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Laboratory study of hydraulic fracturing influenced by stress change.

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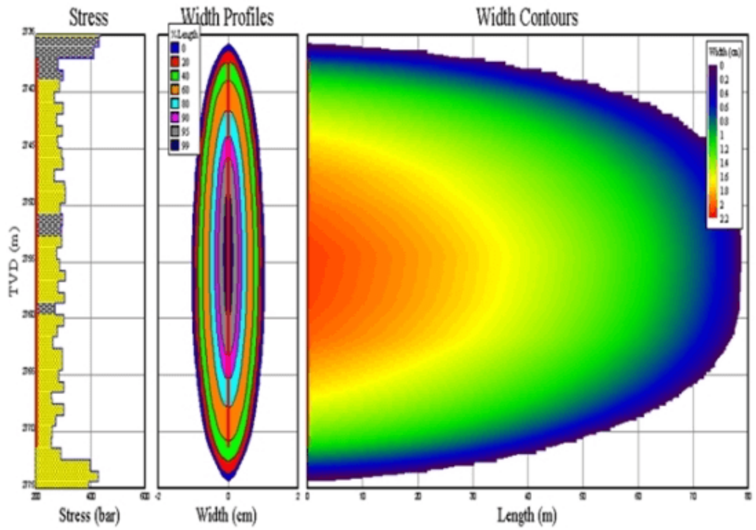
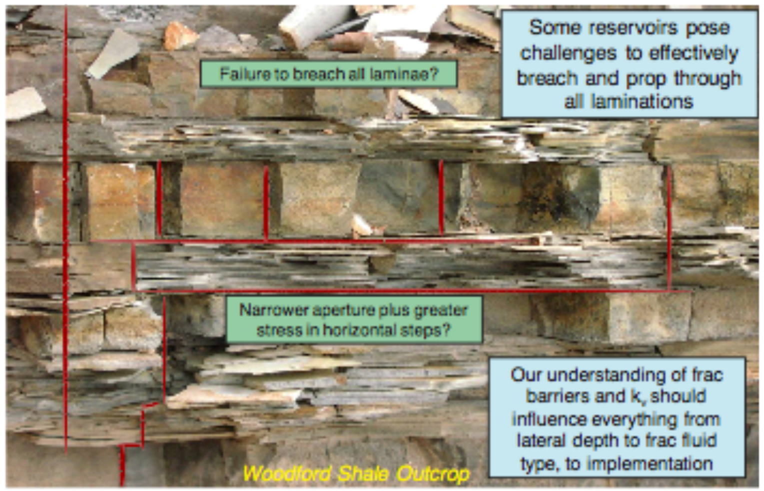
Outline

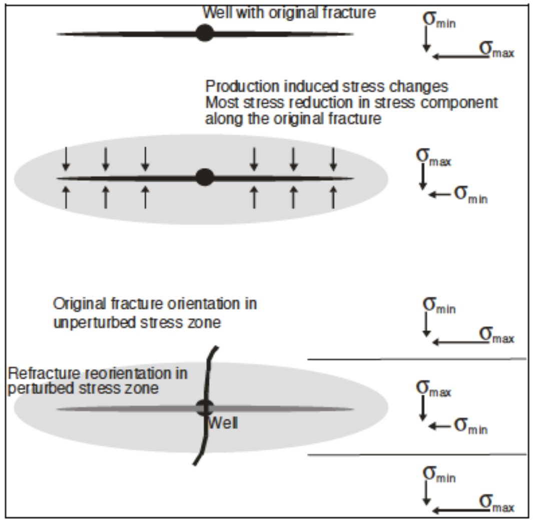
- Motivation and research aims
- Scaling analysis, Experimental setup and procedure
- Experimental results:
  - Refracking reorientation
  - 3 stages of the fracture development
- Discussion, Conclusions, Questions for study, References

Motivation

- Hydraulic fracturing continued to be the main method for oil and gas recovery stimulation
- An increase in the well spatial arrangement density can lead to influence of the neighboring wells on the hydraulic fracturing.
- Oil & Gas producers meet problems related with insufficient hydraulic fracturing model accuracy.
- The model enhancements and sophistications need in lab experiments which allow to estimate influence of the parameters neglected earlier on the fracture.
- The scaled laboratory experiments could be considered as the most reliable method for validation of the models of the hydraulic fracturing.

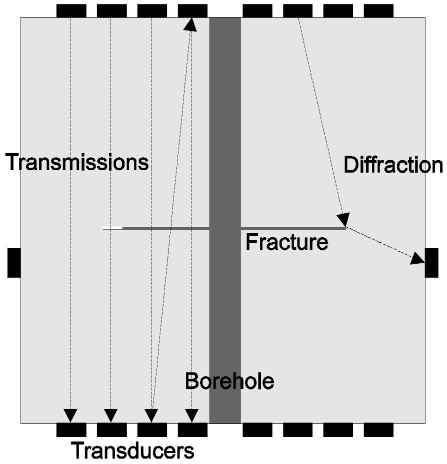




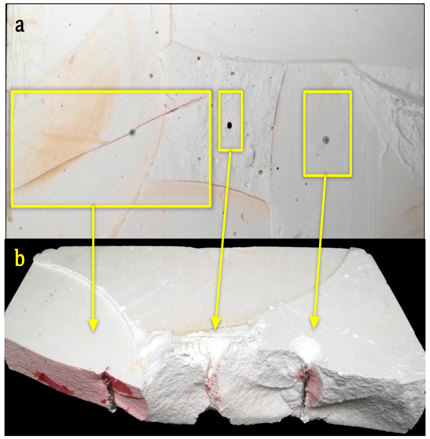


He LIU, SPE, Zhongxiao LAN, Guoliang ZHANG, SPE, Feng HOU, SPE, Xiuqing HE, SPE, PetroChina Daqing Oilfield Co.,Ltd, Xinghui Liu, SPE, Pinnacle Technologies, 2008

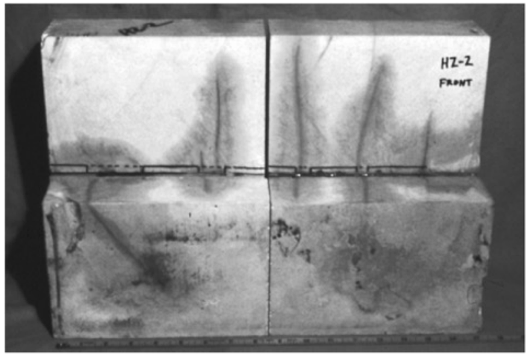
There are a lot of research (experimental in that number) devoted to the study of the hydraulic fractures. Nevertheless, some questions continued to be unresolved and of interest for better understanding the fracturing processes to improve the technology of fracturing in oil & gas reserves.



J. Groenenboom, D.B. van Dam,* SPE, and **C.J. de Pater,** SPE, Delft U. of Technology



Experimental Investigation of Geomechanical Aspects of Hydraulic Fracturing Unconventional Formations by Emad Abbad Alabbad, MS Thesis The University of Texas at Austin, 2014



El Rabaa, W.: SPE 19720, SPE Annual Technical Conference and Exhibition, San Antonio, TX, Oct. 8-11, 1989

Research aims

- Laboratory study of the influence of the stress change and the hydraulic fracture presence in the neighbour boreholes on the fracture propagation
- Study of the fracture propagations
- Study of the possibility to get second fracture from the same perforations

Scaling: dimensionless equations & parameters

$$\frac{\partial p^*}{\partial r^*} = \frac{\bar{\mu} i}{\bar{E} r_w^3}\left(-\frac{q^*}{r^* w^{*3}}\right)$$

$$\frac{\partial w^*}{\partial t^*} + \frac{1}{r^*}\frac{\partial Q^*}{\partial r^*} - \frac{2K_l\sqrt{r_w/i}}{\sqrt{t^* - \tau^*(r)}} = 0$$

$$\frac{w}{r_w} = \frac{2}{\pi}\int_{r^*}^{r_f^*}\frac{u\,du}{\sqrt{u^2 - r^{*2}}}\int_{1/u}^{1}\frac{(p^*(xu) - \sigma/\bar{E})x\,dx}{\sqrt{1 - x_1^2}}$$

$$\pi\frac{K_{1c}}{\sqrt{2r_w}\bar{E}}\sqrt{r_f^*} = \int_1^{r_f^*}\frac{(p^*(r^*) - \sigma/\bar{E})r^*\,dr^*}{\sqrt{r_f^* - r^*}}$$

time $N_t = \frac{ti}{r_w^3}$,

permeability $N_{\bar{E}} = \frac{\bar{E} r_w^3}{\bar{\mu} i}$,

leak-off $N_{K_l} = K_l\sqrt{\frac{r_w}{i}}$,

stress $N_\sigma = \frac{\sigma}{\bar{E}}$,

crack resistance $N_{K_1} = \frac{K_{1c}^2}{4r_w\bar{E}^2}$,

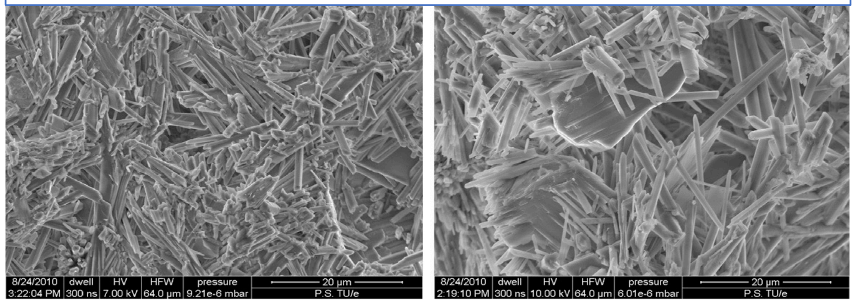
stress ratio $N_\lambda = \frac{\sigma_{max}}{\sigma_{min}}$

C.J. de Pater, M.P. Cleary, T.S. Quinn. *SPE Production & Facilities*. 1994, November: 230-238.
C.J. de Pater, Leen Weijers, Miloi Savic.. *SPE Production & Facilities*. 1994, November: 239-249.
Turuntaev, SB; Zenchenko, EV; Zenchenko, PE; Triminova, MA; Baryshnikov, NA and Aigozhieva, AK. An influence of pore pressure gradient on hydraulic fracture propagation [online]. In: 9th Australasian Congress on Applied Mechanics (ACAM9). Sydney: Engineers Australia, 2017: [712]-[723].

- Gypsum and cement mixed in ratio 10:1 was chosen as a modelling material, 45% water was added to the mixture
- Porosity 40-50%
- Permeability 1 - 2.7 md

$$\sigma_{UCS} = 6.4 \pm 0.93 MPa \quad \sigma_{TSTR} = 0.8 \pm 0.18 MPa$$

Yu Q.L., Brouwers H.J.H. Microstructure and mechanical properties of b-hemihydrate produced gypsum: An insight from its hydration process. Construction and Building Materials 25 (2011) 3149–3157.

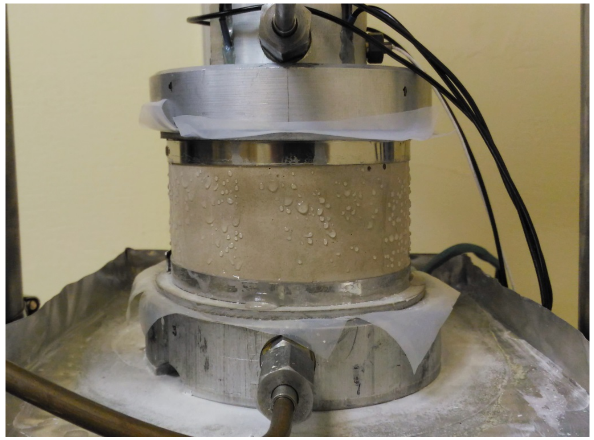


a b

The gypsum water solution was used to simulate the strata fluid. Vacuum mineral oil (viscosity 112 cP, density 0.86 g/cm^3) was used for simulation of the fracturing fluids.

Cement/gypsum ratio	1/8	1/8	1/8 + silicate glue	1/8 + silicate glue	1/10	1/10
Permeability (mDarcy)	23.3	23.6	24.9	24.4	1.7	1.8

Measurement type	Bulk density, g/sm³	P-wave velocity in massif, m/s	Rod p-wave velocity, m/s	Young's Modulus, **GPa**	Poisson's Ratio
Dynamic	1.77	2310	2100	7.7	0.26
Static	1.77	2260	-	3.6	0.21



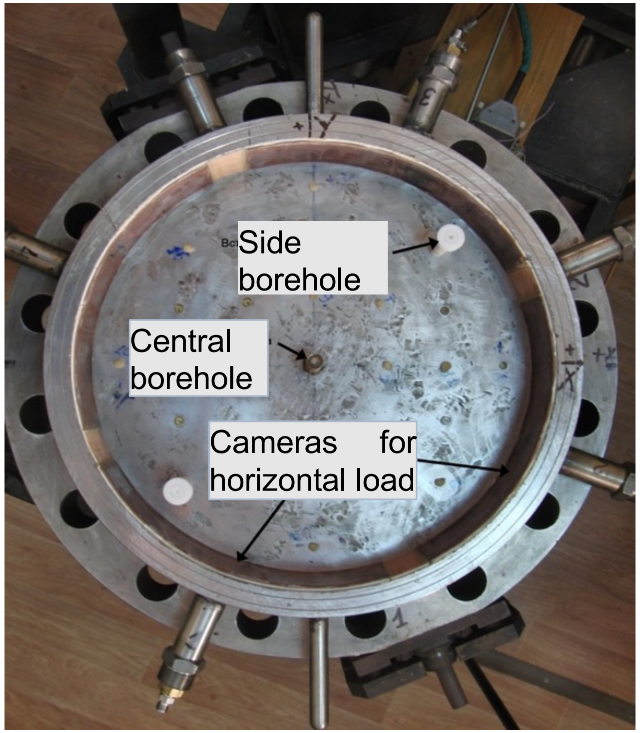
Sample dimensions
- ✓Diameter 430 mm
- ✓Height 65 mm

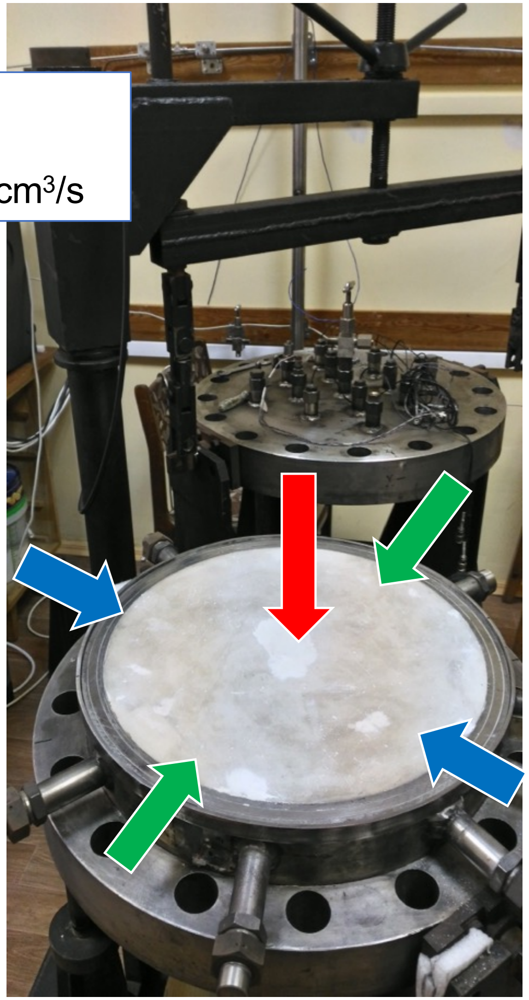
Laboratory setup

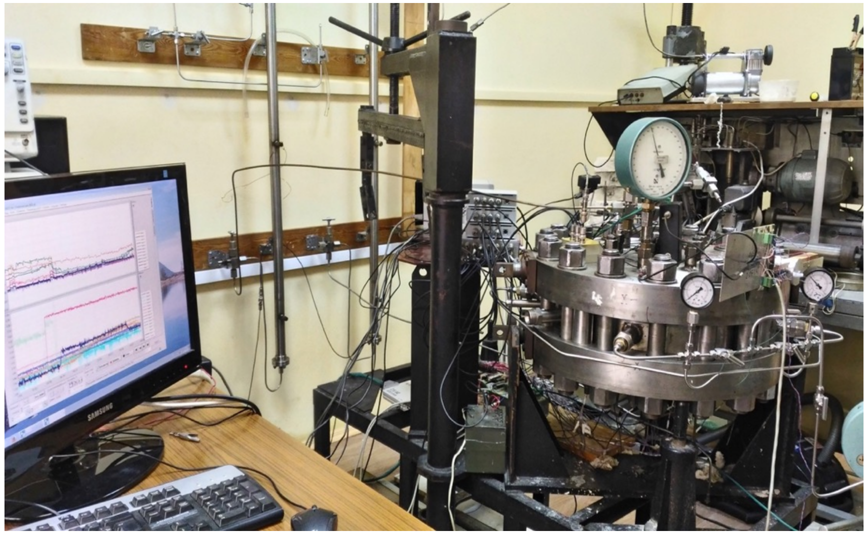
Loading options
- ✓Max vertical stress: 15 MPa
- ✓Max horizontal stress: 10 MPa
- ✓Max pore pressure difference: 9 MPa

Injection options
- ✓Max pore pressure: 15 MPa
- ✓Max constant injection rate: 0.3 cm^3/s

Measurements
- ✓ Flow rate
- ✓ Pore pressure in 15 points of the settings
- ✓ Acoustic emission (15 transducers)
- ✓ Ultrasonic wave propagations
- ✓ Fracture rate
- ✓ Strains

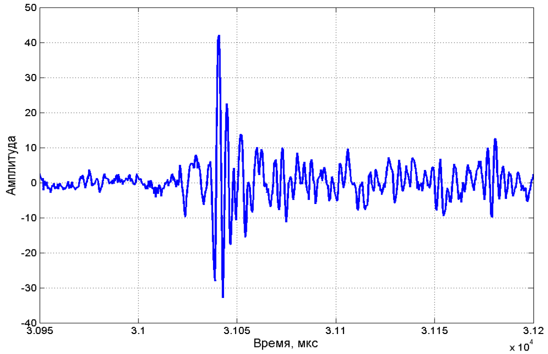


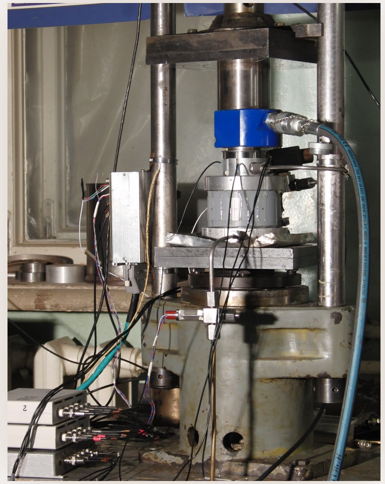




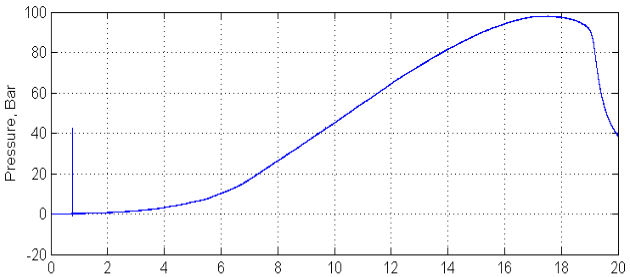
Preliminary experiments with small samples

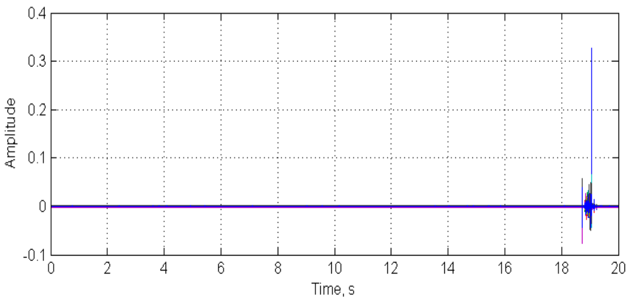
Diameter	105 mm
Hight	65 mm

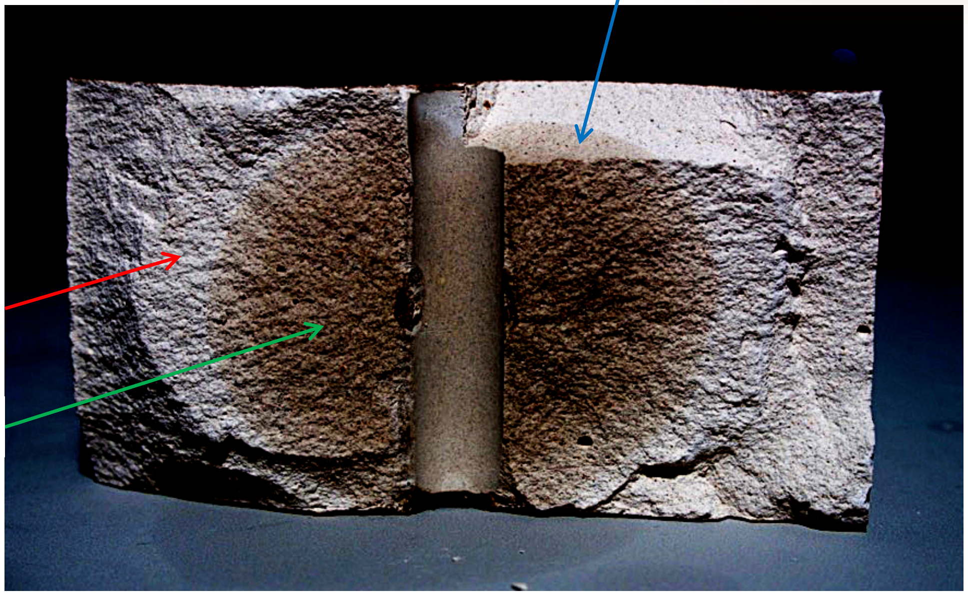




Fracturing fluid leak-off



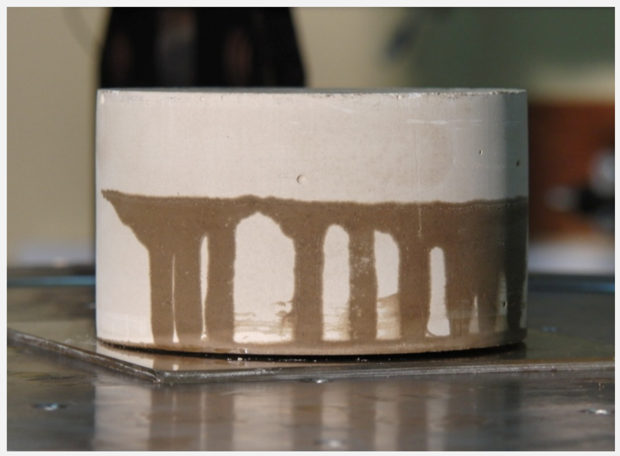


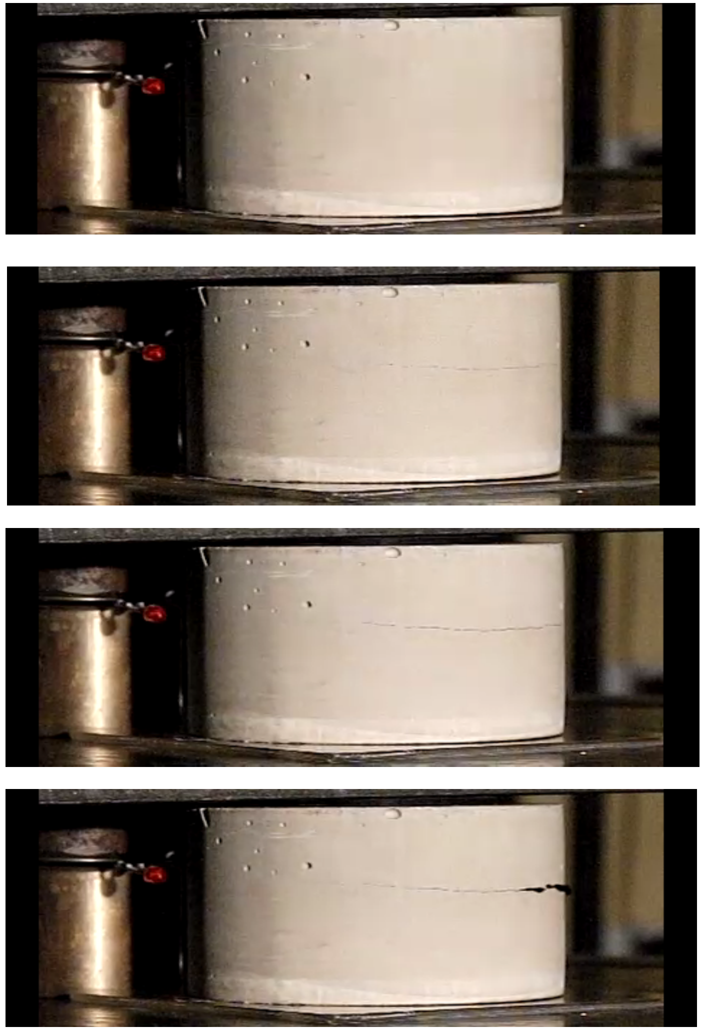


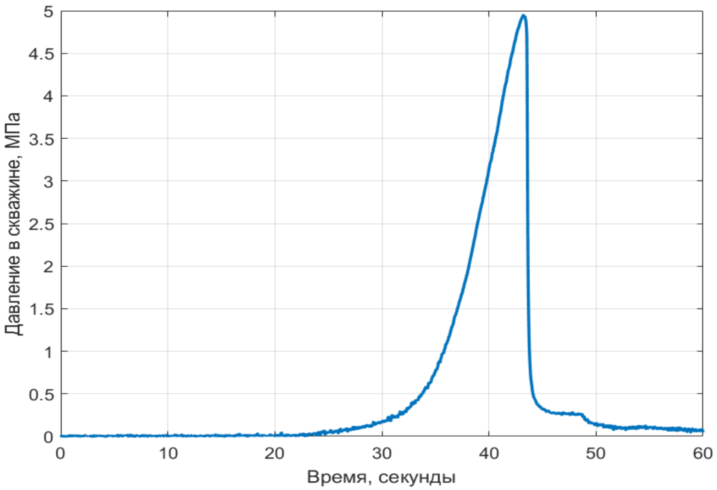
Dry tip of the fracture

Fracture filled by fluid

Preliminary experiment to produce horizontal fracture

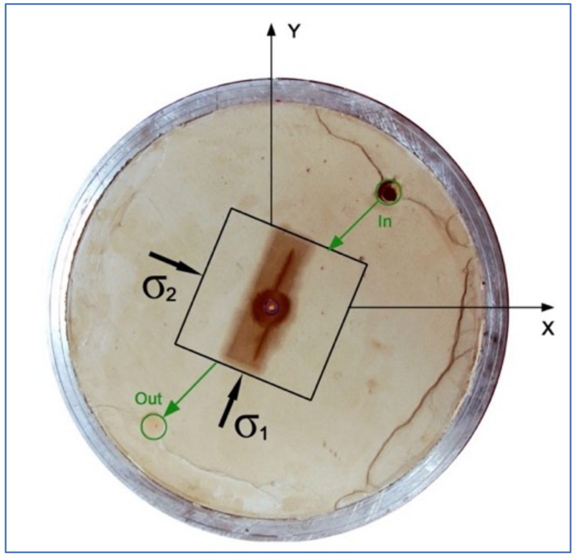


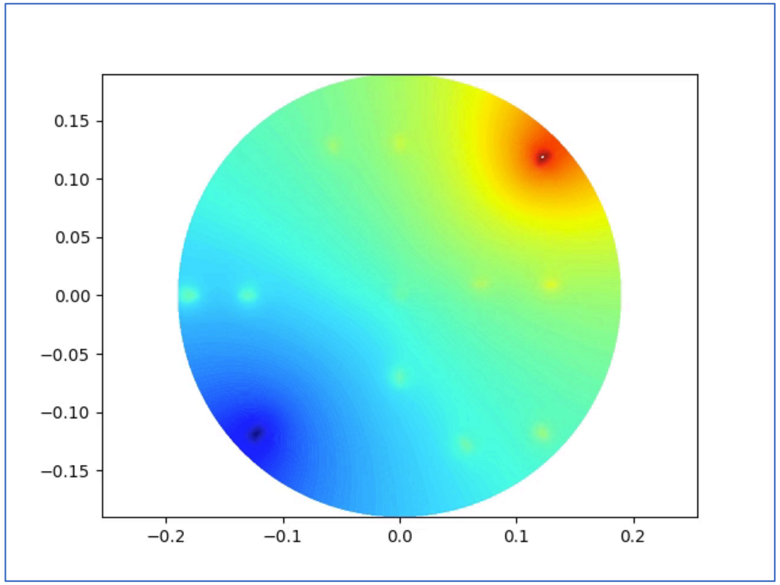


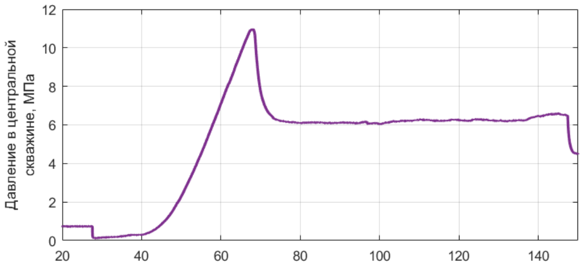


Mean fracture rate 130 mm/sec

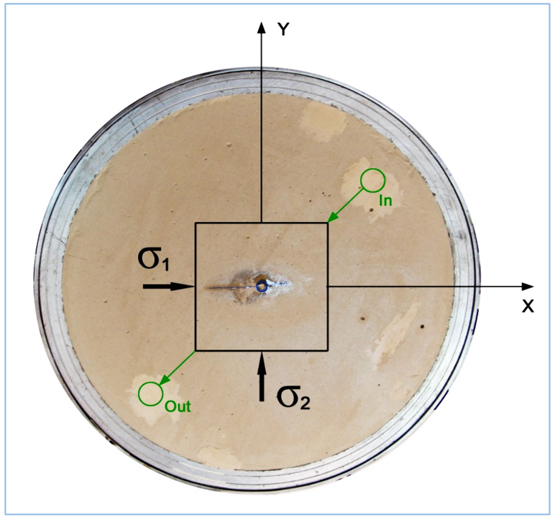
Fluid flow rate inside the fracture 70 mm/sec

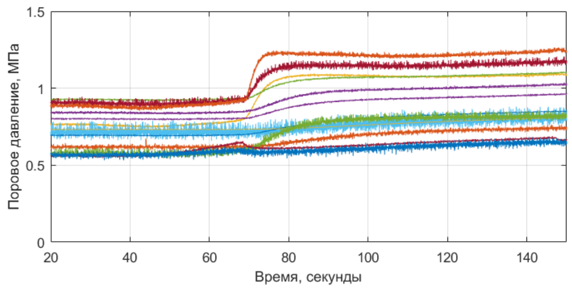


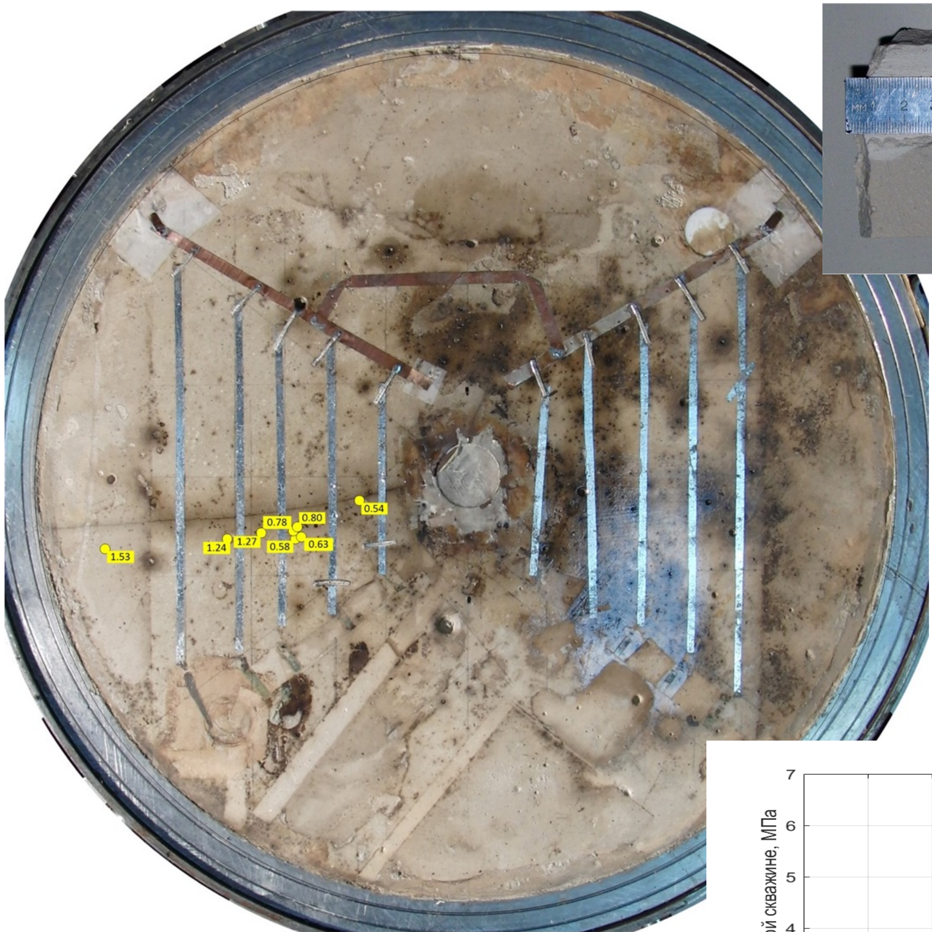


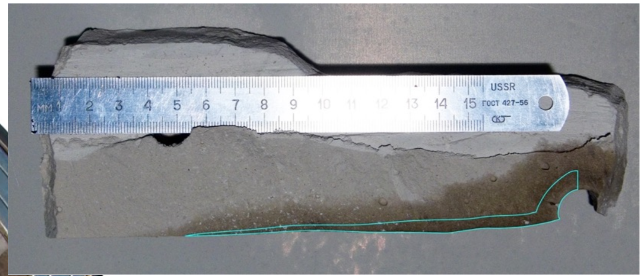


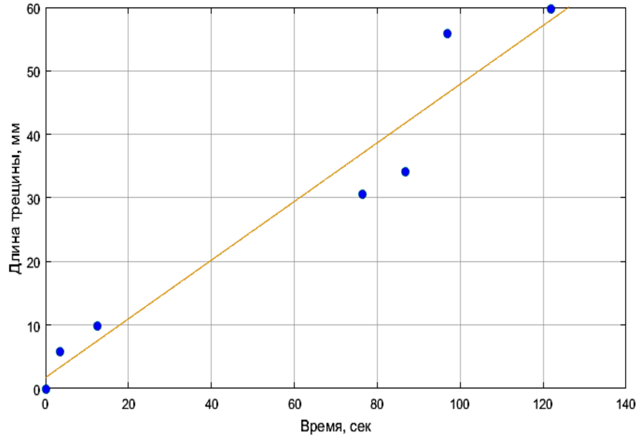
- Vertical stress, Mpa 7,1
- Minimal horizontal stress, Mpa 0,55
- Maximal horizontal stress, Mpa 1,0
- Side well injection pressure, Mpa 1,0
- Central well rate, sm^3/s 0,37
- Angle between pore pressure gradient and max stress direction, grade 22,5







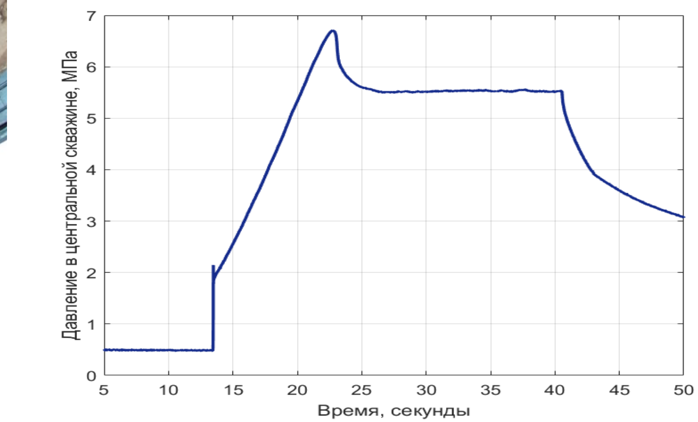


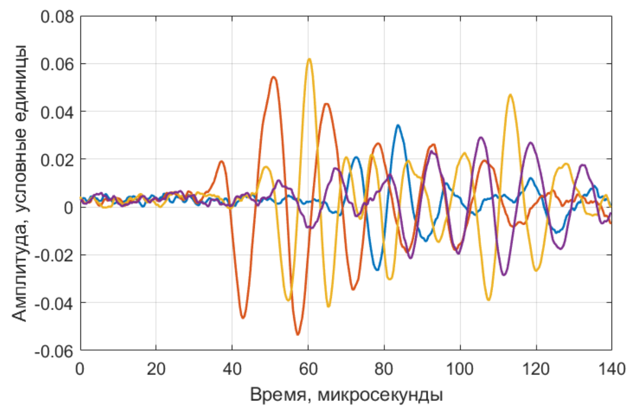


σ_{max}

Fracture rate 0.45 mm/sec ± 0.07 mm/sec.

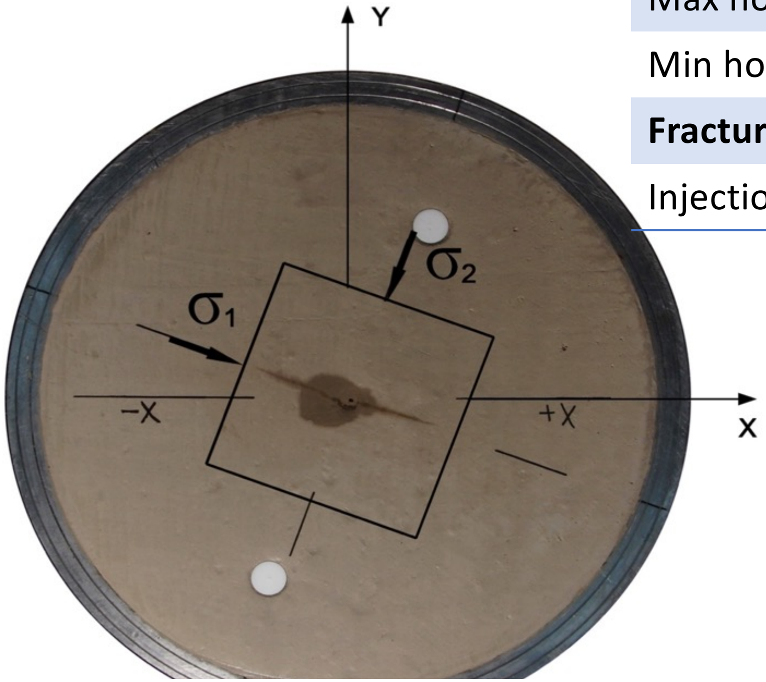
Fracture rate 90 mm/sec



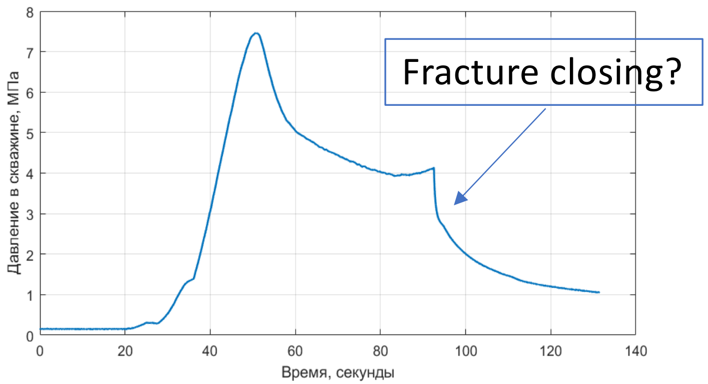


Vertical stress	**6,5 MPa**
Horizontal stress X	**2 MPa**
Horizontal stress Y	**0,6 MPa**

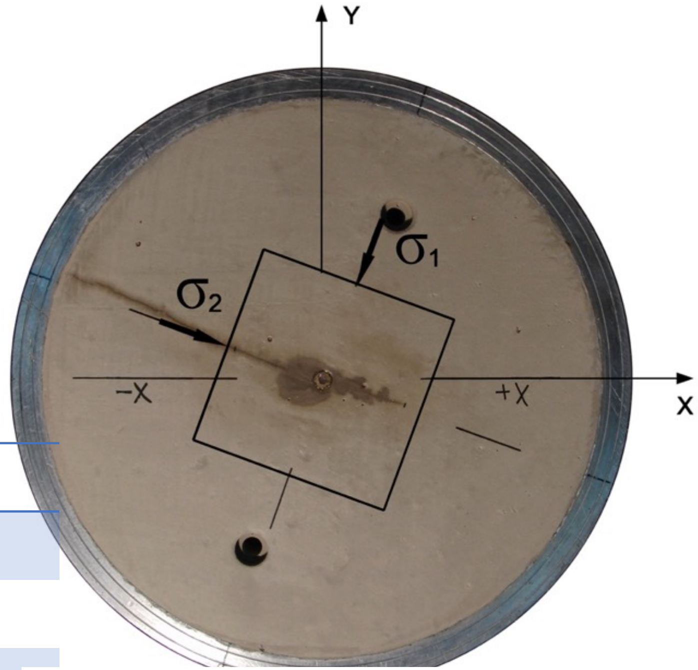
Fracturing 1



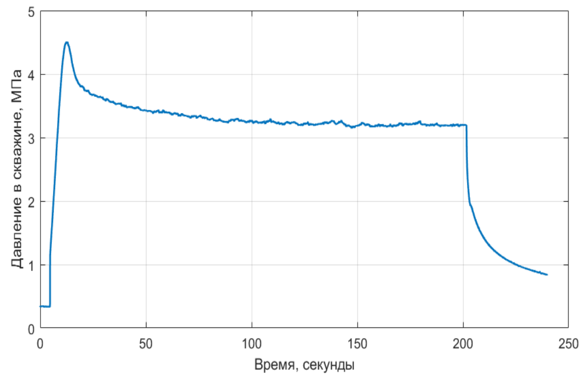
Vertical stress, MPa	3.3
Max horizontal stress, MPa	1.5
Min horizontal stress, MPa	0.2
Fracturing pressure, MPa	**7.4**
Injection rate, cm^3/sec	0.2

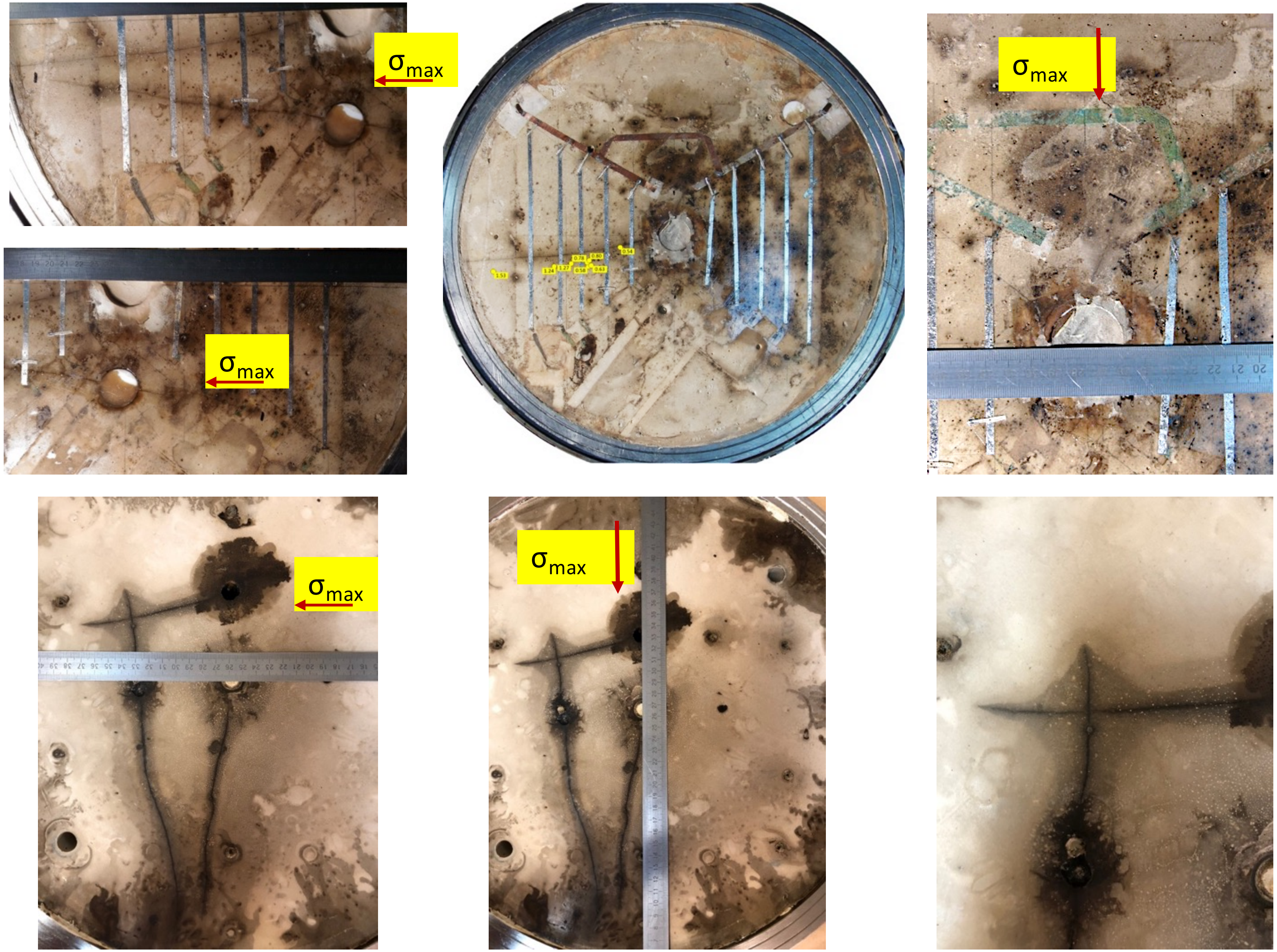


Fracturing 2-3



Vertical stress frac2, MPa	3.3
Max horizontal stress frac2, MPa	1.5
Min horizontal stress frac2, MPa	0.2
Fracturing pressure frac2, MPa	**5.0**
Vertical stress frac3, MPa	3.0
Max horizontal stress frac3, MPa	1.9
Min horizontal stress frac3, MPa	0.1
Fracturing pressure frac3, MPa	**4.5**
Injection rate, cm^3/sec	0.2




σ_{max}
σ_{max}
σ_{max}
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σ_{max}

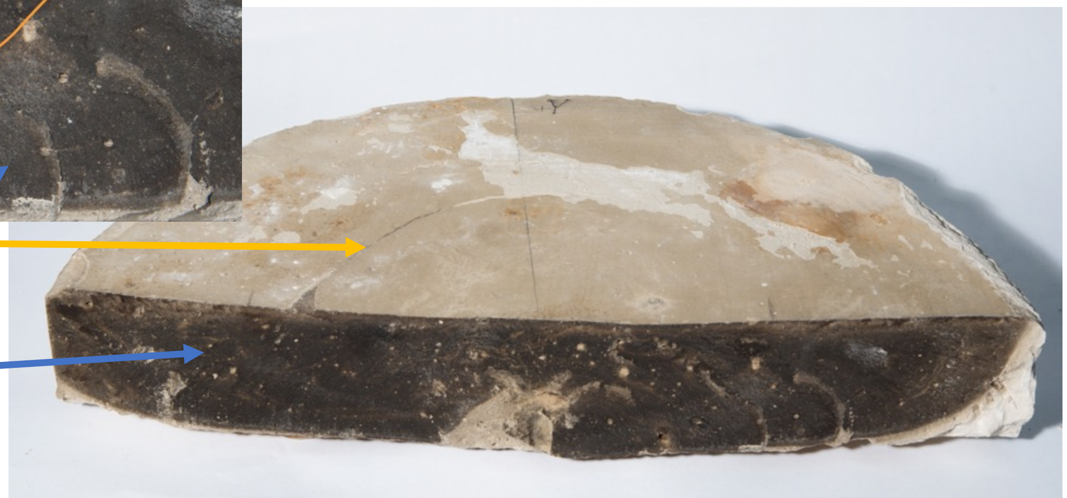
Horizontal fracture and vertical fracture

The fracture had horizontal part of 36 mm in radius, then it declined from the horizontal direction and finally it came to the sample upper surface.

Then, several experiments were made, in which the fluid was injected under different values of the vertical stresses in range 0.5 – 2.5 MPa.

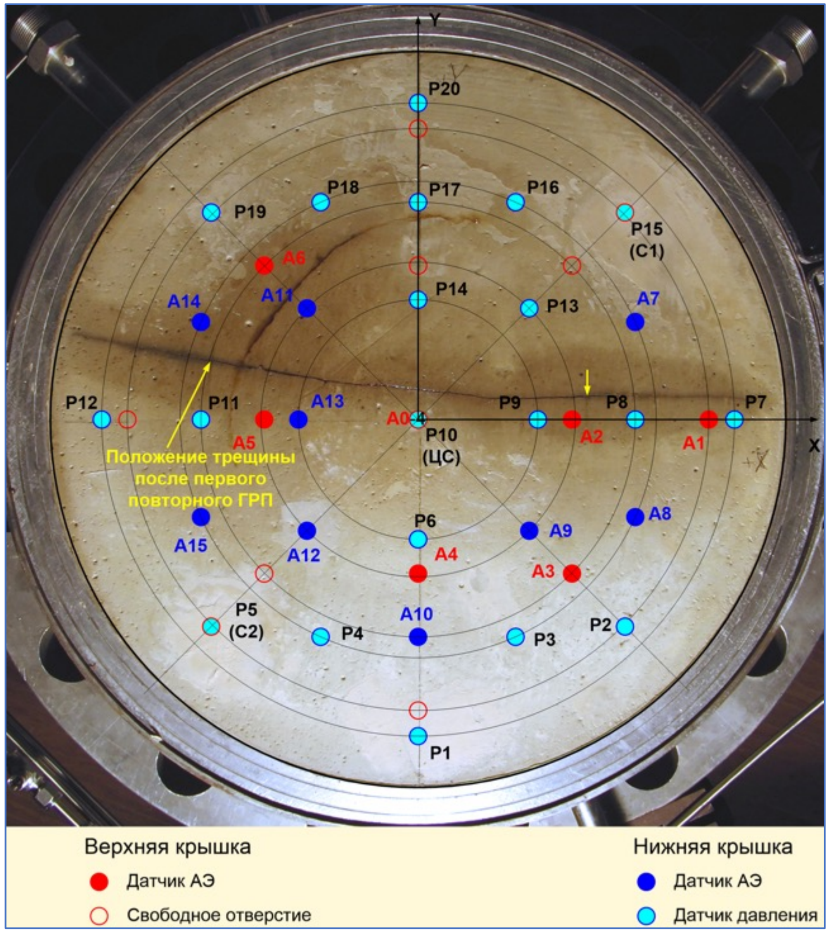
After that, the vertical stress was increased up to 6.9 MPa and horizontal stresses were made 3.2 MPa & 0.95 MPa. A vertical fracture formed, which intersected the horizontal fracture.

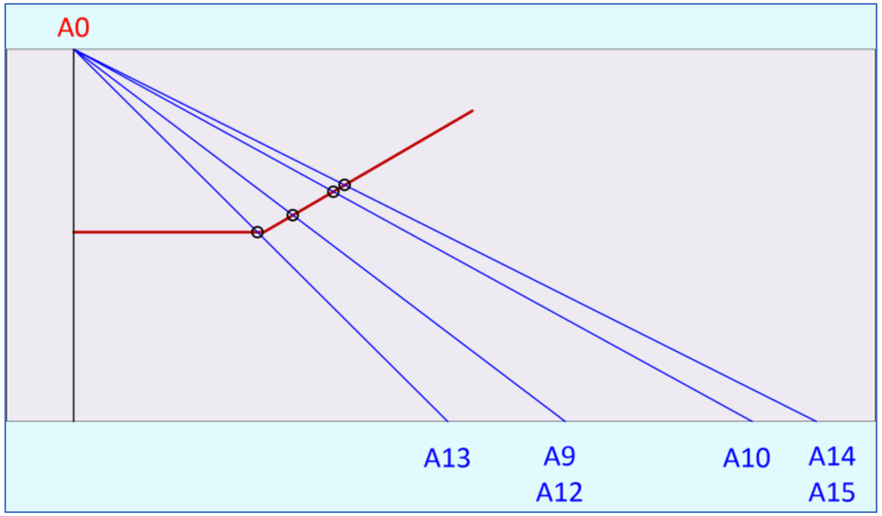
Vertical stress 0.95 MPa
Horizontal stresses (X & Y) 1.5 MPa



Vertical stress 6.9 MPa
Horizontal stresses (X & Y) 3.2 MPa & 0.95 MPa

Measurements of the fracture growth by ultrasonic waves





Sketch of the fracture (red line) and ultrasonic wave rays (blue lines).

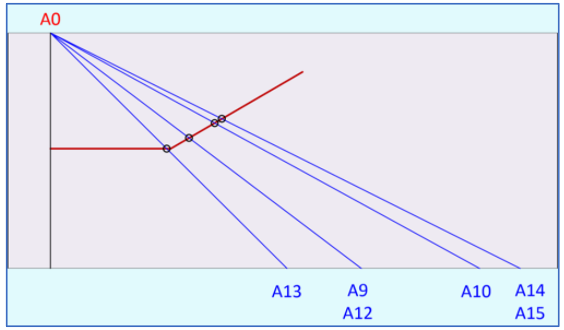
Photo of the sample after the first fracturing and two re-fracturing. The positions of acoustic sensors in upper lid and in bottom lid, as well as fluid pressure transducers are shown by red, blue and light blue points respectively.

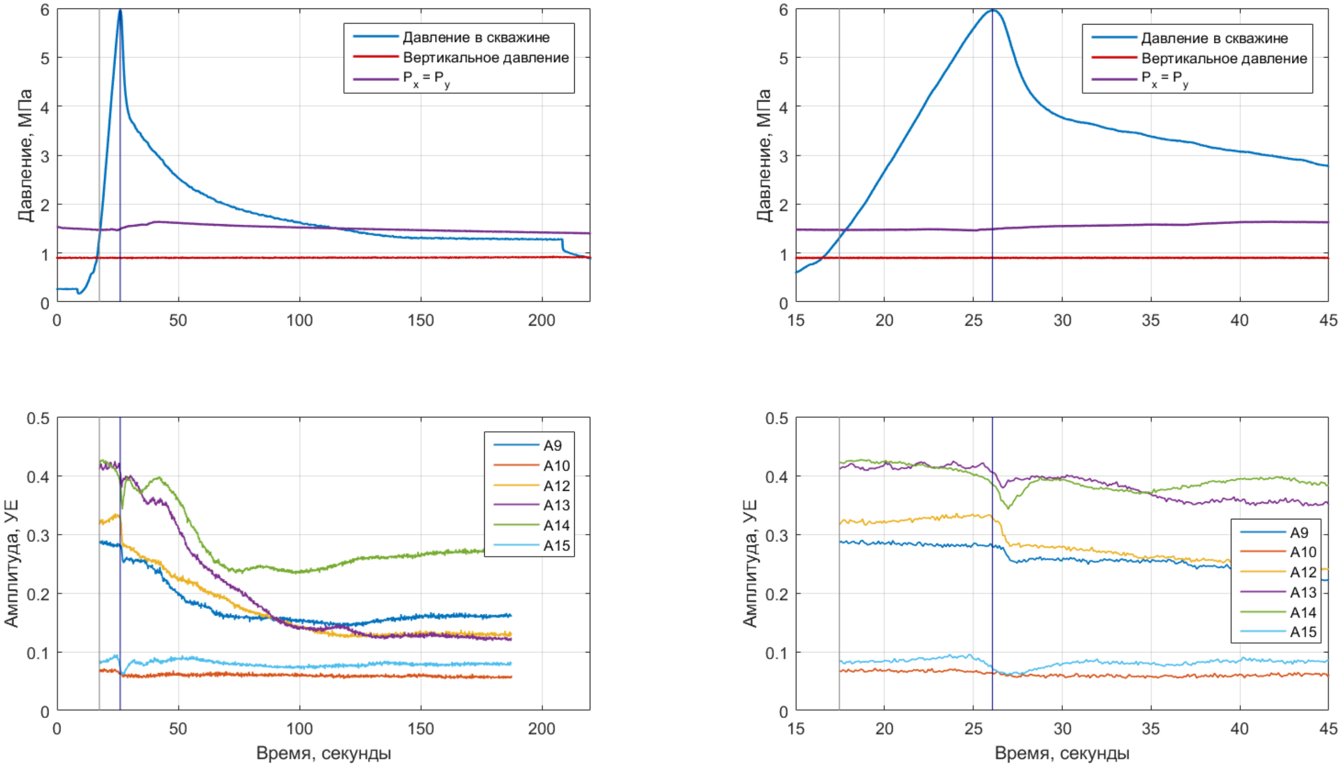
Medlin W, Masse L (1984) Laboratory Experiments in Fracture Propagation. SPE, June 1984, 256-268.

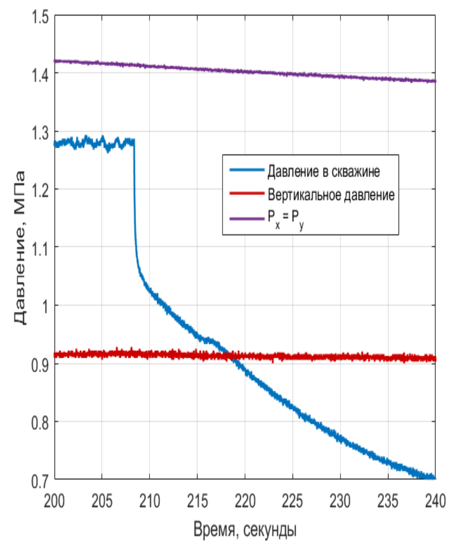
Zoback M, Rummel F, Jung R, Raleigh C (1977) Laboratory hydraulic fracturing experiments in intact and pre-fractured rock. Int J Rock Mech Min Sci Geomech Abstr, 14, 49–58.

Stanchits S, Surdi A, Gathogo P, Edelman E, Suarez-Rivera R (2014). Onset of Hydraulic Fracture Initiation Monitored by Acoustic Emission and Volumetric Deformation Measurements. Rock Mech Rock Eng, 47, 1521–1532.

Fracture 1: injection pressure and ultrasonic wave amplitudes





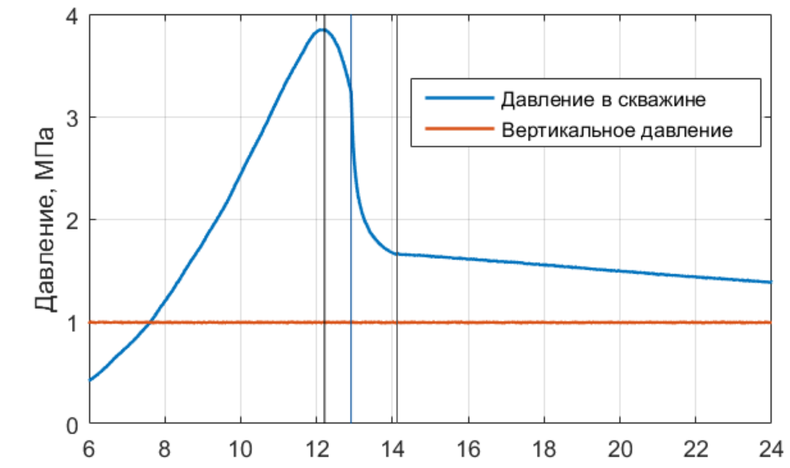


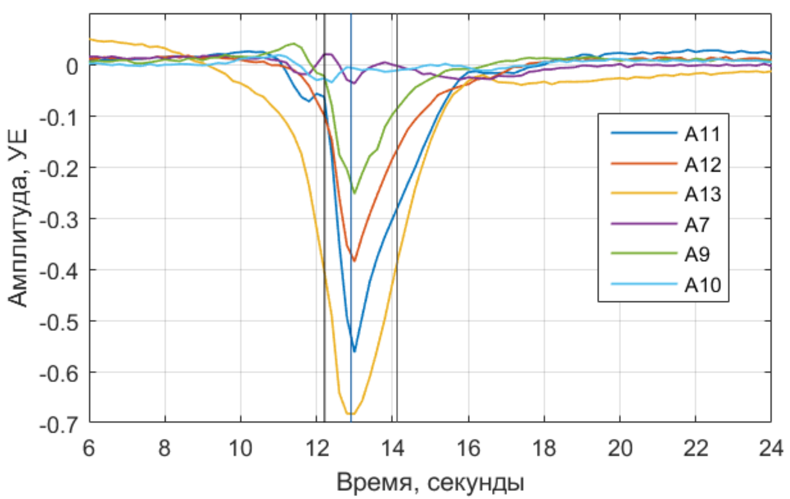
Fracture closing

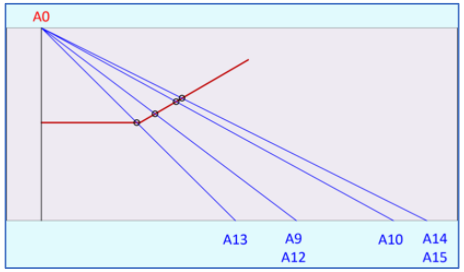
1. First diminishing of the waves amplitudes is caused presumably by the dry fracture forming.
2. Next increase of the amplitudes is related with the fracture infill by fracturing fluid (estimated rate 35 mm/sec).
3. Next decrease of the amplitudes is caused by the fracture opening due to continue of the fluid injection.

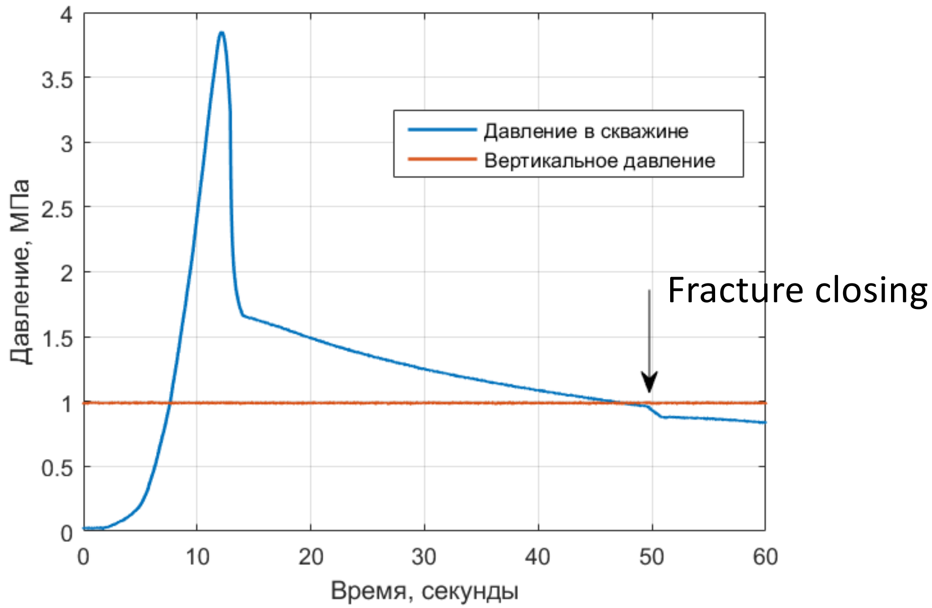
(Medlin W.L., Masse L. Laboratory Experiments in Fracture Propagation. SPE. June 1984. PP 256-268).

Fracture 1 re-opening



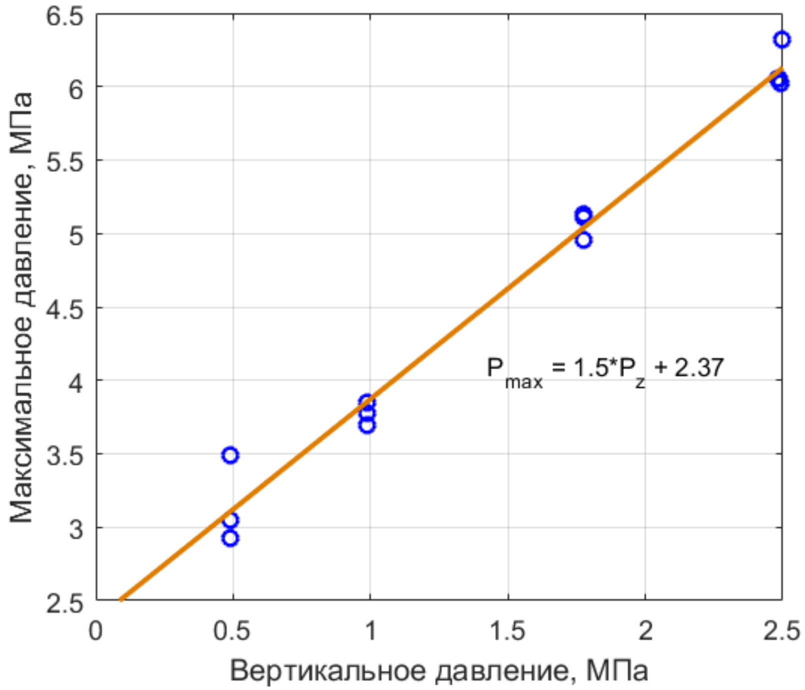


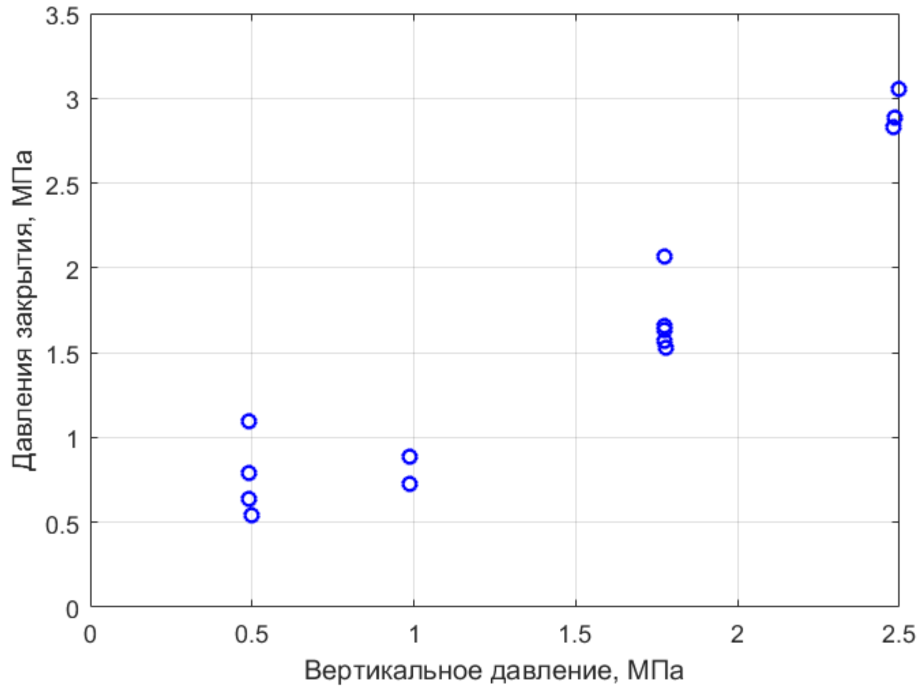


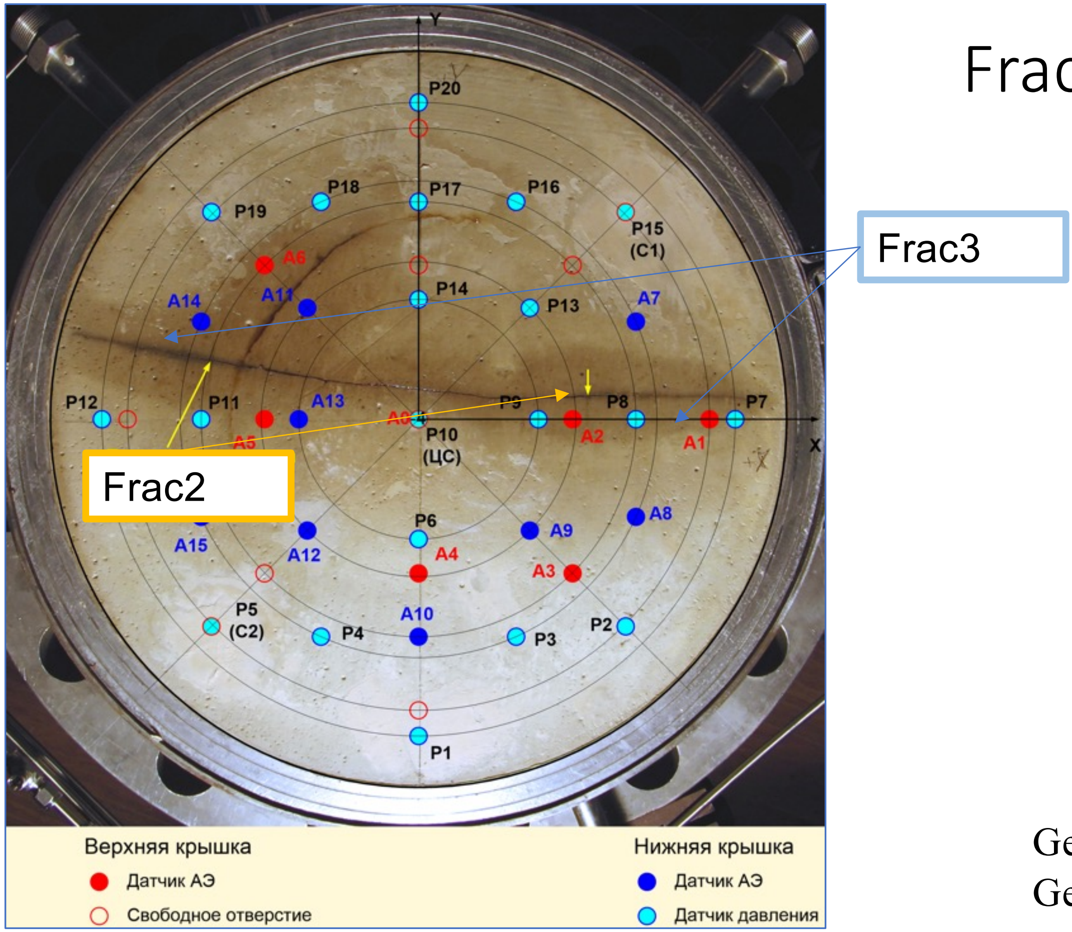


Vertical stress 1 MPa, horizontal stresses 0.2 MPa. The injection was stopped almost immediately after the pressure maximum.

Relations between maximal injection pressure (fracture opening pressure), fracture closing pressure and vertical stresses.







Fracturing 2 & 3: vertical fracture.

Vertical stress 6.8 MPa
Horizontal stress X 3.2 MPa
Horizontal stress Y 1 MPa

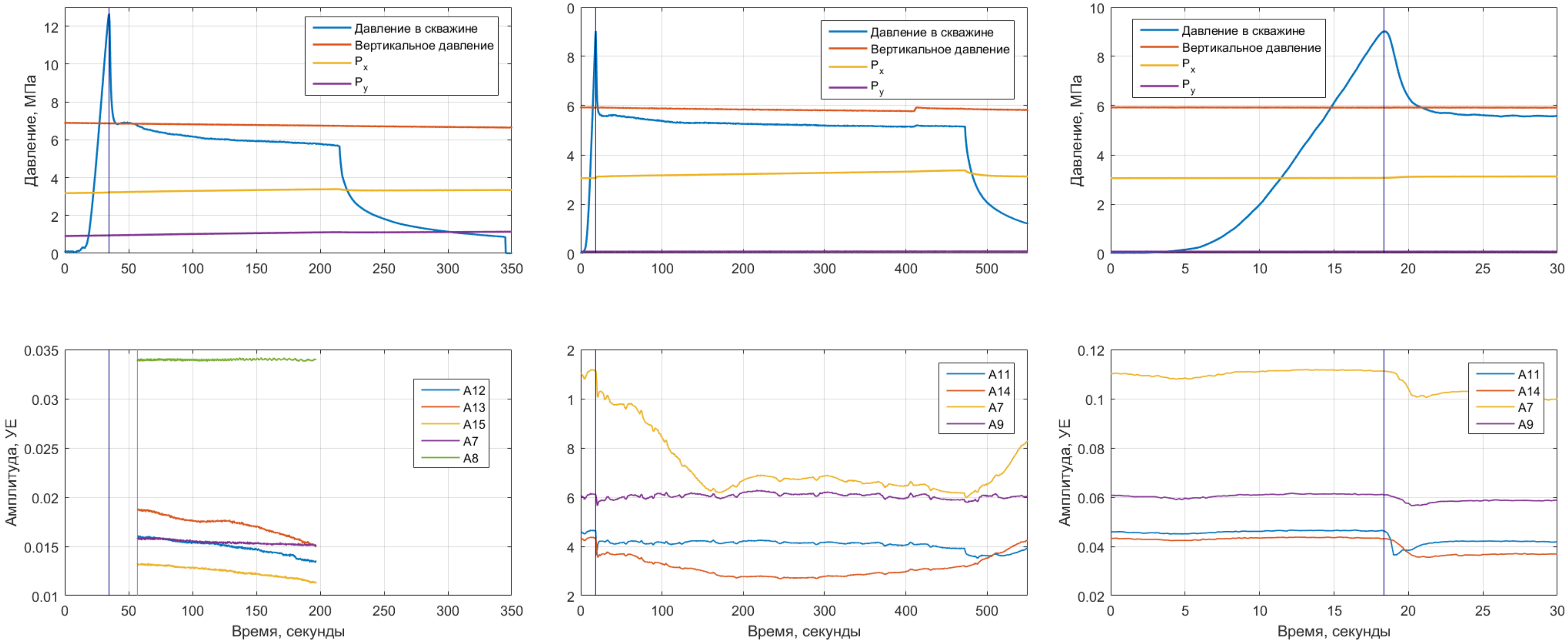
Frac2

Vertical stress 5.8 MPa
Horizontal stress X 3 MPa
Horizontal stress Y 0.1 MPa

Frac3

Generator A6, transducers A12, A13, A15;
Generator A3, transducers A7, A8.

Fracturing 2 & 3: vertical fracture.



Frac2

Frac3

Conclusions

- If the fracturing fluid viscosity is much grater than viscosity of the fluid saturated the sample, there should be no acoustic (microseismic) events outside the fracture.
- It is possible to create another fracture from the same perforation, if the main stress axis orientation is changed dramatically.
- The hydraulic fracture development can be divided into three stages:
  - A dry fracture propagation,
  - Fluid flow in the fracture,
  - An increase of the fracture aperture.
- The dry fracture propagation rate is estimated as 130 mm/sec.
- The fluid flow rate is 35 mm/sec.
- The fracture opening and closure pressures is dependent linear on the minimal main stress.

References

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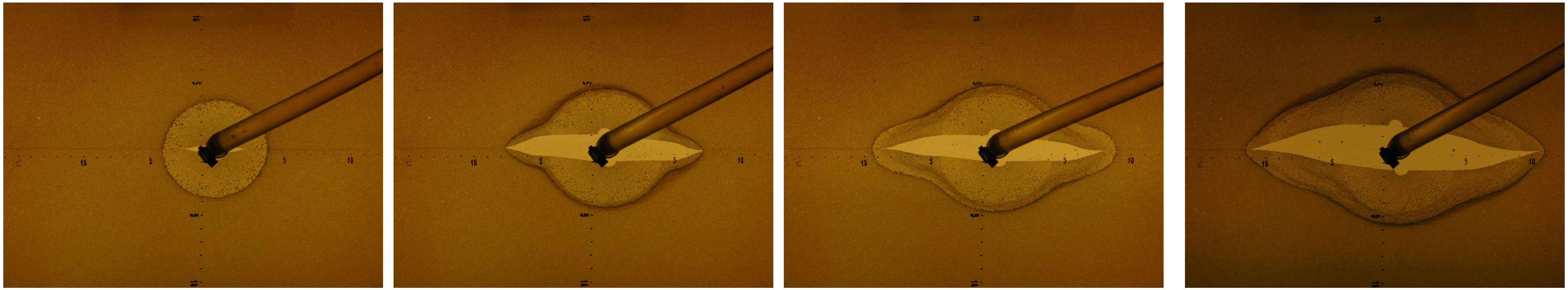
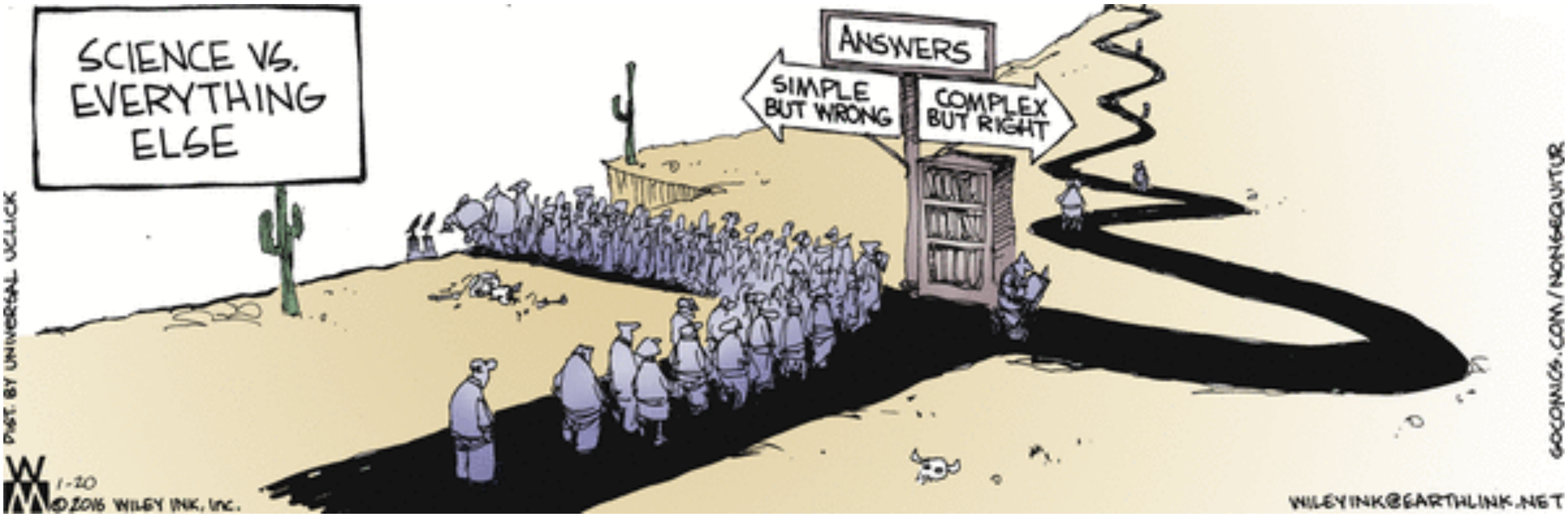
Questions after experiments

1. Why the fracturing pressure is much higher than it should be expected?
2. Why the fracture closing pressure estimated by G-function is much higher in case of the vertical fractures than it should be expected?
3. What is the reasons for absence of the acoustic emission (high viscosity of the fracturing fluid)?



Thank you!



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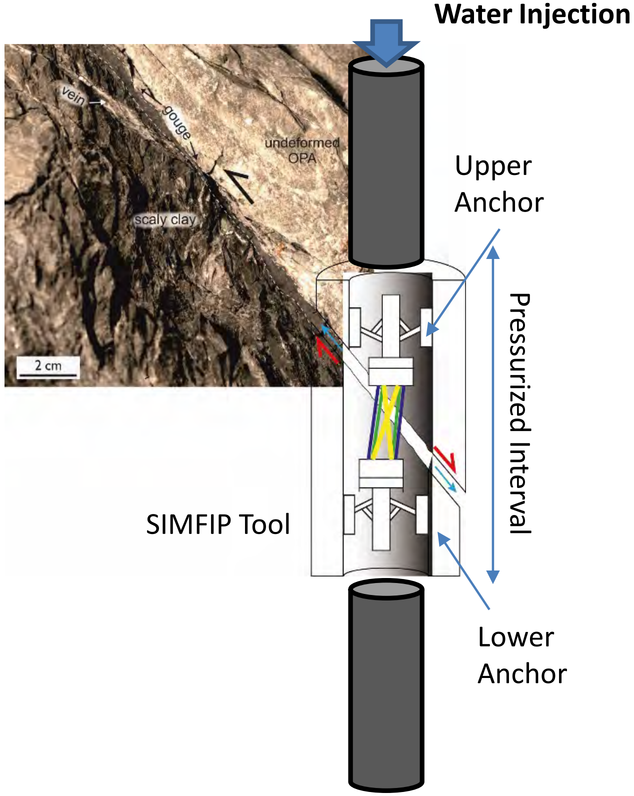
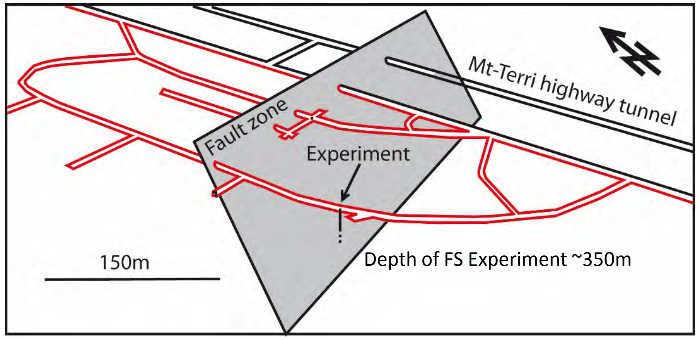
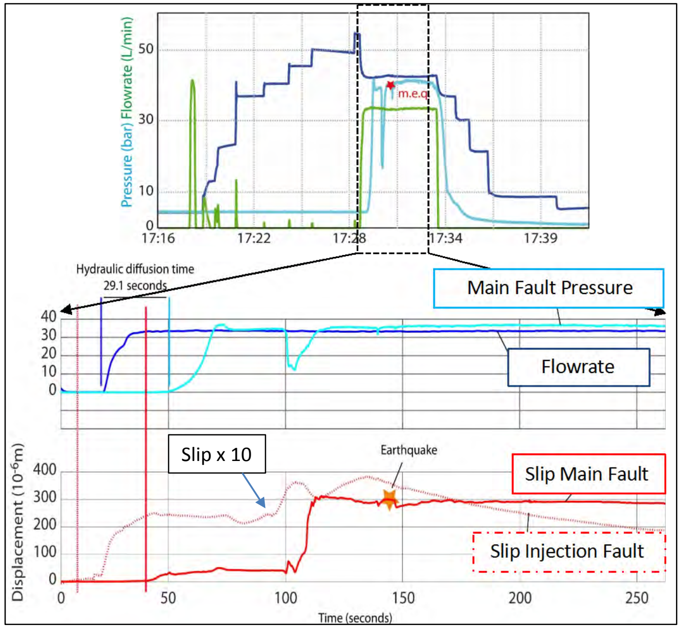
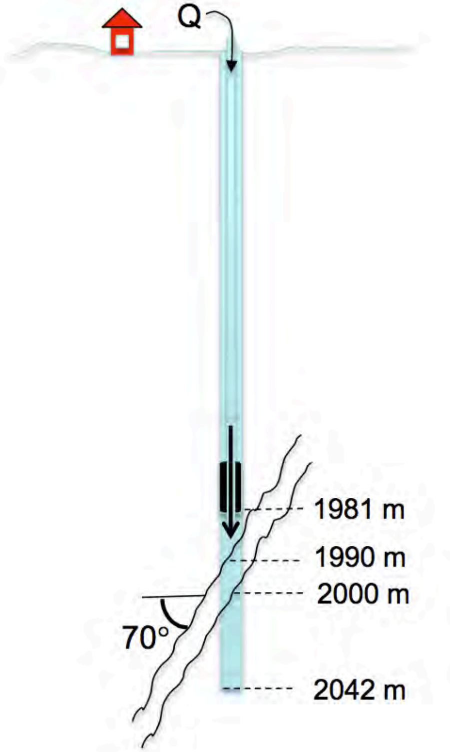






Fenton Hill Experiment: fracture inflation



Fracture radius
Estimated to 270 m

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