NAMIBIA UNIVERSITY OF SCIENCE AND TECHNOLOGY

Professorial Inaugural Lecture: Zircon-a mineral that has revolutionised the concept of time and opened vistas of economic import- the Story of my research journey

BS Mapani

Faculty of Engineering and the Built Environment

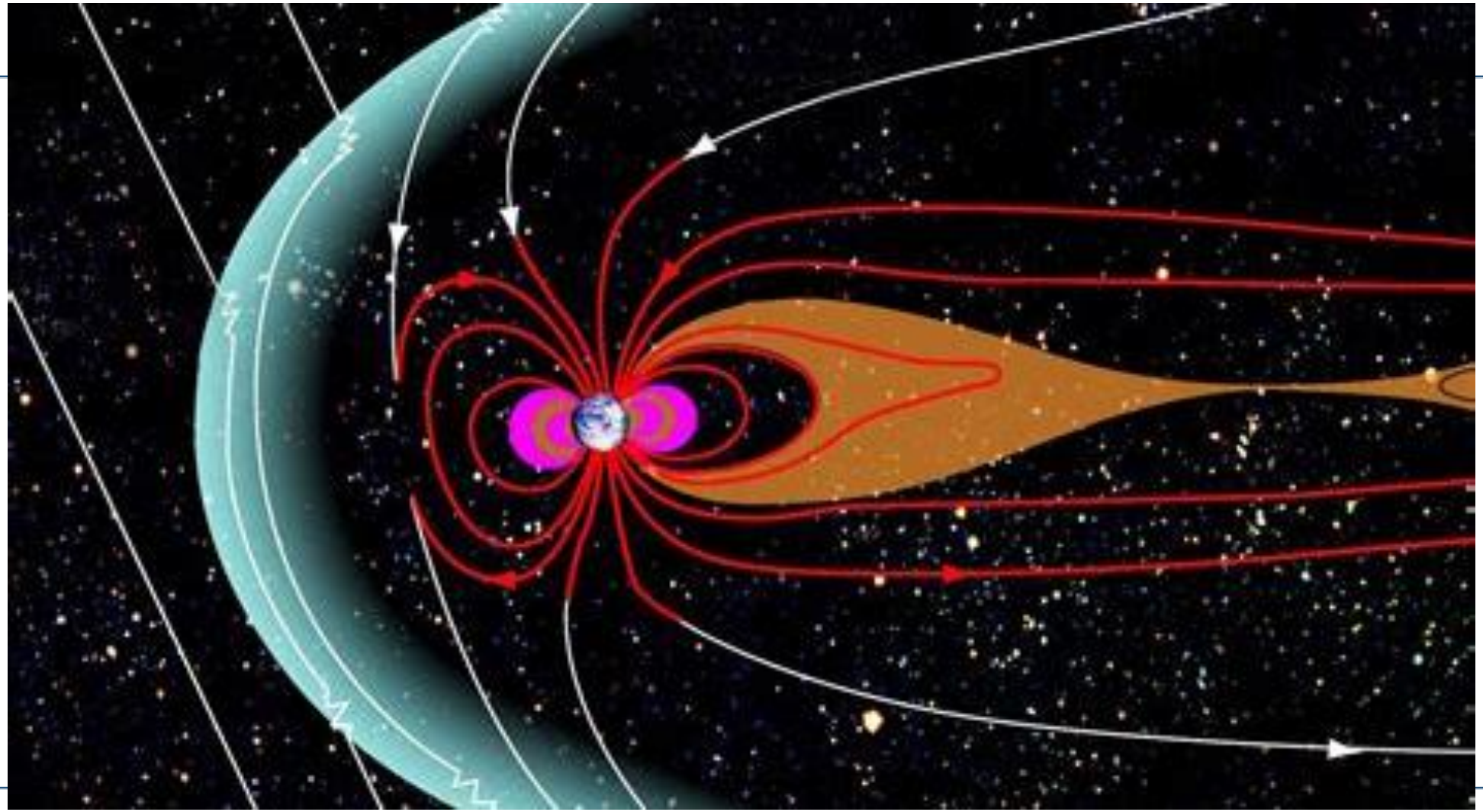
Table of Contents

Why Zircon Geochronology?

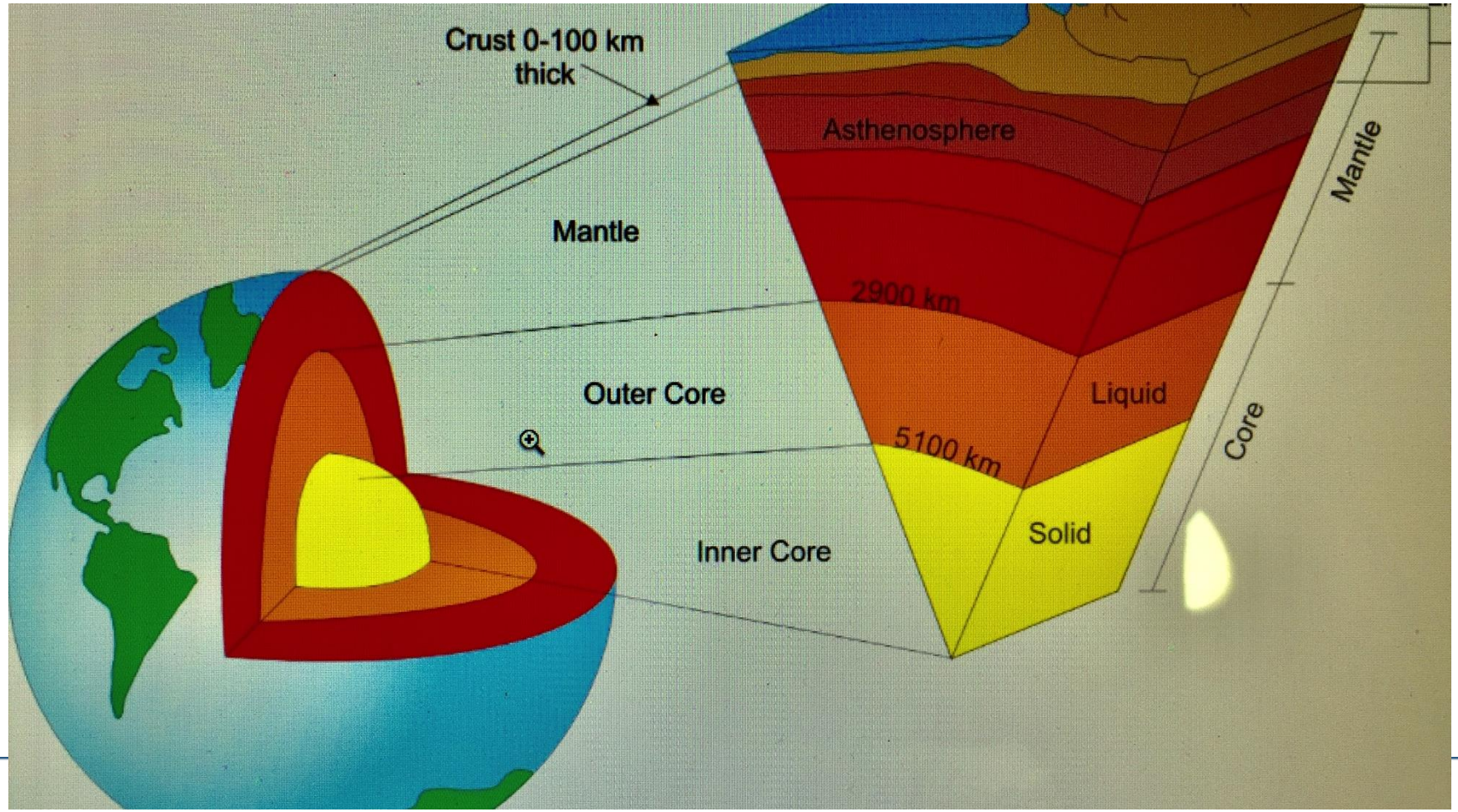
- 1. Its a handle in Plate reconstructions, geological evolution of mobile belts and allows us to select areas suitable for exploration of various mineral deposits- each with its specific setting
- 2. A tool to be used in the detailed assessment of mineral deposit fertility: an example from the Damara, Gariep and Kaoko belts
- Used to date the age of the Solar System and comets


The moon passed between Nasa's Deep Space Climate Observatory and the Earth, allowing the satellite to capture this rare image of the moon's far side in full sunlight.

The Earth has a magnetic field that pushes the Sun's magnetic field and solar wind



Internal structure of the Earth-the liquid core produces Earths' magnetic field.



Dominant processes though Earth's development

- Early Earth - chemical and density differentiation
- Bombardment and Moon collision/extraction (Hadean)
- Plume and/or subduction dominated processes (Paleo/Mesoarchean)
- Plate tectonics (dominates by Paleoproterozoic, possibly Neoarchean)

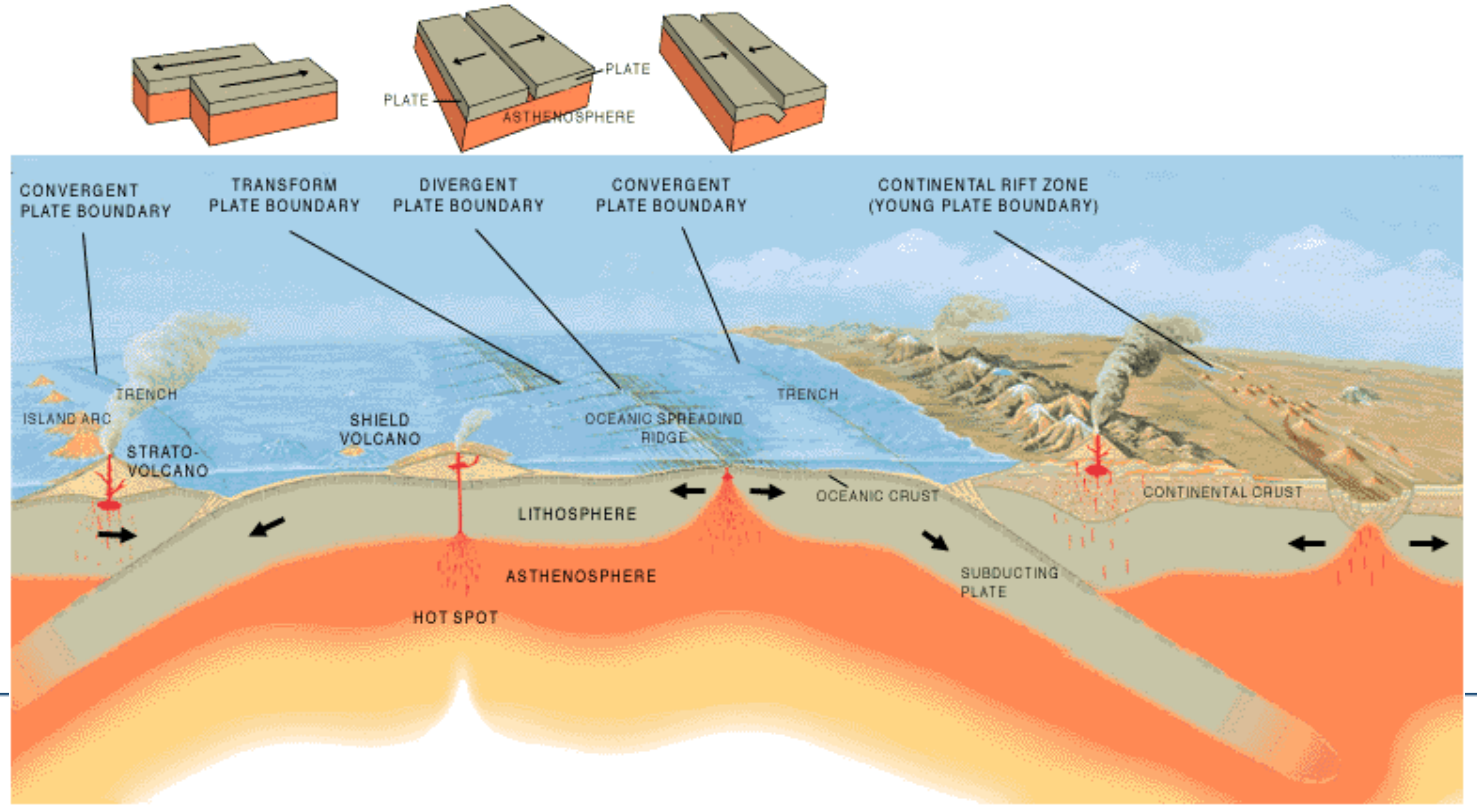
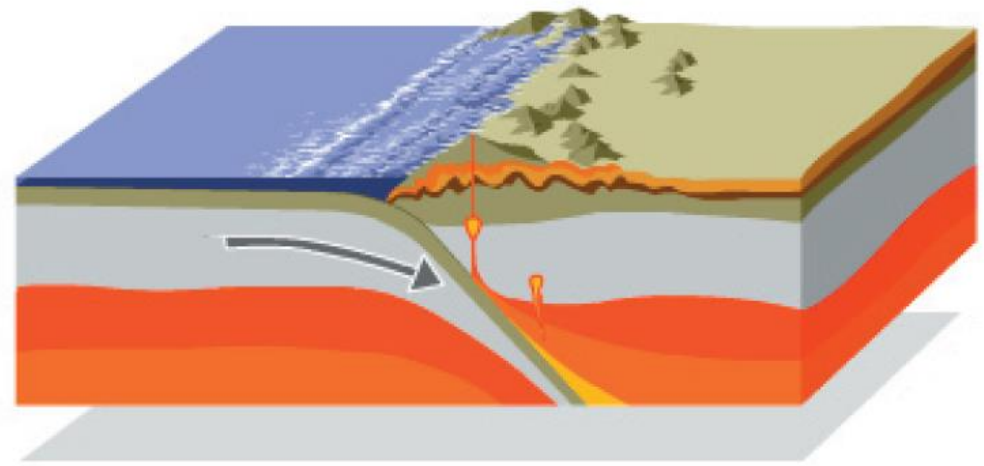
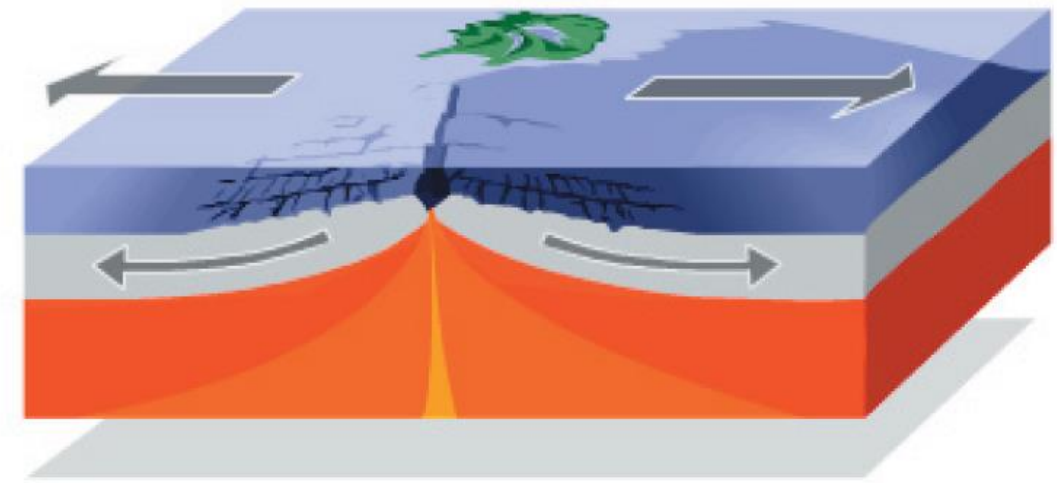


Plate Collisions- the reason mountains form and global oxygen levels are maintained



- When one plate goes below another, it is called subduction.
- The subducted plate melts at depth as it enters the mantle
- The melt rises as magma and forms volcanic rocks in arc regions, e.g., Atlas Mnts, Andes, S. America; Rockies, North America; Himalayas; Asia (zircons form in these magmatic rocks keeping a chemical signature of their origin)
- Each plate setting has unique isotopic and geochemical signatures
- With time we form more continental masses.

Plate Divergence- Where plates move apart- and new crust (solid earth) is produced



- Mid Ocean ridges are places where two plates move away from each other; e.g., the Atlantic Mid Ocean Ridge; the Indian Ocean Mid Ocean Ridge; the Pacific Mid Ocean Ridge.
- On continents, we get Rift basins, e.g., East African Rift
- In these areas basalts form some carrying baddeleyite (a cousin of zircon)

Tectonic Plates

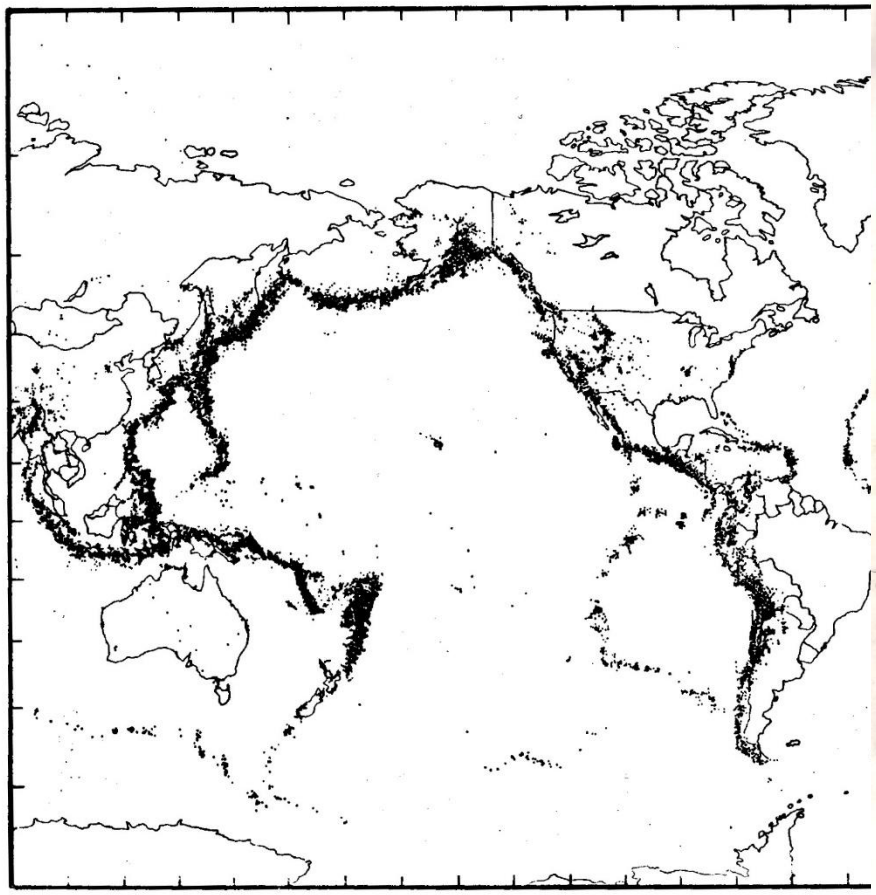


Figure 1.4 Distribution of world earthquakes 1961–1969. From National Earthqu

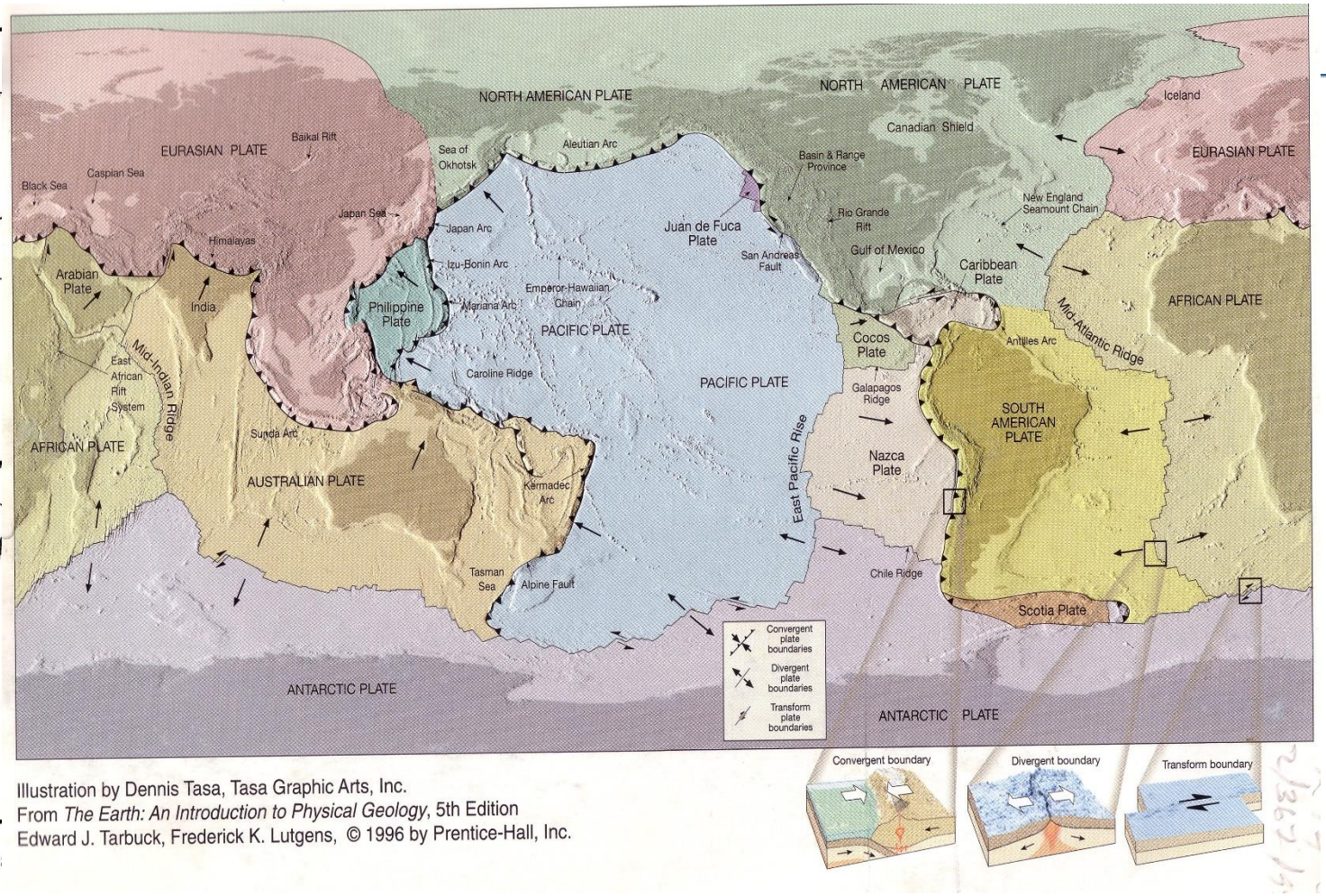
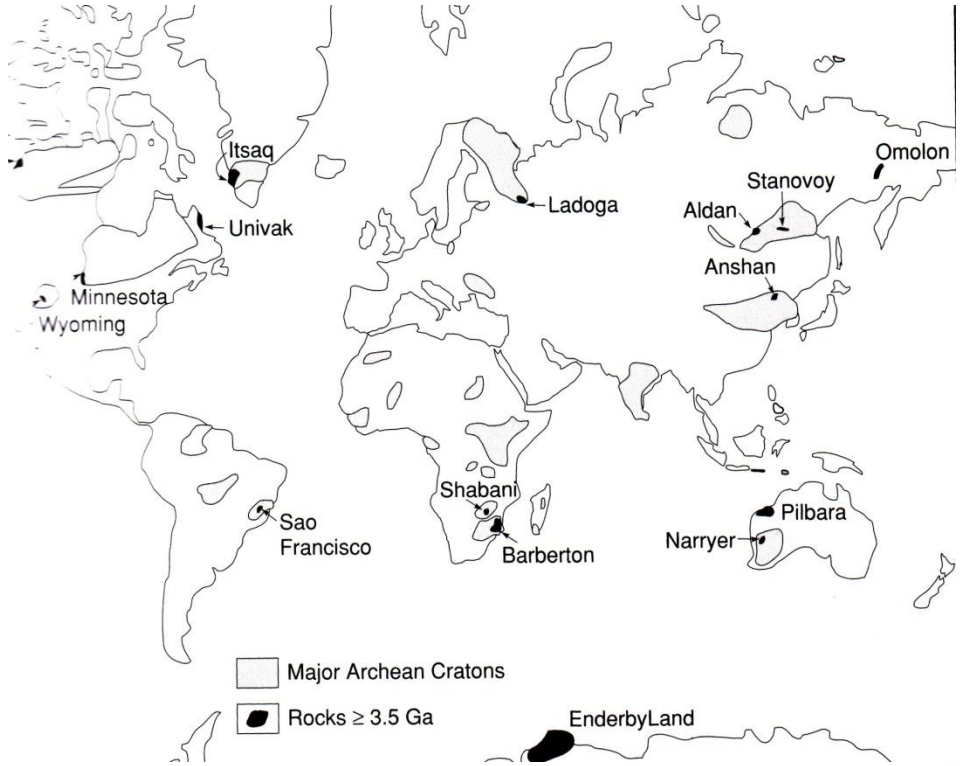
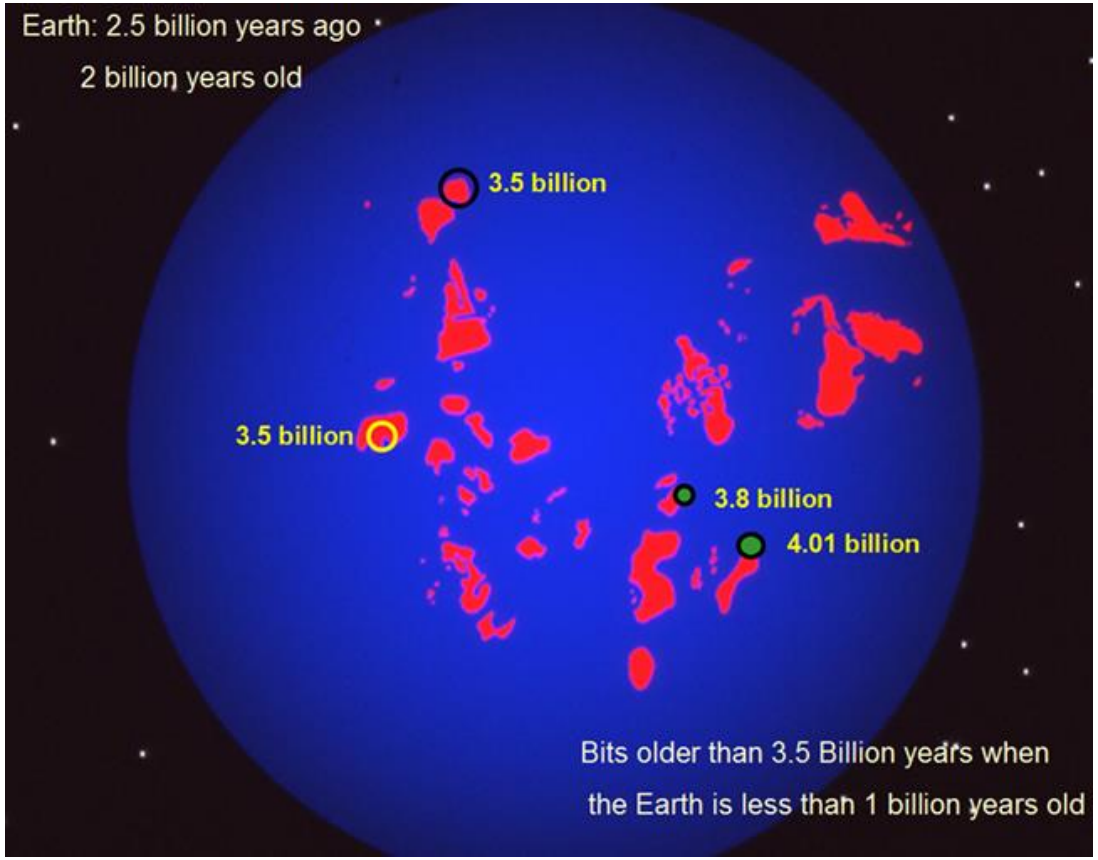
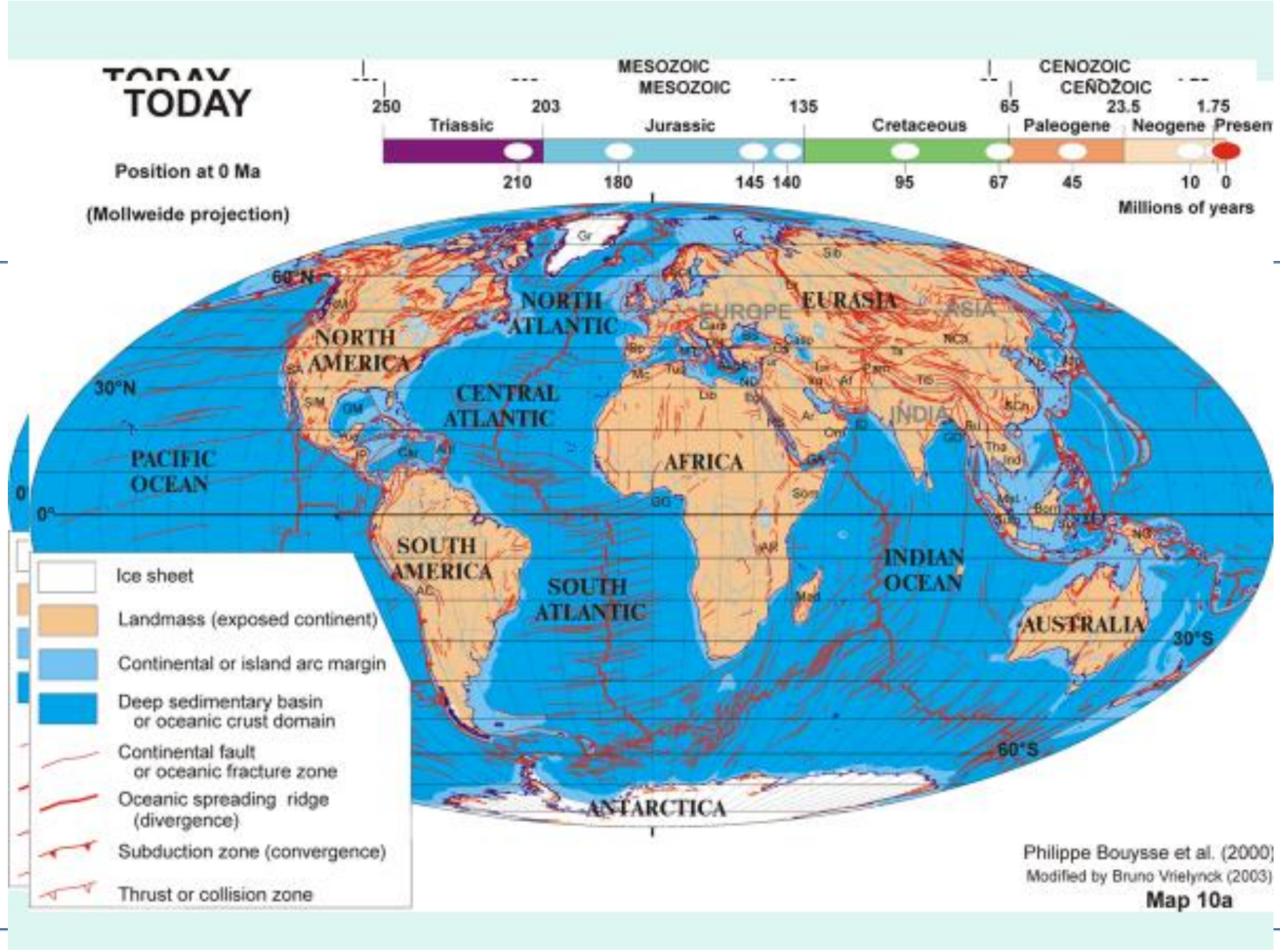


Illustration by Dennis Tasa, Tasa Graphic Arts, Inc.
From *The Earth: An Introduction to Physical Geology*, 5th Edition
Edward J. Tarbuck, Frederick K. Lutgens, © 1996 by Prentice-Hall, Inc.

The World's oldest rocks dated by Zircon geochronology






TODAY
Position at 0 Ma
(Mollweide projection)
MESOZOIC
CENOZOIC
250
203
135
65
23.5
1.75
Triassic
Jurassic
Cretaceous
Paleogene
Neogene
Presen
210
180
145
140
95
67
45
10
0
Millions of years
60°N
30°N
0°
30°S
60°S
NORTH AMERICA
NORTH ATLANTIC
EUROPE
EURASIA
ASIA
CENTRAL ATLANTIC
INDIA
PACIFIC OCEAN
AFRICA
SOUTH AMERICA
SOUTH ATLANTIC
INDIAN OCEAN
AUSTRALIA
ANTARCTICA
Ice sheet
Landmass (exposed continent)
Continental or island arc margin
Deep sedimentary basin or oceanic crust domain
Continental fault or oceanic fracture zone
Oceanic spreading ridge (divergence)
Subduction zone (convergence)
Thrust or collision zone
Philippe Bouysse et al. (2000)
Modified by Bruno Vrielynck (2003)
Map 10a

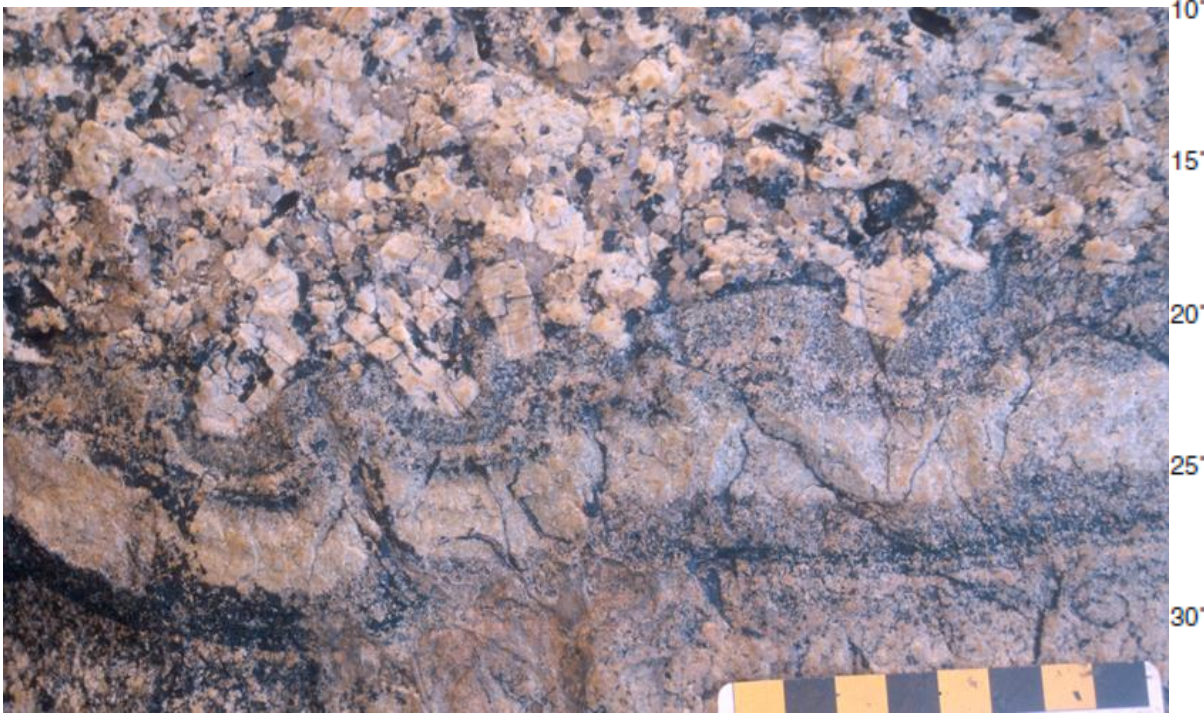
History

- In 1907, Boltwood was the first person to come up with an estimate of the U-Pb decay constant of 10-10/yr which compares well with our current figure of 1.5×10-10/year
- Thus he measured samples that were 422 my and 2200 My.

- Innovation = Insight (light bulb moment) + Societal Value
- (e.g., Dunlop, Faraday, Pasteur, Flemming e.t.c.)

My Research Journey

(picture of Spitzkoppe granite)



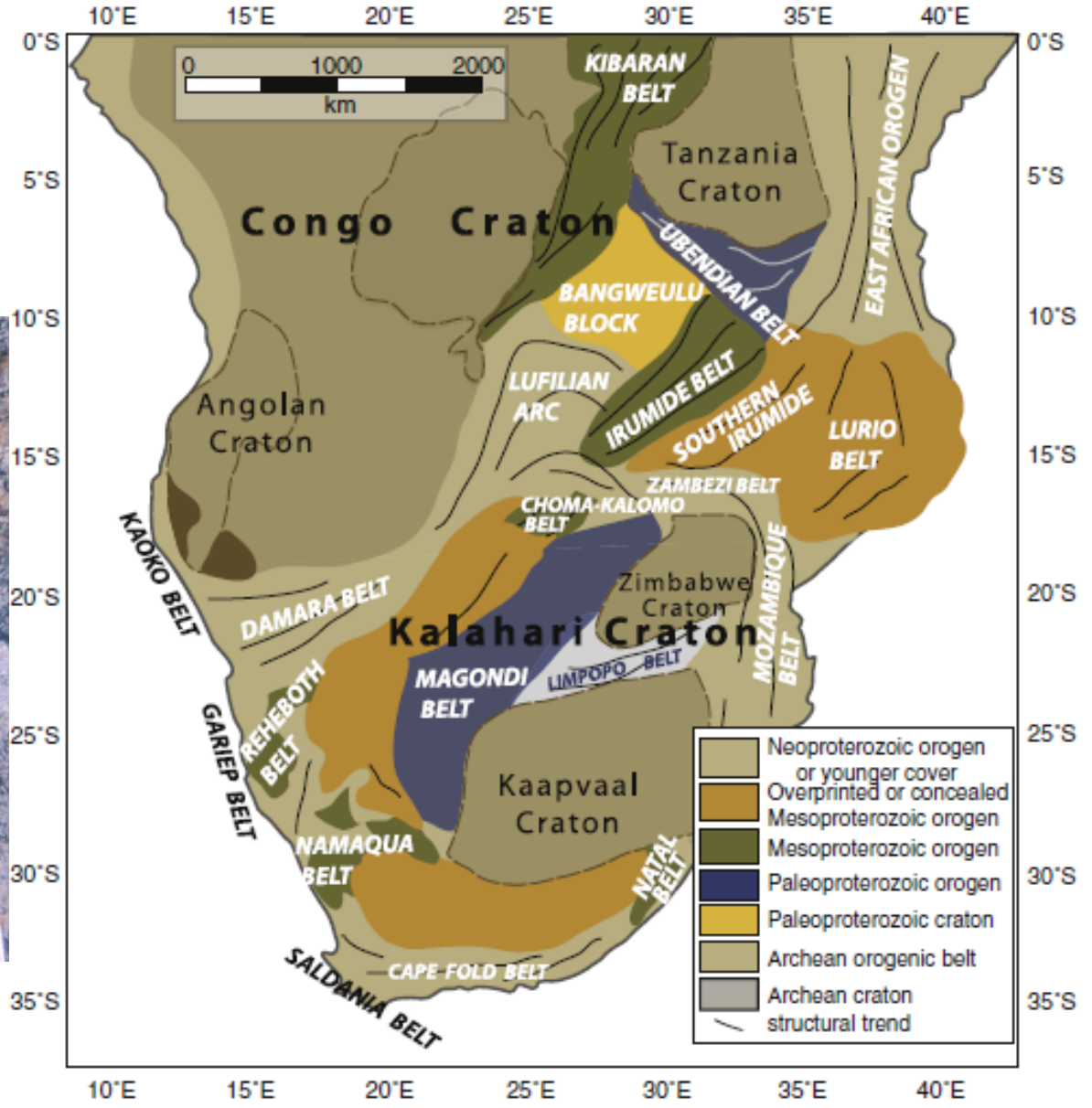


Fig. 2. Map of major geologic provinces and Precambrian orogenic belts in southern Africa. Compiled after Goscombe et al. (2000) and Hanson (2003).

The Half Life and Decay constant

- The half life of a radioactive isotope is the time it takes for the number of ~~parent isotopes to decay away to half~~ their original value. It is related to the decay constant by the expression
  - $T^1/_2 = \ln 2/\lambda$

- For ^{87}Rb, the decay constant is $1.42 \times 10^{-11} y^{-1}$, hence, $t_{1/2}$ $^{87}Rb = 4.88 \times 10^{10}$years.
- In other words after 4.88×10^{10}years a system will contain half as many atoms of ^{87}Rb as it started off with.

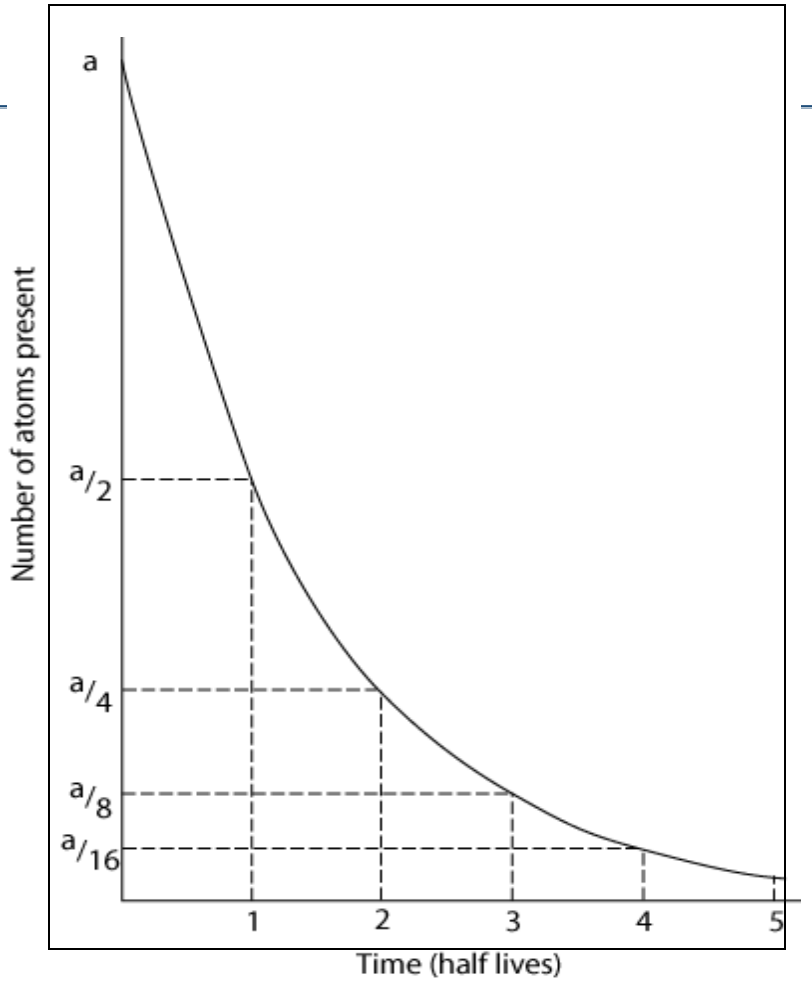
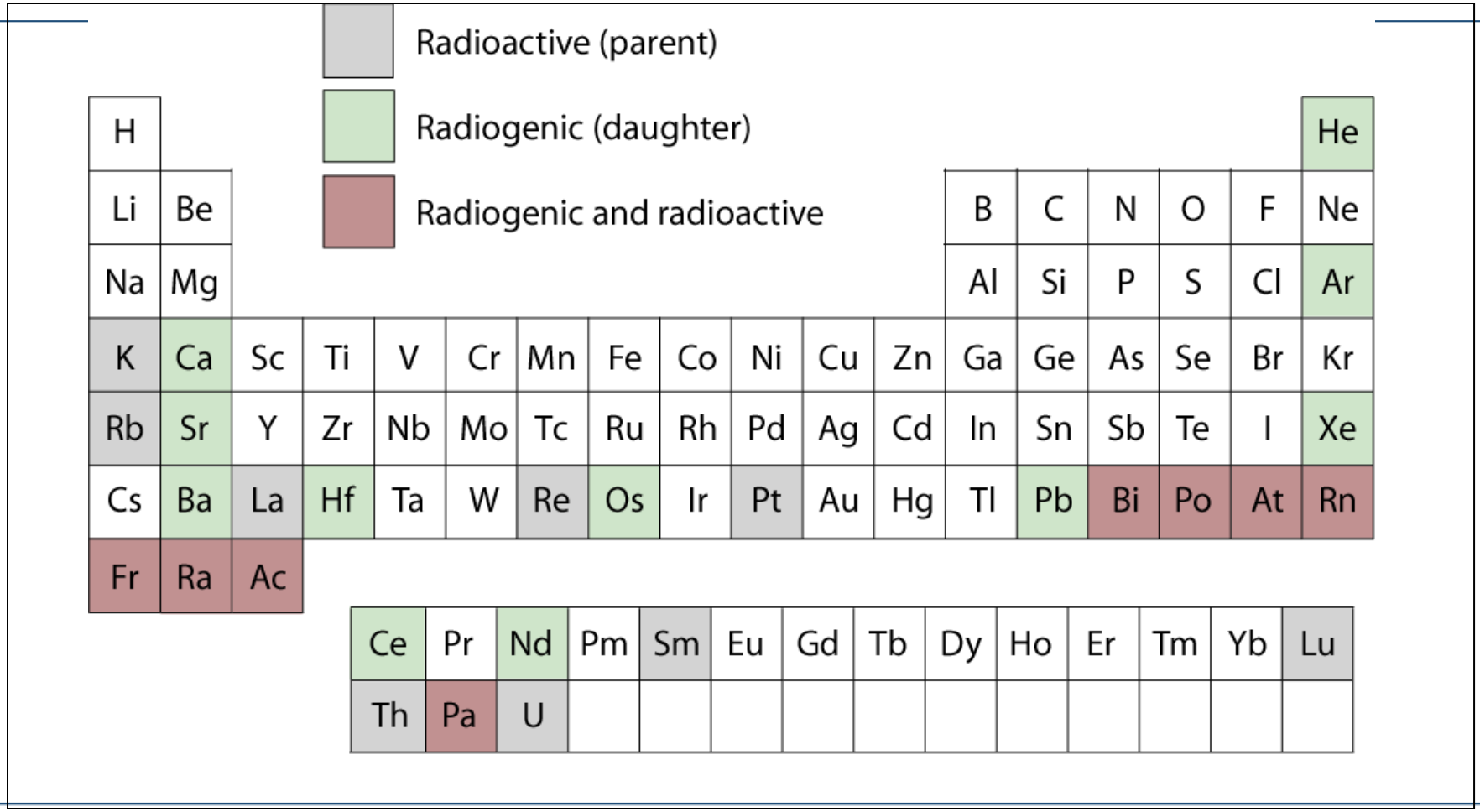
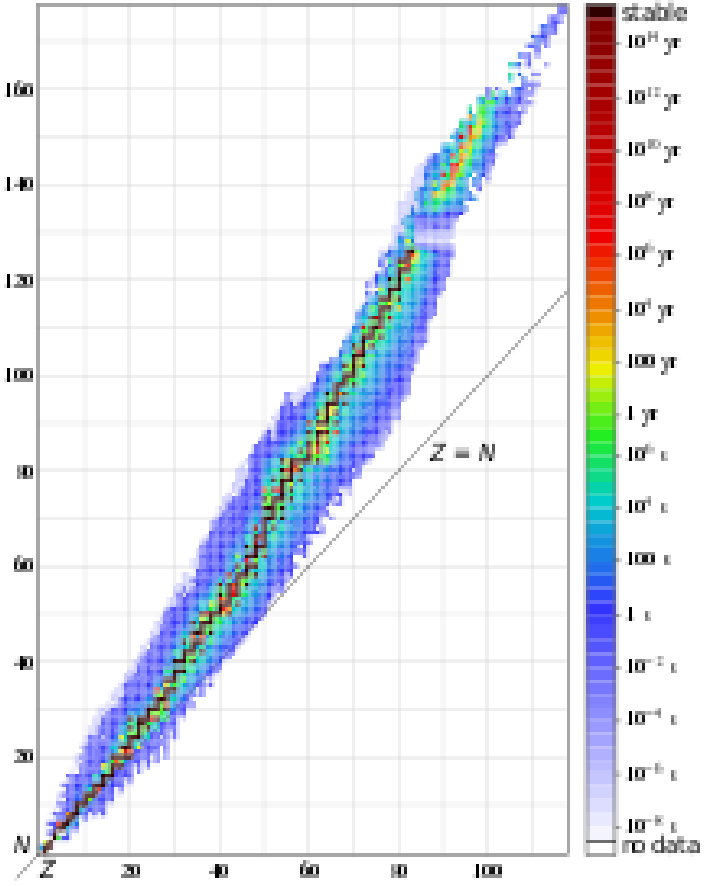


Table of the naturally occurring elements



Radioactive Decay

- Every element has one or more isotopes that have unstable nuclei that are subject to radioactive decay, causing the nucleus to emit particles or electromagnetic radiation.
- Radioactivity can occur when the radius of a nucleus is large compared with the radius of the strong force, which only acts over distances on the order of 1 fm



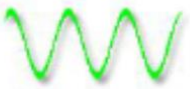
RADIOACTIVE DECAY OCCURS THROUGH THE EMMISSION OF :

Alpha particle:
2 protons
& 2 neutrons

α
- *Essentially an Helium nucleus, positively charged*
- *SLOW moving, HEAVY, LOW penetration*
- *Damage to matter by strong ionization of other atoms*

Beta particle:
The same as
an electron

β
- *high energy electrons from natural radio-isotopes*
- *lower-energy positrons from man-made radio-isotopes*
- *Penetrates further*
- *Also causes damage to matter by ionization, but not as severe*



Gamma ray:
not a particle,
it's a burst of
energy

γ
- *electromagnetic radiation (wave) originating in the nucleus of an atom; has no mass, carries no charge, speed of light*
- *no direct ionization of matter but causes secondary ionization*
- *maximum penetration of the 3 types*

THREE COMMONLY OCCURRING RADIOACTIVE ELEMENTS IN ROCKS AND SOILS

- *Uranium (U_3O_8) – has a decay series*
  - *98.27% occurs as ^{238}U*
  - *0.72% occurs as ^{235}U (used in reactors)*
  - *0.0057% occurs as ^{234}U*
- *Thorium (ThO_2) – has a decay series*
- *Potassium (K_2O) – no decay series, single isotope*

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U is the largest Naturally occurring

Element

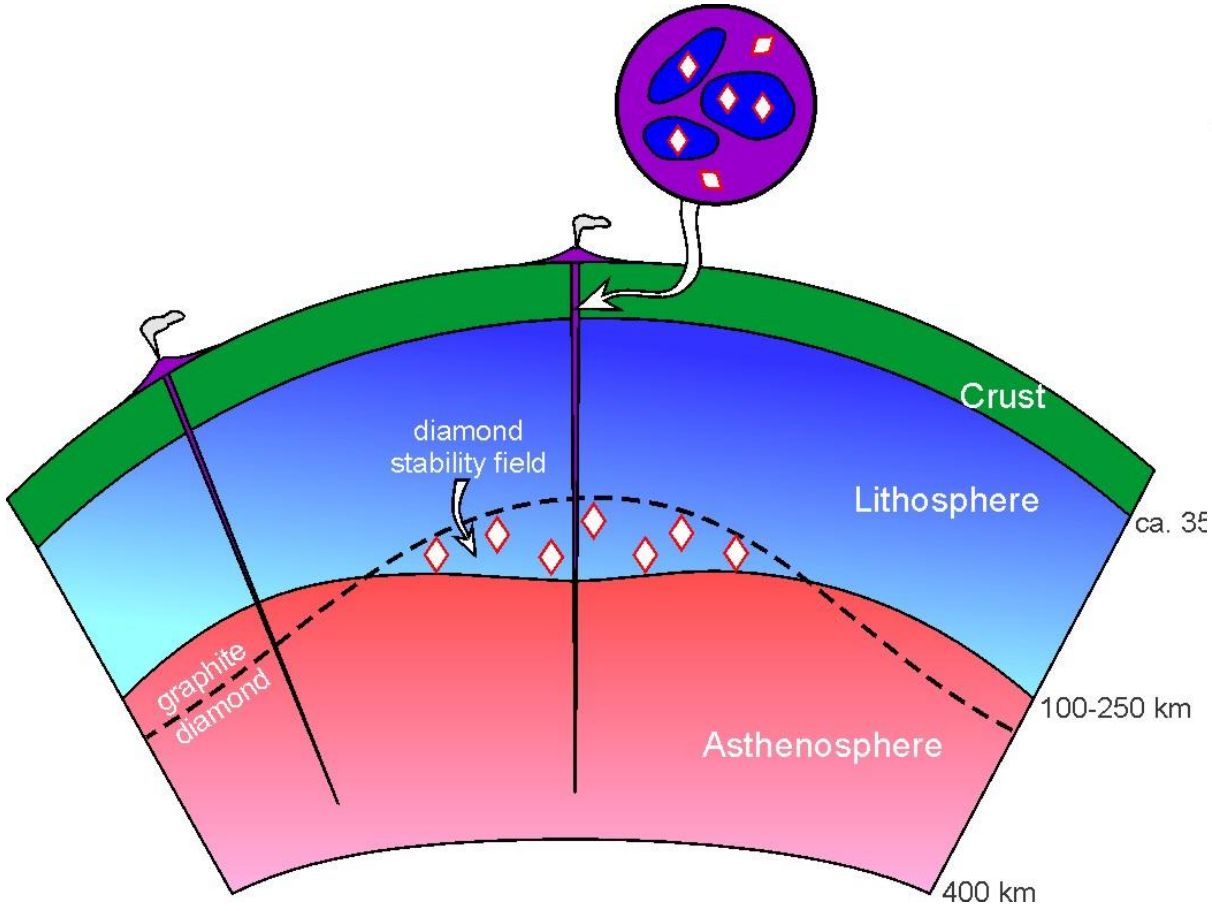
It is radioactive

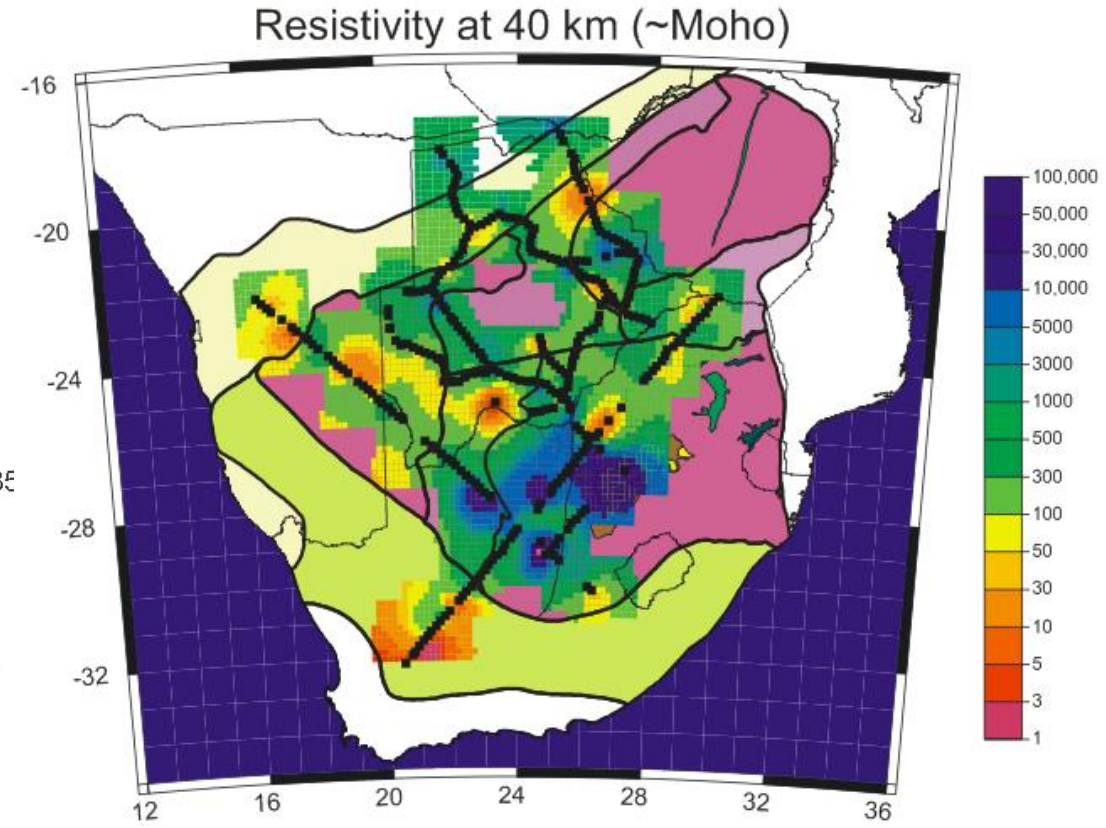
Used for energy purposes

Is always present in the Mineral ZIRCON

How we use Zircons in Mineral Exploration

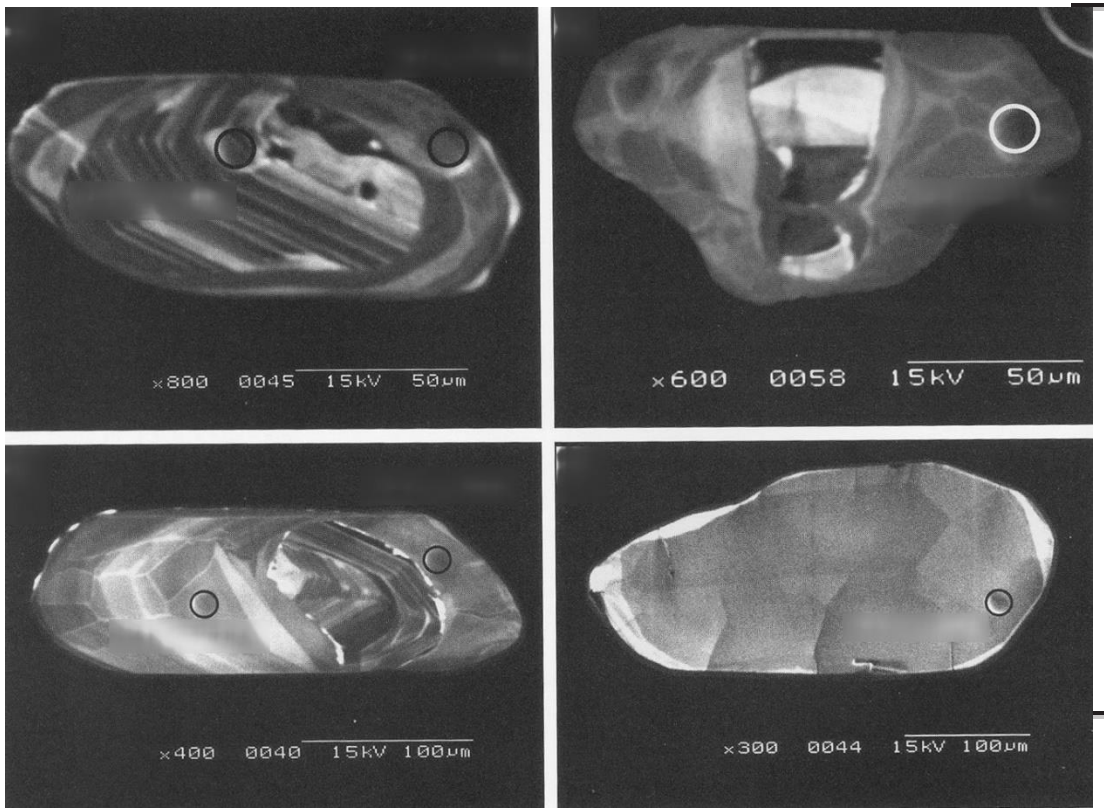
Diamonds do not form in Mobile belts (too warm and not dense enough)- zircon in cratons- we prefer low to med temp





Zircon crystal $(Zr, U, REE)_2SiO_4$

Cathode Luminense images



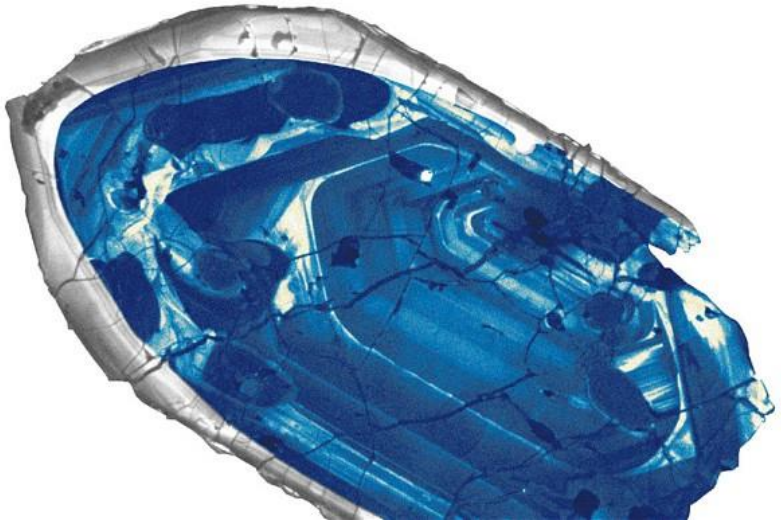
$$^{238}U \rightarrow {}^{206}Pb \qquad \lambda^{238}U = \lambda_1 = 1.55125 \times 10^{-10}$$

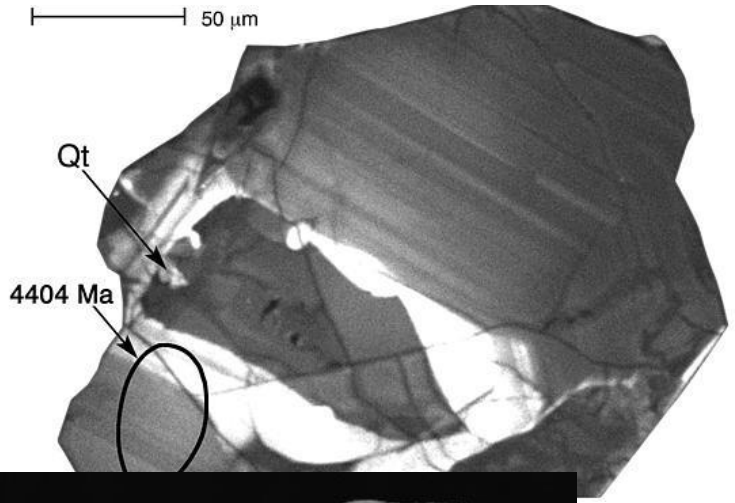
$$^{235}U \rightarrow {}^{207}Pb \qquad \lambda^{235}U = \lambda_2 = 9.8485 \times 10^{-10}$$

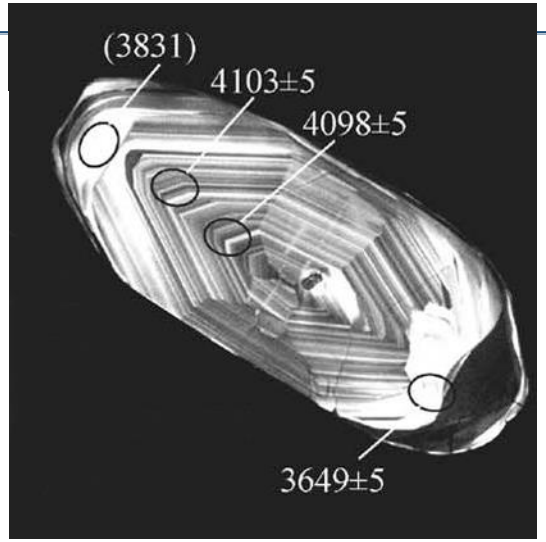
$$^{232}Th \rightarrow {}^{208}Pb \qquad \lambda^{232}Th = \lambda_3 = 4.9475 \times 10^{-11}$$

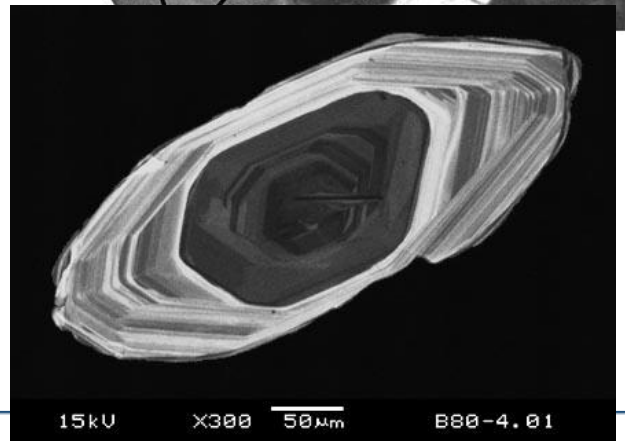
$$^{238}U / {}^{235}U = 137.88$$

Jack hills zircons(Froude et al, 1983-Nature vol 304, 616-618) some of the oldest rocks on Earth. The story of Zircon is the story of life on Earth









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METHODOLOGY- Pick rocks that you are certain that they contain zircon grains

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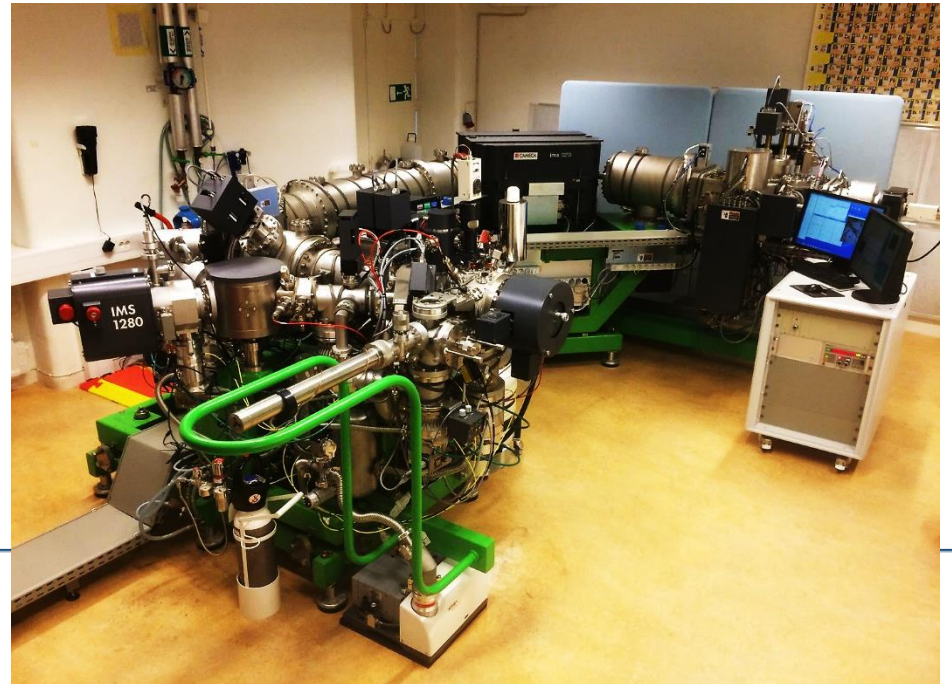
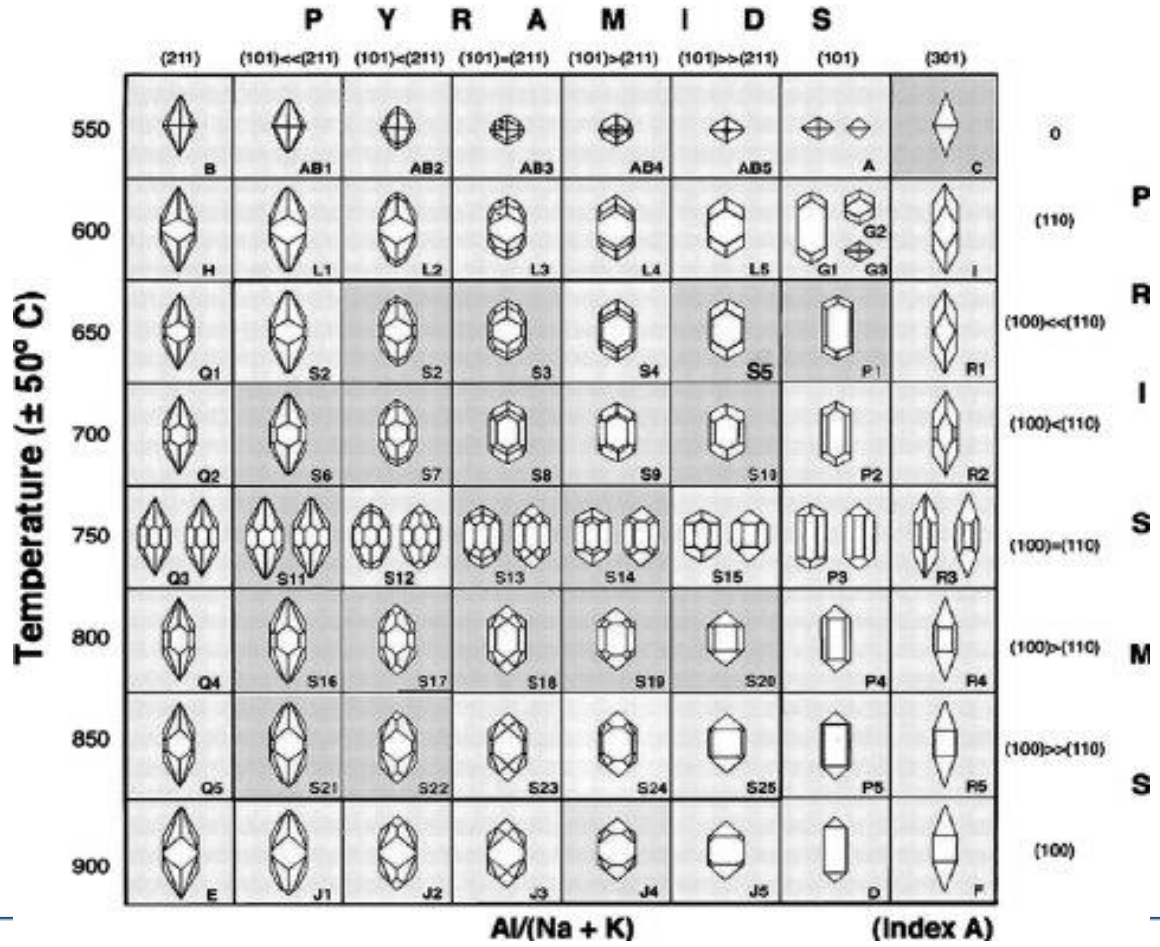
METHODOLOGY-pick the zircons and analyse

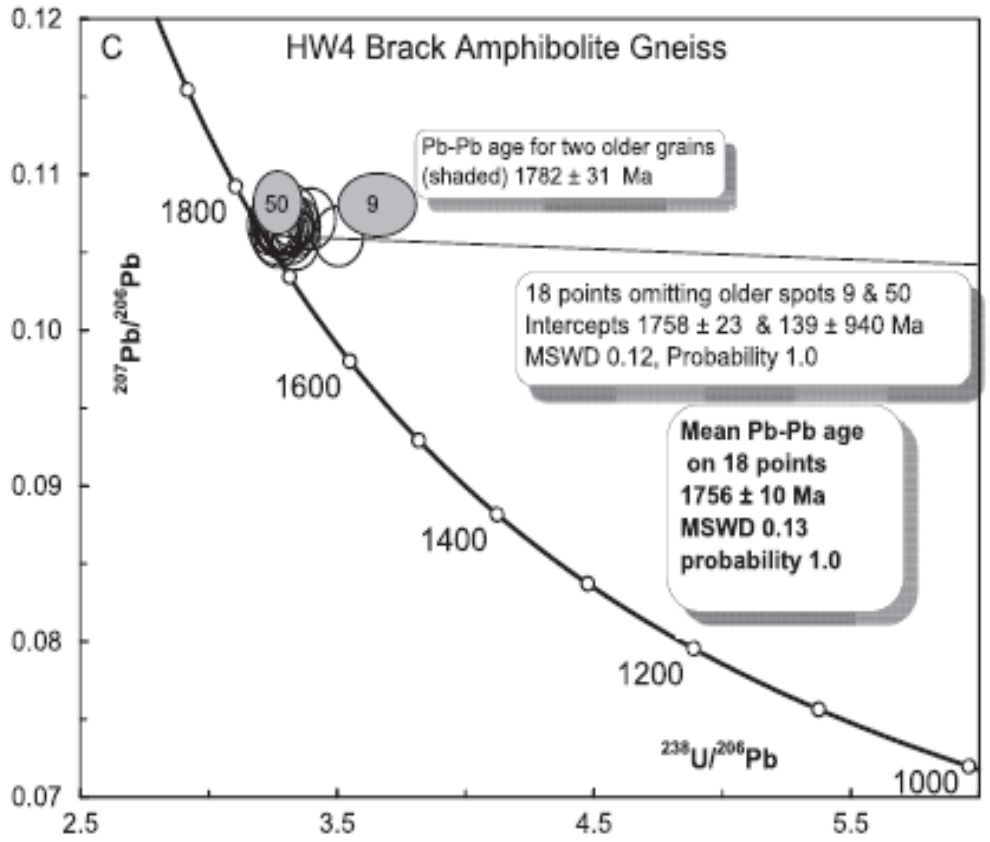


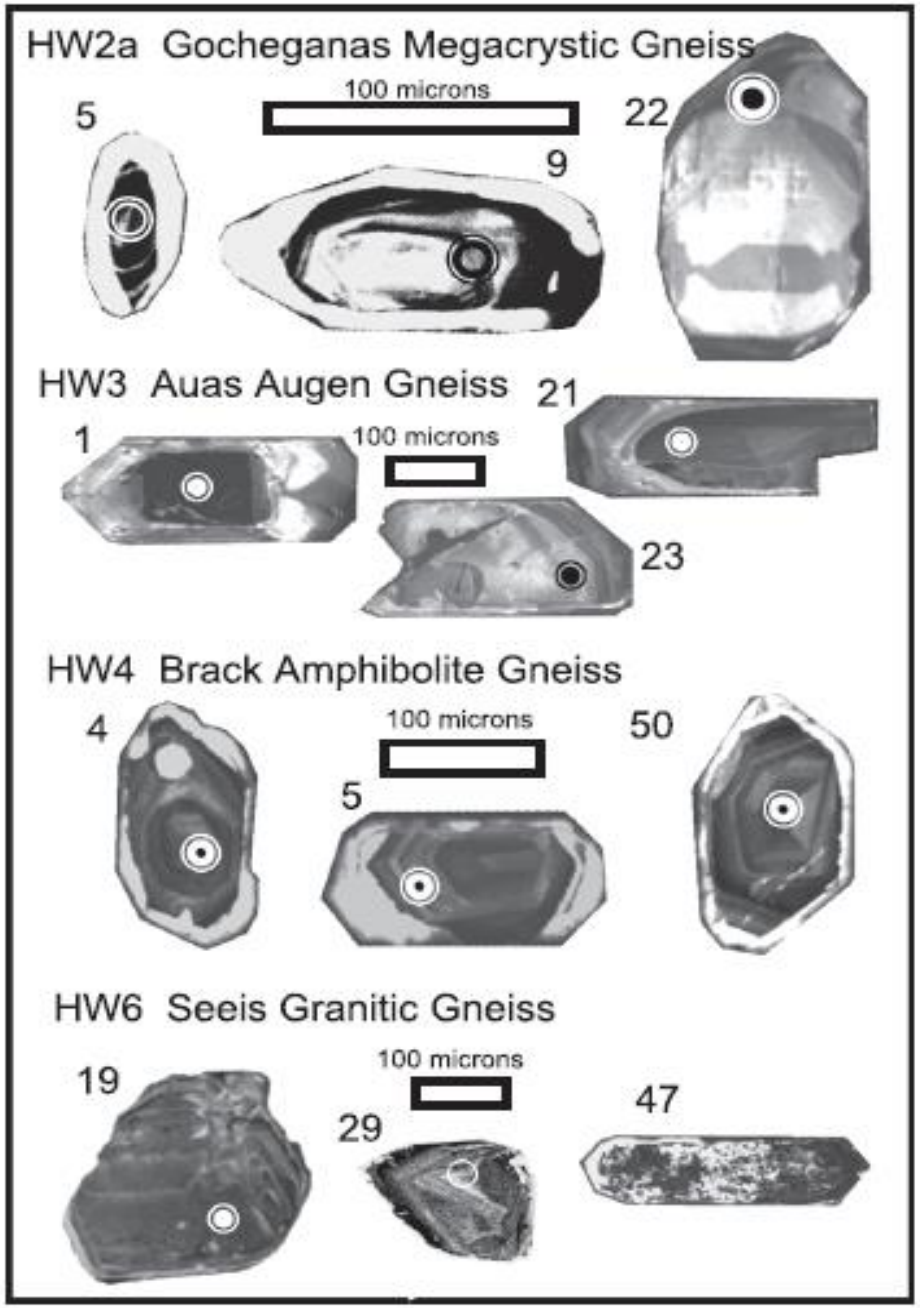
The power of the zircon crystal-thermometry (after Puppin, 1980)-nature's gift to man



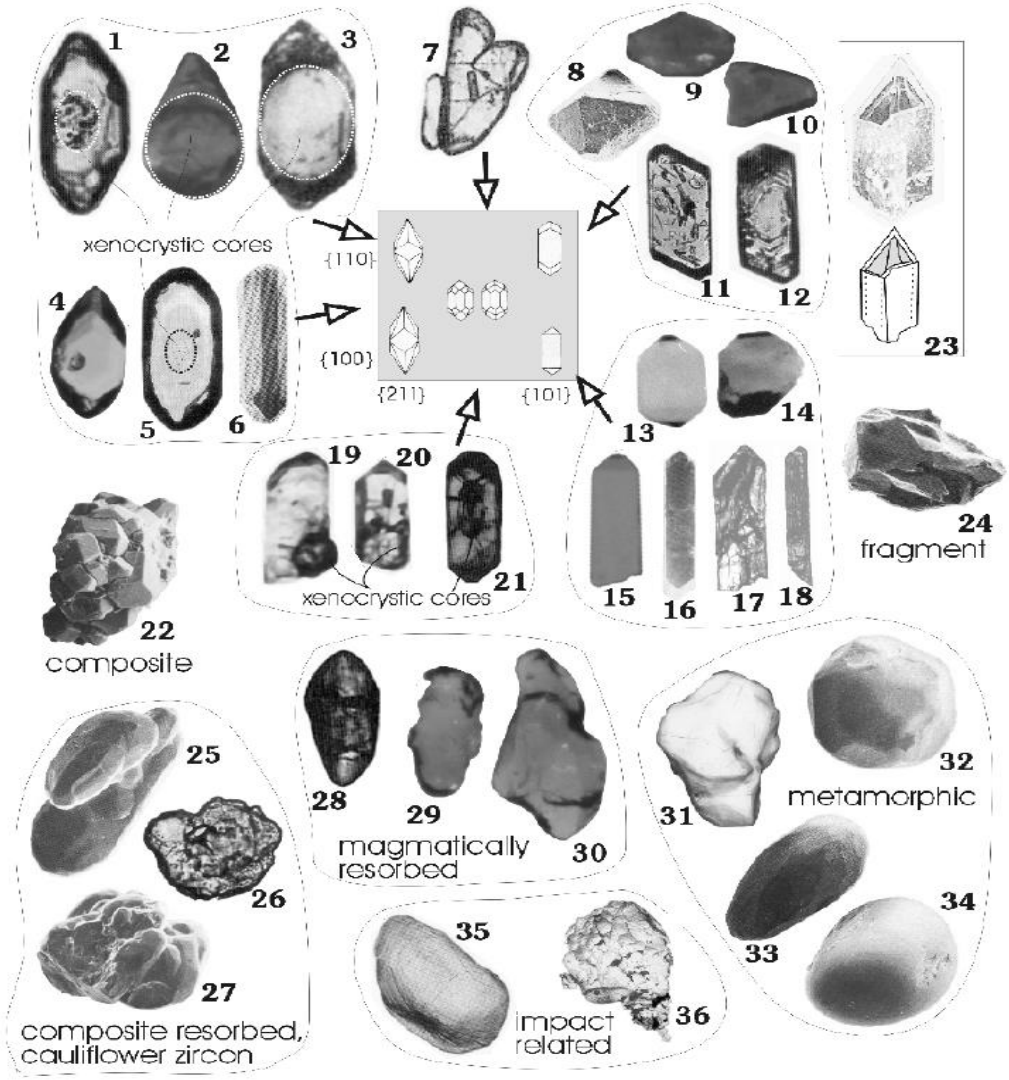
- The shape of the zircon is also an indication of the temperature at which it formed and composition- *important in mineral deposits studies*
- Better pyramids indicate higher Al/(K+Na) ratio- *Tectonic setting indicators*
- Better prisms indicate higher temperatures of formation
- Index A reflects the ratio controlling the development of zircon pyramids, whereas temperature affects the development of zircon prisms.

Mapani et al., 2014

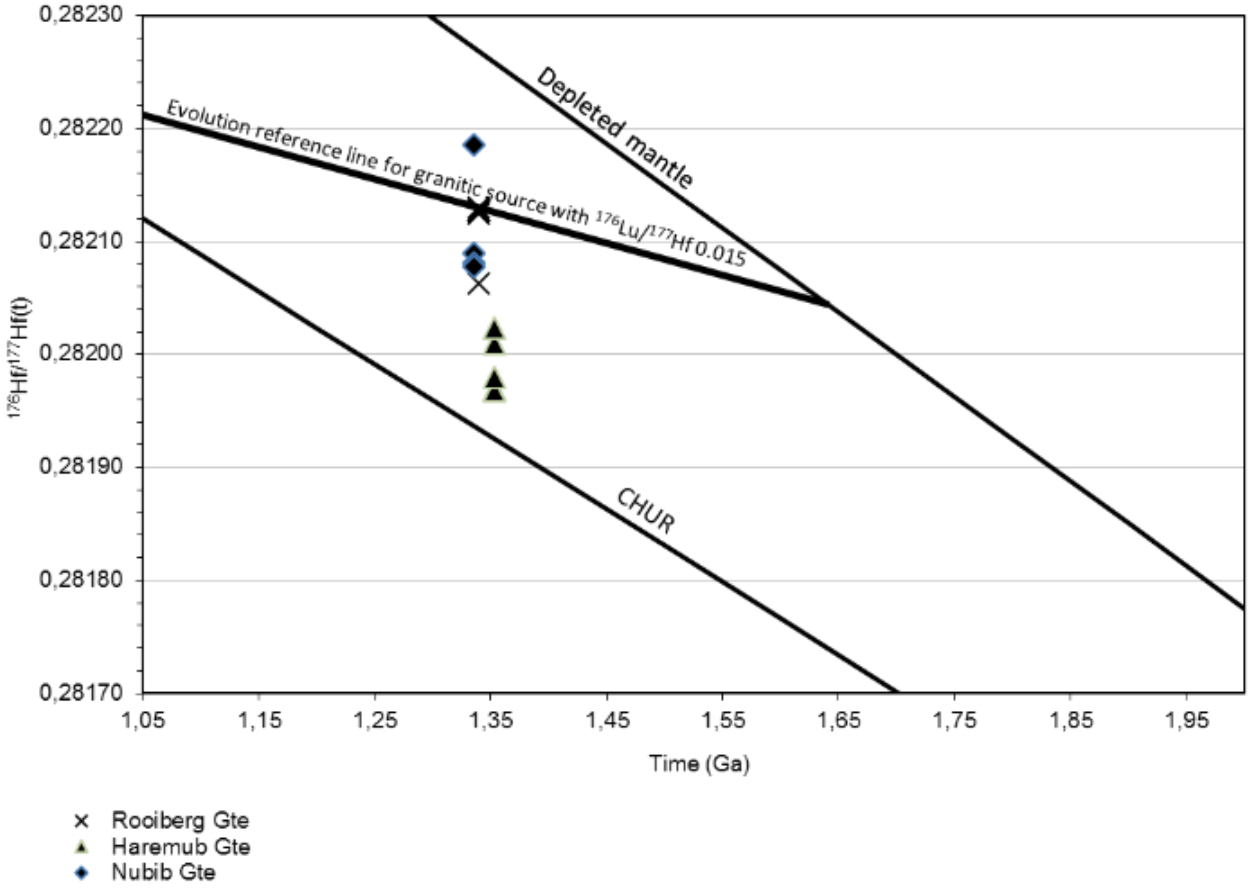




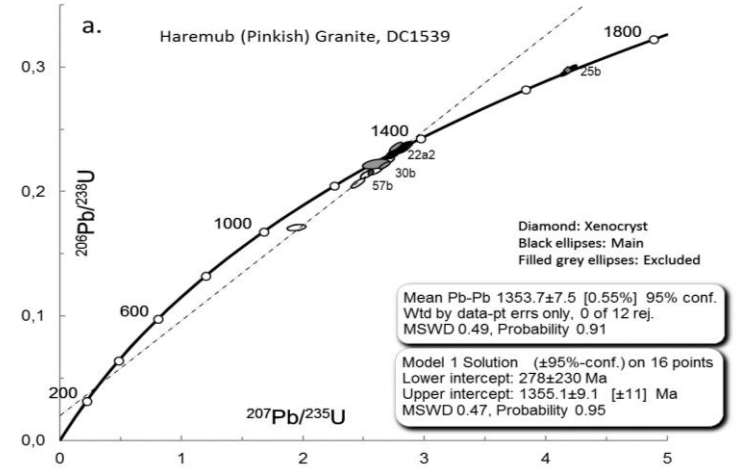
After Corfu et al., 2002-Atlas of Zircon Texture

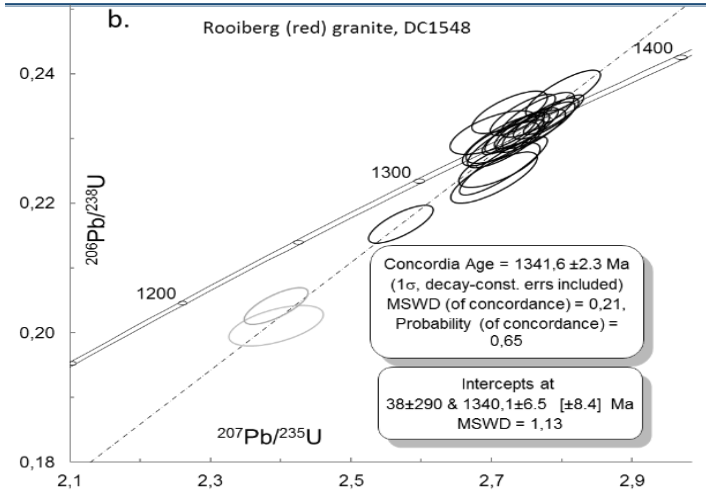


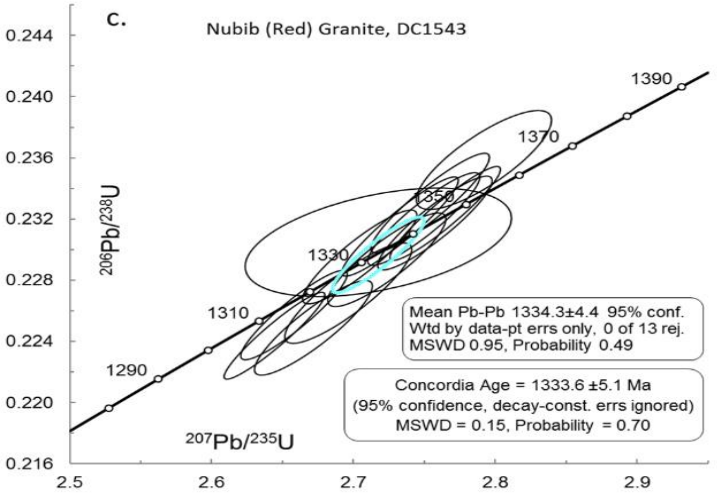
Lu/Hf clock – a window into the crust and mantle (Mapani et al., 2014)

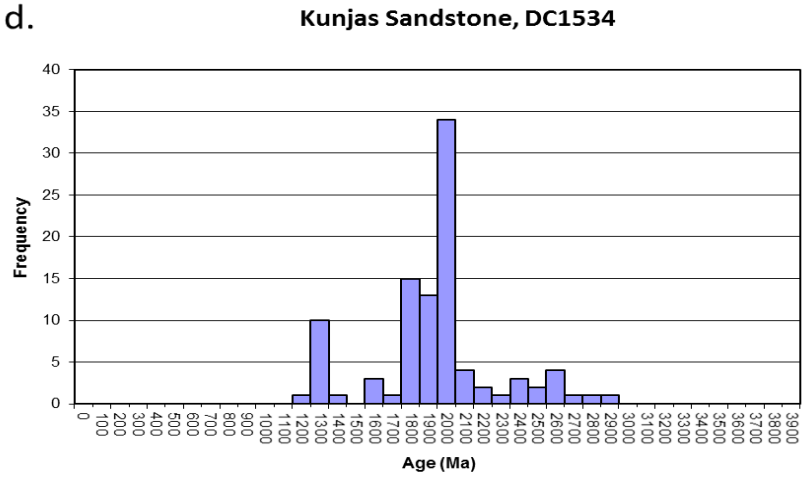


Concordia Diagram after Harris, Mapani, Cornel, Malobela, Weber, Hanson and Kristofersen (2019)









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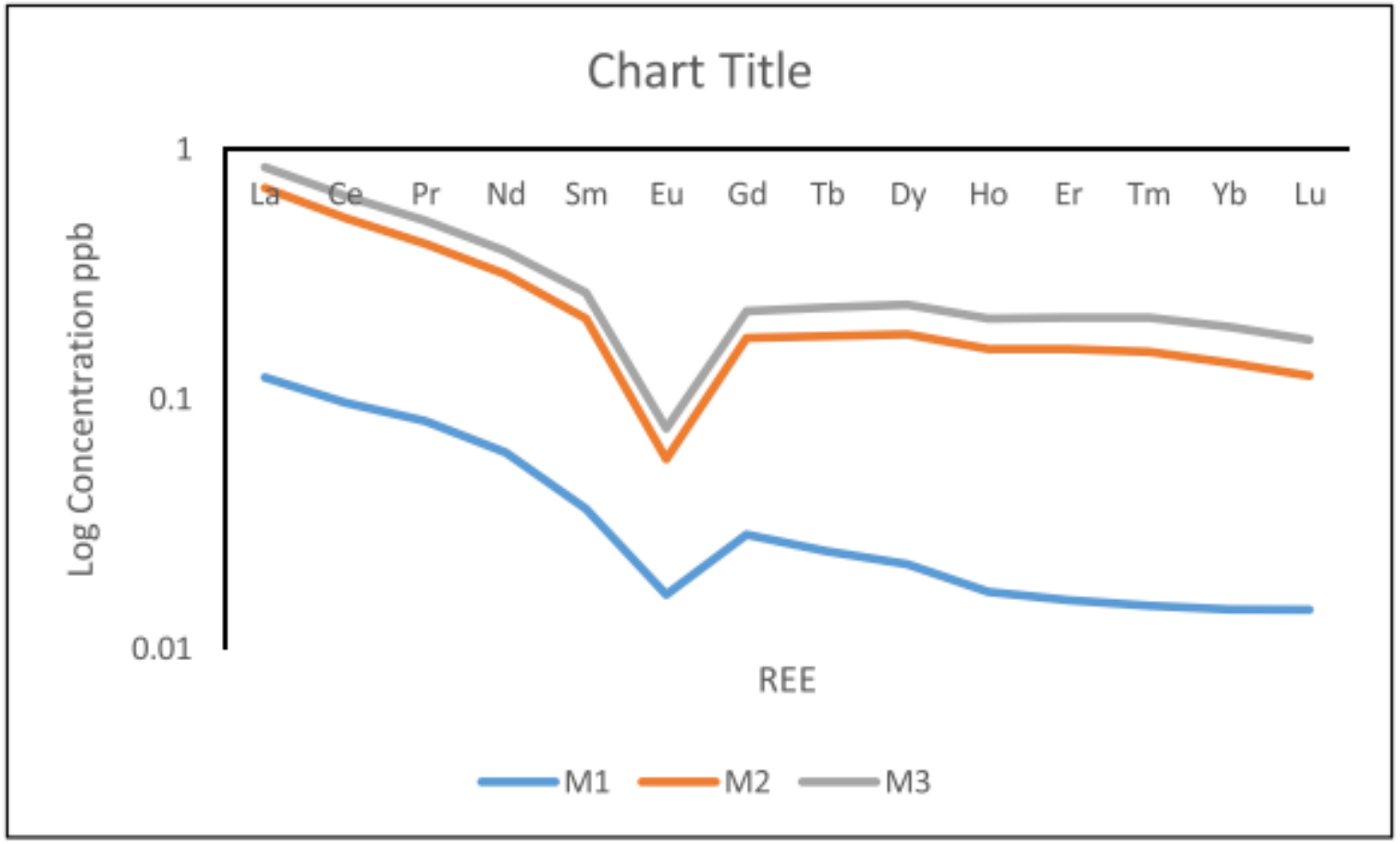
Applications of Zircon geochronology, scientific make up to national economies

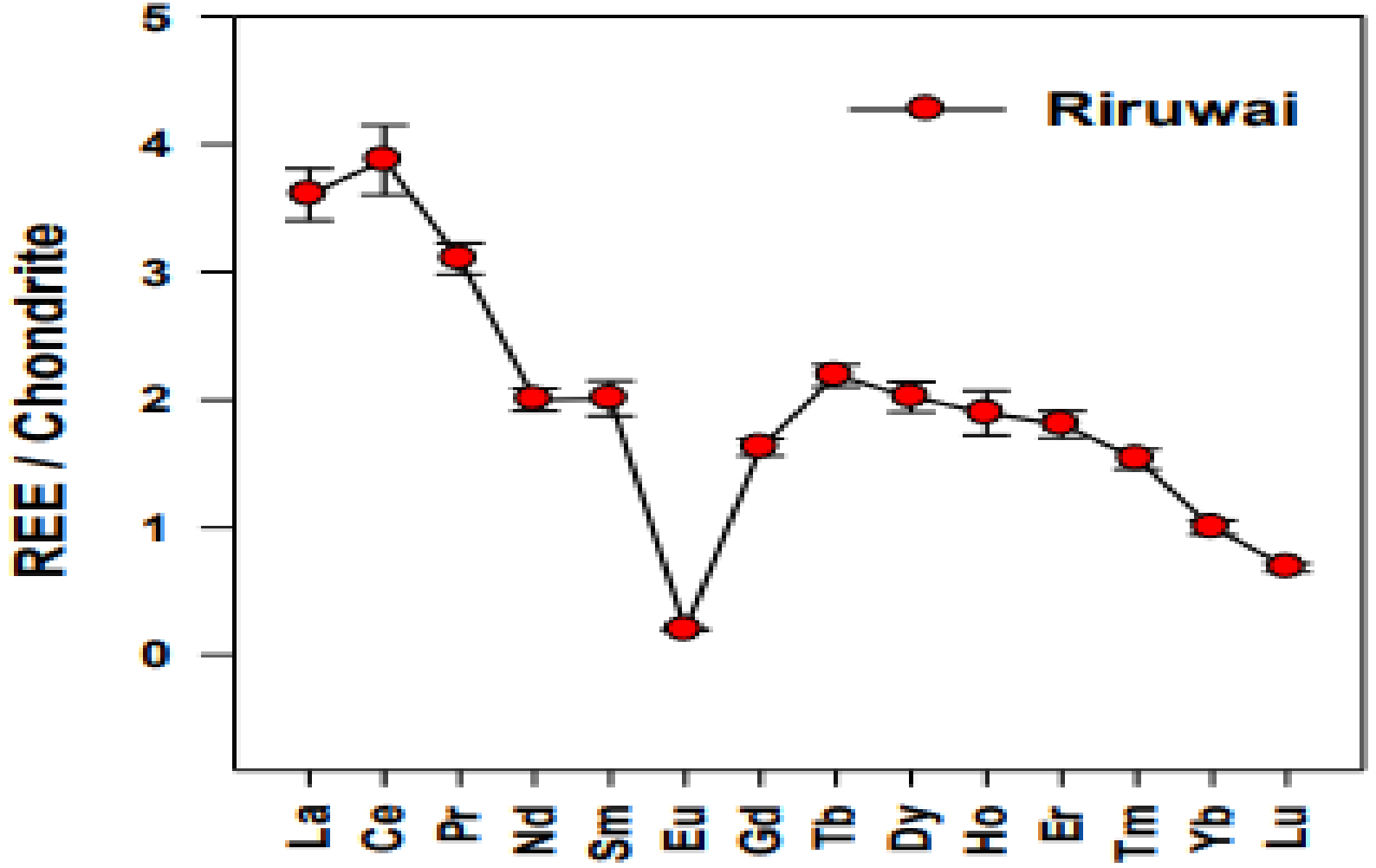
1. Crime control in the trafficking of uranium materials for enrichment (IAEA, Vienna in conjunction with cooperating countries)
2. Identifying sources of uranium in groundwater with a view to remediate and protect communities (e.g., Hamutoko, Mapani and Ellmies) (Khan and Swakop Rivers, Namibia)
3. Used in thermometry on the estimation of orogens and fertility of continents (First used by Foster, Goscombe, Newstead, Mapani, Weber, Mueller and Muvangua, 2012)- Damara Belt vs Congo and Kalahari Cratons collision

(beneficiaries- discovery of Osino Gold, discovery of Gergarub Deposit, Rosh Pinah)

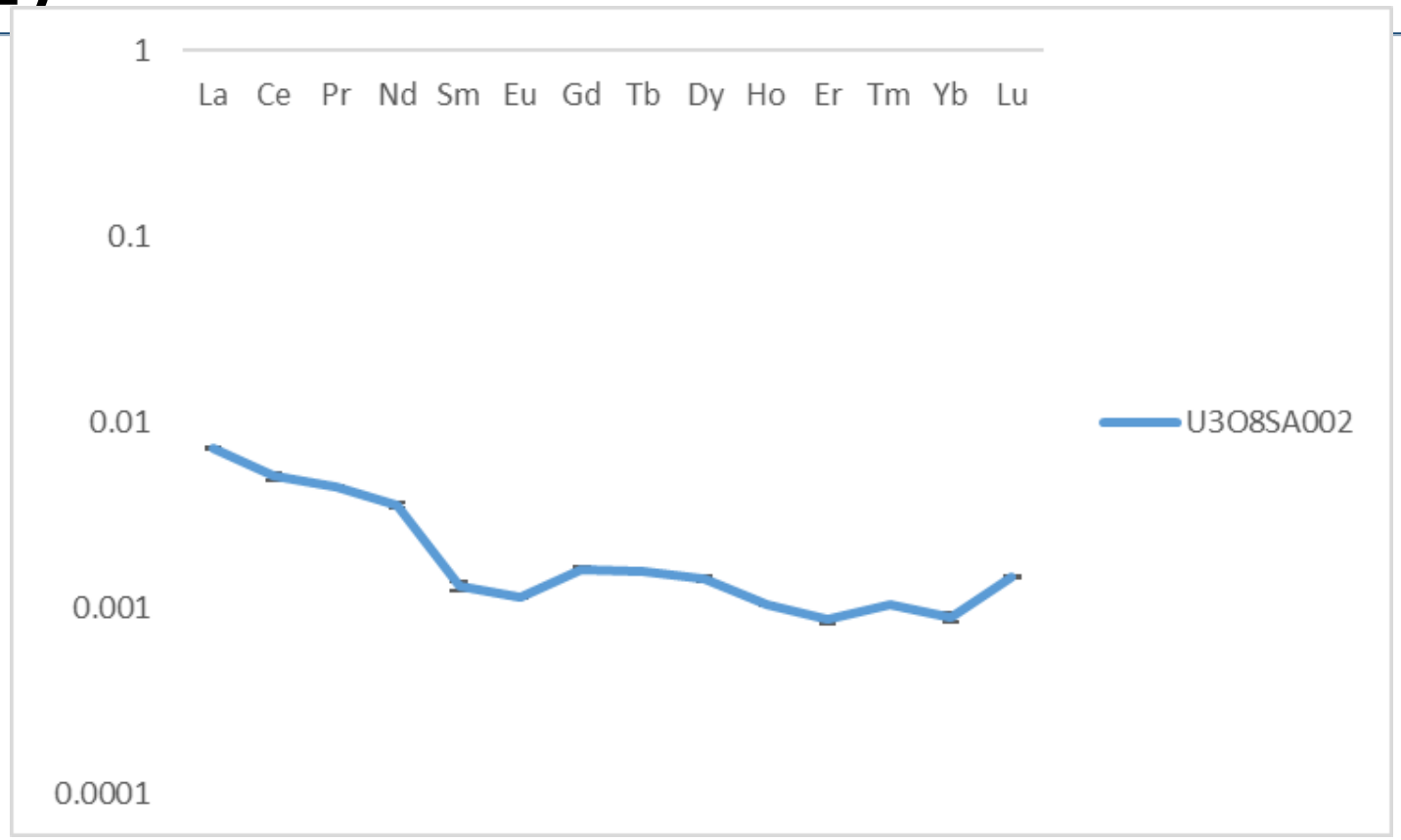
The power of zircon in forensic science-fingerprinting sources of uranium and lead sources-Namibian examples (Madzunya *et al.*, 2021)



Riruwai uranium source, Nigeria (after John et al 2021)



Uranium sources in South Africa (after Kupi, 2022)



The Damara, Gariep and Kaoko Belts – Fertility for metal deposits-The power of Zircon in mineral discovery

Gondwana Research 28 (2015) 179–190

Contents lists available at ScienceDirect

Gondwana Research

journal homepage: www.elsevier.com/locate/gr

U–Pb age and Lu–Hf isotopic data of detrital zircons from the Neoproterozoic Damara Sequence: Implications for Congo and Kalahari before Gondwana

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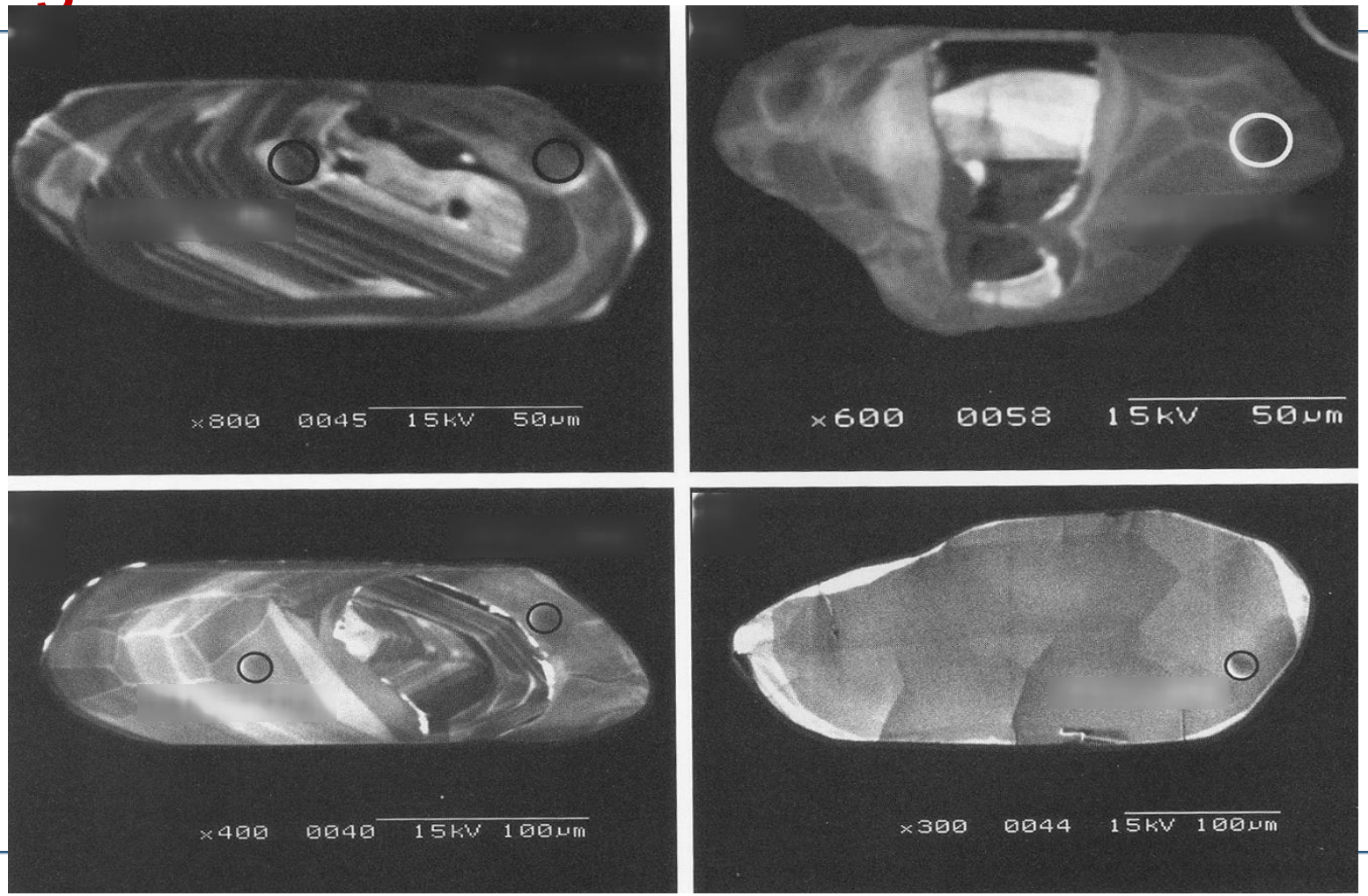
[e] Regional Geosciences, Geological Survey of Namibia, Windhoek, Namibia

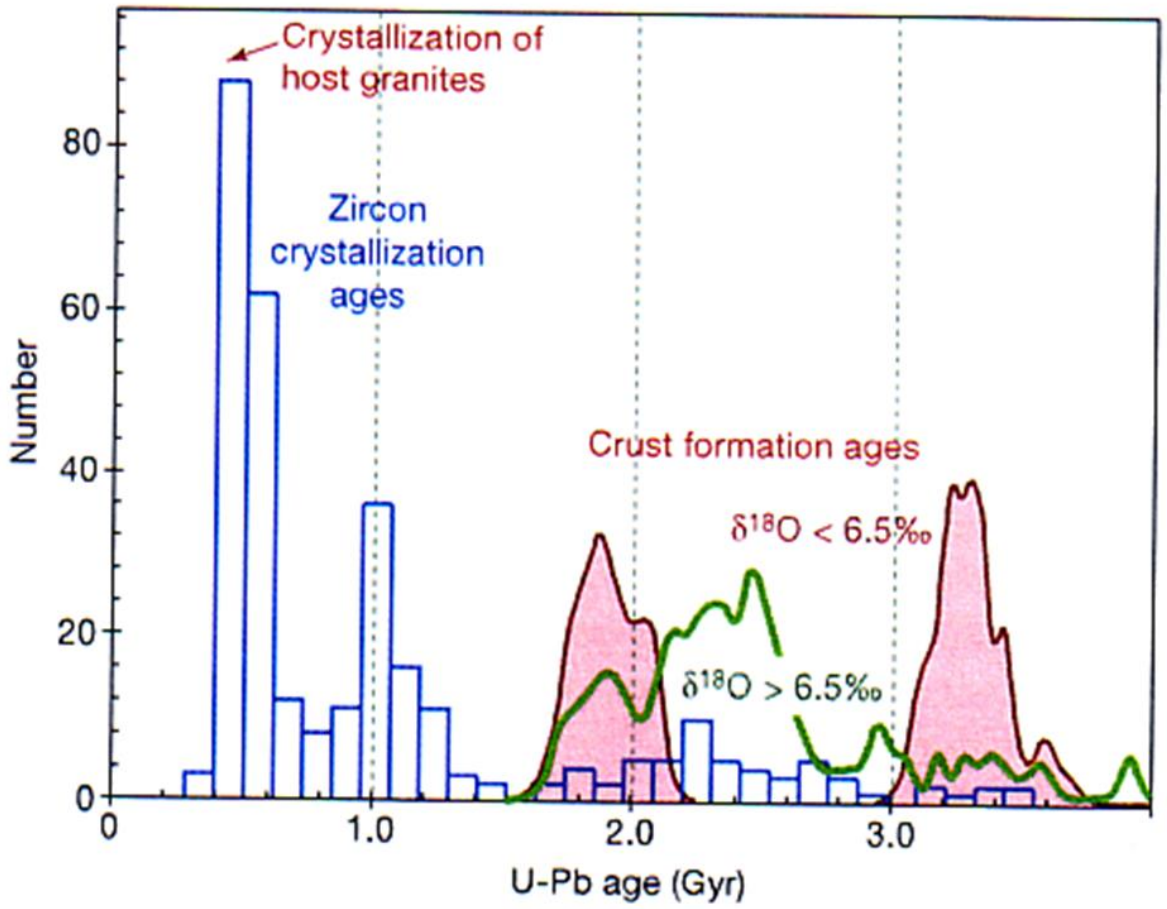
Crustal differentiation, melt generation and melt migration-lessons from zircons

- Continents represent the cycles of repeated differentiation- we see *inherited zircons in granites*.
- Mineral Deposits signatures occur in these igneous and metamorphic processes
- Dense oceanic crust gets recycled in the Upper Mantle, while less dense felsic crust is upwardly stratified by a combinations of geological and tectonic processes- *we see resorbed magmatic zircons*.
- Anything more felsic than basalt will accrete uniquely in magmatic arcs above subduction zones to form Cu-porphyry deposits (e.g., Haib in Namibia)
- However, true felsic crust of granite composition, requires repeated and multiple differentiation events to reach the average composition of continents- *we see complex zircons that have undergone several metamorphic and granite episodes are common*

Recycling and cratonization-zircons can be recycled several times, overgrown in different geologic environments



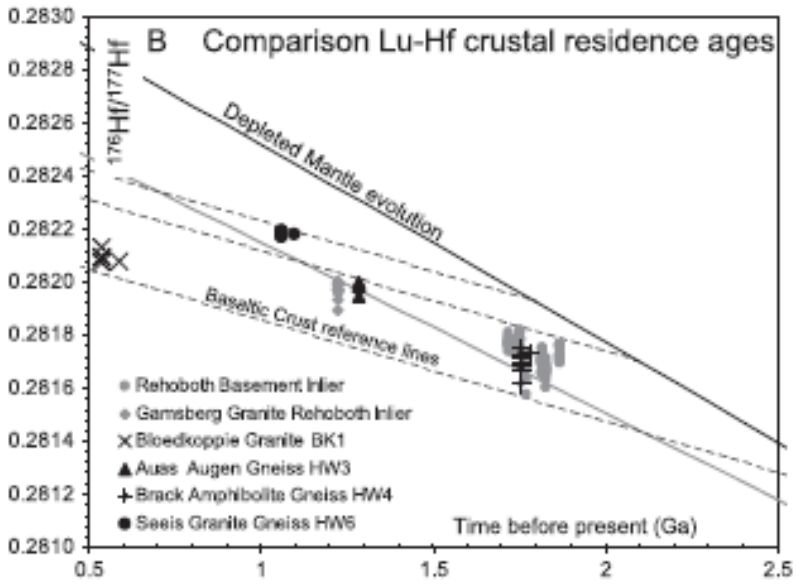
Formation of continental crust and its evolution over the geologic history (after Hawkesworth, 1987) has followed 250 Ma cycles

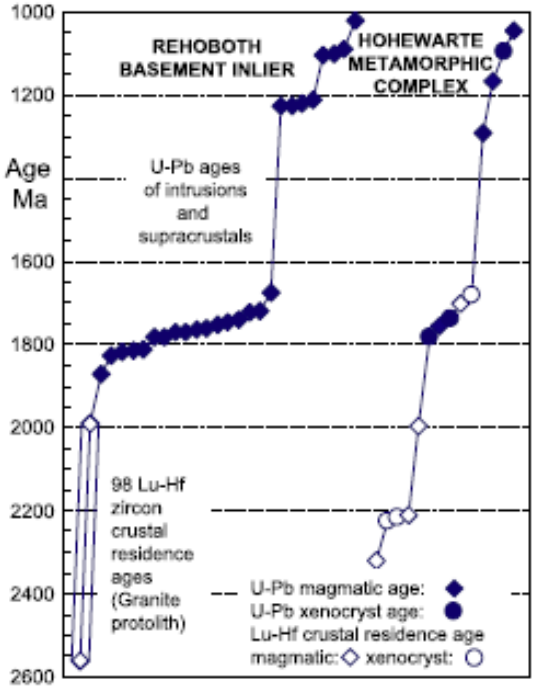


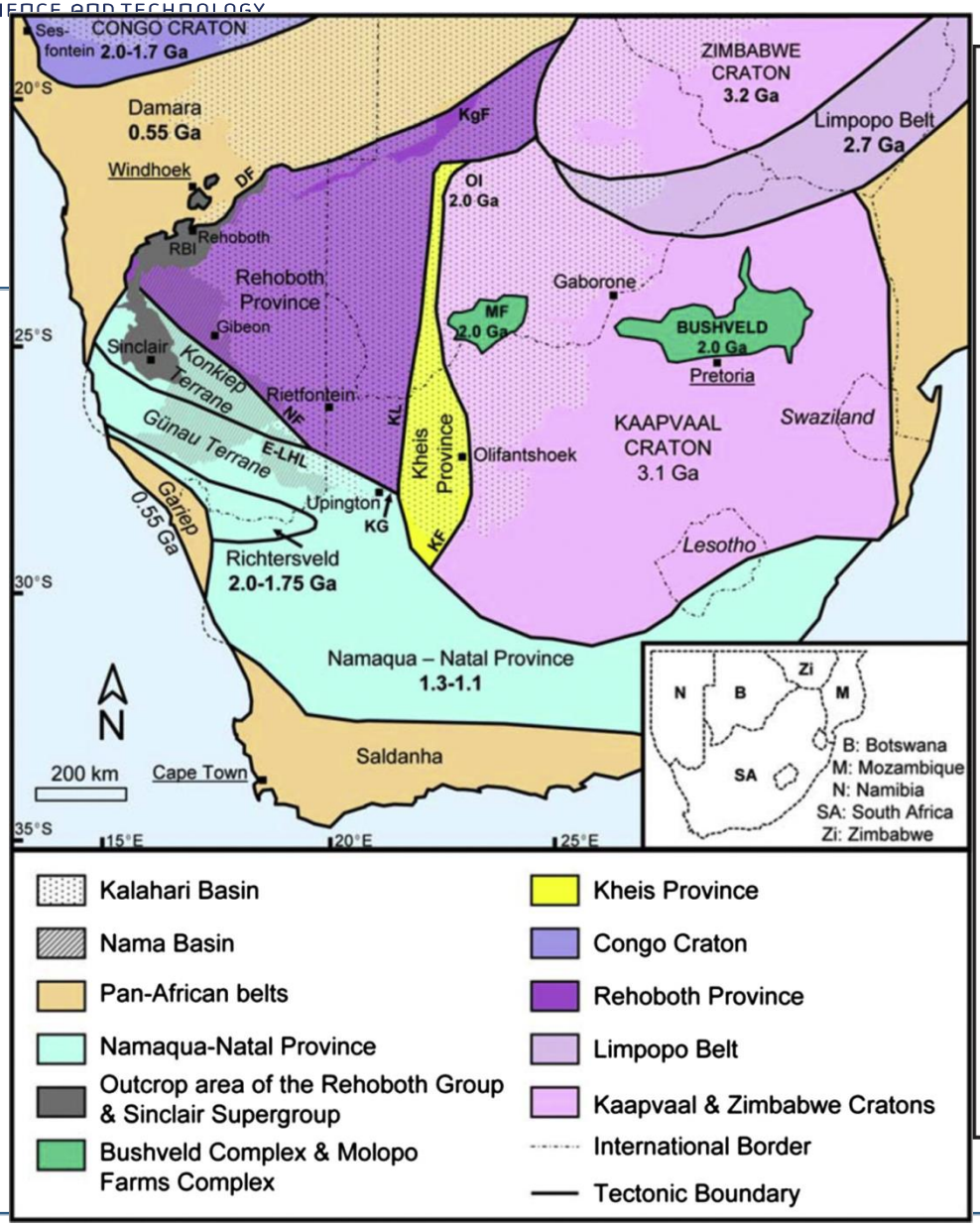
How do we know that the continental crust is juvenile or is not mixed with sedimentary material?

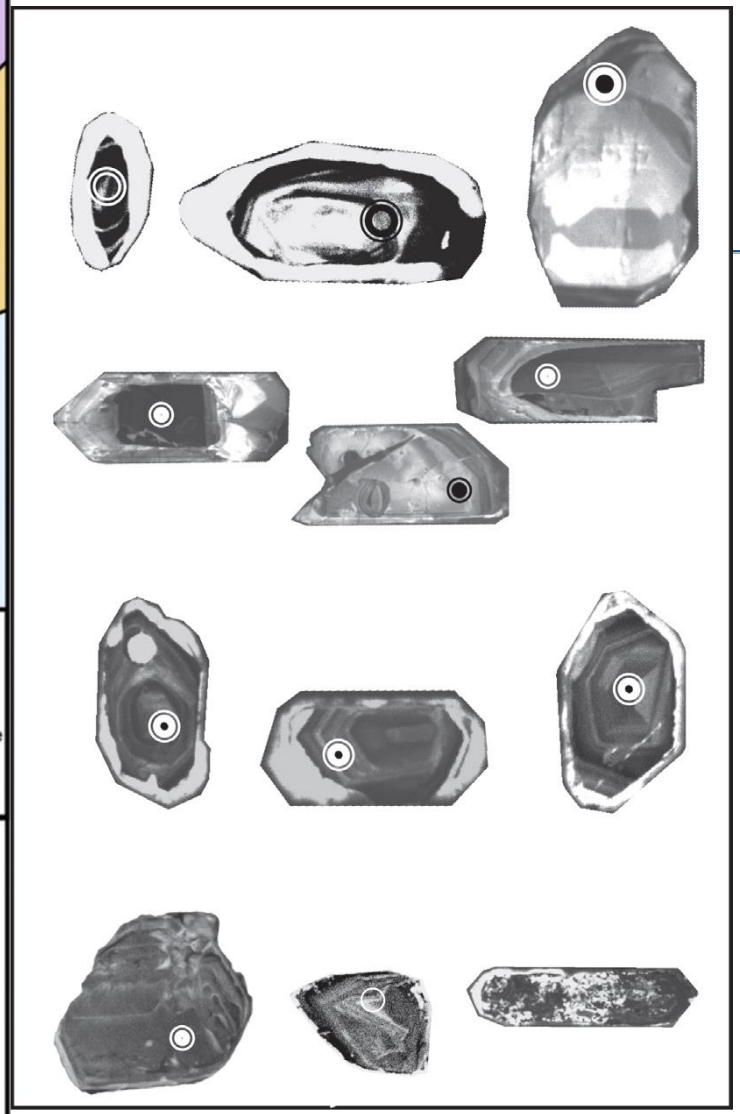
- For this we use a combination of isotopes.
- 1. Sm/Nd isotopes: Nd indicates whether the rock was derived from the crust or mantle.
- Rocks with high Nd values are from the mantle
- La and Rb are high in crustal rocks and therefore Rb/Sr and Nb/La ratios can tell us about the origin.
- High Sr87/Sr86 is common to crustal rocks.
- We use the Hf/Lu ratios from zircons to fully understand the evolution of the rock

Mapani et al., 2014 (Testing the origin of the Hohewarte (Windhoek) and Rehoboth basements






Ses-fontein
CONGO CRATON
2.0-1.7 Ga
ZIMBABWE CRATON
3.2 Ga
Limpopo Belt
2.7 Ga
Damara
0.55 Ga
KgF
Windhoek
DF
OI
2.0 Ga
Rehoboth
RBI
Rehoboth Province
Gaborone
MF
2.0 Ga
BUSHVELD
2.0 Ga
Pretoria
Gibeon
Sinclair
Konkiep Terrane
Rietfontein
NF
KL
Kheis Province
Olifantshoek
KAAPVAAL CRATON
3.1 Ga
Swaziland
Günau Terrane
E-LHL
Gariep
0.55 Ga
Upington
KG
KF
Lesotho
Richtersveld
2.0-1.75 Ga
Namaqua – Natal Province
1.3-1.1
Saldanha
Cape Town
200 km
N
20°S
25°S
30°S
35°S
15°E
20°E
25°E
N
B
Zi
M
SA
B: Botswana
M: Mozambique
N: Namibia
SA: South Africa
Zi: Zimbabwe
Kalahari Basin
Nama Basin
Pan-African belts
Namaqua-Natal Province
Outcrop area of the Rehoboth Group & Sinclair Supergroup
Bushveld Complex & Molopo Farms Complex
Kheis Province
Congo Craton
Rehoboth Province
Limpopo Belt
Kaapvaal & Zimbabwe Cratons
International Border
Tectonic Boundary



Example 1-Damara belt-identification of fertile crust

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U–Pb age and Lu–Hf isotopic data of detrital zircons from the Neoproterozoic Damara Sequence: Implications for Congo and Kalahari before Gondwana

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Damara belt units with different types of zircons or no zircon!

Gondwana at 750 Ma and its dispersal and assembly of Pangea

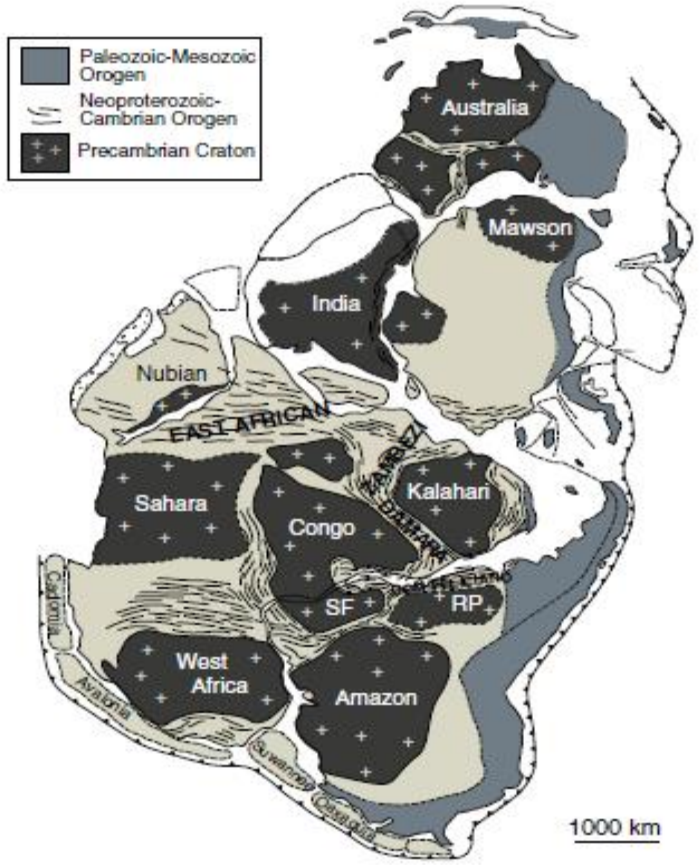


Fig. 1. Map of Gondwana (after Gray et al., 2006) showing the locations of Pan-African orogenic belts in southern Africa. RP, Rio de la Plata craton; SF Sao Franscisco craton.

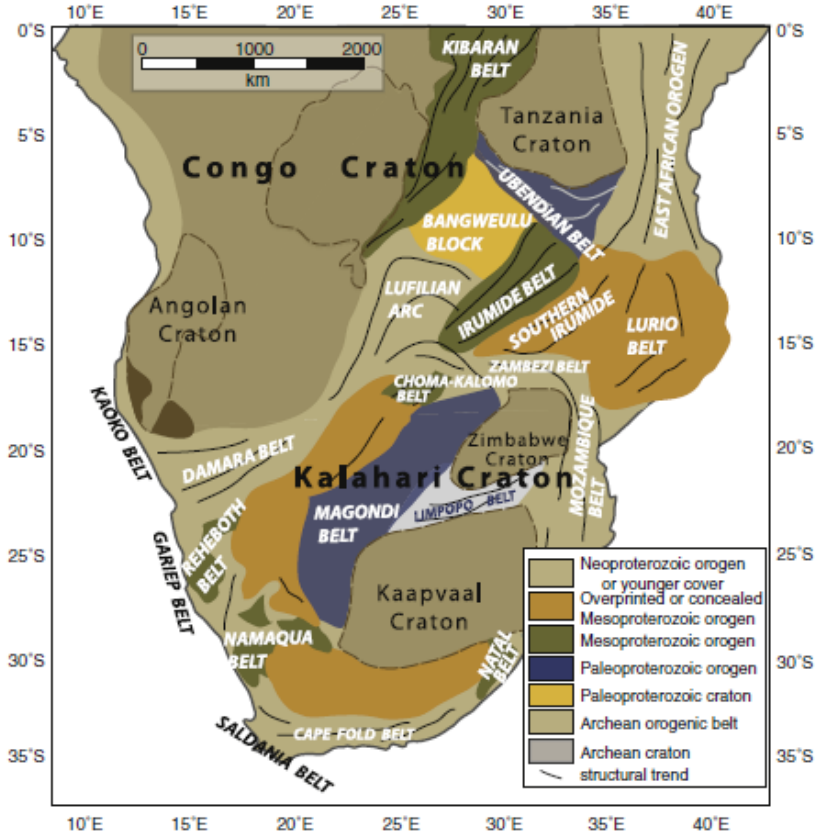


Fig. 2. Map of major geologic provinces and Precambrian orogenic belts in southern Africa. Compiled after Goscombe et al. (2000) and Hanson (2003).

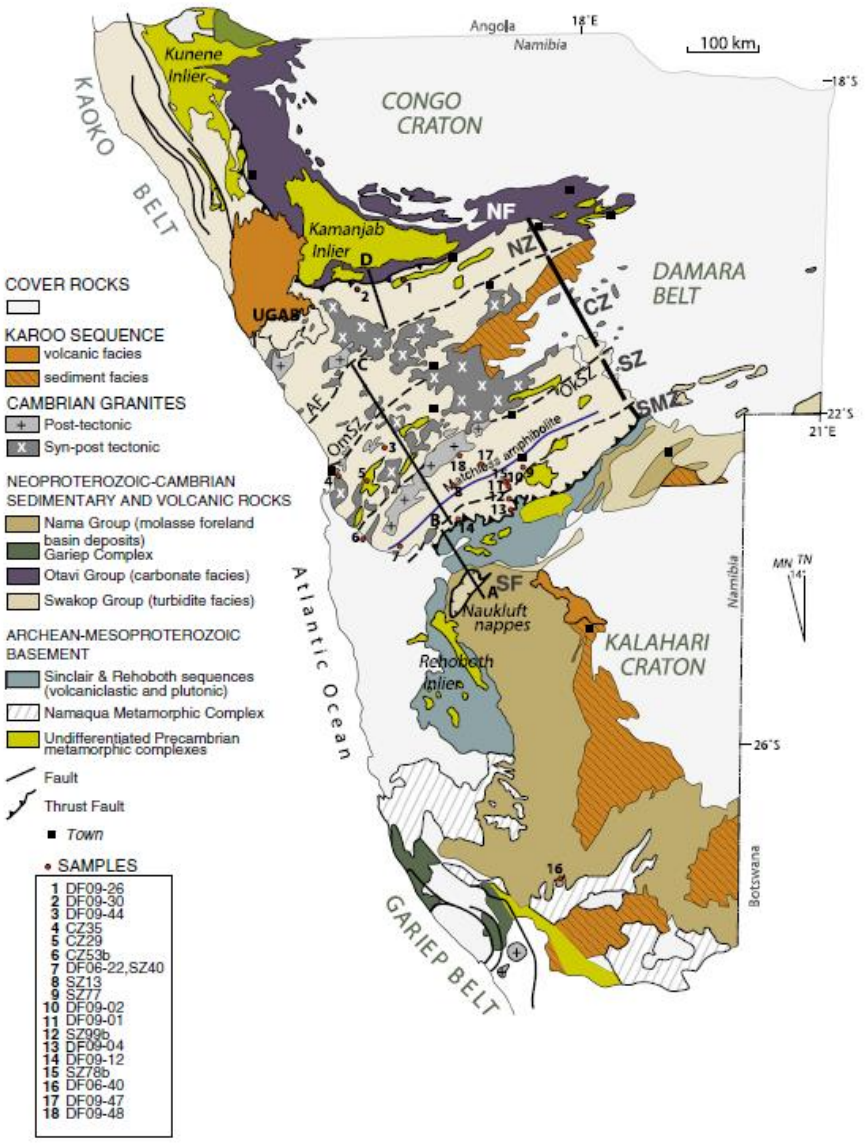
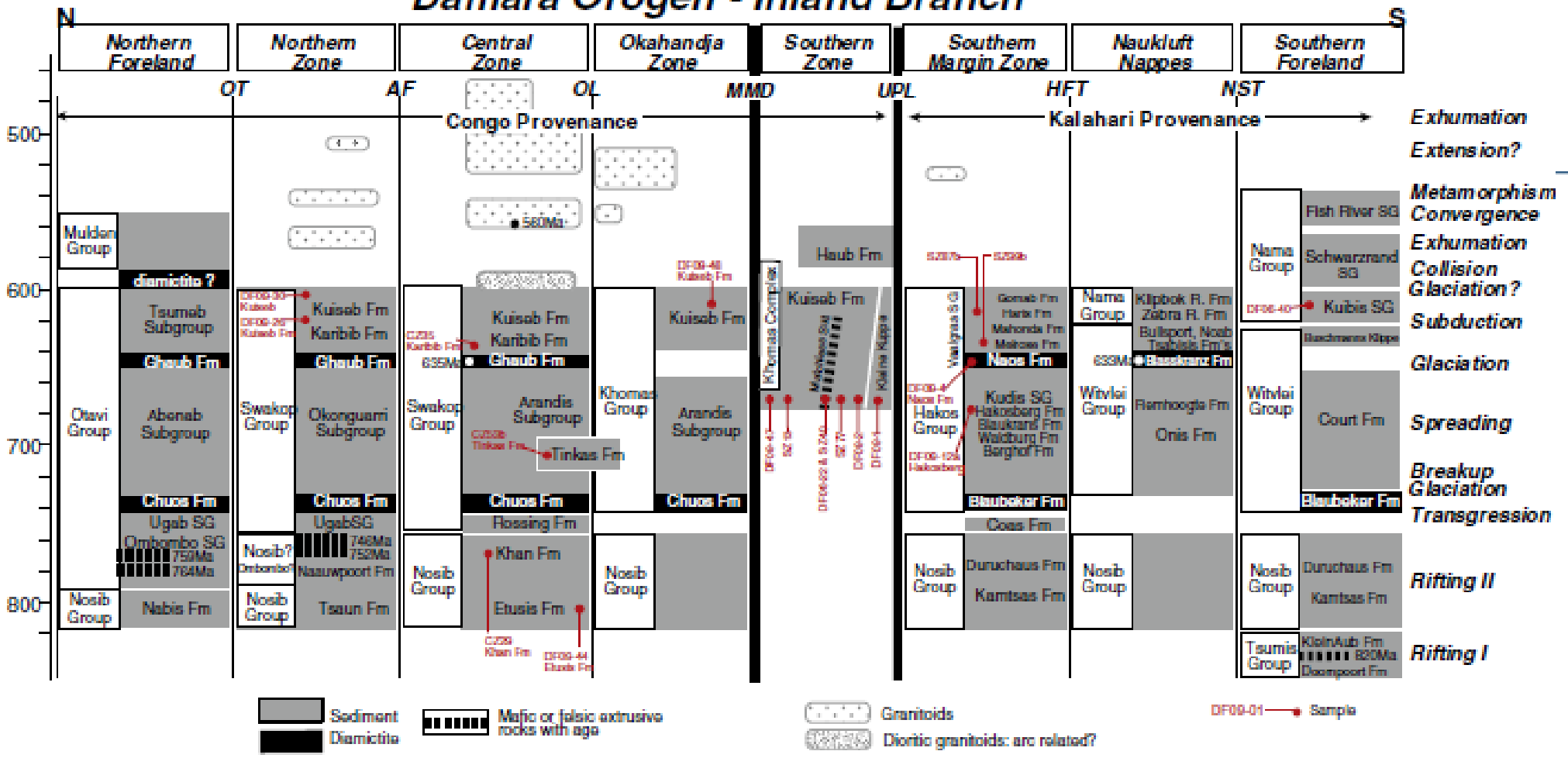


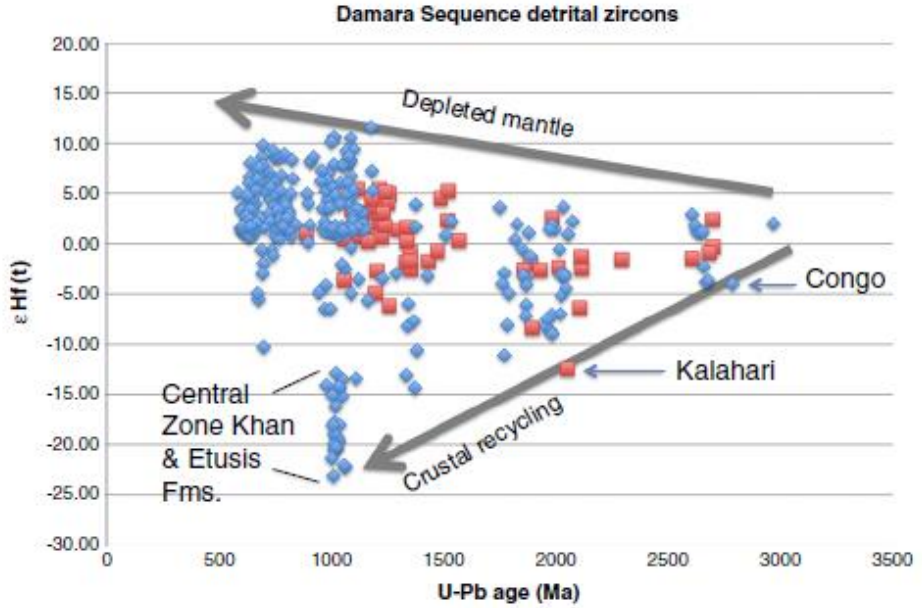
Fig. 3. Simplified geologic map of Namibia and the Damara Orogen (after Gray et al., 2006). Sample locations are indicated by the dots and numbers refer to the sample name. Abbreviations: SF, Southern Foreland; SMZ, Southern Margin Zone; SZ, Southern Zone; CZ, Central Zone; NZ, Northern Zone; NF, Northern Foreland; OkSZ, Okahandja shear zone; OmSZ, Omaruru shear zone; AF, Autseib fault. A–B–C–D denote the endpoints of segments of the cross section in Fig. 5.

Damara Orogen - Inland Branch



OT: OutjoThrust, AF:Autseib Fault, OL: Okahandja Linearment, MMD: Main Metamorphic Discontinuity, UPL: Uis PassLine, HFT: Hakos Frontal Thrust, NST: Naukluft SoleThrust.

SUMMARY FOR CONGO AND KALAHARI CRATONS



- A nearly 1050-1000 Ma detrital zircon population in the Congo strata is absent in the Kalahari craton together with a 900-600 Ma detrital zircon population

- Most abundant zircon grains from Neoproterozoic strata on the Congo margin give ages of 1150-1000 and 800-600 Ma
- The most abundant grains on the Kalahari craton margins range from 1350-1100 Ma.
- A 1350-1200 detrital zircon population is absent in the Congo strata
- This means that in Rodinia, Congo and Kalahari were not proximal and only came together during the collision that assembled Gondwana

Conclusions:
Zircons: the lessons we learn from them

- Collectively, the Northern Foreland provenance contrasts with that of correlative units in the Central Zone of the Damara Orogen, where only two age peaks (1030 Ma and 2040 Ma) have been identified (Foster et al., 2015).
- Zircon chemistry also shows that the Congo grains have favourable O18/O16 ratios pointing to fluid activity- therefore fertility is high.
- Field evidence shows that where conditions were moist, deposits emerged, e.g., Rossing, Husab, Langer Heinrich, Navachab, Ondundu, B2Gold (Otjikoto), Tsumeb, Berg Aukas, Kombat, Kuiseb Springs- all on the Congo platform.
- The edge of the Congo has Cu ores such as Omitiomire, Onganga and Ghanzi in Botswana.
- The Kalahari only has sedimentary type mineral deposits such as Klein Aub Cu and Dordabis Cu.

Kaoko belt a haven for field geology