

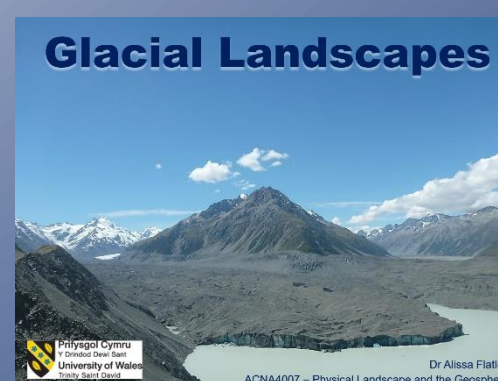
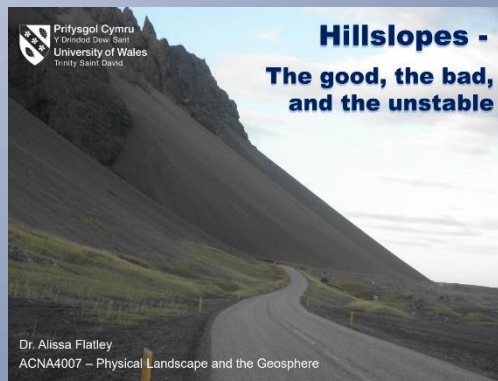
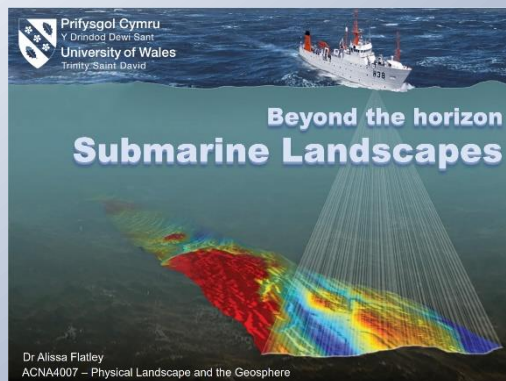
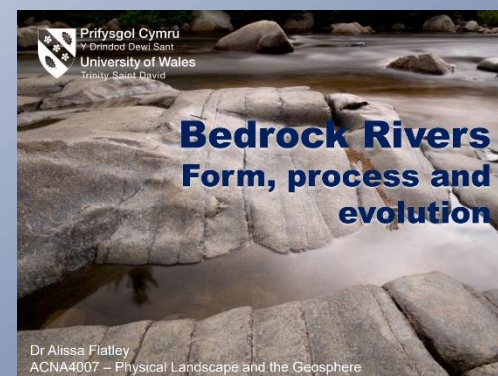
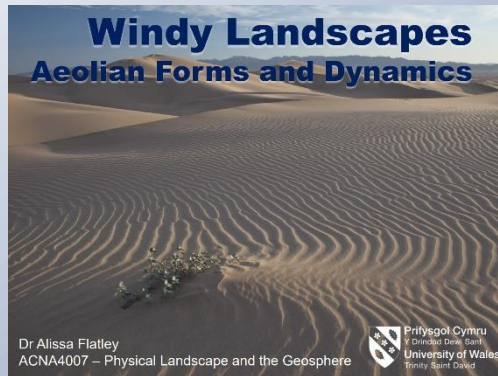
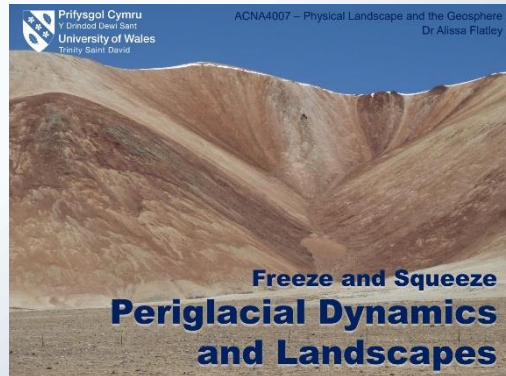
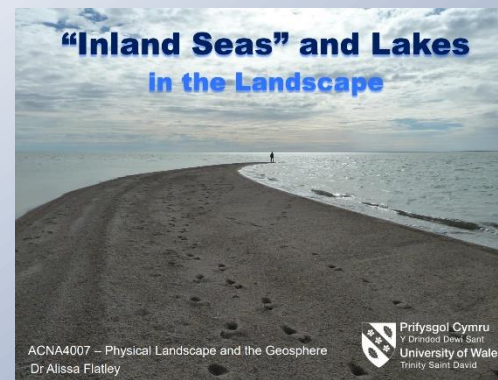
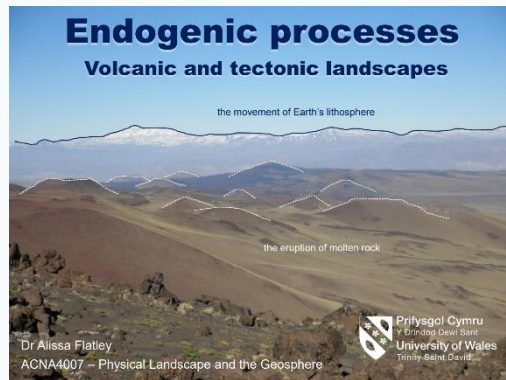
Geochronology

A short introduction to dating landscape processes

Dr Alissa Flatley
ACNA4007 – Physical Landscape and the Geosphere



Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
Trinity Saint David



???

- Modern landscape processes vs landscape evolution
– rates and dates needed...

Introduction

1



How fast and when are rocks forming?

3

When did erosion event happen?

How fast are landscapes weathering?

2

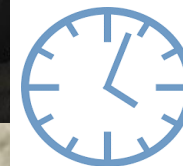


How fast are landscapes eroding?



How long are transport times?

4



When sediment deposition happen?

5

When did organism die?

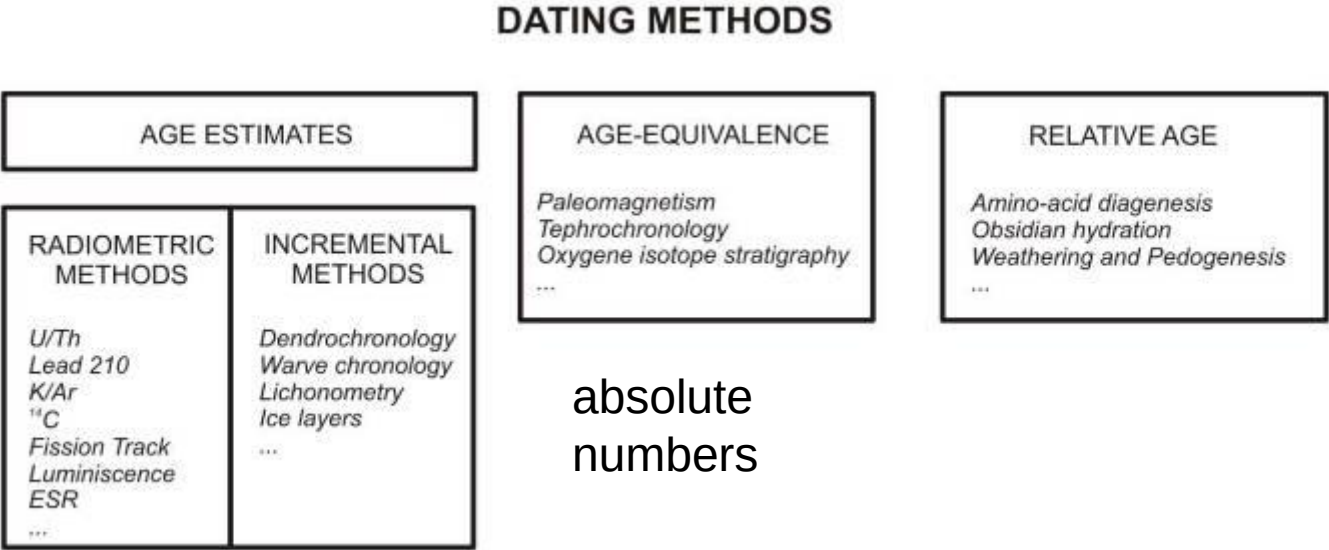


geochronology
toolbox

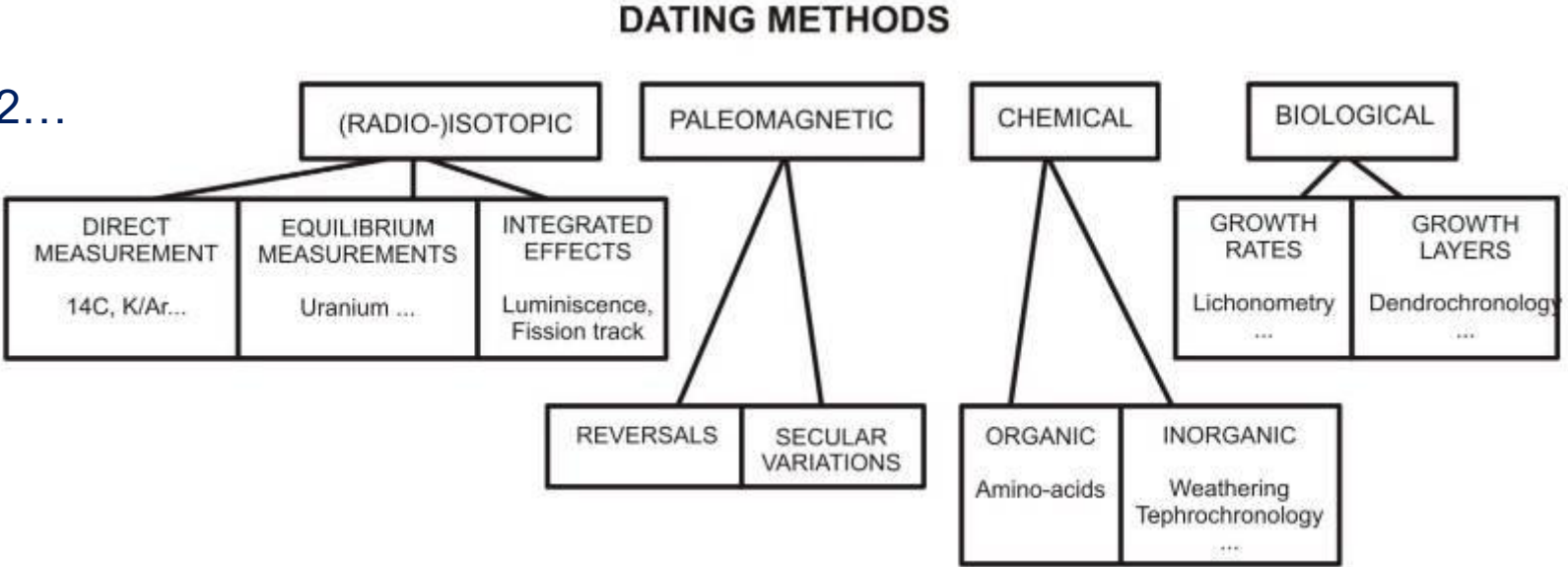


1. Rocks...
2. Weathering
3. Erosion
4. Transport
5. Deposition

1...



2...



Introduction



neither
accurate nor
precise



accurate but
not precise

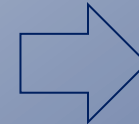


not accurate
but precise

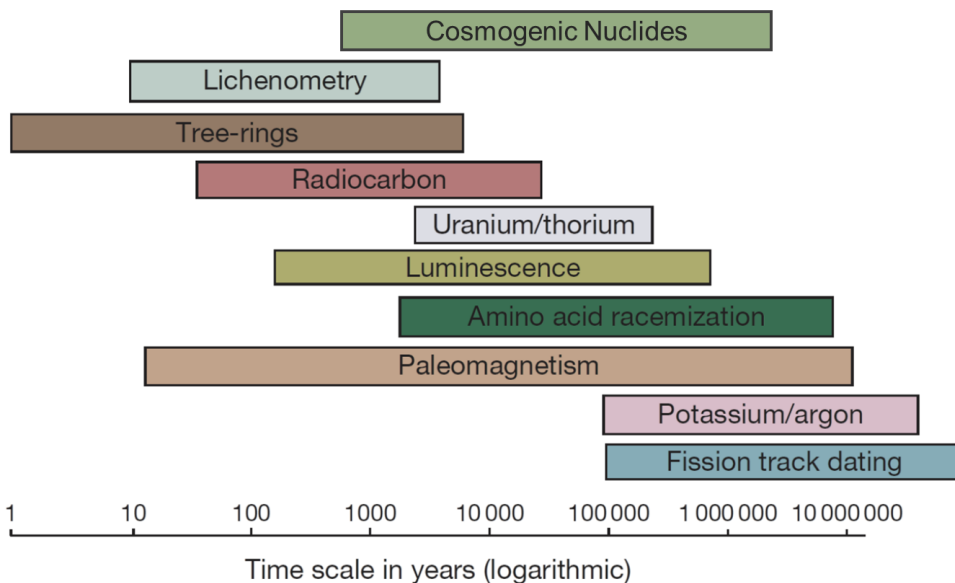


accurate and
precise

1. How good is the date – how large is the error... ?
(accuracy vs precision)



Tree-rings of
Huon Pine,
Tasmania



2. How good is the record
(temporal resolution)...

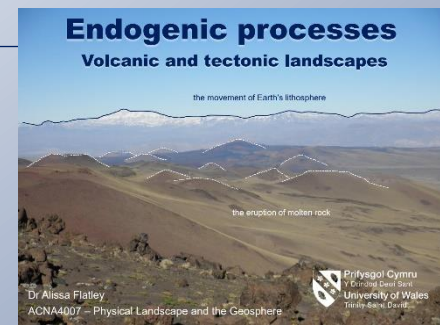
3. Is my timescale covered...

2 minutes...

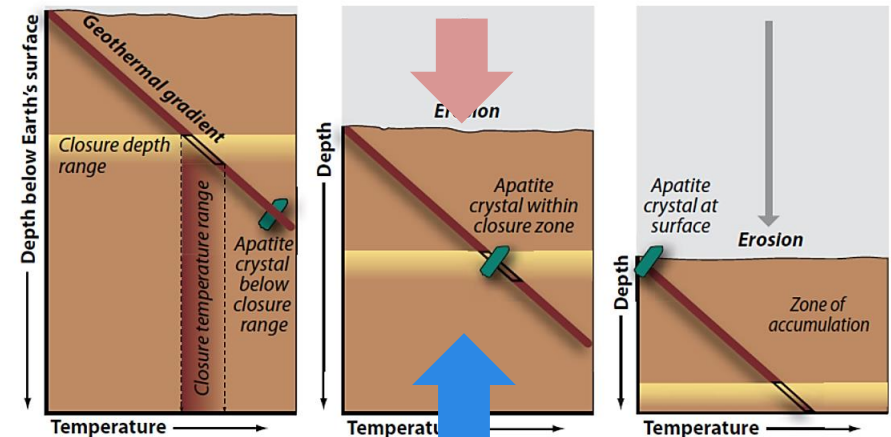
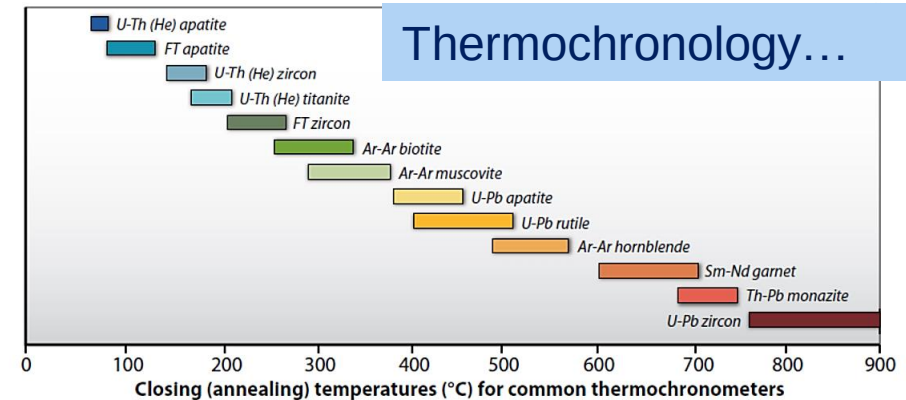


1 – Rock Uplift & Erosion

- Fission tracks produced by **alpha particle emission** during radioactive decay (e.g. U, Th, K)
- Deep below the surface in warm temperature fission tracks rapidly anneal (fade away)
- Uplift and exhumation – rock cools, the crystal enters **closure temperature range**, fission tracks anneal more slowly than at depth
- Minimum temperature of the annealing zone varies by element and mineral for different elements and different minerals
- Crystal moves above the closure temperature range, fission tracks cease to anneal – accumulate...



Thermochronology...

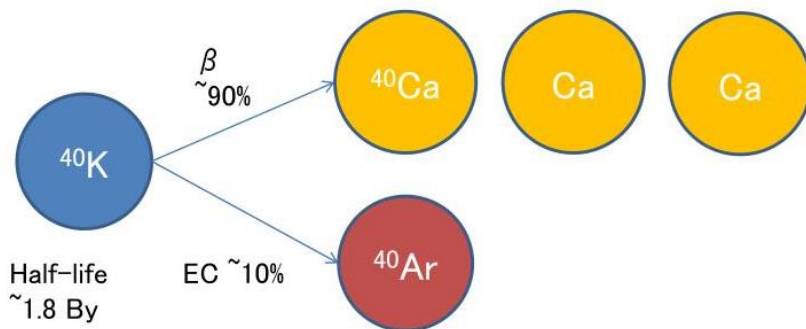


- The fission track or radiometric age of the crystal reflects the time it took erosion to remove the depth of rock overlying the closure temperature range

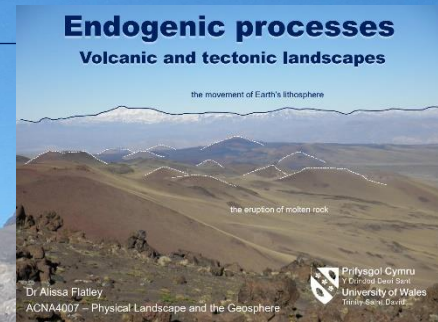
1 – Rock Formation (Volcanic)

- Dating volcanic rock... Potassium (K)-Argon (Ar) method
- Potassium is common element in minerals (e.g. micas, clay minerals, tephra, and evaporates), decays to ^{40}Ar (at known rate)
- In these minerals, decay product ^{40}Ar escapes the liquid (molten) rock, but starts to accumulate when rock solidifies (recrystallizes)

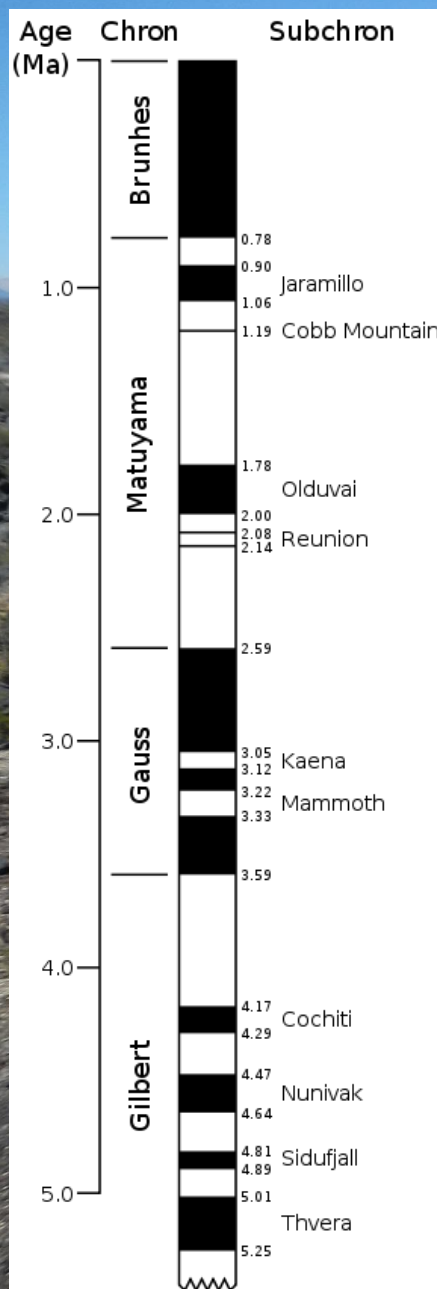
- Time since recrystallization is calculated by measuring the ratio of the amount of ^{40}Ar accumulated in mineral to the amount of potassium (^{40}K) remaining
- Long half-life of ^{40}K allows the method to be used to calculate the absolute age of samples older than a few thousand years (to billions!)



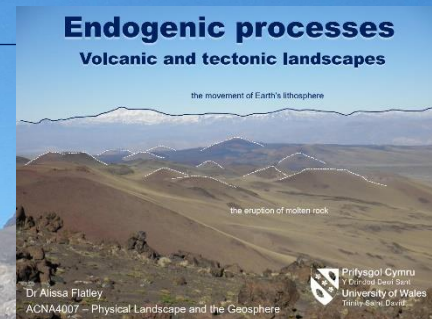
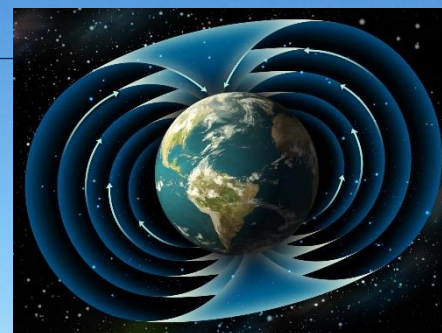
- Variation:** in the $^{40}\text{Ar}/^{39}\text{Ar}$ method, K is indirectly measured by the artificial generation of the ^{39}Ar isotope from K



1 – Rock Formation (Volcanic)



- Dating volcanic eruptions and rocks



- Earth's magnetic field and polarity changes at irregular intervals over time (flips from north to south pole);

- The age and pattern of these 'reversals' is known (from the study of sea floor spreading zones)

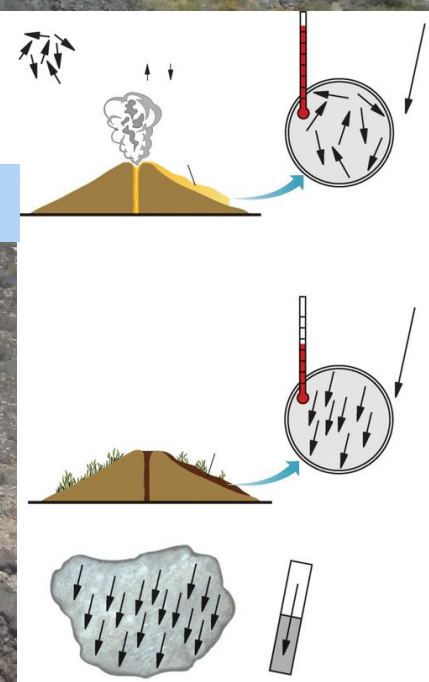
- Magnetization (alignment parallel to the ambient geomagnetic field) during lava cooling

Magnetostratigraphy...

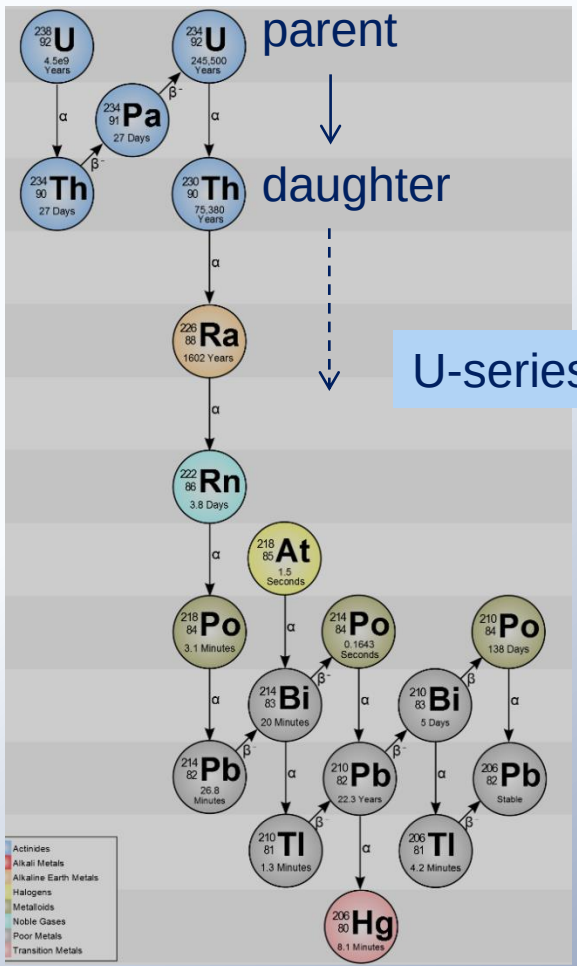


Also works for sediment

- determines polarity from declination and inclination of magnetic minerals in rocks (or sediment) and
- matches this against known pattern



1 – Rock Formation (Carbonate)



secular equilibrium
With time, daughter remains ~ constant (i.e. creation ~ decay): activity of the daughter becomes equal to that of the parent isotope...

U-series (U/Th dating)

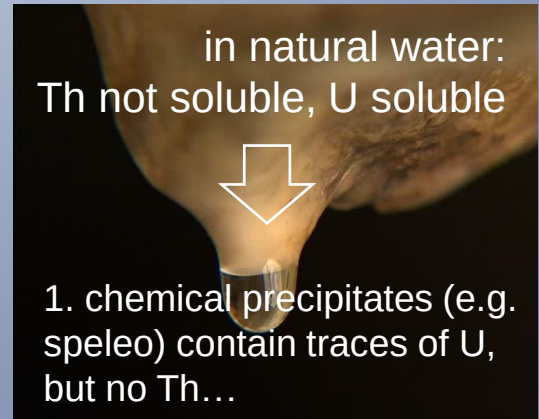
2. Then, ^{234}U in the sample (half-life 245 ka) slowly decays to ^{230}Th

3. ^{230}Th is itself radioactive (half-life 75 ka), so instead of accumulating indefinitely (as e.g in the uranium–lead system), ^{230}Th instead approaches **secular equilibrium** with its radioactive parent ^{234}U

of ^{230}Th decays p/yr
= number of ^{230}Th produced
= number of ^{234}U decays p/yr

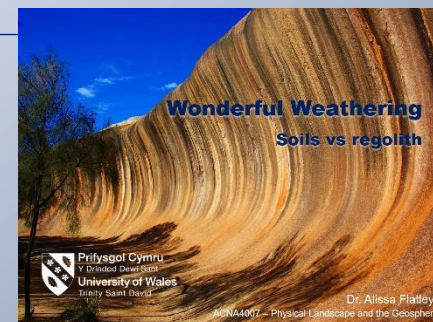
$^{230}\text{Th}/^{234}\text{U}$

4. U/Th technique does not measure accumulation of a stable end-member decay product, but calculates an age from the **degree to which secular equilibrium** has been reached (restored)



2 – Weathering...

How to date weathering?

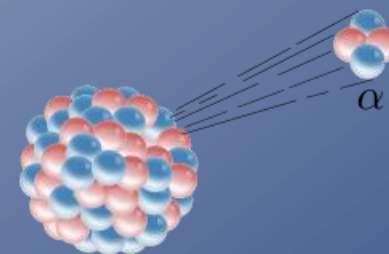


- Weathering leads to formation of clays and Fe oxy-hydroxides (e.g. goethite and hematite)



Weathering front
advances downprofile
over time

- Minerals contain U and Th that decay to Pb (through distinct radioactive decay series)
- Alpha decay - atomic nucleus emits an alpha particle (i.e. helium nucleus)

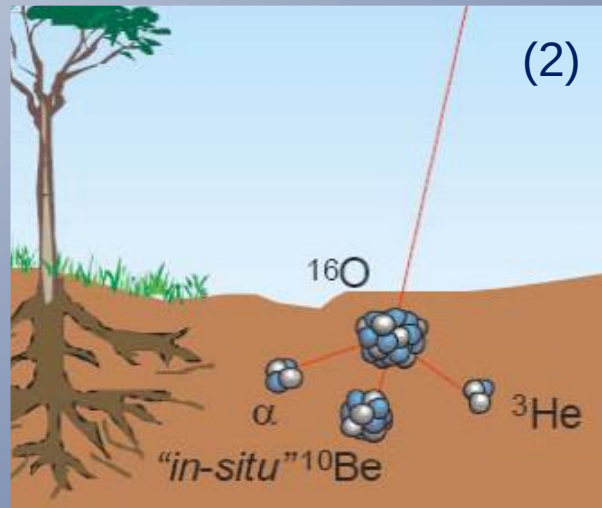
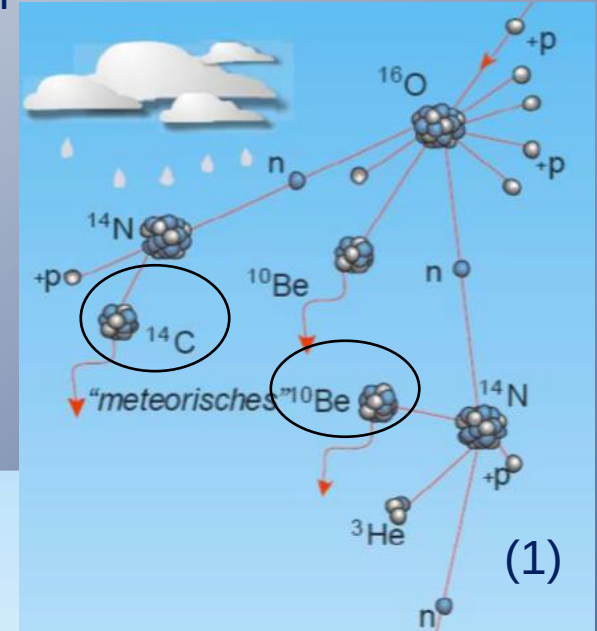


- He accumulates in mineral after the time of mineral formation (by weathering)
- (U–Th)/He dating
- ... measures He relative to U and Th to calculate “weathering age”

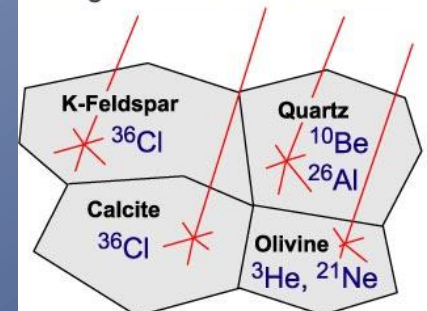


Nuclear cascade

- Cosmogenic Nuclide Dating...
- **Primary cosmic rays** (protons) interact with atomic nuclei in the upper atmosphere and produce neutrons (**secondary cosmic rays**)...
- which interact with atmosphere (1) and Earth surface (2)



Target Minerals and Nuclides



3 – Erosional Processes

Glacial Landscapes



Nuclide	Half-life	Other isotopes	Advantages/minerals used	Disadvantages
^{10}Be	1.51 Myr	^9Be	quartz resistant and ubiquitous	low production rate, ^{10}B interference in AMS generally restricted to quartz (no meteoric ^{10}Be)
^{26}Al	716 kyr	^{27}Al	high production rate quartz resistant and ubiquitous	restricted to quartz (low Al) accurate determination of ^{27}Al required
^{36}Cl	301 kyr	^{35}Cl , ^{37}Cl	low detection limit (low AMS Bkgd) any rock type, silicates & carbonates	complicated production ^{36}S interference in AMS accurate determination of total Cl required determination of rock composition required
^{14}C	5.73 kyr	^{12}C , ^{13}C	useful for short timescales quartz resistant and ubiquitous	short half-life atmospheric ^{14}C contamination
^3He	stable	^4He	high production rate useful for long time scales pyroxene, olivine	diffuses out of quartz or volcanic groundmass radiogenic/nucleogenic/magmatic correction beware pre-exposure
^{21}Ne	stable	^{20}Ne , ^{22}Ne	useful for long time scales, > 50 ka quartz, olivine, pyroxene	nucleogenic/magmatic correction high air background possible beware pre-exposure

- In-situ (terrestrial cosmogenic nuclides)

3 – Erosional Processes

Primary
Cosmic
Radiation

Secondary
Cosmic
Radiation

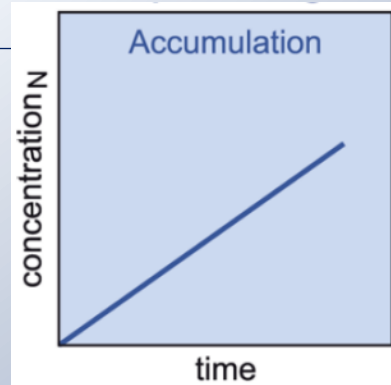


Erosion exposes new
bedrock surface



$$N = P * t$$

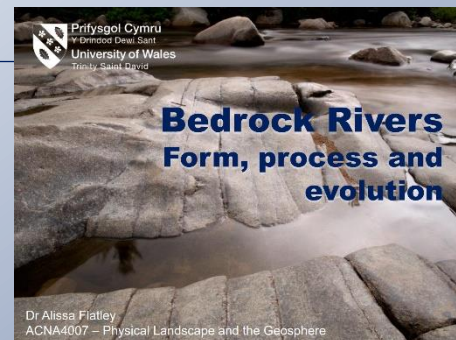
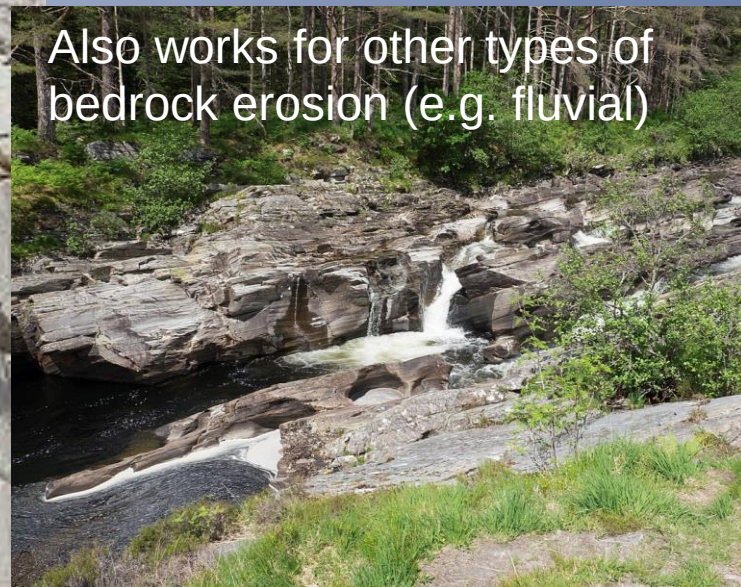
Glacial bedrock erosion



Surface Exposure Dating (with TCN):

- Nuclide concentration (N) “how much is in the mineral?”
- Production rate (P) “how fast has it accumulated?”

Also works for other types of
bedrock erosion (e.g. fluvial)

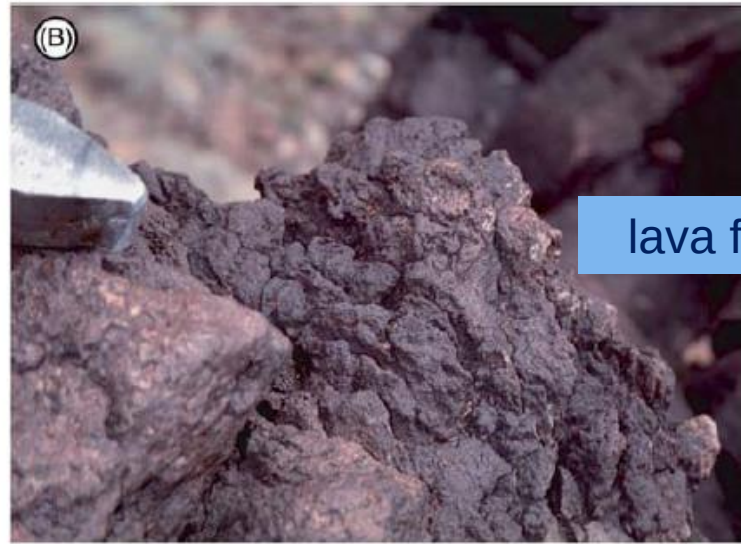


3 – Erosional and Exposure Dating

- Also works for freshly exposed bedrock surfaces via other, non-erosive events



rockfalls



lava flows



glacial moraines

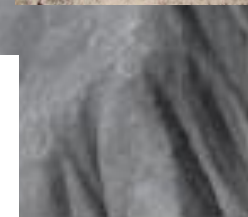
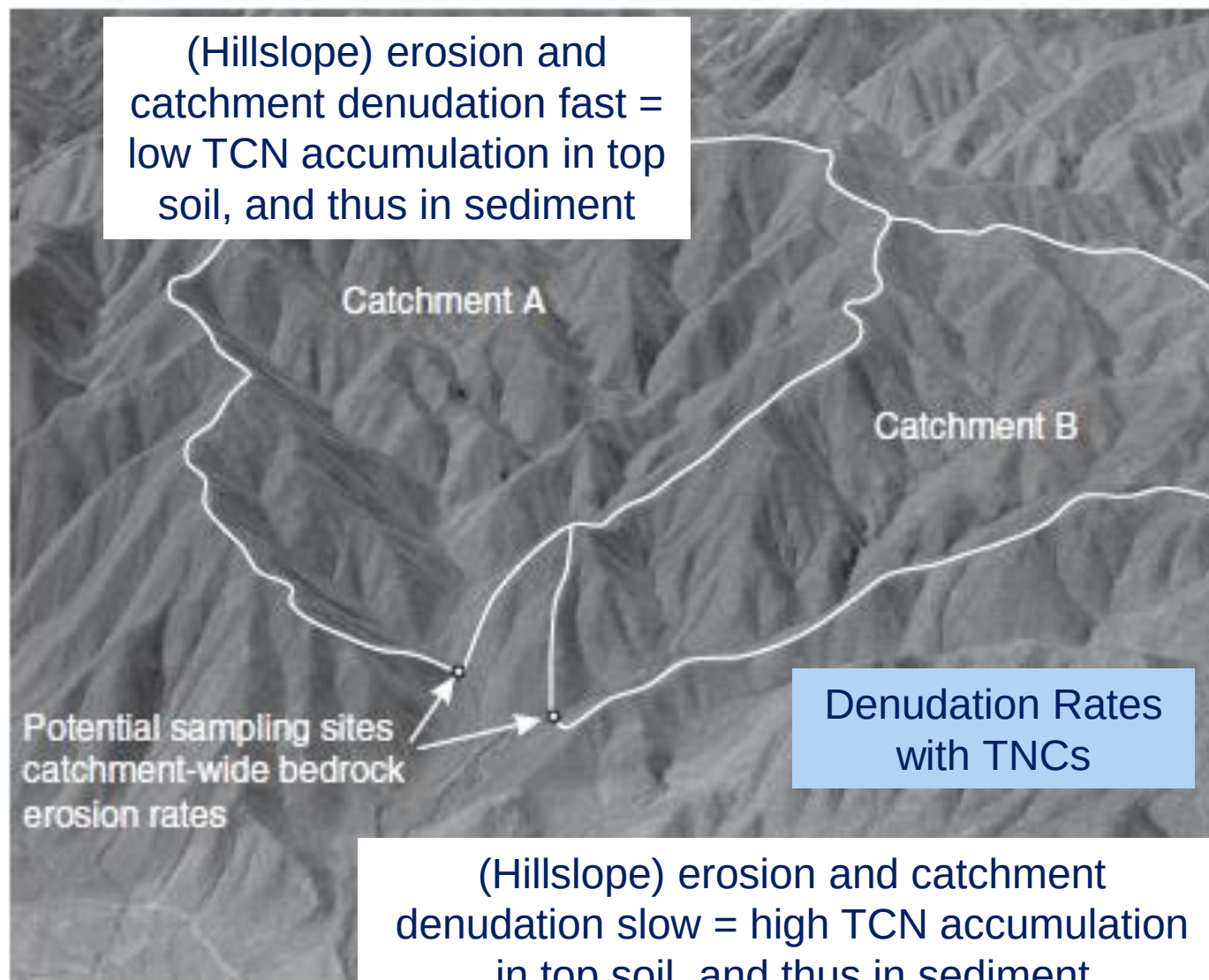
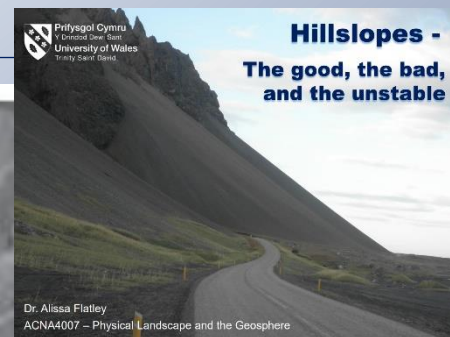


fault scarps

2 minutes...



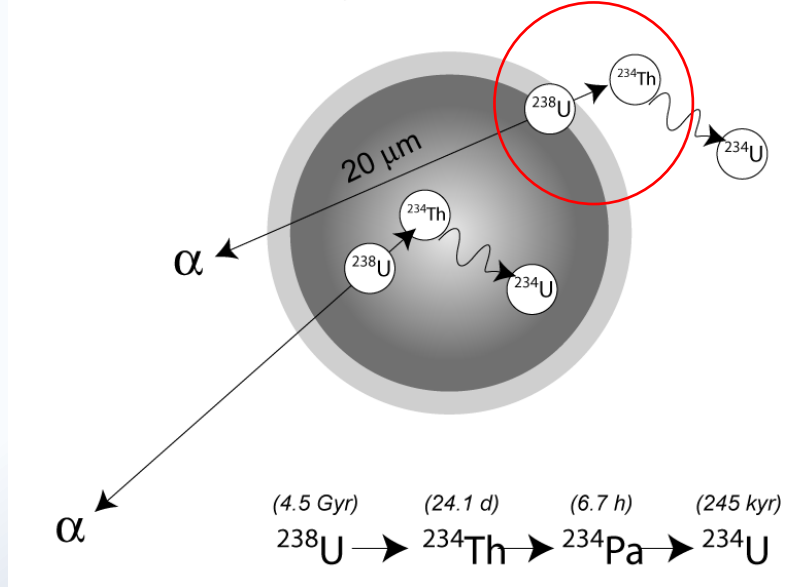
3 – Erosional and Denudation Rates



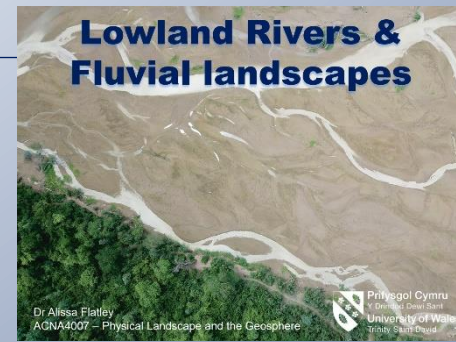
- For well-mixed stream sediment, the average nuclide concentration yields the (spatially) averaged (hillslope) **denudation rate in the watershed** ...Representative?

4 – Sediment Transport Rates

Recoil distance $\sim 0.03 \mu\text{m}$

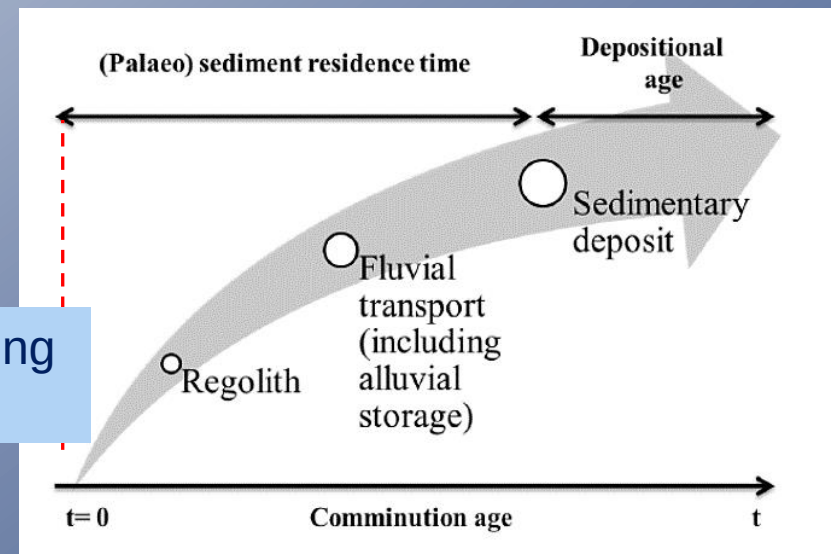


- Recoil effect (relative depletion of ^{234}U) negligible for larger particles, but becomes measurable for particles $< 20 \mu\text{m}$
- **Comminution** - reduction of solid materials from one average particle size to a smaller average particle size, by crushing, grinding, and other processes



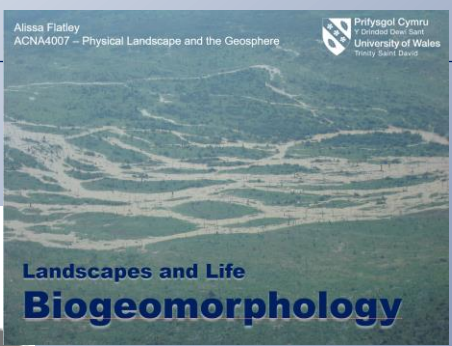
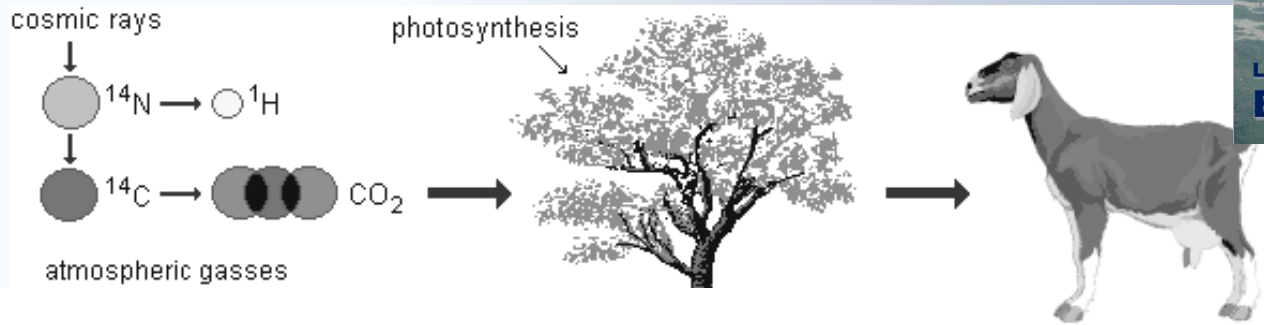
- ^{238}U vs ^{234}U determines **comminution age**, i.e. the formation of fine-grained sediments by chemical or physical weathering
- Combination with depositional chronologies = residence and transport times

Comminution dating approach

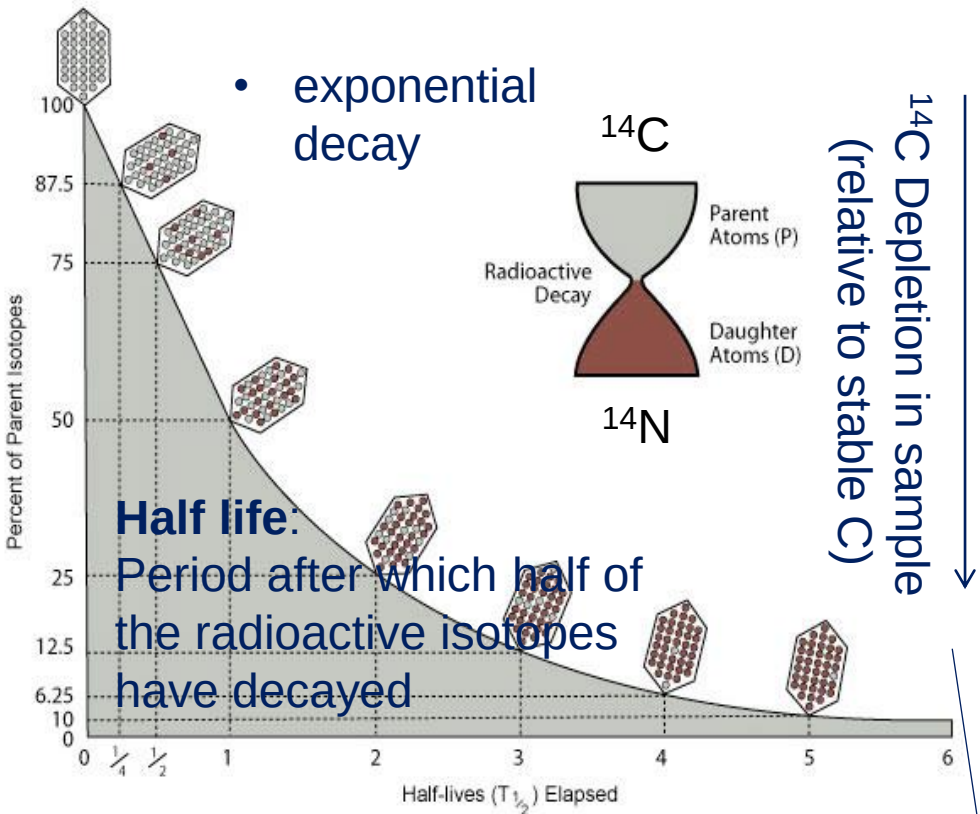


5 – Depositional Ages

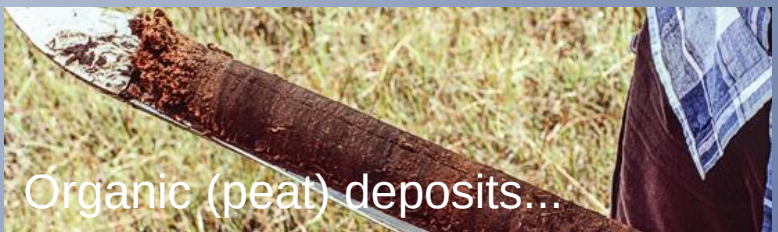
- ^{14}C production in the atmosphere (cosmogenic)



What is dated?

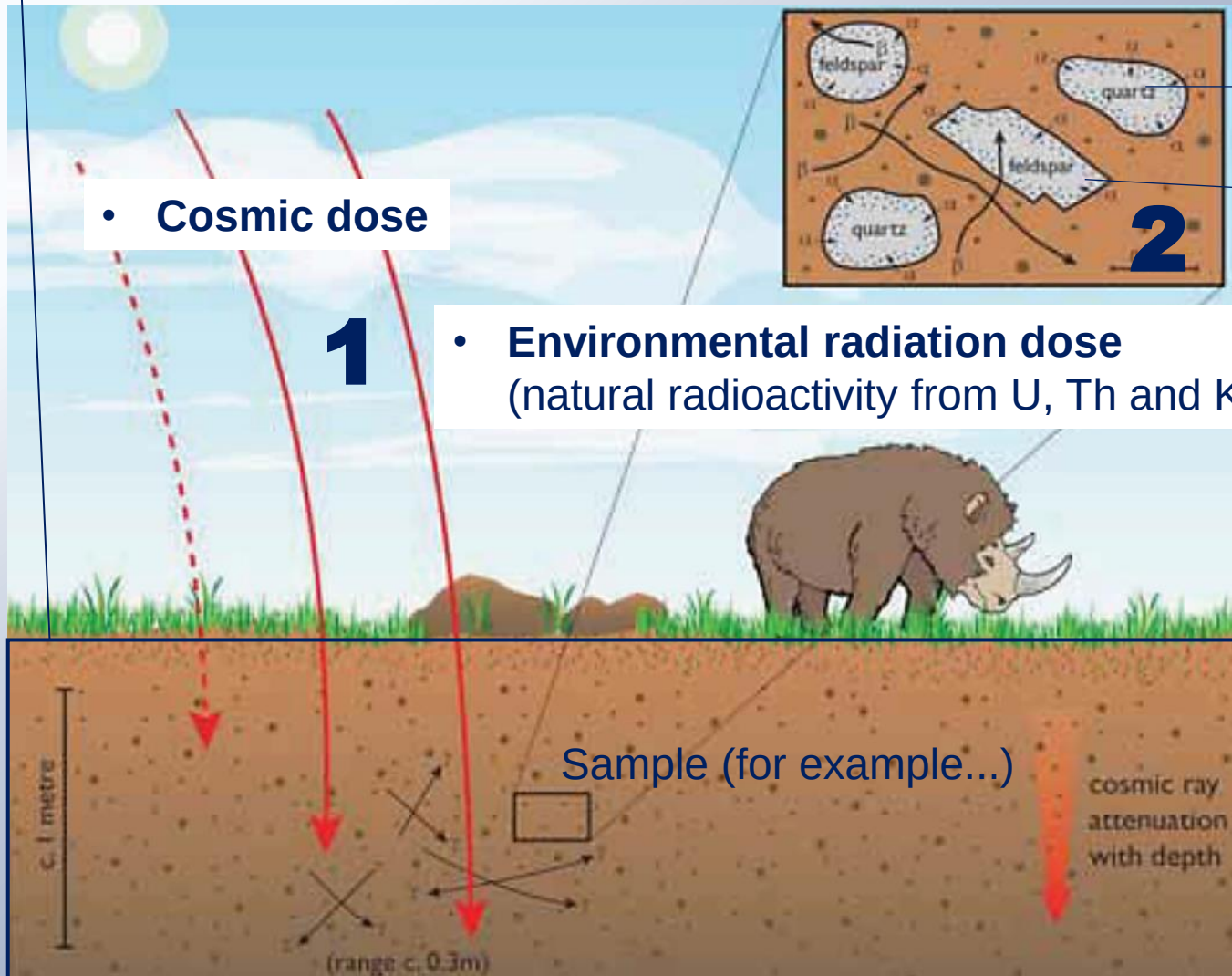


Radiocarbon Dating and Age



5 – Depositional Ages

- Sample deposition and burial... and then?

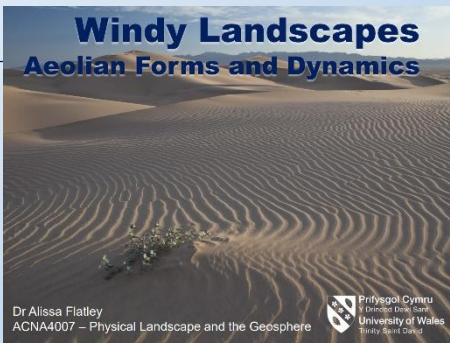


quartz

feldspar

- $1 + 2 =$
signal build-up
during burial
(electrons trapped in
crystal lattice)

Luminescence
dating



Aeolian transport



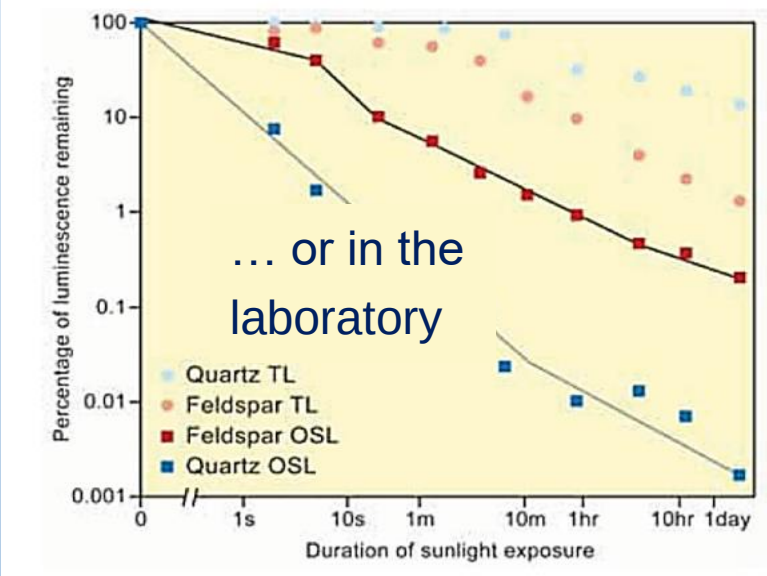
River transport



Alluvial / mass wasting

- Exposure to light (sunlight) = **Signal bleaching** (electrons released) during transport

Mineral $\approx$ battery (analogy)

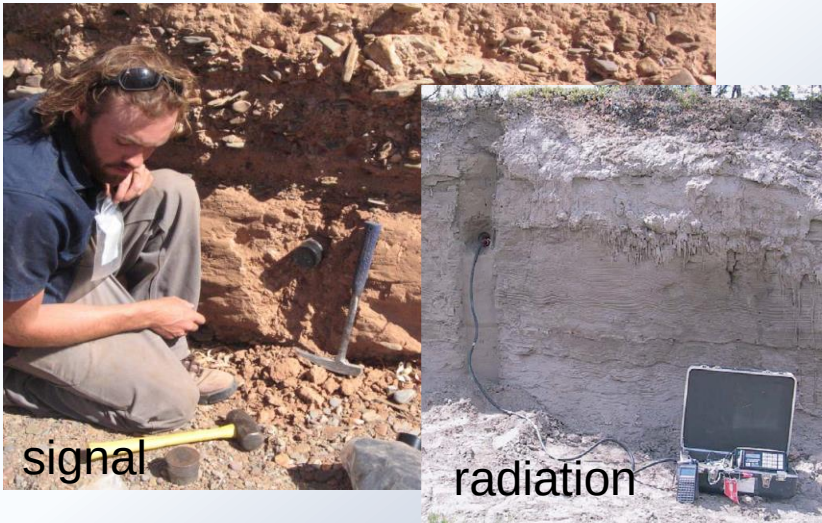
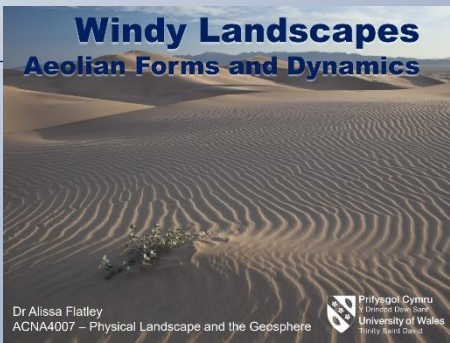


1. How much energy is stored?
2. How much energy charged per time?



How long did it take to get to the measured level of energy in the battery (mineral)?

5 – Depositional Ages



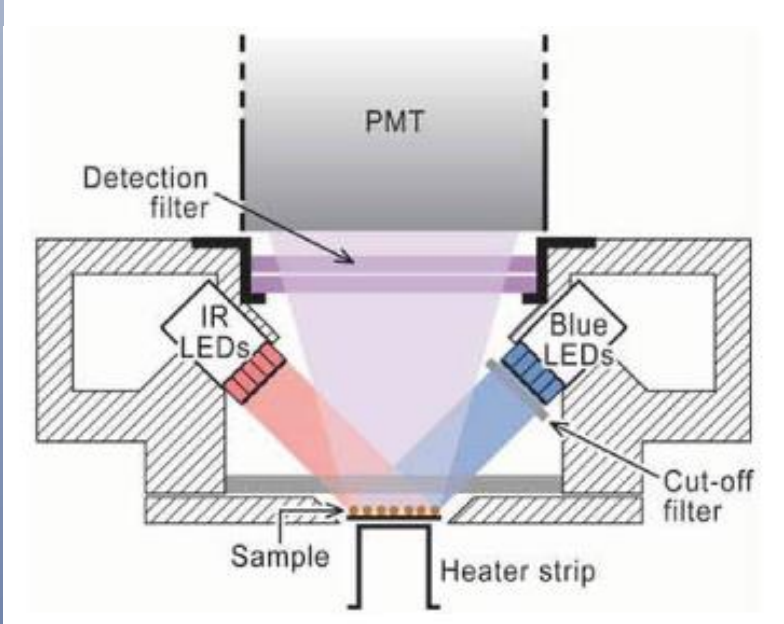
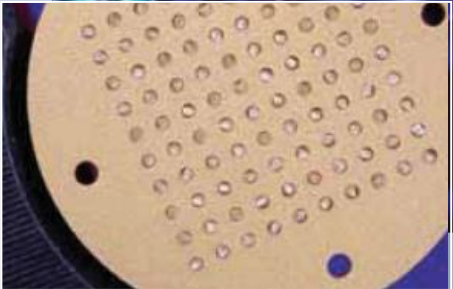
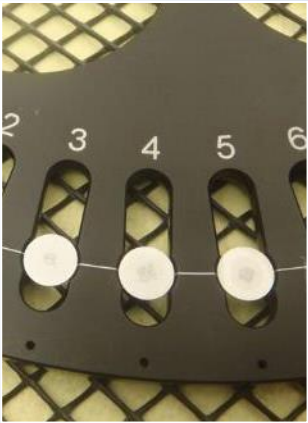
How much energy is stored?



$$\frac{1 \text{ Absorbed dose (Gy)}}{2 \text{ Dose rate (Gy a}^{-1}\text{)}} = \text{Age (a)}$$



How much energy charged per time?





- Australian Antique Bottle Forum

Thank you so much !

(a dry topic?? Hugely important in learning about Earth surface processes)