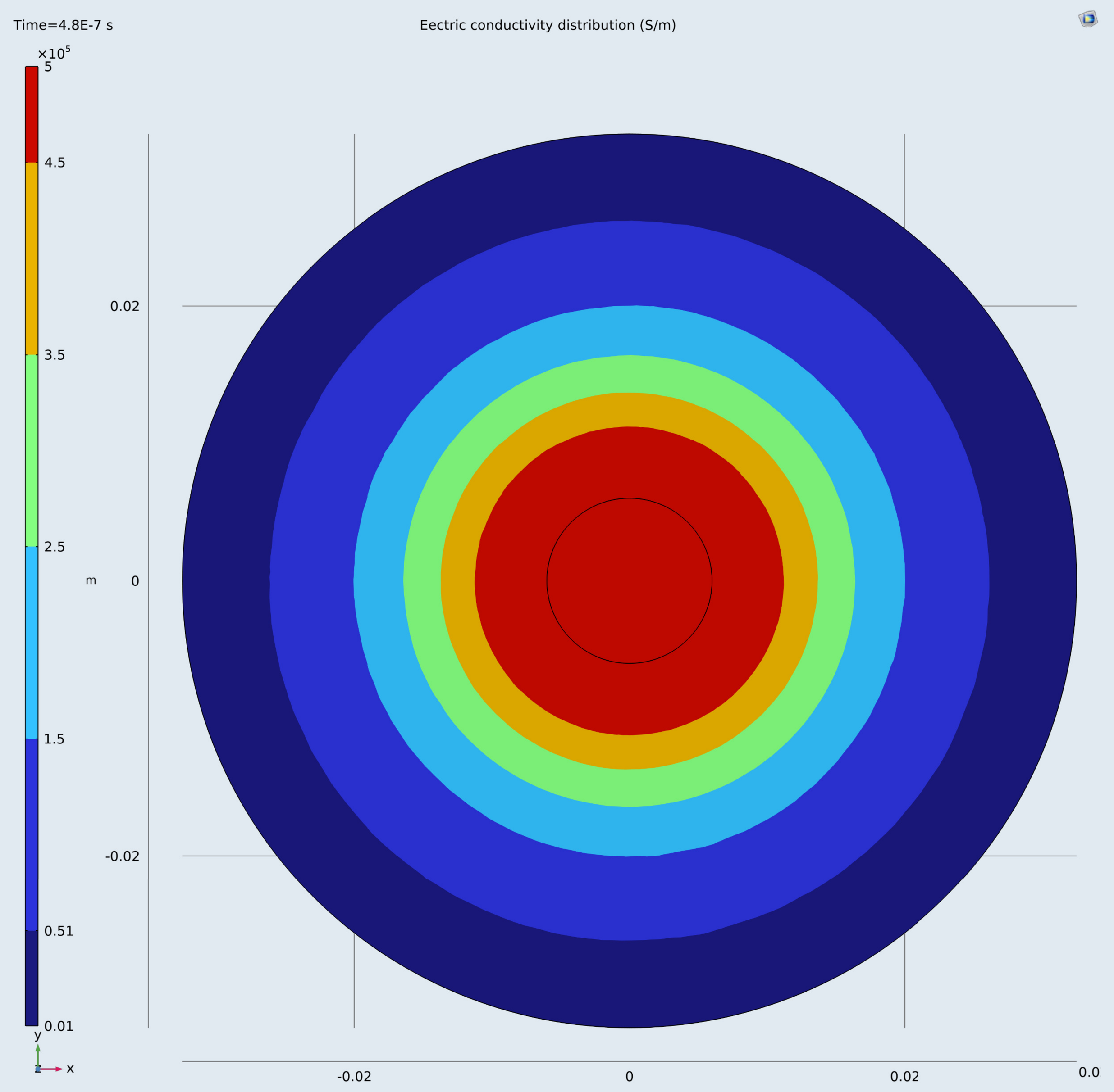

Rock Fragmentation: High-Voltage Electrical Pulse Effects Investigated Through Electrical Modeling

Modeling electrical fragmentation of rocks to understand its underlying mechanisms and potential applications in various fields.

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Introduction and Goals

Rock fragmentation is a main process in mining, quarrying, and civil engineering. In recent years, high-voltage pulse fragmentation (HVPF) has emerged as a promising alternative to rock fragmentation using traditional mechanical tools due to its high energy efficiency.

HVPF uses a high-pulse voltage to initiate electrical breakdown inside a dielectric material immersed in water, generating its disintegration. In HVPF, a discharge channel is formed inside the rock after applying a high-voltage pulse resulting in a high-initial current flow. Consequently, the rock, a non-conductive material, appears to be locally transformed into a conductive material [1], and the electrical energy is transformed into heat and mechanical energy.

The high-voltage rock destruction may be considered a dynamic multiphysical problem consisting of three main physical problems: electric, thermal, and mechanical problems. In this study, we present a focused investigation of the electrical problem only aiming to gain deeper insights into the underlying mechanisms of electrical fragmentation.

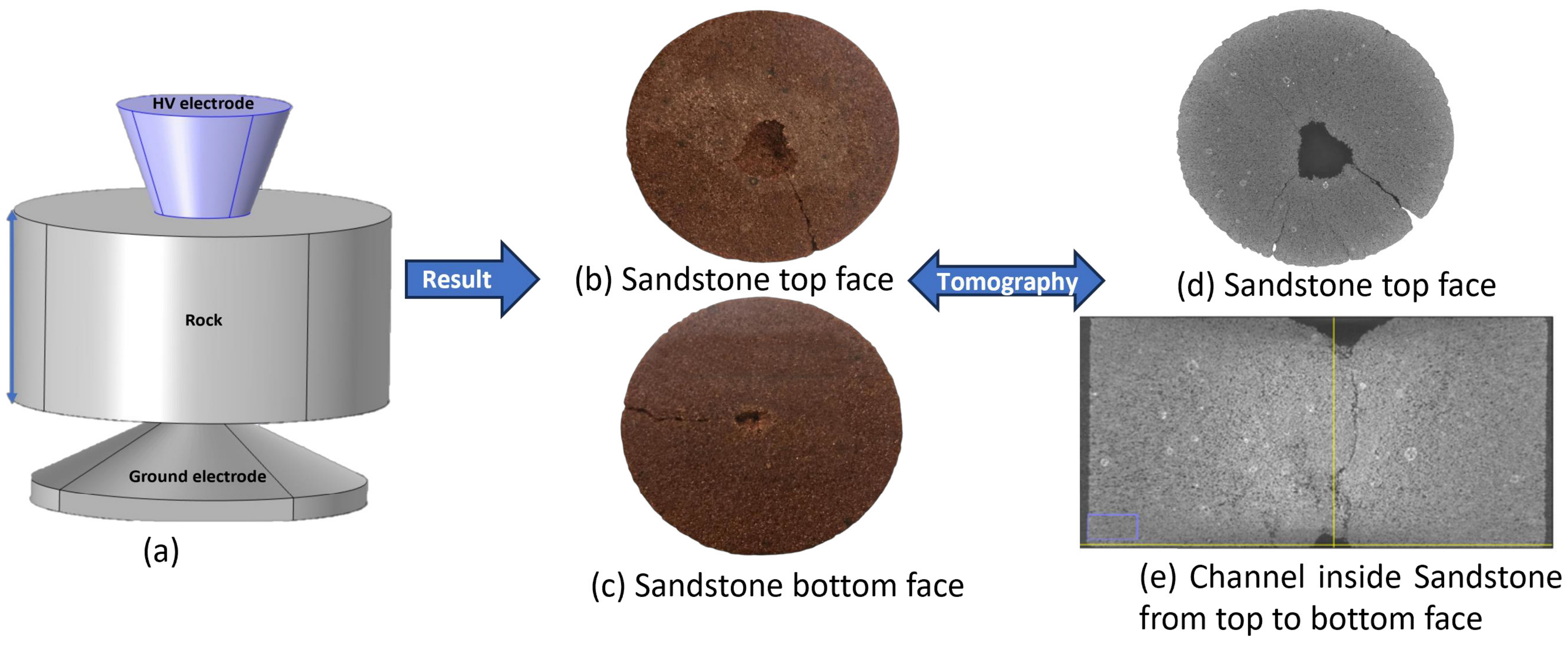

FIGURE 1. (a): HVPF Schematic Diagram in COMSOL® **(b,c):** Macroscopic results of sandstone tested with 90 kV electric pulse **(d,e):** Microscopic results by X-ray tomography of the tested sandstone

Methodology

The electric problem of HVPF is described by the equation of conservation of charge in which the unknown variable is the electric potential V.

$$\vec{\nabla}.(\sigma\vec{\nabla}V) + \frac{\partial}{\partial t}\vec{\nabla}.(\varepsilon\varepsilon_0\vec{\nabla}V) = 0$$

σ is the electric conductivity, and ε is the relative electric permittivity. These two parameters control the dielectric breakdown process and are empirical function of the electric field norm.

The distribution of σ (S/m) at the end of the simulation is our point of interest.

Results

The rock is considered an insulator with constant σ_0 at $t = 0$ *(before Breakdown).* The rock underwent a state transition and became a conductor with varying conductivity levels after breakdown.

Figure 2a highlights regions characterized by σ_{max} values, denoted as "electrical damage zones," which suggest a potential for mechanical damage in these areas. The dimensions (length, depth, width) of these zones can be determined numerically, which can then be compared with experimental data to evaluate the model's performance and accuracy.

Fig. 2b revealed that these electrical damage zones are interconnected by a channel with $\sigma < \sigma_{max}$, suggesting an important role in the overall breakdown mechanism of the rock.

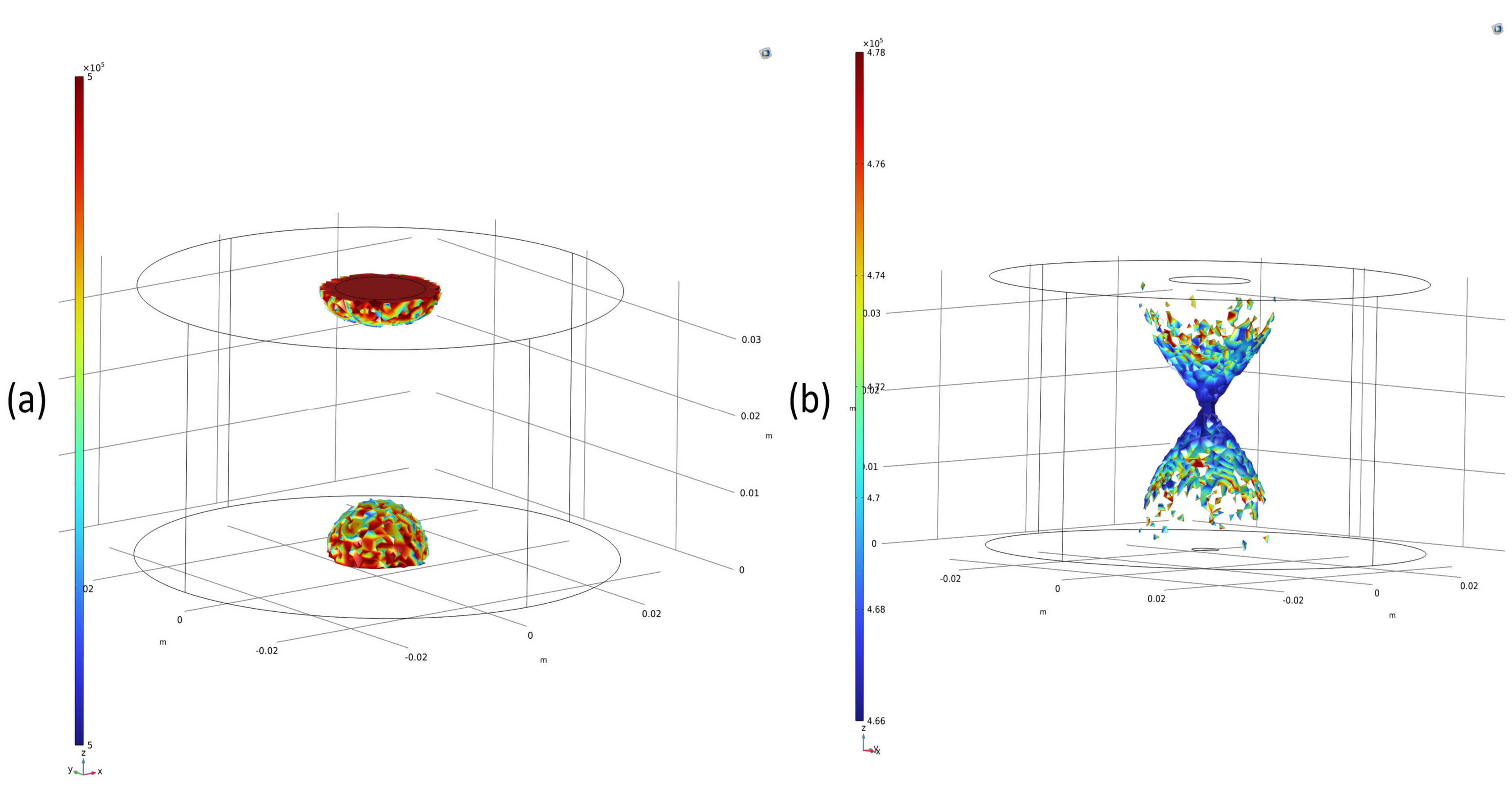

FIGURE 2: Electric Conductivity (S/m) distribution at t_f(s). (a): Region σ_{max} (b): Potential channel

REFERENCES

[1] Xiaohua Zhu, Mengqiu Chen, Weiji Liu, Yunxu Luo, and Hai Hu. The fragmentation mechanism of heterogeneous granite by high-voltage electrical pulses. Rock Mechanics and Rock Engineering, 55(7):4351–4372, 2022