Coupling of hydraulic and electrical transport properties in sandstones

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1. Introduction

- In geothermal reservoirs a characterization of the rock permeability (k) is essential and a knowledge of the permeability dependence on effective pressure (p_{eff}) is important.

- The electrical rock conductivity (σ) is significantly easier to measure both in the lab and in situ.

- Finding a link between both rock transport properties is therefore desirable.

- Such a link should exist if the rock conductivity is governed by the conductivity of a fluid within the pore space as in that case both k and σ were shown to be dependent on effective pressure.

- Scope: search suitable coupling through microstructural parameters.

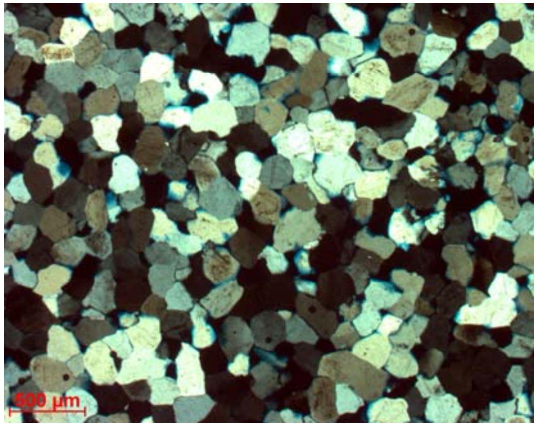
2. Experimental details

Sandstone samples:

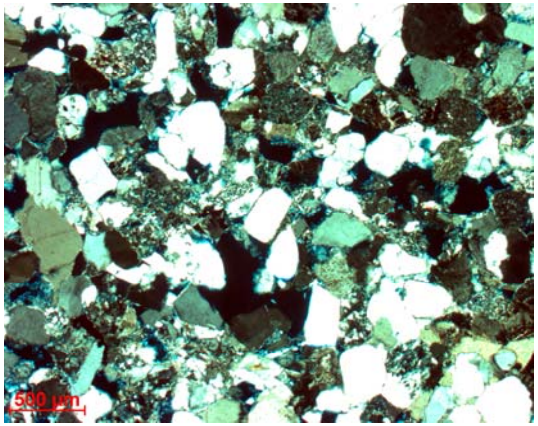
Fontainebleau **Flechtinger** **Eberswalder**

Microstructure:

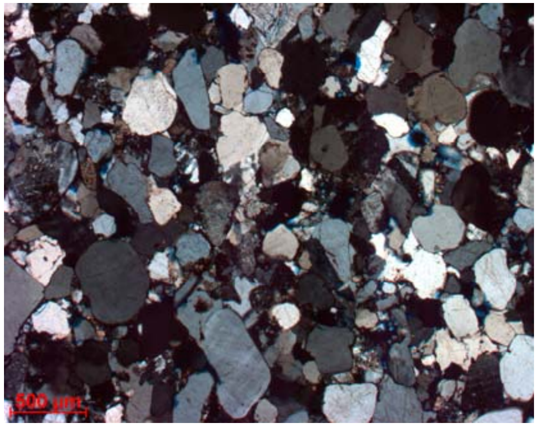
(optical, crossed nicols)



Fontainebleau



Flechtinger



Eberswalder

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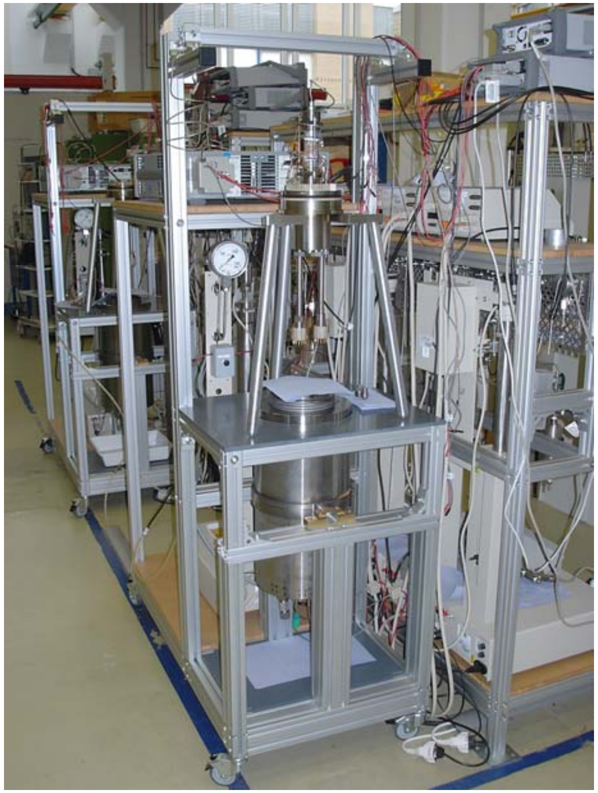
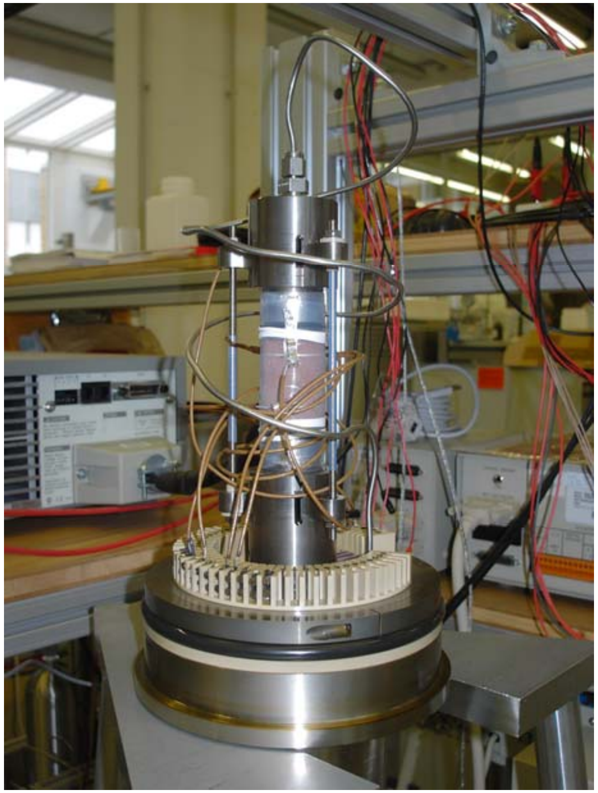
Sample properties:

Sample	Porosity [%]	Permeability [mD]	Formation factor [1]
Fontainebleau	7.5	20	125
Flechtinger	9.0	0.03	38
Eberswalder	4.0	0.01	66
Fluid:	0,1 molar NaCl-solution (σ at 40°C = 13 mS/cm)		

Experimental set-up:





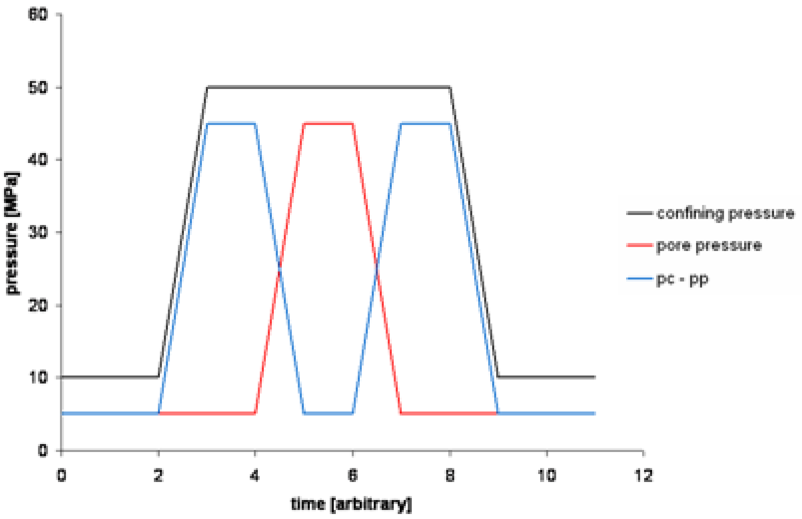
Experimental procedure:

- the experiments were performed at T = 40 °C
- k and σ were simultaneously measured
- effective pressure ramping was performed by successively increasing and decreasing both confining- (pc) and pore pressure (pp):

pc = [10 - 50 MPa]

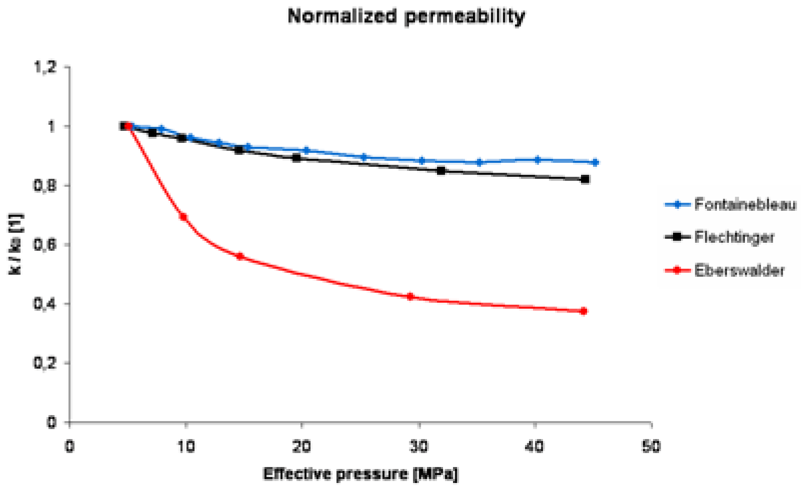
pp = [5 - 45 MPa]

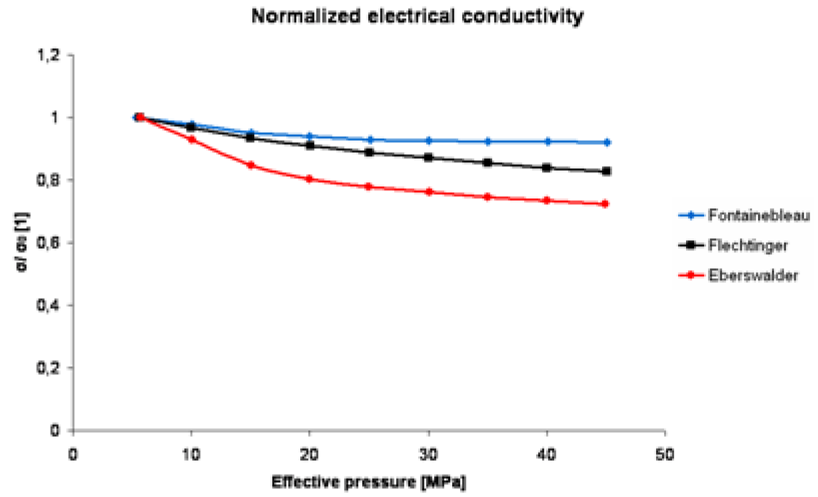
Intervall = [2.5 - 15 MPa]



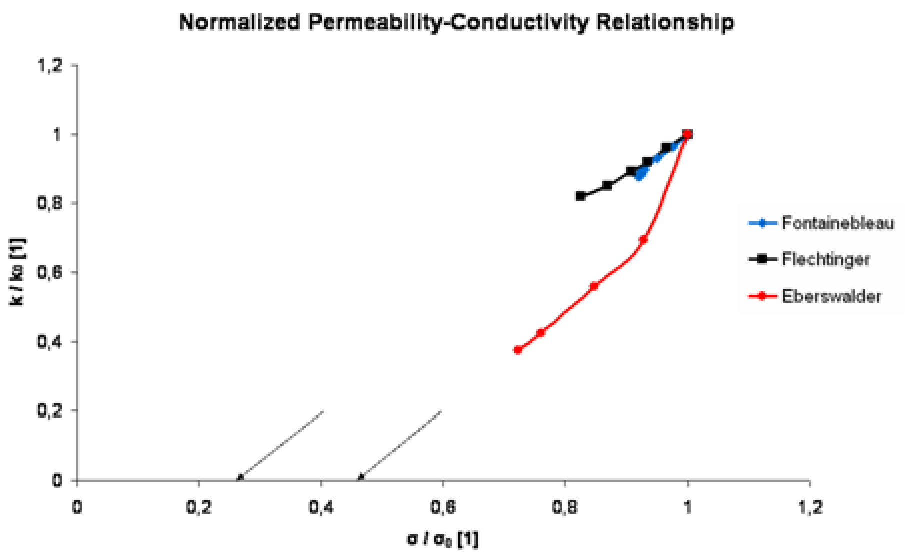
3. Experimental results

Effective pressure dependence of permeability and electrical conductivity:



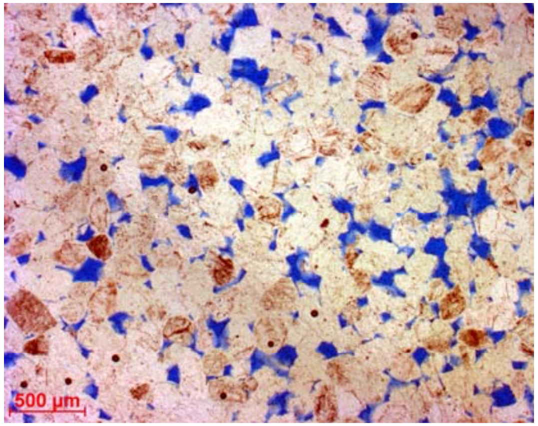


Permeability – conductivity relationship:

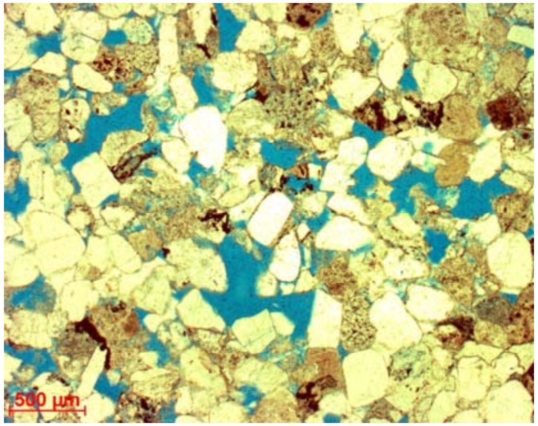


4. Microstructural analysis

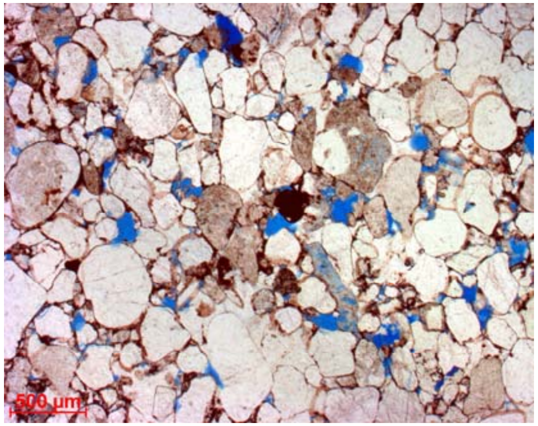
1) 2D Image Analysis:



Fontainebleau

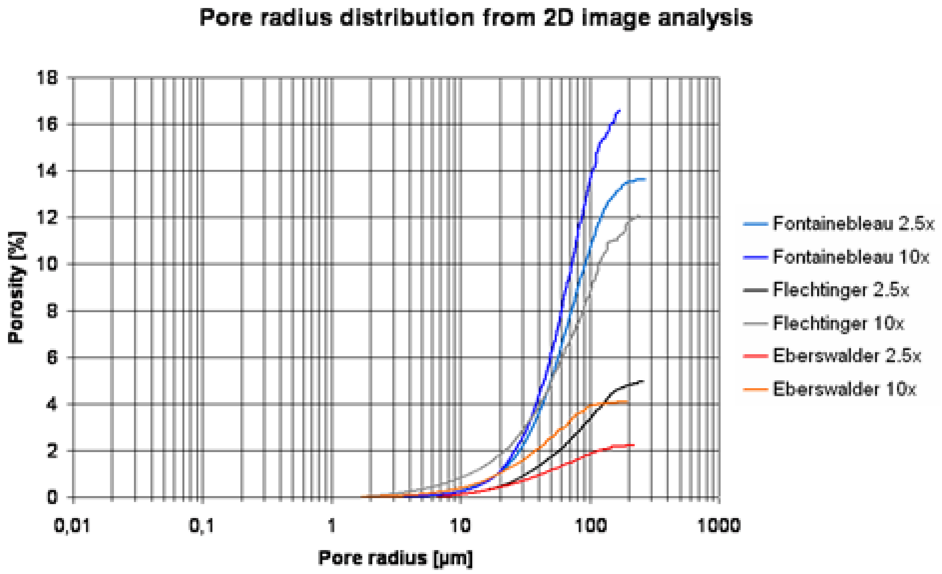


Flechtinger



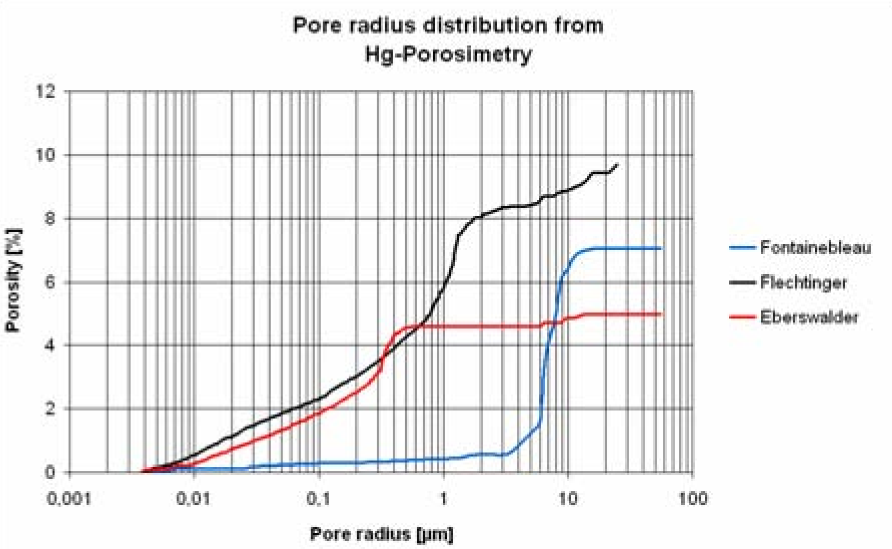
Eberswalder

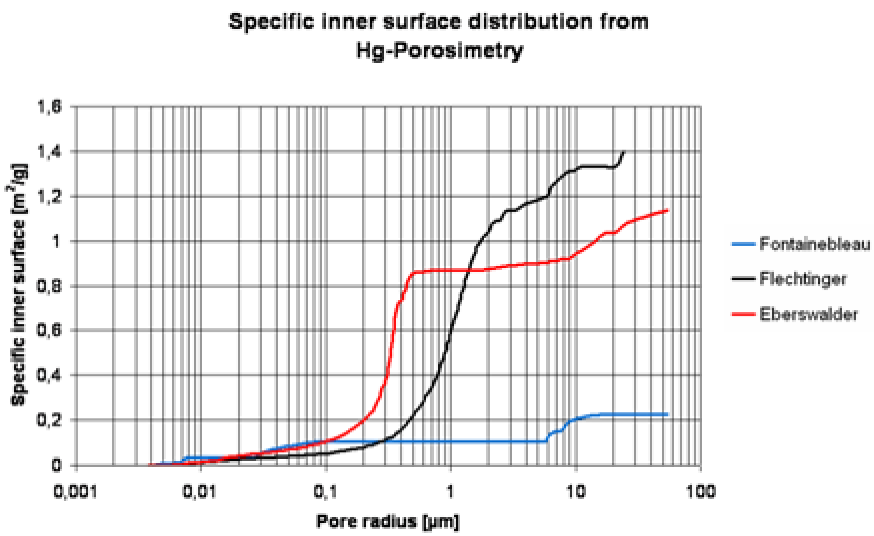
1) 2D Image Analysis (cont.):



Sample	Average Porosity [%]	Average Pore Radius [µm]
Fontainebleau	**15.1**	**21.7**
Flechtinger	**8.9**	**14.4**
Eberswalder	**3,2**	**12,3**

2) Hg-Porosimetry:





Sample	Porosity [%]	Average Pore Radius [µm]	Specific Inner Surface [m^2/g]
Fontainebleau	7.1	7.1	0.23
Flechtinger	9.7	1.3	1.40
Eberswalder	5.0	0.4	1.14

5. Integrated comparison of different scaling models

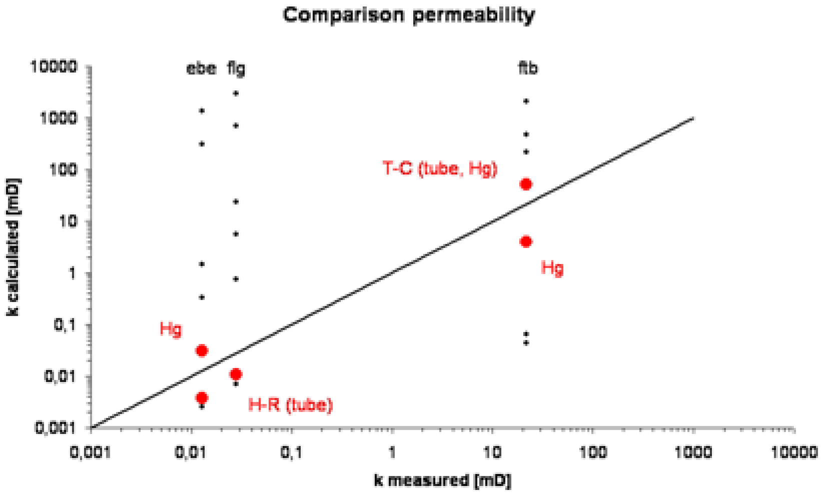
Darcy: $q = -\frac{k}{\eta} \cdot \nabla p$

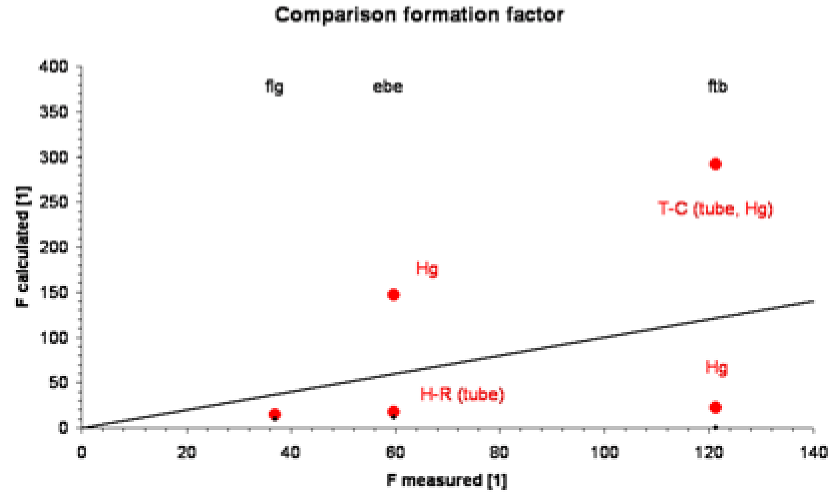
Ohm: $J = -\sigma \cdot \nabla V$

$$k = c \cdot L^2 \cdot \frac{1}{F}$$

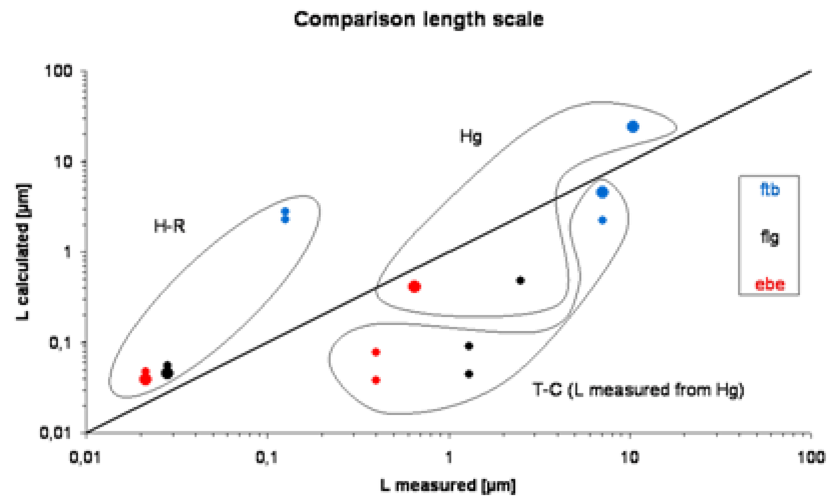
Model	´c [1]	L [m]
Hydraulic radius (Walsh and Brace (1984))	**1/2 (tube)** **1/3 (crack)**	**m = (Vp/Ap)**
Hg-Porosimetry (Katz and Thompson (1986) and (1987))	**1/226**	l_c
Tube-Crack (Guéguen and Dienes (1989))	**1/8 (tube)** **8/15 (crack)**	r_A **(tube)** w_A **(crack)**

Comparison of different scaling models (cont.):

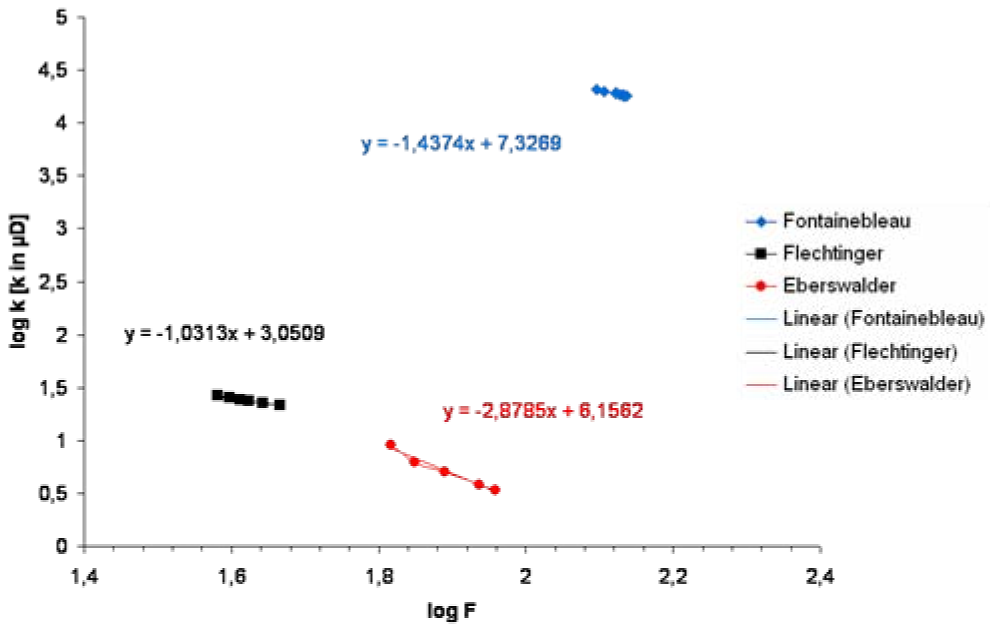




$$k = c \cdot L^2 \cdot \frac{1}{F}$$



Comparison of different scaling models (cont.):



$$\bcancel{k = c \cdot L^2 \cdot \frac{1}{F}}$$ **but** $$k = c \cdot L^2 \cdot \frac{1}{F^r}$$

- experiments yield **sample dependent** parameters

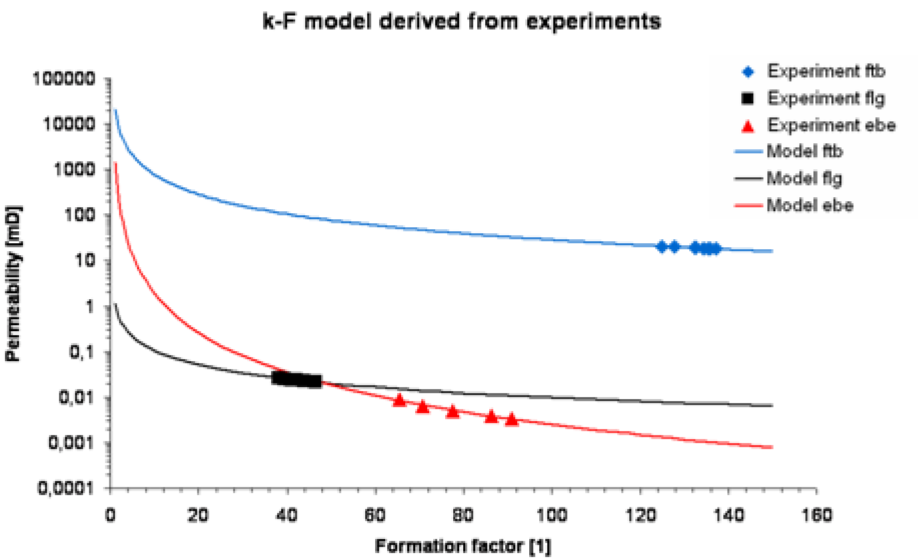
  r and **($c \cdot L^2$)**

- **($c \cdot L^2$)** is a **constant** defining the "permeability" of an equivalent tube-like channel for which **F = 1**

- **c** and **L^2** cannot be derived separately from the experiments but have to be calculated from the model of choice

- **L** is thus a parameter with **no** true **microstructural meaning**

Comparison of different scaling models (cont.):



$$k = c \cdot L^2 \cdot \frac{1}{F^r}$$

Sample	r [1]	cL^2 [mD]	L [µm] with c = 1/8
ftb	1.44	$21.23 \cdot 10^3$	13.03
flg	1.03	1.124	0.095
ebe	2.88	$1.43 \cdot 10^3$	3.38

6. Conclusions

- At present, the investigated models have to be adjusted for each rock by additional empirical parameters to reproduce the experimentally observed k-F relationship adequately.

- Potentially, an independent evaluation of k and F as a function of the (pressure dependent) sample microstructure could yield improved k-F relationships.

- Microstructure-based models require improved analytical methods.

- All models have to be experimentally testable.