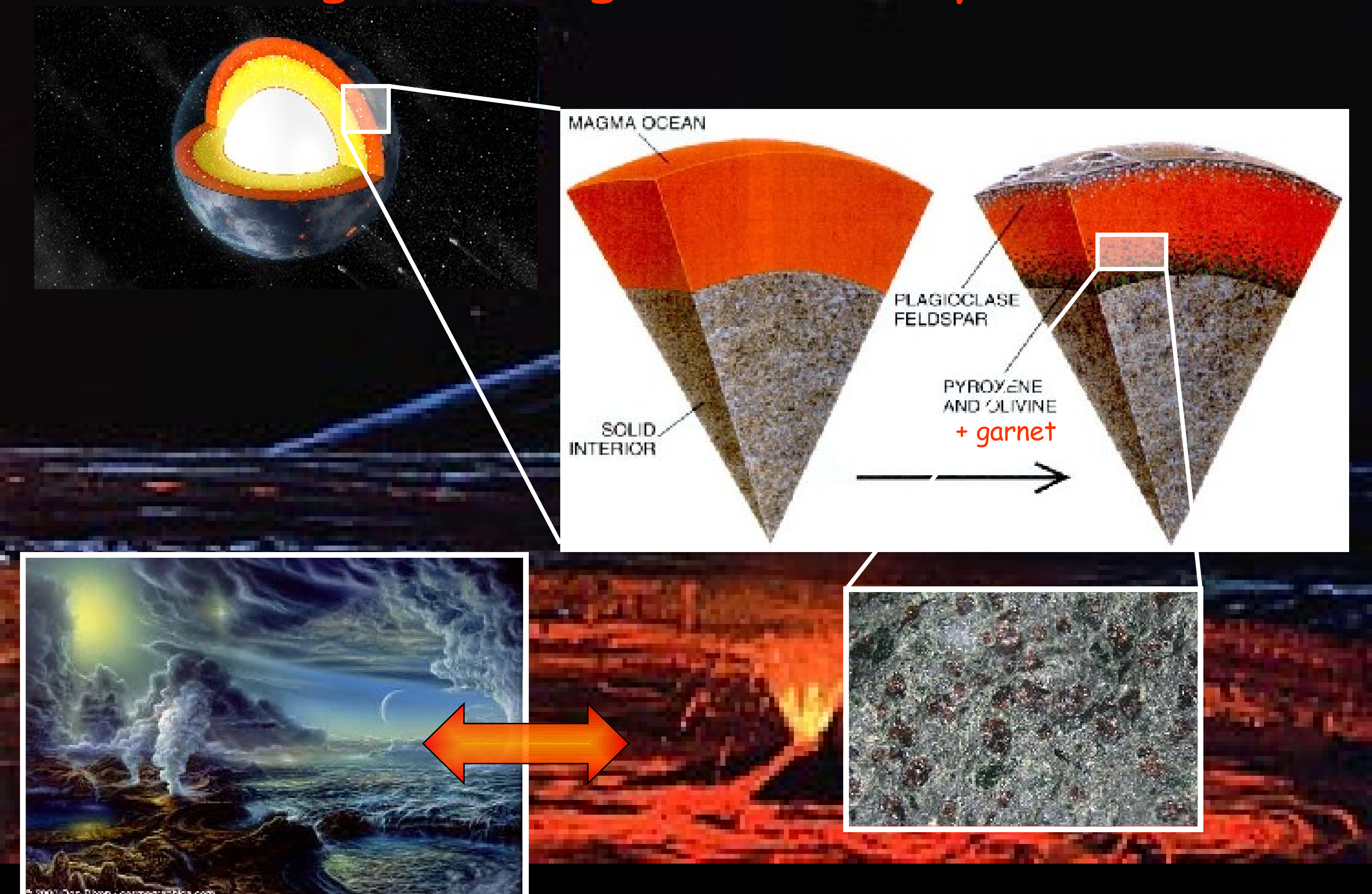


GARNET!!!!

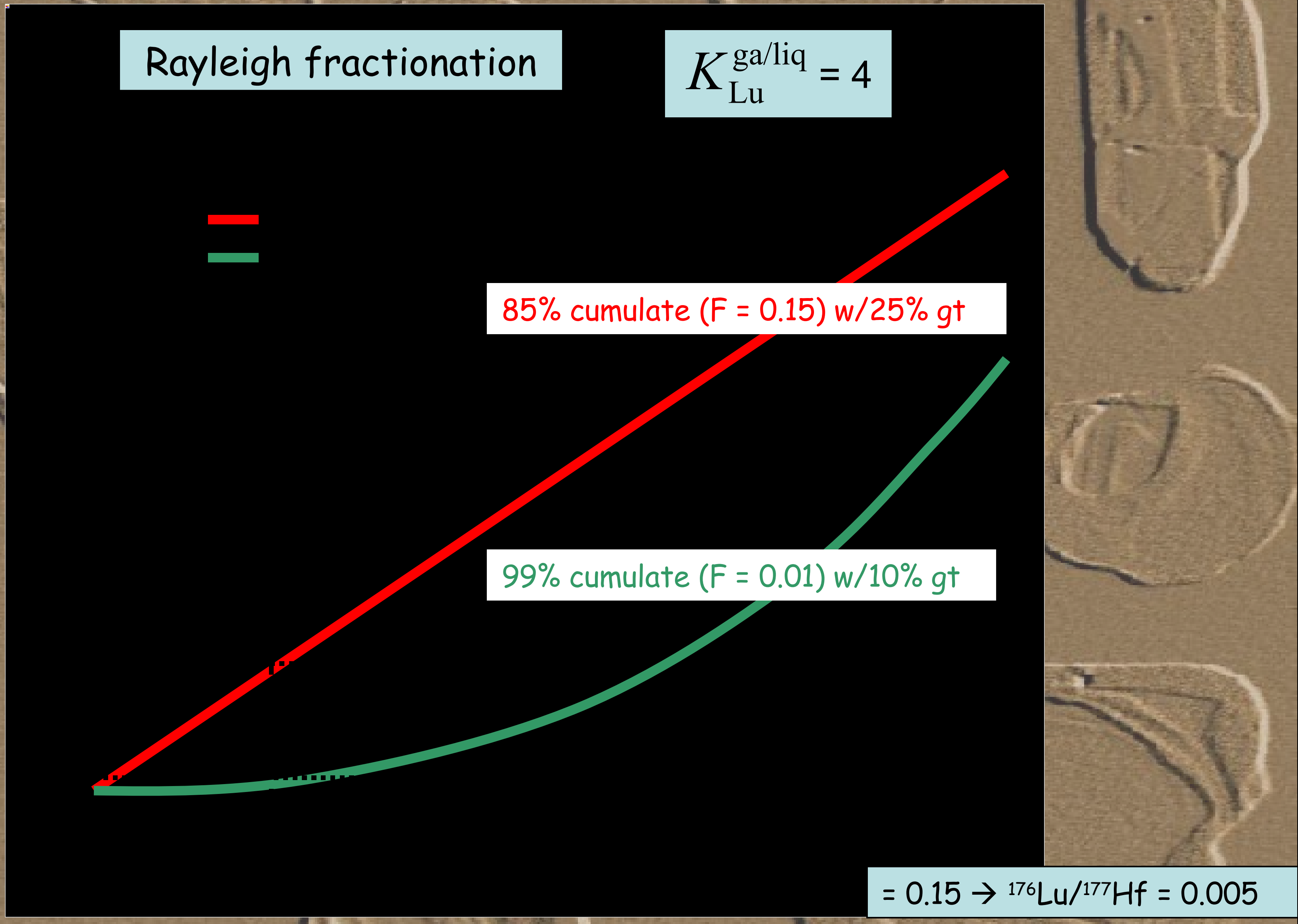
MODERN CC



Last stages of magma ocean crystallization



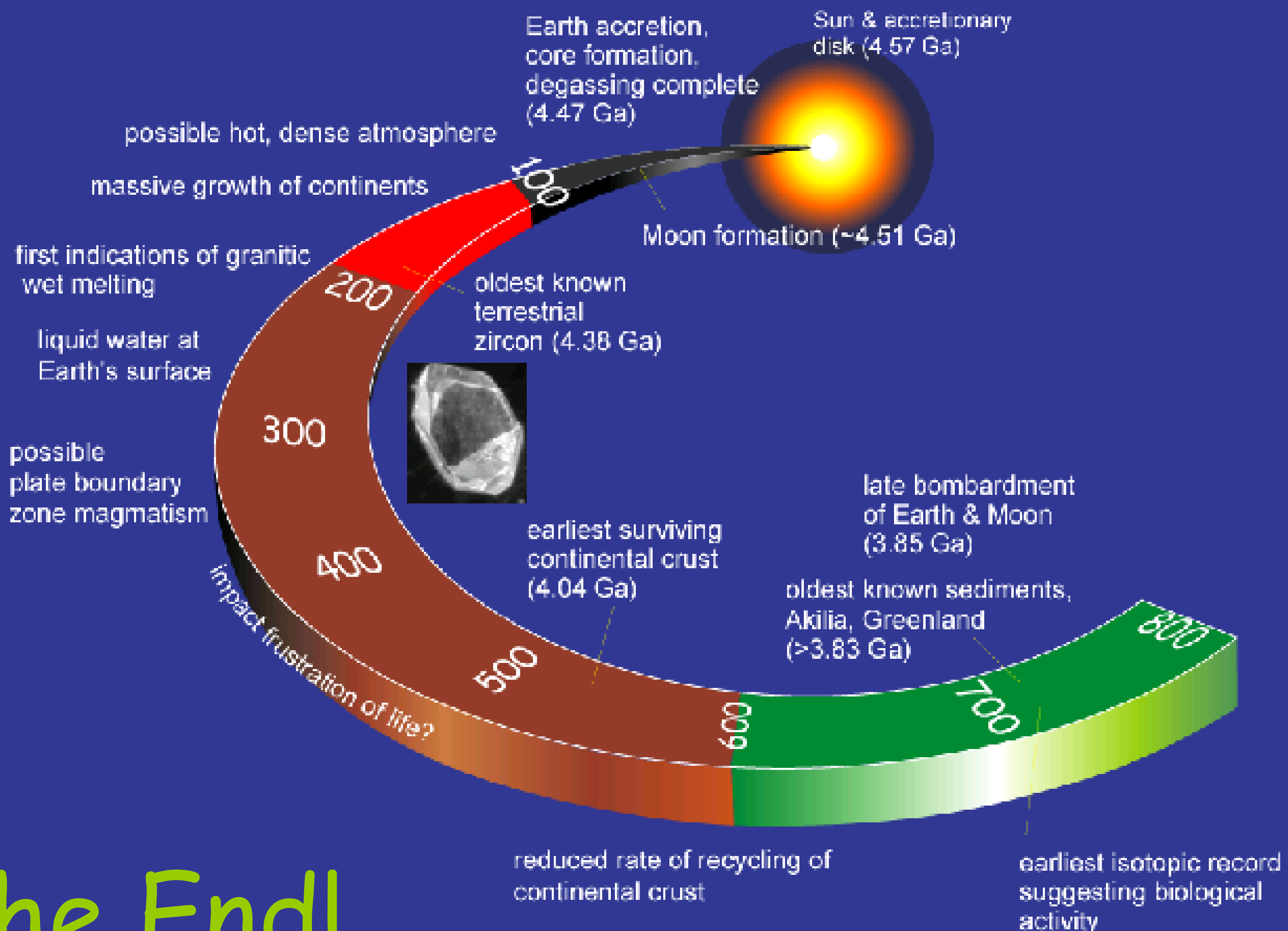
How did the early low-Lu/Hf crust form?



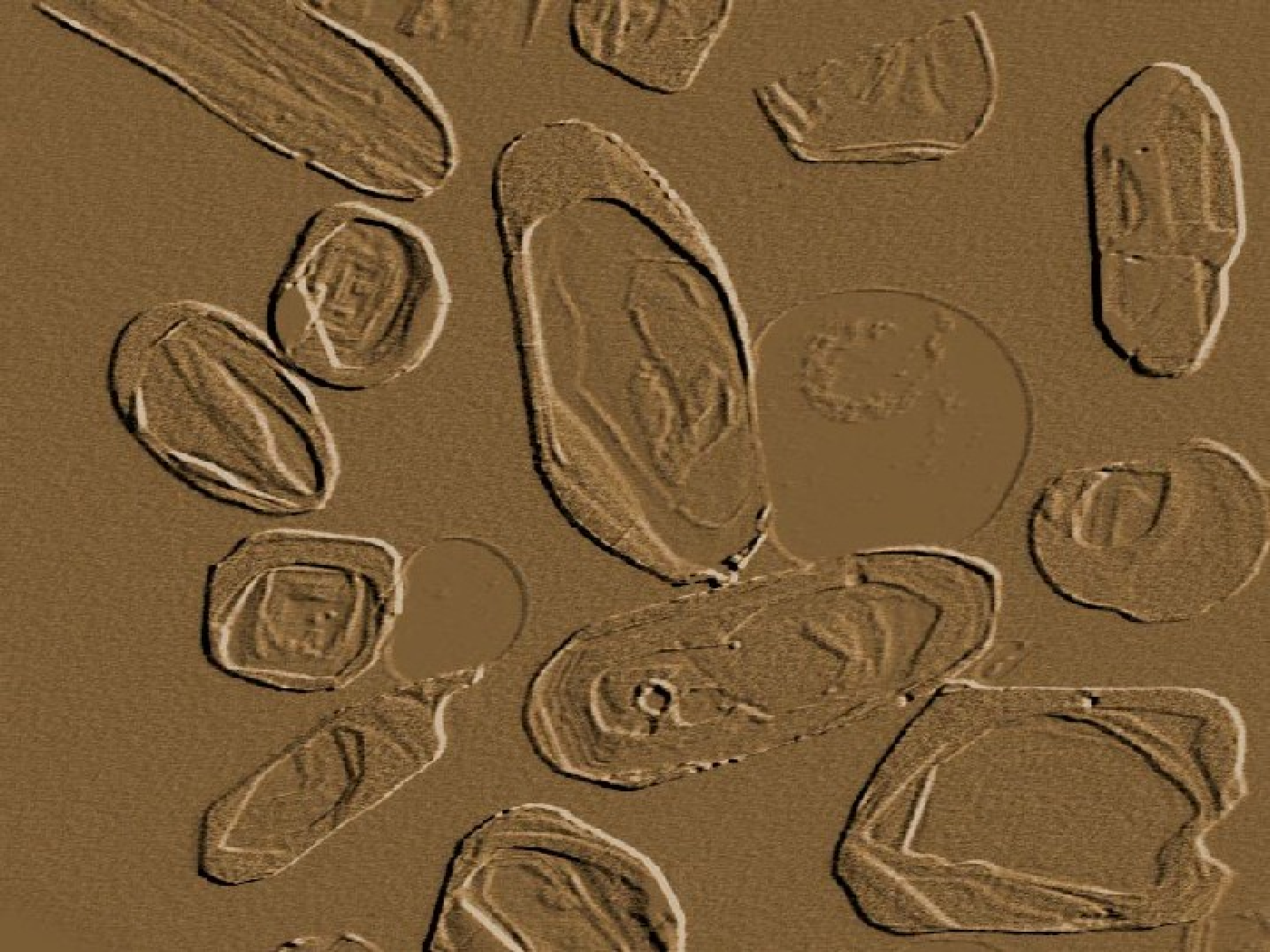
Conclusions

- The parent granites of the Jack Hills zircons formed 4.1 ± 0.1 Gy ago by remelting of a 4.31-4.36 Ga old protocrust…
- …whose inferred low Lu/Hf ratio best fits Archean TTG suites…
- … which themselves may have been produced by melting of the last remains of the magma ocean (hydrous KREEPy basalt)
- Dating the onset of plate tectonics hinges around whether TTGs are subduction zone magmas or not

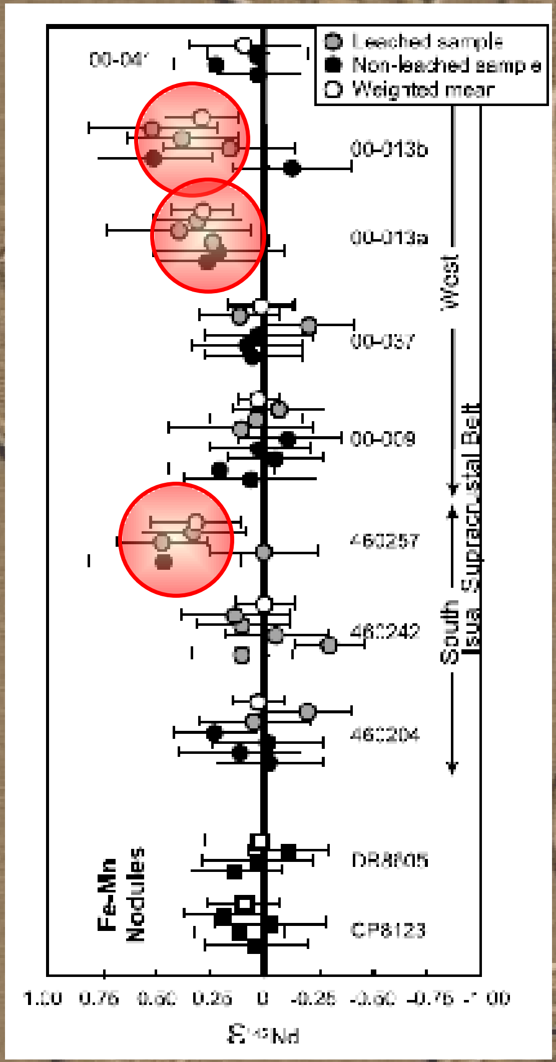
The first 800 million years



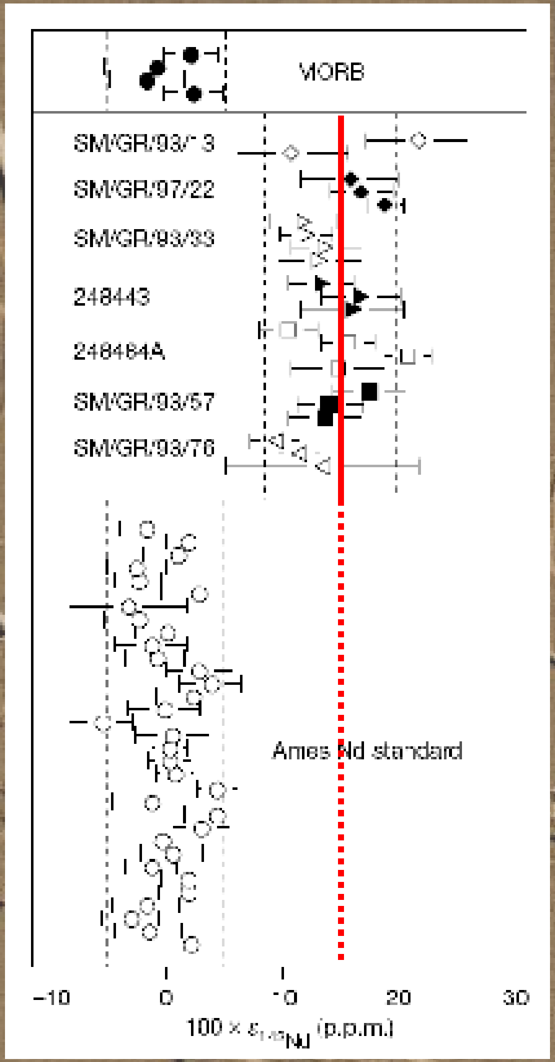
The End!



Différenciation précoce de la Terre à ~4.35 Ga en accord avec les anomalies en ^{142}Nd à Isua….

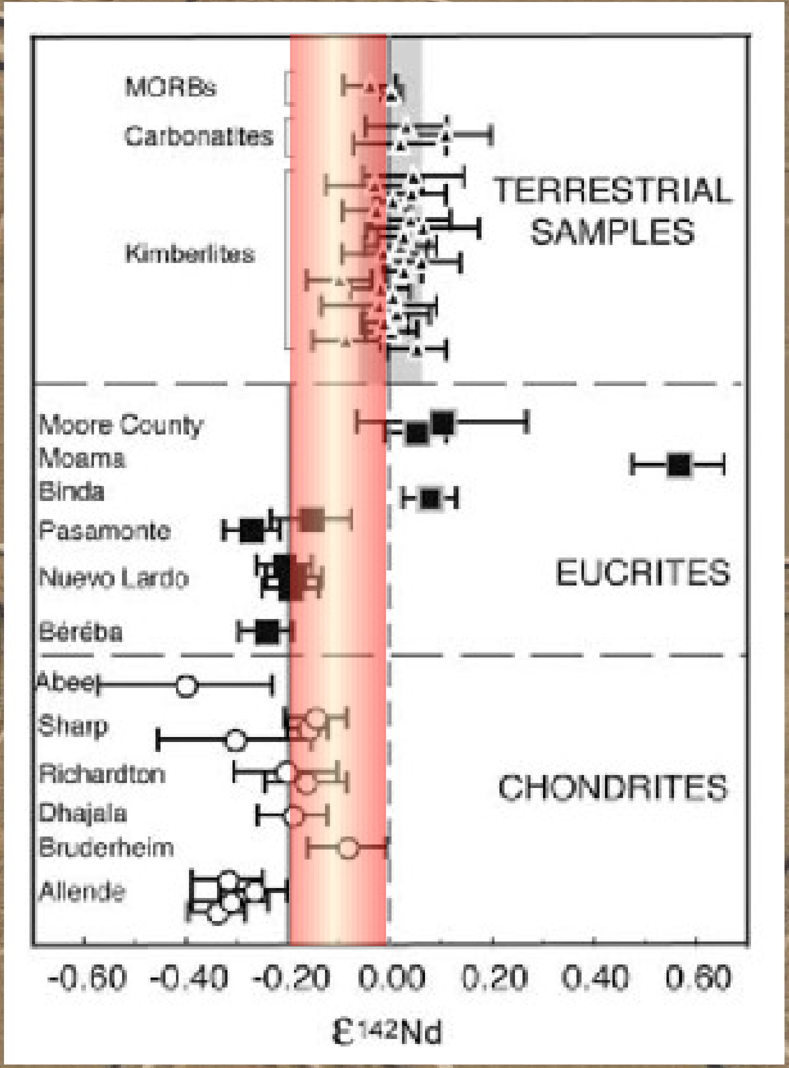


Boyet et al. (2003)



Caro et al. (2003)

….et avec la différenciation majeur du manteau terrestre ~30 Ma après la fin de la nucléosynthèse



Boyet and Carlson (2005)

Méthodologie

ISOTOPIC SYSTEMS

^{238}U — 8 α's, 6 β's → ^{206}Pb

^{235}U — 7 … → ^{207}Pb

^{232}Th — … α's, 4 β's → ^{208}Pb

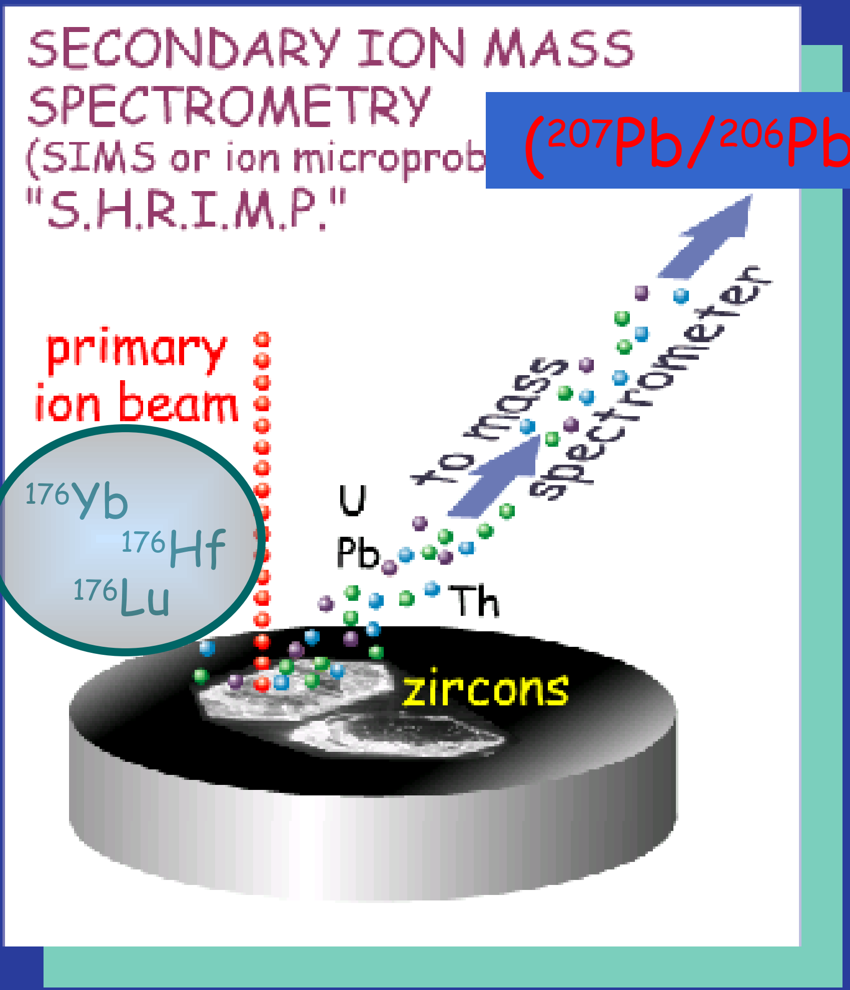
DATING

^{176}Lu → $^{176}Hf^{*}$

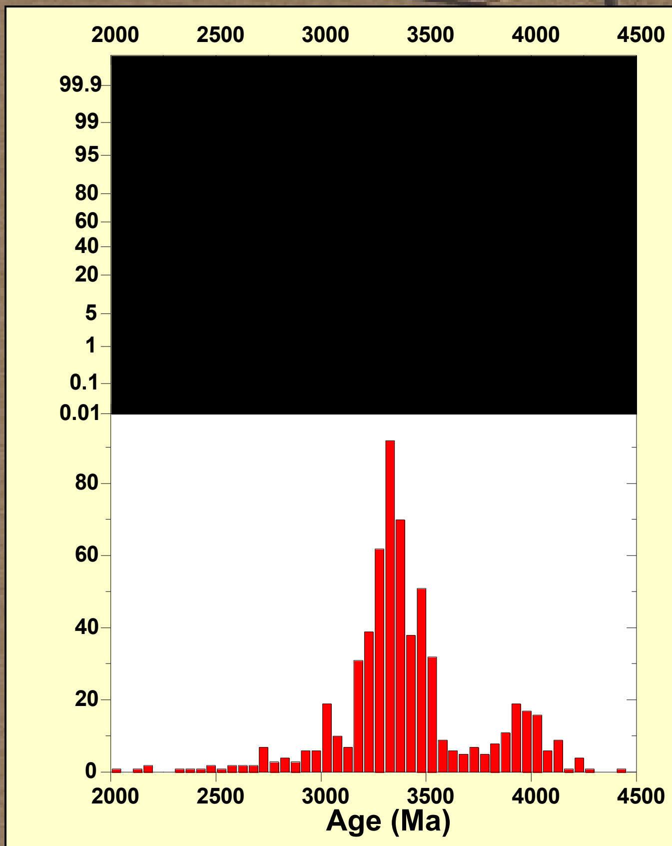
TRACING

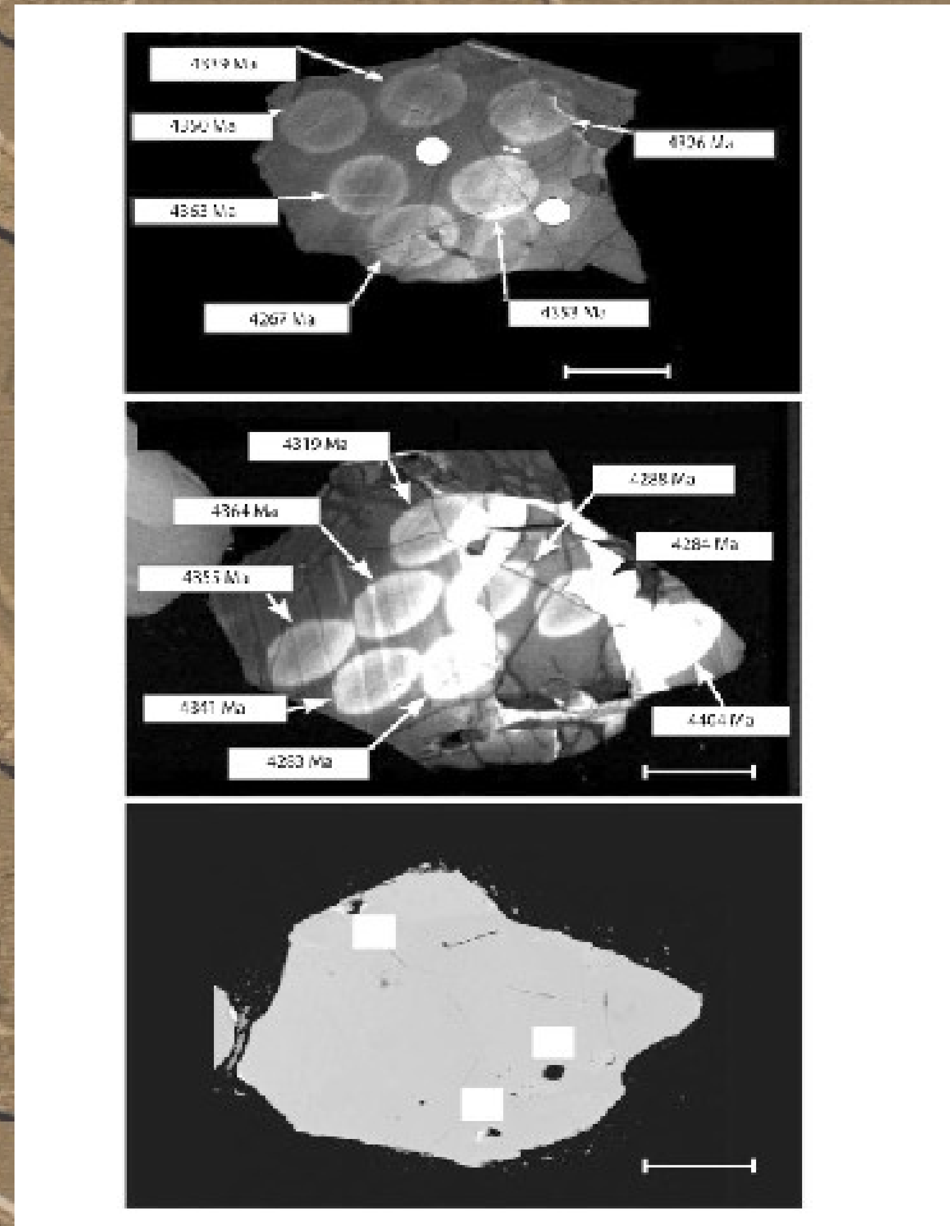
these have been widely exploited

SIMS



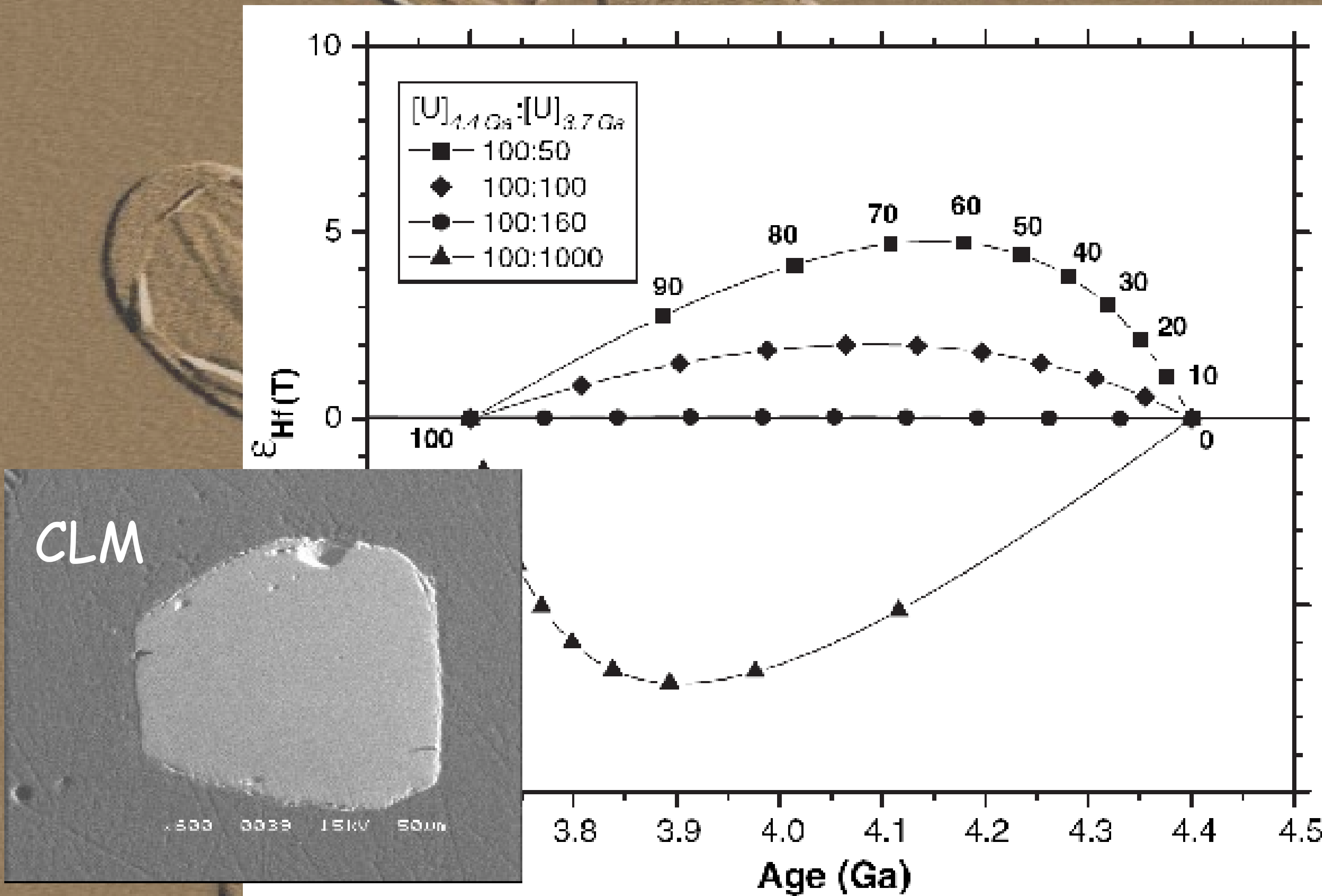
The ion probe has made it possible to determine "in situ" ages on individual ~20-μm spots on zircons and other minerals





Wilde et al. (2001)

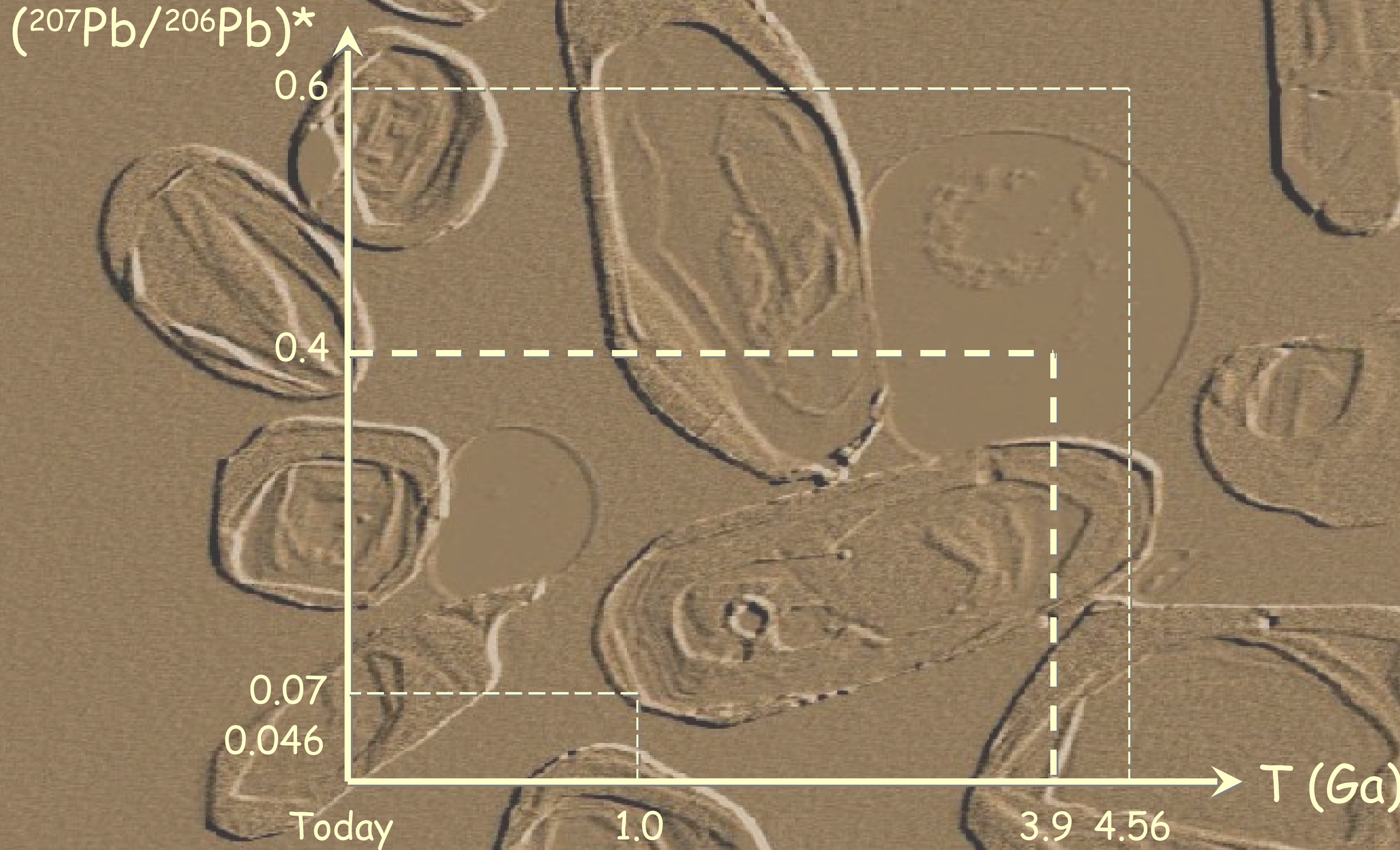
Mixing relationships among domains of different Hf isotope compositions and different U-Pb ages are non-linear



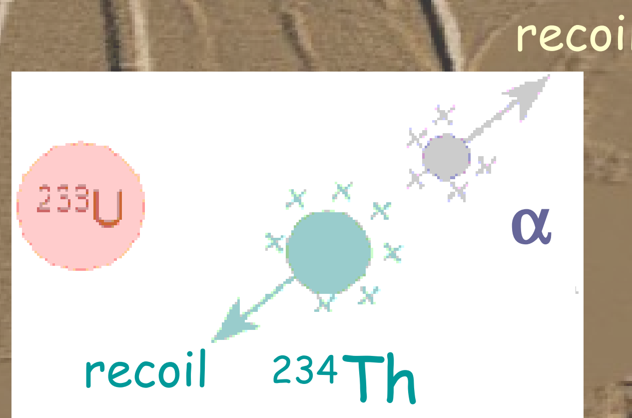
Harrison et al. (2005)

Pb-Pb dating

$(^{207}Pb/^{206}Pb)^* > 0.4 \rightarrow$ zircon > 3.9 Ga



So what are the >4.25 Ga ages? Possibly recoil artifact ages!

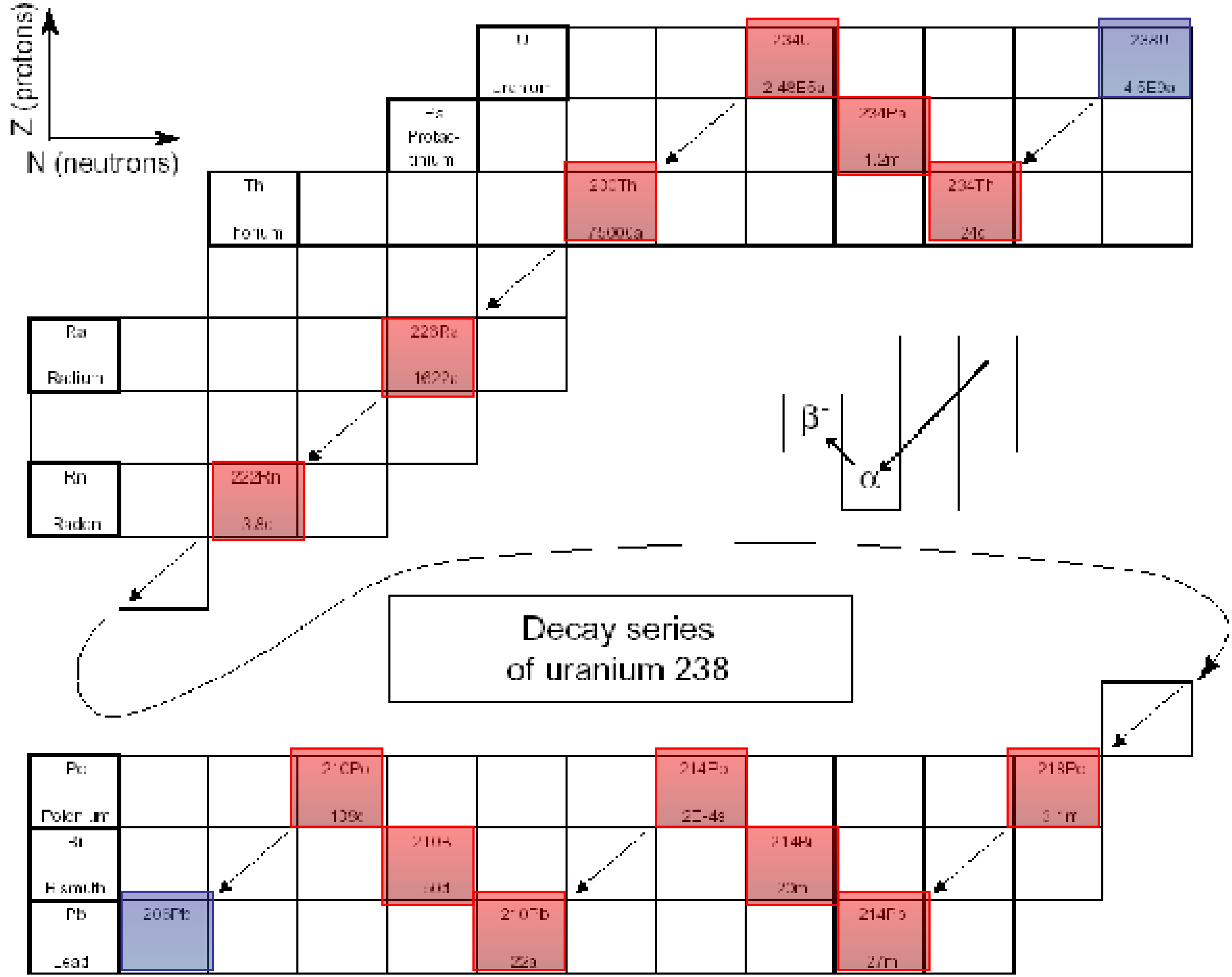


....if crack present or zircon metamict (worse the higher the [U]) daughter lost...

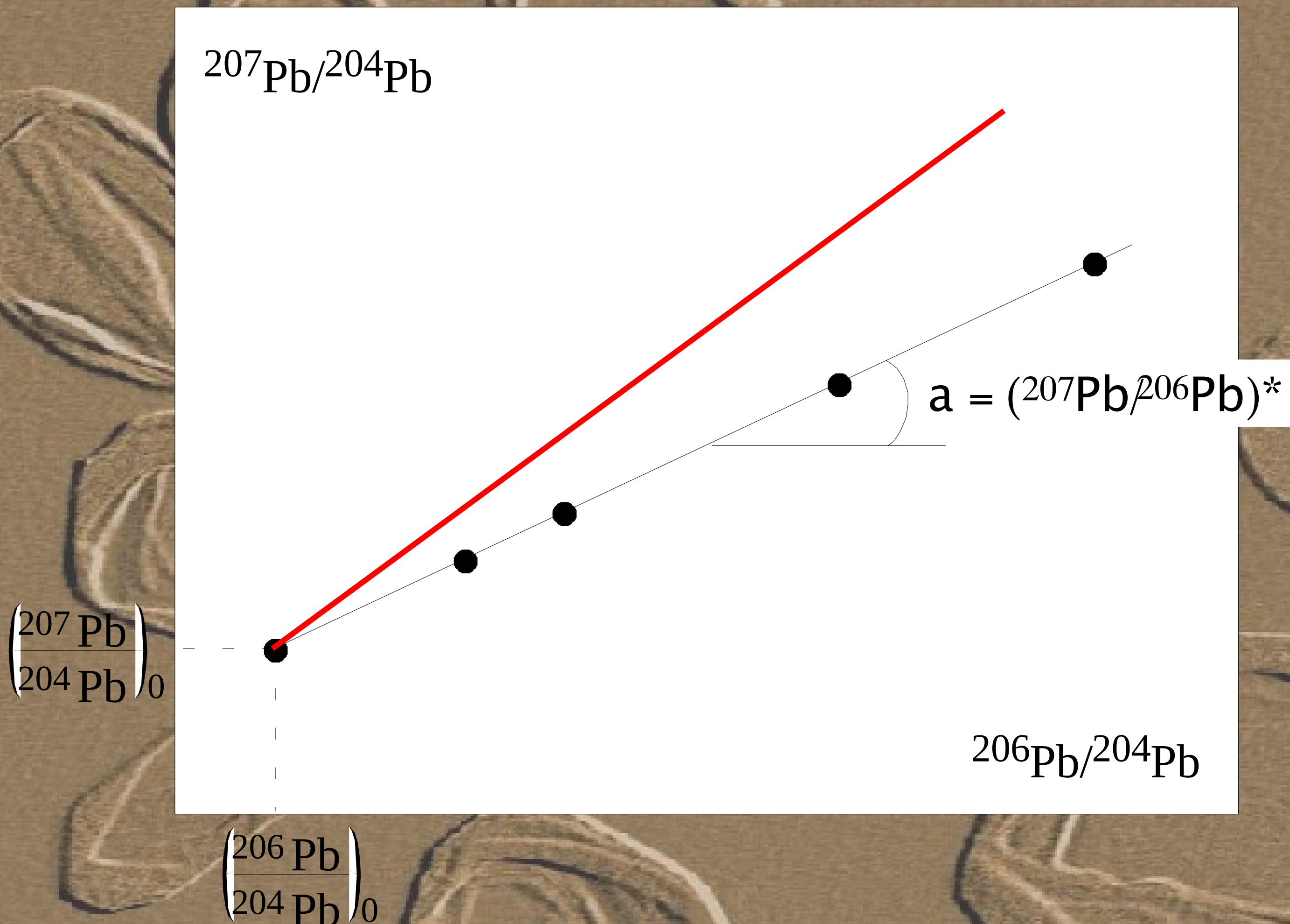
^{238}U ------ 8U,6, - → ^{206}Pb

^{235}U ------ 7U,4, - → ^{207}Pb

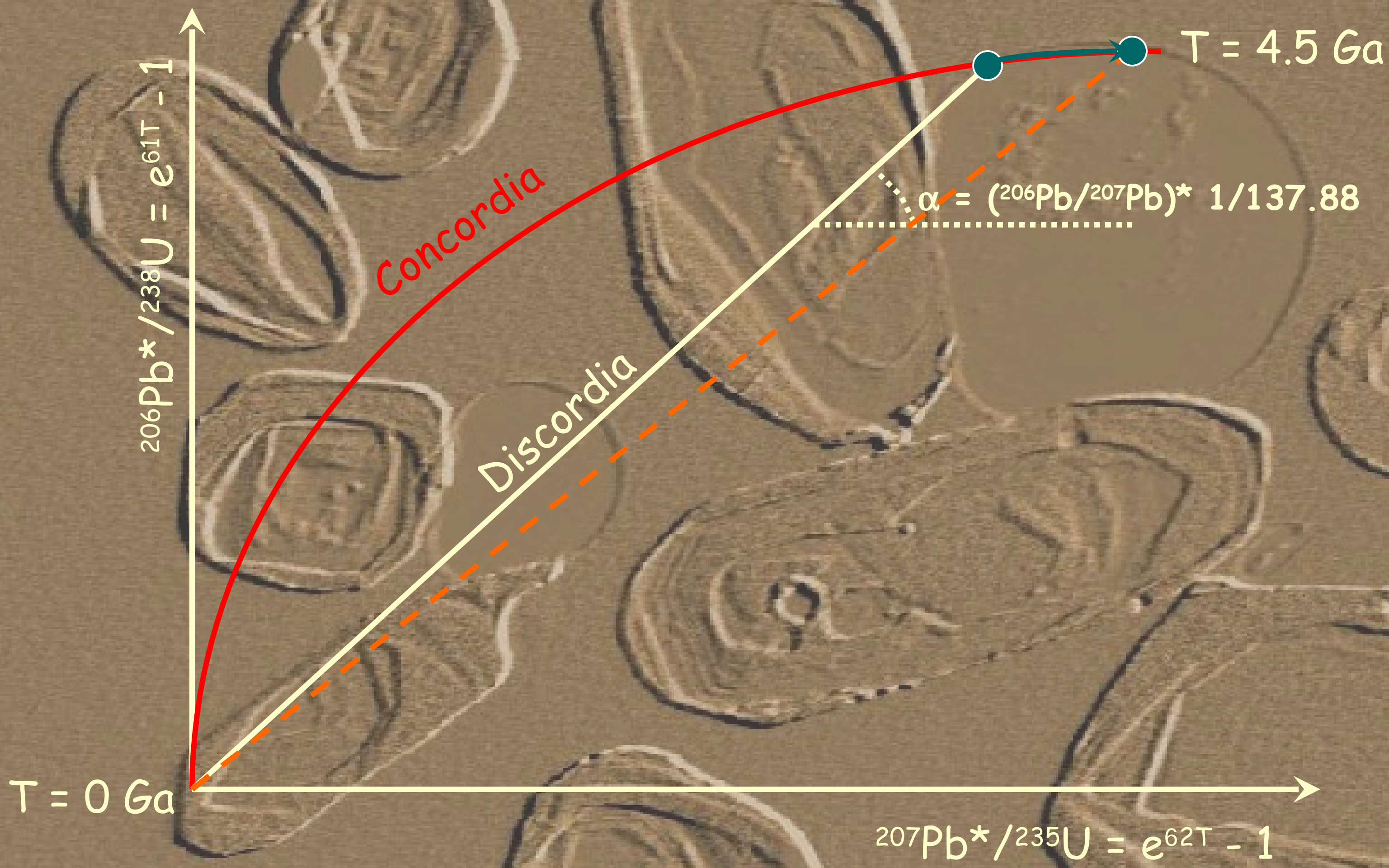
Recoil loss more extensive for ^{238}U/^{206}Pb system than for ^{235}U/^{207}Pb system due to fewer intermediate daughters for the latter → ^{207}Pb*/^{206}Pb* increases (or ^{206}Pb*/^{207}Pb* decreases)


Z (protons)
N (neutrons)
Th
Ra
Radium
Rn
Po
Pb
Lead
226Ra
222Rn
206Pb
β-
α
Decay series
of uranium 238

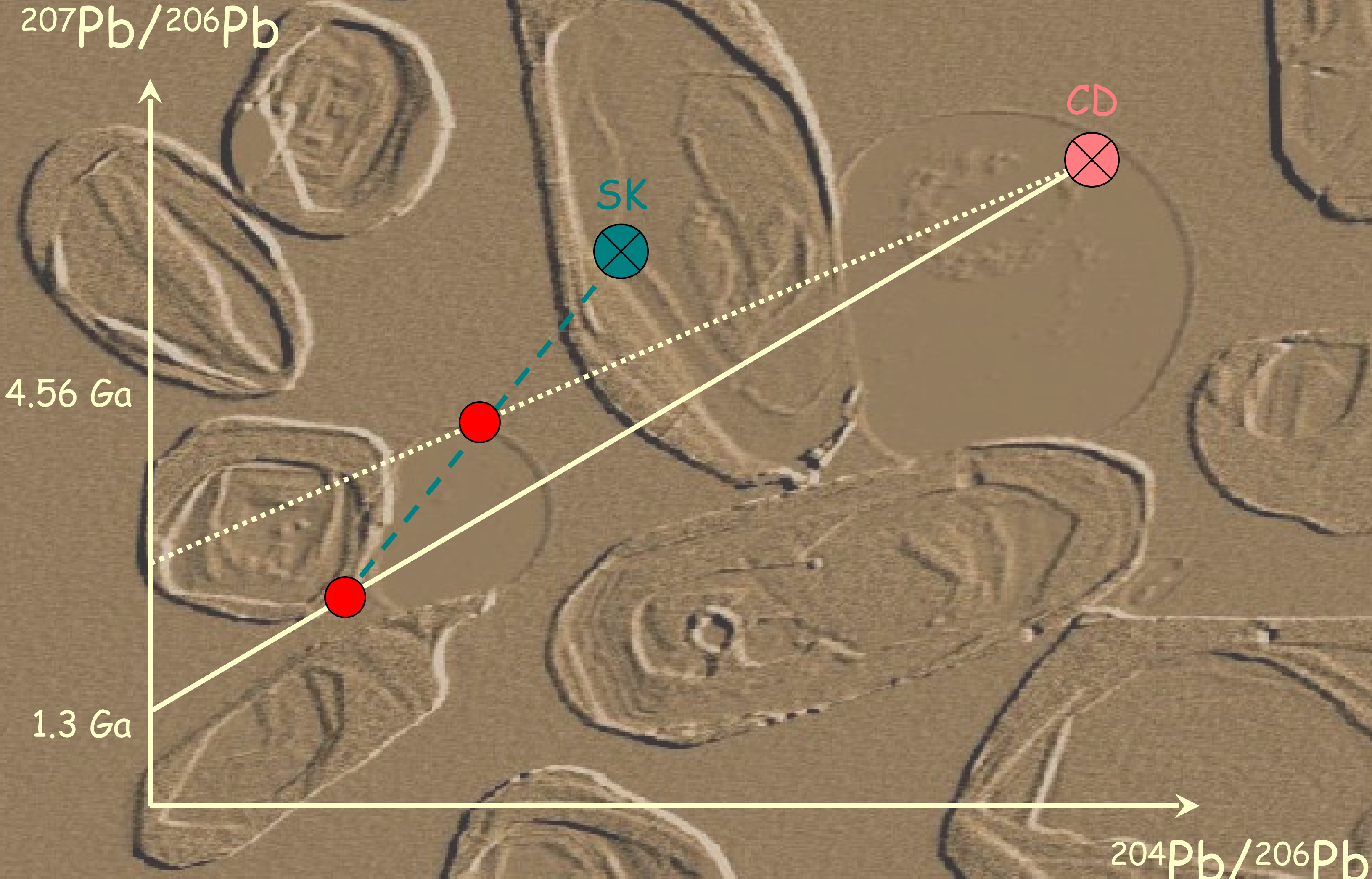
On Pb-Pb plot too high ($^{207}Pb/^{206}Pb$)* gives too steep slope = too old age!

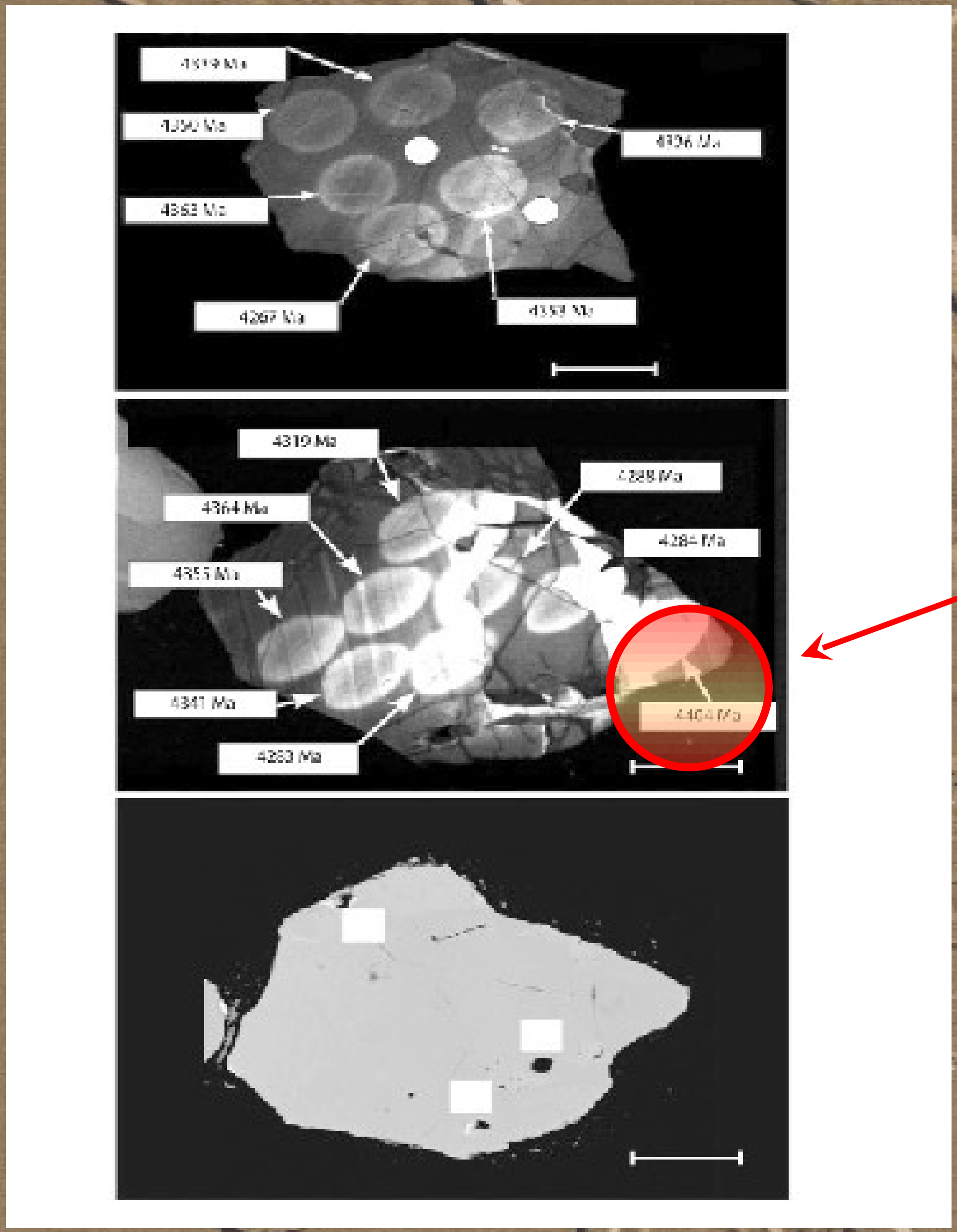


On Concordia plot too low ($(^{206}Pb/^{207}Pb)^*$) forces you up the Corcordia towards too old an age!



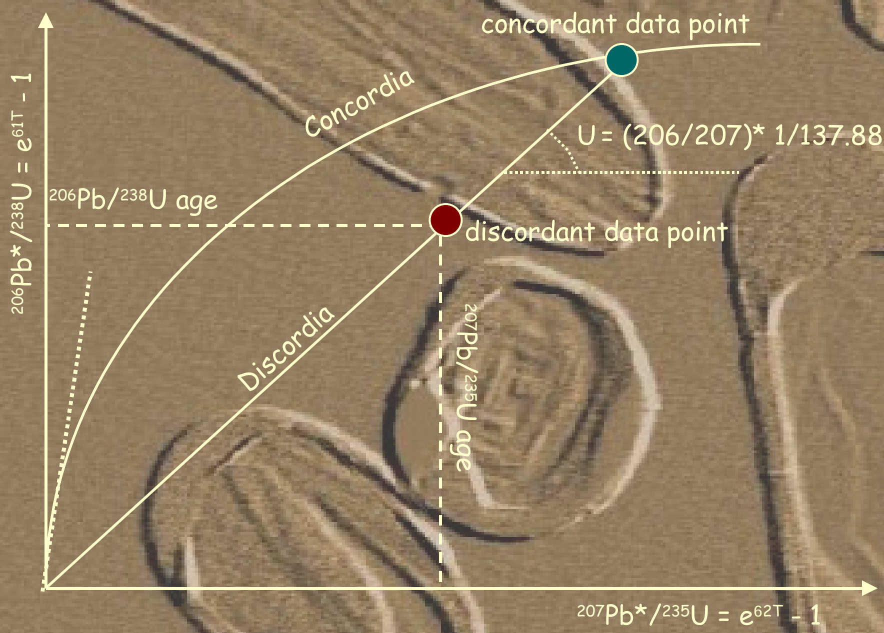
Or contamination by common Pb?





Appears upon reinspection to be right next to a crack!

Wilde et al. (2001)

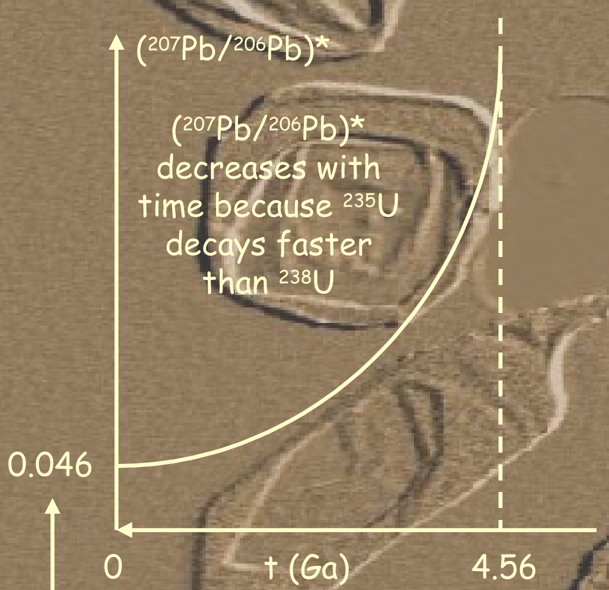


Slope of Discordia = $\Delta y/\Delta x = (^{206}Pb^*/^{238}U)/(^{207}Pb^*/^{235}U) = (^{206}Pb/^{207}Pb)^* \; ^{235}U/^{238}U = (^{206}Pb/^{207}Pb)^* \; 1/137.88 \rightarrow$
$(^{206}Pb/^{207}Pb)^* = 137.88 \, (\Delta y/\Delta x)$ or
$(^{207}Pb/^{206}Pb)^* = 1/[137.88 \, (\Delta y/\Delta x)]$

which compares with the slope of the Pb-Pb diagram in the following way:

$$a = \frac{1}{137.88}\left[\frac{e^{\lambda_2 t} - 1}{e^{\lambda_1 t} - 1}\right] = \left(\frac{^{207}Pb}{^{206}Pb}\right)^*$$

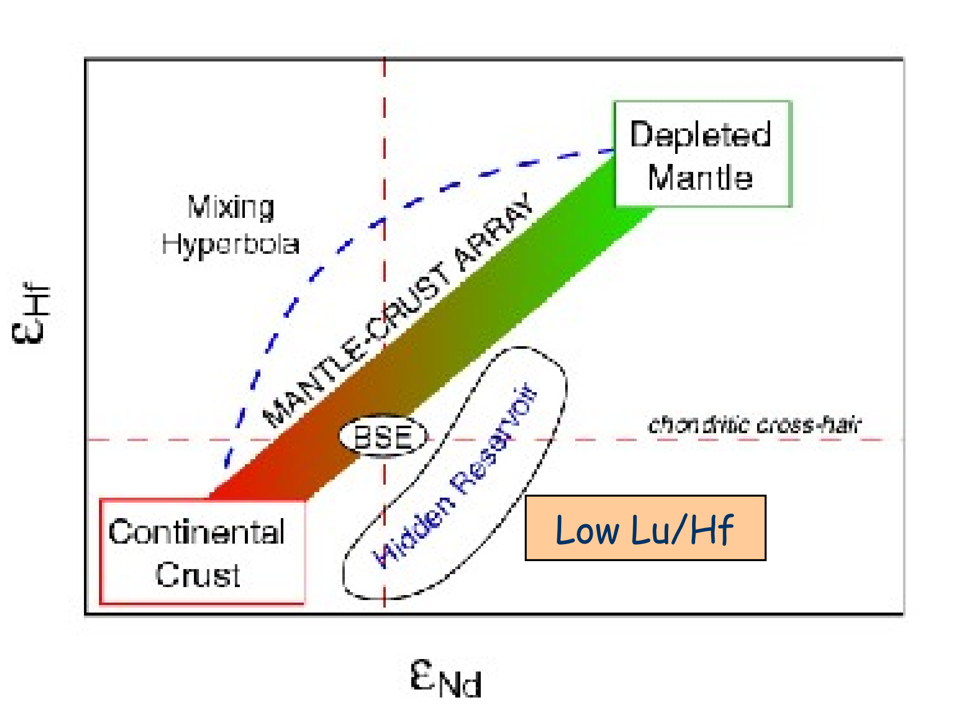
T Ga	y = eλ1T - 1	x = eλ2T - 1	λ1 (238U)	λ2 (235U)	(207Pb/206Pb)*
0	0.0000	0.0000	1.55125E-10	9.8485E-10	
0.2	0.0315	0.2177			0.05011
0.4	0.0640	0.4898			0.05470
0.6	0.0975	0.8056			0.05960
0.8	0.1321	1.1987			0.06580
1	0.1678	1.6774			0.07250
1.2	0.2046	2.2603			0.08012
1.4	0.2426	2.9701			0.08881
1.6	0.2817	3.8344			0.09872
1.8	0.3221	4.8869			0.11004
2	0.3638	6.1805			0.12299
2.2	0.4067	7.7292			0.13782
2.4	0.4511	9.6296			0.15483
2.6	0.4968	11.9437			0.17437
2.8	0.5440	14.7617			0.19682
3	0.5926	18.1931			0.22266
3.2	0.6428	22.3716			0.25242
3.4	0.6946	27.4597			0.28674
3.6	0.7480	33.6558			0.32635
3.8	0.8030	41.2004			0.37210
4	0.8596	50.3878			0.42501
4.2	0.9185	61.5753			0.48623
4.4	0.9789	75.1984			0.55714
4.6	1.0413	91.7873			0.63932



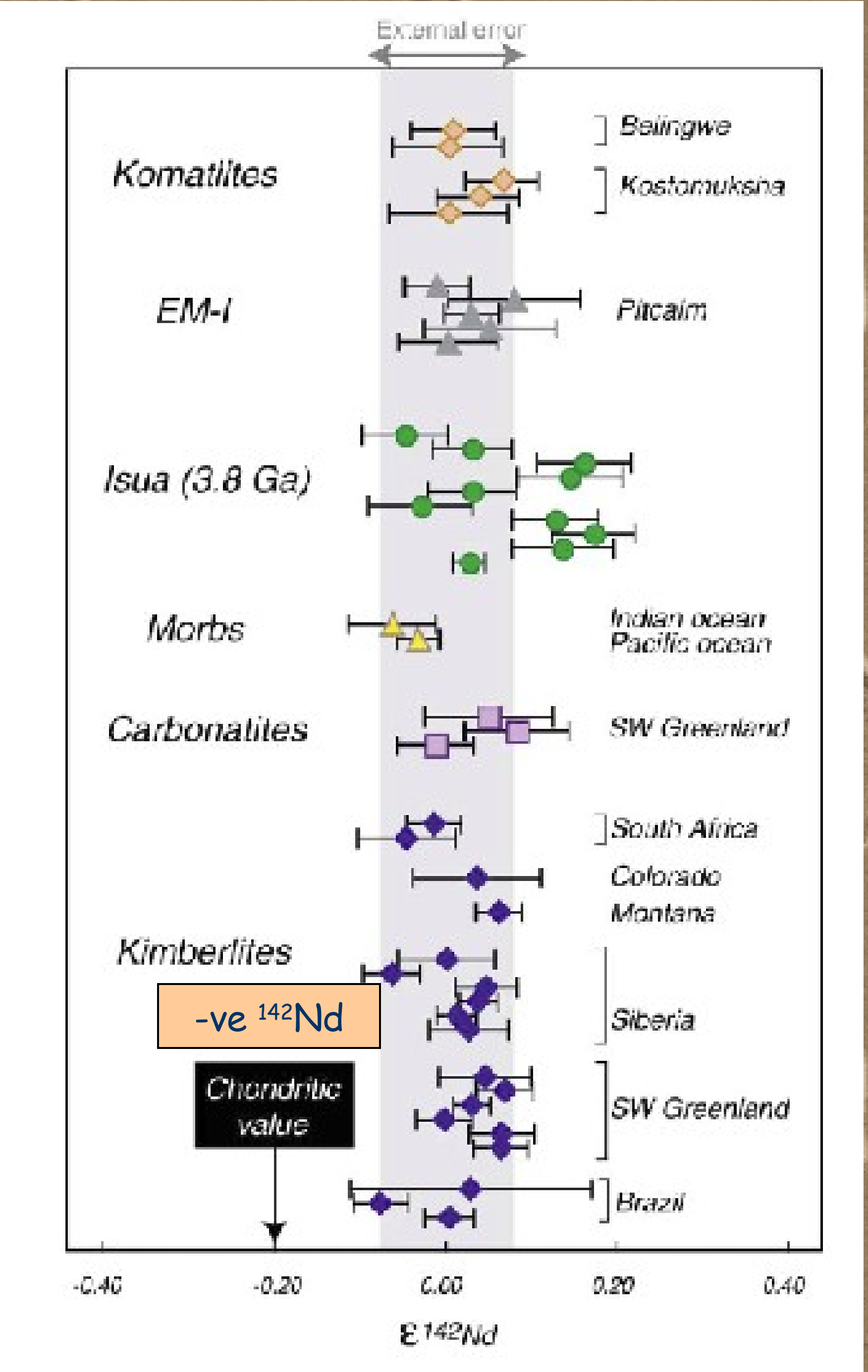
calculated from the slope of the Concordia at its origin

Reconnaissance SHRIMP II: $(^{207}Pb/^{206}Pb)^* \geq 0.4 \rightarrow$ older than 3.9 Ga

Evidence for a "hidden" reservoir from Hf and Nd isotopes in oceanic basalts and ^{142}Nd in chondrites

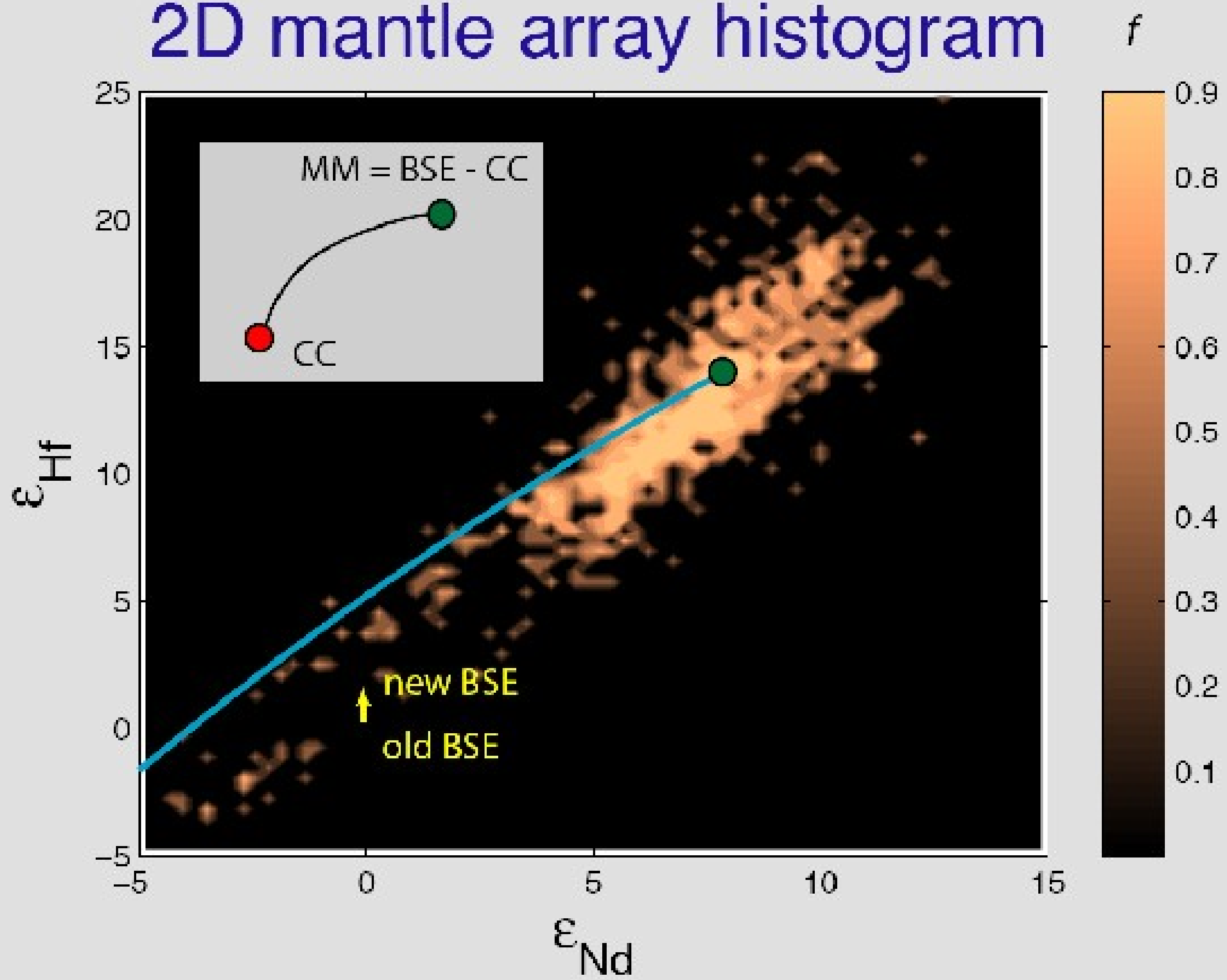


Blichert-Toft and Albarède (1997)

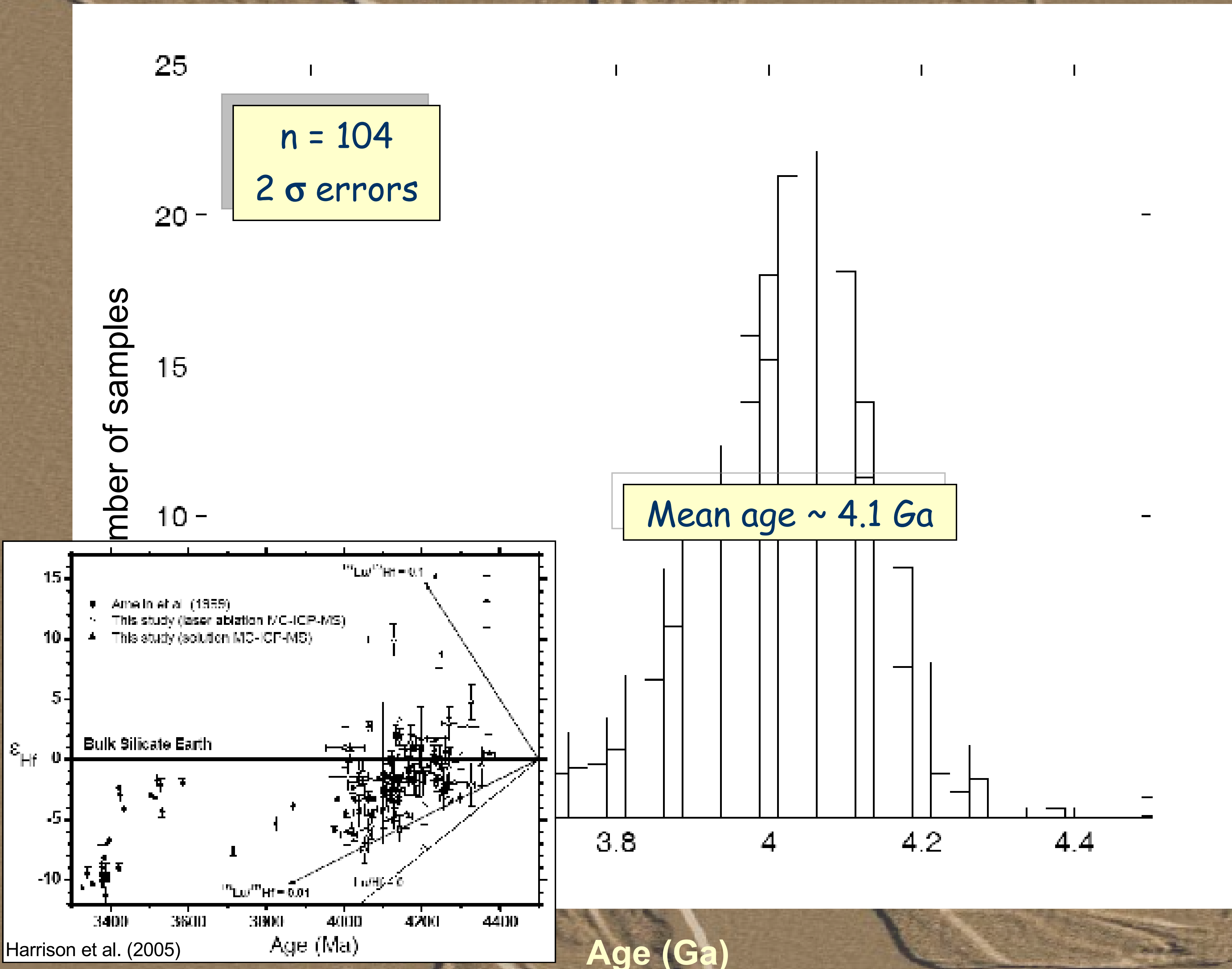


Boyet and Carlson (2006)

2D mantle array histogram



MM = mean mantle CC = continental crust BSE = bulk silicate Earth



Harrison et al. (2005)