Freie Universität Berlin

Stress-dependent permeability

vs

stiff and compliant porosity

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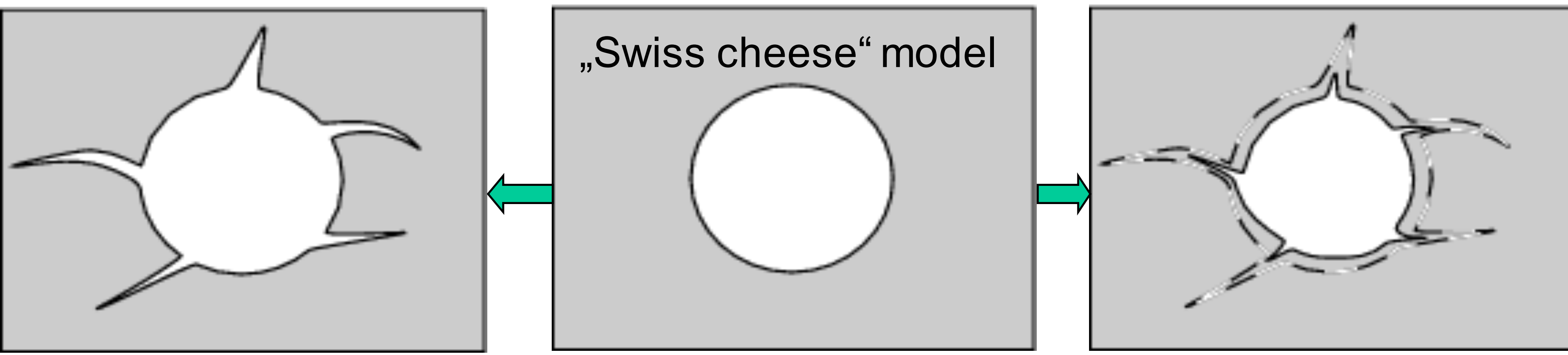
Based on

Shapiro S.A., G.P. Khizhniak, V.V. Plotnikov, R. Niemann, P.Yu. Ilyushin, and S. V. Galkin, 2015, Permeability dependency on stiff and compliant porosities: a model and some experimental examples,

J. Geophys. Eng. **v. 12, pp. 376385, doi:10.1088/1742-2132/12/3/376**

A cooperation with the Perm National Research Polytechnic University, Russia

Stiff and compliant porosity



zero load,
complete pore space

stiff pores only,
zero load

current load

Pore-space deformation

$$\phi(\sigma) = \phi^{s}(0) - (C^{drs}-C^{gr})\sigma + \phi^{c}(0)\exp(-D\sigma)$$

Linear terms: Stiff porosity

Stress exponentials:
Compliant porosity

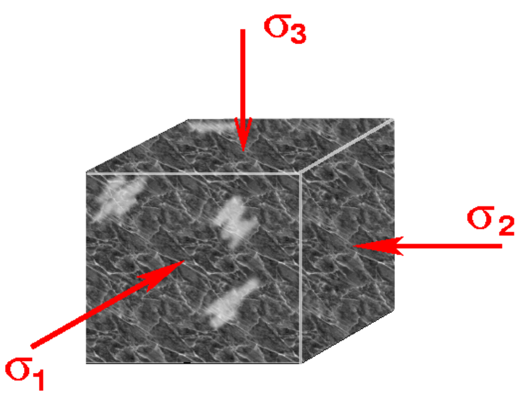
Piezosensitivity theory (porosity deformation approach)

describes elastic compliances as functions of the effective stress:

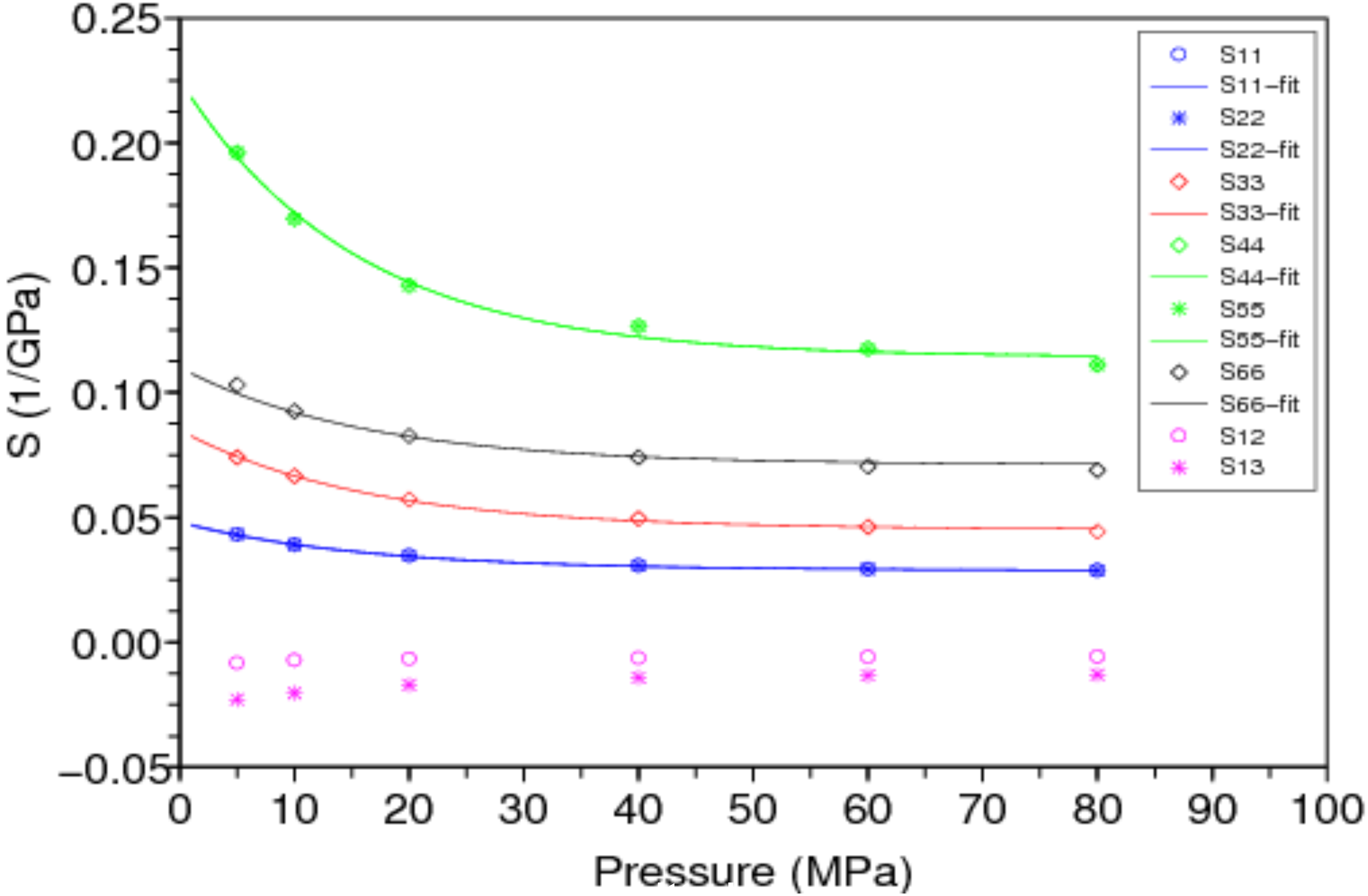
$$\Lambda(\sigma) = \Lambda^{drs} - C_{\Lambda}\sigma + B_{\Lambda}\exp(-D\sigma)$$

Linear terms:
Stiff porosity

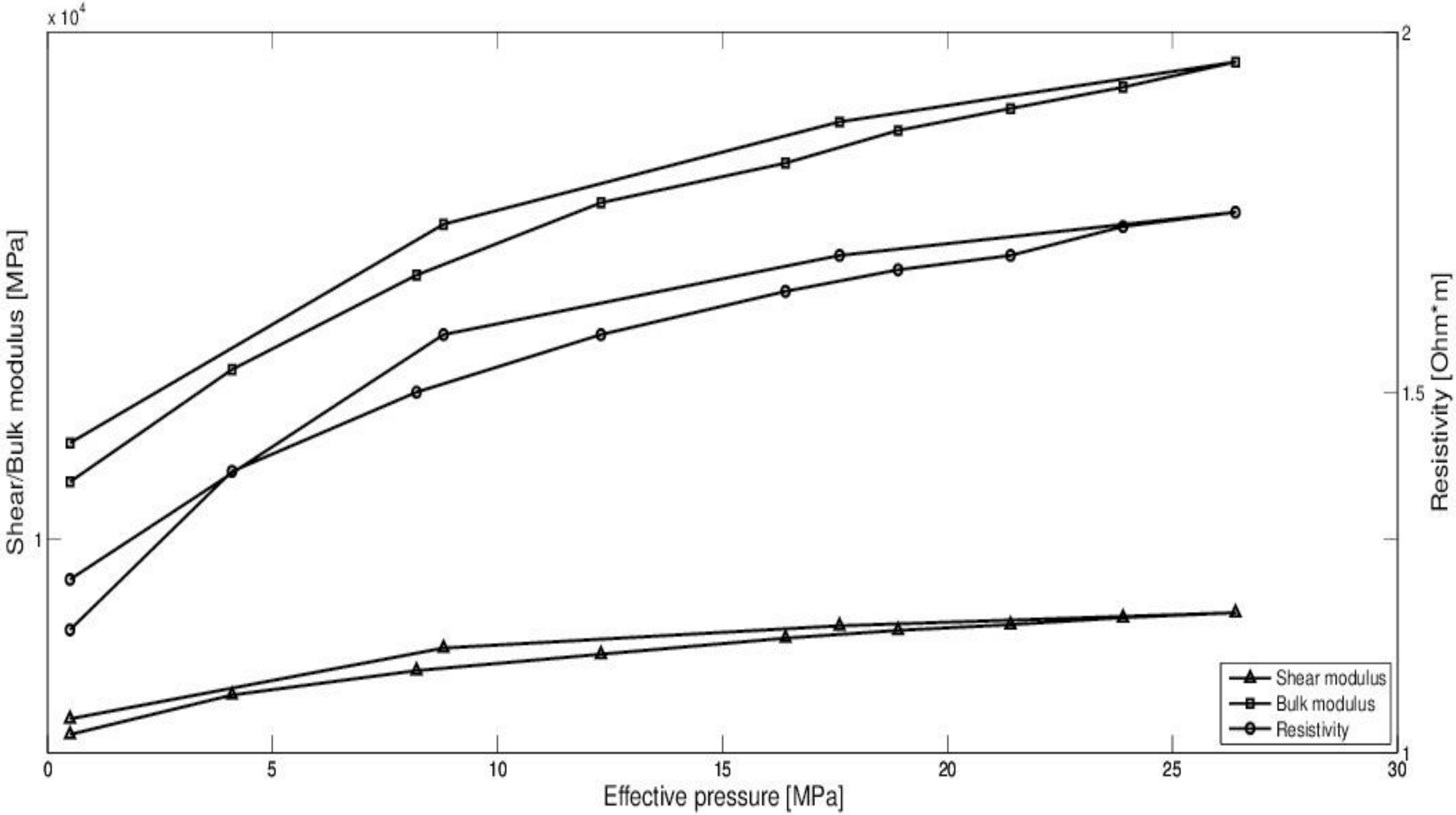
Stress exponentials:
Compliant porosity



Application to a TI Shale Sample



A siltstone from Perm



Models of permeability

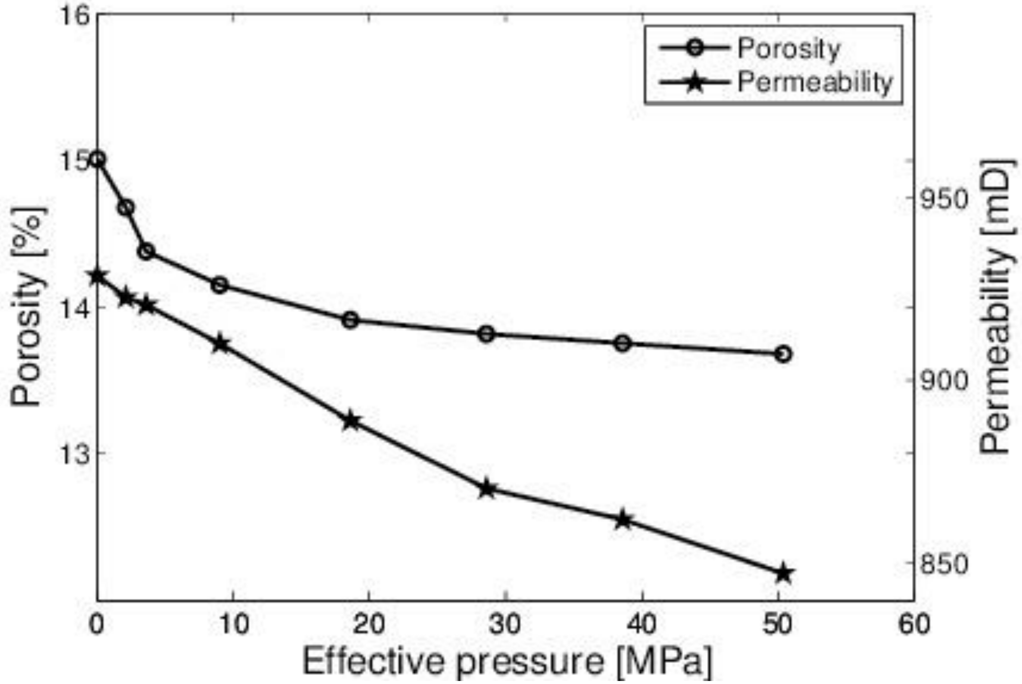
$$\kappa \sim (\phi)^n$$

$$\kappa(\sigma) \sim f(\phi^s(\sigma), \phi^c(\sigma))$$

$$\kappa(\sigma) \sim [\Phi_s \, \phi^s(\sigma) + \Phi_c \, \phi^c(\sigma)]^n$$

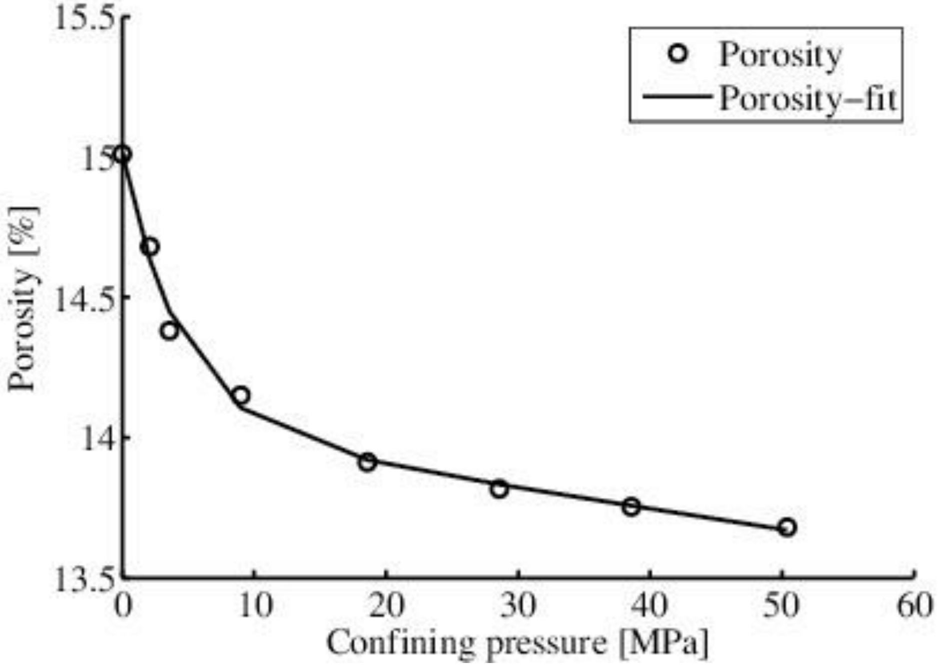
$$\kappa(\sigma) \sim \Phi_s [\phi^s(\sigma)]^{n_s} + \Phi_c [\phi^c(\sigma)]^{n_c}$$

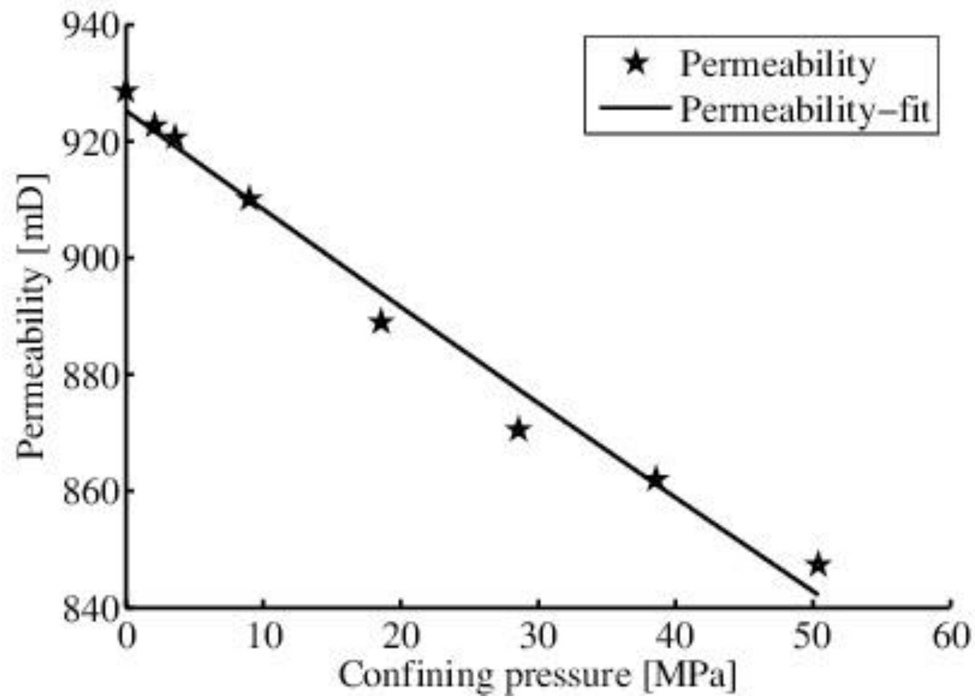
Sandstone A

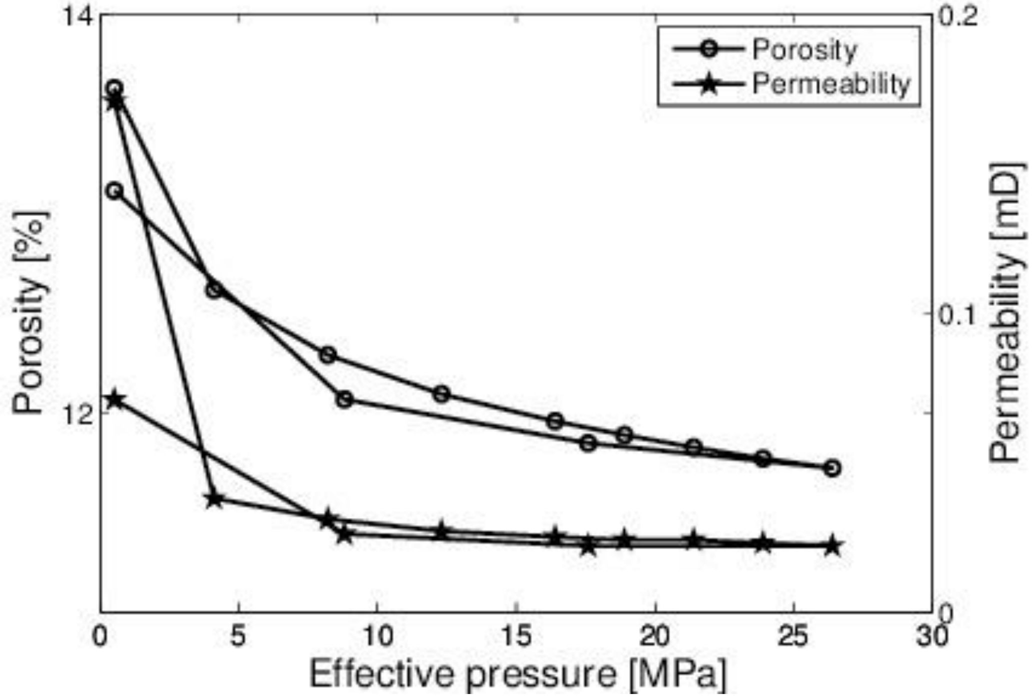


$$\phi(P) \approx 14.04 - 0.0074P + 0.97e^{-0.22P}$$

$$k(P) \approx 925(1 - 3.49\frac{0.0074}{14.04}P)$$



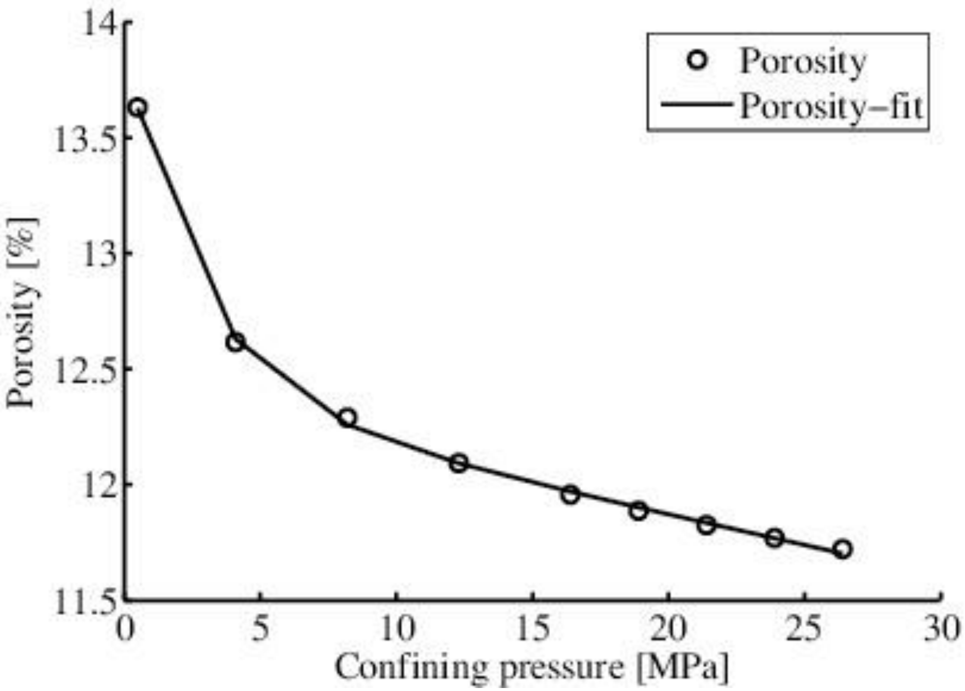


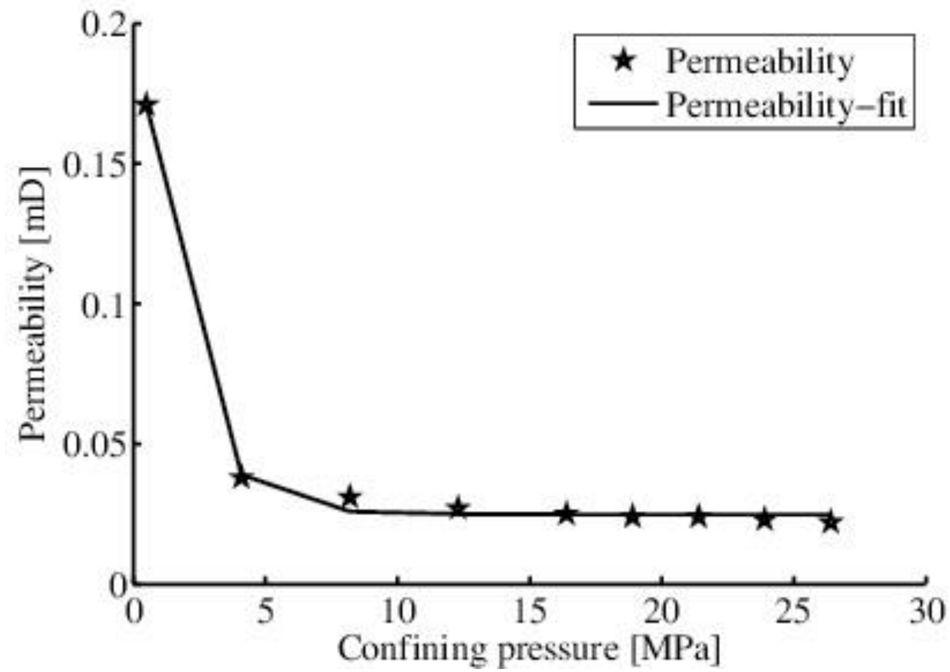


Siltstone B

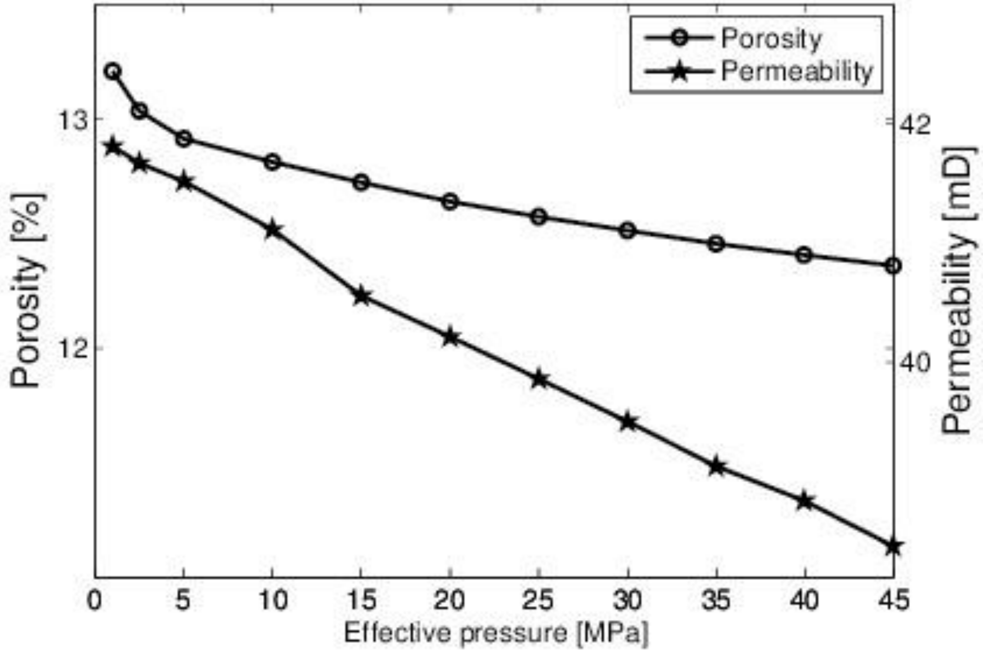
$$\phi(P) \approx 12.4 - 0.026P + 1.5e^{-0.36P}$$

$$k(P) \approx 0.025 + 0.2e^{-0.65P}$$



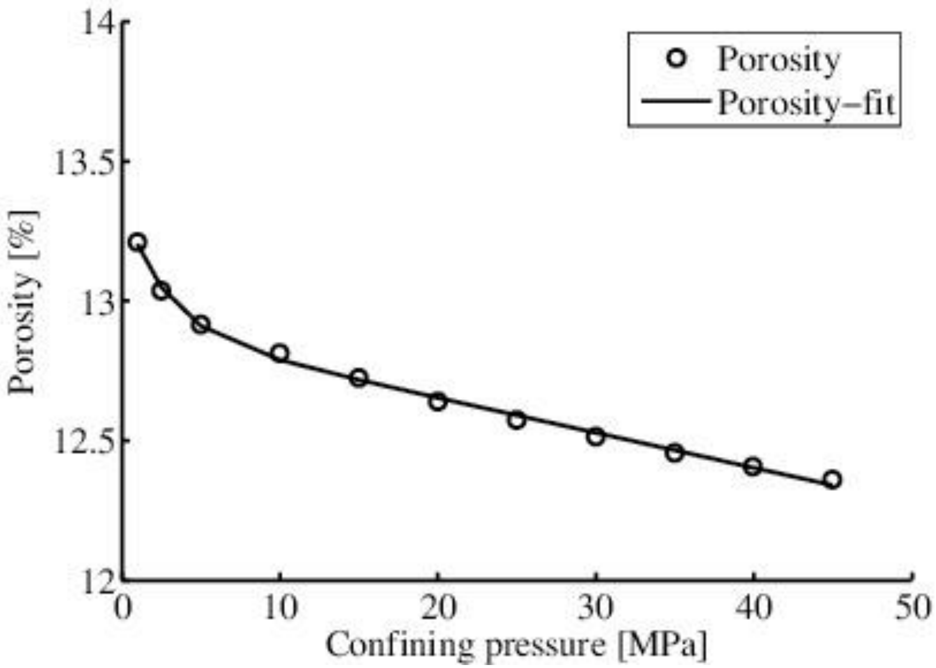


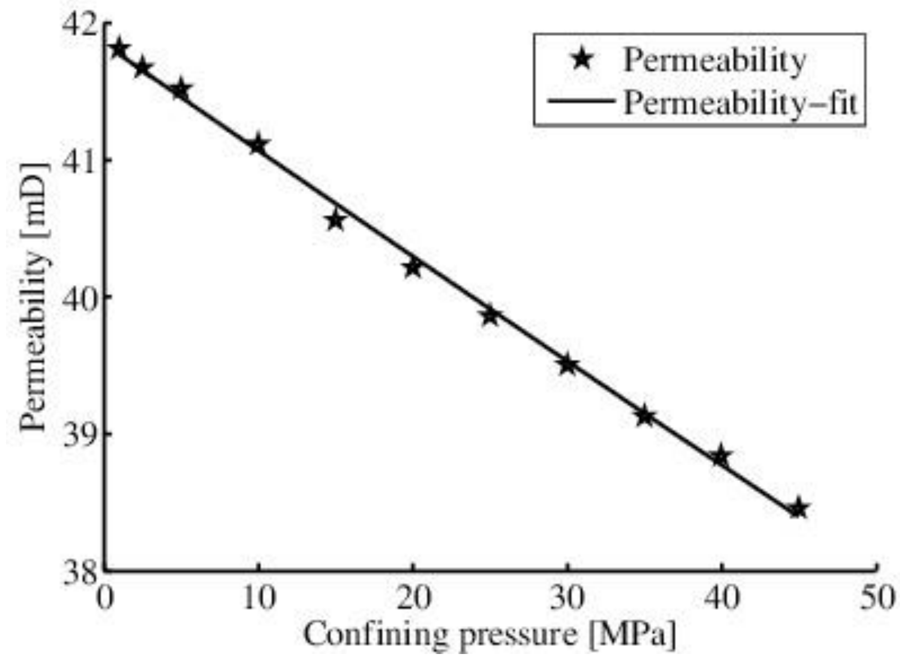
Limestone C

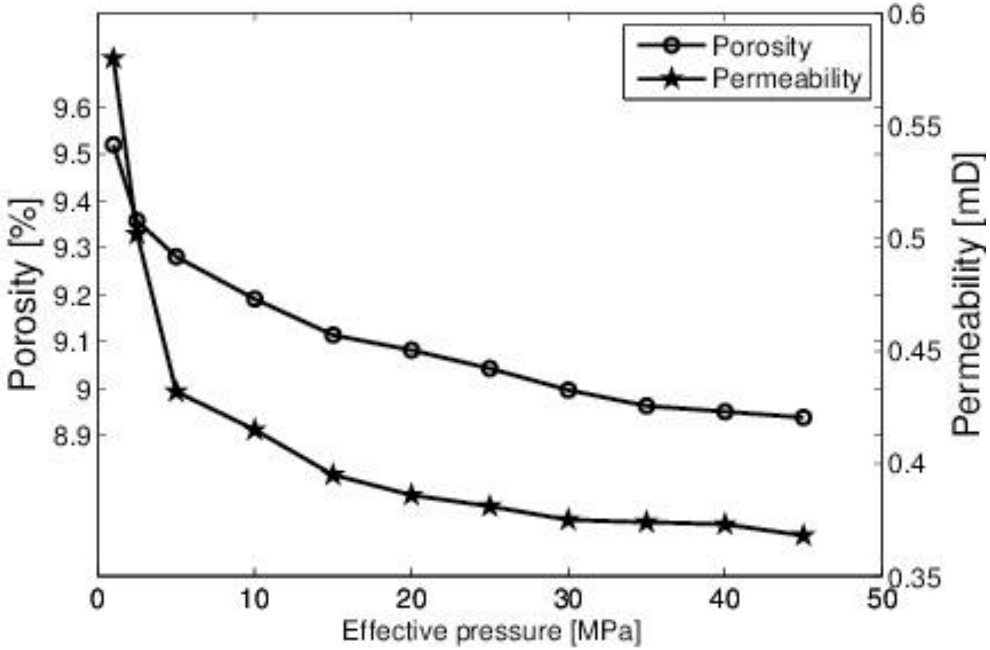


$$\phi(P) \approx 12.9 - 0.0125P + 0.45e^{-0.38P}.$$

$$k(P) \approx 42(1 - 1.93\frac{0.0125}{12.9}P).$$



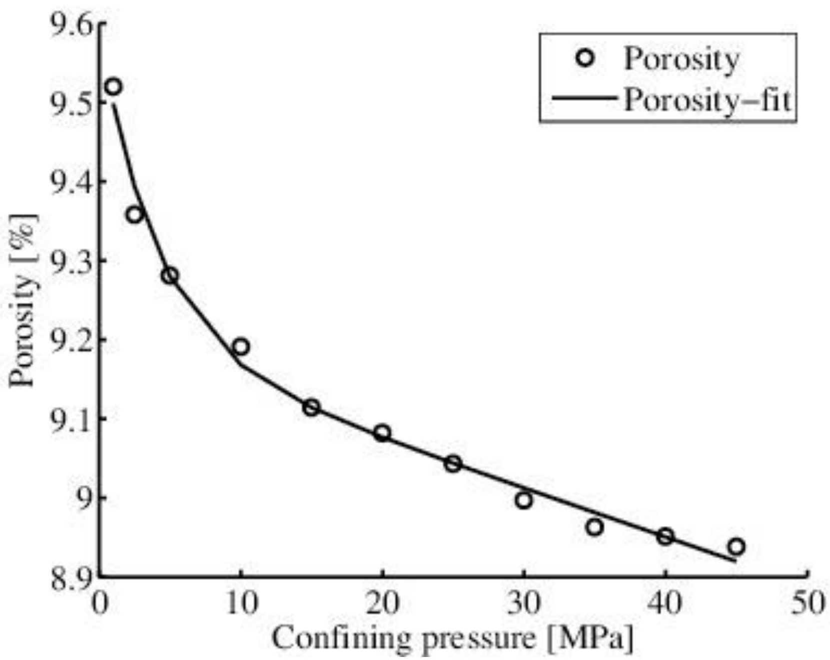


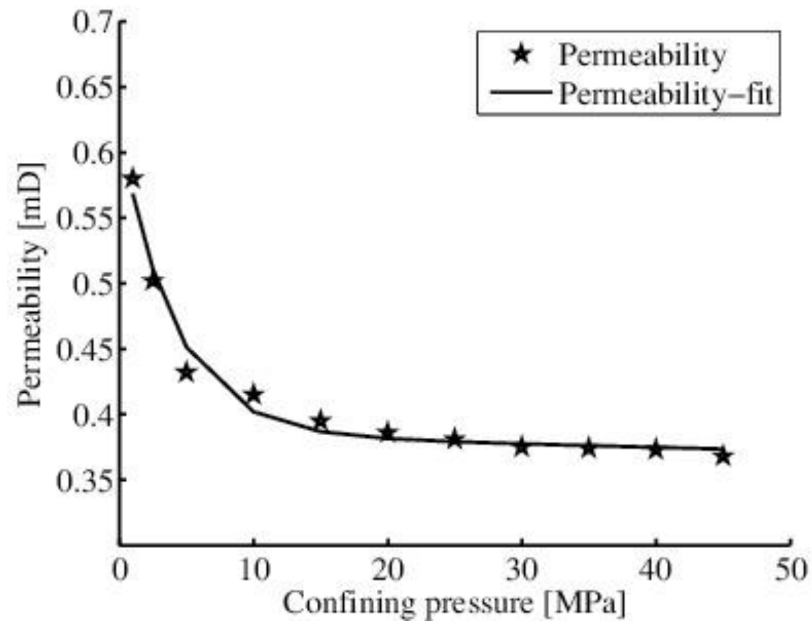


Limestone D

$$\phi(P) \approx 9.2 - 0.006P + 0.4e^{-0.25P}.$$

$$k(P) \approx 0.39 - 0.00026P + 0.24e^{-0.25P}.$$





Sample	ϕ^{s0}	ϕ^{c0}	$C^{drs} - C^{gr}$	$\theta^{c} C^{drs}$	n	$\frac{\Phi_c}{\Phi_s}$	k_0 (mD)
A (sandstone)	14	1	7.4×10^{-11}	2.2×10^{-7}	3.5	$\rightarrow 0$	925
B (siltstone)	12.4	1.5	25×10^{-11}	3.6×10^{-7}	1.8	30–100	0.225
C (limestone)	13	0.45	12.5×10^{-11}	3.8×10^{-7}	1.9	$\rightarrow 0$	42
D (limestone)	9.2	0.4	6.0×10^{-11}	2.5×10^{-7}	1	10–20	0.63

Note: Porosities are given in %; $C^{drs} - C^{gr}$ and $\theta^{c} C^{drs}$ are given in Pa^{-1}.

Conclusions

- Permeability may be controlled by the stiff pore space, by the compliant pore space or by a combination of them.
- This is in contrast to elastic properties: they are mainly controlled by the compliant pore space.
- Several simple models describe well the stress dependency of permeability.
- To understand permeability, it is useful to compare its stress dependency with the one of the porosity.

A conventional approach

Seismic Velocities ⟶ Porosity ⟶ Permeability

A new approach

1. Understanding of the nature of porosity, which controls the permeability

2. Seismic Velocities → Compliant and Stiff Porosity → Permeability

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A German Patent Application 10 2015 216 394

A method for determining the hydraulic permeability of rocks in a subsurface region

We are looking for partners in this new project!