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Numerical models for the design of hydraulic stimulation

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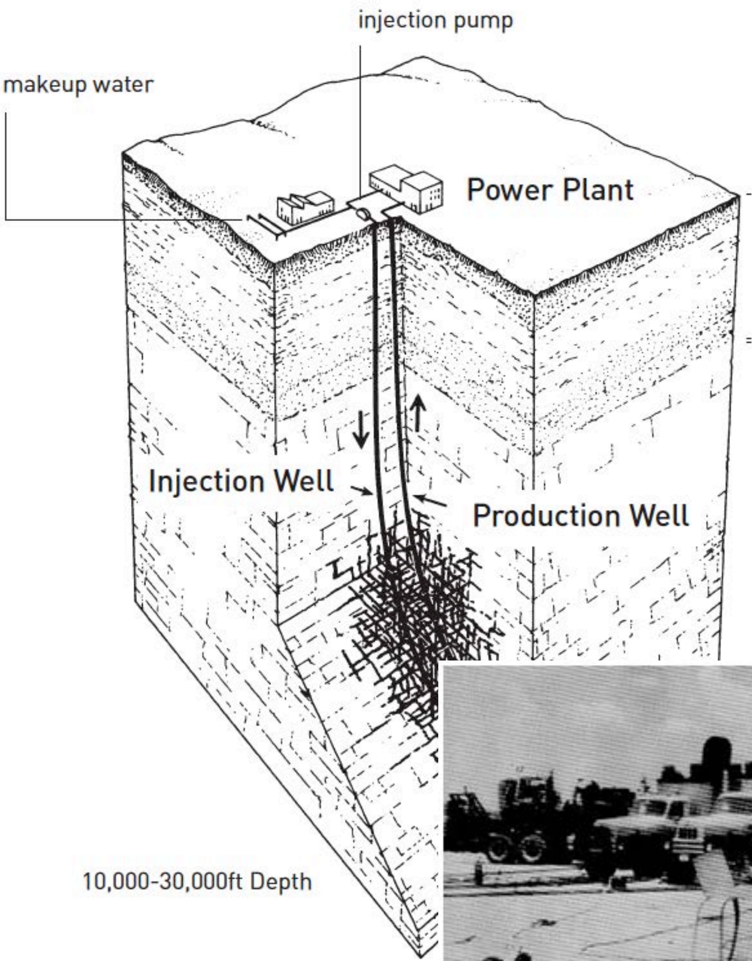
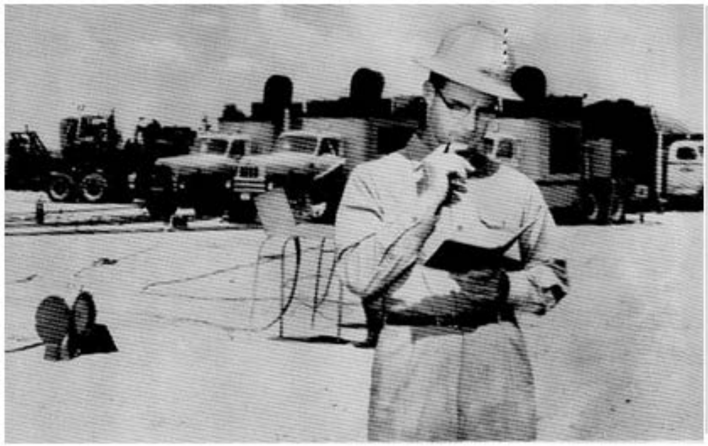
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

GeoEnergyLab

Hydraulic stimulation vs Hydraulic fracturing



[Tester et al, 2006]



Dowell engineers use specialized equipment to perform high-injection-rate fracturing treatments on oil and gas wells.

RIVERFRAC

it could be the best treatment for your well

To an increasing extent, Riverfrac* is proving to be a most profitable well stimulating treatment. More and more operators report that Riverfrac has given greater production increases and a slower decline than oil-base or acid-base well treatments.

Riverfrac uses unthickened water as a fracturing fluid. Its low cost, low viscosity, and salt-dissolving qualities make water an exceptionally efficient medium for many formations. In some formations, successful treatments have been made without the use of sand as a propping agent.

Dowell additives can be used to extend the successful application of Riverfrac to many zones previously considered incompatible with water.

Dowell was a pioneer in the development of Riverfrac and has an unexcelled fund of experience with this service. An experienced Dowell engineer will tailor a treatment to the requirements of your well. Why not consider Riverfrac for your next job?

If your well is a good prospect for Riverfrac, your Dowell representative can tell you. If it isn't, he will recommend the particular Dowell treatment that should be used.

For service, or more information, contact any one of the 165 Dowell offices in the United States and Canada; in Venezuela, contact United Oilwell Service. Or write Dowell Incorporated, Tulsa 1, Oklahoma.

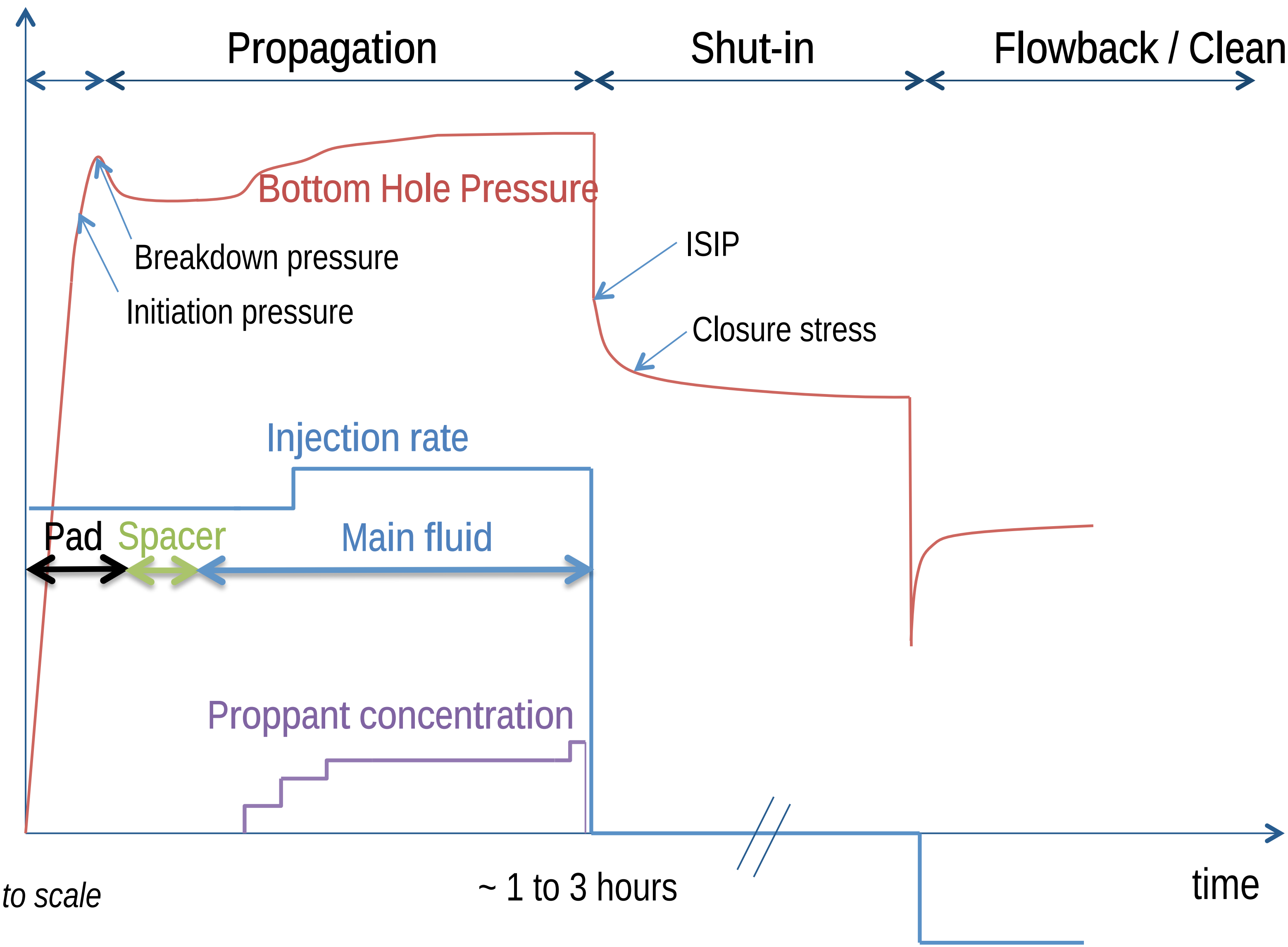
*Service Mark of Dowell Incorporated

Services for the oil industry DOWELL

A SERVICE SUBSIDIARY OF THE DOW CHEMICAL COMPANY

1956 advertisement

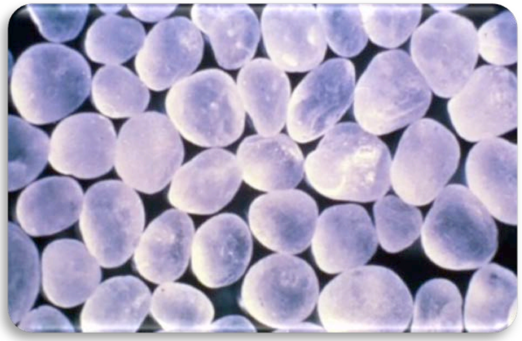
Treatment & Fluid Schedule Schematic



Not to scale

Hydraulic Fracturing design

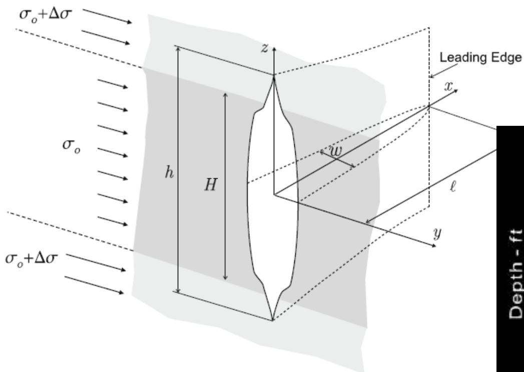
- Well landing (for horizontals)
- Completion type
  - Perfs vs sleeve, perforation design
- Fluids & fluid scheduling
  - Fluid engineering (chemistry & rheology)
- Proppant
  - Proppant type & load



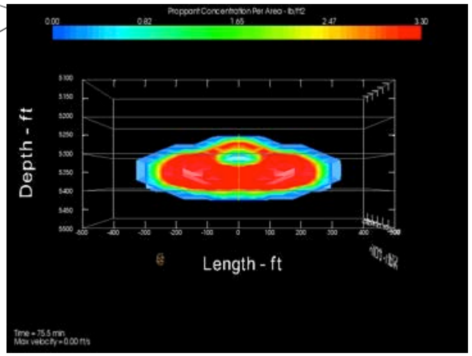
- Necessary inputs
  - In-situ stresses, pore-pressure
  - Lithology, rock parameters (logs)
  - Well geometry
  - Chosen fluid schedule

Numerical HF growth Models

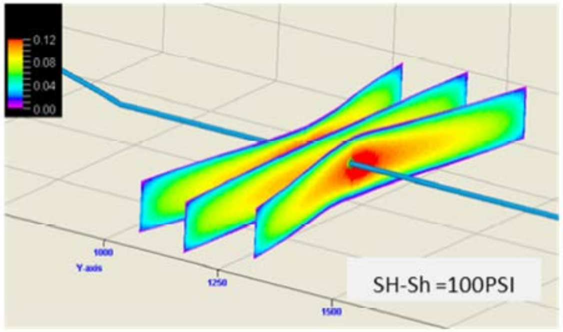
Simplified P3D models
(1980s)

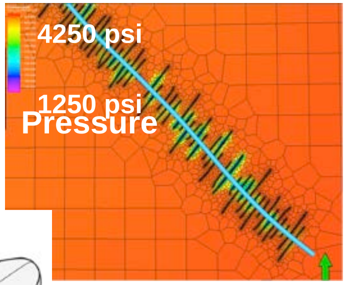


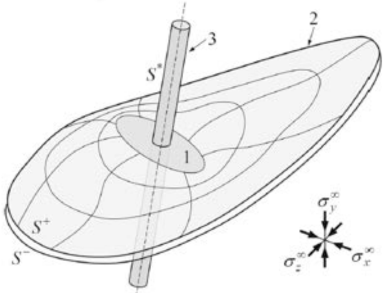
Planar 3D models
(2000s)



Multiple HFs models
(2010s)





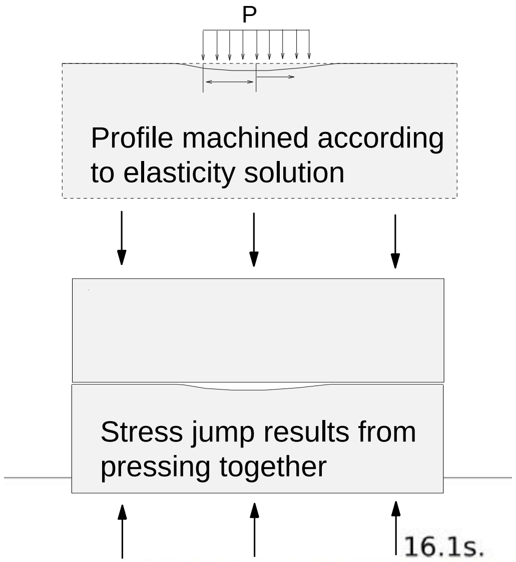


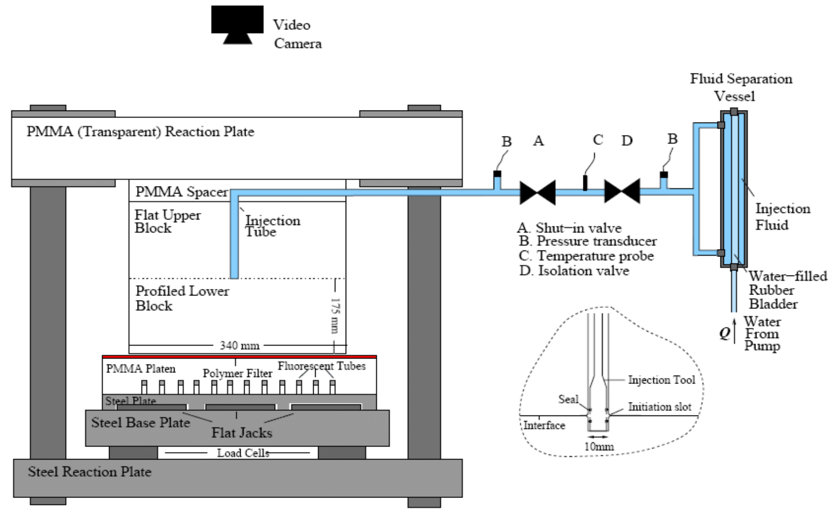
Full 3D
(2010s)

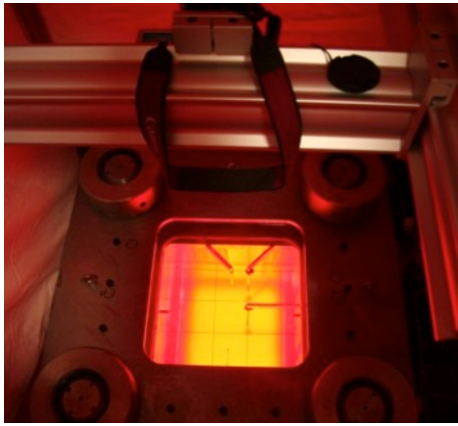
Are we drowning in complexity ? M.A. Biot 1962 Timoshenko medal speech

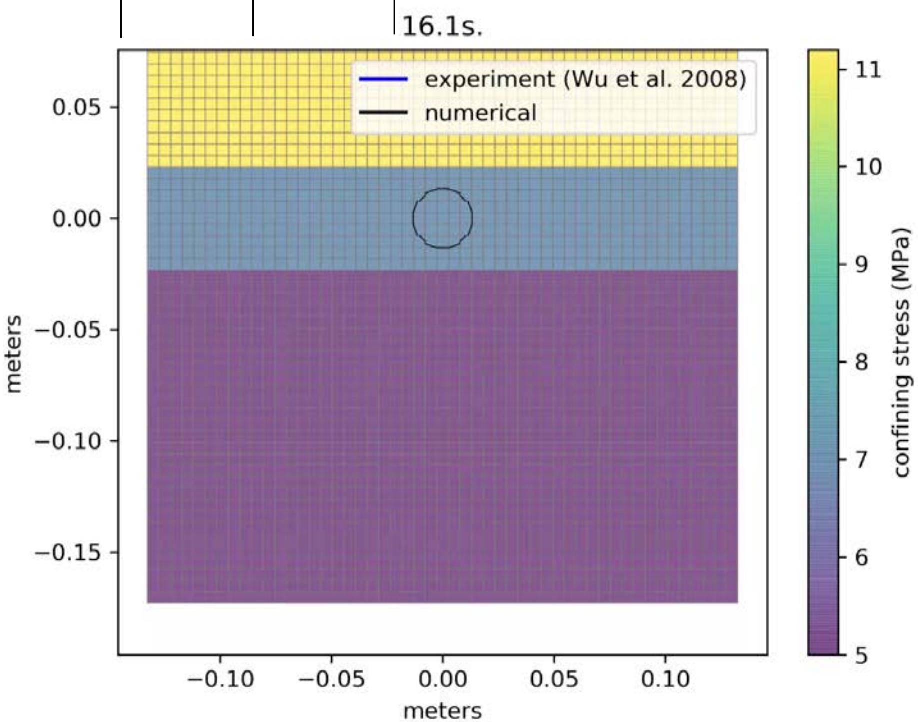
"We should not overlook simplicity combined with depth of understanding not only for its cultural value, but as a technological tool."

Experimental Validation: Stress jumps



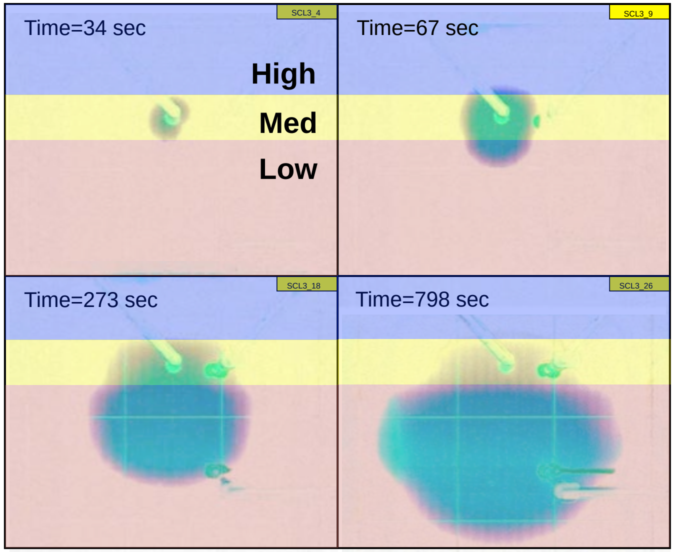






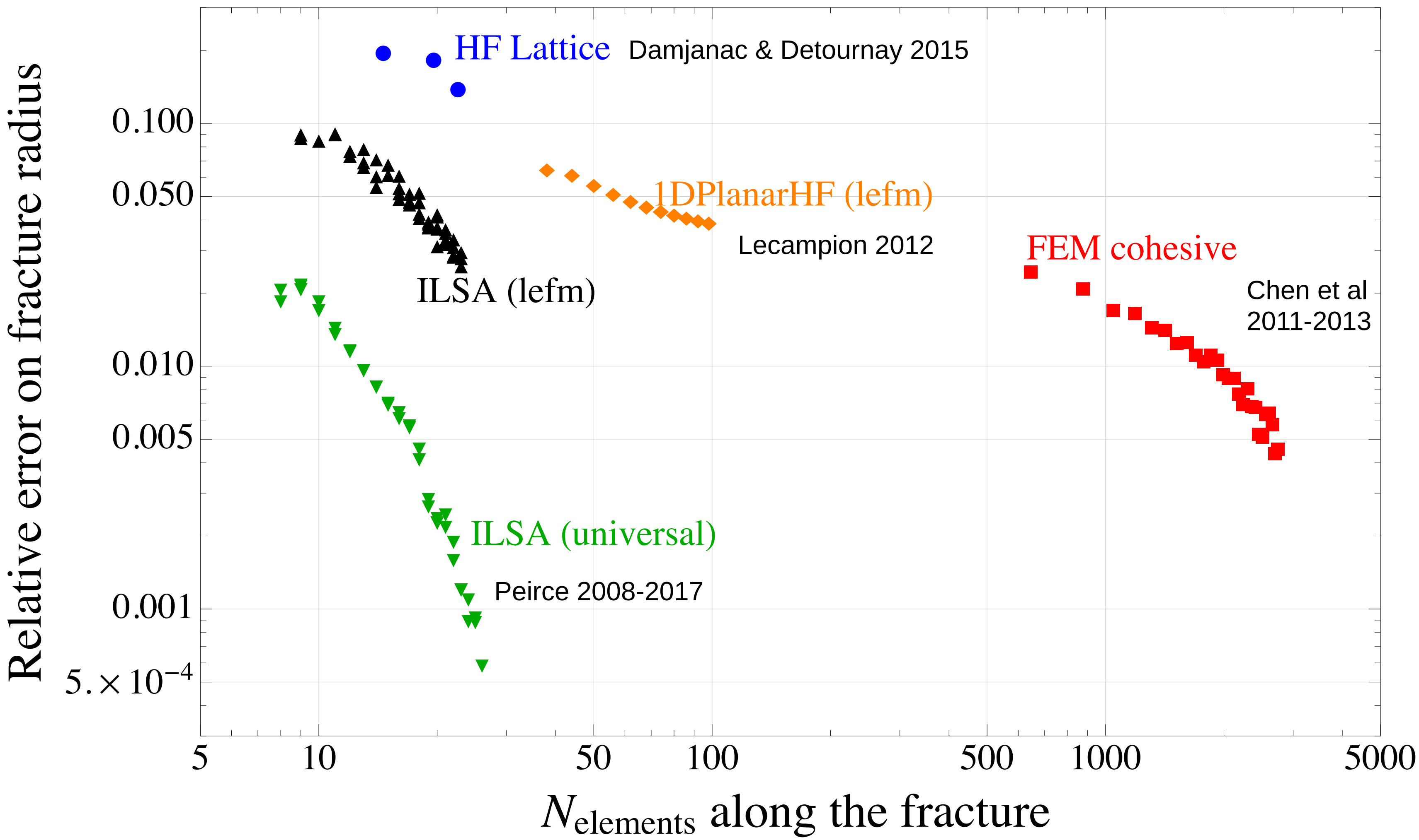
PyFrac

Herniation into low stress zone



Numerical model verification

Radial HF Storage / Viscosity dominated benchmark (solution in Savitski & Detournay 2002)



B. Lecampion, A. P. Bunger, and X. Zhang. Numerical methods for hydraulic fracture propagation: A review of recent trends. *Journal of Natural Gas Science and Engineering*, 49:66–83, 2018.

E.Detournay, Mechanics of Hydraulic Fractures, *Ann. Rev. Fluid Mech.* 2016

What about hydraulic stimulation ?

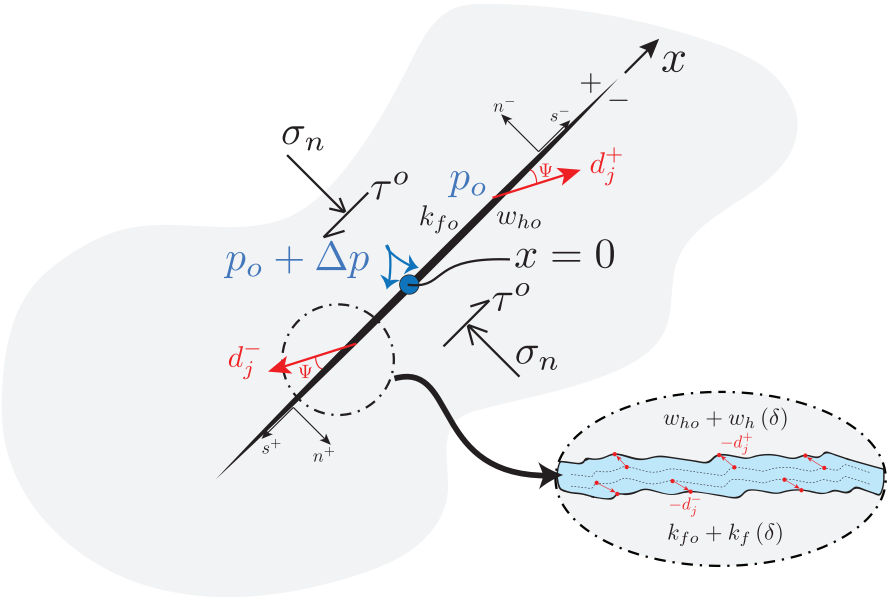
- Design ?
  - Little to no fluid engineering (besides geochemical compatibility)
  - Max. injection pressure, Max volume
  - “listen to seismicity & decide”

- Limited return of experience
- Lack of verified & validated /physics-based models for combined shear + opening fluid driven fracture propagation

  - Semi-analytical solutions for simplified geometries
  - Controlled decimeter scales laboratory experiment

Model ingredients

- Mixed mode fluid-driven fractures
  - Mode I+II (+III in 3D)
  - Frictional contact (with weakening / R&S friction -> EQ/µseismic nucleation) + dilatancy & fault permeability changes
  - Multiple pre-existing fractures

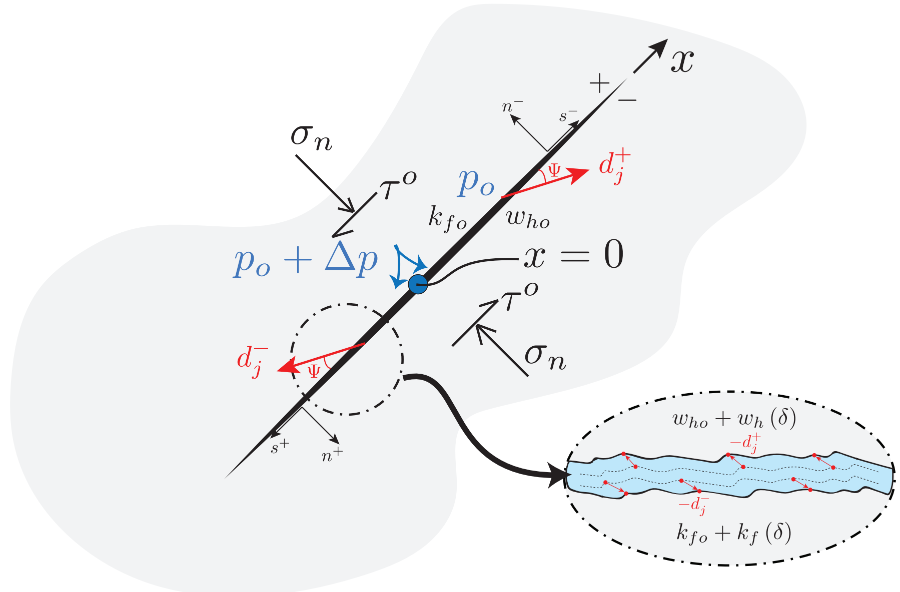


- Boundary element for mechanical deformation (with acceleration techniques)
- Finite Volume/Finite element scheme for fluid flow
- Fully coupled Hydro-mechanical solvers

Solutions & verifications

Pure shear frictional fluid driven fracture growth solution

- Plane-strain geometry
  - Garagash & Germanovitch (JGR 2012): with linear slip weakening / constant permeability
  - Viesca (2018): constant friction (solely aseismic growth) / constant perm.
  - Zhang et al. (GJI 2005): constant friction + uniform pressure
  - Azad & Garagash (JGR 2016): combined shear + opening
- Axisymmetric
  - Viesca (2018): constant friction (solely aseismic growth)



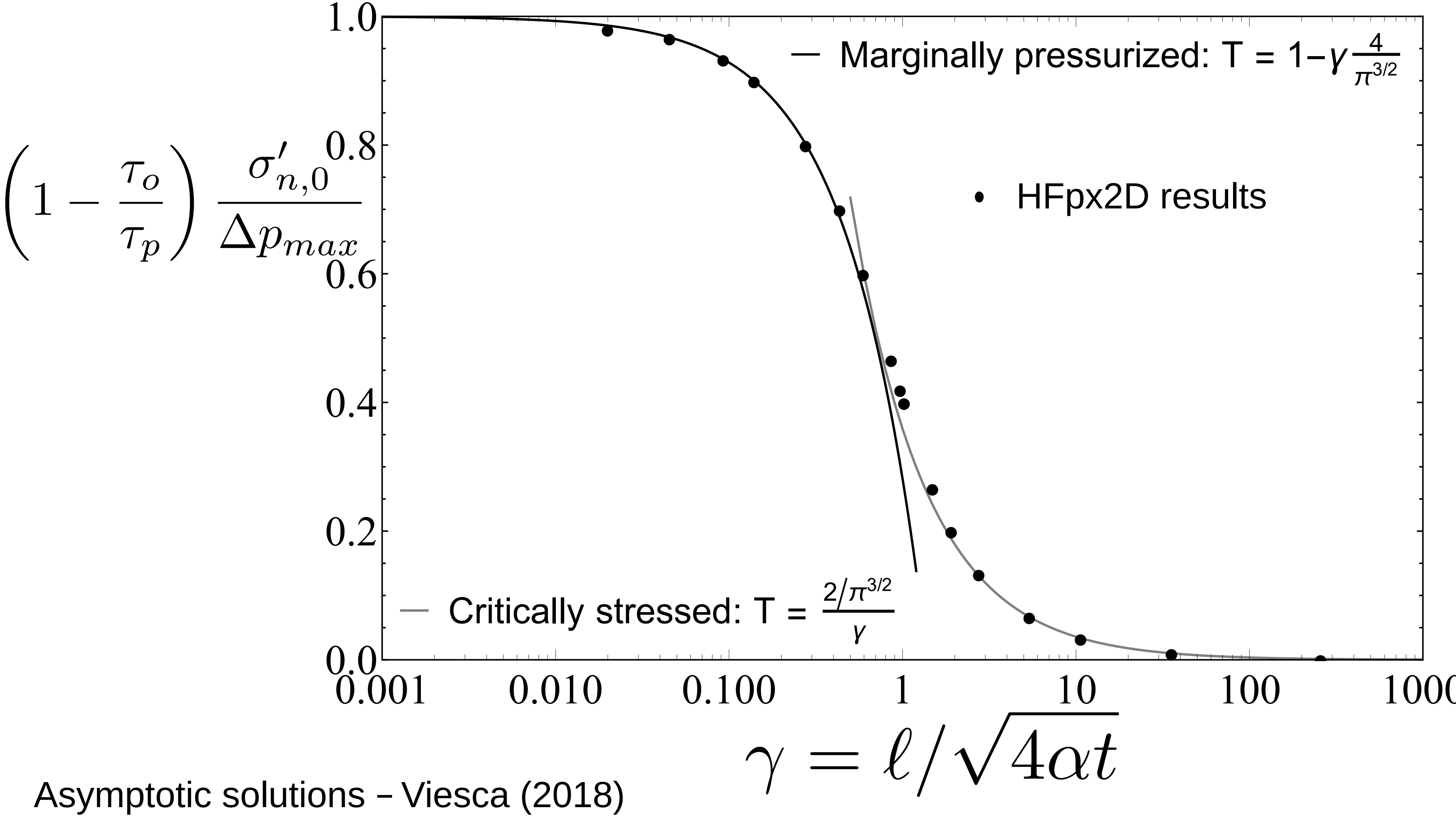
- Aseismic growth scales as

$$\ell \propto \sqrt{4\alpha t}$$

but can be way ahead the diffusion front for critically stressed configuration

Example – friction neutral solution

Shear crack driven by constant pressure injection



Asymptotic solutions – Viesca (2018)

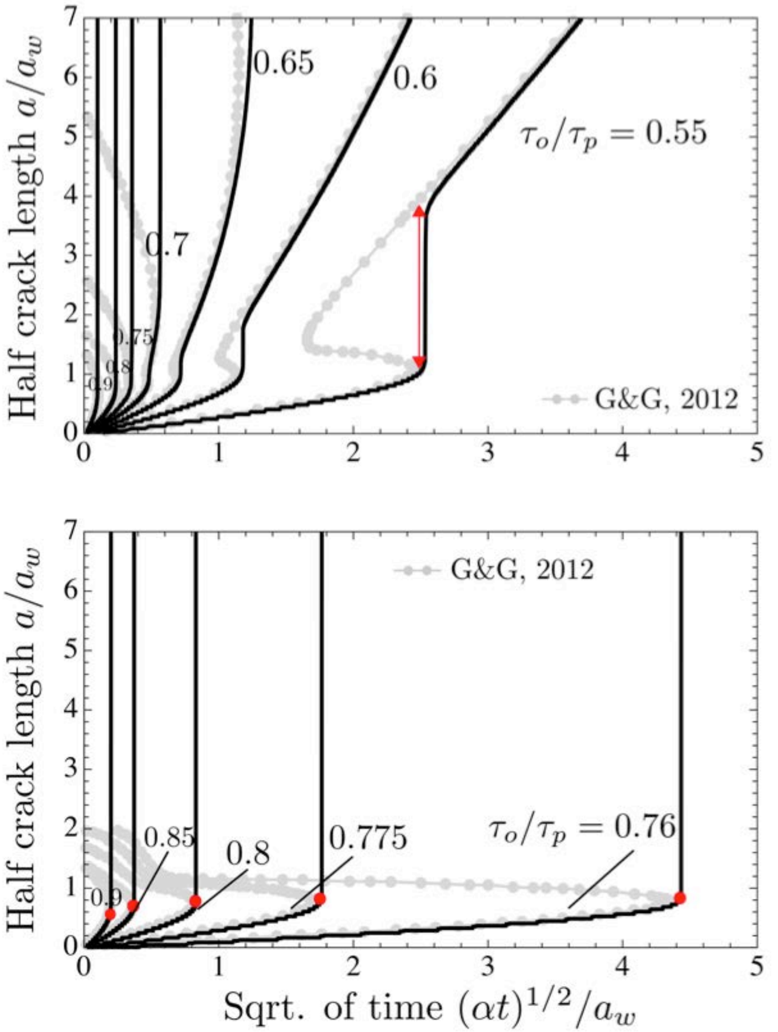
Examples – nucleation & arrest

Medium overpressure

$$\Delta p/\sigma'_o = 0.5$$

Moderate overpressure

$$\Delta p/\sigma'_o = 0.25$$

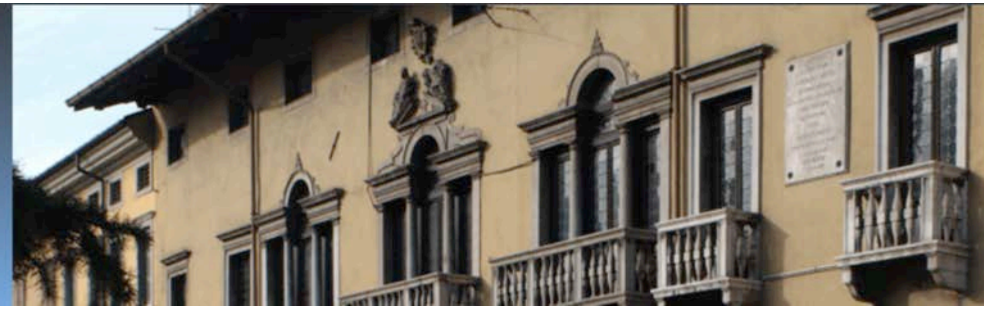


Numerics (HFpx2D) vs Analytical results of Garagash & Germanovitch (JGR 2012)

Conclusions

- Design for hydraulic stimulation is still immature
- The situation is better for hydraulic fracturing (at least for planar fractures)
- Numerical model verification for fracture propagation is a must & it's hard
  - A majority of HF numerical models do not even pass simple comparison with known propagation solutions
  - Semi-analytical propagation solutions are a huge help for the development of robust solver
  - Laboratory experiments of shear mode fluid-driven cracks (at sufficient scale) are also required

International Centre
for Mechanical Sciences



Udine, Italy
June 10 to 14, 2019

Coupled processes in fracture propagation in geo-materials: from hydraulic fractures to earthquakes

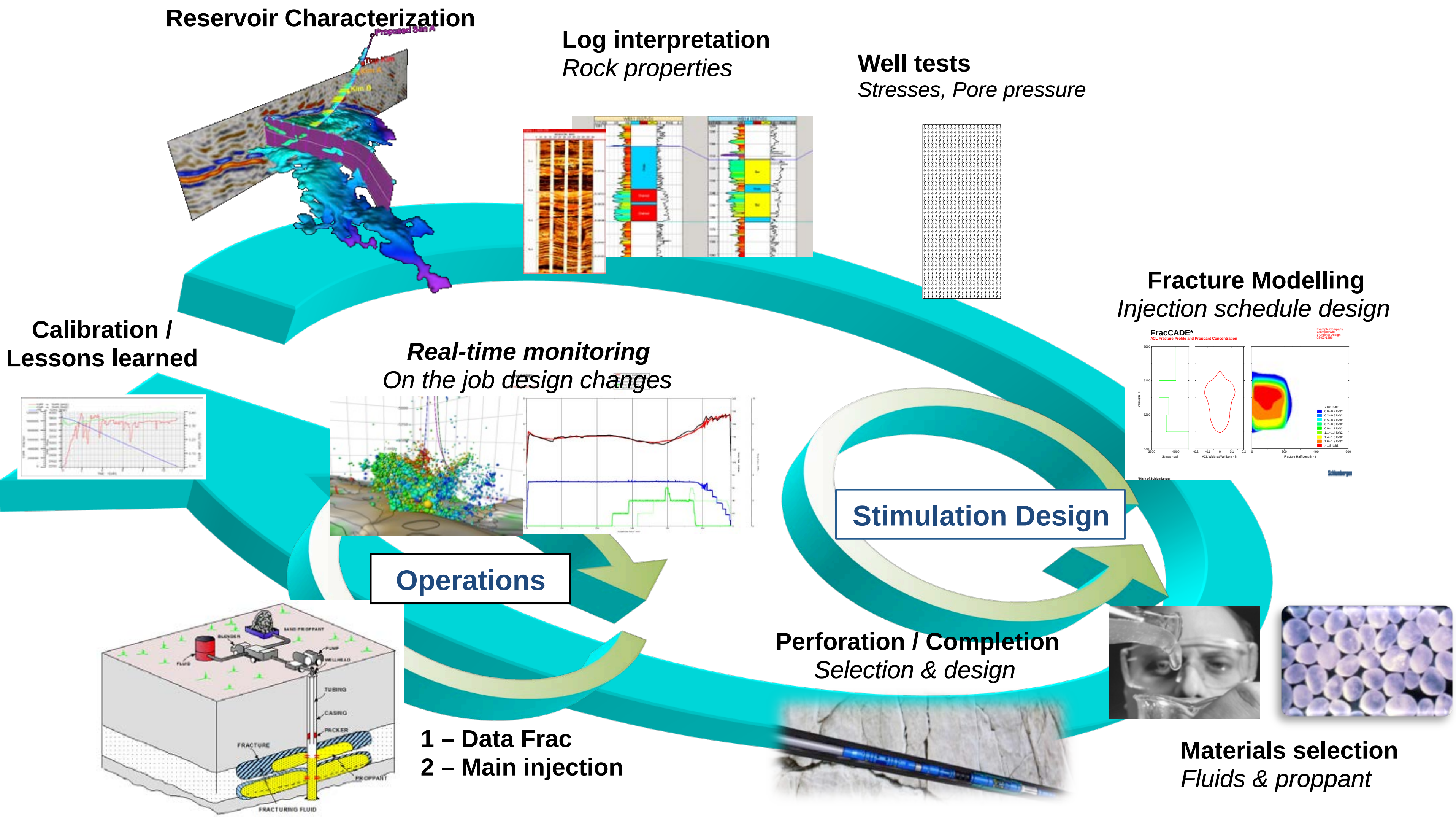
5 days advanced course

Organized by B. Lecampion & H. Bhat

Lecturers:

- Harsha Bhat, Dmitry Garagash, Leonid Germanovitch, Brice Lecampion, Alexandre Schubnel, Robert Viesca

The usual ‘workflow’

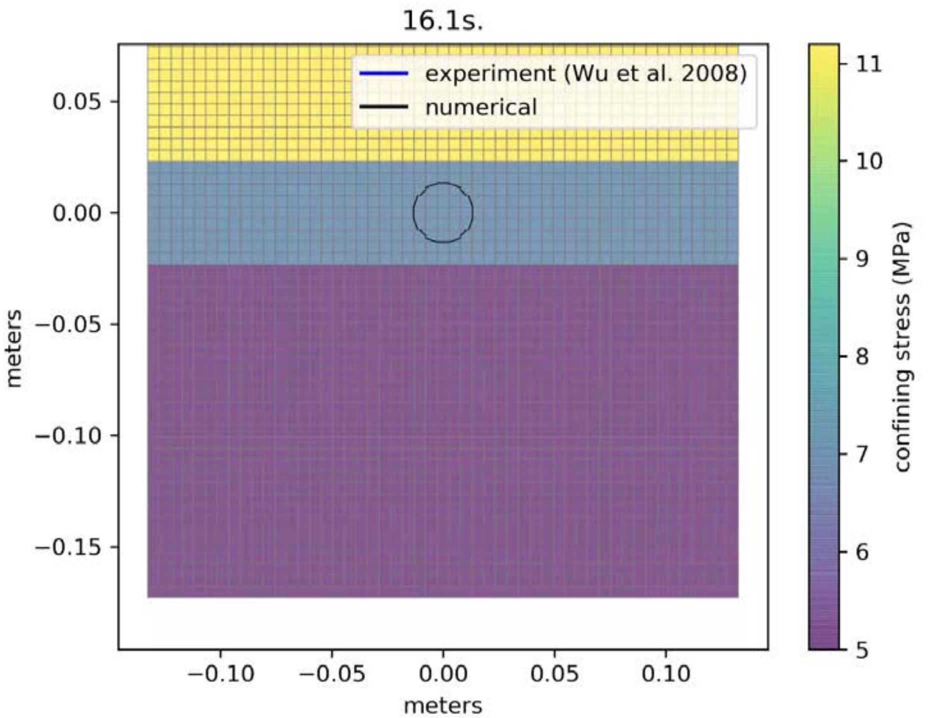


Complexity depends on criticality of the job: *from hours to months of preparation*

PyFrac – an efficient simulator for hydraulic fractures

SWISS NATIONAL SCIENCE FOUNDATION

- Implicit Level Set scheme
  - Planar 3D mode I hydraulic fracture propagation
  - Homogeneous elasticity
  - Heterogeneous in-situ stress
  - Heterogeneous fracture energy
  - Isotropy & Transverse Isotropy
  - Newtonian fluid
    - Laminar or turbulent conditions
  - Carter's leak-off in the matrix
  - Reproduce very well all available Hydraulic Fracture solutions & experiments



- Boundary elements + Finite volume + Fast marching Method + HF tip asymptotics
- Open-source