U–Th–Pb monazite dating and the timing of arc–continent collision in East Timor

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SUPPLEMENTARY PAPERS

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Supplementary papers

Correction of monazite ages for disequilibrium ^{230}Th

In young monazite grains the measured ^{206}Pb/^{238}U and ^{207}Pb/^{206}Pb values are disturbed by incorporation of disequilibrium ^{230}Th during crystal growth. ^{230}Th is a short half-life (75 ka) isotope in the decay chain of ^{238}U. Monazite preferentially incorporates Th relative to U during growth. Thus the incorporation of excess ^{230}Th into the grain leads to a small but significant excess disequilibrium component of ^{206}Pb in the grain (Schärer, 1984). The ^{207}Pb/^{206}Pb value should also be corrected for this component before calculating the common Pb component. The disequilibrium component can be calculated from

$$^{206}\text{Pb}/^{238}\text{U}^{d} = \lambda_4 \text{ x } (\text{UThf}-1)/\ \lambda_1$$

where λ_4 = decay constant of ^{230}Th; λ_1= decay constant of ^{238}U and UThf is the U/Th fractionation factor (Faure & Mensing, 2005; Schärer, 1984). UThf depends on the other minerals that host U and Th in the rock and this cannot easily be determined. However, in this study with monazite containing an order of magnitude higher Th than U, the ^{206}Pb/^{238}U and ^{208}Pb/^{232}Th ages have similar precision and a fractionation factor can be determined that gives the same age for the two systems. The algorithm for calculating the age using this method with full error propagation has been included in the supplementary material. The error propagation includes an estimate of the error in the fractionation factor. The calculated fractionation factors vary from 7–10 and the disequilibrium correction leads to a calculated ^{206}Pb/^{238}U age 0.8 to 1.1 Ma less than the uncorrected age. For this paper the corrected ^{208}Pb/^{232}Th age is accepted as the preferred age and this value is 0.03 to 0.04 Ma lower than the uncorrected age. The main value in the introduction of a fractionation factor is to improve the calculation of the common Pb correction using the "207 method". A fractionation factor of 7 to 10 is consistent with the analysed monazite composition and typical shale compositions (e.g. Taylor & McLennan, 1985). The fractionation factor for monazite in equilibrium with granitic melts has been reported as 20 to 35 (Schärer *et al.*, 1984) and can also be estimated from published data on migmatites (9 to 14, Crowley *et al.*, 2009). However, we are unaware of any previous reported U/Th fractionation factor for monazite in metamorphic rocks formed in the absence of melts.

Calculation protocol

Stage 1

Disequilibrium correction to ^{206}Pb/^{238}U from (Scharer, 1984)

$^{206}\text{Pb}_{dis}/^{238}\text{U} = (\lambda_{238}/\lambda_{230}) \text{ x } (\text{ff}-1)$

Where ff= fractionation factor of Th/U for monazite (or other mineral of Interest)

$^{206}\text{Pb}/^{238}\text{U}_{corr} = {}^{206}\text{Pb}/^{238}\text{U}_{meas} - {}^{206}\text{Pb}_{dis}/^{238}\text{U}$

Then correct the ^{207}Pb/^{206}Pb value

$^{207}\text{Pb}/^{206}\text{Pb}_{corr} = {}^{207}\text{Pb}/^{206}\text{Pb}_{meas} \text{ x } ((^{206}\text{Pb}/^{238}\text{U}_{meas}) / (^{206}\text{Pb}/^{238}\text{U}_{corr}))$

Stage 2

Then correction for common Pb using the 207/206 correction as explained by Chew et al. (2011)

Set $f_{206} = {}^{206}Pb_{common}/{}^{206}Pb_{corr}$ then

$f_{206} = ({}^{207}Pb/{}^{206}Pb_{corr} - {}^{207}Pb/{}^{206}Pb_{radiogenic})/({}^{207}Pb/{}^{206}Pb_{common} - {}^{207}Pb/{}^{206}Pb_{radiogenic})$

Then 207 corrected 206 age comes from

${}^{206}Pb/{}^{238}U_{radiogenic} = (1-f_{206}) \times {}^{206}Pb/{}^{238}U_{corr}$

Stage 3

But this also identifies the total common Pb in the system

${}^{208}Pb_{common}/{}^{232}Th = f_{206} \times {}^{206}Pb/{}^{238}U_{corr} \times {}^{208}Pb/{}^{206}Pb_{common} \times {}^{238}U/{}^{232}Th$

The 207/206 corrected 208 age then comes from

${}^{208}Pb/{}^{232}Th_{radiogenic} = {}^{208}Pb/{}^{232}Th_{measured} - {}^{208}Pb_{common}/{}^{232}Th$

Stage 4

But the 208/232 age should be the same as the 206/238 age. Adjust ff until this is true.

Some constants (from Faure & Mensing, 2005)

$\lambda_{230} = 9.1929\text{x}10^{-6}$	$\lambda_{232} = 4.9475 \times 10^{-11}$
$\lambda_{235} = 9.8485\ \text{x}10^{-10}$	$\lambda_{238} = 1.55125 \times 10^{-10}$

Common Pb (?at crystallisation age) from Stacey and Kramer (1985)

${}^{207}Pb/{}^{206}Pb_{common} \approx 0.8360$ for very young ages

Otherwise measure common Pb on your sample.

Radiogenic Pb ratio comes from

${}^{207}Pb/{}^{206}Pb_{radiogenic} = ({}^{235}U/{}^{238}U) \times ((\exp(\lambda_{235} \times t)-1)/(\exp(\lambda_{238} \times t)-1))$

≈ 0.046045 for very young ages

Error Propagation

Input Data

		1sigma	
	Value	relative error	absolute error
${}^{206}Pb/{}^{238}U$	6#8	6#8re	6#8ae = 6#8re x 6#8
${}^{207}Pb/{}^{206}Pb$	7#6	7#6re	
${}^{208}Pb/{}^{232}Th$	8#2	8#2re	
${}^{232}Th/{}_{238}U$	T#U	T#Ure	

Calculated from growth curve

${}^{207}Pb/{}^{206}Pb$ at 5 Ma	c7#6	0	0
${}^{208}Pb/{}^{206}Pb$ at 5 Ma	c8#6	0	0

Assumes errors on growth curve values at young ages are so small they can be ignored

Assumed at start of numerical solution

UThf fractionation ff = 10 re = 1/10 ae = 1

Start of calculation

$^{206}Pb/^{238}U$dis dis=1.55125x10^{-10} x (ff–1)/9.1929x10^{-6}

disre = re

disae=1.55125x10^{-10} x (ae)/9.1929x10^{-6}

corrected $^{206}Pb/^{238}U$ cor6#8 = 6#8–dis

cor6#8re = (SQRT(6#8ae^2+disae^2))/cor6#8

corrected $^{207}Pb/^{206}Pb$ cor7#6 = 7#6 x 8#6/cor8#6

cor7#6re = SQRT(7#6re^2+((disre x SQRT(6#8re^2+re^2)/6#8)/(1–6#8/dis))^2)

f206 f206 = (cor7#6–0.04605)/(0.836003–0.04605)

assumes negligible error in model common Pb and modern radiogenic Pb

f206ae = (cor7#6 x cor7#6re)/(0.836003–0.04605)

f206re = f206ae/f206

= cor7#6 x cor7#6re/(cor7#6–0.046045)

$^{206}Pb/^{238}U$radiogenic rad6#8 = (1–f206) x cor6#8

rad6#8re = SQRT((f206 x f206re/(1–f206))^2+cor6#8re^2)

$^{206}Pb/^{238}U$ age by "Isoplot" age6#8

age6#8ae = age6#8– 'isoplot3'!AgePb6U8((1–rad6#8re) x rad6#8)

Common $^{208}Pb/^{232}Th$ com8#2 = c8#6 x f206 x cor6#8 / T#U

com8#2re = SQRT(f206re^2+cor6#8re^2+T#Ure^2)

Radiogenic $^{208}Pb/^{232}Th$ rad8#2 = 8#2 – com8#2

rad8#2re = SQRT((com8#2re x com8#2)^2+(8#2re x 8#2)^2)/rad8#2

$^{208}Pb/^{232}Th$ age and error by isoplot as above for $^{206}Pb/^{238}U$ age

Compare ages to calculate actual fractionation factor

Weighted average $^{206}Pb/^{238}U$ age = wa6#8 = Σ(age6#8/(age6#8ae^2)) / Σ (1/(age6#8ae^2)

Error on weighted average = wa6#8ae = SQRT(1/ Σ (1/(age6#8ae^2))

Weighted average $^{208}Pb/^{232}Th$ age = wa8#2 = Σ(age8#2/(age8#2ae^2)) / Σ (1/(age8#2ae^2)

Error on weighted average = wa8#2ae = SQRT(1/ Σ (1/(age8#2ae^2))

Difference= wa6#8– wa8#2

Error on difference = edif = SQRT(wa6#8ae^2+ wa8#2ae^2)

Adjust ff until difference = 0 to get preferred ff

Adjust ff until difference = +edif and –edif to find one sigma bounds on value of ff. Use these to infer value for ae (the one sigma error on ff)

Repeat one or more times for convergence.

References

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