Automated fluid substitution from non-linear regression

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Outline

- Takeaways
- Fluid substitution – some background
- New method – Rock physics fluid substitution (ROFS)
- Automation of the workflow
- Results and applications

Takeaways

New method for fluid substitution (ROFS)

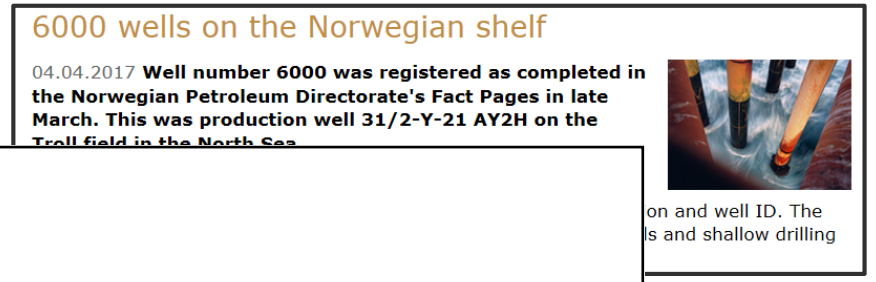
http://mentalfloss.com/article/30400/12-underappreciated-equally-precious-bodily-fluids

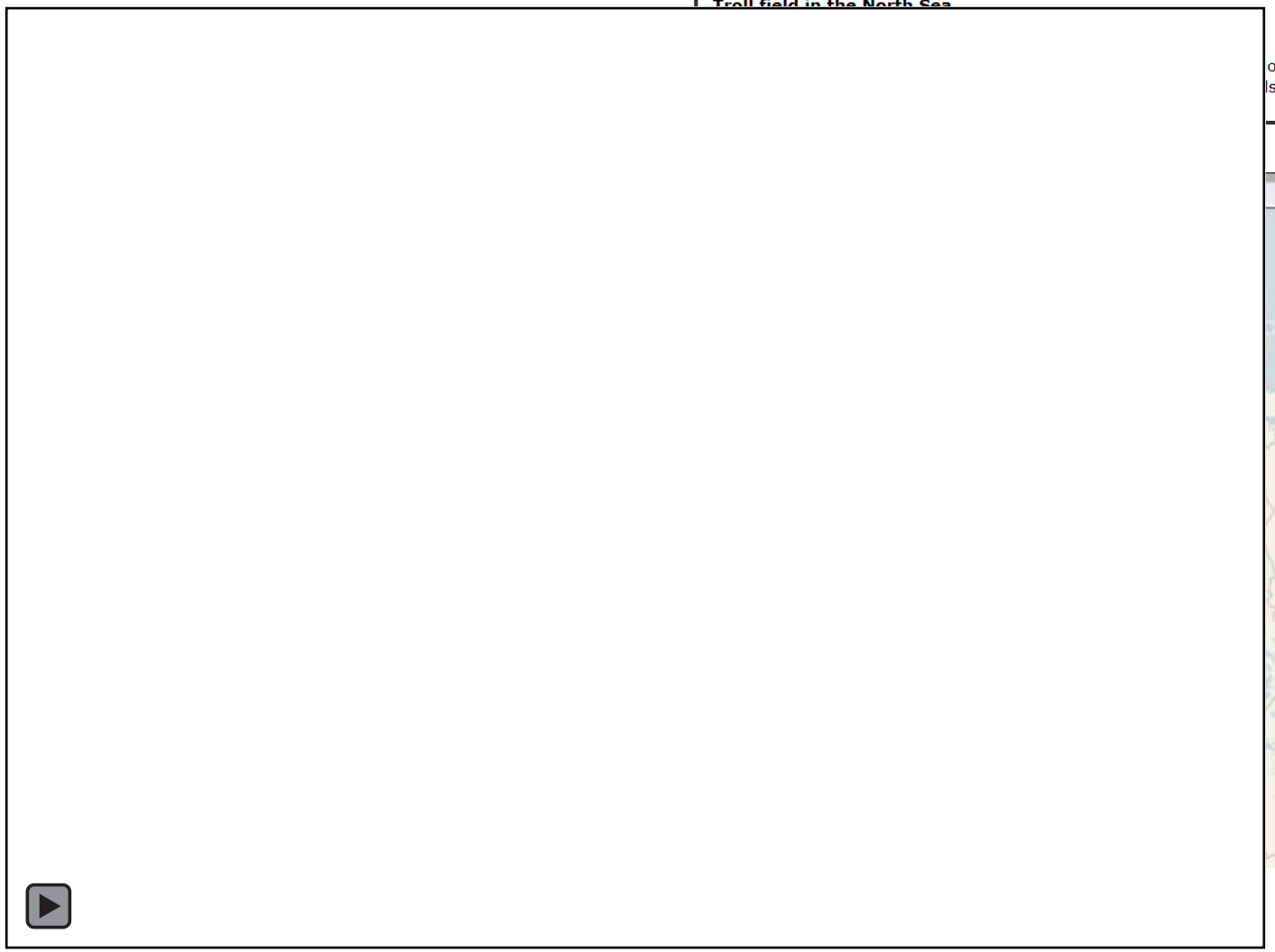
Automation of processes

https://www.canstockphoto.com/illustration/automatization.html

Fluid substitution – some background

- Exploration
  - Modeling of target reflectivity
  - Seismic inversion
  - Amplitude versus angle
  - Drill or drop
- Reservoir monitoring
  - Monitoring fluid movement
  - Look at pressure effects
  - Increased oil recovery





Effect of fluids on P-wave velocity

Vertical seismic: Reflection coefficient is dependent on contrast in accoustic impedance (I)

$$I = V_p * \rho$$

$$V_p = \sqrt{\frac{K_{eff} + \frac{4}{3}\mu_{eff}}{\rho_{eff}}}$$

Increase velocity

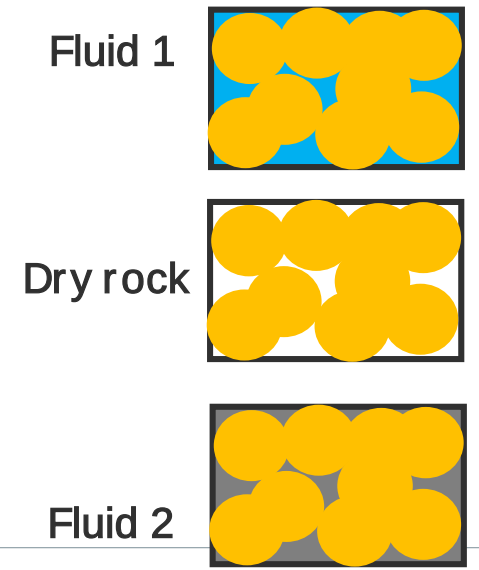
Decrease velocity

Standard workflow - Gassmann

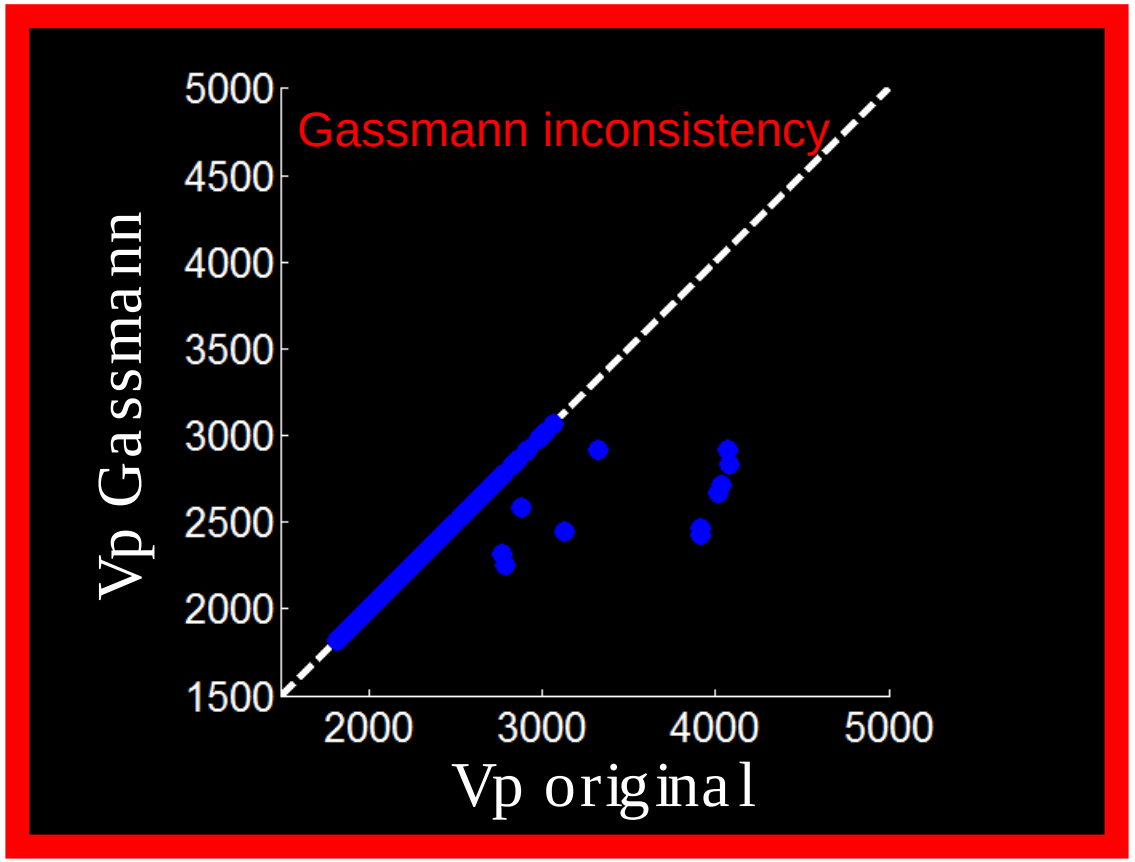
- Normally fluid substitution has been performed by Gassmann (1951) modeling
- Important Gassmann approach assumptions:
  - Homogeneous pore pressure, homogeneous solid material, free fluid flow between pores, no interaction between solids and fluid
- The procedure of using Gassmann in a well log is as follows:
  - Use Vp, Vs, porosity, Sw, fluid bulk modulus, solid rock bulk modulus to estimate dry rock properties

$$K_{dry} = \frac{K_{sat}(\phi K_0/K_{fl} + 1 - \phi) - K_0}{\phi K_0/K_{fl} + K_{sat}/K_0 - 1 - \phi}$$

$$K_{sat} = K_{dry} + \frac{(1 - K_{dry}/K_0)^2}{\phi/K_{fl} + (1-\phi)/K_0 - K_{dry}/K_0^2}$$



Standard workflow - Gassmann

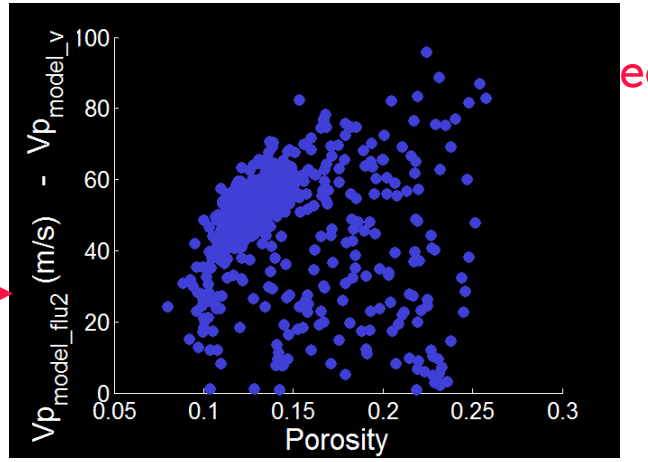


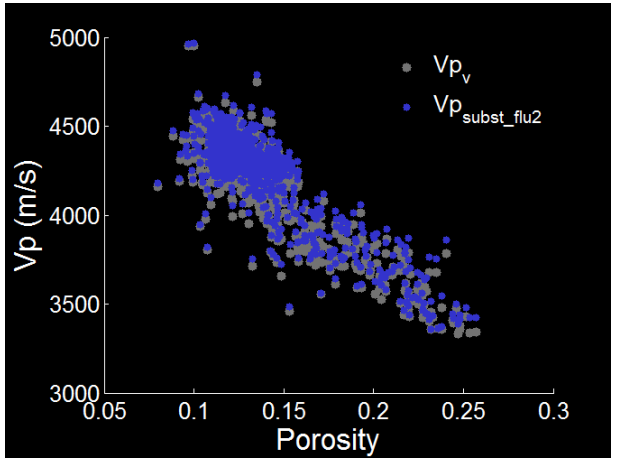
Rock physics fluid substitution (ROFS)

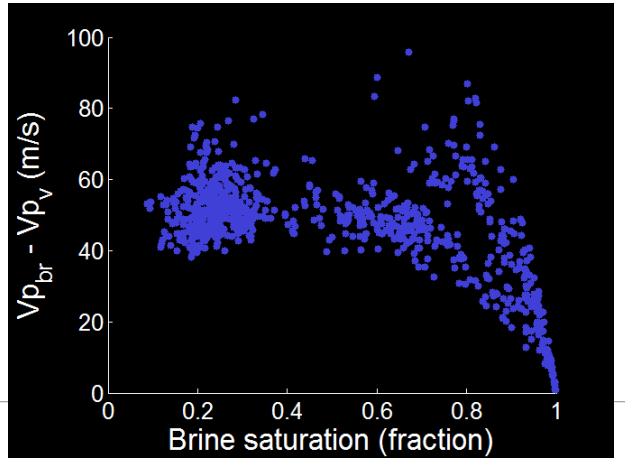
Workflow

1. Calibration of a suitable rock physics model to logged P-wave velocities
   - Use well log saturation and original fluid properties
2. Use the calibrated rock physics model with new fluid properties
3. Estimate the difference of rock physics model with new and original fluid
4. Apply the difference on the original well log Vp

$$Vp_{new\ fluid} = Vp_{org\ fluid} + (Vp_{mod\ new\ fl} - Vp_{mod\ org\ fl})$$







Automation of workflow

- Calibration of rock physics model:

$$V_p = \sqrt{\frac{K_{eff} + \frac{4}{3}\mu_{eff}}{\rho_{eff}}}$$

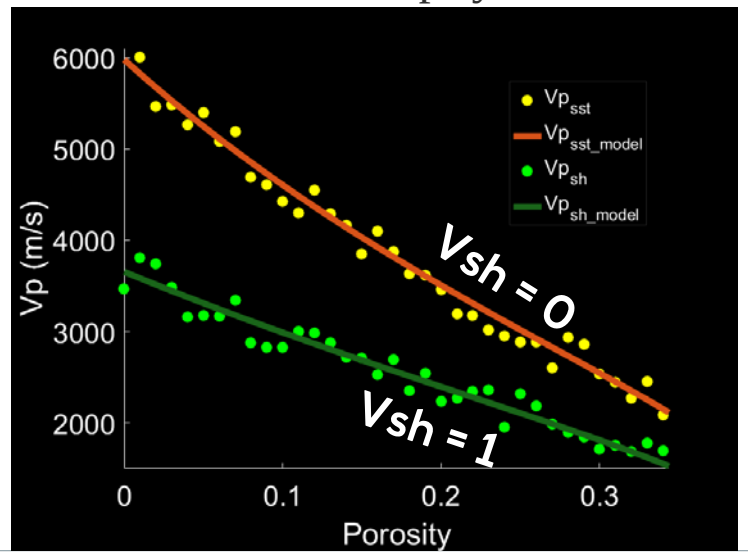
Hertz-Mindlin model:

$$K_{eff} = \left[\frac{C^2 + (1-\varphi)^2 \mu^2}{18\pi^2(1-\sigma)^2} P\right]^{1/3}$$

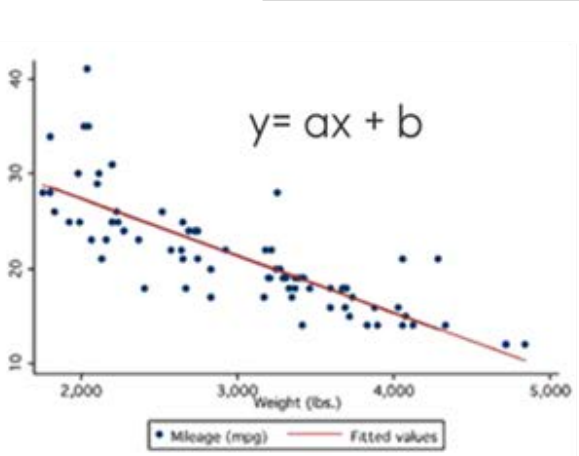
$$\sigma = f(K_{clay}, K_{non-clay}, \mu_{clay}, \mu_{non-clay}, V_{sh})$$

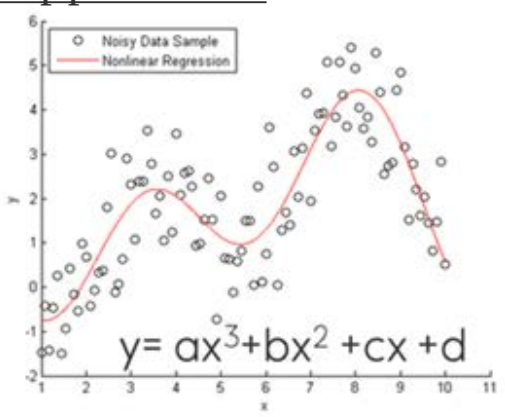
(Mineral densities are assumed to be 2.65 for non-clays and 2.62 for clays)

Calibration of rock physics model

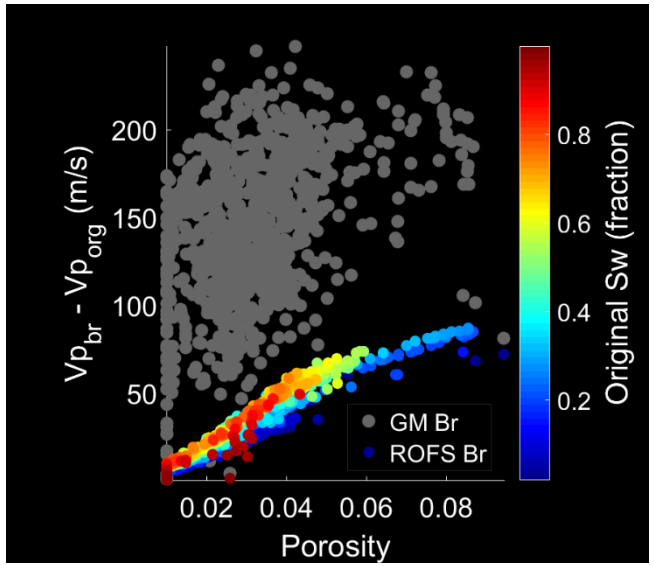


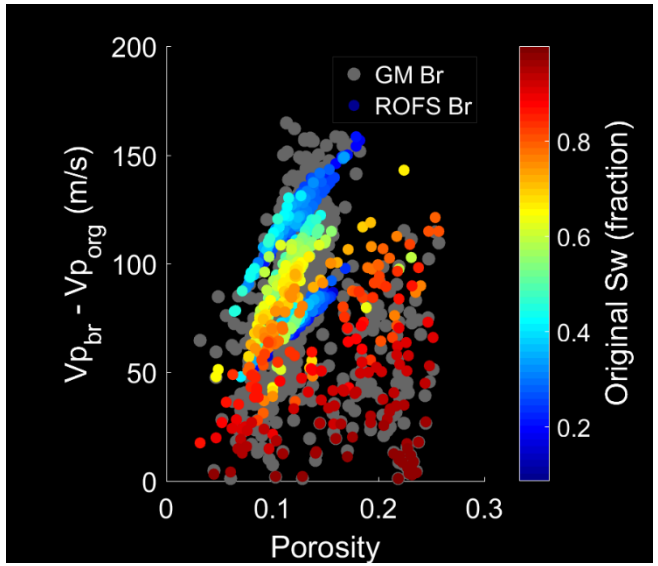
Machine learning approaches

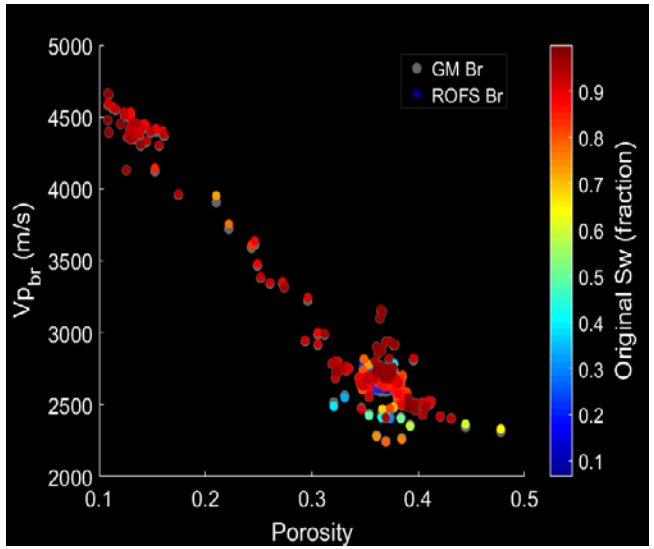


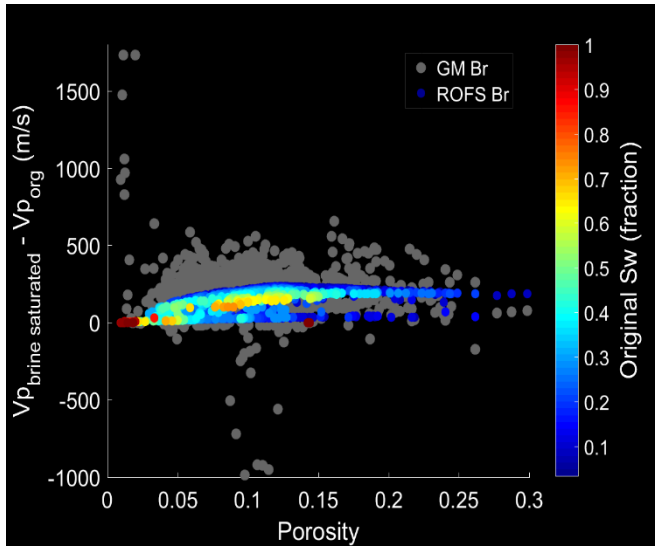


Results

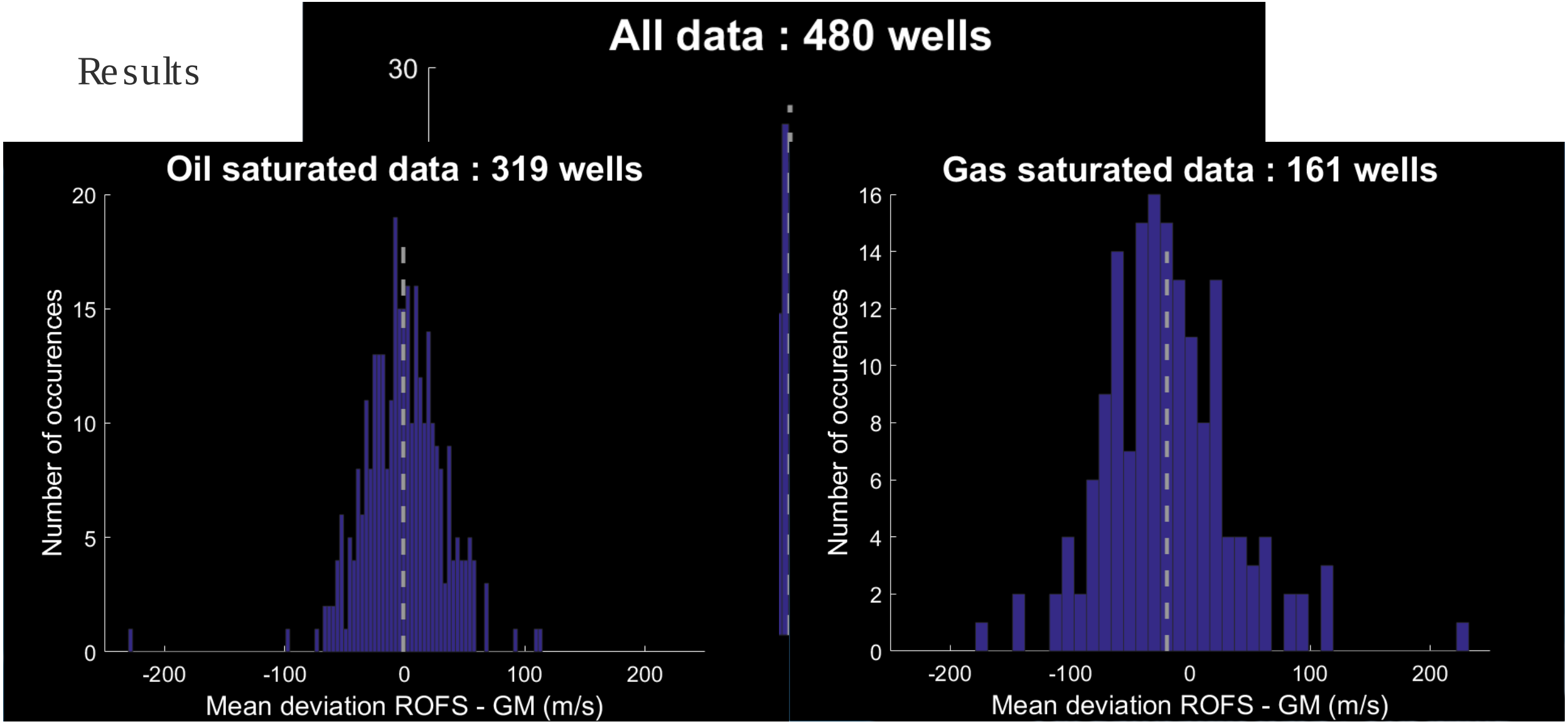

Vp_{br} - Vp_{org} (m/s)
200
150
100
50
0.02
0.04
0.06
0.08
Porosity
GM Br
ROFS Br
0.8
0.6
0.4
0.2
Original Sw (fraction)


Vp_{br} - Vp_{org} (m/s)
200
150
100
50
0
0
0.1
0.2
0.3
Porosity
GM Br
ROFS Br
0.8
0.6
0.4
0.2
Original Sw (fraction)

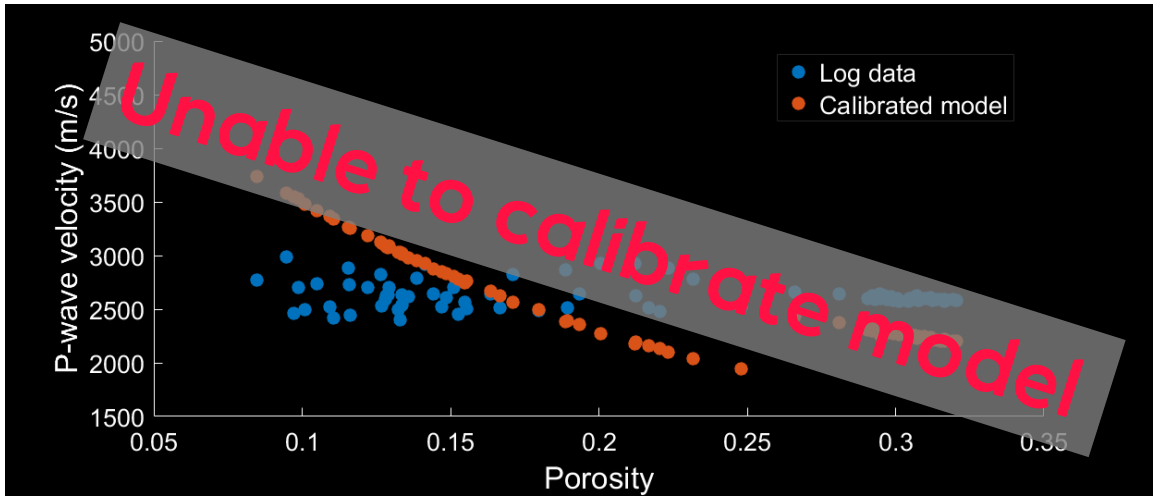

Vp_{br} (m/s)
5000
4500
4000
3500
3000
2500
2000
0.1
0.2
0.3
0.4
0.5
Porosity
GM Br
ROFS Br
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Original Sw (fraction)

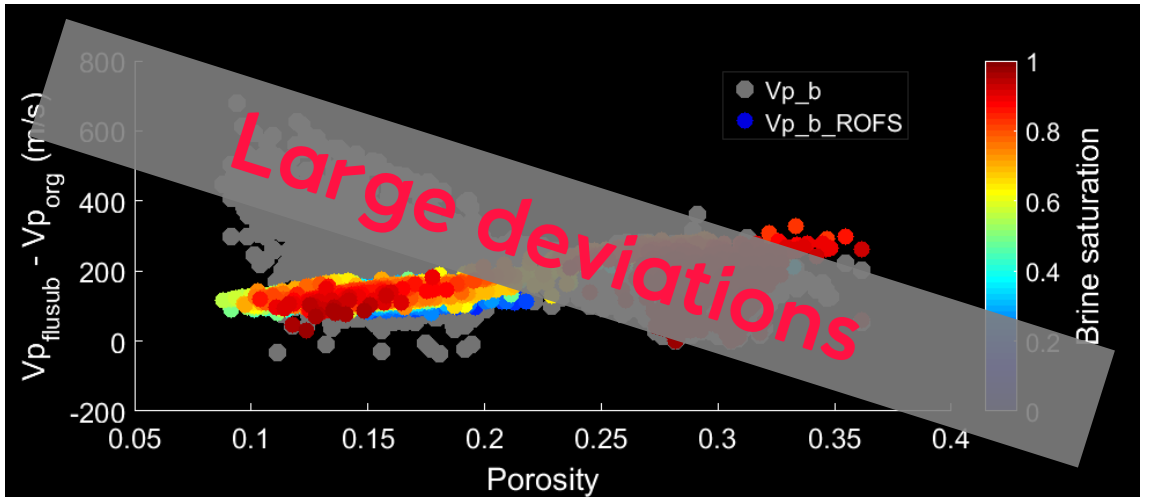

$Vp_{brine\ saturated}$ - Vp_{org} (m/s)
1500
1000
500
0
-500
-1000
0
0.05
0.1
0.15
0.2
0.25
0.3
Porosity
GM Br
ROFS Br
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Original Sw (fraction)

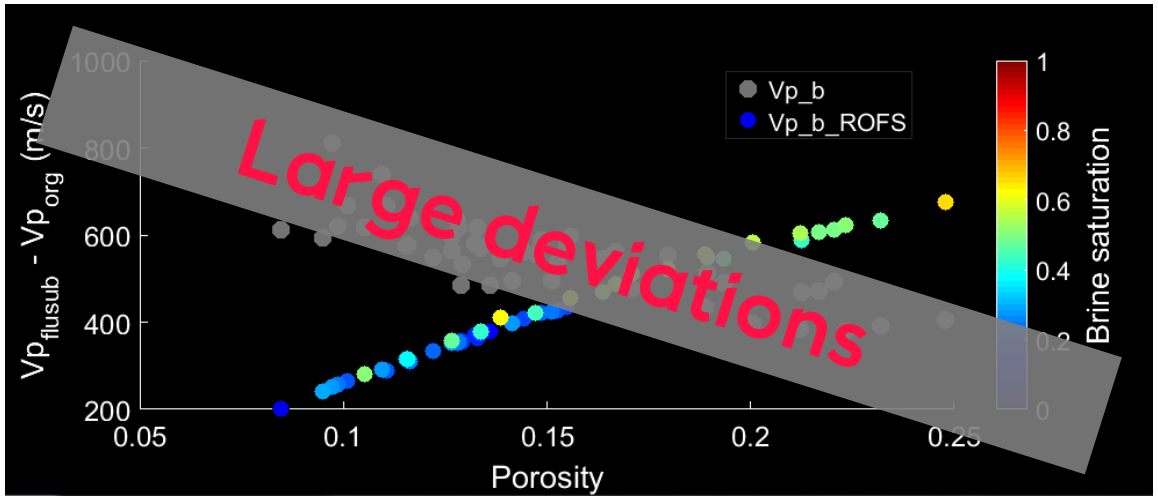
Results

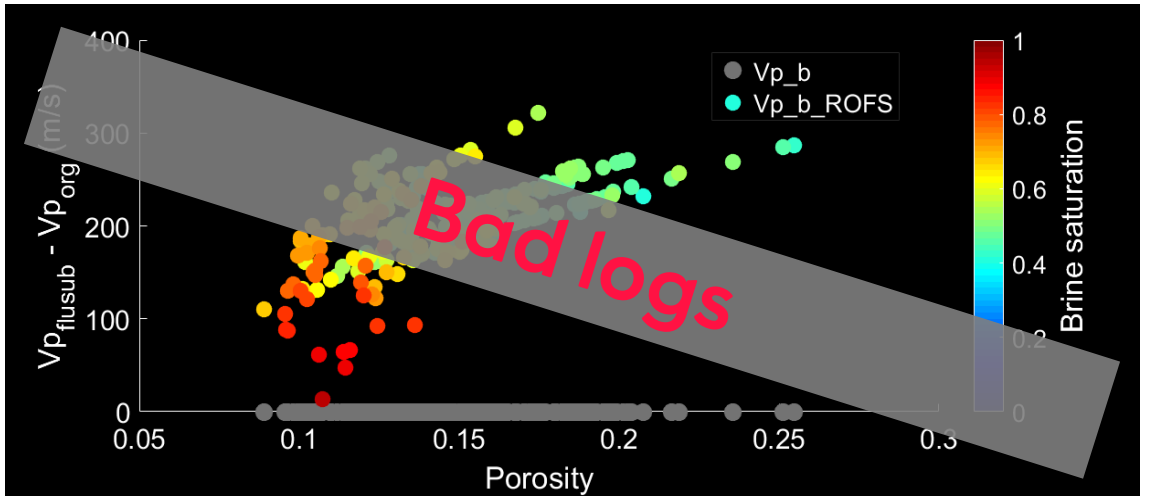


Use method as a QC on individual wells or reservoirs









Summary and conclusions

- A new method called «Rock physics fluid substitution» has been presented
- ROFS seems to handle low porosity cases where Gassmann conditions are not met
- Method is fit for automation:
  - Can perform fluid substitution in hundreds of wells in a few minutes
  - Automatic QC of well logs and fluid substitution
- New wells can be QC-ed and fluid substituted before human interference
- Potential for cost and time saving