ISPRA 14-15-16 giugno 2011
Corso di formazione ambientale:
Geocronologia: tecniche di datazione e metodi di correlazione

U-Th-Pb Geochronology

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Back to basics

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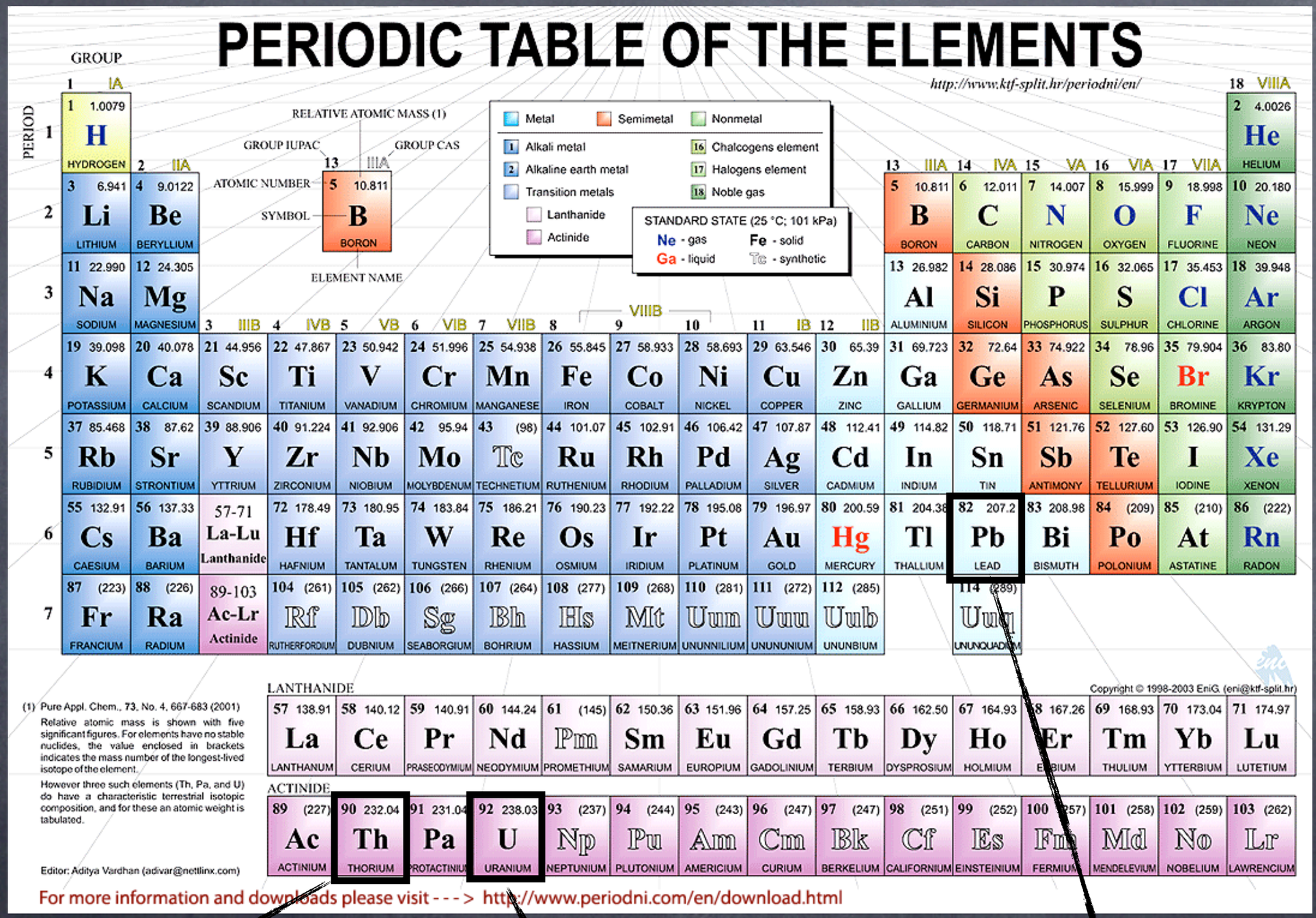
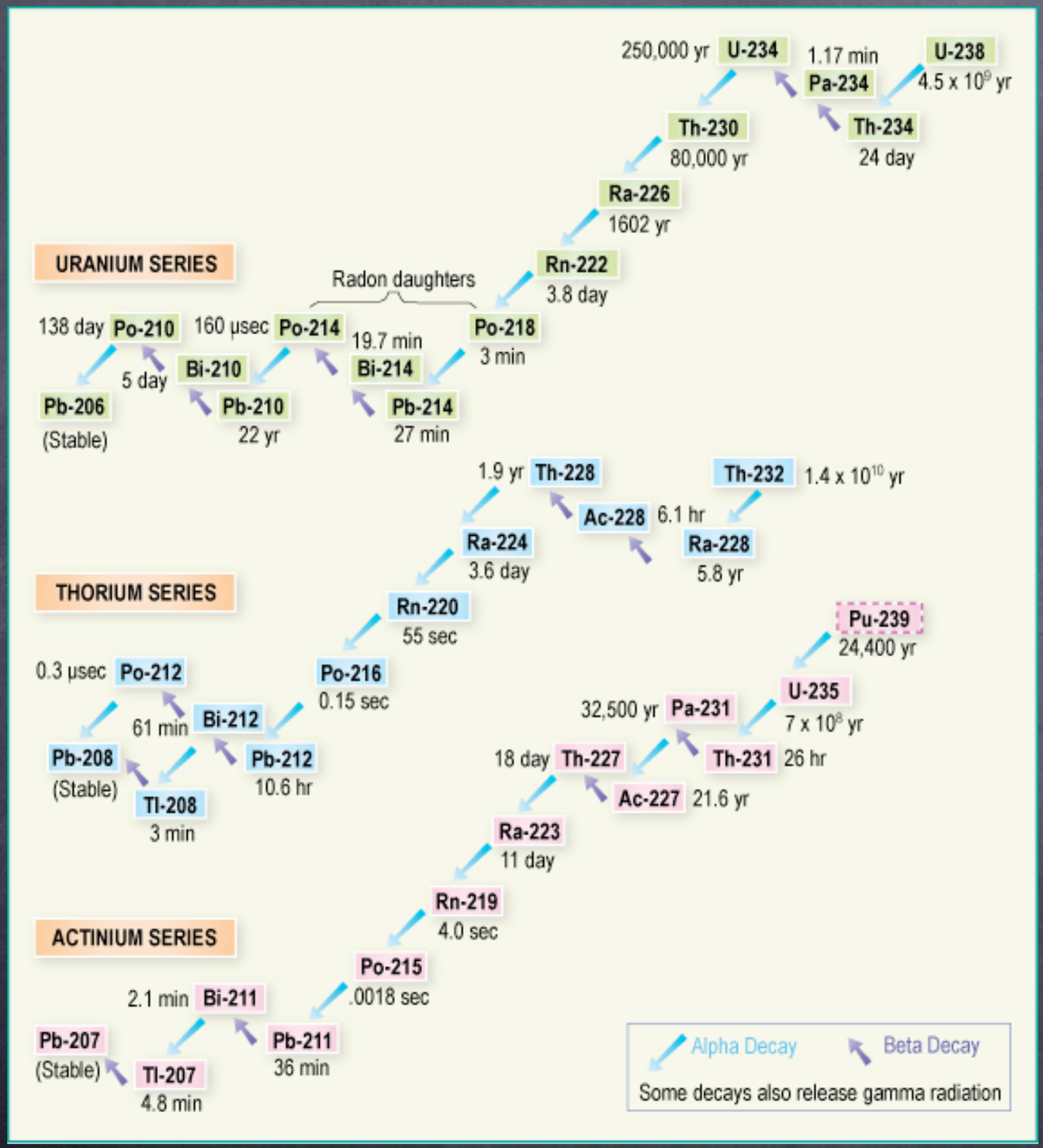


charge: 4+
ir. 1.05 (Å)

charge: 4+ (6+)
ir. 1.00 (0.86) (Å)

charge: 2+
ir. 1.29 (Å)

U and Th



$^{238}U \rightarrow ^{206}Pb$

$\lambda_1 = 1.55125 \times 10^{-4}$ (Ma^{-1})

$^{232}Th \rightarrow ^{208}Pb$

$\lambda_3 = 4.9475 \times 10^{-5}$ (Ma^{-1})

$^{235}U \rightarrow ^{207}Pb$

$\lambda_2 = 9.8585 \times 10^{-4}$ (Ma^{-1})

U-Th-Pb age equations

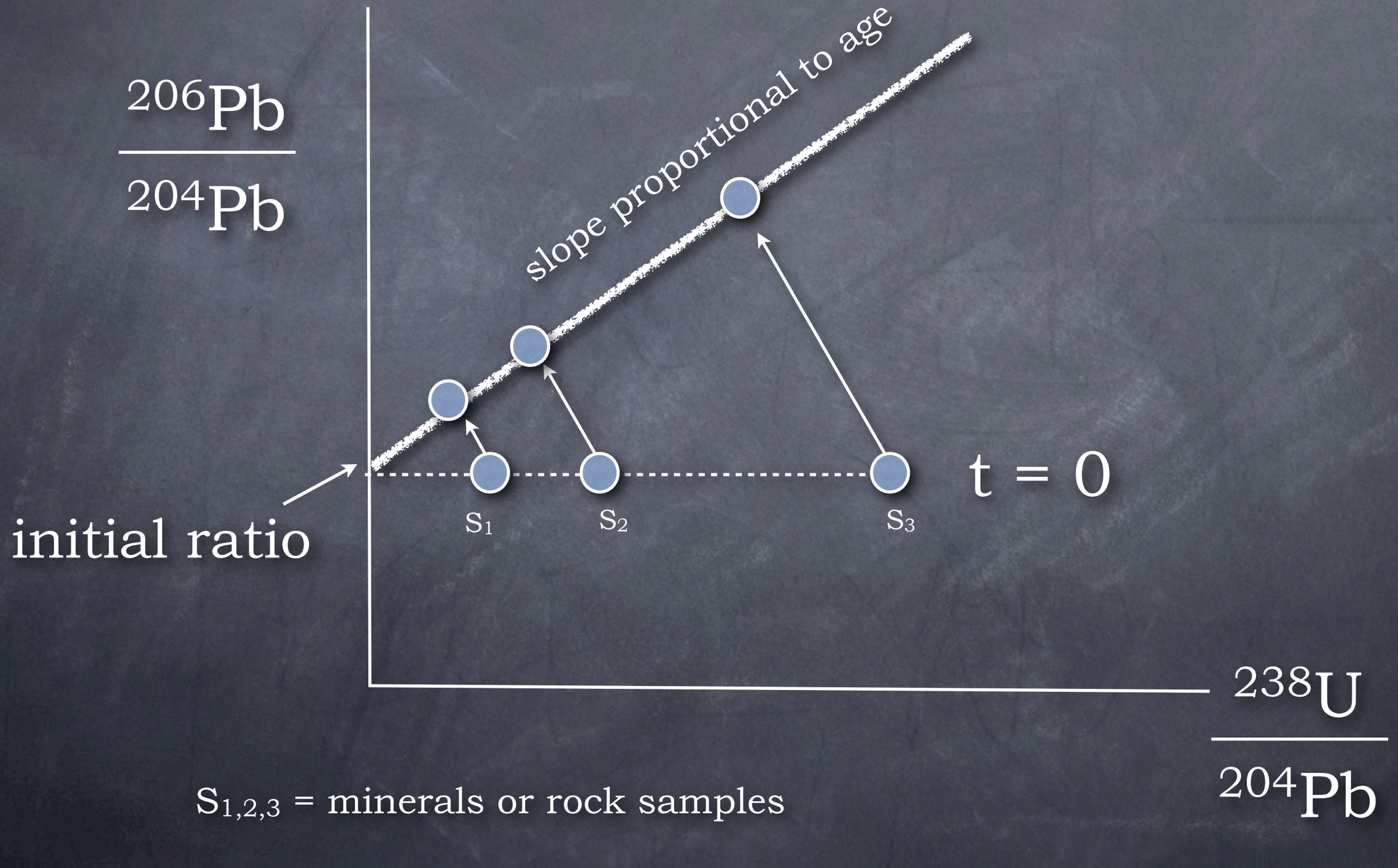
$$\frac{^{206}Pb}{^{204}Pb} = \left(\frac{^{206}Pb}{^{204}Pb}\right)_I + \frac{^{238}U}{^{204}Pb}\left(e^{\lambda t} - 1\right)$$

$$\frac{^{207}Pb}{^{204}Pb} = \left(\frac{^{207}Pb}{^{204}Pb}\right)_I + \frac{^{235}U}{^{204}Pb}\left(e^{\lambda t} - 1\right)$$

$$\frac{^{208}Pb}{^{204}Pb} = \left(\frac{^{208}Pb}{^{204}Pb}\right)_I + \frac{^{232}Th}{^{204}Pb}\left(e^{\lambda t} - 1\right)$$

How to solve age equations?

Isochron age



$S_{1,2,3}$ = minerals or rock samples

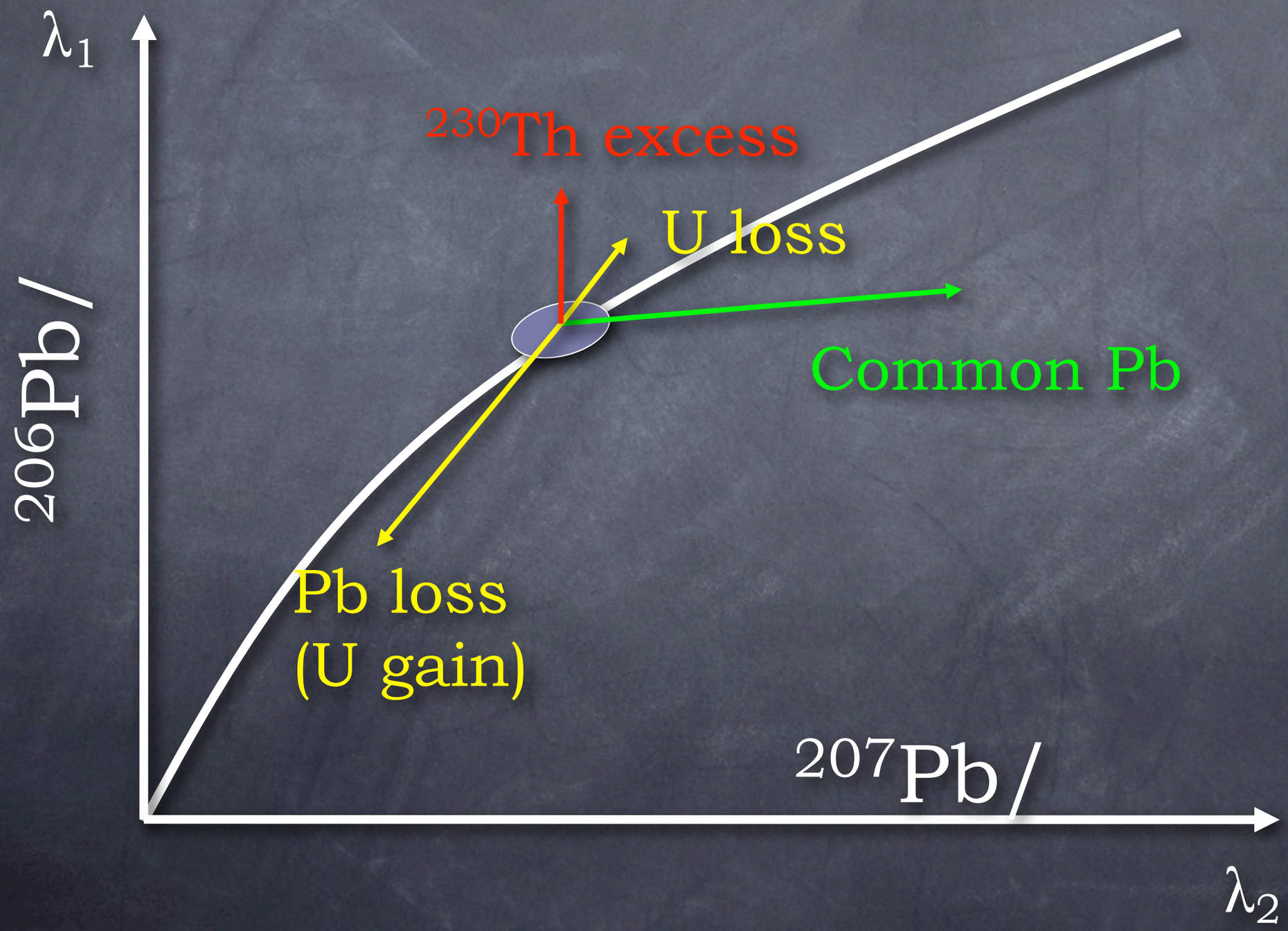
if initial Pb = 0

$$\frac{^{206}Pb}{^{204}Pb} = \left(\frac{^{206}Pb}{^{204}Pb}\right)_I + \frac{^{238}U}{^{204}Pb}\left(e^{\lambda t} - 1\right) \longrightarrow \frac{^{206}Pb}{^{238}U} = \left(e^{\lambda t} - 1\right)$$

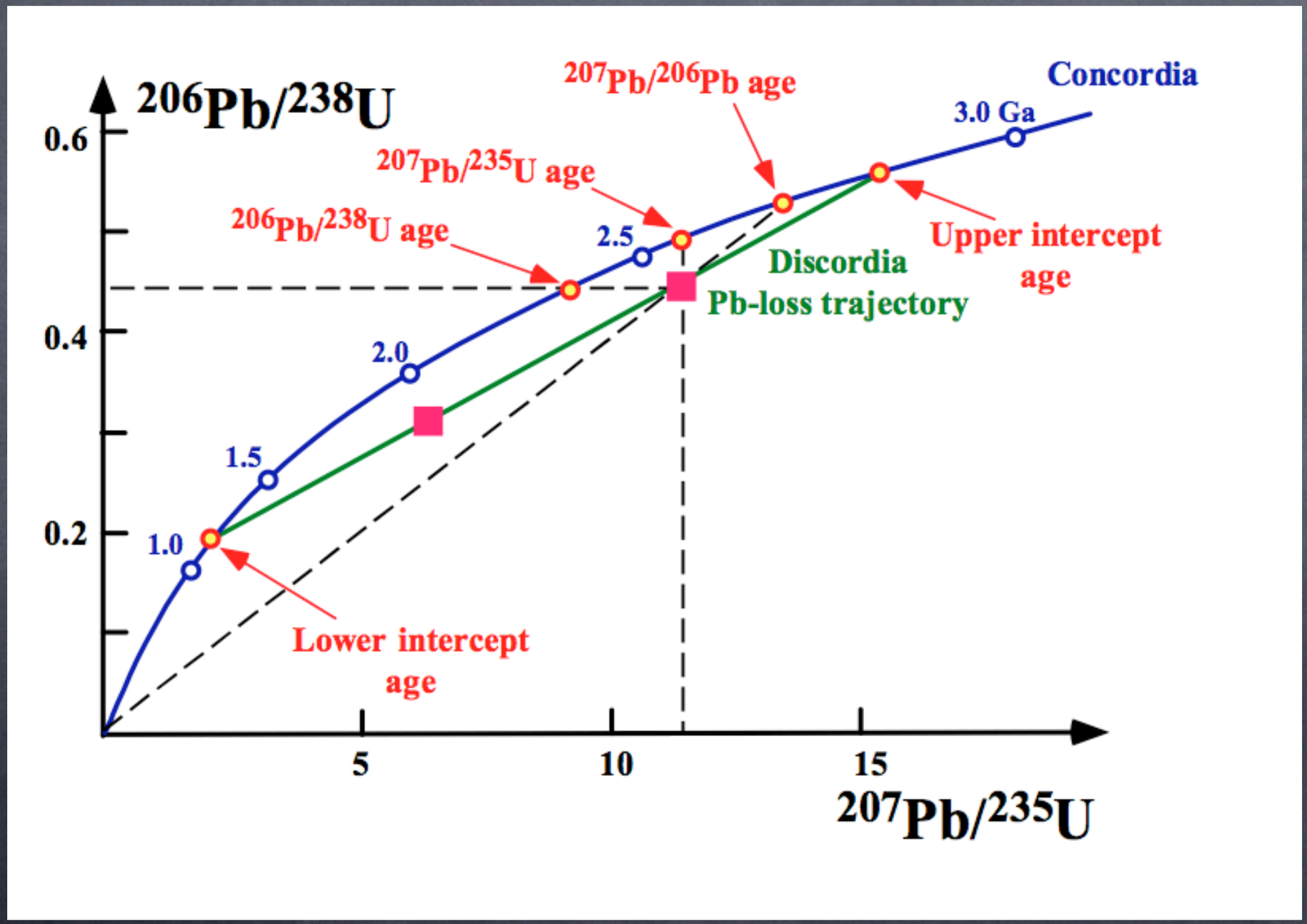
$$\frac{^{207}Pb}{^{204}Pb} = \left(\frac{^{207}Pb}{^{204}Pb}\right)_I + \frac{^{235}U}{^{204}Pb}\left(e^{\lambda t} - 1\right) \longrightarrow \frac{^{207}Pb}{^{235}U} = \left(e^{\lambda t} - 1\right)$$

$$\frac{^{208}Pb}{^{204}Pb} = \left(\frac{^{208}Pb}{^{204}Pb}\right)_I + \frac{^{232}Th}{^{204}Pb}\left(e^{\lambda t} - 1\right) \longrightarrow \frac{^{208}Pb}{^{232}U} = \left(e^{\lambda t} - 1\right)$$

The concordia plot



Discordant data



Suitable

high U or Th
low initial Pb

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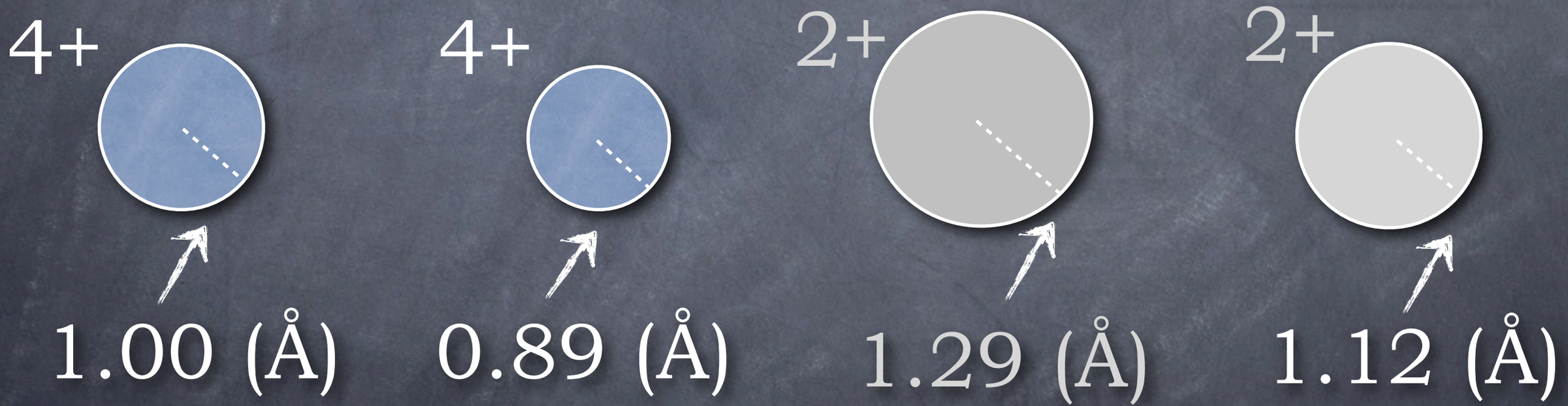
When Pb_0 is low?

U ⟷ Zr Pb ⟷ Ca



in highly selective structures

Mineral	U content (ppm)	Common Pb (% of total Pb)
Zircon	1 to >10 000	<2%
Monazite	282 to >50 000	<2%
Baddeleyite	58 to 3410	<2%
Rutile	<1 to 390	<2 to 95%
Xenotime	5000 to 29 000	<5%
Titanite	4 to 500	5 to 40%
Allanite	130 to 600	5 to 30%

Data from Heaman and Parrish (1991), Parrish and Tirrul (1989) and Noble and Searle (1995)

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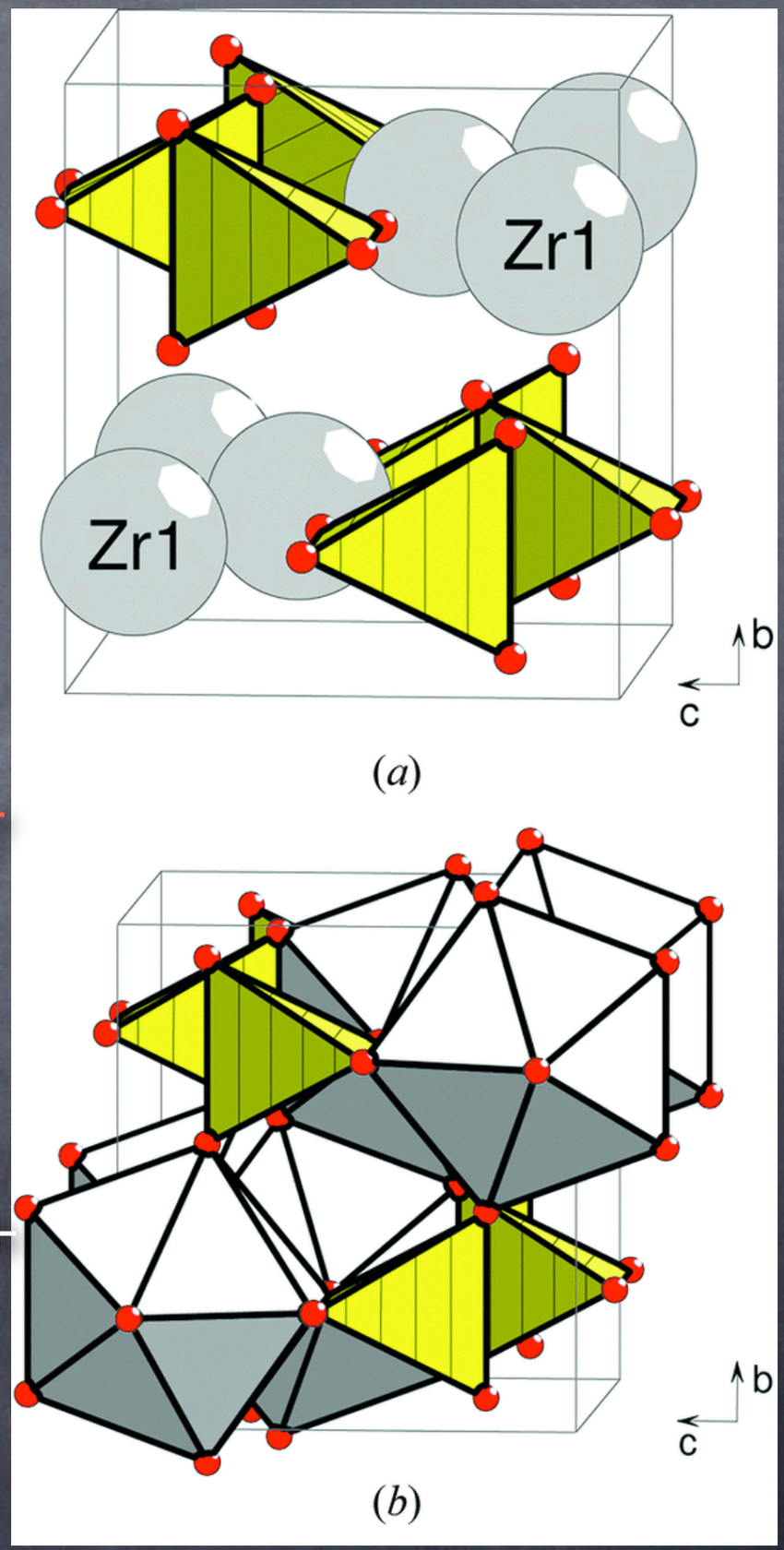
Zircon
(tetragonal)

$^{[4]}Si^{4+}$

$^{[8]}A^{[4]}TO_4$ stoichiometry

$^{[8]}Zr^{4+}$, (HREE^{3+}), U^{4+}, Th^{4+}



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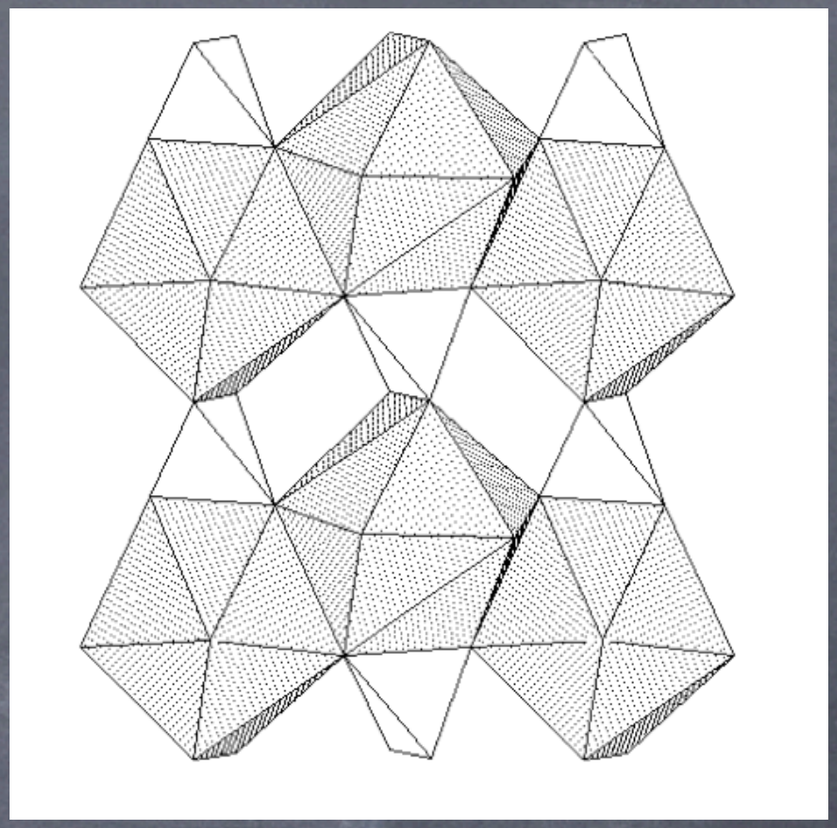
Monazite
(monoclinic)

$^{[4]}P^{5+}$

$^{[8]}A^{[4]}TO_4$ stoichiometry

$LREE^{3+}$, Th^{4+}

(U^{4+}, Ca^{2+}, Sr^{2+}, Pb^{2+}, Ba^{2+})



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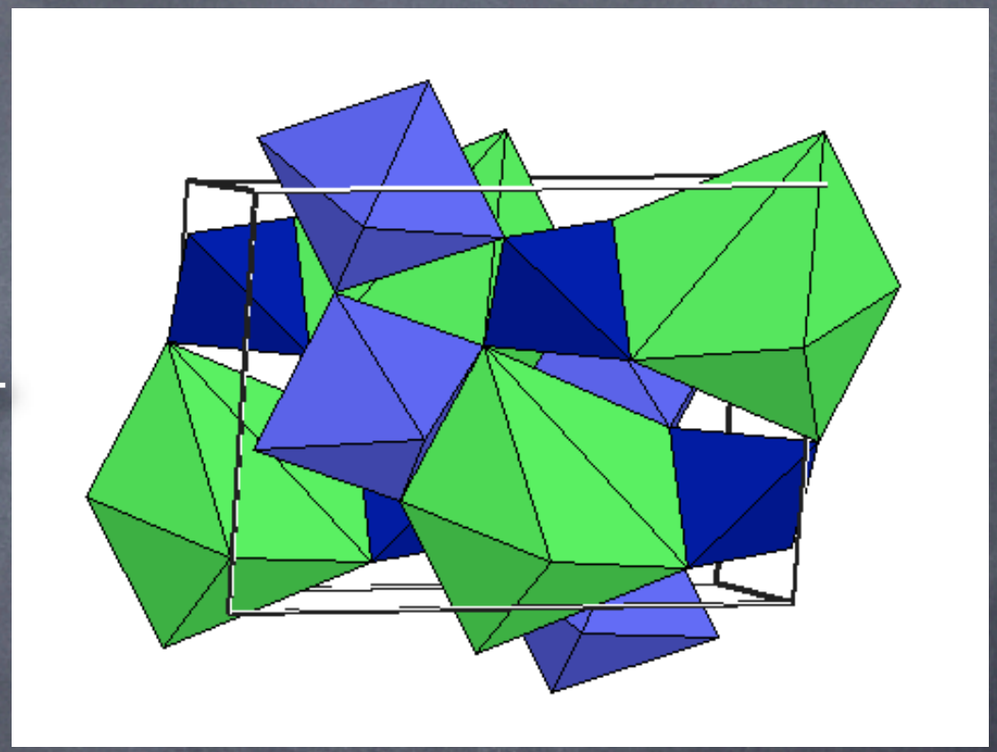
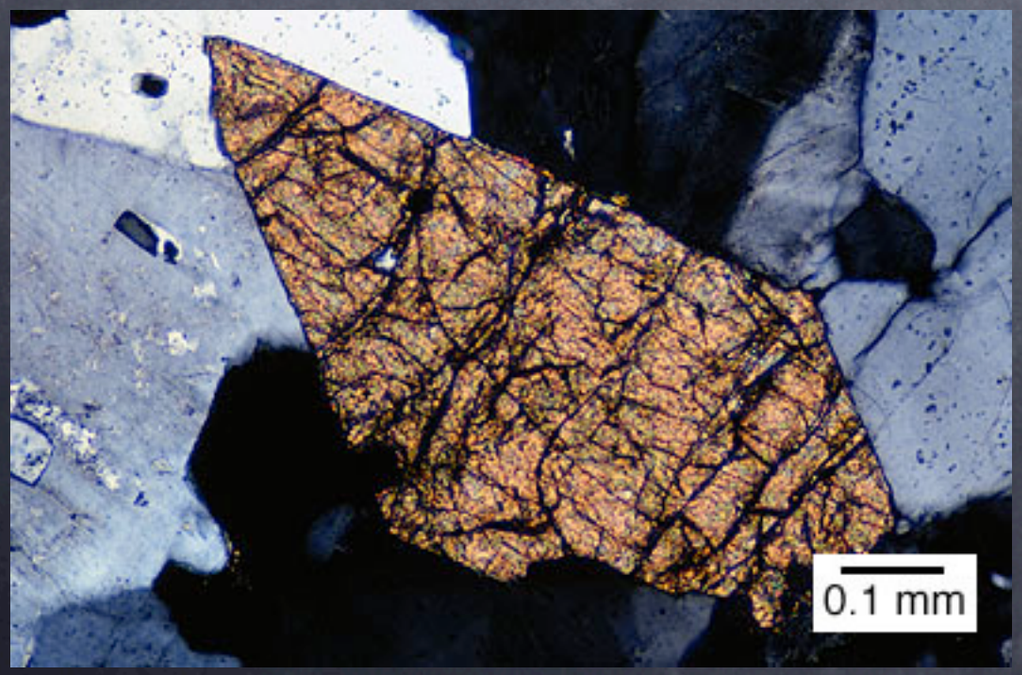
Titanite

$^{[7]}Ca^{[6]}Ti^{[4]}SiO_5$

$LREE^{3+}$, U^{4+}, Th^{4+}, Pb^{2+}





Different

different P, T, x stability fields

different closure temperatures

different ages

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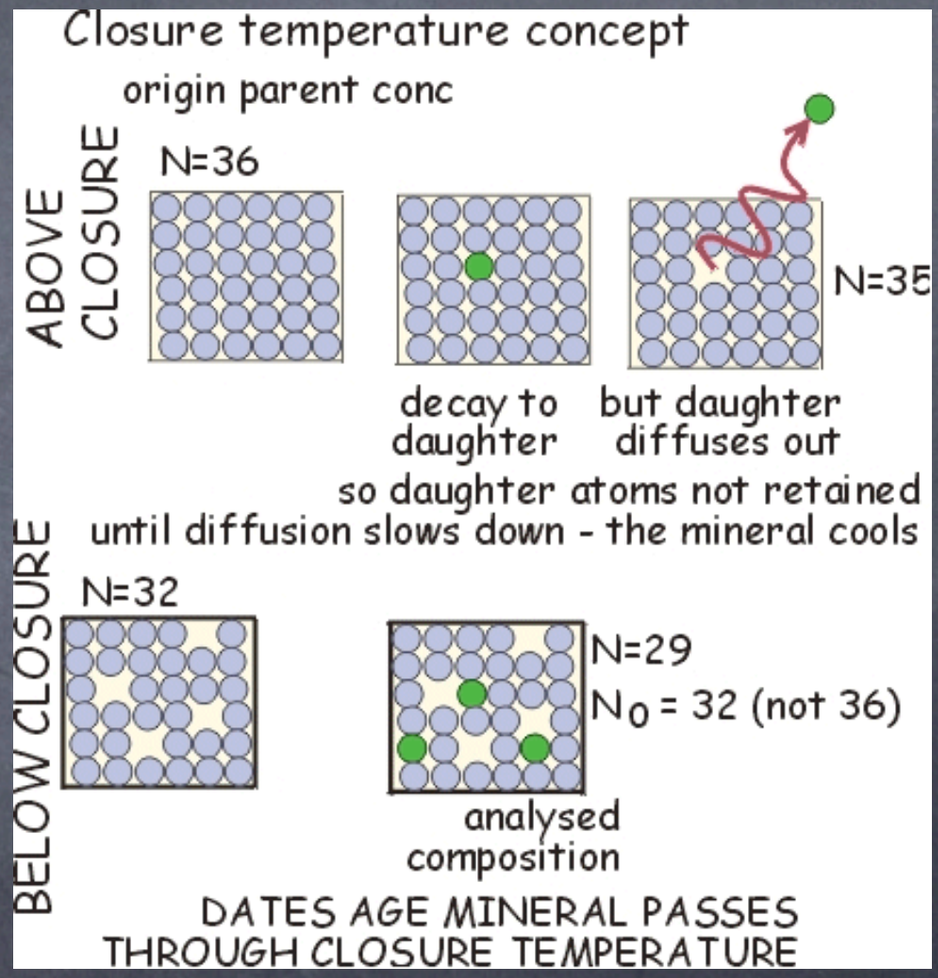
“What is closing temperature??? “

“Closing temperature is an individual concept !!!”

closure temperature

The closure temperature of a geochronolgical system may be defined as the temperature at the time corresponding to the apparent age...

The temperature recorded by a ”frozen“ chemical system, in which a solid phase in contact with a large reservoir has cooled slowly from high temperatures, is formally identical with geochronological closing temperature



M.H. Dodson (1973),
Contrib. Min. Pet., 40, 259-274

Once a mineral cools enough, then the daughter product can accumulate, and the radiometric "clock" has started.

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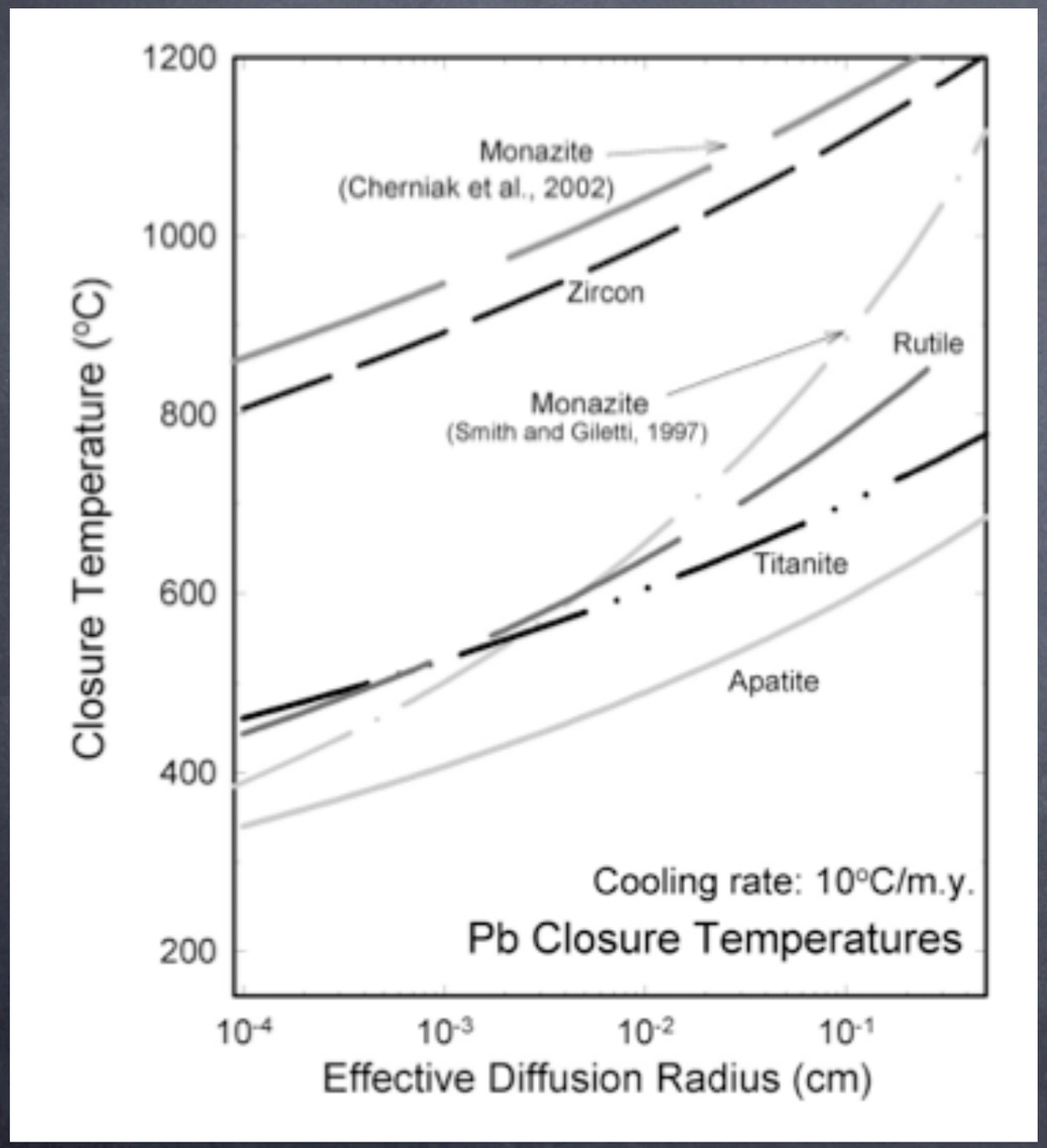
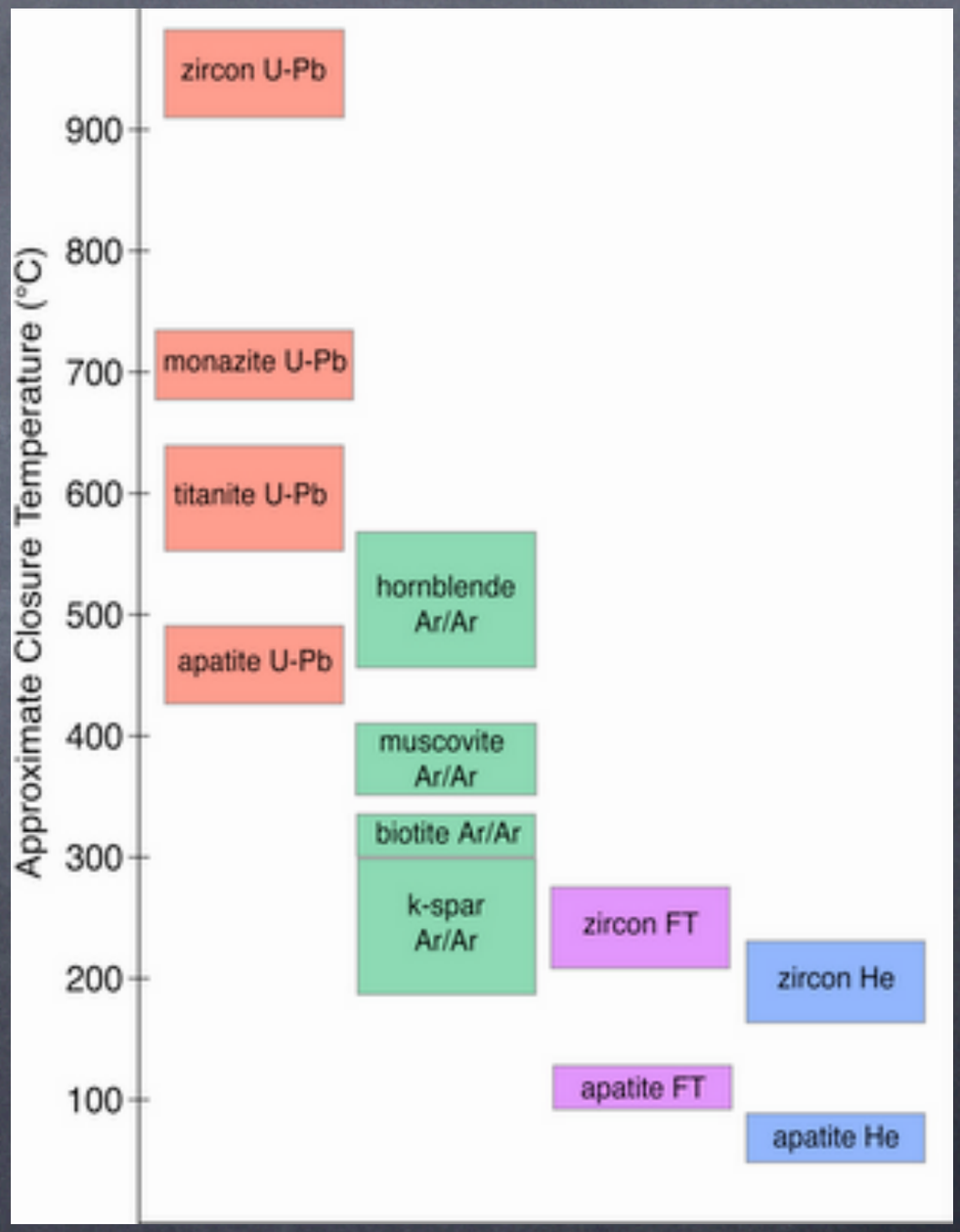
T_c vs. minerals

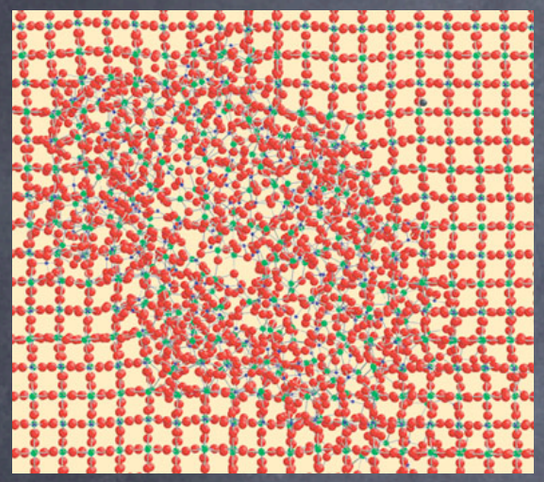


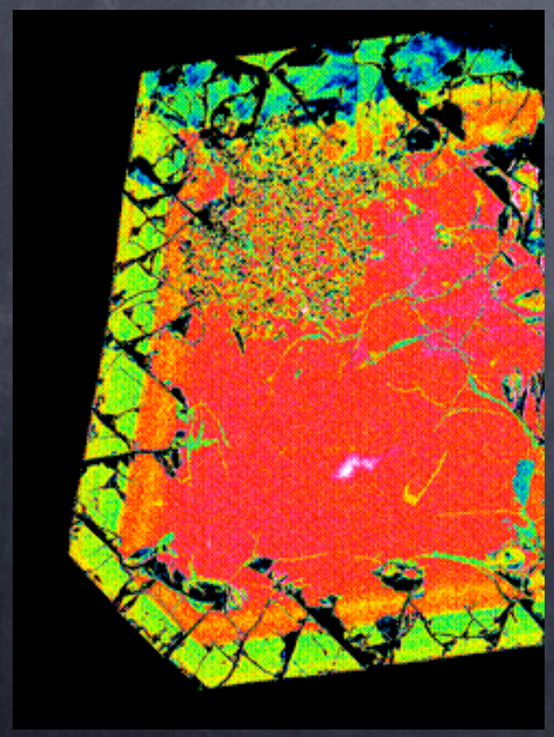
Cherniak & Watson, 2003

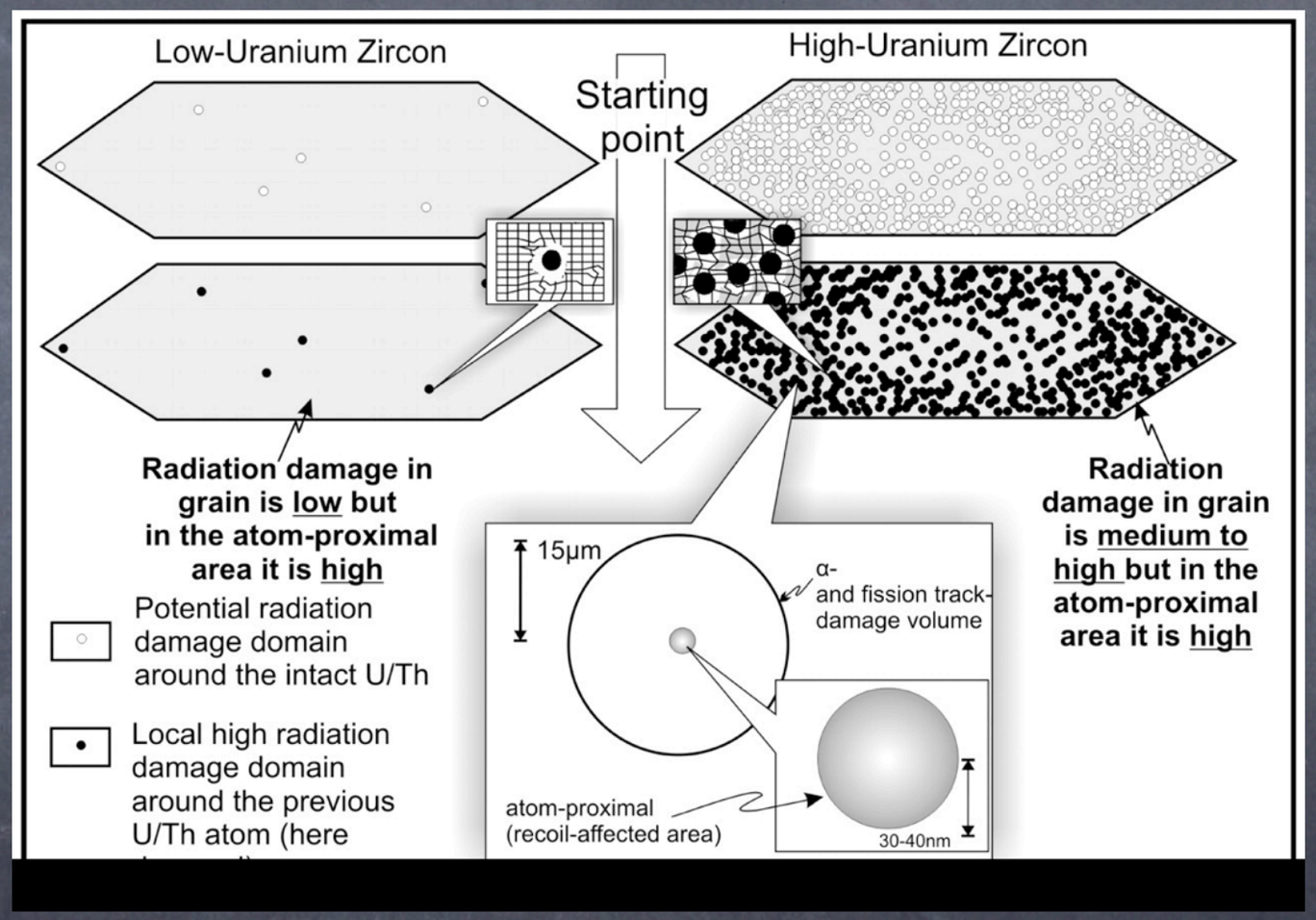


after Dodson (1973),
Contrib. Min. Pet., 40, 259-274

High U = radiation damage



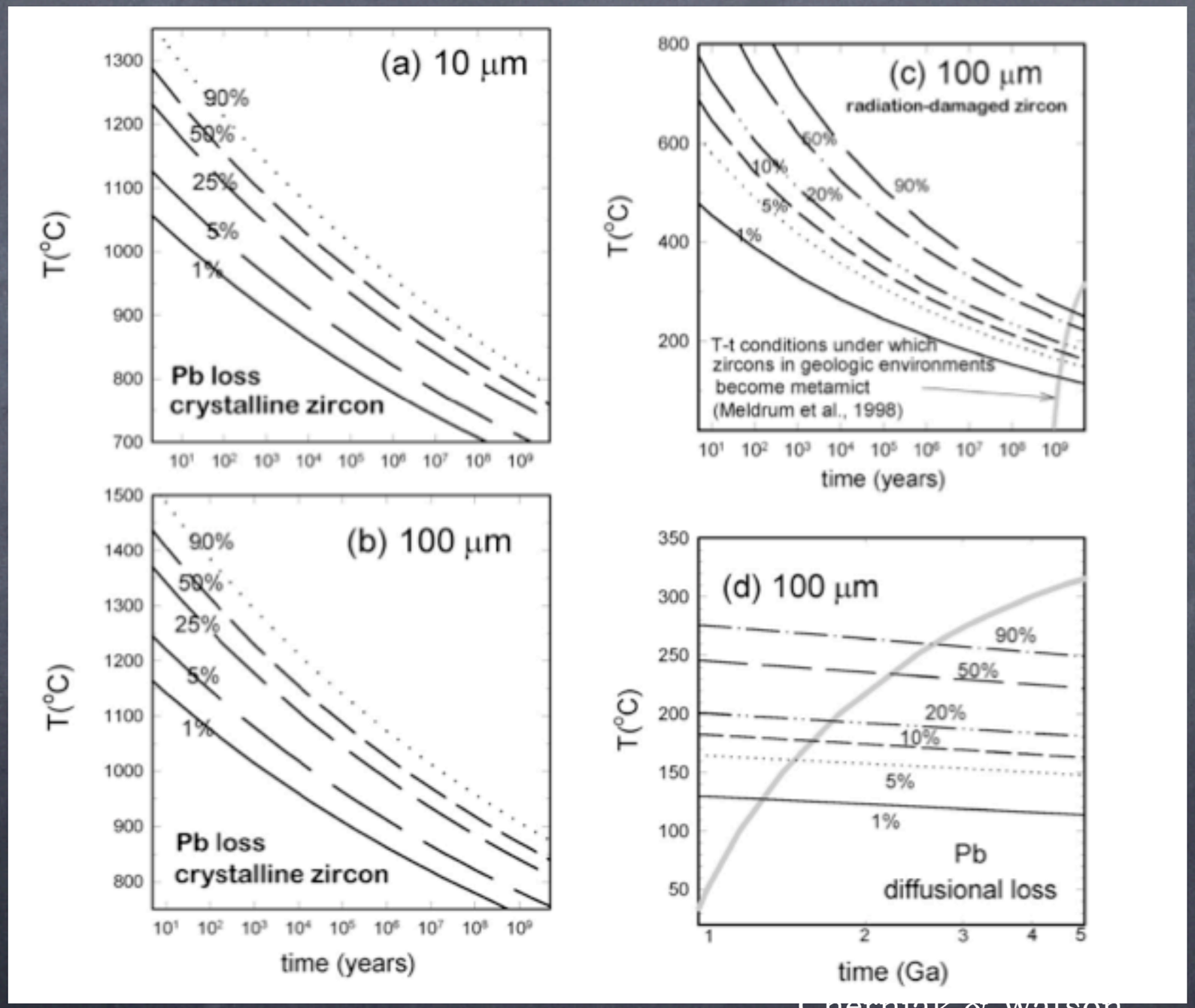




Marsellos and Garver *American Mineralogist.* 2010; 95: 1192-1201

→ Pb loss

Pb loss in zircon



Cherniak & Watson, 2003

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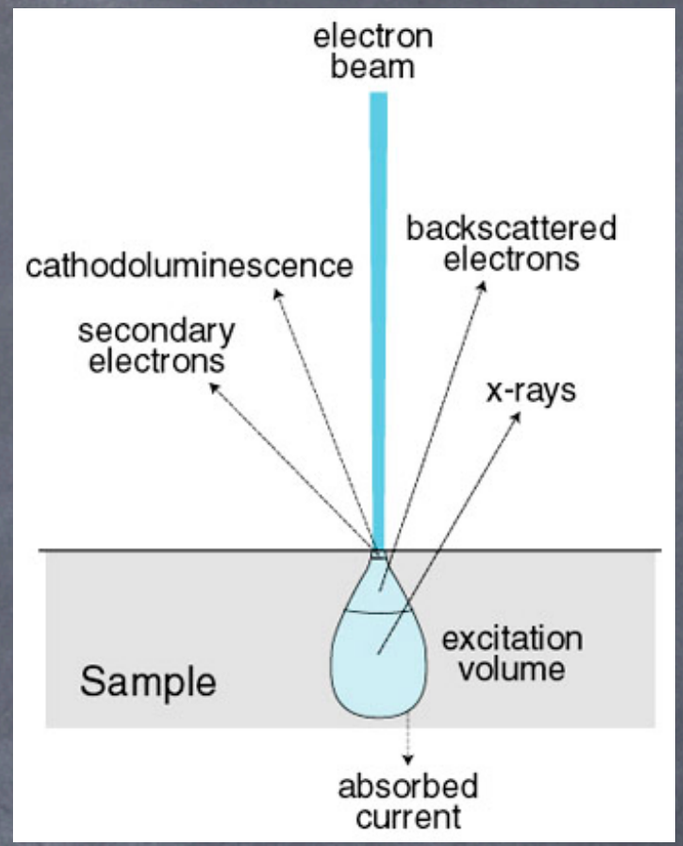
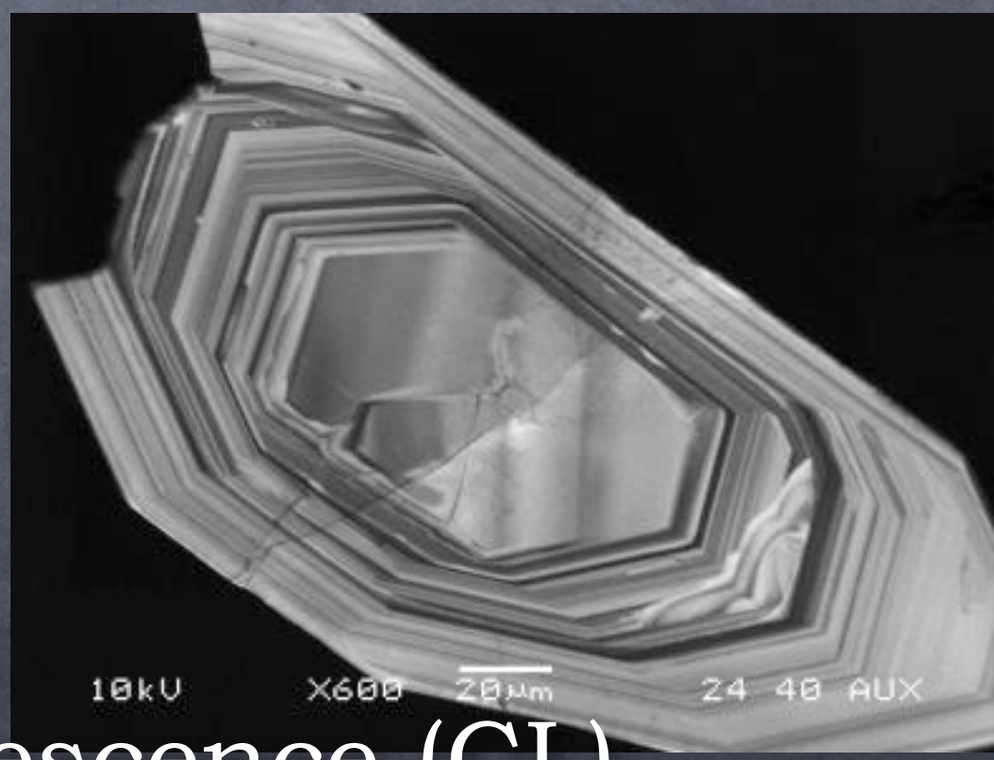
Zircon structure



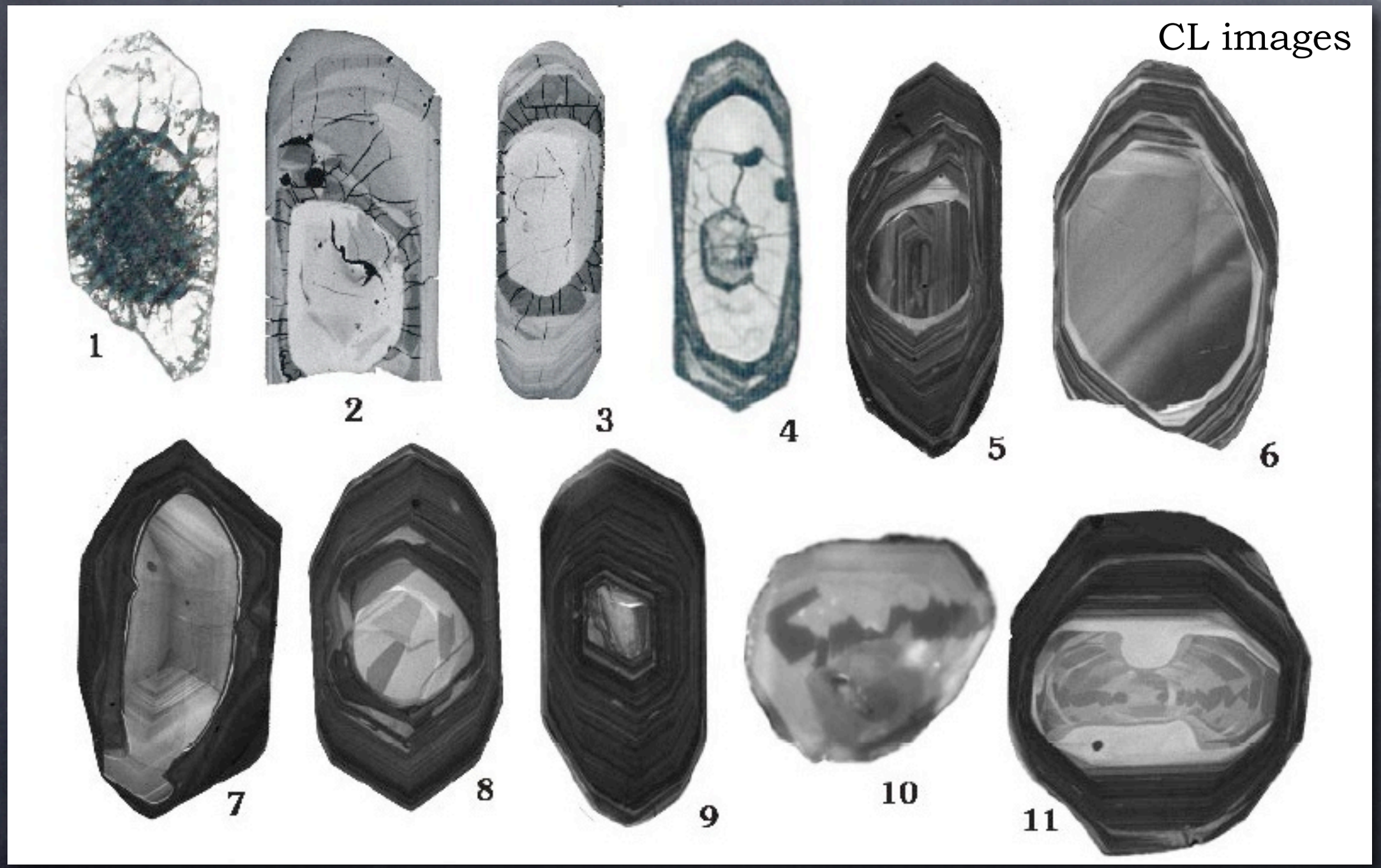
Backscattered image



cathodoluminescence (CL) image

Zircon

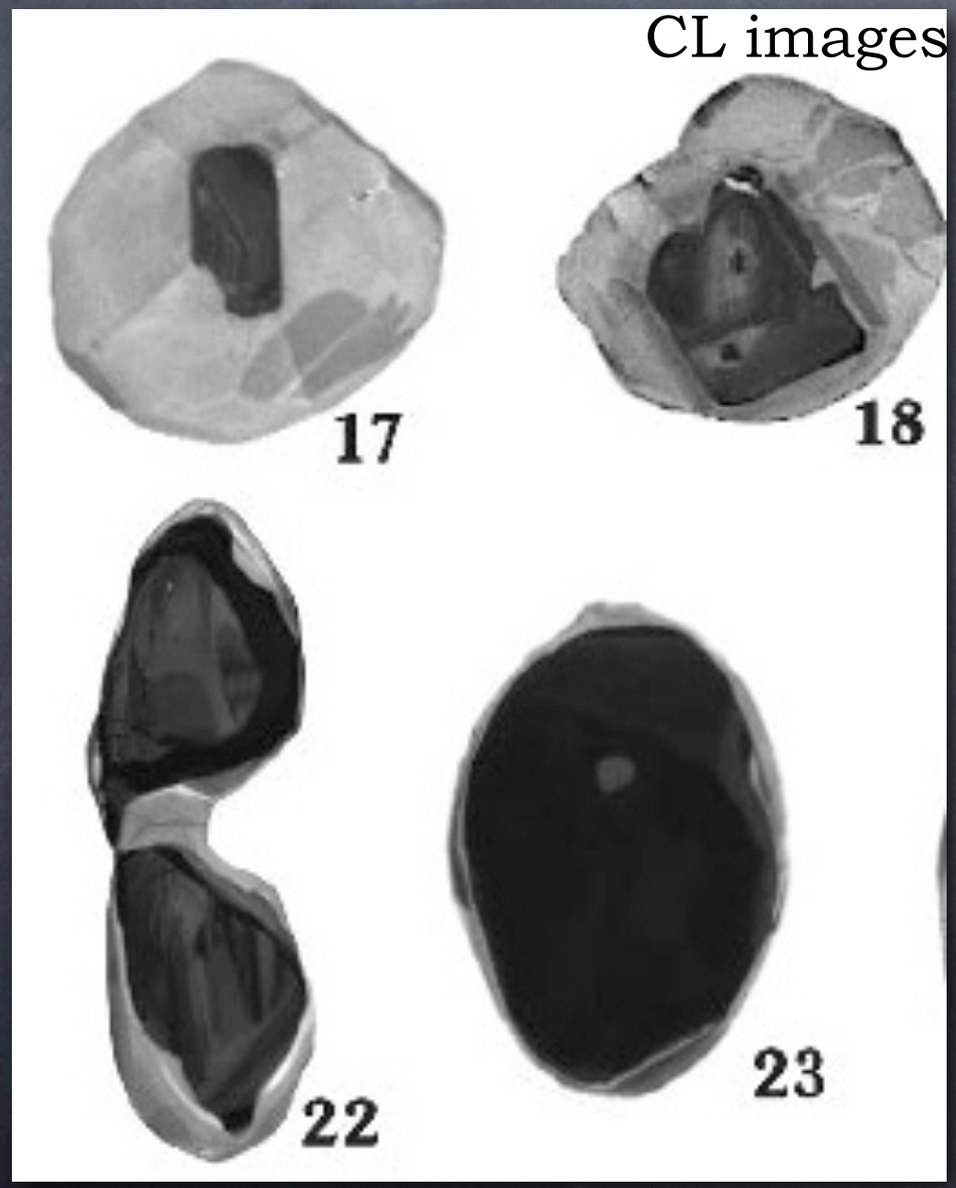
Corfu et al., RiMG 2003



Xenocrystic cores in magmatic zircons

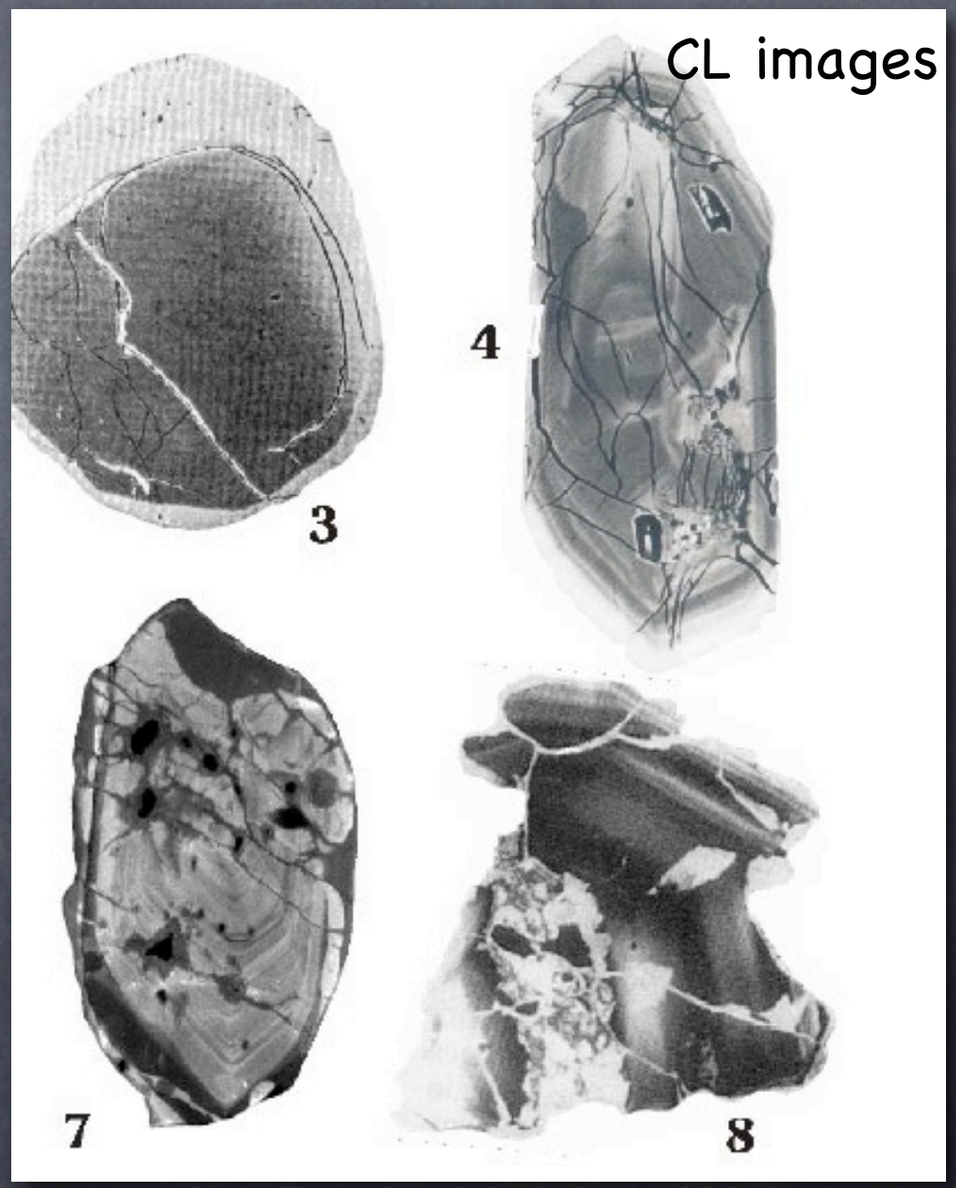
Zircon textures

High grade metamorphic rocks



Corfu et al., RiMG 2003

Highly fractured zircons



Corfu et al., RiMG 2003

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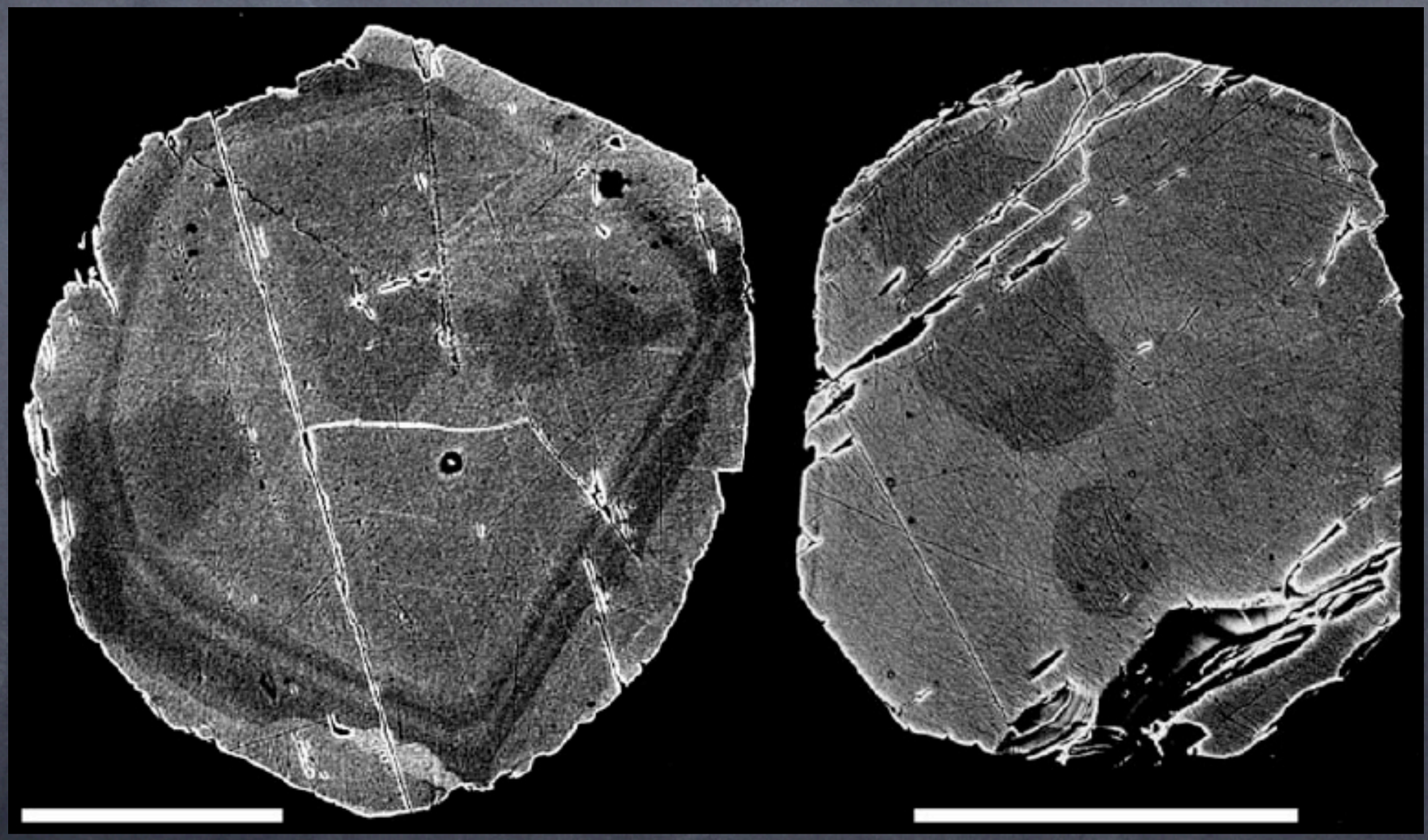
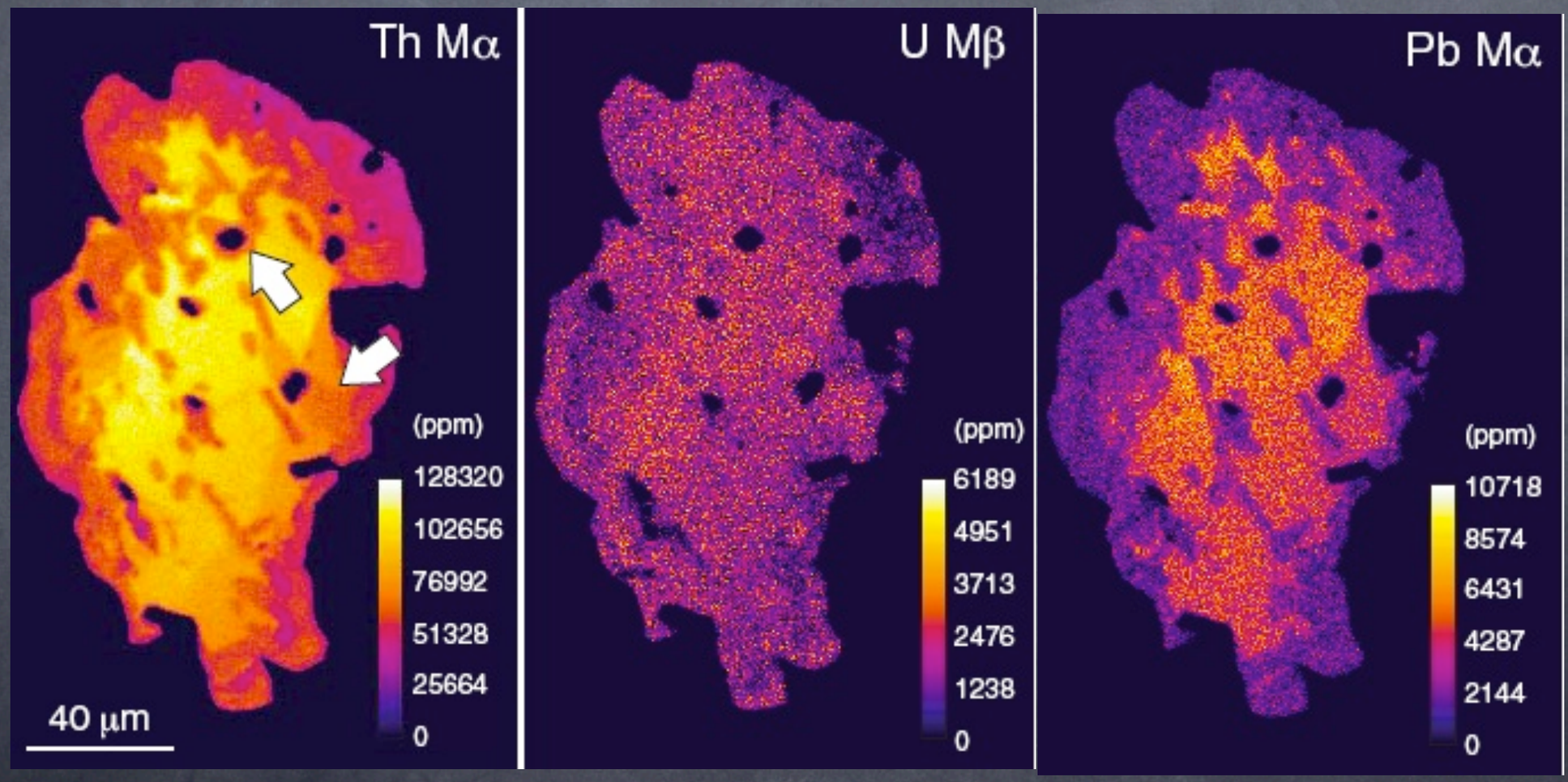
Monazite textures



Backscattered image

From Catlos et al., 2002

Monazite textures



From Goncalves et al., 2005

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The analytical point of view

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Required masses

^{204}Pb for common Pb correction

^{206}Pb ^{238}U → 206/238 age

^{207}Pb ^{235}U 207/235 age

^{208}Pb ^{232}Th 208/232 age

"Wish list"

- Submicron spatial resolution
- nm scale depth profiling

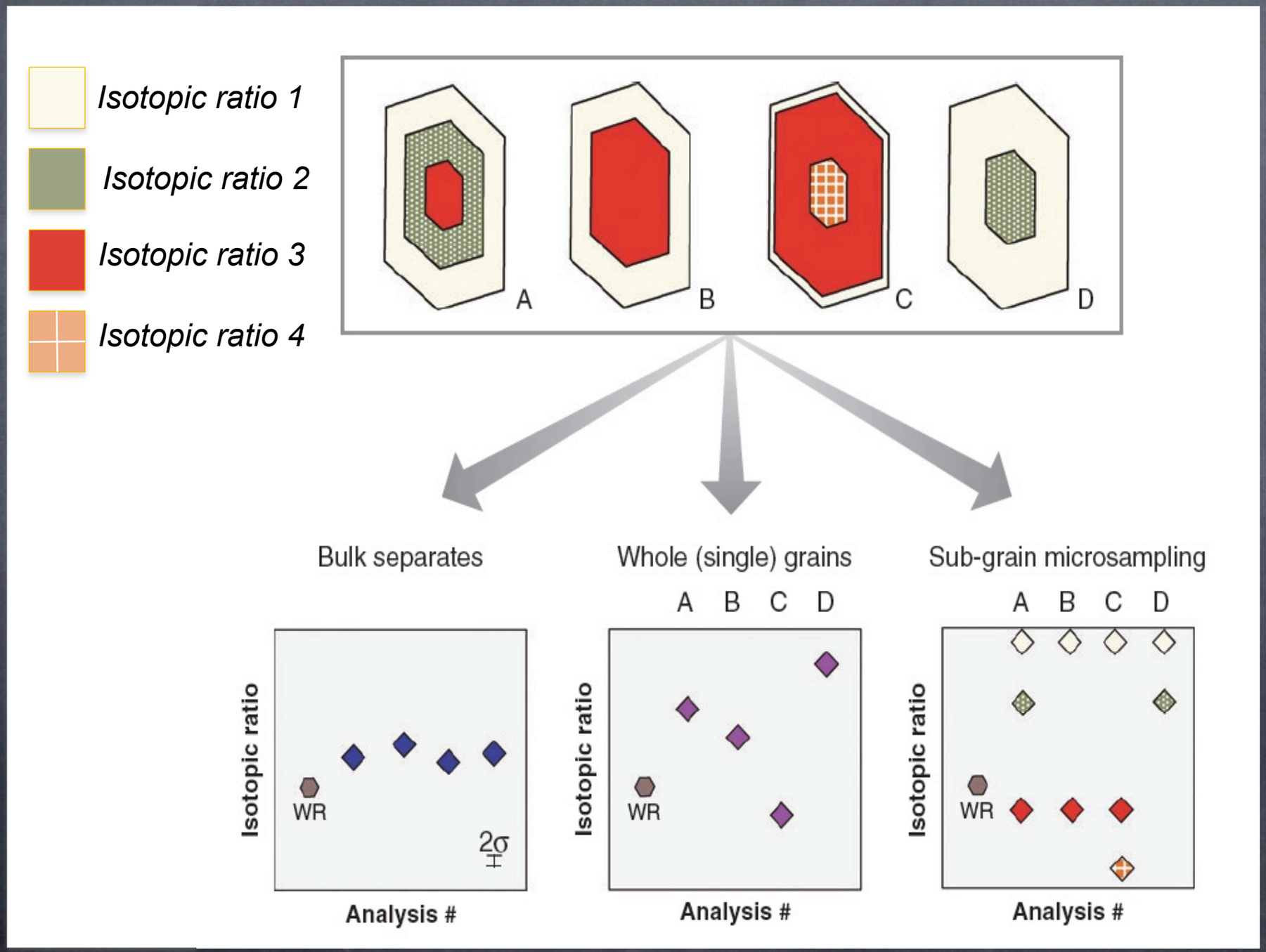
To distinguish age domains

- Stoichiometric sampling
- 100% transport efficiency

To avoid parent/ daughter fractionation

- ppm precision and accuracy

In situ vs. bulk analysis



Davidson et al., 2007