U-Th Dating of Pedogenic Carbonate: Applications to Southern California

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&

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^{230}Th/U Dating of Pedogenic Carbonate

Strengths

- **Provides precise, accurate minimum ages for deposition of host alluvium.**
- **Is resistant to the effects of fan "smoothening" and erosion.**
- **Provides "inheritance-free" dates. (*cf*. CRN inheritance, OSL partial bleaching, ^{14}C in-built age)**

^{230}Th/U Dating of Pedogenic Carbonate

Limitations

- **Restricted to gravelly alluvium with calcic soils that develop in arid to sub-humid climates.**
- **Requires formation and preservation of carbonate penecontemporaneous with fan deposition for best results.**
- **Subject to averaging effects when samples are large relative to carbonate accumulation rates.**

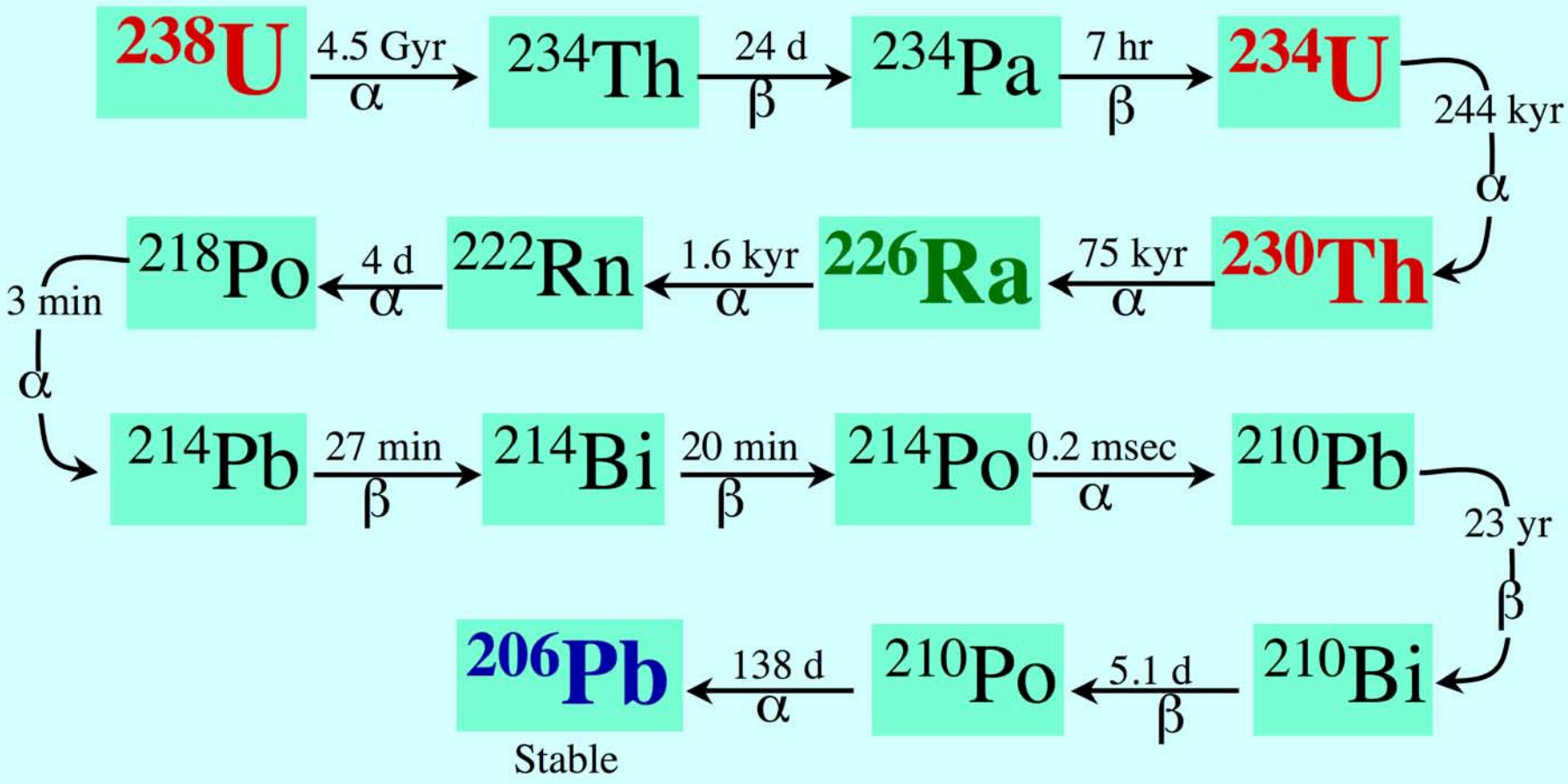
Outline of Talk

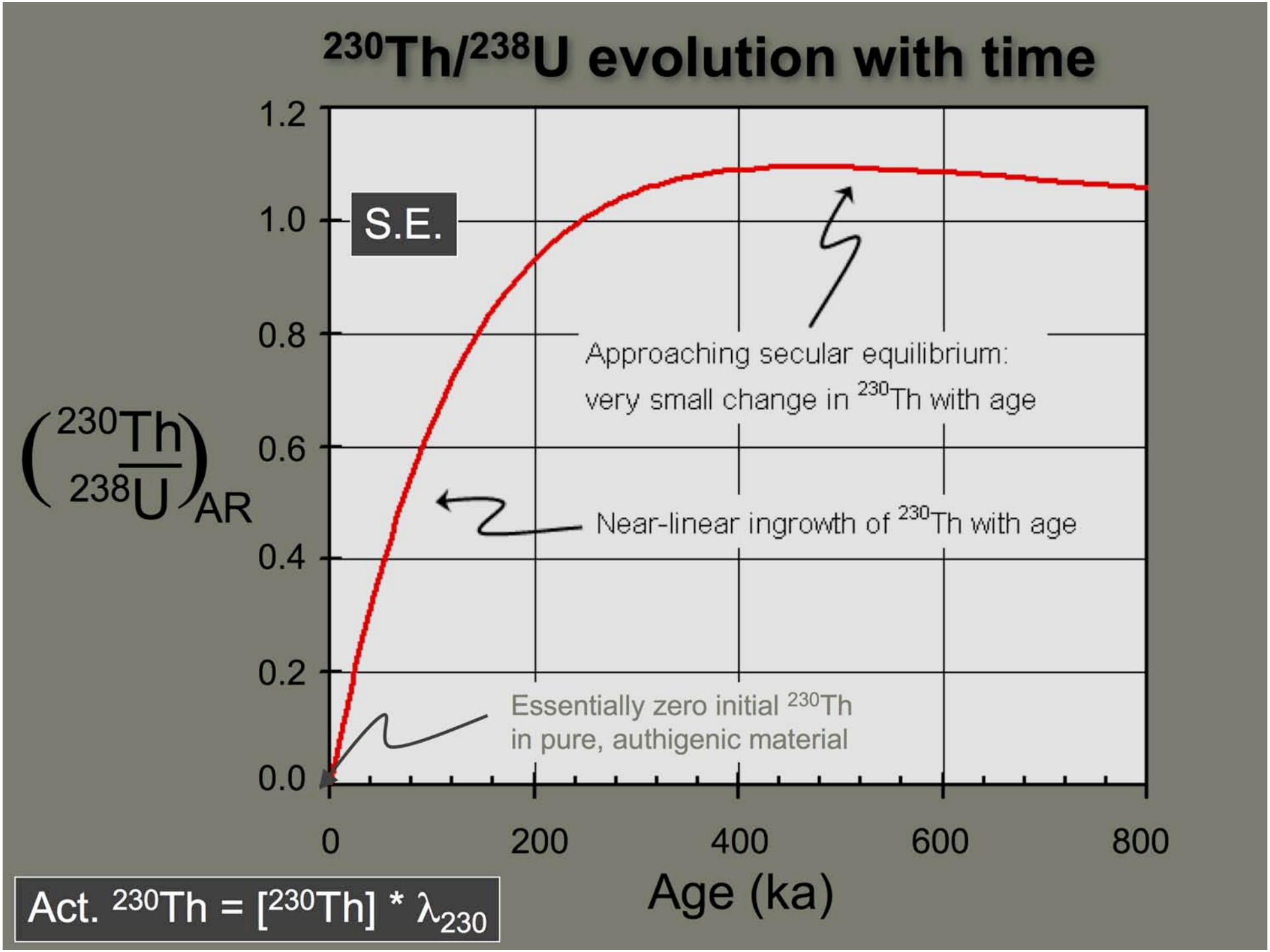
- Basis of the U-series technique
- Pedogenic carbonate: a primer
- Case studies in southern California
  - Biskra Palms fan, Mission Creek Fault
  - Alverson Canyon fan, Elsinore Fault
- Recent analytical developments

Geochemistry of Uranium and Thorium in the Near-Surface Environment

- **Uranium** in oxygenated waters complexes to form the uranyl ion, $(UO_2)^{2+}$ with appreciable solubility at low temperature.
- **Thorium** occurs only in the +4 oxidation state in natural waters and does not generally complex; hence thorium is extremely insoluble at low temperature.

The ^{238}U Decay Series




$^{230}Th/^{238}U$ evolution with time
$\left(\frac{^{230}Th}{^{238}U}\right)_{AR}$
1.2
1.0
0.8
0.6
0.4
0.2
0.0
S.E.
Approaching secular equilibrium:
very small change in ^{230}Th with age
Near-linear ingrowth of ^{230}Th with age
Essentially zero initial ^{230}Th
in pure, authigenic material
0
200
400
600
800
Age (ka)
Act. ^{230}Th = [^{230}Th] * λ_{230}

Geochemistry of Uranium-234

- Alpha recoil of both ^{234}U and its immediate parent, ^{234}Th, tends to enrich the concentration of ^{234}U over its secular equilibrium abundance in near-surface waters. As a result, their ($^{234}U/^{238}U$) ratios generally range from 1.3 to as high as 10.

- Carbonates acquire these enriched ($^{234}U/^{238}U$) ratios upon formation.

The $^{230}Th/^{238}U$ and $^{234}U/^{238}U$ Equations

$$\left(\frac{^{230}\mathrm{Th}}{^{238}\mathrm{U}}\right) = 1 - e^{-\lambda_{230}t} - \left[\left(\frac{^{234}\mathrm{U}}{^{238}\mathrm{U}}\right) - 1\right]\left(\frac{\lambda_{230}}{\lambda_{234} - \lambda_{230}}\right)\left[1 - e^{(\lambda_{234} - \lambda_{230})t}\right]$$

Must be solved numerically

$$\left(\frac{^{234}\mathrm{U}}{^{238}\mathrm{U}}\right)_t = 1 + \left[\left(\frac{^{234}\mathrm{U}}{^{238}\mathrm{U}}\right)_0 - 1\right] e^{-\lambda_{234}t}$$

Can be solved directly

Correcting for initial ^{230}Th and U from detritus

- **Thorium observed in carbonate samples** comes from included detritus.
- Use ^{232}Th as index to correct for accompanying initial ^{230}Th and U.

- For samples with $(^{230}Th/^{232}Th)_{activity} \geq 10$, a widely used model correction is suitable.

Therefore:

Most pedogenic carbonate will contain ppm levels of ^{238}U, with excess ^{234}U, but (when pure) only ppb levels of ^{232}Th.

So if samples are:

- Reasonably free of incorporated detritus (and initial ^{230}Th from other sources);
- Have behaved as closed systems;
- Are a few hundred to a few hundred thousand years old;

Then:

Samples of 1-10 mg will yield $^{230}Th/U$ dates with accuracy at the percent level.

Pedogenic Carbonate: a primer

Forms

- In arid to sub-humid climates where annual evaporation > precipitation.
- At depths of 0.3 to >2.0 m, positively correlated with mean annual precipitation.

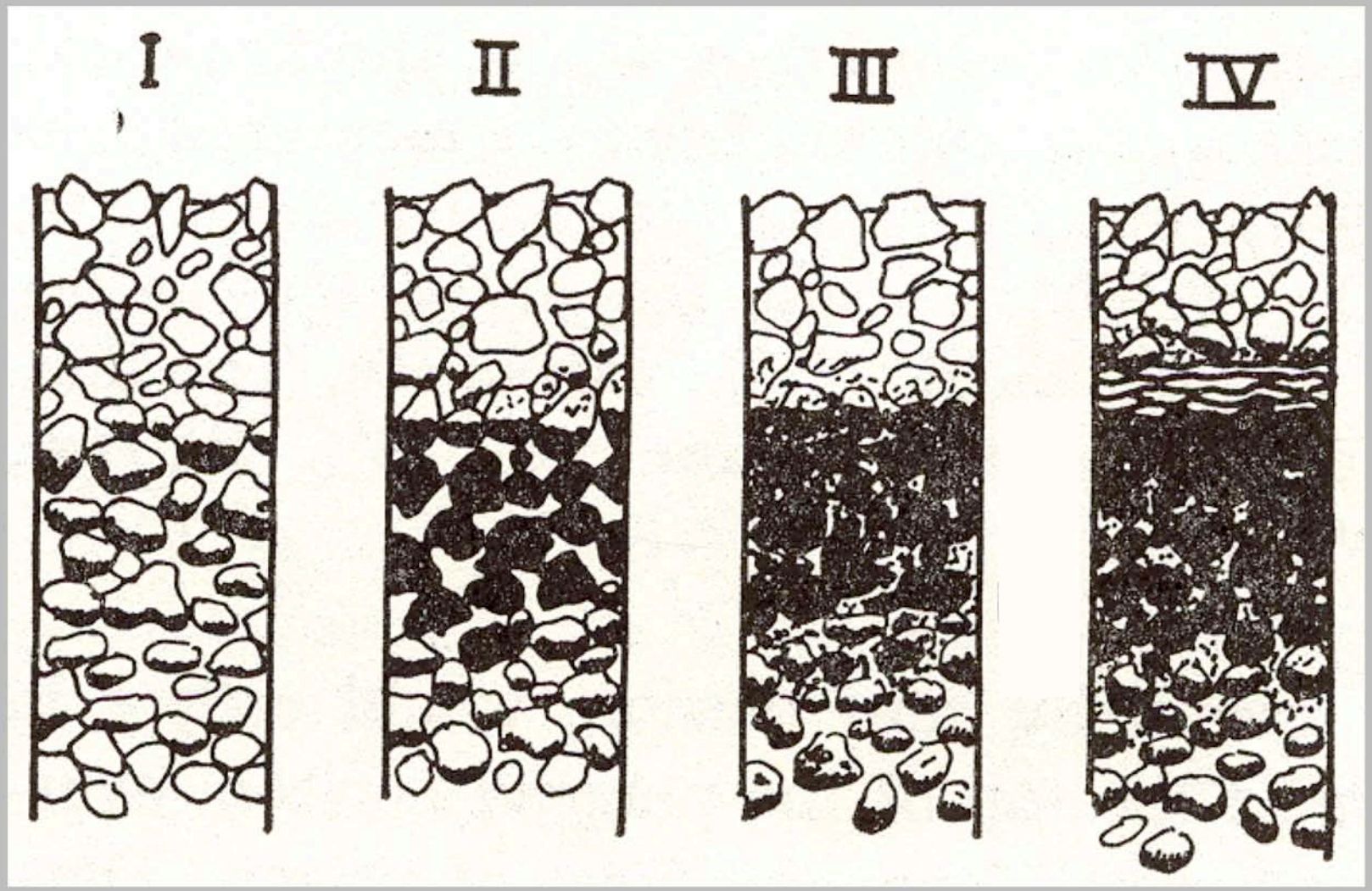
Composed of

- Ca^{+2} from eolian dust or parent material, and CO_2 (as HCO_3^- in soil water) derived from the atmosphere and plant-root respiration.

Precipitation from solution

- Caused by increased ion strength due to evaporation, transpiration, or freezing.

Morphology of Carbonate Accumulation in Gravelly Soils

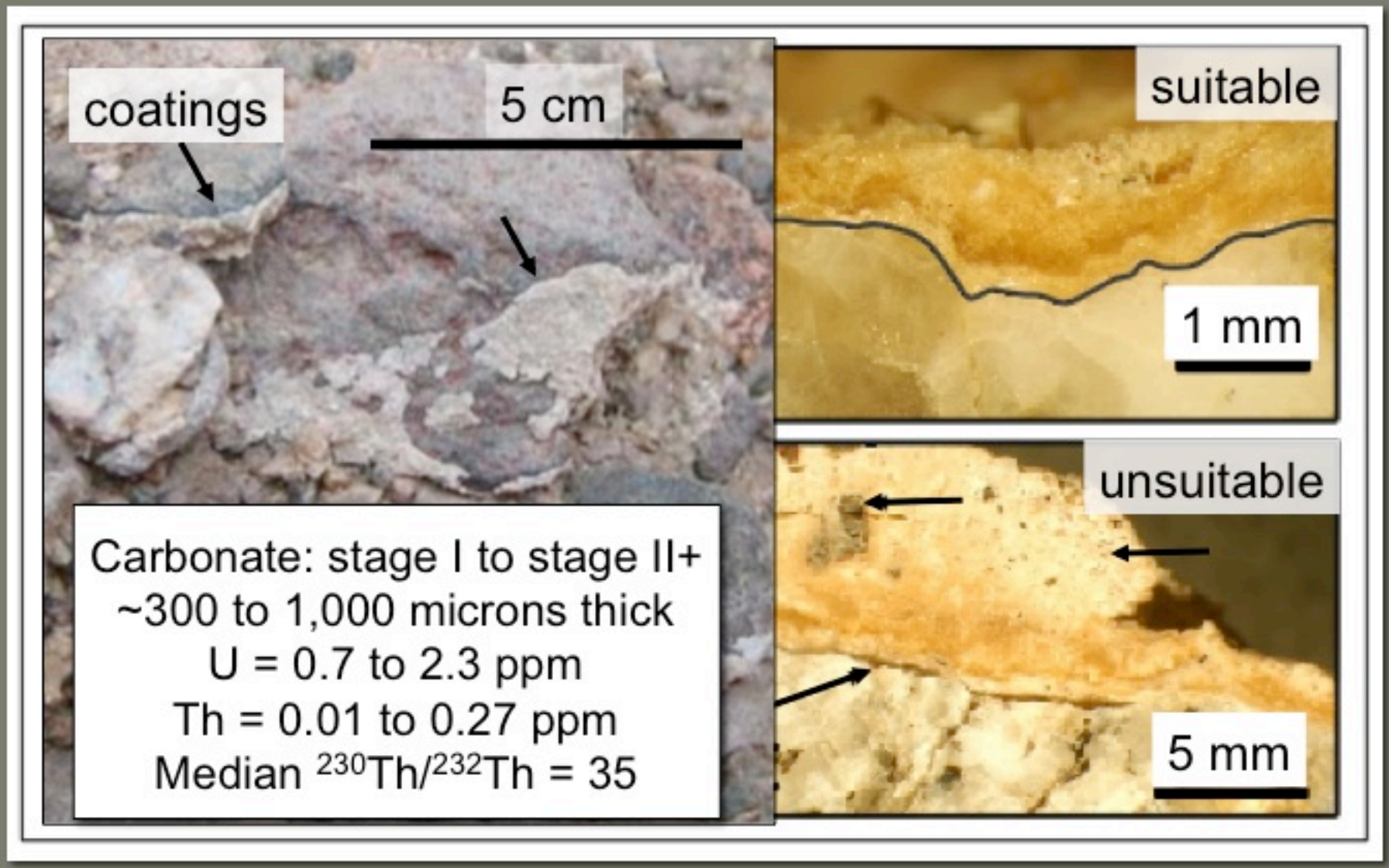


Gile et al., 1966

Time

Pedogenic Carbonate:
20 ka terrace: Wind River Basin, Rocky Mts.

Pedogenic carbonate coatings, Elsinore Fault



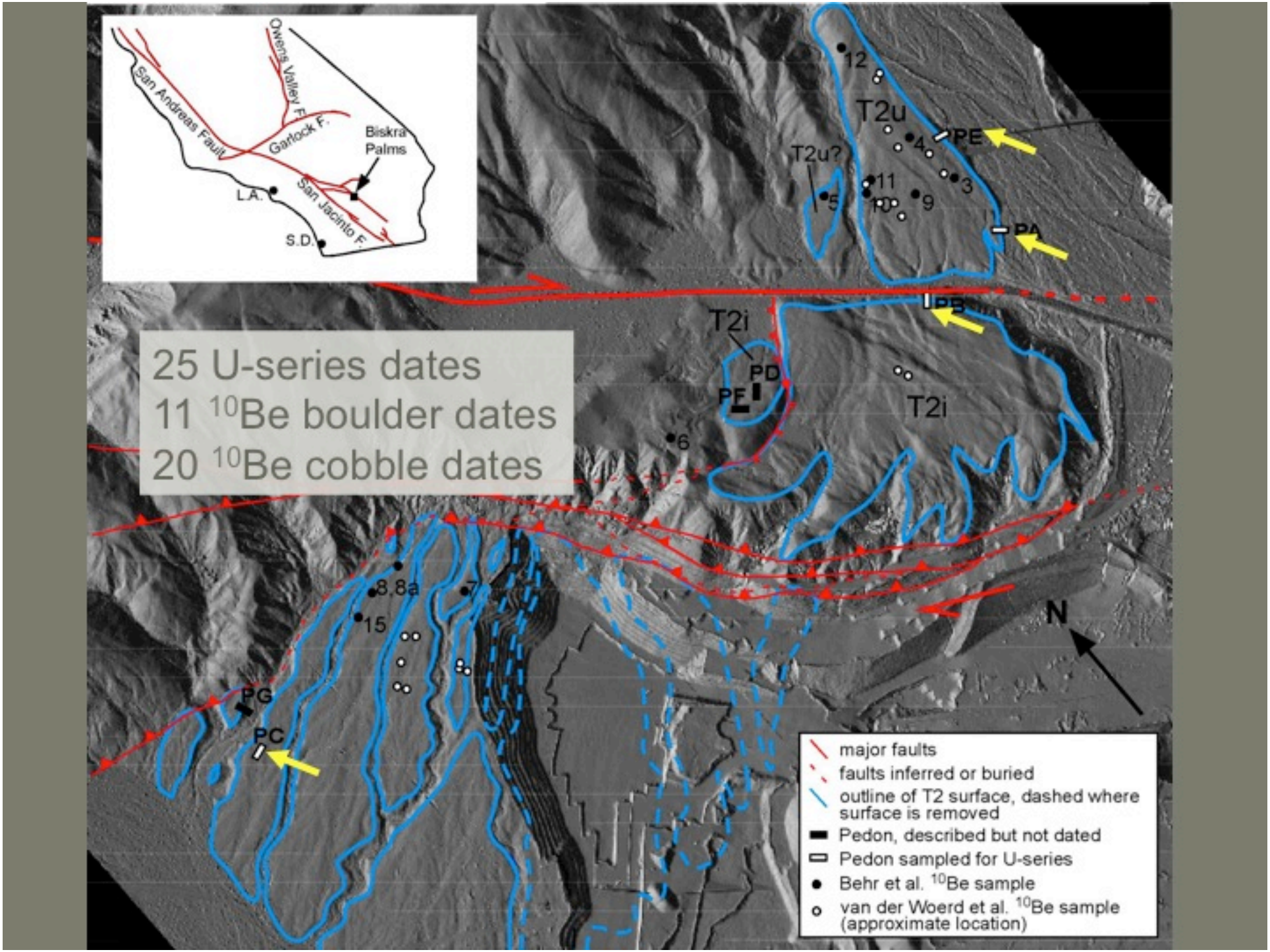
Measurement & Sampling

Mass spectrometry via ICP-MS

- Ages precise to ~1.0% (conventional samples) & 3-5% (laser ablation) at one standard deviation.
- Accuracy closely approaches precision.

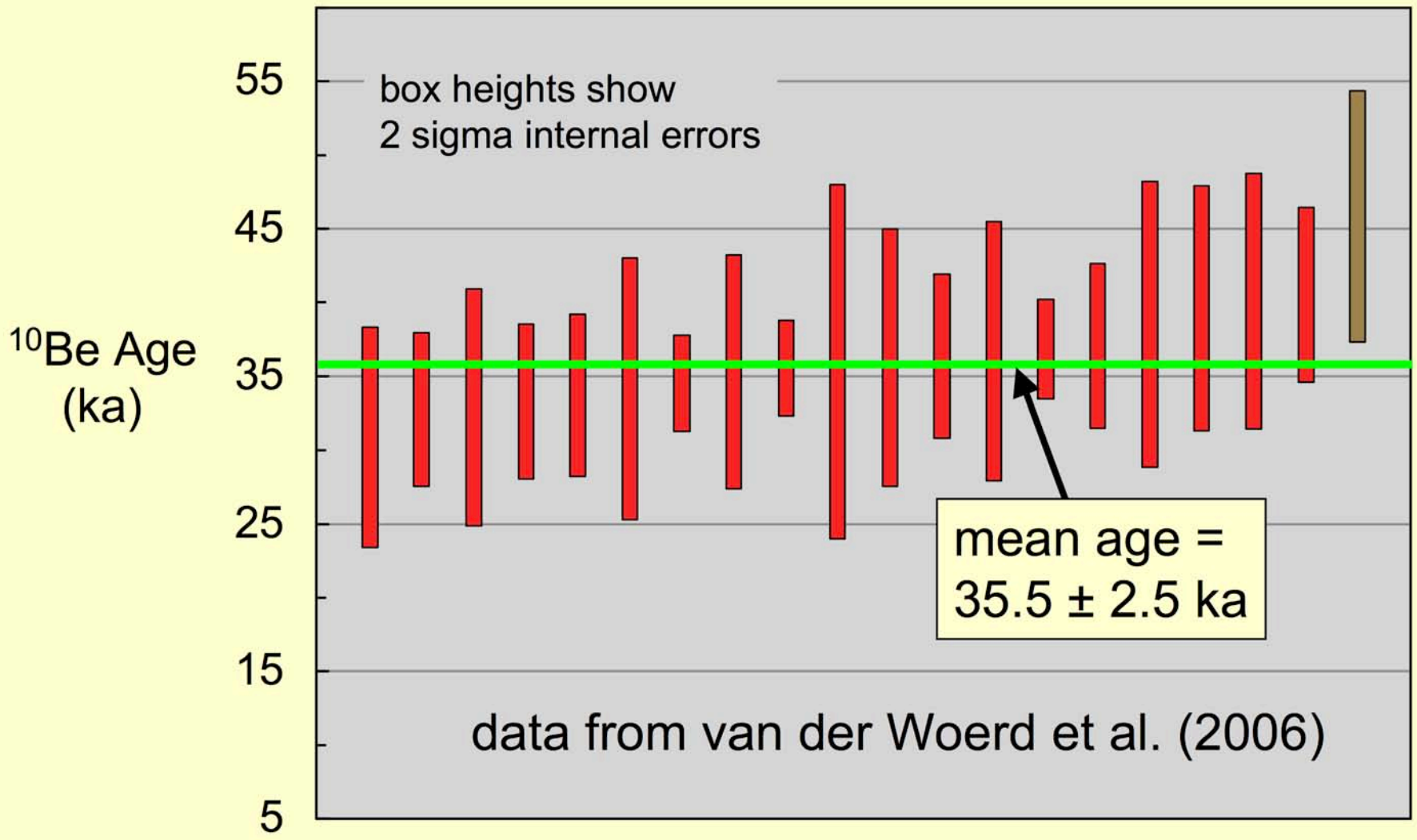
Sampling modes

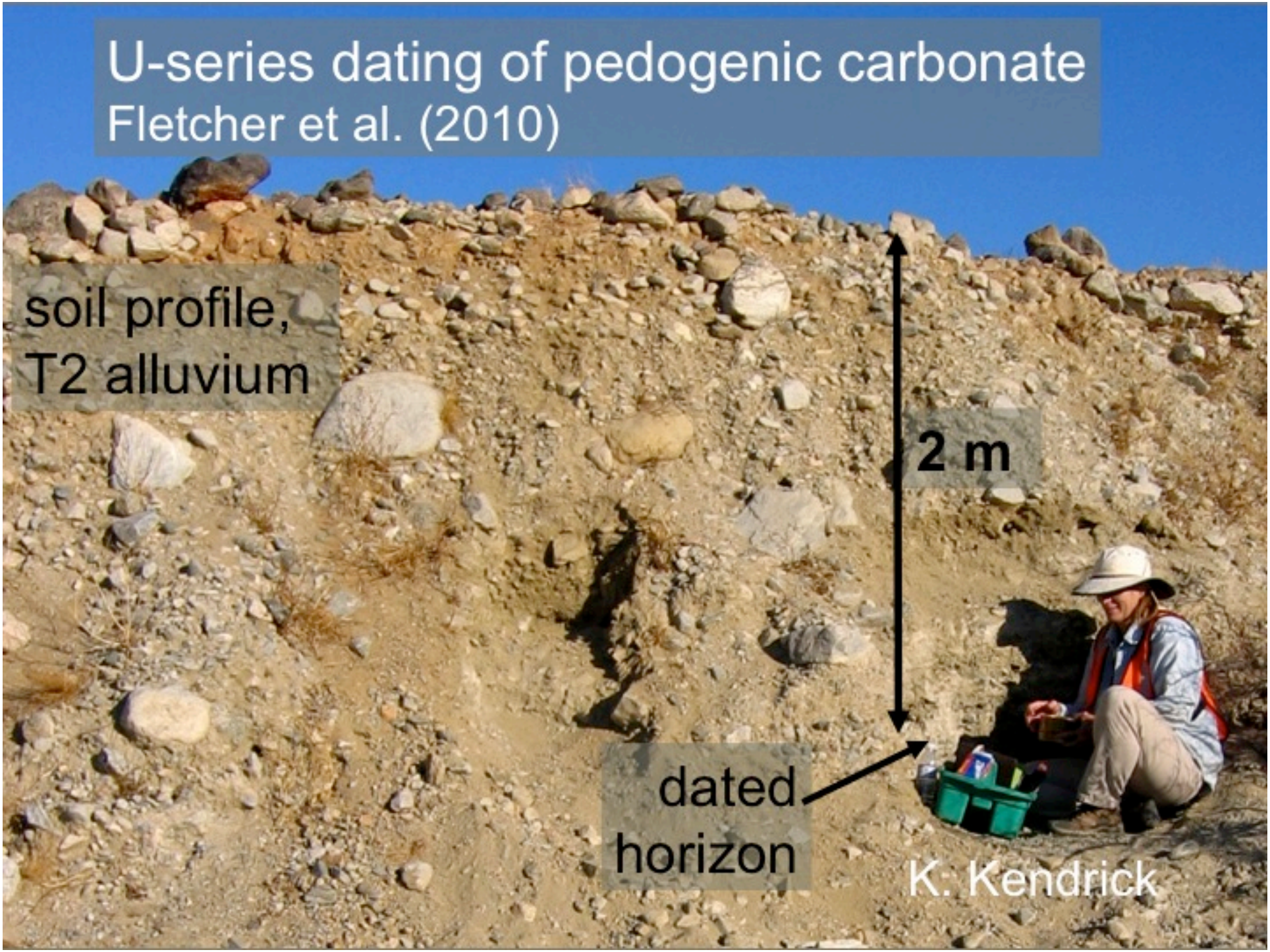
- 1-10 mg samples drilled or scraped from clast-coating; "no-chem." option for pre-Holocene samples.
- Laser ablation with 0.1 mm beam; can probe age structure of coatings in profile view


San Andreas Fault
Owens Valley F.
Garlock F.
San Jacinto F.
Biskra Palms
L.A.
S.D.
25 U-series dates
11 10Be boulder dates
20 10Be cobble dates
T2u
T2u?
T2i
T2i
12
4
3
11
5
9
6
8,8a
7
15
PA
PB
PC
PD
PE
PE
PG
N
major faults
faults inferred or buried
outline of T2 surface, dashed where surface is removed
Pedon, described but not dated
Pedon sampled for U-series
Behr et al. 10Be sample
van der Woerd et al. 10Be sample (approximate location)

The Biskra Palms surface is considered “well preserved”

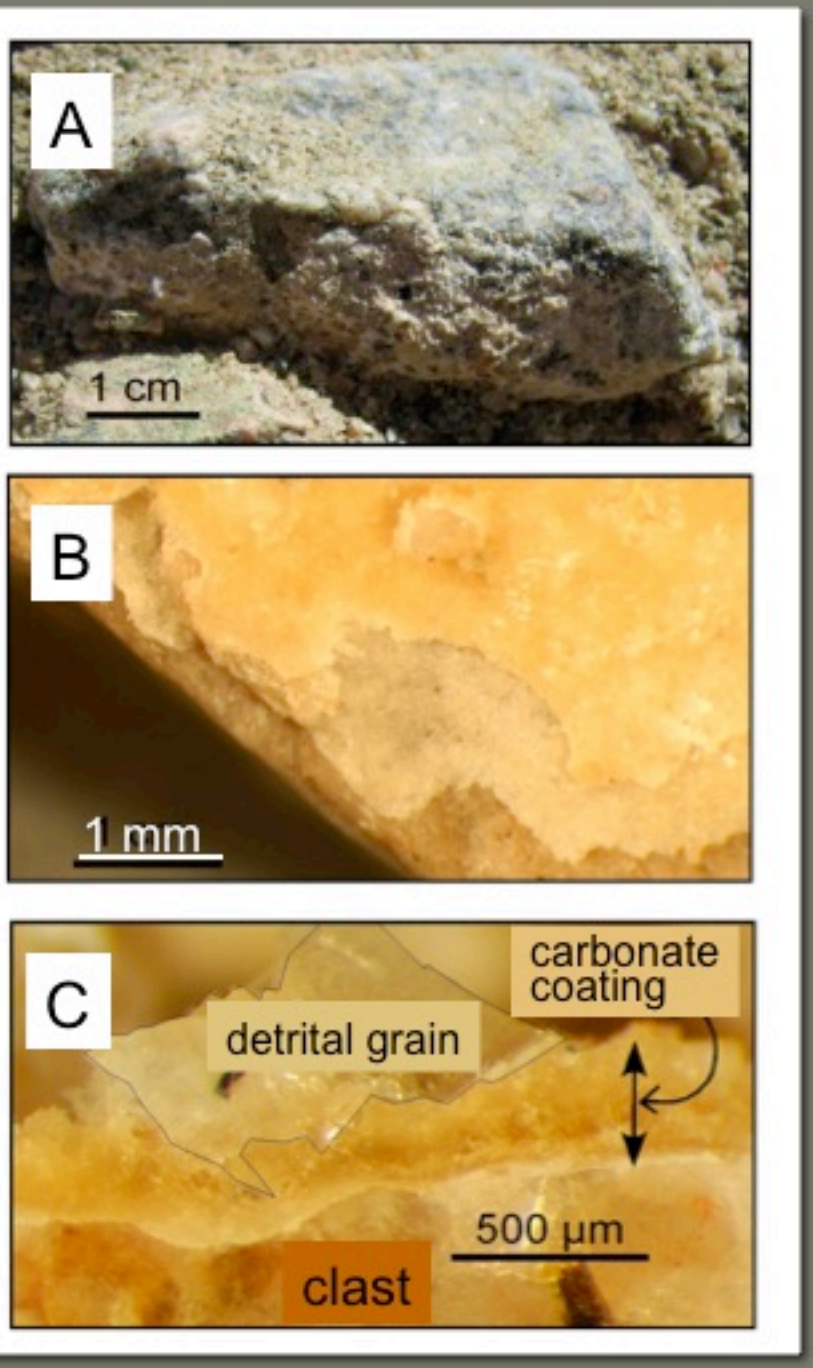
^{10}Be ages for pavement cobbles from T2 surface

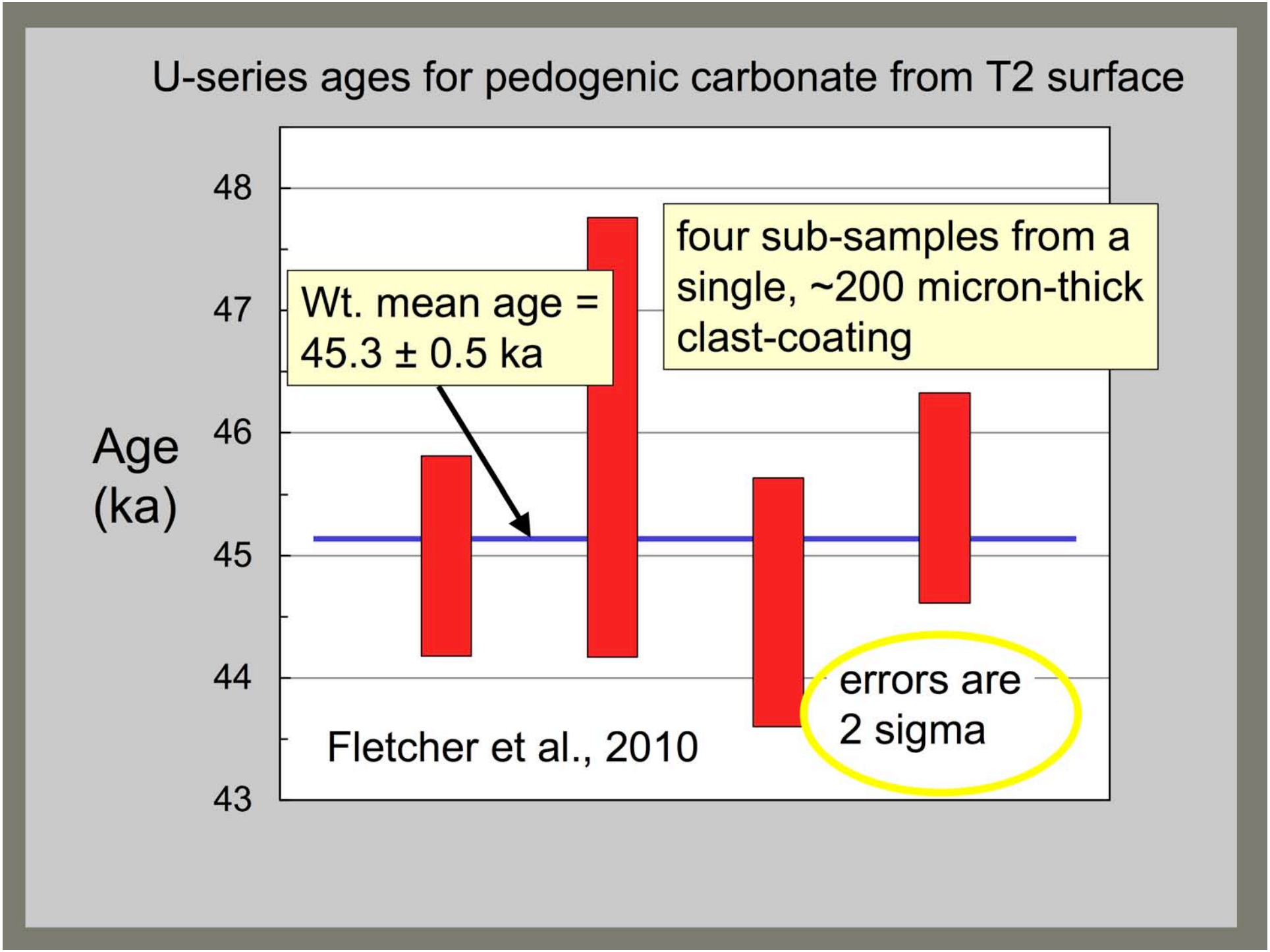


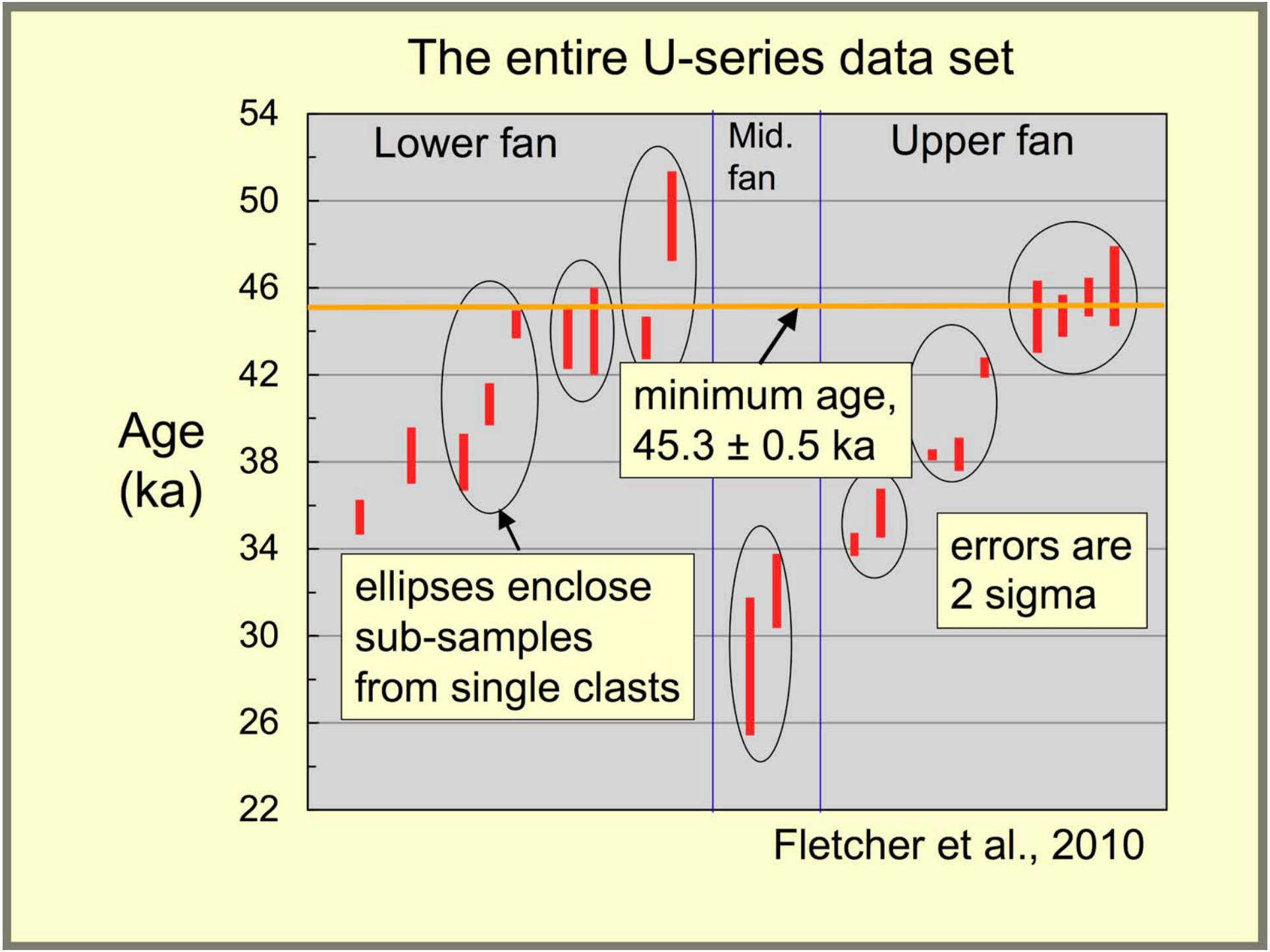

U-series dating of pedogenic carbonate
Fletcher et al. (2010)
soil profile,
T2 alluvium
2 m
dated
horizon
K. Kendrick

Biskra Palms Pedogenic Carbonate:

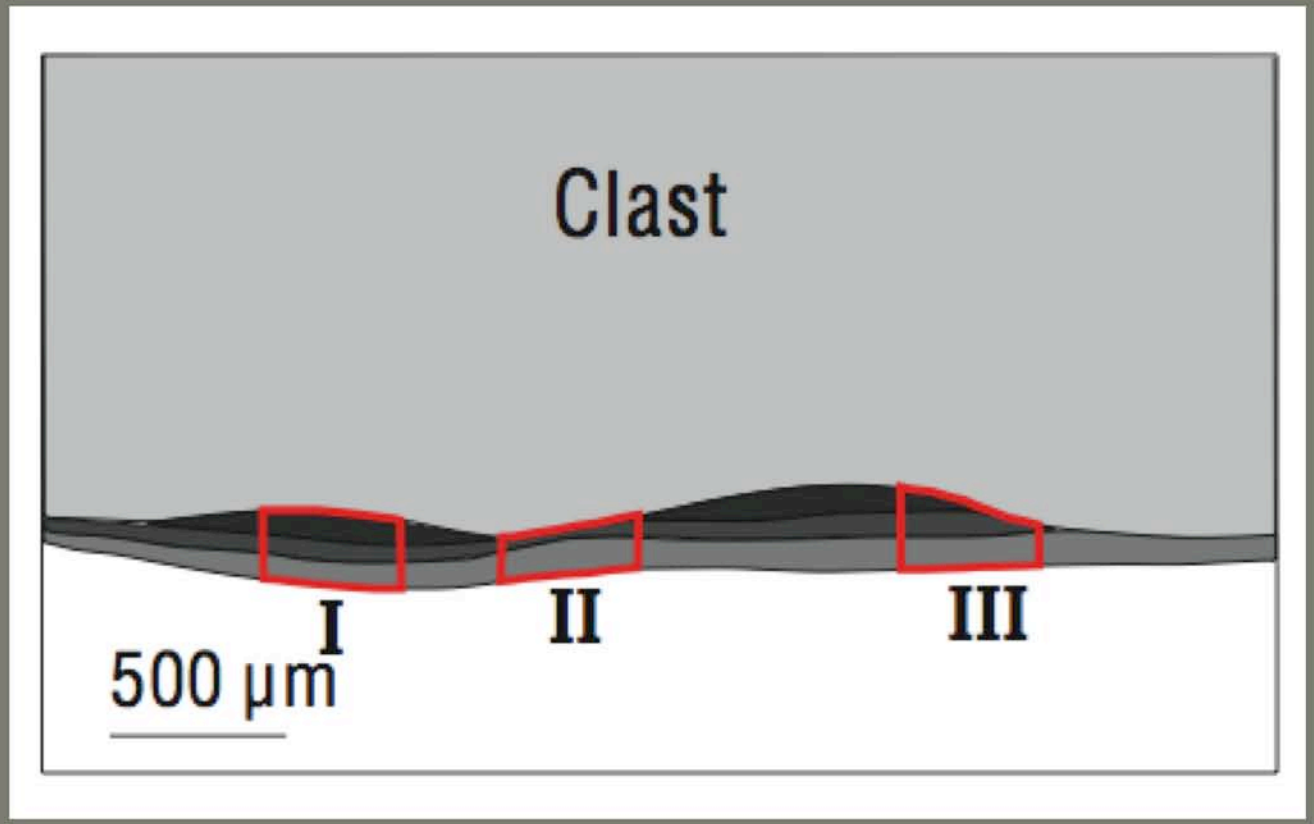
- Stage I
- dense yellow carbonate is 200-300 microns thick
- highly suitable for U-series dating:
  - U_{median}= 4.5 ppm
  - Th_{median} = 0.12 ppm
  - Median $(^{230}Th/^{232}Th)_{AR}$ = 40



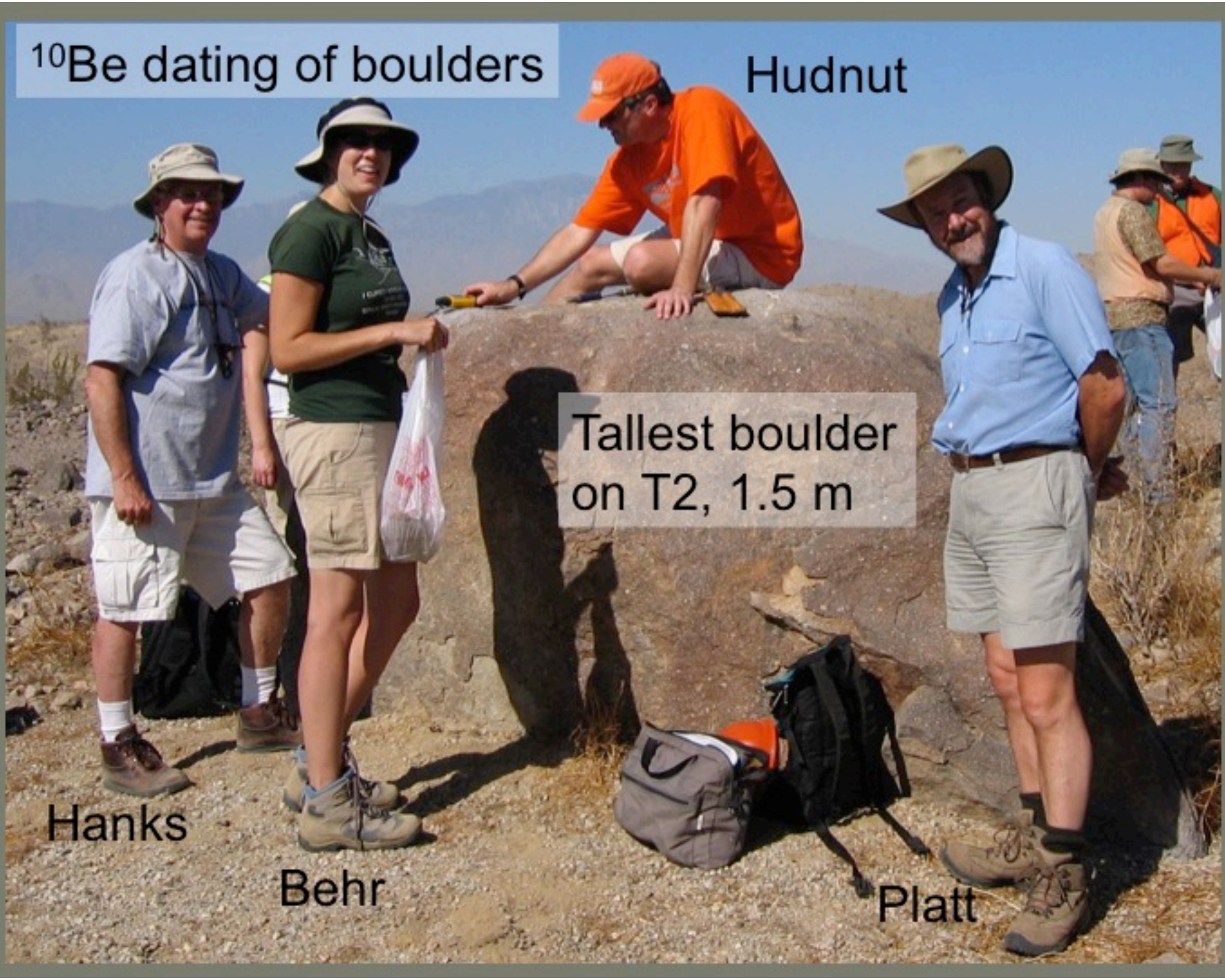

U-series ages for pedogenic carbonate from T2 surface
Age (ka)
48
47
46
45
44
43
Wt. mean age = 45.3 ± 0.5 ka
four sub-samples from a single, ~200 micron-thick clast-coating
errors are 2 sigma
Fletcher et al., 2010


The entire U-series data set
Age (ka)
54
50
46
42
38
34
30
26
22
Lower fan
Mid. fan
Upper fan
minimum age, 45.3 ± 0.5 ka
ellipses enclose sub-samples from single clasts
errors are 2 sigma
Fletcher et al., 2010

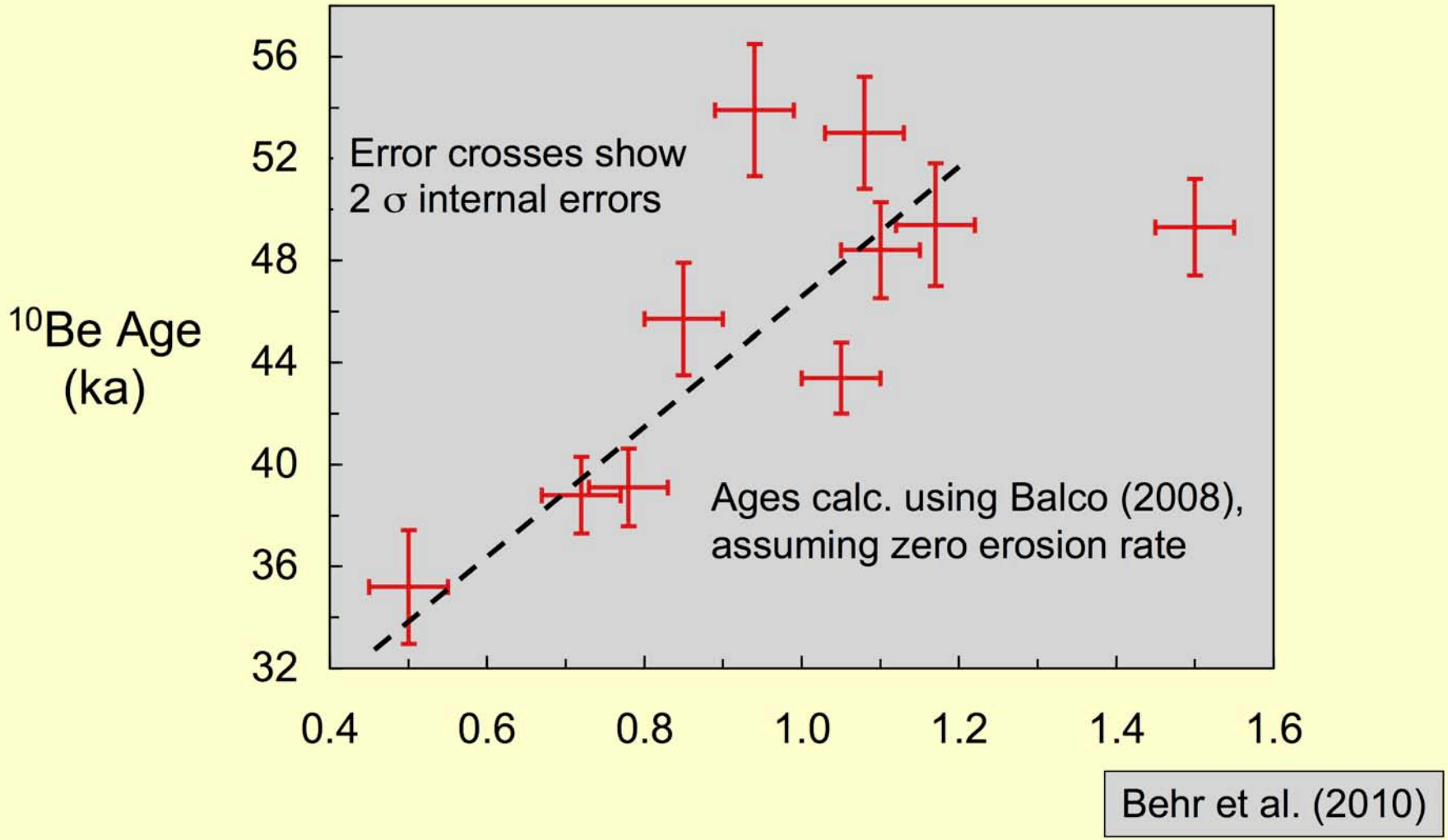
Using samples of 20-50 mg needed for TIMS analyses…



we analyzed all, or most, of the micro-stratigraphic sequence present in a carbonate coating, yielding average ages for the sampled intervals.

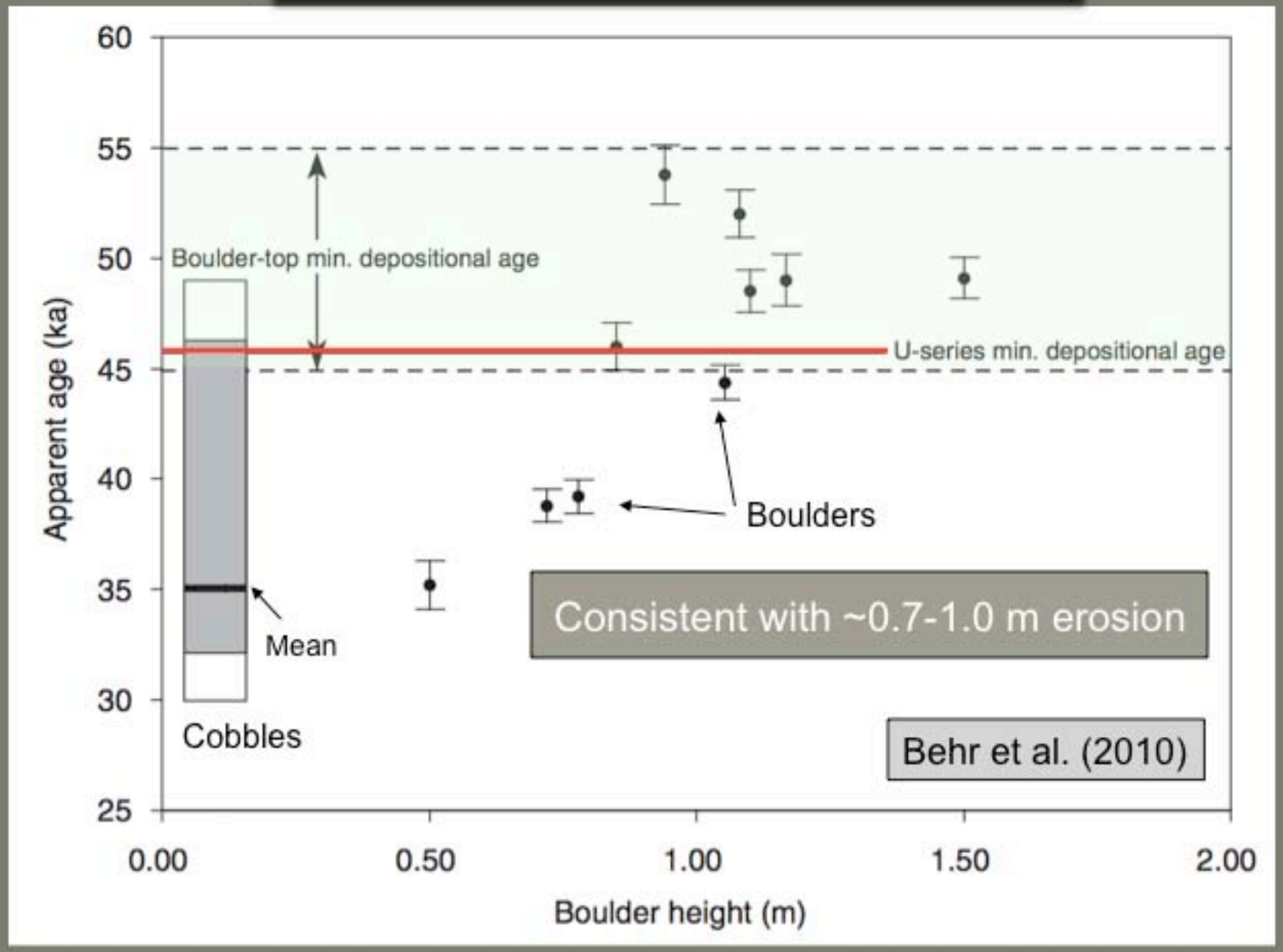

^{10}Be dating of boulders
Hudnut
Tallest boulder
on T2, 1.5 m
Hanks
Behr
Platt

^{10}Be ages for tonalite and granite boulders from T2 surface

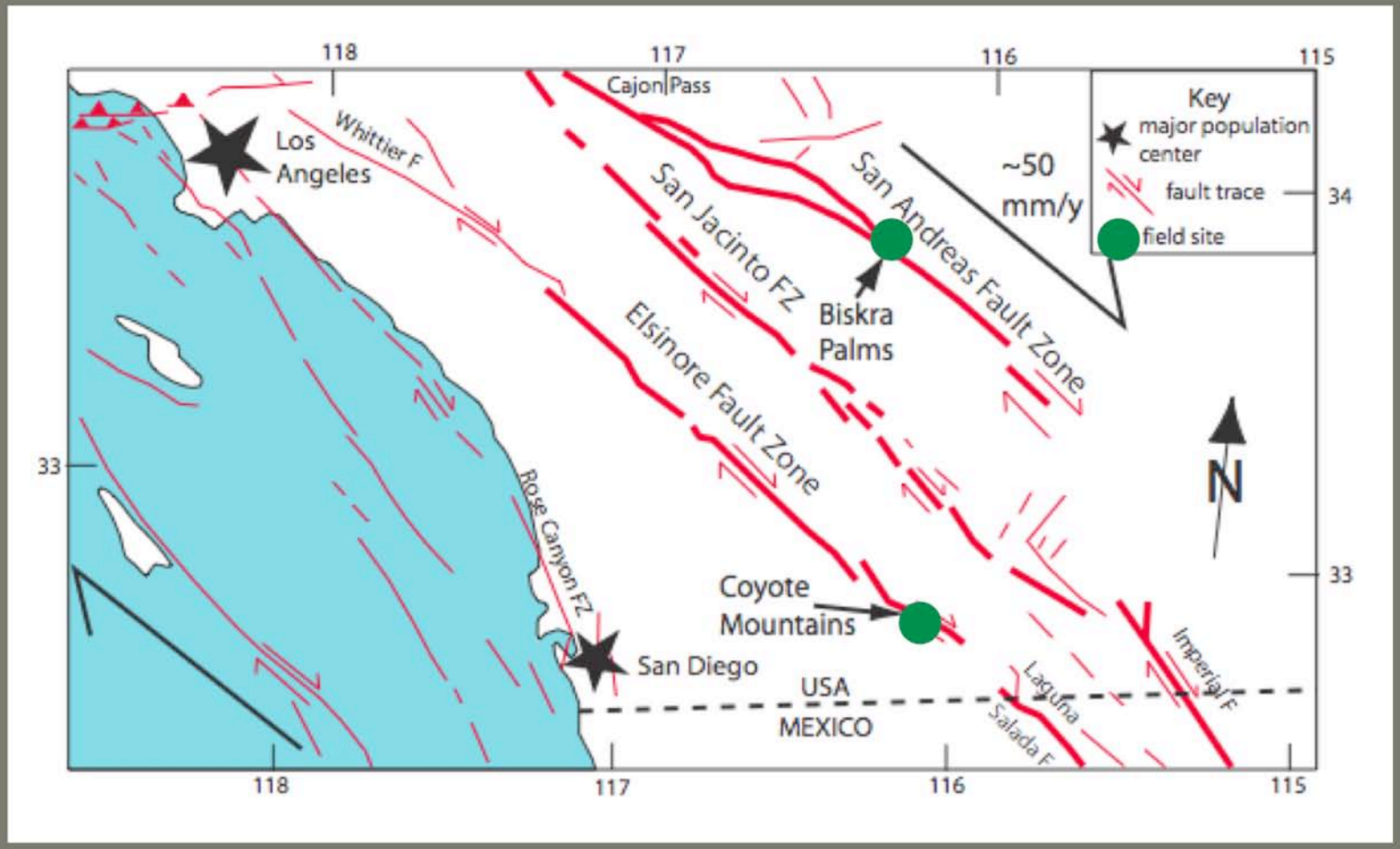


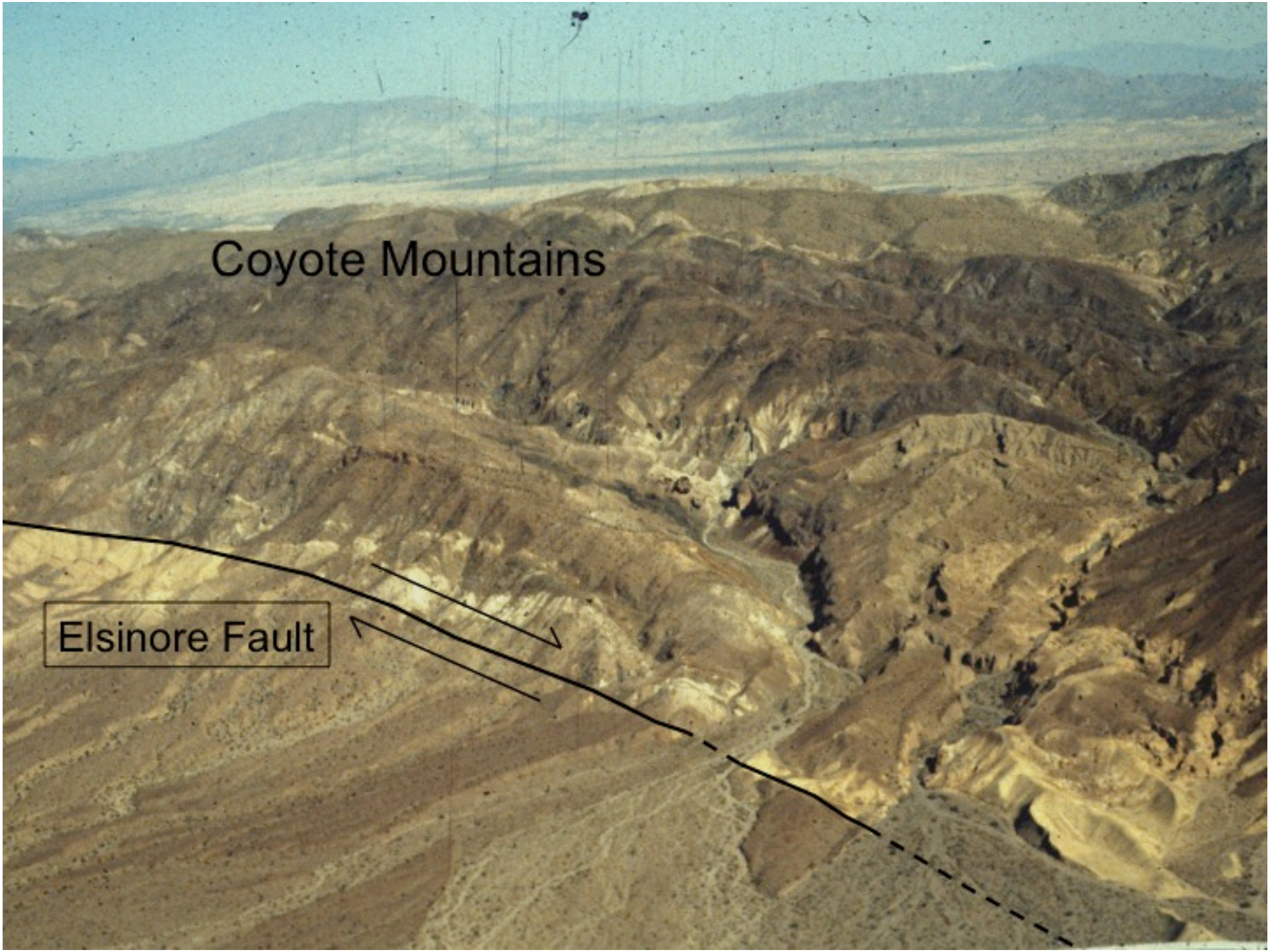
Behr et al. (2010)

Biskra Palms age summary



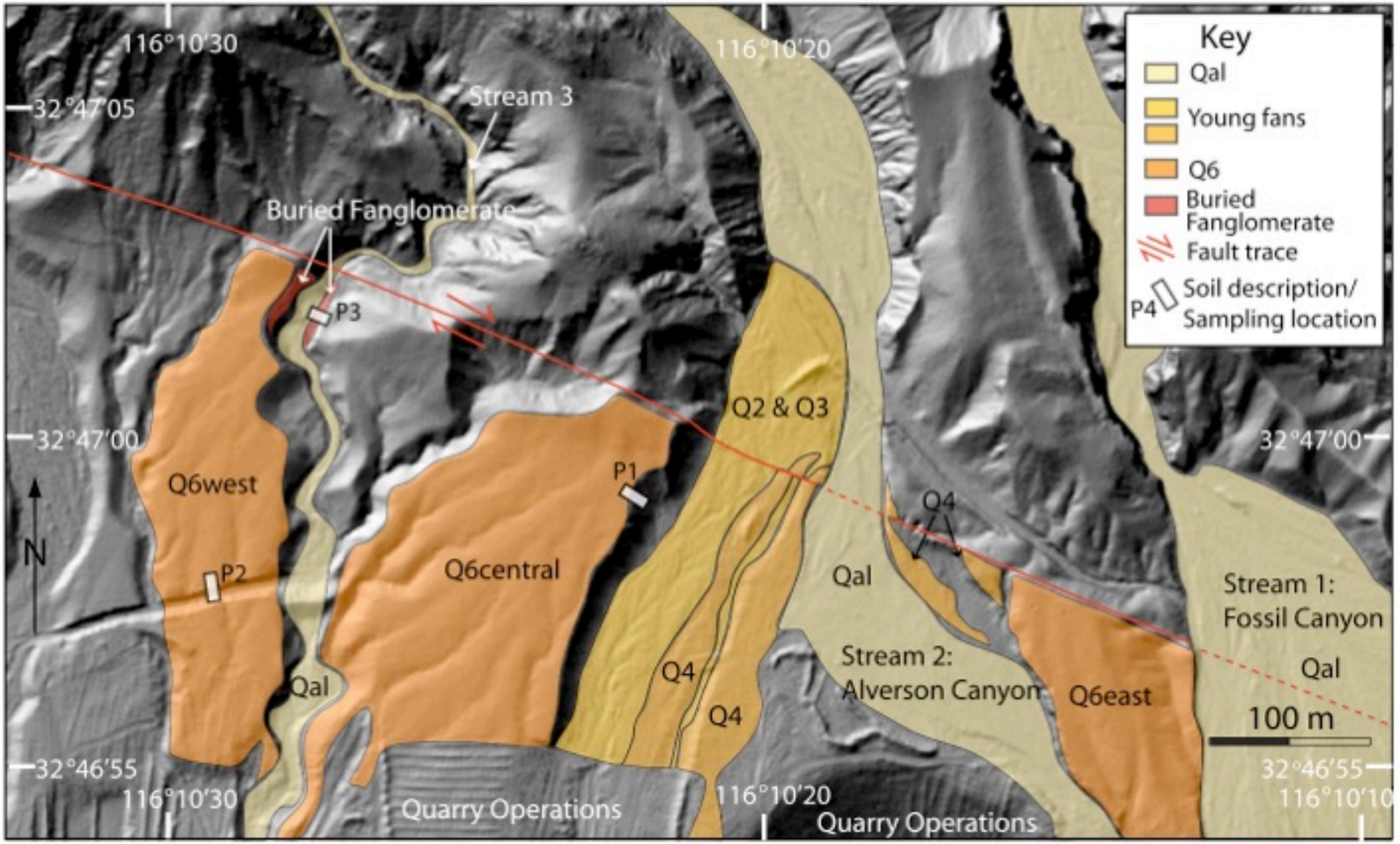
Field Location: Coyote Mountains




Coyote Mountains
Elsinore Fault

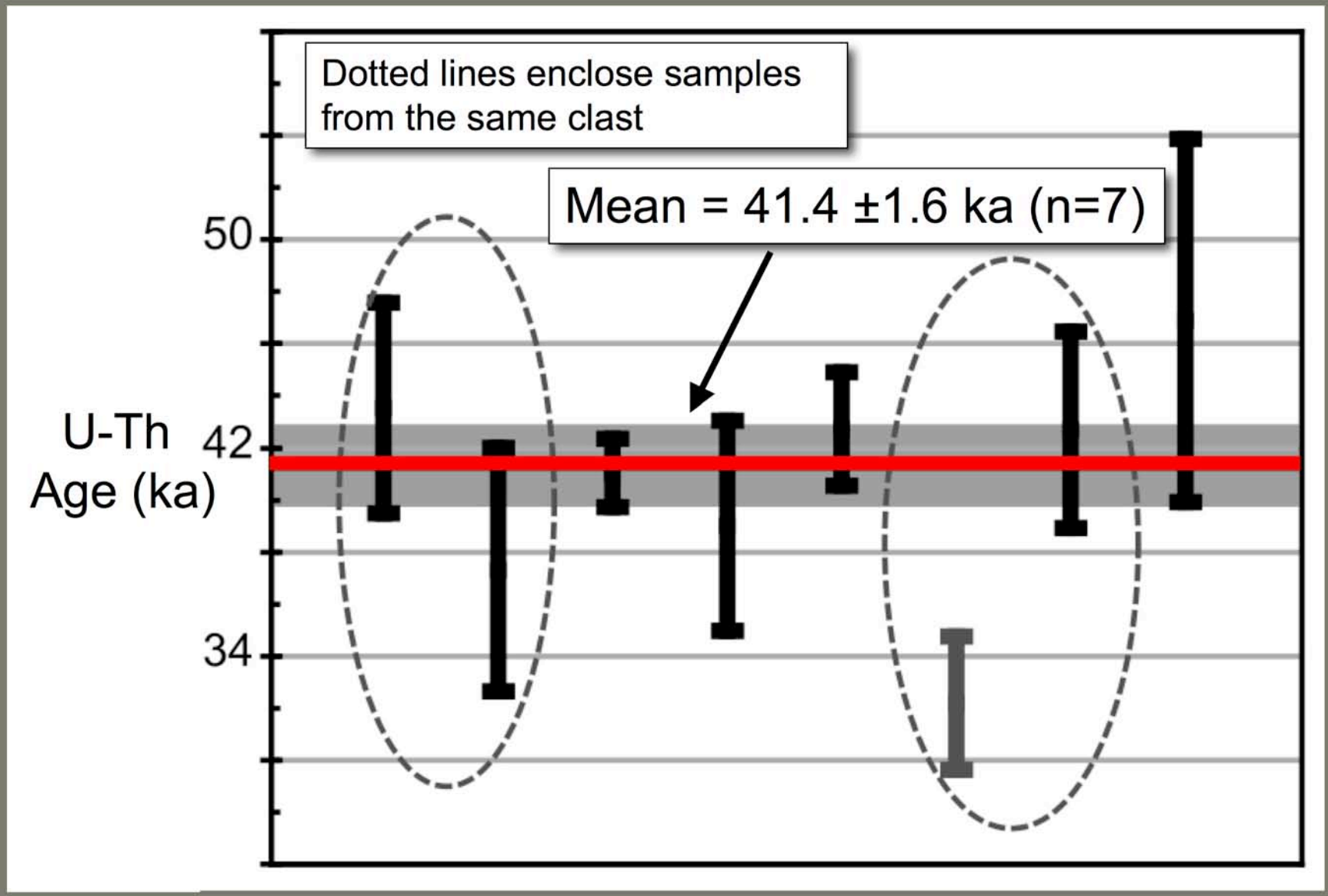
Elsinore Fault at Alverson Canyon

Fletcher et al. (2011)



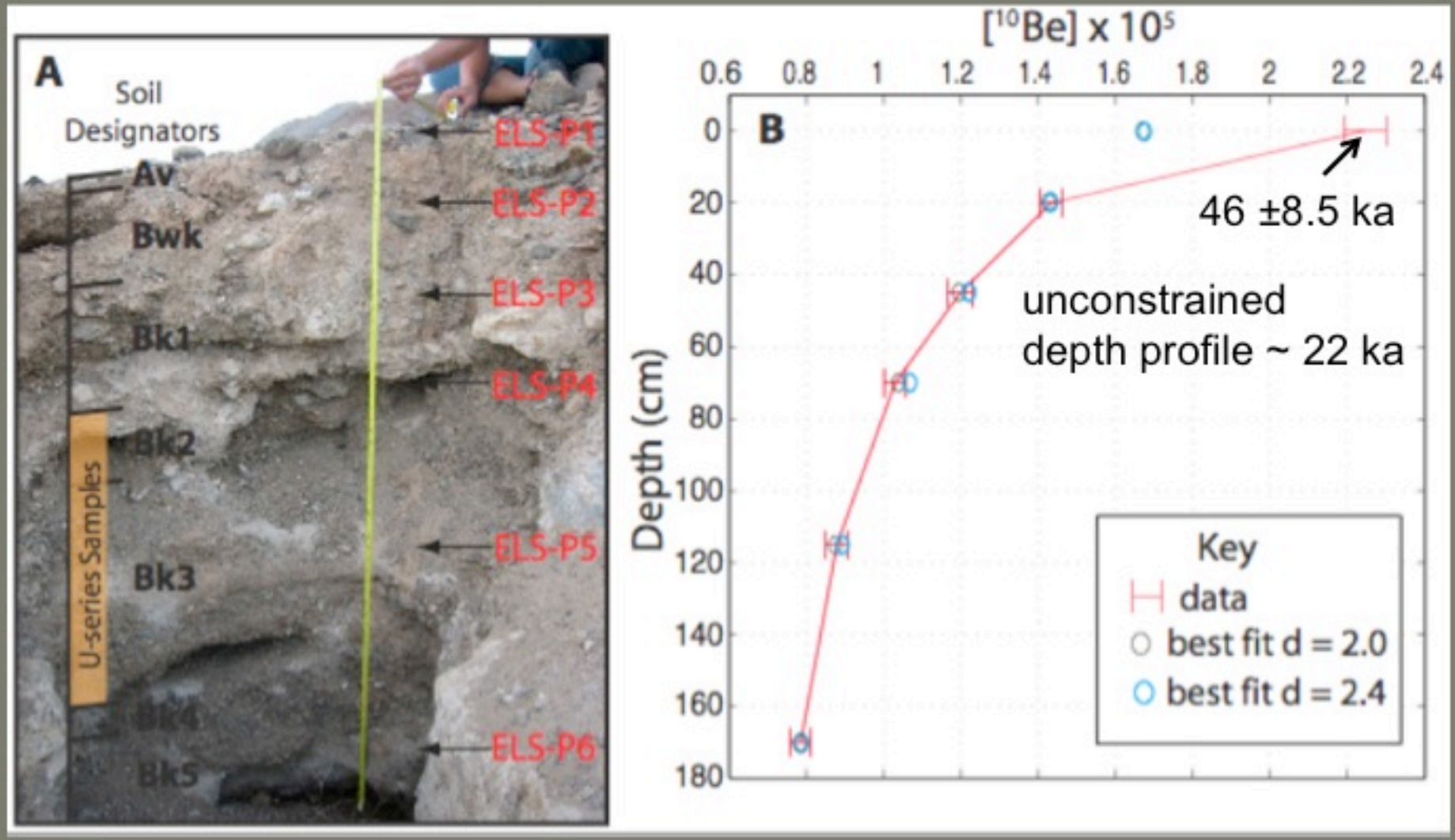
Q6central fan at P1, Elsinore Fault

U-series dates for Q6central fan



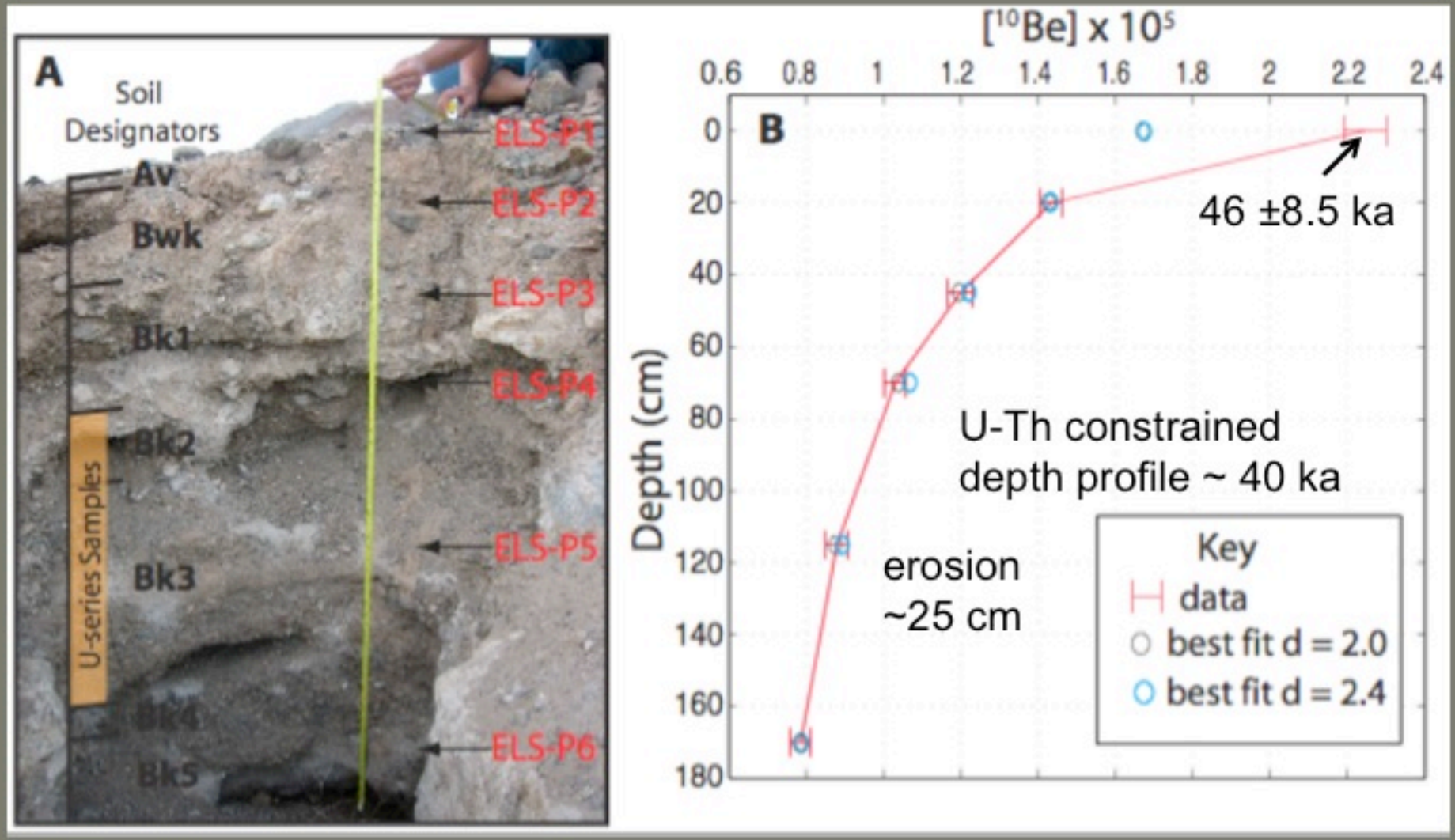
^{10}Be depth profile at Q6, Elsinore Fault

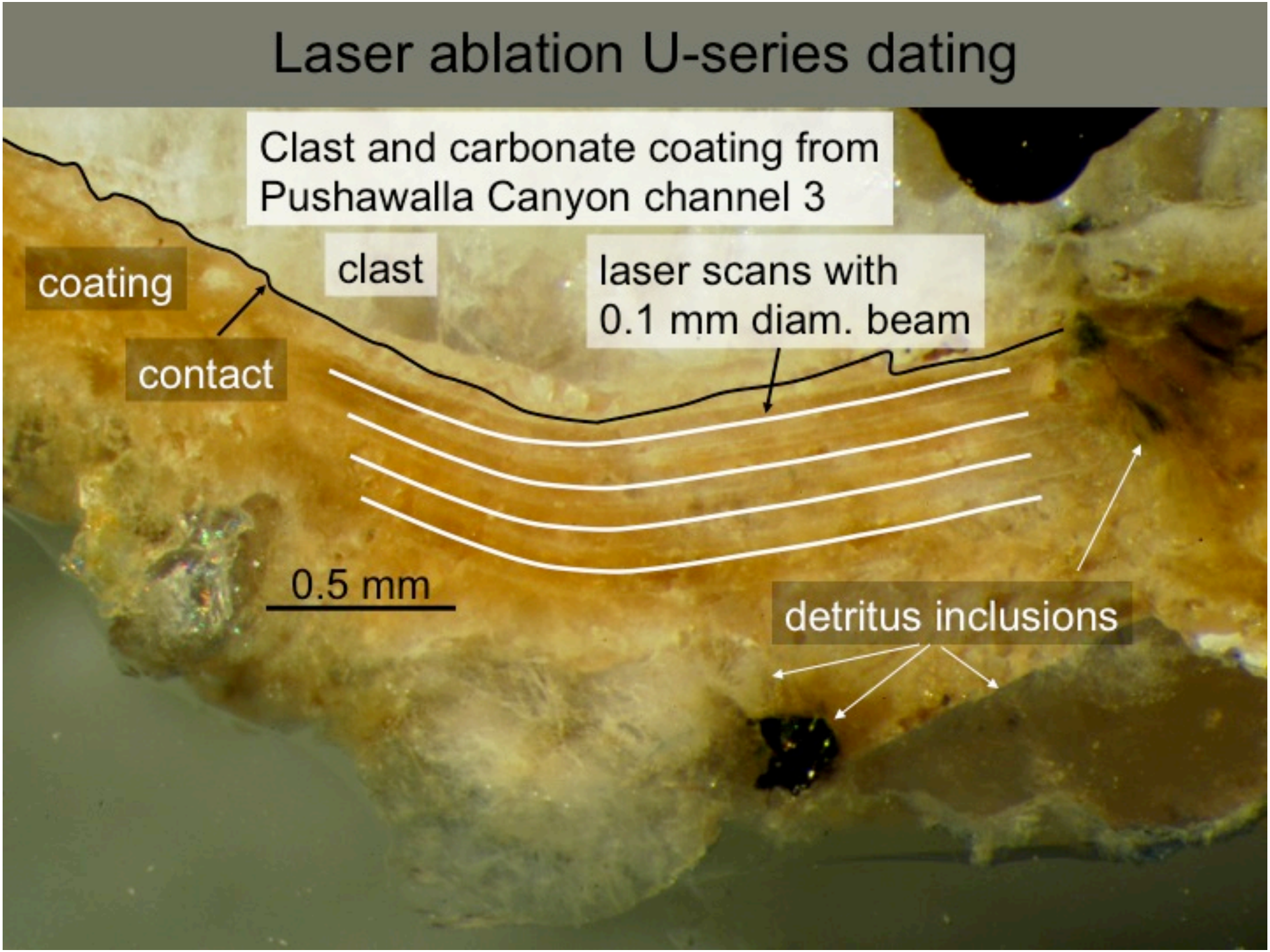
Blisniuk et al. (2012)



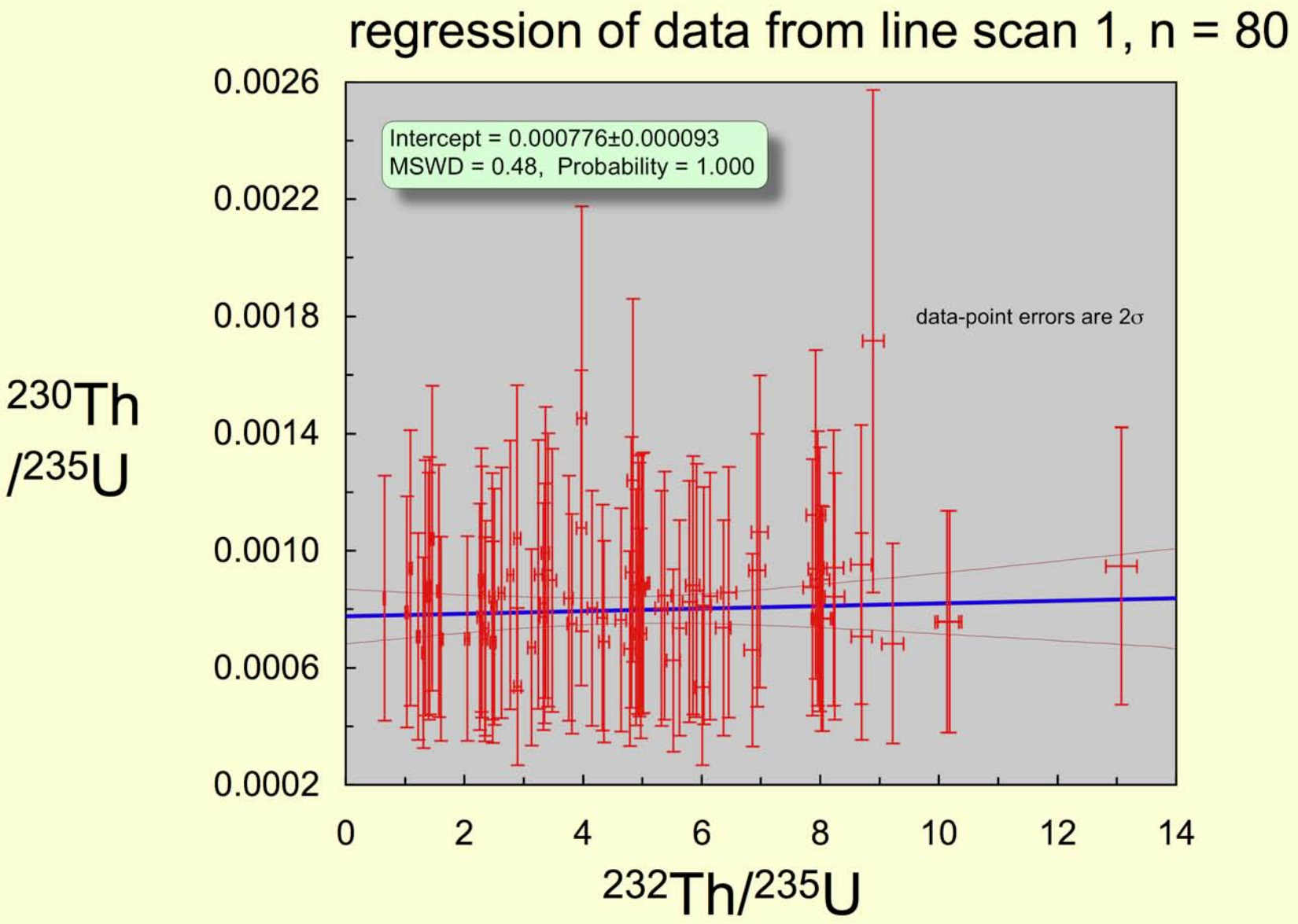
^{10}Be depth profile at Q6, Elsinore Fault

Blisniuk et al. (2012)




Laser ablation U-series dating
Clast and carbonate coating from
Pushawalla Canyon channel 3
coating
clast
laser scans with
0.1 mm diam. beam
contact
0.5 mm
detritus inclusions

Laser ablation U-series dating



Laser ablation U-series dating