Relationship between electrical and hydraulic properties of reservoir rocks

DFG SPP 1135: Dynamics of sedimentary basins

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- Outline
  - Drillings: Schleswig, Fehmarn, Oldenbüttel, Glückstadt, Lingen
  - Petrophysics:
    - density,
    - porosity
    - pressure dependence of the permeability,
    - complex electrical conductivity and its pressure dependence
    - relation to transport properties
- Conclusion & cooperations
Physical properties of reservoir rocks

(elastic, transport, mechanical, electrical, thermal, magnetic, density, etc.)

Lithological Parameters (intrinsic)

- Single crystal properties
- Mineral composition
- Rock fabric
  (a) components
    - type, size, shape, arrangement
    - bedding/layering
    - shape preferred orientation (SPO)
    - lattice preferred orientation (LPO)
  (b) pore space
    - type, size, shape, arrangement
    - degree and type of saturation
  (c) fractures
    - type and filling
    - fracture fabric
  (d) networks
    - of open pores and/or open fractures
  (e) stylolites
    - type and composition
    - stylolite fabric

Physical Parameters (extrinsic)

- Pressure
  - effective pressure
    (lithostatic pressure, differential stress, pore fluid (reservoir) pressure)
- Temperature

Dürrast, 1997
Petrophysics: Density

Rotliegendes: conglomerate: clay, sandstone, coarse silt

- Matrix density
- Porosity
- Mineralogical composition
Petrophysics: Porosity
Fehmarn Z1; Schleswig Z1; Glückstadt T1

1. Archimedian,
2. Volumetric
Petrophysics: Permeability Pressure Dependence; instationary technique

- Sample diameter: 10 - 45 mm
- Sample length: 10 - 60 mm
- Confining pressure: up to 350 MPa
- Flow media: gas (argon), fluids (water, oil)
- Permeability range: mD - nD (10⁻¹⁵ - 10⁻二十五 m²)
Petrophysics results:
Pressure Dependence of the Permeability Anisotropy

Lingen limestone

Fehmarn Anisotropy
Permeability: Pressure dependence; Anisotropy
Sandstones from a tight gas reservoir, NW Germany
### Petrophysics

**Electrical Properties and their relation**

#### Table: Physical Property

<table>
<thead>
<tr>
<th>Physical Property</th>
<th>Density</th>
<th>Magnetic Susceptibility</th>
<th>Electrical Resistivity</th>
<th>Dielectric Permittivity</th>
<th>Seismic Velocity</th>
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<tbody>
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<td>Porosity (pore, fracture)</td>
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<td>Permeability</td>
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<td>Water content</td>
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<td>Magnetic mineral content</td>
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<td>Mechanical properties</td>
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<td>Subsurface structure</td>
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#### Degree of interconnection

- **R konstant**
  - $\varepsilon$ steigt

- **R fällt**
  - $\varepsilon$ steigt

#### Electrolyte, Double layer

<table>
<thead>
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<th>Degree of relationship</th>
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<td>strong</td>
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</table>

**R.E.V.**

- $\sigma_f$
- Free Electrolyte
- E.D.L.: Electrical Diffuse layer

**S.P.**

- Stern Plane
- Mineral surface
- Na$^+$
- CF

**Local conductivity (L.D.):**

- $\sigma_f$
- $x_0$
- $\sigma_{m}$
- $\sigma_{m} = 0$
Electrolytic Charge Transport – Model

Figure 1. Schematic representation of the electric double layer on the mineral surface. The parameters $\sigma$ and $\sigma_m$ are the effective conductivity of a representative elementary volume (REV), whereas $\sigma_0$ is the free electrolyte conductivity. The disturbed conductivity in the electrical diffuse layer can be taken into account by a specific conductance parameter $2Z$. 
Complex Electrical Conductivity: 5Hz – 1MHz
Pressure Dependence

Abbildung 3.6: Parallelschichtmodell mit zugehörigem Ersatzschaltbild und Impedanzspektrum [27]
Pressurized dependence

Permeability

Volume conductivity
Crossplot: Porosity - Volume conductivity
Anisotropy

Anisotropy of electrical conductivity
Crossplot: Pressure Dependence
Permeability – Volume conductivity
Complex response: Measured data – Model

**Interpretation:**
- **RC-equivalent circuit** (2 relaxation model)
  - \((R_1||C_1)\) \((R_2||C_2)\)
  - bulk conductivity
  - surface conductivity
  - Relaxation time
    (time constant of polarisation)
Crossplot: pressure dependence of the relaxation time
Conclusion

Electrical rock properties depend on:

- petrophysical parameters, porosity, permeability, aspect ratio
- Fabric, texture, grain size distribution, metamorphic overprint
- Anisotropy of layering
- Degree of interconnection of the pores

But,

the correlation between electrical and hydraulic properties still requires further experiments.

RWTH, Aachen: Petrophysics, permeability, porosity, Data Base
Uni Münster: Electrical conductivity, correlation lab-borehole data
GFZ: BET surface, porosity
BGR: Carbon enhanced conductivity
Uni Göttingen: Correlation of lab data: Vp, Vs, permeability, el. Cond.