EGU General Assembly 2020: NP7.1 Nonlinear Waves and Fracturing D2877 | EGU2020-20594

3D Simulation of Fracture Propagation in Complex Reservoirs Rocks at Microscale

Victor Nachev[1,2,3], Andrey Kazak[3], and Sergey Turuntaev[2]

[1]Moscow Institute of Physics and Technology, Moscow, Russian Federation (Nachev@phystech.edu)

[2]Sadovsky Institute of Geospheres Dynamics RAS, Moscow, Russian Federation (S.Turuntaev@gmail.com)

[3]Skolkovo Institute of Science and Technology, Moscow, Russian Federation (A.Kazak@skoltech.ru)

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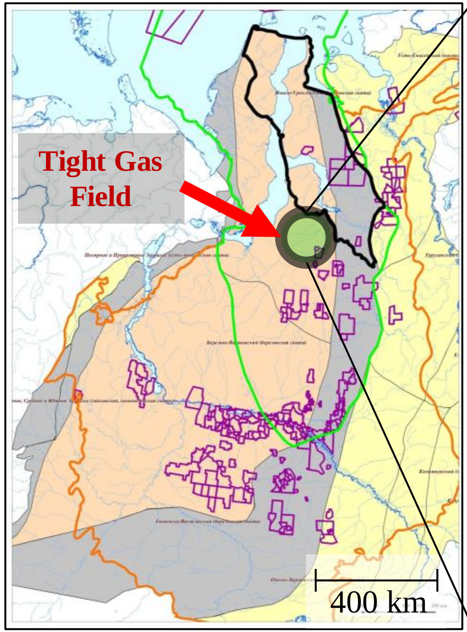
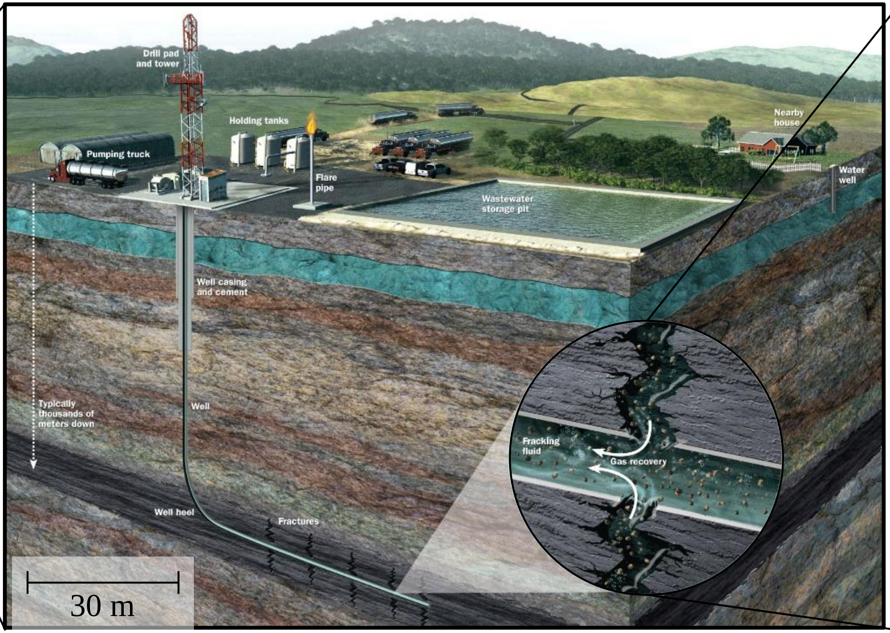
Industrial Context

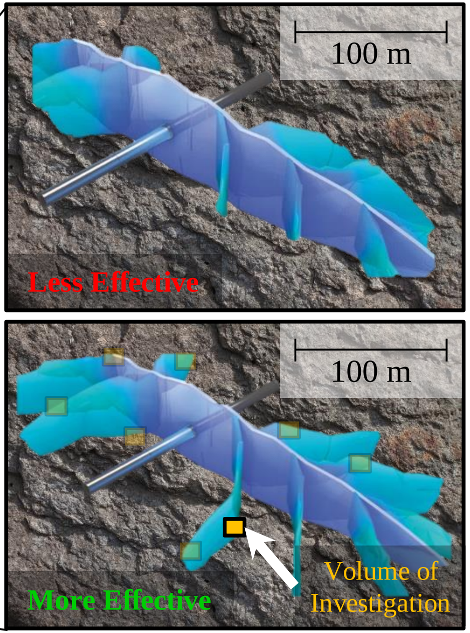


The Northern Part of Western Siberia, Russia



Schematic of a Typical Hydraulic Fracturing Operation

https://www.geologypage.com/wp-content/uploads/2016/05/Hydraulic-fracturing-GeologyPage.jpg



Optimal versus Non-Optimal Fracture Configuration

https://www.gazprom-neft.ru/images/z-template/technologies/ru//3_6-2.jpg

Nachev V. et al. Development of an Integrated Model of Rock Fracturing at Nano/Microscale, Poster for Skoltech & MIT Conference "Shaping the Future: Big Data, Biomedicine and Frontier Technologies", 2017

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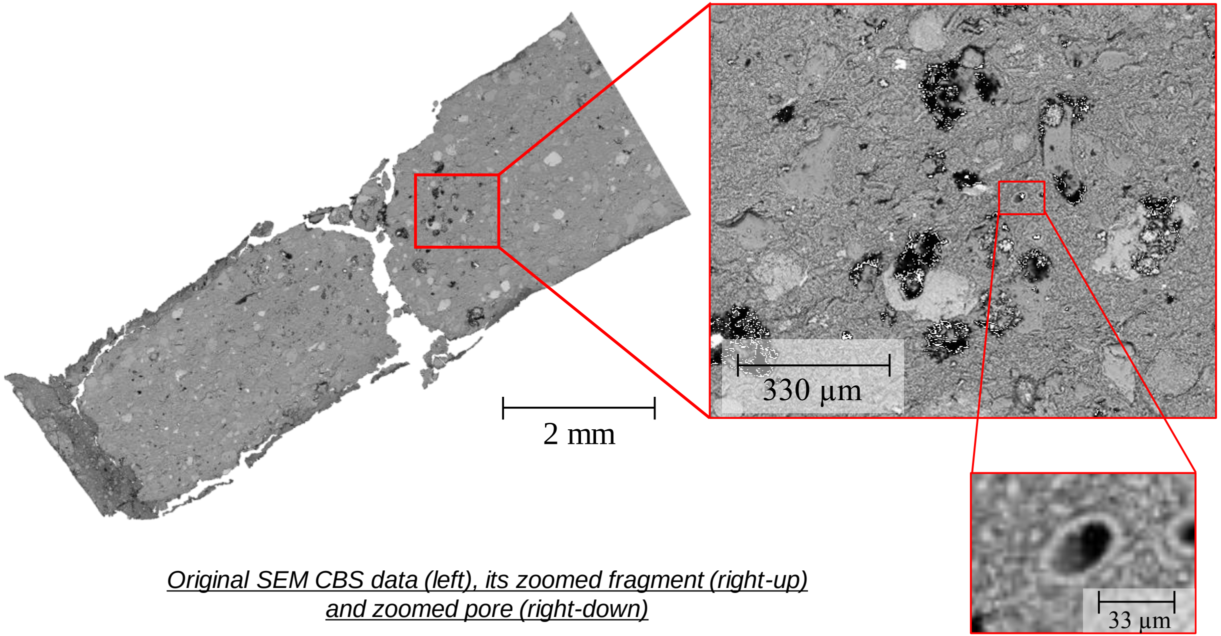
Industrial Issues Statement

1) What void types compose the pore space structure? How are they connected to each other? → Understanding pore-scale rock model and its behavior
2) What voids are originally occupied with gas? → Input for gas resource estimation
3) What pores would be connected to filtration path in the result of mechanical fracturing? → Requirements for the optimal technology of field development.



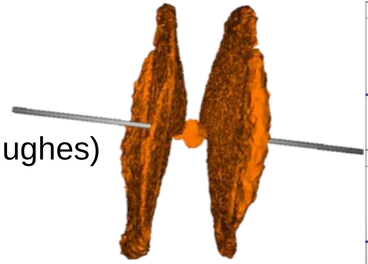
Original SEM CBS data (left), its zoomed fragment (right-up) and zoomed pore (right-down)

Kazak A. et al. Integration of Large-Area SEM Imaging and Automated Mineralogy-Petrography Data for Justified Decision on Nano-Scale Pore-Space Characterization Sites, as a Part of Multiscale Digital Rock Modeling Workflow, URTeC, 2017

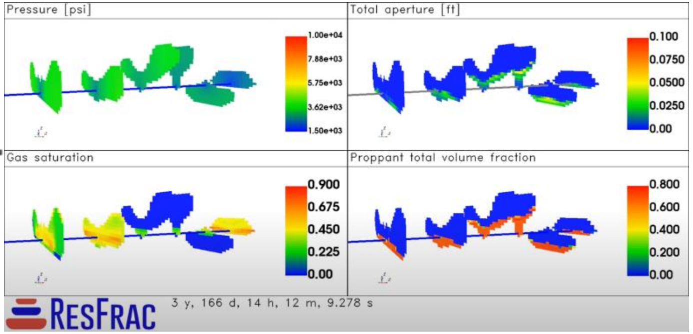
Current State of Hydraulic Fracturing Simulation

3D Commercial Simulators:

- VISAGE (Schlumberger)
- Mangrove (Schlumberger)
- MFrac (Meyer Fracturing Simulators) (Baker Hughes)
- GOHFER (Halliburton)
- FRACPRO (Carbo)
- ResFrac (ResFrac)
- Elfen tgr (Rockfield)



Elfen tgr
https://www.youtube.com/watch?v=MAtH5gNUrmY



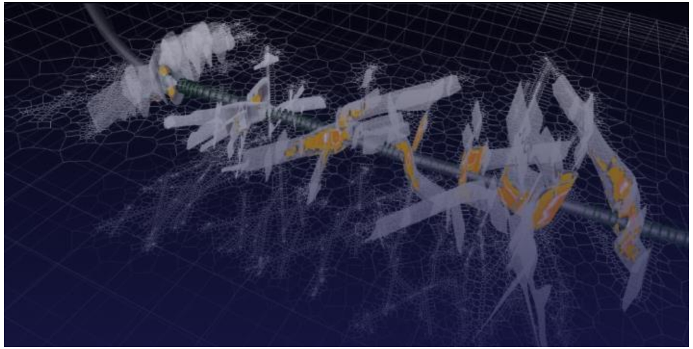
https://www.youtube.com/watch?v=n3M1UC_6_eE

Advantages:

- Modeling possible scenarios of single fracture and fracture network development
- Simulation input data can include a variety of acquired parameters, such as pump rates, bottomhole and surface pressures, proppant concentrations, and nitrogen and carbon dioxide injection rates versus time.

Disadvantages:

- Explicitly do not simulate interaction between fracture and voids
- Do not model complexity of reservoir development at microscale



Petrel
https://www.software.slb.com/-/media/software-media-items/software/images/image-viewer/petr_hydr_frac_mode/petr_hydr_frac_mode_3_xl.ashx?h=896&w=1216&la=en&hash=97B64D88286E0A5A5695D179D02A1A98CC229A08

Problem Solving

Assumptions

1) Hard contacts with no shear along contact surfaces
2) The knowledge of the mechanical properties and shape of the grains is sufficient for modeling
3) The created microstructural model sufficiently solves the contacts
4) The fracture is initiated in zones where the geometry of the “weak” material is thinner at the same load values
5) The fracture is initiated in zones where more defects are at the same load values

Pressure-Dependent Models (Yield Criterions)

- Mohr-Coulomb
- Drucker-Prager

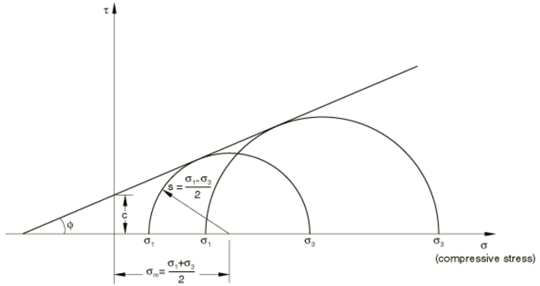
Research Approach

The model is represented by a piecewise continuous medium in which mechanical properties are locally changed.

Limitation(s)

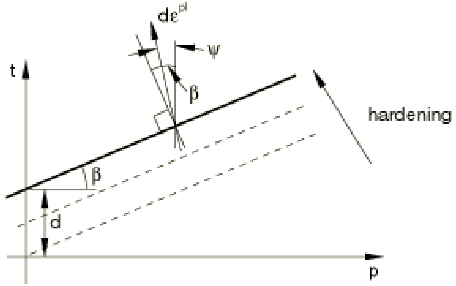
Simulation of single (nano & micro) scale without upscaling

Mohr-Coulomb Model



$$\tau = c - \sigma tan\varphi \qquad \tau = scos\varphi \qquad \sigma = \sigma_m + ssin\varphi$$

Linear Drucker-Prager Model



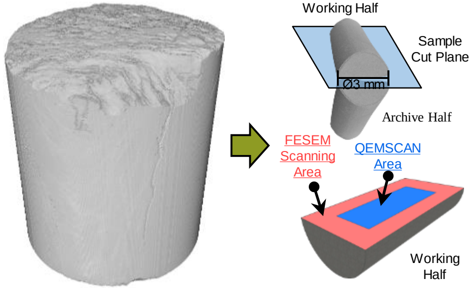
ABAQUS FEA Documentation

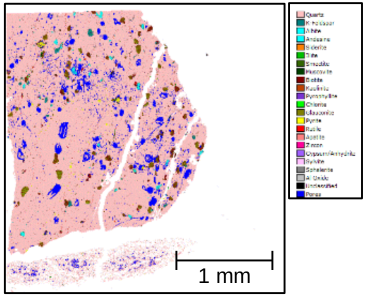
$$F = t - ptan\beta - d = 0 \qquad t = \frac{1}{2}q\left[1 + \frac{1}{K} - (1 - \frac{1}{K})\left(\frac{r}{q}\right)^3\right]$$

Research Workflow

Microstructural Characterization

Computed Tomography
Scanning Electron Microscopy
Energy Dispersive Spectroscopy
X-ray Analysis





Processing of Experimental Data

Processing & Segmentation
Registration of 2D QEMSCAN & CT Data
Distribution of 2D Mineral Data in 3D CT
The choice of Zones for Numerical Simulations

Preparation of Digital Rock Model

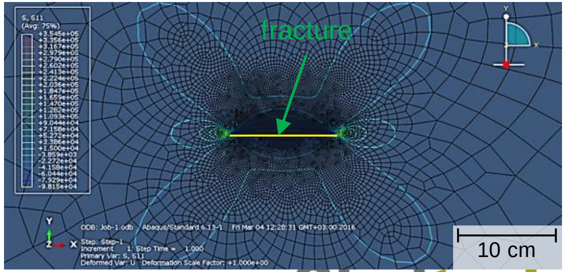
Meshing
Filling with mechanical properties
Defining Contacts
Setting Boundary Conditions

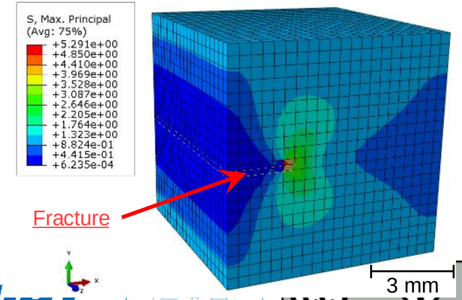
Fracture Modeling

Simulation of Stress-Strain State
Obtaining Branched Fracture Models

Geomechanical Characterization

Multi-Stage Compressive Strength Test
Direct Tensile Strength Test
Brazilian Tensile Strength Test
Micro- & Nanoindentation





Previously Completed Phases of the Research

Steps related to microstructural, geomechanical characterization and processing of experimental data can be studied in the following studies:

1) Nachev V., Chugunov S., Kazak A., Myasnikov A. Development of an Integrated Model of Rock Fracturing at Nano/Microscale Skoltech & MIT Conference “Shaping the Future: Big Data, Biomedicine and Frontier Technologies” Skolkovo Innovation Center, Moscow, April 25th-26th, 2017.
2) Kazak A., Chugunov S., Nachev V., Spasennykh M., Chashkov A., Pichkur E., Presniakov M., Vasiliev A. Integration of Large-Area SEM Imaging and Automated Mineralogy-Petrography Data for Justified Decision on Nano-Scale Pore-Space Characterization Sites, as a Part of Multiscale Digital Rock Modeling Workflow, URTeC 2017 Austin, Texas, July 24-26, 2017.
3) Nachev V., Kazak A., Myasnikov A. 3D Digital Mineral Modeling of Complex Reservoir Rock as an Essential Step for Fracture Propagation Simulation at Microscale 3rd Skoltech - MIT Conference “Collaborative Solutions for Next Generation Education, Science and Technology” Skolkovo Innovation Center, Moscow, October 15-16, 2018.
4) Nachev V., Kazak A., Myasnikov A. 3D Numerical Modeling of Fracture Propagation in Complex Reservoirs Rocks at Microscale EGU General Assembly 2019 Vienna, Austria, April 7-12, 2019.
5) Nachev V. A., Kazak A. V., Turuntaev S. B. Physico-Mathematical Modelling of Mechanical Processes of Rock Fracturing at the Micro- and Nano-scales PROneft. Professionally about oil 4(14) December, 2019.

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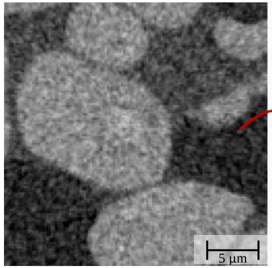
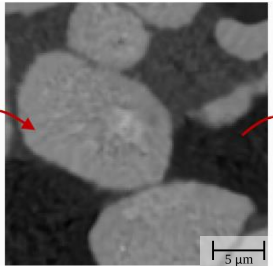
Preparation of Digital Rock Model: Mesh Generation

FEI PerGeos 1.5.0

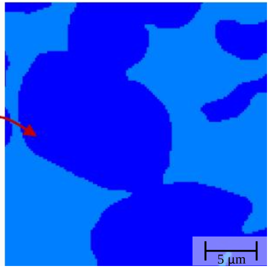
1. Generating surfaces with controlled smoothing
2. Surface simplification
3. Automated / Manual surface edition
4. Remeshing
5. Generating tetrahedral mesh



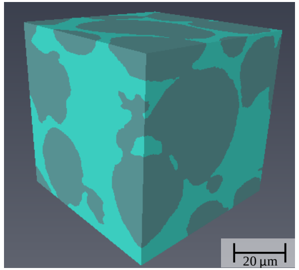
Computed Tomography Data



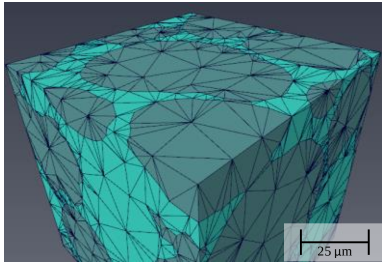
Filtration of CT Data



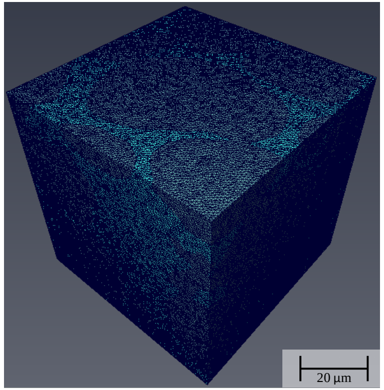
Segmentation of CT Data



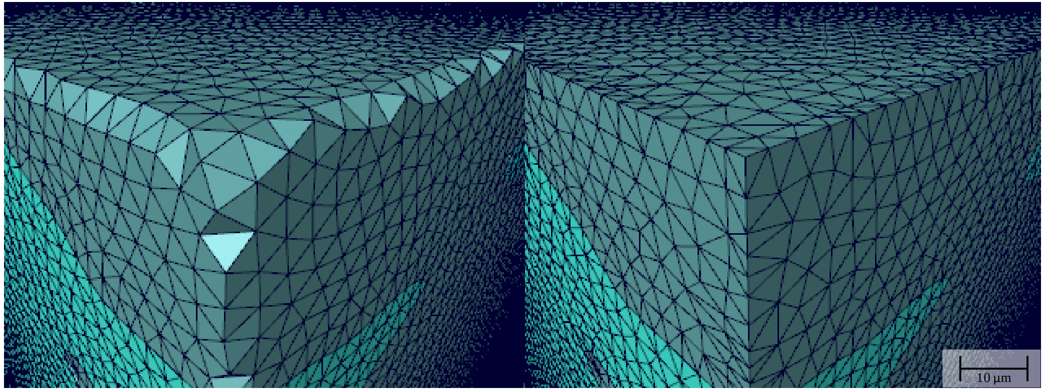
Surface Generated from the Two Phases Label Image



Rough Simplification of the Surface



Simplified Surface



Surface Remeshed with Two Different Values for Smoothness Parameter: 0 (left) and 0.6 (right)

FEI PerGeos Documentation

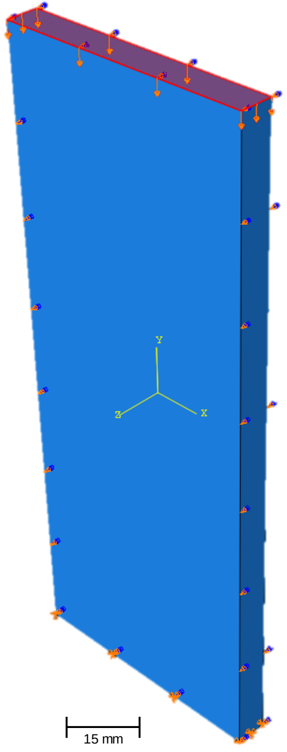
Fracture Modeling: Fracture Propagation in Homogeneous Material

Mechanical Parameters

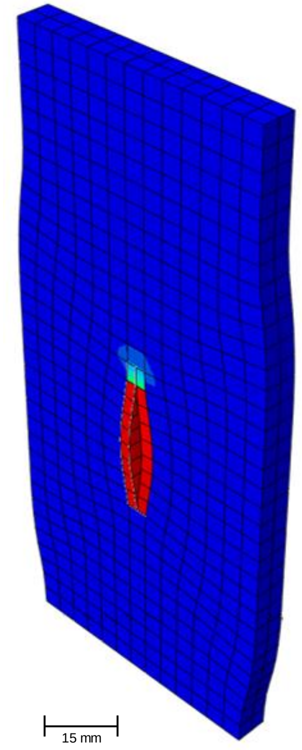
Parameter	Value
E (MPa)	10.0
μ	0.3
σ_{max} (Pa)	500.0
Damage Evolution Parameters	
Type	Displacement
Softening	Linear
Degradation	Maximum
Displacement at Failure (mm)	0.1

Boundary Conditions

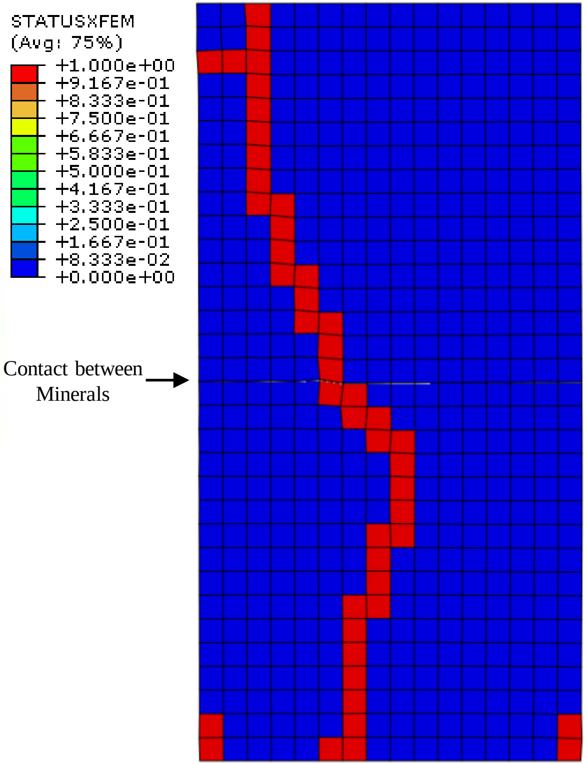
Parameter	Value
U_{x_up} (μm)	0.0
U_{y_up} (μm)	-5.0
U_{x_down}, U_{y_down} (μm)	0.0



Applied BC in Homogeneous Model



Fracture Propagation in Homogeneous Model



Fracture Propagation in Homogeneous Model with Contact

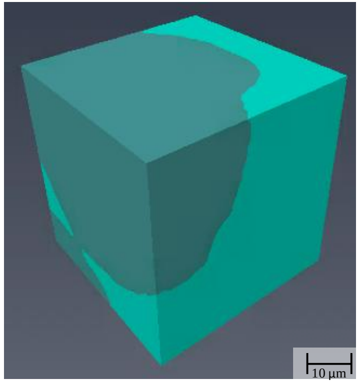
Fracture Modeling: Stress-Strain State of Complex Contact

Mechanical Parameters

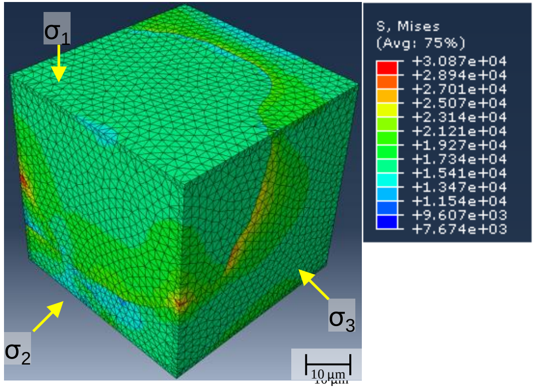
Parameter	Value
Dolomite	
E (GPa)	130.700
μ	0.271
Quartz	
E (GPa)	97.900
μ	0.071

Boundary Conditions

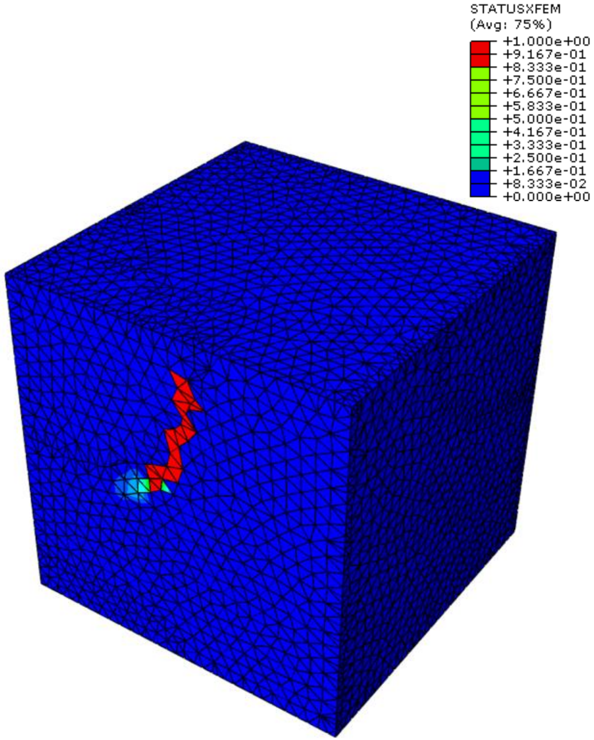
Parameter	Value
σ_1 (MPa)	50.0
σ_2 (MPa)	20.0
σ_3 (MPa)	14.0



Surface of the Complex Segmented Contact between Quartz and Dolomite



Generated Mesh and Stress-Strain State of the Complex Contact between Two Minerals

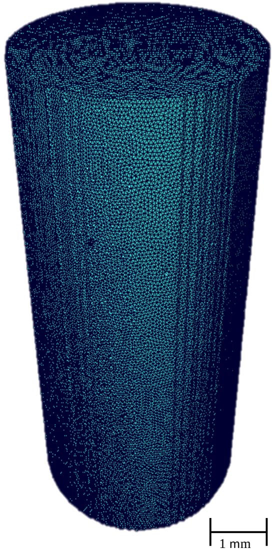


Fracture Propagation between Two Minerals

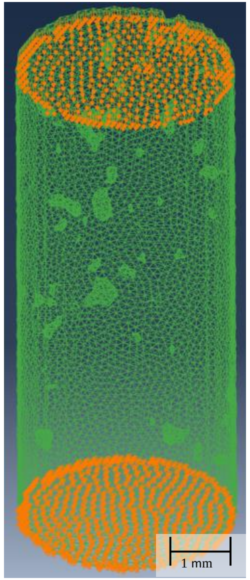
Fracture Modeling: Fracture Initiation in Porous Matrix

Mechanical Parameters

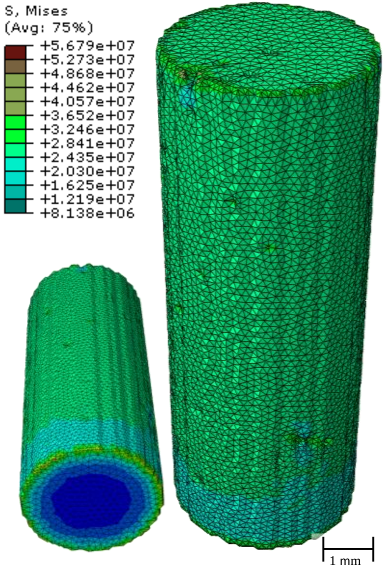
Parameter	Value
E (GPa)	14.610
μ	0.408
ε_{max} (mm)	0.001
Damage Evolution Parameters	
Type	Displacement
Softening	Linear
Degradation	Maximum
Displacement at Failure (mm)	0.00025
Drucker Prager	
Angle of Friction (°)	46.1
Dilation Angle (°)	30.0
Drucker Prager Hardening	
Yield Stress (Pa)	**Abs Plastic Strain (mm)**
60048000	0.00000
72050000	0.00011
73418000	0.00016
75050000	0.00023



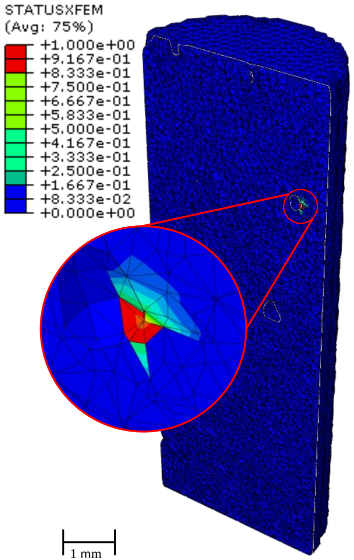
Generated Mesh for Porous Matrix



Applied BC to Porous Matrix



Stress-Strain State of Porous Matrix



Fracture Initiation in Porous Matrix

Boundary Conditions

Parameter	Value
U_{x_down}, U_{y_down}, U_{z_down} (μm)	0.0
U_{z_up} (μm)	-60.0

Nachev V. A., Kazak A. V., Turuntaev S. B. Physico-Mathematical Modelling of Mechanical Processes of Rock Fracturing at the Micro- and Nano-scales PROneft. Professionally about oil

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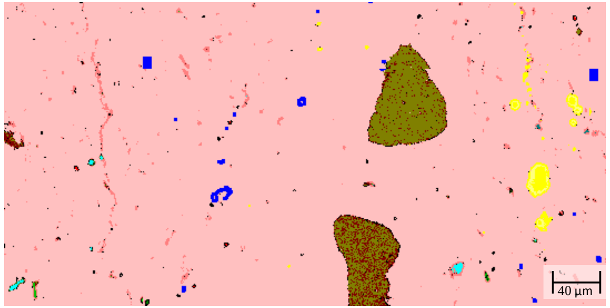
Fracture Modeling: Stress-Strain State of Heterogeneous Material

Mechanical Parameters

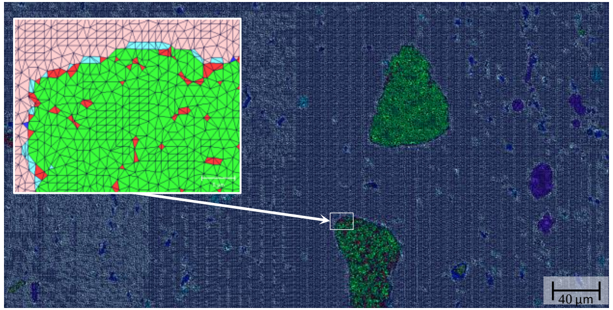
Mineral	E (GPa)	μ
Albite	66.70	0.303
Apatite	94.60	0.066
Glauconite	7.26	0.300
Illite	7.26	0.300
Muscovite	63.00	0.230
Pyrite	281.60	0.169
Pyrite-Quartz	150.00	0.130
Quartz	97.90	0.071
Smectite	7.26	0.300

Boundary Conditions

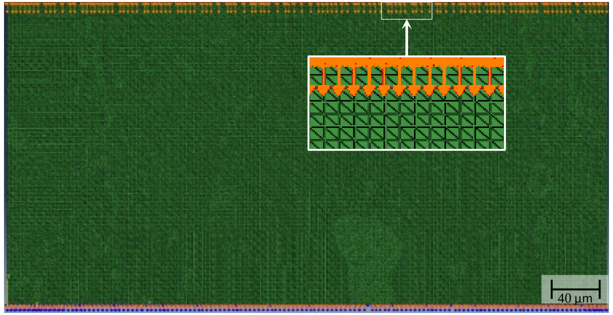
Parameter	Value
U_{x_up} (μm)	0.0
U_{y_up} (μm)	-5.0
U_{x_down}, U_{y_down} (μm)	0.0



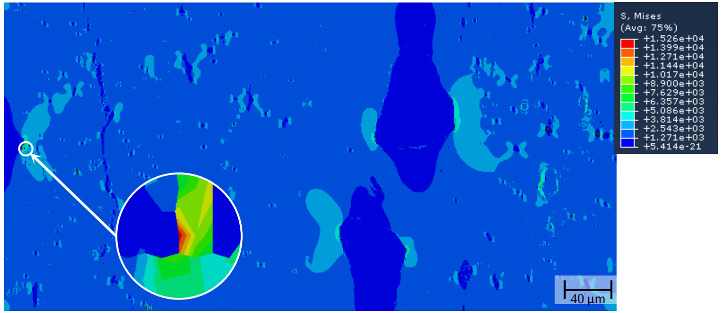
Selected QEMSCAN Zone of Rock



Generated Mesh for Selected QEMSCAN Zone of Rock



Applied BC to Selected QEMSCAN Zone of Rock



Stress-Strain State of Selected QEMSCAN Zone of Rock

Conclusions

- → A set of tools necessary for numerical modeling is proposed.
- → Numerical elastic-plastic fracture propagation modelings in 2D homogeneous models and 3D heterogeneous ones were performed.
- → The stress-strain state of heterogeneous material with nine minerals was calculated.

- → Next steps:
  - → distribution of mineral data from one 2D planar cross-section of the studied samples to the rest for the construction of 3D mineral models.
  - → numerical simulation of probable crack propagation scenarios taking into account the uncertainties arising from the study and validation of the obtained mechanical results, as well as DIC experiments.