Top specialists in cosmogenic-nuclide geochronology

Three basic concepts

1. Trace nuclides (Be-10, Al-26, Cl-36, He-3, Ne-21) produced (in nature, mostly uniquely) by cosmic-ray-induced nuclear reactions.

2. The cosmic-ray flux essentially stops a few meters below the Earth's surface, so production only occurs at the surface.

3. The production rate is (for practical purposes) constant through time, and we know what it is.

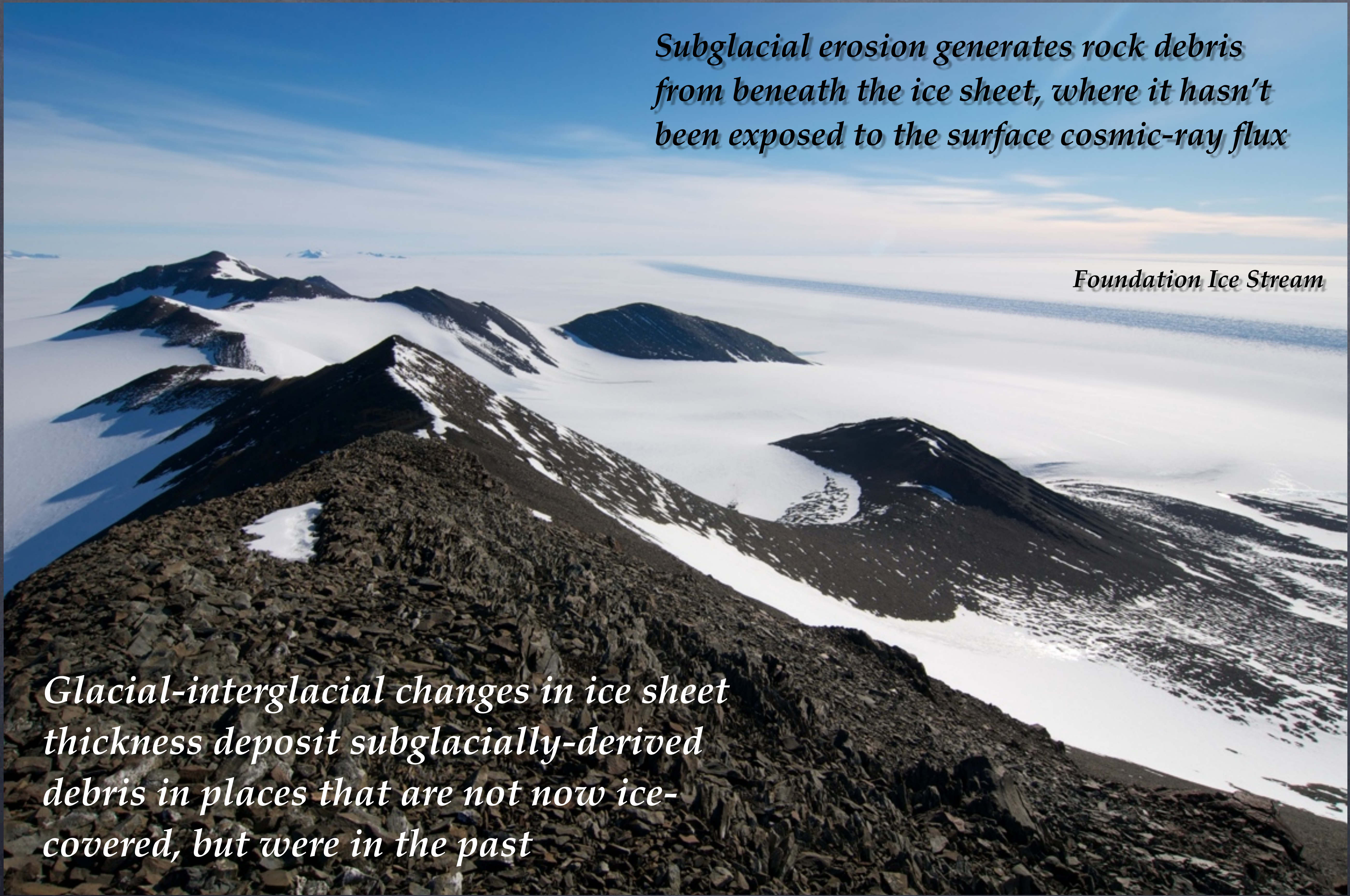
Geological processes act to bring rock from the subsurface -- where it's never been exposed to the cosmic-ray flux -- to the surface.

Quartz (SiO_2)

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

High-energy neutron spallation reaction recorded in photographic film emulsion

For example, Antarctic ice sheet change

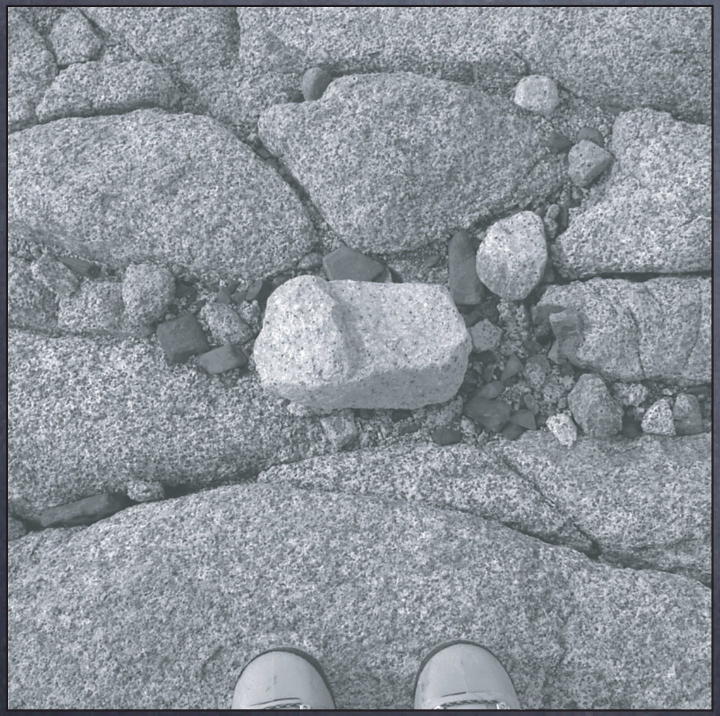


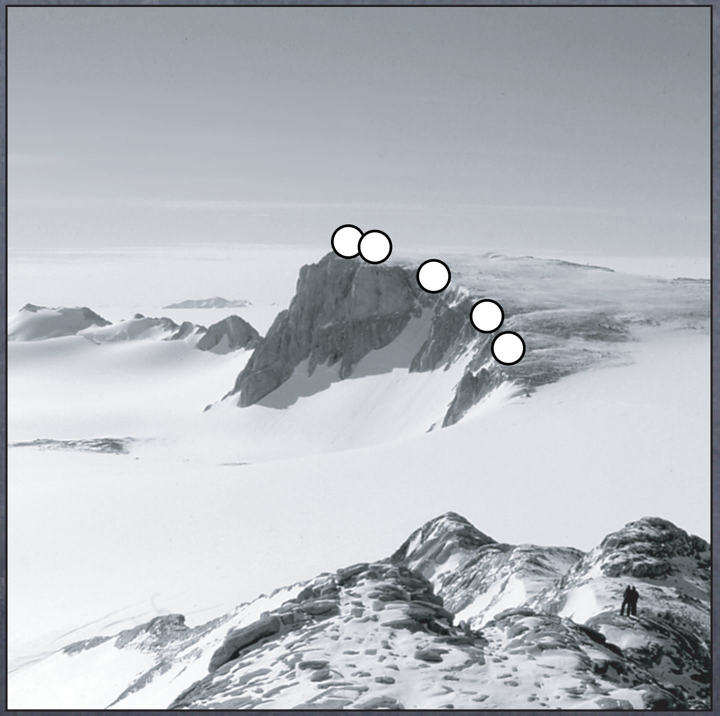
How exposure dating is supposed to work:

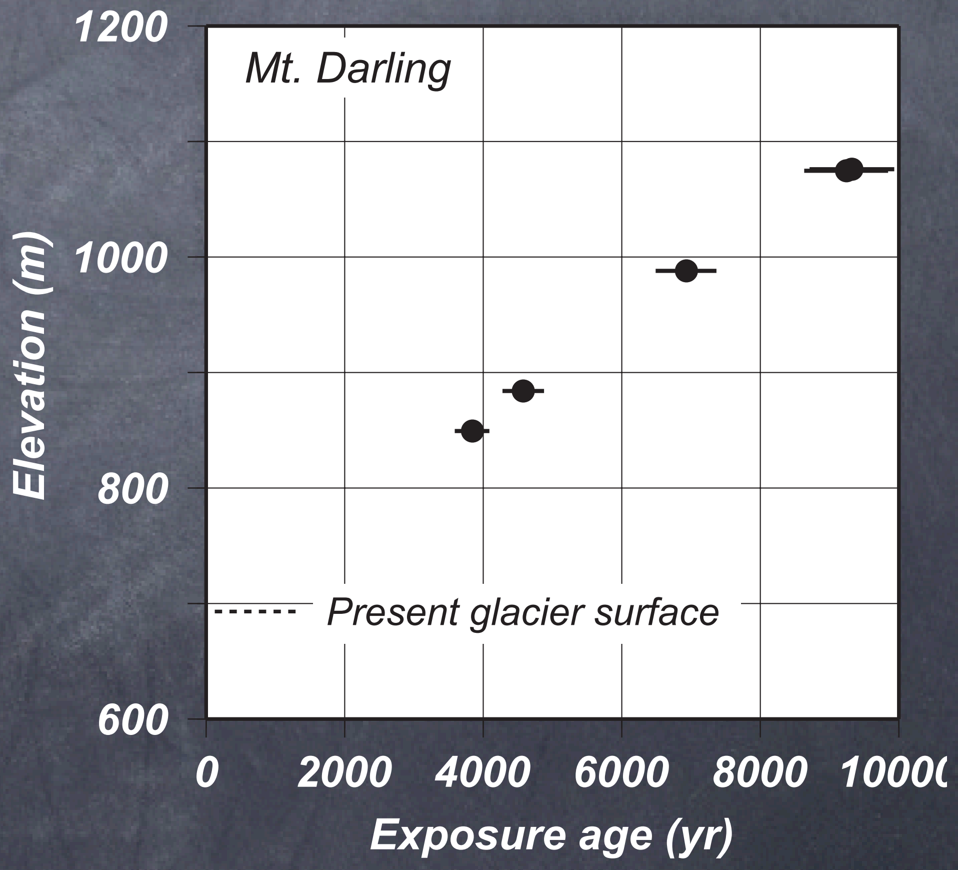
1. Collect glacially transported rocks from a range of elevations on a nunatak

2. Measure cosmogenic-nuclide concentration N; compute exposure ages: $t = N/P$

3. Exposure ages yield an ice surface lowering history







(Example from the Ford Ranges of West Antarctica; Stone, others, 2003)

Laurentide Ice sheet recessional moraines, Connecticut

Cordilleran Ice Sheet recessional deposits, Puget Sound

Eastern Sierras, CA

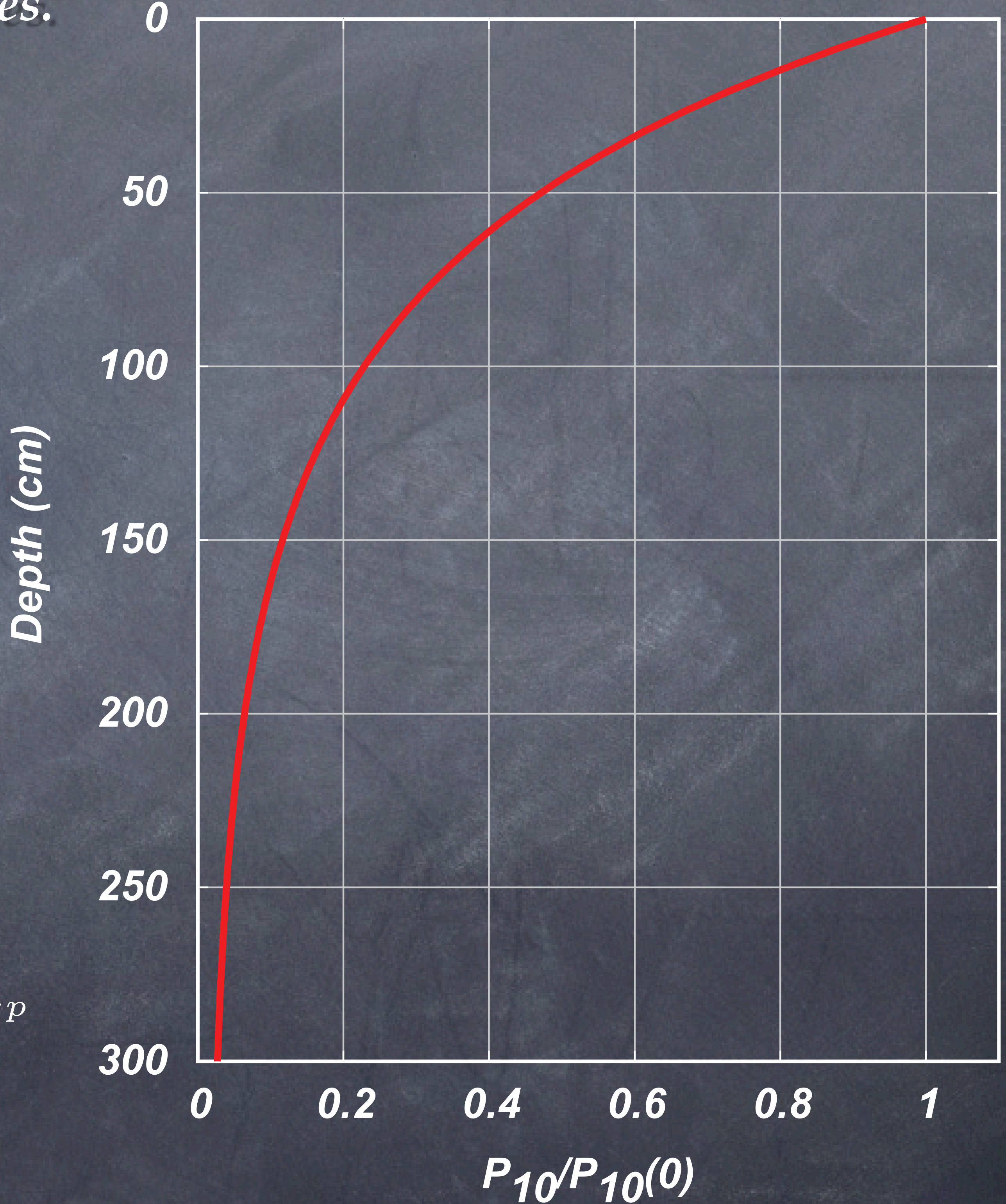
Mt. Rainier, WA

The opposite of exposure dating -- steady state erosion rates.

In simple exposure dating, the nuclide concentration is proportional only to the exposure time. Not so for eroding surfaces.

Think of steady erosion as rock being pushed up through the thin zone near the surface in which cosmogenic-nuclide production takes place. Then the nuclide concentration at the surface is directly proportional to the length of time that sample spent in the production zone, which is inversely proportional to the erosion rate.

$$N_{10,0} = \frac{P_{10,0}}{\lambda_{10} + \epsilon_0 \rho / \Lambda_{sp}} e^{-z\rho/\Lambda_{sp}}$$



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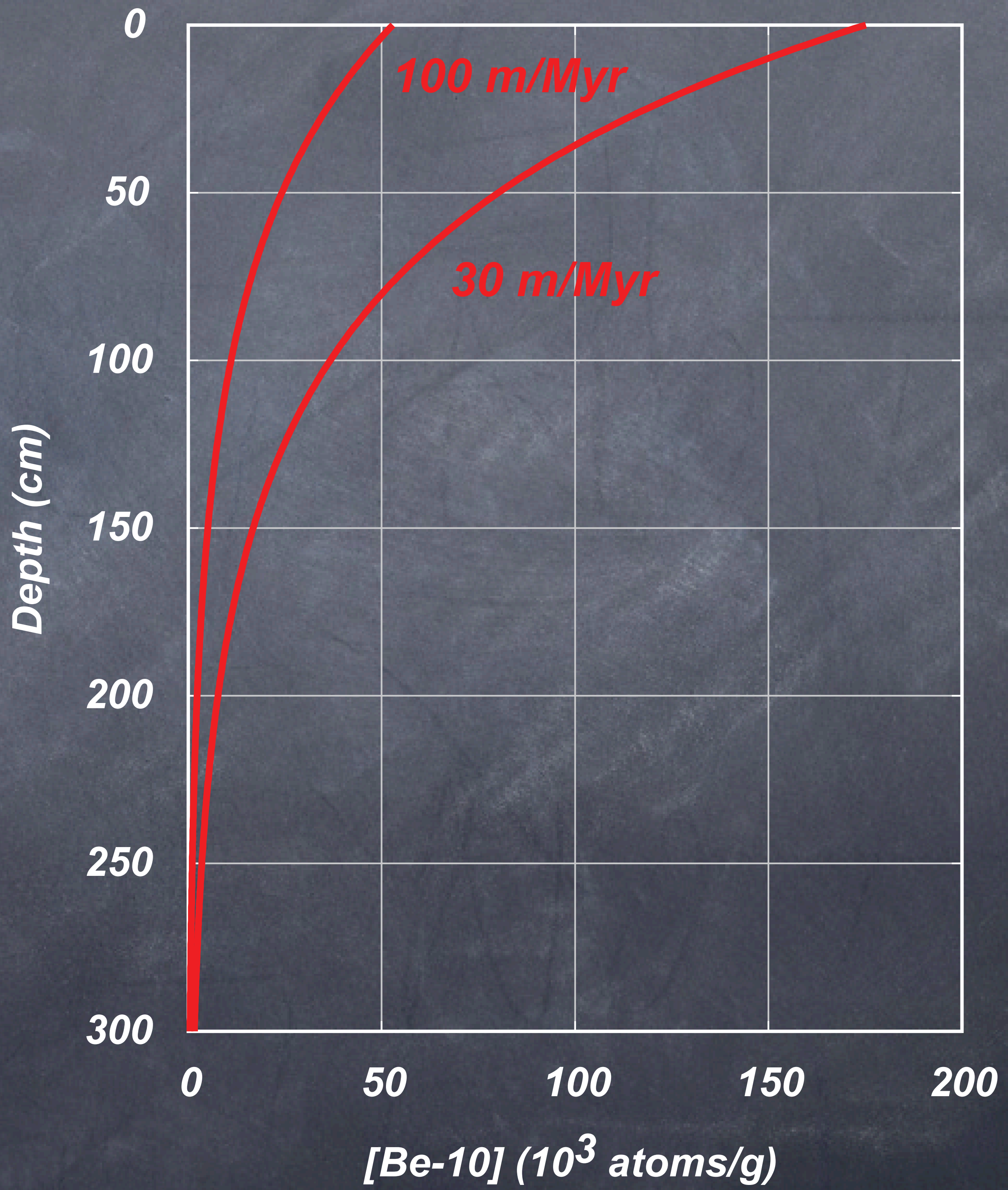
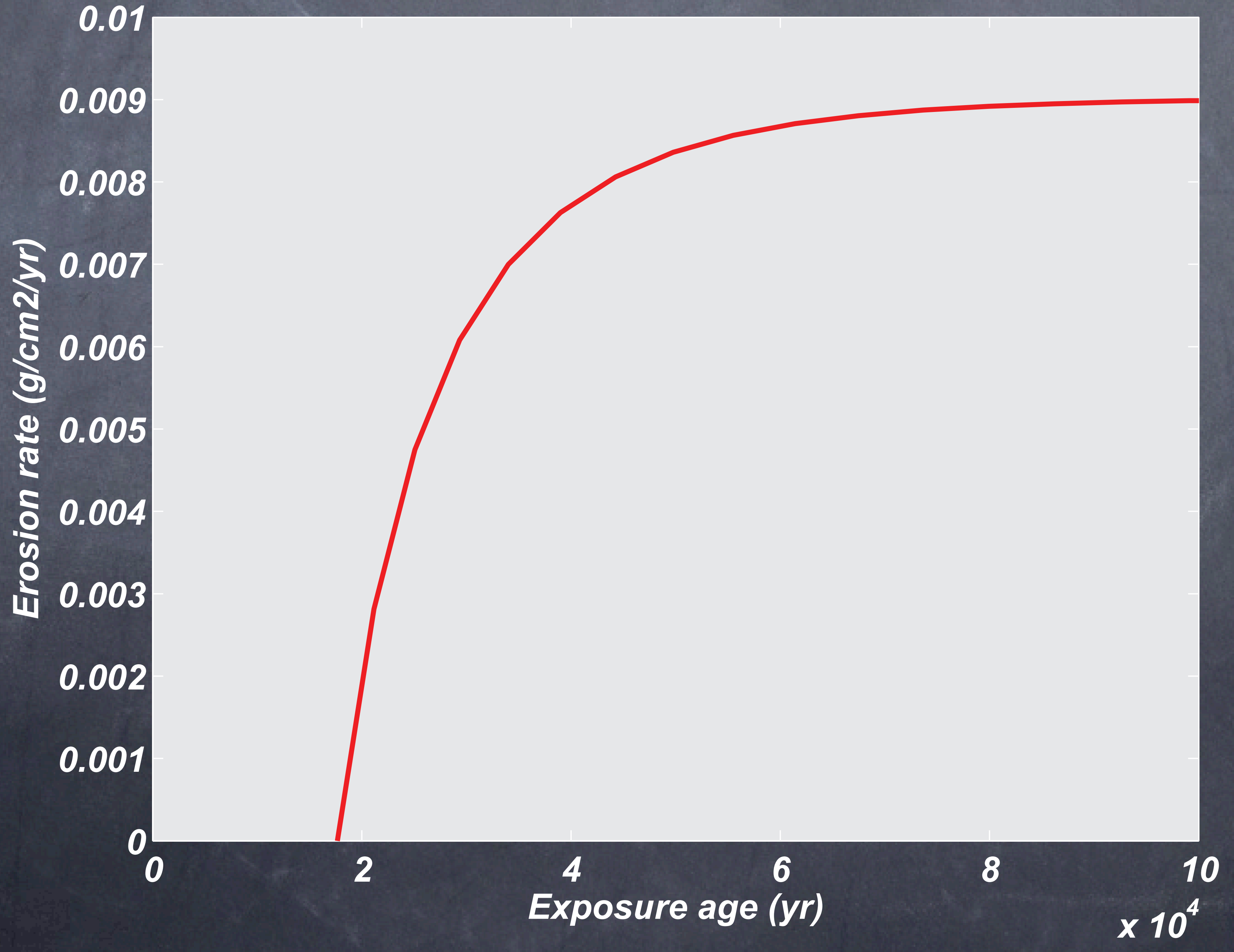


Nuclide concentration reflects residence time in production zone...

Which reflects both the exposure time and the erosion rate.

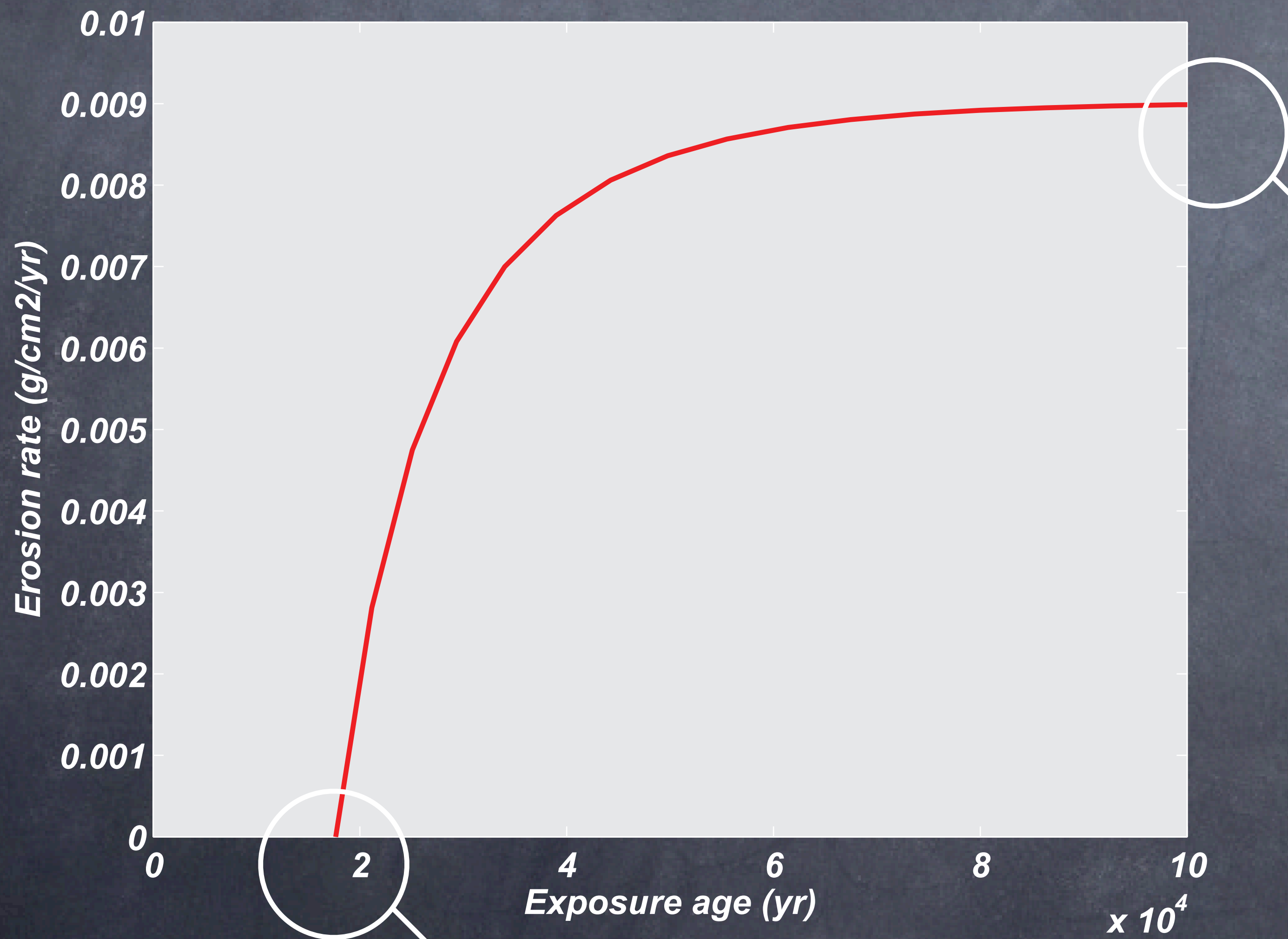
$$N = \frac{P}{\lambda + \epsilon/\Lambda}\left[1 - e^{-t_{exp}(\lambda+\epsilon/\Lambda)}\right]$$



Nuclide concentration reflects residence time in production zone...

In most applications, we assert infinite t, or zero E, based on geomorphic observations.

$$N = \frac{P}{\lambda + \epsilon/\Lambda}\left[1 - e^{-t_{exp}(\lambda + \epsilon/\Lambda)}\right]$$



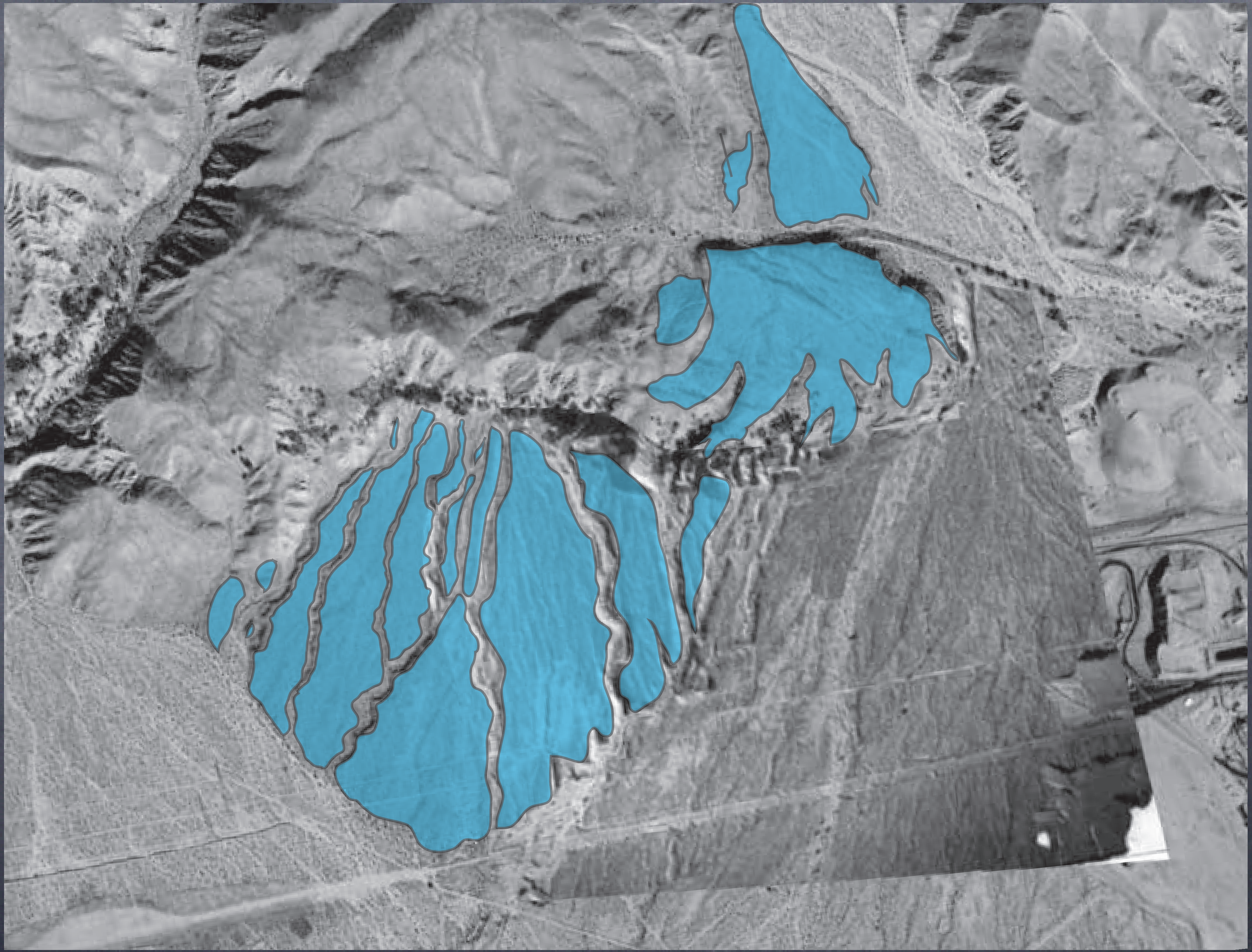
Steadily eroding landscapes: eroding long enough to come to production-erosion equilibrium. 0.009 g/cm2/yr = 35 m/Myr.

Glacially transported boulders: no inheritance, no erosion. 17,000 years.

Offset alluvial fan at Biskra Palms, CA

Goal: age that the fan was emplaced. This constrains slip rate of San Andreas.

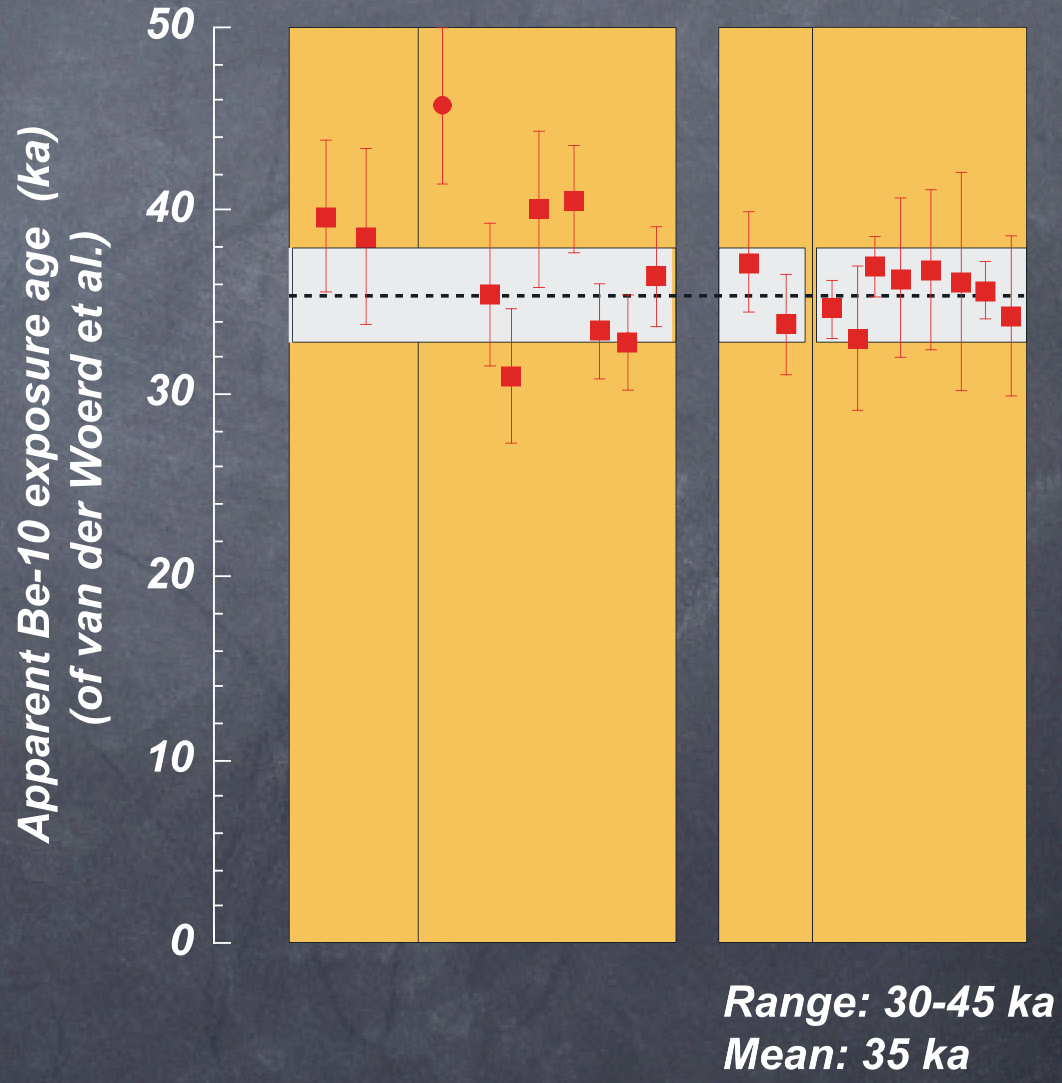
Three different studies attempted to date this with Be-10 measurements. Came up with incompatible conclusions.



From Behr et al., GSAB 09

Study of van der Woerd et al. (JGR 2006)

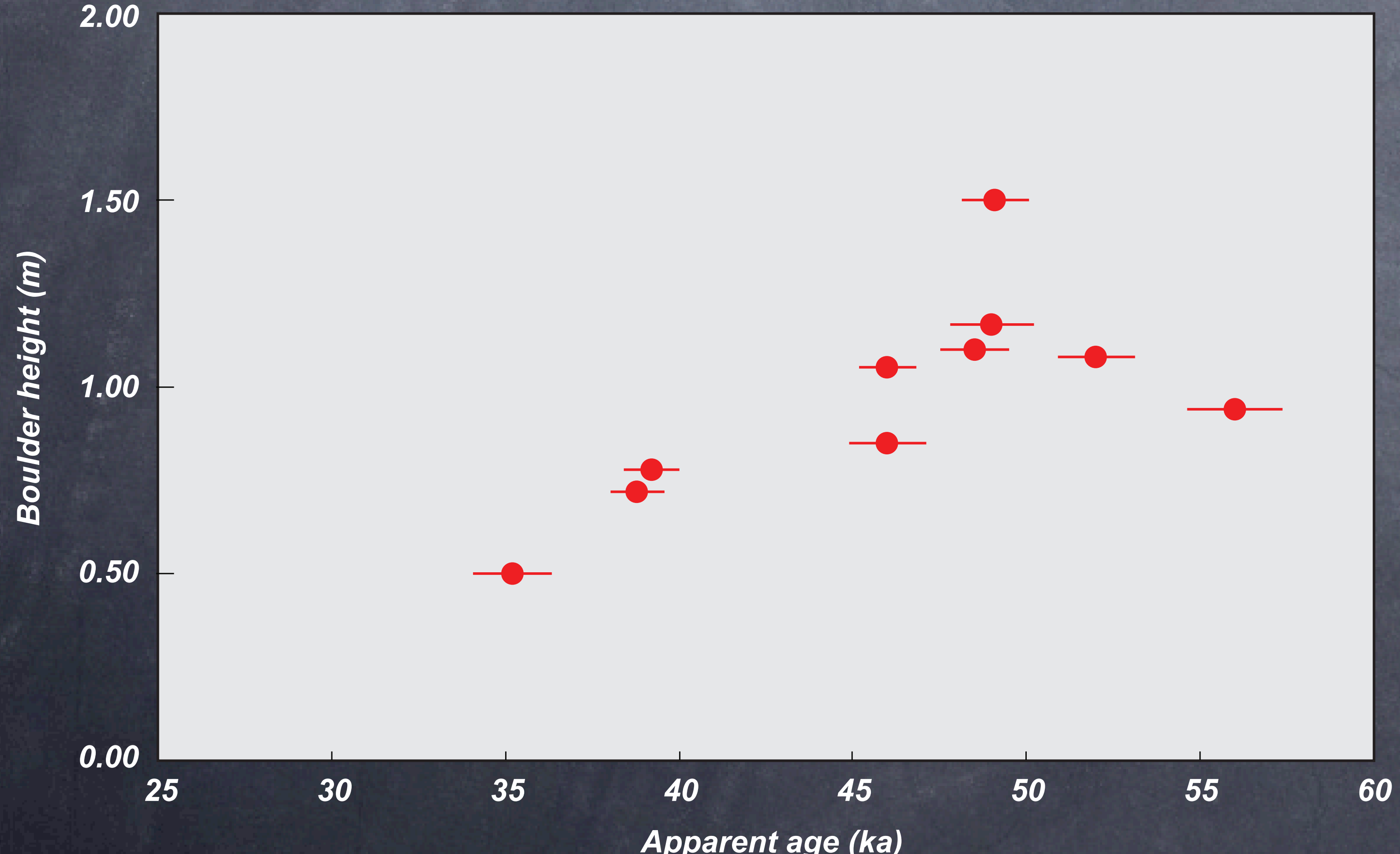
- Exposure-dated cobbles from fan surface
- Asserted that there was neither inheritance nor erosion, so the mean of cobble ages (35 ka) gives the age of the fan



From van der Woerd et al., JGR 06

Study of Behr et al. (GSAB 2009)

- *Exposure-dated boulder tops*
- *Interpreted height-apparent age relation to indicate erosion*
- *Concluded that older boulders (45-50 ka) best approximated fan age*

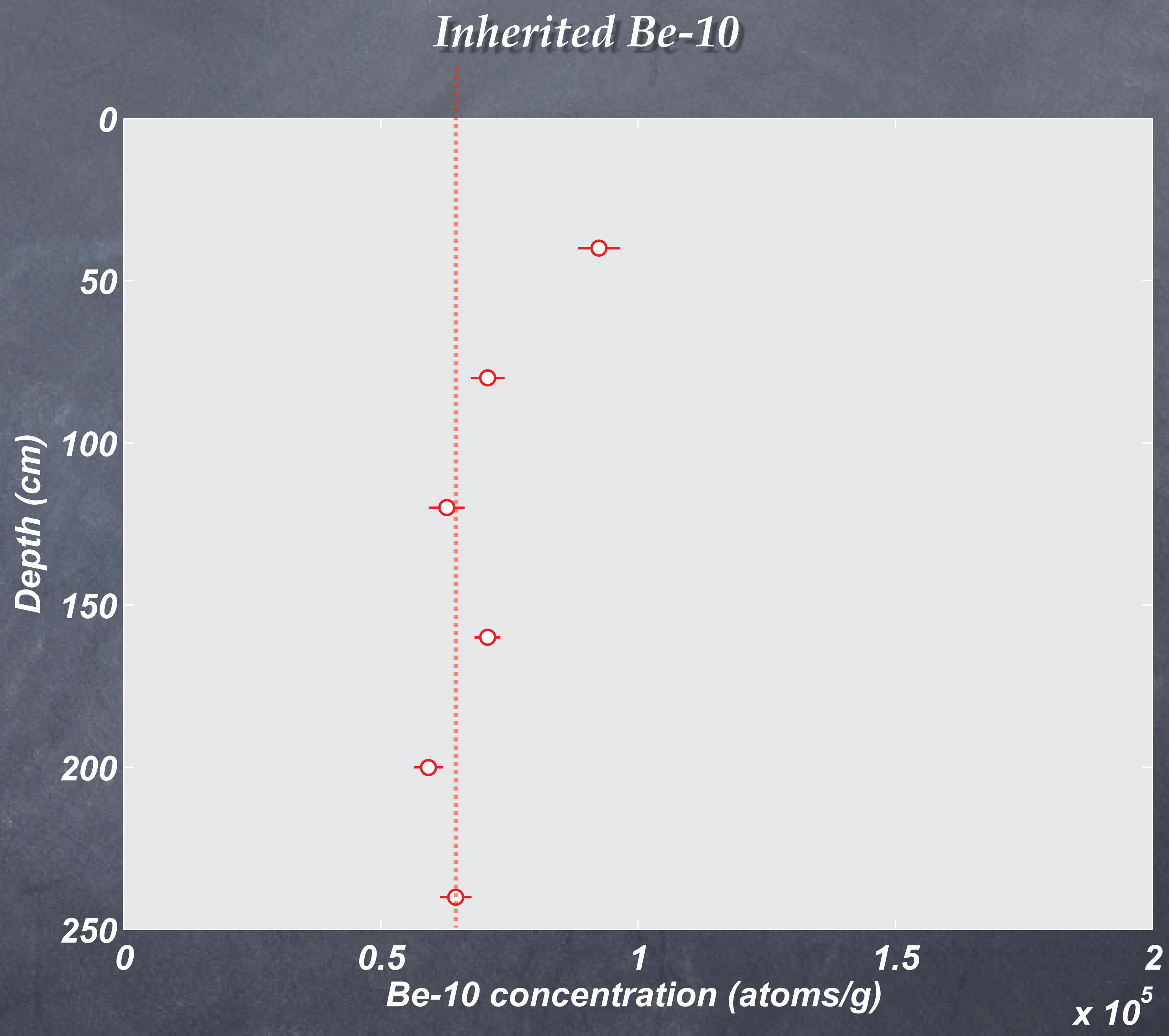


From Behr et al., GSAB 09

Depth profile by D. Rood

Be-10 concentrations converge to a constant value at depth, which represents inherited Be-10 present at the time of fan emplacment. Inherited Be-10 is a large fraction of the total Be-10.

Apparent surface age when inheritance is accounted for is 30 ka.



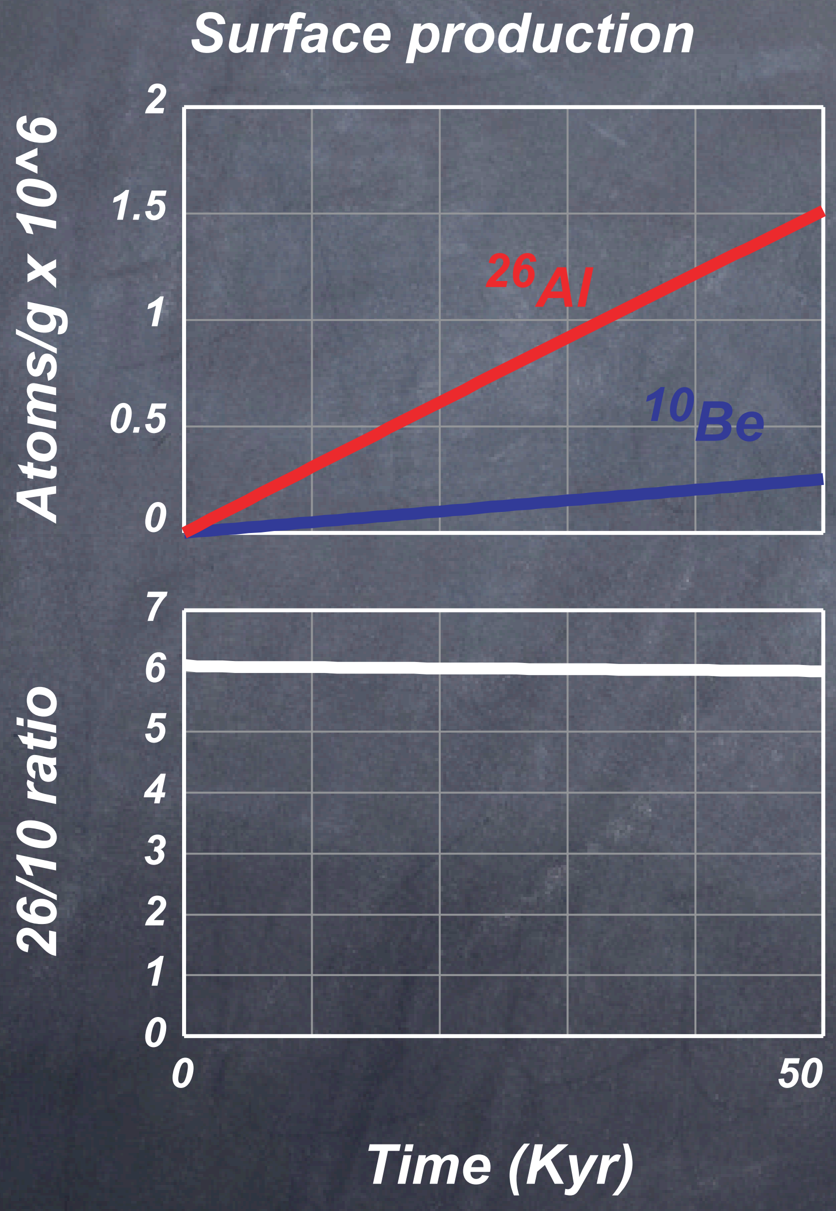
The rest of the talk

Brief introduction to one more application -- burial dating

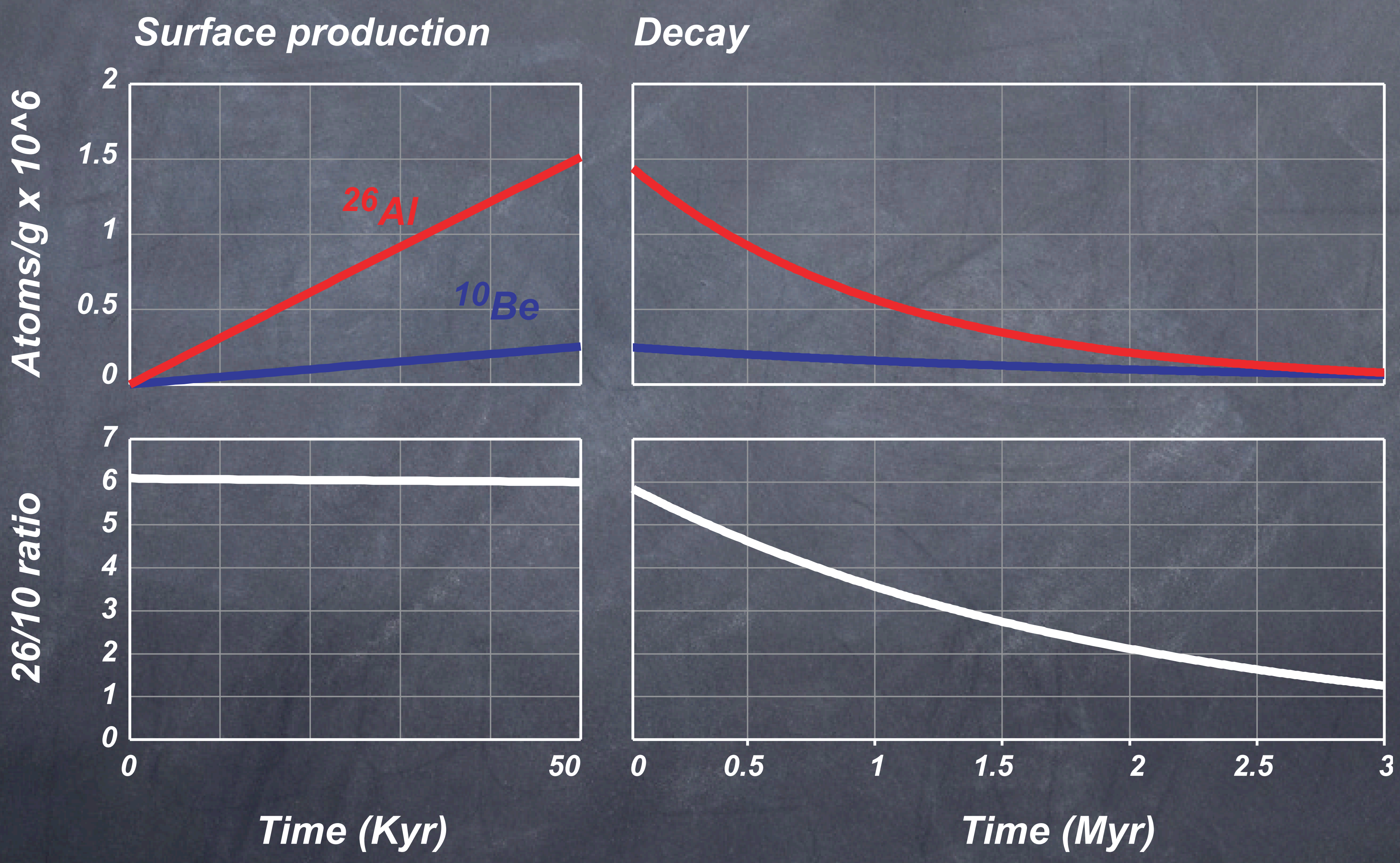
Nuclide alphabet soup

Practicalities of actually making cosmogenic-nuclide measurements

`Burial dating' with pairs of cosmic-ray-produced radionuclides: Production ratio fixed; half-lives differ

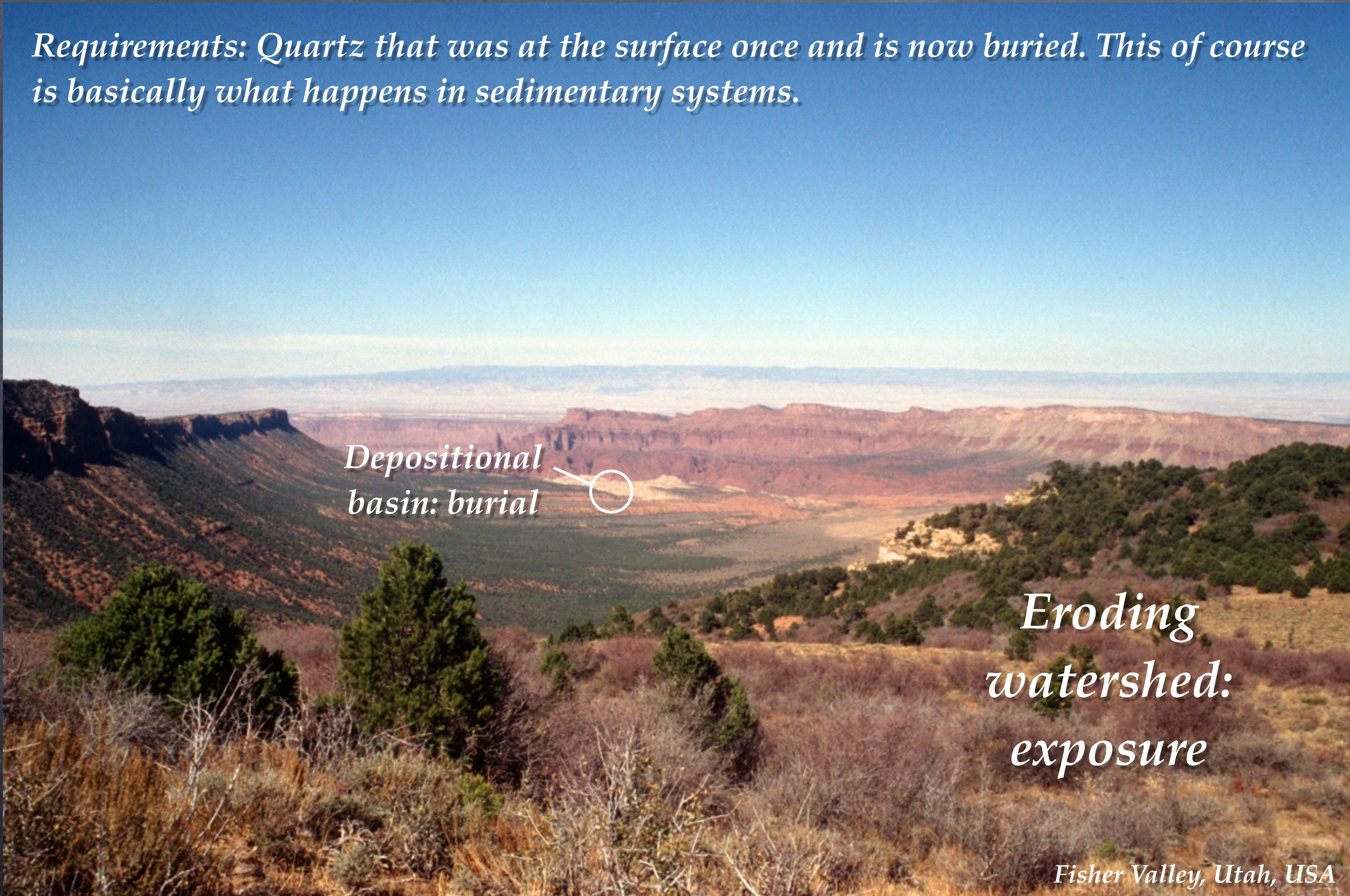


`Burial dating' with pairs of cosmic-ray-produced radionuclides: Production ratio fixed; half-lives differ So the $^{26}Al/^{10}Be$ ratio can be used as a burial clock.

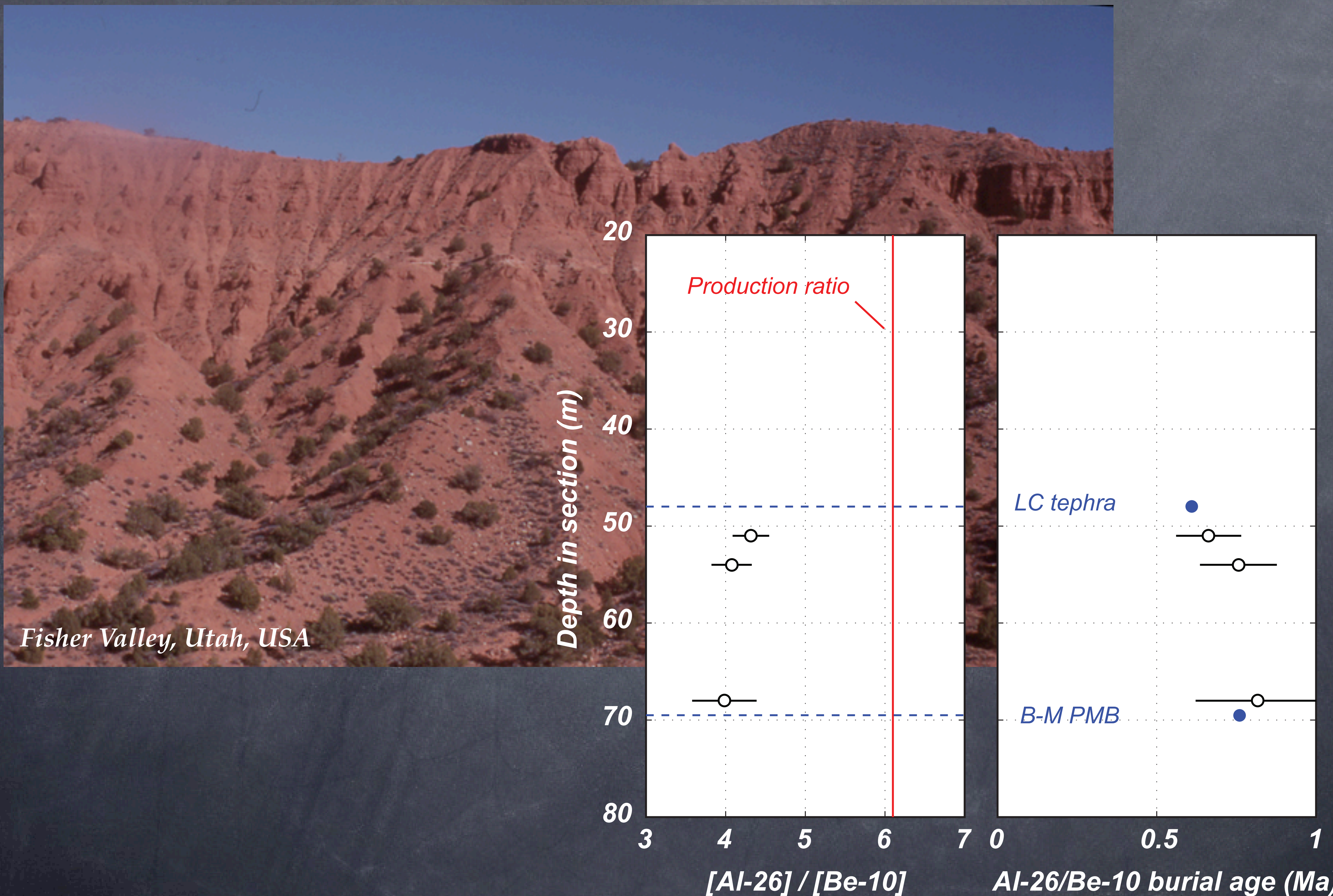


Cosmogenic-nuclide burial dating -- geological applications

Requirements: Quartz that was at the surface once and is now buried. This of course is basically what happens in sedimentary systems.



Cosmogenic-nuclide burial dating -- geological applications



The rest of the talk

From the huge array of nuclides produced by cosmic-ray reactions, which are geologically useful?

1. Needs to be rare in Earth materials so it is a useful dosimeter.

2. Geologically useful half-life.

3. Produced in reasonably common minerals.

4. Can be actually measured in typical minerals:
trace/common > 1e-14 or thereabouts. In practice.

This leaves the following reasonably useful nuclide-mineral pairs:

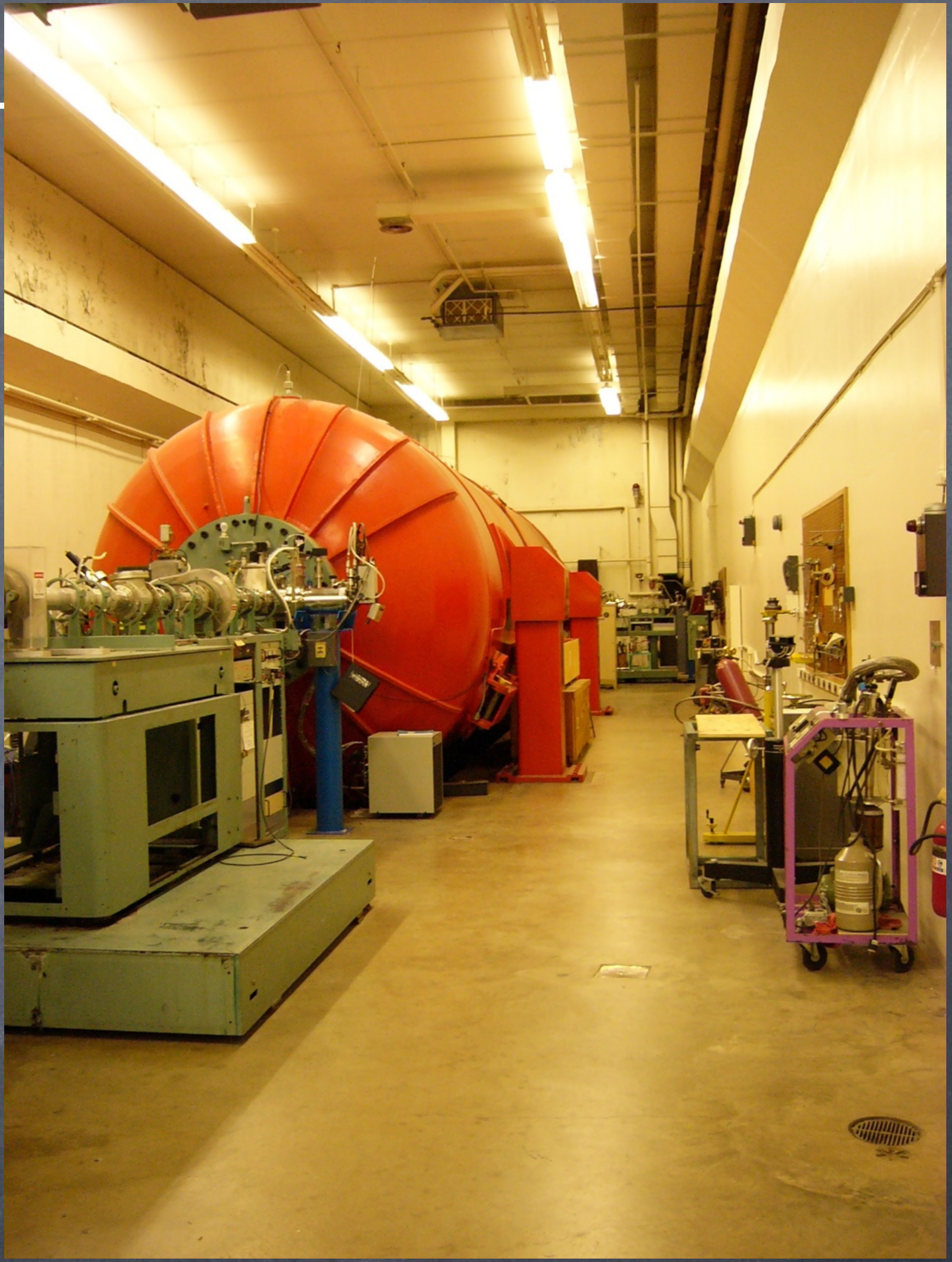
Nuclide	Target	Half-life	Measurement	Sample prep	S/N
beryllium-10	Quartz (Si, O)	1.5 Ma	AMS	Hard	Best
aluminum-26	Quartz (Si)	0.7 Ma	AMS	Hard	Good
carbon-14	Quartz (Si, O)	5 ka	AMS	Hard	Not so good
chlorine-36	Calcite, K,Ca feldspars, bulk rock (Ca, K, Fe, Ti, Cl)	0.3 Ma	AMS	Hard	Highly variable
helium-3	Nearly anything (nearly anything)	Stable	NGMS	Easy	Generally good
neon-21	Quartz, Ol, Px, K-feldspars (Na, Mg, Al, Si, Ca)	Stable	NGMS	Easy	Highly variable

AMS = Accelerator Mass Spectrometer

Accelerates ions of interest to extremely high velocities, which enables nuclide-specific ion detection.

Generally major national facilities. In US, 2 available for cosmogenic-nuclide measurements other than C-14.

Expensive; AMS measurement is $250-600.



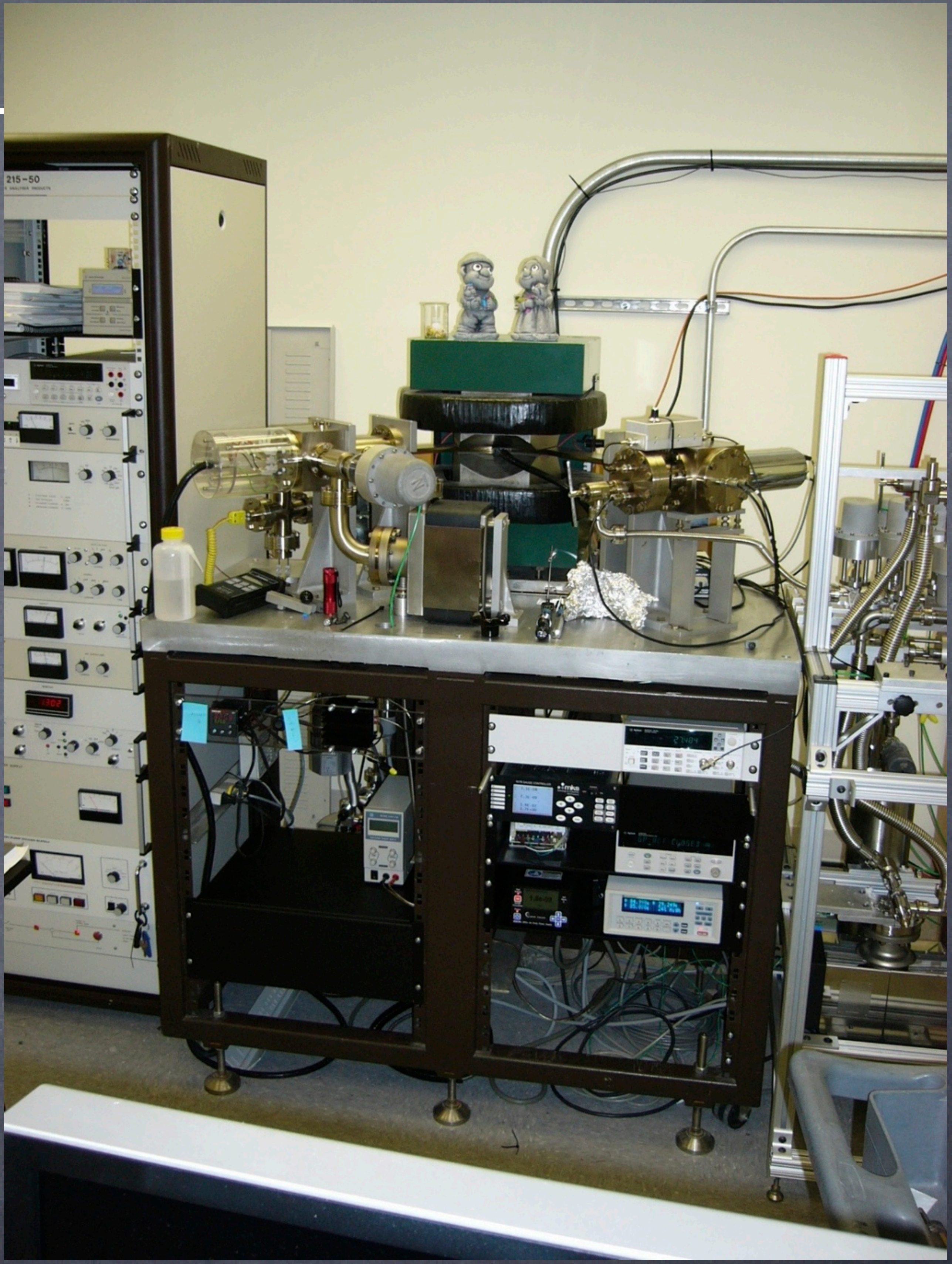
About 1/3 of an AMS

NGMS = Noble Gas Mass Spectrometer

Comparatively very simple device that is capable of measuring very small amounts of cosmogenic noble gases simply because of various advantages conferred by their being noble.

Basically same system used for Ar-Ar dating; many available (although mostly not used for cosmogenic noble gas measurements).

Generally a lot less expensive.



Complete NGMS

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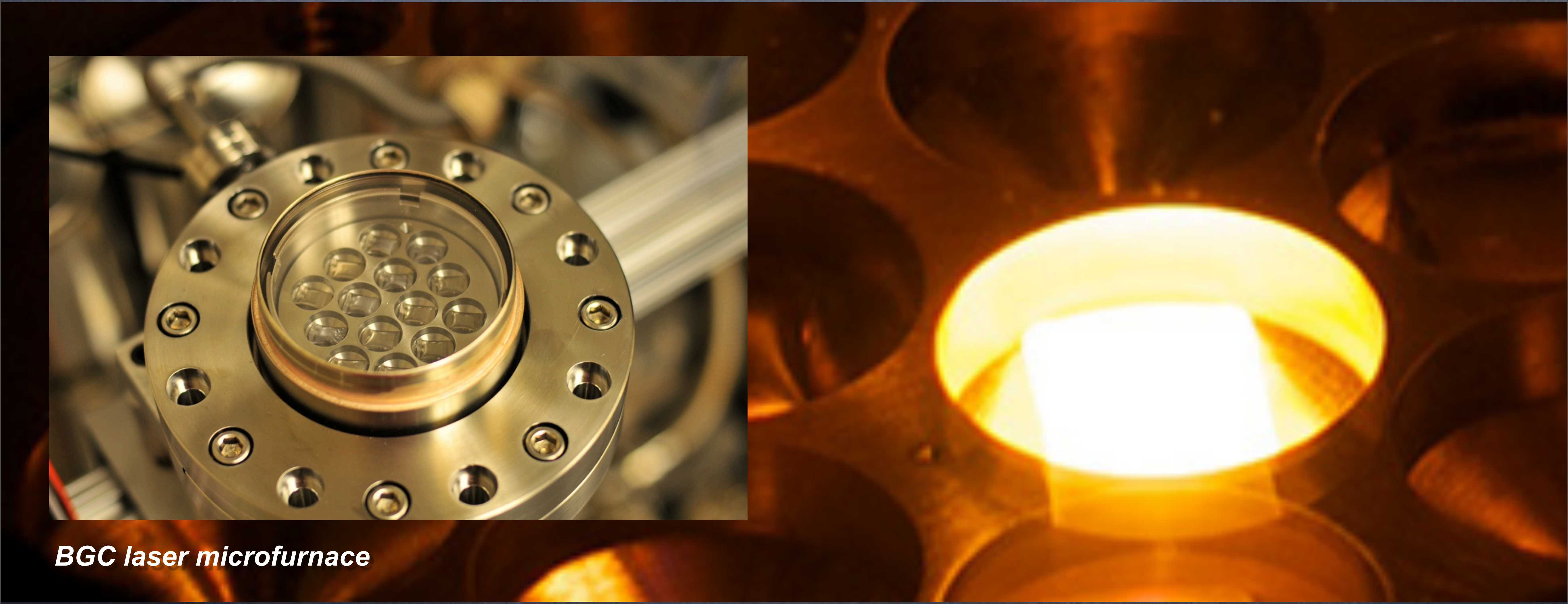
Easy vs. hard sample preparation

Easy - samples for cosmogenic noble gas measurement.

One lab | | **Another lab**

Prepare clean mineral separate → **Heat under vacuum** → **Pipe directly to mass spectrometer**



BGC laser microfurnace

Easy vs. hard sample preparation

Easy - samples for cosmogenic noble gas measurement.

One lab | **Another lab**

Prepare clean mineral separate → **Heat under vacuum** → **Pipe directly to mass spectrometer**

BGC laser microfurnace

Resources needed: normal geological crushing/sieving apparatus; heavy liquid separation; magnetic separation; acid etching under routine chem lab conditions. Most people have most of this stuff; possible exception is suitable chem lab space for weak HF etching.

Easy vs. hard sample preparation

Hard - samples for AMS measurement.

One lab		**Another lab**		**Perhaps a third**		**Completely separate AMS facility**
Prepare clean mineral separate	→	**Complete sample dissolution and purification under clean lab conditions**	→	**AMS target preparation**	→	**AMS**

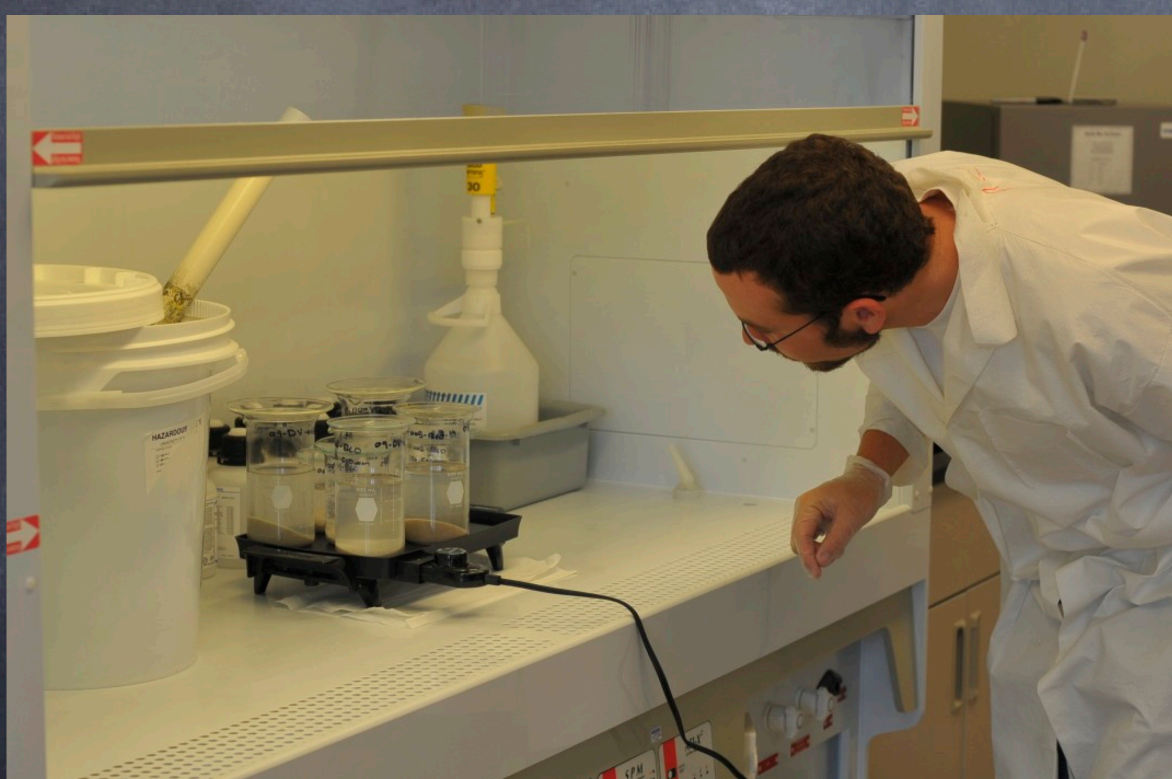
Resources needed: normal geological crushing/sieving apparatus; heavy liquid separation; magnetic separation; acid etching under routine chem lab conditions.

Plus: well-equipped clean lab for trace element geochemistry; significant experience and wet chemistry expertise.

Easy vs. hard sample preparation

Hard - samples for AMS measurement.

Prepare clean mineral separate



Acid cleaning

Dilute HF etching

Easy vs. hard sample preparation

Hard - samples for AMS measurement.

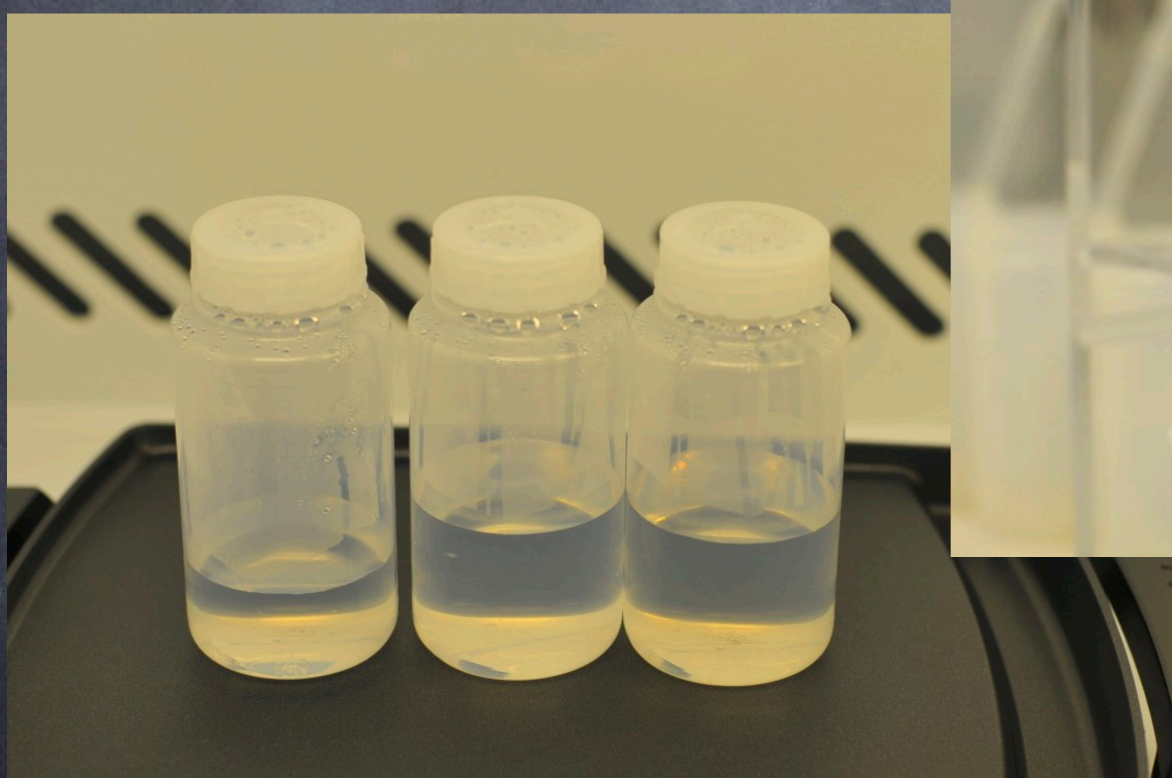
Prepare clean mineral separate

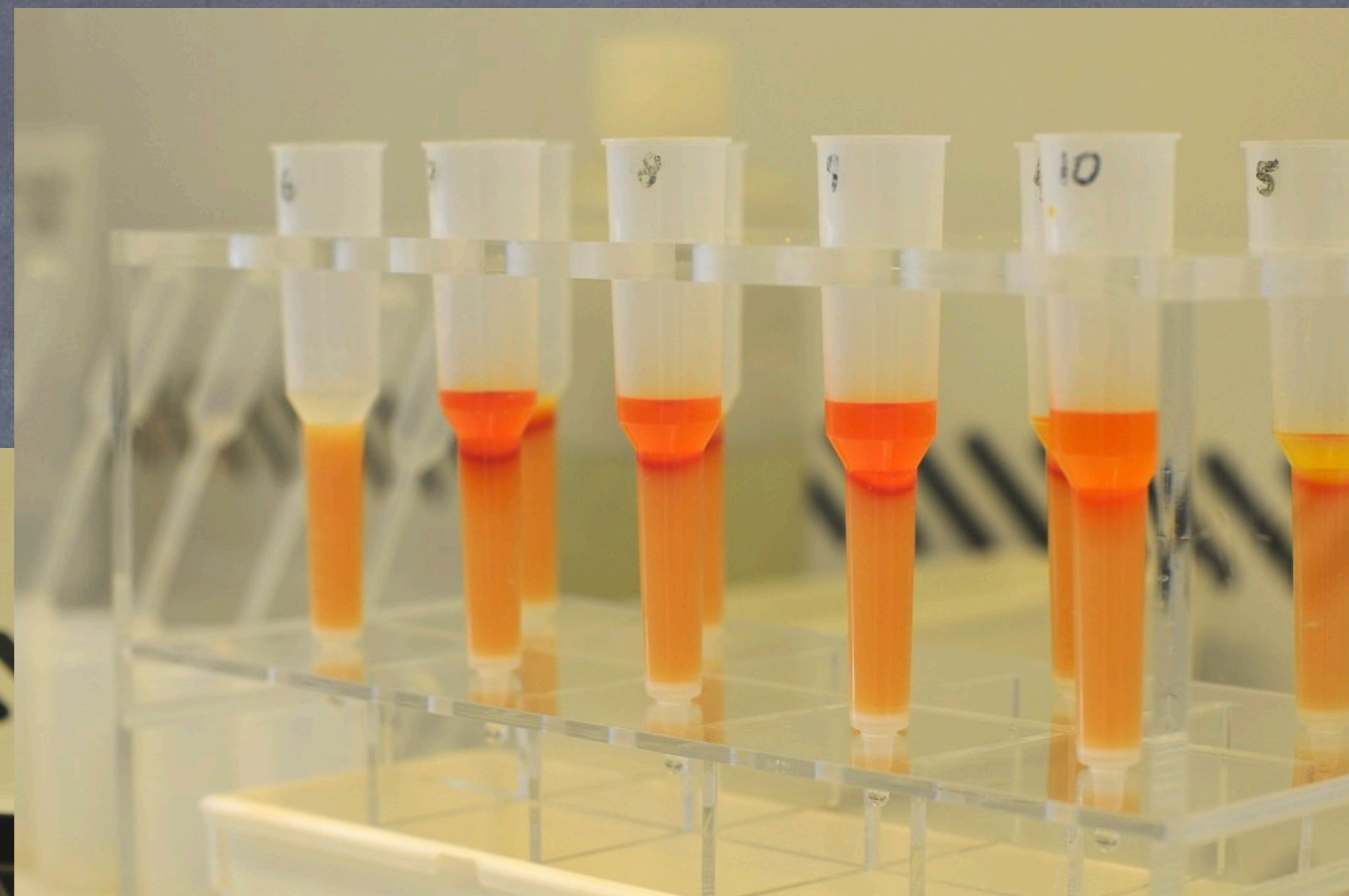
Determine sample purity by ICP-OES

Easy vs. hard sample preparation

Hard - samples for AMS measurement.

Complete dissolution

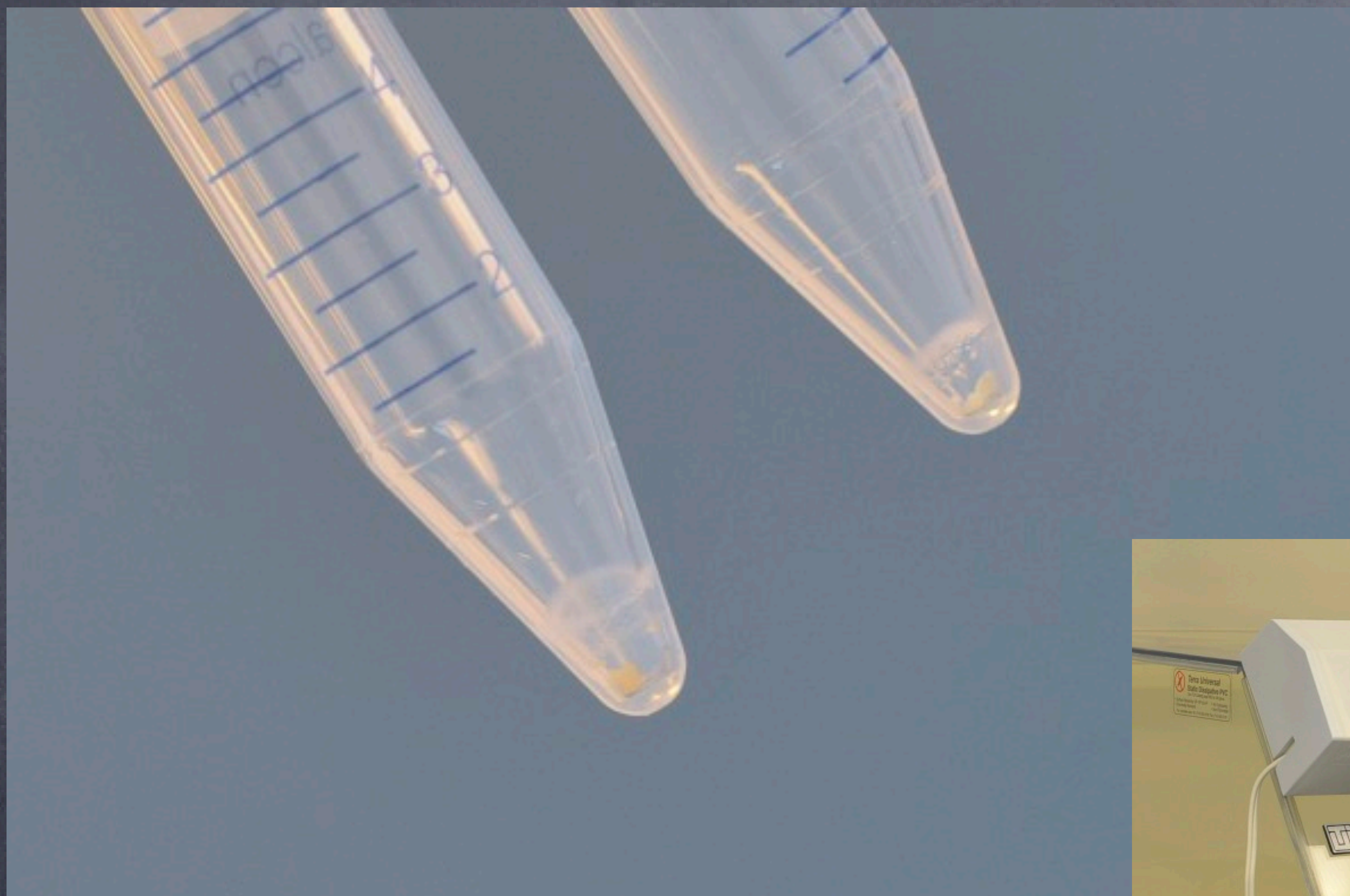




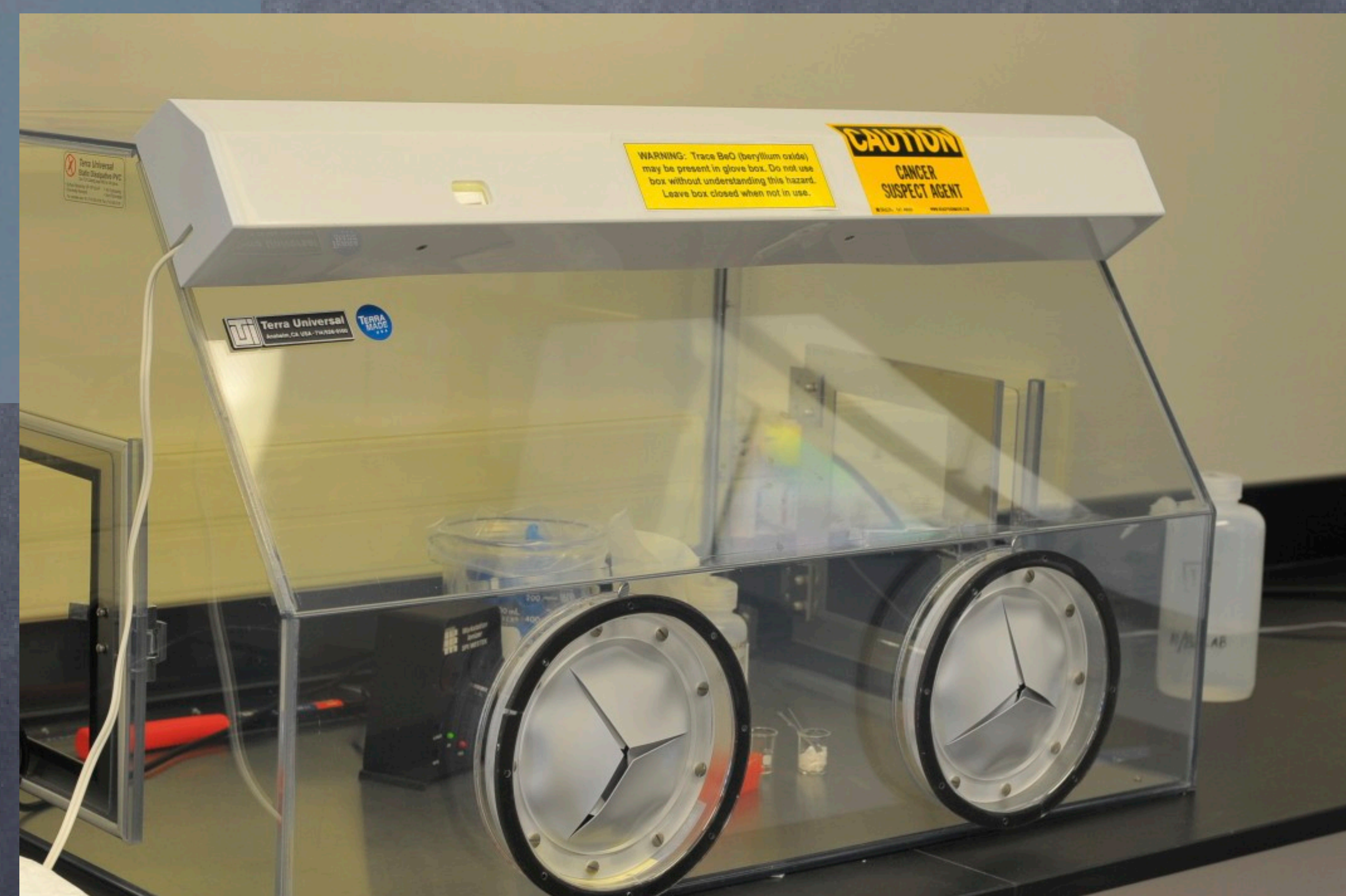
Column chromatography

Easy vs. hard sample preparation

Hard - samples for AMS measurement.



AMS target preparation

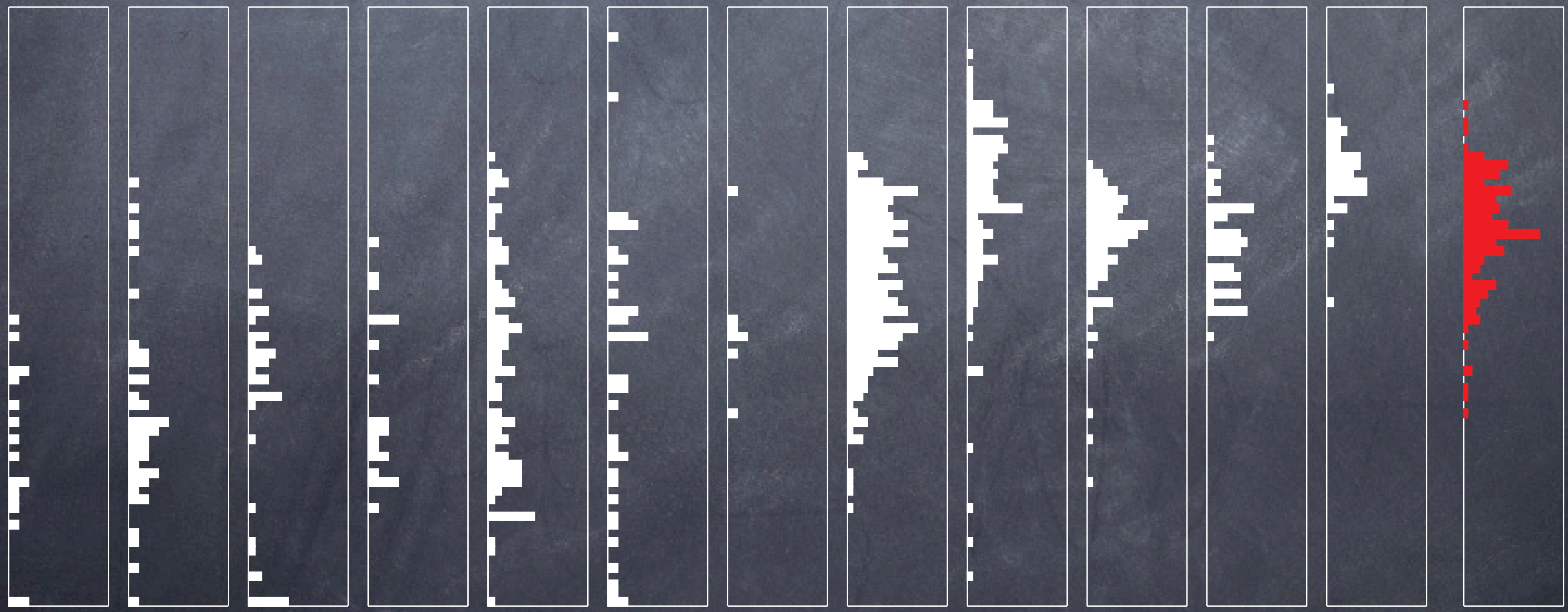


Easy vs. hard sample preparation

Hard - samples for AMS measurement.

Prepare clean mineral separate → **Complete sample dissolution and purification under clean lab conditions** → **AMS target preparation** → **AMS**

Measure of Be AMS target performance



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