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# Laser-rock interactions, is drilling rocks possible with a laser?

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# Introduction

## 1. Aims of the study

The potential of geothermal resources is currently constrained by existing drilling technology. To address this issue, **the DeepU Project is investigating the application of laser and cryogenic gas for drilling deep wells** (>4 km) to realise a U-shaped closed-loop geothermal heat exchanger. Laser drilling is one of the **non-contact drilling techniques** that offers a promising solution by enhancing efficiency and reducing well completion costs.

## 2. Laser drilling experiments

Two types of laboratory-scale laser drilling experiments were performed on granite, sandstone, limestone: **1) preliminary laser tests** performed on 5cm cubes, beam diameter 1-10mm, power 200-12500W, shown in **Fig. 1a** and **2) DeepU drill head tests** performed on rock slabs 50x35x15cm, beam diameter 5-20cm, power 6-30kW, with $N_2$ as a flushing medium, shown in **Fig. 1b**.

Laser drilling experiments were performed in Fraunhofer IAPT laboratories in Hamburg. The drilling process was recorded by a **high-resolution infrared camera** FLIR GF77a (Fig. 1). Cuttings and lasing products were collected and studied. The morphology of drilled boreholes was investigated with photogrammetry.

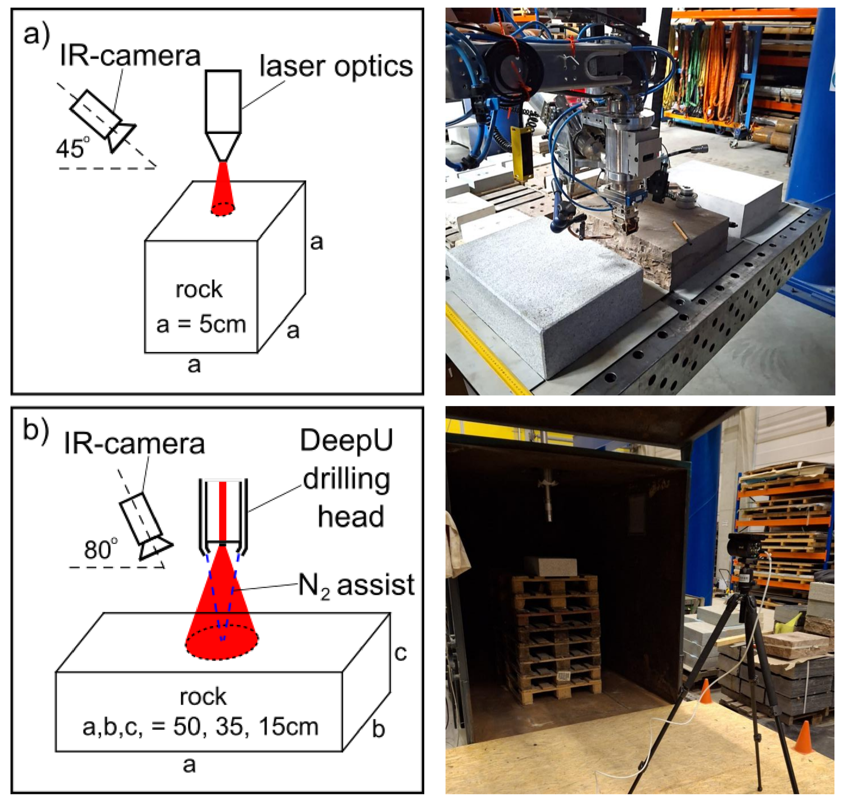



**Fig. 1** Schematic drawings and pictures showing two experimental setups; preliminary laser tests (a), DeepU drill head tests (b).

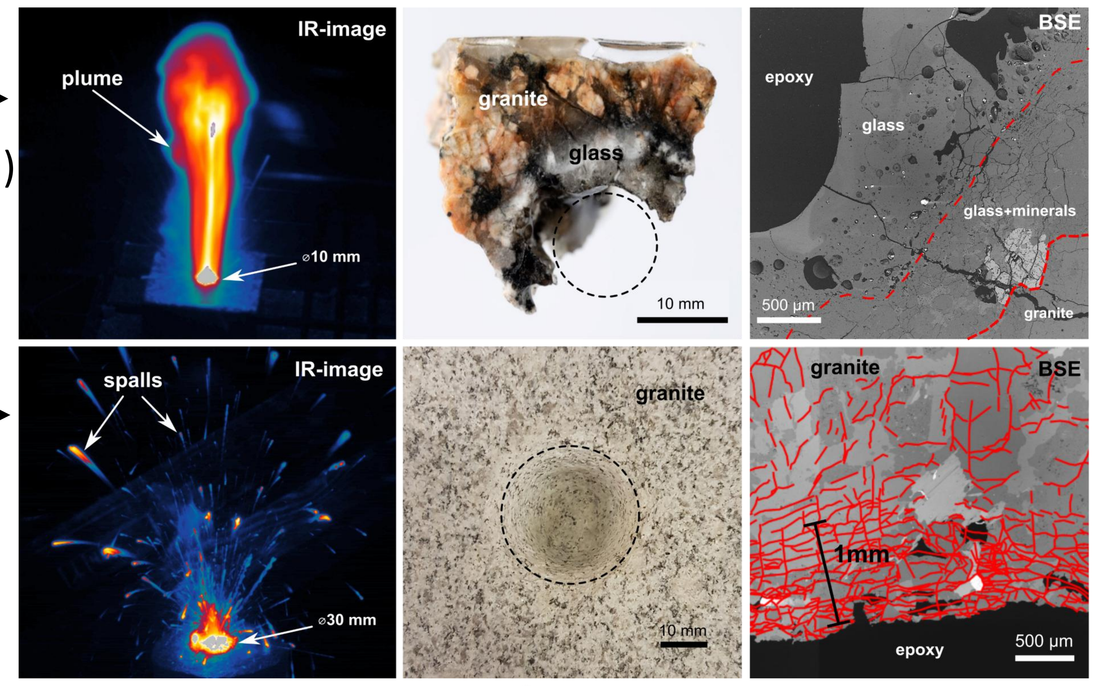
## Summary of the preliminary laser tests – drilling regimes

**Melting-vaporization laser drilling**

- High Pp (>10 kW/cm²) or long $t_i$ (min)
- Small diameters (c. 10mm)
- Vitrified layer

**Thermal spallation laser drilling**

- Low power density (>300 W/cm²)
- Big diameters (>50 mm)
- Fractures up to 1mm in depth




# Results

## 3. Laser - rock interactions

Combined analysis of IR-images and lasing products from preliminary laser tests showed minimum required power density (Pρ) to induce each of the rock breaking process, such as: **spallation (S), melting (M) and vaporization (V)**

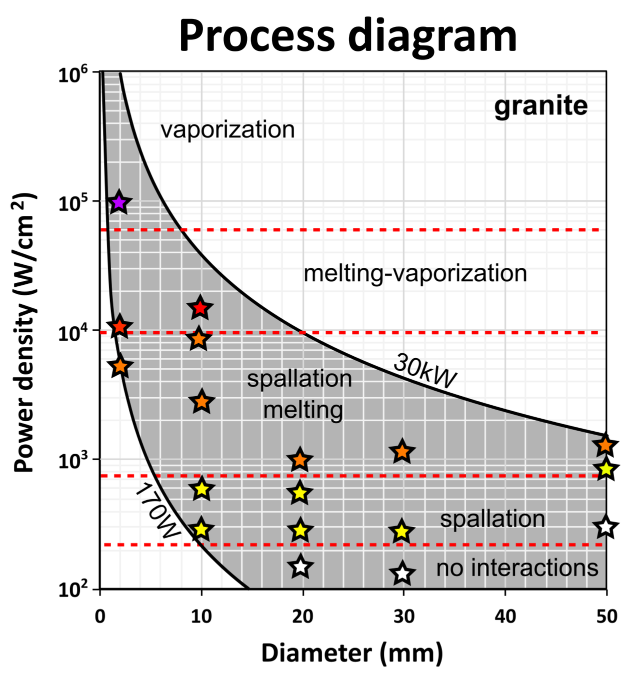
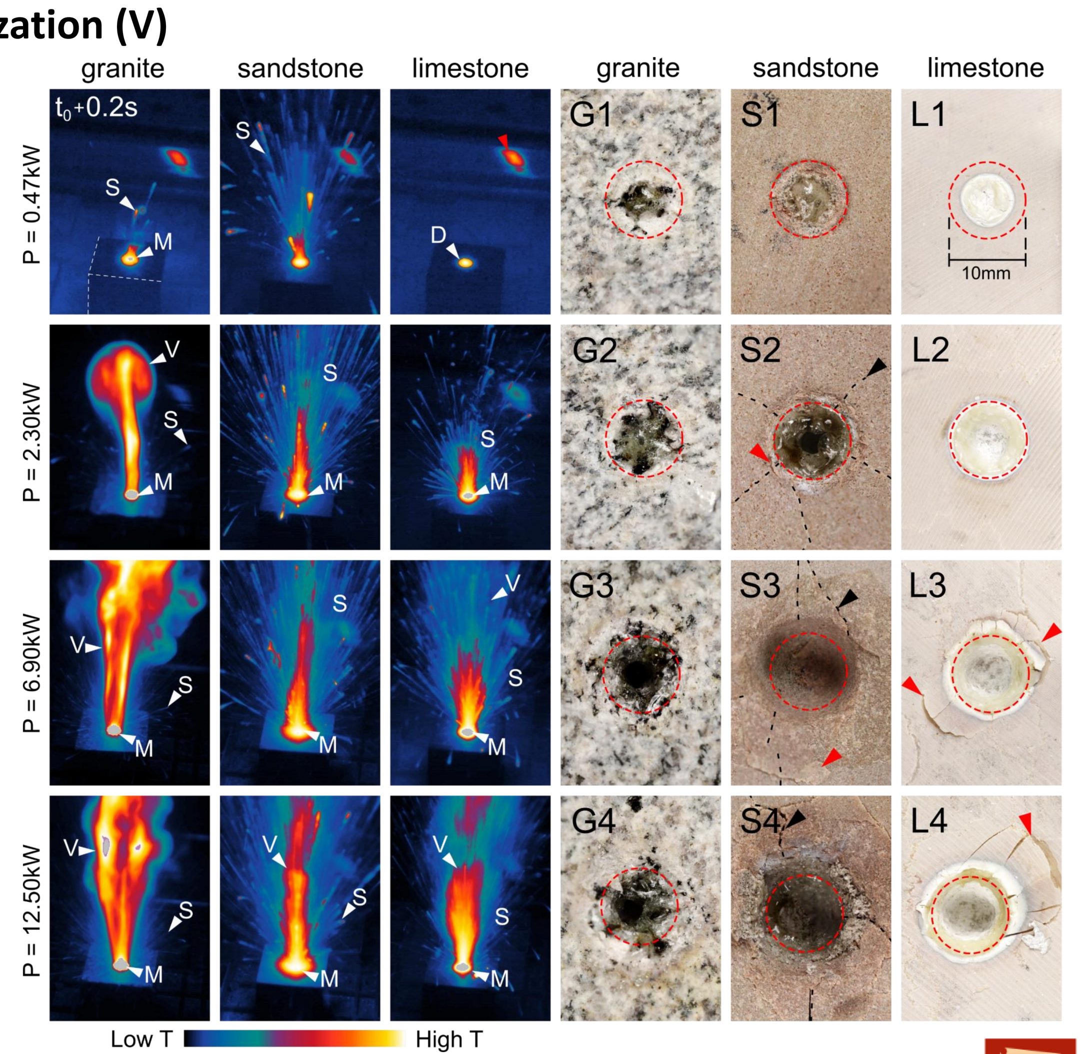



**Fig. 2** Analytical matrix showing IR-images and lasing products of preliminary laser tests used for construction of process diagrams.




## 4. DeepU thermal spallation laser drilling

DeepU laser drilling head was optimized for thermal spallation laser drilling according to results from preliminary laser tests. The laser spallation system can easily break and penetrate the rock when border conditions are archived and sustained.

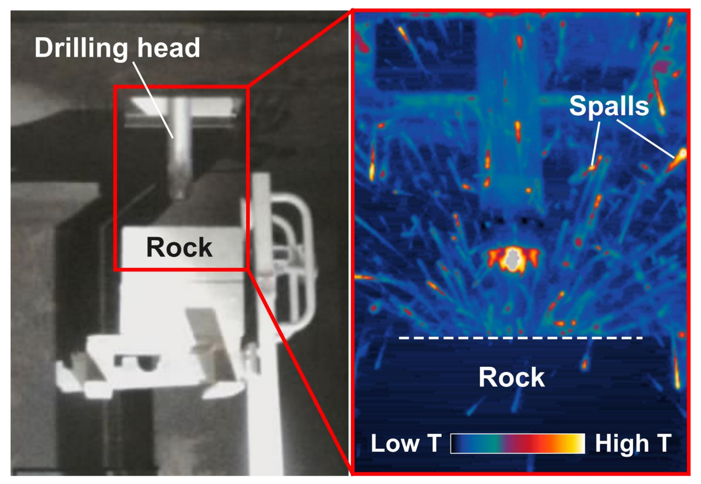



**Fig. 3** Thermal spallation drilling in DeepU drill head test and IR image of the process.

Quartz-bearing lithologies are prone to thermal spallation, such as granite and sandstone. Limestone and basalt displayed extensive meting during the laser irradiation that gradually hampered spallation.

The average temperature of spallation was measured for **granite, sandstone,** basalt and limestone and its **550°C, 400 °C,** up 1100 °C, and 1000 °C, respectively.

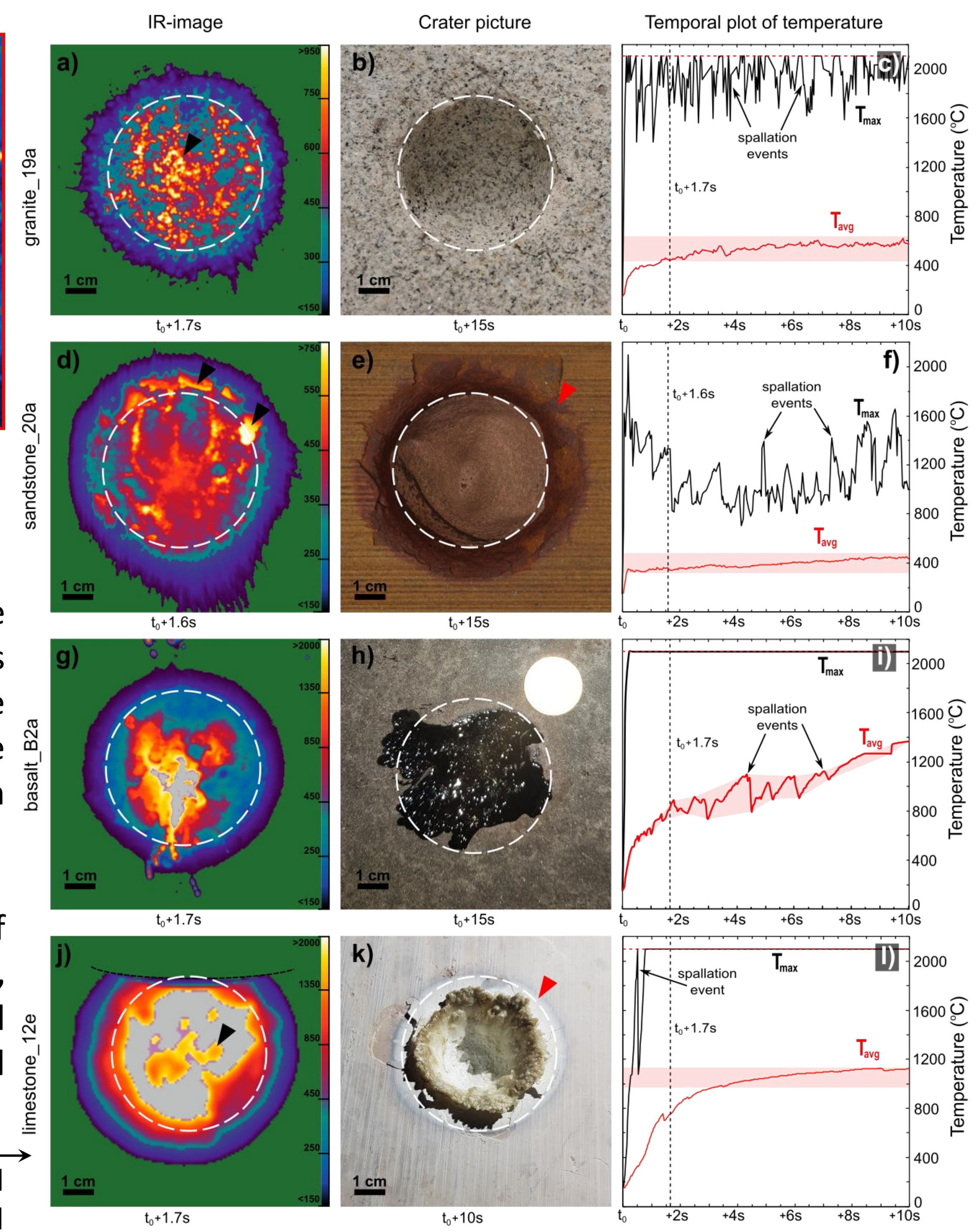



**Fig. 4** IR images, pictures of craters and records of temperature from DeepU drill head tests

## 5. Efficiency of laser-induced thermal spallation

The efficiency of laser drilling was assessed using two parameters rate of penetration (ROP) and specific energy (SE), shown in the table.

The main factor limiting laser drilling performance is: 1) accessible power and 2) efficiency of flushing system. The evolution of spallation process degradation due to cuttings accumulation is shown in Fig. 5

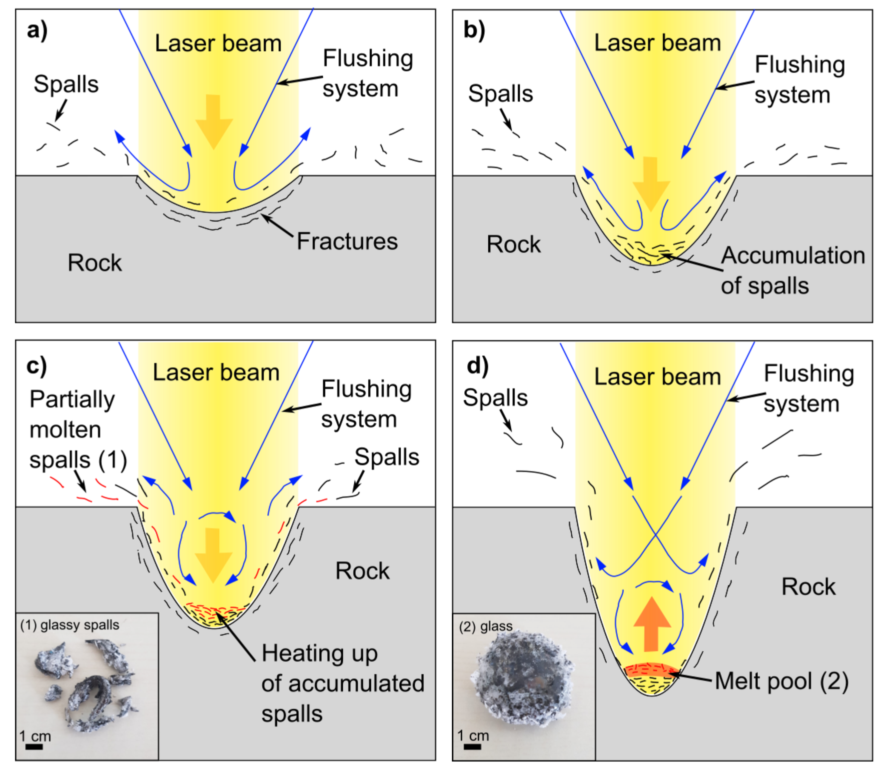
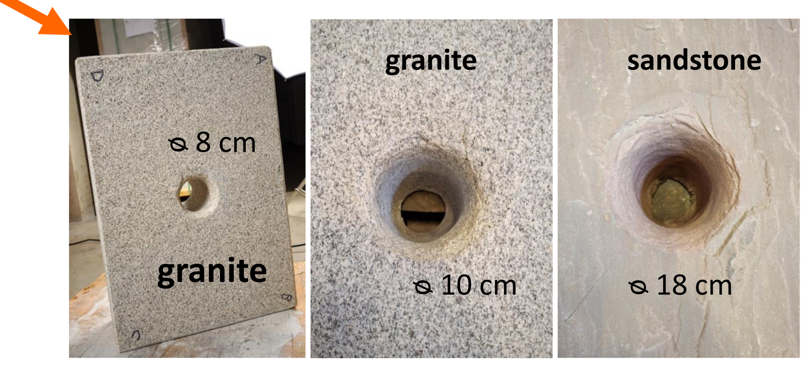



**Fig. 5** IR images, pictures of crater and records of temperature from DeepU drill head tests

| Lithology | ROP (m/h) | SE (kJ/cm³) |
|---|---|---|
| Granite | 10,0 | 5,6 |
| Sandstone | 14,8 | 4,1 |
| Limestone*(Fig. 4k) | 2,5 | 86,7 |
| Limestone $H_2O$ sat. | 4,5 | 16,3 |
| Sandstone $H_2O$ sat. | 25,1 | 2,3 |




# Conclusions

Characterization of laser -rock interactions and construction of process diagrams for the first time allowed to successfully design laser-induced thermal spallation system. Based on results from the experiments two drilling concepts were proposed, see Fig. 6

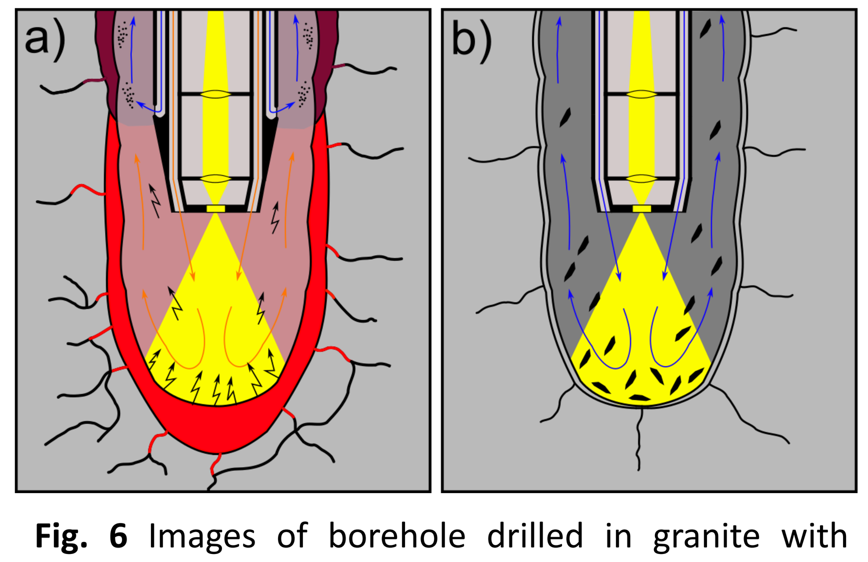



**Fig. 6** Images of borehole drilled in granite with vitrified layer (a, b), and BSE images showing glas

## References

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