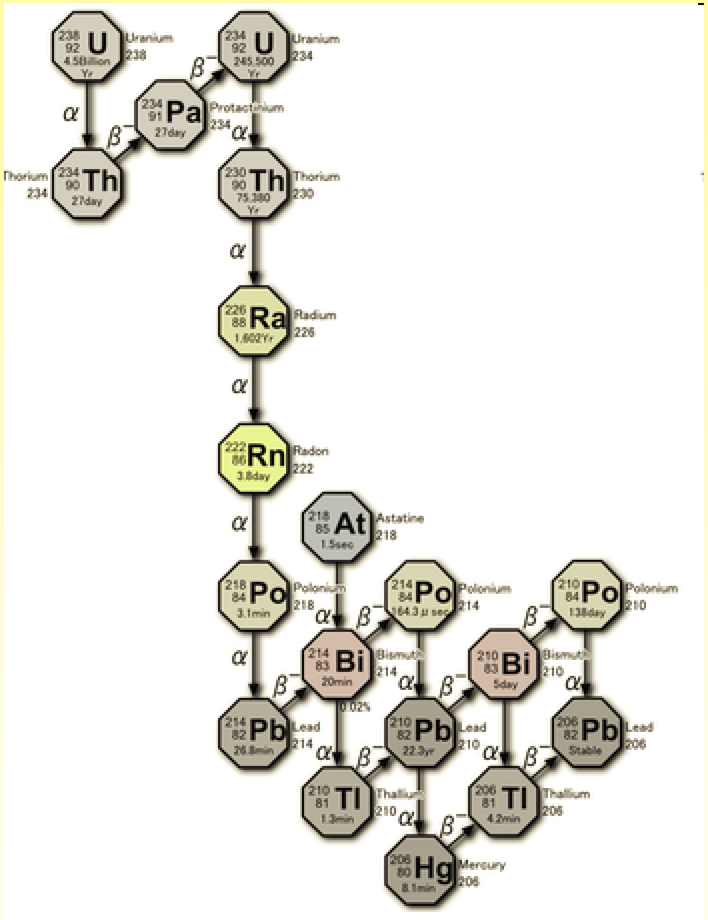
Uran-Serien-Methode(n)



Uran-Serien-Methode(n)

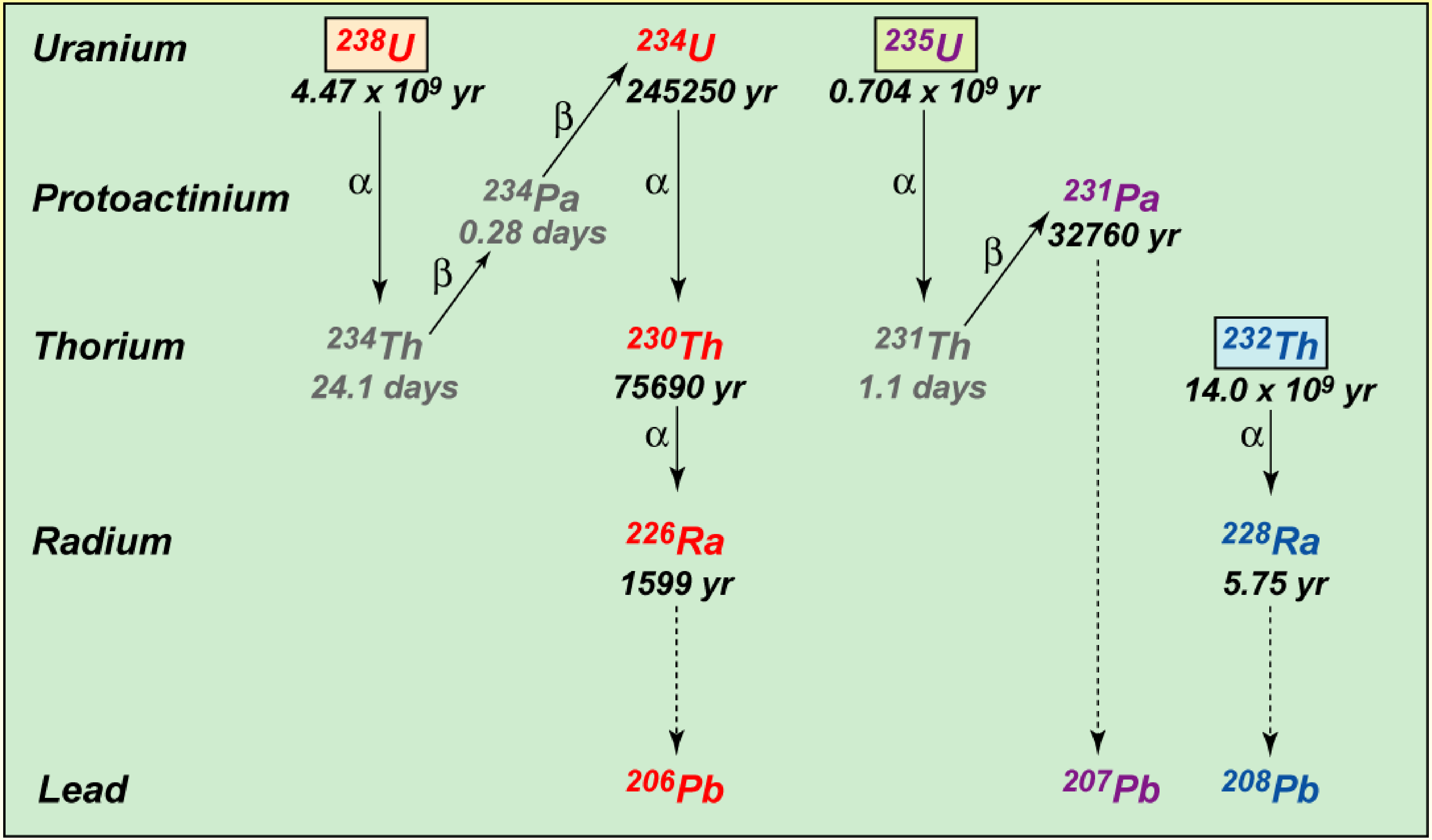
Besonderheiten

einsetzbar auf Zeitskalen (Tage!!! bis 10er kilo-Jahre), mit denen (physikalische) Prozesse quantifiziert werden können

Es wird **nicht** die Akkumulation eines stabilen Tochternuklids gemessen

Das Alter ist vielmehr eine Funktion des existierenden Ungleichgewichtes

Uran-Serien-Methode(n)



Uranium
^{238}U 4.47 x 10^9 yr
^{234}U 245250 yr
^{235}U 0.704 x 10^9 yr

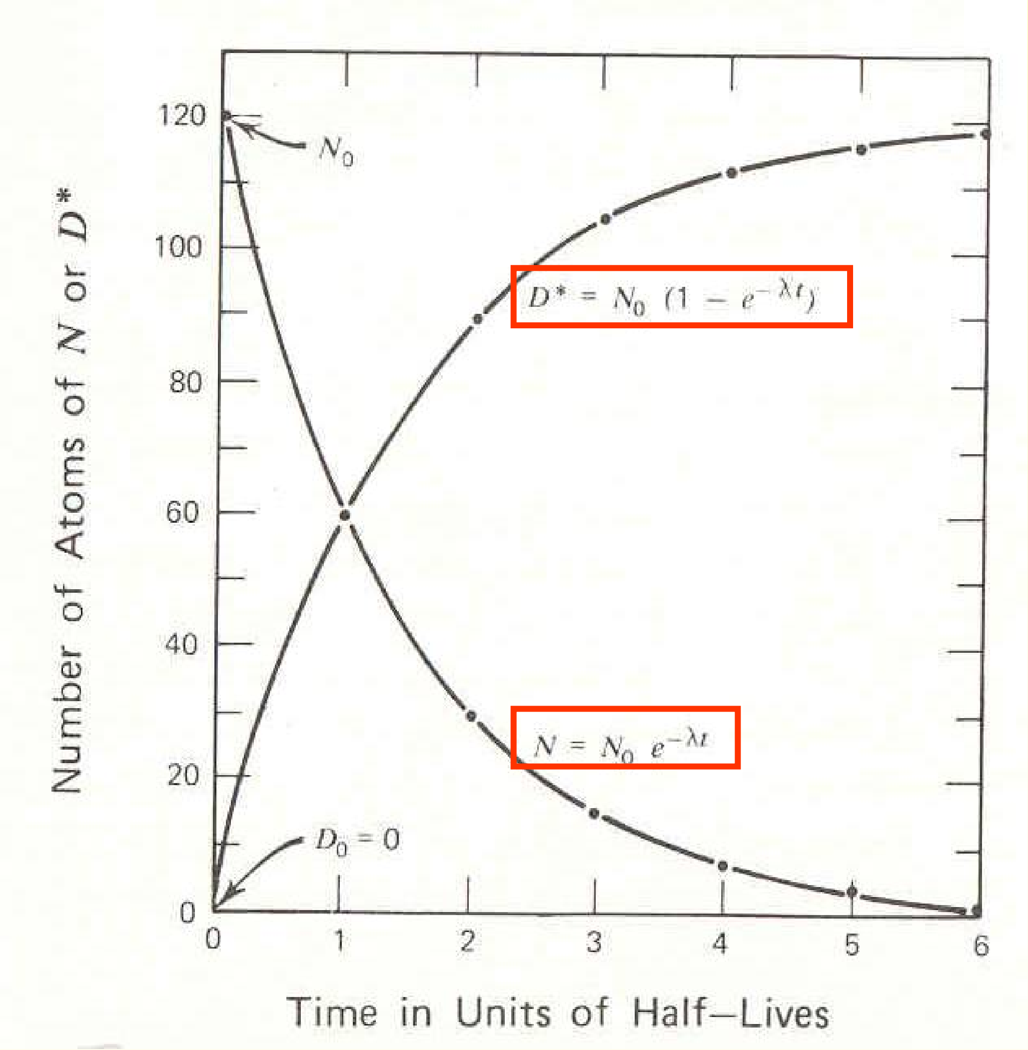
Protoactinium
^{234}Pa 0.28 days
^{231}Pa 32760 yr

Thorium
^{234}Th 24.1 days
^{230}Th 75690 yr
^{231}Th 1.1 days
^{232}Th 14.0 x 10^9 yr

Radium
^{226}Ra 1599 yr
^{228}Ra 5.75 yr

Lead
^{206}Pb
^{207}Pb
^{208}Pb

Decay of radionuclide (N) to stable radiogenic daughter (D*)



$N = N_0 e^{-\lambda t}$

$D^* = N_0 - N$

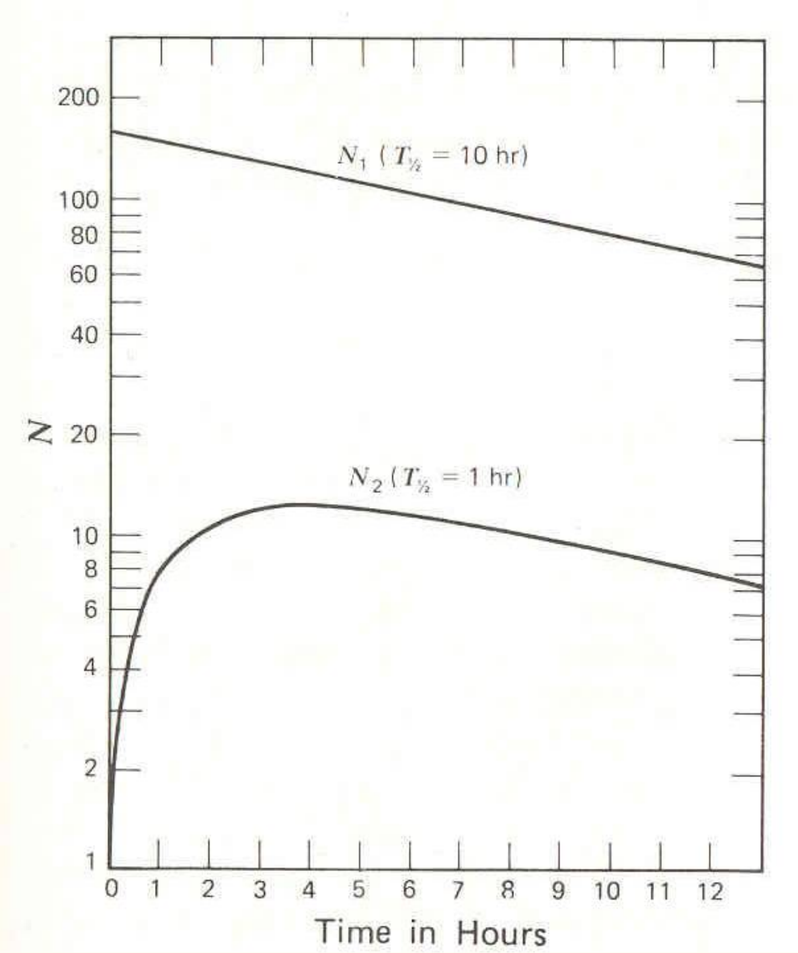
$D^* = N_0 - N_0 e^{-\lambda t}$

$D^* = N_0 (1 - e^{-\lambda t})$

$t = \ln(1 + D^*/N_0)/\lambda$

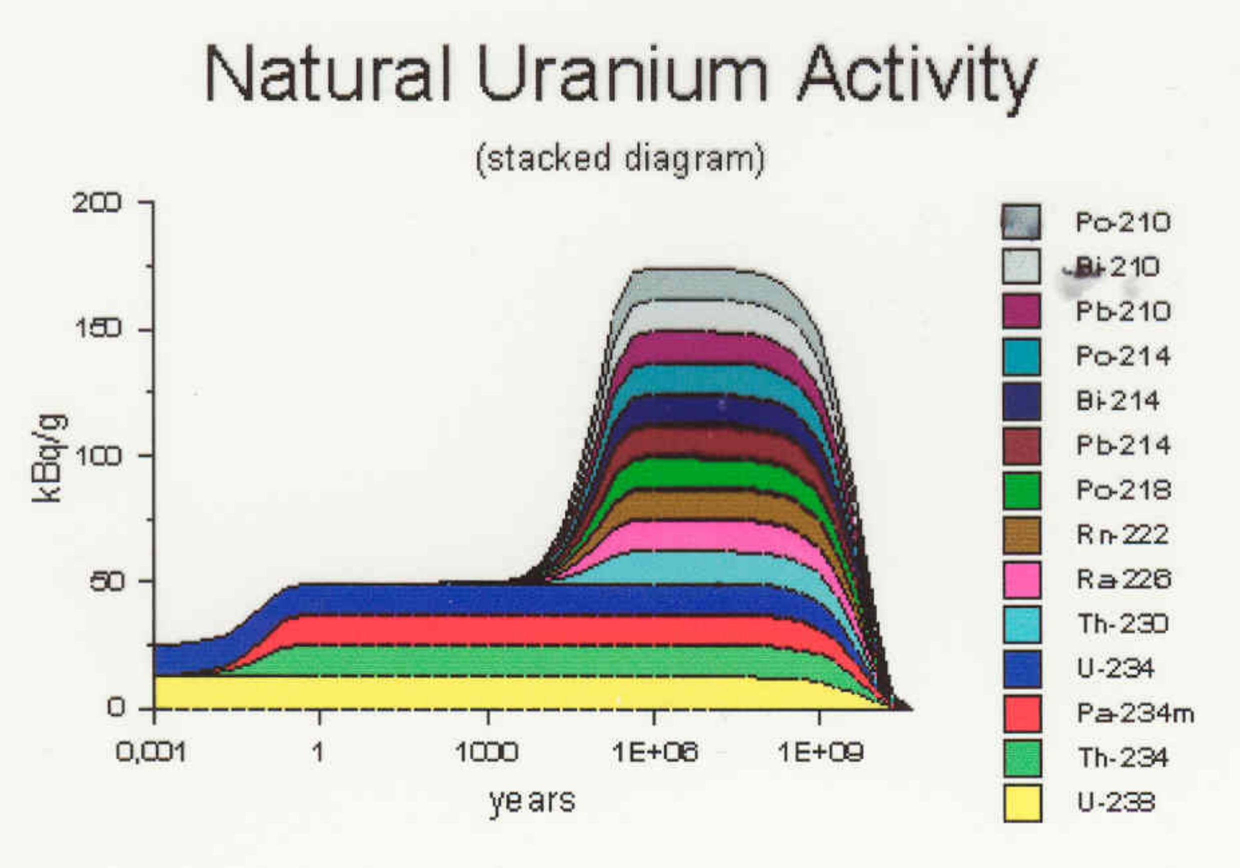
Decay series

Decay of a long-lived parent N_1 to a short lived daughter N_2
(similar to U-Pb decay-chain)

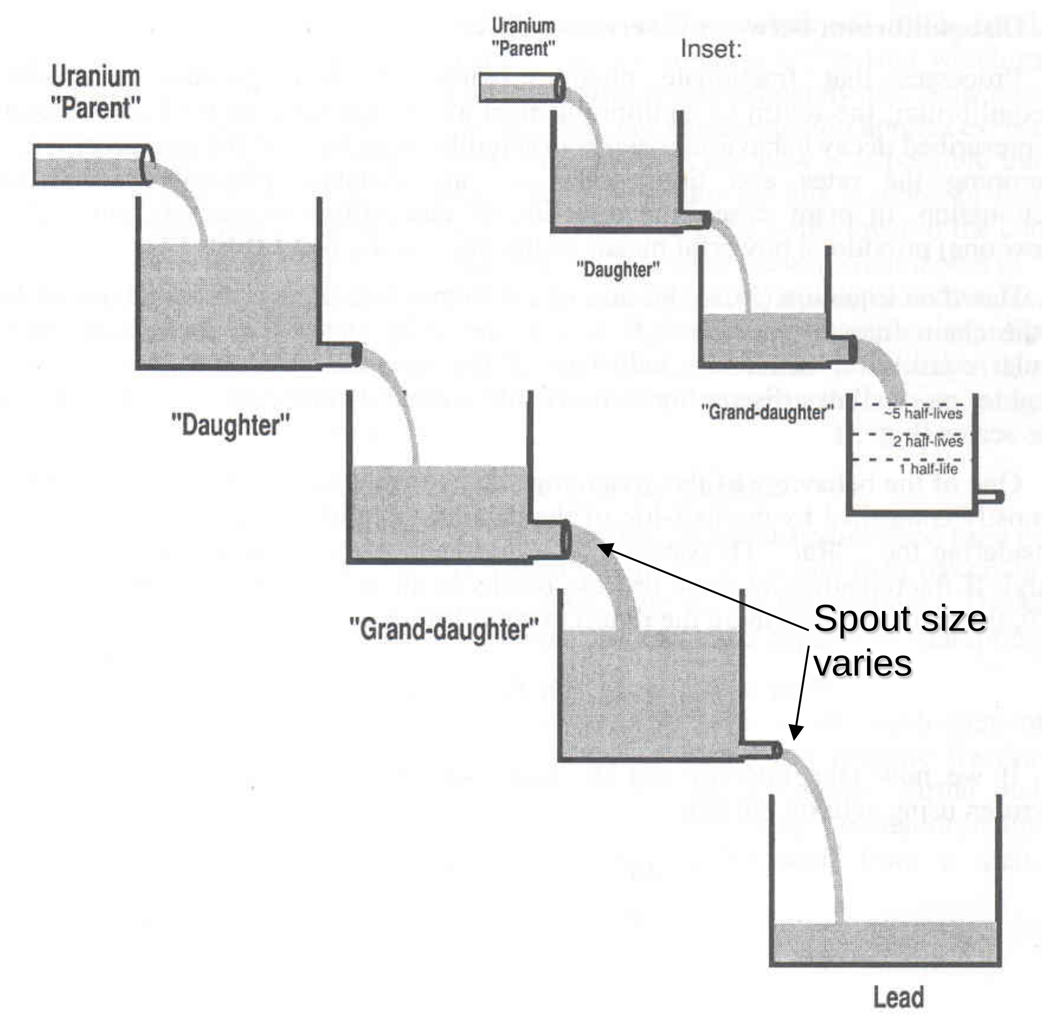


Radiochemical equilibrium is established after several half-lifes of N_2

Visualisierung



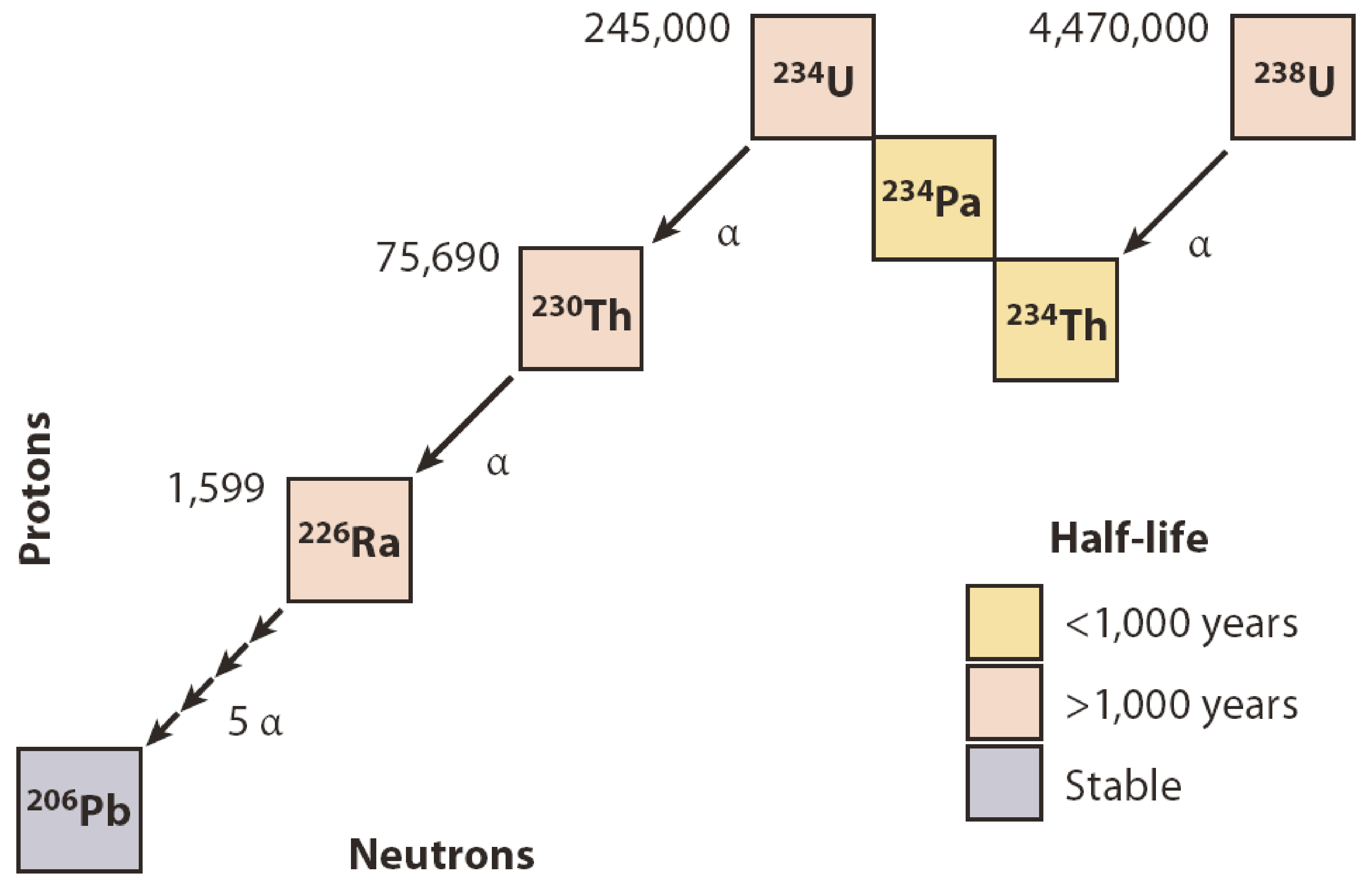
Visualisierung



Spout size varies

^{238}U Zerfallsreihe

(nur langlebige Nuklide gezeigt)



Uran-Serien-Methode(n)

- Disturbing secular equilibrium:
- **Removal of immediate daughter atoms**
  Production of new daughter atoms will continue, so the number of daughter atoms will gradually **increase** at rate determined by its half life, until secular equilibrium is restored (after about 5 half-lives).
- **Removal of immediate parent atoms**
  The amount of daughter atoms will **decrease** at rate determined by its half life until secular equilibrium is re-established with the lower abundance levels of parent atoms.
  - The daughter atoms are said to be “unsupported”. i.e. there are not enough of the parent atoms left to supply daughter atoms by decay

Uran-Serien-Methode(n)

$$\frac{dN_1}{dt} = -\lambda_1 N_1 \quad (1)$$

$$\frac{dN_i}{dt} = -\lambda_i N_i + \lambda_{i-1} N_{i-1} \quad (2)$$

If we solve Equations (1) and (2) for the first two nuclides in a decay chain, we obtain:

$$\boxed{N_1 = N_1^0 e^{-\lambda_1 t}}$$

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

General principles

Bateman equation (1910)

Für t > 10^6 a geht $e^{-\lambda 230t}$ gegen 0 bzw. $(1 - e^{-\lambda 230t})$ gegen 1,

also: $A_{230}/A_{232} = A_{238}/A_{232} \rightarrow A_{230} = A_{238}$

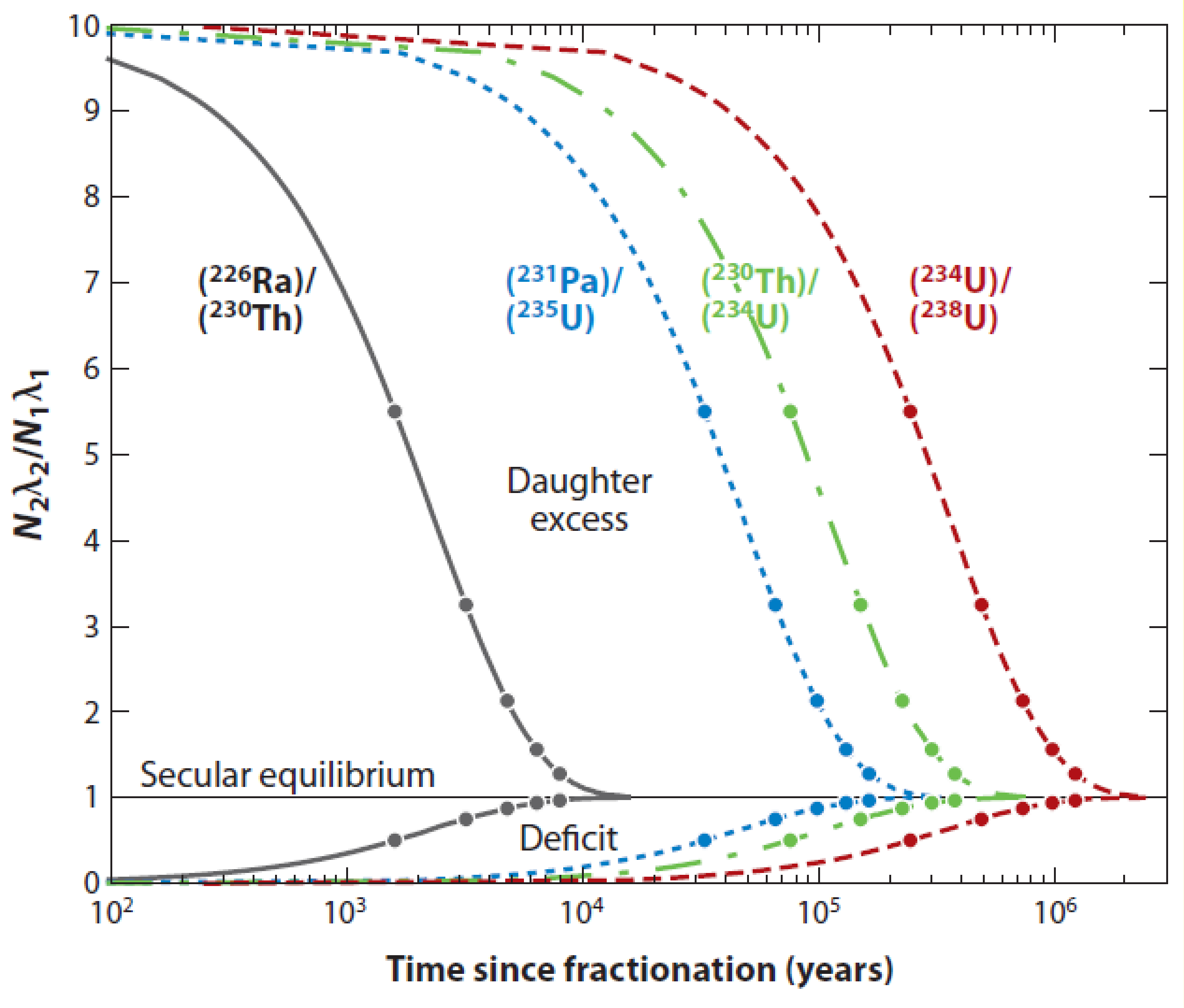
Für $t = 0$ wird $e^{-\lambda_{230}t} = 1$ und $\left(1 - e^{-\lambda_{230}t}\right) = 0$, also

$A_{230}/A_{232} = (A_{230}/A_{232})_0$.

For the s:

$$\frac{A230}{A232} = \left(\frac{A230}{A232}\right) e^{-\lambda 230t} + \left(\frac{A238}{A232}\right)(1 - e^{-\lambda 230t})$$

Activity ratios for intermediate daughter and parent pairs (^{238}U decay chain) as a function of time after disturbance



Uran-Serien-Methode(n)

- State of ***“secular equilibrium”***: $N_{238U}.\lambda_{238} = N_{234U}.\lambda_{234} = N_{230Th}.\lambda_{230} = N_{226Ra}.\lambda_{226} = \ldots.$

- BUT all of these nuclides are of different elements and will have different chemical properties, so it is possible to disturb this secular equilibrium between nuclides

Relation between activity and isotope ratio

$$für \quad \frac{A_{230}}{A_{238}} = 1 \; gilt:$$

$$\boxed{\frac{A_{230}}{A_{238}} = \frac{\lambda_{230} \times N_1}{\lambda_{238} \times N_2}}$$

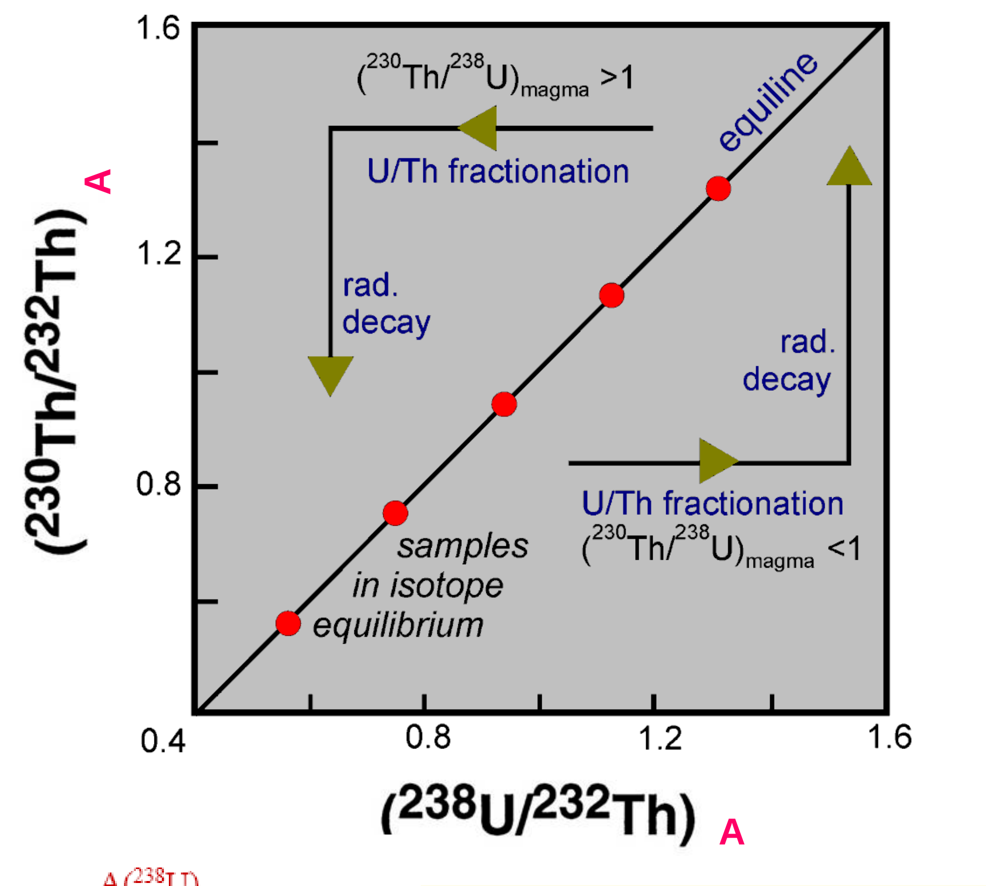
$$\lambda_1 N_1 = \lambda_2 N_2 \Rightarrow$$

$$\frac{{}^{230}Th}{{}^{238}U} = \frac{1.55125 \times 10^{-10}\, a^{-1}}{9.217 \times 10^{-6}\, a^{-1}} = 1.7 \times 10^{-5}$$

U-series disequilibrium in young volcanic rocks

$^{238}U \rightarrow {}^{234}U \rightarrow {}^{230}Th \rightarrow {}^{206}Pb$ (excluding some "shorties")

$T_{1/2}$ = 75 ka **$T_{1/2}$ = 1.6 ka**



Equilibrium:
$\lambda_1 N_1 = \lambda_2 N_2$
$A_1 = A_2$
$(^{230}Th/^{238}U) = 1$

Allègre & Condomines (1976) EPSL 28, (1982) Nature 299

$$\frac{A(^{230}Th)}{A(^{232}Th)} = \left[\frac{A(^{230}Th)}{A(^{232}Th)}\right]_{excess} \cdot (e^{\lambda 230 t}) + \frac{A(^{238}U)}{A(^{232}Th)} \cdot (1 - e^{\lambda 230 t})$$

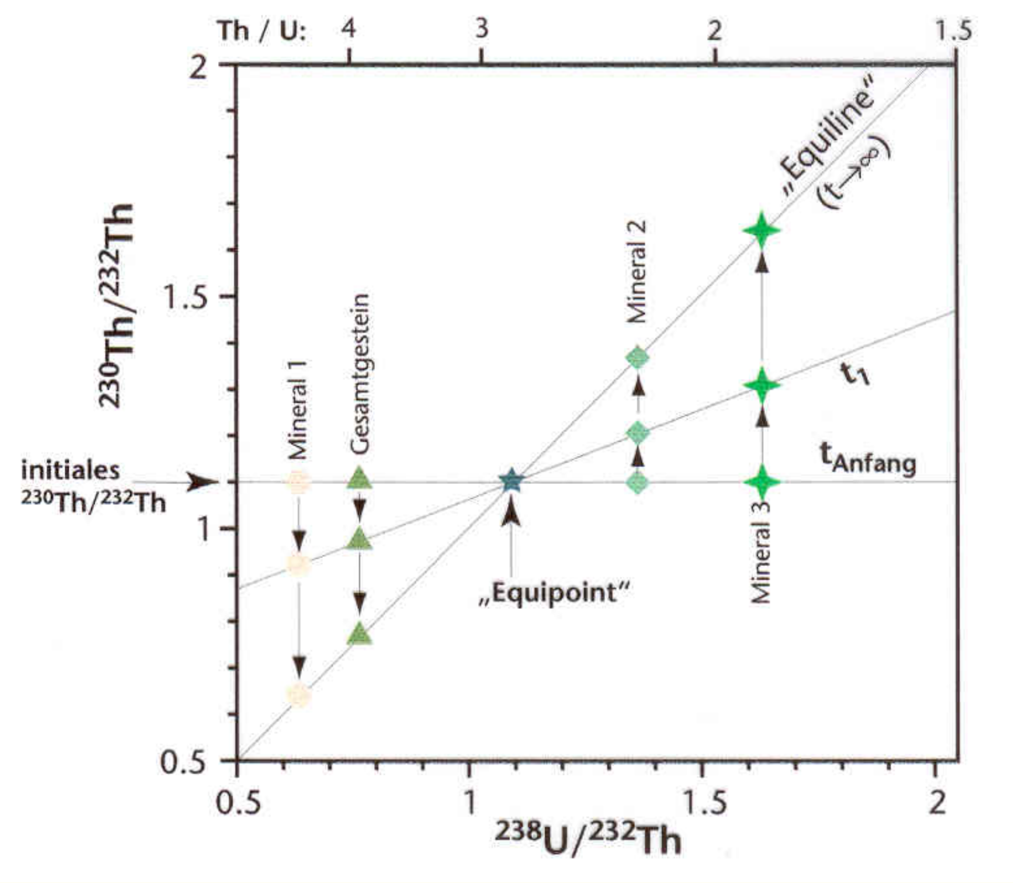
^{230}Th aus excess Th

^{230}Th aus ^{238}U-Zerfall

Uranium series dating

$^{238}\mathrm{U} \rightarrow {}^{234}\mathrm{U} \rightarrow {}^{230}\mathrm{Th} \rightarrow {}^{206}\mathrm{Pb}$ (excluding some "shorties")

$T_{1/2}$ = 75 ka



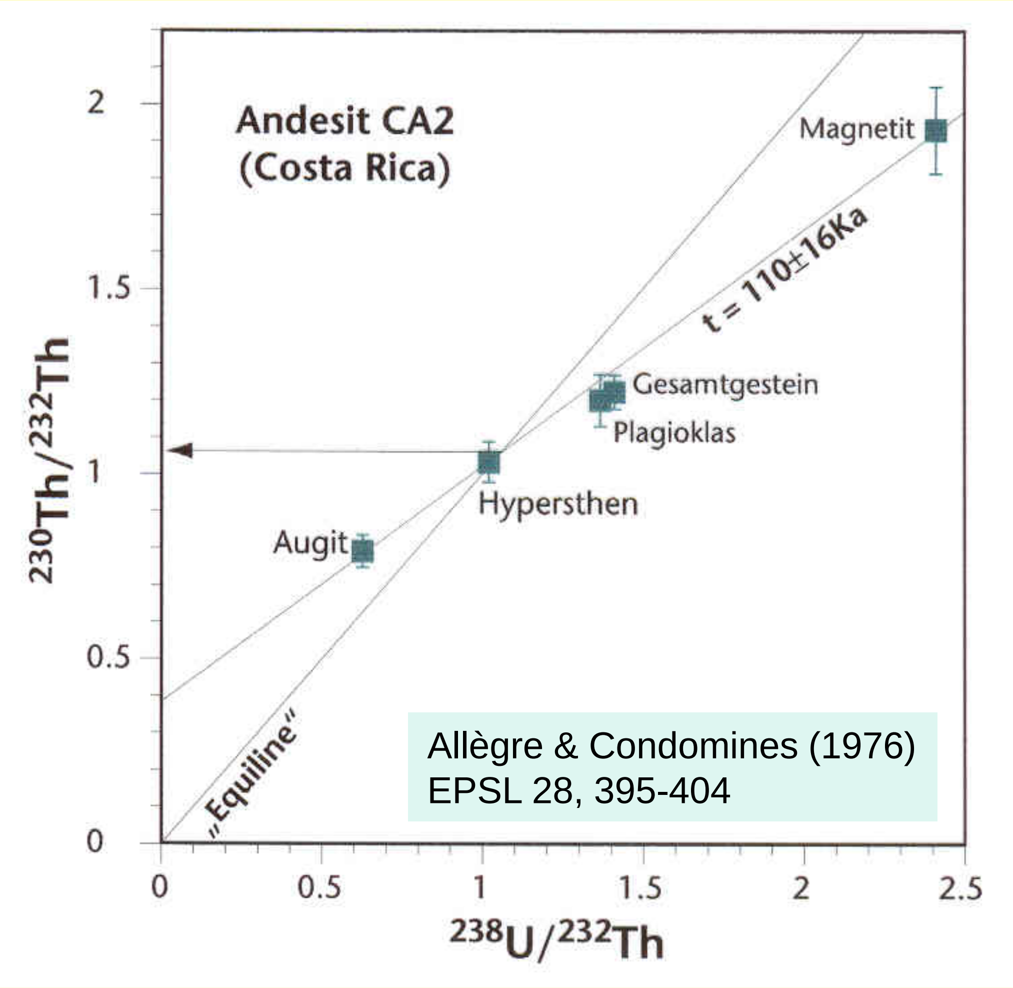
For equilibrium:

$\lambda_1 N_1 = \lambda_2 N_2$

$A_1 = A_2$

$(^{230}\mathrm{Th}/^{238}\mathrm{U}) = 1$

Uranium series dating



Allègre & Condomines (1976)
EPSL 28, 395-404

Bateman's equation:

$$\frac{A_{230}}{A_{232}} = \left(\frac{A_{230}}{A_{232}}\right) e^{-\lambda_{230} t} + \left(\frac{A_{238}}{A_{232}}\right)\left(1 - e^{-\lambda_{230} t}\right)$$

unsupported

Übung

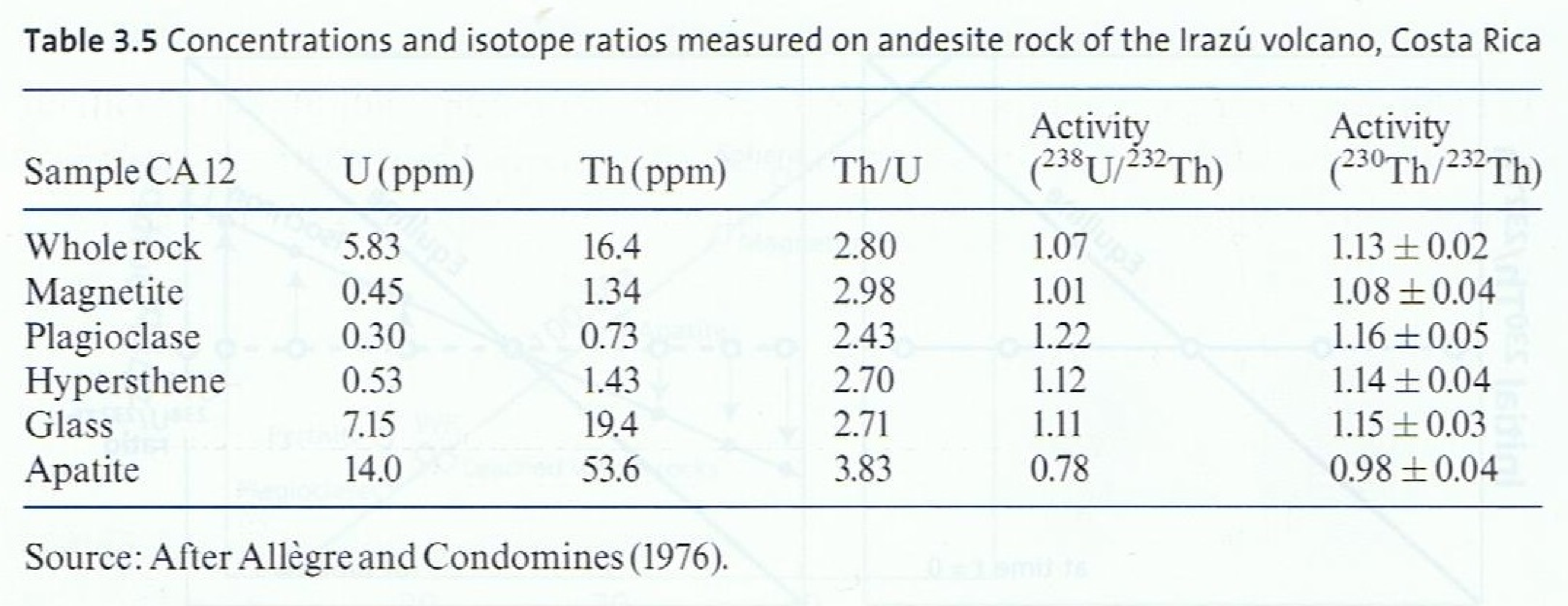


Table 3.5 Concentrations and isotope ratios measured on andesite rock of the Irazú volcano, Costa Rica

Sample CA 12	U (ppm)	Th (ppm)	Th/U	Activity ($^{238}U/^{232}Th$)	Activity ($^{230}Th/^{232}Th$)
Whole rock	5.83	16.4	2.80	1.07	1.13 ± 0.02
Magnetite	0.45	1.34	2.98	1.01	1.08 ± 0.04
Plagioclase	0.30	0.73	2.43	1.22	1.16 ± 0.05
Hypersthene	0.53	1.43	2.70	1.12	1.14 ± 0.04
Glass	7.15	19.4	2.71	1.11	1.15 ± 0.03
Apatite	14.0	53.6	3.83	0.78	0.98 ± 0.04

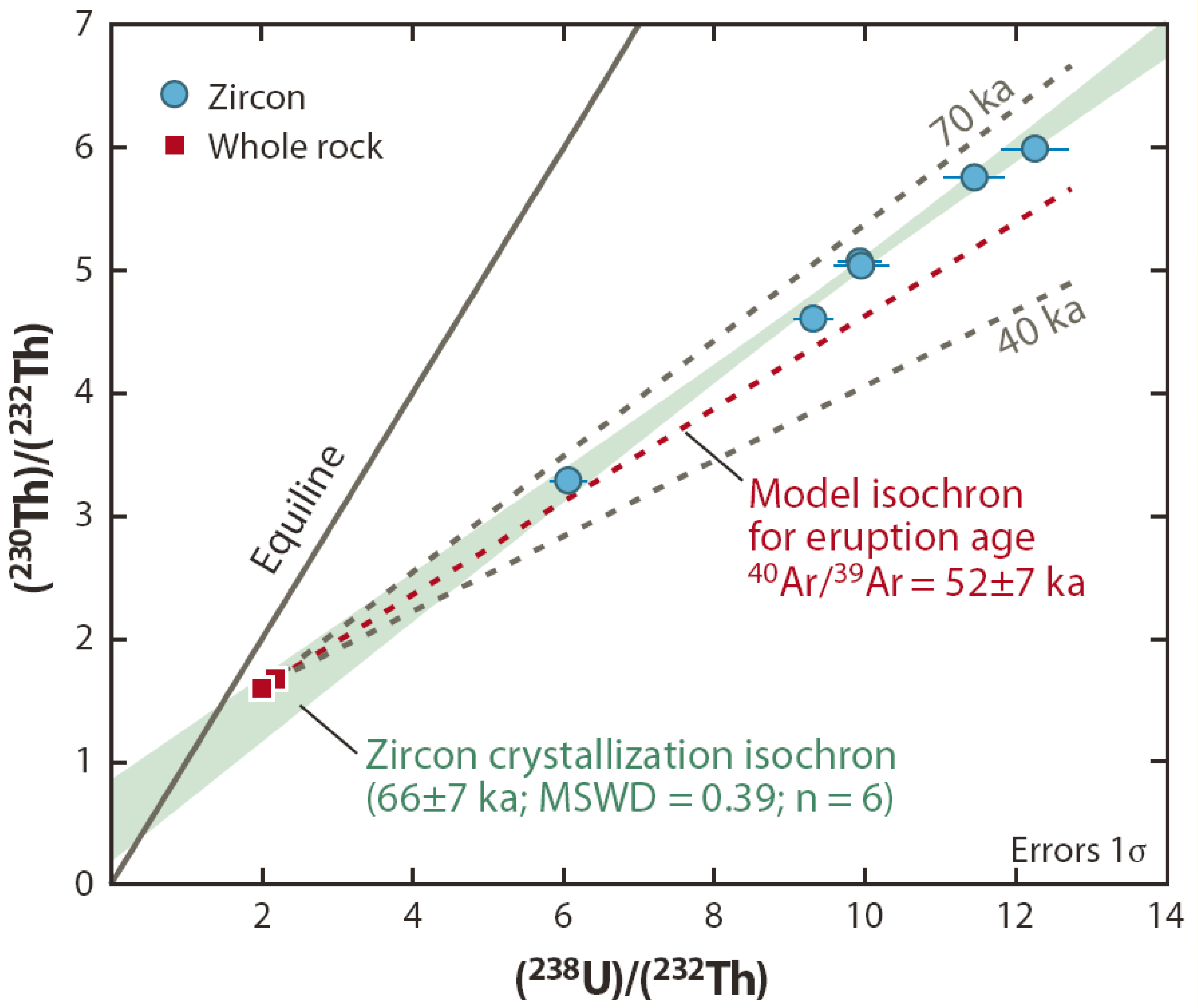
Source: After Allègre and Condomines (1976).

Zeichnen Sie ein Ungleichgewichstdiagramm mit den Datenpunkten und berechnen Sie das Alter der Lava

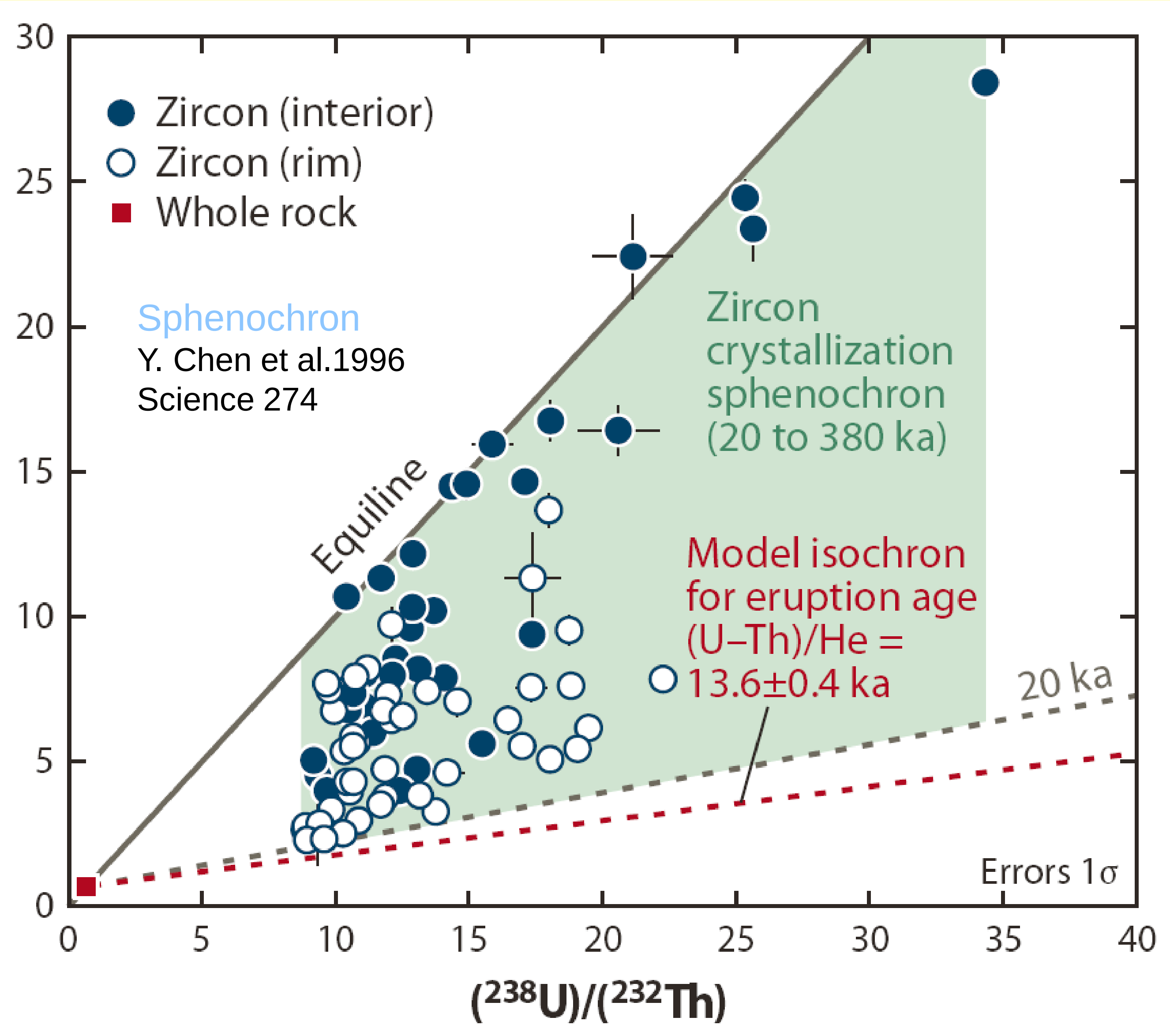
$$\boxed{\frac{A_{230}}{A_{232}} = \left(\frac{A_{230}}{A_{232}}\right) e^{-\lambda_{230} t} + \left(\frac{A_{238}}{A_{232}}\right)\left(1 - e^{-\lambda_{230} t}\right)}$$

Die Steigung entspricht dem Ausdruck $(1 - e^{-\lambda_{230} t})$

China hat (Blackfood lava field)

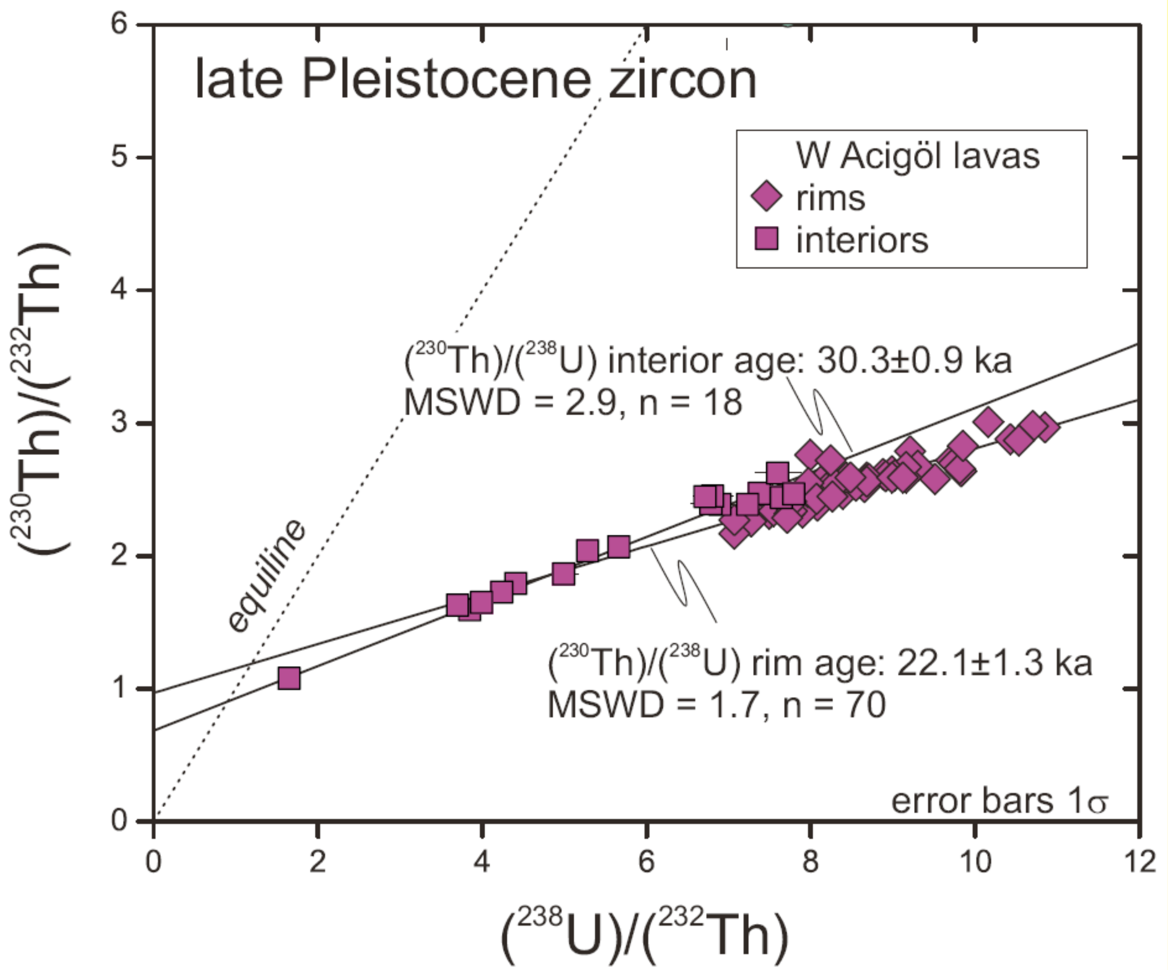


Belfond dome (Saint Lucia): sphenochron

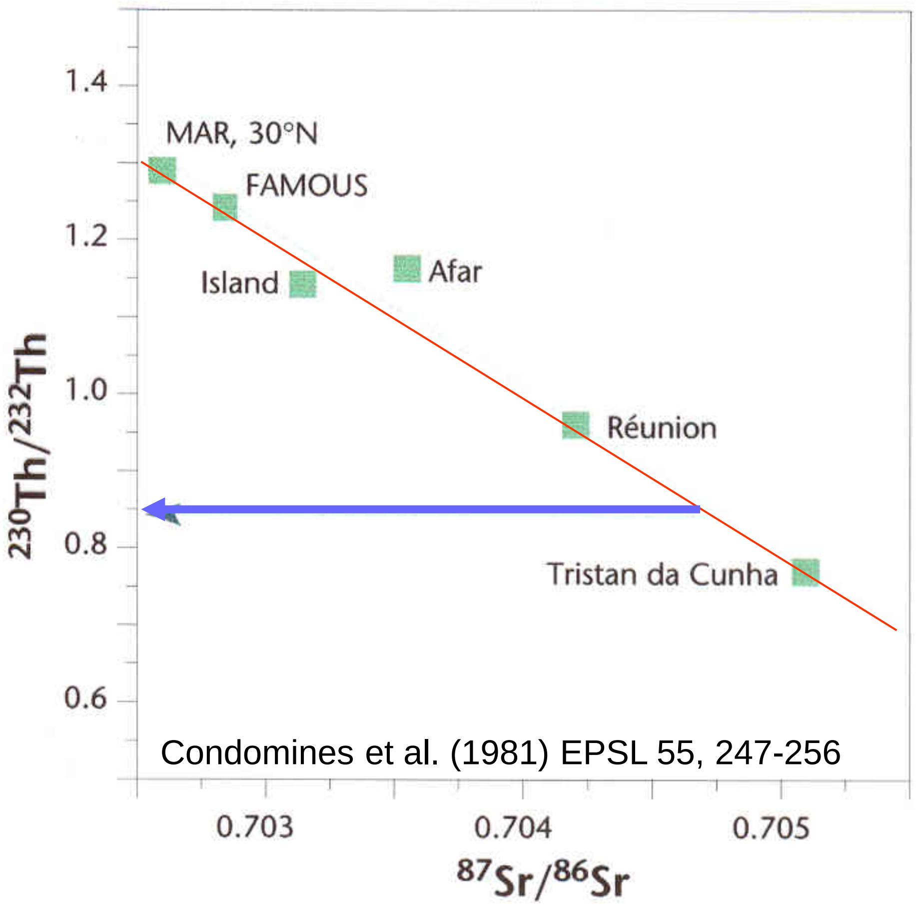


Sphenochron
Y. Chen et al.1996
Science 274

Acigöl, Cappadocia



U-Th Isotope in jungen Vulkaniten



Condomines et al. (1981) EPSL 55, 247-256

$$A_{230} = A_{238} \Rightarrow \frac{A_{230}}{A_{232}} = \frac{A_{238}}{A_{232}}$$

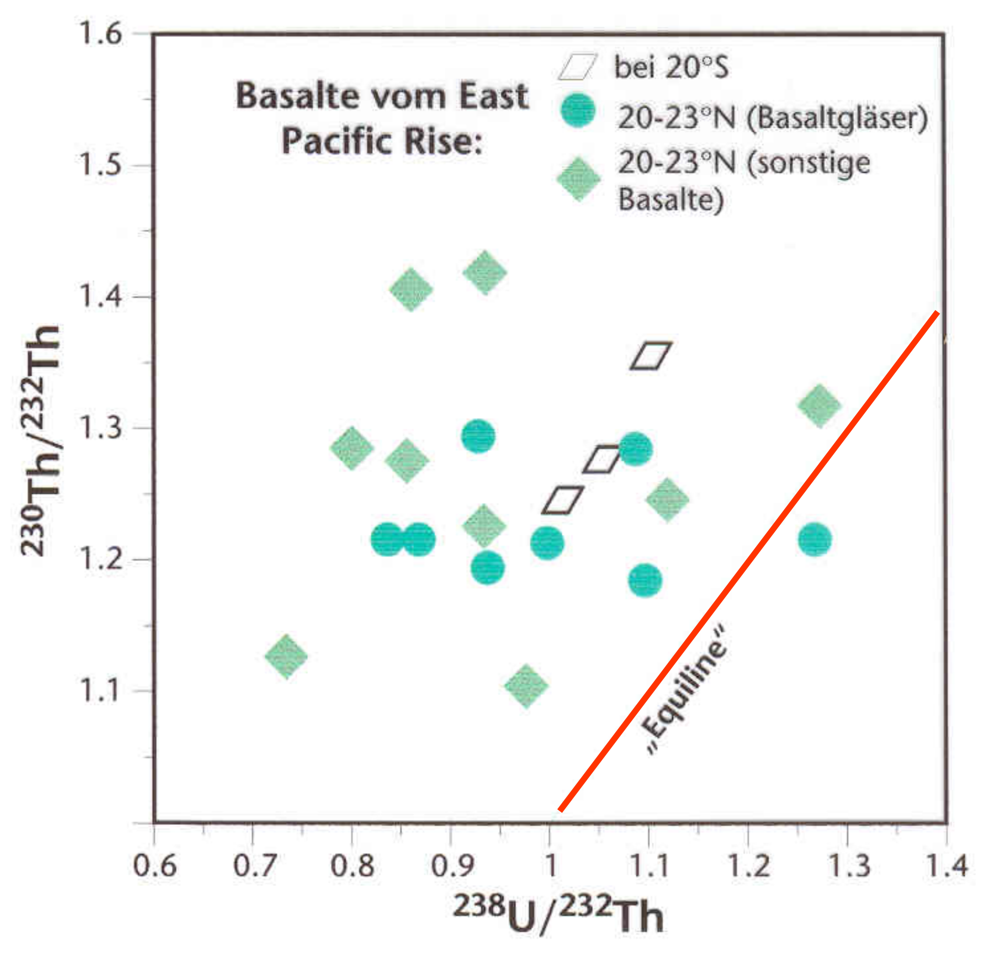
$$\frac{A_{230}}{A_{232}} = \frac{N_{238}}{N_{232}} \times \frac{\lambda_{238}}{\lambda_{232}}$$

$$\frac{N_{232}}{N_{238}} = \frac{A_{232}}{A_{230}} \times \frac{\lambda_{238}}{\lambda_{232}}$$

Thorium-Uranium ratio:

$$\frac{N_{232}}{N_{238}} = \frac{1}{0.86} \times \frac{1.55125 \times 10^{-10}}{4.9475 \times 10^{-11}} = 3.65$$

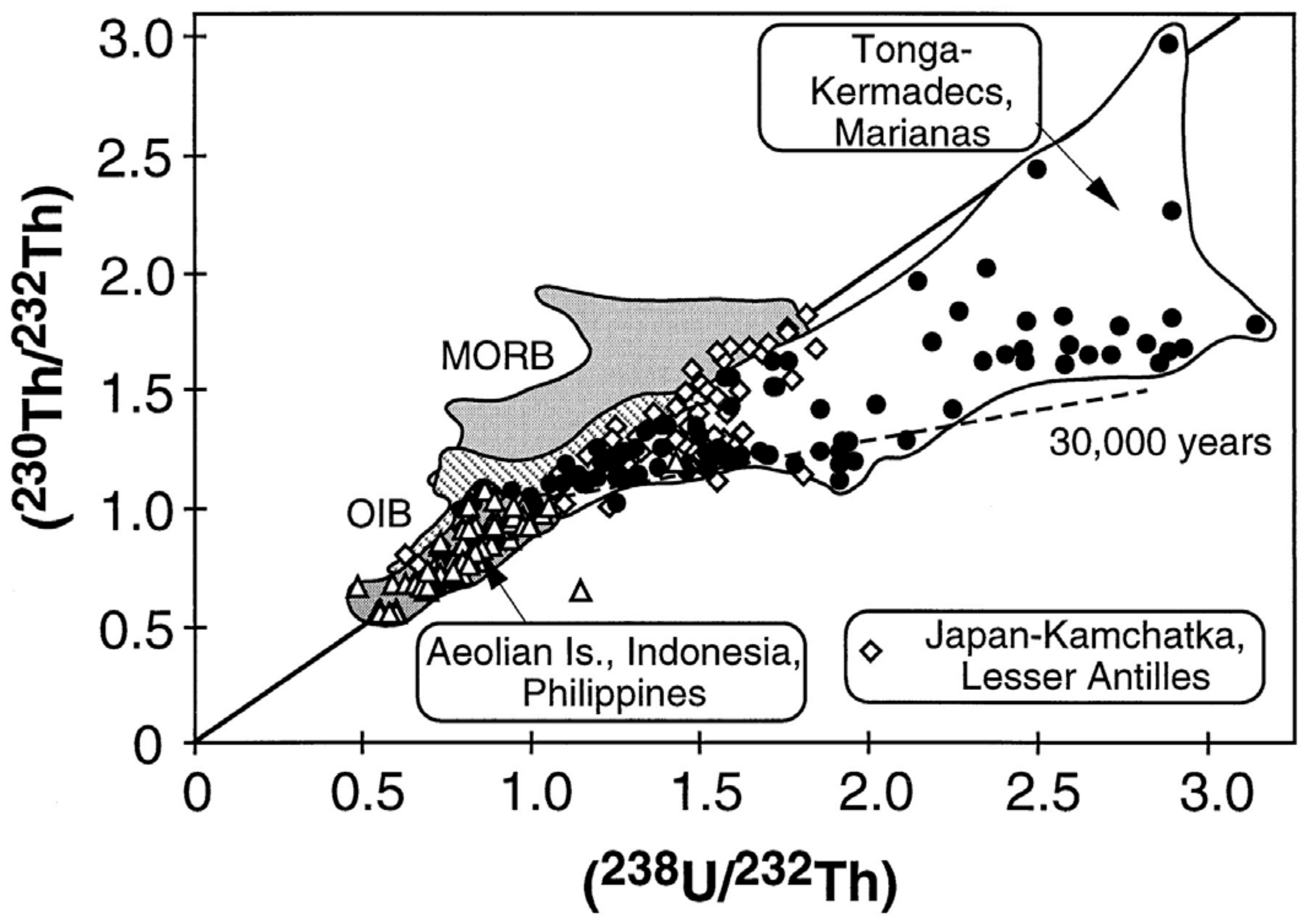
U-Th isotopes in arc magmas



$$\frac{^{232}Th}{^{238}U} = \left(\frac{1}{1.22}\right) \times \left(\frac{\lambda^{238}U}{\lambda^{232}Th}\right) = 2.57$$

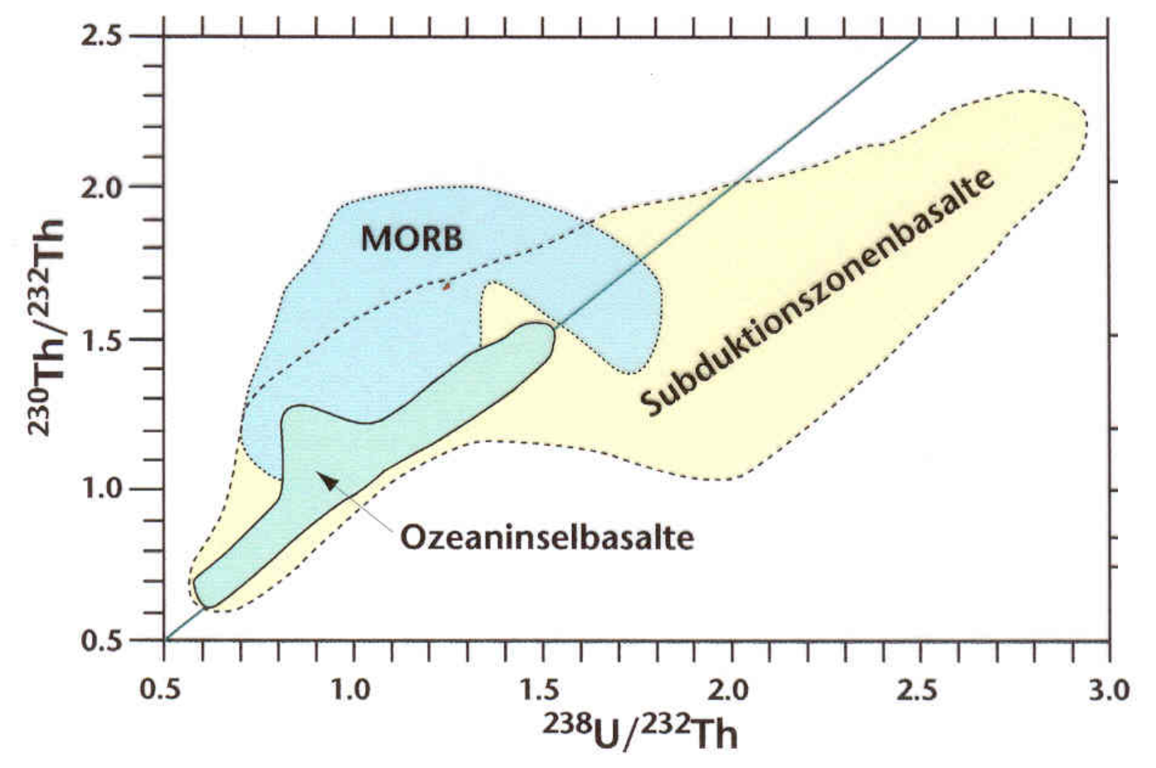
Newman et al. (1983)
EPSL 65, 17-33

U–Th isotopes

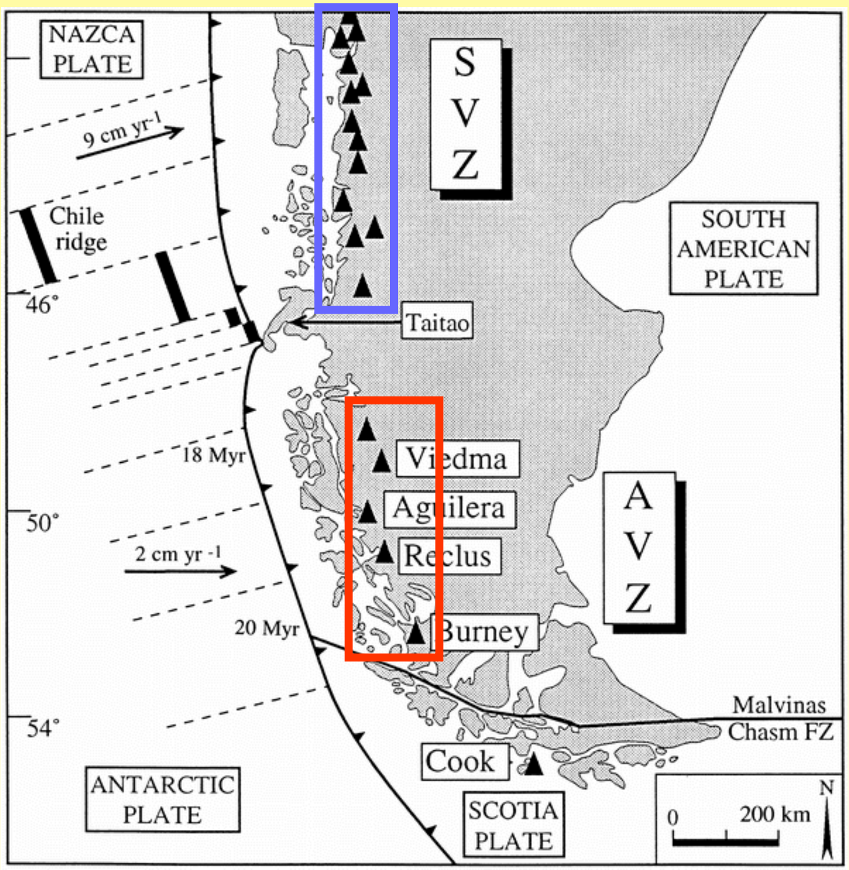


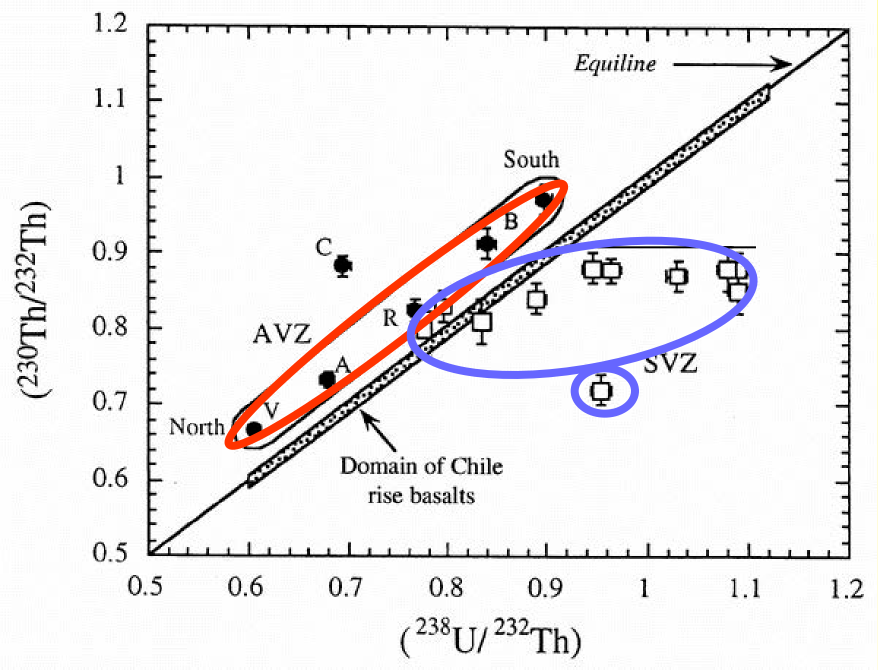
Hawkesworth et al. (1997) Science 276

U–Th isotopes



Melting of a subducting oceanic slab?





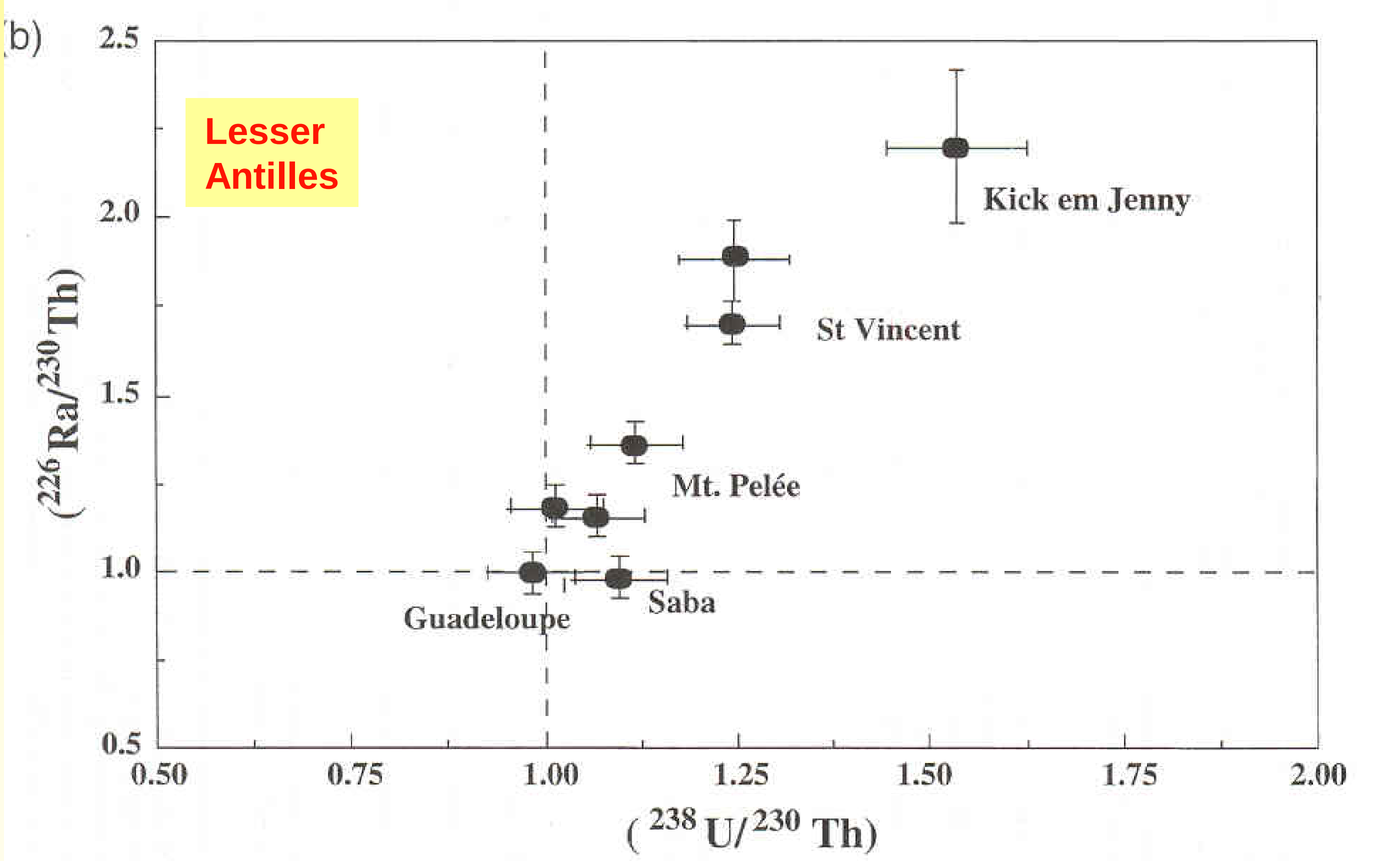
Sigmarsson et al. (1998) Nature 394

Timescales of melt transport

$^{238}U \rightarrow {}^{234}U \rightarrow {}^{230}Th \rightarrow {}^{226}Ra \rightarrow {}^{206}Pb$ (excluding some “shorties”)

$T_{1/2}$ = 75 ka

$T_{1/2}$ = 1.6 ka

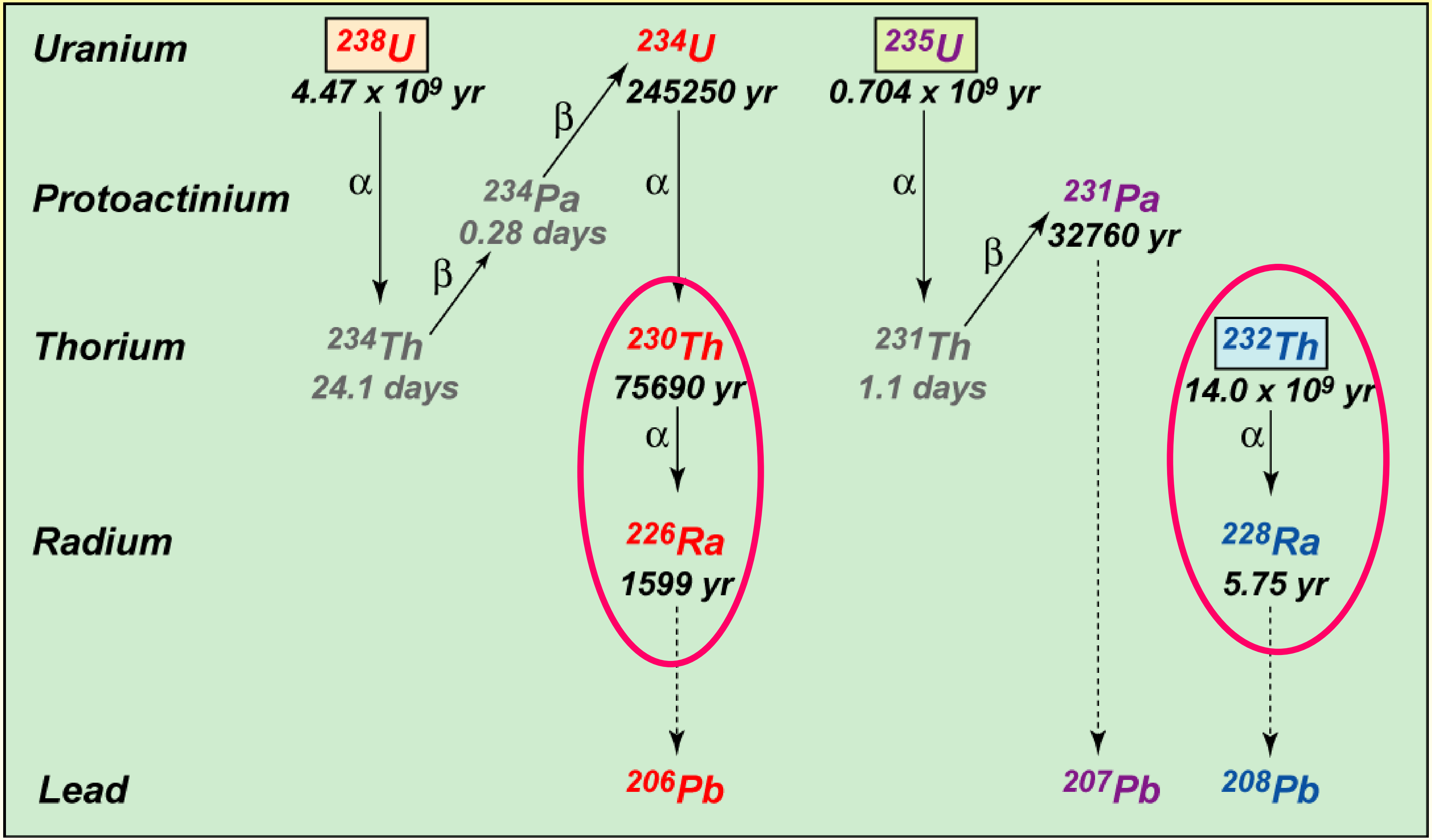


Chabaux et al. (1999)
Chem Geol 153

Ultrafast source to surface movement: 10-100 m/year

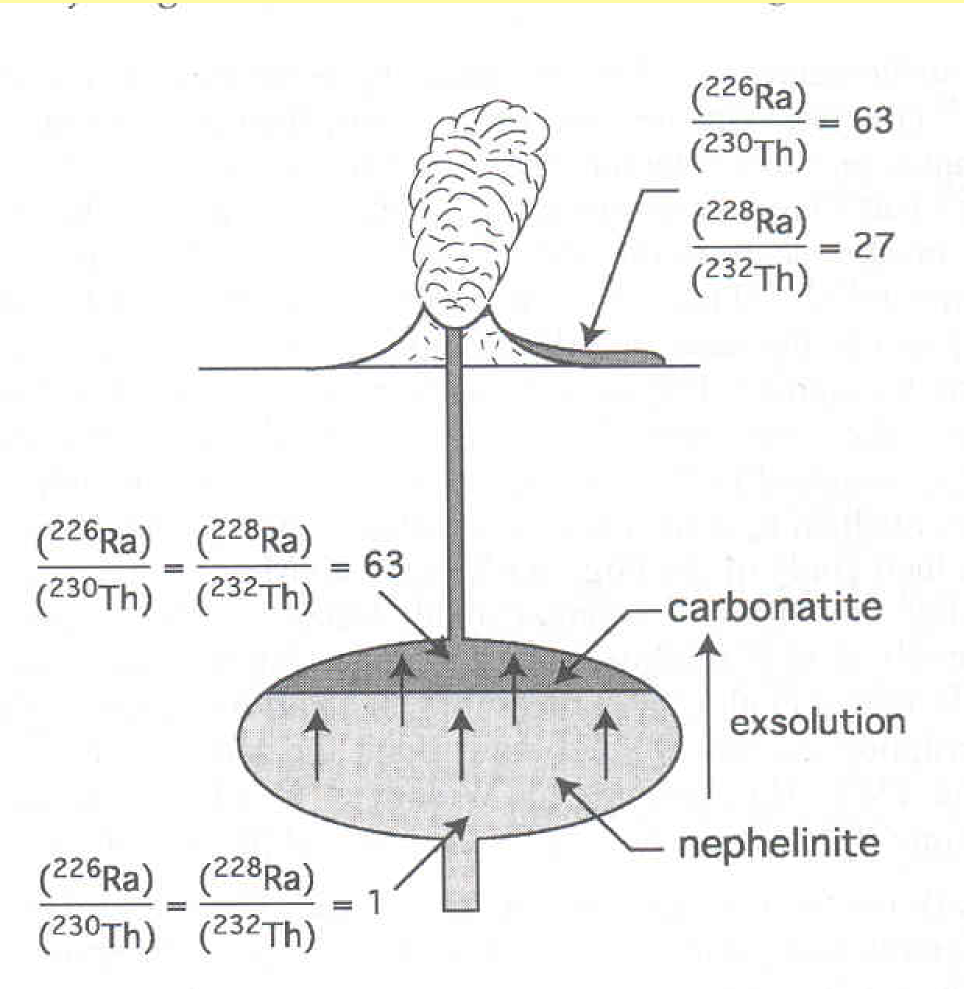
Oldoinyo Lengai, Tanzania

U-series dating



Timescales of exolution and fractionation

Oldoinyo
Lengai
(Tanzania)



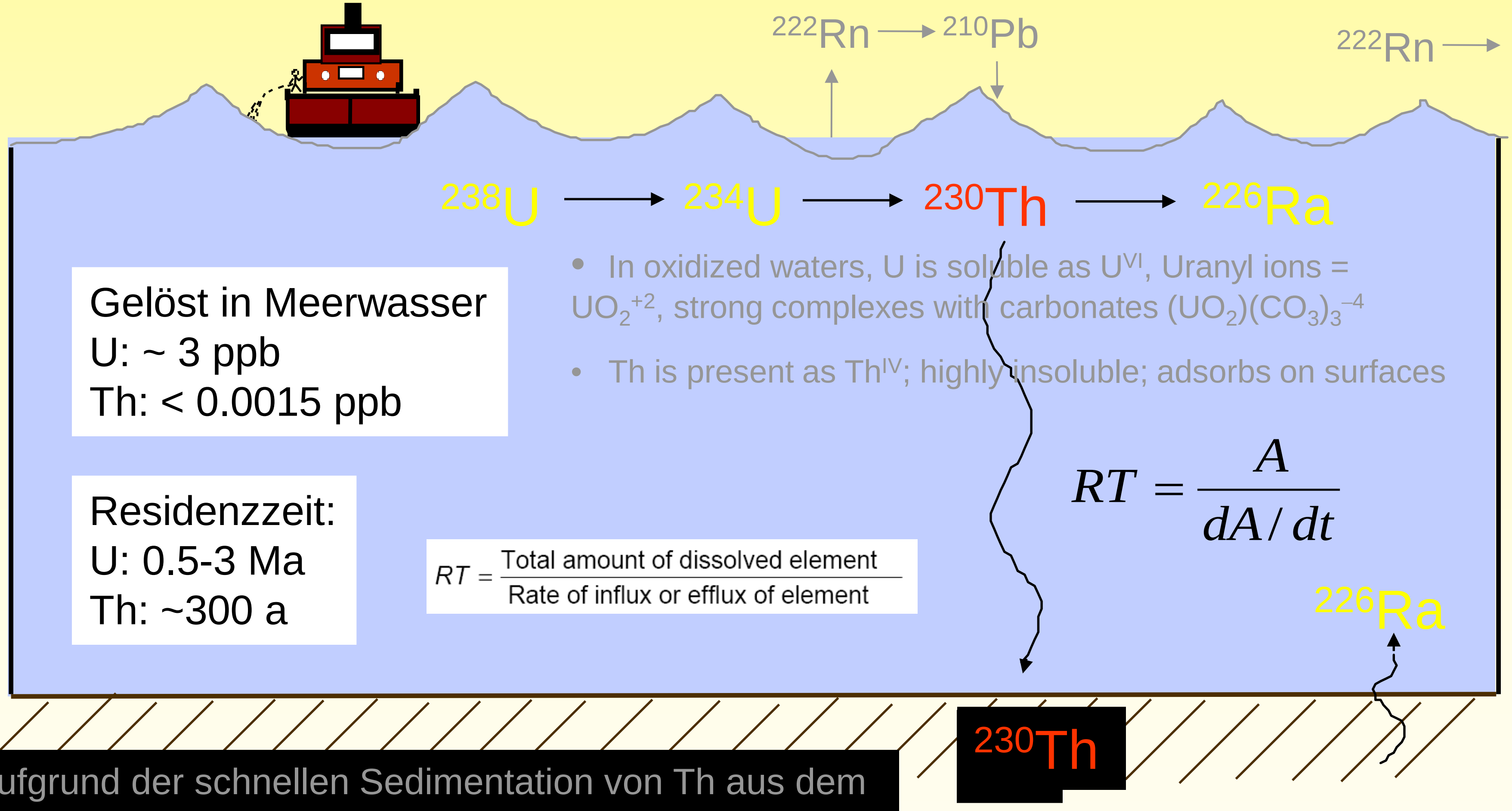
exolution
occurred only
7 years
before
eruption!

**Williams & Gill (1986)
GCA 50**

^{226}Ra-^{230}Th equilibrium reched after 8000 a
^{228}Ra-^{232}Th equilibrium reached after 30 a

U-Serien Elemente

$^{238}U \rightarrow {}^{234}U \rightarrow {}^{230}Th \rightarrow {}^{206}Pb$



- In oxidized waters, U is soluble as U^{VI}, Uranyl ions = UO_2^{+2}, strong complexes with carbonates $(UO_2)(CO_3)_3^{-4}$
- Th is present as Th^{IV}; highly insoluble; adsorbs on surfaces

Gelöst in Meerwasser
U: ~ 3 ppb
Th: < 0.0015 ppb

Residenzzeit:
U: 0.5-3 Ma
Th: ~300 a

$$RT = \frac{\text{Total amount of dissolved element}}{\text{Rate of influx or efflux of element}}$$

$$RT = \frac{A}{dA/dt}$$

Aufgrund der schnellen Sedimentation von Th aus dem Meerwasser weisen junge pelagische Gesteine einen **^{230}Th-Überschuß** auf!

(^{231}Pa, ^{210}Pb, *etc.*)

Die ^{230}Th (Ionium) Methode

$$^{238}\mathrm{U} \rightarrow {}^{234}\mathrm{U} \rightarrow {}^{230}\mathrm{Th} \rightarrow {}^{206}\mathrm{Pb}$$

^{230}Th-Überschuß wird in der Folgezeit durch Zerfall von ^{230}Th abgebaut. Aus der Aktivitätsabnahme mit der Tiefe im Sediment lassen sich Sedimentationsraten bestimmen

$$R = R_o e^{-\lambda t}$$

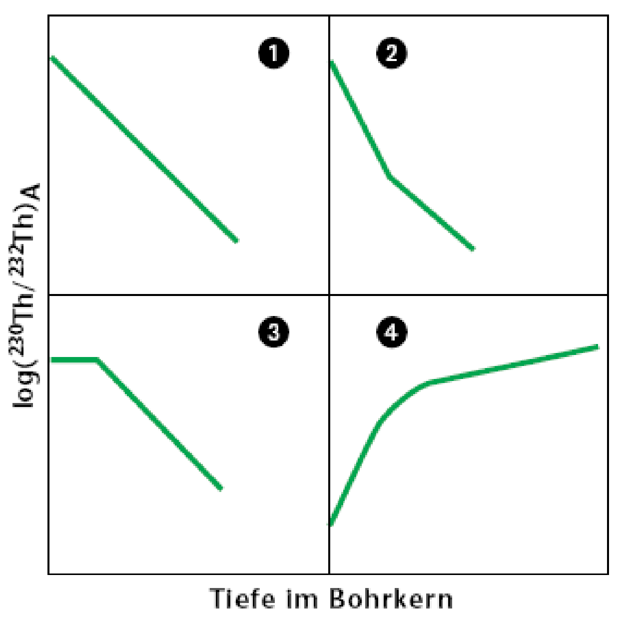
$$T = 1/\lambda \ln(R_o/R)$$

Bestimmung von Sedimentationsraten:

$a = h/t$ (h = Tiefe)

$R = R_o e^{-\lambda h/a}$

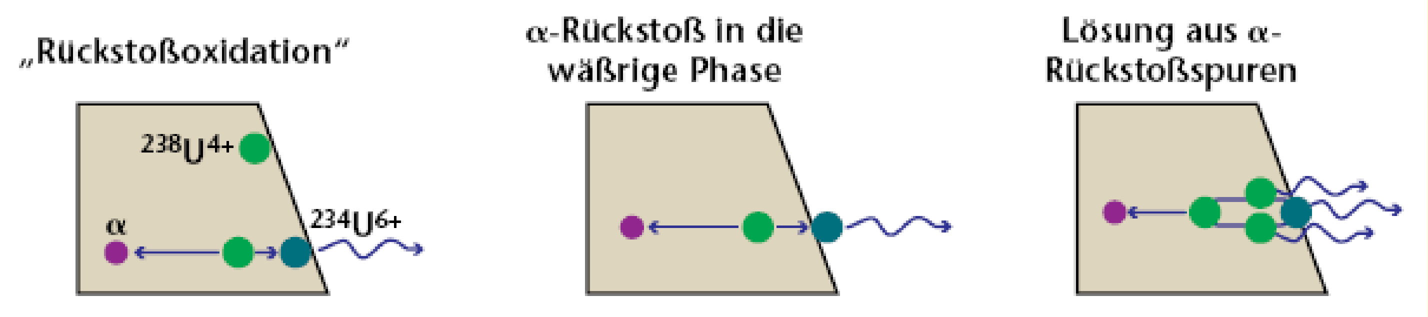
$\ln R = \ln R_o - \lambda h/a$



① normales Muster
② Änderung in Sedimentationsrate
③ Bioturbation
④ ^{230}Th Nachbildung durch U-Zerfall

Stosch: http://www.dmg-home.de/Ressourcen/Internet-Kurse/Isotopengeochemie.pdf

Die ^{234}U-^{238}U Methode



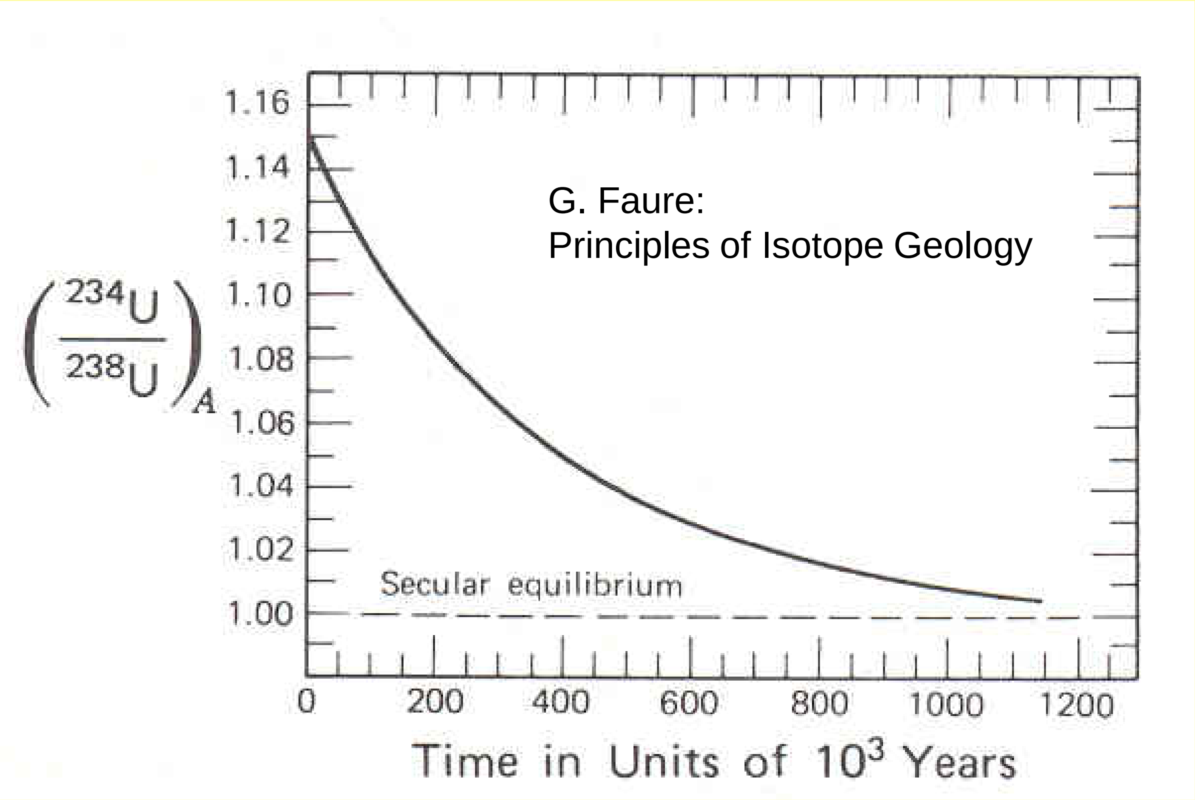
Stosch: http://www.dmg-home.de/Ressourcen/Internet-Kurse/Isotopengeochemie.pdf

The activity of ^{234}U in seawater not in secular equilibrium with that of ^{238}U

^{234}U is preferentially leached out of radiation damaged crystal lattice sites during weathering.

The $^{234}U_A/^{238}U_A$ ratio of sea water is about 1.15.

Die ^{234}U-^{238}U Methode



G. Faure:
Principles of Isotope Geology

Muscheln, Korallen und Foraminiferen weisen eine gegenüber dem Wasser tausendfach höhere U-Konzentration auf und enthalten fast kein Th.
Sobald es vom Meerwasser isoliert ist, zerfällt das überschüssige ^{234}U bis sich ein sekundärer Gleichgewichtszustand zwischen den Uranisotopen ^{234}U und ^{238}U eingestellt hat.

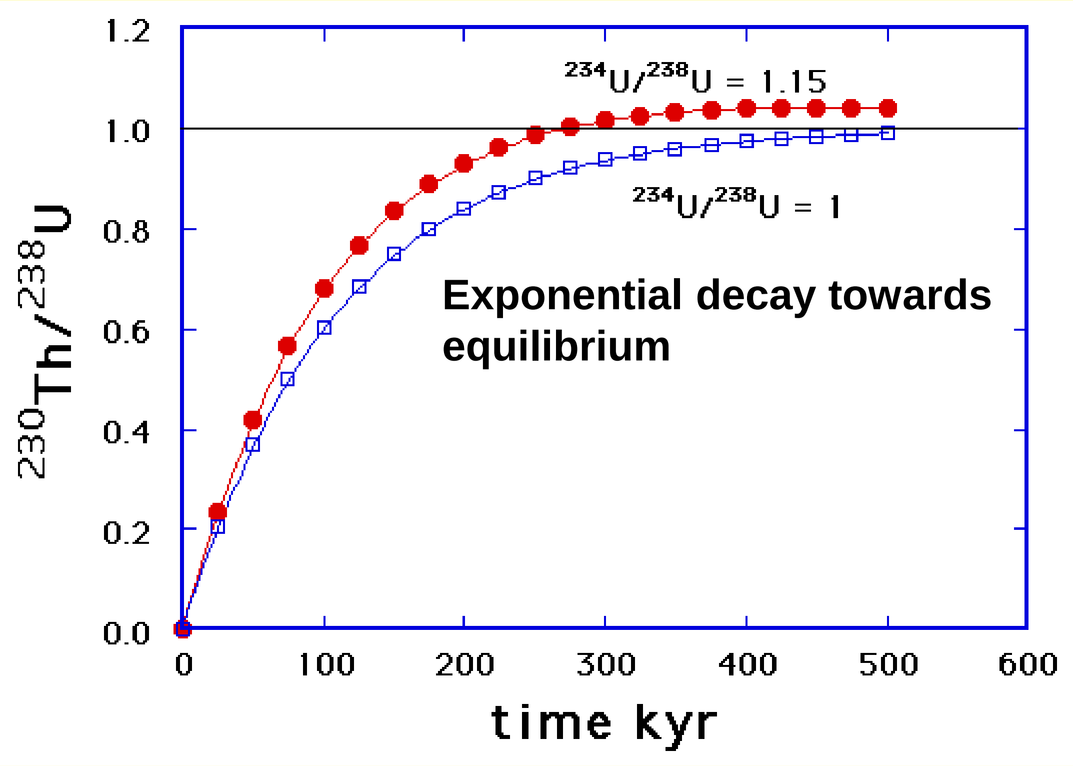
Die ^{230}Th-^{238}U und ^{230}Th-^{234}U Methoden

$^{238}\mathrm{U} \rightarrow {}^{234}\mathrm{U} \rightarrow {}^{230}\mathrm{Th} \rightarrow {}^{206}\mathrm{Pb}$

Th/U isotope ratio can be used to date carbonates provided we know:

(1) the initial ^{234}U/^{238}U ratio

(2) that the initial ^{230}Th/^{238}U ratio was close to zero and that the sample has remained closed with respect to U, Th and their intermediate isotopes



Exponential decay towards equilibrium