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Experimental Study of Hydromechanical Behavior of Fracture of Vaca Muerta Gas Shale

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OUTLINE

- Context
- Experimental set-up
- Mechanical behavior of Vaca Muerta shale during shear fracturing
- Permeability of a fresh fracture of Vaca Muerta gas shale
  - Permeability to gas
  - Permeability to water
  - Permeability to gas after wetting the fracture by water
- Permeability to gas of a fracture filled with proppants
- Conclusions

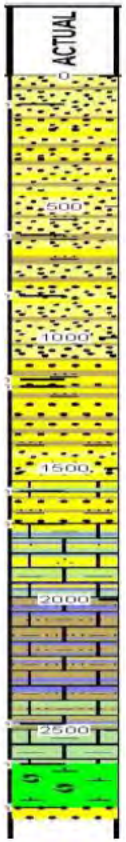
Neuquén Basin & Vaca Muerta Shale

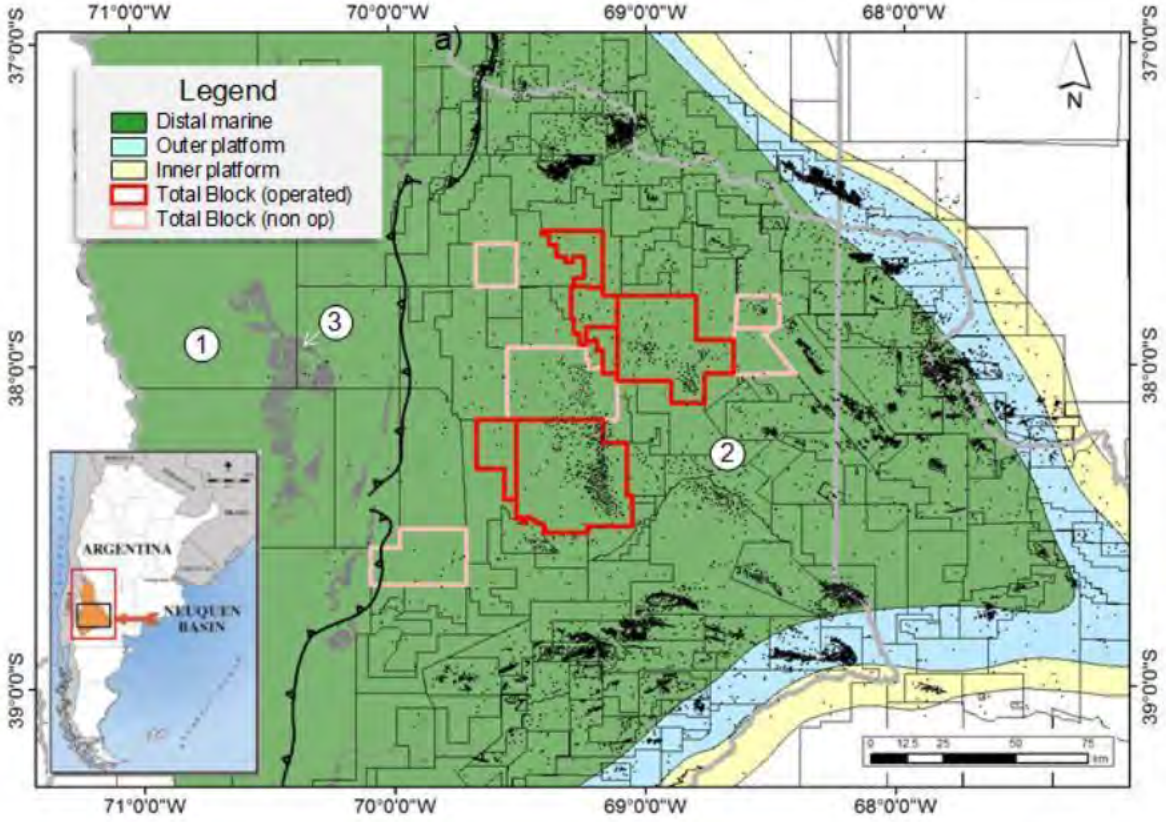
Total operated blocks within the “embayment area” of the Neuquén Basin.

①: Andean fold belt,

②: Neuquén embayment and foreland zone,

③: Vaca Muerta Fm





VM shale

Depth: ~2800 m

Ppore:
1.7~2.1 sg

Clay content:
10 to 30%,

Carbonate and quartz:10 to 80%

bulk density:
2.3 to 2.6 g/cc

Porosity:
6 to 10%.

TOC: 4.0 - 6.0%

TOTAL

NEEDS OF LAB FRACTURE PERMEABILITY TESTS

➔ **Quality of Stimulated Rock Volume (SRV) is affected by number of the natural fractures activated by hydraulic fractures**

➔ **Long term performance of a SRV depends on :**

The ability of both induced and pre-existing fractures to remain sufficiently open when effective stresses increases during production (depletion).

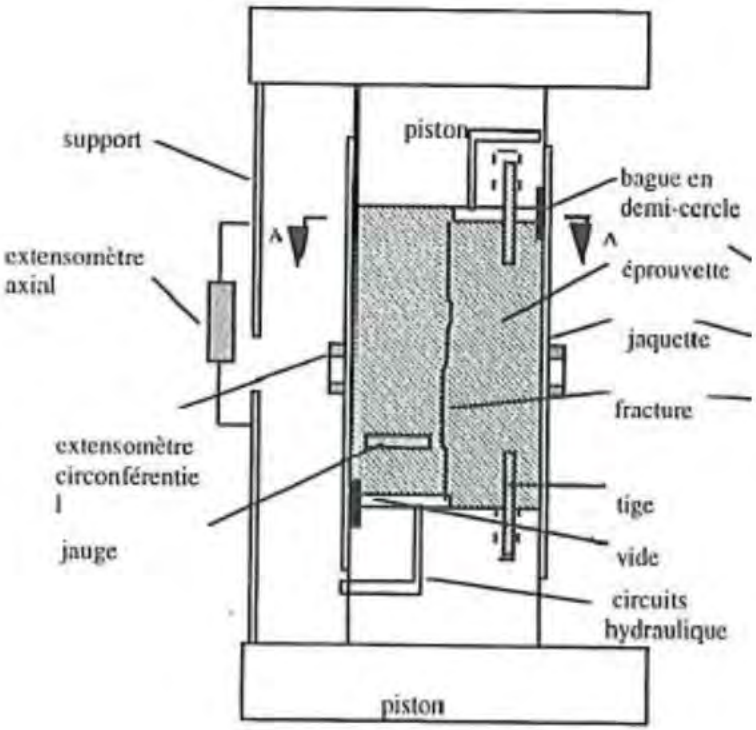
➔ **Need for lab characterization of shale gas fracture permeability:**

1) Determine the rate of fracture permeability reduction during depletion, → so for interpretation/prediction of the decline of well productivity
2) Evaluate the time-dependent behavior of fracture due to creep/water shale chemical interaction, etc.:→optimization of landing point of drain

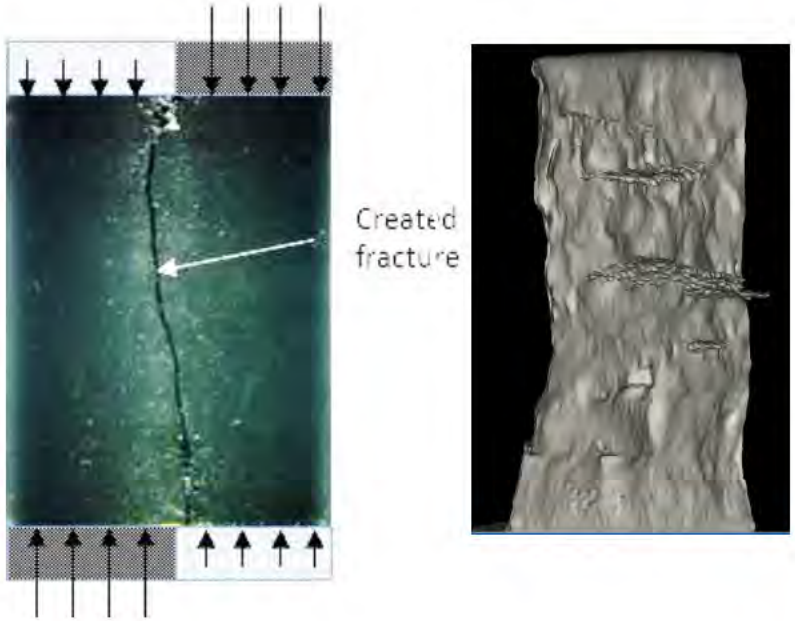
3) For optimizing the fracture fluid recipe and the concentration of proppants in order to keep the fracture hydraulically open during lifetime of the field
4) To supply the data set of stress sensitive fracture permeability for numerical modeling of SRV (Stimulation and production)

EXPERIMENTAL SET-UP

- Creating a fracture in lab in shear mode inside a triaxial cell



Su Kun 1998



TopIndustrie-France

CLARIFICATION OF UNIT OF PERMEABILITY OF FRACTURE

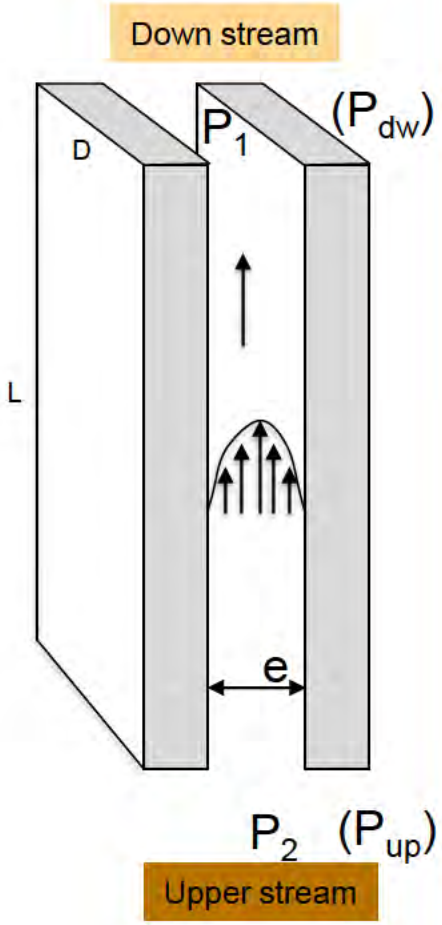
Gas: $\emptyset = \frac{e^3}{24\mu P_0} \frac{(P_2^2 - P_1^2)}{L} D$ => $e = \sqrt[3]{\frac{24\mu P_0 Q_{P_0} h}{(P_{up}^2 - P_{dw}^2)D}}$

Water: $\Phi = \frac{e^3}{12\,\mu} \frac{P_2 - P_1}{L} D$ => $e = \sqrt[3]{\frac{12 Q \mu h}{\Delta P D}}$

➔ Two possible notations for permeability of fracture

❶ Hydraulic opening of fracture (m): e

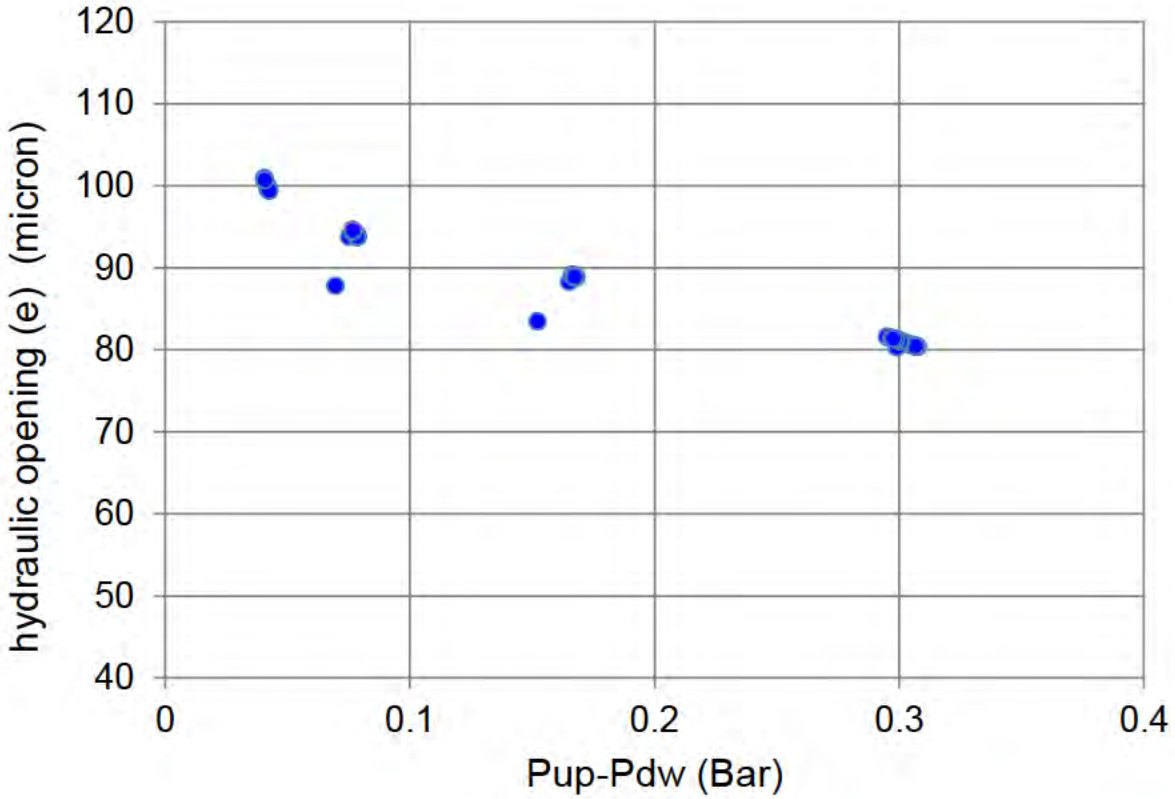
❷ Hydraulic conductivity K (mD*m) =(e^3/12)* 10^{15}



TOTAL

PERMEABILITY OF THE SYSTEM

➔ The experimental set-up can't measure an fracture opening higher than 80~90 microns, because of small tubing used inside the triaxial cell



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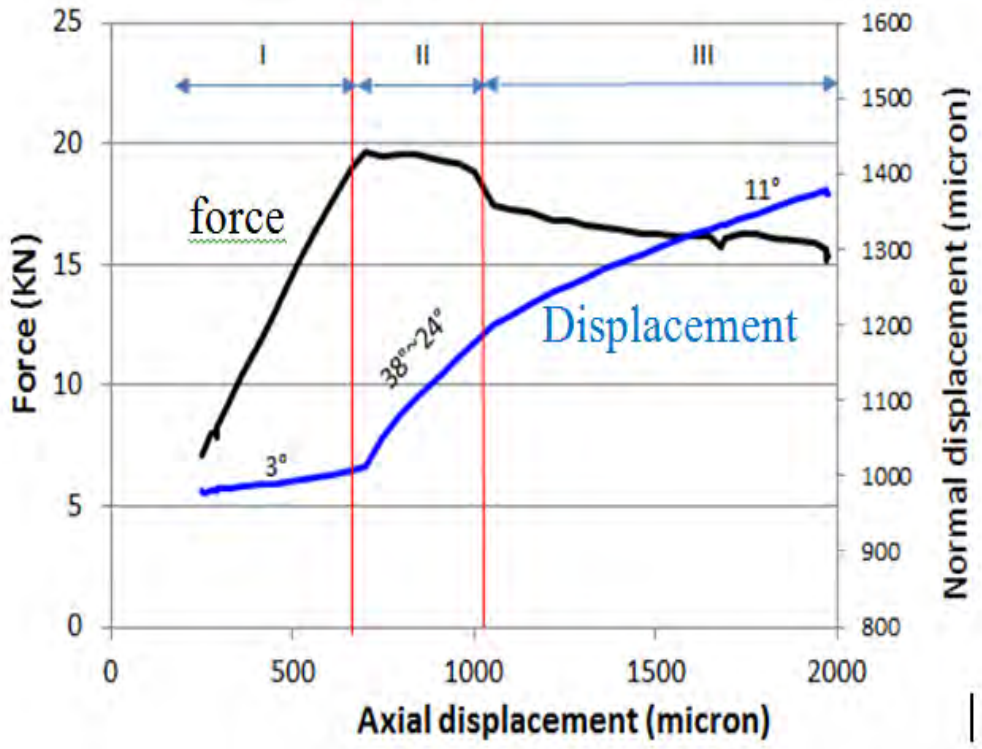
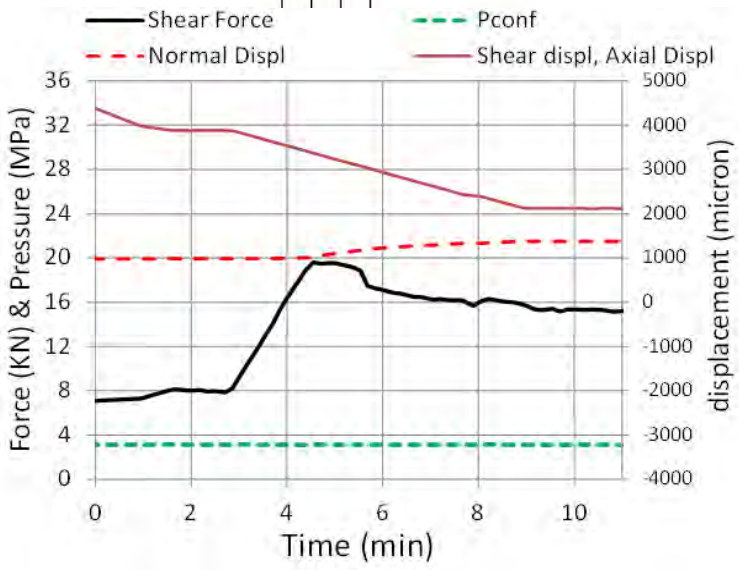
MECHANICAL BEHAVIOR OF VM SHALE DURING SHEAR FRACTURING





Phase I: linear phase where the force increases proportional to the axial displacement

Phase II: propagation of shear fracture characterized by dilatancy

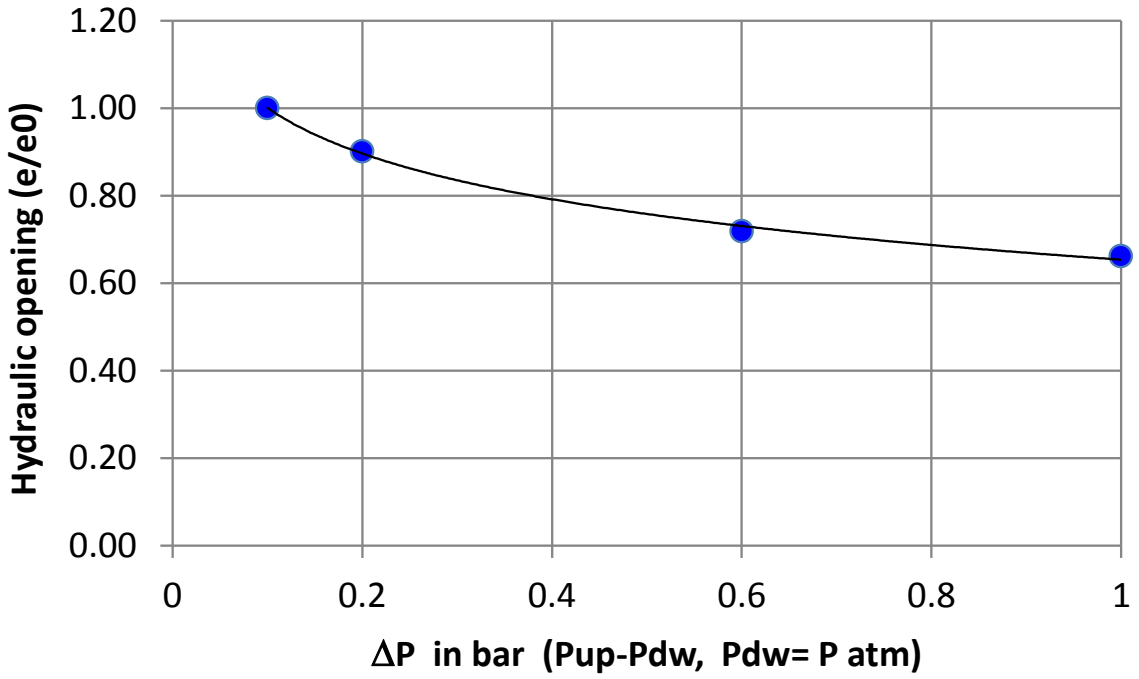
Phase III: residual shear strength phase

GAS PERMEABILITY OF A FRESH FRACTURE

➔The hydraulic opening of a fresh fracture of Vaca Muerta shale is several microns under 50 bar of confining pressure

➔The hydraulic opening varies with the pressure gradient applied

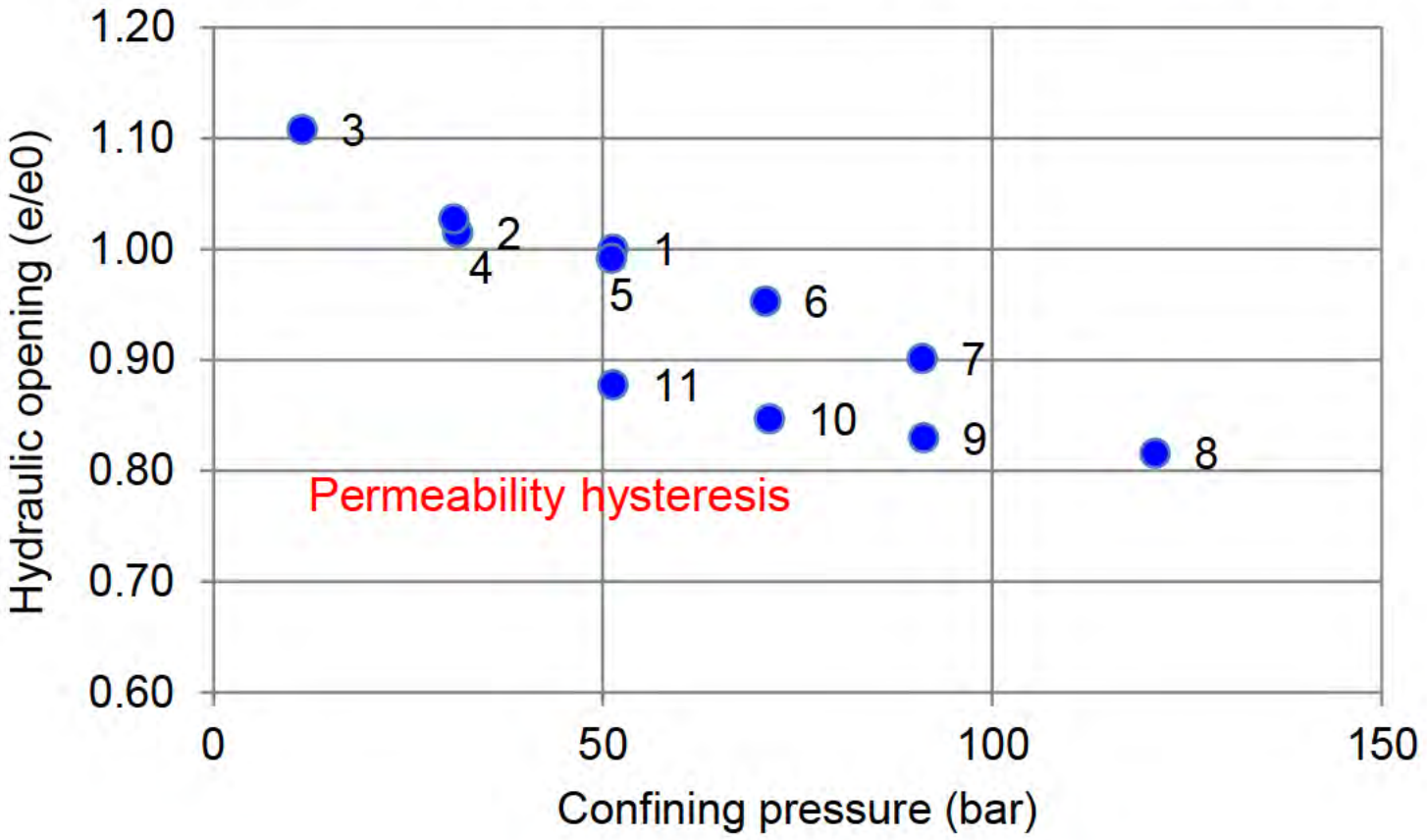
➔Turbulence of flow might increase the friction of gas flow with fracture walls, therfore reduces the apparent hydraulic opening of the fracture.



TOTAL

EVOLUTION OF FRACTURE GAS PERMEABILITY AS FUNCTION OF CONFINING PRESSURE

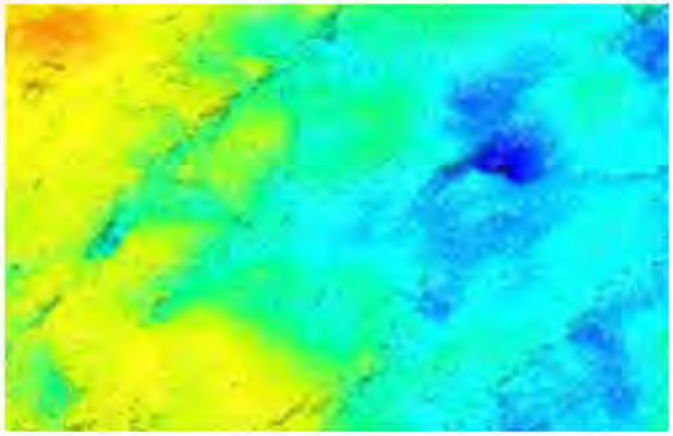
- At constant pressure gradient P_{up}-P_{dw}=0.1 bar. The number indicates the step of confining pressure. Step n°1 is considered as reference
- Fracture opening is sensitive to normal stress to fracture plane

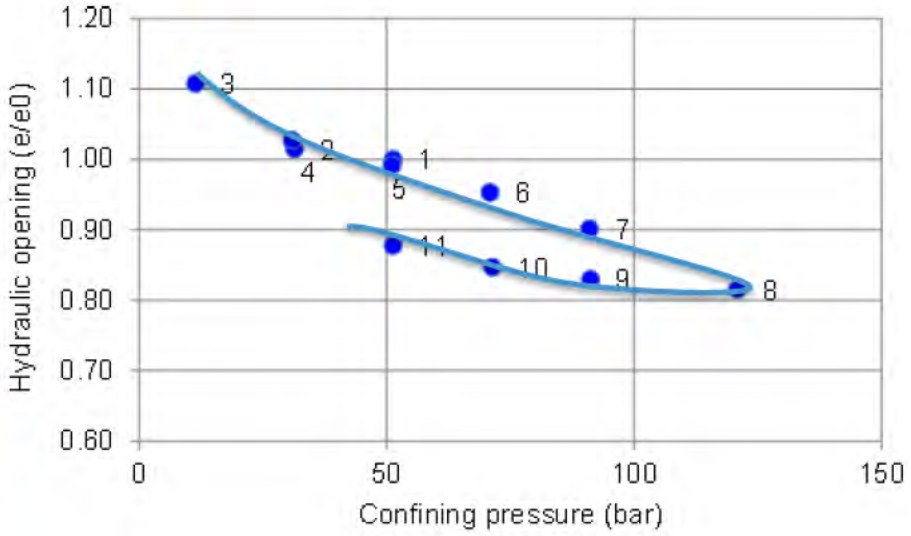


TOTAL

PERMEABILITY HYSTERESIS, WHY?

- ➔ Such a hysteresis can be explained by the plastic deformation produced at the fracture walls
- ➔ We will investigate the surface roughness effect in future, the surfaces are digitalized by an optical profilometer





Example of a fracture surface digitalized by a profilometer

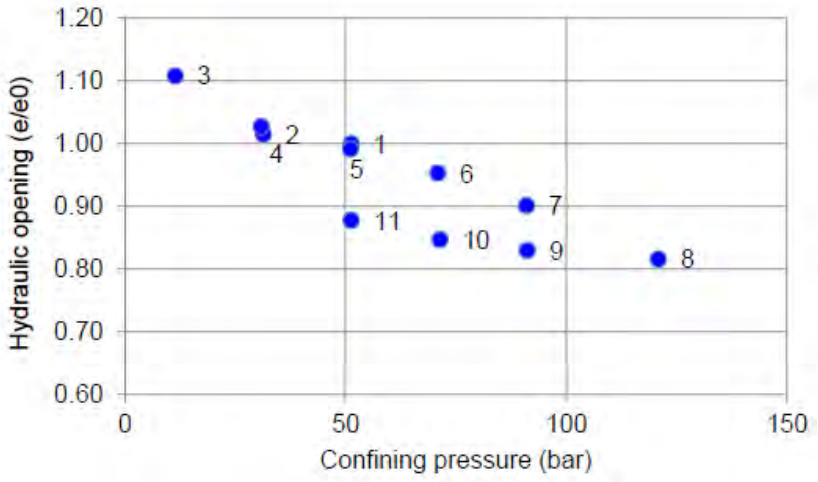
TOTAL

EVOLUTION OF FRACTURE WATER PERMEABILITY AS FUNCTION OF CONFINING PRESSURE

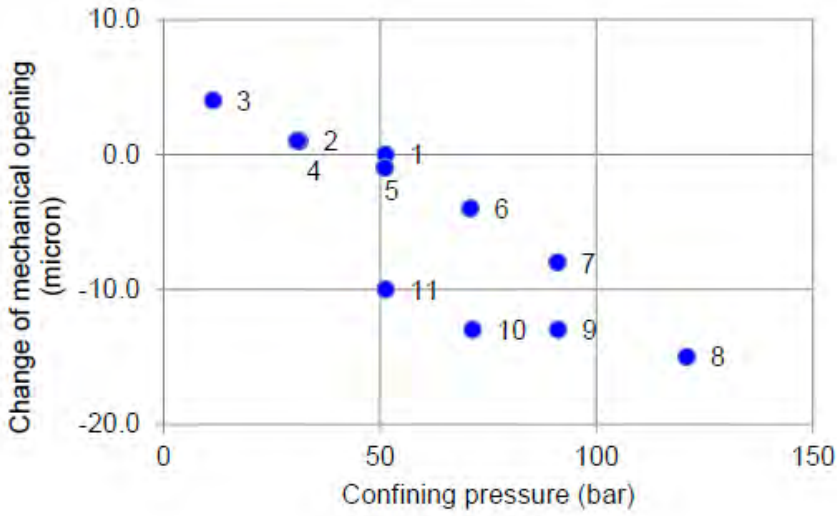
➔ The hydraulic opening to water is much smaller compared to that to gas (wetting effect?)

➔ hydraulic opening to water is about 4~6 μm for Vaca Muerta shale under 50 bars of confining pressure

➔ wetting the fracture by water reduced significantly the fracture hydraulic opening



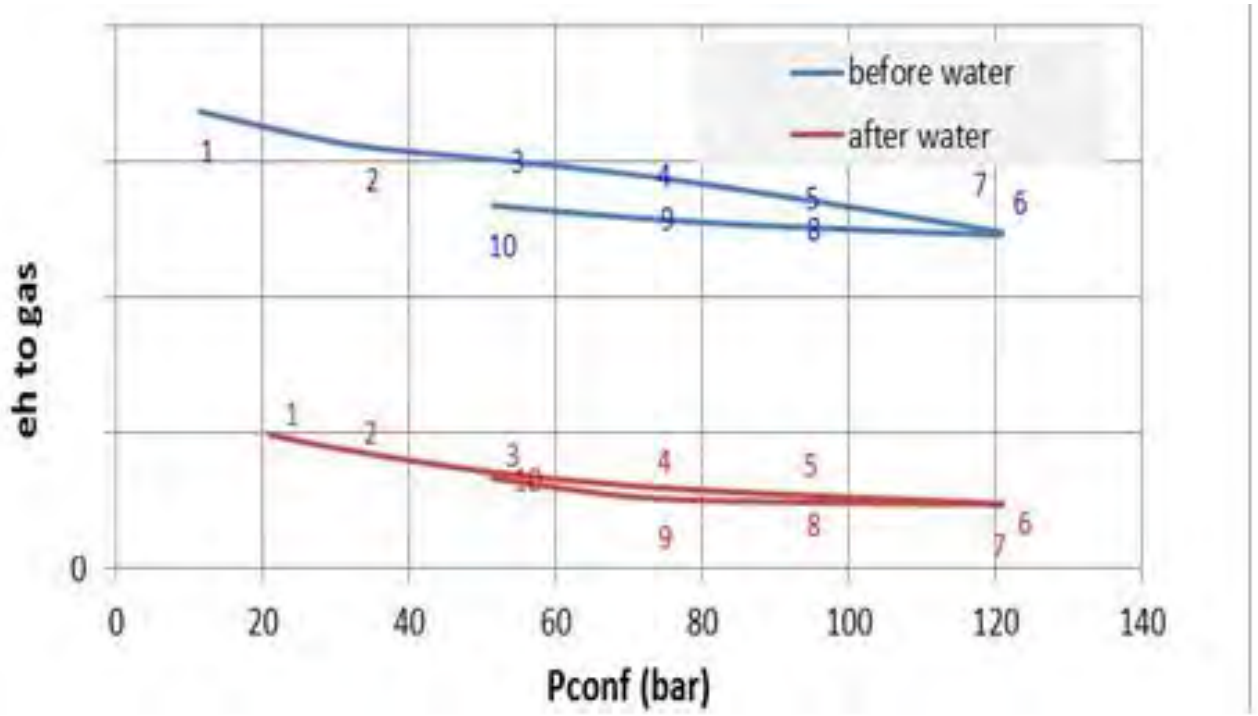
hydraulic opening



Mechanical opening

TOTAL

EVOLUTION OF FRACTURE GAS PERMEABILITY AS FUNCTION OF CONFINING PRESSURE

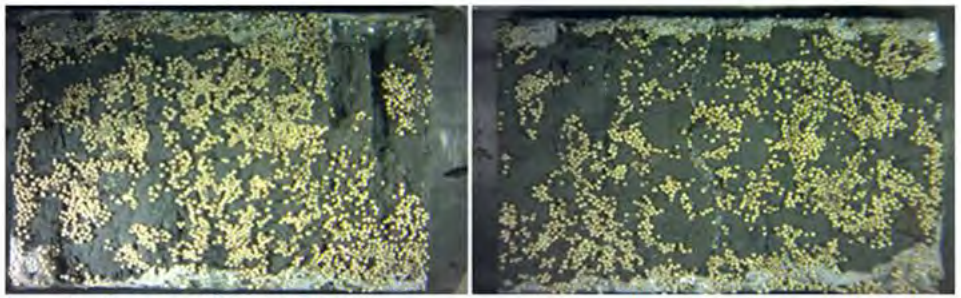


➔ Fracture hydraulic opening is sensitive to increasing effective stress Pc

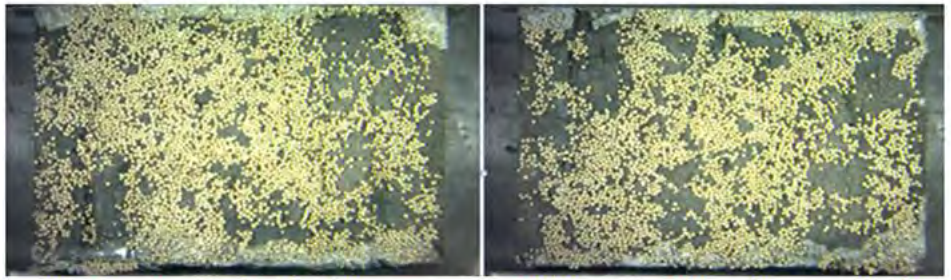
➔ After wetting the fracture with tap water, the fracture opening to gas flow is reduced by a factor ~3

➔ Change of gas permeability due to wetting by water can be an excellent parameter to measure the potential alteration of fresh shale fracture to water

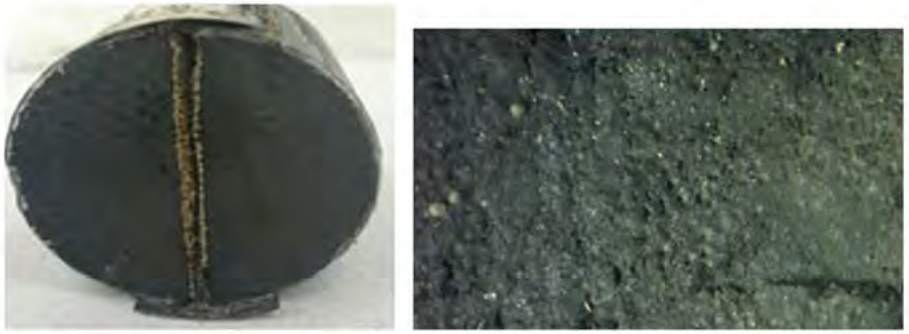
FRACTURE FILLED WITH PROPPANTS



Top view of a fracture filled with 1 layer proppants 30/50 mesh, taken after test, sample size: (36x50mm)

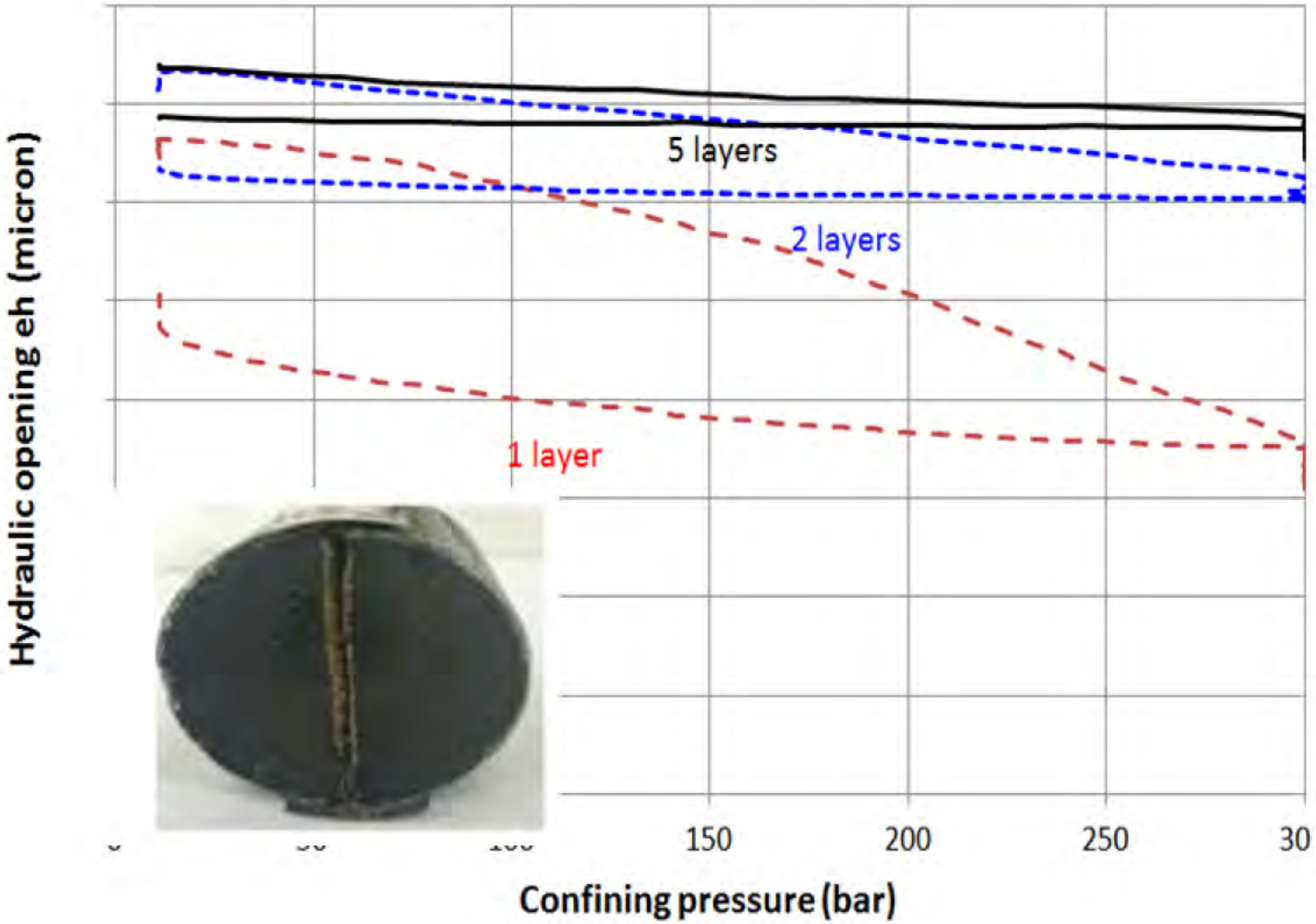


Top view of a fracture filled with 2 layers proppants 30/50 mesh, taken after test, sample size: (36x50mm)



Left: Side view of fracture filled with 5 layers of proppants 30/50 mesh, photo taken before test, right: footprint of proppants, picture taken after test with 2 layers 30/50 mesh proppants

GAS PERMEABILITY OF FRACTURE FILLED WITH PROPPANTS



CONCLUSIONS

- Specific set-up for creation of the fracture in shear mode and measurement of the fracture permeability inside a conventional triaxial cell has been developed at Total
- Vaca Muerta shale fracture behavior has been studied:
    1. VM fresh fracture permeability (hydraulic opening) is sensitive to normal effective stress
    2. VM fracture permeability (hydraulic opening) to water is about 4~6 microns under 50 bars of confining pressure (wetting effect?)
    3. After wetting the fresh fracture with water, the new fracture permeability (opening) to gas was reduced by a factor of ~3-4.
    4. A fracture permeability hysteresis was observed while loading/unloading
- Other work is ongoing testing propped fractures: we observe clearly the closure of fracture vs confining pressure using one layer of CQ30/50
- But the residual fracture opening under high confining pressure is still relative high for that propped fracture