中国科学院武汉岩土力学研究所
Institute of Rock and Soil Mechanics,Chinese Academy of Sciences

岩土力学与工程前沿讲坛

Forum on Geomechanics and Geo-engineering

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应岩土力学与工程安全全国重点实验室邀请，德国地球科学研究中心 GFZ Arno Zang 教授来访交流并做系列讲座，报告信息如下：

报告人 Lecturer	**Prof. Arno Zang**
讲座题目 Theme	**Laboratory fatigue and in-situ hydraulic testing for geothermal purposes at Äspö Hard Rock Laboratory, Sweden**
报告时间 Time	**2025 年 9 月 22 日（周一）下午 15:00**
报告地点 Spot	**武汉岩土所科研楼 4 楼 1 号会议室**

欢迎广大科研人员及研究生参加！

岩土力学与工程安全全国重点实验室
State Key Laboratory of Geomechanics and Geotechnical Engineering Safety

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报告简介

Enhanced Geothermal Systems (EGS) offer potential as a renewable energy resource. However, there are technological challenges to be addressed. How to stimulate fractures in crystalline rock effectively under various in situ stress conditions? How to capture the permeability enhancement process? How to minimize environmental impacts like injection-induced seismic events? As field tests in deep wells are costly, we see controlled experiments in underground research facilities combined with laboratory tests as a valuable alternative for optimizing energy extraction methods with advanced fluid-injection schemes. We report on underground in situ tests performed at the Äspö Hard Rock Laboratory, Sweden, with different water injection schemes and acoustic emission measurements to quantify the seismically radiated and hydraulic energy budget.

An array of eleven 70 kHz acoustic emission sensors, four accelerometers and two broadband seismometers is used to quantify the extension of six hydraulic fractures propagated from intact sections of a 28 m long horizontal borehole at 410 m depth drilled from an existing tunnel in the direction of minimum horizontal compressive stress. Additionally, the evolution of fractures is mapped with impression packers at the borehole wall. The stimulated rock volume 20 x 20 x 20 meters in size consists of granodiorites, diorite gabbro and granites. Injection protocols include conventional monotonic, innovative cyclic progressive and pulsed hydraulic stimulations to increase fracture complexity and permeability for heat extraction.

Hydraulic tests in naturally fractured granite with a maximum of 30 litres of water injected generate small scale hydraulic fractures up to 40 square meters in size. The seismic response of the hydraulic fracture strongly depends on injection style and rock type. In the same rock type, the cyclic injection produces larger seismic b-values as compared with the monotonic injection. This indicates a safer treatment. The fracture pattern inferred from impression packer results and acoustic emission hypocentre solutions turn out to be more complex when replacing

conventional by fatigue hydraulic testing. In laboratory tests, we could confirm lower breakdown pressures, a shift to smaller AE amplitudes and a more branching fracture pattern as a function of fatigue cycles.

We interpret the larger fracture process zone evolving during cyclic hydraulic fracturing as a result of depressurization phases and stress relaxation at the fracture tip. Evidence comes from natural proppants (debris material) observed in granite fracture walls in the laboratory, reactivation of natural fractures, and larger seismic b-values indicating a replacement of larger amplitude AE events by a cloud of smaller events in the laboratory and underground fatigue tests. We admit that full-scale field tests are required once the tailor-made fatigue concept of the target rock has been determined.

报告人介绍

Arno Zang is a Professor at the GFZ German Research Center for Geosciences, which is located in Potsdam, Germany.

With over 30 years of service at the German Research Centre for Geosciences (GFZ), my work has spanned two key focus areas. In the early stage of my career, I contributed to the establishment and operation of a rock deformation laboratory. My responsibilities there included conducting tri-axial testing on rock cores—coupled with acoustic emission measurements—and performing post-mortem fracture analysis. Over the past 15 years, my research focus has shifted to the design and execution of underground experiments aimed at enabling efficient geothermal heat extraction. These experiments leverage underground research facilities located in Germany, France, and Sweden.

In addition to my research at GFZ, I hold a professorship in Geophysics and Rock Mechanics at the University of Potsdam, where I teach master's-level courses on Fracture Mechanics, Rock Physics, and Crustal Stress Measurements.

For more detailed information about my work and a complete list of my publications, please visit my webpage: https://www.gfz-potsdam.de/en/staff/arno.zang/sec26