AN EMERGING THERMO-CHRONOMETER FOR CARBONATE ROCKS: $\Delta_{47}/(U-Pb)$

A case study from the Middle Jurassic reservoirs of the Paris basin

Xavier Mangenot

Supervision team:

IFP Energies Nouvelles
Marta Gasparini
Virgile Rouchon

IPGP, Sorbonne Paris Cité
Magali Bonifacie
Magali Ader
THERMAL HISTORY CHARACTERIZATION

- **Identify** the timing of dominant episodes of heating and cooling
- **Quantify** the paleotemperatures through time
- **Characterise** the mechanisms of heating and cooling

**MAIN THERMAL INDICATORS**

- Vitrinite reflectance
- Apatite fission track analyses
- Fluid inclusions studies

- Ro% of continental OM
- Apatite in sandstone
- FI in silica/carbonate minerals
AN EMERGING THERMO-CHRONOMETER FOR CARBONATE-BEARING ROCKS?

RECENT ANALYTICAL DEVELOPMENTS IN CARBONATE GEOCHEMISTRY

1. Carbonate clumped isotope geothermometry ($\Delta_{47}$)
2. in-situ U/Pb dating of carbonates (LA-ICPMS)

PROBLEMATICS OF THIS STUDY:

1) Does the coupling of $\Delta_{47}$ and U-Pb provides a direct determination of burial paleotemperature and timing of paleo-thermal episodes reached by an individual carbonate rock?

2) Are these tools useful to identify, quantify and characterize an entire heating and/or cooling history of buried carbonate sequences in sedimentary basins?
CLUMPED ISOTOPES ($\Delta_{47}$) – THEORETICAL PRINCIPLES

Applicable to all carbonate mineralogies: Calcite, aragonite, dolomite ….

Temperature ($^\circ$C)

<table>
<thead>
<tr>
<th>Temperature ($^\circ$C)</th>
<th>$\Delta_{47}$ CD95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>0.750</td>
</tr>
<tr>
<td>150</td>
<td>0.650</td>
</tr>
<tr>
<td>80</td>
<td>0.550</td>
</tr>
<tr>
<td>50</td>
<td>0.450</td>
</tr>
<tr>
<td>25</td>
<td>0.350</td>
</tr>
<tr>
<td>5</td>
<td>0.250</td>
</tr>
</tbody>
</table>

- Dolomite (This study)
- Inorg. calcite (Tang 14)
- Inorg. siderite (Fernandez 14)
- Travertine aragonite & calcite (Kele 15)
- Inorg. aragonite (Defliese 15)
- Inorg. calcite (Defliese 15)

Mangenot et al. 2017 (Chemical Geology)

Cover the range of temperatures relevant for diagenetic processes (0-300°C)

Bonifacie et al. 2017 (GCA)
**U-PB DATING – IN-SITU ANALYSES**

Small Scale isochron measured on a calcite cement (61My ± 2.5)

**Introduction**

Material and methods: Δ47 and U/Pb

Thermo-chronology results

Conclusion

Cathodoluminescence imaging = selection of homogeneous carbonate phases prior to analyse

Concordia & Y-Intercepts at 61.1 ± 2.5 My (4.1%)

\[ \frac{^{207}\text{Pb}}{^{206}\text{Pb}} : 0.8707 \pm 0.0002 \]

MSWD = 1.5

n spot = 25

data-point error ellipses are 2σ
SAMPLING STRATEGY AT THE BASIN SCALE

Introduction

Material and methods: $\Delta_{47}$ and U/Pb Thermo-chronology results

Paleo-fluids geochemistry

Conclusion

Mangenot et al. 2018 Sedimentology

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Paris basin

BASIN DEPOCENTER

West-East cross section

Studied core sections:
Middle Jurassic carbonate formation (Upper Bathonian) 1700-1900m depth

Baulne en Brie: 1774-1794m
Villeperdue: 1884-1924m
Fossoy: 1910-1920m
Rigny la nonneuse: 1550-1572m
Medical CT imaging

A complete cementation history in a single rock sample

Introduction

Material and methods: $\Delta_{47}$ and U/Pb Thermo-chronology results

Conclusion

Cal1 cement (BEB12)

Dol 1- saddle (FOS1610)

Porosity

Cal 2

Dol 2

Dol 1

Cal 1

Micrite

Bioclast

Medical CT imaging

3 cm
CLUMPED ISOTOPE THERMOMETRY

**Carbonates**
- Dol2
- Cal2
- Dol1
- Cal1
- Micrites
- Bioclasts

**Sampled cores**
- Baulne en Brie
- Rigny la Nonneuse
- Villeperdue
- Fossoy

Mangenot et al. 2018 (Sedimentology)

**Introduction**

**Material and methods:** $\Delta_{47}$ and U/Pb Thermo-chronology results

**Thermo-chronology results**

**Conclusion**

![Graph showing isotope thermometry results with various symbols representing different samples and their temperatures.]
CLUMPED ISOTOPE THERMOMETRY

**Introduction**

**Material and methods:** $\Delta_{47}$ and U/Pb Thermo-chronology results

**Conclusion**

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**Carbonates**

- 6: Dol2
- 5: Cal2
- 4: Dol1
- 3: Cal1
- 2: Micrites
- 1: Bioclasts

**Sampled cores**

- Baulne en Brie
- Rigny la Nonneuse
- Villeperdue
- Fossoy

Mangenot et al. 2018 (Sedimentology)
LASER ABLATION U-PB DATING

Concordia & Y-Intercepts at 154.2 ± 5.1 My (3.3%)

$^{207}\text{Pb}/^{206}\text{Pb}$: 0.8297 ±

MSWD = 0.80

n spot : 26

data-point error ellipses are 2σ

Introduction

Material and methods: $\Delta_{47}$ and U/Pb

Thermo-chronology results

Conclusion
LASER ABLATION U-PB DATING

Material and methods: \( \Delta_{47} \) and U/Pb

**Concordia & Y-Intercepts at 151.5 \( \pm \) 6.2 My (4.1%)**

\[
\frac{^{207}Pb}{^{206}Pb} : 0.8306 \pm = MSWD = 1.3 \\
n \text{spot: 28}
\]
LASER ABLATION U-PB DATING

Introduction

Material and methods: $\Delta_{47}$ and U/Pb

Thermo-chronology results

Conclusion

Concordia & Y-Intercepts at 120.7 ± 2.2My (1.8%) $^{207}$Pb/$^{206}$Pb = 0.8475 ± MSWD = 0.79

n spot : 28

data-point error ellipses are $2\sigma$
LASER ABLATION U-PB DATING

Introduction

Material and methods: $\Delta_{47}$ and U/Pb

Thermo-chronology results

Conclusion

Concordia & Y-Intercepts at 107 ± 13 My (12.1%)

$^{207}$Pb/$^{206}$Pb: 0.8432 ±

MSWD = 1.4

n spot: 26

data-point error ellipses are 2$\sigma$
LASER ABLATION U-PB DATING

Introduction

Material and methods: $\Delta_47$ and U/Pb

Thermo-chronology results

Conclusion

Concordia & Y-Intercepts at $61.1 \pm 2.5$ My (4.1%)

$^{207}\text{Pb}/^{206}\text{Pb} : 0.8707 \pm$

MSWD = 1.5

n spot : 25

data-point error ellipses are $2\sigma$
LASER ABLATION U-PB DATING

Introduction

Material and methods: $\Delta_{47}$ and U/Pb

Thermo-chronology results

Conclusion

Concordia & Y-Intercepts at $37.2 \pm 5.3$ My (14.2%) $^{207}\text{Pb} / ^{206}\text{Pb} : 0.8535 \pm$ MSWD = 1.3 n spot : 39

data-point error ellipses are $2\sigma$
THERMAL HISTORY OF THE CARBONATE RESERVOIRS

Very good agreement between vitrinite reflectance and $\Delta_{47}$-U-Pb thermal histories

$\Delta_{47}$-U/Pb thermo-chronometer allows to:

- (1) identify heating and cooling history
- (2) quantify paleotemperatures through time
- (3) Detect hydrothermal activity

Mangenot et al. 2018. Geology (in rev)
GENERAL CONCLUSIONS

TAKE HOME MESSAGE

Clumped isotope paleothermometry can be paired with direct radiogenic dating (U/Pb) in carbonate to obtain a more accurate and detailed record of the thermal history of sedimentary basins.

1. Improvement of thermal history characterization of the Paris Basin
2. Calibration of the paragenetic sequence both in time (U/Pb) and temperature ($\Delta_{47}$)
3. Determination of a detailed fluid-flows history in time and space

A NEW THERMOCHRONOMETER IS EMERGING FOR STUDYING CARBONATE BEARING ROCKS
This study would not have been possible without the collaboration of a large team of scientists coming from different universities and research institute.

Thanks to all of you!

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IFPEN  IPGP  Goethe Univ.  Université Paris-Sud