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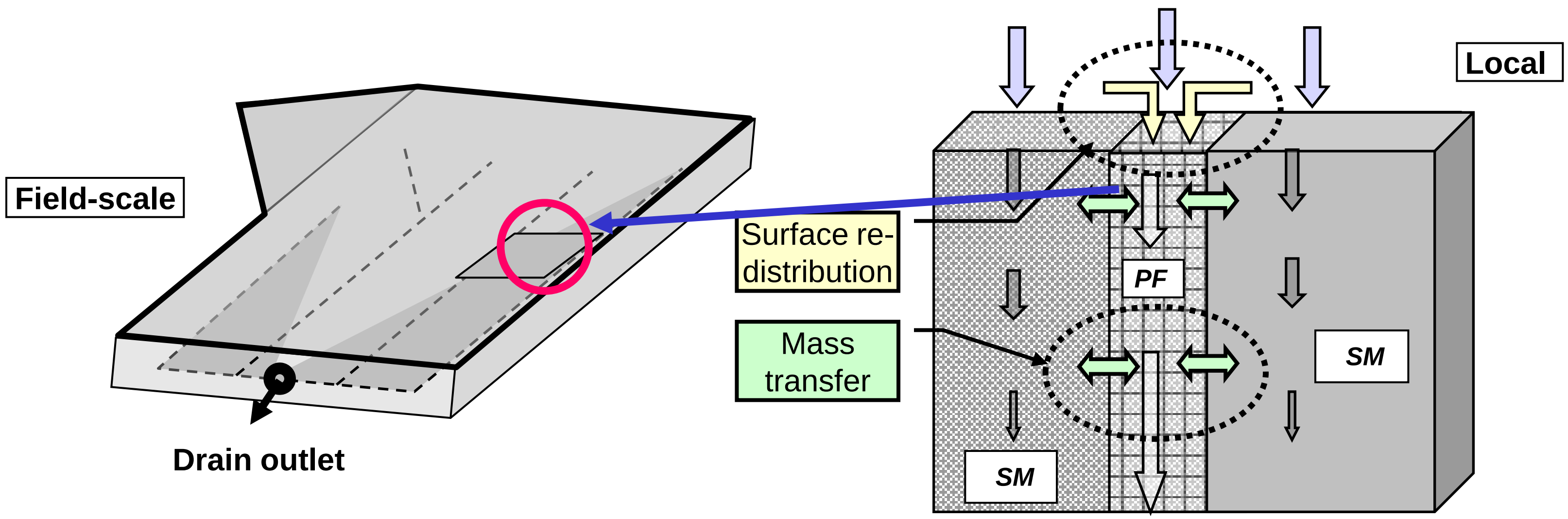
- 1980 Dipl.-Ing., Agriculture, University Göttingen
- 1987 Ph.D. Forestry Faculty, University Göttingen
- 1990-92 Post-doc, US Salinity Lab., Riverside, CA, USA
- 2004 Habilitation Environ. Sci., BTU Cottbus

“Dual-permeabilility modelling of preferential flow in structured soil”

Motivation

How small scale phenomena affect flow and transport processes

Hillslopes, drain catchments, landscape, …



What are the main reasons?
How to describe, quantify?

Dual-Permeability model analysis “mobil-mobil”

1D vertical model

SPM

Water flow: 2 Richards-equations

$$C_f \frac{\partial h_f}{\partial t} = \frac{\partial}{\partial z}\left(K_f \frac{\partial h_f}{\partial z} - K_f\right) - \frac{\Gamma_w}{w_f} - S_f$$

$$C_m \frac{\partial h_m}{\partial t} = \frac{\partial}{\partial z}\left(K_m \frac{\partial h_m}{\partial z} - K_m\right) + \frac{\Gamma_w}{1-w_f} - S_m$$

Water transfer, Γ_w:

$$\Gamma_w = \alpha_w (h_f - h_m) \qquad \alpha_w = \frac{\beta}{a^2}\gamma_w K_a(h)$$

Solute transport: 2 CDE

$$\frac{\partial}{\partial t}(\theta_f R_f c_f) = \frac{\partial}{\partial z}\left(\theta_f D_f \frac{\partial c_f}{\partial z} - q_f c_f\right) - \theta_f \mu_f c_f - \frac{\Gamma_s}{w_f}$$

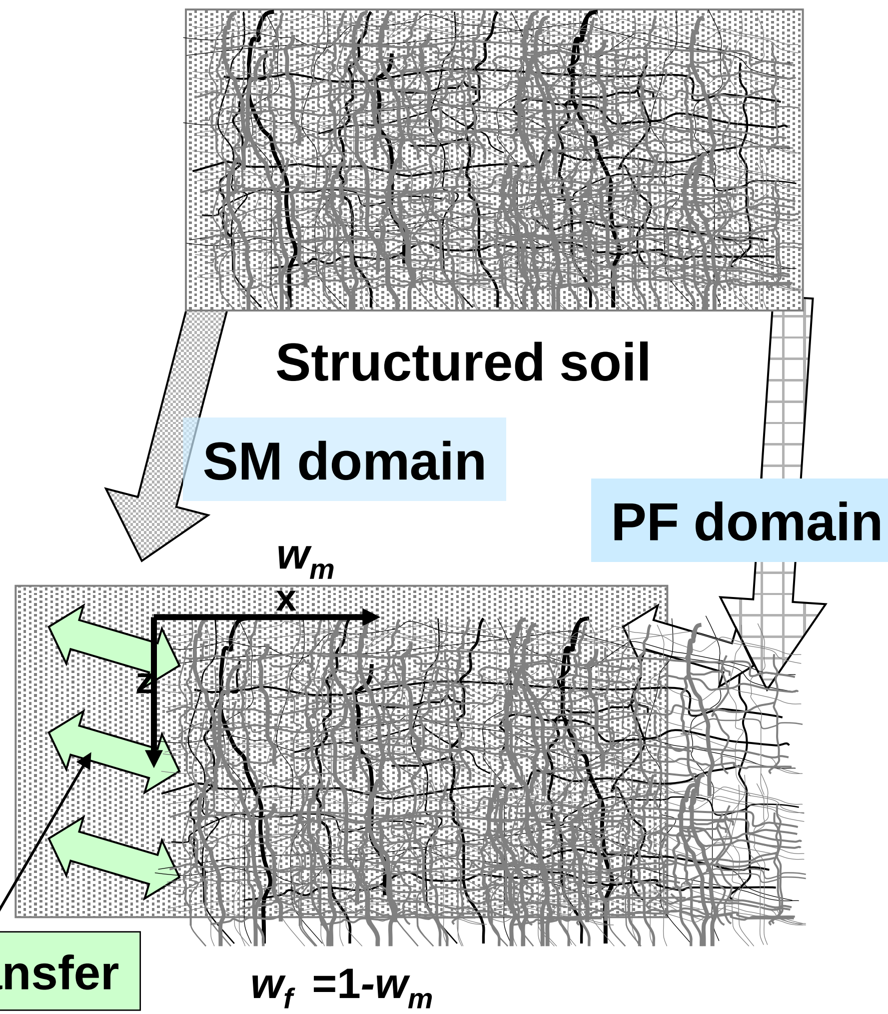
$$\frac{\partial}{\partial t}(\theta_m R_m c_m) = \frac{\partial}{\partial z}\left(\theta_m D_m \frac{\partial c_m}{\partial z} - q_m c_m\right) - \theta_m \mu_m c_m + \frac{\Gamma_s}{(1-w_f)}$$

Solute transfer, Γ_s:

$$\Gamma_s = (1-d)\,\Gamma_w c_f + d\,\Gamma_w c_m + \alpha_s (1-w_f)\,\theta_m (c_f - c_m)$$

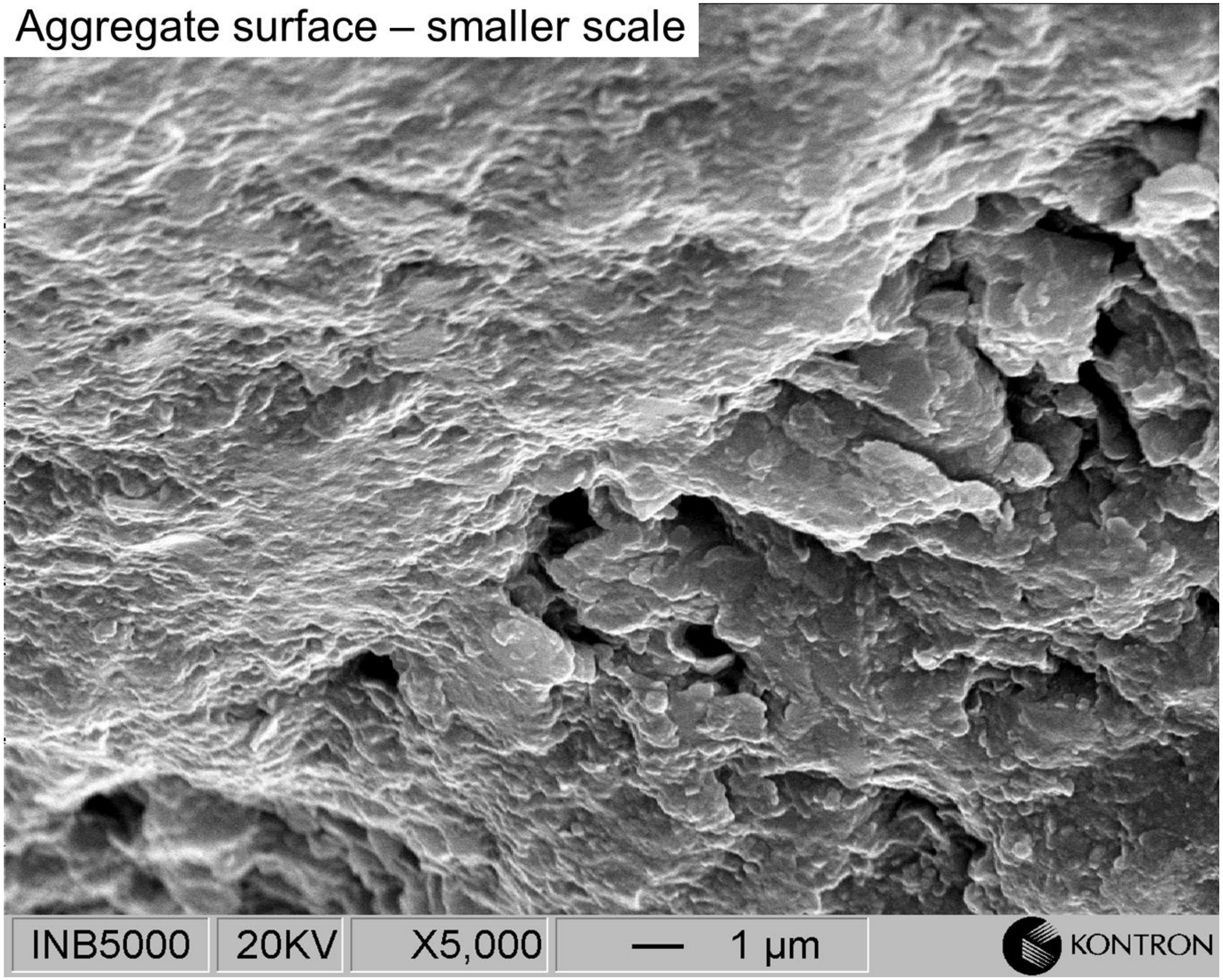
$$\alpha_s = \frac{\beta}{a^2} D_a(\theta)$$

Illustration of the concept



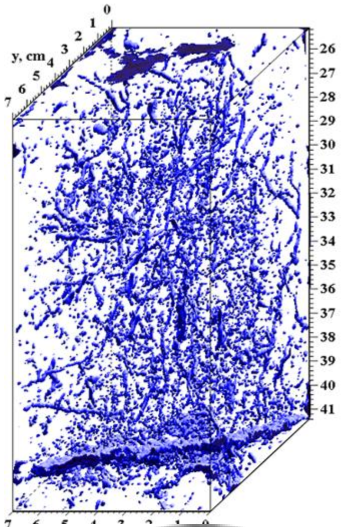
Gerke & van Genuchten WRR 1993a, AWR 1996

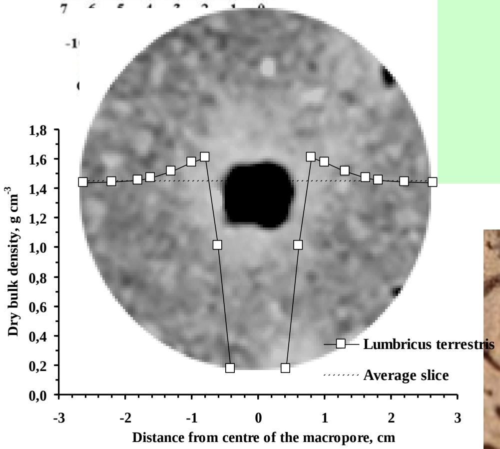
Soil structure effecting mass exchange, example



Processes and properties: smaller-scale ⟺ Impact: larger-scale

Local-scale properties related to soil structures





Schrader, Rogasik, et al., Geoderma, 2007

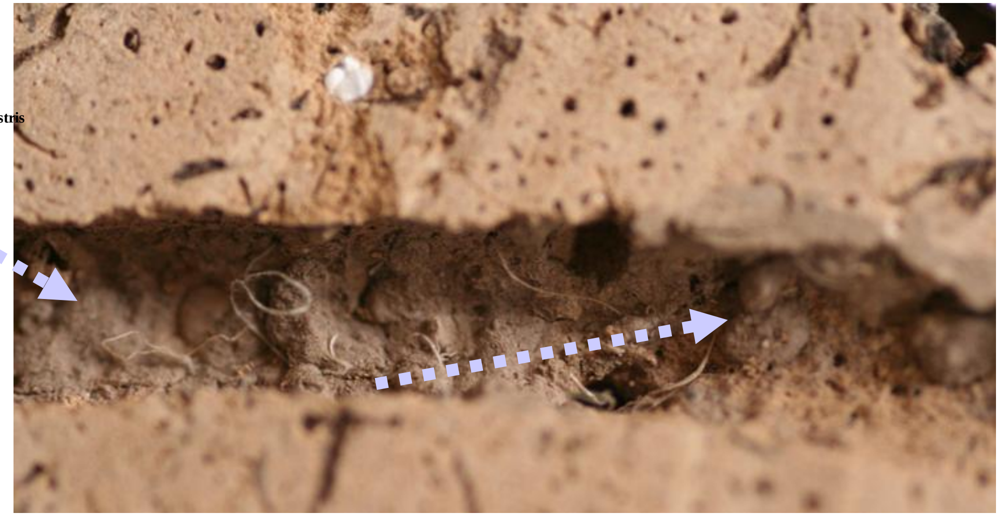
- Physical
  - Pore network, geometry, shape and size (CT…)
  - Density and stability
  - Permeability, diffusivity
- Mineralogical (thin sections…)
- Organo-chemical
  - Elements,
  - OM content, composition
  - Exchange/sorption sites…

Relevant for

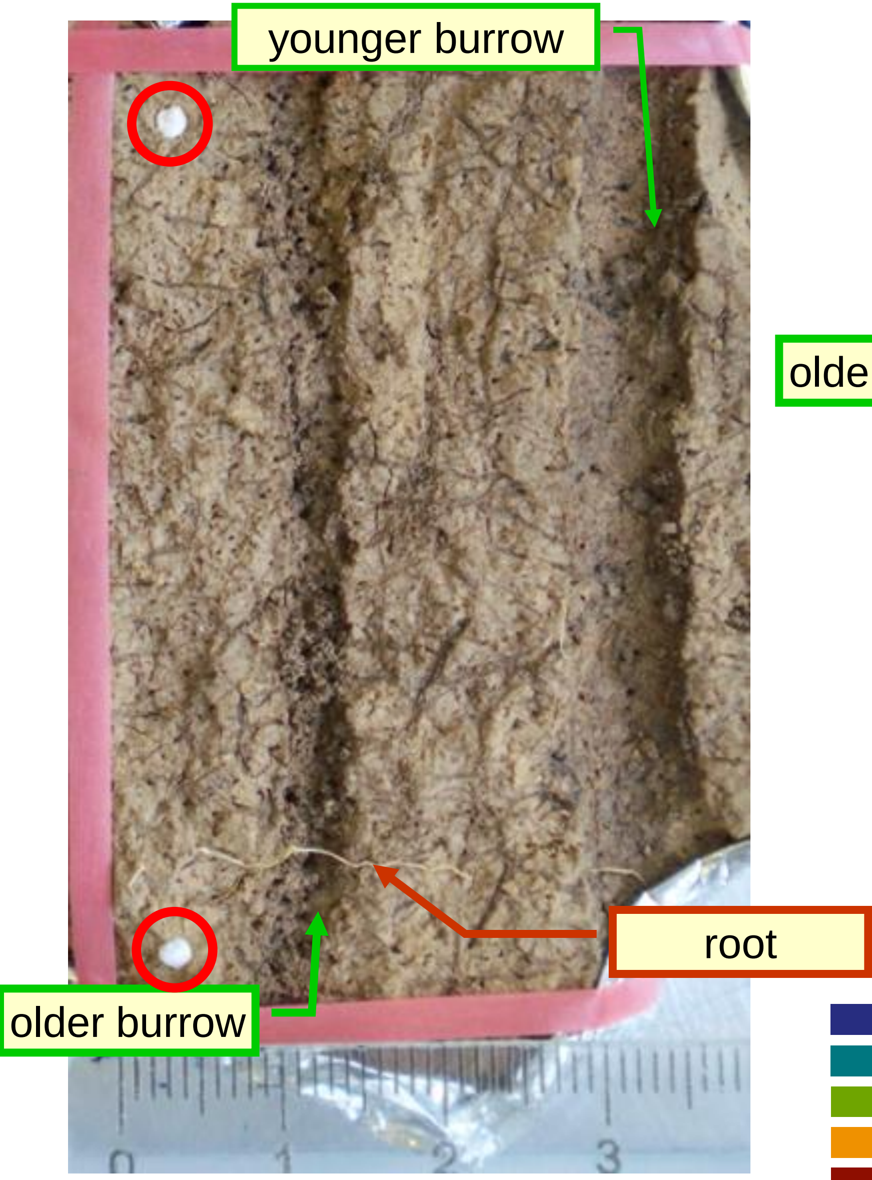
Flow of water

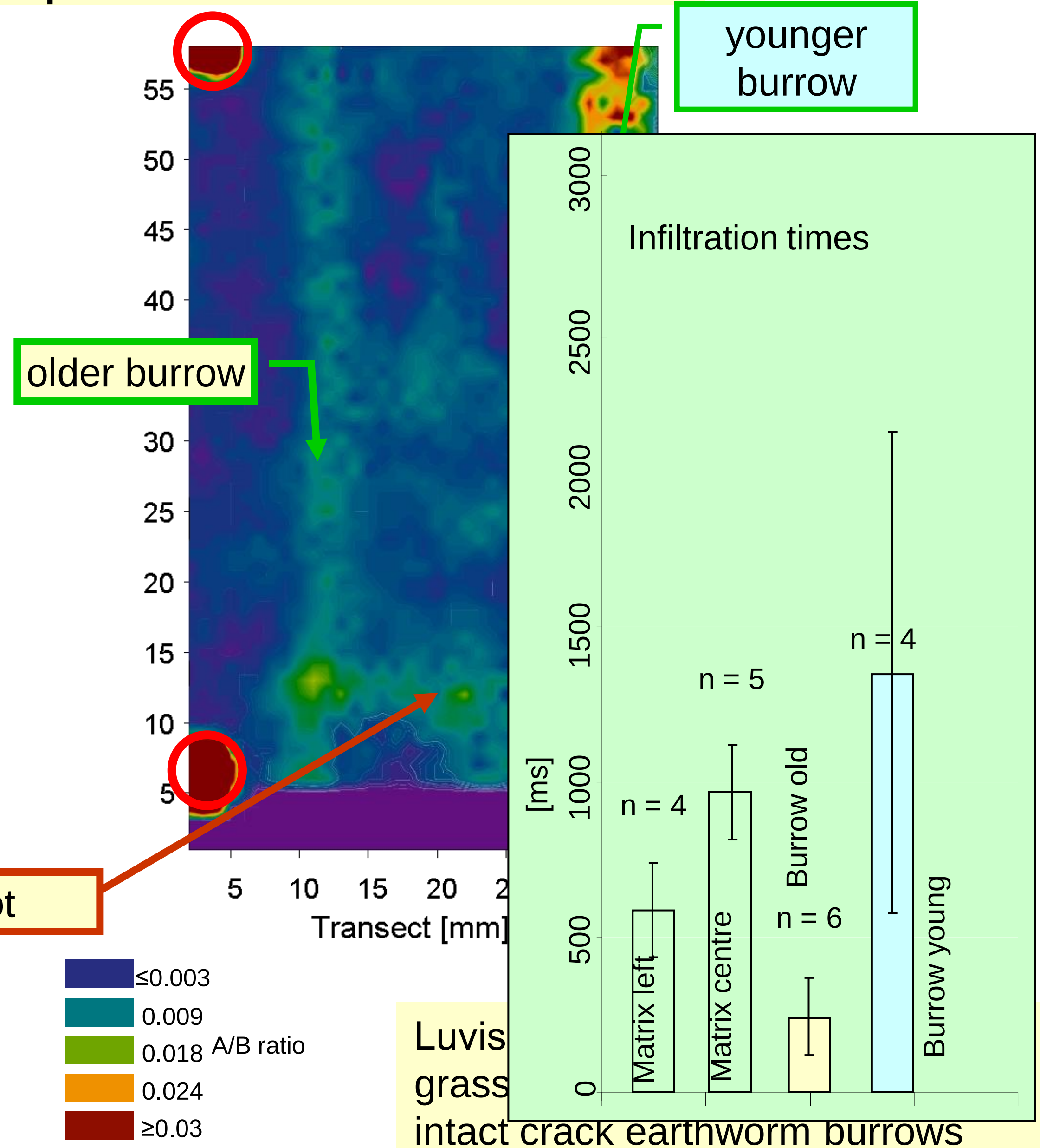
Solute transport

Transport of reactive solutes
Organic contaminants



Map of OM – composition at intact surface





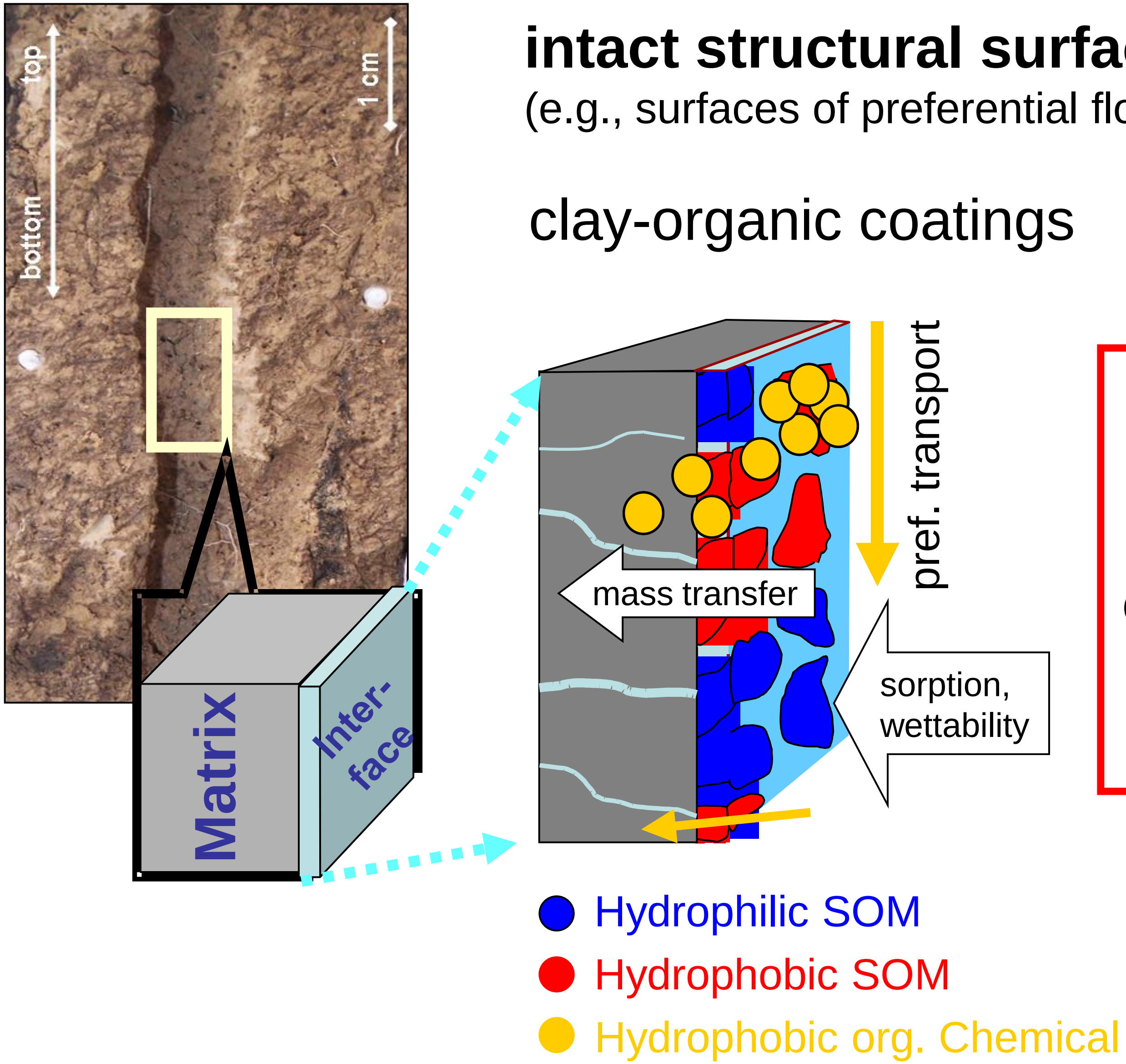
Luvis... grass... intact crack earthworm burrows

Leue, Ellerbrock, Gerke, VZJ 2010

Research Focus

intact structural surfaces
(e.g., surfaces of preferential flow paths)

clay-organic coatings



?
distribution
and
composition
of OM
?

Concluding remarks

Incorporation of “effective” properties of soil structure to describe

- local redistribution at the soil surface (or subsurface layers) and
- local mass transfer between flow paths and soil matrix

➢ Link to soil management and crop production

Description of reactive transport remains challenging

Related: Colloid and particle transport, structure dynamics, …

Thank you for your attention!

Exchange between PF & SM domains

Transfer term derivation – effective local properties

(1) Horizontal Flow (local, matrix blocks)

$$C_a(h_a)\frac{\partial h_a(x,t)}{\partial t}=\frac{\partial}{\partial z}\left[K_a(h_a)\frac{\partial h_a(x,t)}{\partial x}\right]\quad ;\quad 0\le x\le a$$

Linearising K_a und C_a

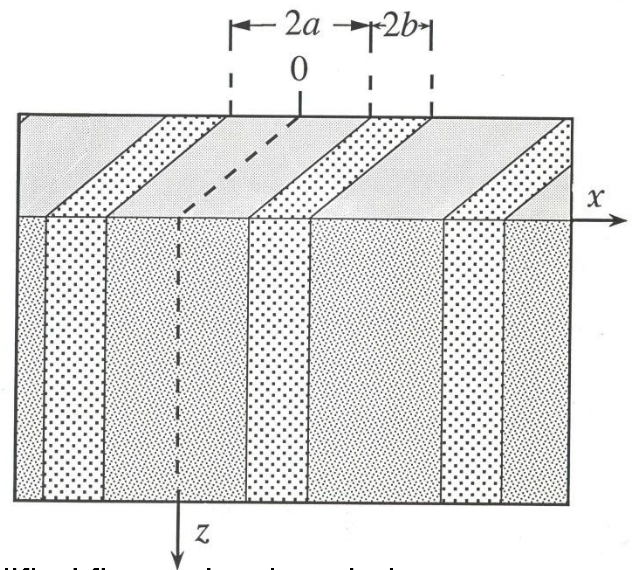
$$(1-w_f)C_m(h_m)\frac{\partial h_a(x,t)}{\partial t}-K_a(h_m)\frac{\partial^2 h_a(x,t)}{\partial x^2}=0$$

$$h_a(x,0)=h_{m,i}\qquad 0\le x\le a$$
$$\partial h_a(0,t)/\partial x=0\qquad t>0$$
$$h_a(a,t)=h_f\qquad t>0$$

"Averaging‘ the pressure heads

$$h_m(t)=\frac{1}{a}\int_0^a h_a(x,t)\,dx$$

Idealized 2-Regions slab-type



(2) Simplified first order description

$$\Gamma_w\approx(1-w_f)C_m(h_m)\frac{dh_m(t)}{dt}=\alpha_w\left(h_f(t)-h_m(t)\right)$$

Solution of Laplace-transformed equation

$$\bar{h}_m(s)=\frac{h_f}{s}\left[1-\frac{a^2(1-w_f)C_m s}{3K_a}\right]+\frac{h_{m,i}}{s}\left[1-\frac{a^2(1-w_f)C_m s}{3K_a}\right]$$

Solution of Laplace-transformed equation

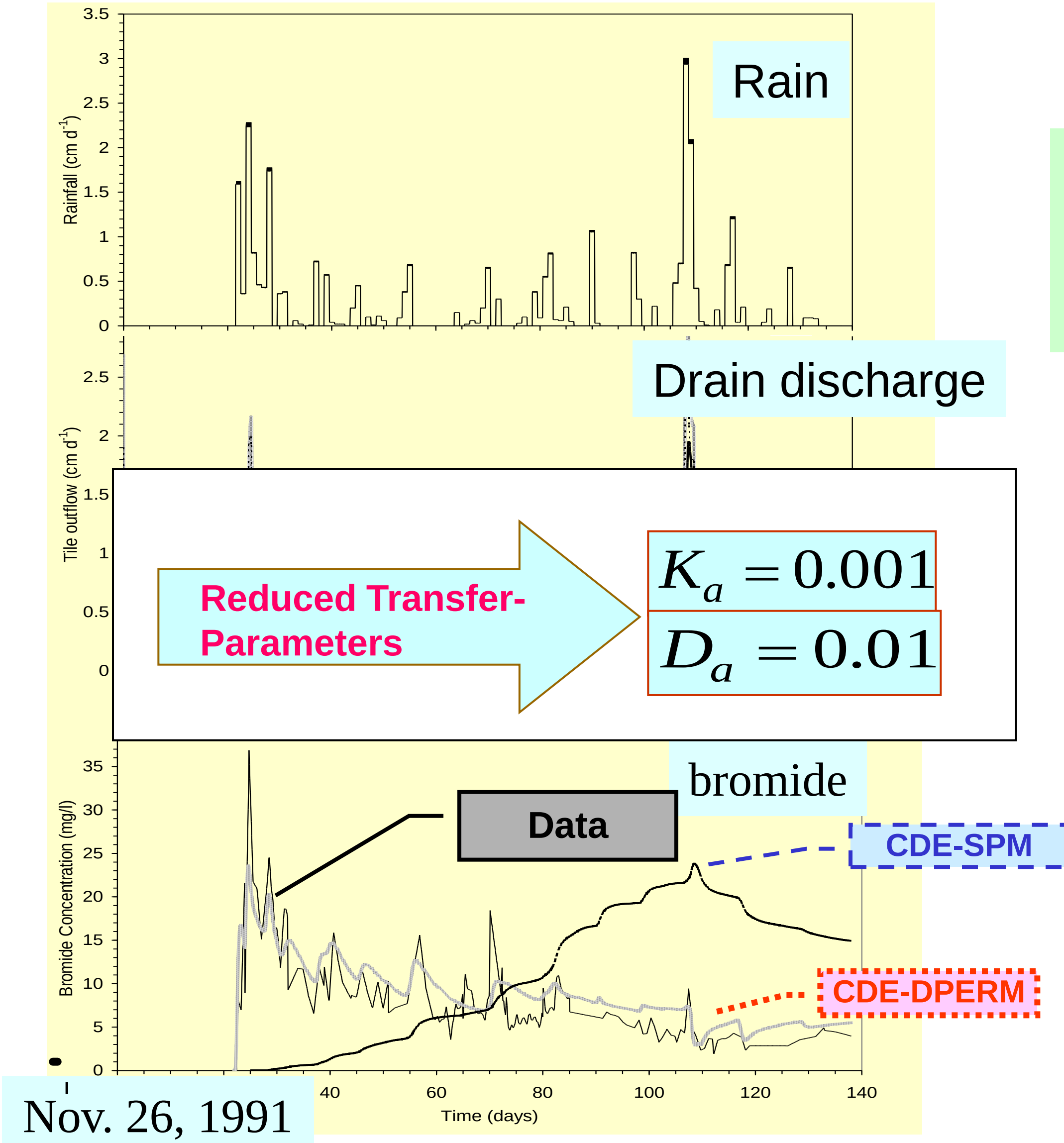
$$\bar{h}_m(s)=\frac{h_f}{s}\left[1-\frac{(1-w_f)C_m s}{\alpha_w}\right]+\frac{h_{m,i}}{s}\left[\frac{(1-w_f)C_m s}{\alpha_w}\right]$$

$$\alpha_w=\frac{3}{a^2}K_a$$

For platy geometry

(Gerke und van Genuchten, WRR 1993b)

1D results: local effects



<u>Experimental:</u> aggregate samples with intact and removed surface:

- water up to 70-times
- solute diffusion about 35-times

Gerke & Köhne, SSSAJ 2002

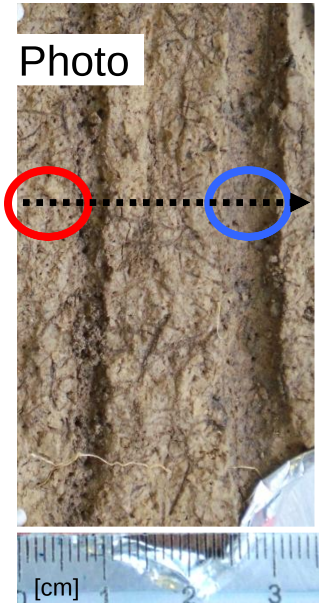
Köhne et al., SSSAJ 2002

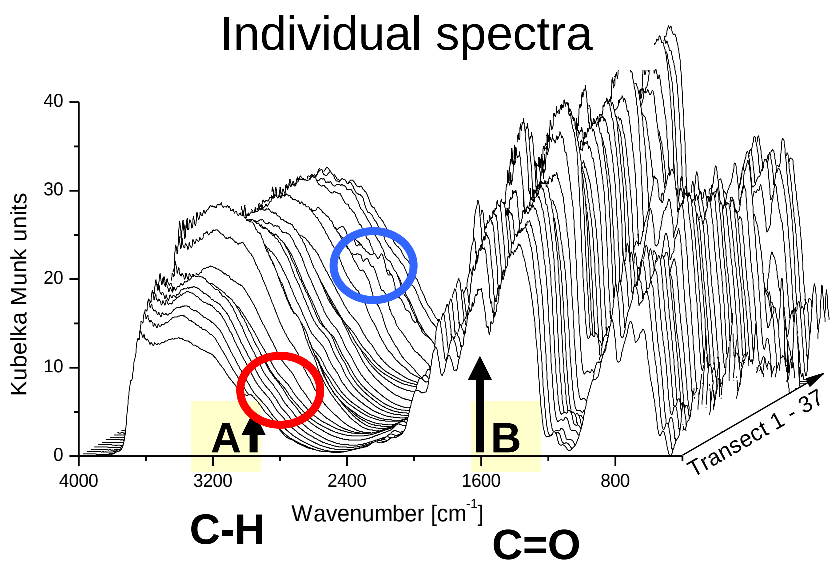
Mass transfer sensitivity

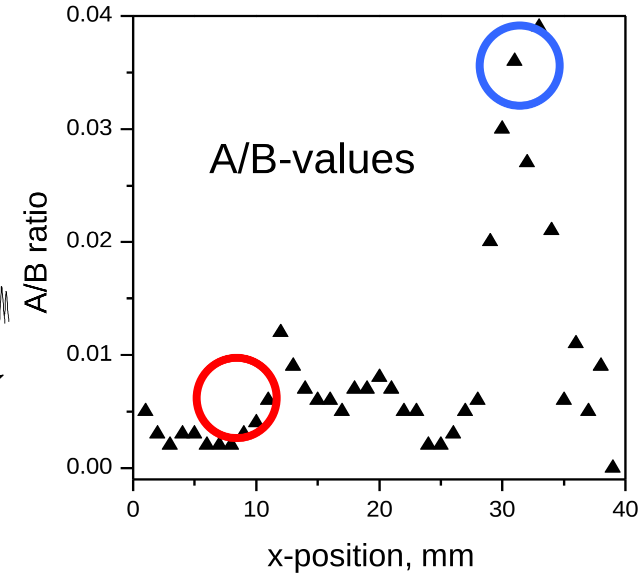
- Low to drainage rates
- High to solute leaching

Gerke & Köhne, J. Hydrol. 2004

OM composition along a transect, intact samples







Attempt using DRIFT measurements

➢ Large variation perpendicular to worm burrows

The OM composition (A/B-ratio) relates to sorption and exchange properties

IR-spectroscopy → (**DRIFT**: **D**iffuse **R**eflectance **I**nfrared **F**ourier **T**ransform Spectroscopy)

Ellerbrock, Gerke, Böhm, SSSAJ, 2009

Thank you for your attention!

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Soil structure in flow modelling

Laloi et al. 2010, J. Hydrol.:
Tested the efficiency of 1D models reproducing flow in structured soil

Synthetic structure, multistep outflow experiment
Comparing several 1D models using HYDRUS code

- Single domain unimodal Mualem-van Genuchten
- Single domain bimodal Mualem-van Genuchten
- Two-domain mobile-immobile
- Two-domain mobile-mobile (Dual-permeability)

→Dual can provide consistent results for infiltration in structured soil
(as designed including water exchange)
frequent convergence problems of the HYDRUS-1D code
→S1D numerical code (Vogel et al., 2010, VZJ)