



equinor

# Automated fluid substitution from non-linear regression

Anders Dræge

# Outline

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

Take aways

# New method for fluid substitution (ROFS)

## Automation of processes



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




<https://www.cdnstockphoto.com/illustration/automation.html>

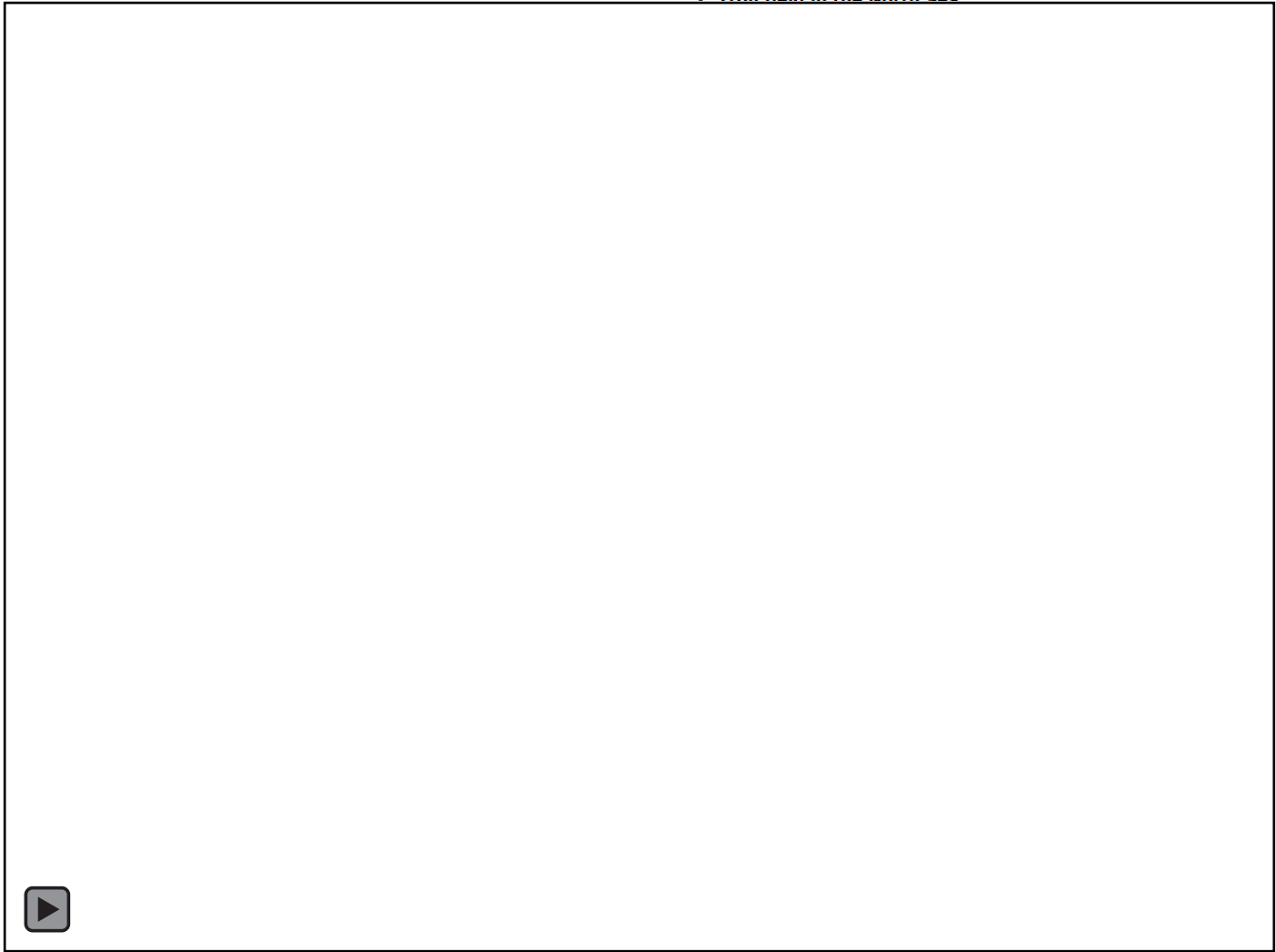
# Fluid substitution – some background

- 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

**6000 wells on the Norwegian shelf**  
 04.04.2017 Well number 6000 was registered as completed in the Norwegian Petroleum Directorate's Fact Pages in late March. This was production well 31/2-Y-21 AY2H on the Troll field in the North Sea.



on and well ID. The  
s and shallow drilling



## Effect of fluids on P-wave velocity

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

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

Increase velocity

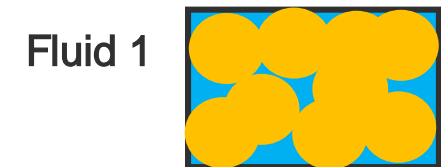
Decrease velocity

## Standard workflow - Gassmann

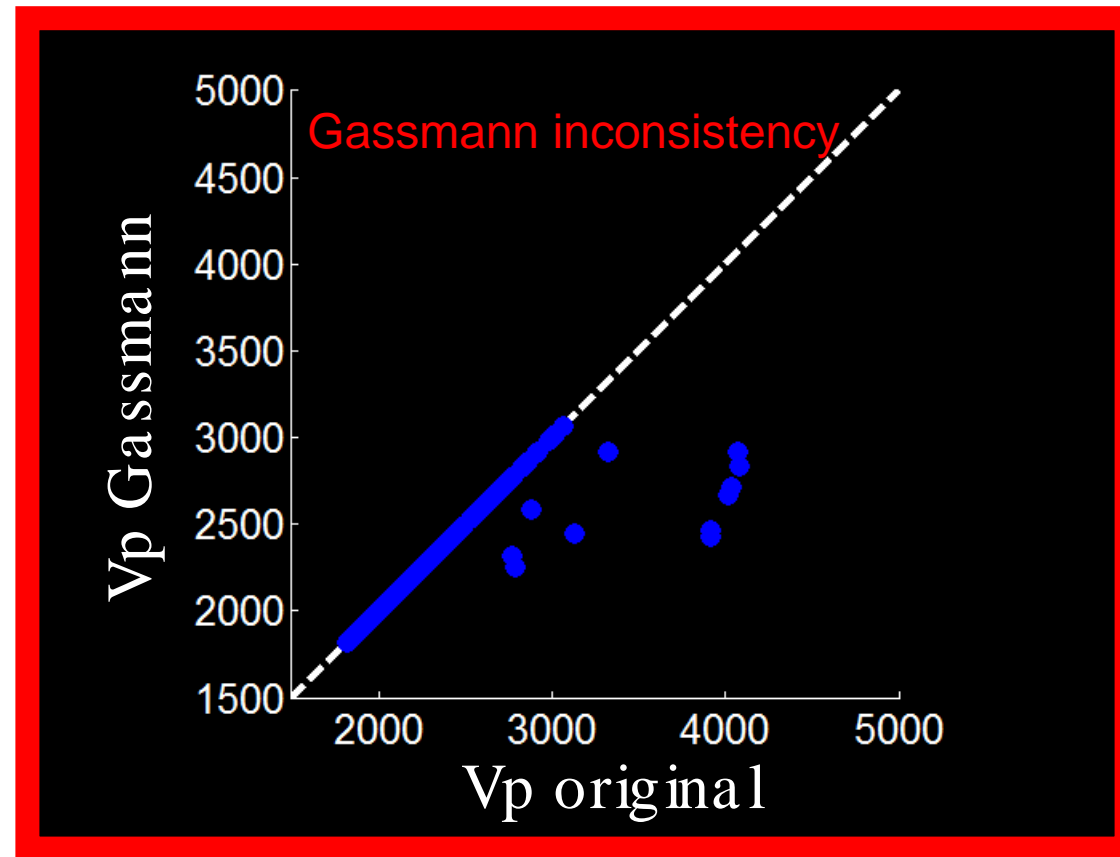
- Normally fluid substitution has been performed by Gassmann (1951) modeling
- Important Gassmann approach assumptions:
  - Homogeneous pore pressure, **homogeneous solid material**, **free fluid flow between pores**, no interaction between solids and fluid
- The procedure of using Gassmann in a well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

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

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



## Standard workflow - Gassmann

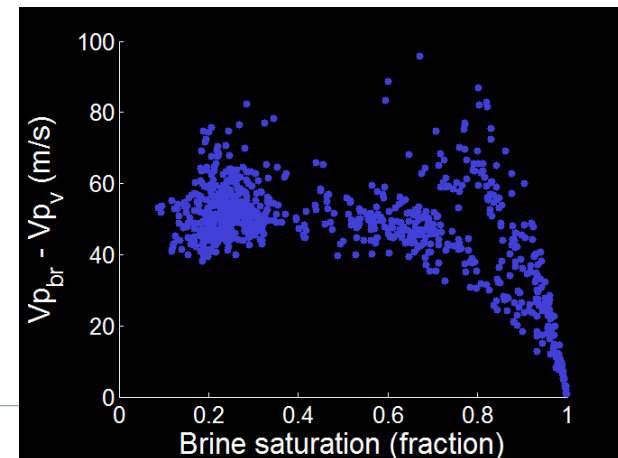
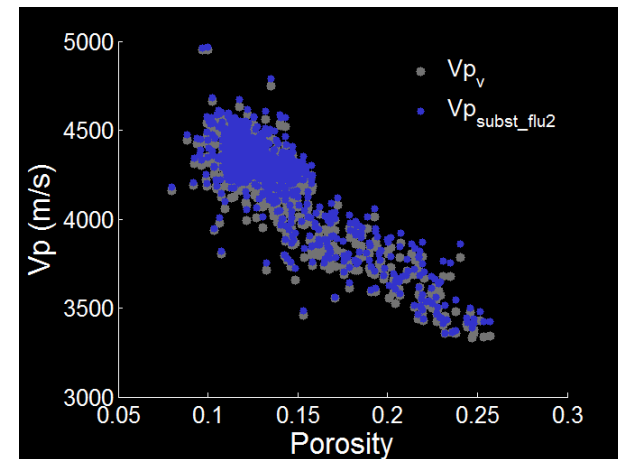
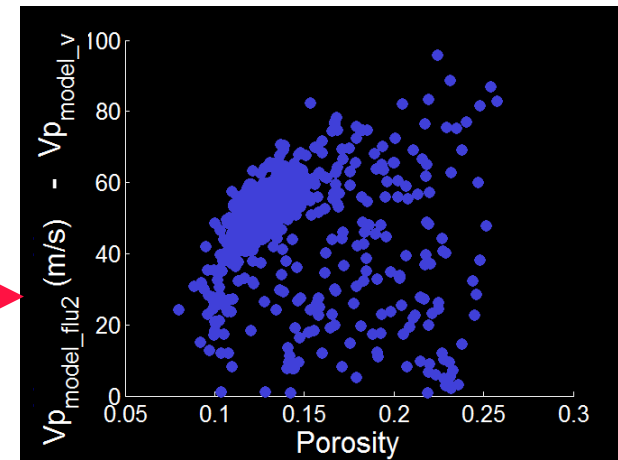


# Rock physics fluid substitution (ROFS)

## 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

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





# Automation of workflow

- Calibration of rock physics model:

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

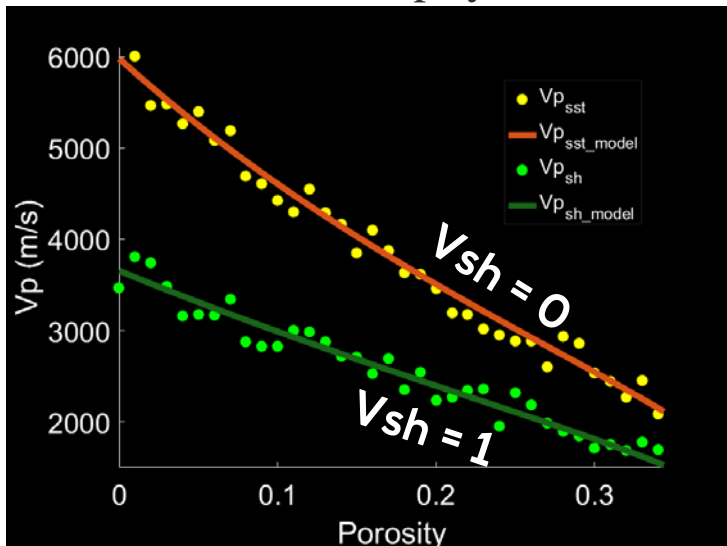
Hertz-Mindlin model:

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

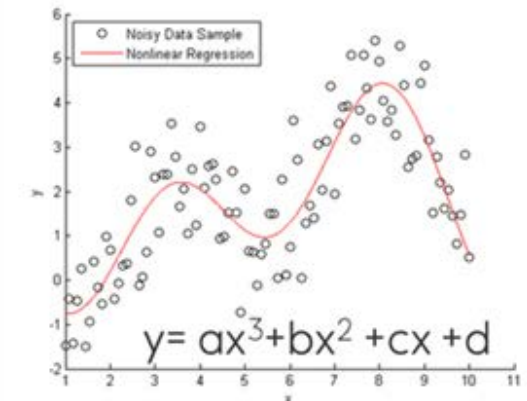
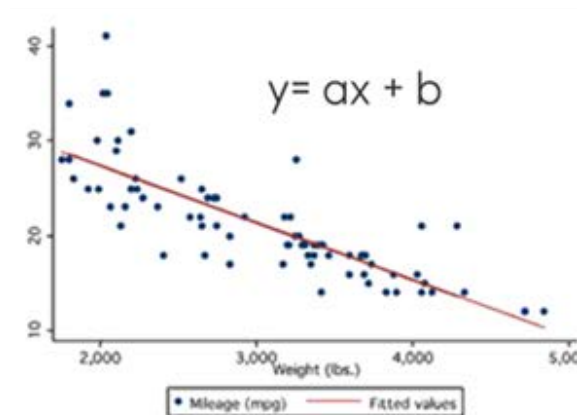
$$\sigma = f(K_{clay}, K_{non-clay}, \mu_{clay}, \mu_{non-clay}, V_{sh})$$

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

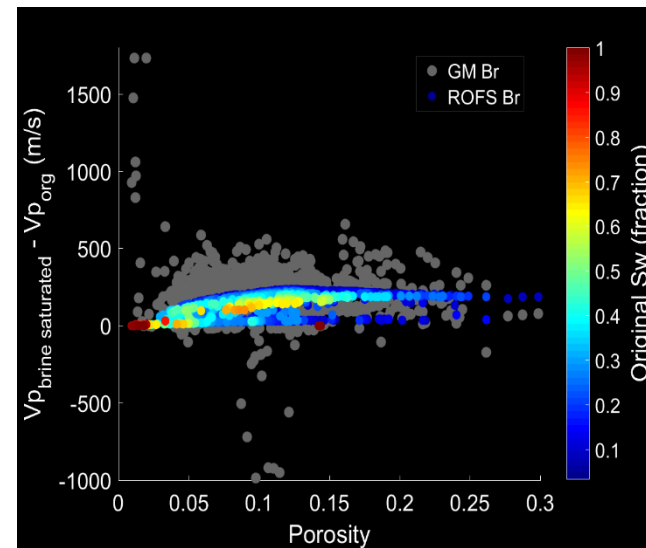
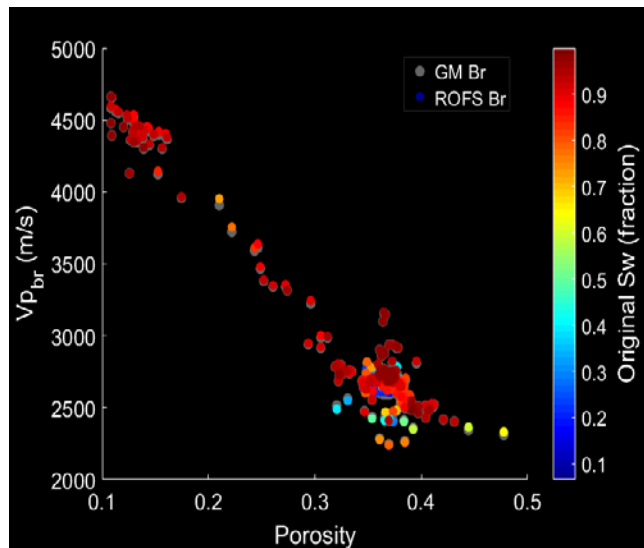
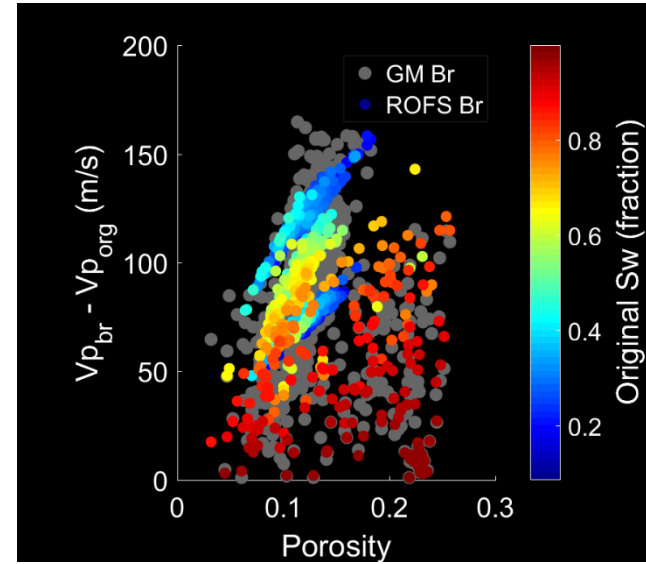
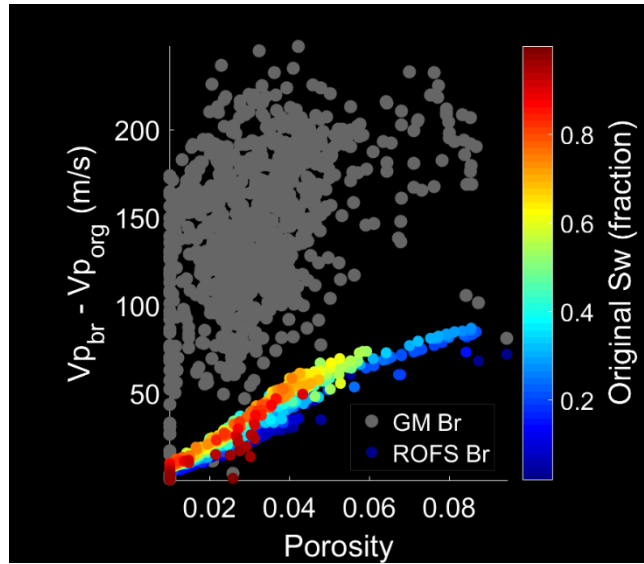
## Calibration of rock physics model



## Machine learning approaches



# Results

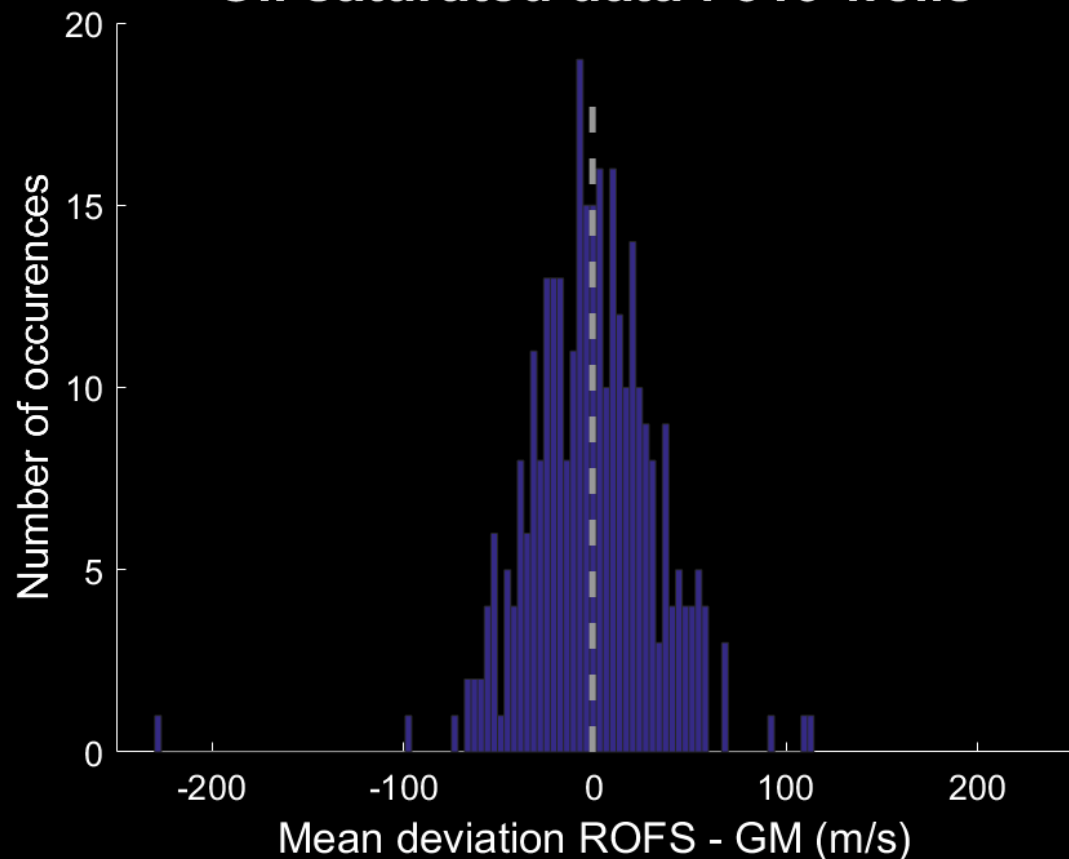


Results

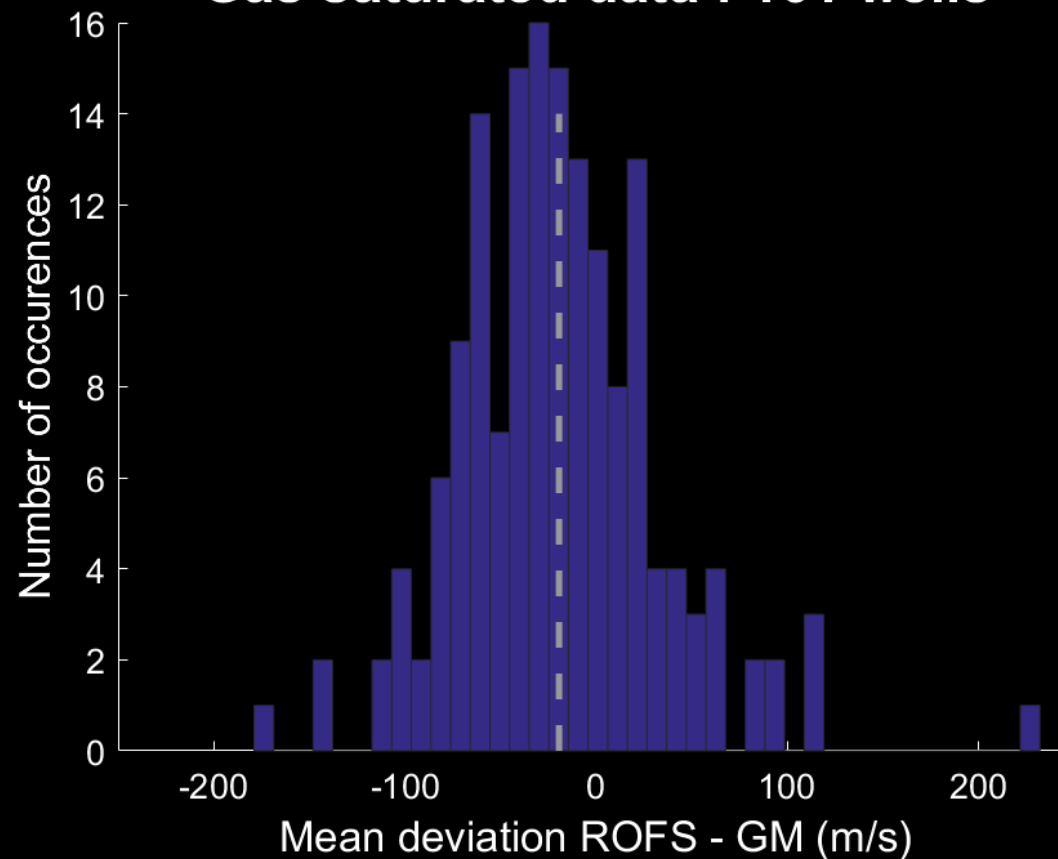
### All data : 480 wells

30

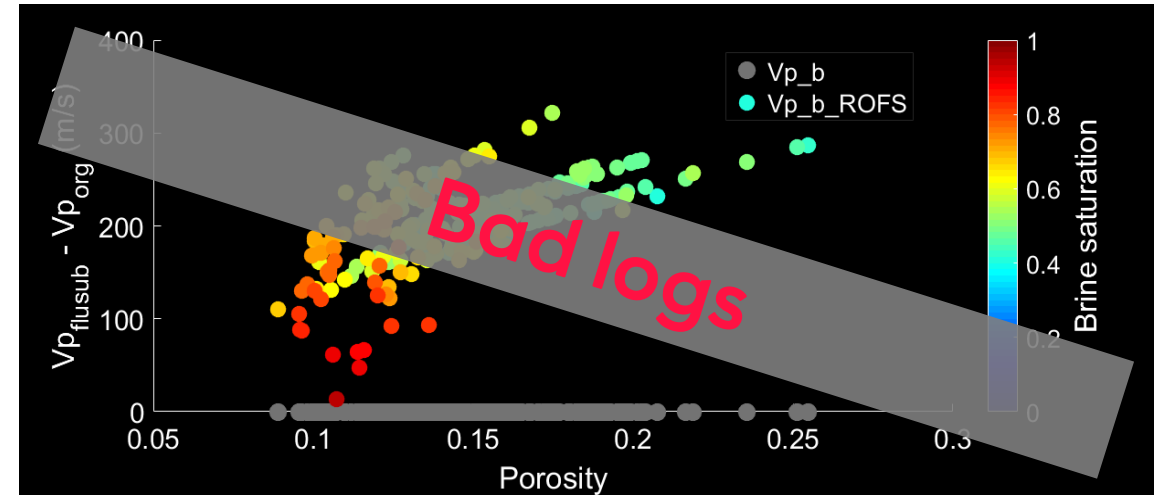
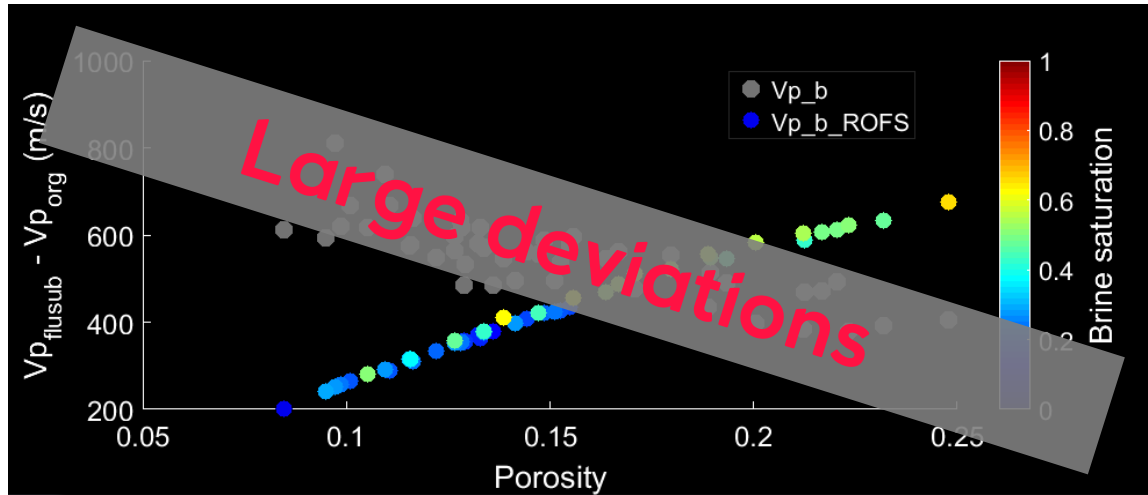
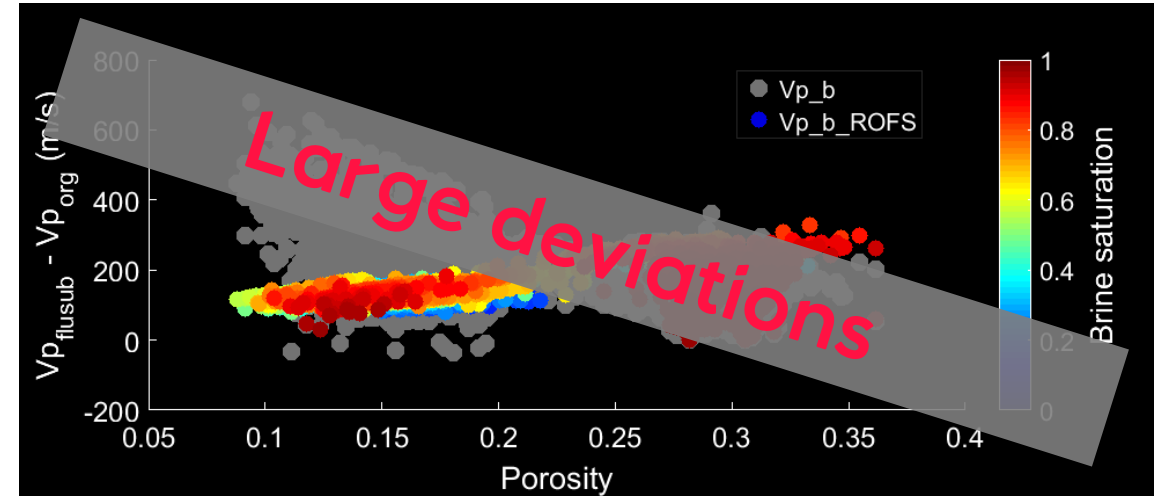
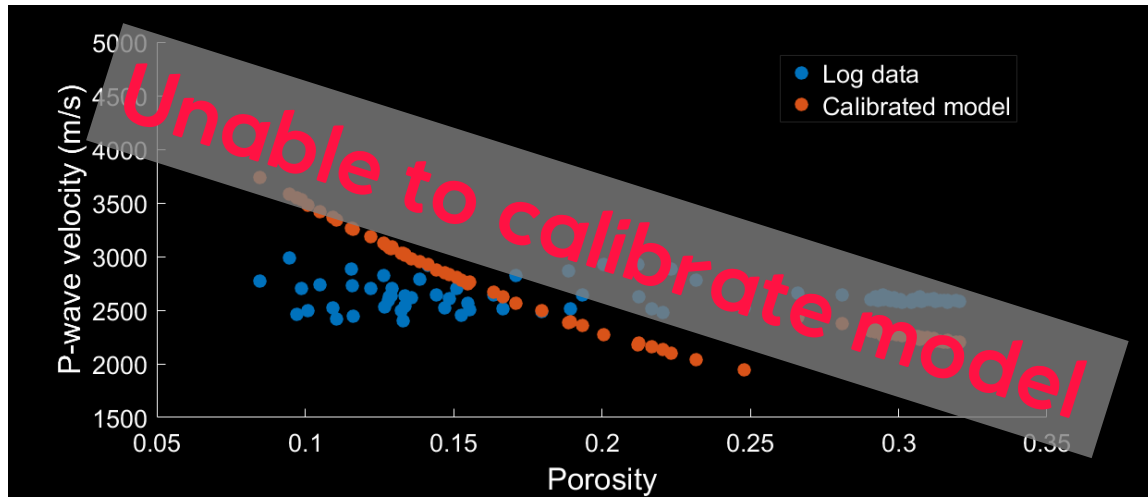
#### Oil saturated data : 319 wells



#### Gas saturated data : 161 wells



# 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



equinor

© Equinor ASA

This presentation, including the contents and arrangement of the contents of each individual page or the collection of the pages, is owned by Equinor. Copyright to all material including, but not limited to, written material, photographs, drawings, images, tables and data remains the property of Equinor. All rights reserved. Any other use, reproduction, translation, adaptation, arrangement, alteration, distribution or storage of this presentation, in whole or in part, without the prior written permission of Equinor is prohibited. The information contained in this presentation may not be accurate, up to date or applicable to the circumstances of any particular case, despite our efforts. Equinor cannot accept any liability for any inaccuracies or omissions.