This research is funded by the European Union
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# **Deep U-tube heat exchanger breakthrough**: Combining Laser and Cryogenics Gas for Geothermal Energy Exploitation – Laser-Rock Interaction Perspective

Università degli Studi di Padova

Wrocław University of Science and Technology

**Pawel Slupski**, Enrico Zampieri, Antonio Galgaro, Adele Manzella, Riccardo Pasquali, Luc Pockéle, Arno Romanowski, Raffaele Sassi, Olaf Steinemier, Eloisa Di Sipio

Fraunhofer IAPT

Geoserv

Prevent CO2

RED Renewable Energy Development

Institute of Geosciences and Earth Resources
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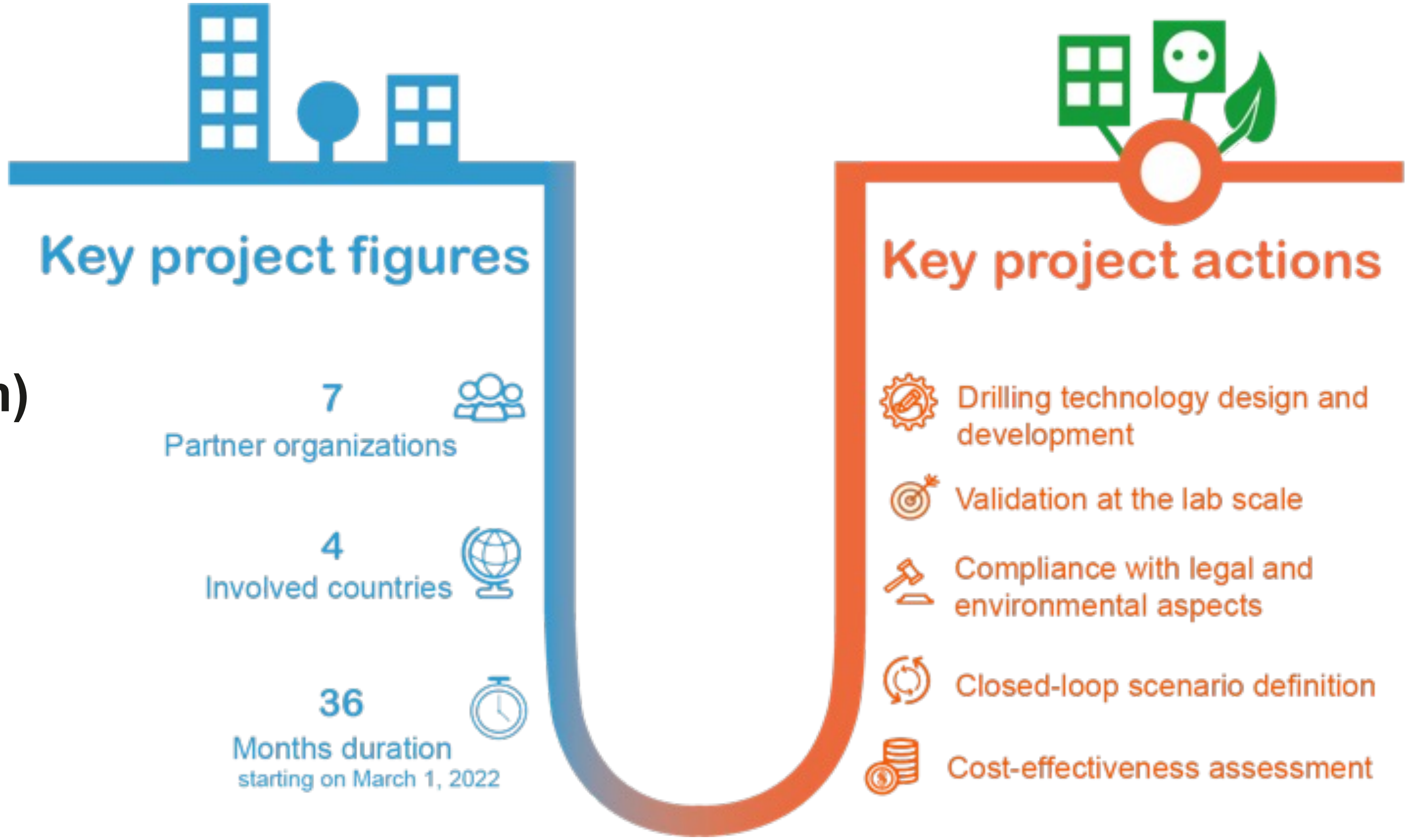
# DeepU Project

## Goals

- Developing new **laser drilling technology**
- Extracting energy from **deep (>4 km)** U-shaped closed-loop
- **Reducing the costs** of well drilling
- Making accessible **geothermal energy anywhere**



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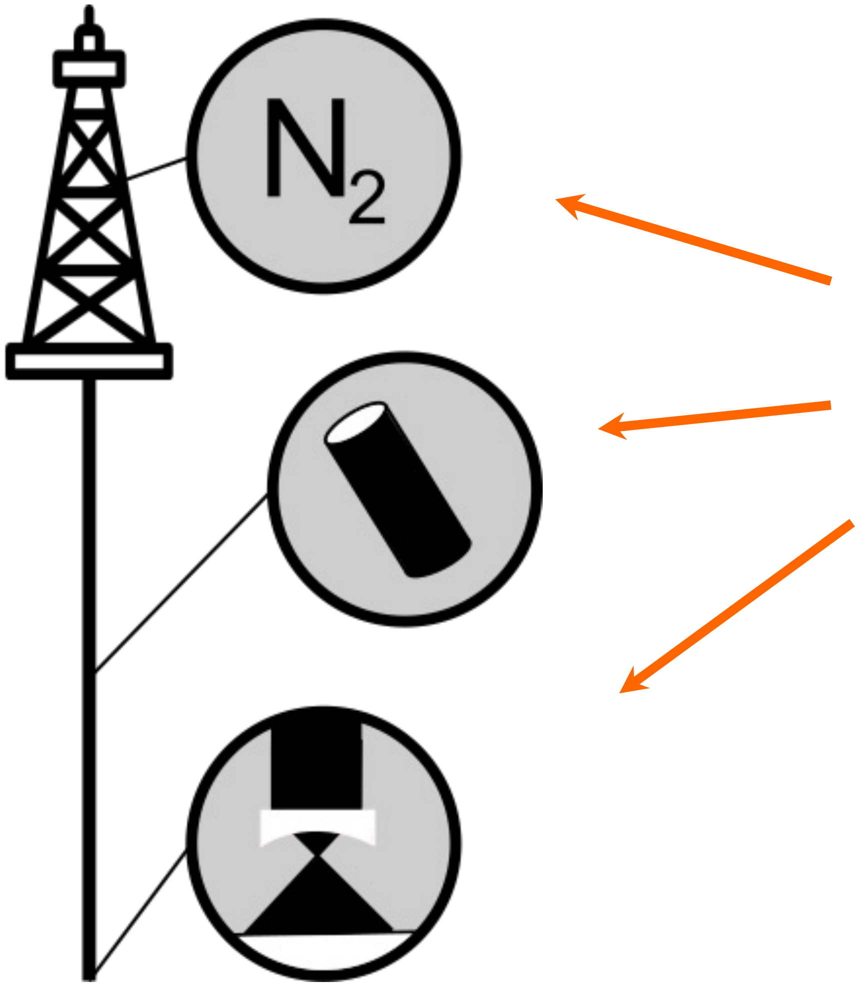
# Workflow in DeepU Project




**7 international teams work on different aspects of DeepU Project, such as:**

- Gas flushing medium
- Scaled model of U-tube heat exchanger
- **Petrophysical characterization of drilling process**
- Geothermal modeling
- Standards and regulatory integration
- Exploitation planning and IPR management
- Communication and dissemination

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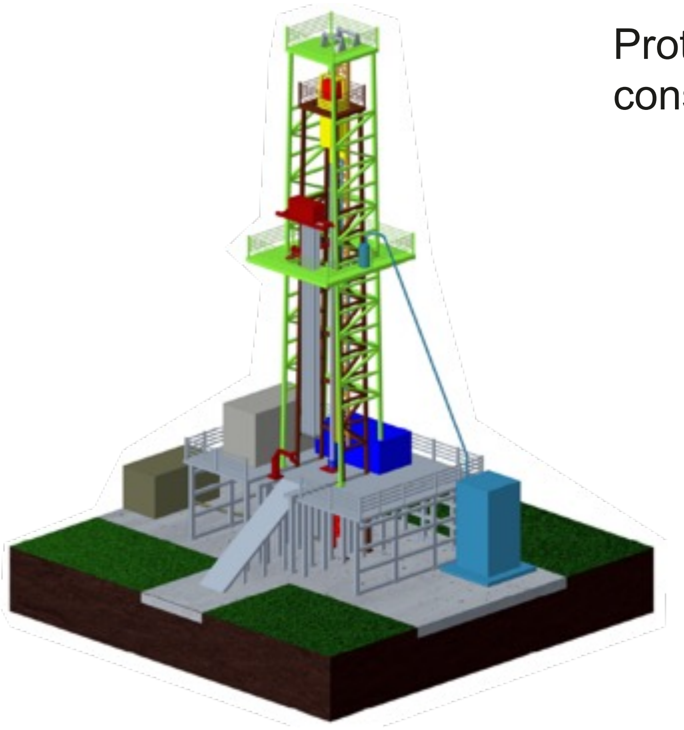
# Advancements in DeepU Project

## 3D design of the Drilling Tower



## Few 3D solutions of the drilling strings

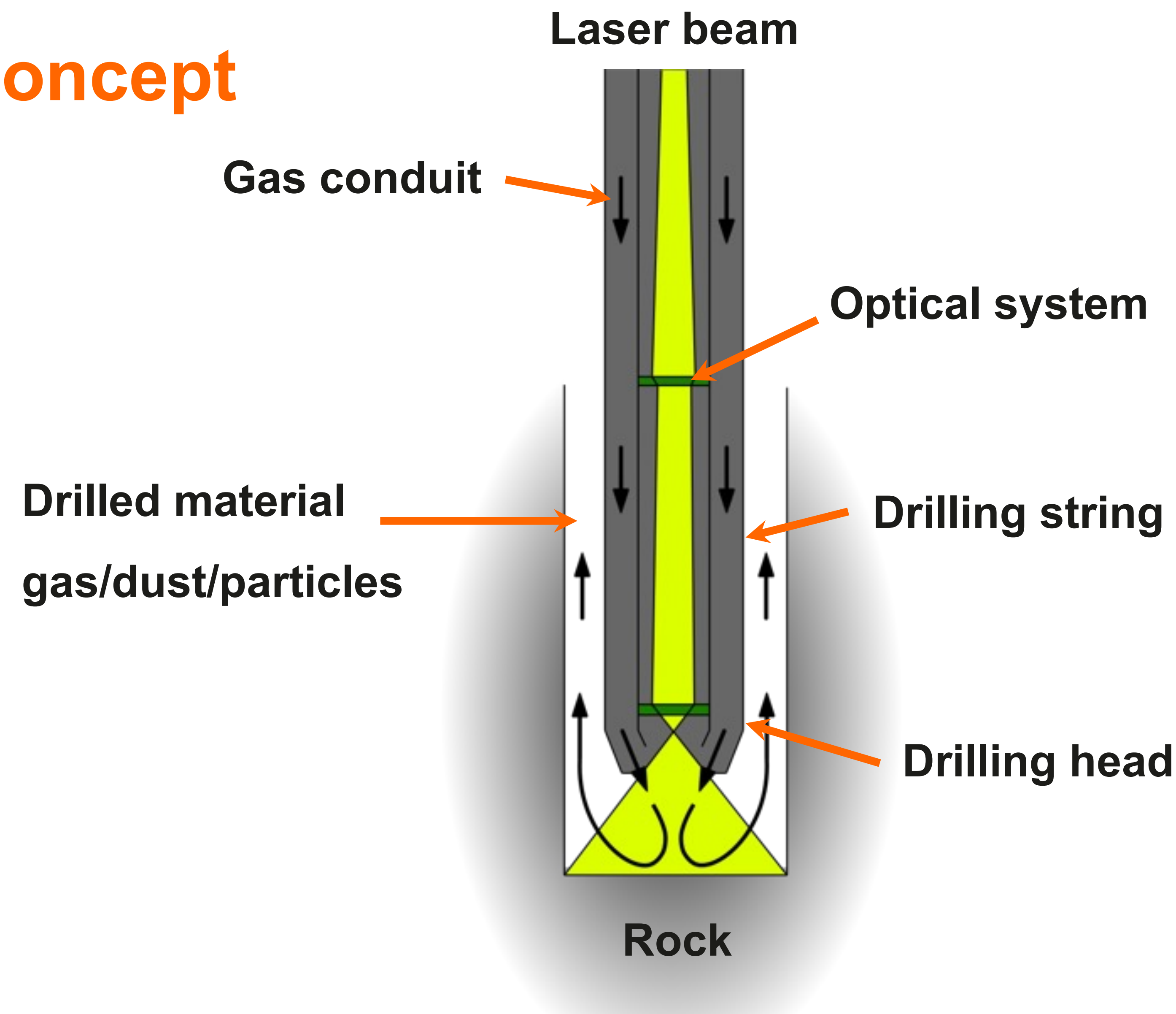
Prototype has been constructed!

## Designed and 3D printed drilling head

Fully operational and tested!

## Perforation of granite and sandstone

# Drilling concept



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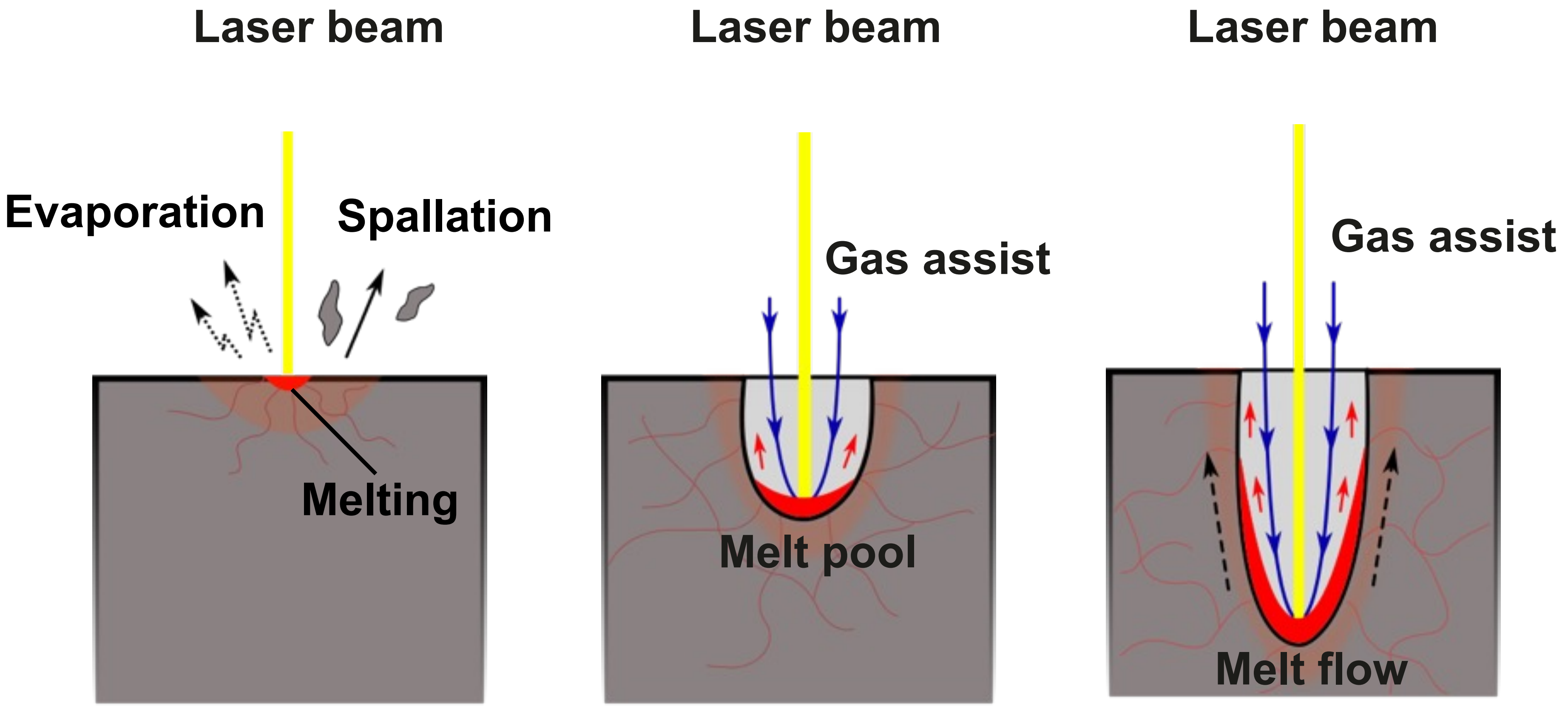
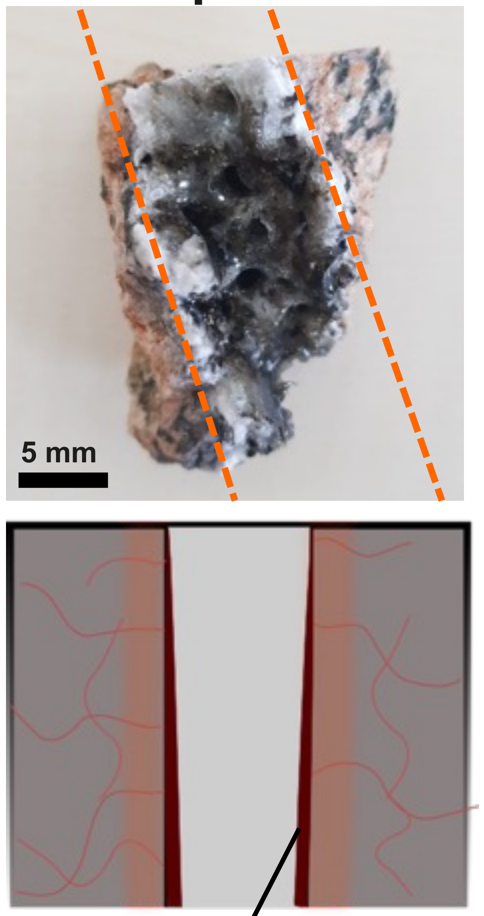
# Laser-rock interactions




*Based on Li et al. 2015*

RFE Exp



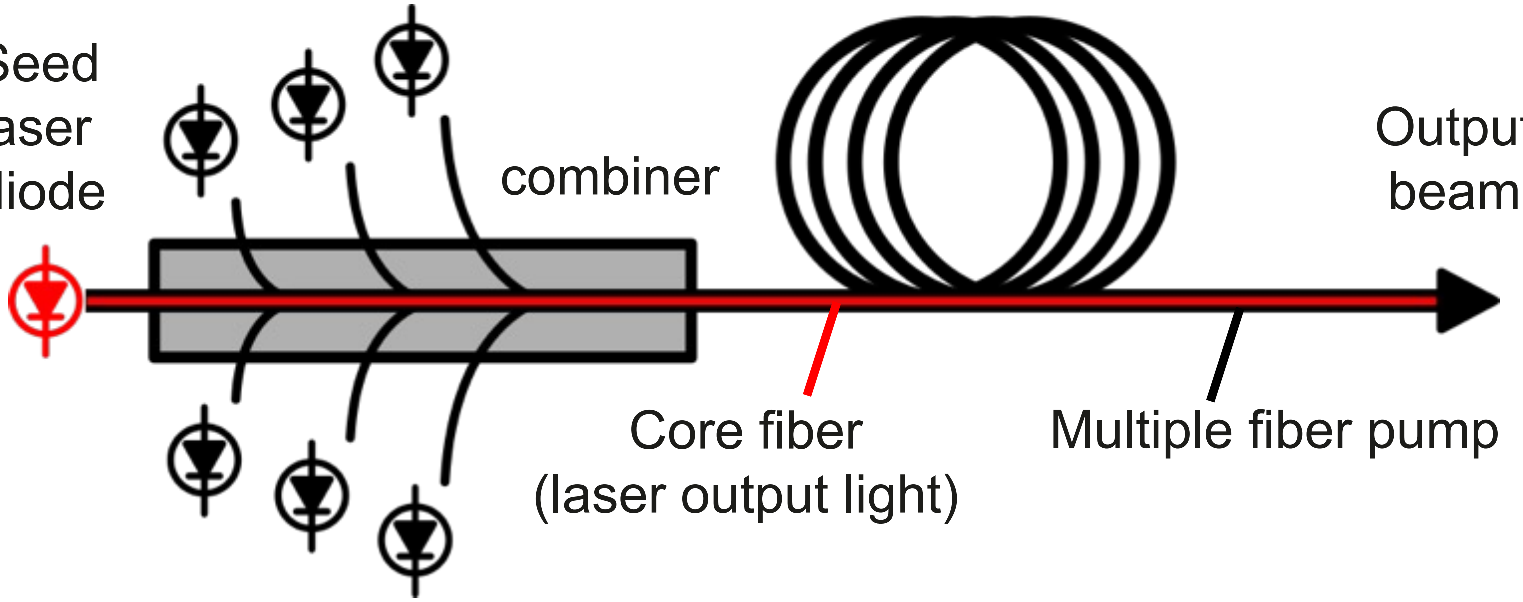

Vitrified walls

# Fiber laser principle

**Advantages of fiber laser**

- Scalable power
- High beam quality
- Modularity
- Efficiency (cost per Wat)
- Average output power grow exponentially every year

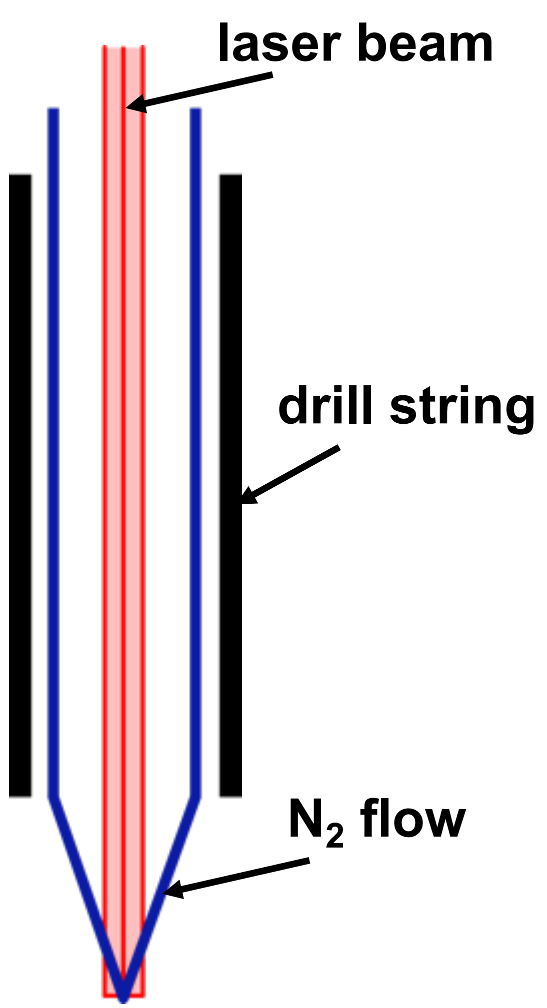
***Jagureui et al. 2013***



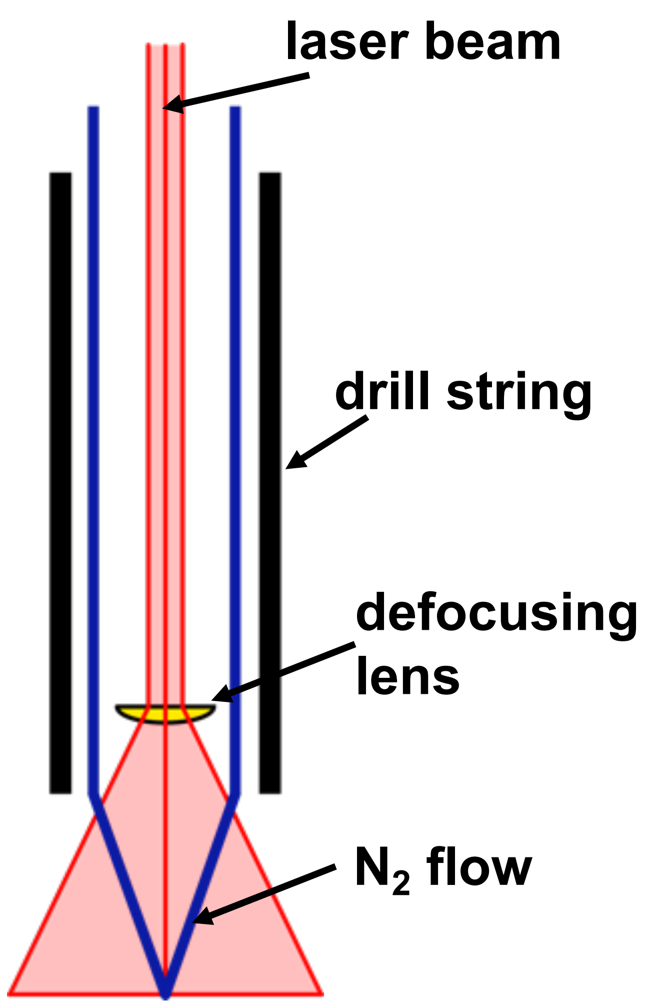

**Laser parameters**

- Up to 30 kW
- Power amplification c. 40%
- Red laser, 1070 nm

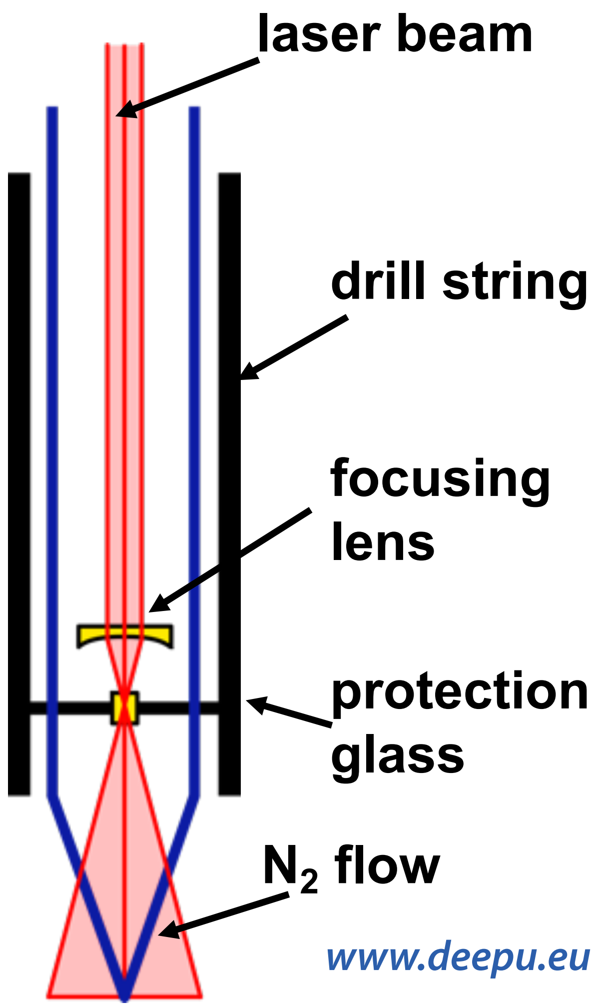
## 1) collimated beam




## 2) defocusing lens




## 3) focusing lens



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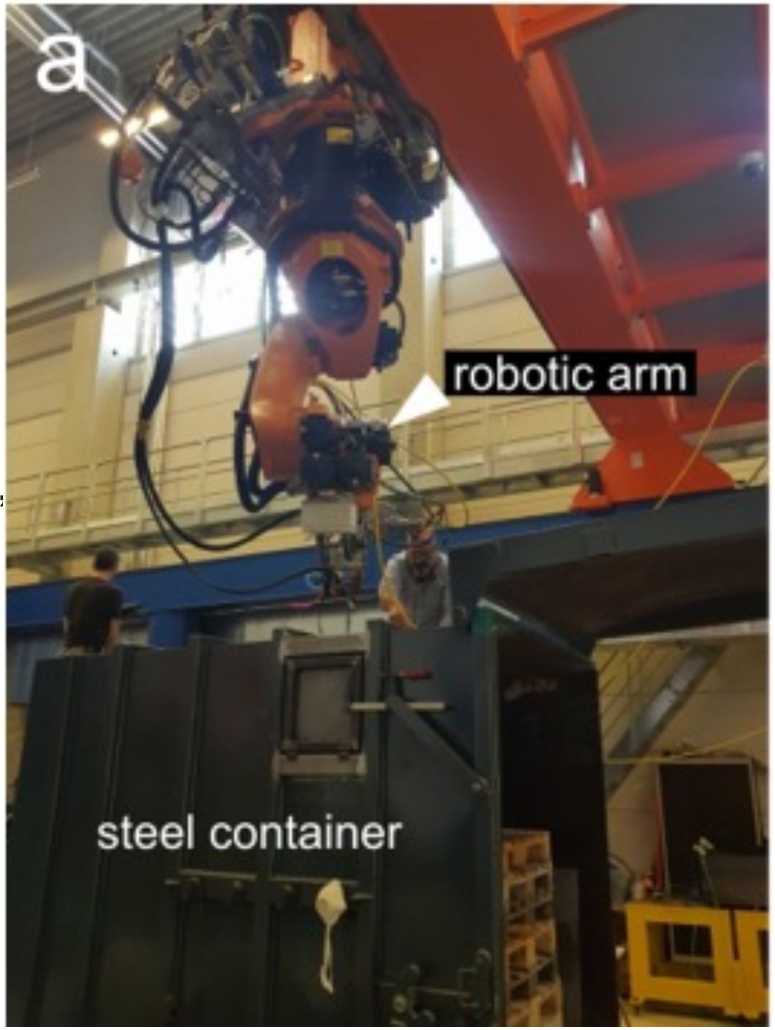
# Experimental setup

- Fixed position of robotic arm (**250 mm working distance**)
- Drills with and without assistance of room temperature **$N_2$ flux**
- Fixed laser power **6, 16, 26 kW**
- Selected lithologies: granite, sandstone, limestone
- **Wet samples**: limestone, sandstone

- Vis video documentation (low-res camera)
- IR video documentation (thermocamera)
- Gas spectrometry

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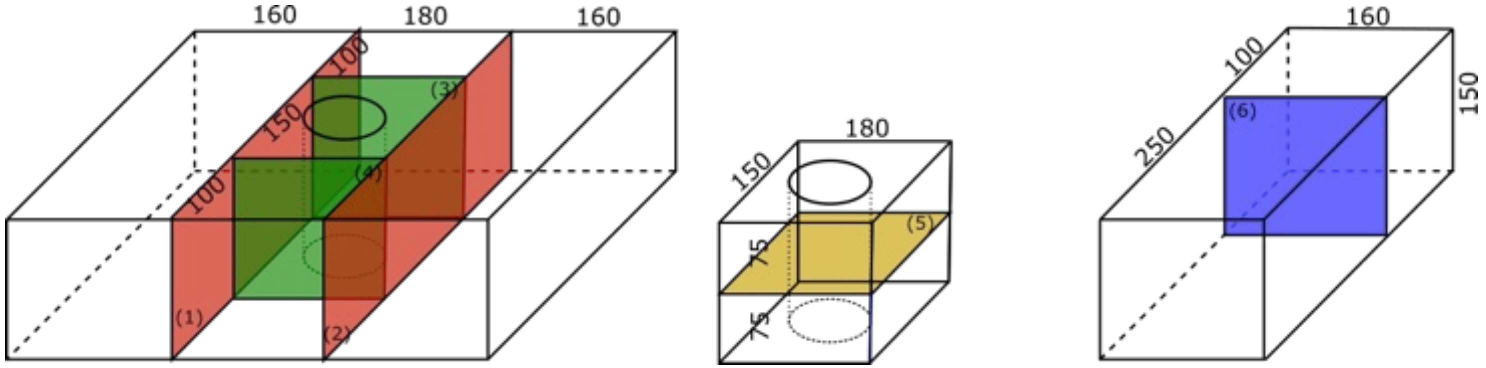
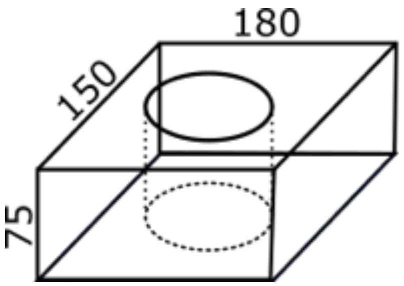
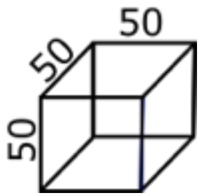
# Sample preparation



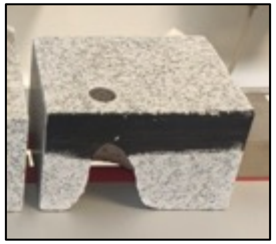

Slab with hole




cubes

Oriented thin sections

Oriented blocks cut through borehole



Whole cubes

Powder

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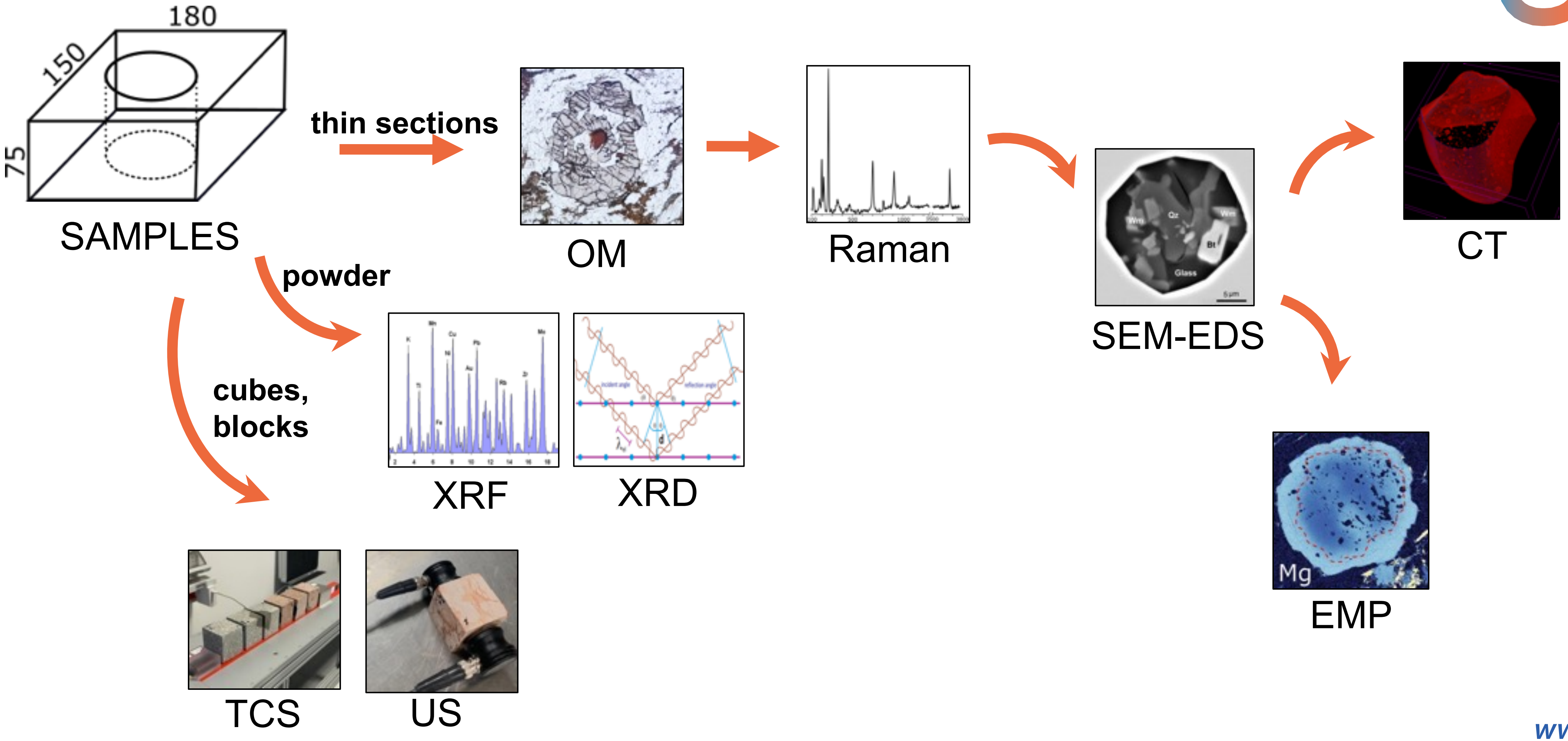
# Workflow - methodology



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# Spallation dominated laser drilling with gas assist

Granite (10s, 16kW, $N_2$)

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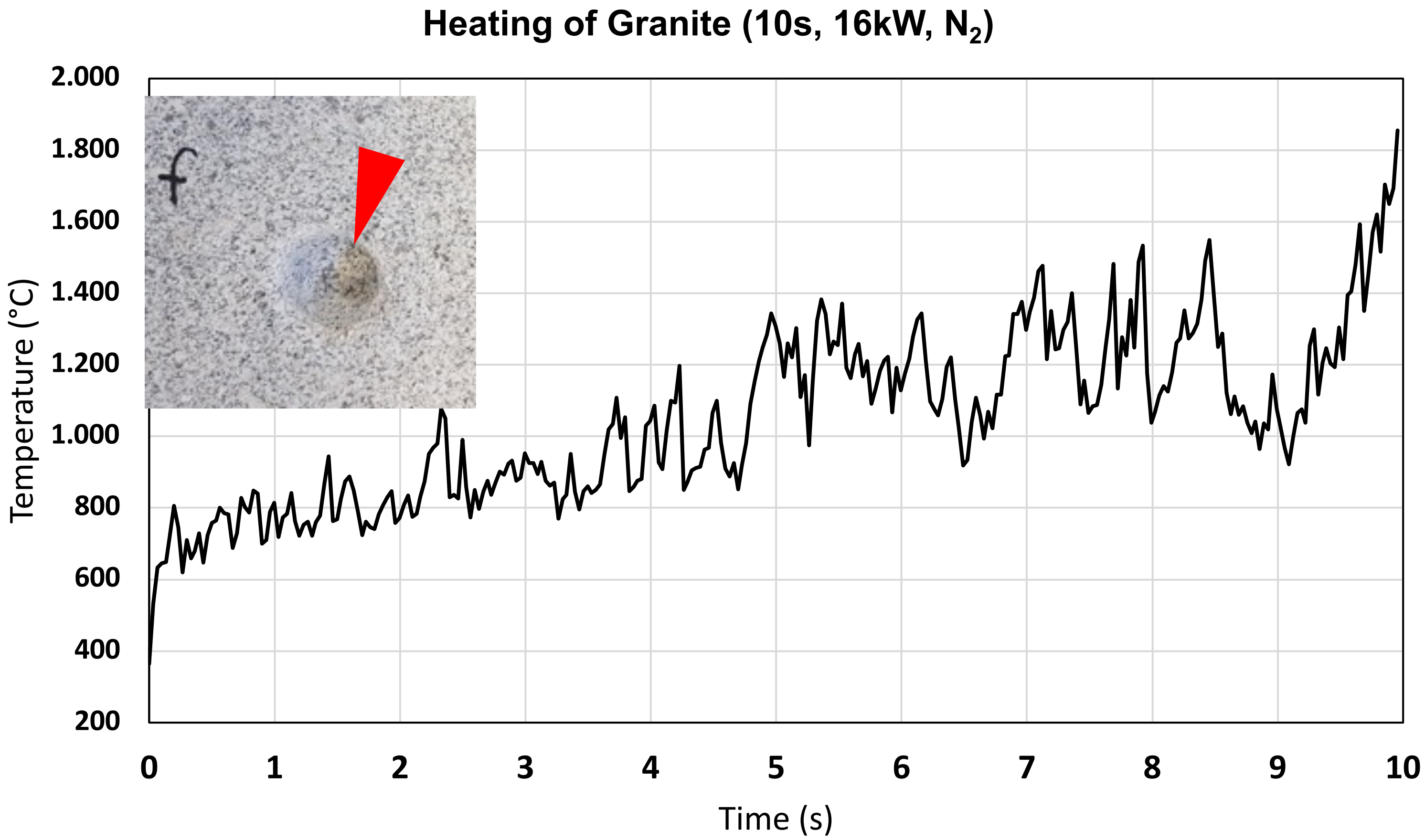
# Thermal analysis of spallation dominated drilling



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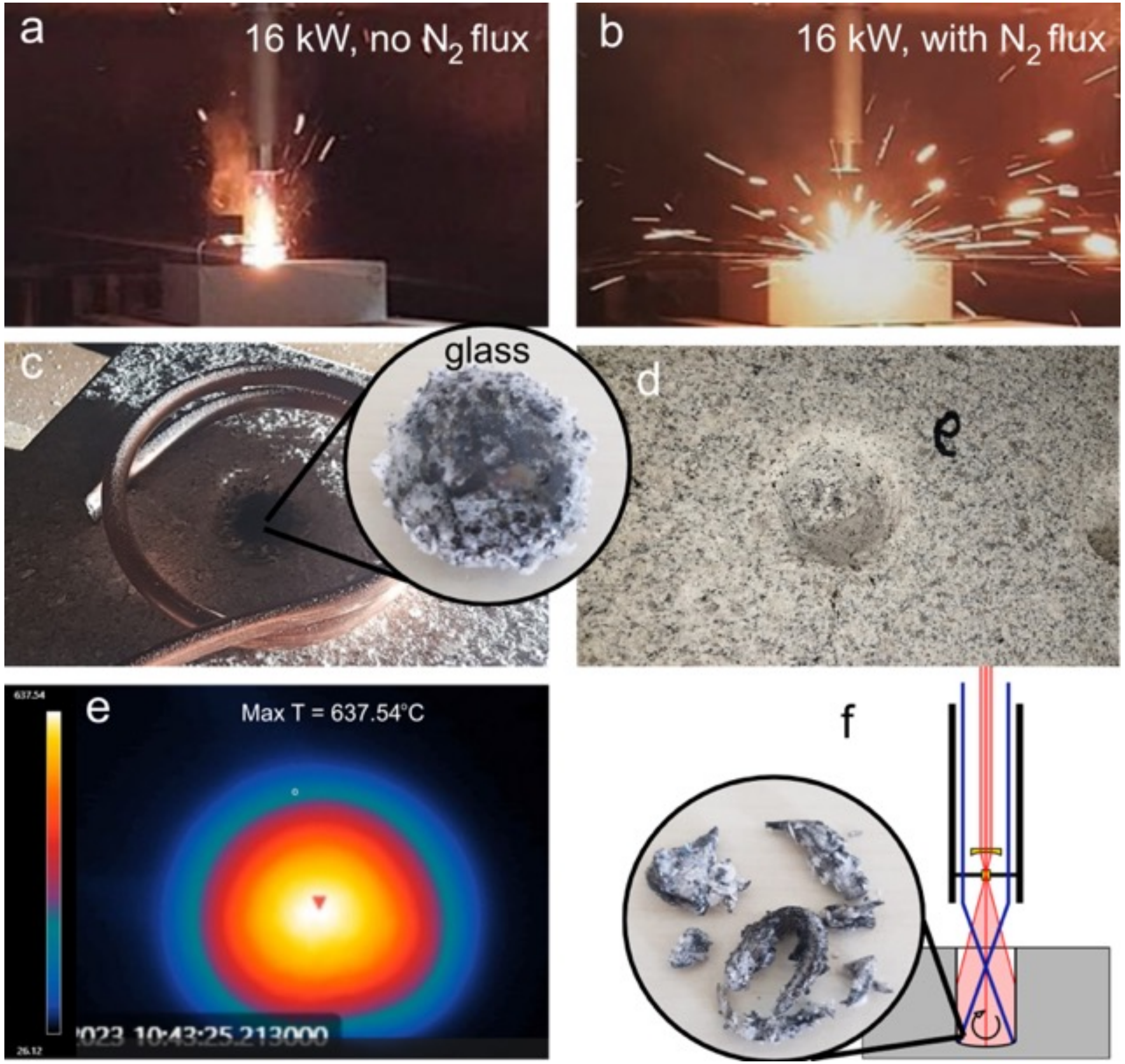
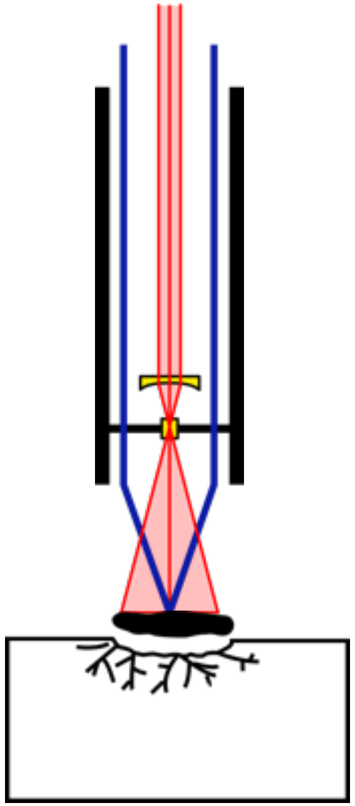
# Granite




- The power has little effect on efficiency of the drilling
- $N_2$ flux has crucial effect on the drilling
- Spallation dominated drilling occurs at low temperature



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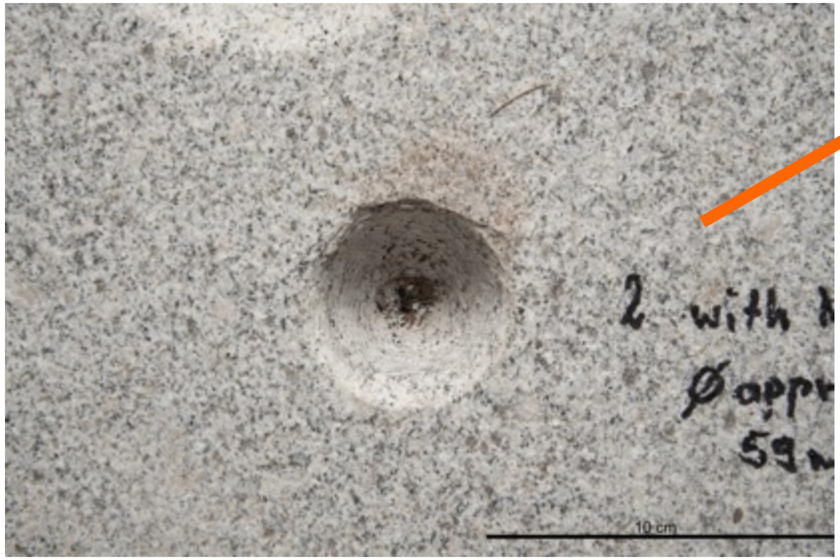
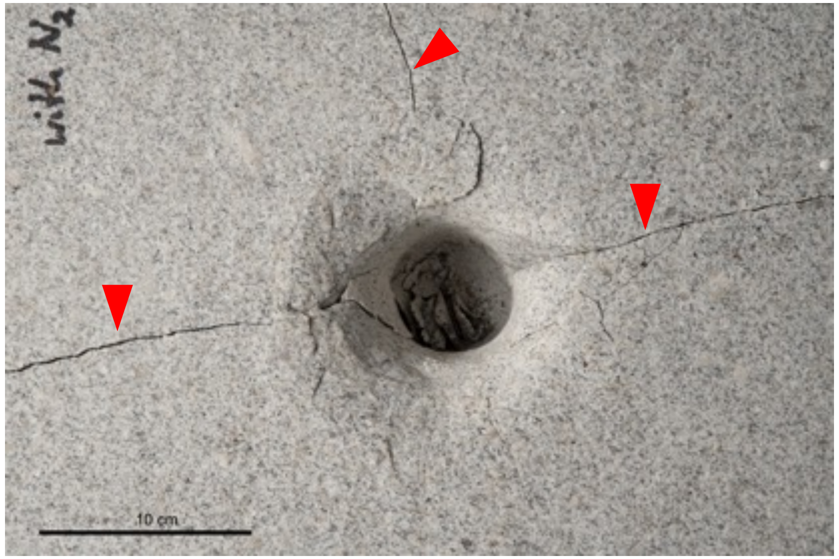
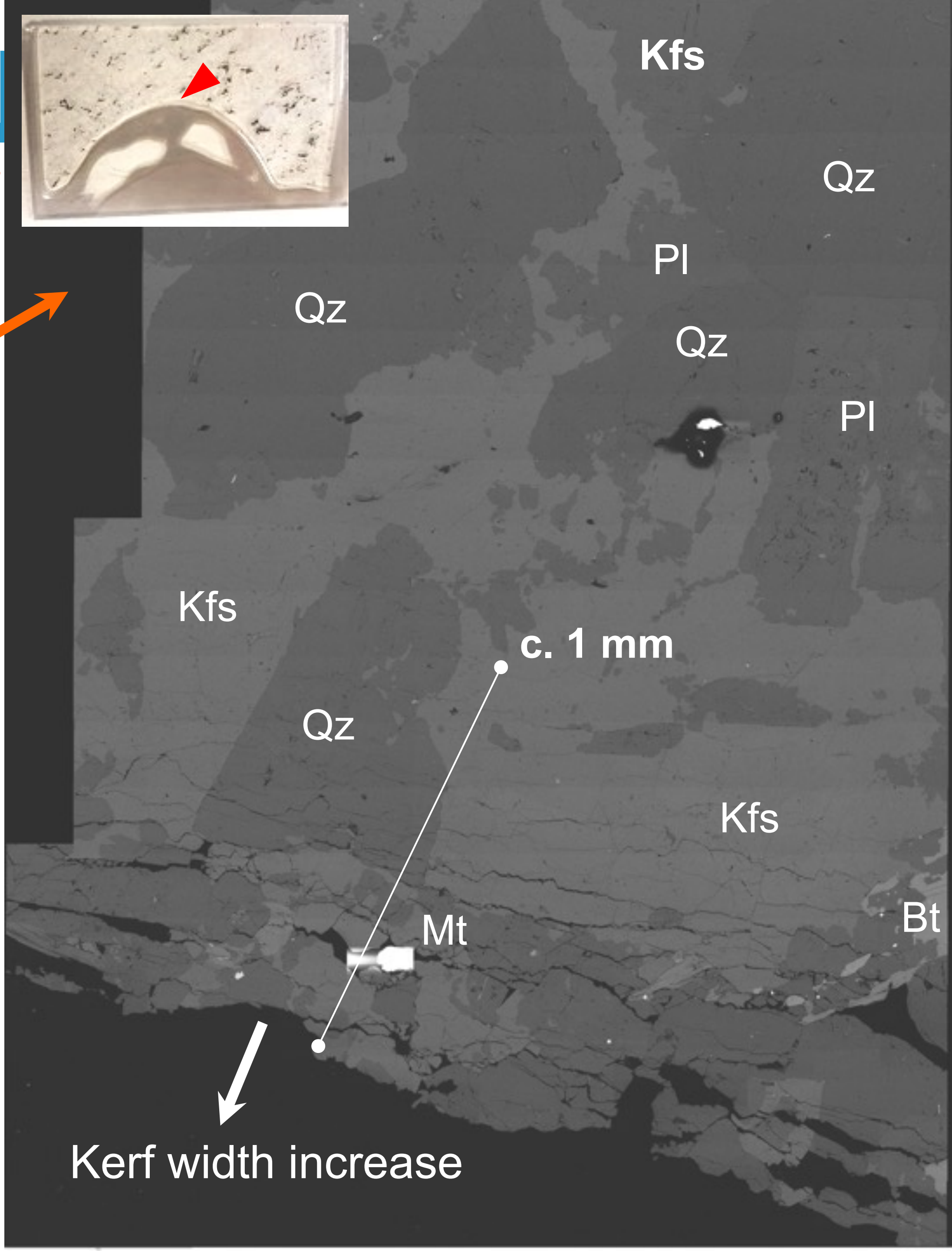
# Granite

- Radial fractures reach c. 1mm depth into the rock
- No alteration of minerals was observed so far

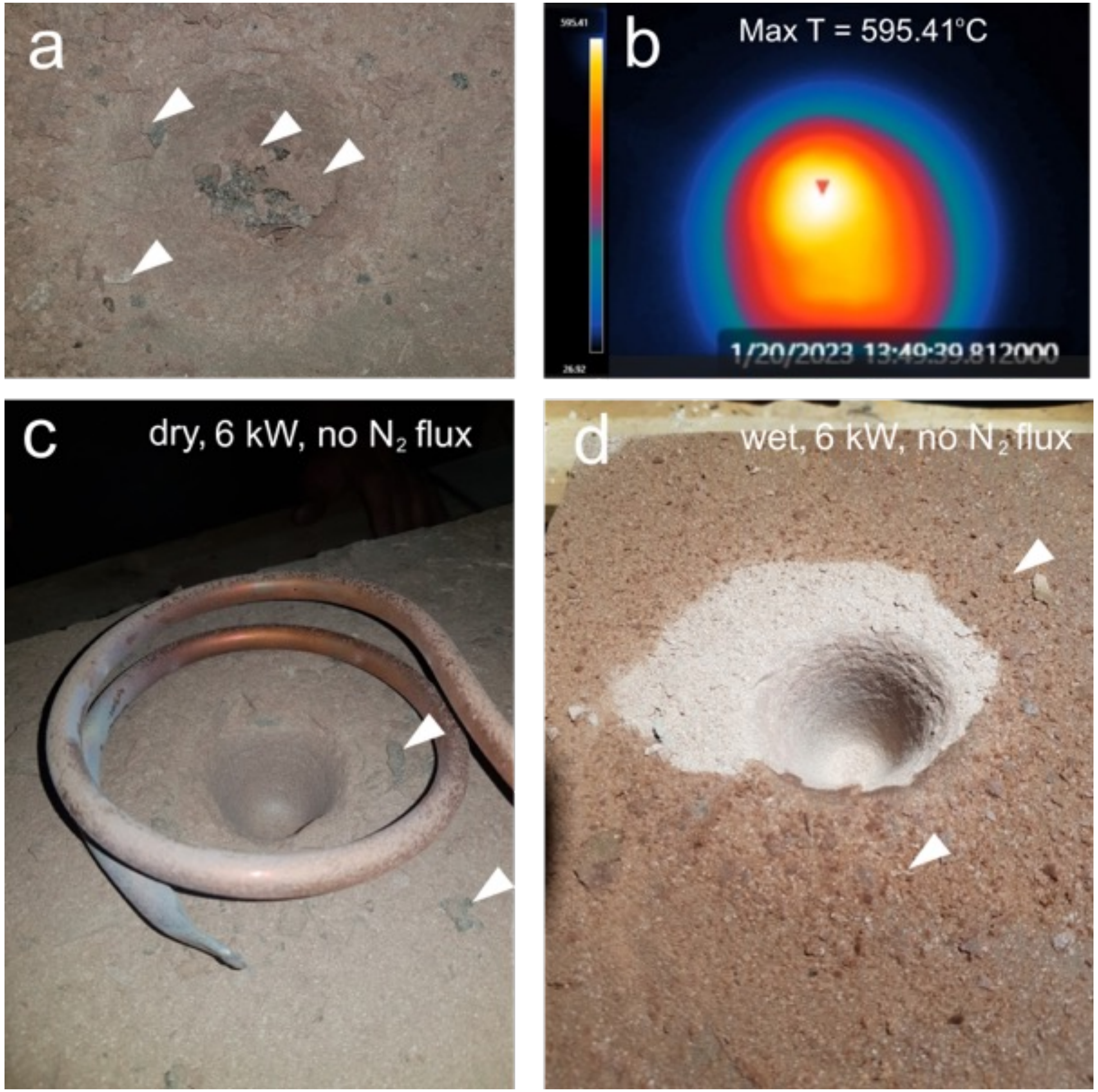


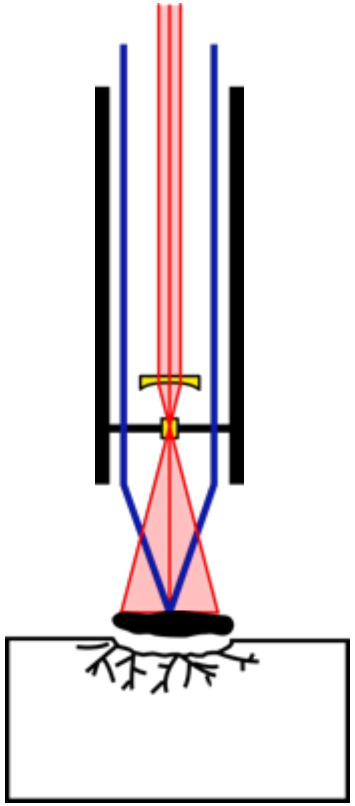



# Sandstone

- The power has little effect on efficiency of the drilling
- $N_2$ flux has crucial effect on the drilling
- Spallation dominated drilling is much more efficient that in granite
- In wet sample size of spalled flakes decreased



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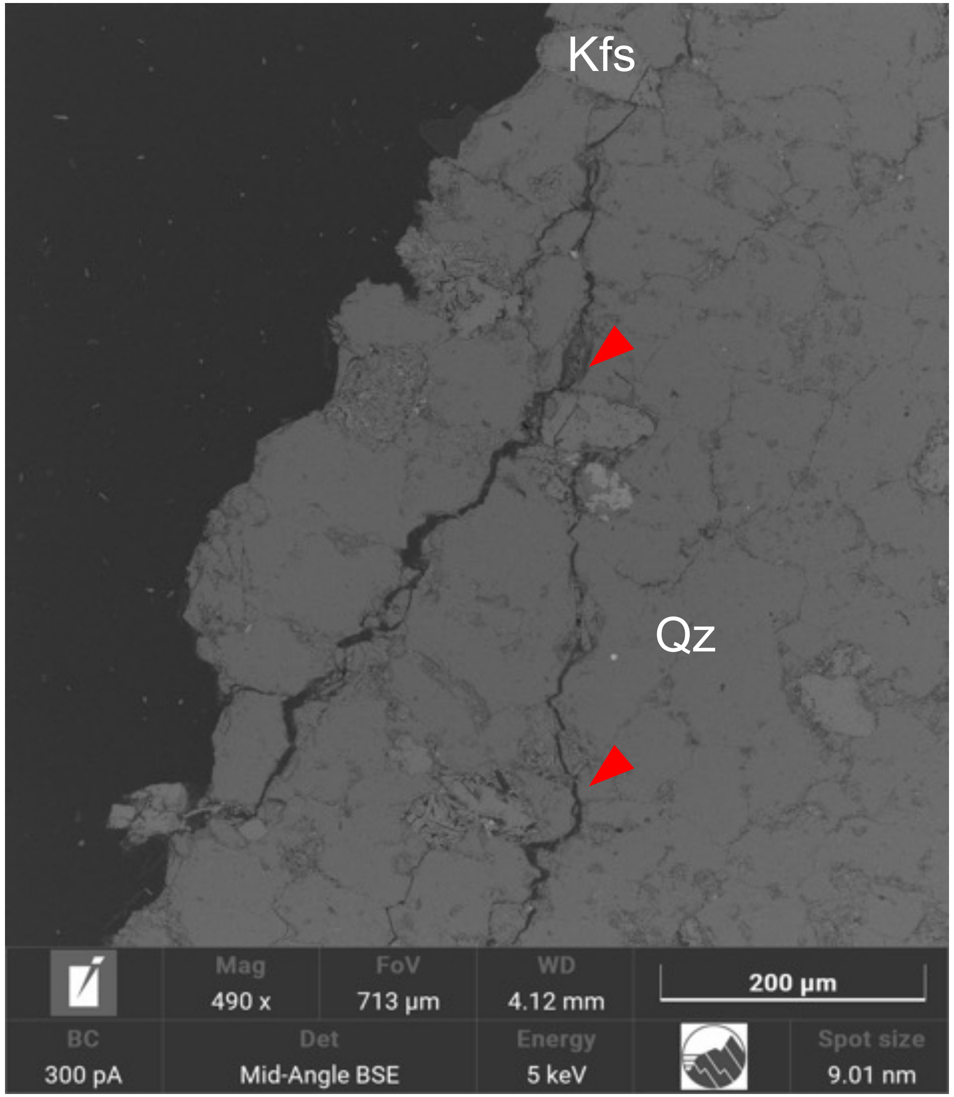
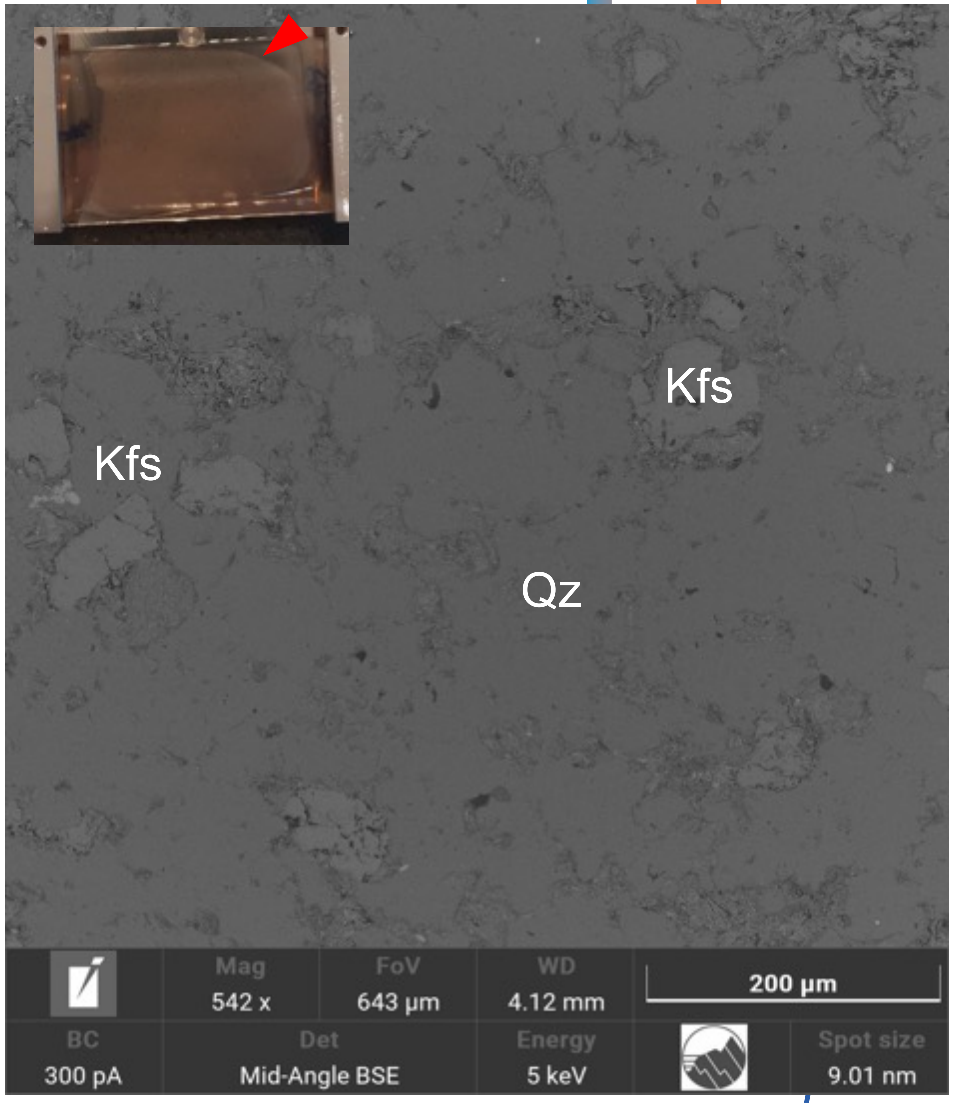
# Sandstone

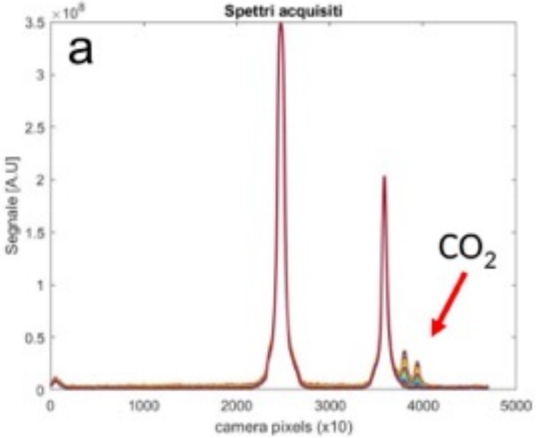
- No visible alteration caused by laser
- Rarely observed radial fractures

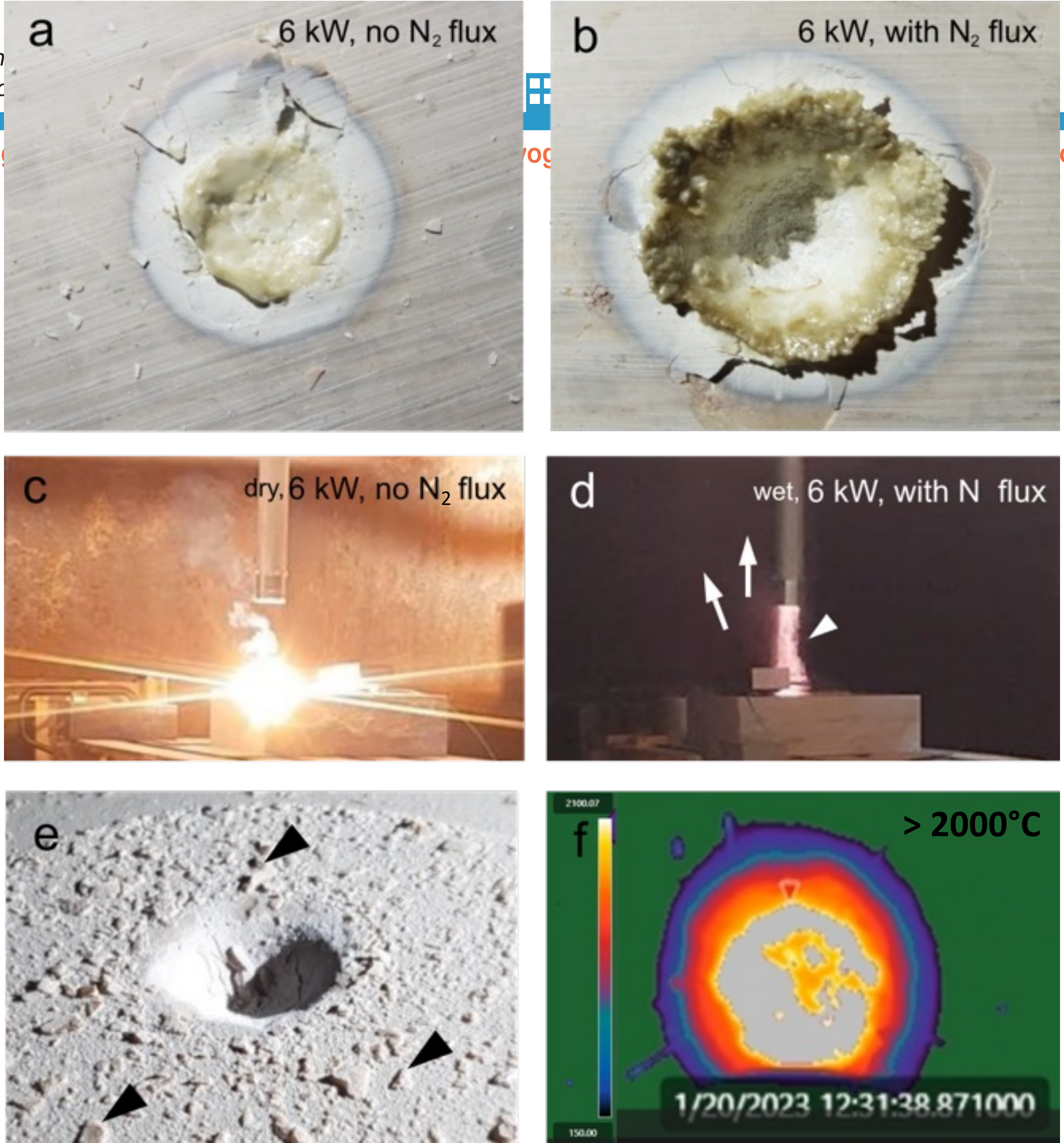


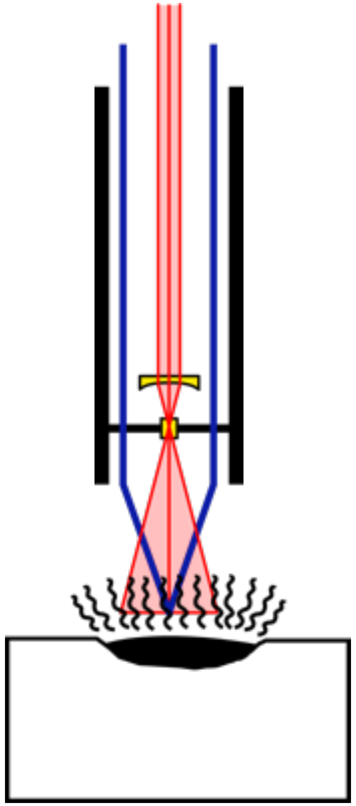



# Limestone

- **Spallation can be induced** by introducing $H_2O$ into the natural porosity of the rock



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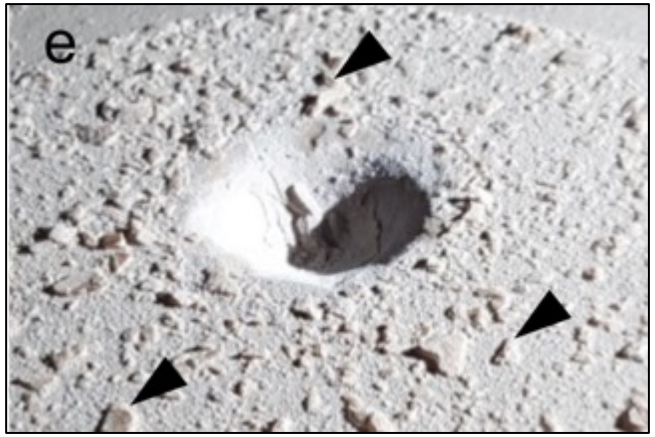
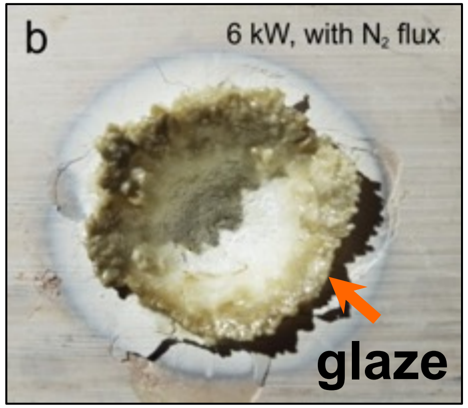
# Limestone

**Mineral composition (XRD):**

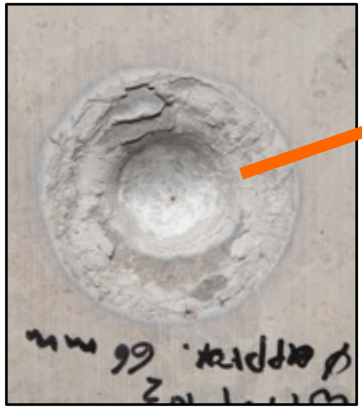
- calcite(trigonal)
- portlandite(trigonal) - $Ca(OH)_2$
- aragonite(orthorhombic)
- vaterite(hexagonal)
- lime - CaO

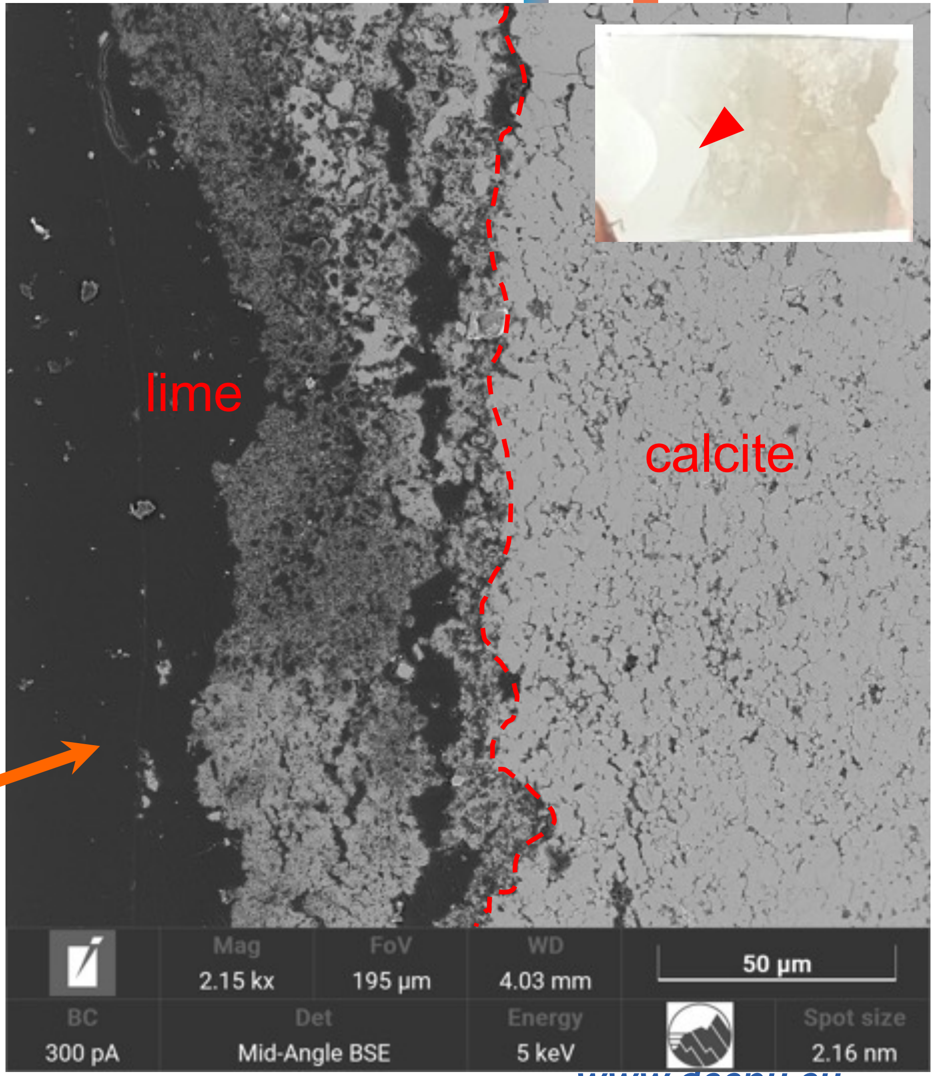



**Spallation of limestone**









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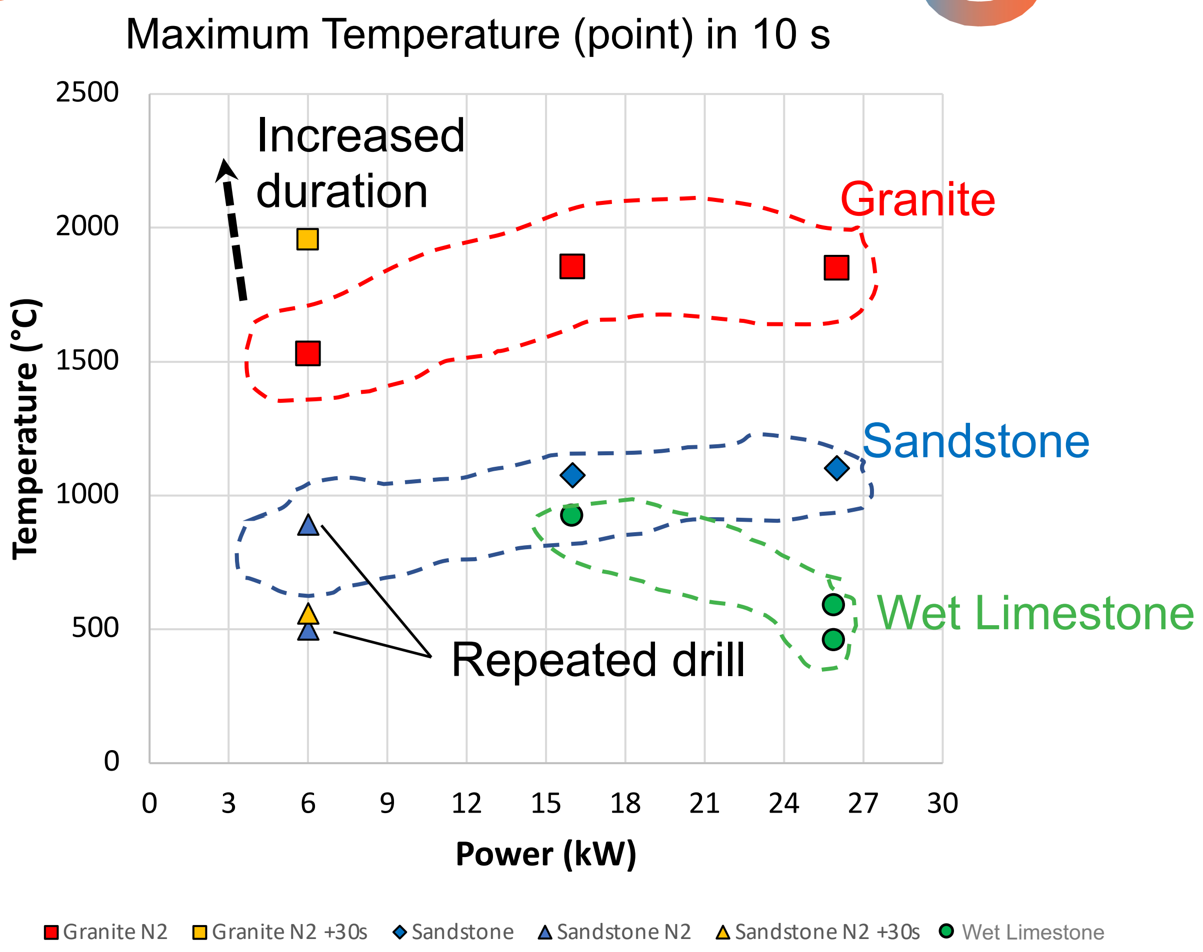
# Thermal analysis of spallation dominated drilling

- Maximum temperature in point acquired for **granite and sandstone was 1800°C and 1100°C respectively**
- Maximum temperature can be variable due to spallation
- Increase of the power has little effect on maximum temperature



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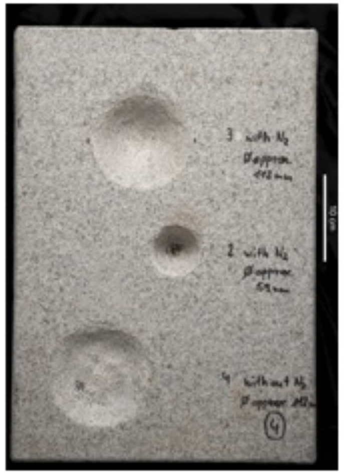
# Summary

(3) sandstone

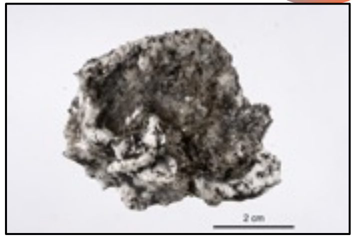
(4) granite



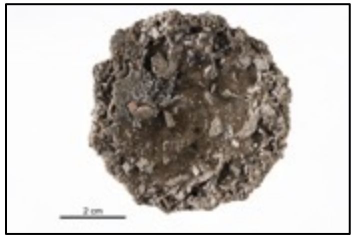
(5) limestone

(6) sandstone

(7) granite

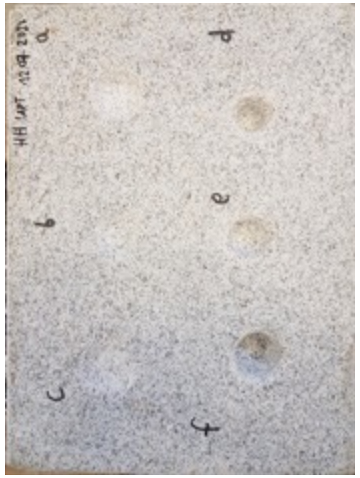



Granite glass



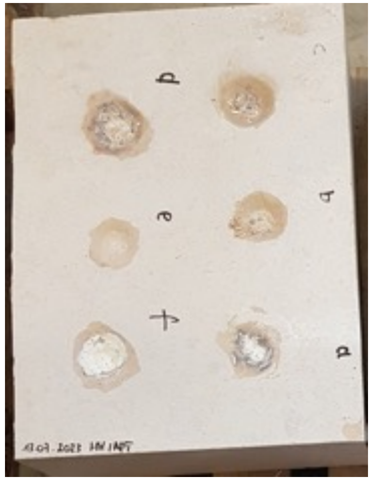

Sandstone glass

(8) granite



(9) sandstone

(10) limestone






Flakes and powder collected from the boreholes and during the drilling

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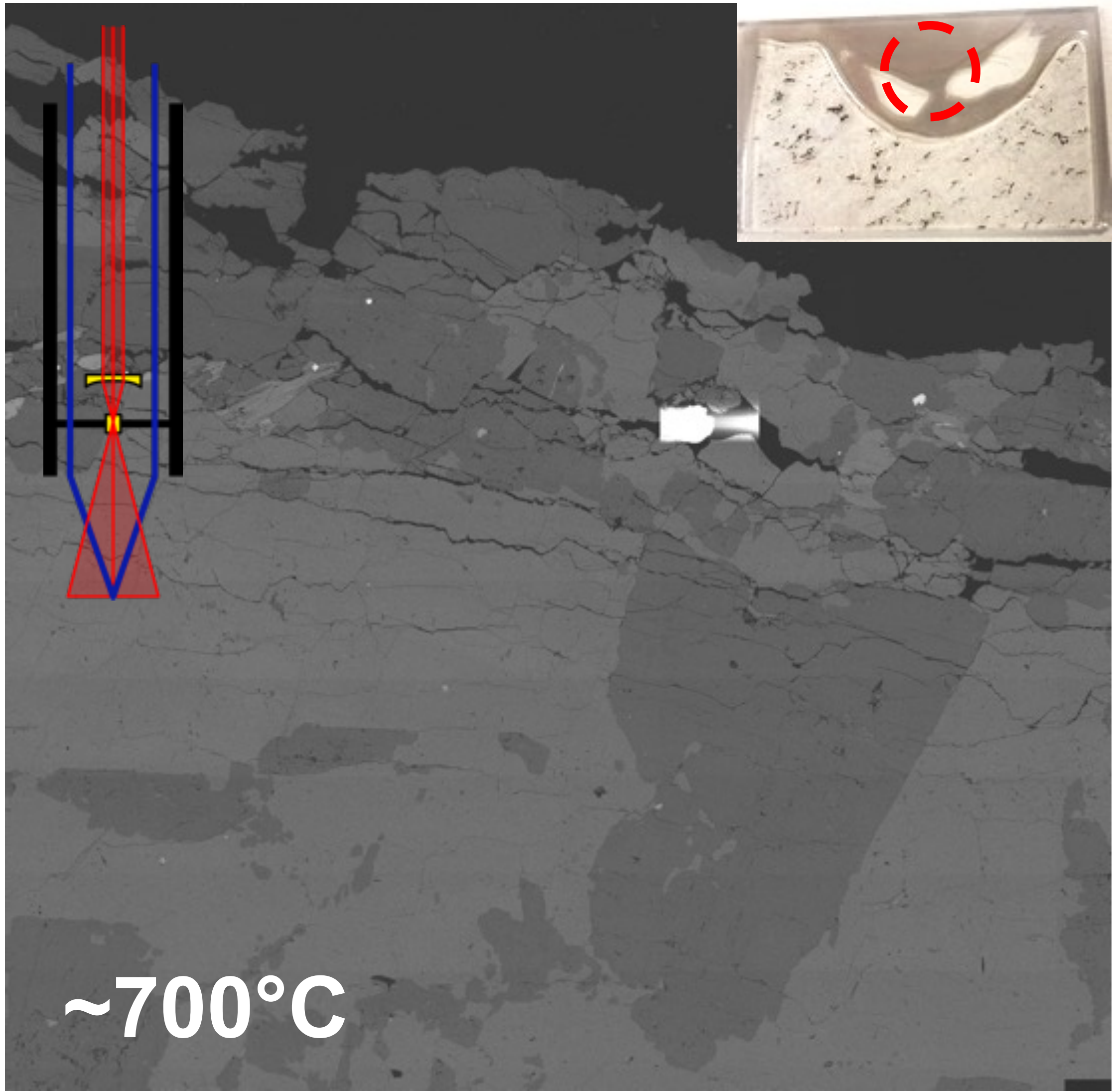
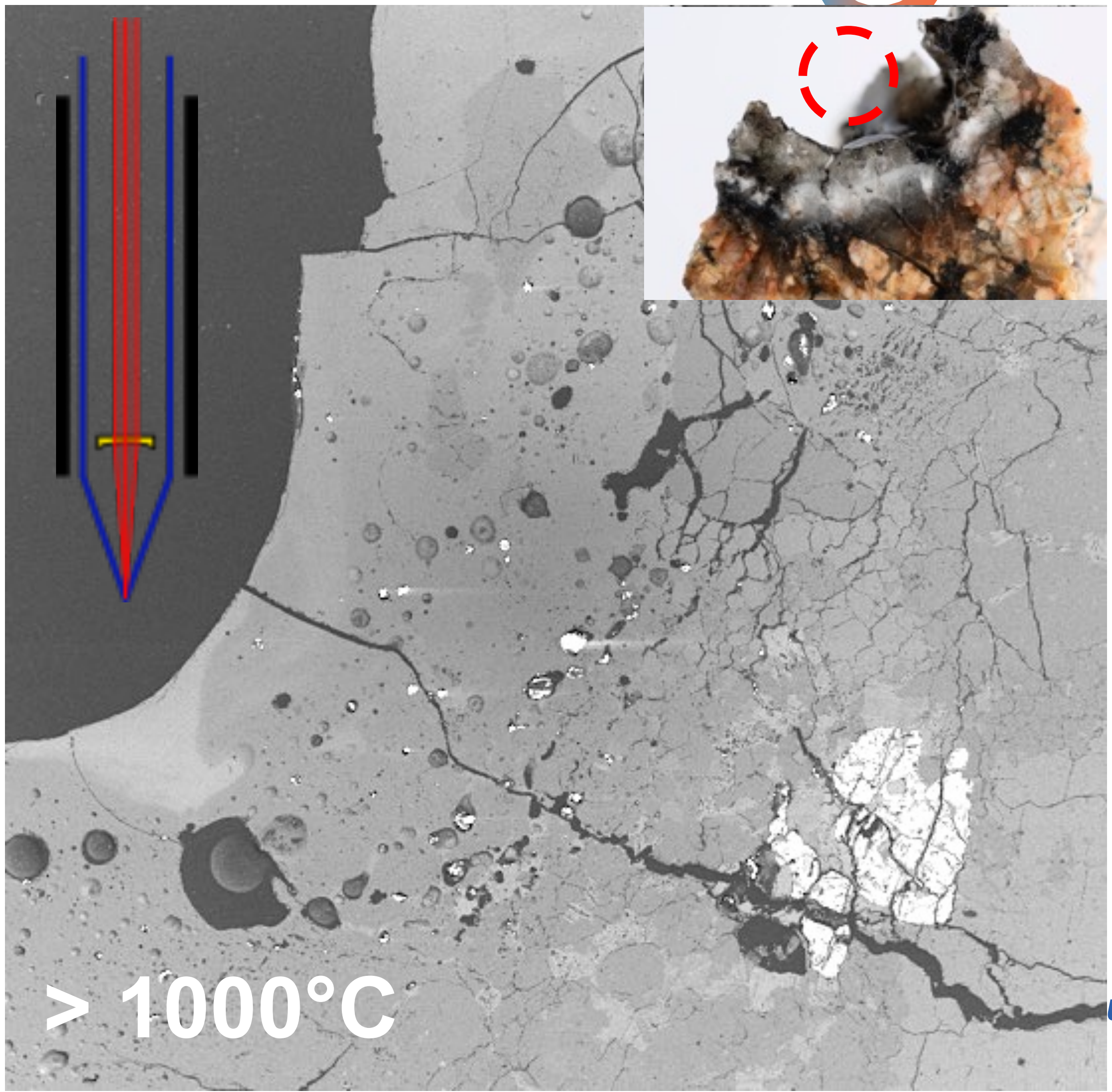
# Spallation vs Melting as a drilling process



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# Conclusions

- Description of petro-thermo-mechanical phenomena; **spallation, melting, evaporation**
- **Formation of the glass** at the bottom of the borehole
- No vitrification of walls!
- **Successful drills** of selected lithologies
- Diameter of the boreholes up to **18 cm**
- ROP up to **20 m/h**
- **Drilling with laser is possible!**



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# Future developments

- Drilling tests with assistance of **cryogenic $N_2$ flux**
- Testing drills on **different lithologies**, such as claystone
- Improving drilling technique of limestone
- Understanding and modeling petro-thermo-mechanical phenomena
- **Optimizing laser parameters**
- Increasing laser power

DeepU

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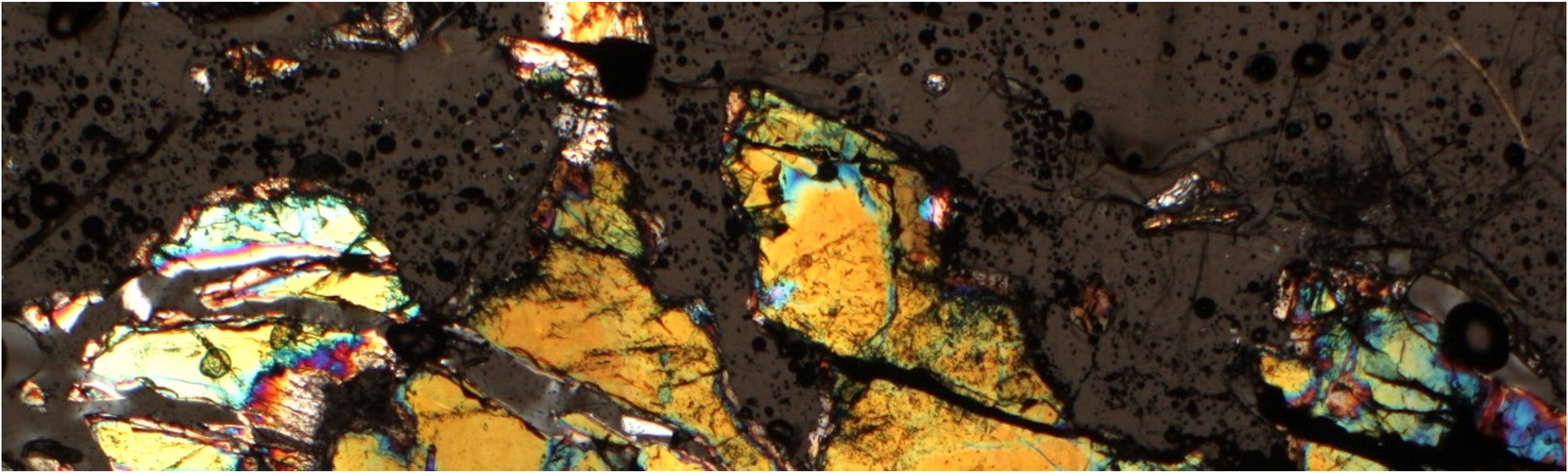
Deep U-tube heat exchanger breakthrough: combining laser and cryogenic gas for geothermal energy exploitation

# Thank You for Your Attention!



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**Check it out! DeepU.eu** *www.deepu.eu*

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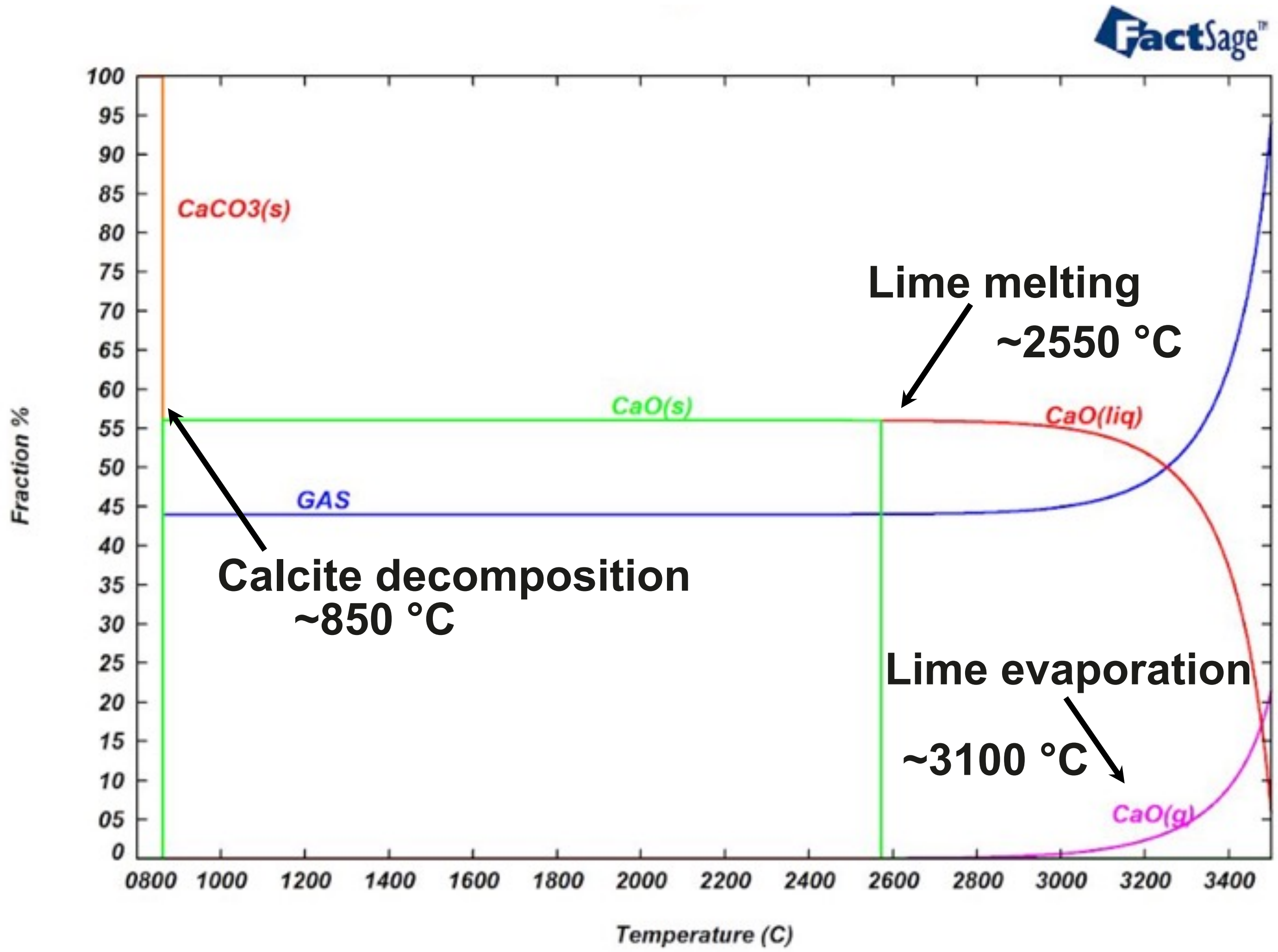
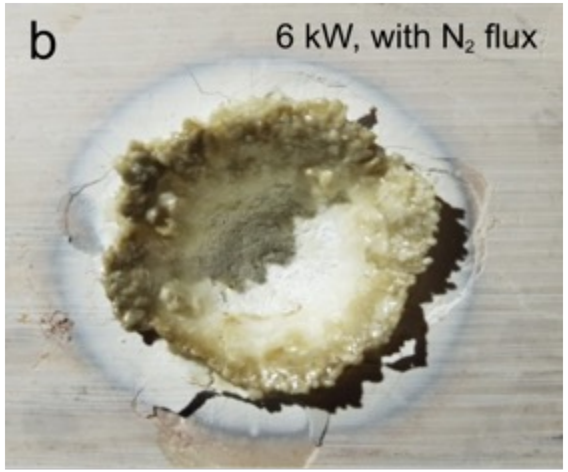
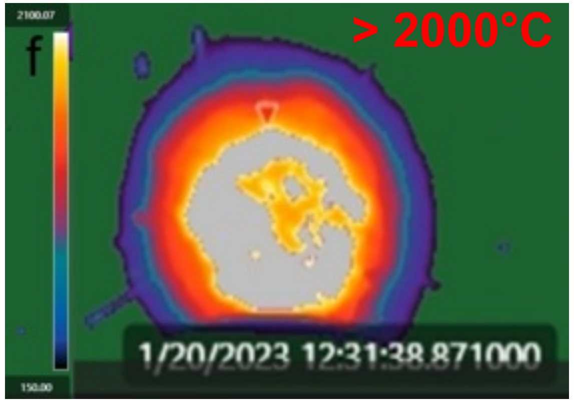
# Thermochemical modeling (FactSage)



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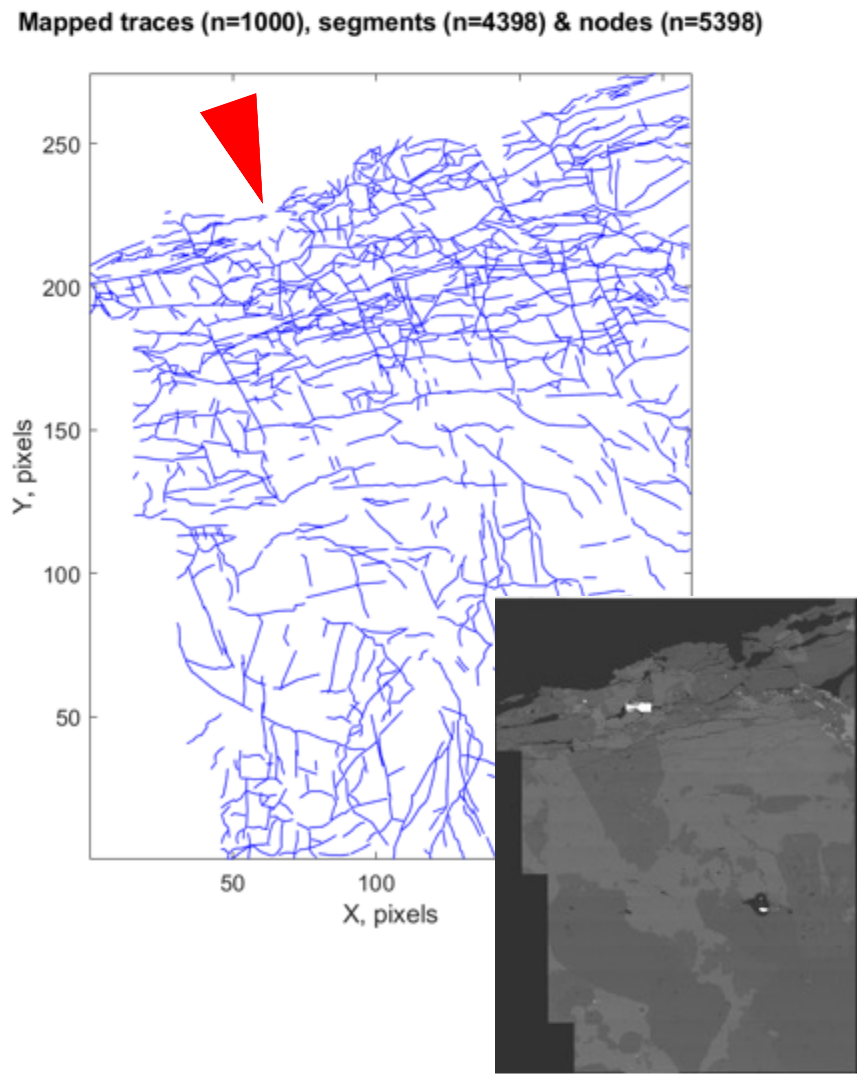
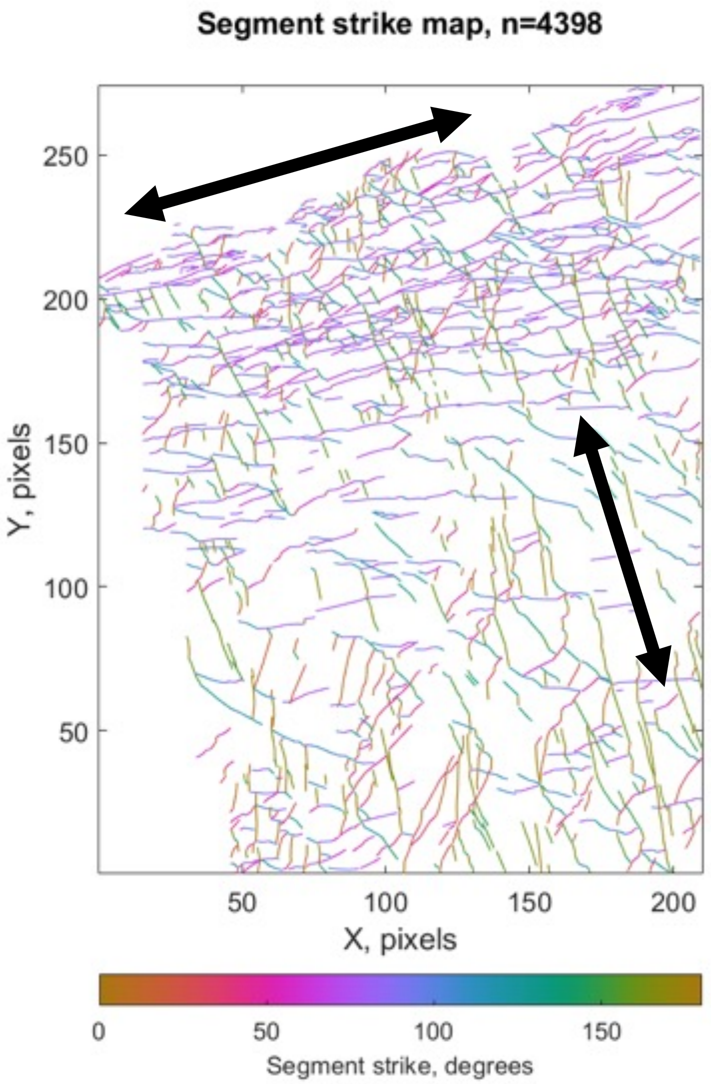
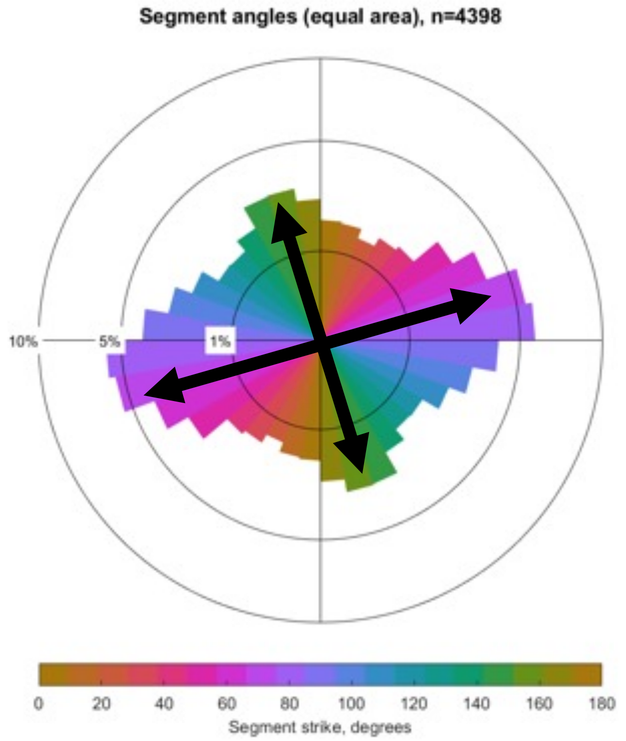
# Deep U-tube heat exchanger breakthrough: combining laser and cryogenic gas for geothermal energy exploitation



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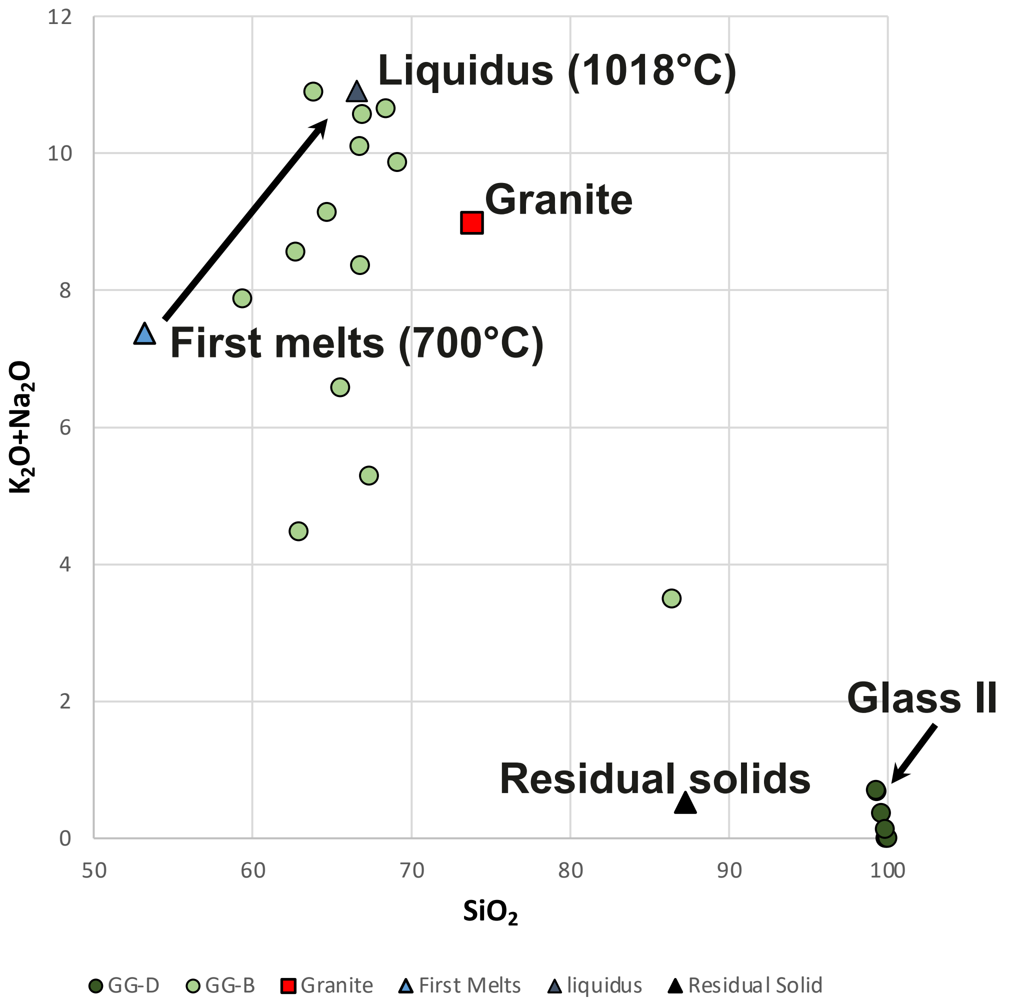
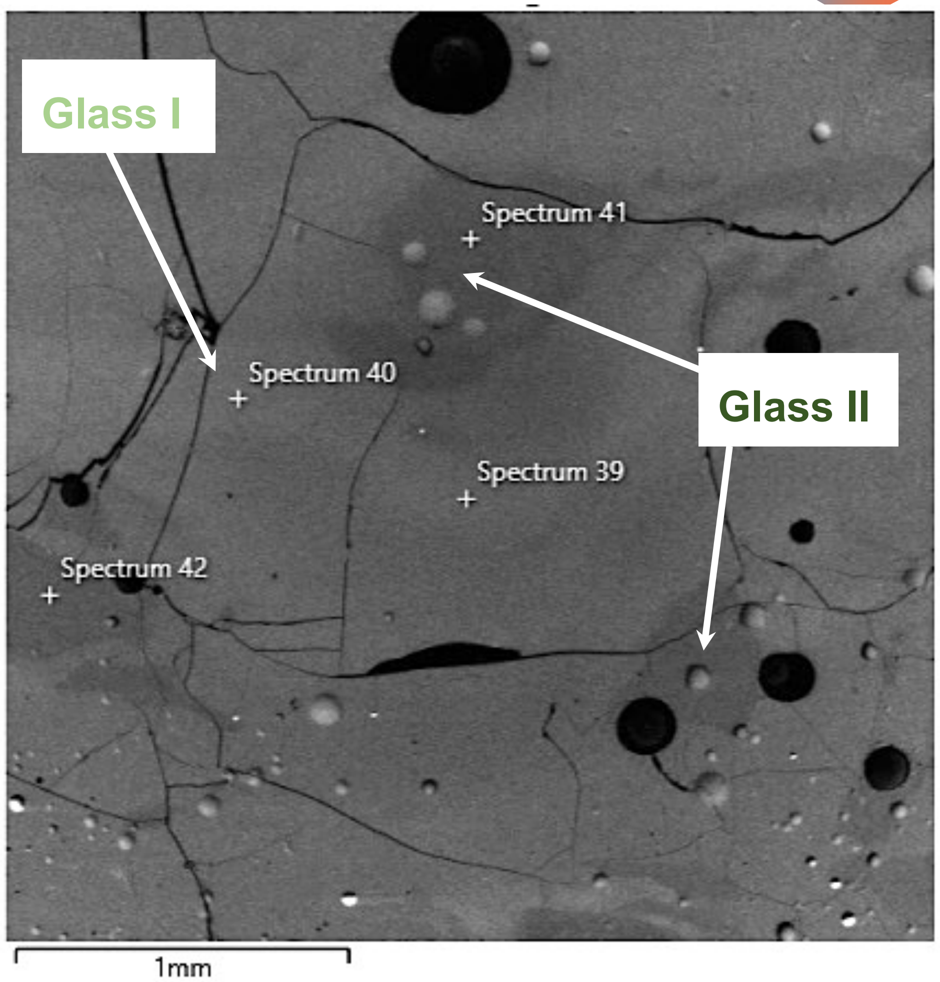
# Thermodynamic modeling (MELTS) - granite



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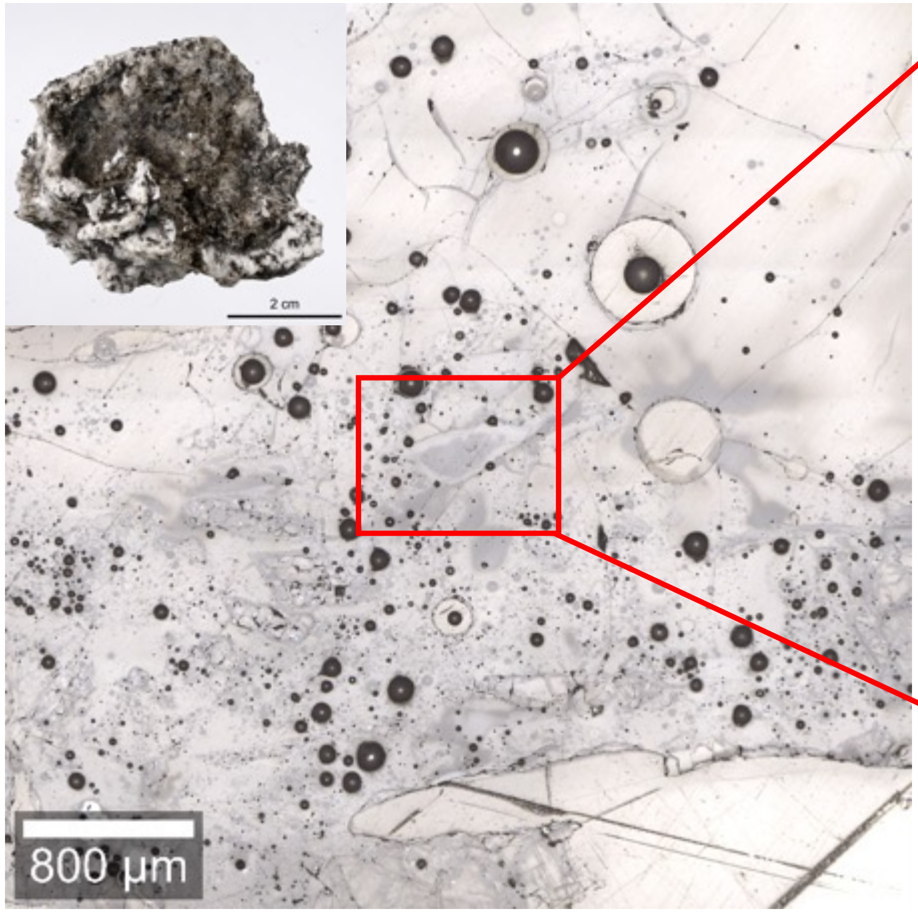
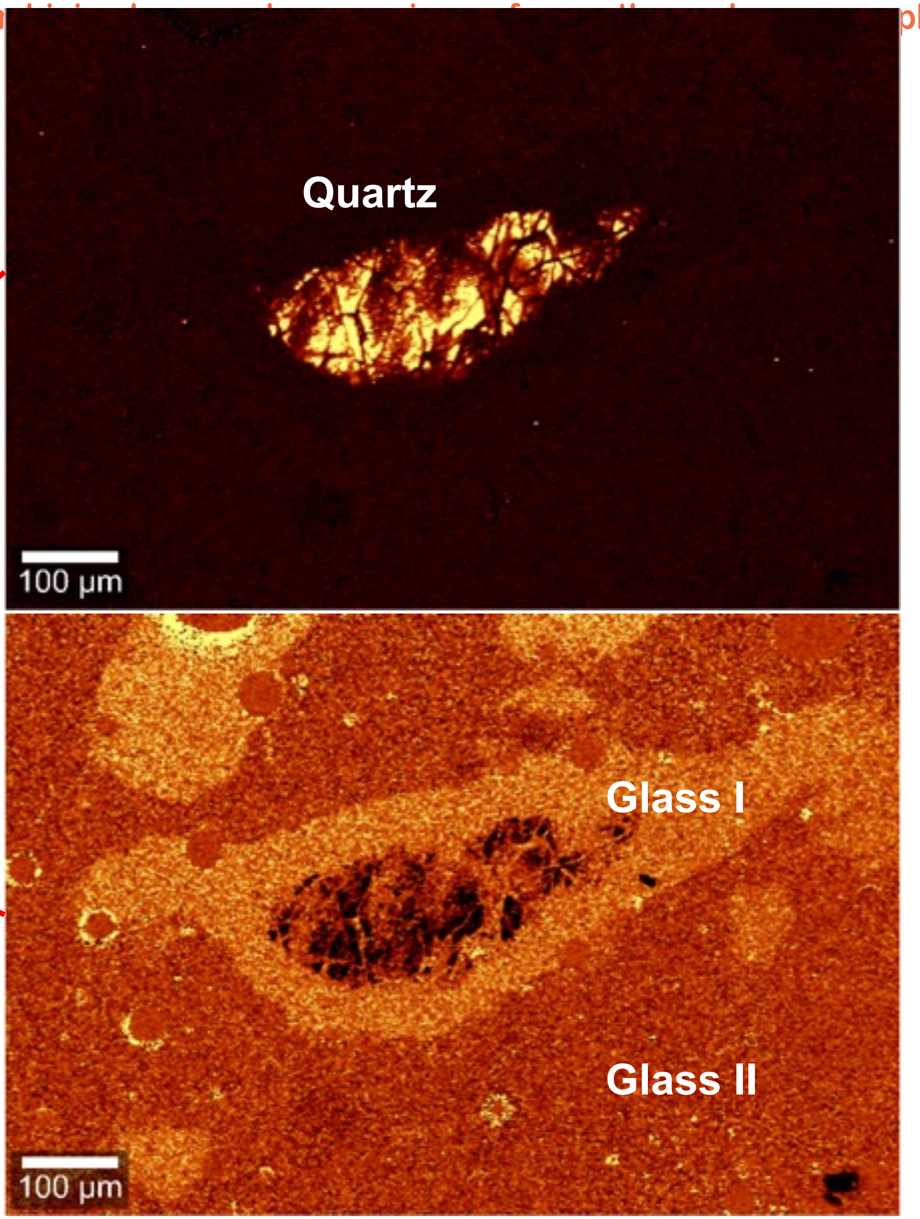
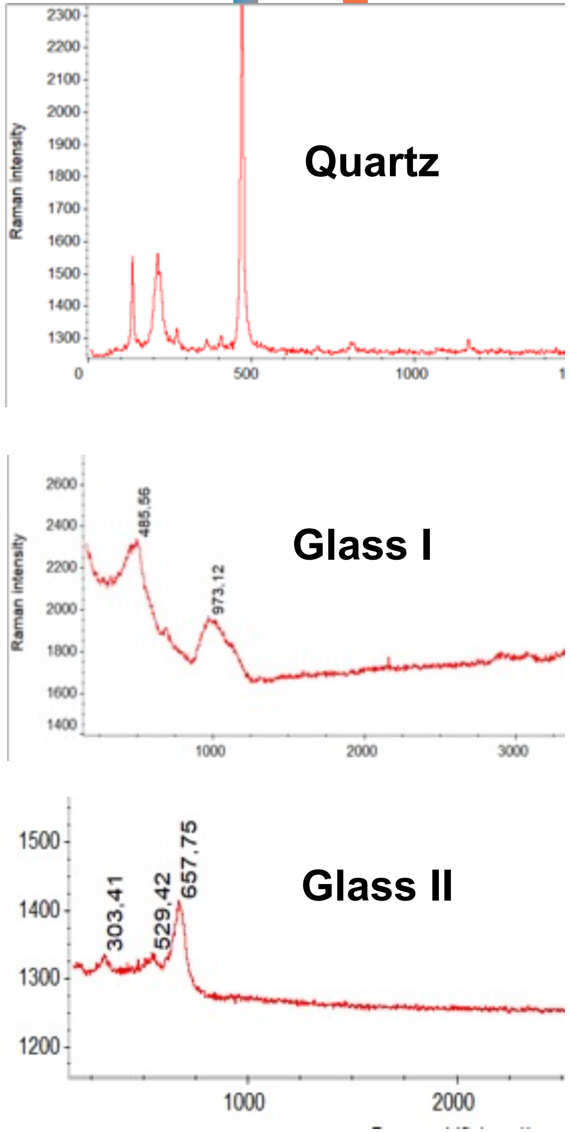
# Granite Glass - Raman



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# Laser-rock interactions perspective – WP3

- **determine laser beam impacts** on the thermo-physical characteristics of hard/soft rocks and alluvial deposits
- **verify the presence of vitrification** along the borehole walls
- **characterize the cutting material** produced by rocks’ melting and/or evaporation
- **analyze the thermal shocks** induced on selected rock samples
- **thermodynamic modeling of phase equilibria** (mineral, liquid, rock) during melting and crystallization