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# Petrophysical effects induced by laser on hard/soft rocks

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Dissemination Level

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| **PU** | Public, fully open | |
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# TABLE OF CONTENTS

# TABLE OF FIGURES

# LIST OF TABLES



# ABBREVIATIONS AND GLOSSARY OF ACRONYMS

| Acronym | Extended definition |
|---|---|
| BSE | Backscattered electron |
| DG | Department of Geosciences |
| DLT | Discrete Laser Tests |
| EDS | Energy Dispersive Spectroscopy |
| FEG | Field emission gun |
| IR | Infrared |
| LLT | Linear Laser Tests |
| OM | Optical microscopy |
| PPL | Plane polarized light |
| ROP | Rate of Penetration |
| SE | Secondary electron |
| SEM | Scanning Electron Microscopy |
| SR | Red sandstone |
| SY | Yellow sandstone |
| TCS | Thermal Conductivity Scanner |
| UNIPD | University of Padua |
| WD | Working distance |
| XPL | Crossed polarized light |
| XRD | X-Ray Diffraction |
| XRF | X-Ray Fluorescence |
| **Symbol** | **Definition** |
| P | power (kW) |
| $\rho$ | density ($g/cm^3$) |
| $P_\rho$ | power density ($W/cm^3$) |
| E | Young's Modulus (GPa) |
| Ab | water absorbance (%) |
| $V_p$ | P-wave velocity (km/s) |
| $V_s$ | S-wave velocity (km/s) |
| v | Poisson's ratio (-) |
| G | shear modulus (GPa) |
| $\lambda$ | thermal conductivity ($W/m \cdot K$) |
| $C_p$ | volumetric thermal capacity ($J/m^3 \cdot K$) |
| $\alpha$ | thermal diffusivity ($m^2/s$) |
| $S_E$ | specific energy ($kJ/cm^3$) |
| $t_i$ | time of irradiation (s) |
| T | temperature (°C) |
| $T_s$ | average temperature of spallation (°C) |

# EXECUTIVE SUMMARY

This report focuses on the project activities related to the laser-rock interactions studied in the three experimental laser drilling tests, performed during two campaigns in the dedicated test facility of Fraunhofer-IAPT in Hamburg, Germany. Three types of lithologies were selected for initial laboratory tests: granite, sandstone, and limestone. The petro-thermo-mechanical phenomena occurring during laser irradiation, such as spallation, melting, and evaporation, were recognized and described in detail. The laser drilling process was assessed by IR imaging, and analysis of irradiated rocks. This comprehensive approach provided information about the most effective process for rock removal as being spallation, occurring at low temperature (<700°C) and capable of drilling boreholes up to 18cm in diameter. Melting-evaporation drilling was also achieved (>2000°C). The presence of vitrified walls was confirmed, however for a much smaller borehole diameter < 2cm. The laser working parameters and experimental setup were optimized based on the observed phenomena. After the experiments, sections of boreholes were cut out and examined. The microscopic observations on the unaffected and affected rock thin sections have been performed with use of polarized optical and scanning electron microscopy revealing micro-fracturing of the rock. The depth and density of damages was characterized and quantified.

# REFERENCES

Brian C. Gahan, Richard A. Parker, Ramona Graves, Samih Batarseh, Claude B. Reed, Zhiyue Xu, Humberto Figueroa, and Neal Skinner, 2001, Laser Drilling: Drilling with the Power of Light Phase 1: Feasibility Study: 924031, 924031 p., doi:10.2172/924031.

Han, Y., Zheng, C., Liu, Y., Xu, Y., Liu, P., Zhu, Y., and Wu, X., 2024, Study on the rock-breaking characteristics of high-energy pulsed plasma jet for granite: Geoenergy Science and Engineering, v. 232, p. 212466, doi:10.1016/j.geoen.2023.212466.

Healy, D., Rizzo, R.E., Cornwell, D.G., Farrell, N.J.C., Watkins, H., Timms, N.E., Gomez-Rivas, E., and Smith, M., 2017, FracPaQ: A MATLAB™ toolbox for the quantification of fracture patterns: Journal of Structural Geology, v. 95, p. 1–16, doi:10.1016/j.jsg.2016.12.003.

Kant, M.A., Rossi, E., Madonna, C., Höser, D., and Rudolf von Rohr, P., 2017, A theory on thermal spalling of rocks with a focus on thermal spallation drilling: Journal of Geophysical Research: Solid Earth, v. 122, p. 1805–1815, doi:10.1002/2016JB013800.

Li, M., Han, B., Zhang, Q., Zhang, S., and He, Q., 2019, Investigation on rock breaking for sandstone with high power density laser beam: Optik, v. 180, p. 635–647, doi:10.1016/j.ijleo.2018.10.059.

Rossi, E., Jamali, S., Saar, M.O., and Rudolf von Rohr, P., 2020, Field test of a Combined Thermo-Mechanical Drilling technology. Mode I: Thermal spallation drilling: Journal of Petroleum Science and Engineering, v. 190, p. 107005, doi:10.1016/j.petrol.2020.107005.

Seo, Y., Lee, D., and Pyo, S., 2022, The interaction of high-power fiber laser irradiation with intrusive rocks: Scientific Reports, v. 12, p. 680, doi:10.1038/s41598-021-04575-z.

Yang, X., Zhou, J., Zhou, X., Nie, A., and Jian, Q., 2020, Investigation on the rock temperature in fiber laser perforating: Optik, v. 219, p. 165104, doi:10.1016/j.ijleo.2020.165104.

Zhu, X., Luo, Y., and Liu, W., 2020, On the rock-breaking mechanism of plasma channel drilling technology: Journal of Petroleum Science and Engineering, v. 194, p. 107356, doi:10.1016/j.petrol.2020.107356.