EGU General Assembly 2022

FIERCE
Frankfurt Isotope & Element Research Center

The petrochronologic potential of LASS-ICPMS U–Pb dating of garnet and evidence for an ultra-high closure temperature

Horst Marschall,
Richard von Mutius,
Axel Gerdes,
Leo Millonig,
Richard Albert,
Aratz Beranoaguirre,
Dominik Hezel

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Element XR single collector ICPMS & 193 nm Resonetics laser

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Exploring laser ablation U–Pb dating of regional metamorphic garnet – The Straits Schist, Connecticut, USA

Leo J. Millonig [a,b,*], Richard Albert [a,b], Axel Gerdes [a,b], Dov Avigad [c], Craig Dietsch [d]

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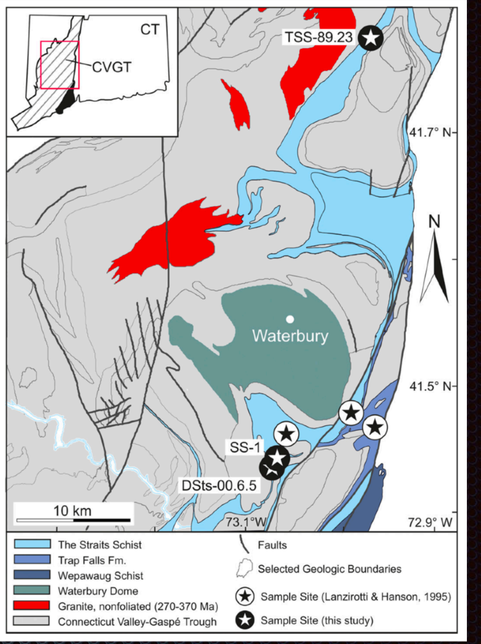
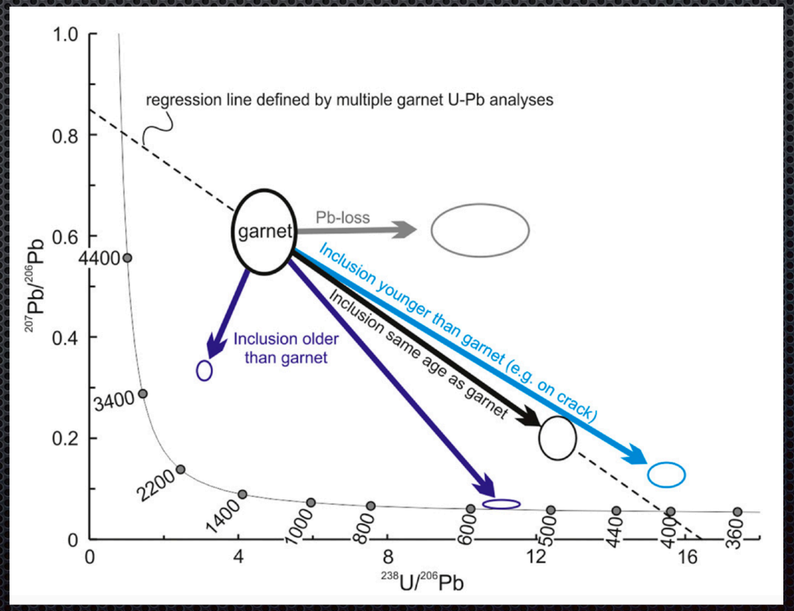
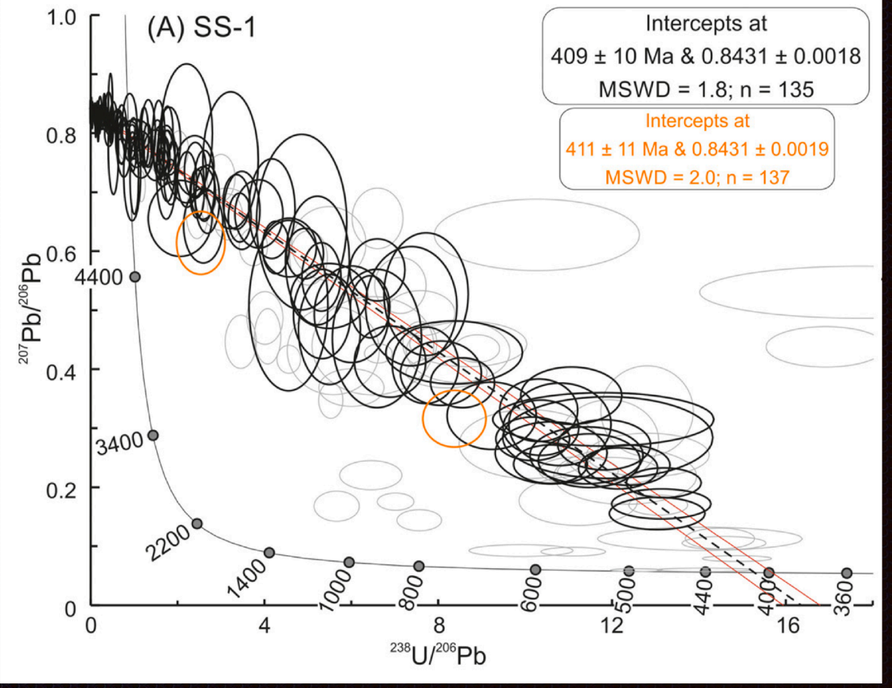
[b] Frankfurt Isotope and Element Research Center (FIERCE), Goethe-University Frankfurt, Frankfurt am Main, Germany
[c] Institute of Earth Sciences, Hebrew University of Jerusalem, Givat Ram, 9190401, Israel
[d] Department of Geology, University of Cincinnati, P.O. Box 0013, Cincinnati, OH 45221-0013, USA



- Screening for U-rich inclusions in the time-resolved ablation signal
- 213 x 213 µm² spots
- [U] = 1–90 ng/g
- age precision appr. ±2–4 %



L.J. Millonig, R. Albert, A. Gerdes et al.



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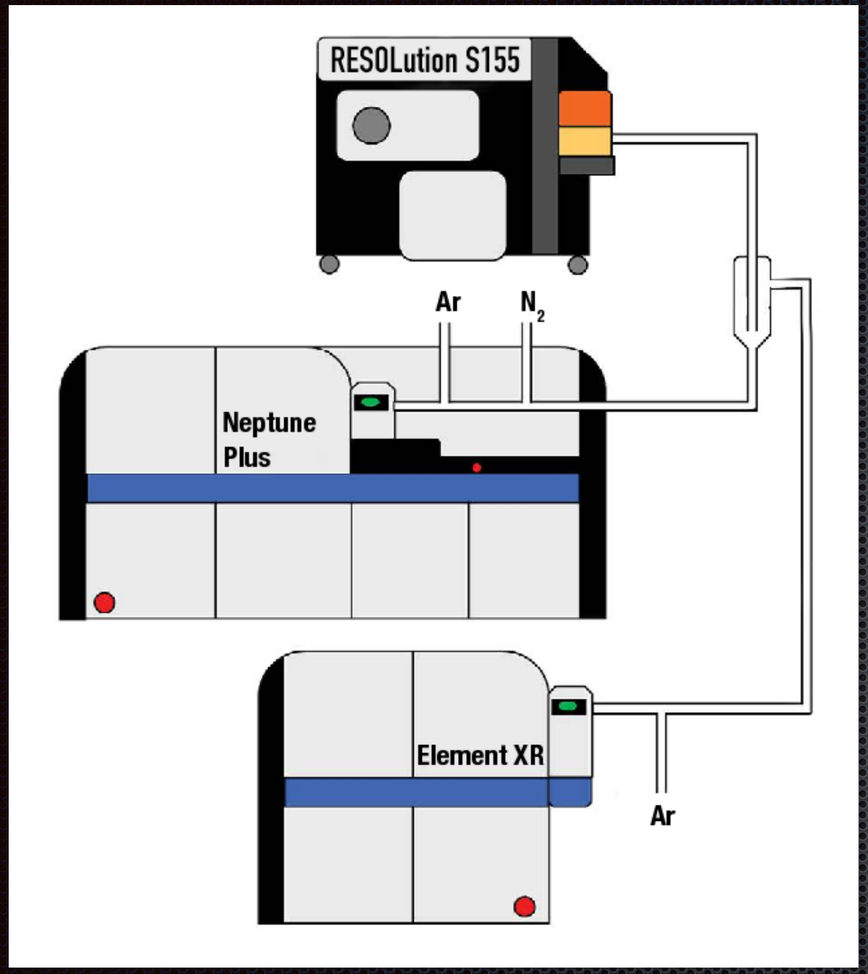
Laser-Ablation Split-Stream MC/SC-ICPMS



modified from Craig et al. (2017), ThermoScientific

193 nm laser ablation system
RESOLution S155
large two-volume ablation cell

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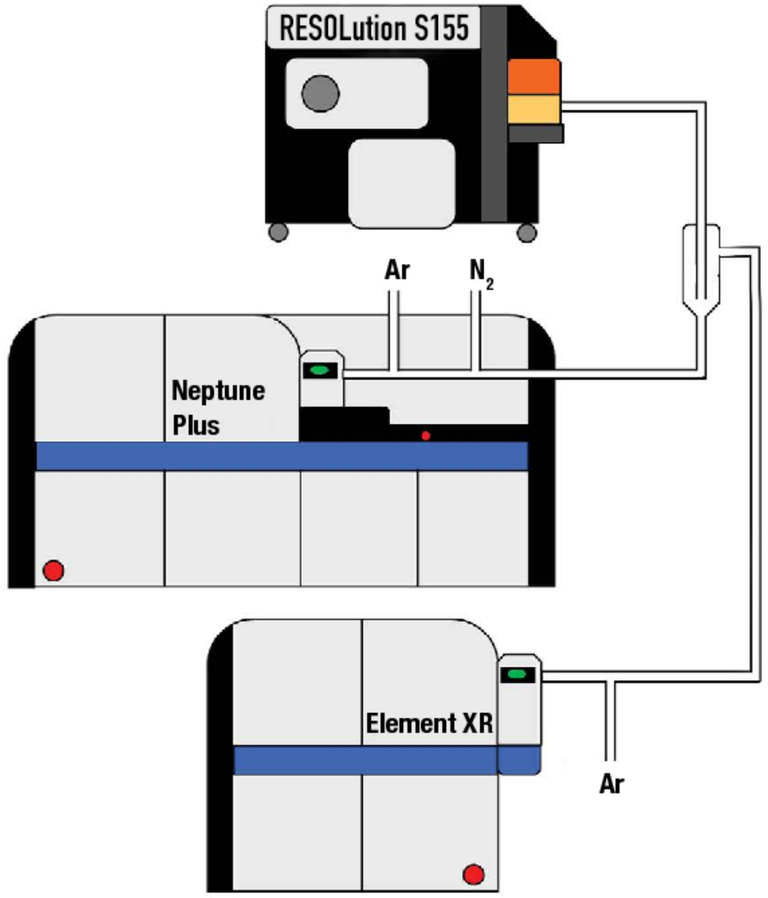

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- 130 x 130 μm^2 spots

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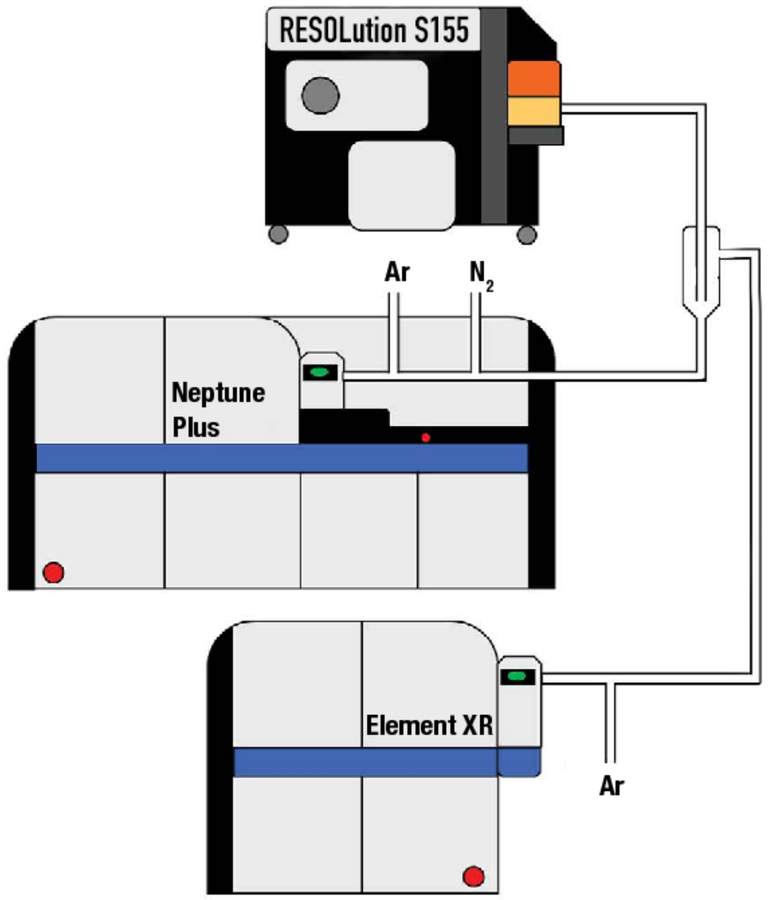

modified from Craig et al. (2017), ThermoScientific

193 nm laser ablation system
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- 130 x 130 μm^2 spots
- 20 s ablation

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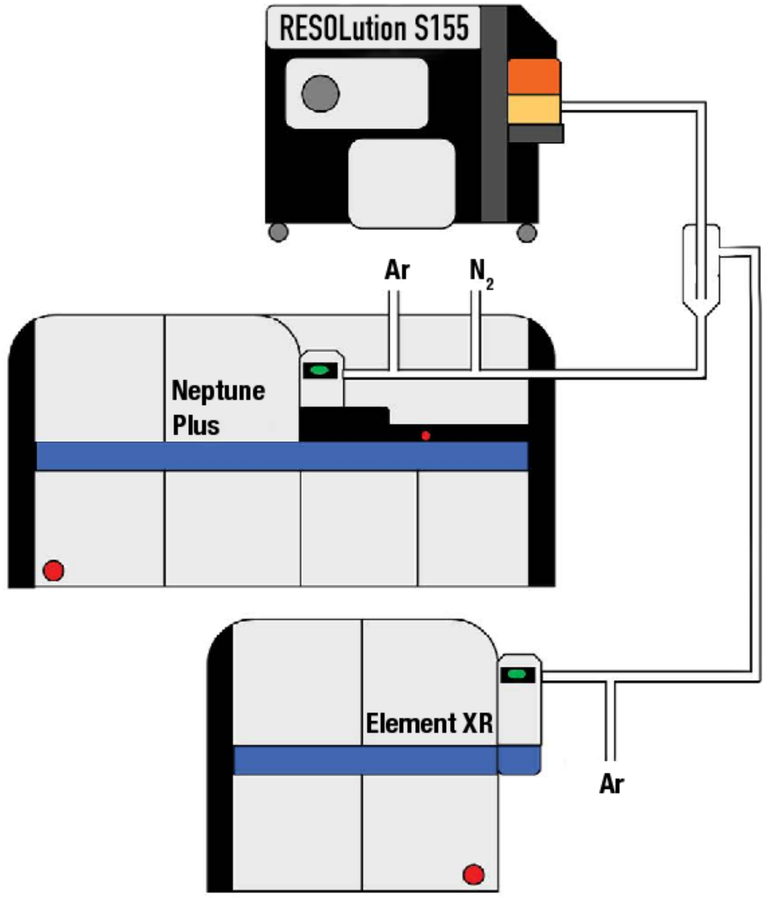
Laser-Ablation Split-Stream MC/SC-ICPMS



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Neptune Plus
multi-collector ICPMS
with 2 SEM, 5 CDD and
9 FC (10^{11} and 10^{13} Ω)

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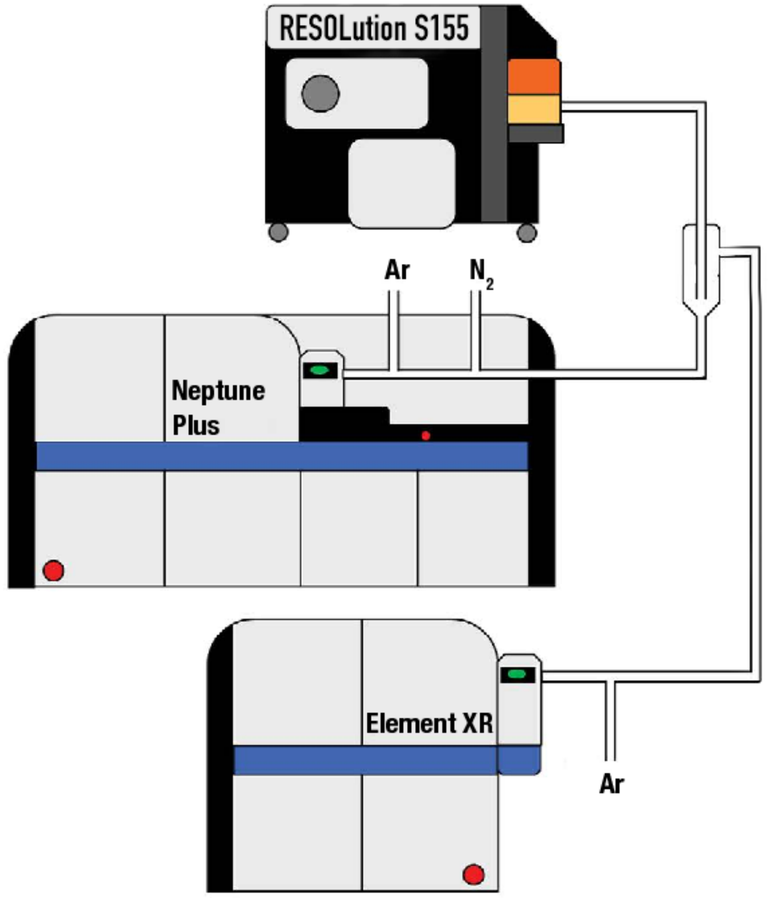
Laser-Ablation Split-Stream MC/SC-ICPMS



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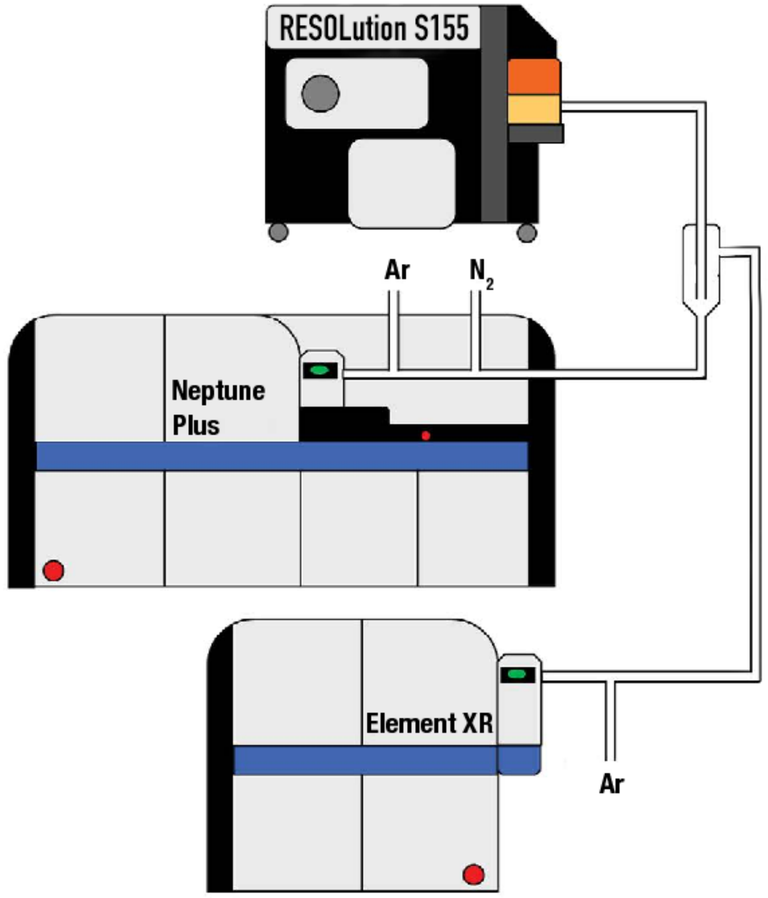

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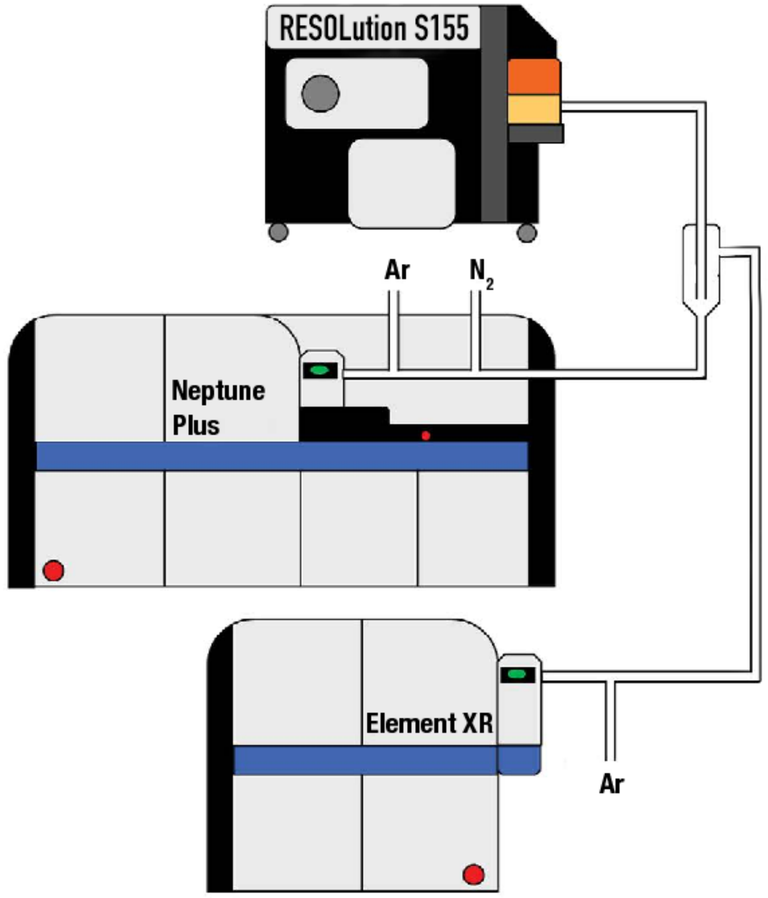
Laser-Ablation Split-Stream MC/SC-ICPMS



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Element XR single-collector ICPMS

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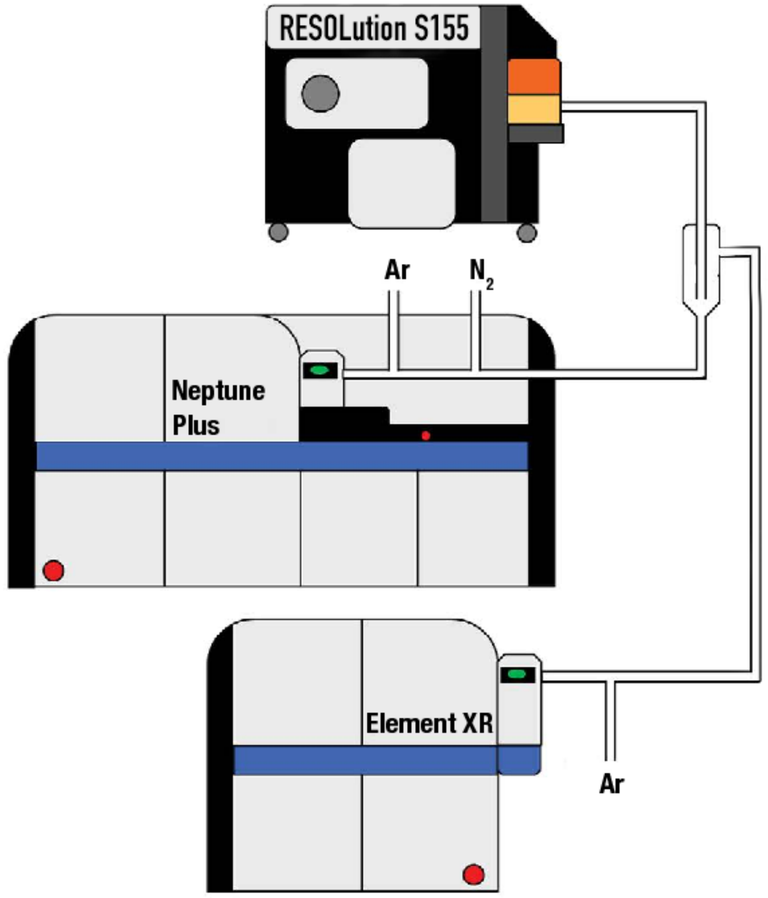
Laser-Ablation Split-Stream MC/SC-ICPMS



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- ^{232}Th on Faraday (10^{13} Ω)

Element XR single-collector ICPMS

- garnet major elements (Ca, Fe, Mg, Mn)

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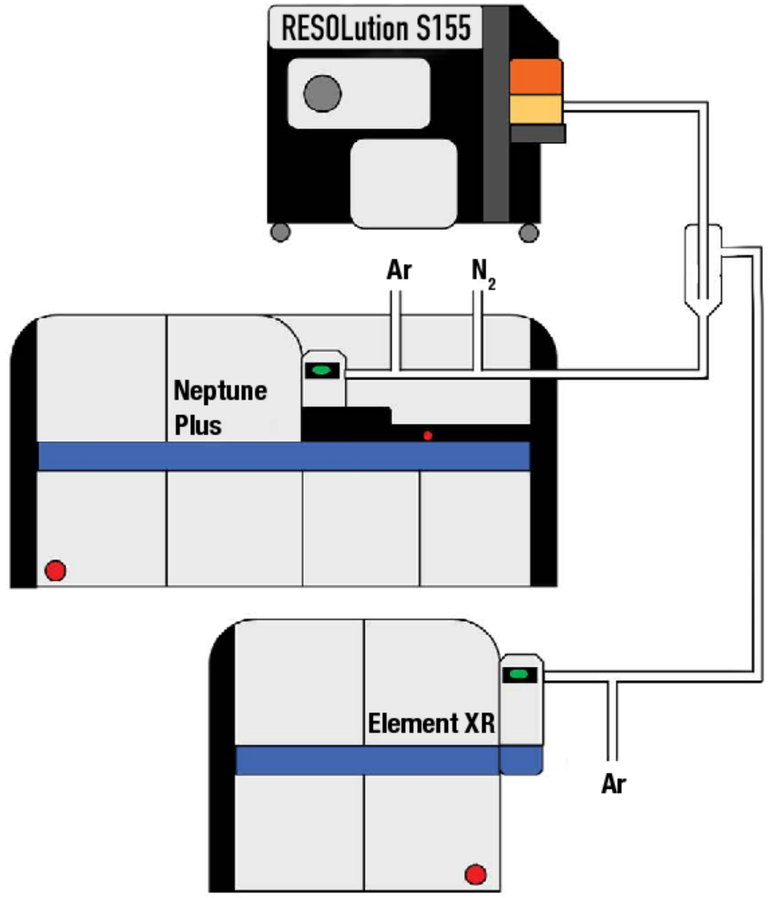
Laser-Ablation Split-Stream MC/SC-ICPMS



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Element XR single-collector ICPMS

- garnet major elements (Ca, Fe, Mg, Mn)
- trace elements as accessory mineral indicator (REE, Y, Zr, Ti, Nb, P)

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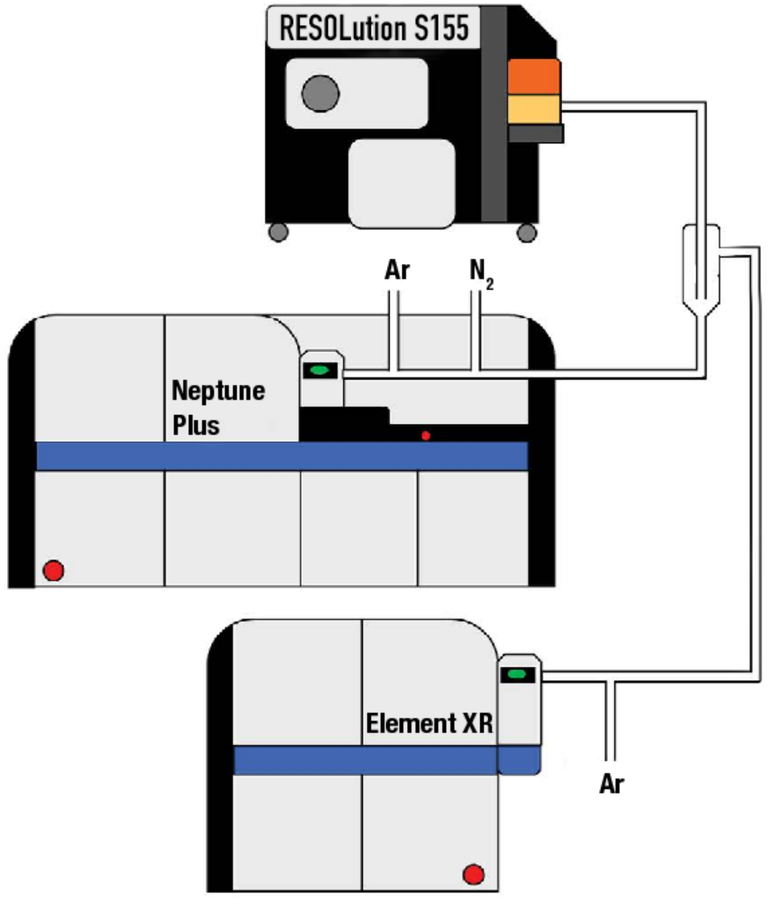
Laser-Ablation Split-Stream MC/SC-ICPMS



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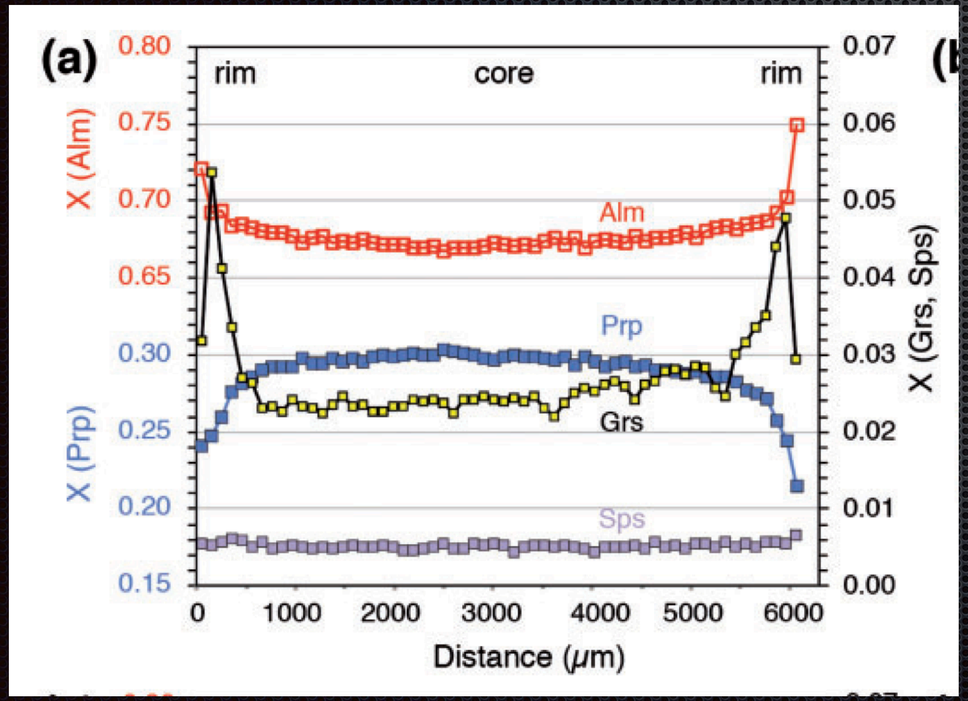
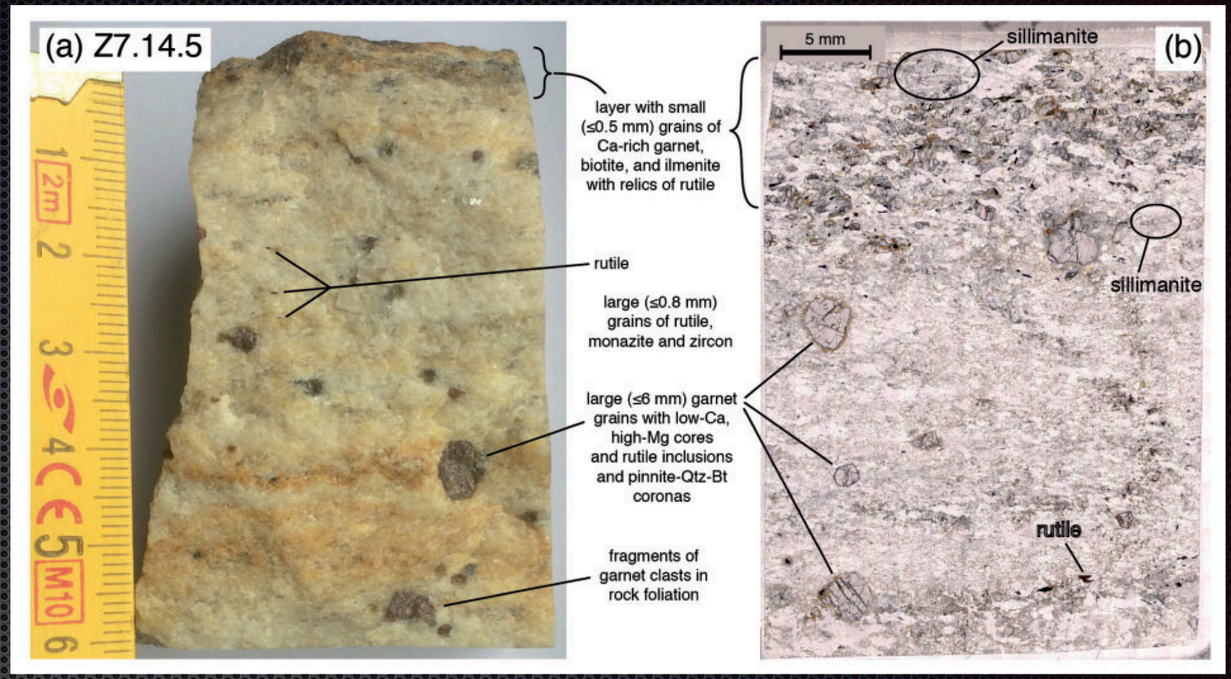
- ^{206}Pb, ^{207}Pb and ^{238}U on ion counters
- ^{232}Th on Faraday (10^{13} Ω)

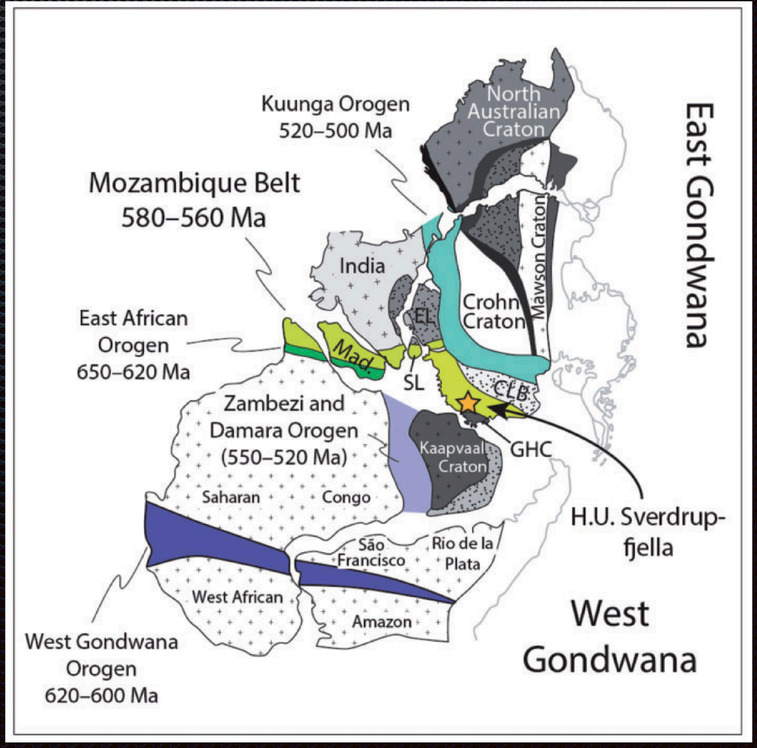
Element XR single-collector ICPMS

- garnet major elements (Ca, Fe, Mg, Mn)
- trace elements as accessory mineral indicator (REE, Y, Zr, Ti, Nb, P)
- trace elements as other inclusion indicator (K, Rb, Sr)

Ultra-High Temperature granulite (930 °C)
Dronning-Maud Land, East Antarctica



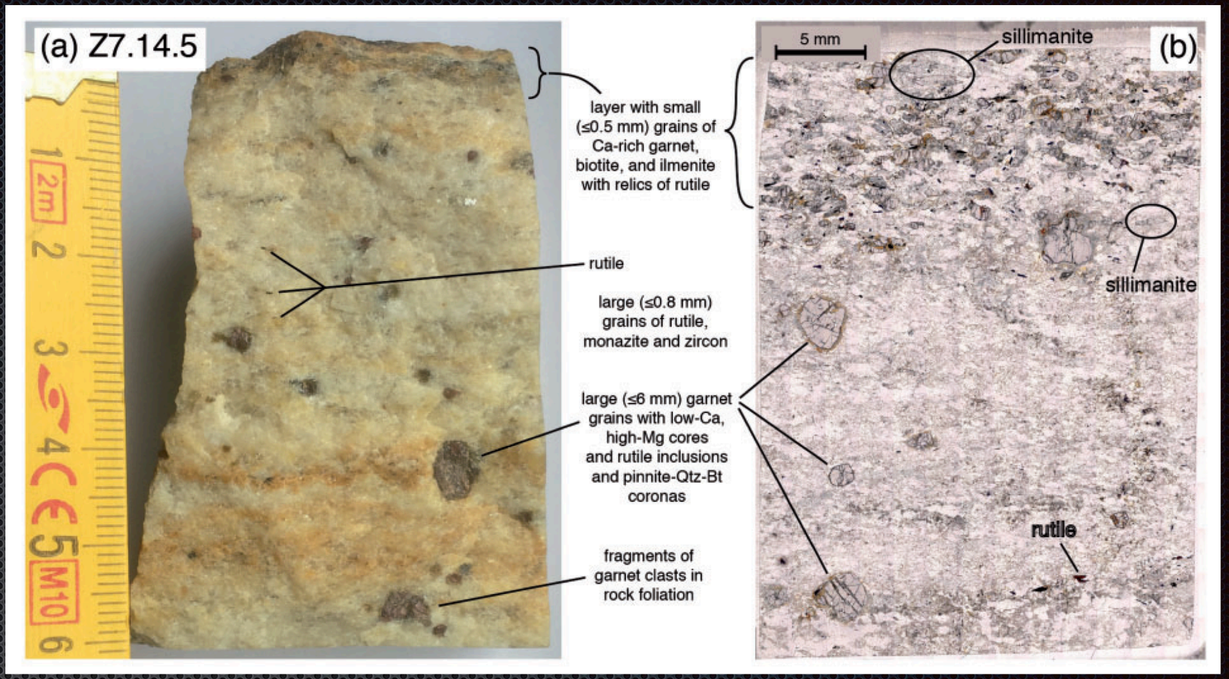


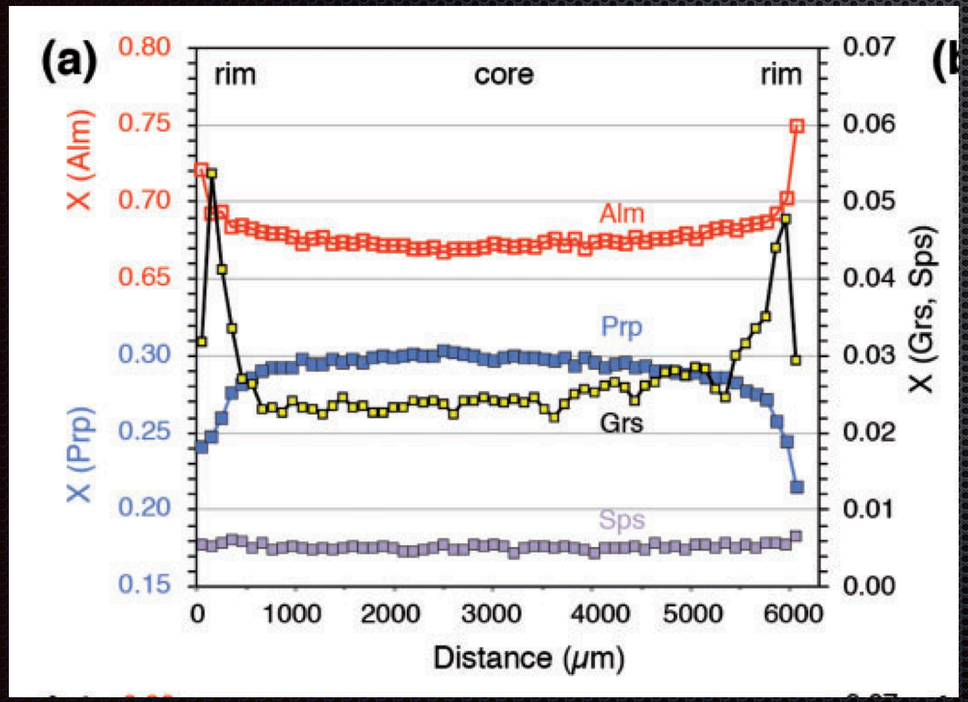


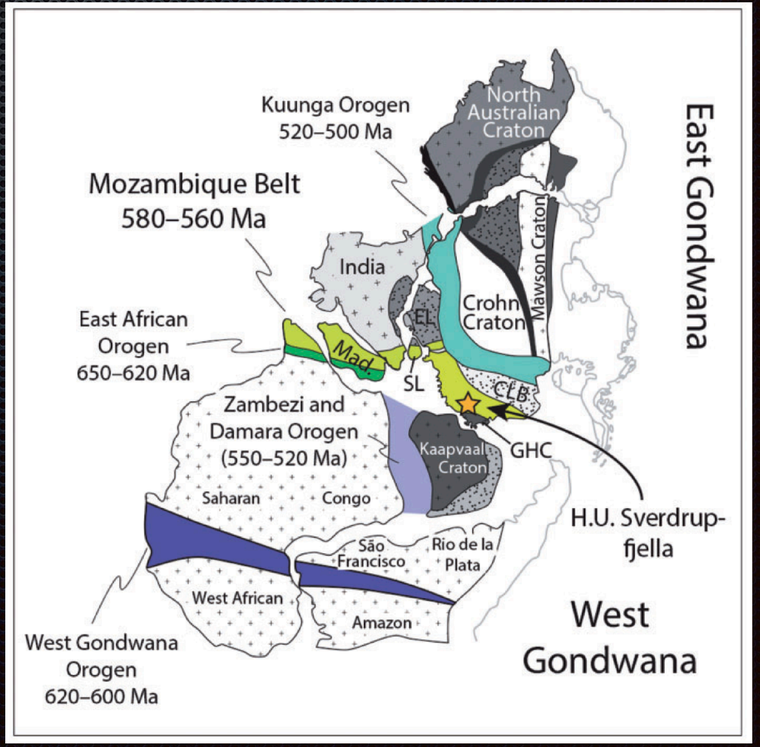
Pauly et al. (2016), JPet

Ultra-High Temperature granulite (930 °C) Dronning-Maud Land, East Antarctica

- Felsic granulite (feldspar + quartz)



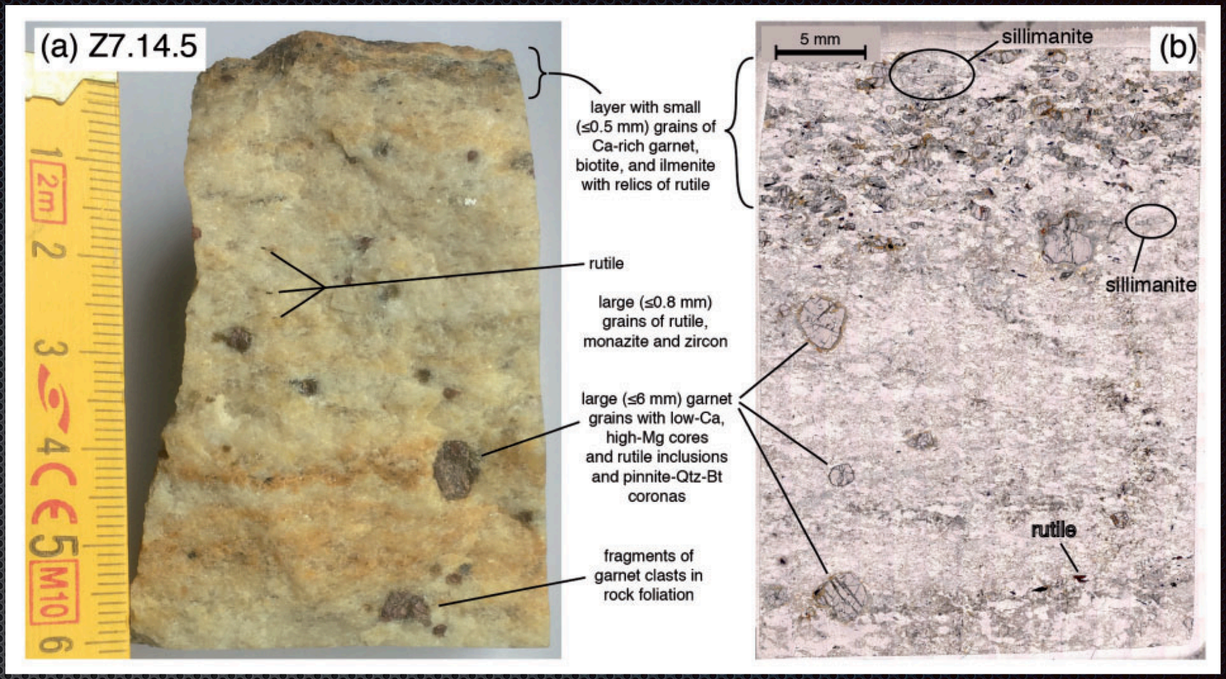


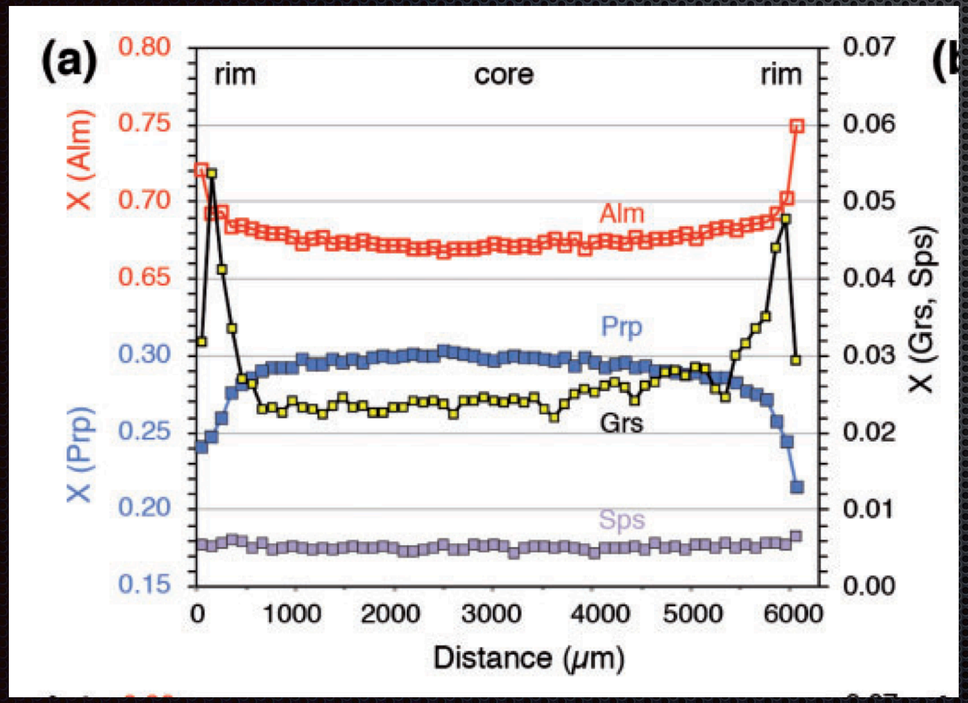


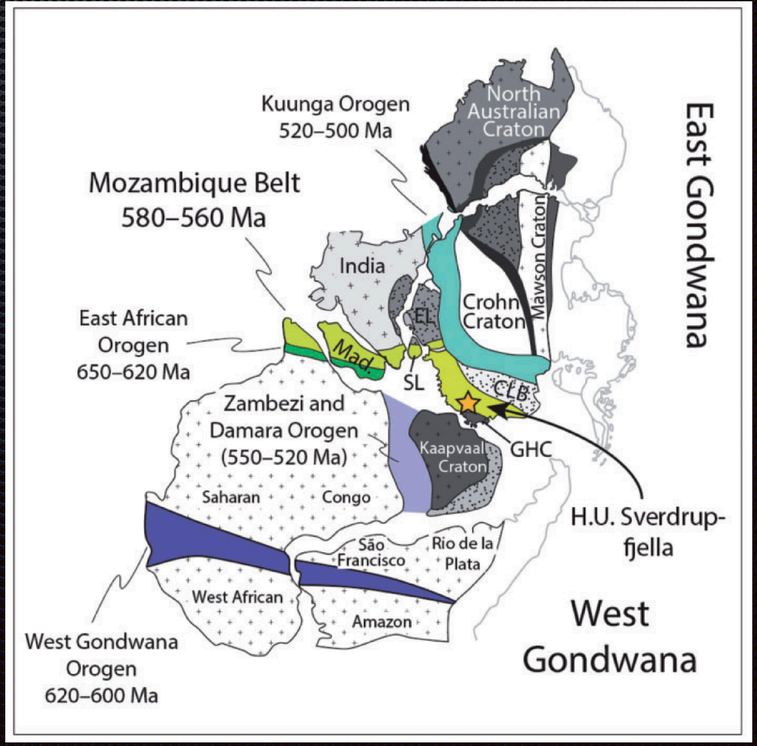
Pauly et al. (2016), JPet

Ultra-High Temperature granulite (930 °C) Dronning-Maud Land, East Antarctica

- Felsic granulite (feldspar + quartz)
- Sillimanite pseudomorphs after kyanite



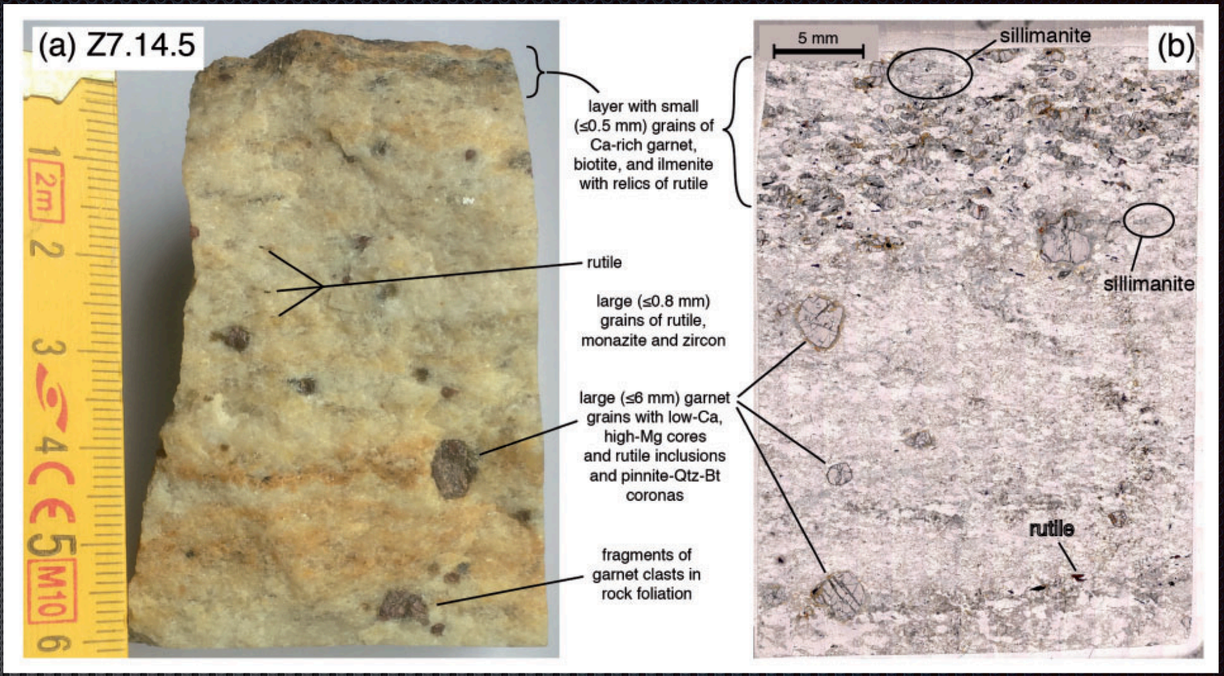


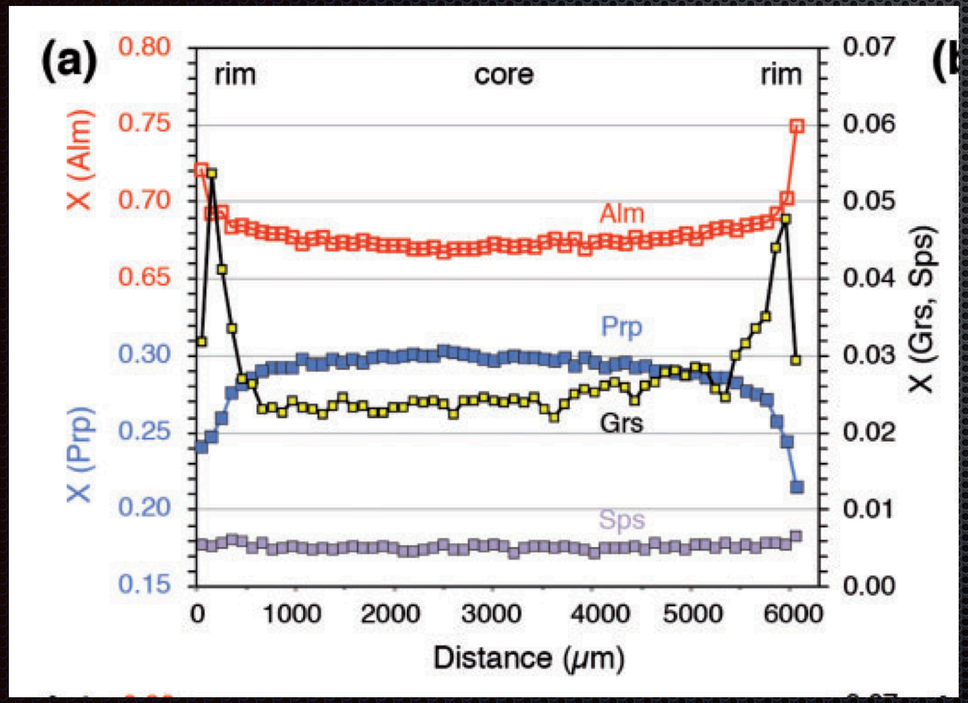


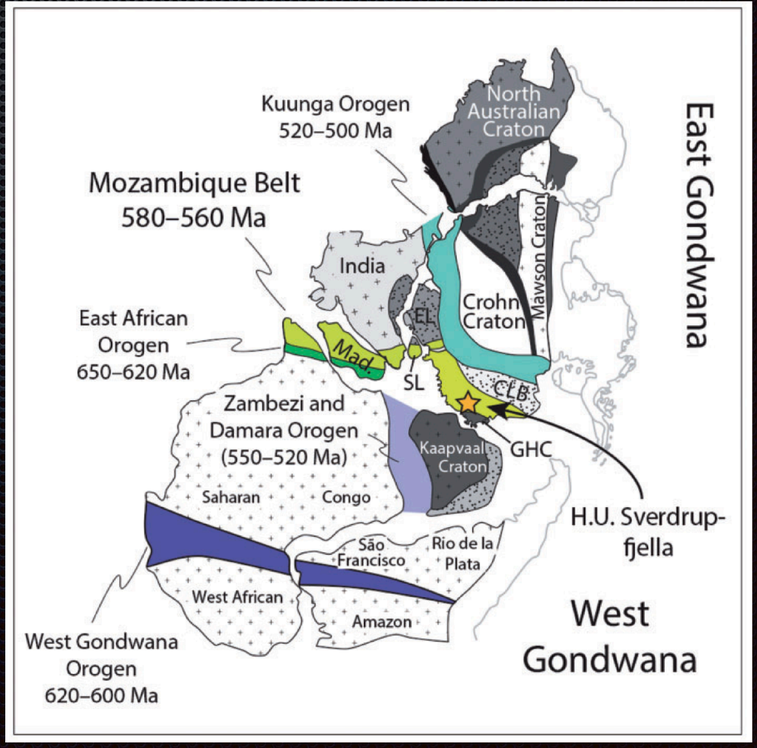
Pauly et al. (2016), JPet

Ultra-High Temperature granulite (930 ºC) Dronning-Maud Land, East Antarctica

- Felsic granulite (feldspar + quartz)
- Sillimanite pseudomorphs after kyanite
- Rutile + monazite + zircon + apatite







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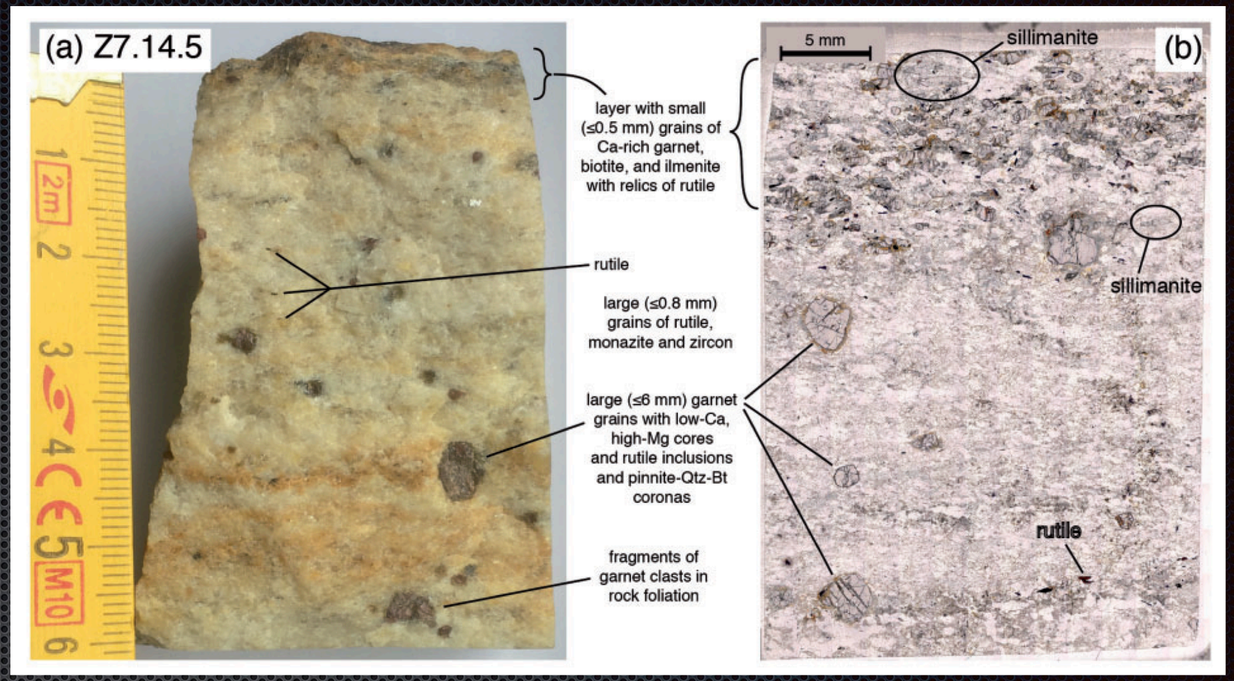
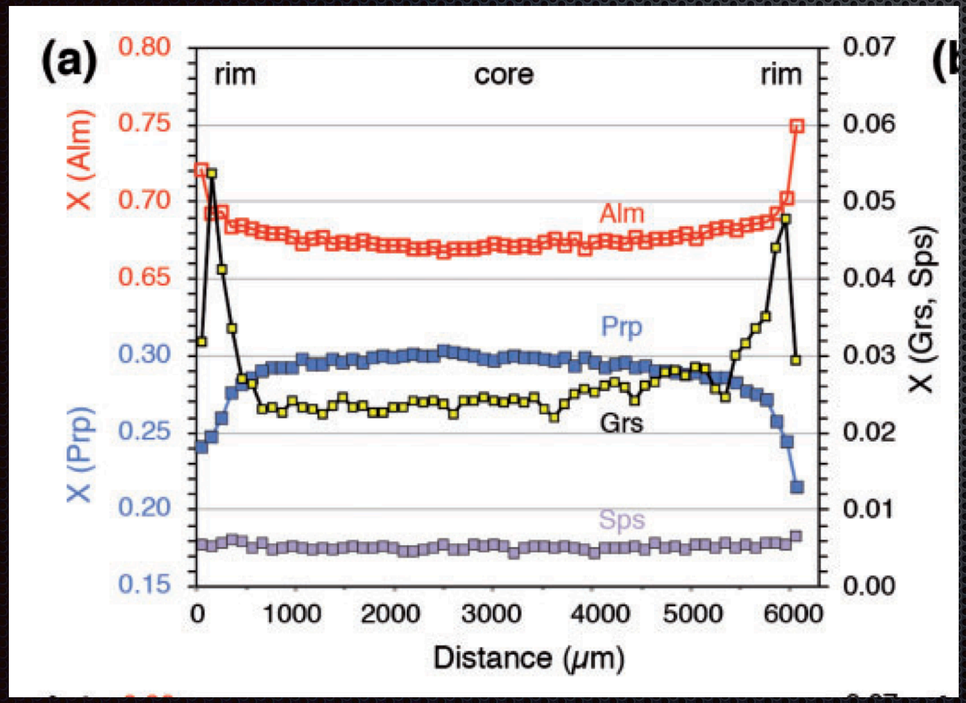
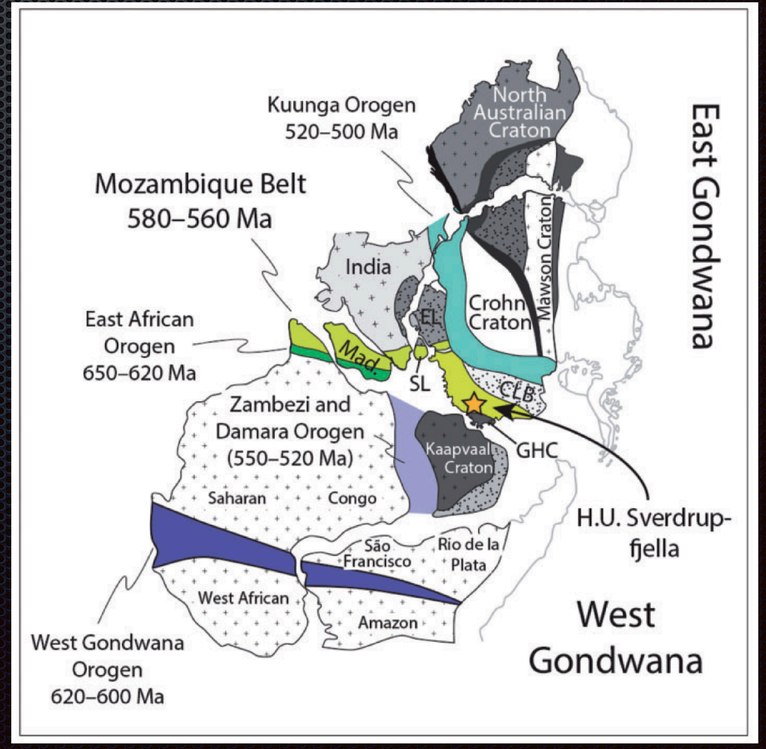
Ultra-High Temperature granulite (930 ºC) Dronning-Maud Land, East Antarctica

- Felsic granulite (feldspar + quartz)
- Sillimanite pseudomorphs after kyanite
- Rutile + monazite + zircon + apatite
- Garnet (up to 6 mm in diameter)



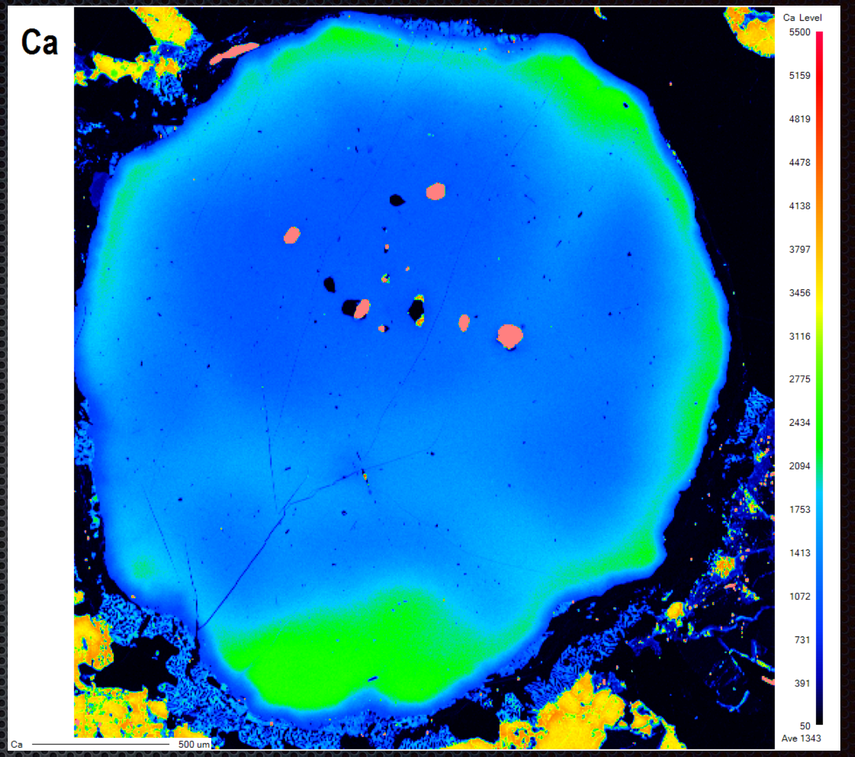


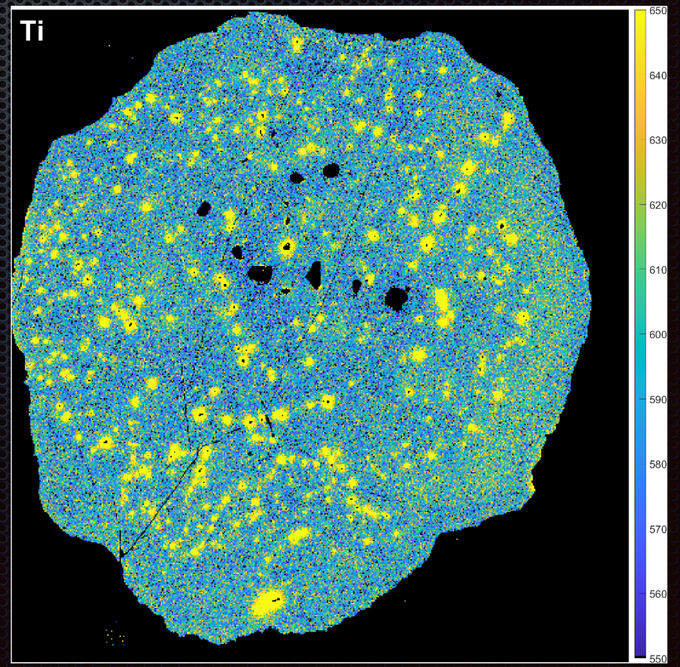


Pauly et al. (2016), JPet

Ultra-High Temperature granulite Dronning-Maud Land, East Antarctica

Garnet low-Ca cores Stage M2a



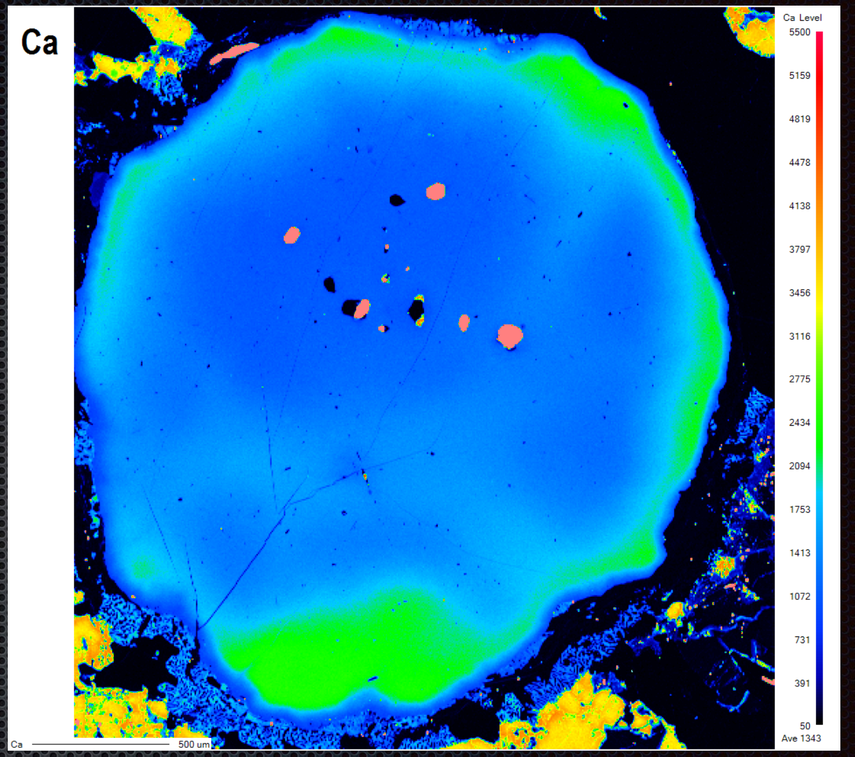


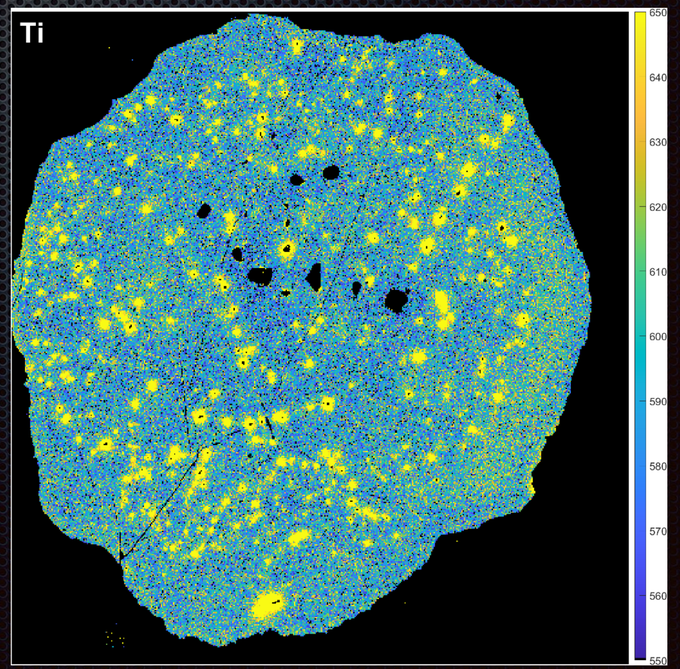
Ultra-High Temperature granulite Dronning-Maud Land, East Antarctica

Garnet low-Ca cores

Stage M2a

- 790 ºC, 0.95 GPa



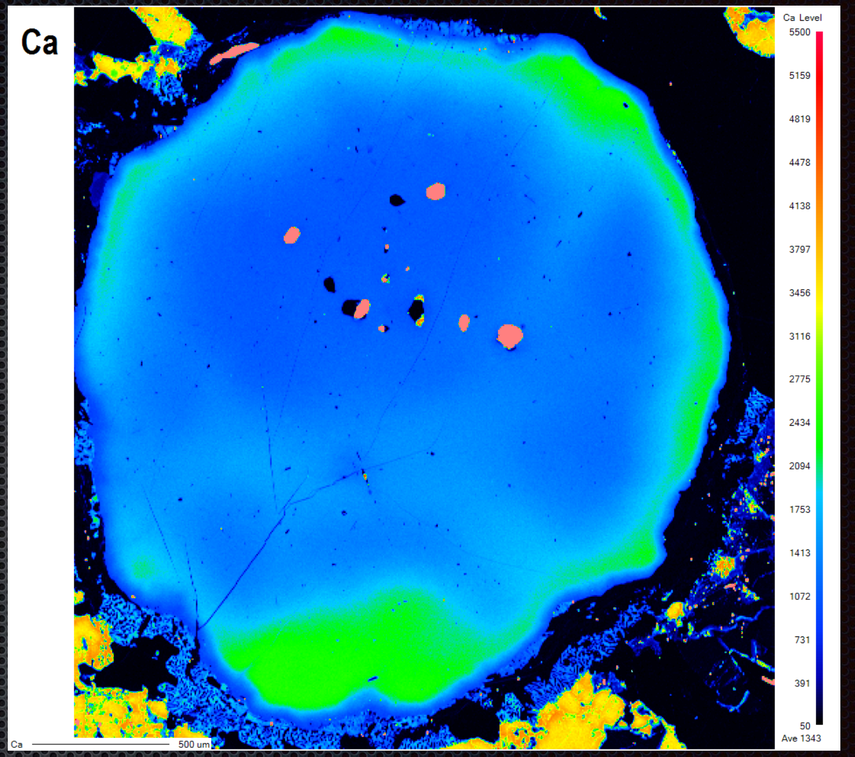


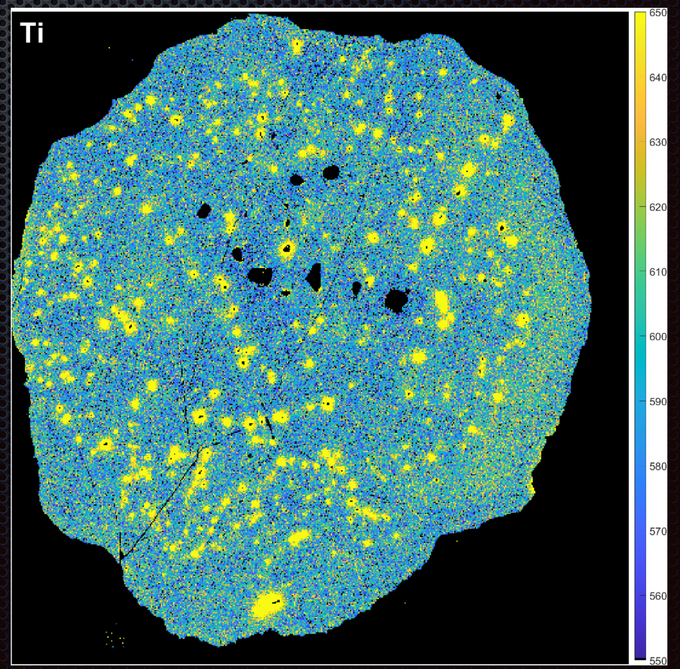
Ultra-High Temperature granulite Dronning-Maud Land, East Antarctica

Garnet low-Ca cores

Stage M2a

- 790 ºC, 0.95 GPa
- metamorphic age previously unknown (≥593 Ma)



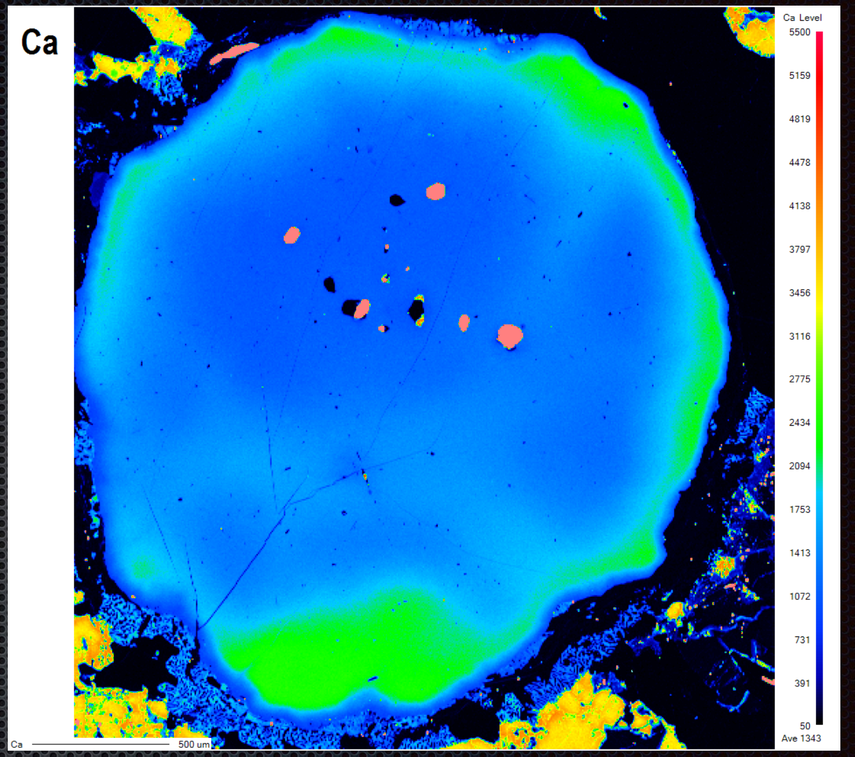


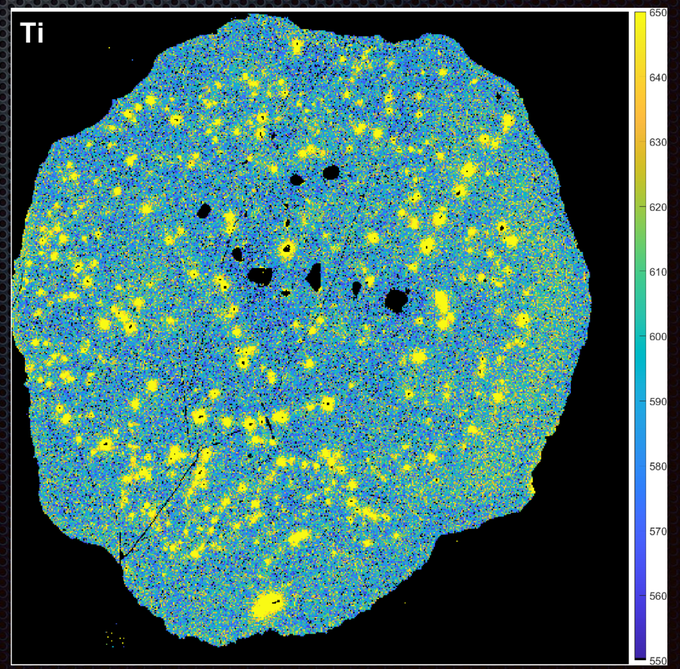
Ultra-High Temperature granulite Dronning-Maud Land, East Antarctica

Garnet low-Ca cores

Stage M2a

- 790 °C, 0.95 GPa
- metamorphic age previously unknown (≥593 Ma)
- appr. 4.5 vol.% garnet in rock





Ultra-High Temperature granulite Dronning-Maud Land, East Antarctica

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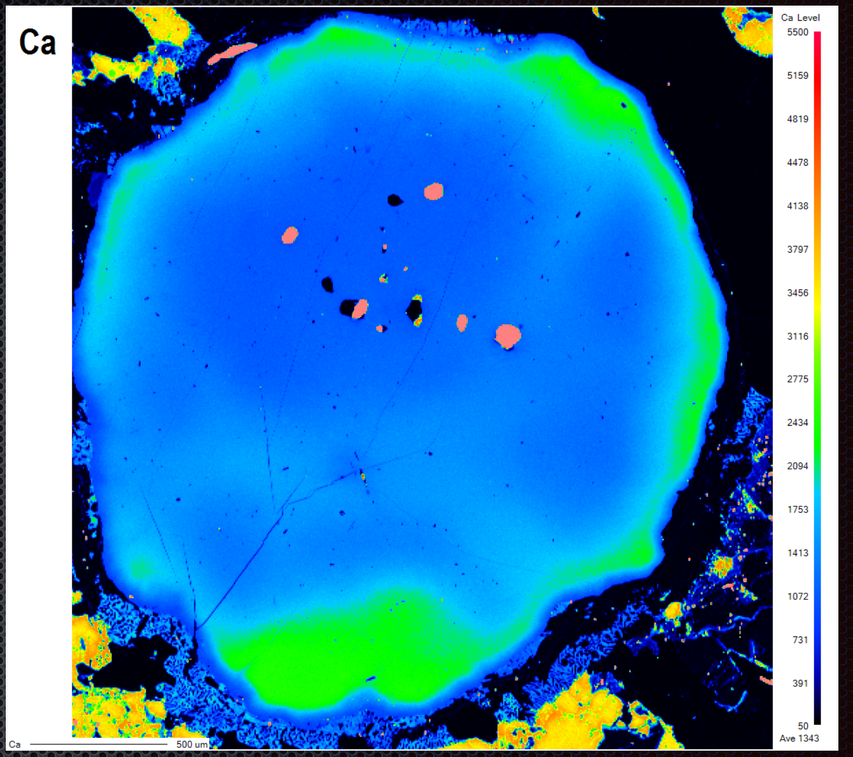
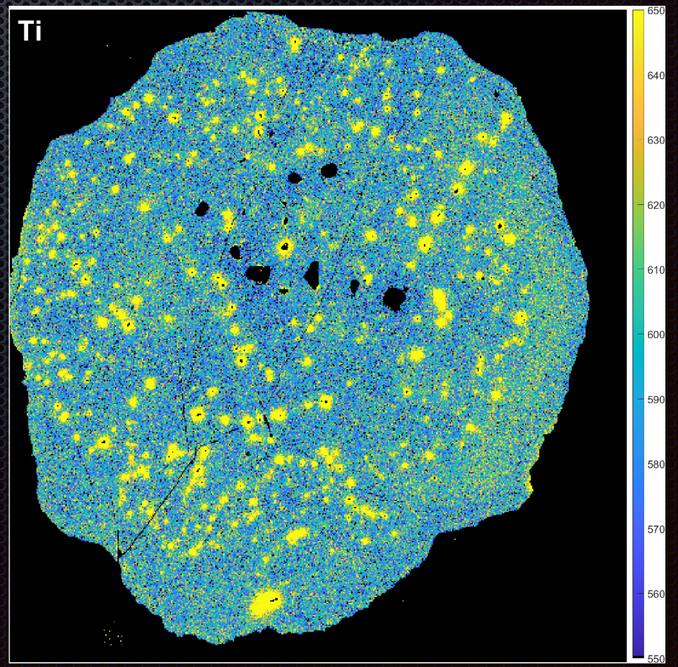
Garnet high-Ca rims



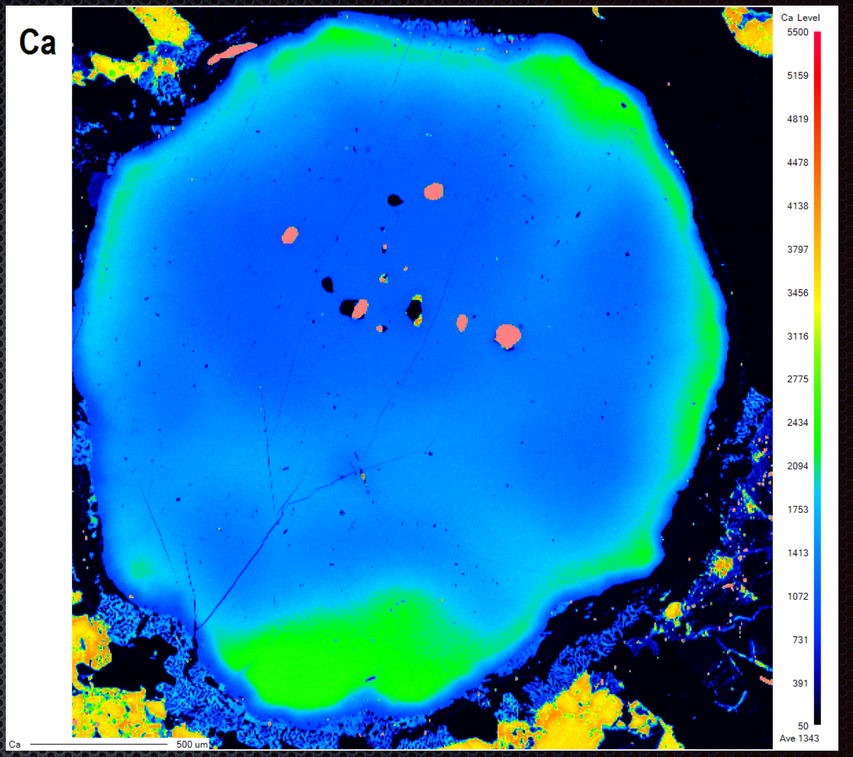


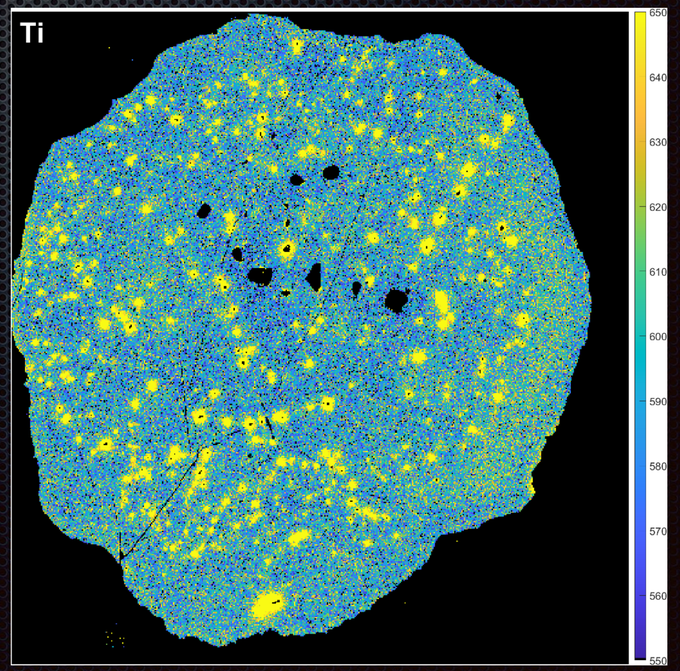
Ultra-High Temperature granulite Dronning-Maud Land, East Antarctica

Garnet low-Ca cores — Stage M2a

- 790 °C, 0.95 GPa
- metamorphic age previously unknown (≥593 Ma)
- appr. 4.5 vol.% garnet in rock

Garnet high-Ca rims — Stage M2b





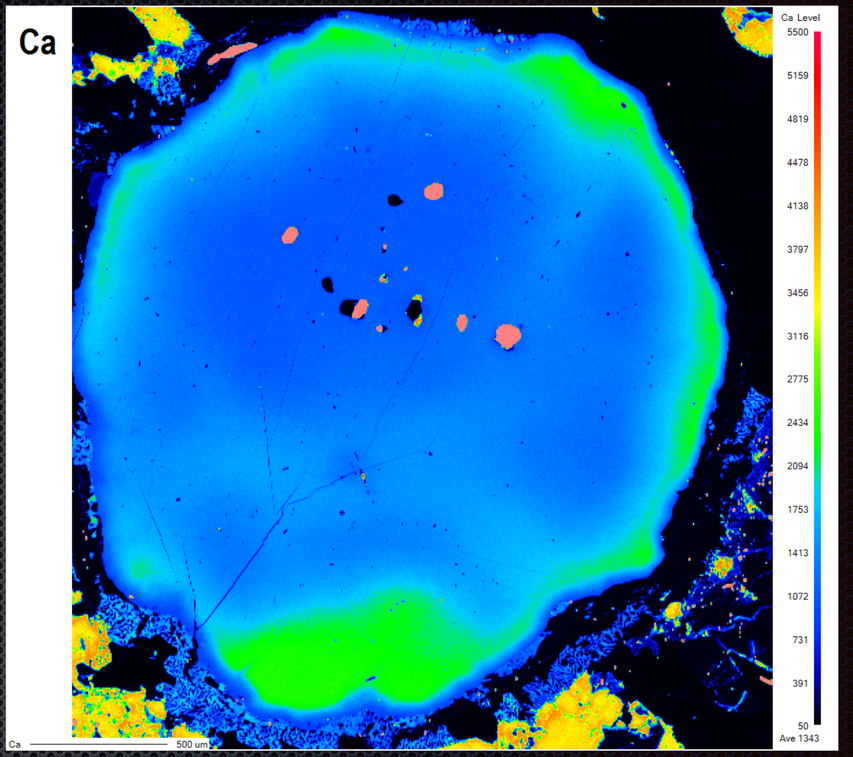
Ultra-High Temperature granulite Dronning-Maud Land, East Antarctica

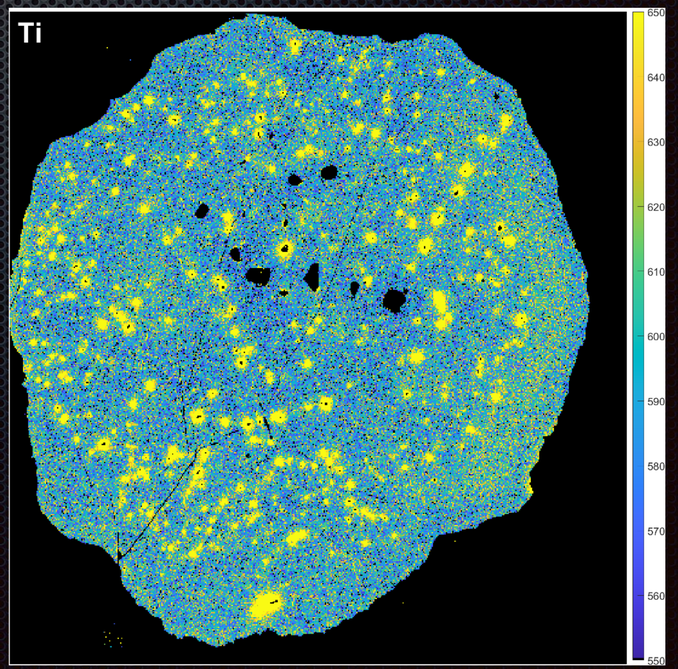
Garnet low-Ca cores — Stage M2a

- 790 °C, 0.95 GPa
- metamorphic age previously unknown (≥593 Ma)
- appr. 4.5 vol.% garnet in rock

Garnet high-Ca rims — Stage M2b

- 845 °C, 1.45 GPa





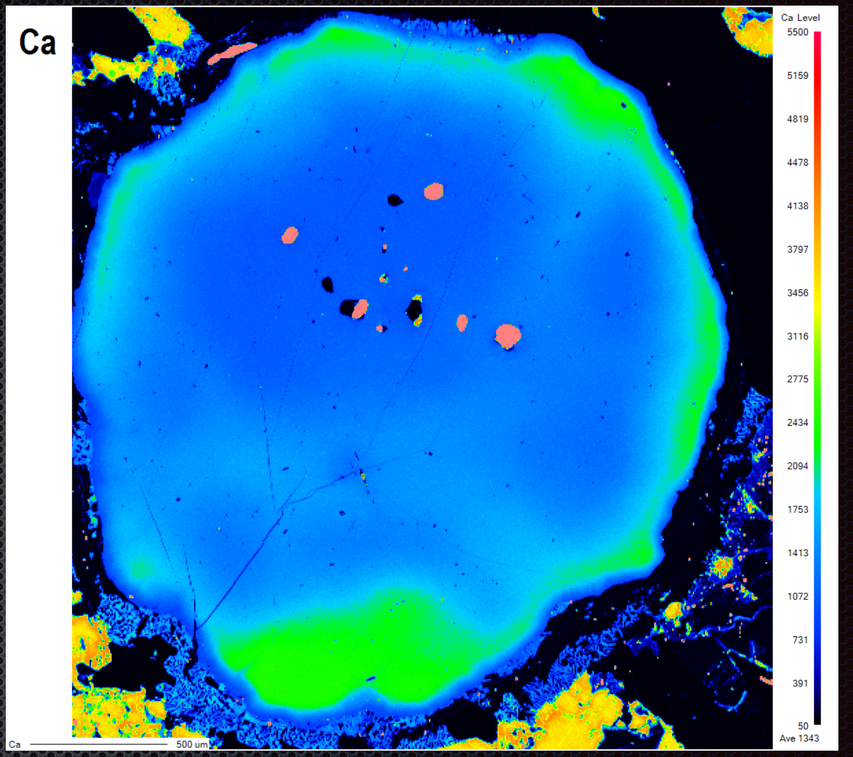
Ultra-High Temperature granulite Dronning-Maud Land, East Antarctica

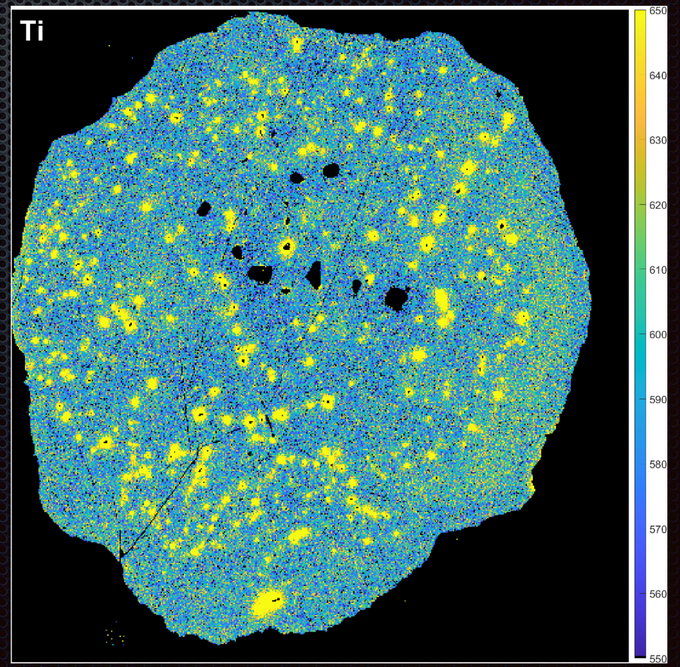
Garnet low-Ca cores — Stage M2a

- 790 °C, 0.95 GPa
- metamorphic age previously unknown (≥593 Ma)
- appr. 4.5 vol.% garnet in rock

Garnet high-Ca rims — Stage M2b

- 845 °C, 1.45 GPa
- metamorphic age (U–Pb zircon) 593–570 Ma





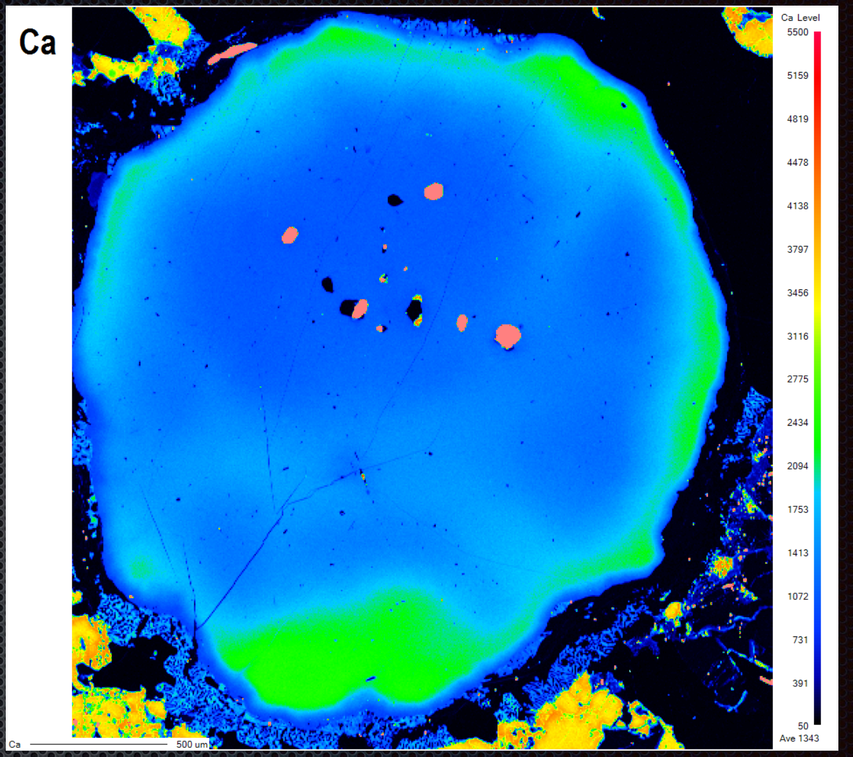
Ultra-High Temperature granulite Dronning-Maud Land, East Antarctica

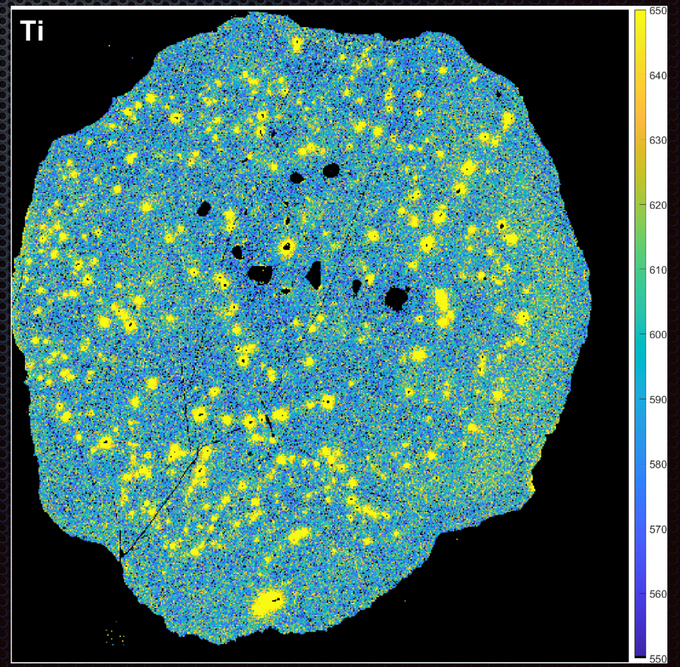
Garnet low-Ca cores — Stage M2a

- 790 °C, 0.95 GPa
- metamorphic age previously unknown (≥593 Ma)
- appr. 4.5 vol.% garnet in rock

Garnet high-Ca rims — Stage M2b

- 845 °C, 1.45 GPa
- metamorphic age (U–Pb zircon) 593–570 Ma
- Garnet mode increased to 6.5 vol.%





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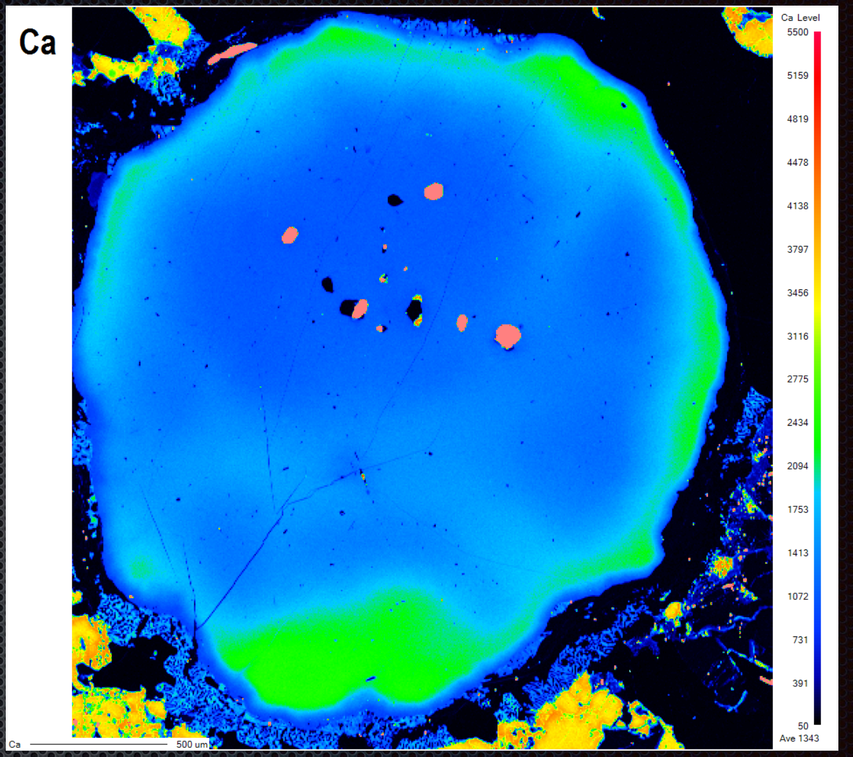
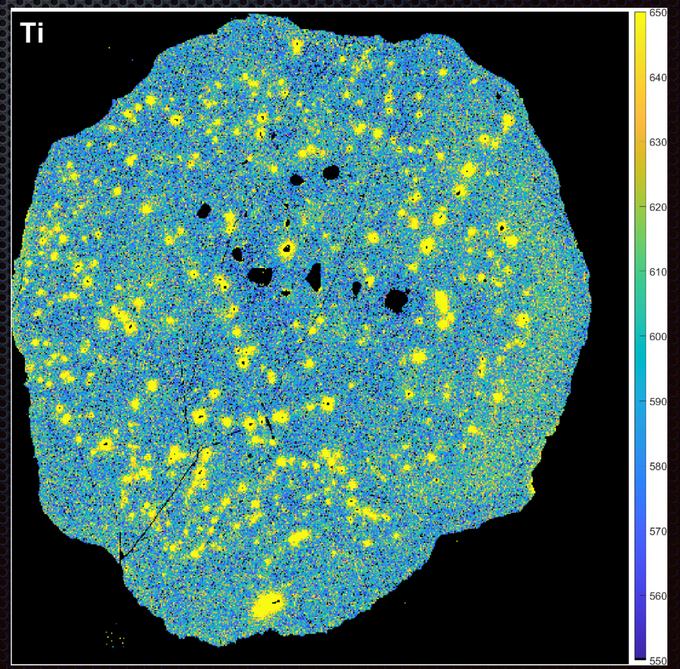
Stage M2c (UHT)





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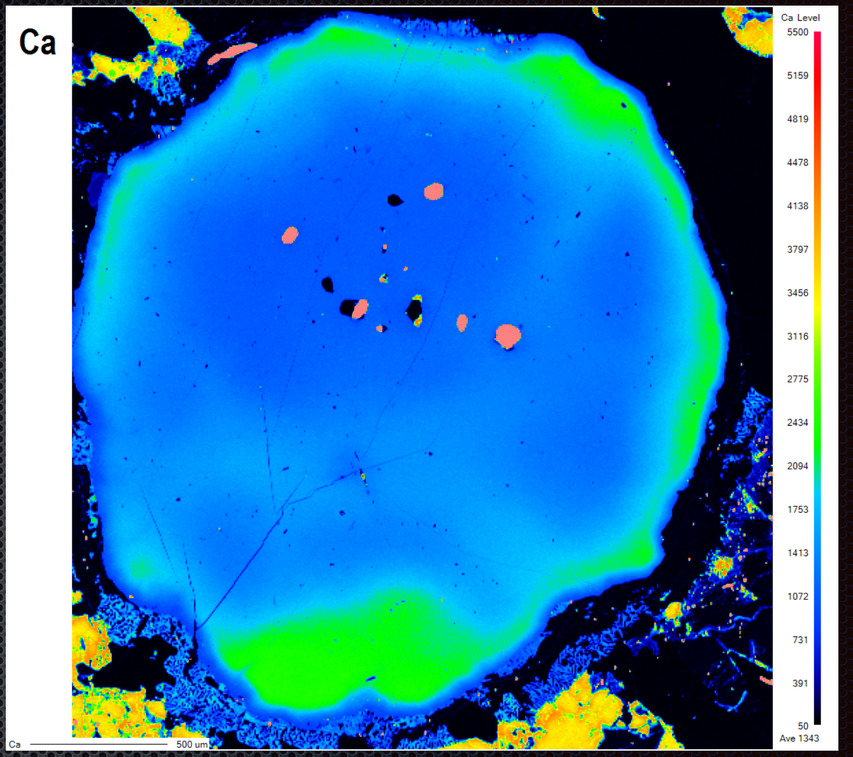
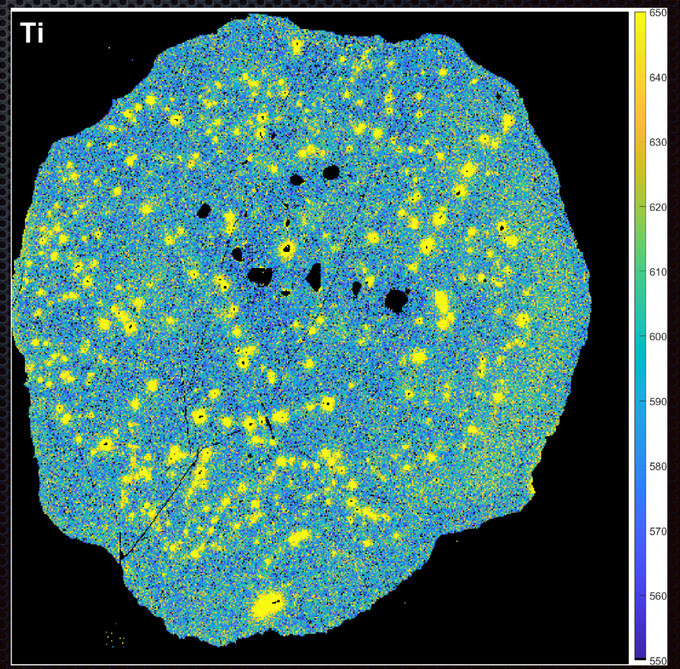
Stage M2c (UHT)

- 930 °C, 1.45 GPa





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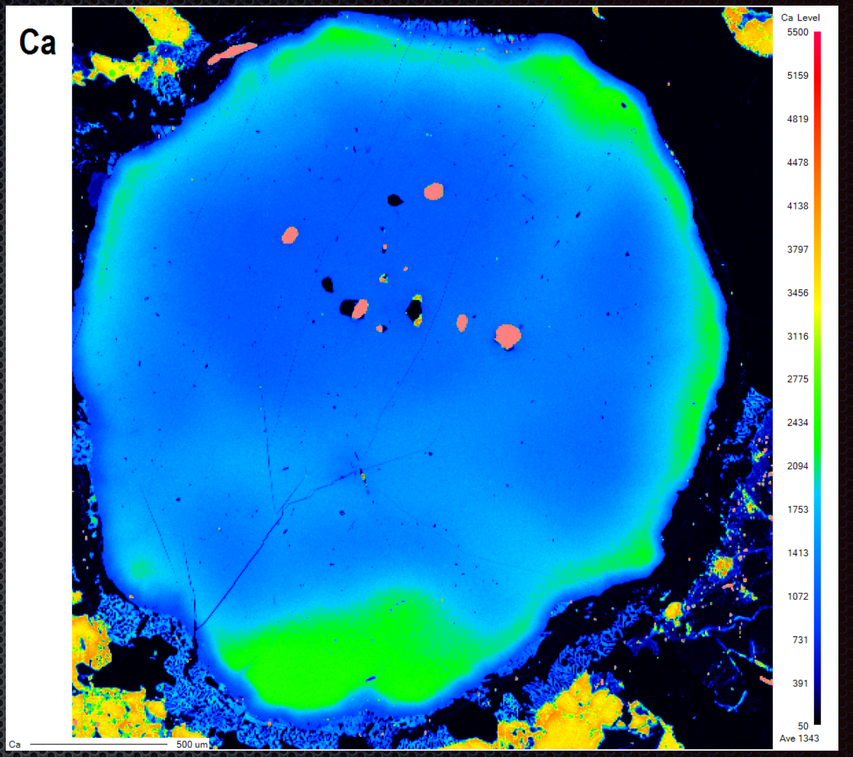
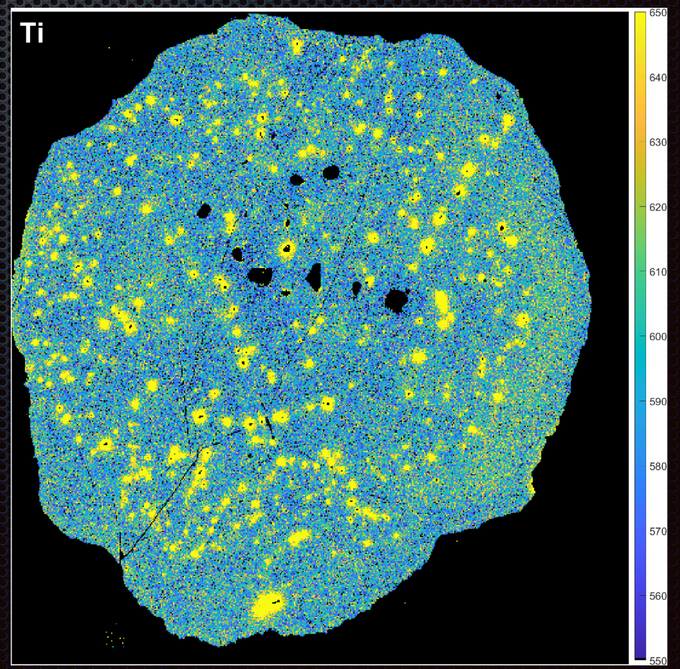
- Garnet mode increased to 6.5 vol.%

Stage M2c (UHT)

- 930 °C, 1.45 GPa
- metamorphic age (U–Pb zircon) 570 ±7 Ma





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- 930 °C, 1.45 GPa
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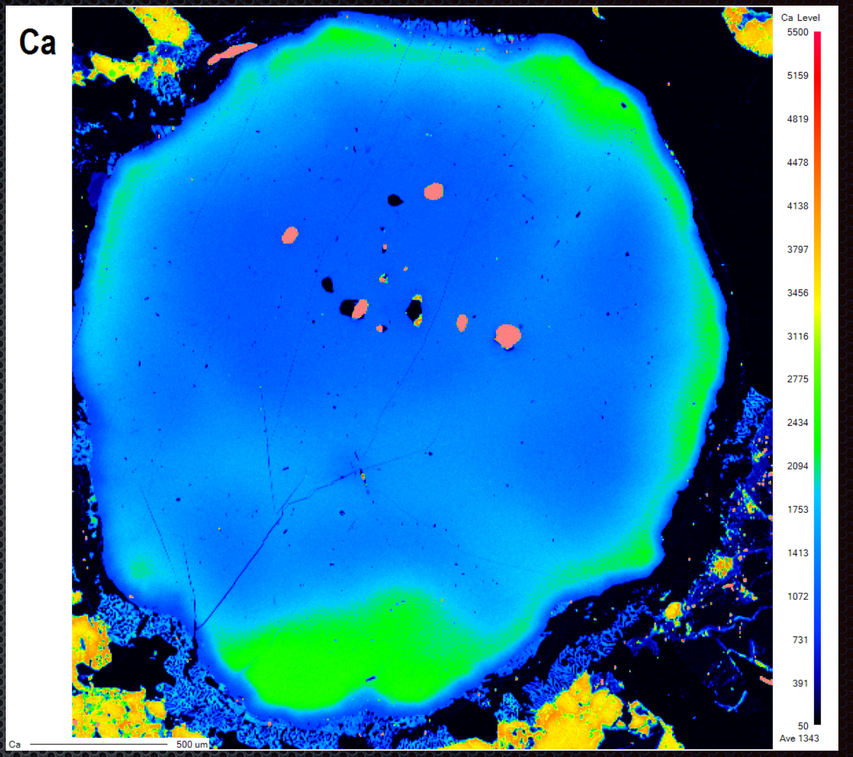
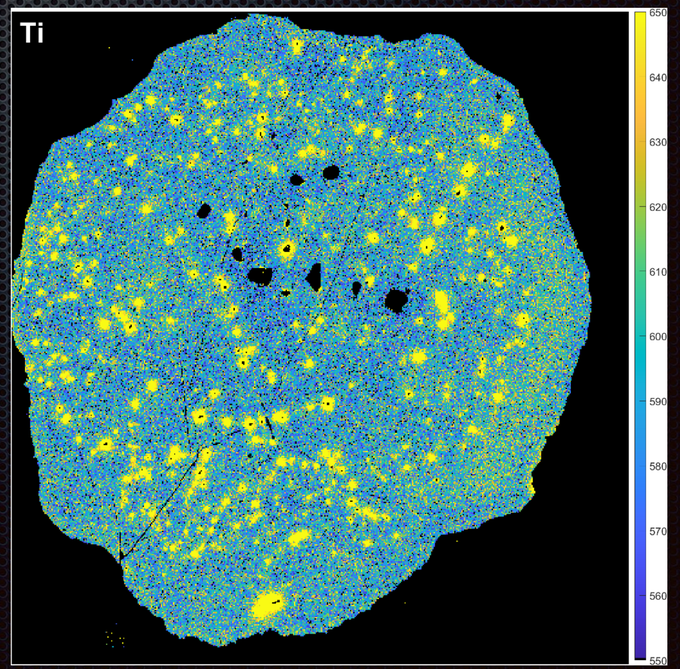
- duration of UHT stage appr. 1 million years





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Stage M2c (UHT)

- 930 °C, 1.45 GPa
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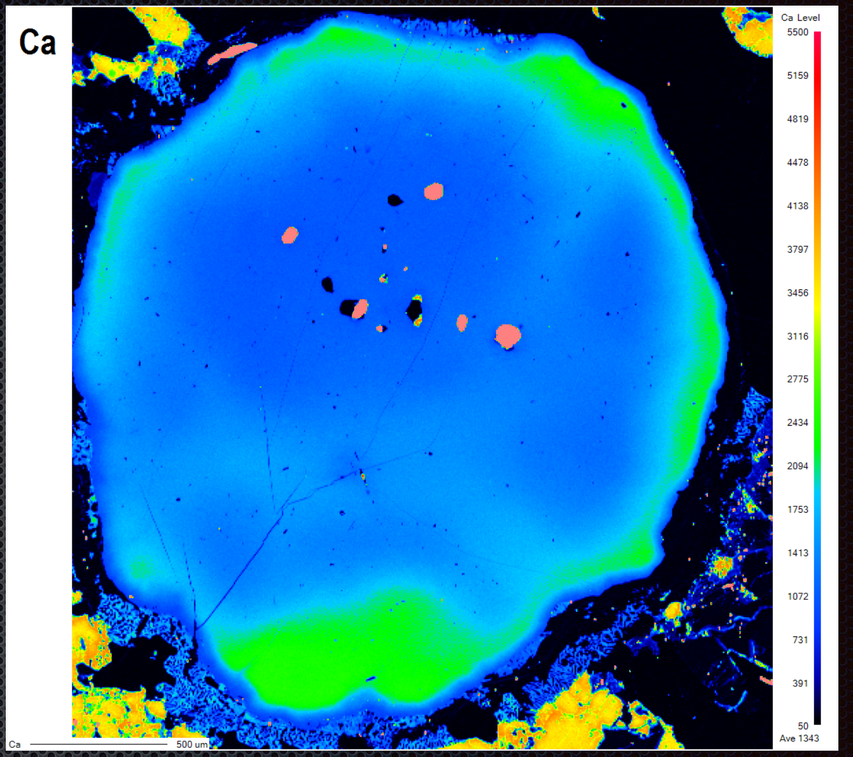
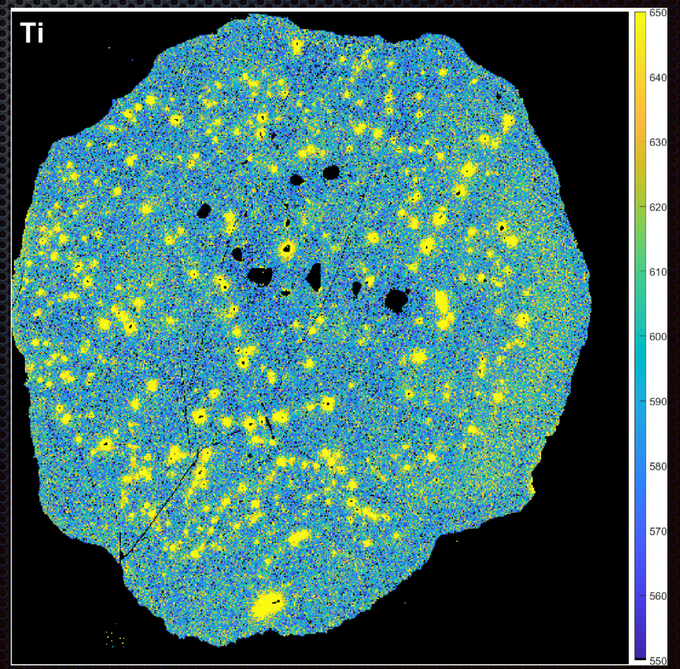
- duration of UHT stage appr. 1 million years
- Garnet mode constant at 6.5 vol.%





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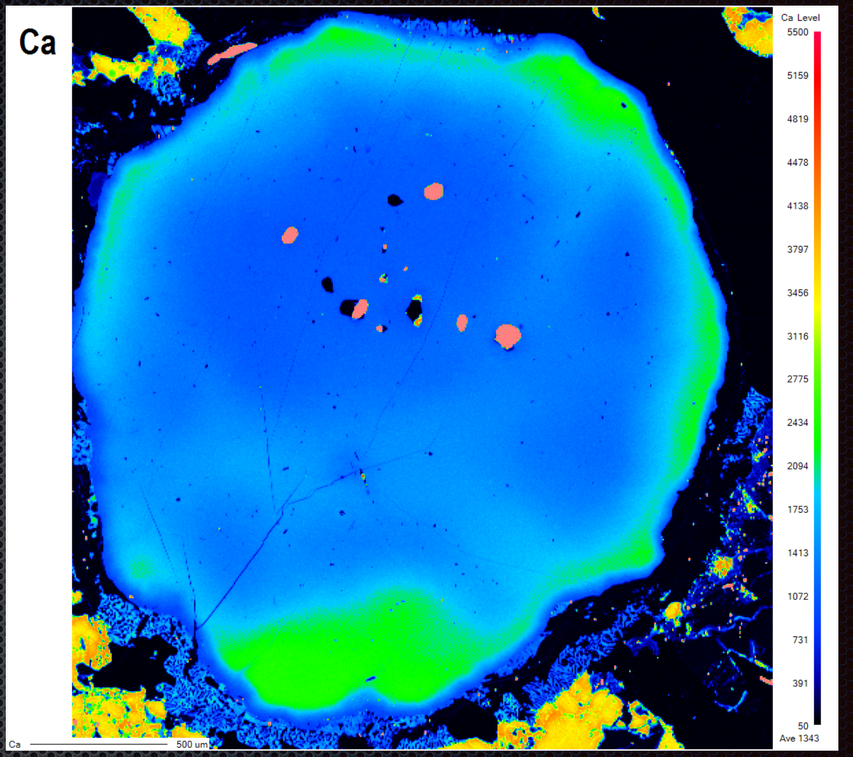
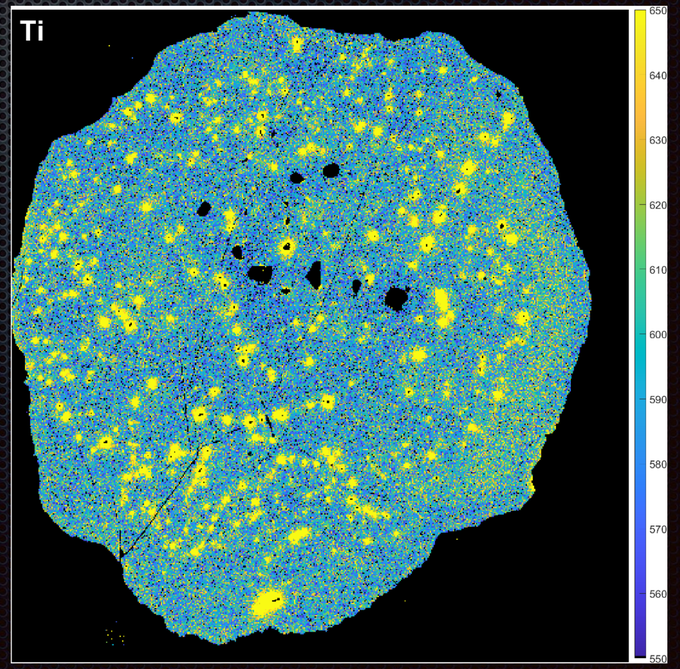
- Garnet mode constant at 6.5 vol.%

UHT metamorphism
930°C at 570 Ma





Ultra-High Temperature granulite Dronning-Maud Land, East Antarctica

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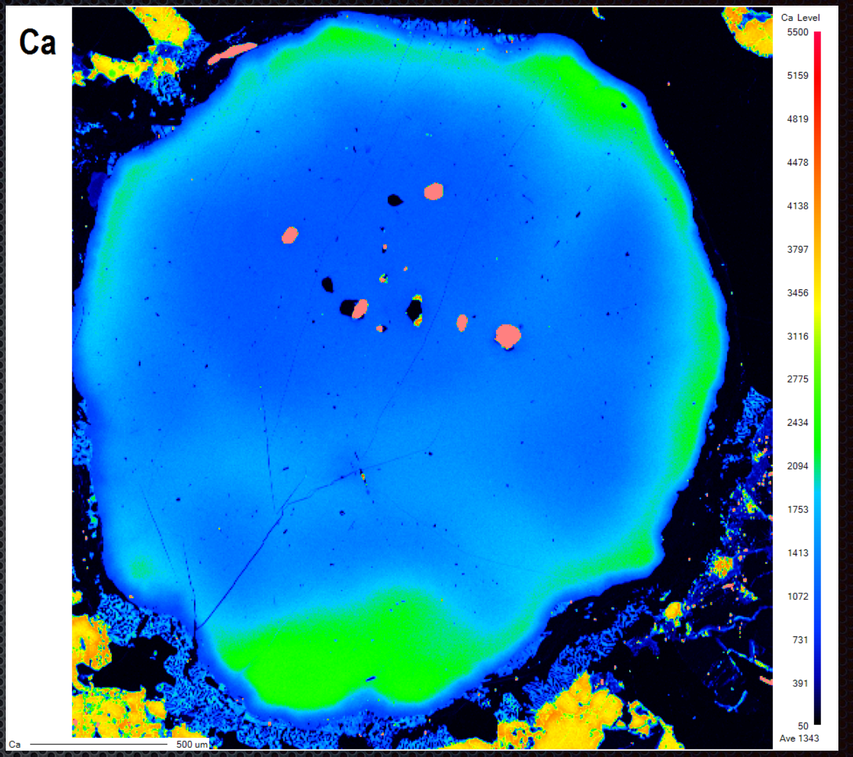
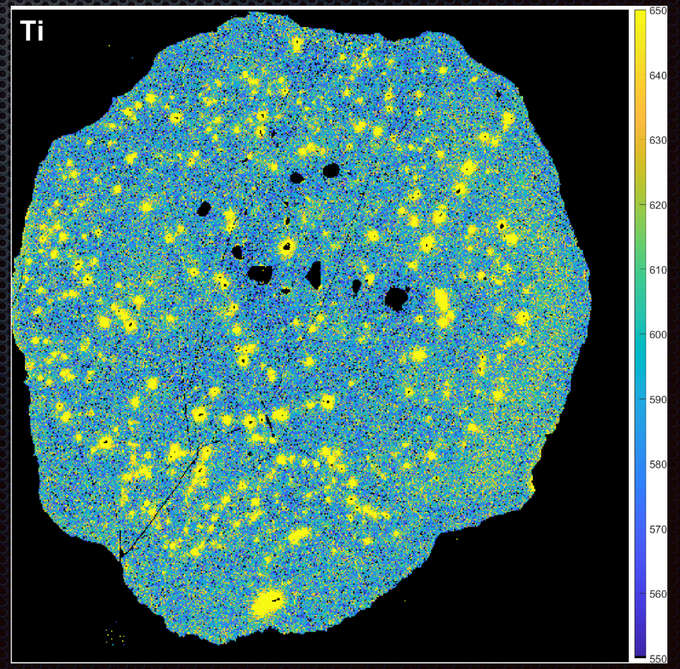
Stage M2c (UHT)

- 930 °C, 1.45 GPa
- metamorphic age (U–Pb zircon) 570 ±7 Ma
- duration of UHT stage appr. 1 million years
- Garnet mode constant at 6.5 vol.%

UHT metamorphism 930°C at 570 Ma

Metamorphism ≥800°C for >40 million years (593 to 550 Ma)





Ultra-High Temperature granulite
Dronning-Maud Land, East Antarctica

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Stage M2c (UHT)

- 930 °C, 1.45 GPa
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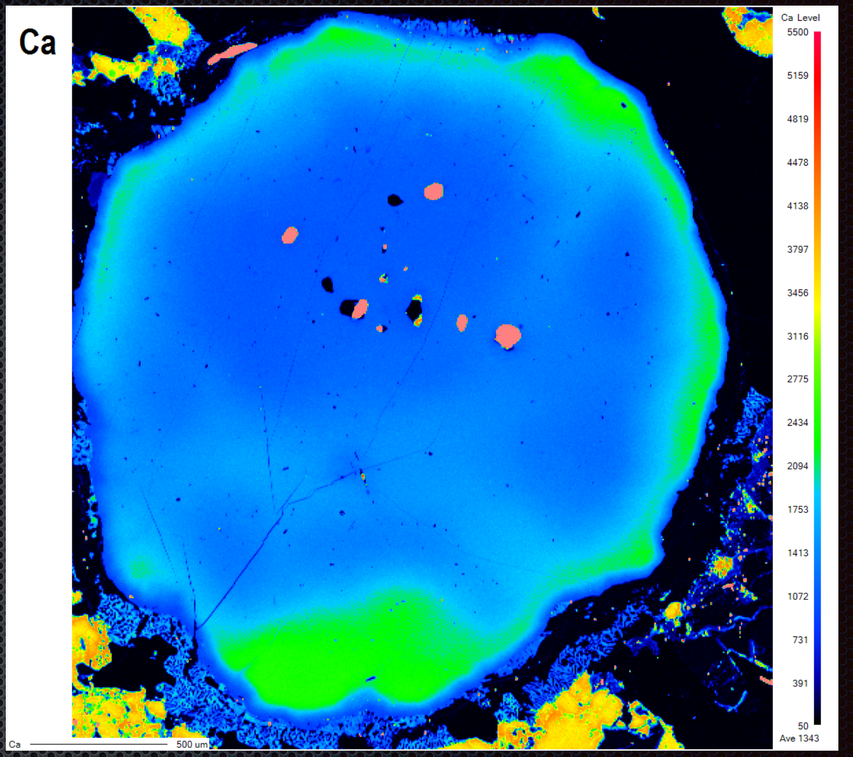
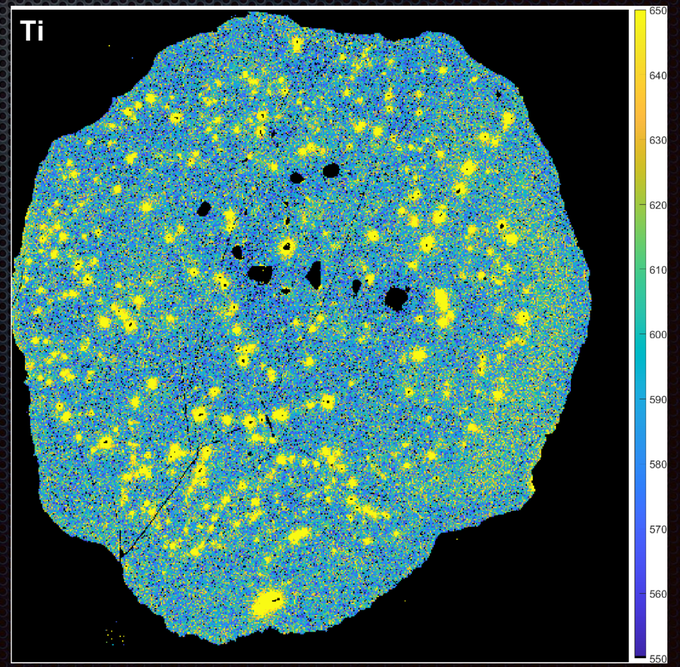
UHT metamorphism
930°C at 570 Ma

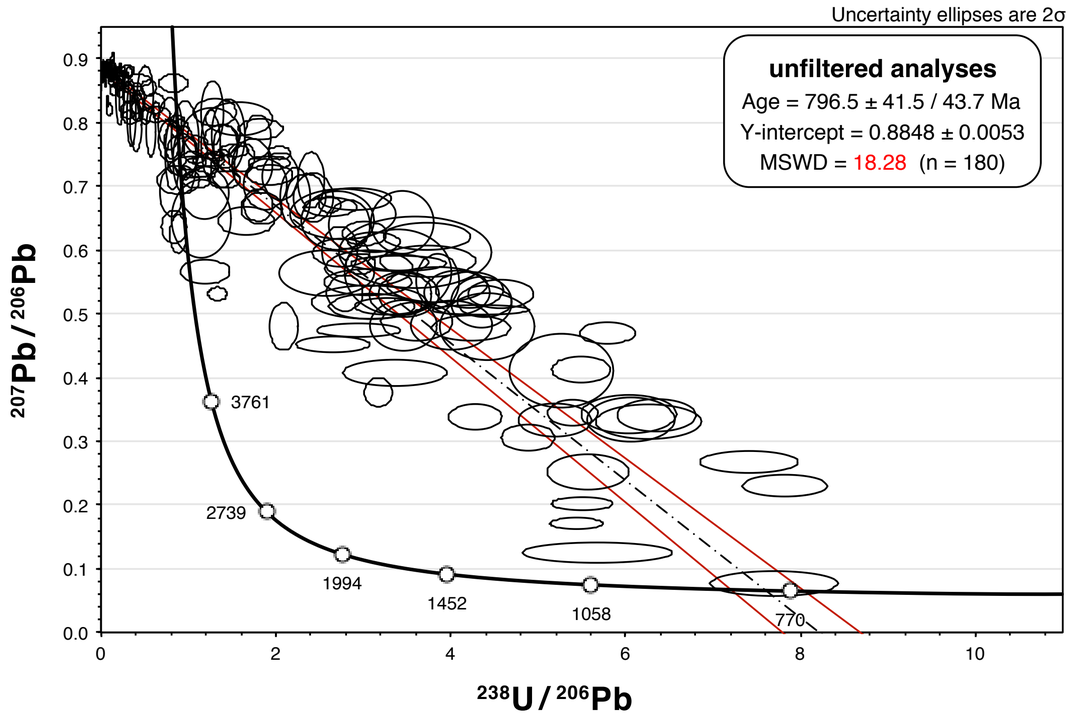
Metamorphism ≥800°C
for >40 million years
(593 to 550 Ma)

Cooling ≤500 °C
at 450-410 Ma
(U-Pb rutile)



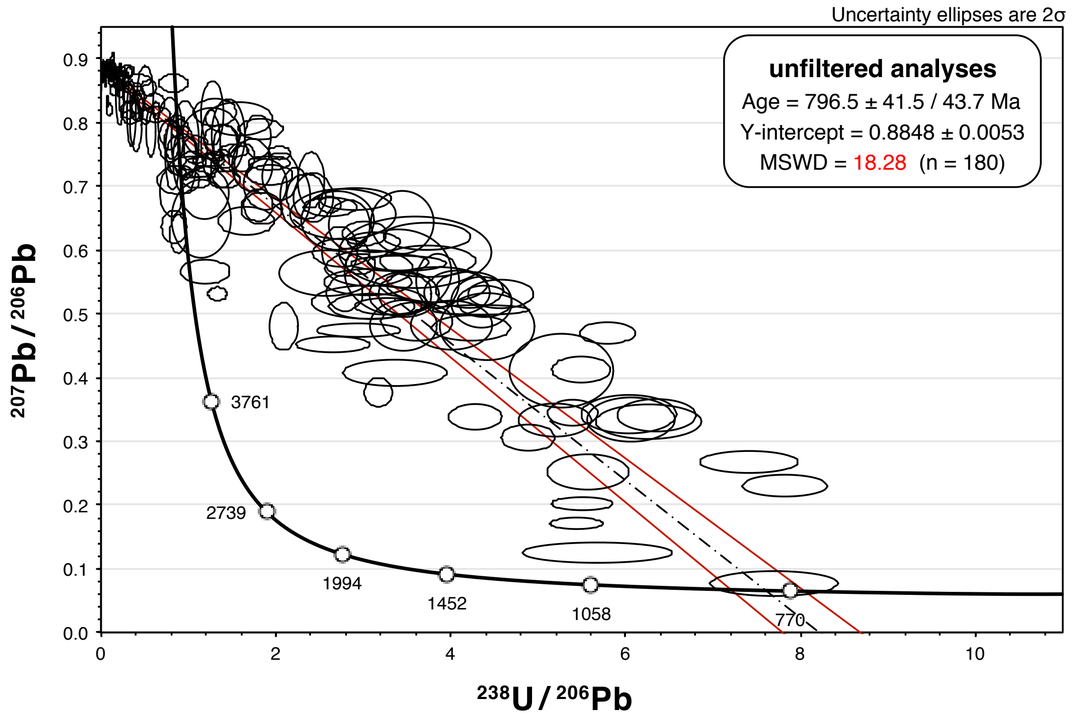


Ultra-High Temperature granulite (930 ºC)
Dronning-Maud Land, East Antarctica



Analyses of inclusion-rich domains in garnet

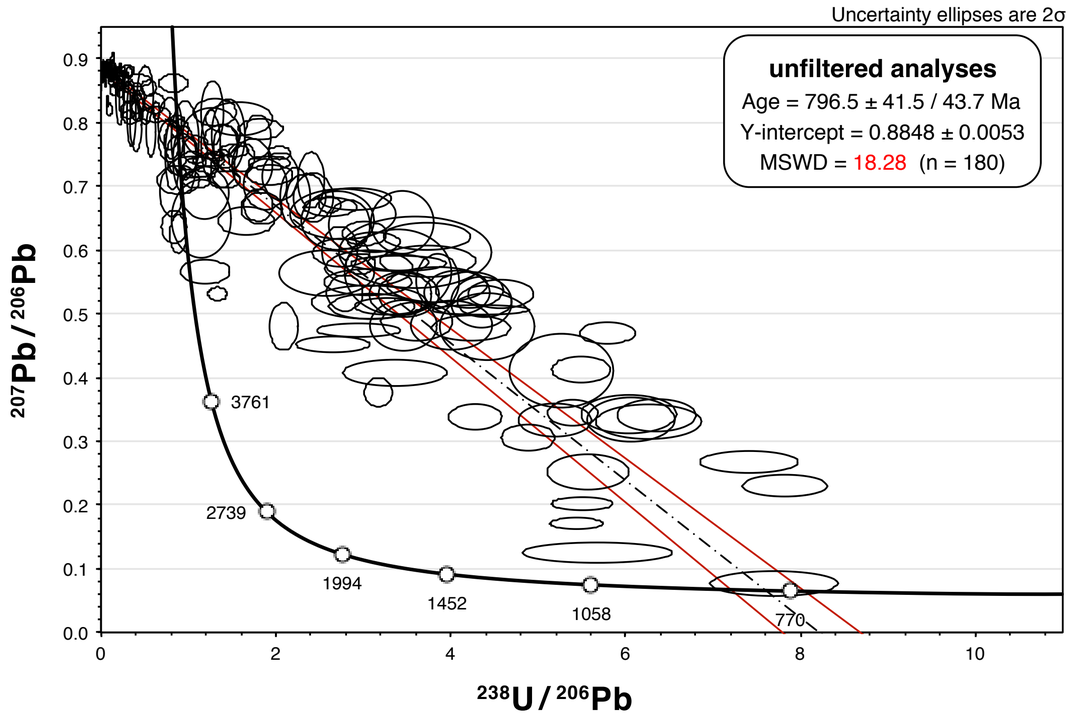
Ultra-High Temperature granulite (930 ºC)
Dronning-Maud Land, East Antarctica



Analyses of inclusion-rich domains in garnet

- large scatter (large MSWD)

Ultra-High Temperature granulite (930 ºC)
Dronning-Maud Land, East Antarctica



Analyses of inclusion-rich domains in garnet

- large scatter (large MSWD)
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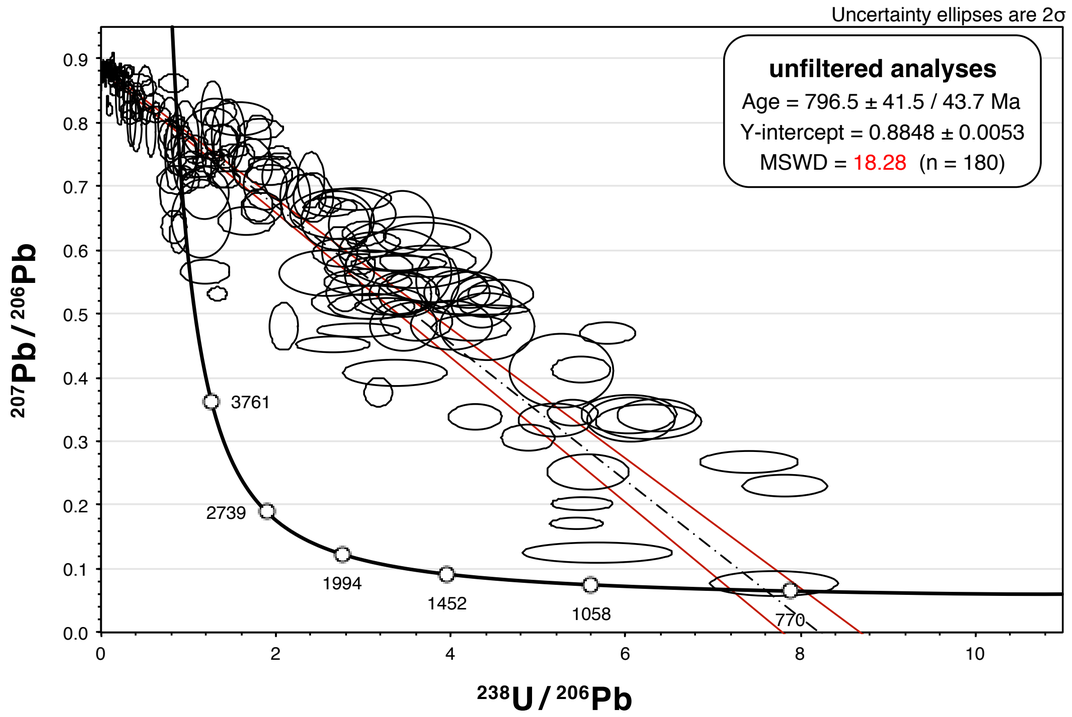
Ultra-High Temperature granulite (930 ºC)
Dronning-Maud Land, East Antarctica



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- large scatter (large MSWD)
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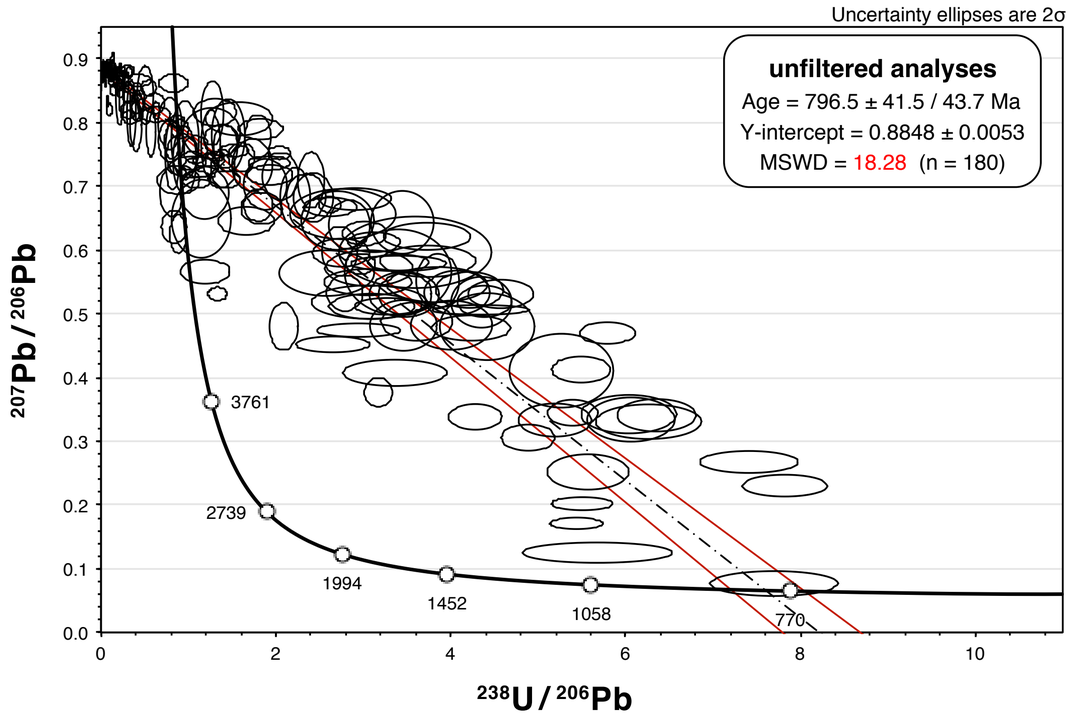
Dronning-Maud Land, East Antarctica



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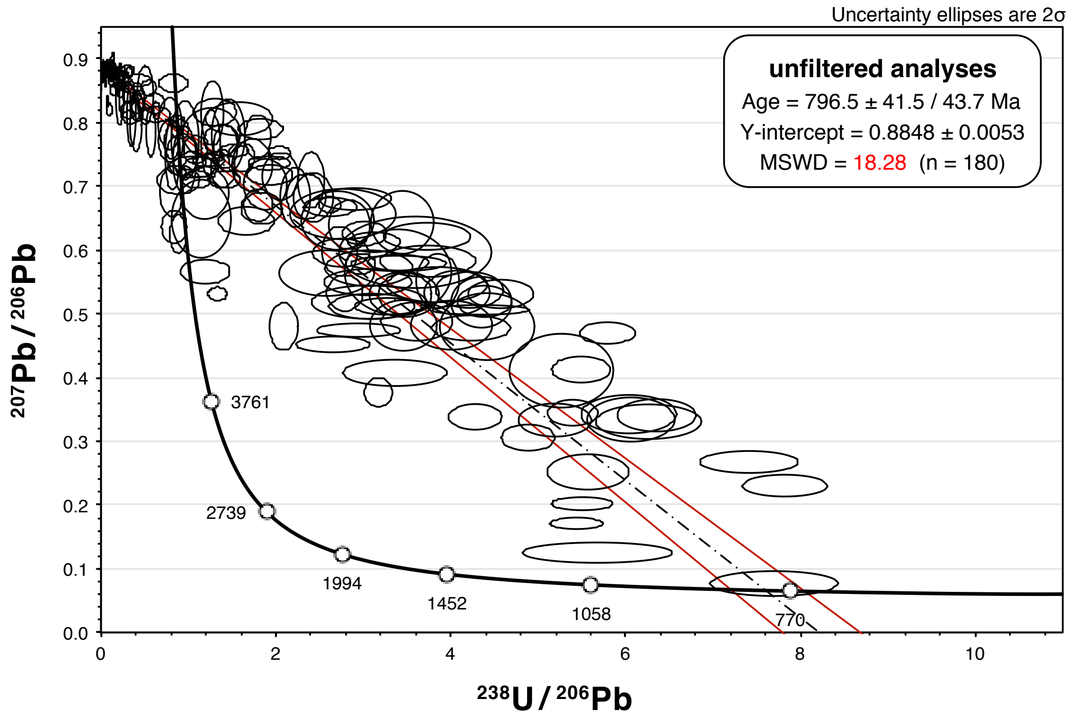

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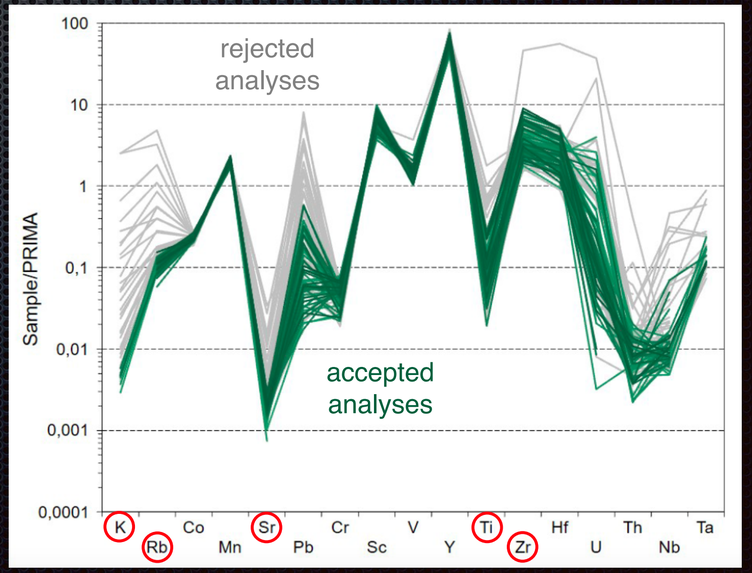
LASS-ICPMS data filtering scheme

rejected analyses

- Mn > 2,500 *µ*g/g
- Ti > 400 *µ*g/g
- Zr > 200 *µ*g/g
- Ce > 0.85 *µ*g/g
- Rb > 0.12 *µ*g/g
- K > 2.4 *µ*g/g
- Sr > 0.06 *µ*g/g
- $(Ce/Pr)_N > 1$

No filtering for U or Pb

n = 540



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Garnet low-Ca cores

- Ca < 8,000 *µ*g/g
- Eu/Eu* < 0.05

n = 169

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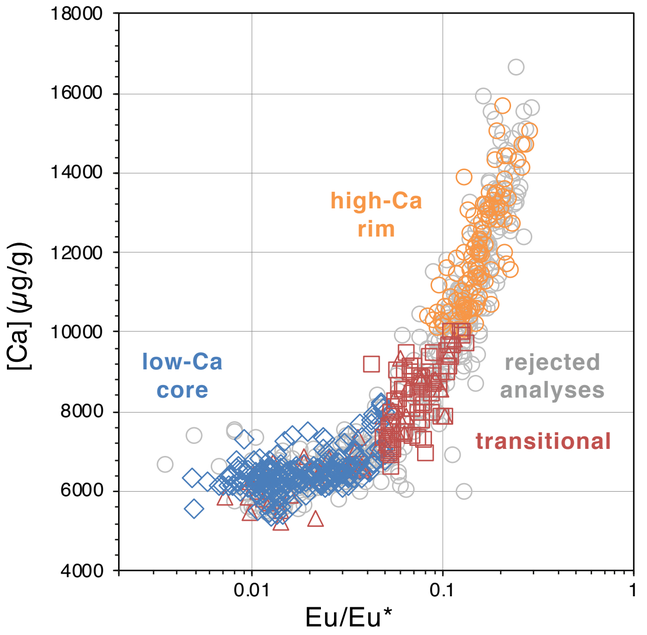

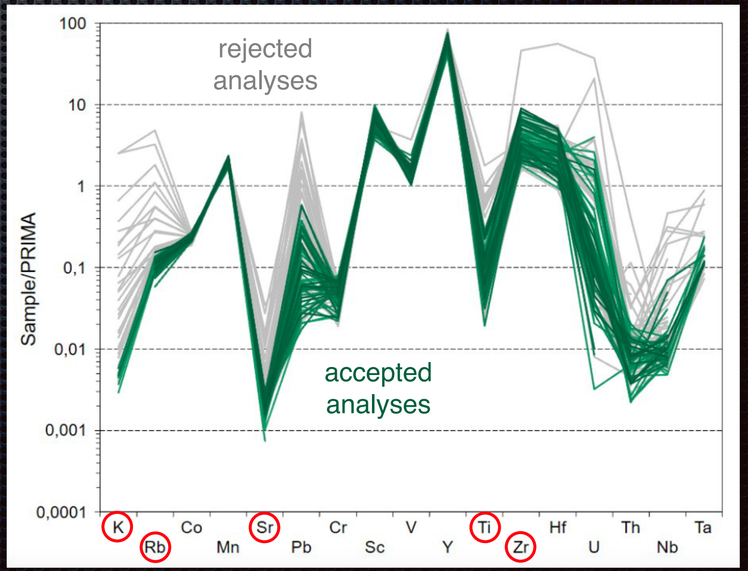

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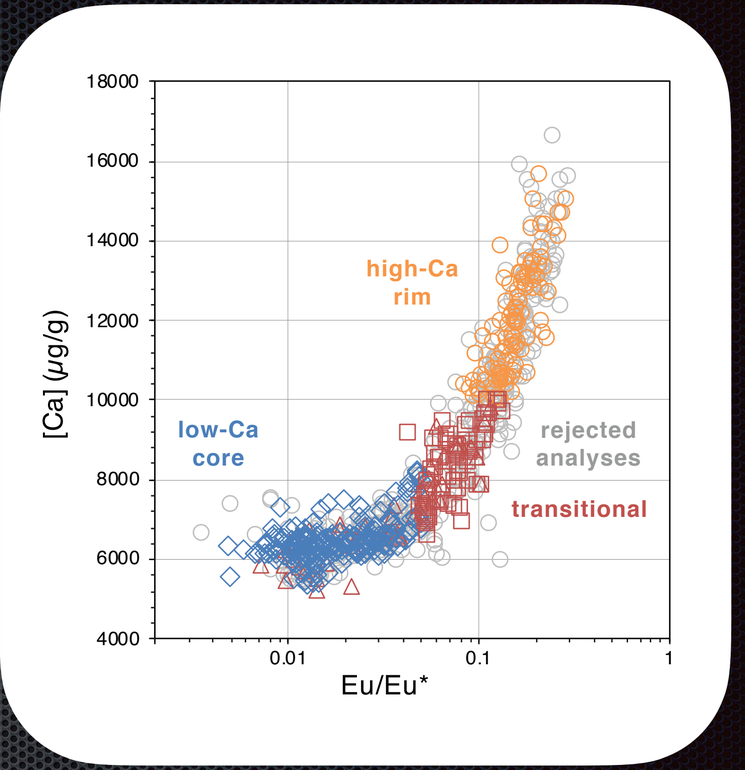
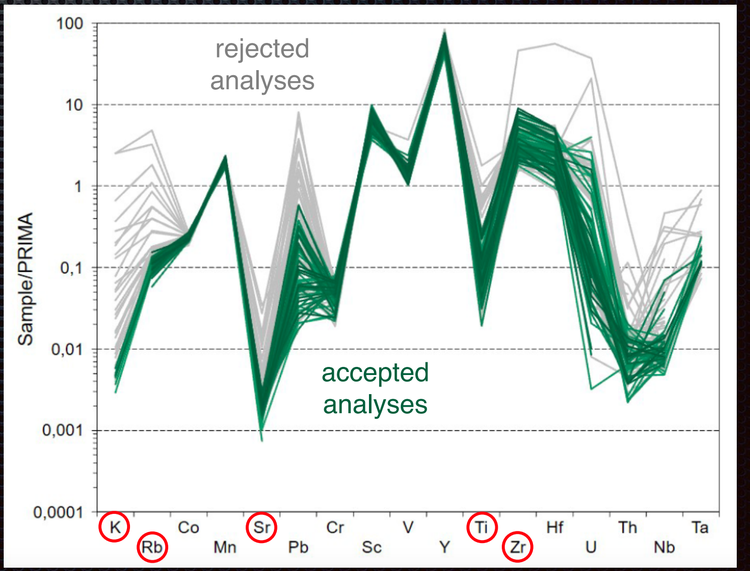
Garnet high-Ca rims

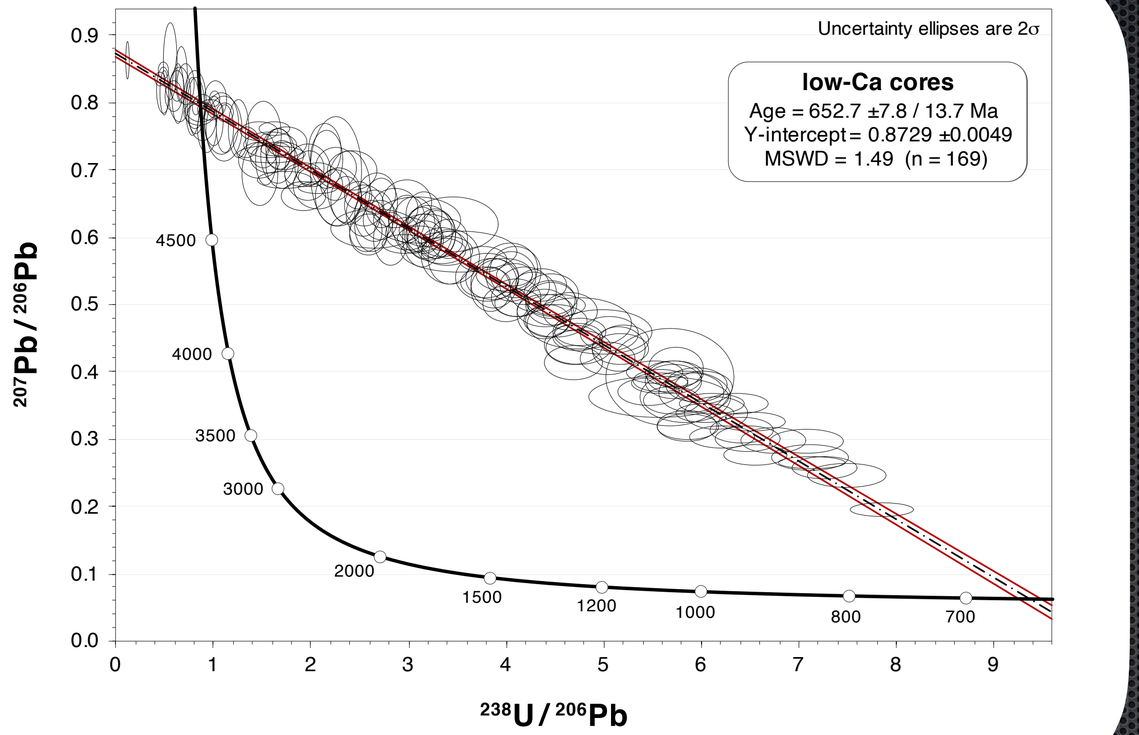
- Ca > 10,000 *µ*g/g
- Mg > 40,000 *µ*g/g

n = 88





Ultra-High Temperature granulite (930 ºC)
Dronning-Maud Land, East Antarctica



Garnet low-Ca cores

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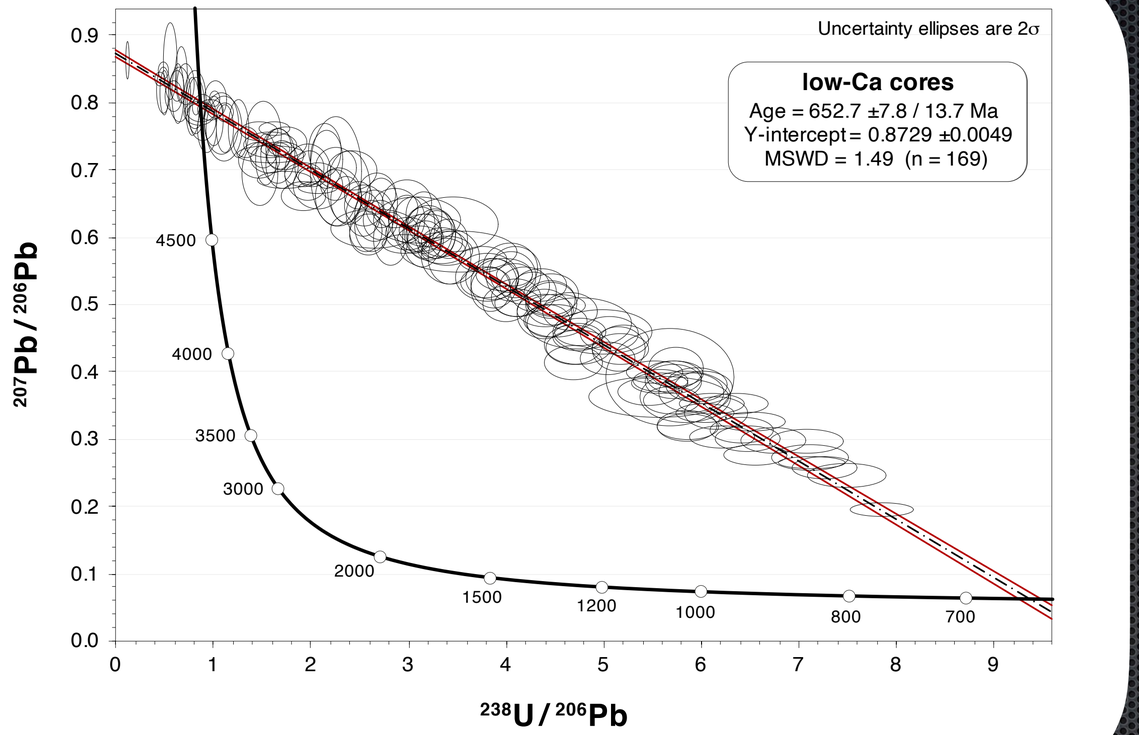
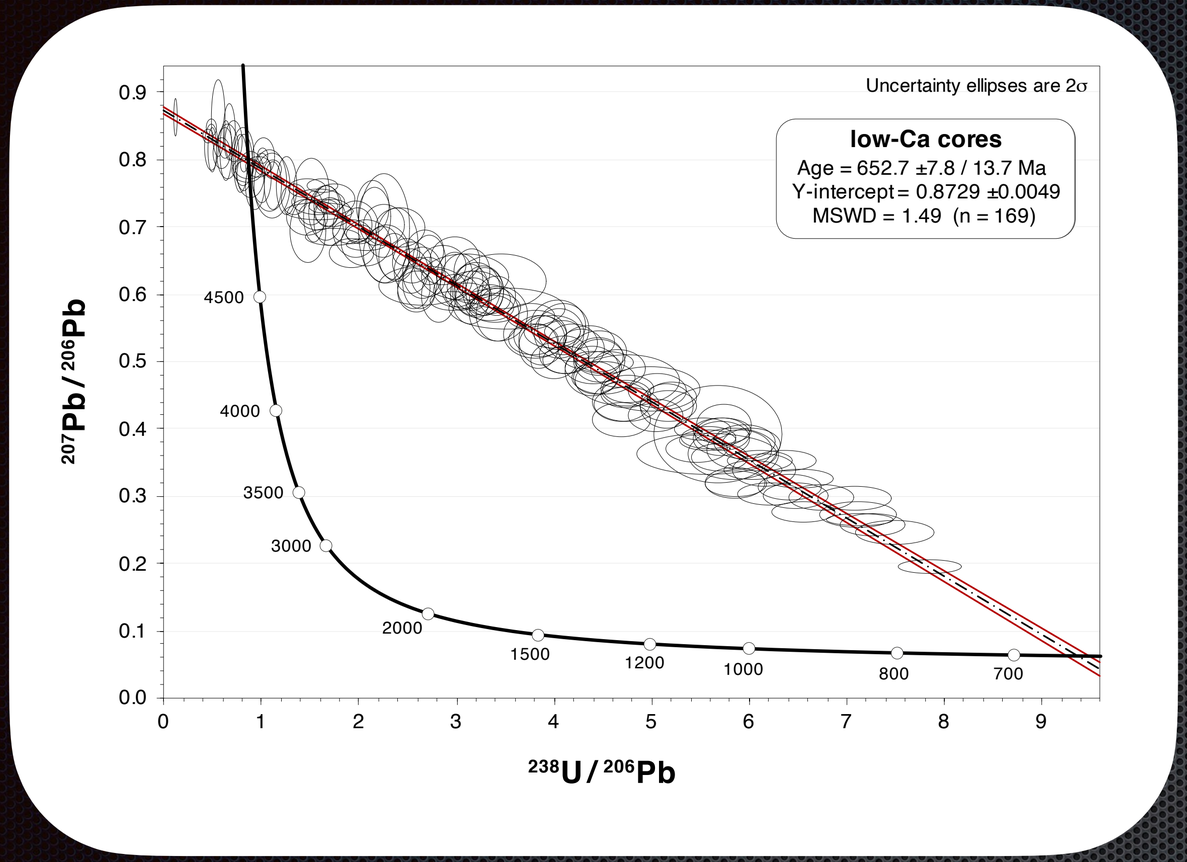


Garnet low-Ca cores

- garnet U–Pb age: 653 ±8 Ma

Ultra-High Temperature granulite (930 °C)
Dronning-Maud Land, East Antarctica



Garnet low-Ca cores

- garnet U–Pb age: 653 ±8 Ma
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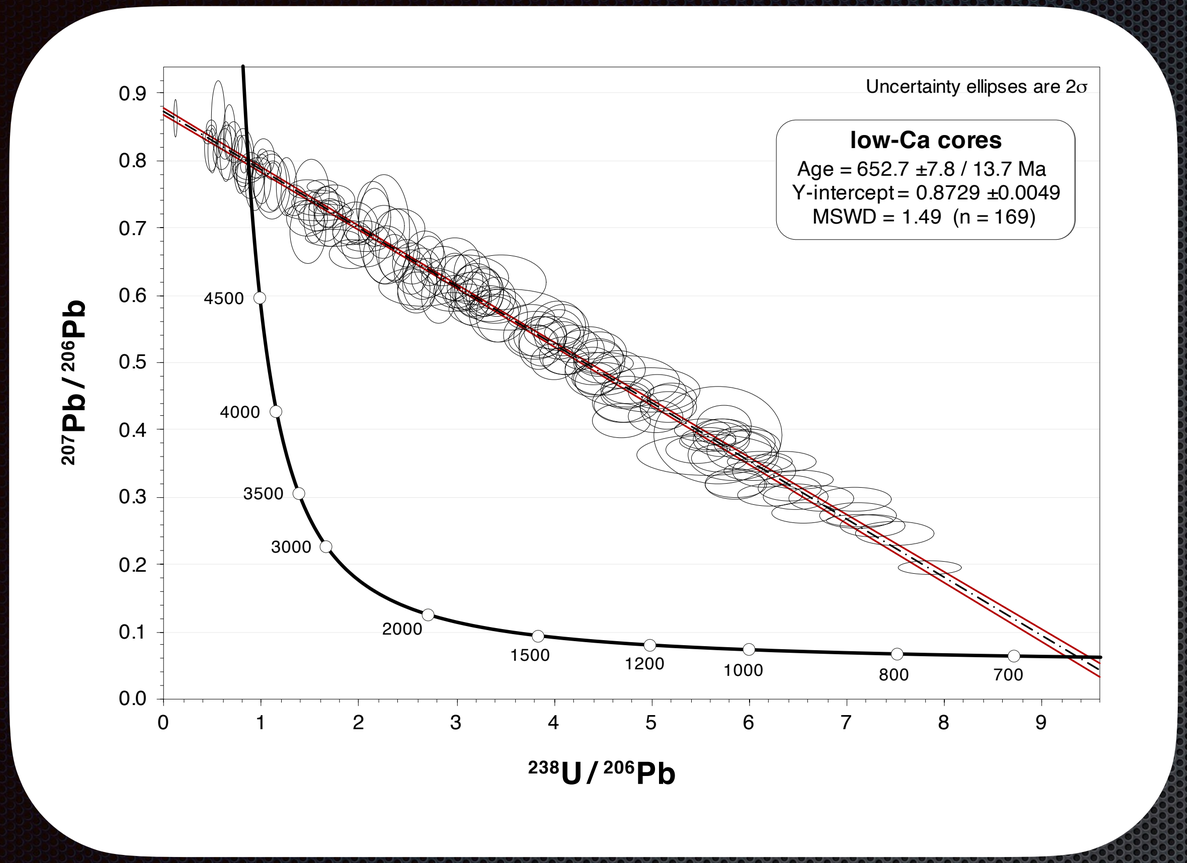
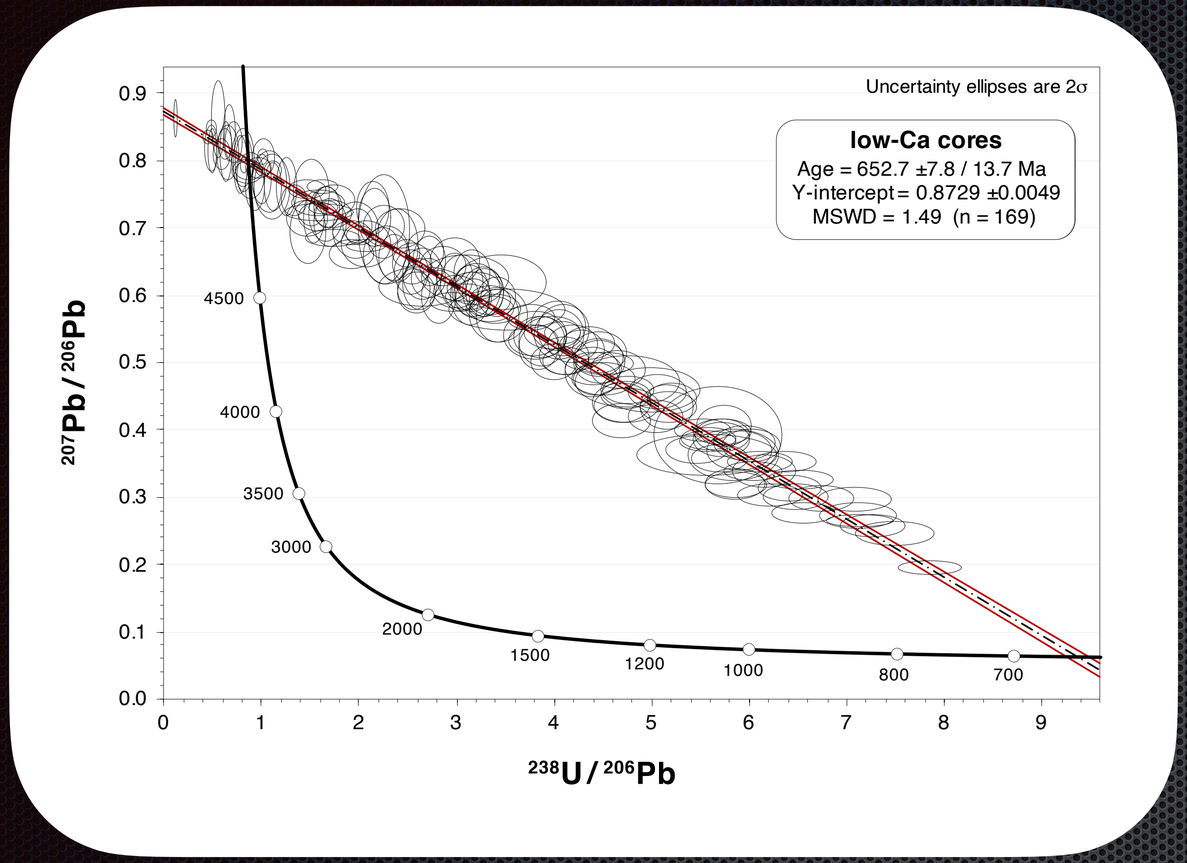
Dronning-Maud Land, East Antarctica

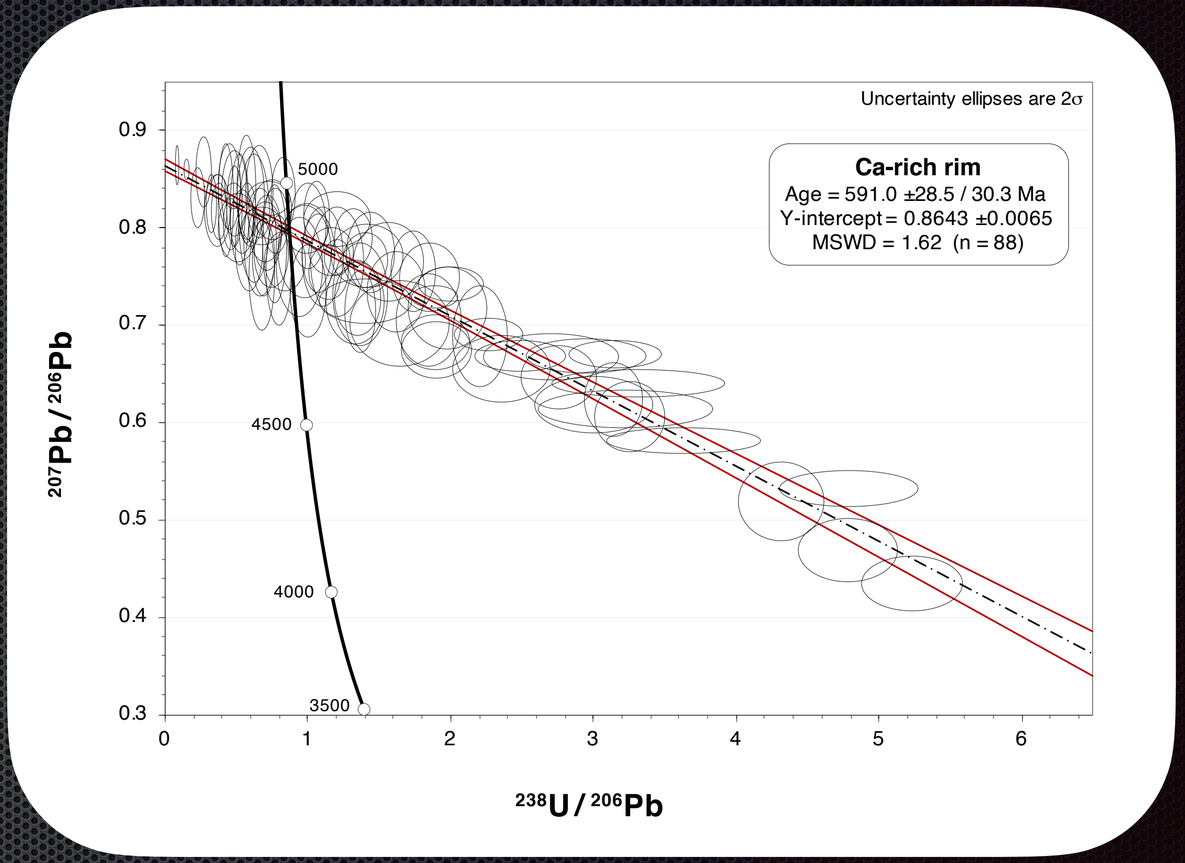


Garnet low-Ca cores

- garnet U–Pb age: 653 ±8 Ma
- no sign of resetting during subsequent UHT event
- consistent with 650 Ma back-arc rifting in DML

Ultra-High Temperature granulite (930 °C)
Dronning-Maud Land, East Antarctica





Garnet low-Ca cores

Garnet high-Ca rims

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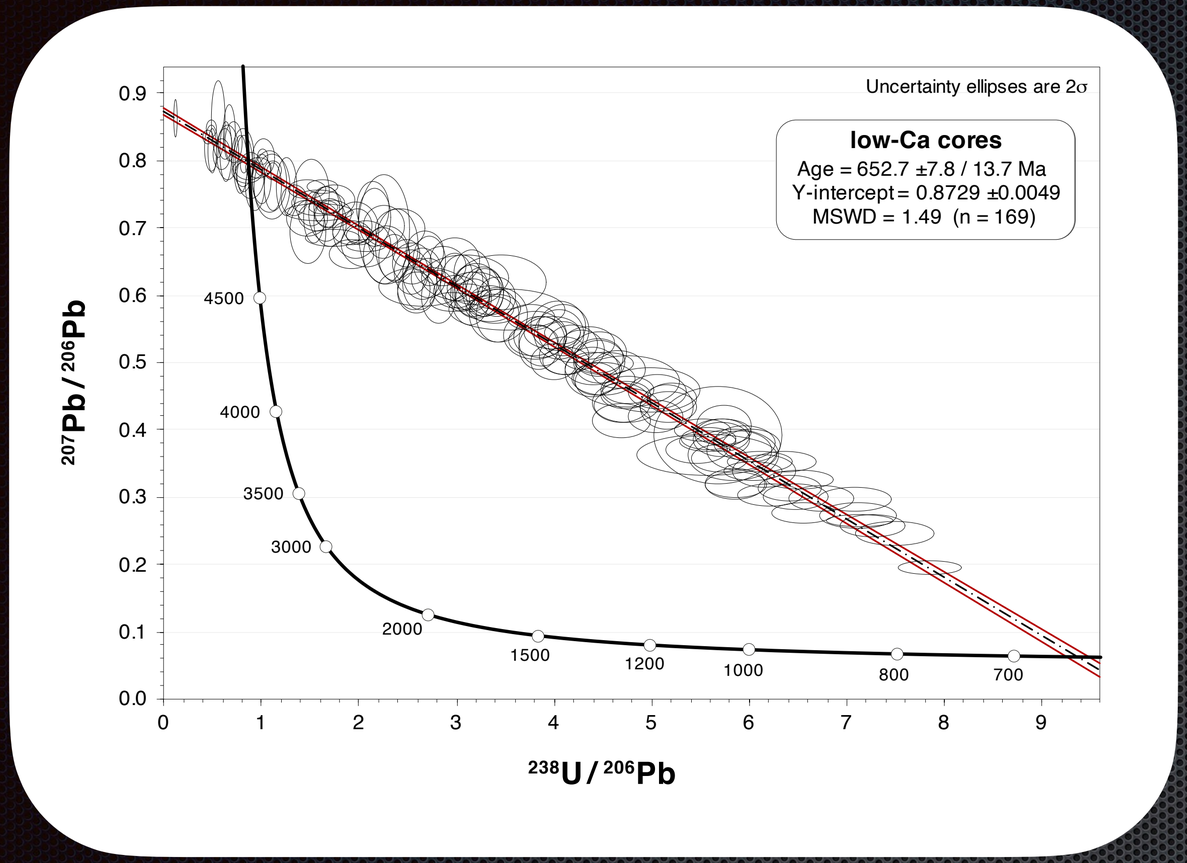
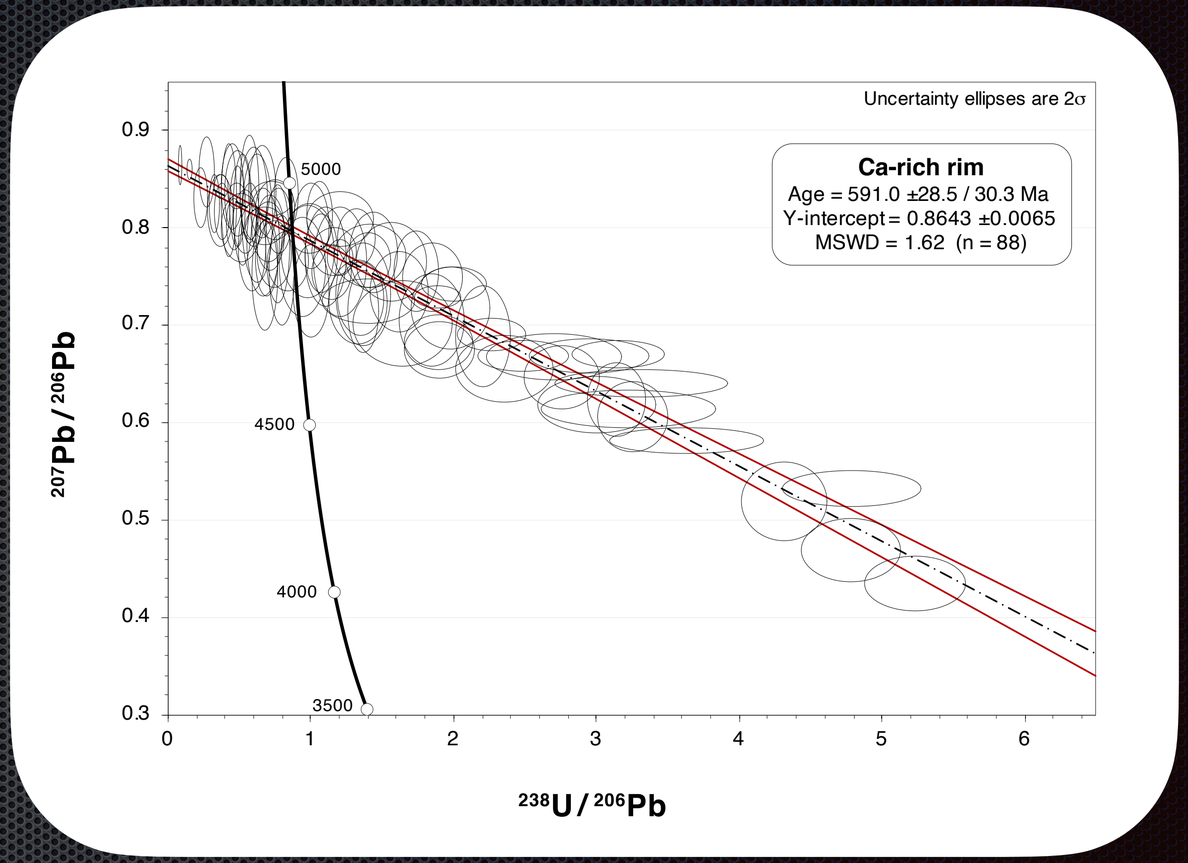
Dronning-Maud Land, East Antarctica





Garnet low-Ca cores

- garnet U–Pb age: 653 ±8 Ma
- no sign of resetting during subsequent UHT event
- consistent with 650 Ma back-arc rifting in DML

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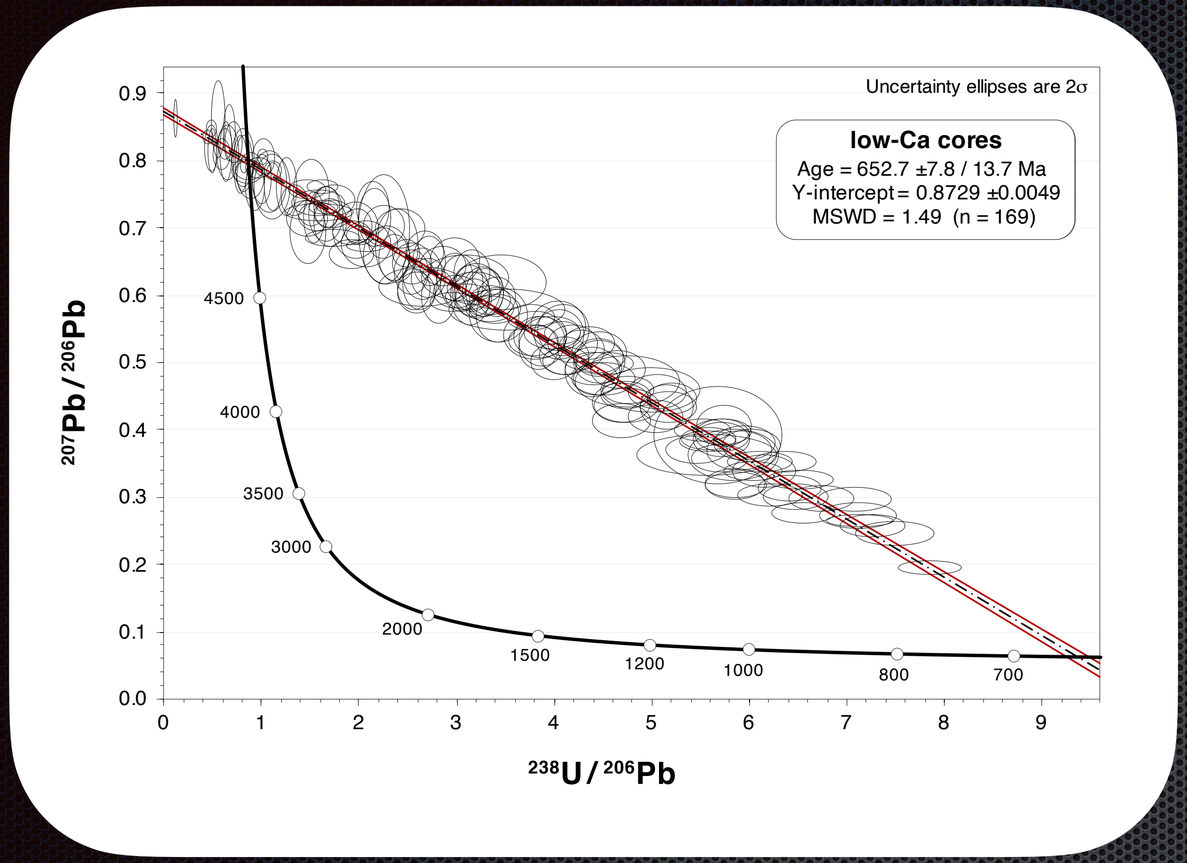
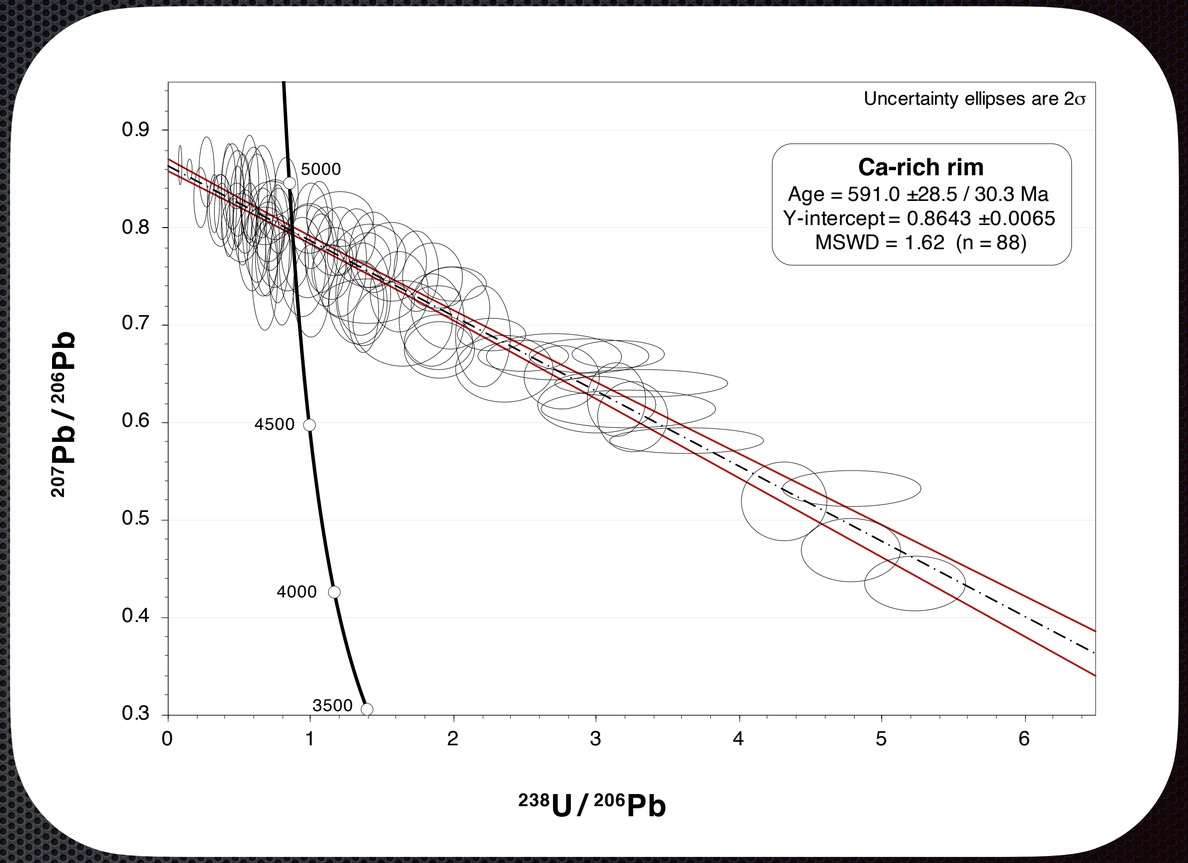
Ultra-High Temperature granulite (930 °C)
Dronning-Maud Land, East Antarctica





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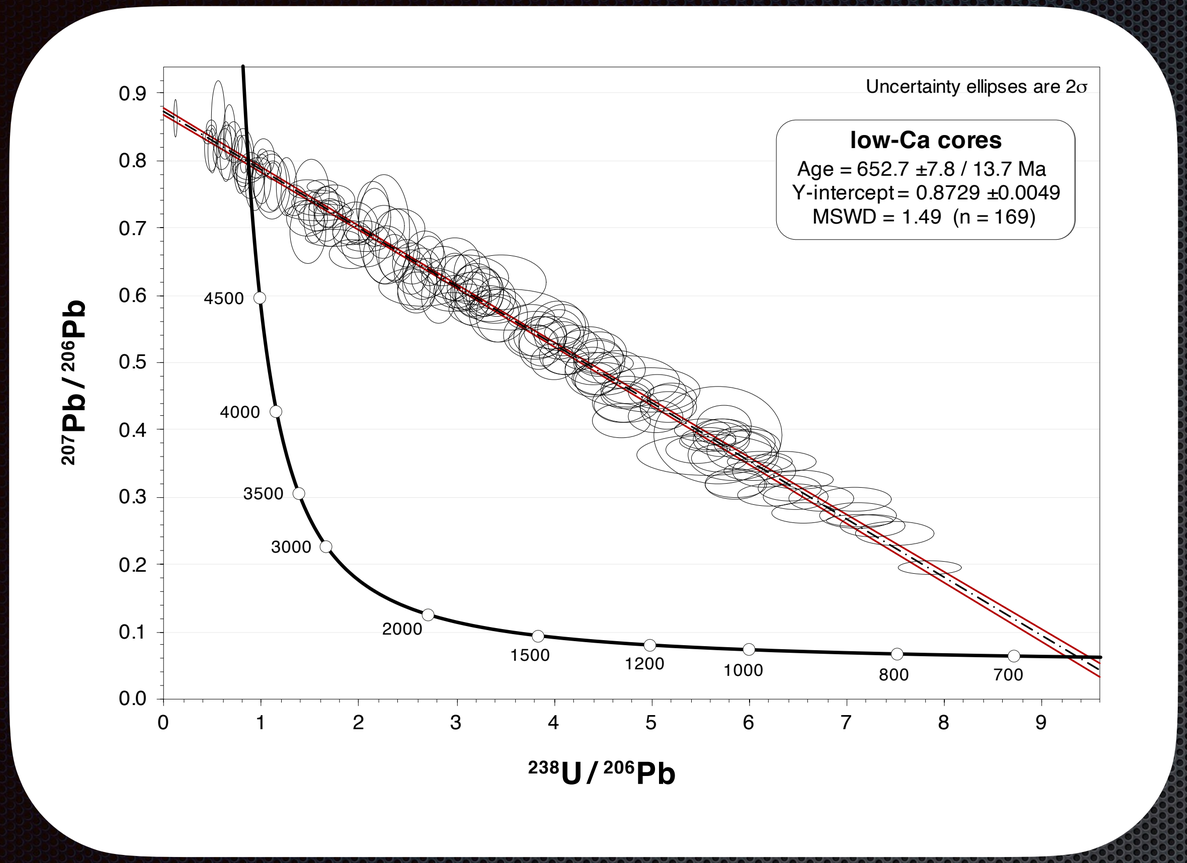

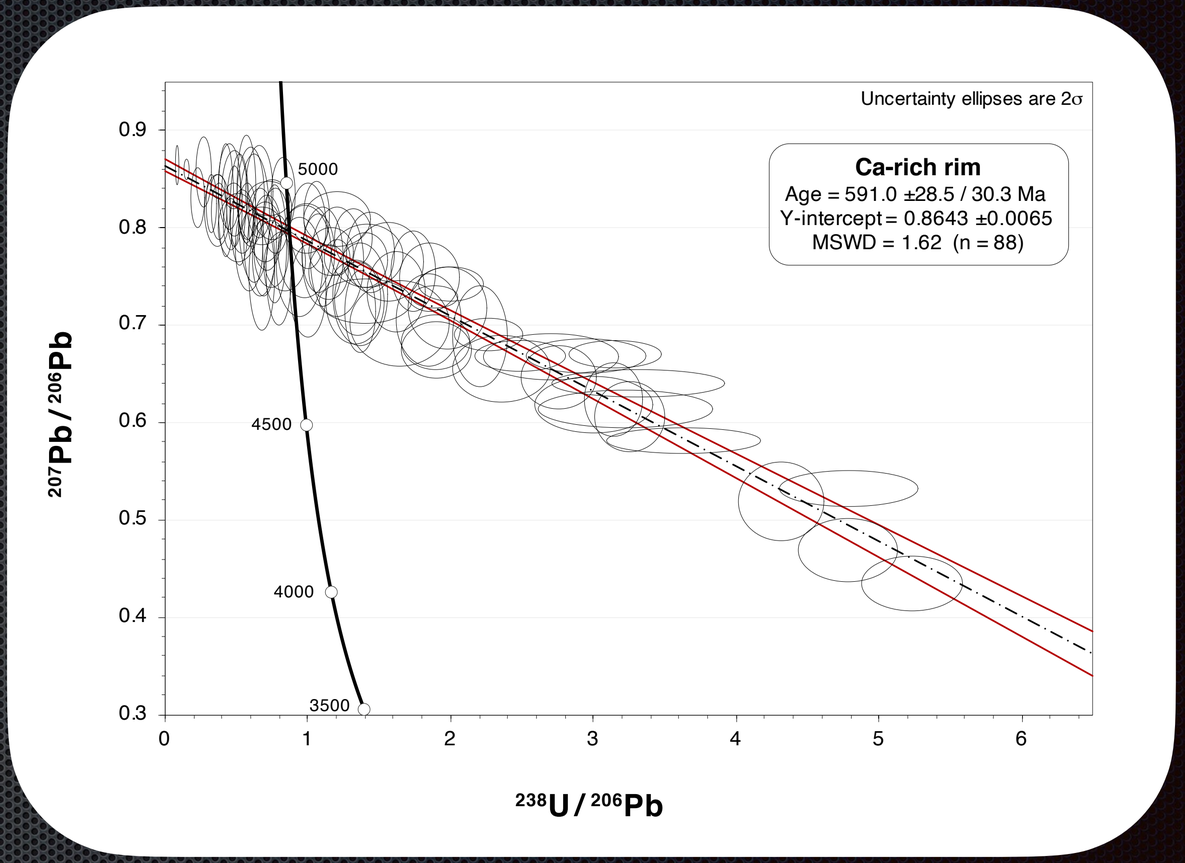

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- finally a petrochronometer that records mountain building (not just collapse and exhumation)