5.3. 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

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

$^{238}$U

$T_{1/2}=4.47 \cdot 10^9$ y

$^{234}$U

$T_{1/2}=2.46 \cdot 10^5$ y

$^{230}$Th

$T_{1/2}=7.54 \cdot 10^4$ y
The growth of daughter isotopes

Over the natural abundance (e.g. 0.005% for $^{234}\text{U}$)
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 $^{238}\text{U}$ and $^{230}\text{Th}$. The half-life of $^{238}\text{U}$ is $T_{1/2}=4,470,000,000$ y. The half-life of $^{230}\text{Th}$ 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 $^{230}\text{Th}$ content.

\[
\frac{^{230}\text{Th}}{^{238}\text{U}} = (1 - e^{-\lambda_{230} \cdot t}) + \\
+ \lambda_{230} \cdot \left( \frac{^{234}\text{U}}{^{238}\text{U}} - 1 \right) \cdot \left( 1 - e^{-(\lambda_{230} - \lambda_{234}) \cdot t} \right)
\]
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 $\lambda_1$ and $\lambda_2$.

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

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

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

with $N_1(t = 0) \approx N_1(t)$
Example of Growth

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

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

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

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

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

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

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

$$N_{234\text{U}}(t) \approx 2.53\cdot10^{21} \cdot \frac{2.46\cdot10^5}{4.47\cdot10^9} \cdot \left(1 - e^{-\frac{\ln 2}{2.46\cdot10^5}\cdot100000}\right) = 3.41\cdot10^{16}$$
If the parent is longer lived: $\lambda_1 < \lambda_2$.

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

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

$$A = \lambda \cdot N$$

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

$$\frac{A(^{230}\text{Th})}{A(^{234}\text{U})} = 3.26 \cdot \frac{N(^{230}\text{Th})}{N(^{234}\text{U})}$$
Number Ratio for Thorium and Uranium Isotopes

![Graph showing the number ratio for Thorium and Uranium isotopes over time. The graph includes two curves: one for $^{234}\text{U}/^{238}\text{U}$ (Normalized) and another for $^{230}\text{Th}/^{234}\text{U}$. The x-axis represents time in years, ranging from 0 to 1 million years. The y-axis represents the number ratio, ranging from 0 to 1. The $^{234}\text{U}/^{238}\text{U}$ curve starts at a lower ratio and increases gradually, while the $^{230}\text{Th}/^{234}\text{U}$ curve starts at a higher ratio and remains relatively flat.]
Equilibrium between U & Th Activities

\[ ^{230}\text{Th} / ^{234}\text{U} = 0.8 \rightarrow \sim 160,000 \pm 5000 \text{ y} \]

\[ ^{230}\text{Th} / ^{234}\text{U} = 0.98 \rightarrow \sim 460,000 \pm 50,000 \text{ y} \]

equilibrium level is reached after \( \sim 600,000 \text{ y} \). This limits the method to \( < 1,000,000 \text{ y} \).
Analyzing Technique

There are various procedures which can be used with this dating technique. Until the mid 80\textsuperscript{ies} alpha activity counting was used. Subsequent to that Th/U mass spectrometry was used which allowed higher sensitivity by mass separating the $^{238}\text{U}$, $^{234}\text{U}$ and the $^{230}\text{Th}$ 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 $^{238}\text{U}$, $^{234}\text{U}$ and $^{230}\text{Th}$ ($E_\gamma \approx 50-60$ keV) This method has the advantage that no pre-treatment of sample is requires, but the counting efficiency is low 1\%-10\%. 
Ion microprobes
Out of Africa
Multi-regional or Mono-regional Evolution?

New age estimates on China's hominid "Nanjing Man" (classified *Homo erectus*) determine that the fossils are roughly 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. The supporters of the multi-regional evolution hypothesis for the origins of the modern human (*Homo Sapiens*) indicate 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 yielding 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 $^{238}\text{U}$ in sample material!

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

Enrichment through rapid ground water absorption during exposure. No absorption of $^{230}\text{Th}$, thorium is insoluble in water. This can be checked with long-lived $^{232}\text{Th}$ ($T_{1/2}=1.4\cdot10^{10}$ y)!

Enrichment rate may cause uncertainties for age determination.

Rock dating is based on constant $^{238}\text{U}$ abundance values (environmental independent) for specific rock species. Mostly used for stalagmite dating (formed of Ca rich water with $\sim1000$ ppm $^{238}\text{U}$ content)
Gigantopithecus met Homo Erectus

*Gigantopithecus* appeared in the fossil record about 6.3 million years ago and thrived in Southeast Asia for five and a 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

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

accumulations through fluvial processes.

Hominoids are ~ 5% of ~2000 specimens mostly teeth (difficulty to distinguish human teeth from teeth of extinct species Pongo Pygmaeus)
Big tooth, small teeth

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

Gigantopithecus canine

homo erectus molars

both are dated to 475 000 y!
Tribal Memories? The Yeti

More than 1000 hits on Google, it got to exist! Is it the snow version of Gigantopithecus in hide?
A recent model of coexistence for Gigantopithecus & Homo Sapiens?
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 at an earlier time than originally thought?
2 Million Years old Human Fossil Findings
Out of Africa, more than one time?