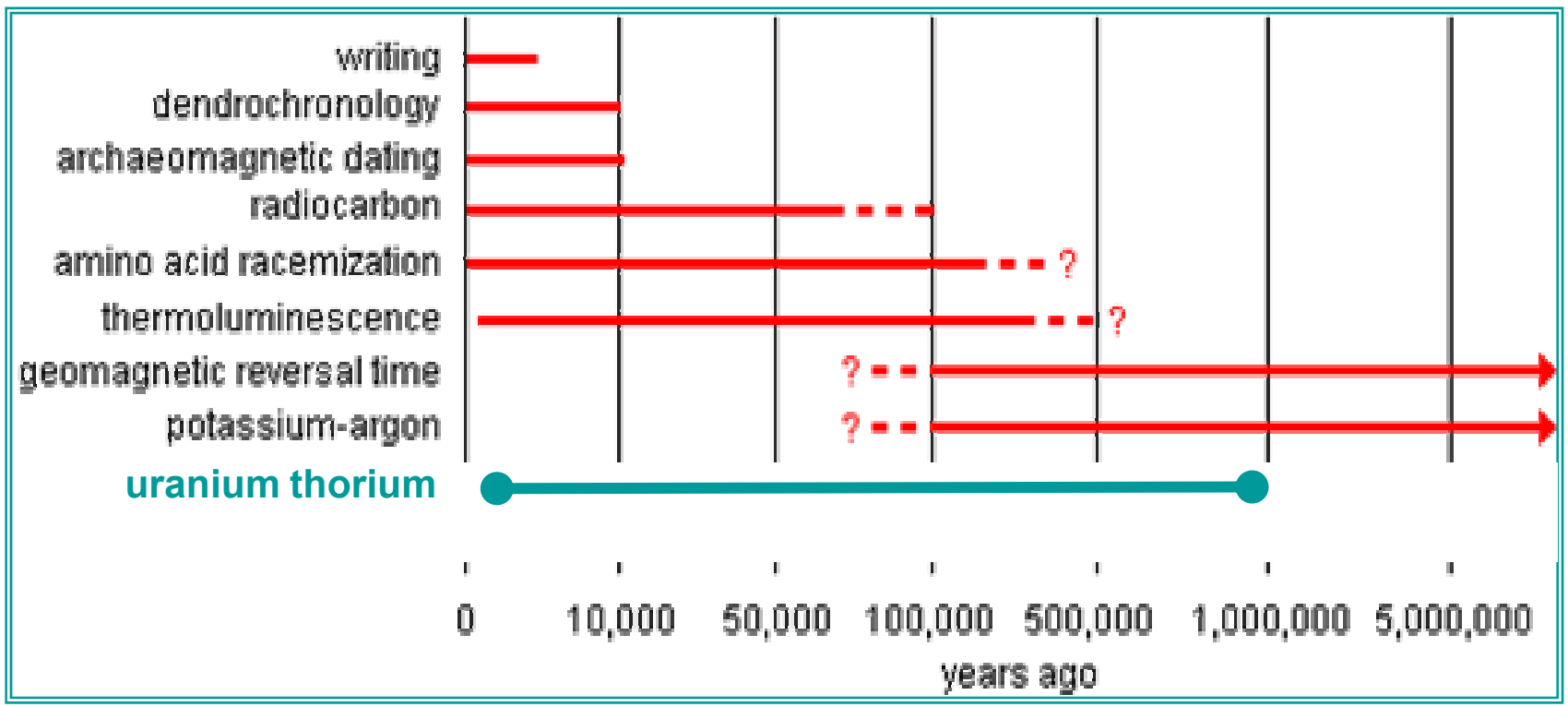
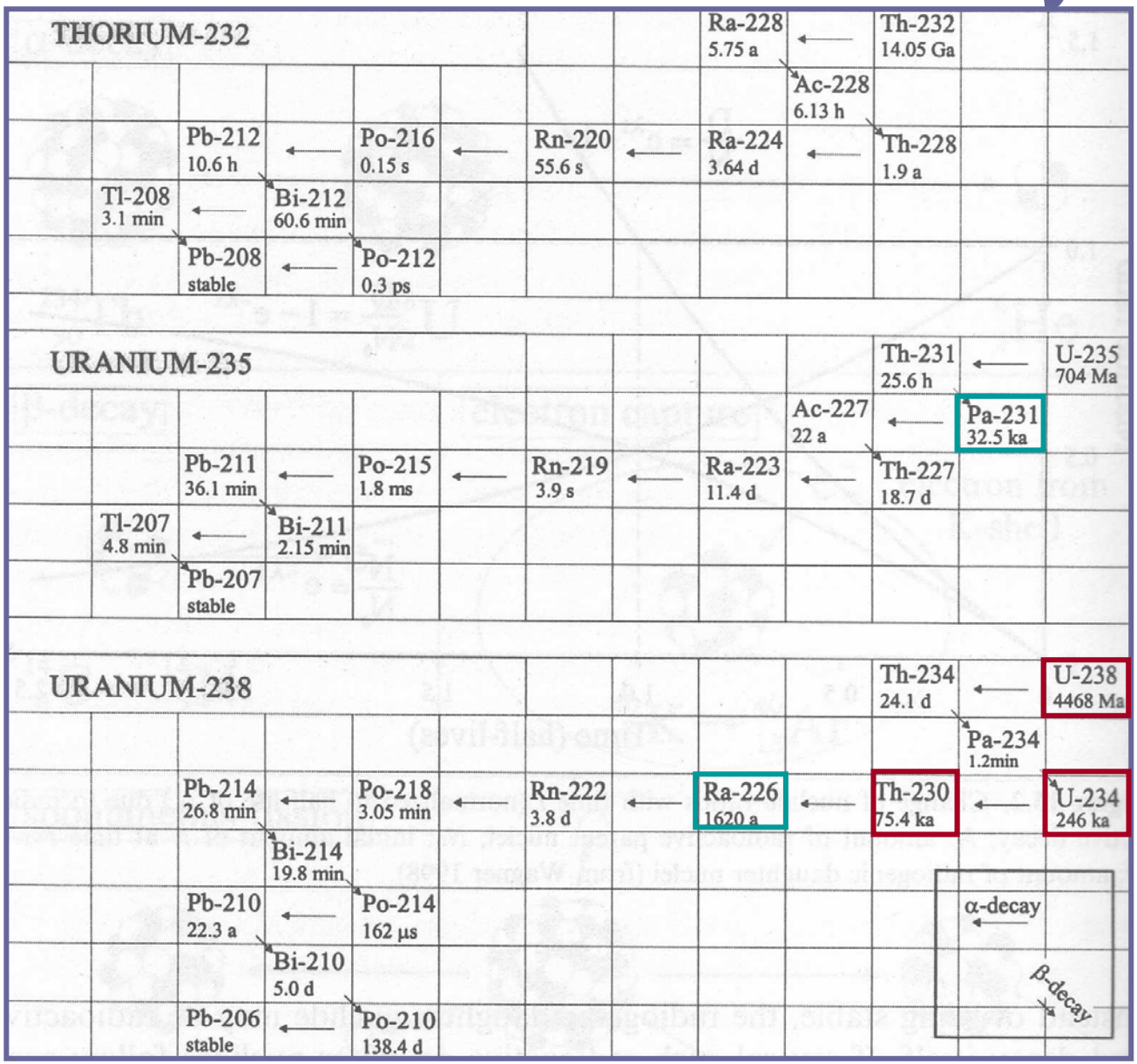
3-6: Uranium Thorium dating

While radiocarbon dating is limited to about <50 000 y and the ^{40}K-^{40}Ar dating method is limited to volcanic material and also used to be limited to samples of more than 100 000 y of age, the Uranium Thorium method is an alternative approach to extend the radiocarbon dating range to 1 000 000 y in time.



Uranium Thorium decay chains



Four natural decay chains; the ^{238}U decay chain seems suitable for age determination.

^{238}U

$T_{1/2}=4.47\cdot10^{9}y$

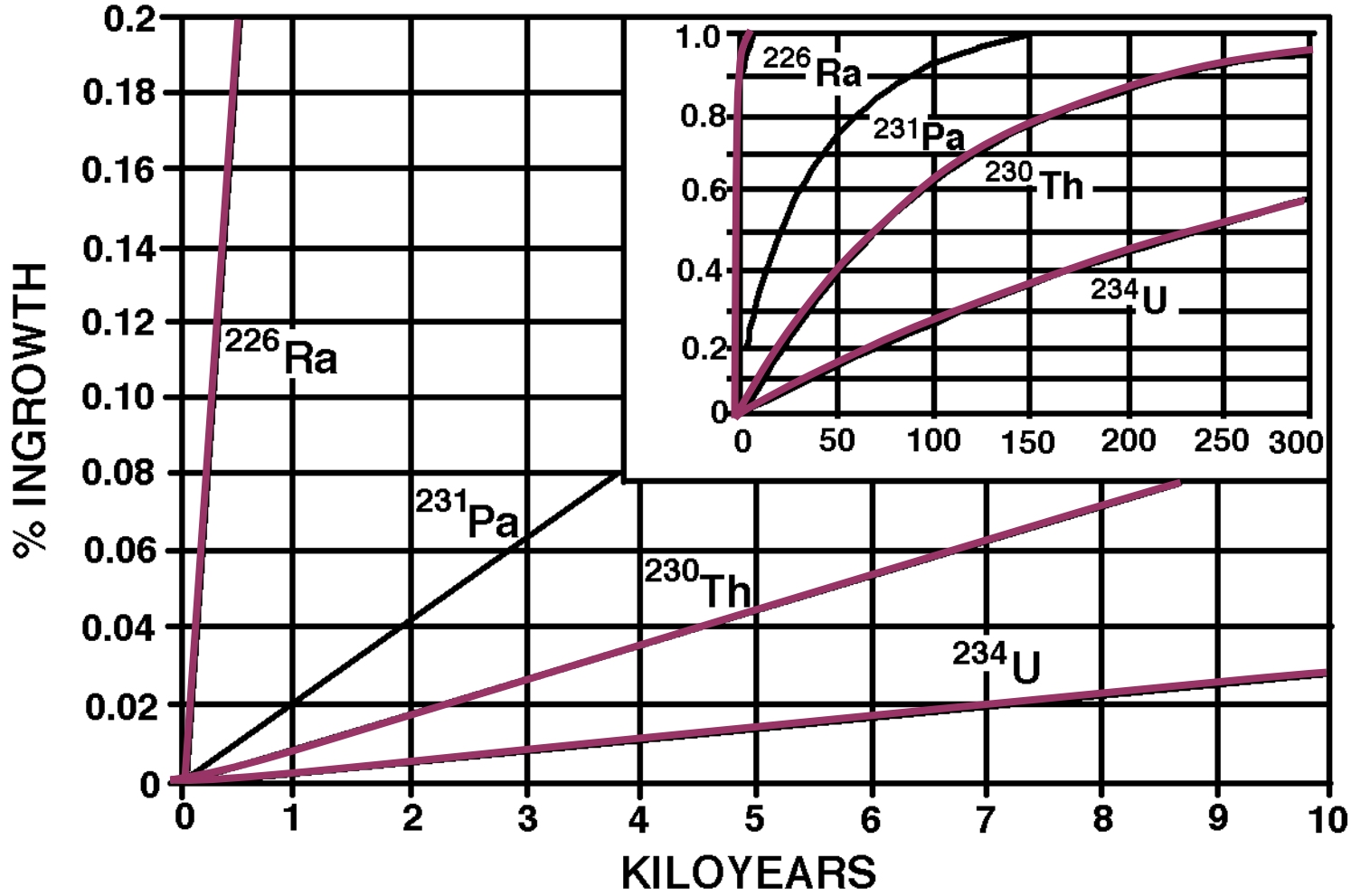
^{234}U

$T_{1/2}=2.46\cdot10^{5}y$

^{230}Th

$T_{1/2}=7.54\cdot10^{4}y$

The growth of daughter isotopes



Over the natural abundance (e.g. 0.005% for ^{234}U)

Uranium-Thorium clockwork

Uranium-Thorium dating is an absolute dating technique which uses the properties of the radio-active half-life of the two alpha emitters ^{238}U and ^{230}Th. The half-life of ^{238}U is $T_{1/2}$=4,470,000,000 y. The half-life of ^{230}Th is comparably short, only $T_{1/2}$=75,380 y. When the amounts of uranium and thorium are compared an accurate estimation of the age of an object can be obtained. This method can only be applied to objects which initially had no ^{230}Th content.

$$\frac{^{230}Th}{^{238}U} = (1 - e^{-\lambda_{230} \cdot t}) + \frac{\lambda_{230}}{\lambda_{230} - \lambda_{234}} \cdot \left(\frac{^{234}U}{^{238}U} - 1 \right) \cdot \left(1 - e^{-(\lambda_{230} - \lambda_{234}) \cdot t} \right)$$

Daughter Activities I

If a radioactive isotope N_1 decays to a radioactive daughter isotope N_2 the emerging abundances depend on the decay constants λ_1 and λ_2.

$$N_2(t) = N_1(t=0) \cdot \frac{\lambda_1}{\lambda_2 - \lambda_1} \cdot \left(e^{-\lambda_1 \cdot t} - e^{-\lambda_2 \cdot t} \right)$$

If the parent is very long-lived: $\lambda_1 << \lambda_2$.

$$N_2(t) \approx N_1(t=0) \cdot \frac{\lambda_1}{\lambda_2} \cdot \left(1 - e^{-\lambda_2 \cdot t} \right)$$

$$with \quad N_1(t=0) \approx N_1(t)$$

Example of Growth

Assume you have 1 g of ^{238}U,
calculate the amount of ^{234}U after 100,000 years

^{238}U
$T_{1/2}=4.47\cdot10^{9}y$

^{234}U
$T_{1/2}=2.46\cdot10^{5}y$

^{230}Th
$T_{1/2}=7.54\cdot10^{4}y$

$$N_{^{234}U}(t) \approx N_{^{238}U}(t)\cdot\frac{\frac{\ln 2}{4.47\cdot10^{9}}}{\frac{\ln 2}{2.46\cdot10^{5}}}\cdot\left(1-e^{-\frac{\ln 2}{2.46\cdot10^{5}}\cdot t}\right)$$

$$N_{^{234}U}(t) \approx N_{^{238}U}(t)\cdot\frac{2.46\cdot10^{5}}{4.47\cdot10^{9}}\cdot\left(1-e^{-\frac{\ln 2}{2.46\cdot10^{5}}\cdot t}\right)$$

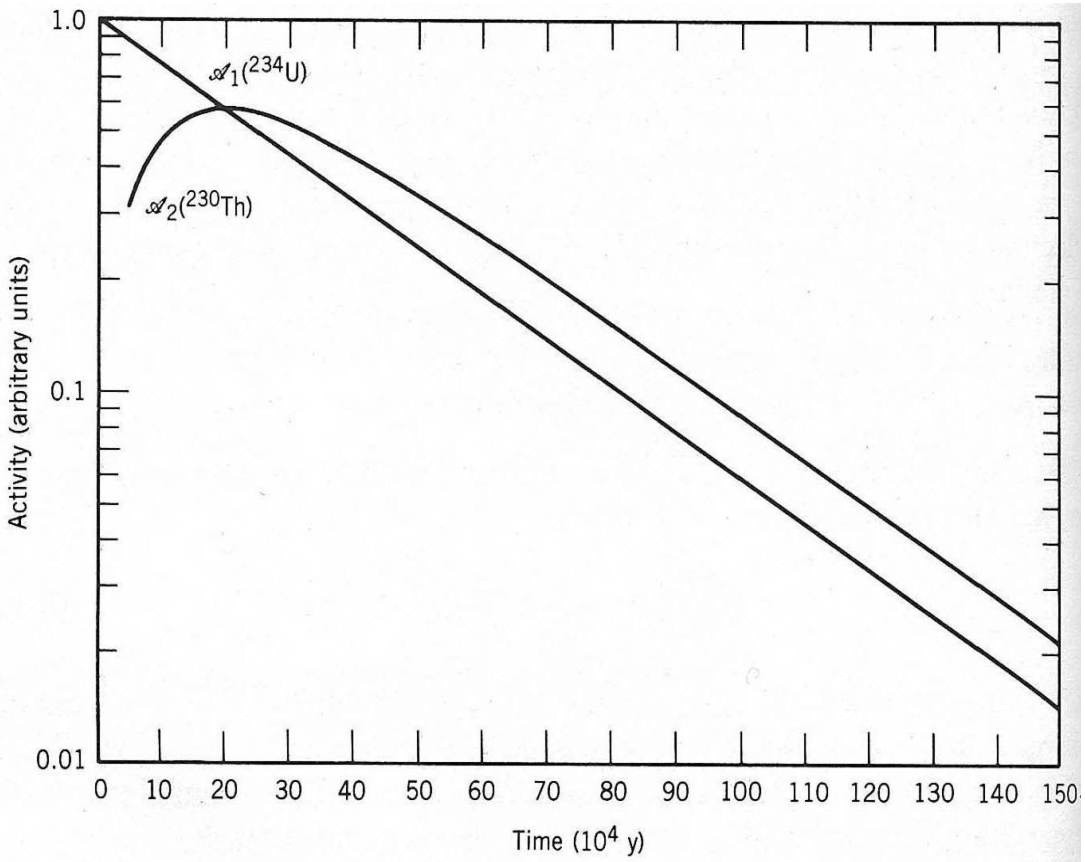
$$1g \quad {}^{238}U \equiv \frac{6.023\cdot10^{23}}{238} \equiv 2.53\cdot10^{21}$$

$$N_{^{234}U}(t) \approx 2.53\cdot10^{21}\cdot\frac{2.46\cdot10^{5}}{4.47\cdot10^{9}}\cdot\left(1-e^{-\frac{\ln 2}{2.46\cdot10^{5}}\cdot 100000}\right) = 3.41\cdot10^{16}$$

Daughter Activities II

If the parent is longer lived: $\lambda_1 < \lambda_2$.

$$N_2(t) \approx N_1(t) \cdot \frac{\lambda_1}{\lambda_2} \cdot \left(1 - e^{-(\lambda_2 - \lambda_1)\cdot t}\right)$$



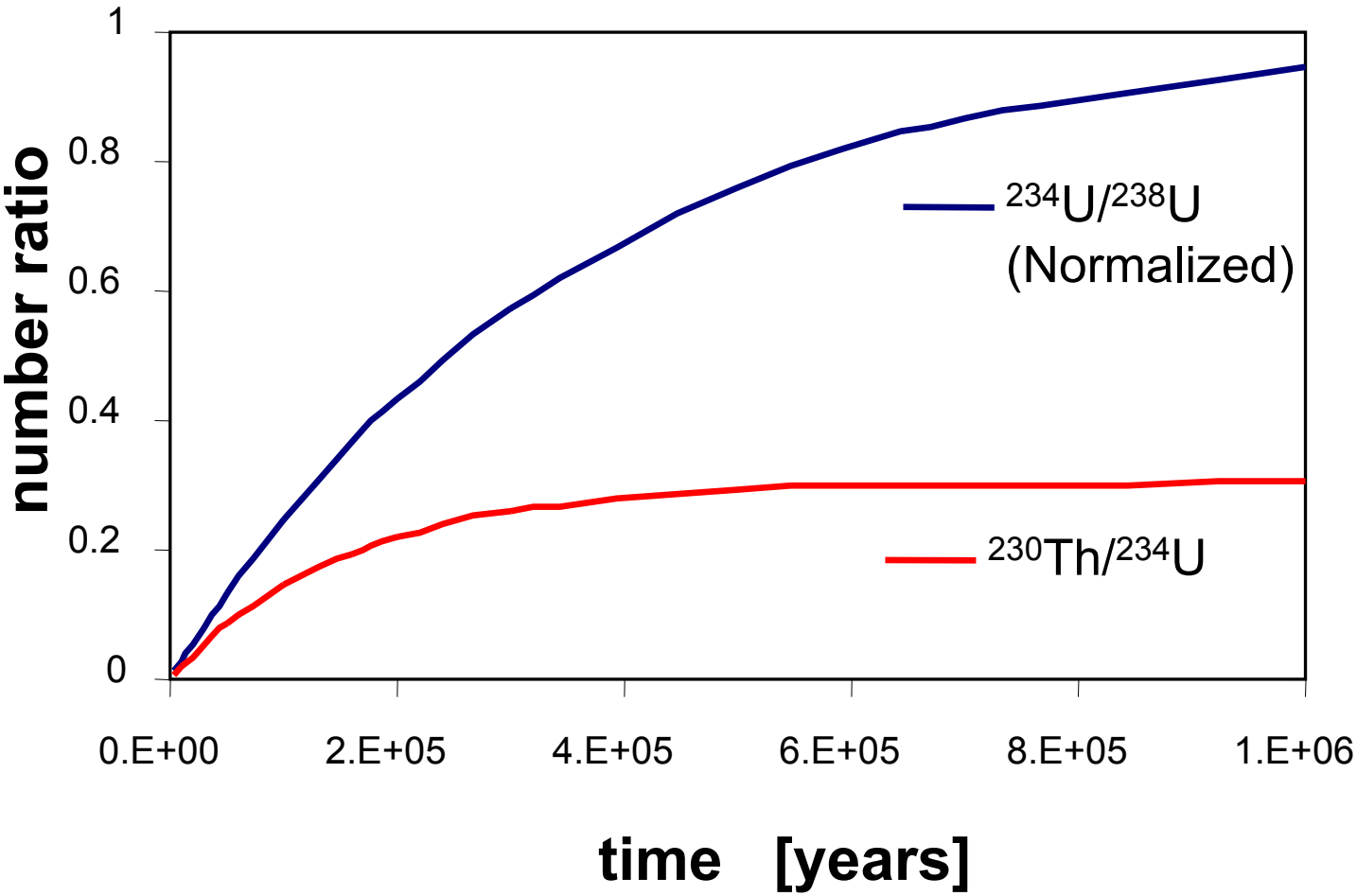
Ratio N_2/N_1 reaches an equilibrium value!
$^{230}Th/^{234}U \approx 0.3$

$$A = \lambda \cdot N$$

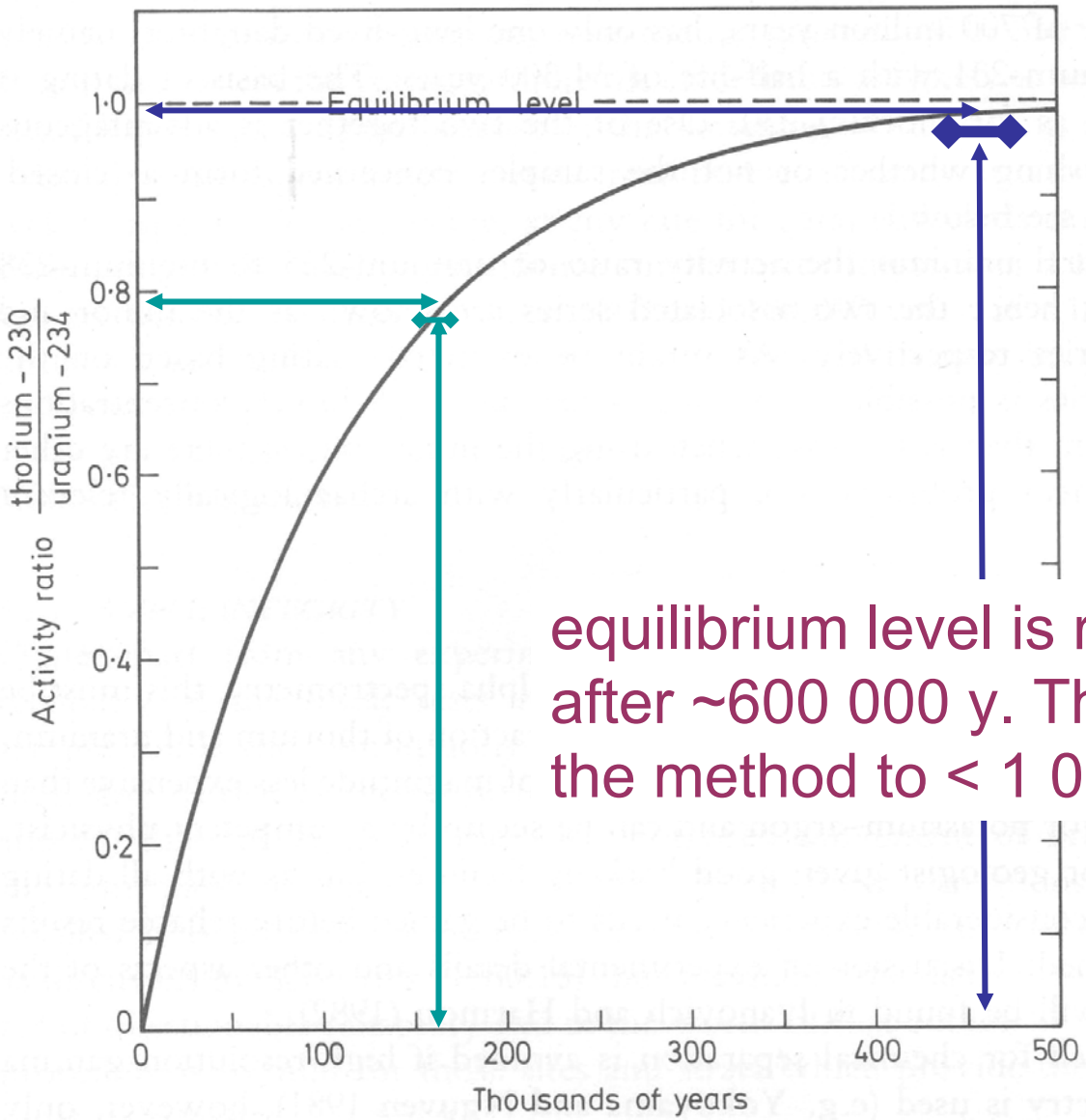
$$\frac{A(^{230}Th)}{A(^{234}U)} = \frac{\lambda_{230}}{\lambda_{234}} \cdot \frac{N(^{230}Th)}{N(^{234}U)}$$

$$\frac{A(^{230}Th)}{A(^{234}U)} = 3.26 \cdot \frac{N(^{230}Th)}{N(^{234}U)}$$

Number Ratio for Thorium and Uranium Isotopes



Equilibrium between U & Th Activities



$^{230}Th/^{234}U=0.8$
→ ~160 000±5000 y

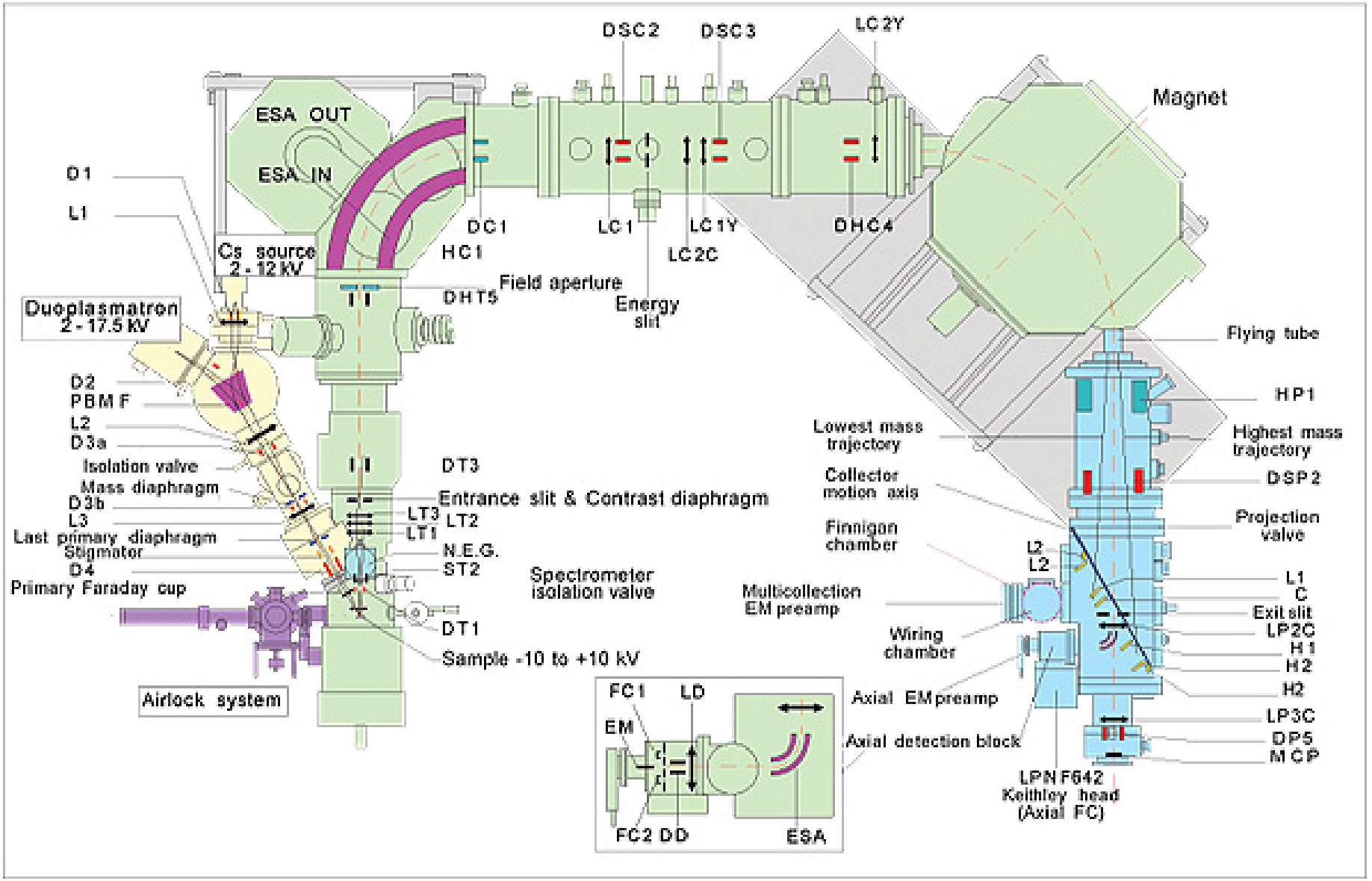
$^{230}Th/^{234}U=0.98$
→ ~460 000±50 000 y

equilibrium level is reached after ~600 000 y. This limits the method to < 1 000 000 y.

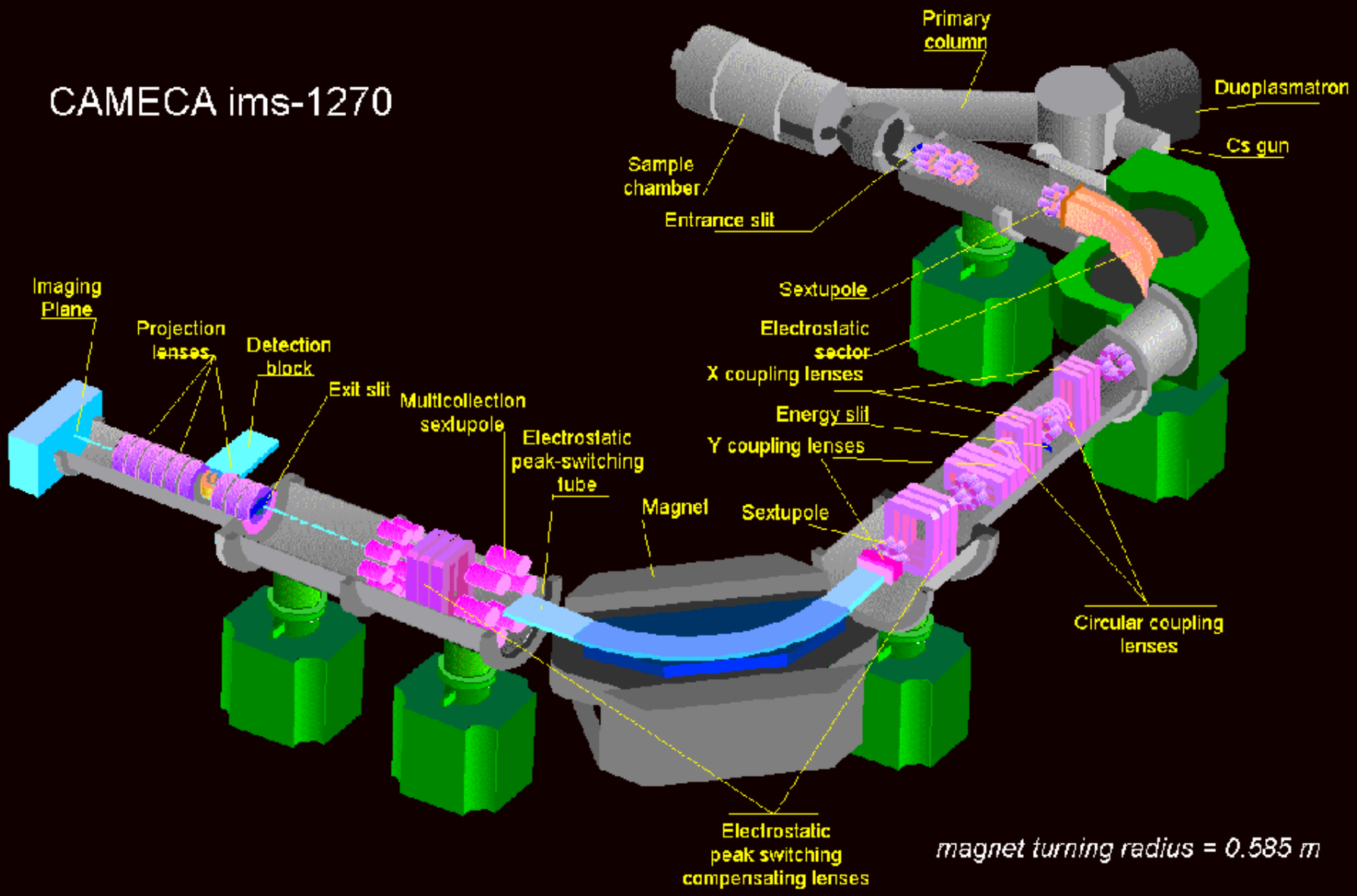
Analyzing Technique

There are various procedures which can be used with this dating technique. Until the mid 80ties alpha activity counting was used. Subsequent to that Th/U mass spectrometry was used which allowed higher sensitivity by mass separating the ^{238}U, ^{234}U and the ^{230}Th atoms from chemically prepared sample. Processes are Isotope Dilution Mass Spectrometry (IDMS), Secondary Ion Mass Spectrometry (SIMS) and IDMS-Thermal Ionization Mass Spectrometry (TIMS). For any process there must be correction for Thorium-232, the common thorium which is not radioactive. Alternative method is gamma counting of ^{238}U, ^{234}U and ^{230}Th ($E_\gamma \approx 50$-60 keV) This method has the advantage that no pre-treatment of sample is requires, but the counting efficiency is low 1%-10%.

Ion microprobes



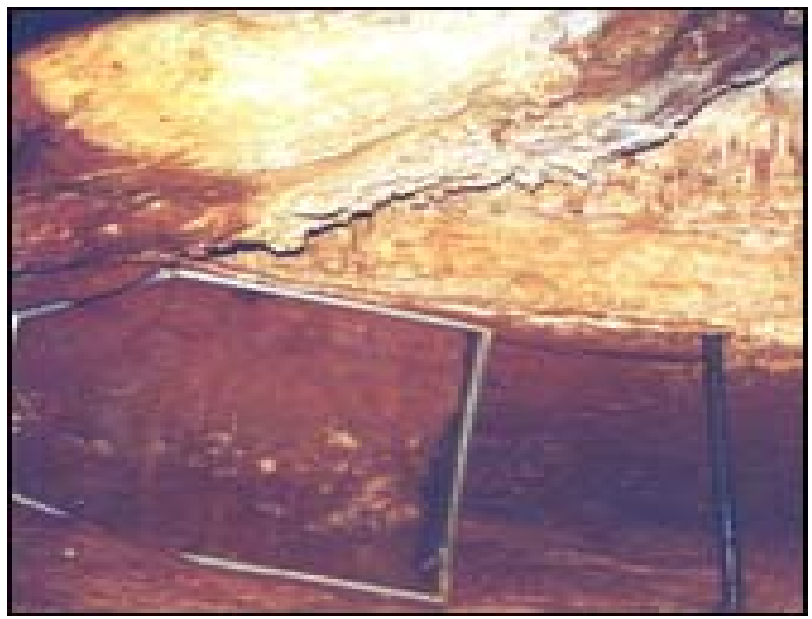
Commercial Instruments



Out of Africa

Example 1: Multi-regional or Mono-regional Evolution?

New age estimates on China's "Nanjing Man" (classified as *Homo erectus*) scientists believe the fossils are around 600,000 years old. This is approximately 200,000 years older than originally thought. The dates are based on uranium/thorium dates on rocks above and below the fossils. The new dates indicate that migration of *Homo Erectus* from Africa to China began earlier than originally thought. Supporters of the multi-regional evolution hypothesis of modern human (*Homo Sapiens*) origins are indicating that the new dates support their hypothesis.



Reliability and impact of data?

Scientists dated rock material below and above site. Previous U-Th dating (alpha counting) was done on tooth and bone material it yielded 380 000 y with large uncertainties ±150 000 y!

Previous theory was that early homo erectus was driven to extinction by homo sapiens immigrating out of Africa around 200 000 y ago. New data indicate that they may not have met (or the eastern homo erectus may have had more time to evolve.

Uranium in Bone and Rock

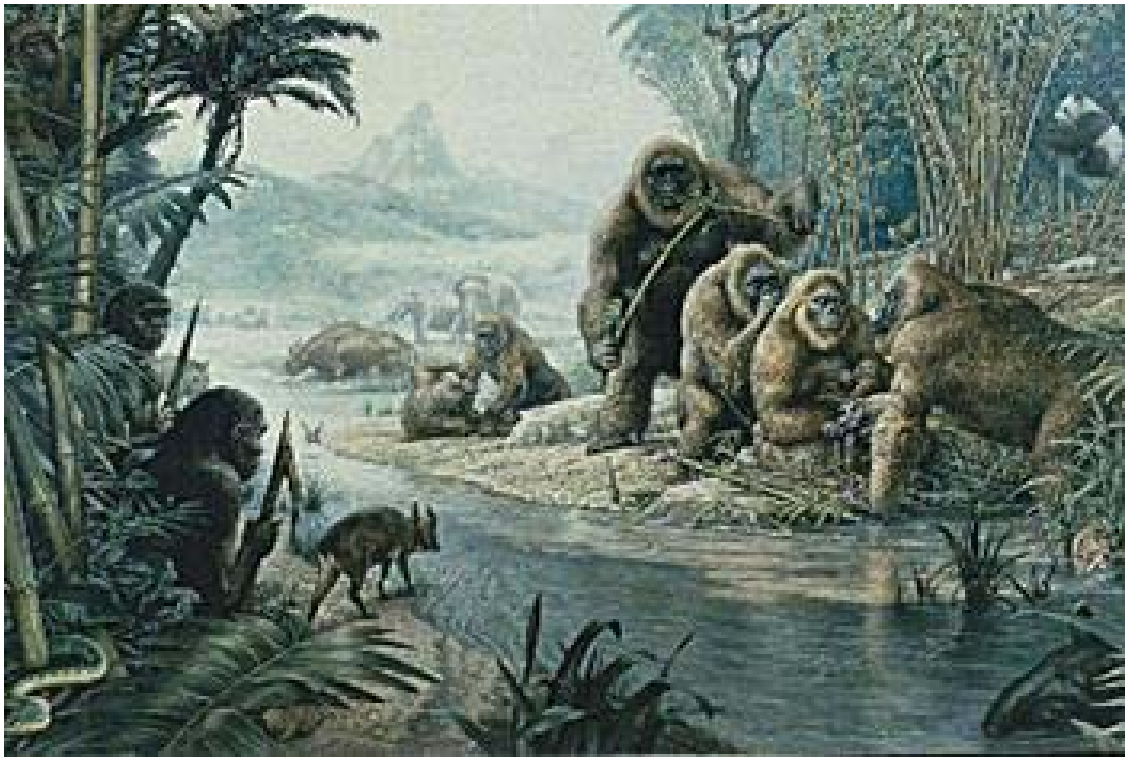
Reliable dating requires appreciable amount of initial ^{238}U in sample material!

Living bone: <0.1 ppm
Fossil bone: 1-1000 ppm

Enrichment through rapid ground water absorption during exposure. No absorption of ^{230}Th, thorium is insoluble in water. This can be checked with long-lived ^{232}Th ($T_{1/2}=1.4 \cdot 10^{10}$ y)! Enrichment rate may cause uncertainties for age determination.

Rock dating is based on constant ^{238}U abundance values (environmental independent) for specific rock species. Mostly used for stalagmite dating (formed of Ca rich water with ~1000 ppm ^{238}U content)

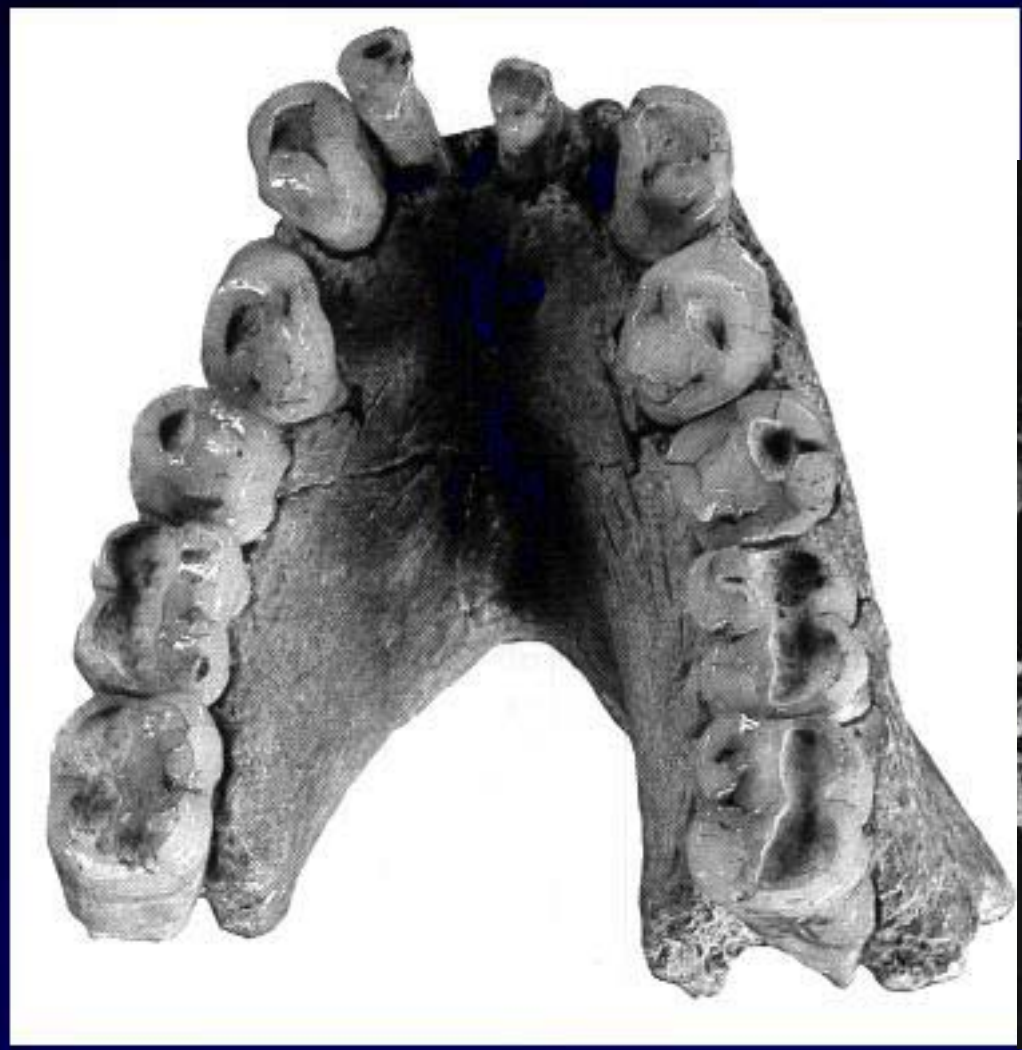
Example 2: Gigantopithecus meets Homo Erectus



Gigantopithecus appeared in the fossil record about 6.3 million years ago and thrived in Southeast Asia for five and half million years. Early humans, *Homo erectus*, spread into Giganto's territory about 800,000 years ago. Within half a million years of the arrival of these early humans, Giganto had gone extinct. Is there scientific evidence of interaction?

Contact with Humans

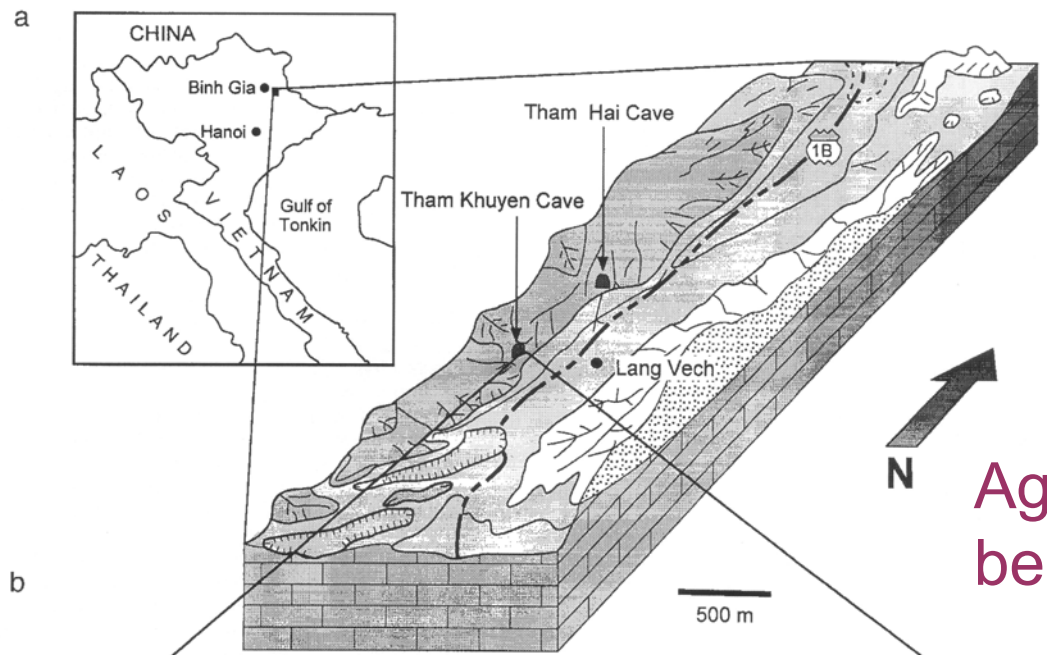
Jaw of *Gigantopithecus*, a 6-million-year-old ape from China. *Gigantopithecus* was the largest ape ever known, but how it's related to other apes isn't clear.

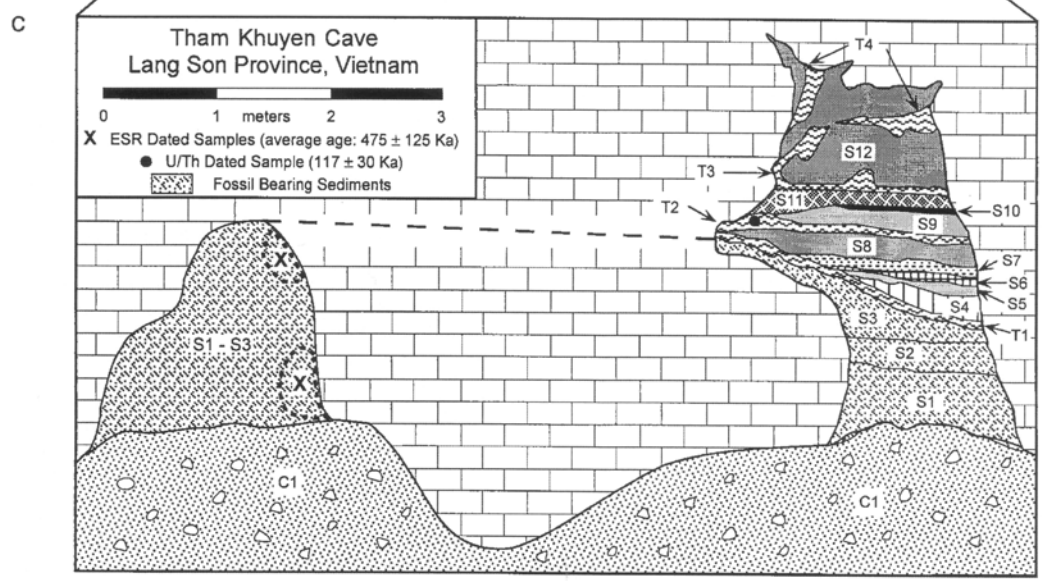


Habitat in South East Asia

Limestone tower at Liucheng was site for three jaw bones and > 1000 teeth.

Recent findings in Tham Khuyen Cave in Vietnam





accumulations through fluvial processes.

Age of specimens in cave has been determined to 475±125 ky

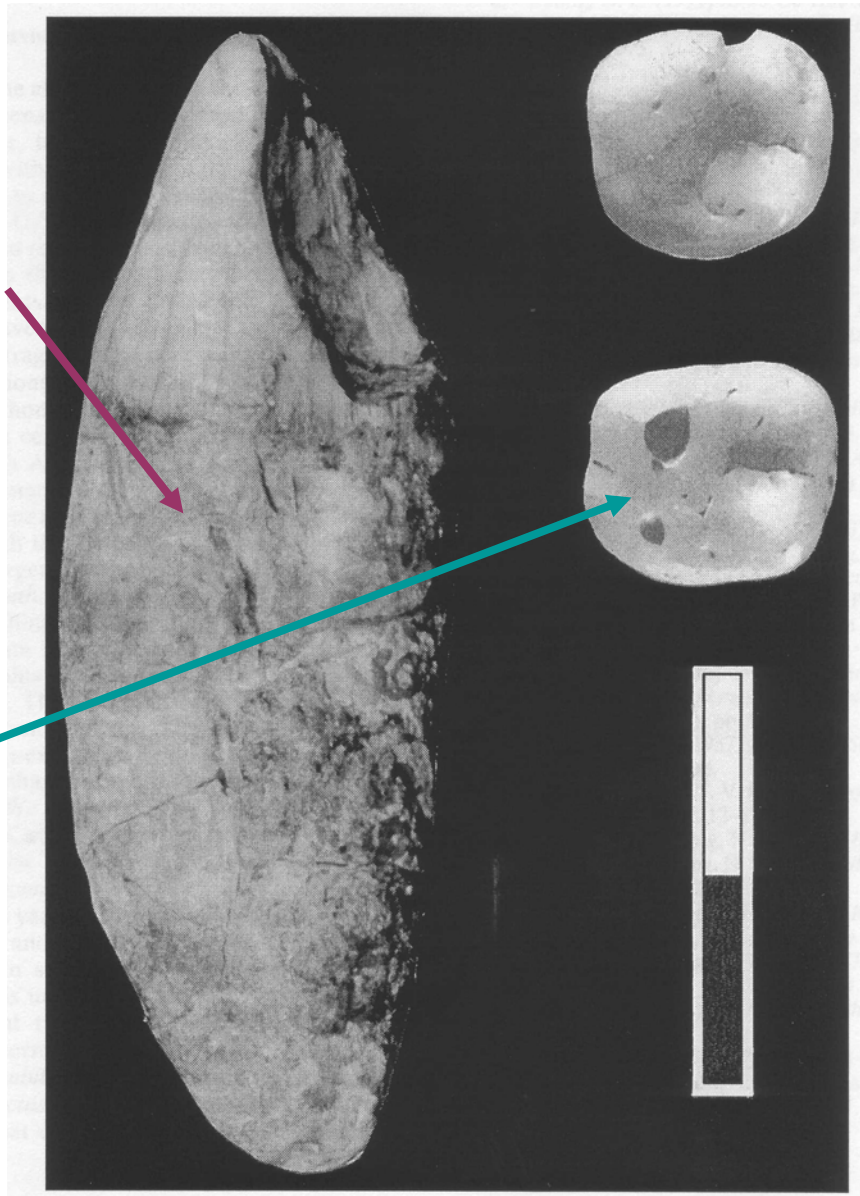
Hominoids are ~ 5% of ~2000 specimens. mostly teeth (difficulty to distinguish human teeth from teeth of extinct species *Pongo Pygmaeus)*

Big tooth, small teeth

Gigantopithecus canine

homo erectus molars

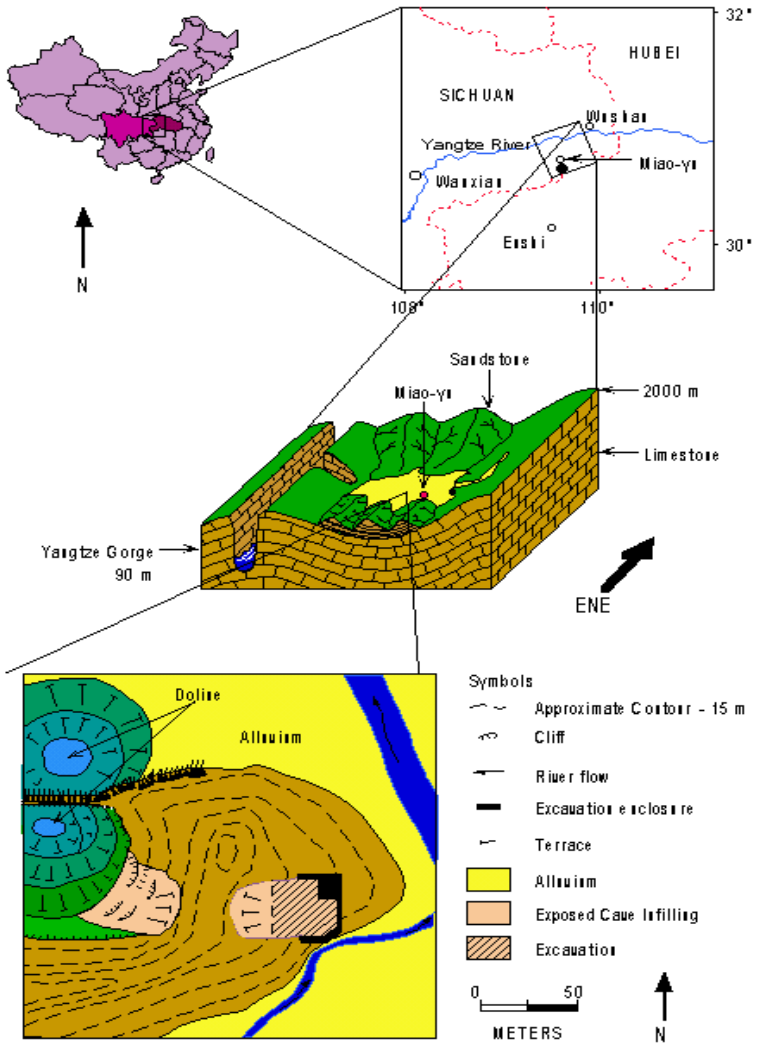
both are dated to 475 000 y !

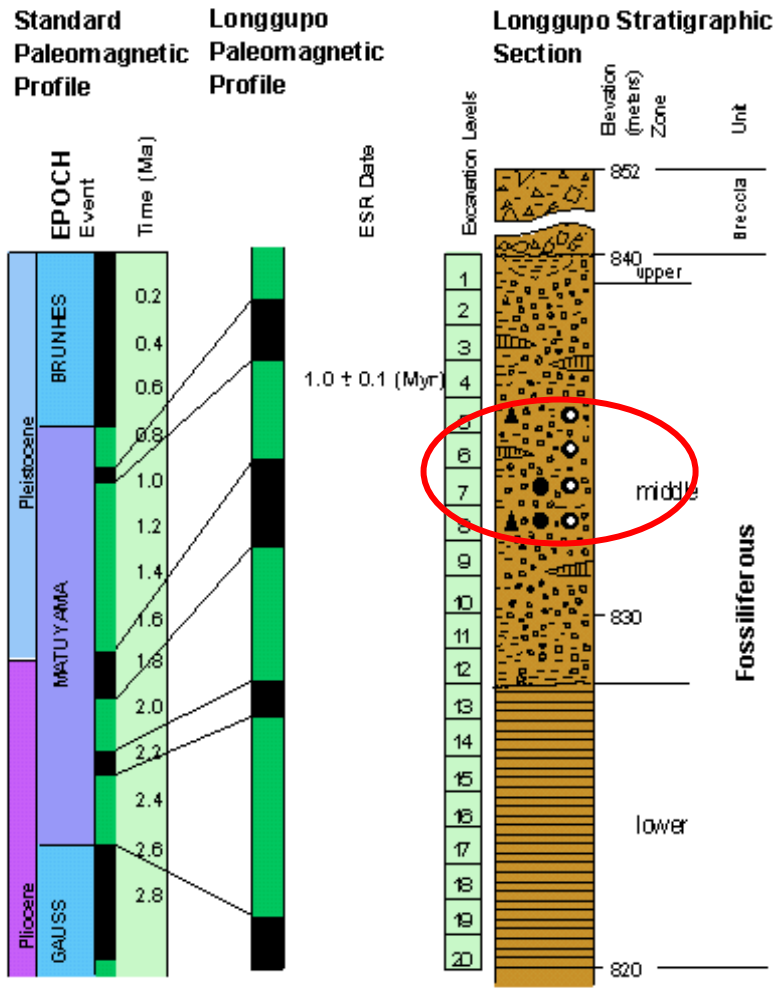


This result of 475 ky age, together with similar find at Longgupo cave dated to 1.5 My age gives clear evidence that Gigantopithecus & homo erectus co-existed in South East Asia through the early and the middle Pleistocene for more than a million years.

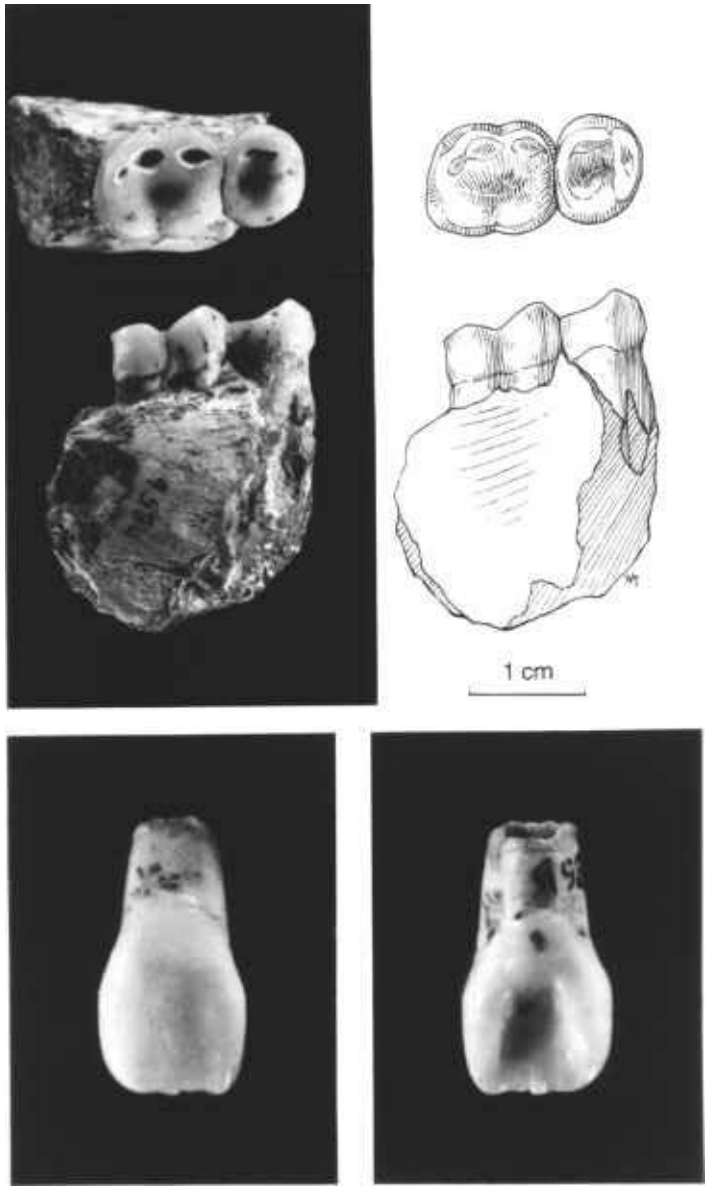
Coexistence Model between Gigantopithecus & Homo Erectus?

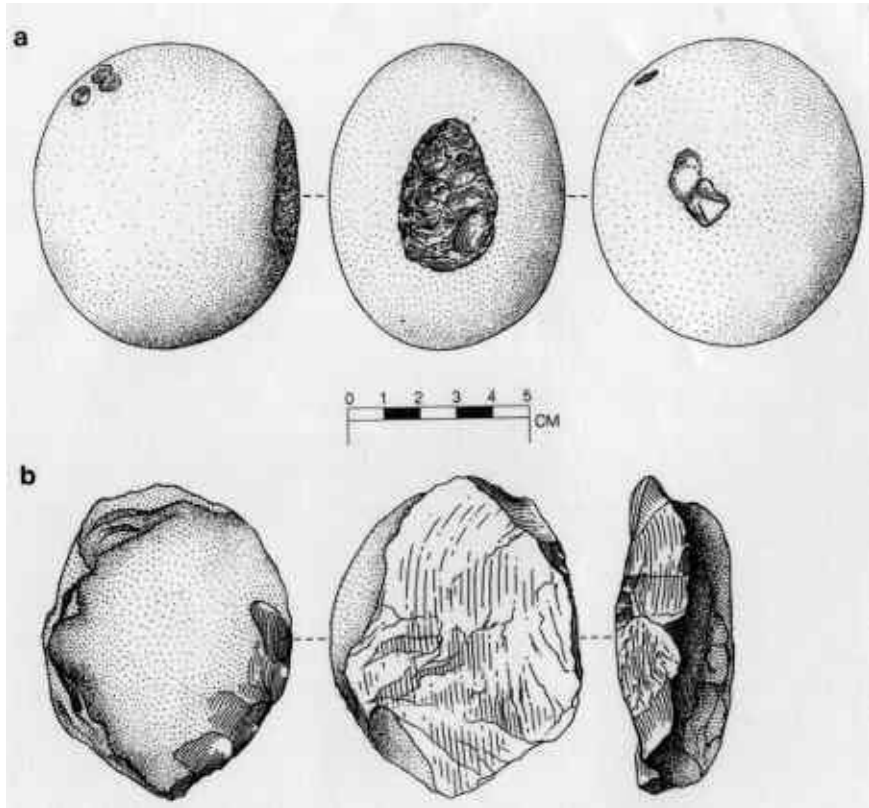
Findings in the Longgupo Cave, China





fossils and tools





Age comparable to Olduvai fossils; did homo erectus originate from Asia or did he immigrate from Africa?

Early Routes from Africa