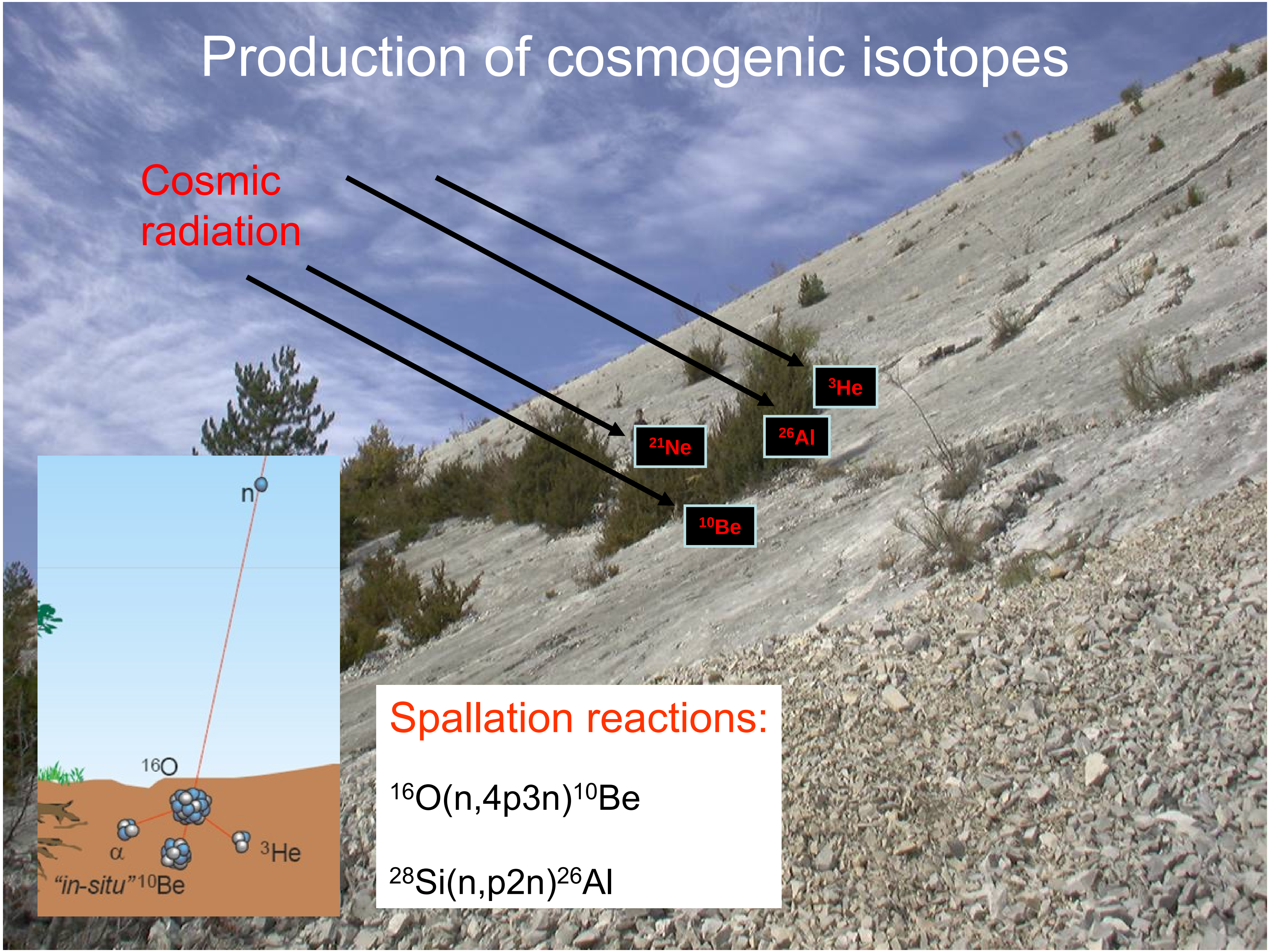
# Production of cosmogenic isotopes

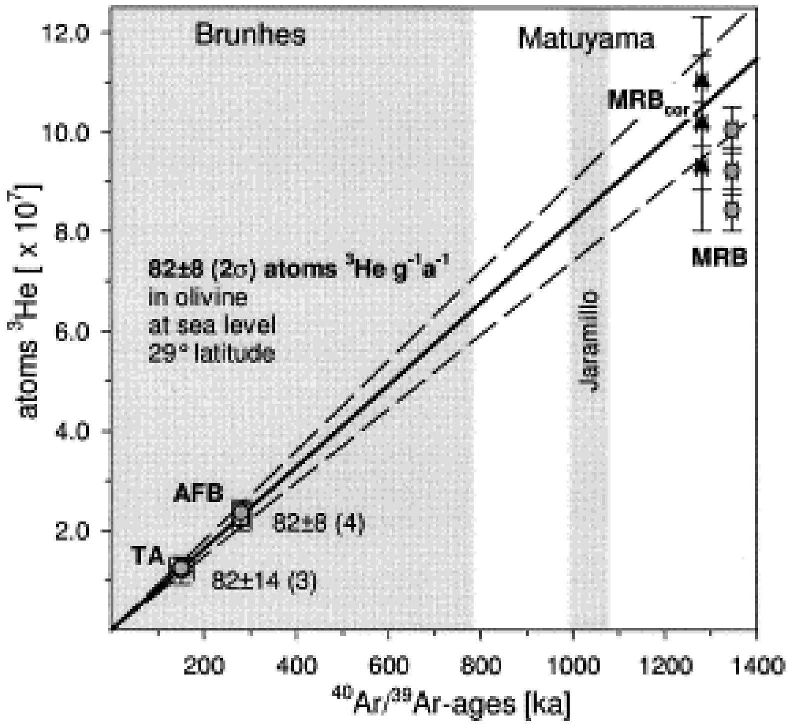



## Spallation reactions:

$^{16}O(n,4p3n)^{10}Be$

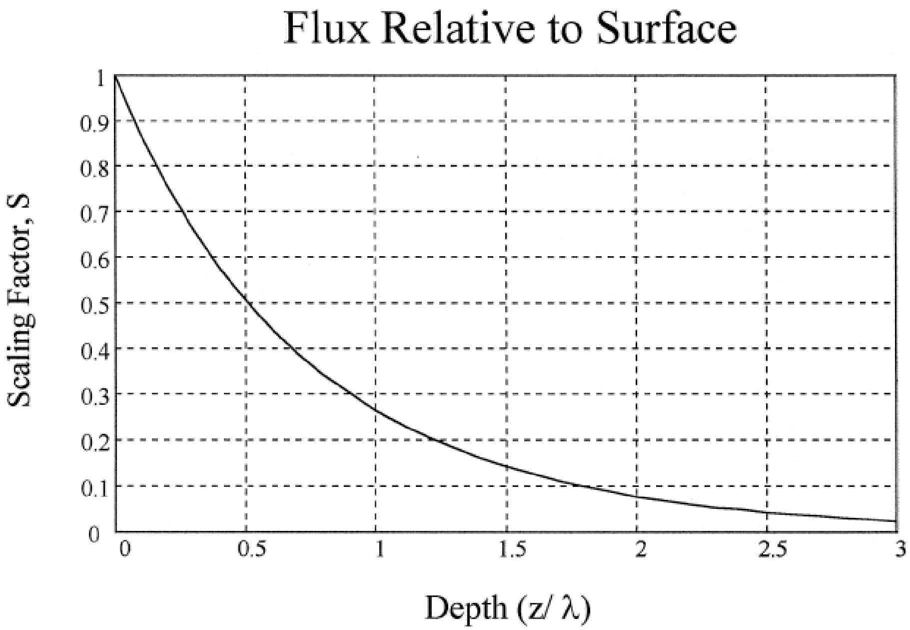
$^{28}Si(n,p2n)^{26}Al$

# How to determine production rates?

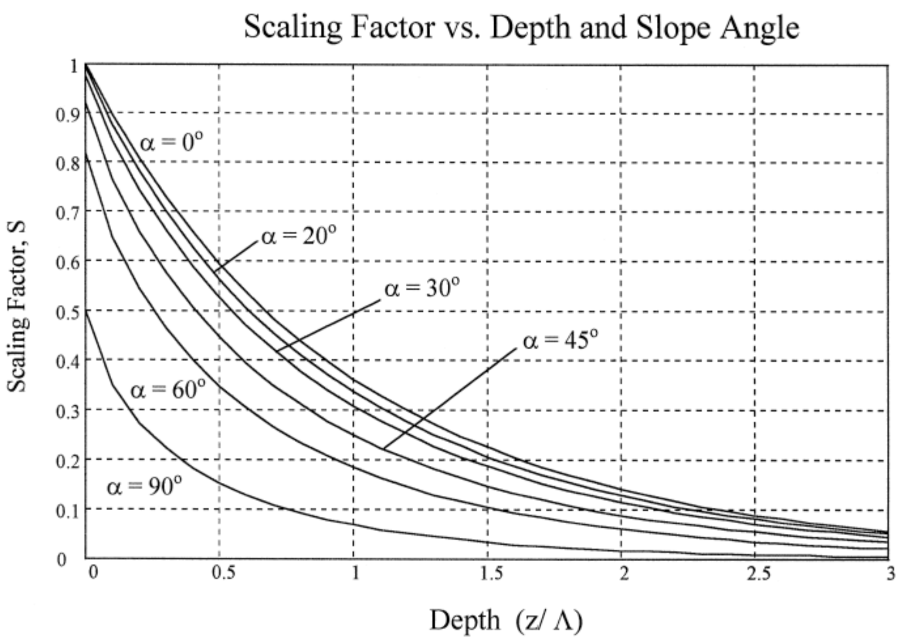



Production rate of $^3$He in olivine derived from 3 lava flows dated by the $^{40}$Ar/$^{39}$Ar technique at 152, 281 and 1350 ka (from Dunai & Wijbrans 2000).

# Scaling factors and Topographic shielding




z = Tiefe, λ = Abschwächungsfaktor




**Scaling factor:**
ratio of the actual radiation flux through the surface to the flux that would be present if the horizon were horizontal

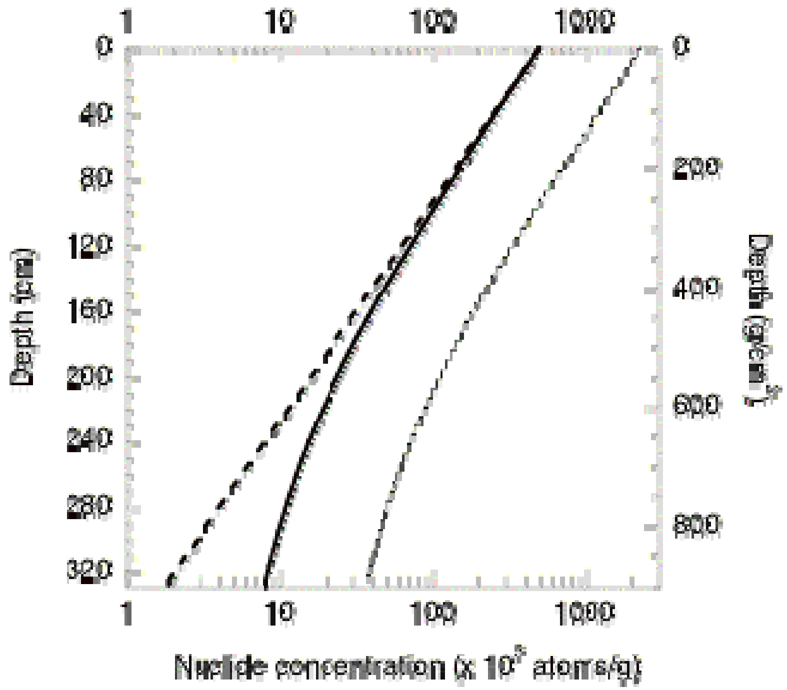
Dunne et al. 1999, *Geomorphology* **27**

# Production rates

**Nucleonic production profile with depth P(d):**

$P(d) = P_{(0)} e^{-d/L}$

$P_{(0)}$ = production rate at surface
d = depth
L = absorption length scale
L = 160/$\rho$ cm ($\rho$ = overburden pressure)


$^{10}Be$ concentration vs. depth after 100 ka exposure calculated for nucleon production (dashed line) and for combined nucleon and muon production (solid curve) with a surface production rate of 5.1 atoms $g^{-1}$ $a^{-1}$, a rock density of 2.75 g $cm^{-3}$ and **no erosion**.

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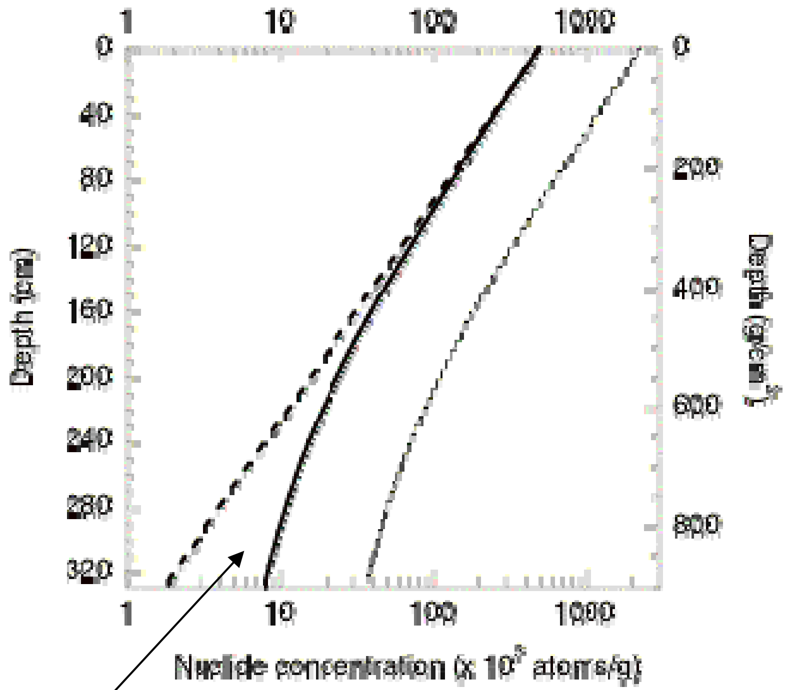


In situ cosmogenic isotopes are produced near the surface of the earth because the cosmic flux is attenuated by rock at depths that exceed 2-3 m.

**For nucleon and muon production (solid curve in fig.):**

$$P(d) = P_{(0)}e^{-d/L0} + P_{(1)}e^{-d/L1} + P_{(2)}e^{-d/L2} + P_{(3)}e^{-d/L3}$$

# Production rates

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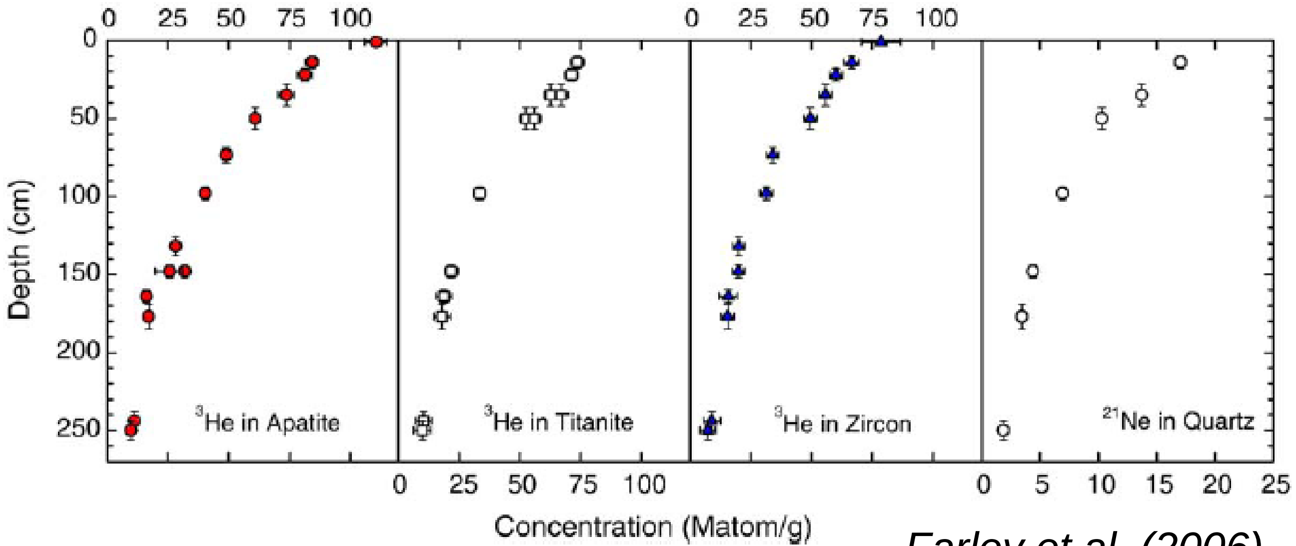
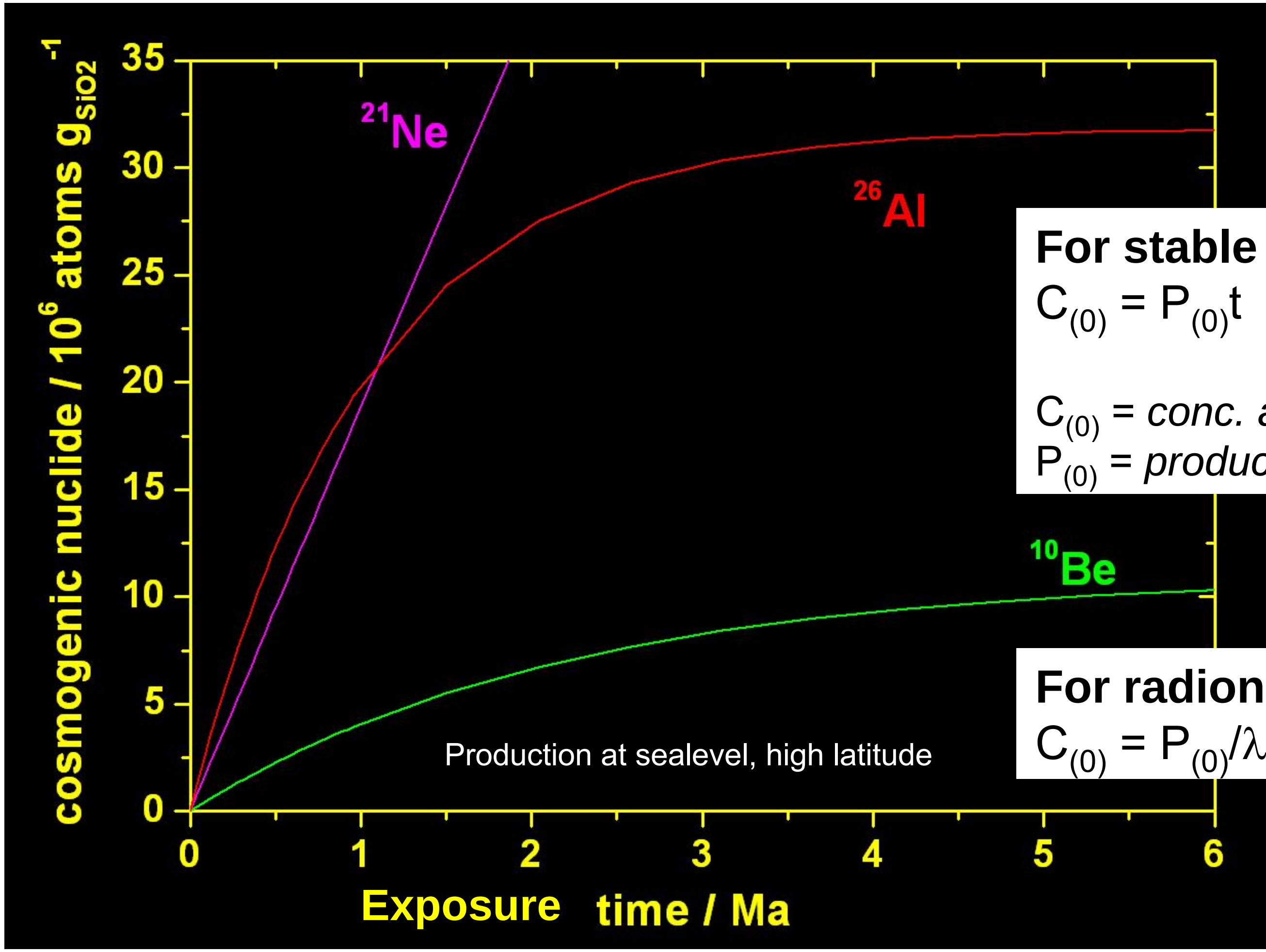



*Farley et al. (2006)*

# Production rates




**For stable nuclides (e.g. $^{21}$Ne):**

$C_{(0)} = P_{(0)}t$

$C_{(0)}$ = *conc. at surface*

$P_{(0)}$ = *production rate at surface*

**For radionuclides ($^{26}$Al, $^{10}$Be):**

$C_{(0)} = P_{(0)}/\lambda(1–e^{-\lambda t})$

build-up of cosmogenic nuclides in case of **no erosion**

# Assuming no erosion….

…the exposure age can be determined using the following equation:

$$T = \frac{\ln(1 - C\lambda/P)}{-\lambda}$$

T = the length of irraditation (i.e., exposure age),

C = number of cosmogenically produced atoms

P = cosmogenic isotope production rate

$\lambda$ = decay constant

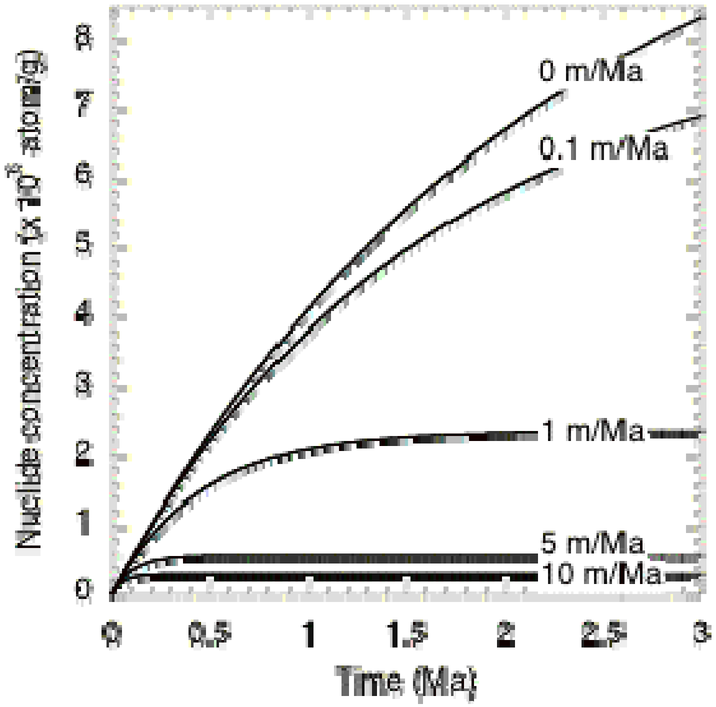
# Production rates, considering erosion

$C = P_{\Lambda}/D$

C = concentration of cosmogenic nuclide
P = production rate
Λ = penetration length scale
D = denudation rate

$N_{(0)} = [P_{(0)}/(\lambda + \rho\varepsilon/L_0)]$

$N_{(0)}$ = concentration at surface
$P_{(0)}$ = production rate at surface
$\lambda$ = decay constant
$\varepsilon$= (constant) erosion rate
$\rho$ = density
$L_0$ = attenuation length




Surface concentration of in-situ cosmogenic stable isotope ($^{10}Be$) for steady-state erosion rates ranging from 0 to 10 m/Ma.

# Exposure age dating and erosion

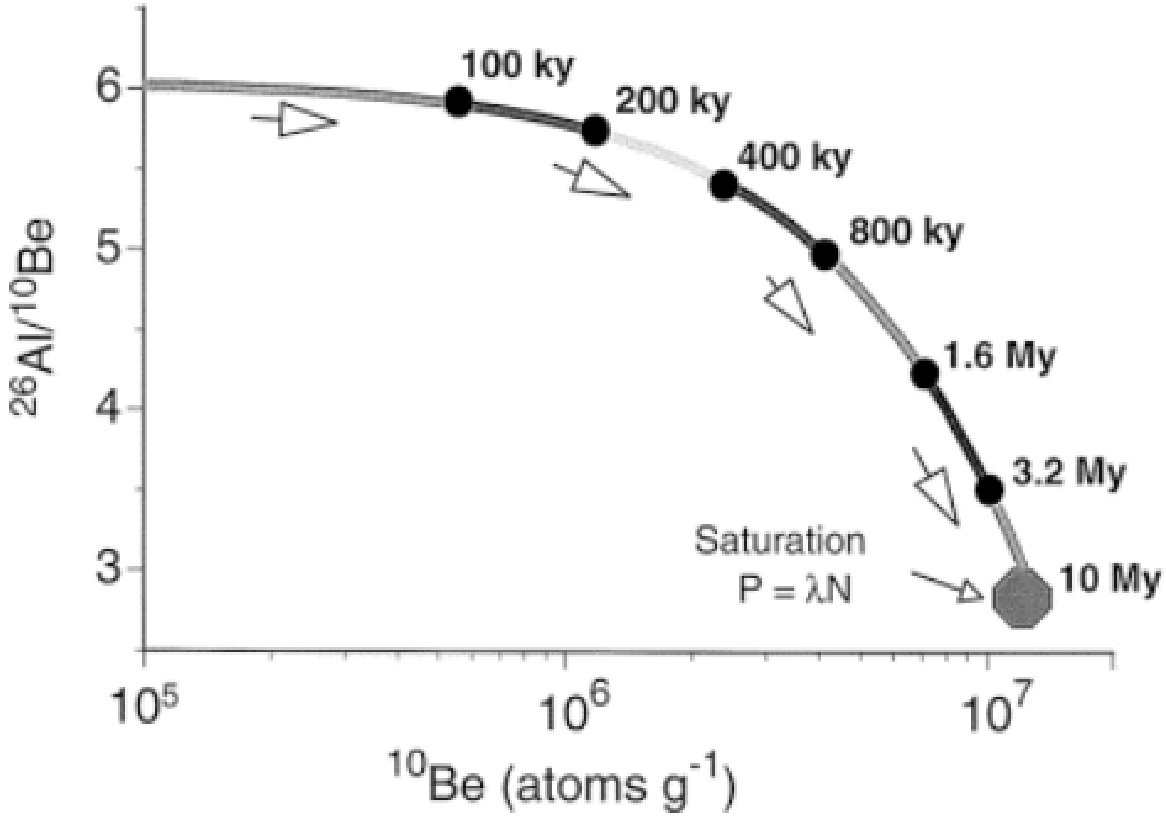
Assumptions:

- No *inheritance* of nuclide concentrations
- Steady state erosion
- Simple exposure history (e.g. no shielding)
- Production rate can be constrained

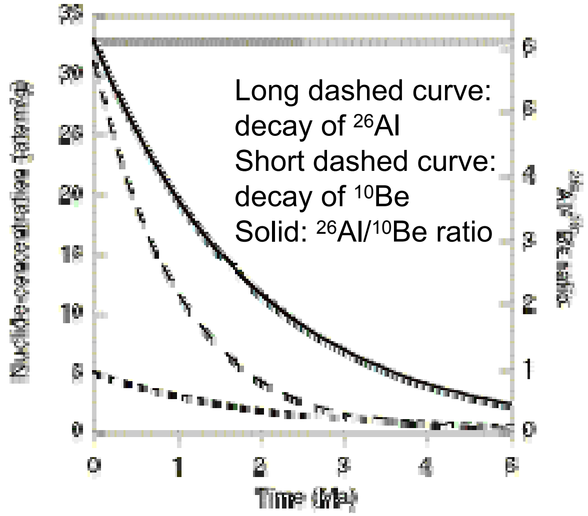
Questions:

- Exposure age of a surface
- Exposure age of terraces (bedrock and deposits)
- Erosion rate of exposed bedrock
- Soil production rates

# Banana plot 1/2

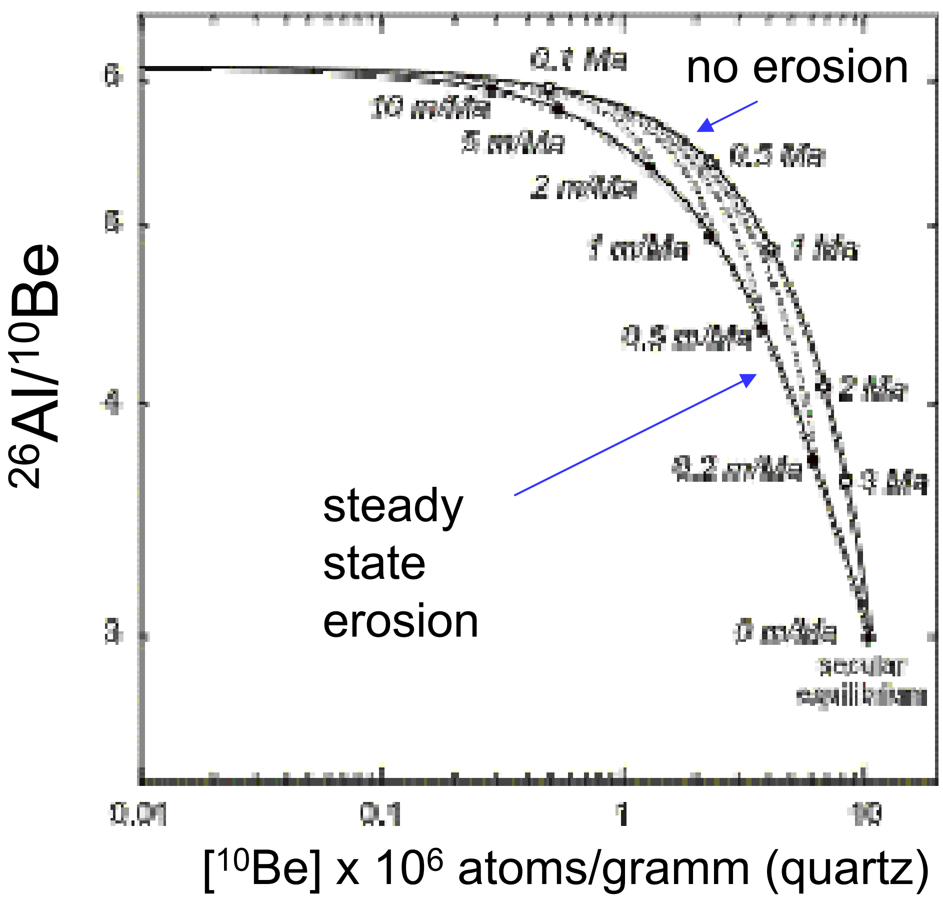



$^{26}Al$ is produced six times faster than $^{10}Be$, but $^{26}Al$ decays more quickly (half-life = 0.71 Ma) than $^{10}Be$ (half-life = 1.5 Ma)




The line is the isotopic trajectory of non-eroding sample exposed continuously at the surface. Numbers to right of curve are exposure ages.
Trajectory ends at saturation where in situ production is equal to decay. In reality, saturation is rarely reached as nuclides are lost by surface erosion.

# Banana plot 2/2




Continuously exposed samples fall on the curve connecting the open circles labelled with exposure time (same as in last figure)

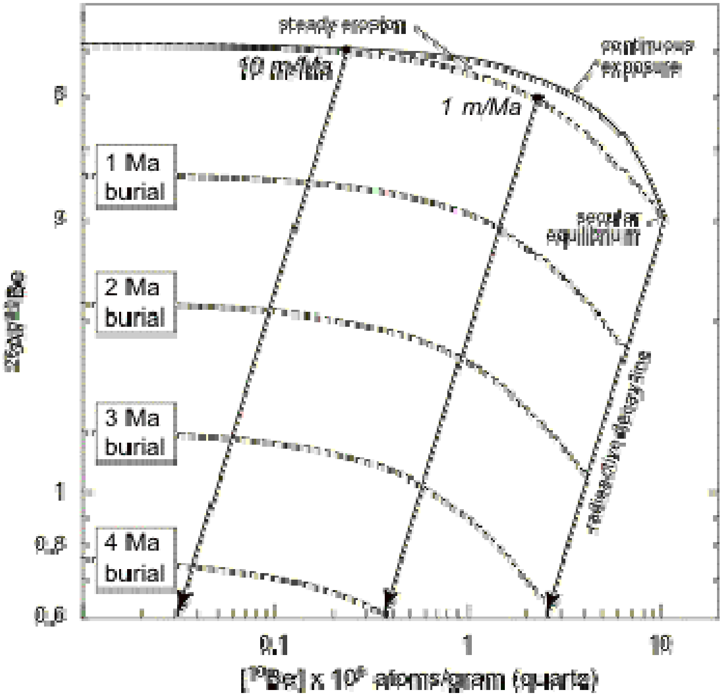
Steadily eroding samples lie on the lower curve connecting the labelled steady-state erosion end points (solid dots).

Dashed curves show the trajectory of samples within the $^{10}Be$ concentration vs. $^{26}Al/^{10}Be$ space for the given steady-state erosion rates.

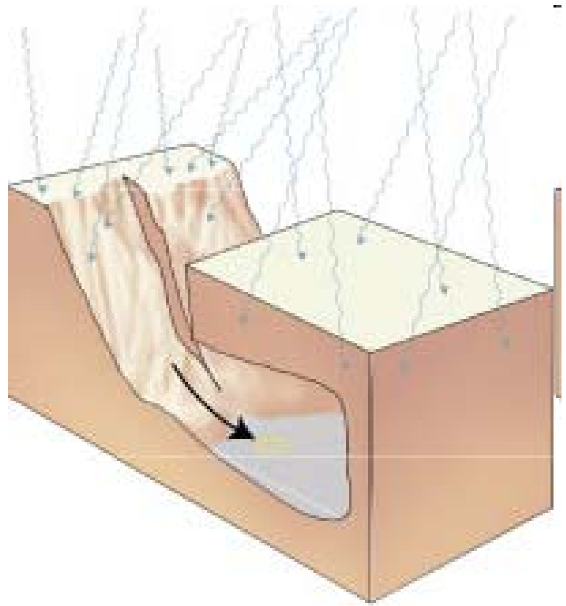
Samples that have been shielded will plot below the "*banana- window*" i.e., below the line of steady-state erosion

# Burrial dating

Burrial dating plot




A mineral with no burial history should plot between the steady erosion and continuous exposure curves (i.e., in the “banana-window”)



For completely buried and shielded minerals, the $^{26}Al/^{10}Be$ decreases along a line parallel to the solid "radioactive decay line".

Measured $^{26}Al/^{10}Be$ ratio in a sample determines the burial time, and can also be used to calculate the pre-burial erosion rate.