Factors impacting the process and system performance Or How to help the methanotrophs do their job

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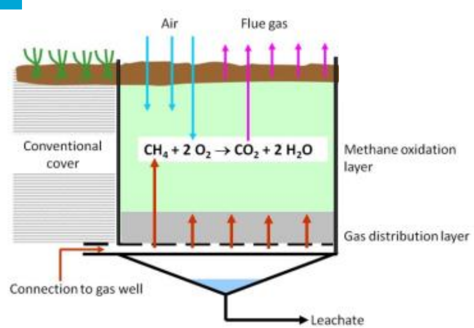
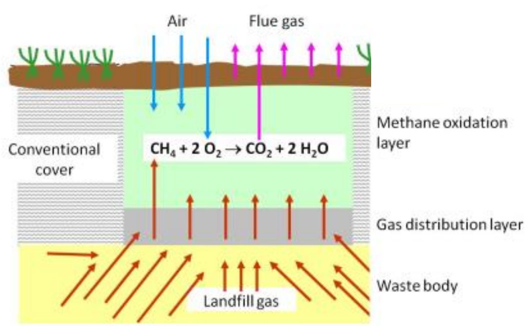
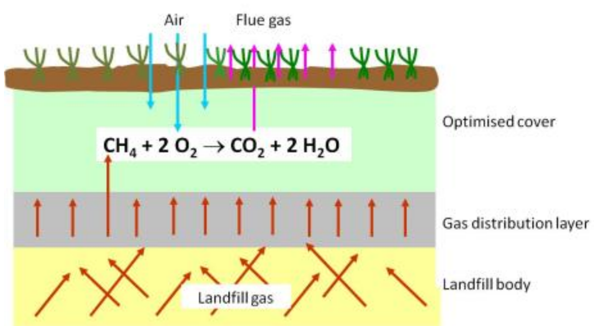
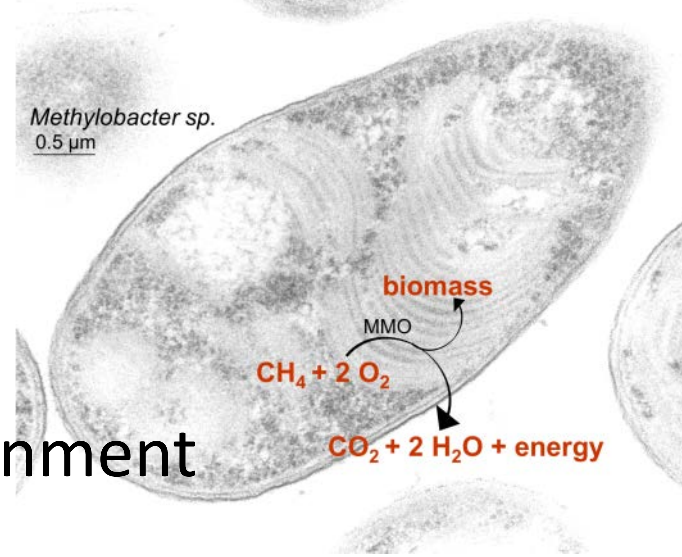
CH_4 oxidation systems: Design goals







Design goals



(1) Adequate physicochemical environment of high structural stability

(2) Optimal diffusive ingress of oxygen

(3) Maximum spatial evenness of gas load

(4) Robust dimensioning of the system, adapted to load

Physical properties of material

Choice also depends on

- Intention of measure (e.g. safety, climate)
- After-use of landfill (e.g. access for the public?)

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(1) Create adequate physicochemical environment of high structural stability

Aims:

– Support biological activity for both bacteria and vegetation
– Avoid loss of permeability and formation of preferential pathways

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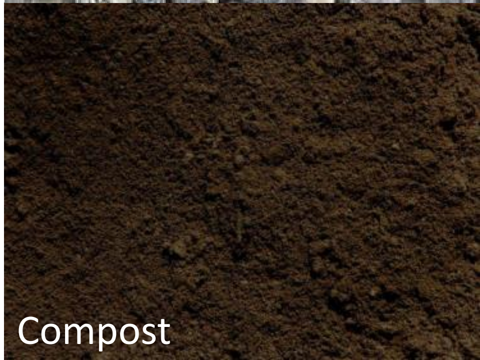
Requirements properties of MOL

Parameter	Value	Meaning
Soil pH	5.5 to 8.5	Optimum MOB
El. conductivity	< 4 mS/cm	Avoid osmotic stress
Plant-available water	14 vol.%	Support vegetation and MOB
Air-filled porosity at field capacity	14 vol.%	Diffusion of O_2
Organic matter	2 to 4%, 8% if stable	Nutrient supply to MOB and vegetation
Low susceptibility to consolidation	Preservation of pore structure	
Low susceptibility to cracking	Avoid preferential pathways	



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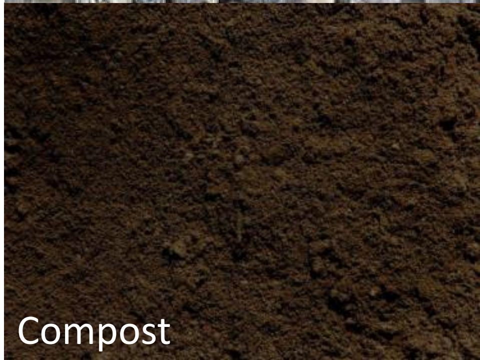
More in Scheutz et al., 2009

Conclusions adequate geophysical environment

- Conditions for methanotrophic bacteria can be met by a wide range of materials
- What is good for the vegetation, is good for methanotrophic bacteria (nutrients, water)
- Special attention for aeration
- No nitrogen fertilizer or nitrogen-rich amendments due to inhibitory effects of NH_4^+
- Organic materials (keynote 2) have to be stable
  → minimize competition for O_2
  → minimize settlement and loss of permeability



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(2) Optimize diffusive ingress of oxygen

Aim:

Maximize depth of aeration to

- Create thick and “redundant” CH_4-oxidation layer
- render oxidation process less susceptible to surface effects (frost, drought, heat, cold)

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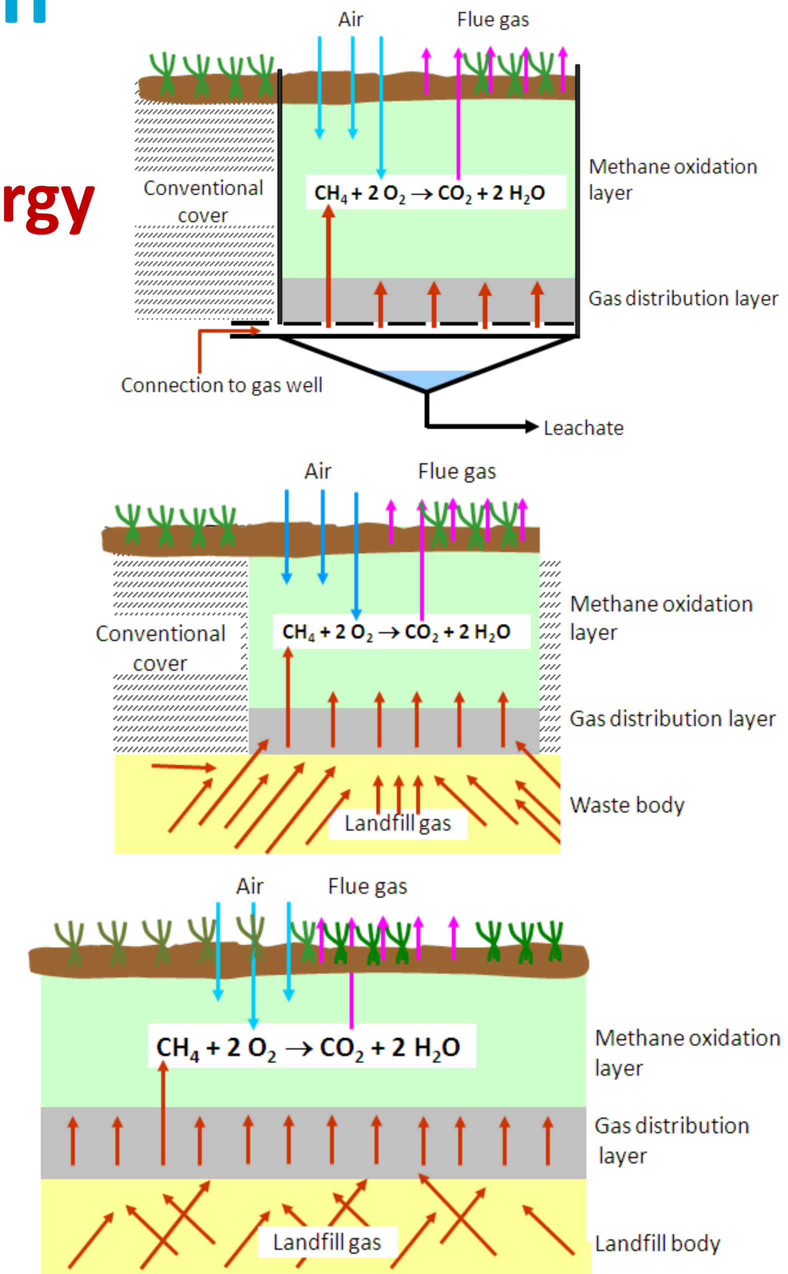
Optimize ingress of oxygen

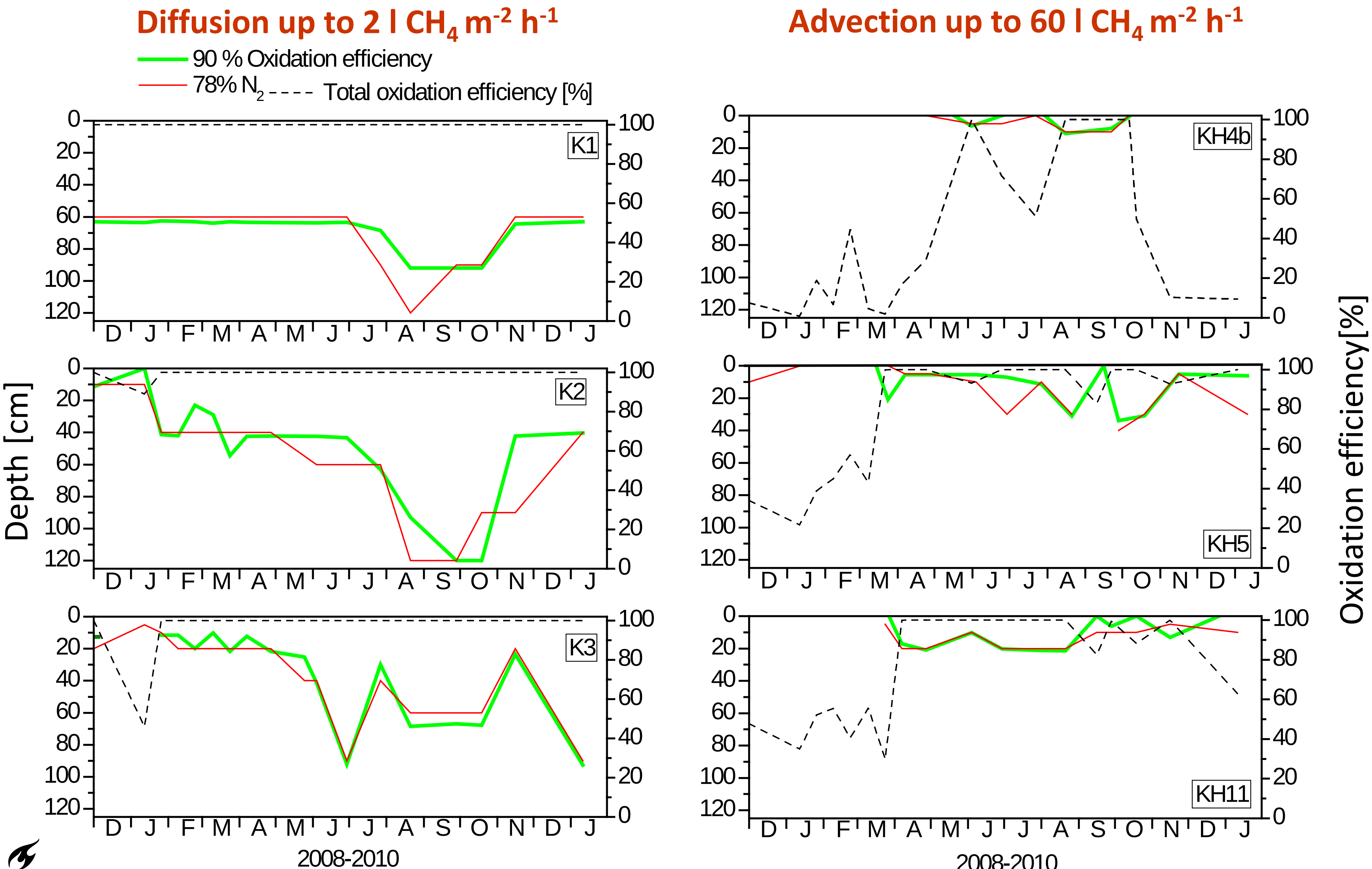
$$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O + \text{energy}$$

- **Twice** the volume of O_2 is needed for complete oxidation
- O_2 is provided only from the atmosphere
- Main driver is the concentration gradient, main transport process is diffusion

→ Effective diffusivity of the soil is absolutely crucial



Relevance of O_2 supply



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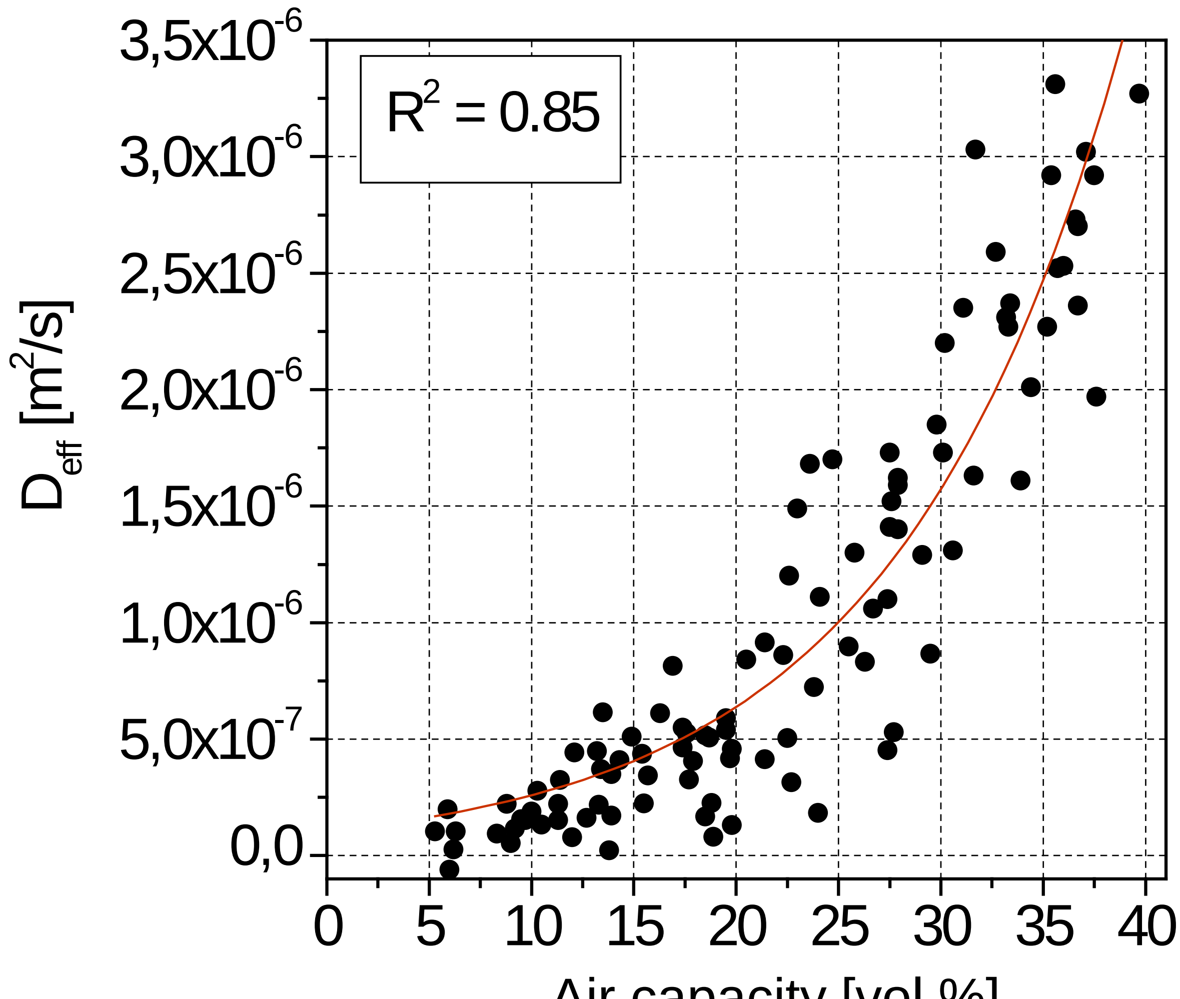
Rachor, 2012; Gebert et al., 2016

Diffusivity depends on air-filled porosity



= Air-filled porosity at Ψ_m = -6 kPa

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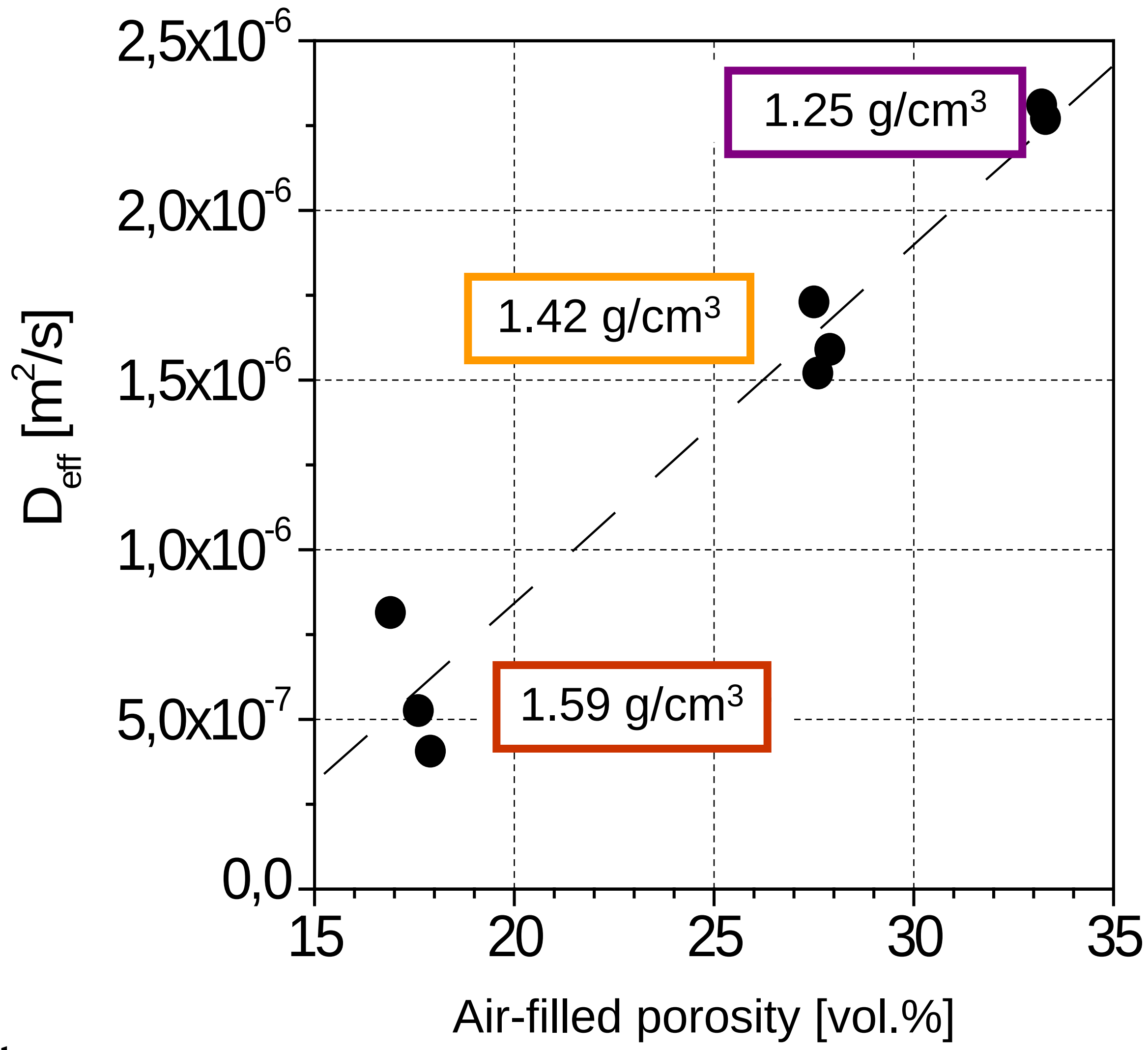
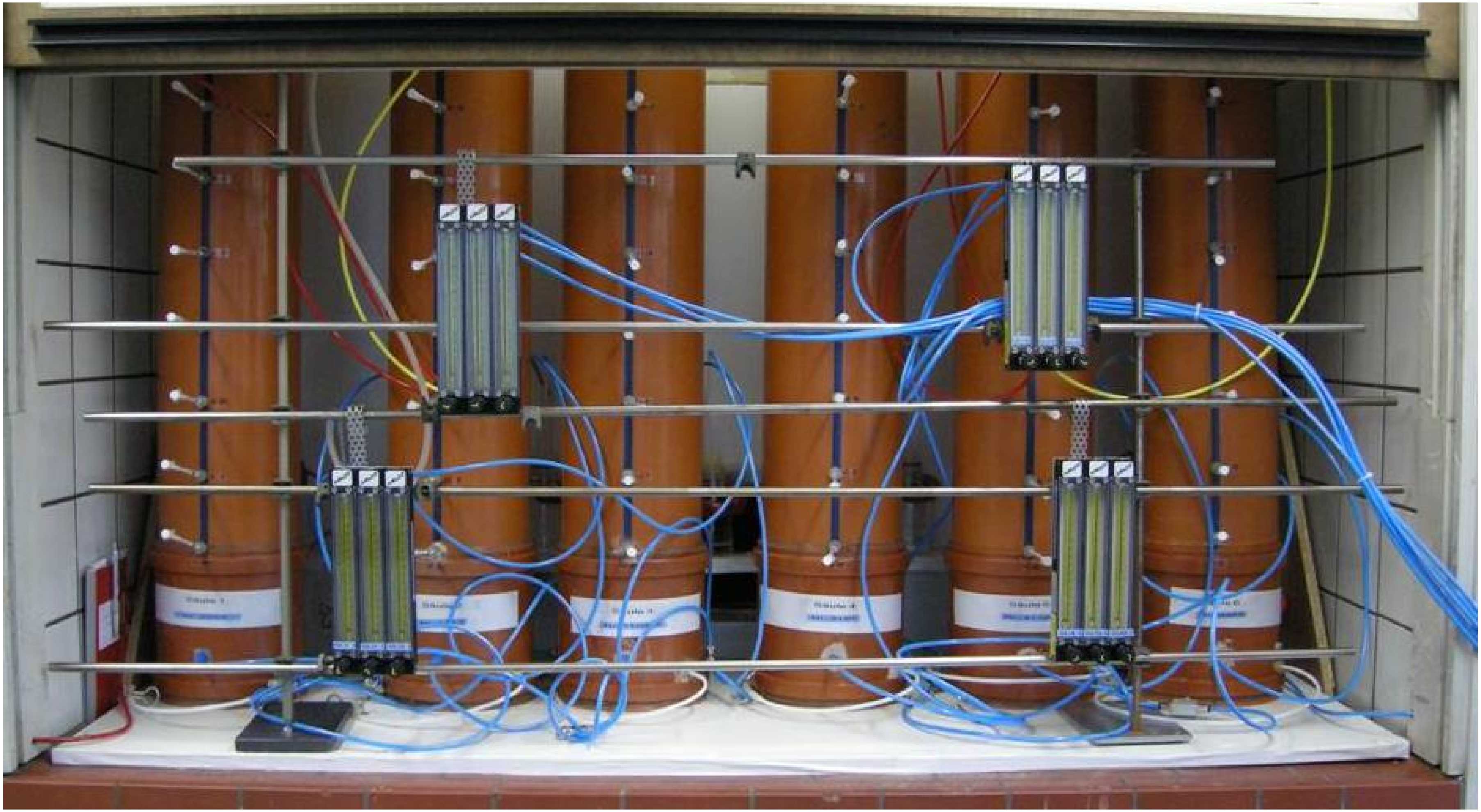
From Gebert et al., 2011

Compaction decreases diffusivity

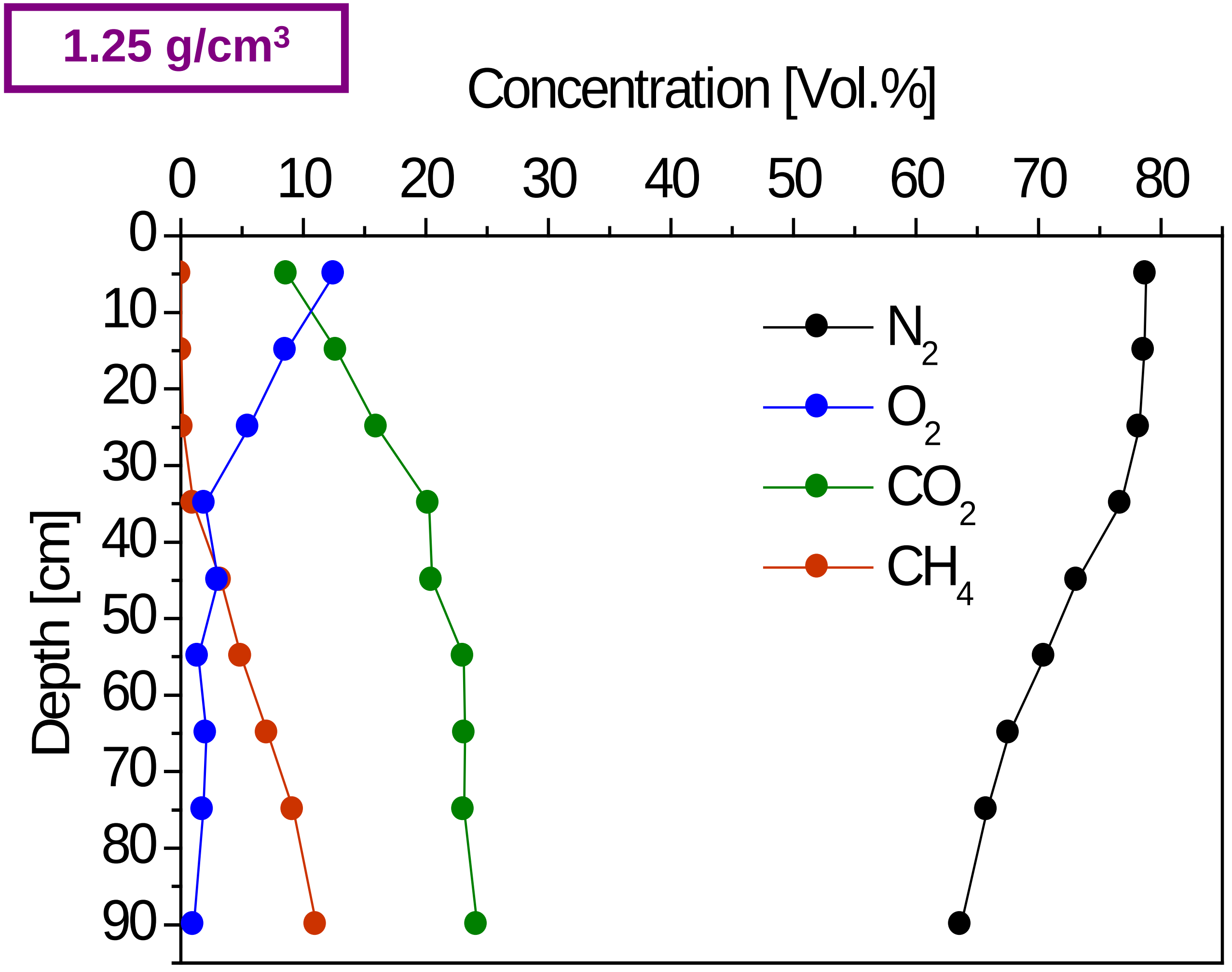


After Gebert et al., 2011

Column experiment



Gas profiles with compaction ↑



CH_4 load = 2.2 l m^{-2} h^{-1} (1.4 g m^{-2} h^{-1})

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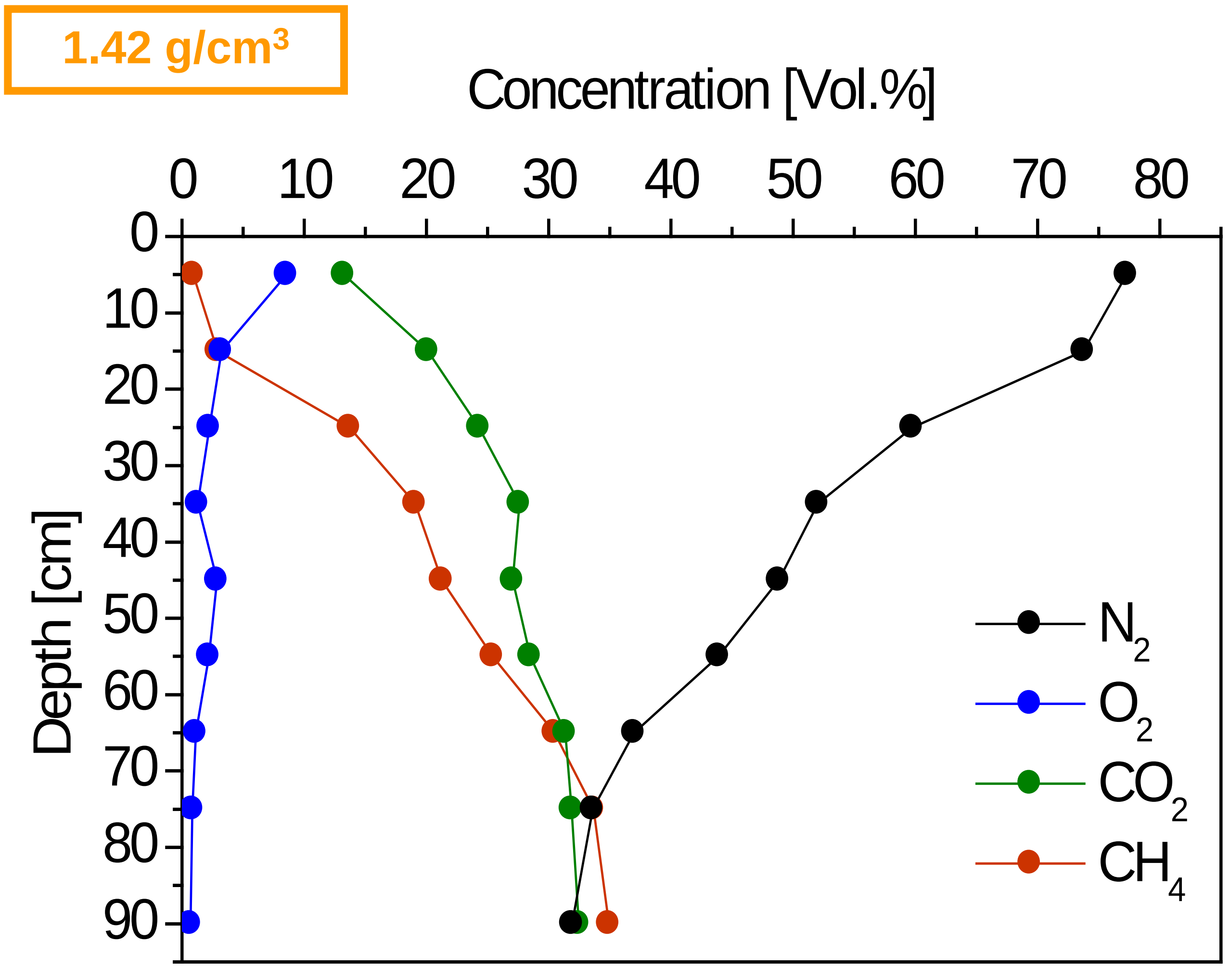
After Gebert et al., 2011

Gas profiles with compaction ↑



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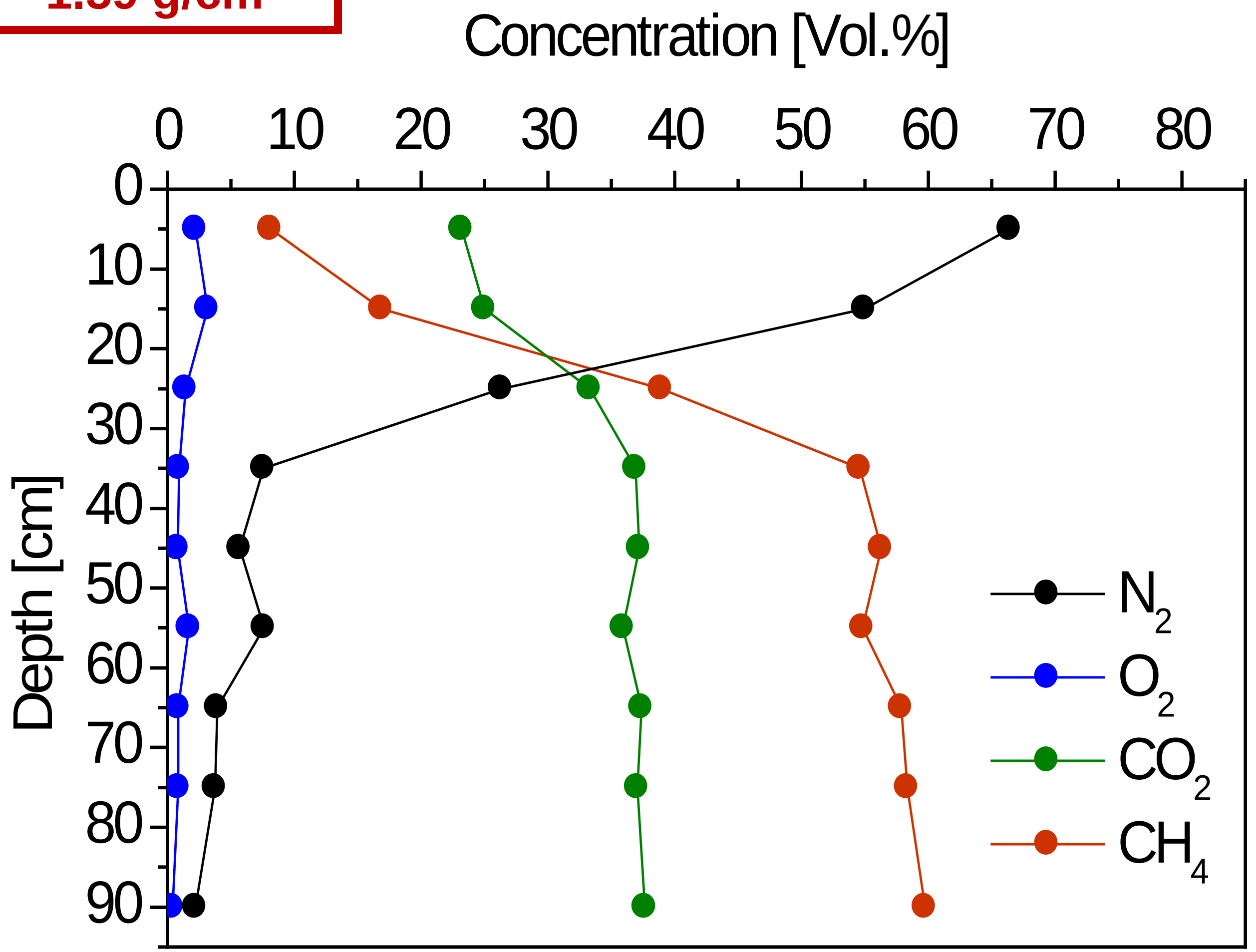
1.59 g/cm³



CH_4 load = 2.2 l m^{-2} h^{-1} (1.4 g m^{-2} h^{-1})

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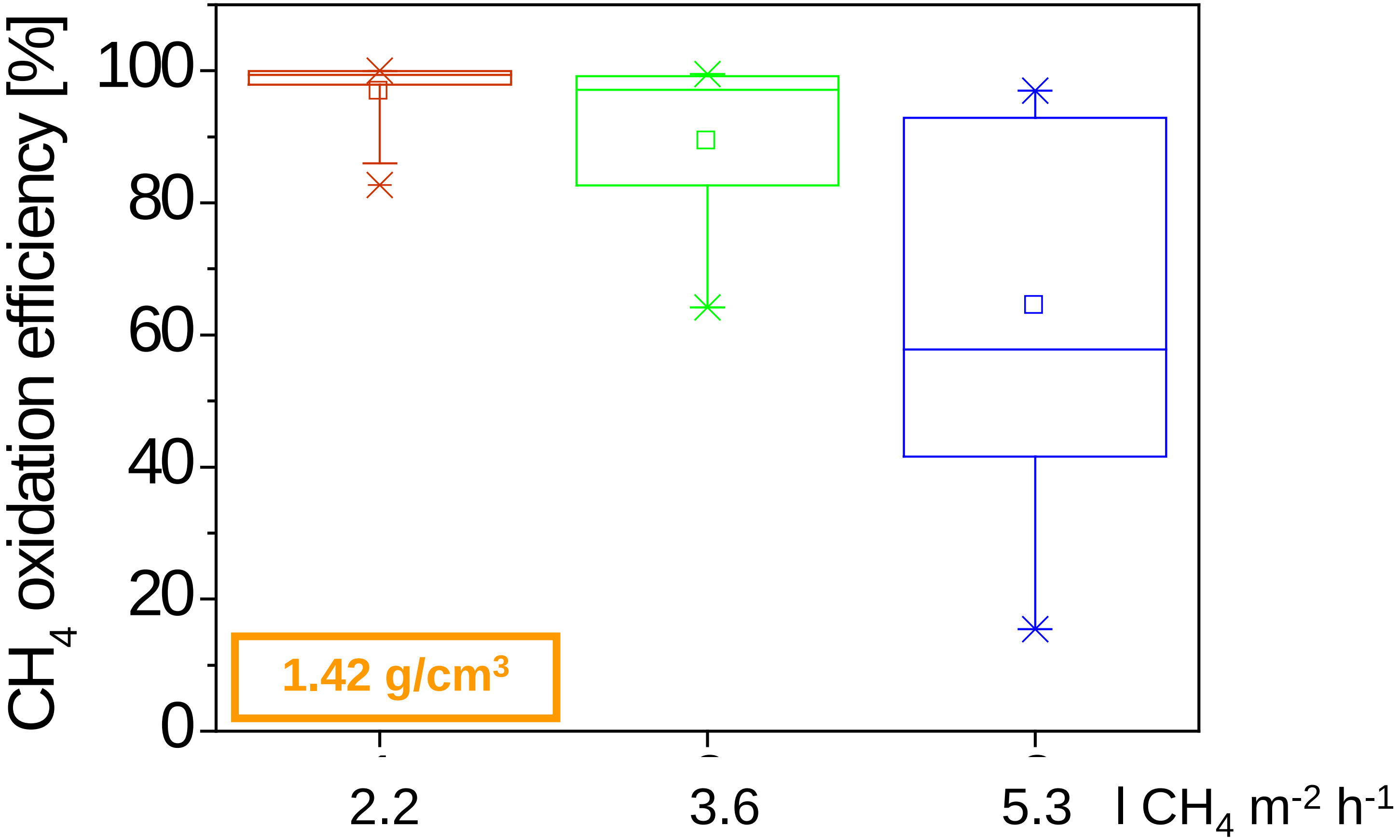
After Gebert et al., 2011

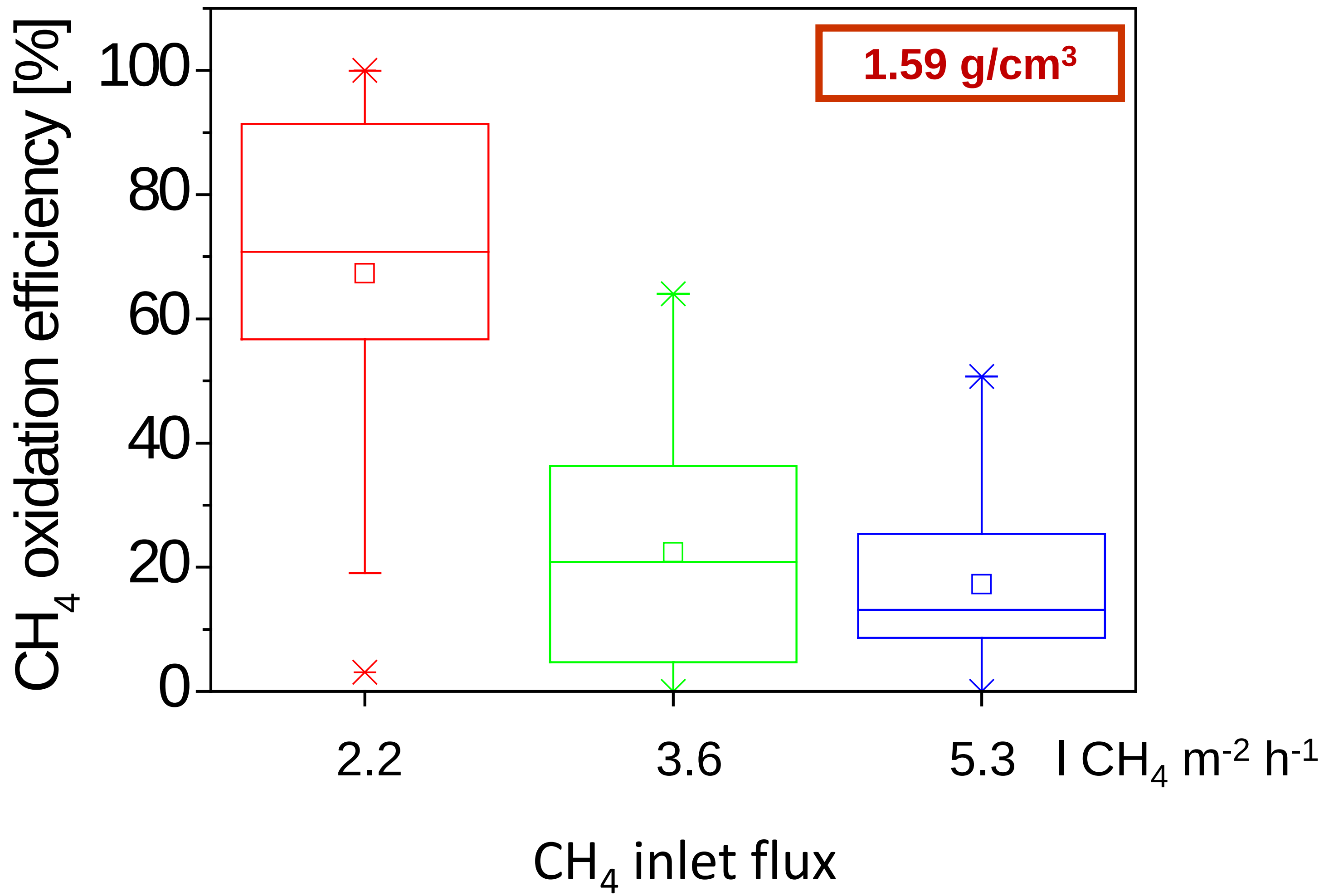
Oxidation efficiency with advection ↑, medium bulk density



CH_4 inlet flux

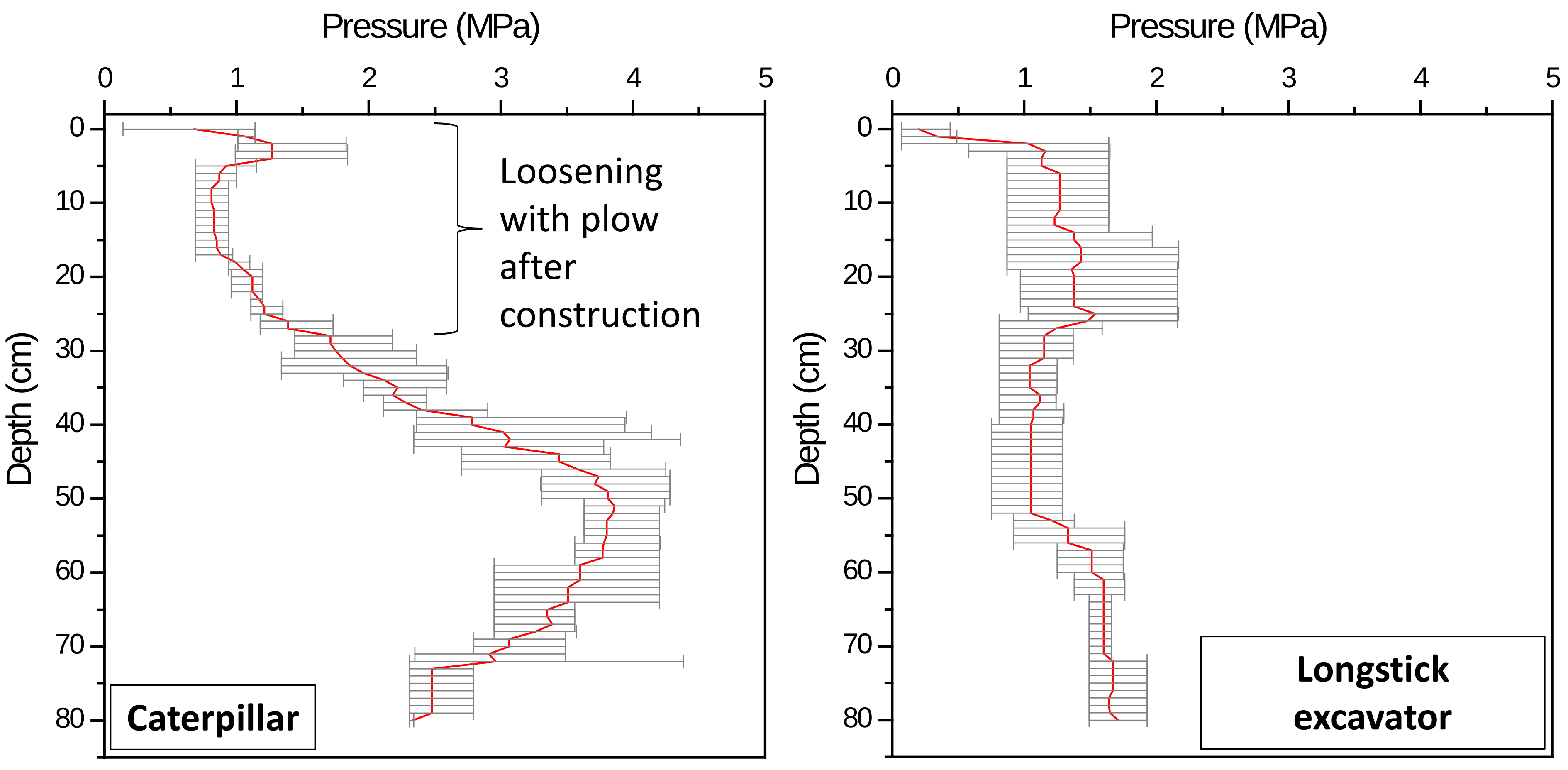
After Gebert et al., 2011

Oxidation efficiency with advection ↑, high bulk density



After Gebert et al., 2011

Impact of construction practice on compaction



Cone penetration test

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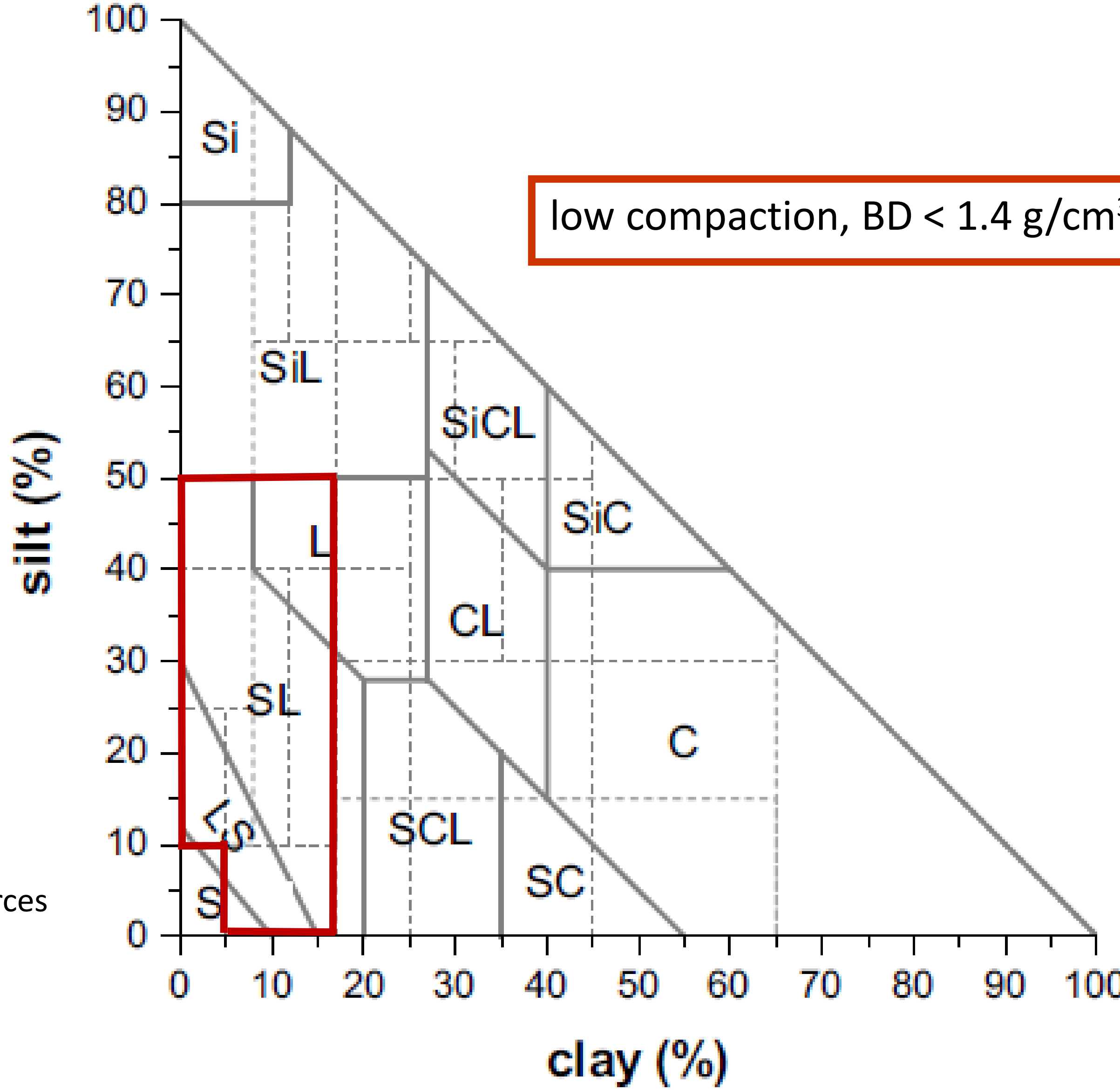
Soil textures meeting target of 14 vol.% AFP



FAO/ISS (2006): World reference base for soil resources

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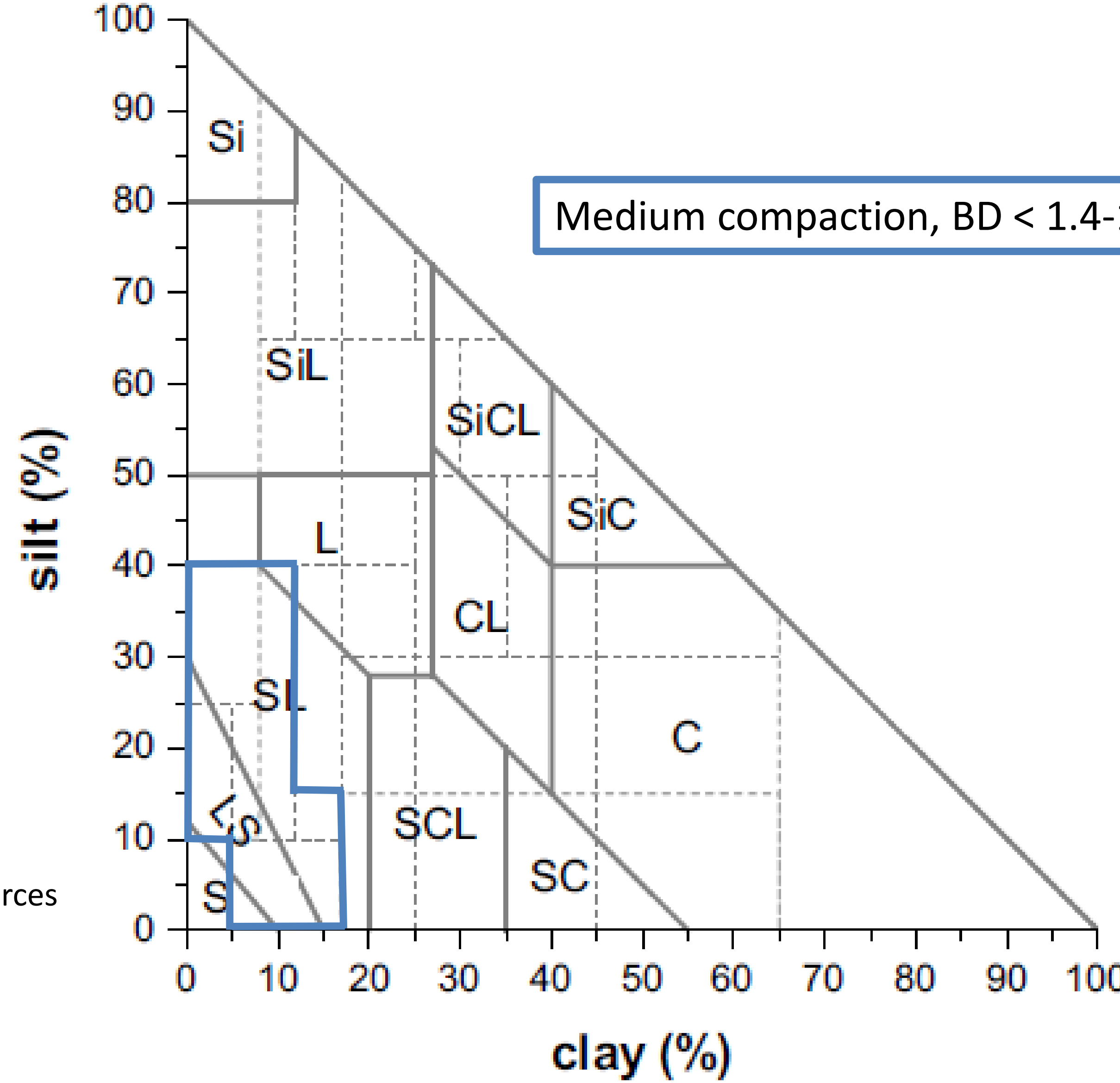
Soil textures meeting target of 14 vol.% AFP



FAO/ISS (2006): World reference base for soil resources

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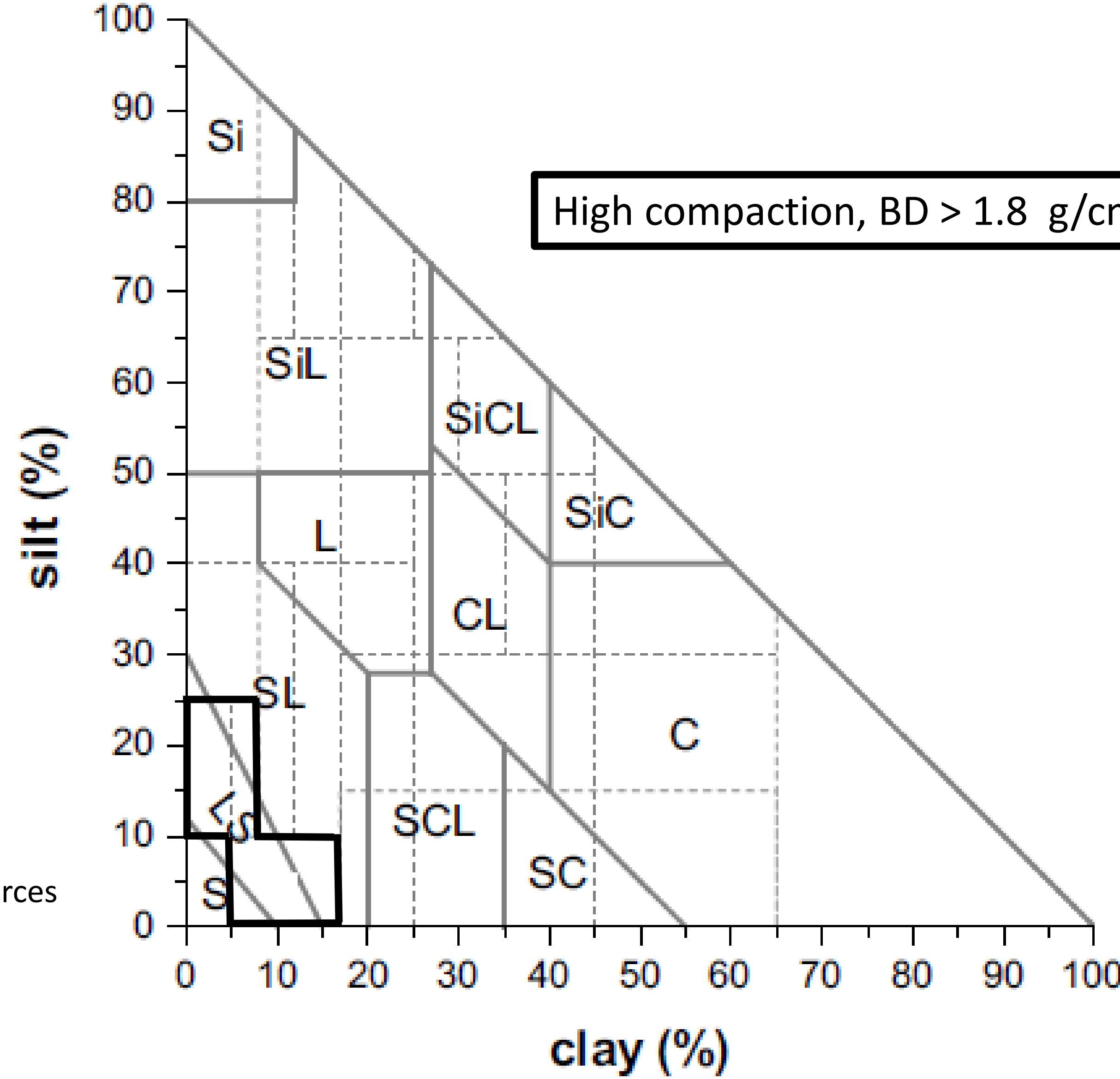
Soil textures meeting target of 14 vol.% AFP



FAO/ISS (2006): World reference base for soil resources

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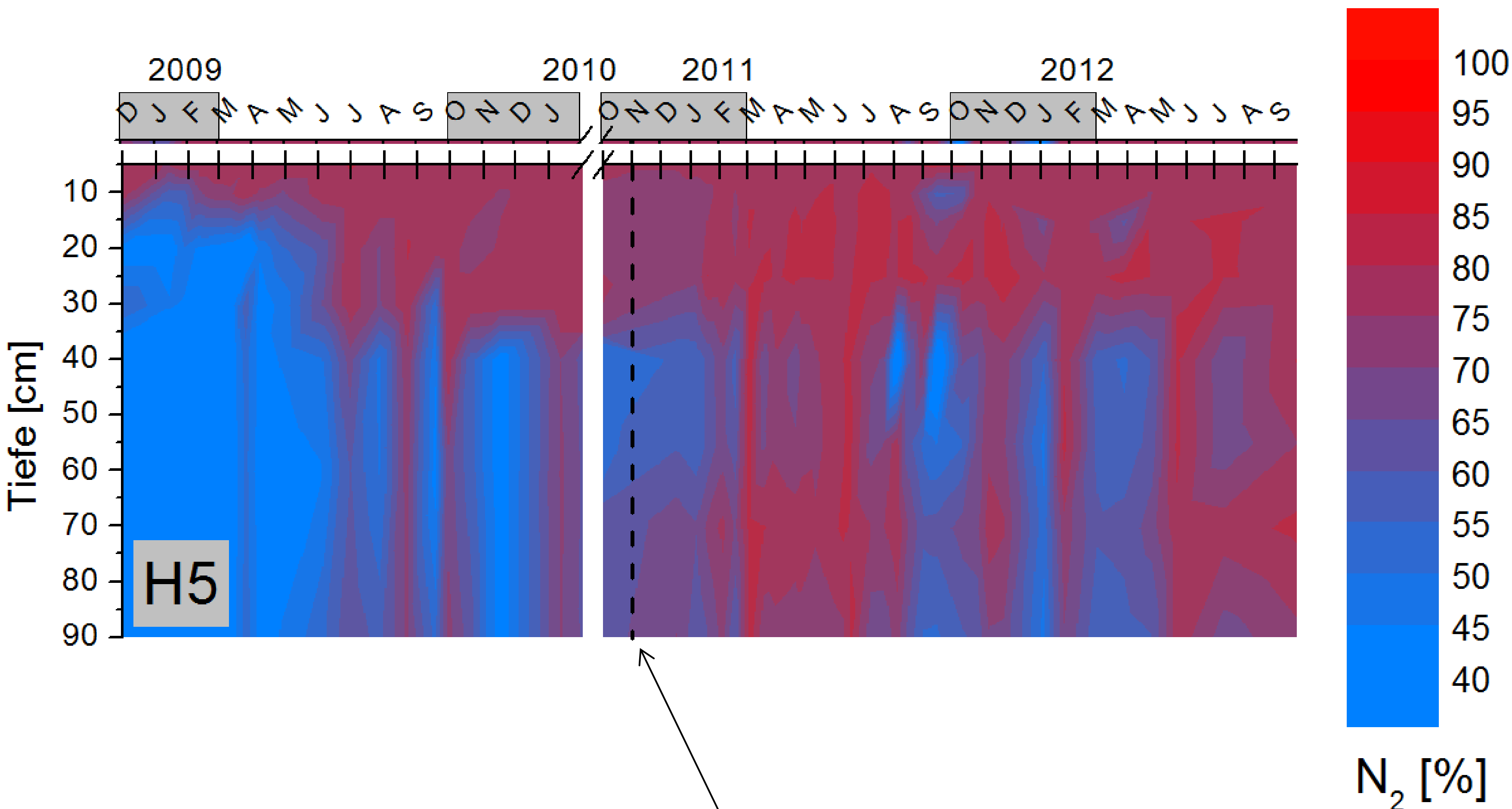
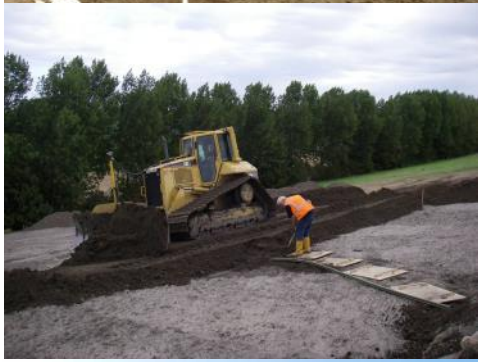
Enhancing aeration by hotspot remediation



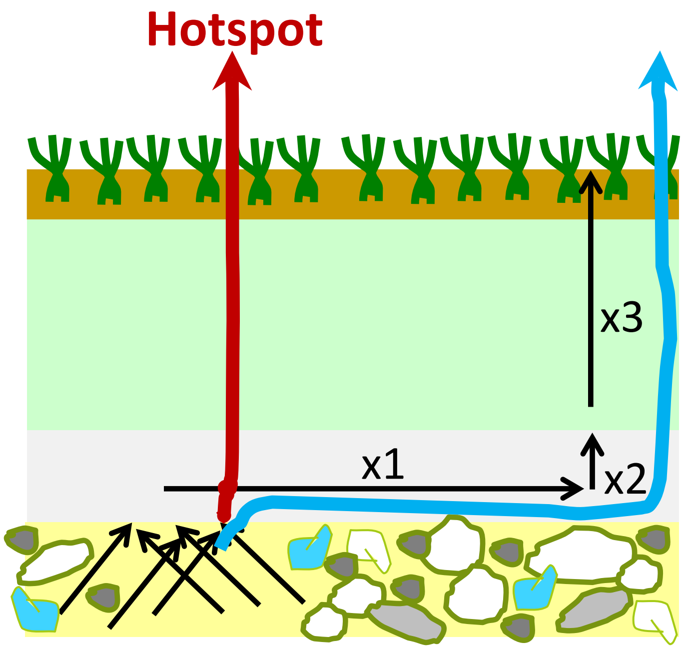
Implementation of methane oxidation window optimized for aeration

Conclusions O_2 supply

- Process heavily dependent on adequate O_2 supply
- O_2 diffusive ingress governed by soil effective diffusivity
- Diffusivity depends on air-filled porosity at given water content and hence on texture and compaction
- Empirical relationships allow for good estimate
- Choice of suitable soil textures and construction practice is crucial



(3) Spatial evenness of gas load



Aims:

– Avoid overloading of individual compartments
– Tap full system potential
– Avoid channelled advective transport

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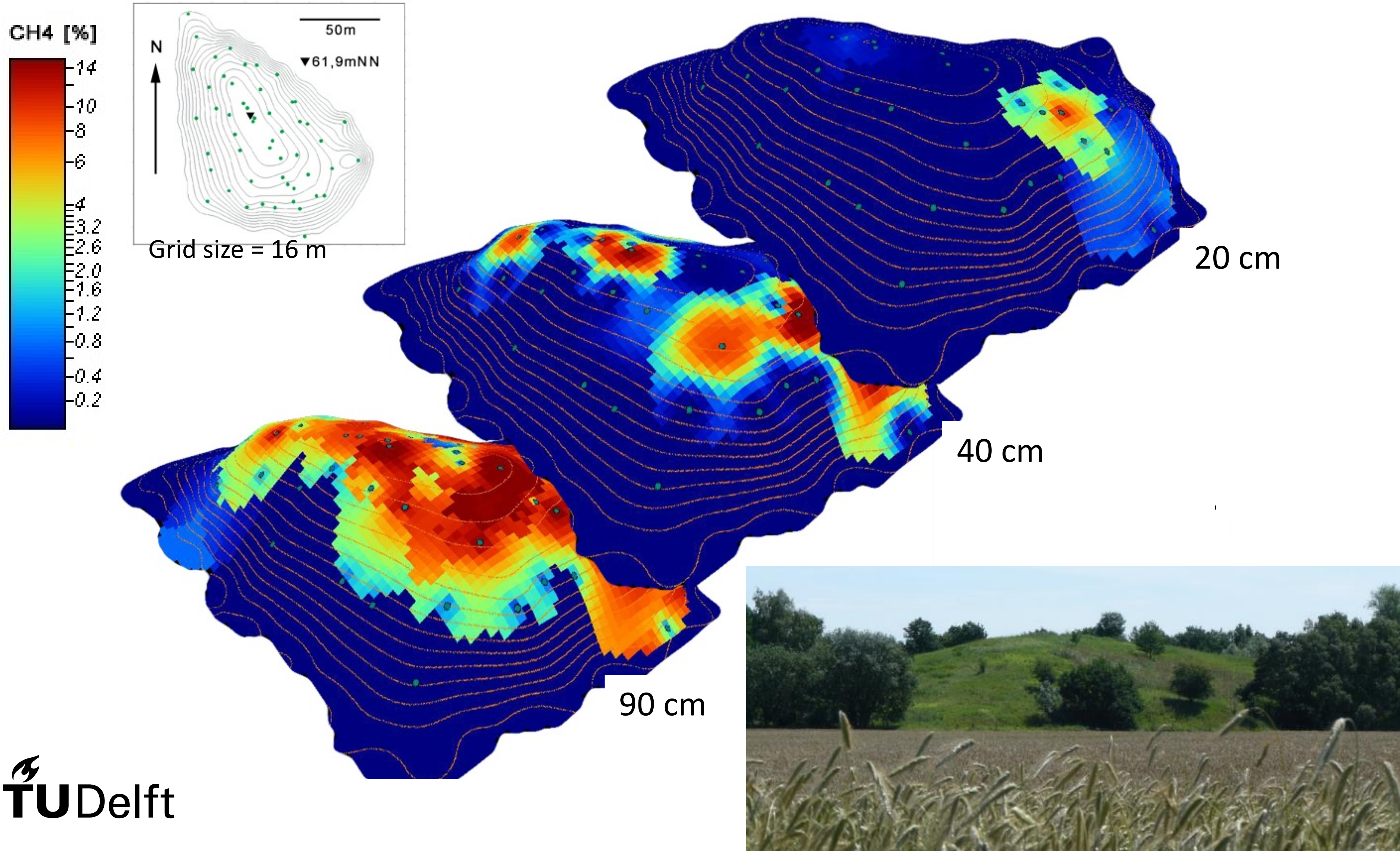
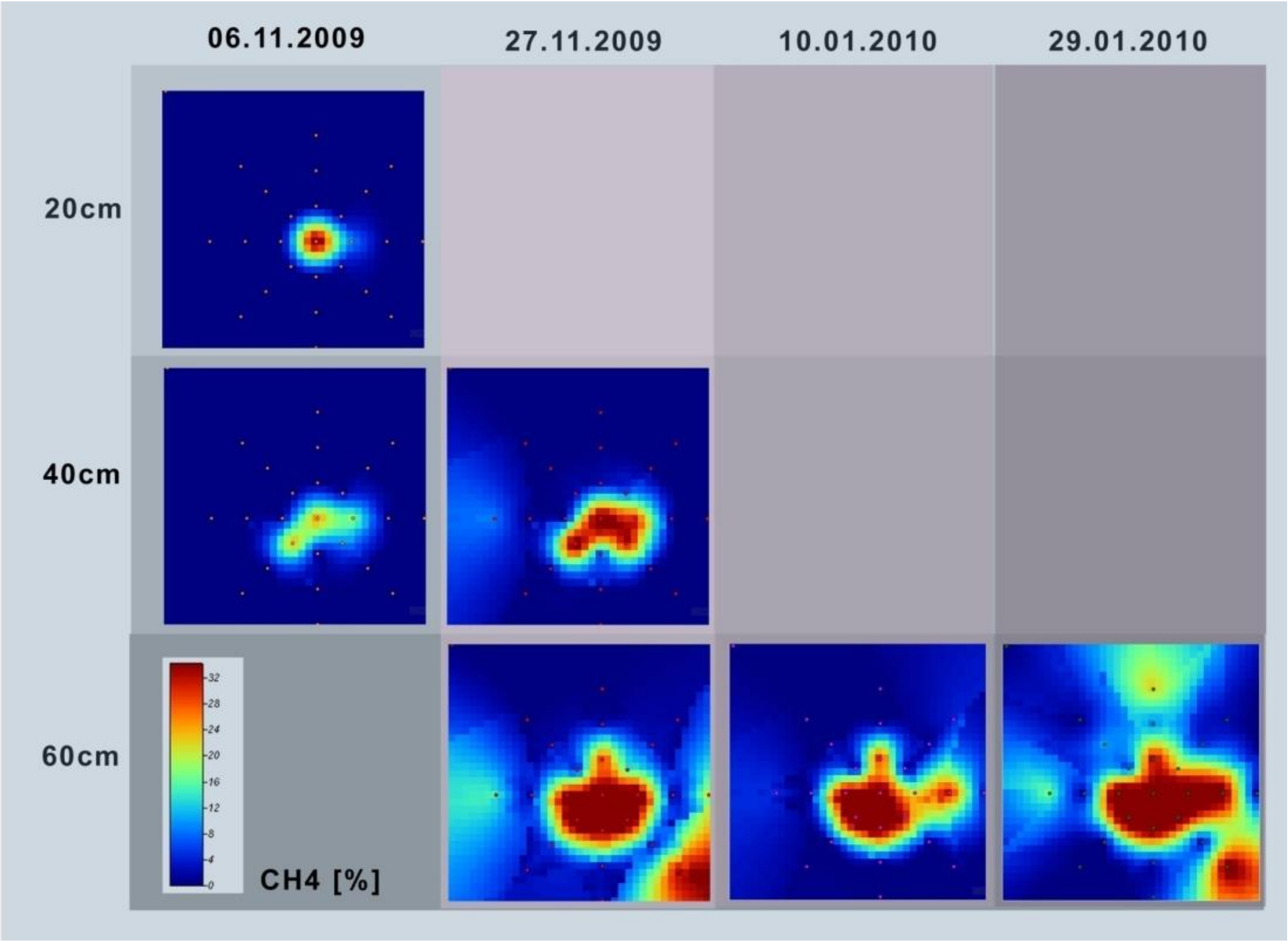
Spatial variability of soil gas composition in a cover soil of a non-sanitary landfill

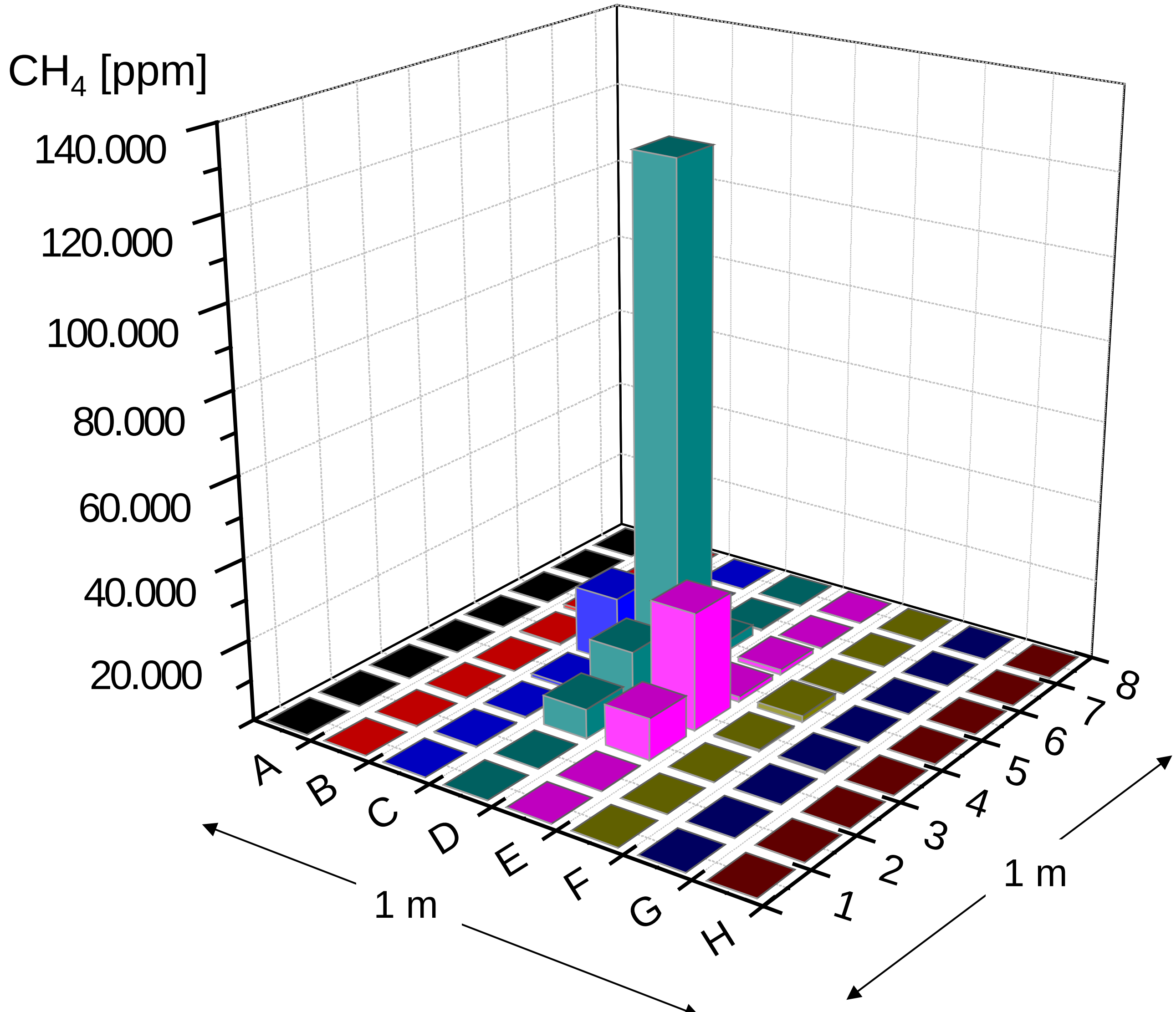


Methane concentration at hotspot



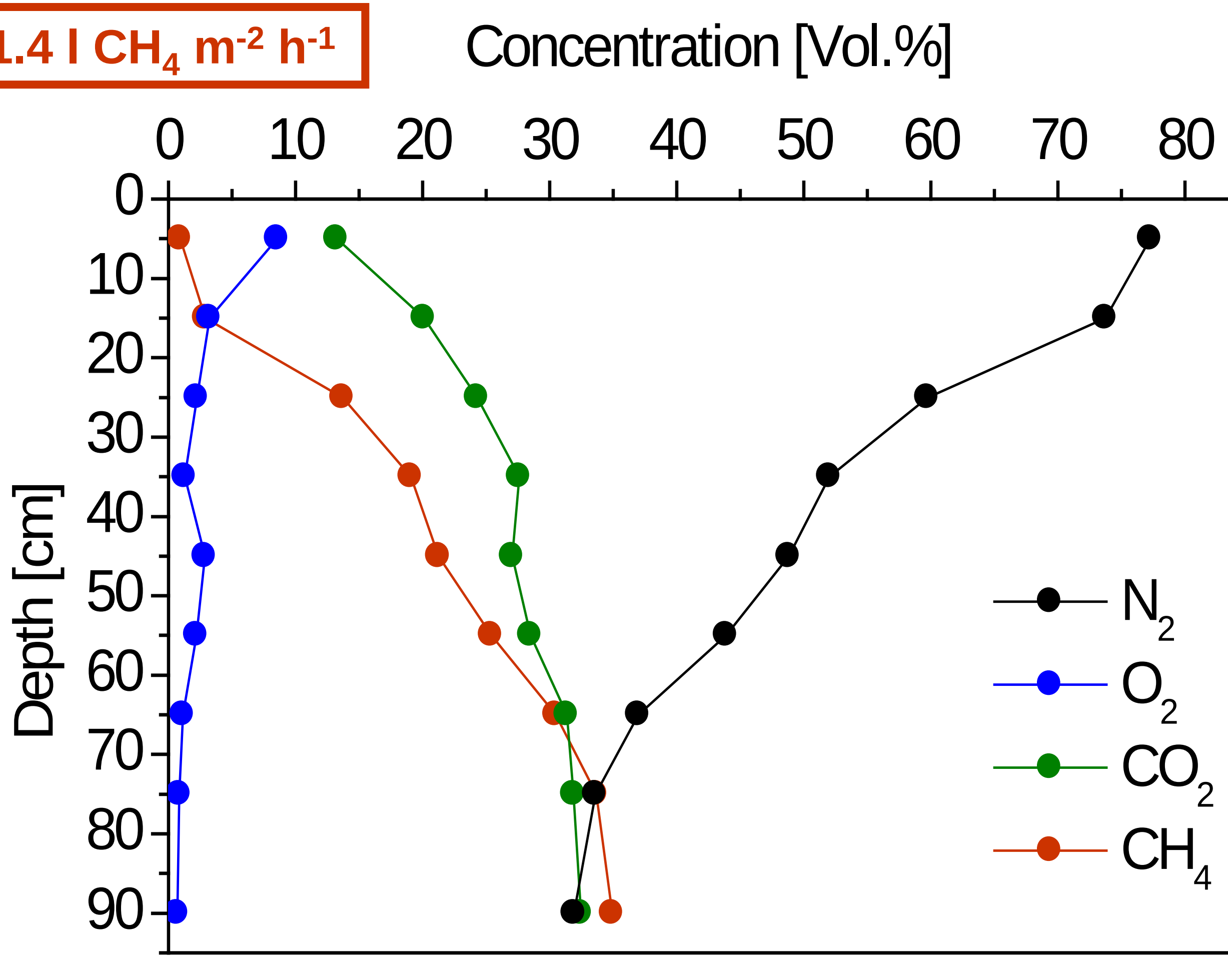
Morphology of hotspot soil profile

Small scale variability of surface CH_4 concentrations



Gas profiles with advection ↑

1.4 l CH_4 m^{-2} h^{-1}



BD = 1.59 g/cm³, 85 % Proctor

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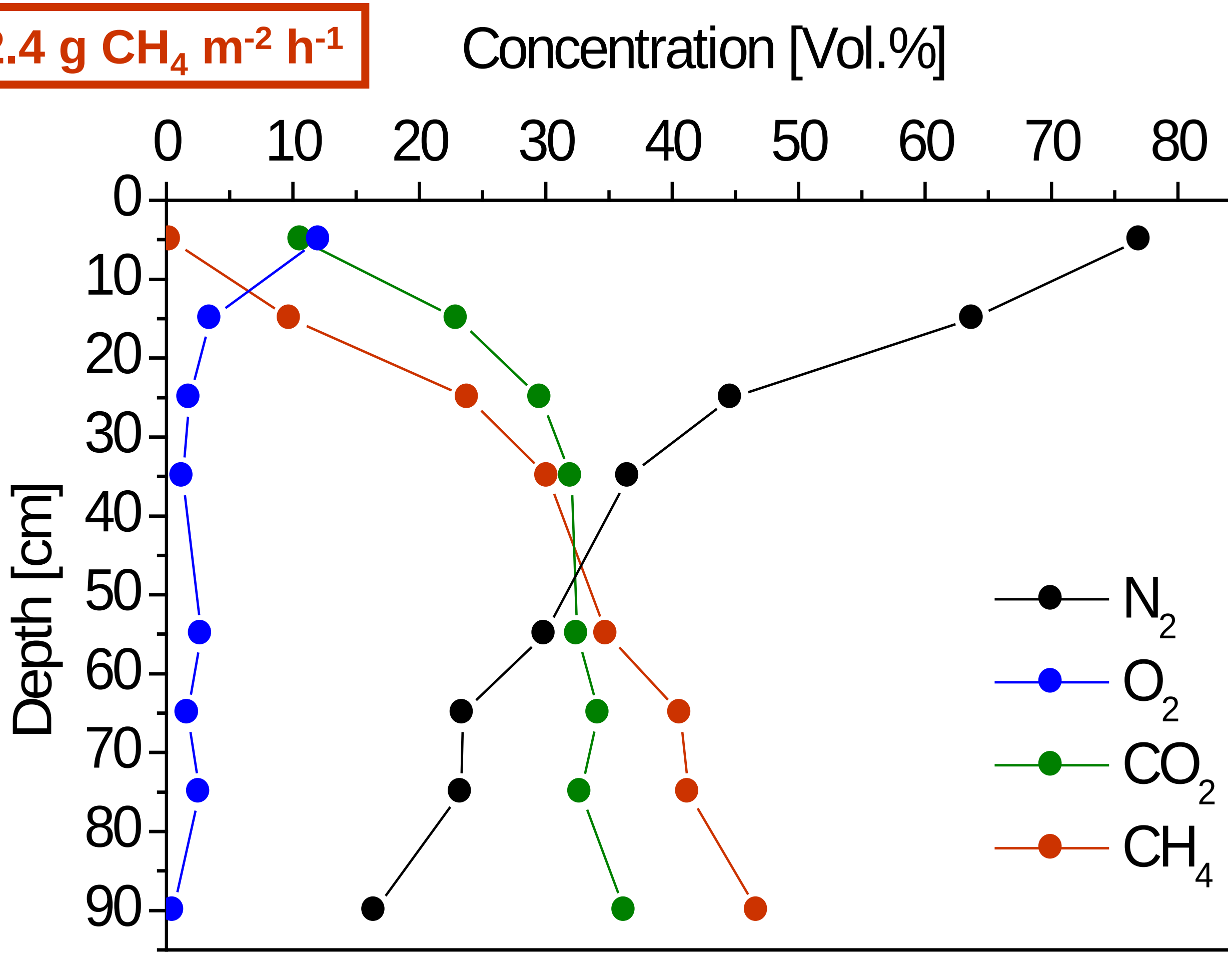
After Gebert et al., 2011

Gas profiles with advection ↑

2.4 g CH_4 m^{-2} h^{-1}



BD = 1.59 g/cm³, 85 % Proctor

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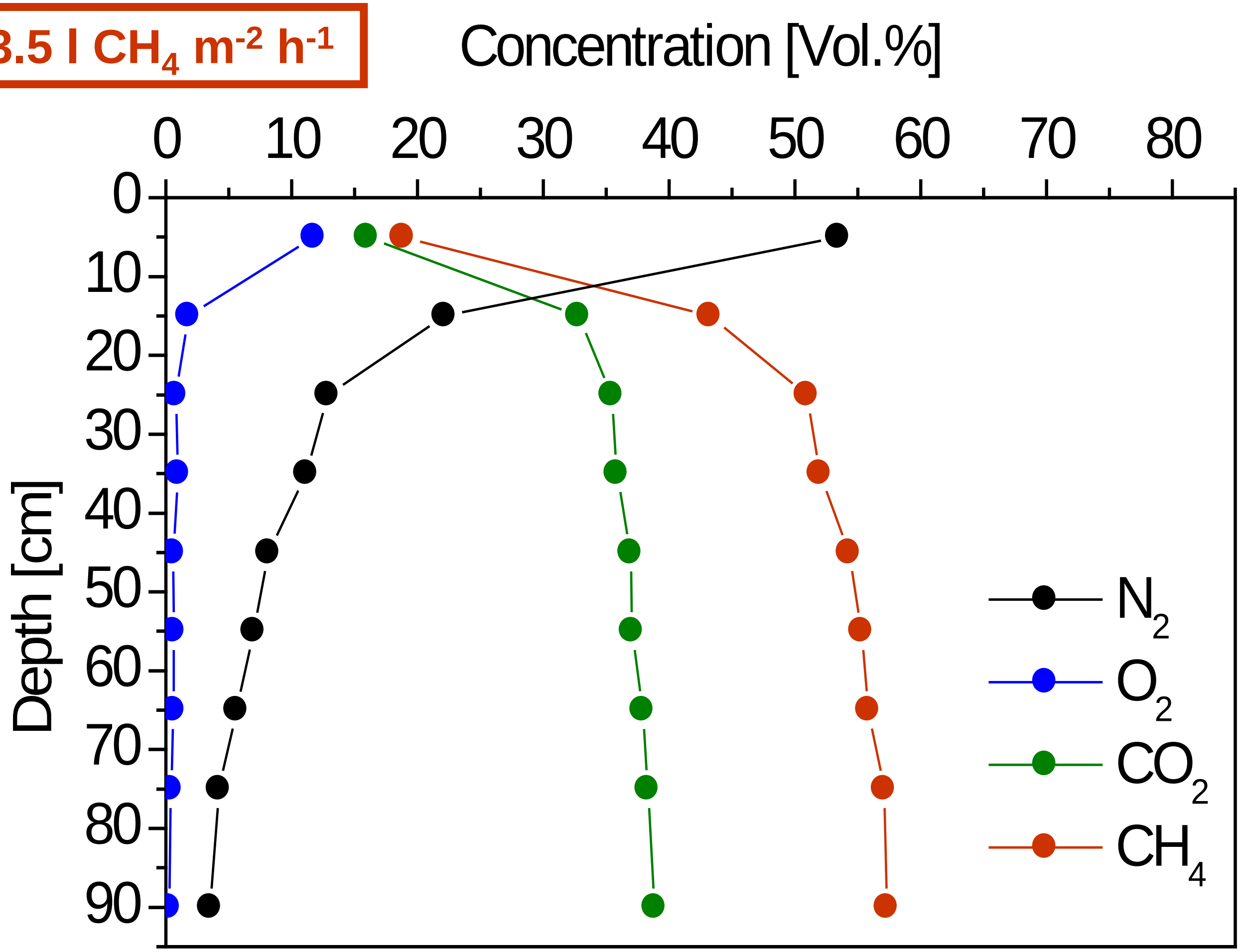
Gas profiles with advection ↑

3.5 l CH_4 m^{-2} h^{-1}



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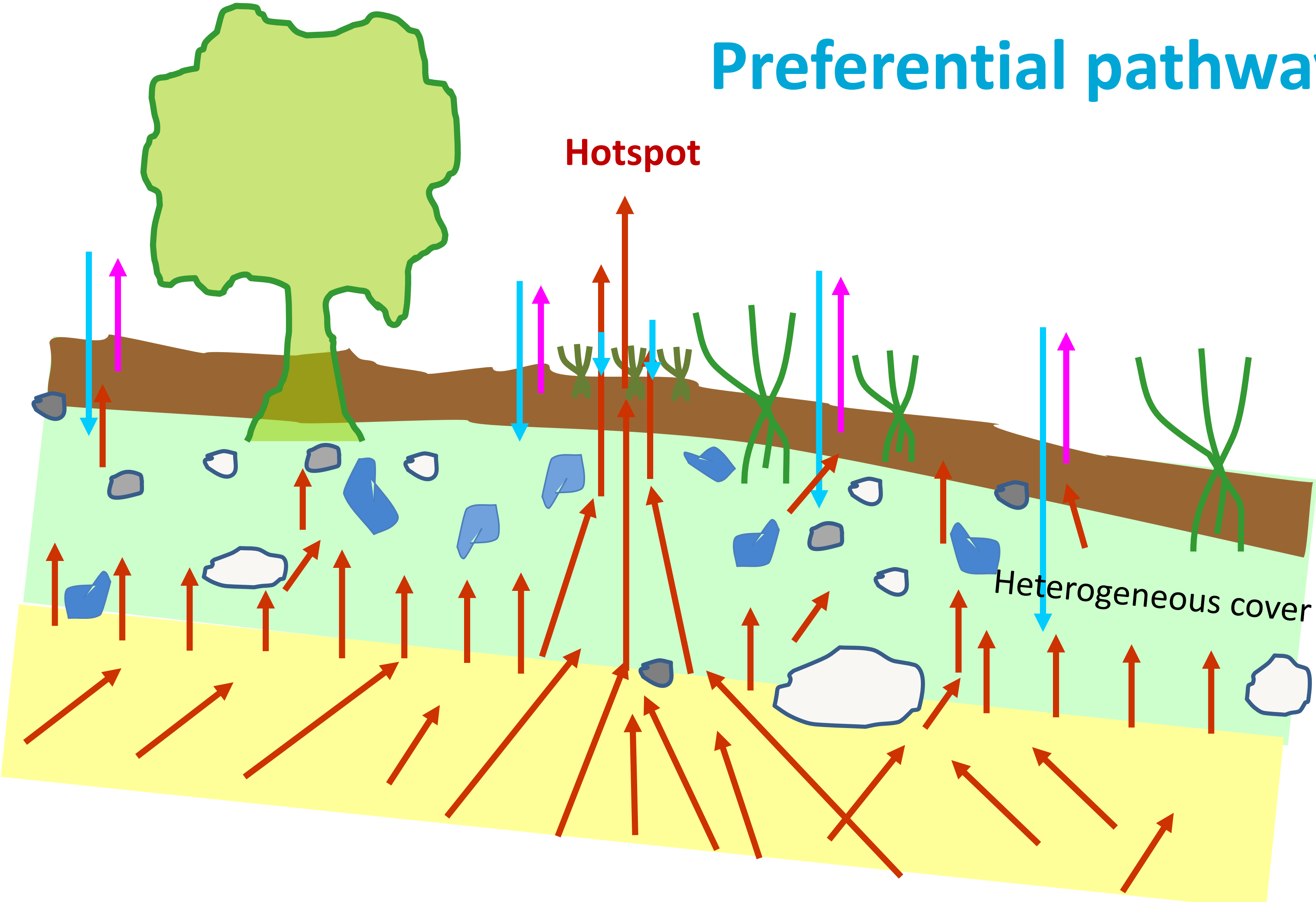
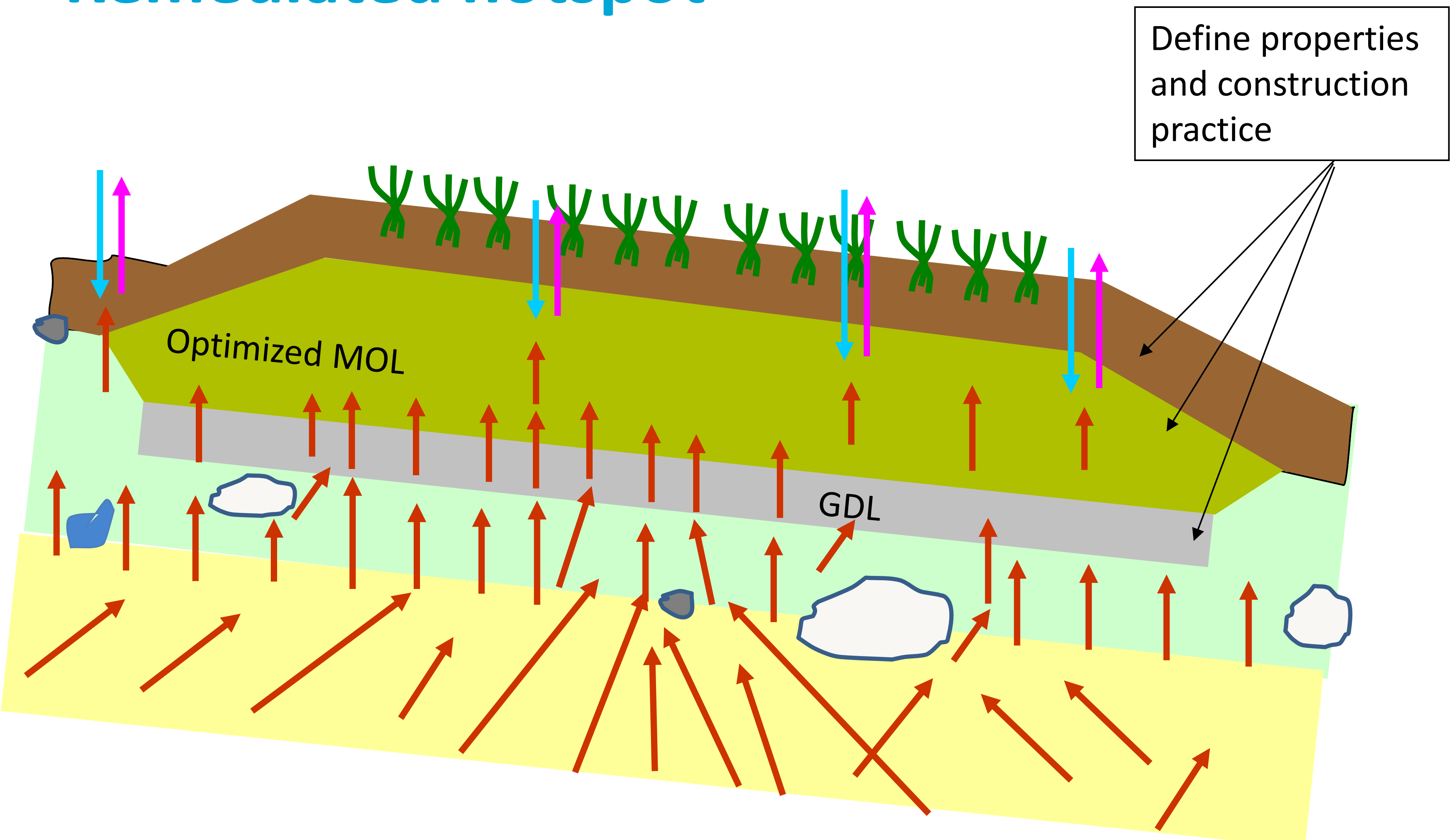
After Gebert et al., 2011

Preferential pathways



Remediated hotspot



Universität Hamburg
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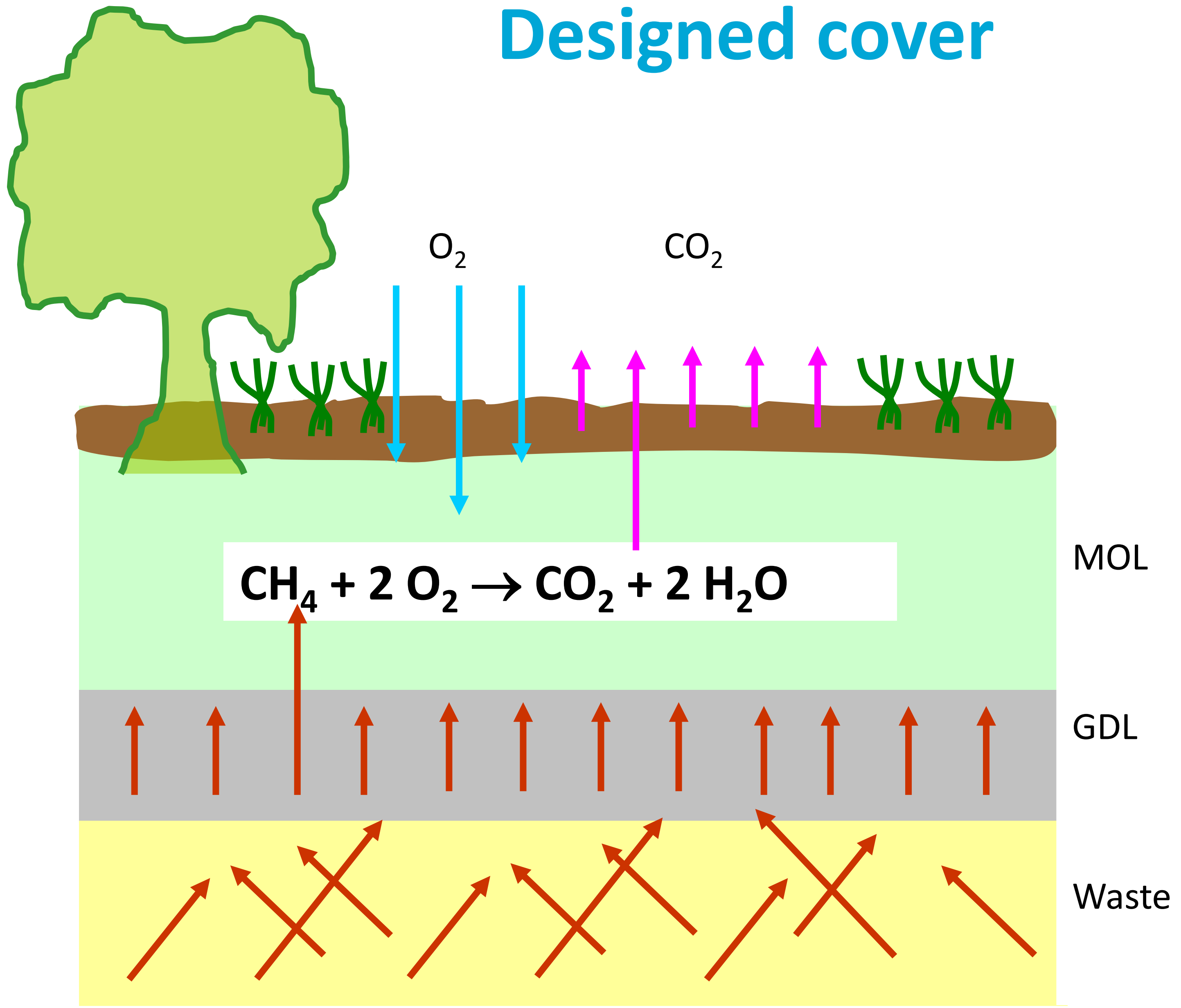
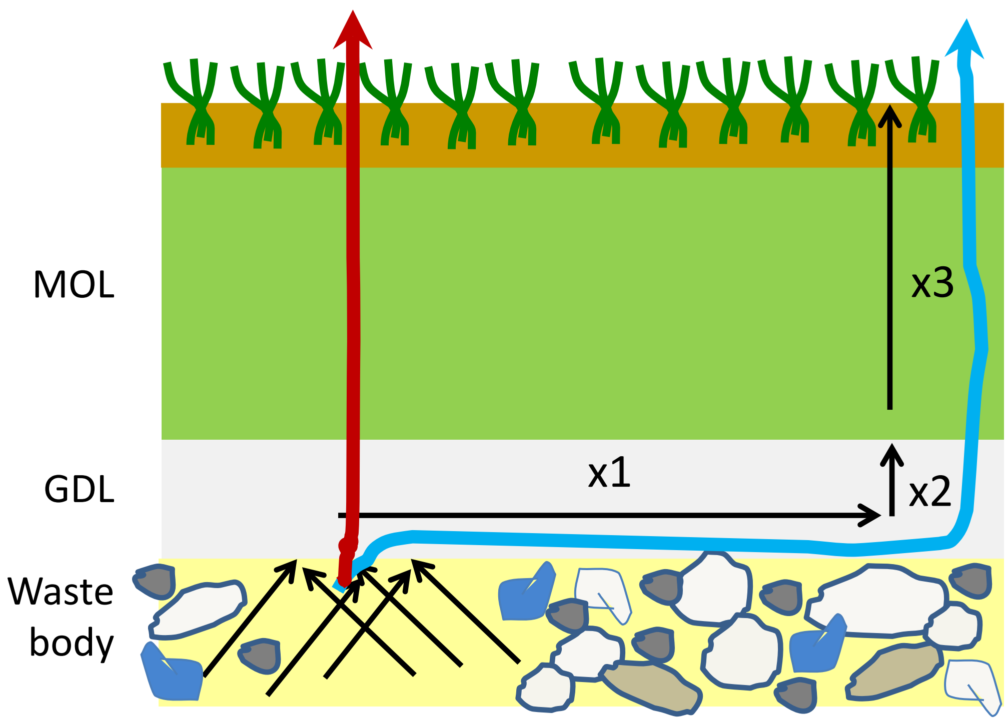
Designed cover



Requirements gas distribution layer

1. < 2% $CaCO_3$ → Avoid precipitation of CO_2
2. Purely mineral → High structural stability
3. High gas coductivity → k_{Gas_GDL} >> k_{Gas_MOL} , so that



$\Sigma(R_{x1+x2+x3}) >> \Sigma(R_{x1})$

→ Sum resistance should be homogenous over all path lengths

→ horizontal gas transport favoured in GDL

With $R = 1/k_{Gas}$

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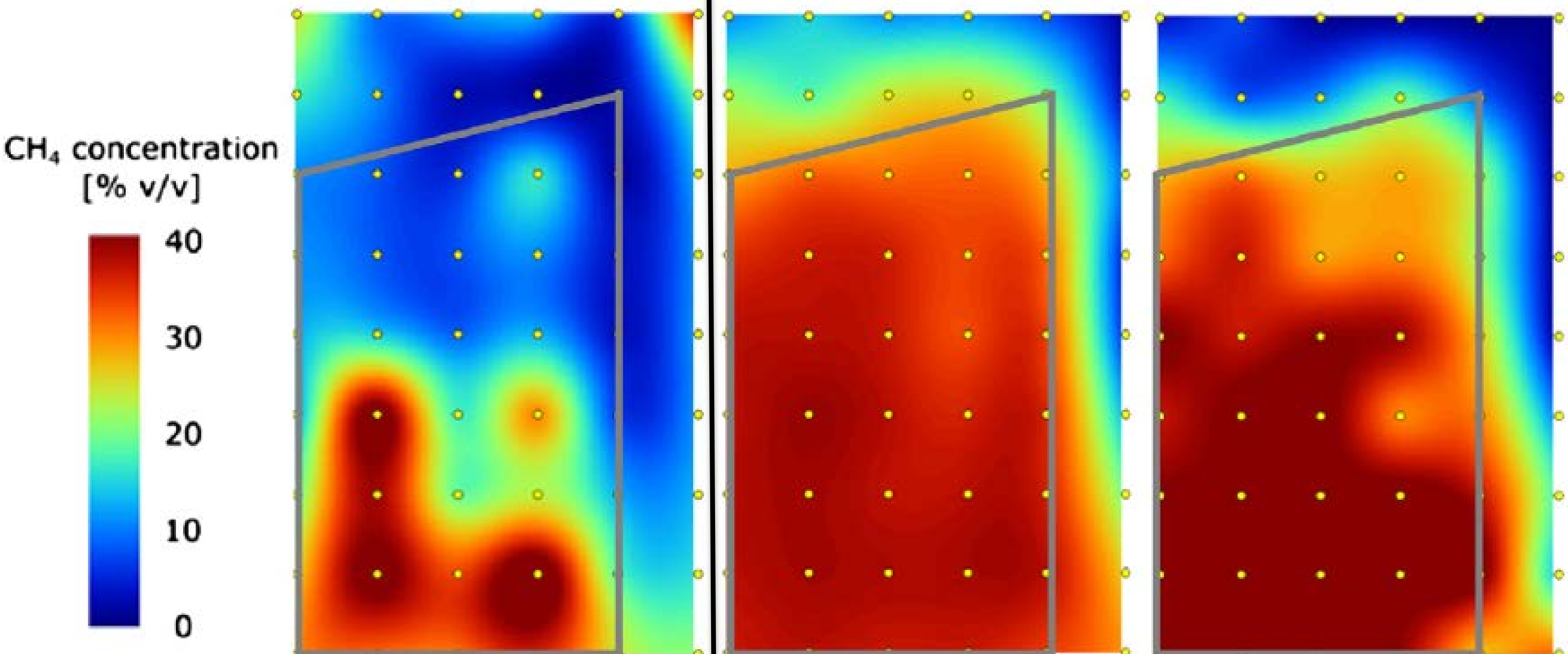
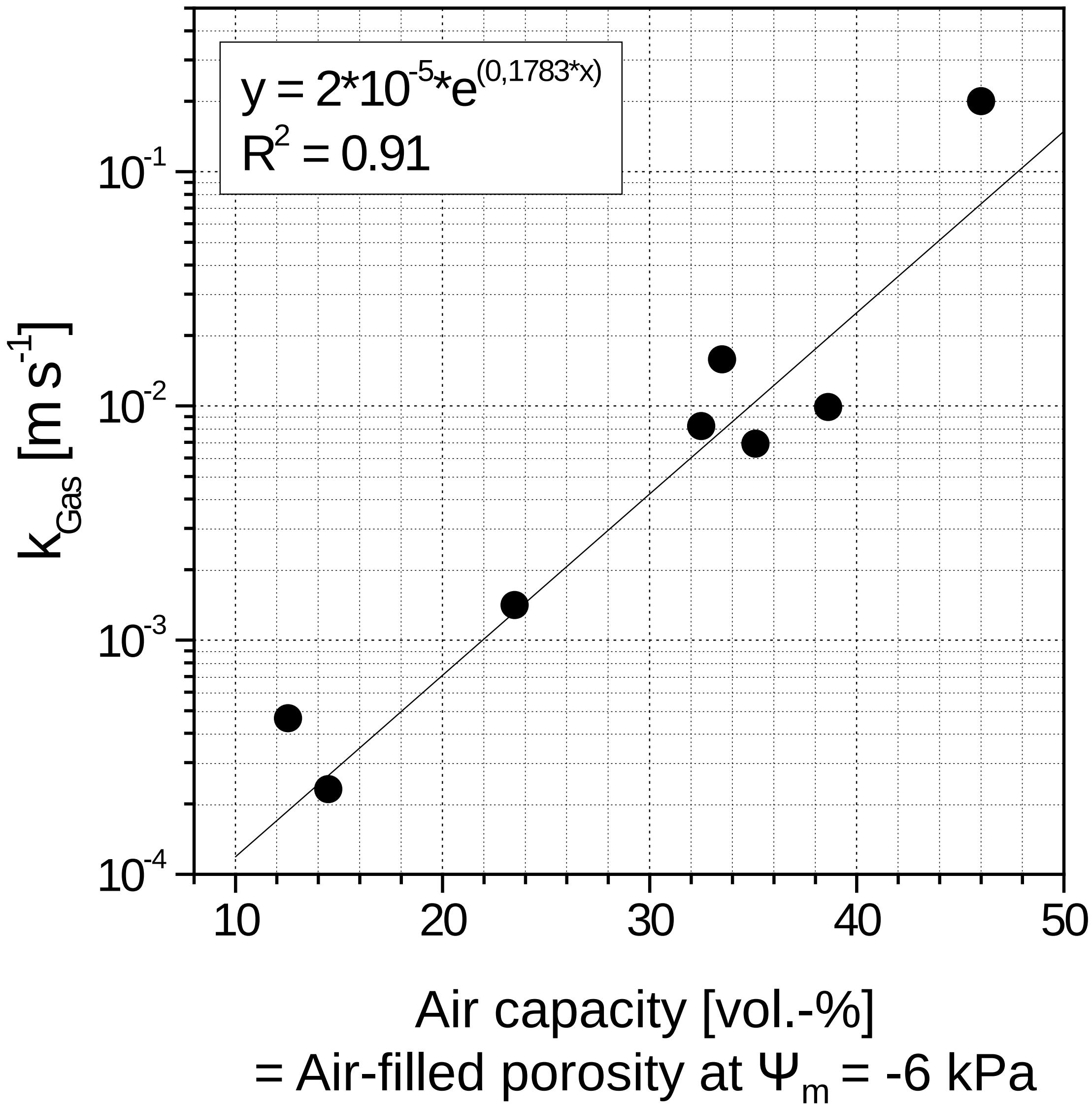
Impact of decreasing kgas in the MOL

MOL loose | MOL slightly compacted



Conductivity (advection) depends on air-filled porosity



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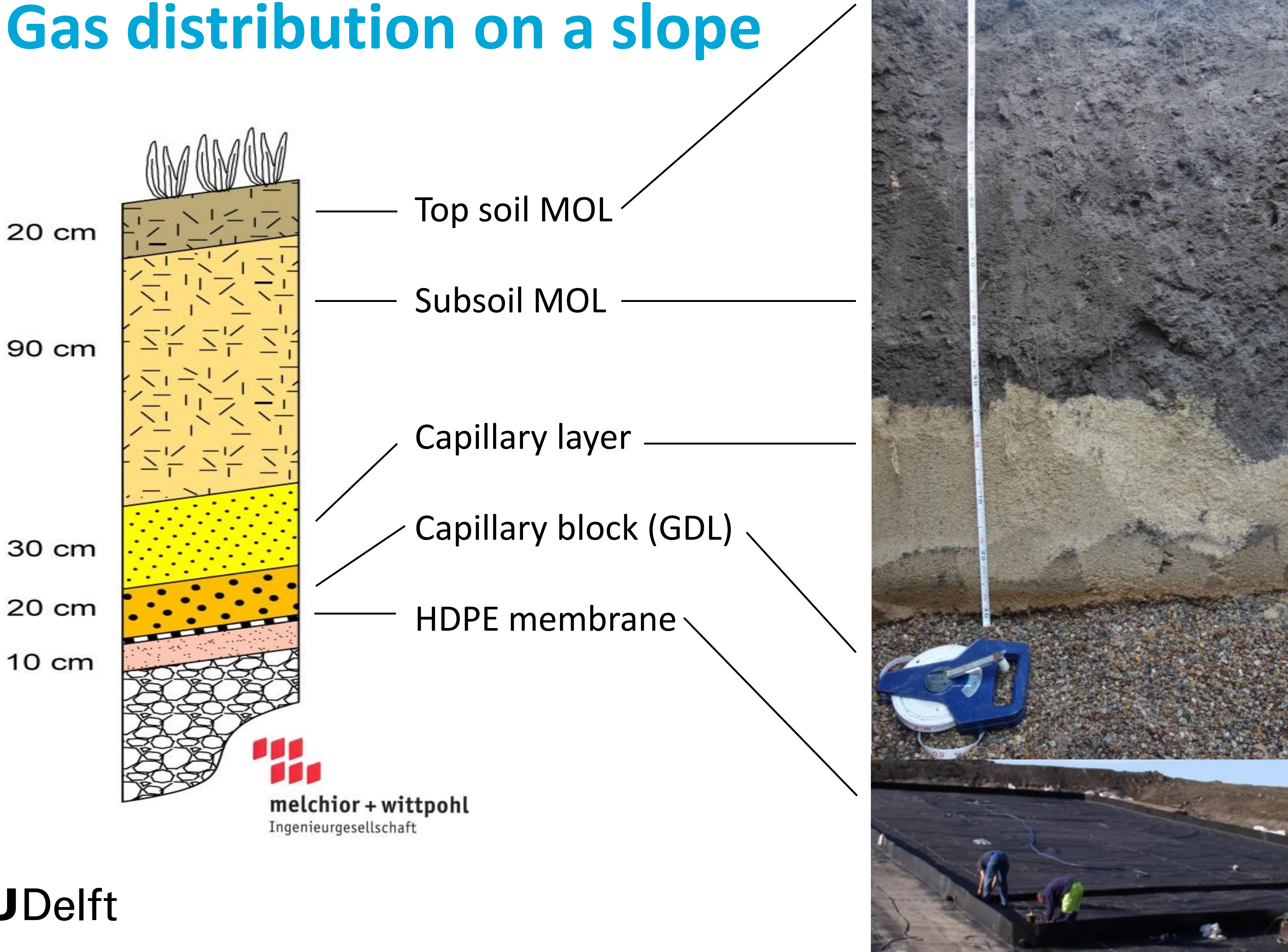
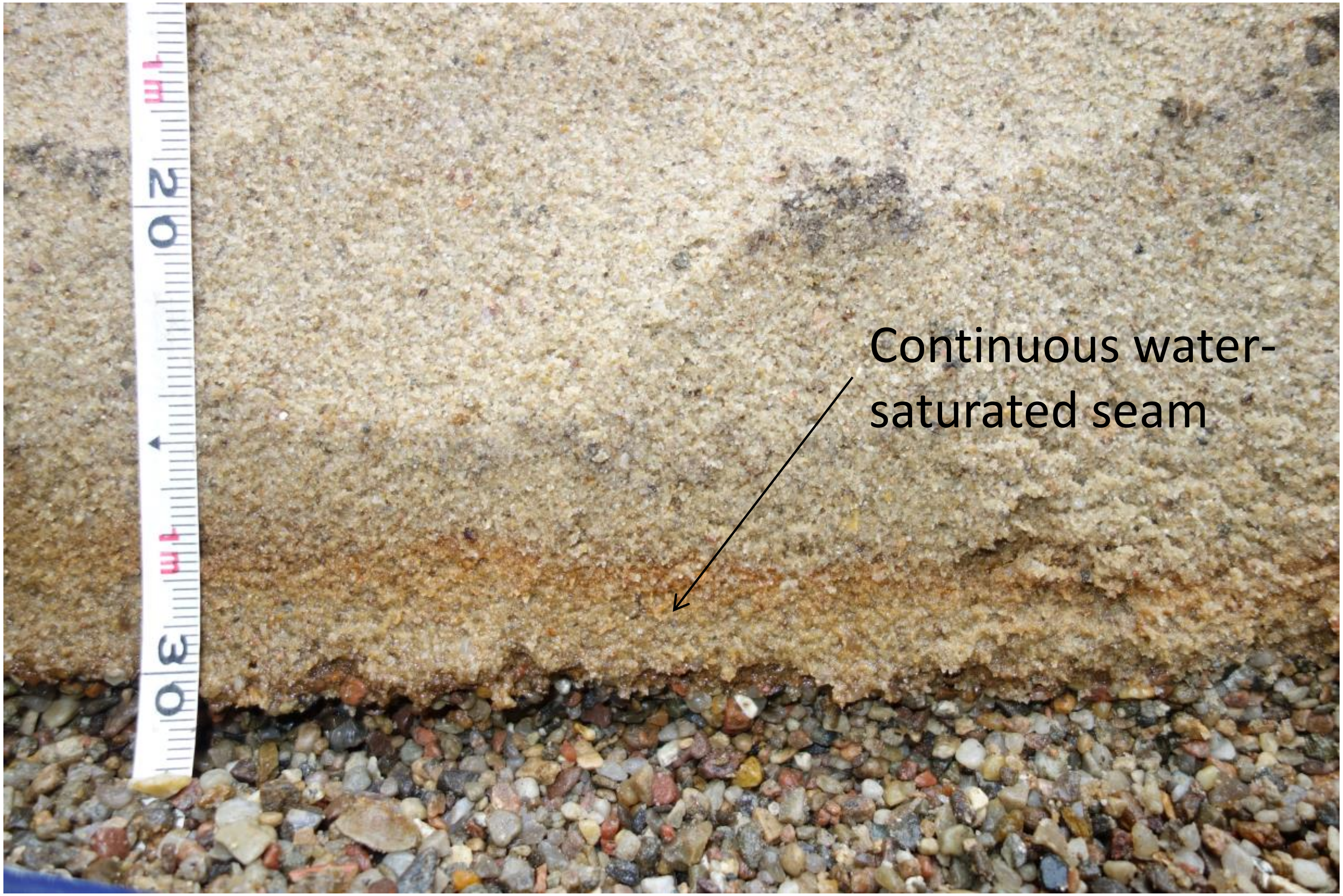
Gas distribution on a slope

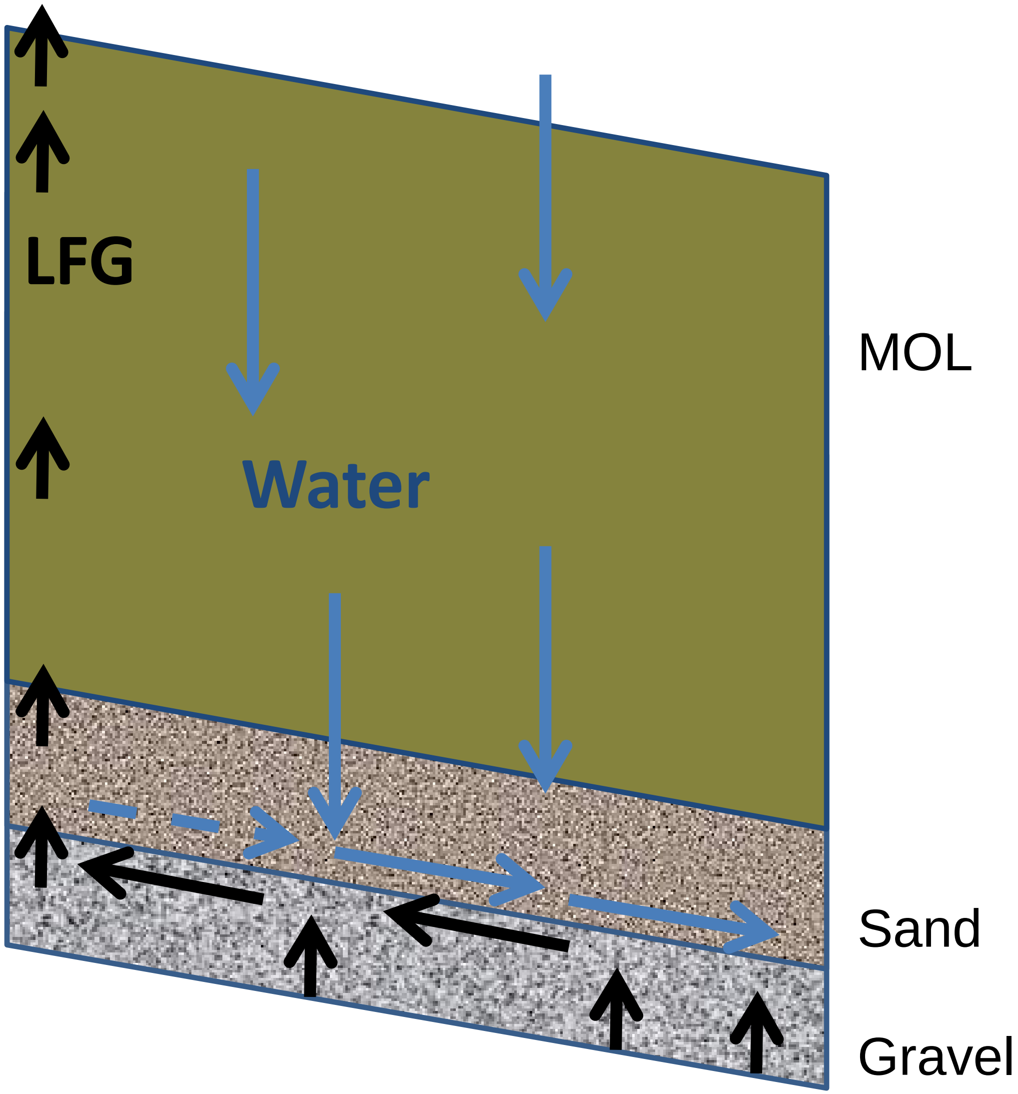


Detail capillary layer



Combination of CH_4 oxidation and water diversion on slopes

- Downslope movement of water following gravity leads to a closed capillary seam at foot of slope
- Gas travels upslope along preferential gas pathway



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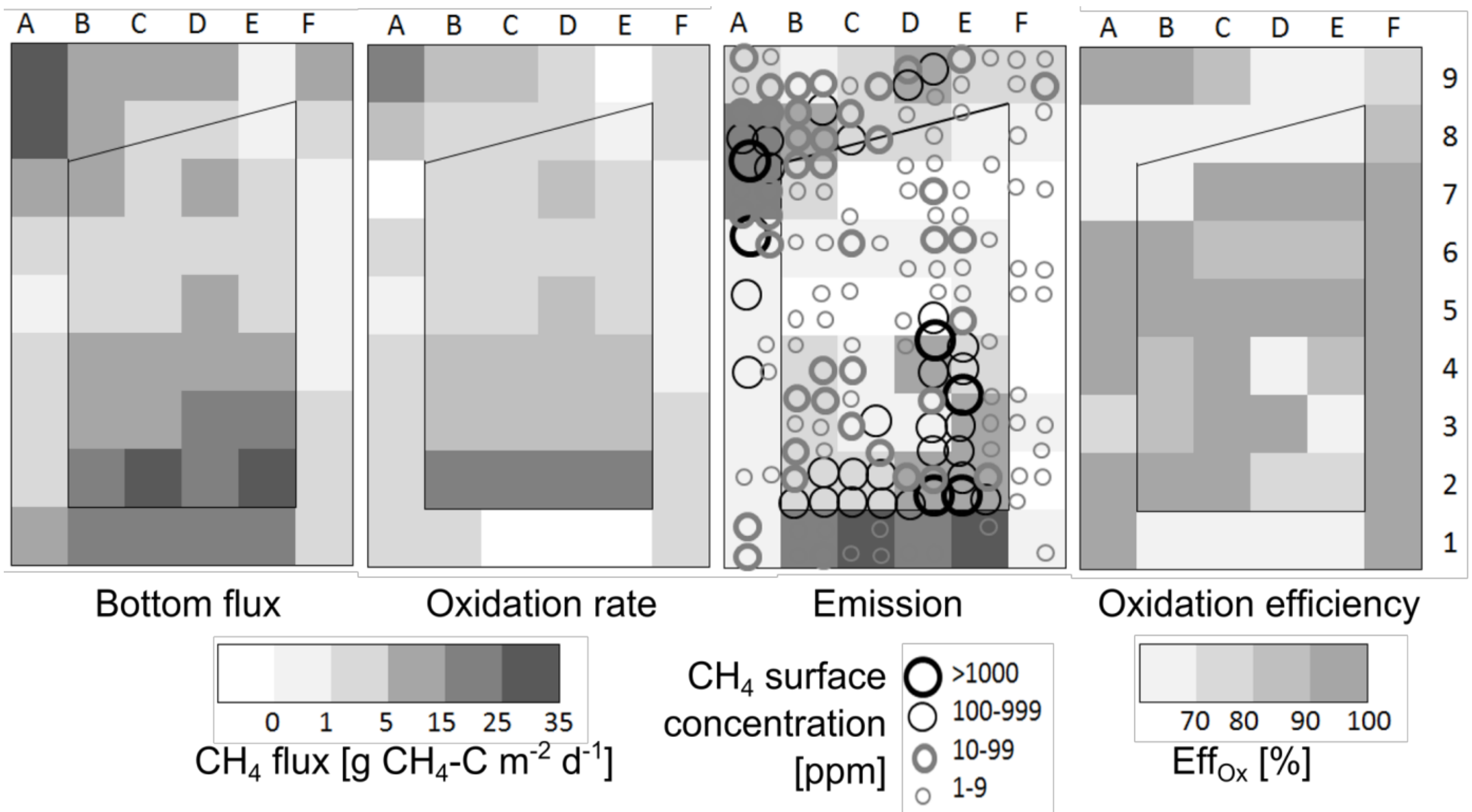
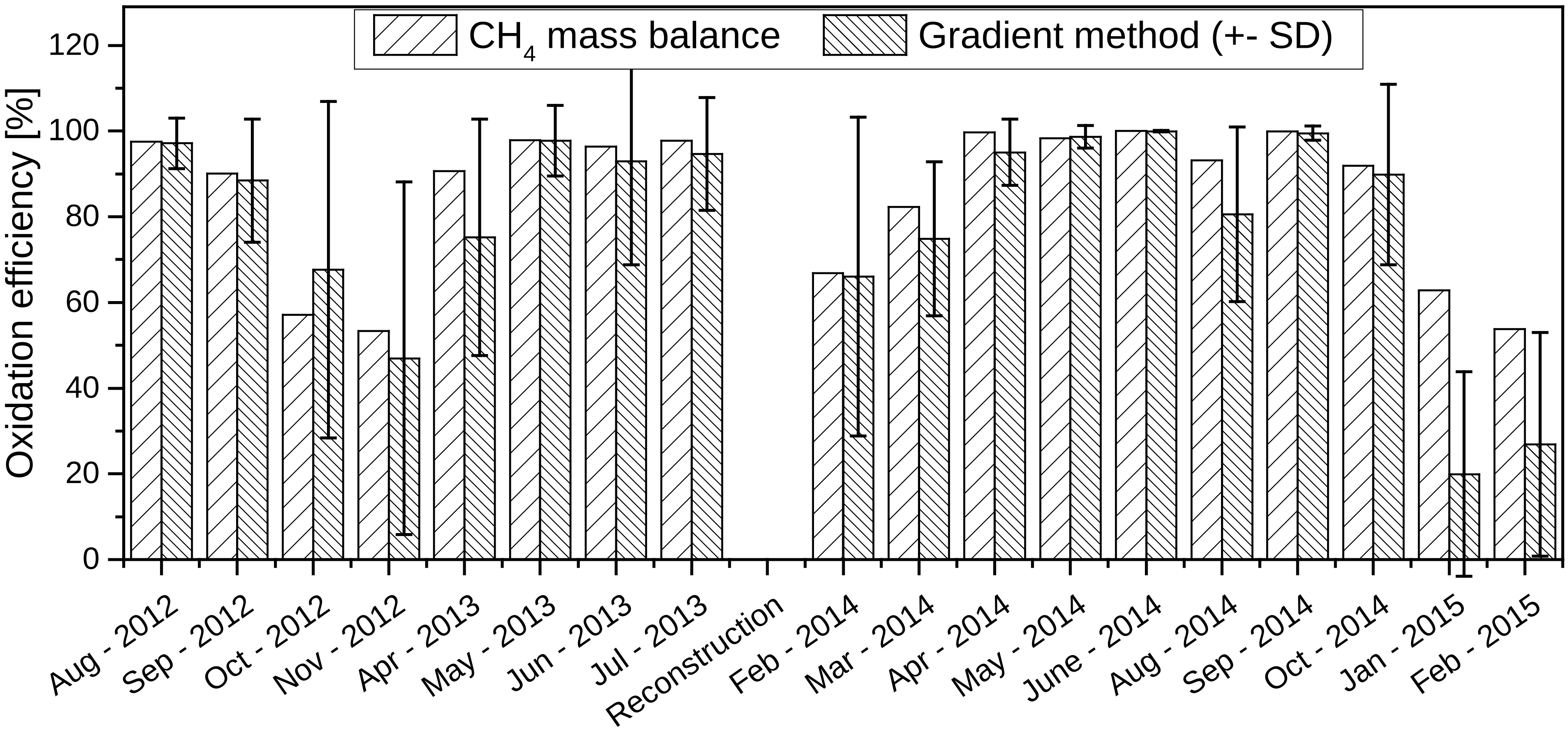
CH_4 fluxes in relation to slope

downslope



Röwer, 2014

Ox. eff. of the whole test field still 84% !



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CH_4-load: 35 g m-^{2} d^{-1}

Conclusions spatial distribution

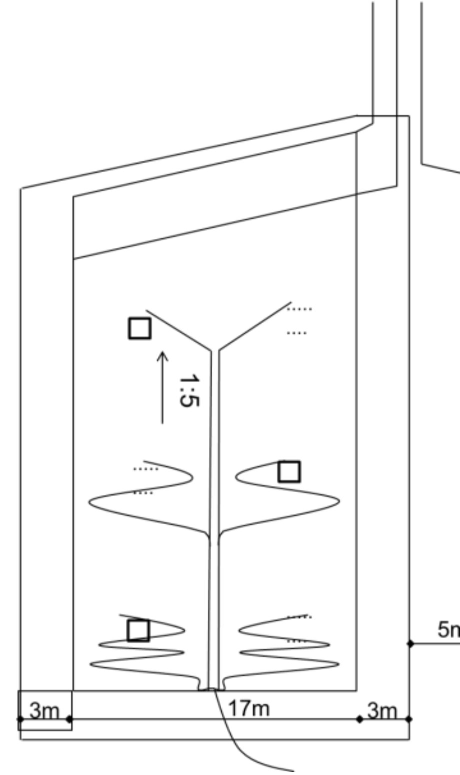
- Gas distribution layers are an essential element of MOS design
- Spatial evenness of gas load depends on difference in gas conductivity between GDL and MOL
- Maximizing this difference is limited by the requirement on diffusivity for the MOL

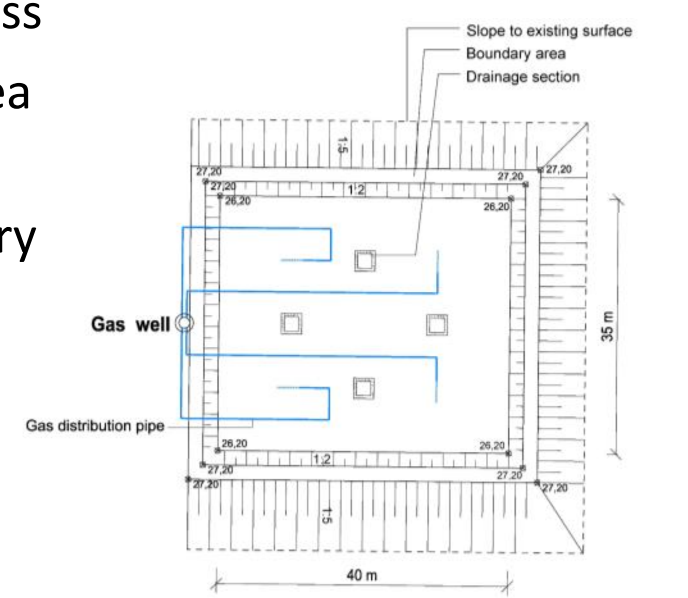
  → Calculate pressure losses over path lengths

  → Decide on maximum difference in pressure loss

  → Define number of gas inlet points per unit area

- If system is on slope, account for higher necessary oxidation capacity upslope





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(4) Dimension adapted to load

Aims:

- Decrease spatial load to below the expected spatial CH_4 oxidation potential
- Consider seasonal variation of oxidation rate (temperature and saturation)

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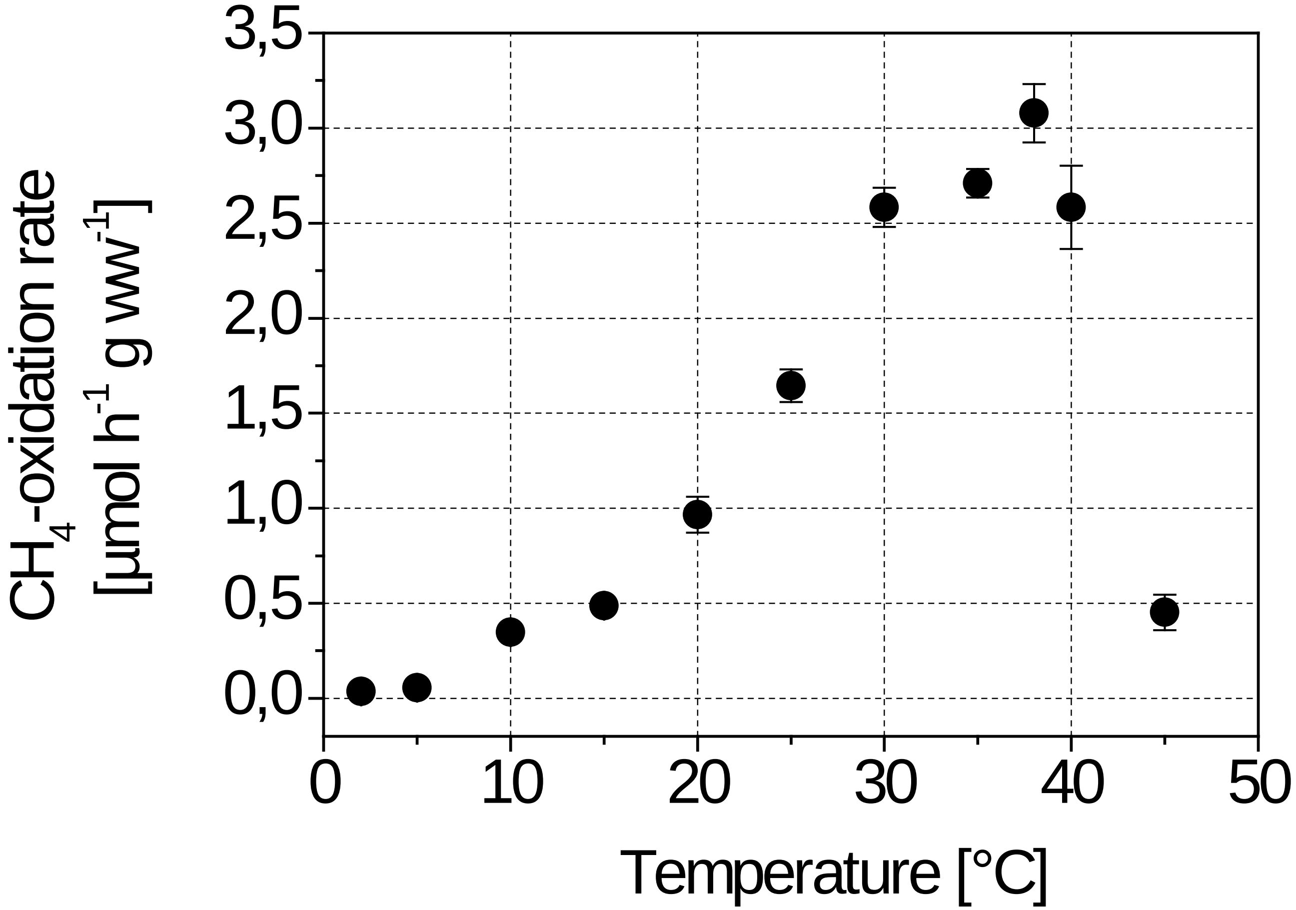
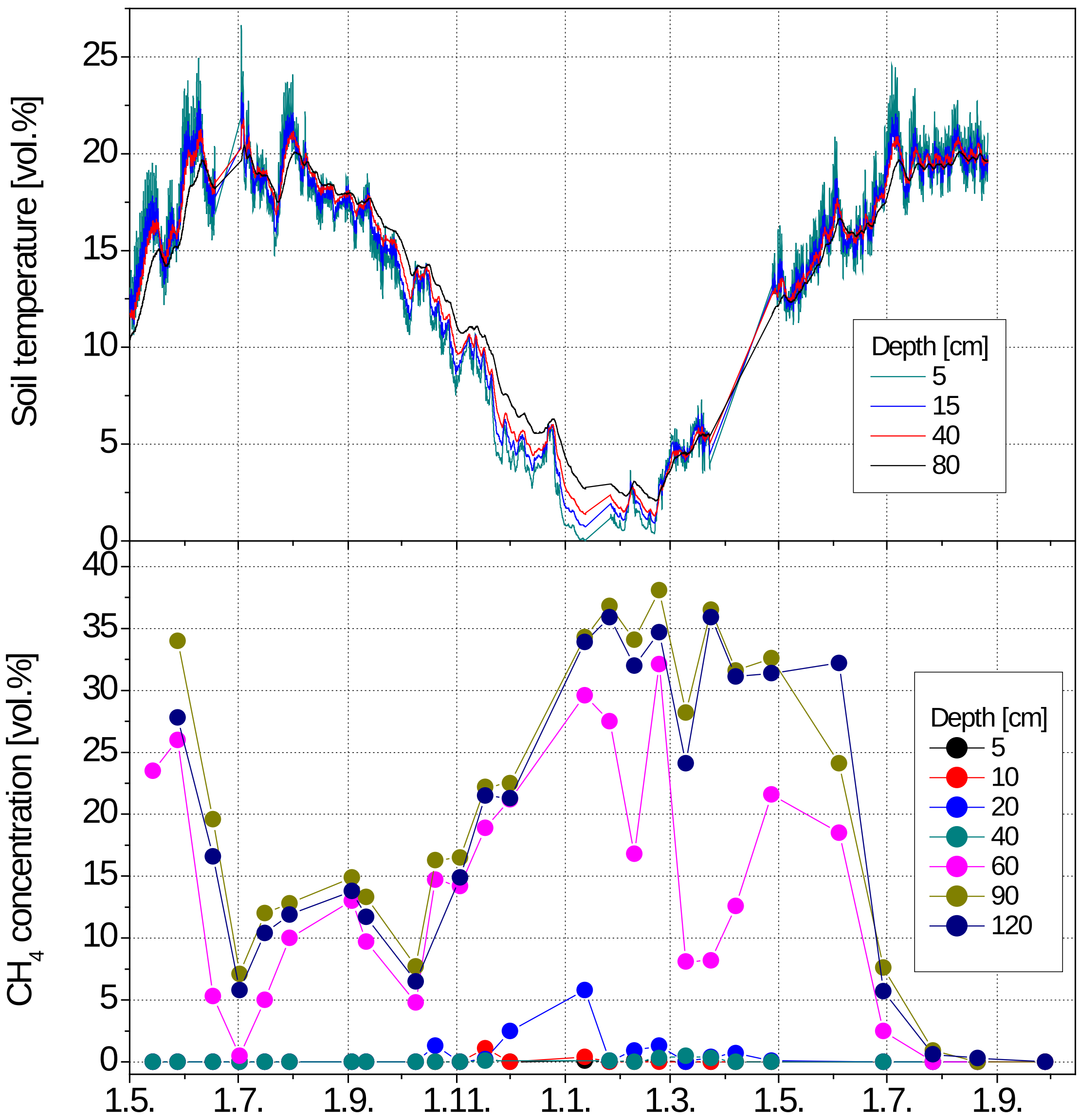
Impact of temperature



Gebert et al., 2003

Seasonal effects: Temperature



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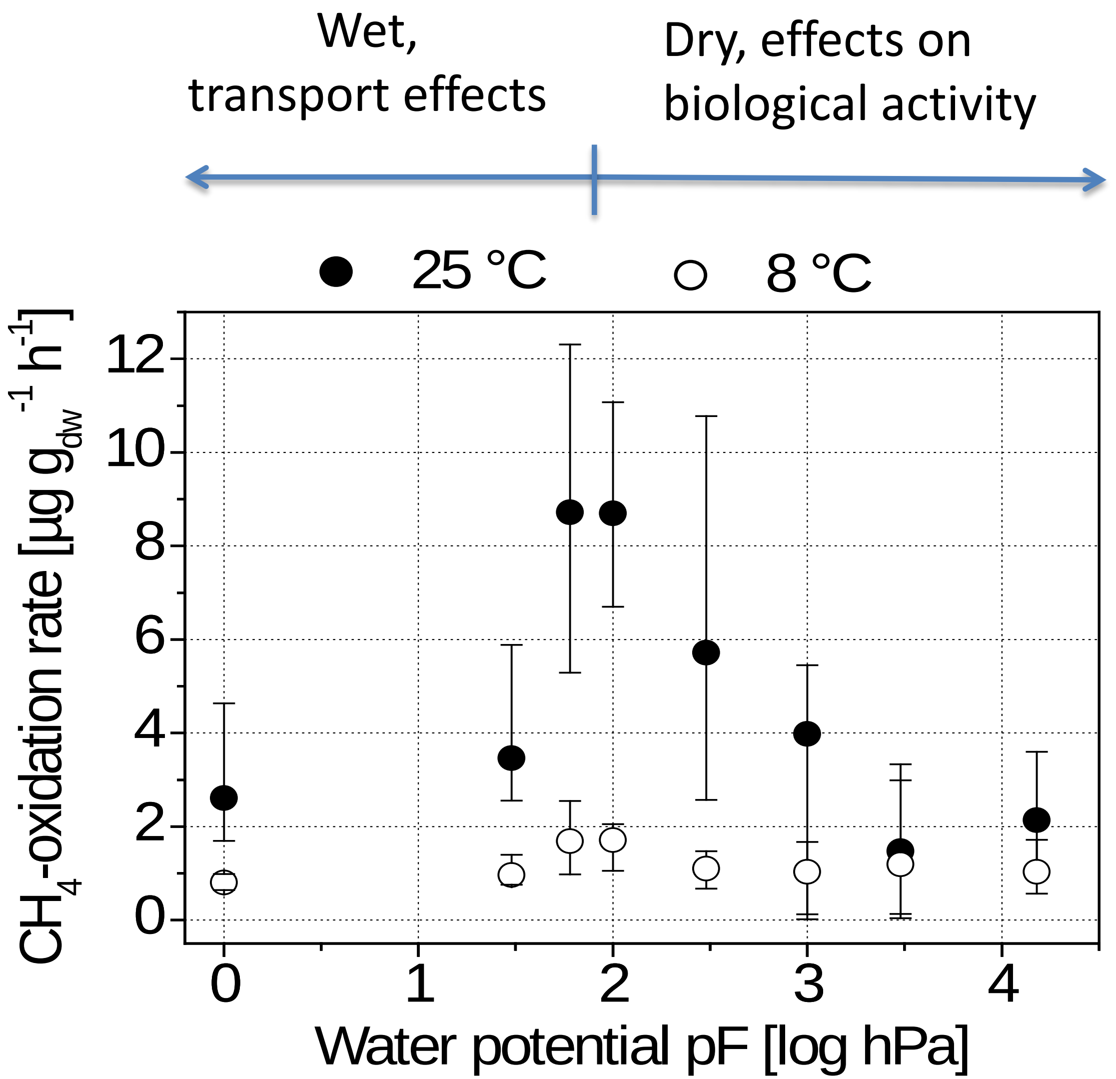
Impact of water potential

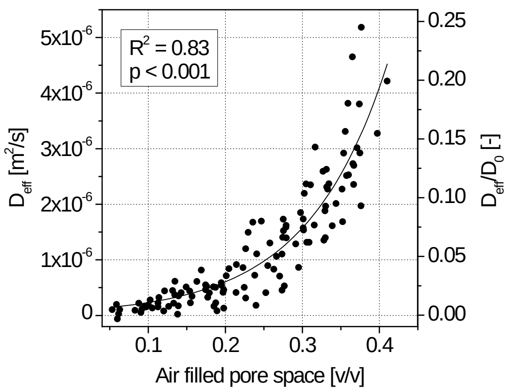


Gebert, 2013

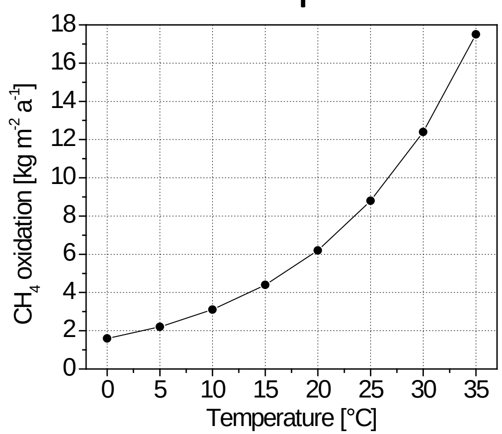
Methane Oxidation Tool (MOT)

Standard Oxidation Unit
6.2 kg m^{-2} a^{-1}

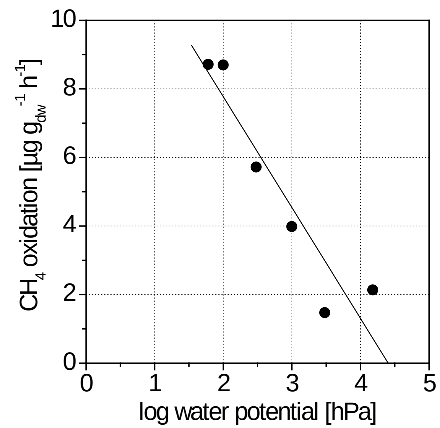
Factor Porosity



Factor Temperature



Factor Water Potential



Estimated ox potential
10.2 kg m^{-2} a^{-1}

$\frac{\text{Load (kg } a^{-1})}{\text{Oxidation (kg } m^{-2} a^{-1})}$ = area (m^2)

http://www.afvalzorg.nl/EN/About-us/Publications/Methane-oxidation.aspx.

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Designing for load

- Estimate CH_4 oxidation potential based on soil properties and climatic conditions
- Design follows limiting factor:
  high quality soil vs. availability of space
- Consider seasonal changes in CH_4 oxidation activity
- Consider required performance
- Given the soil texture, water potential, porosity and hence diffusivity can be easily predicted and modelled

Monitoring

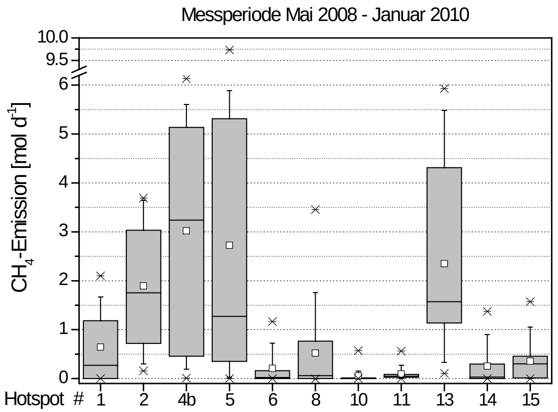
What do you want to know

- Detection of emissive spots?
- Quantification of emissive spots?
- Performance of windows or filters?
- Whole-site emissions?

} Point measurements

} Spatially integrating measurements

- Consider high spatial and temporal variability of gas fluxes and CH_4 oxidation rates
- Is it research (process information), is it long-term performance monitoring, should it prove on-site safety?
  → different techniques and timely resolution, maybe even limit values



Rachor et al., 2013

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Novel chamber for emission quantification on windows, remediated hot spots and hot areas or test cell scale

Size: 4,2 * 4,2 m, Volume: 8,8 m^3, Weight: ~17 kg

Report:
http://www.afvalzorg.nl/Afvalzorg/EN/PDF/Novel%20large%20emission%20measurement%20chamber.pdf

Added value of combined CH_4 and CO_2 measurement

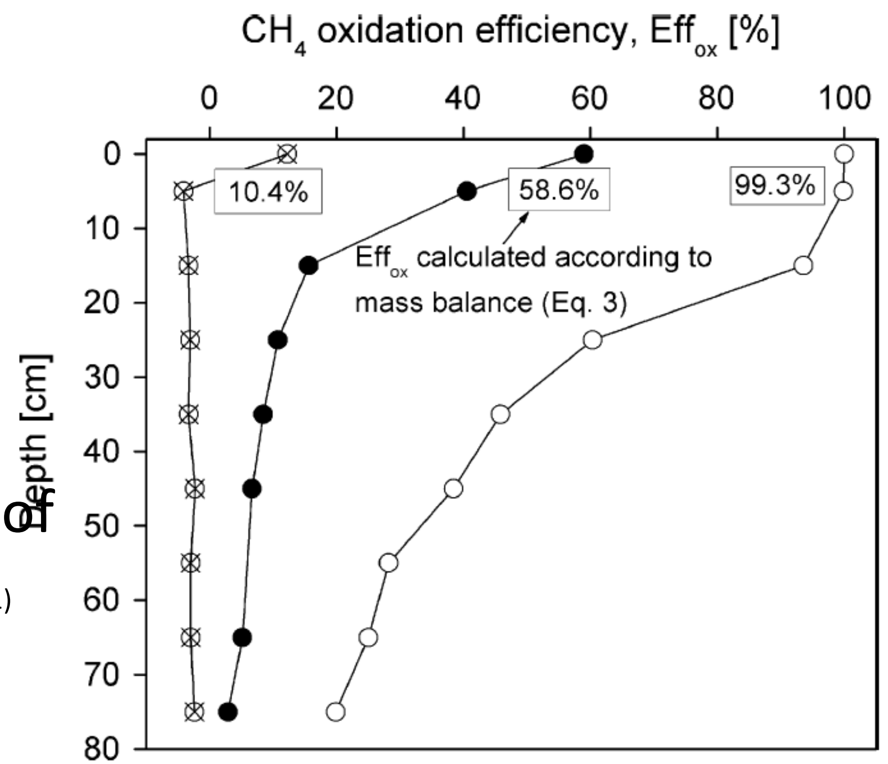
$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O$

C-balance: 1 CH_4 goes to 1 CO_2

CH_4 ↓ and CO_2 ↑

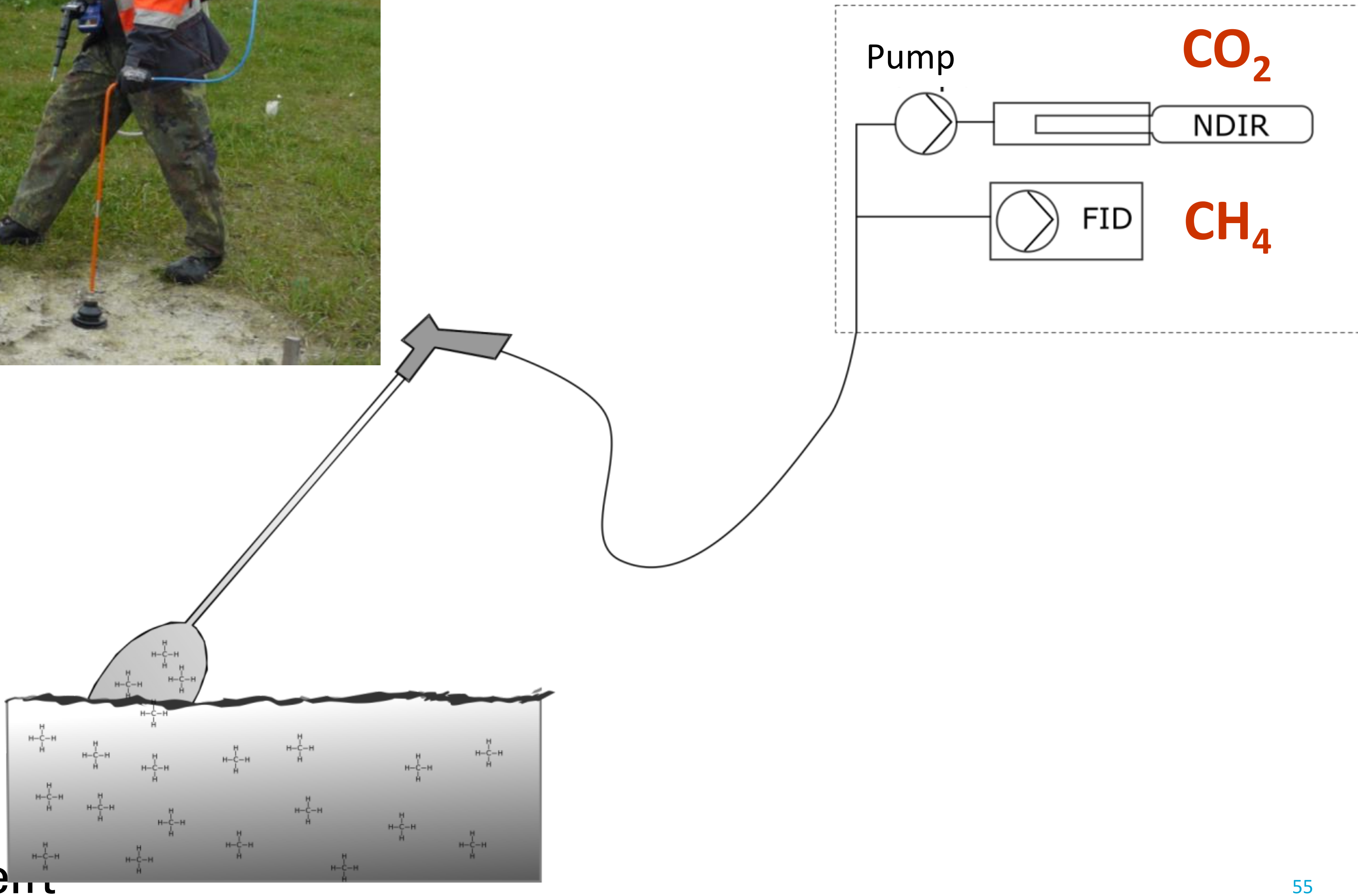
Ratio CO_2 : CH_4 ↑

Shift of ratio enables calculation of oxidation efficiency (Christophersen et al., 2001)



Gebert et al., 2011

Surface screening



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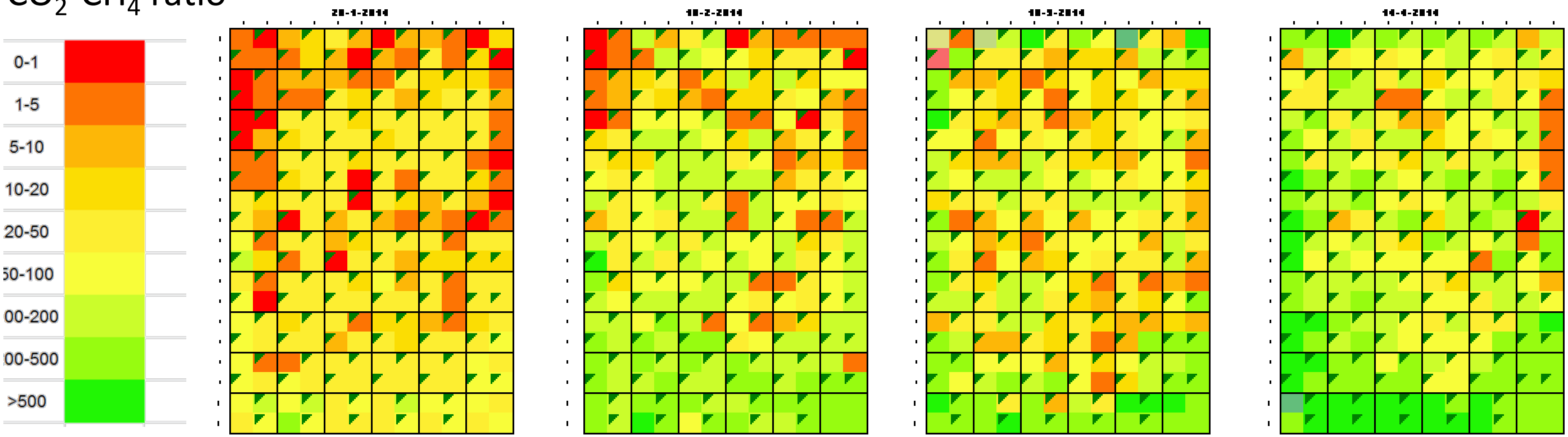
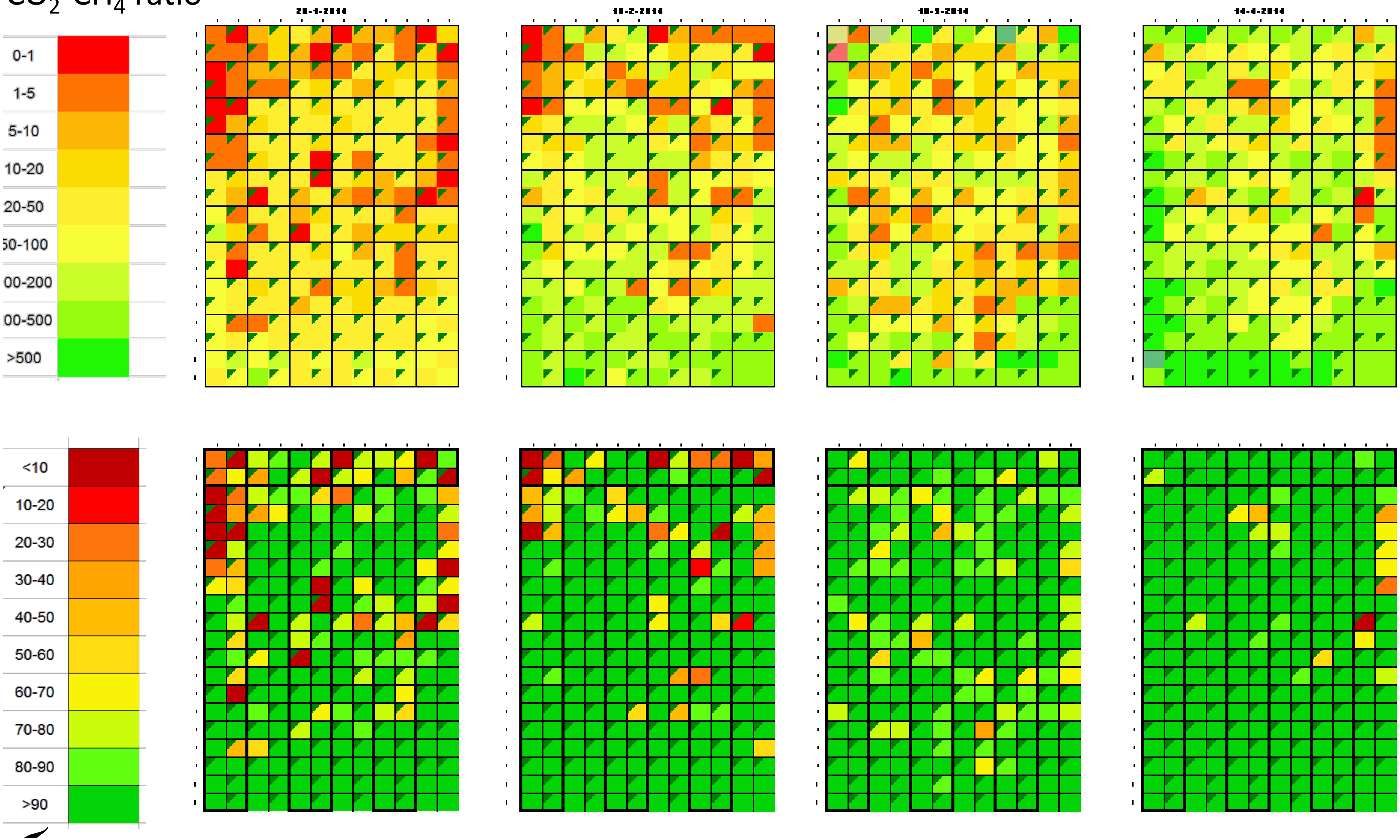
Results of combined CH_4 and CO_2 measurement

CO_2-CH_4 ratio



Results of combined CH_4 and CO_2 measurement

CO_2-CH_4 ratio



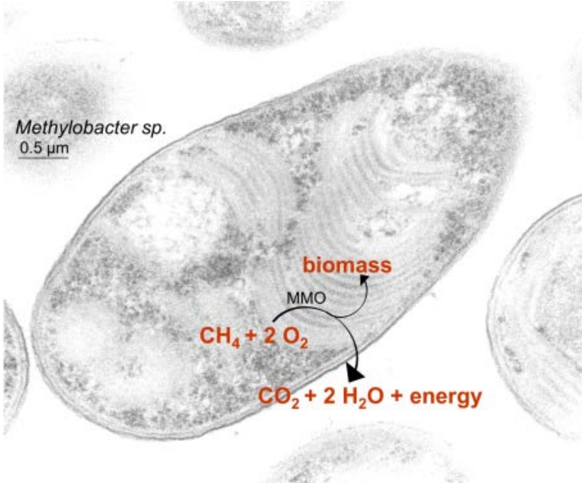
Effciency (% load)

Conclusions factors impacting the process and system performance

Potential oxidation rates of > 1.200 g CH_4 m^{-2} d^{-1} have been reported. Whether this is achieved depends on

- Seasonal changes in temperature and saturation
- Supply of oxygen
- Spatial homogeneity of gas load to system
- Increased load → increased rates (up to a limit)

- Empirical evidence abundant
- MOS can be designed



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Project partners in MiMethox

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Thank you!
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