Passive weak gas degradation in methane oxidation systems

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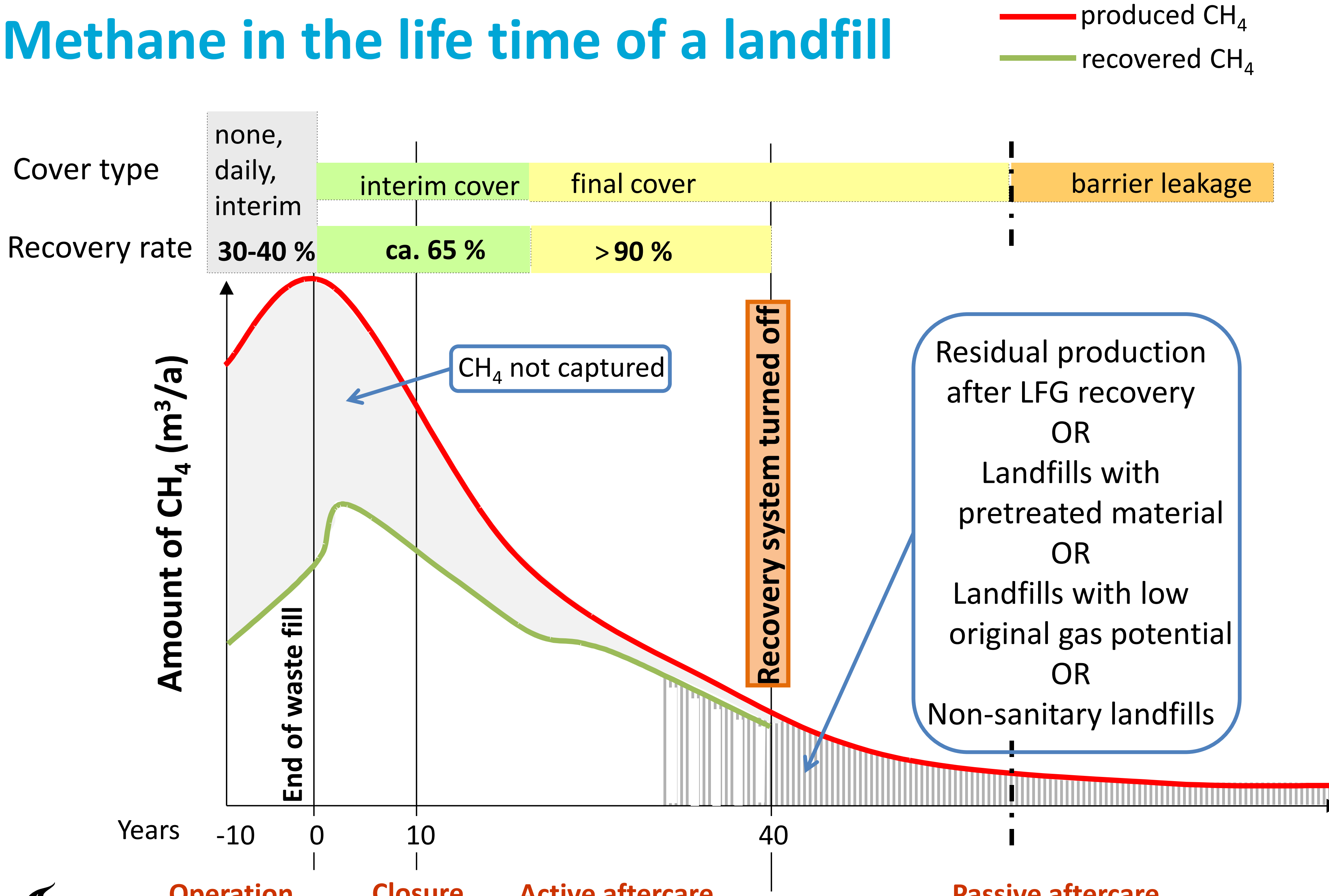
Methane in the life time of a landfill



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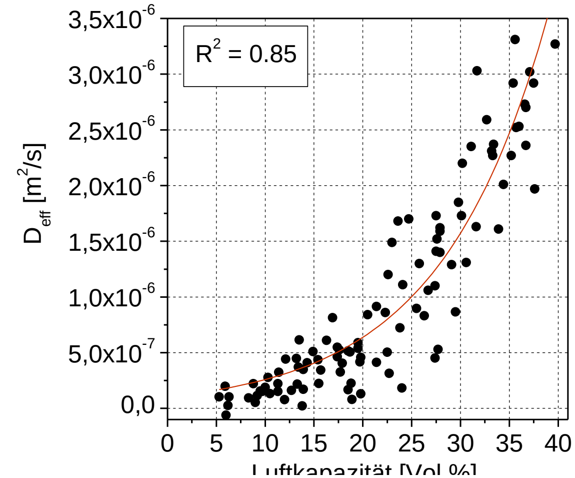
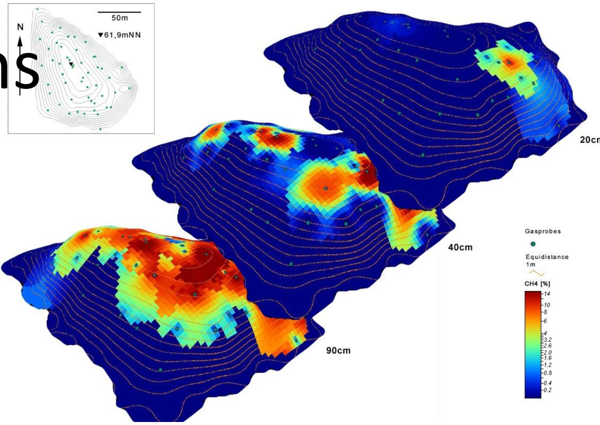
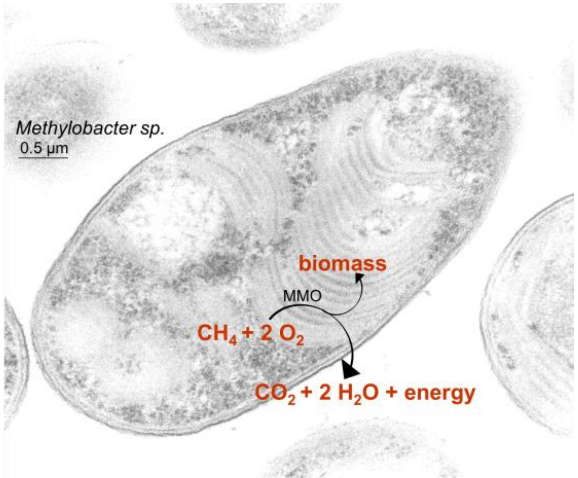
Adapted from Huber-Humer et al., 2008

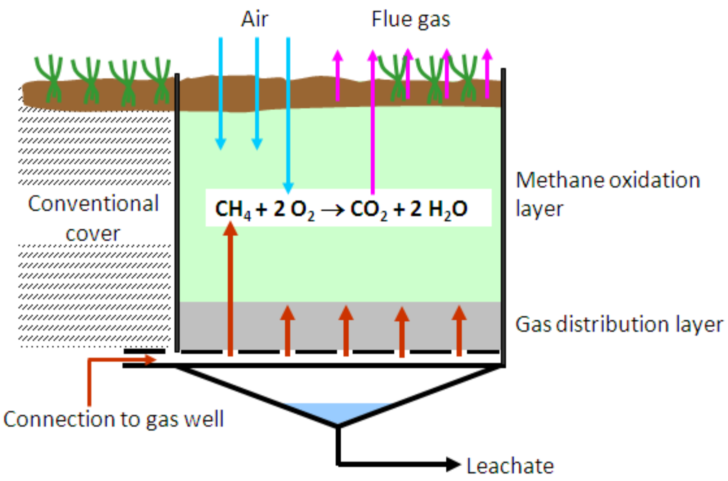
Outline

1) The methane oxidation process
2) Process controls
3) Intro to methane oxidation systems
4) Design goals & tools
5) Conclusions
6) Summary

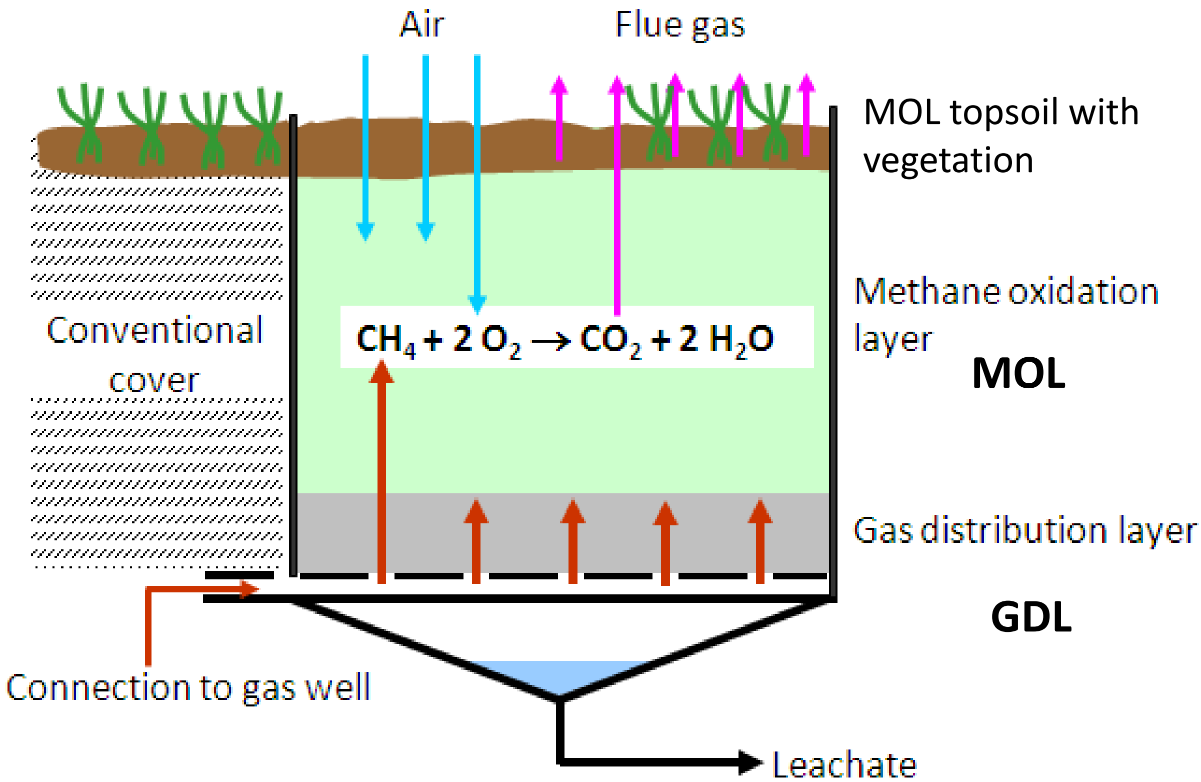


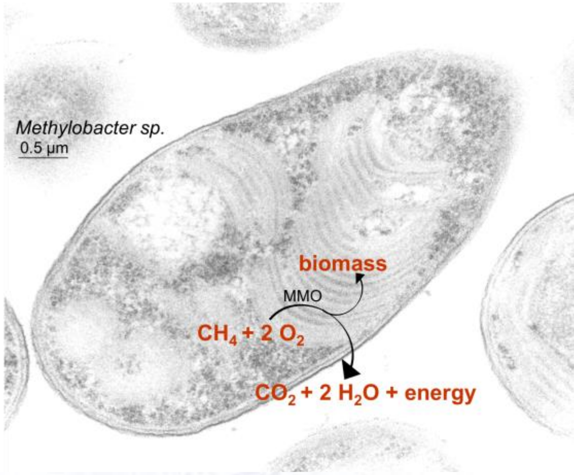






The methane oxidation process





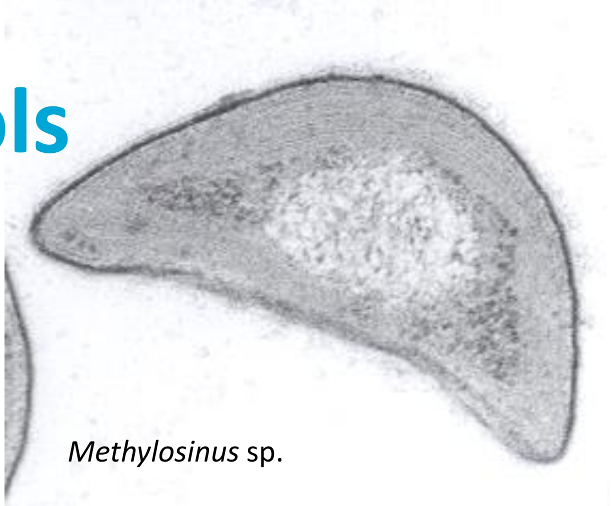
Methylosinus sp.

– Ubiquitous bacteria that accumulate under favourable conditions
– No inoculation necessary
– Requirements on environmental conditions (pH, nutrients etc.) are relatively low
– Re-activation after unfavourable conditions (e.g. desiccation, frost) is fast

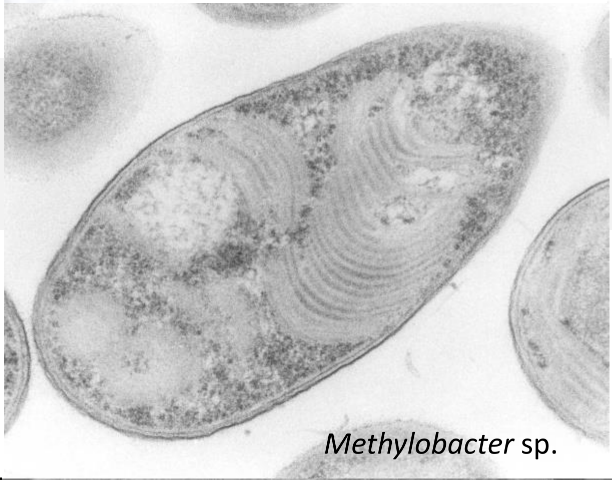
Process and performance controls

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

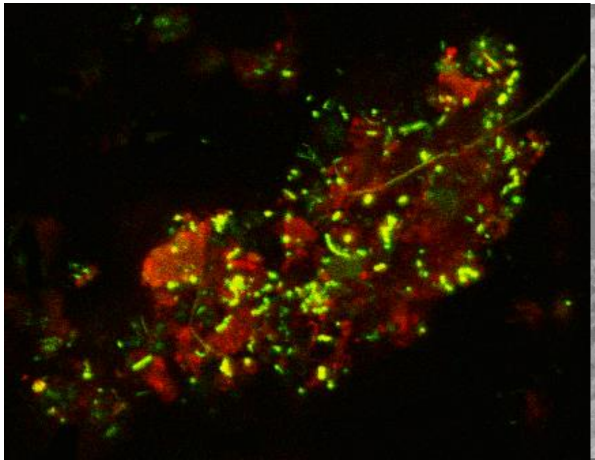
- CH_4 load
- Spatial evenness of gas load
- Supply of O_2
- Conditions for microbial activity
  - Temperature
  - Water tension
  - Nutrient status
  - pH, salinity
  - ...

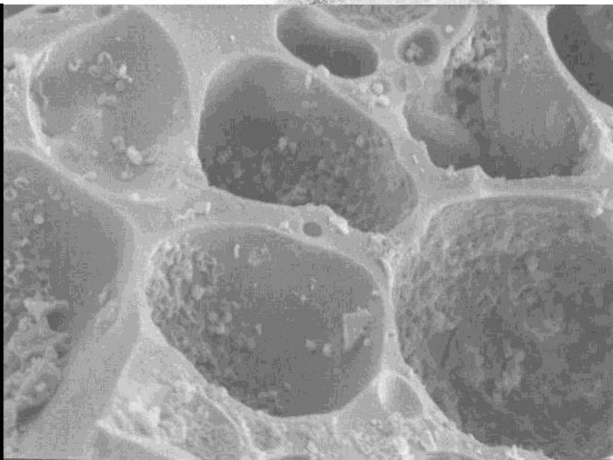


Methylosinus sp.



Methylobacter sp.





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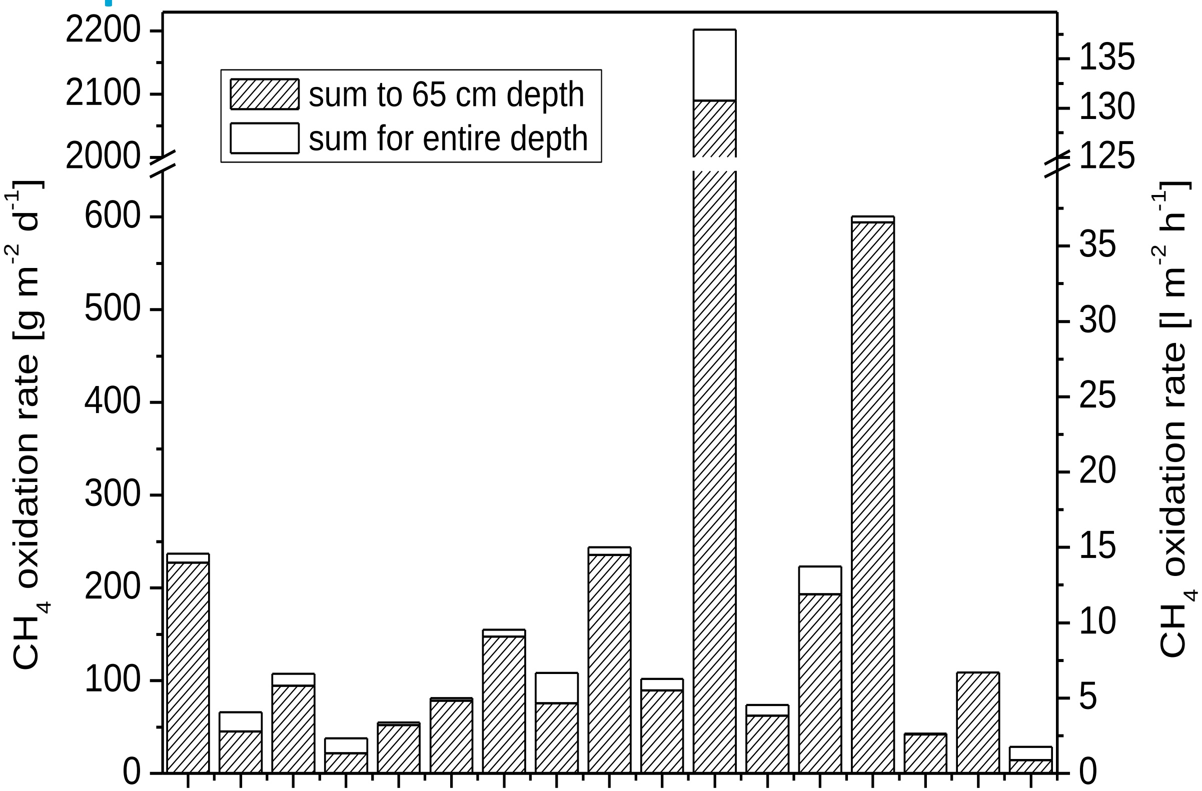
The potential:
CH_4 oxidation in landfill cover soils



Factor 10^3 higher than in natural habitats
(rice paddies, peatlands, tundra)

t et al., 2013

Methane oxidation systems (MOS)

Filter

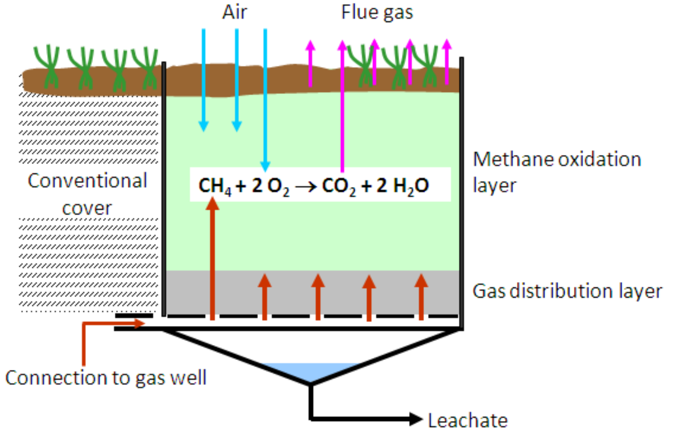
– Landfills with gas collection system

(Streese & Stegmann, 2003; Gebert & Gröngröft, 2006)

– Stable exhausts from animal husbandry (Melse & van der Werf, 2005; BiMoLa)

– Manure storage (Oonk & Koopmans, 2012)

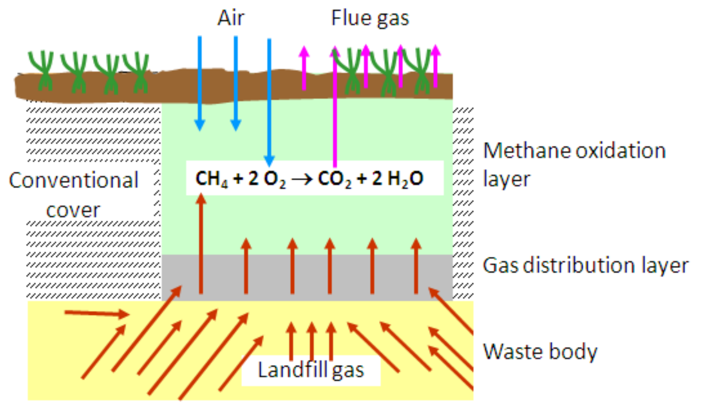
– Coal mine ventilation (Du Plessis et al., 2003)



Window

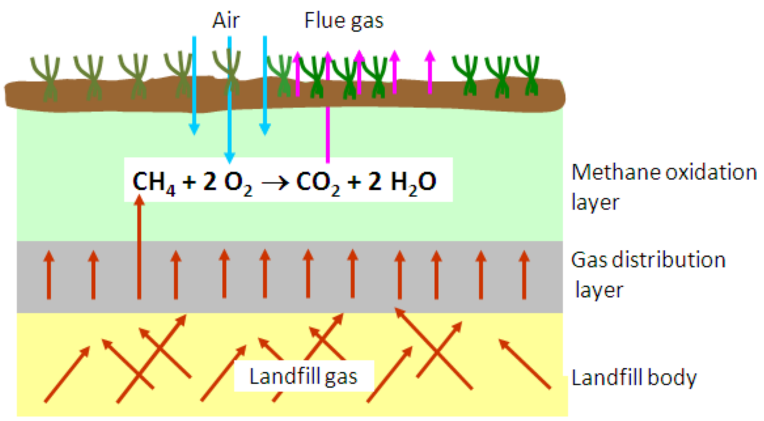
– Landfills without gas collection and surface lining (Pedersen et al., 2010)

– Remediation of emission hotspots on old non-sanitary landfills (Röwer et al., 2012)



Cover

– Landfills with or without gas collection and surface lining (Huber-Humer et al., 2008; Geck et al., 2013)



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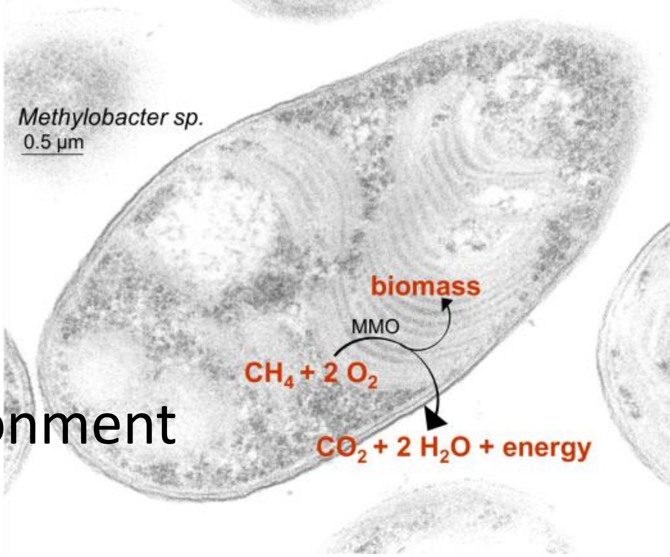
Design goals



(1) Provide suitable physicochemical environment of high structural stability
(2) Optimize oxygen flux into soil
(3) Maximize spatial evenness of gas load
(4) Robust dimensioning of the system, adapted to load

Choice also depends on

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

(1) Suitable physicochemical environment of high structural stability

Aims:

- Support biological activity of bacteria and vegetation
- Avoid loss of permeability, avoid preferential pathways

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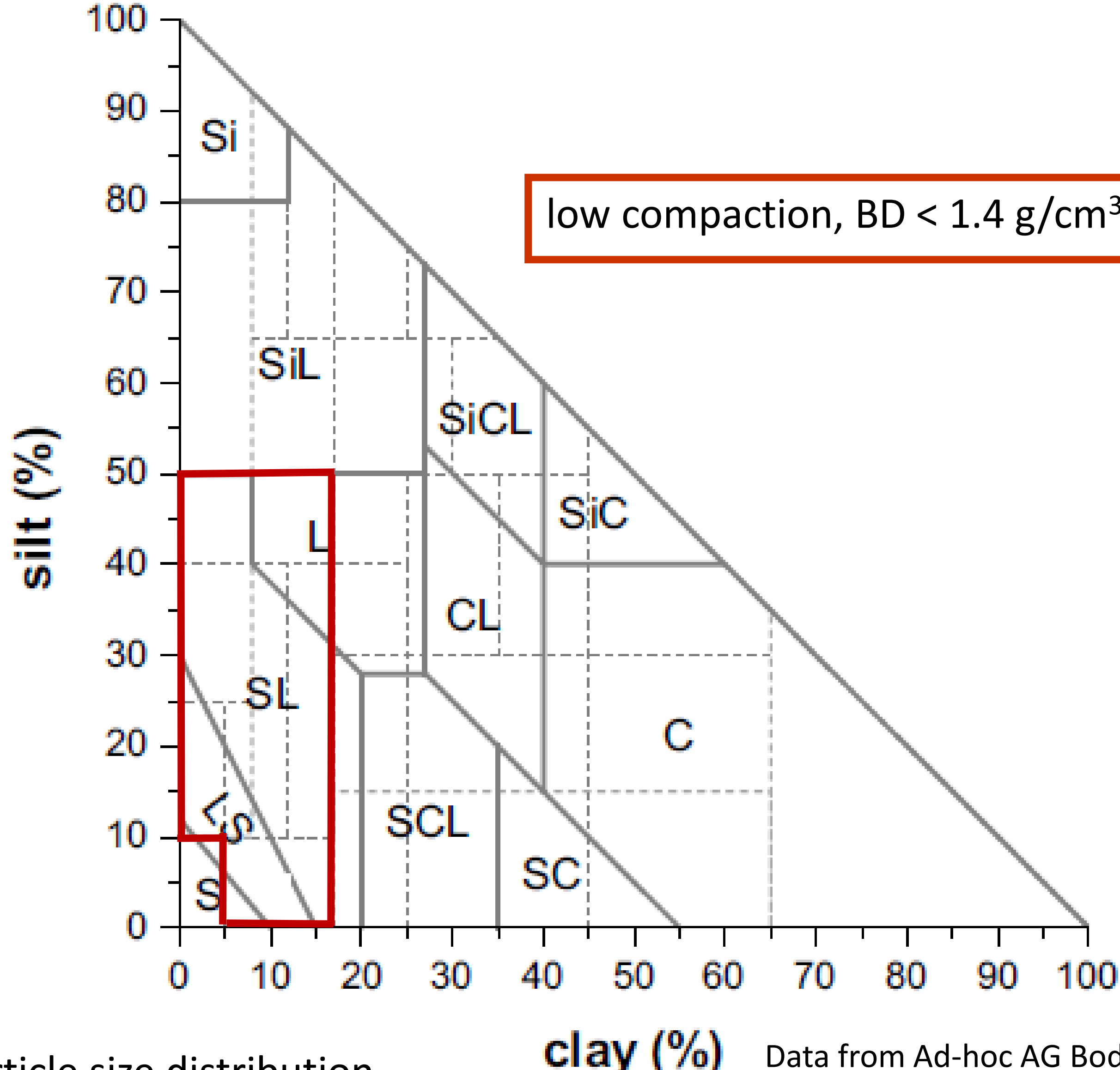
Requirements properties of MOL

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 bacteria
Min. air-filled porosity (AFP) at given water content	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	

More in Scheutz et al., 2009

Soil textures* meeting target of 14 vol.% AFP

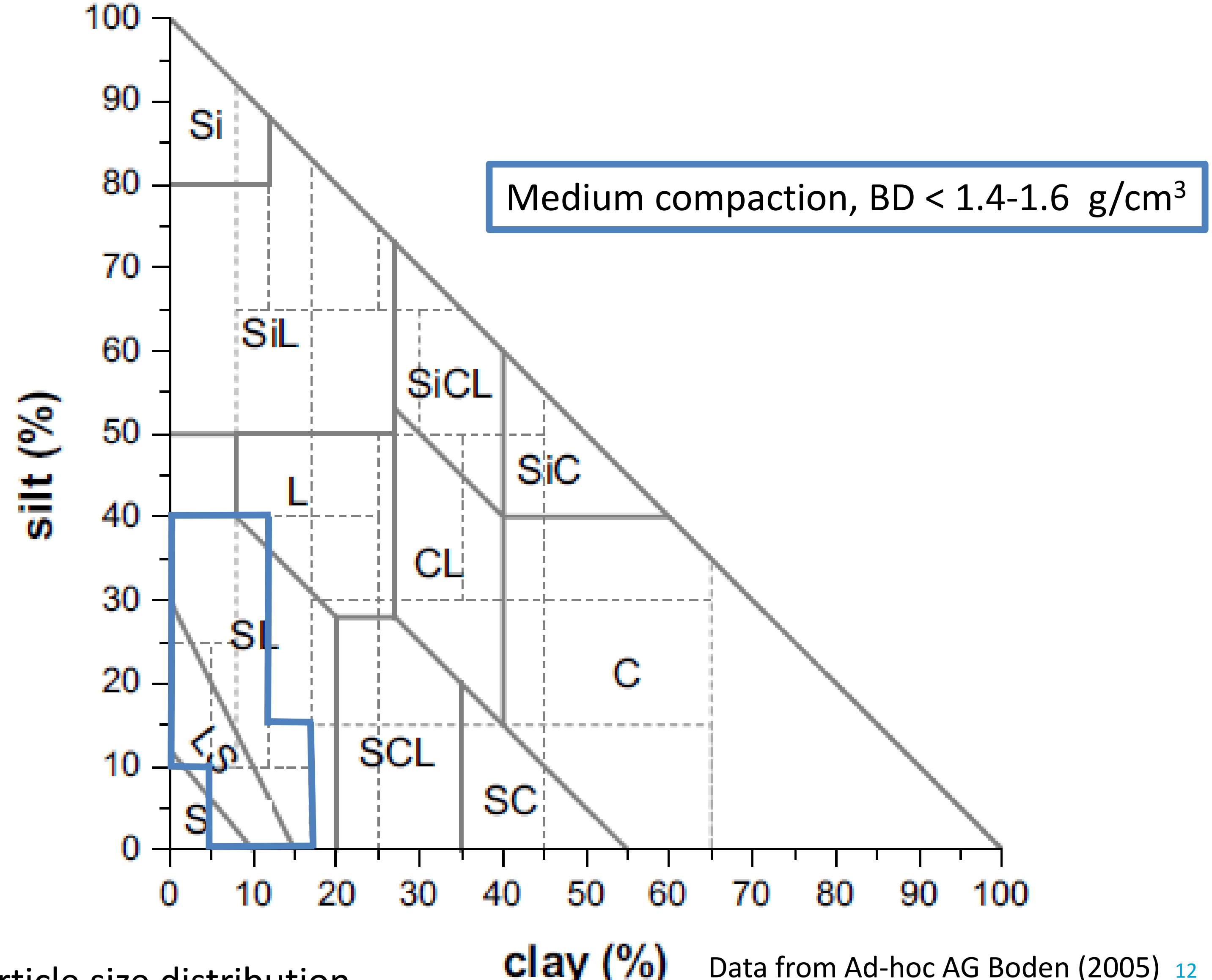


low compaction, BD < 1.4 g/cm^3

*Particle size distribution

Data from Ad-hoc AG Boden (2005)

Soil textures* meeting target of 14 vol.% AFP



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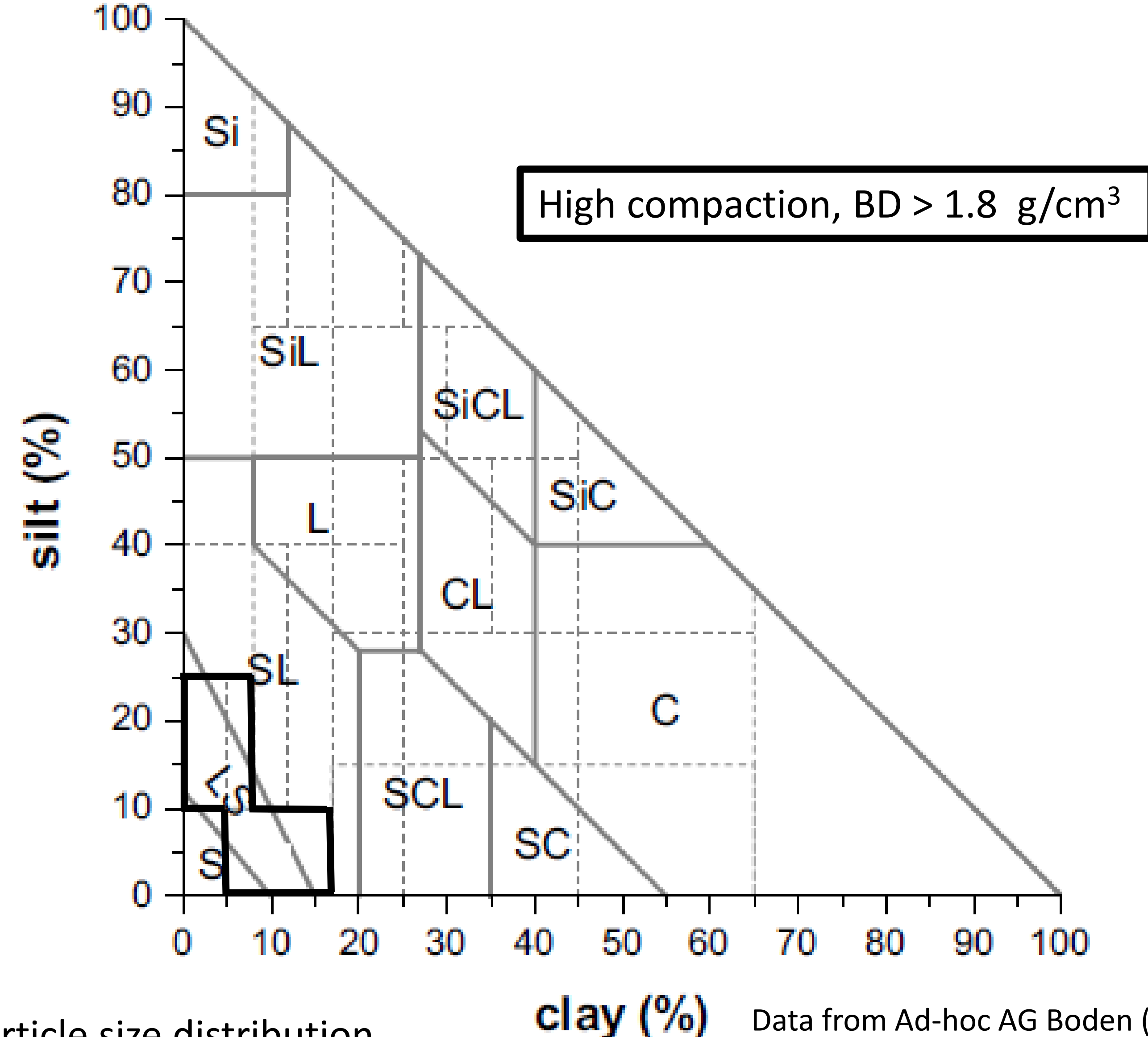

*Particle size distribution

Data from Ad-hoc AG Boden (2005)

(2) Optimize oxygen flux into soil

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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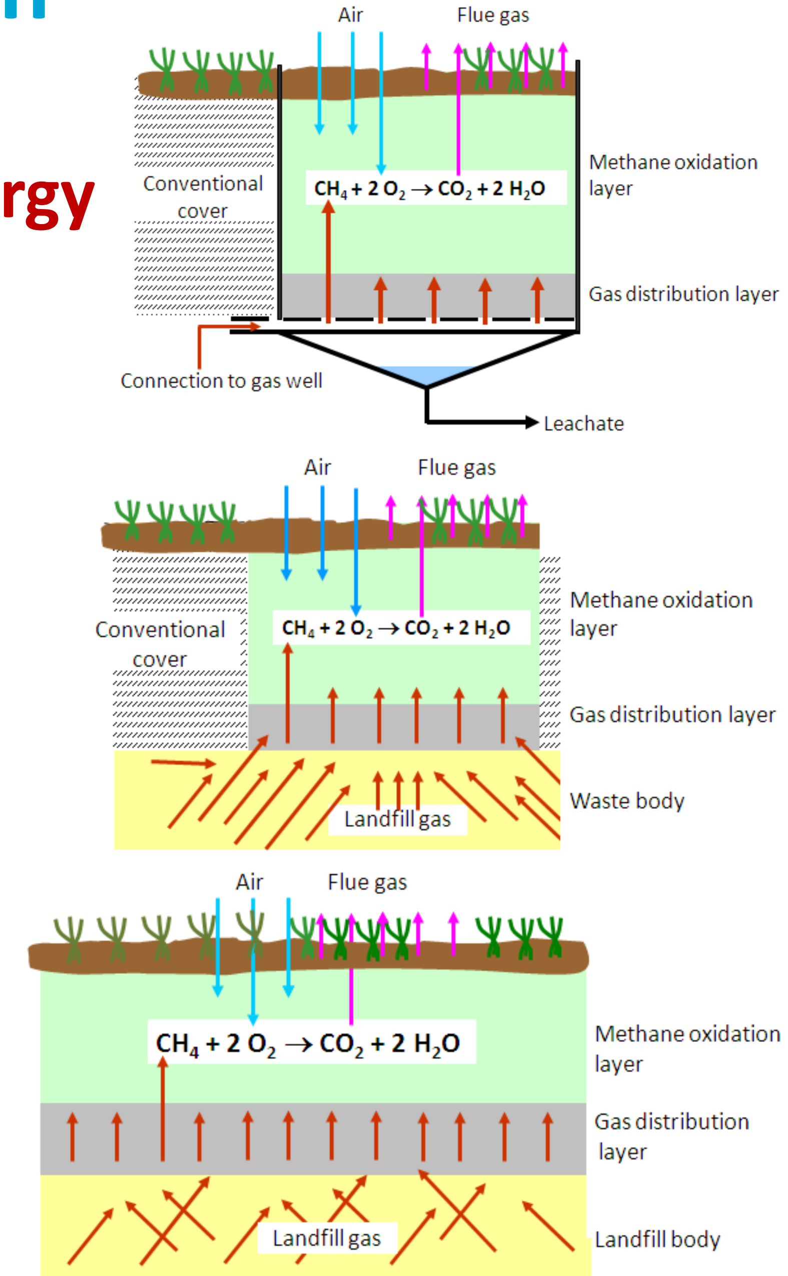
Optimize ingress of oxygen

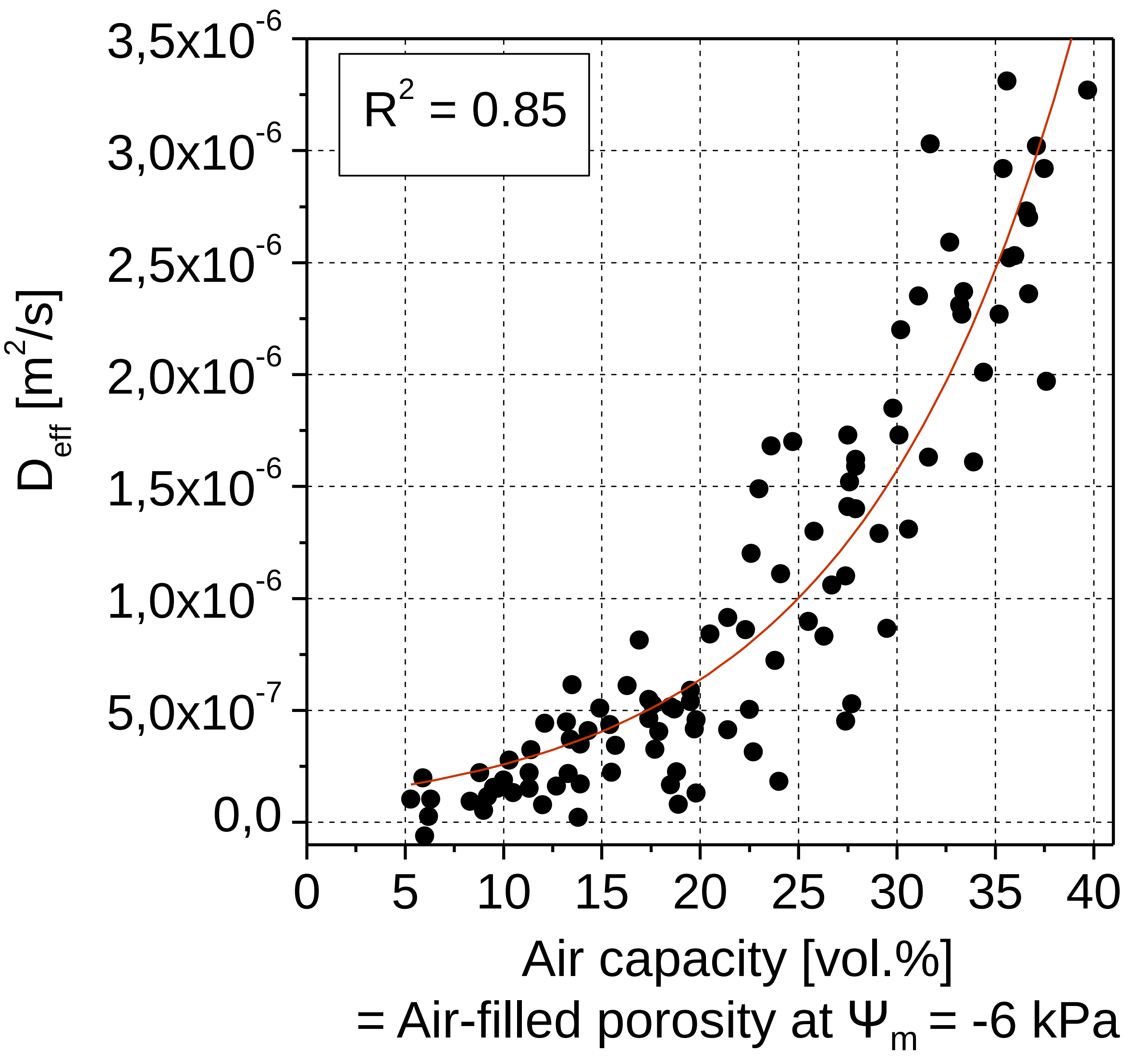
$$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O + \text{energy}$$

- **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



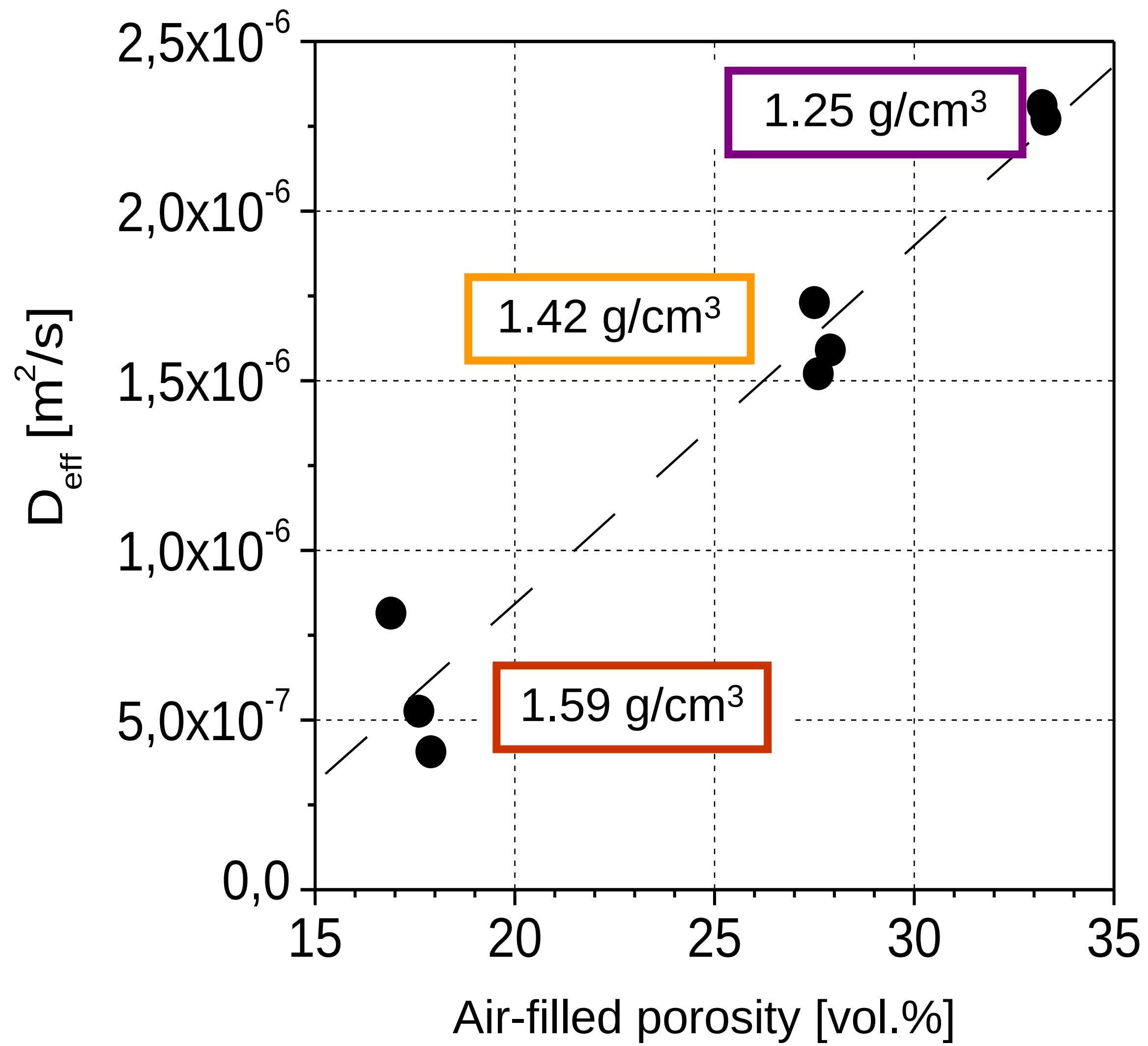
Diffusivity depends on air-filled porosity



Choice of texture (particle size distribution)

From Gebert et al., 2011

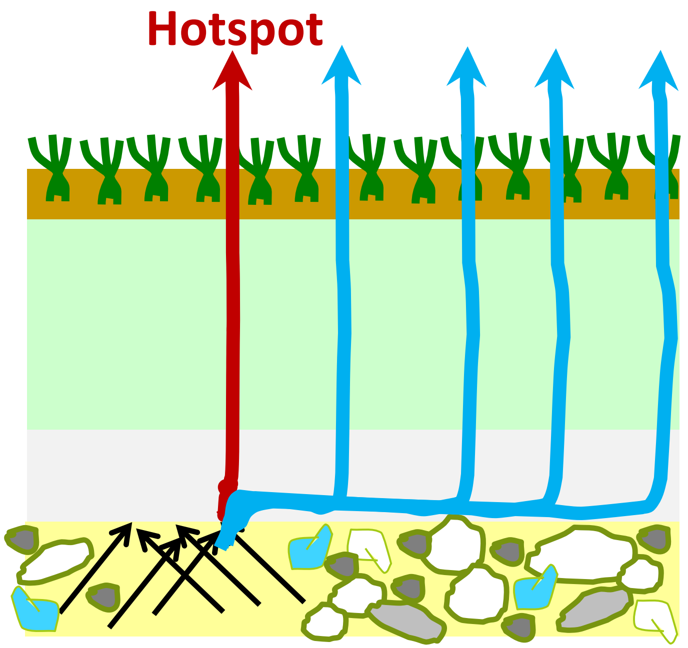
Compaction decreases diffusivity



Choice of construction practice

After Gebert et al., 2011

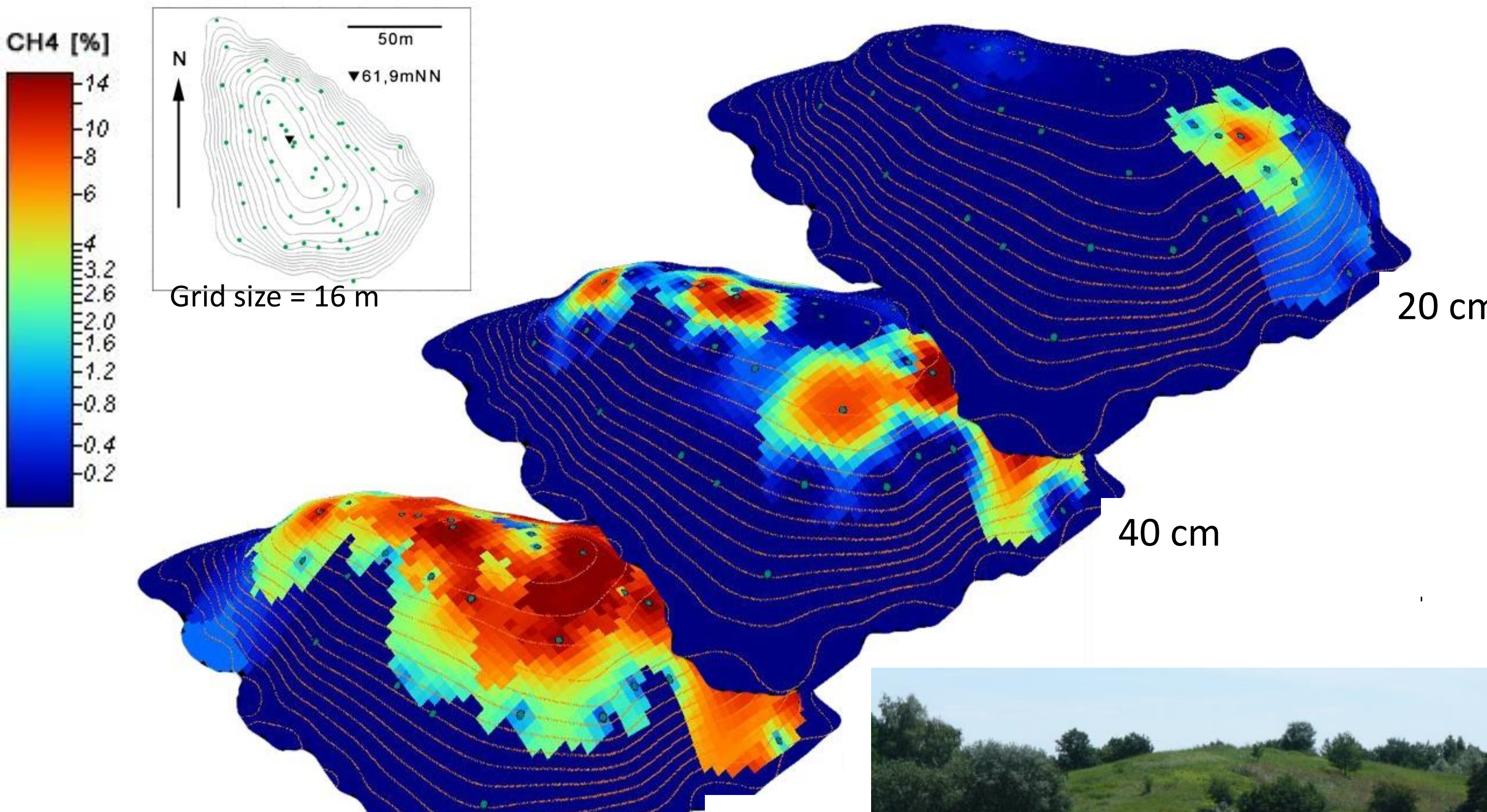
(3) Maximize spatial evenness of gas load



Aims:

– Avoid overloading of individual compartments
– Use full system potential
– Avoid channelled preferential transport (hotspots)

Spatial variability of methane concentration in a cover soil of an old landfill



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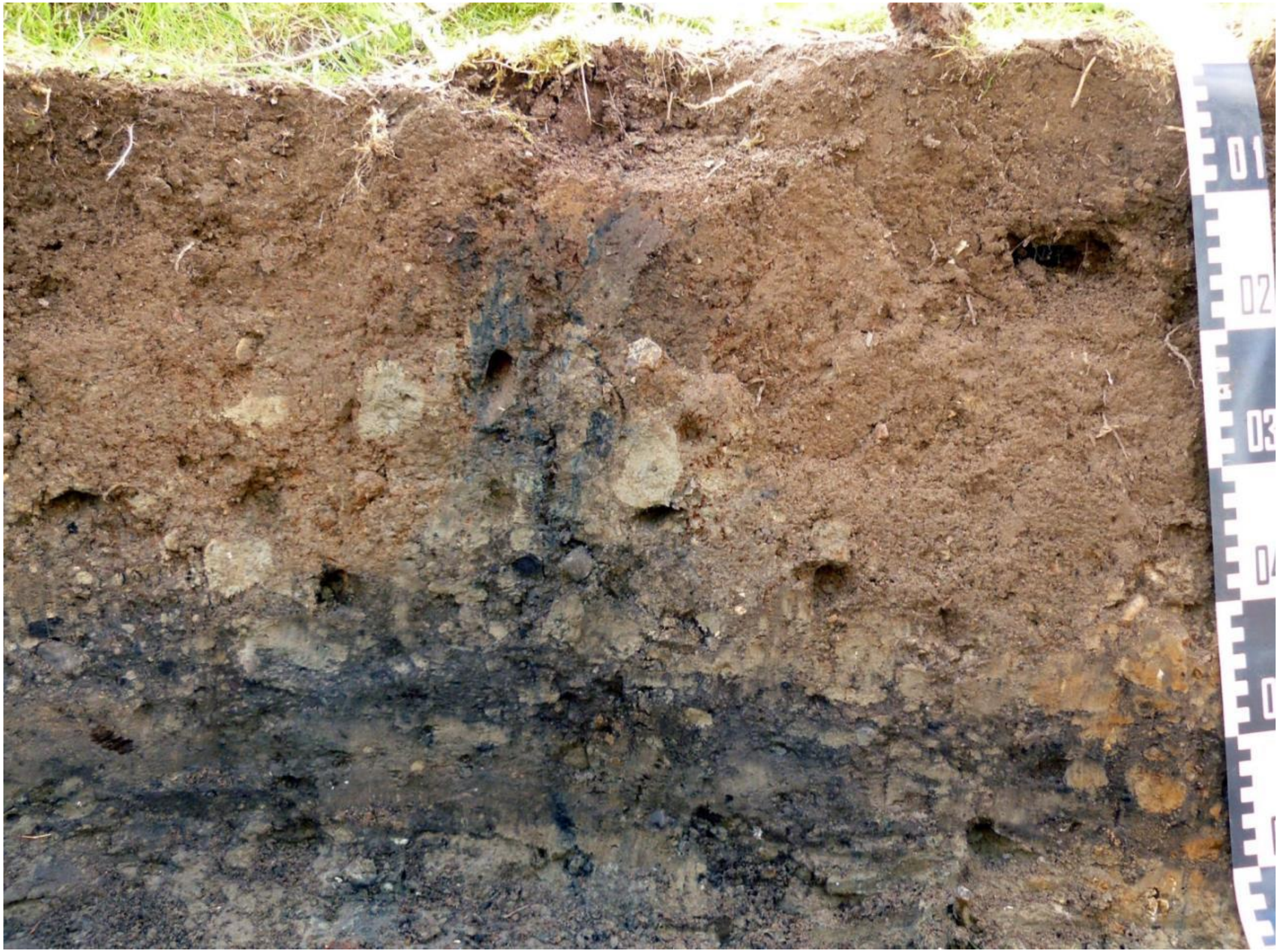
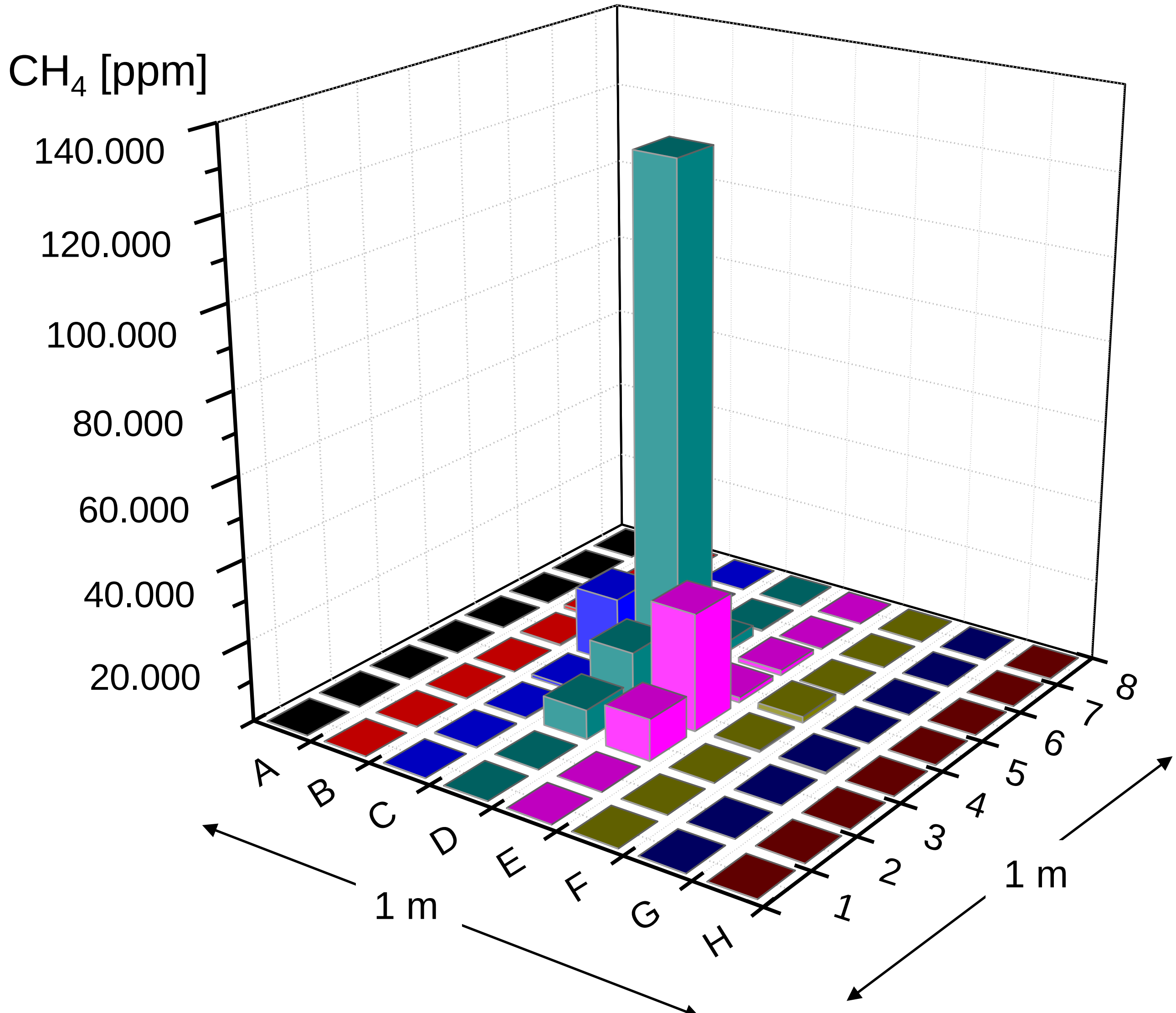
Morphology of hotspot soil profile



Surface CH_4 concentrations at hotspot



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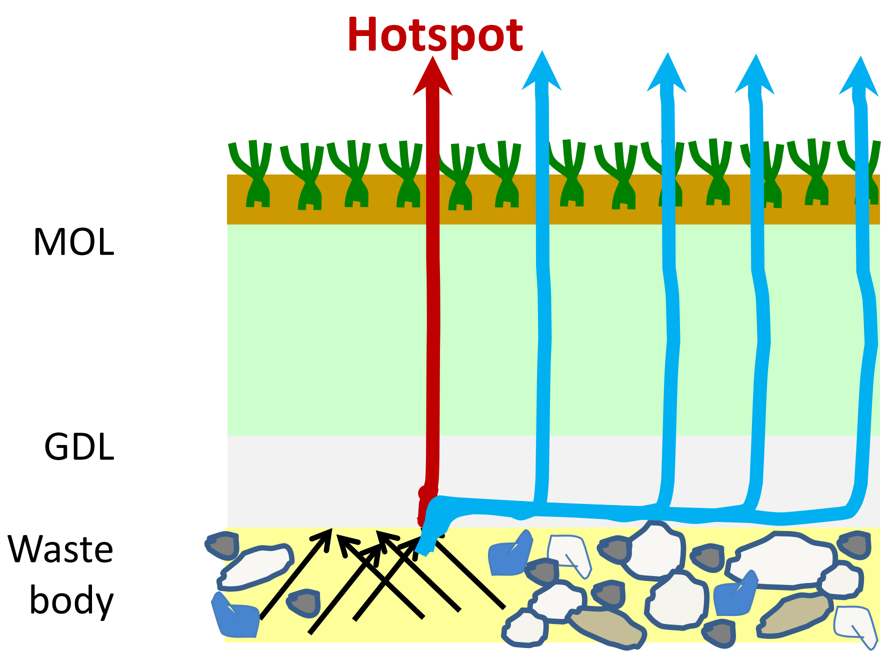
Requirements gas distribution layer

1. < 2% $CaCO_3$ → Avoid precipitation of CO_2
2. Purely mineral → High structural stability
3. High gas conductivity (k_{gas}) → $k_{Gas\_GDL} >> k_{Gas\_MOL}$, so that



Pressure loss is +/- homogenous over all path lengths

→ horizontal gas transport favoured in GDL

Typical materials: coarse sand, gravel

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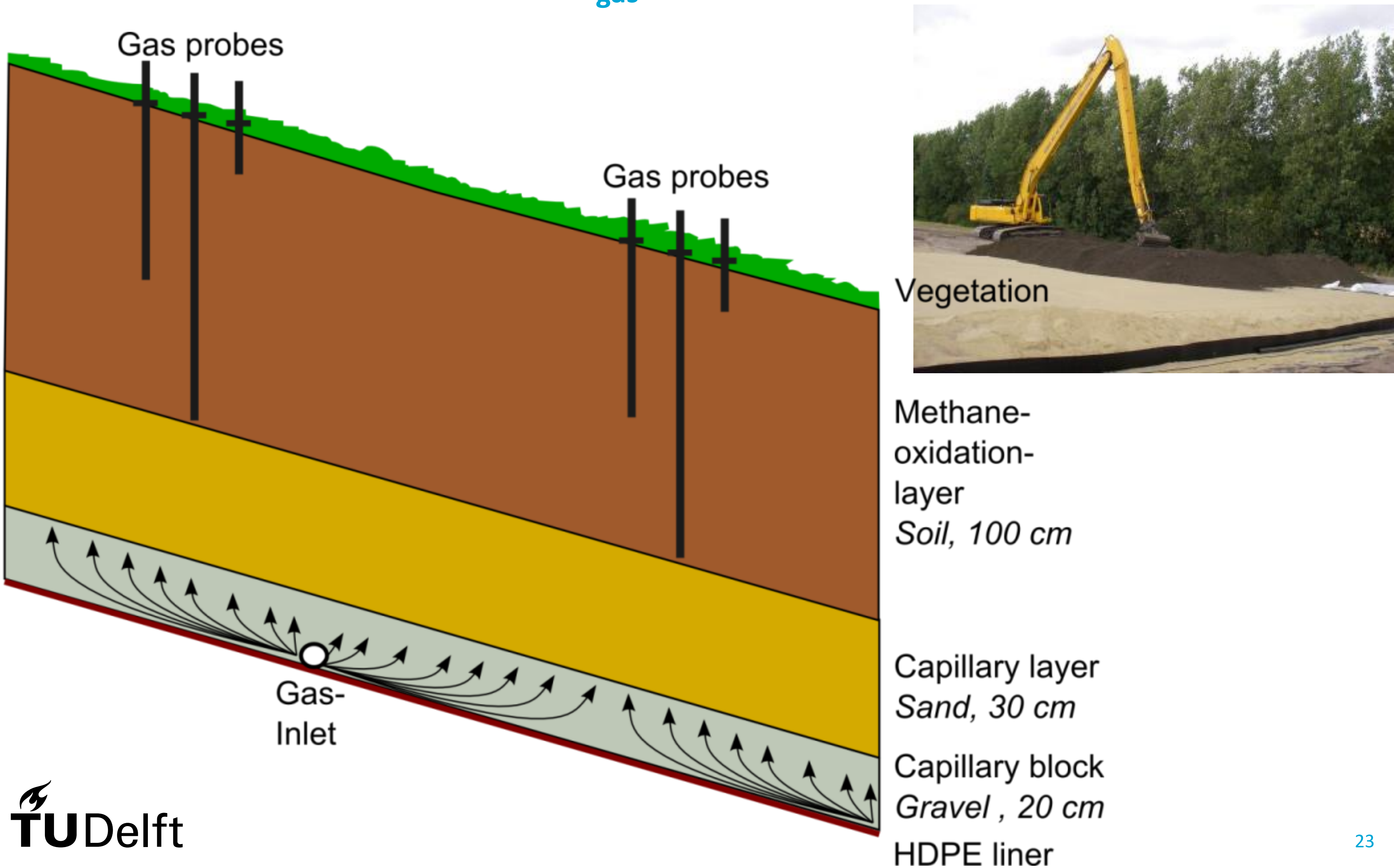
Example: Effect of decreasing k_{gas} in the MOL

= increasing difference in k_{gas} between MOL and GDL



Example: Effect of decreasing k_{gas} in the MOL
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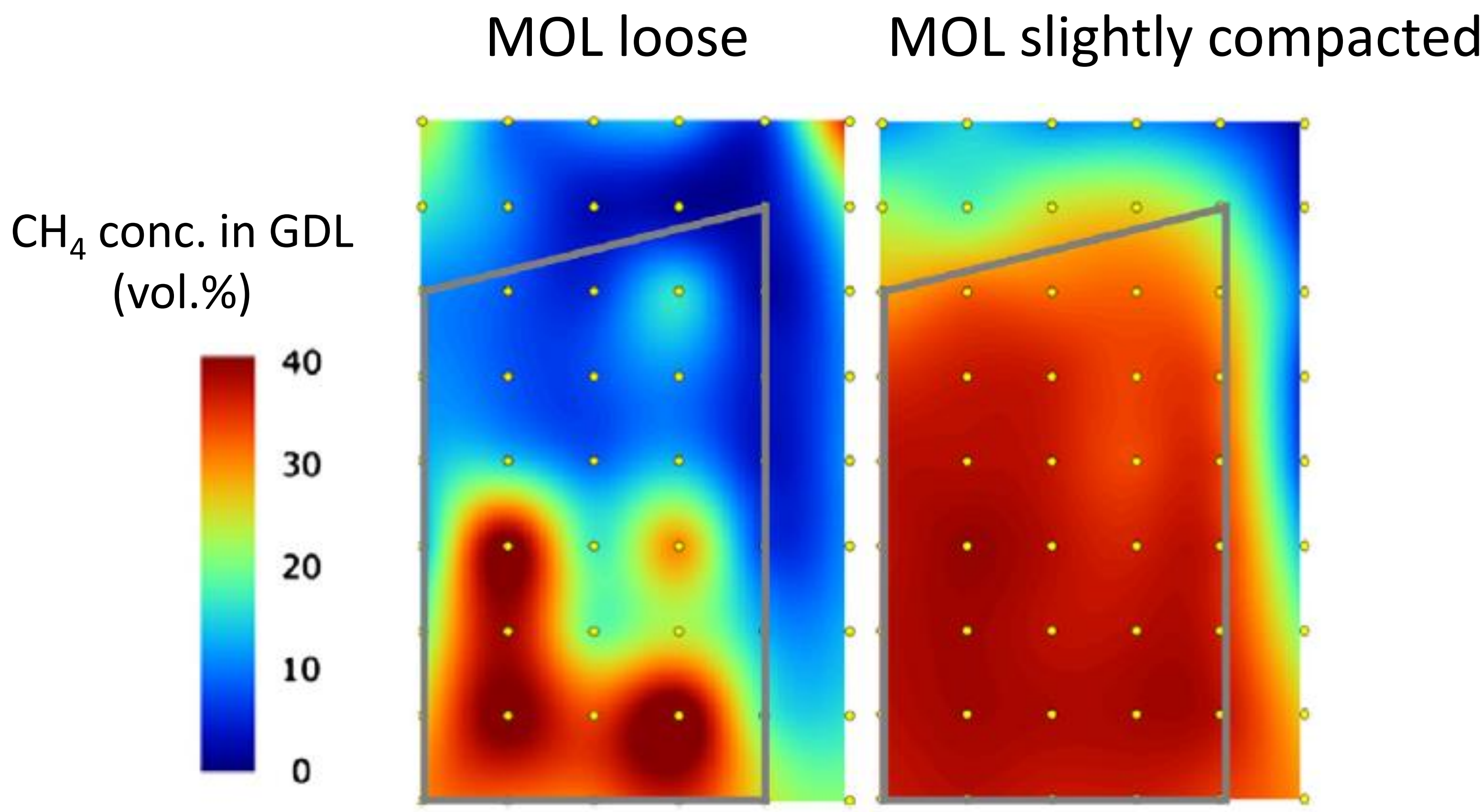
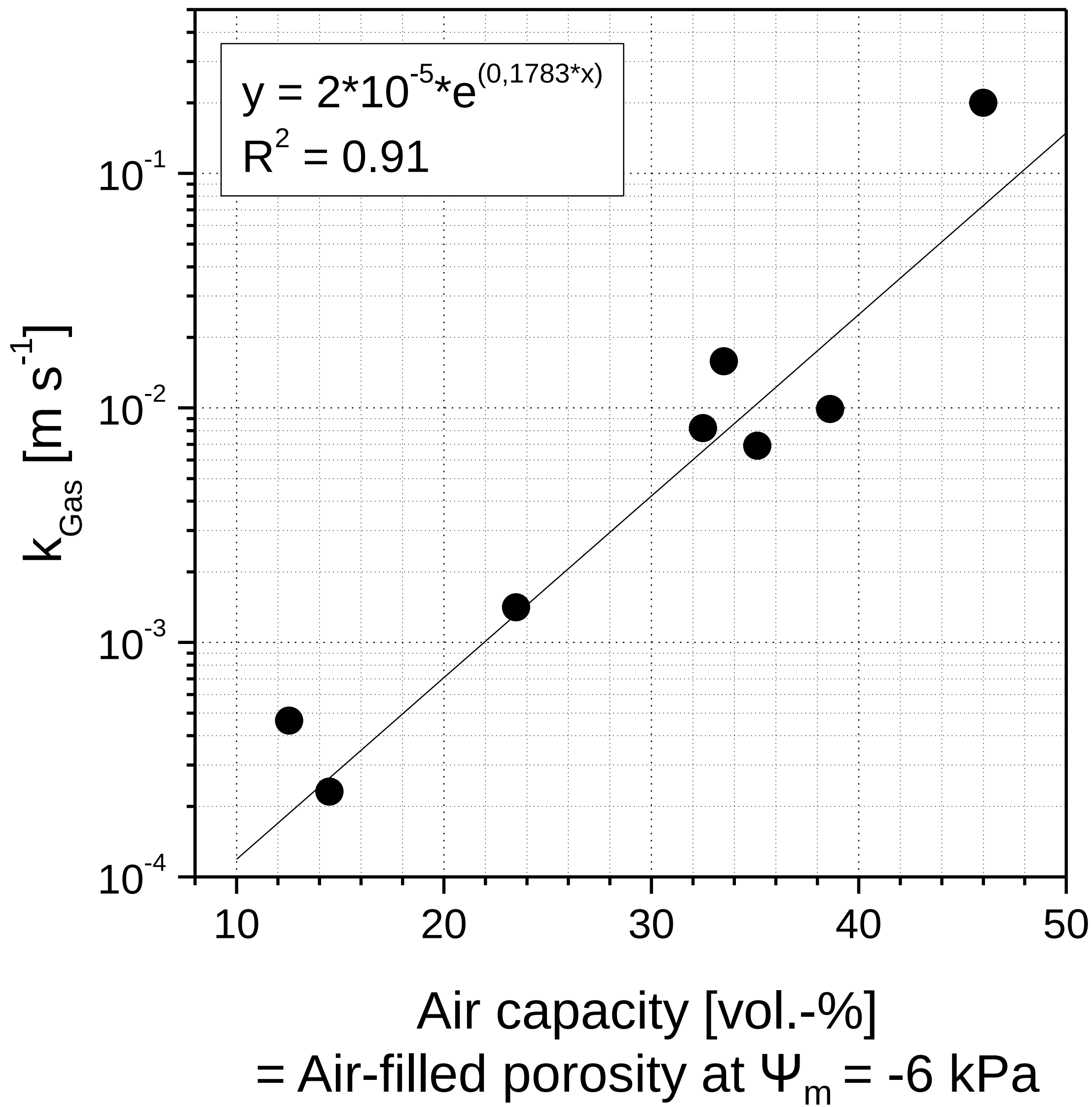


Conductivity (advection) depends on air-filled porosity



Choice of texture (particle size distribution)

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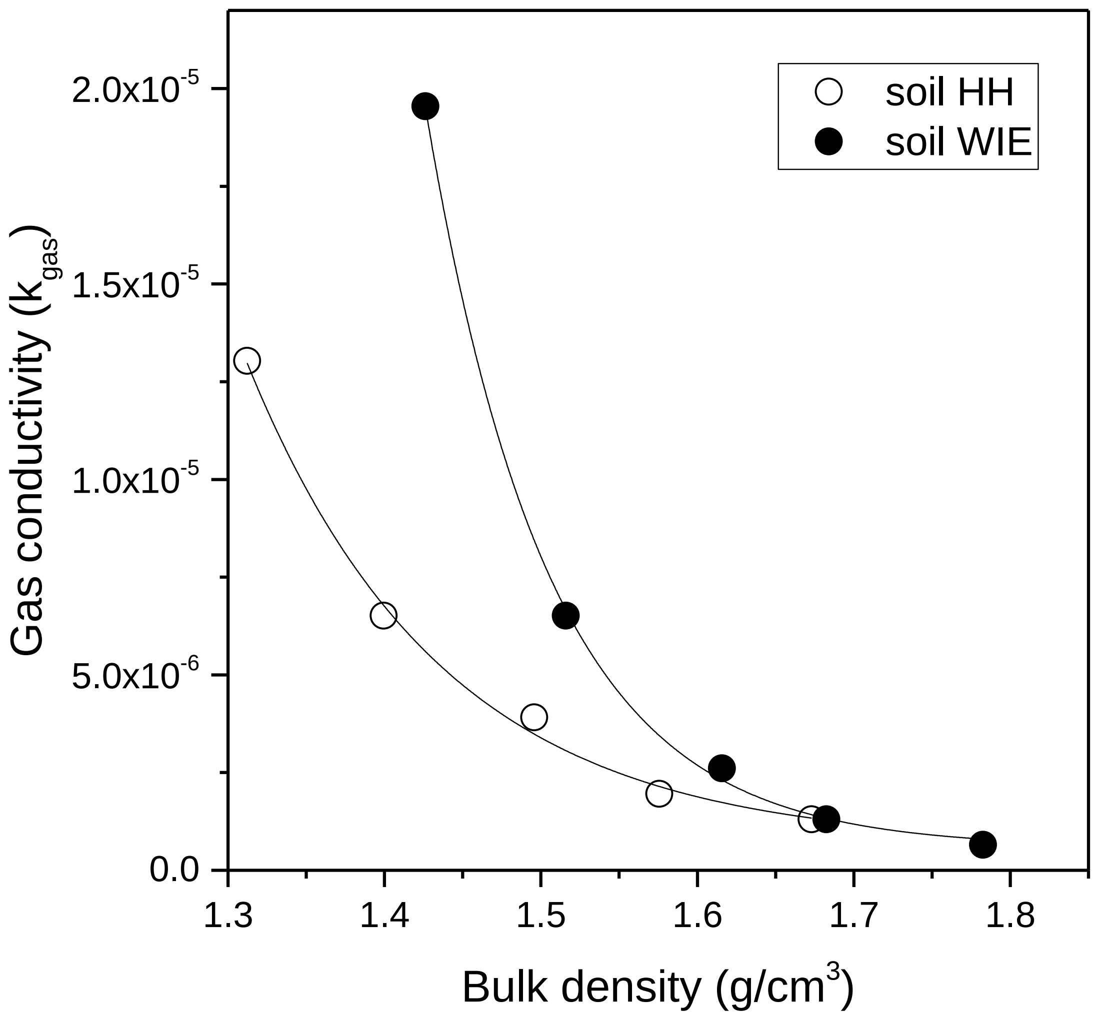
Compaction decreases gas conductivity (MOL)



Choice of construction practice

Data from Van Verseveld, 2018

(4) Dimension adapted to load, Methane Oxidation Tool

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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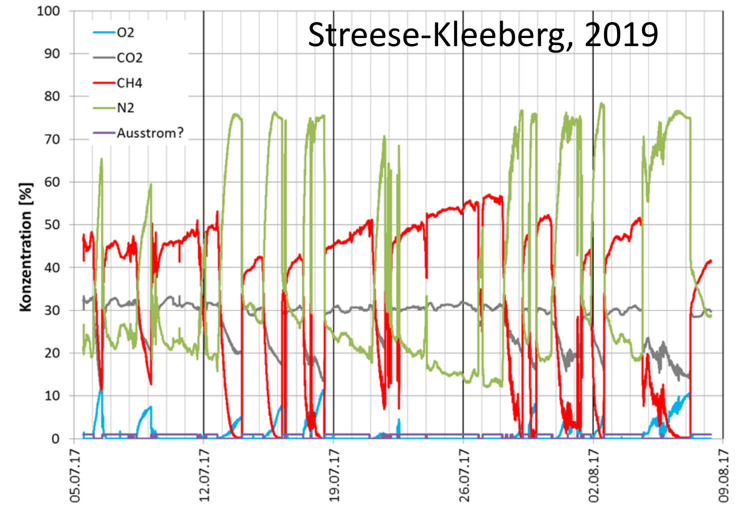
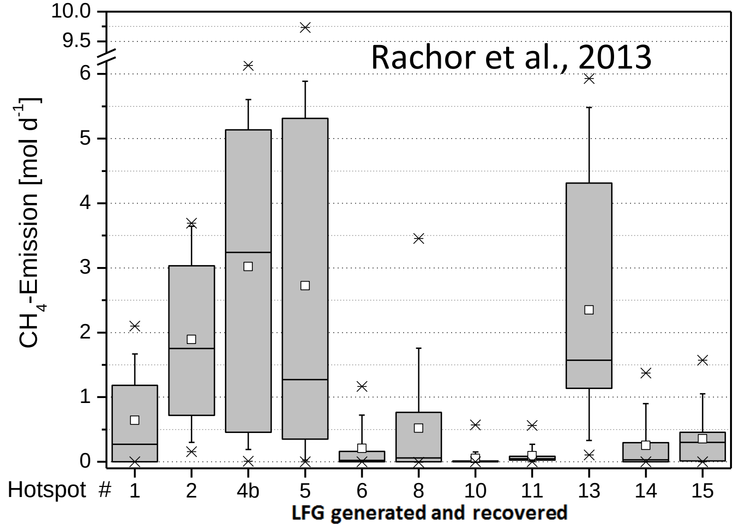
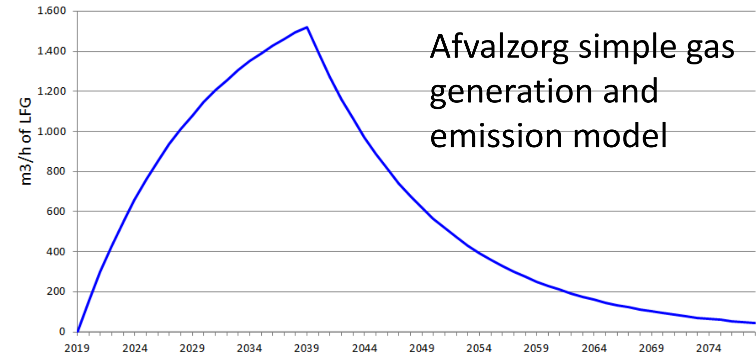
How to determine the methane load to the system

- CH_4 oxidation **filter**: Measurement of flow & concentration at gas well
- CH_4 oxidation **window**: Measurement of emissions at prospective site of window
- CH_4 oxidation **cover**: gas production modeling in combination with gas extraction tests







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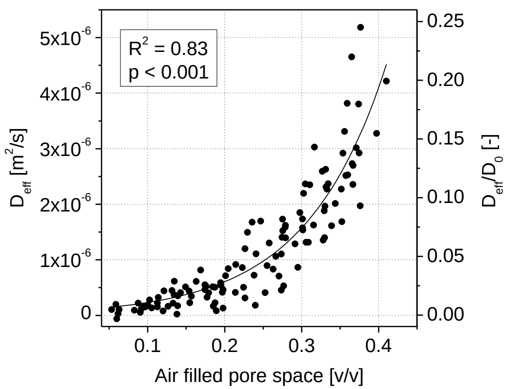
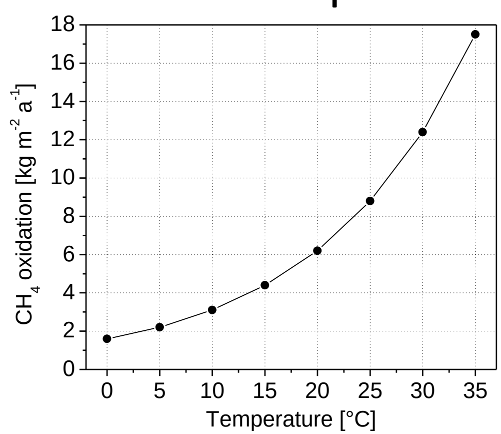
How do determine the methane oxidation potential: Methane Oxidation Tool (MOT)

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

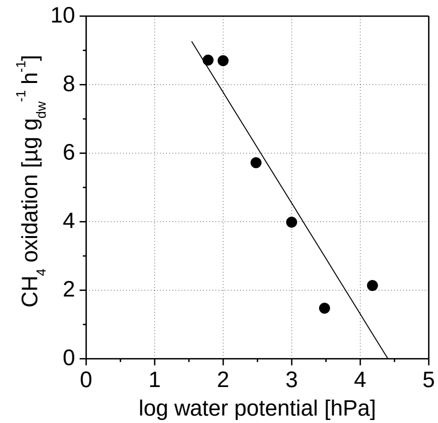
Factor Porosity



Factor Temperature



Factor Water Tension



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

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

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

Conclusions I: Choice of MOL material

- Requirements of methanotrophs met by wide range of materials
- What is good for the vegetation, is good for methanotrophs (nutrients, water)!
- Organic materials have to be stable
  → minimize competition for O_2
  → minimize settlement and loss of permeability
- IMPORTANT: Choice of suitable soils and adequate construction practice = gas transport properties in relation to particle size distribution and compaction
- Enough is known for a good estimate!

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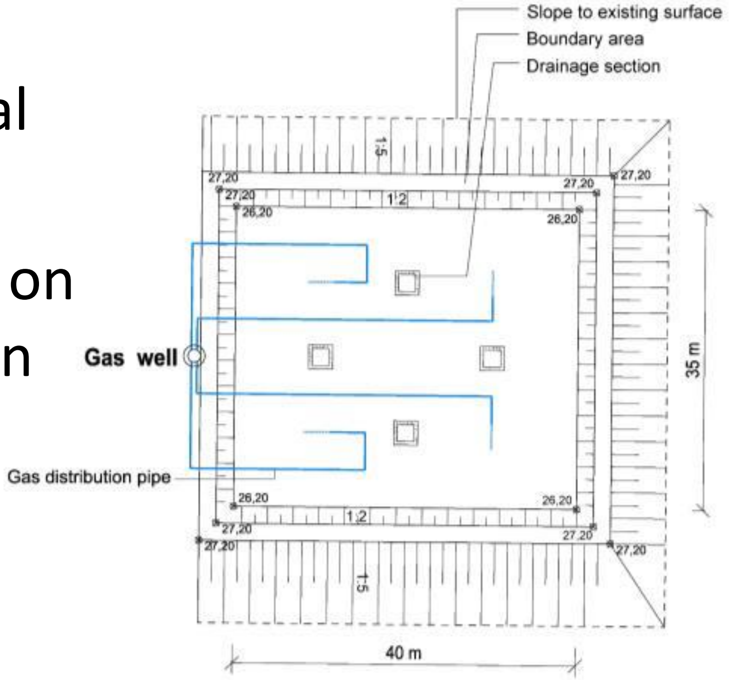
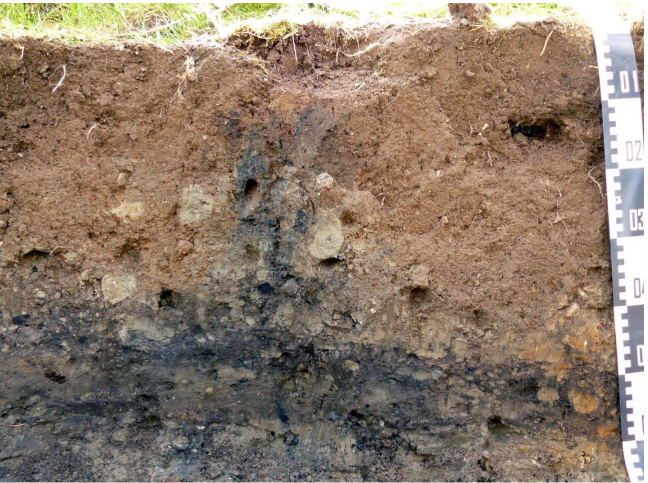
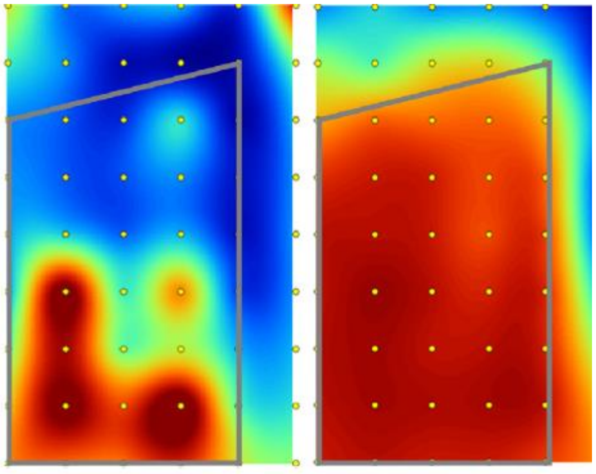
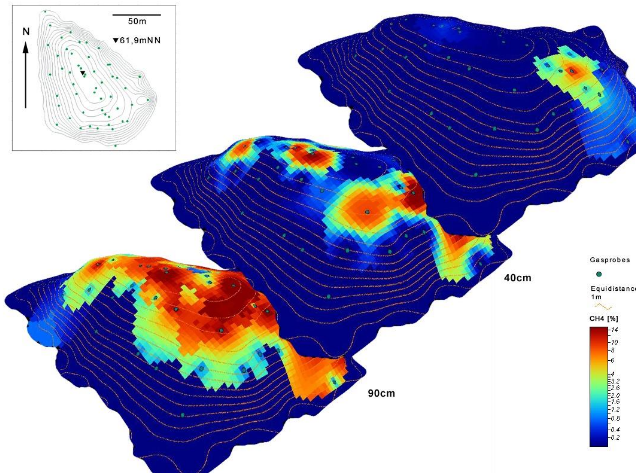
Conclusions II: Spatial distribution

- Gas distribution layers are an essential element of MOS
- Spatial evenness of gas load depends on difference in gas conductivity between GDL and MOL
  - Pressure loss over all path lengths
  - Number of gas inlet points









Conclusions III: Dimensioning

- Estimate or measure load
- Estimate CH_4 oxidation potential based on soil properties and climatic conditions (example MOT)
- Design follows limiting factor:
  high quality soil or availability of space?
- Consider seasonal changes in CH_4 oxidation activity
- Consider required performance and after use

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Summary

- CH_4 oxidation is a robust technology to mitigate “weak gas” emissions
- Process controls are well known
- Design parameters are available
- Large scale systems have been successfully constructed

Questions?

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TU Delft

MiMethox

Mikrobielle Methanoxidation in Deponie-Abdeckschichten

Ziel des Projekts MiMethox war die Entwicklung eines hinsichtlich der Methanoxidation optimierten Aufbaus von Deponieabdeckschichten sowie einer Methodensammlung zur Quantifizierung der Methanoxidationsleistung derartiger Systeme. Hierfür wurden durch die Projektpartner Universität Hamburg, Technische Universität Hamburg-Harburg, Technische Universität Darmstadt und melchior + wittpohl Ingenieurgesellschaft umfangreiche Feld- und Laborstudien zur Methanbildung, Methanoxidation und Methanemission und den sie steuernden Faktoren durchgeführt, die den Kenntnisstand zur biologischen Behandlung von Deponiegas stark erweitert haben.

Die mikrobielle Oxidation von Methan eignet sich zur Behandlung von Schwachgasemissionen, wie sie von Deponien in der Anfangsphase der Ablagerung, von Altdeponien, Deponien mit geringem Gasbildungspotenzial sowie von Deponien mit abgeschlossener technischer Gasbehandlung ausgehen. Die hier vorliegenden Leitfäden sollen den in der Praxis Tätigen Hinweise zu Dimensionierung und Aufbau sowie zur Überwachung von Methanoxidationssystemen geben.

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