# Zircon oxybarometer - hygrometer

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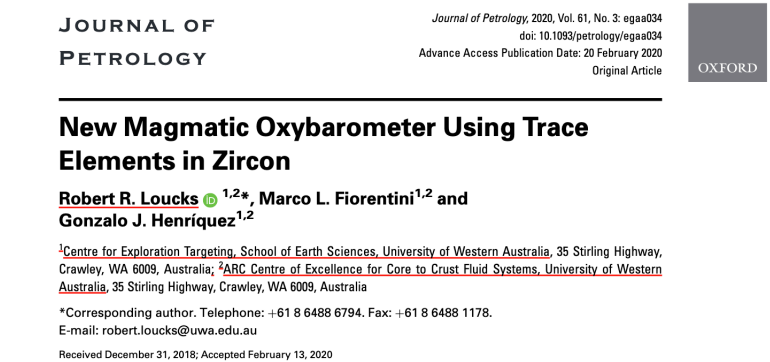
# Outline

# 1. Zircon oxybarometer

# Literature



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Original Article

OXFORD

## New Magmatic Oxybarometer Using Trace Elements in Zircon

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Figure 1: Loucks et al., 2020

Click here to download the literature.

# 数据准备

- Zircon Trace elements
- 适用范围：
  - Fe–Ti oxide phenocrysts and hornblende phenocrysts quenched in eruptive I- and A-type dacites and rhyolites
  - slowly cooled plutonic rocks
  - detrital and xenocrystic zircons

# Magma oxygen fugacity (Loucks et al., 2020)

**Loucks et al., 2020**

$$\Delta FMQ = log\ fO_{2(\mathrm{sample})} - log\ fO_{2(\mathrm{FMQ})} = 3.99 \times log\frac{Ce}{\sqrt{U_i \times Ti}} + 2.28 \quad (1)$$

- $U_i$: age-corrected initial U content; $U_i = U \times e^{\lambda t}$
- **太古宙样品必须校正**
- **independent estimates**

# Magma oxygen fugacity (Smythe and Brenan, 2016)


Figure 2: Smythe and Brenan, 2016

- Principal: zircon-melt equilibrium

**Smythe and Brenan, 2016**

$$\ln\left[\frac{x^{\mathrm{melt}}_{\mathrm{Ce}^{4+}}}{x^{\mathrm{melt}}_{\mathrm{Ce}^{3+}}}\right] = \frac{1}{4}\ln fO_2 + \frac{13,136}{T} - 2.064\frac{\mathrm{NBO}}{\mathrm{T}} - 8.878 \times x\mathrm{H_2O} - 8.955 \quad (2)$$

# Crystallization Temperature (Ferry and Watson, 2007)

**Ferry and Watson, 2007**

$$log\,(\text{Ti in Zicron}) + log\,\alpha_{SiO_2} - log\,\alpha_{TiO_2} = 5.711 - \frac{4800}{T} \tag{3}$$

- $\alpha_{SiO_2}$:
  1. **中酸性熔体（石英饱和）** $\alpha_{SiO_2} = 1$
  2. **基性岩** $\alpha_{SiO_2} < 1$，**高级变质岩需考虑 P-T 影响，需用热力学模拟计算**
- $\alpha_{TiO_2} = 0.6$
  1. **金红石饱和** $\Rightarrow$ **出现金红石，** $\alpha_{TiO_2} = 1$
  2. **实验岩石学表明硅酸盐熔体中** $\alpha_{TiO_2} = 0.6 - 0.9$ (Watson et al., 2006; Hayden and Watson, 2007)

# 2. Zircon hygrometer

# Literature

Article

## Earth's early continental crust formed from wet and oxidizing arc magmas

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Check for updates

Rong-Feng Ge[1✉], Simon A. Wilde[2], Wen-Bin Zhu[1] & Xiao-Lei Wang[1]

Formation of continental crust has shaped the surface and interior of our planet and generated the land and mineral resources on which we rely. However, how the early continental crust of Earth formed is still debated[1–7]. Modern continental crust is largely formed from wet and oxidizing arc magmas at subduction zones, in which

Figure 3: Ge et al., 2023

Click here to download the literature.

# 数据准备

- Zircon trace element data
- Whole-rock/melt inclusion data (parental magma composition)
- Filtered criteria (Laurent et al., 2022):
  1. LREE-I (Bell et al., 2016): $\frac{Dy}{Sm} + \frac{Dy}{Nd} \geq 30$ decrease with increasing degree of hydrothermal alteration or contamination
  2. $La \leq 0.5$ ppm (largest extent of modification during post-magmatic alteration)
  3. $Ca \leq 150$ ppm and $Fe \leq 150$ ppm (below the limit of detection)
  4. discordance of U-Pb ages within 5% and common Pb $< 1\%$
- Calculate the median and 2SEM of the composition (Zircon and whole rock/melt)

# Retrieve equilibrium magmatic $H_2O$ content

## Smythe and Brenan, 2016

$$\ln\left[\frac{x^{\text{melt}}_{\text{Ce}^{4+}}}{x^{\text{melt}}_{\text{Ce}^{3+}}}\right] = \frac{1}{4}\ln fO_2 + \frac{13,136}{T} - 2.064\frac{\text{NBO}}{\text{T}} - 8.878 \times x\text{H}_2\text{O} - 8.955 \quad (4)$$

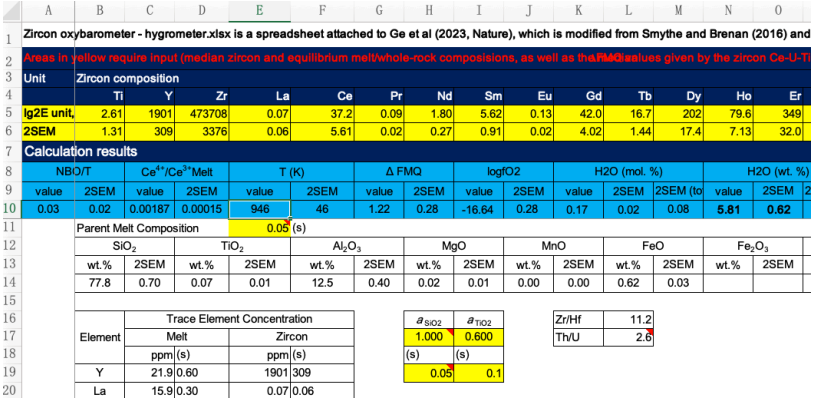
## Loucks et al., 2020

$$\Delta FMQ = 3.99 \times log\frac{Ce}{\sqrt{U_i \times Ti}} + 2.28 \quad (5)$$

## Ferry and Watson, 2007

$$log\ (\text{Ti in Zicron}) + log\ \alpha_{\text{SiO}_2} - log\ \alpha_{\text{TiO}_2} = 5.711 - \frac{4800}{T} \quad (6)$$

# Macro Excel



Zircon oxybarometer - hygrometer.xlsx is a spreadsheet attached to Ge et al (2023, Nature), which is modified from Smythe and Brenan (2016) and

Areas in yellow require input (median zircon and equilibrium melt/whole-rock compositions, as well as the FMQ values given by the zircon Ce-U-Ti

| Unit | Zircon composition | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ti | Y | Zr | La | Ce | Pr | Nd | Sm | Eu | Gd | Tb | Dy | Ho | Er | |
| lg2E unit, | 2.61 | 1901 | 473708 | 0.07 | 37.2 | 0.09 | 1.80 | 5.62 | 0.13 | 42.0 | 16.7 | 202 | 79.6 | 349 | |
| 2SEM | 1.31 | 309 | 3376 | 0.06 | 5.61 | 0.02 | 0.27 | 0.91 | 0.02 | 4.02 | 1.44 | 17.4 | 7.13 | 32.0 | |

Calculation results

| NBO/T | | $Ce^{4+}/Ce^{3+}$Melt | | T (K) | | Δ FMQ | | logfO2 | | H2O (mol. %) | | | H2O (wt. %) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| value | 2SEM | value | 2SEM | value | 2SEM | value | 2SEM | value | 2SEM | value | 2SEM | 2SEM (to | value | 2SEM | 2 |
| 0.03 | 0.02 | 0.00187 | 0.00015 | 946 | 46 | 1.22 | 0.28 | -16.64 | 0.28 | 0.17 | 0.02 | 0.08 | **5.81** | **0.62** | |

Parent Melt Composition 0.05 (s)

| $SiO_2$ | | $TiO_2$ | | $Al_2O_3$ | | MgO | | MnO | | FeO | | $Fe_2O_3$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| wt.% | 2SEM | wt.% | 2SEM | wt.% | 2SEM | wt.% | 2SEM | wt.% | 2SEM | wt.% | 2SEM | wt.% | 2SEM |
| 77.8 | 0.70 | 0.07 | 0.01 | 12.5 | 0.40 | 0.02 | 0.01 | 0.00 | 0.00 | 0.62 | 0.03 | | |

| Element | Trace Element Concentration | | | |
|---|---|---|---|---|
| | Melt | | Zircon | |
| | ppm | (s) | ppm | (s) |
| Y | 21.9 | 0.60 | 1901 | 309 |
| La | 15.9 | 0.30 | 0.07 | 0.06 |

| $a_{SiO2}$ | $a_{TiO2}$ |
|---|---|
| 1.000 | 0.600 |
| (s) | (s) |
| 0.05 | 0.1 |

| Zr/Hf | 11.2 |
|---|---|
| Th/U | 2.6 |

Figure 4: Macro Excel

# Metamorphic disturbance

- Preferential U loss (high Th/U ratios of several TTG suites)

  $\Rightarrow$ Overestimate magmatic $H_2O$ content

- Assuming Th/U = 5 (the median composition of the global sodic TTGs)

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# Thank You!