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AquaConSoil Copenhagen 2015

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Performance of Carbo-Iron particles in *in-situ* groundwater plume and source treatment approaches

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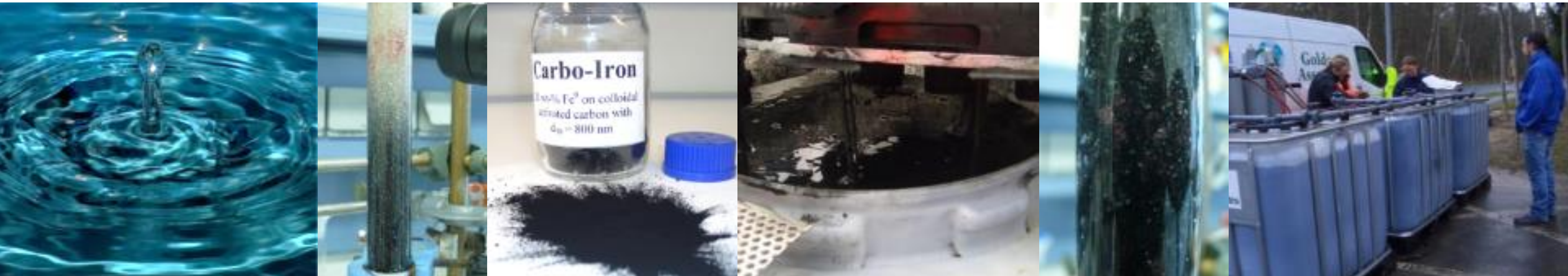
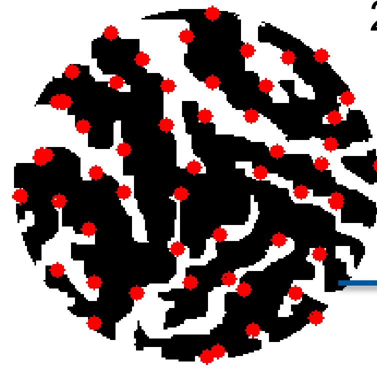
Golder Associates



Particle Description

25…30 wt% Fe^0

AC + Fe(III) salt + reduction →



properties from
both materials

Fe(0) nanostructures embedded ***in*** the activated carbon grain

= true composite

AC + **Fe**

Highly sorption active
Porosity = low density
Hydrophobicity
Neg. surface charge

Iron-specific reactivity
Iron-specific contaminant spectrum
Hydrogen generation

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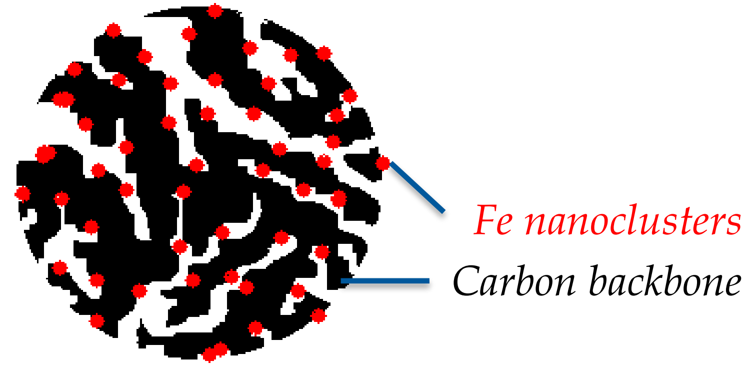
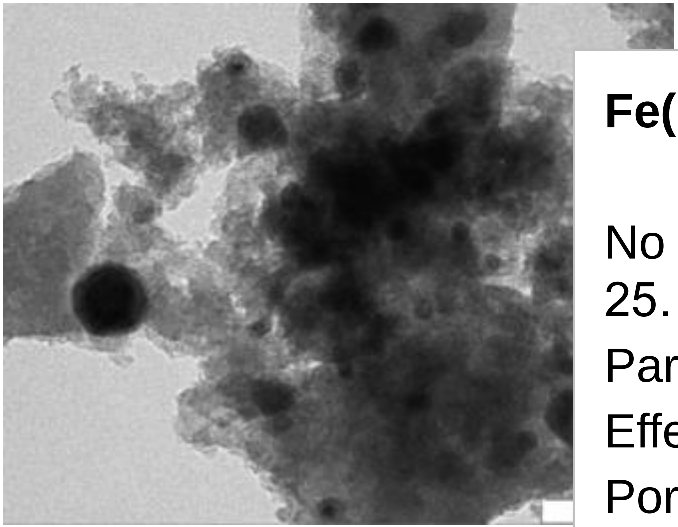
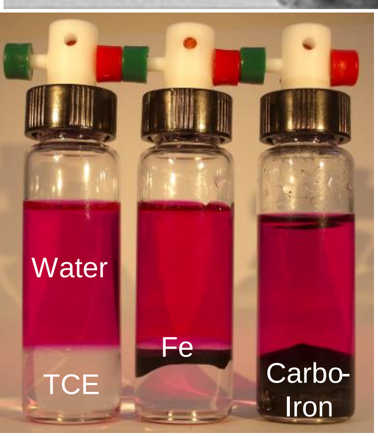
Particle Description

AC + Fe(III) salt + reduction →







Fe(0) + Activated Carbon (AC) as true composite

No leaching of nanoparticles! Built-in Fe!

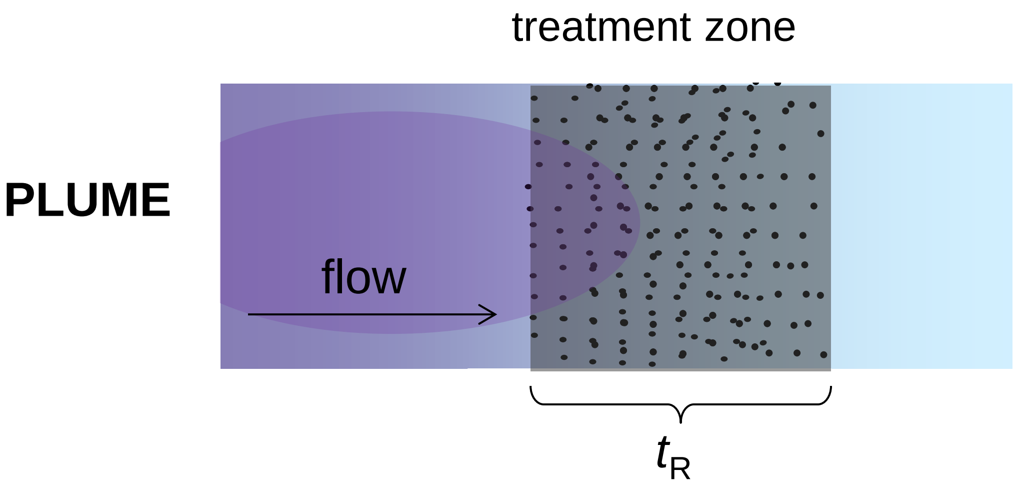
25…30 wt-% Fe^0, 50…60 wt-% C, Rest: Fe oxides

Particle size	≈ 0.8…1.3 µm
Effective particle density	≈ 1.7 g/cm^3
Porous, sorption active particles	BET ≈ 600 m^2/g
Sorption coefficient for PCE	≈ 10000…30000 L/kg

Hydrophobic surface: easy to wet by solvents

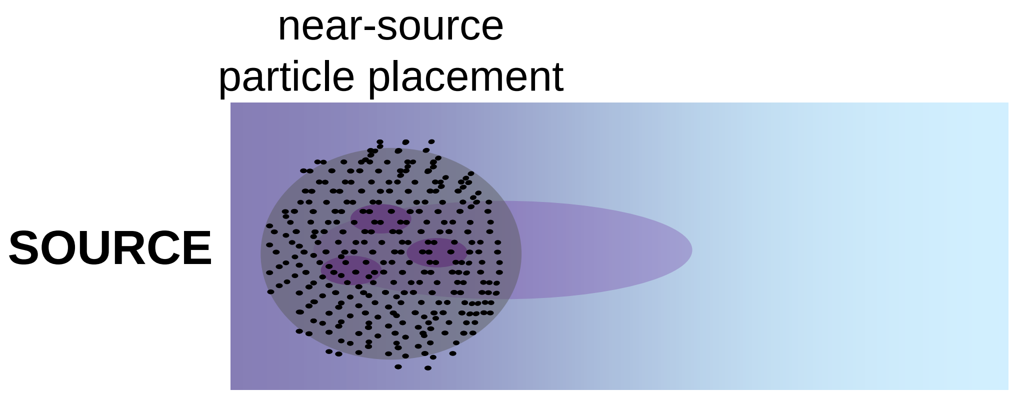
Improvement of nanoiron performance?

Particles as *in-situ* reagent



Requirements:

- → sufficient retention time in treatment zone
- → broad zone means sufficient mobility
- → irreversible attachment
- → no blockage



- → selective source attack
- → placement of particles near source
- → sufficient Fe mass

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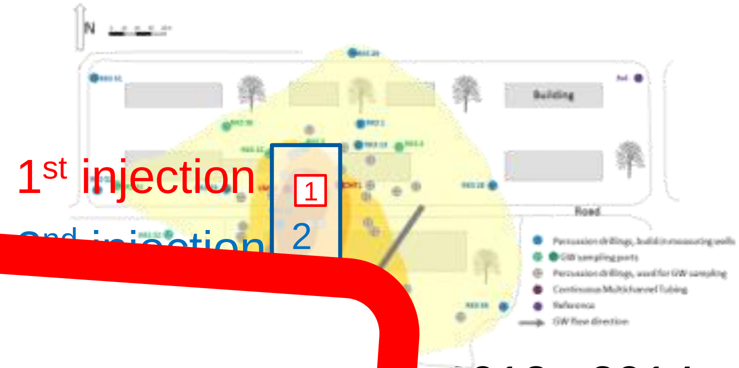
Particle up-scaled tests

Field sites:

Bergen/Celle (Lower Saxony, Germany)



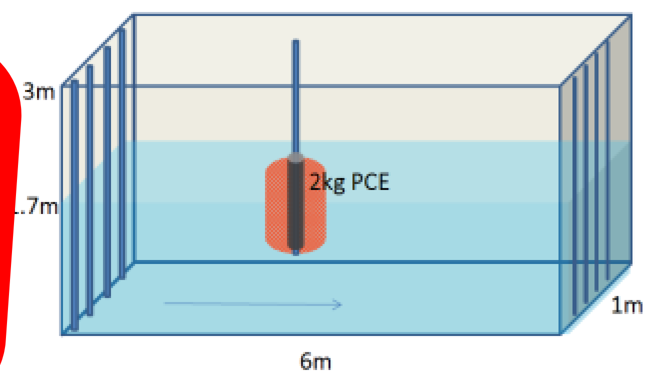
2012...2014

Balassagyarmat (Hungary)

2015

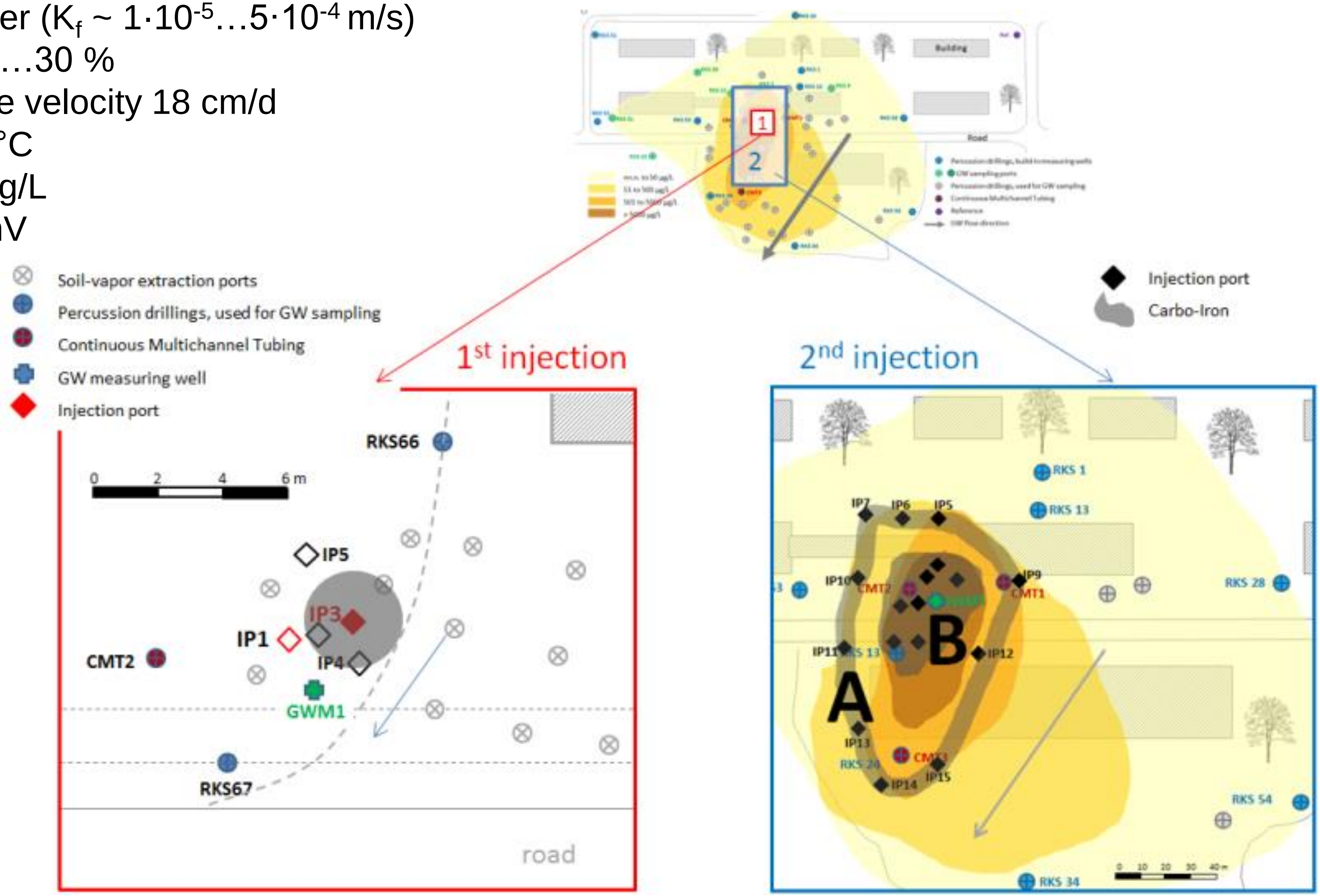
Up-scaled Pilot Test:

Vegas Facility, Stuttgart, Ge



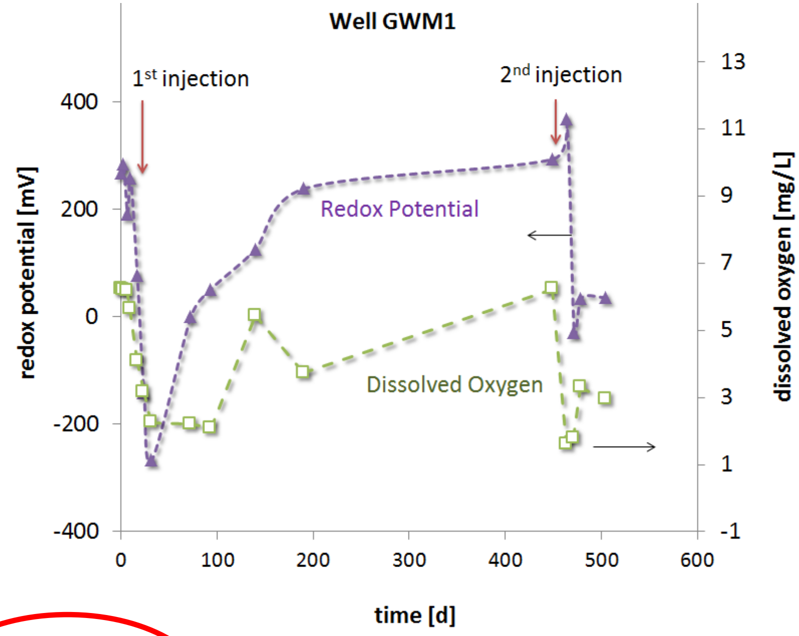
First Field Site

PCE contamination ($c_{PCE,max}$ = 125 mg/L)
Sandy aquifer (K_f ~ $1 \cdot 10^{-5} \ldots 5 \cdot 10^{-4}$ m/s)
Porosity: 15…30 %
GW distance velocity 18 cm/d
T_{GW} = 10.5 °C
C_{O2} = 0.3 mg/L
E_H < -100 mV



20 kg Carbo-Iron (10 g/l, 2 g/l CMC) 120 kg Carbo-Iron (15 g/l, 1,5 g/l CMC)

Reaction of Iron



Anaerobic iron corrosion:

$$Fe^{0} + 2H_{3}O^{+} \xrightarrow{k_{korr}} Fe^{2+} + H_{2} + 2H_{2}O$$

Reductive dechlorination of PCE:

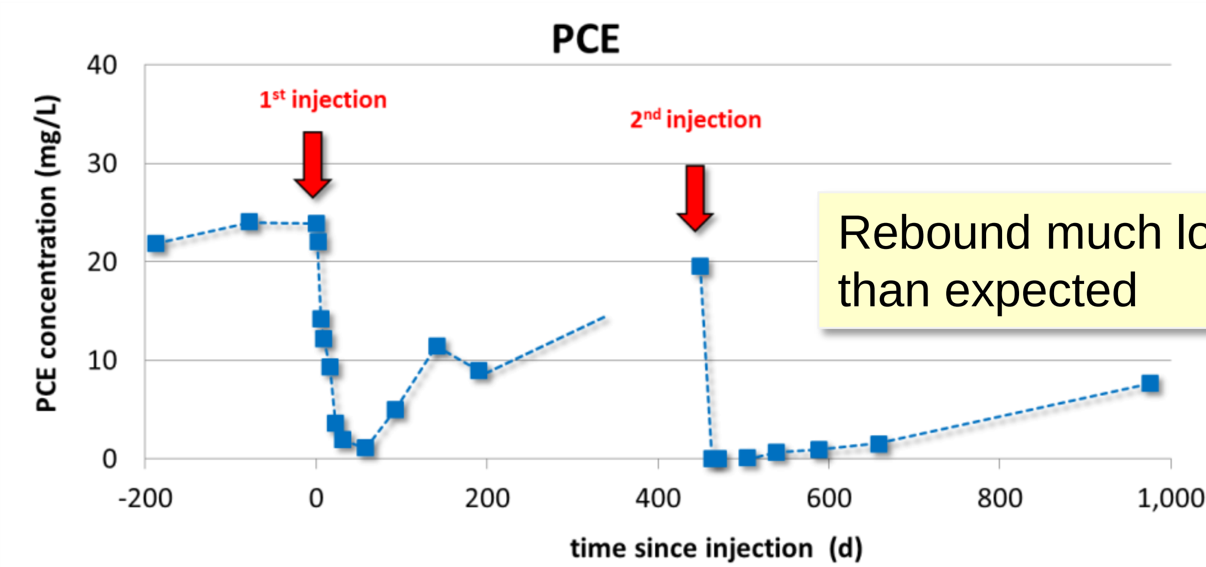
$$n\,Fe^{0} + C_{2}Cl_{4} + (2n-4)\,H_{2}O \xrightarrow{k_{dechl}} n\,Fe^{2+} + C_{2}H_{(2n-4)} + (2n-4)\,OH^{-} + 4\,Cl^{-}$$

Pollutants: **PCE,** TCE, ~~DCEs~~, ~~VC~~

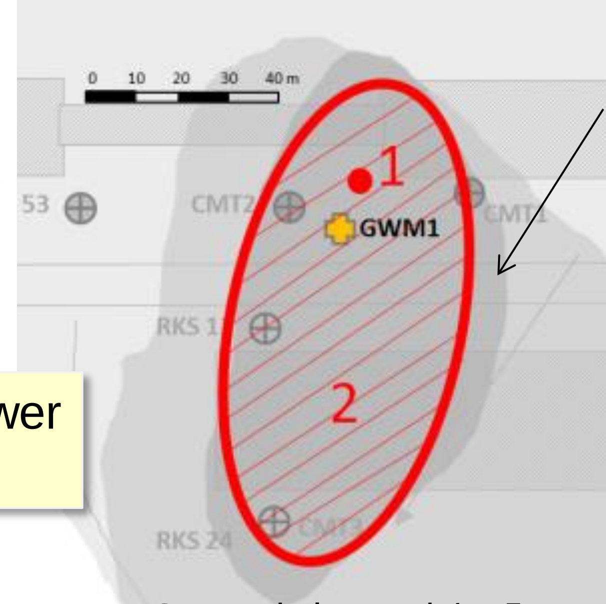
Products: **H_2** ~~TCE~~, DCEs, ~~VC~~, ~~**Acetylene**~~, **Ethene, Ethane,**

= Proof for abiotic dechlorination reaction

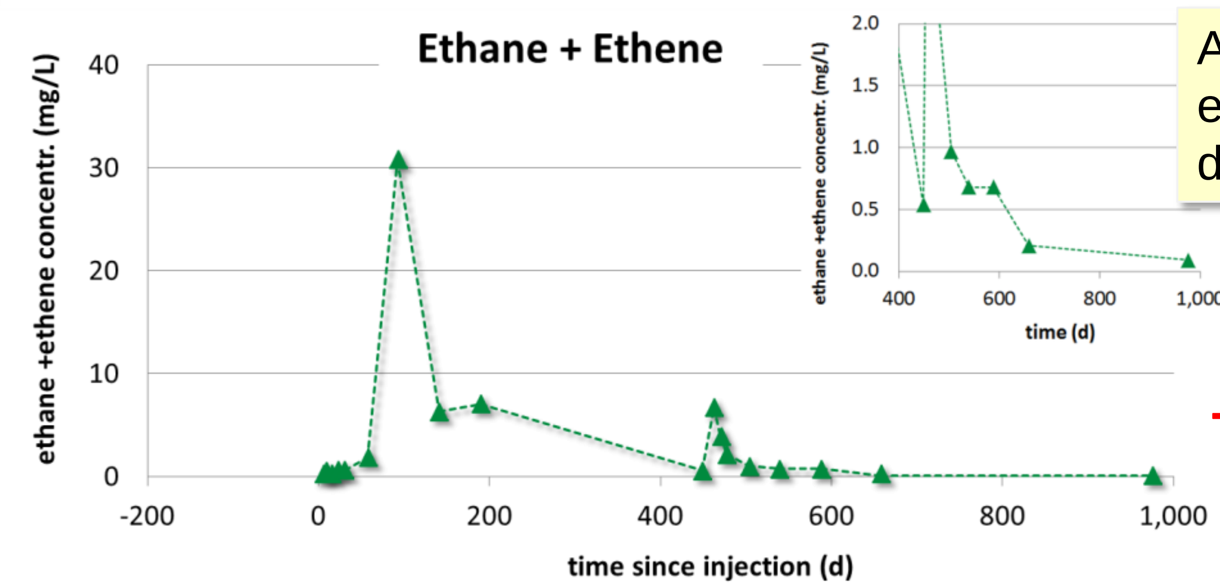
Reaction Pattern at Well GWM1



Rebound much lower than expected



GWM1 is located 4…5 m from injection 1.



After 500 days still ethane and ethene detectable

→ Microbial participation

Second Field Site

Balassagyarmat, Hungary

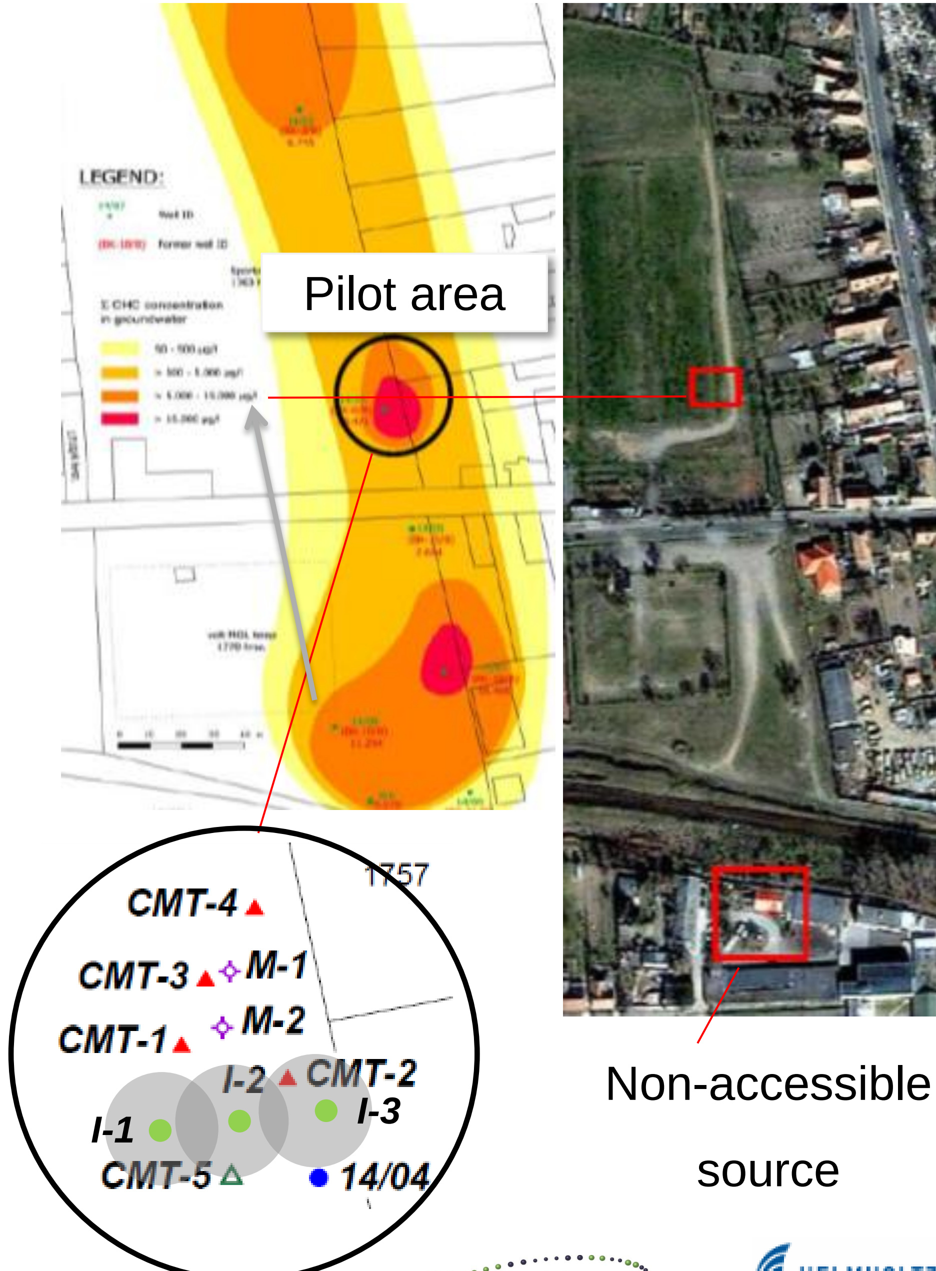
c_{PCE} > 20 ppm

12…14 m below ground

$\varepsilon = 0.4$

$K_f = 5 \cdot 10^{-3}$ m/s

→ **Plume treatment**



Measurements:

- COCs, pH, O_2, redox…
- microbiol. community
- isotope fractionation…

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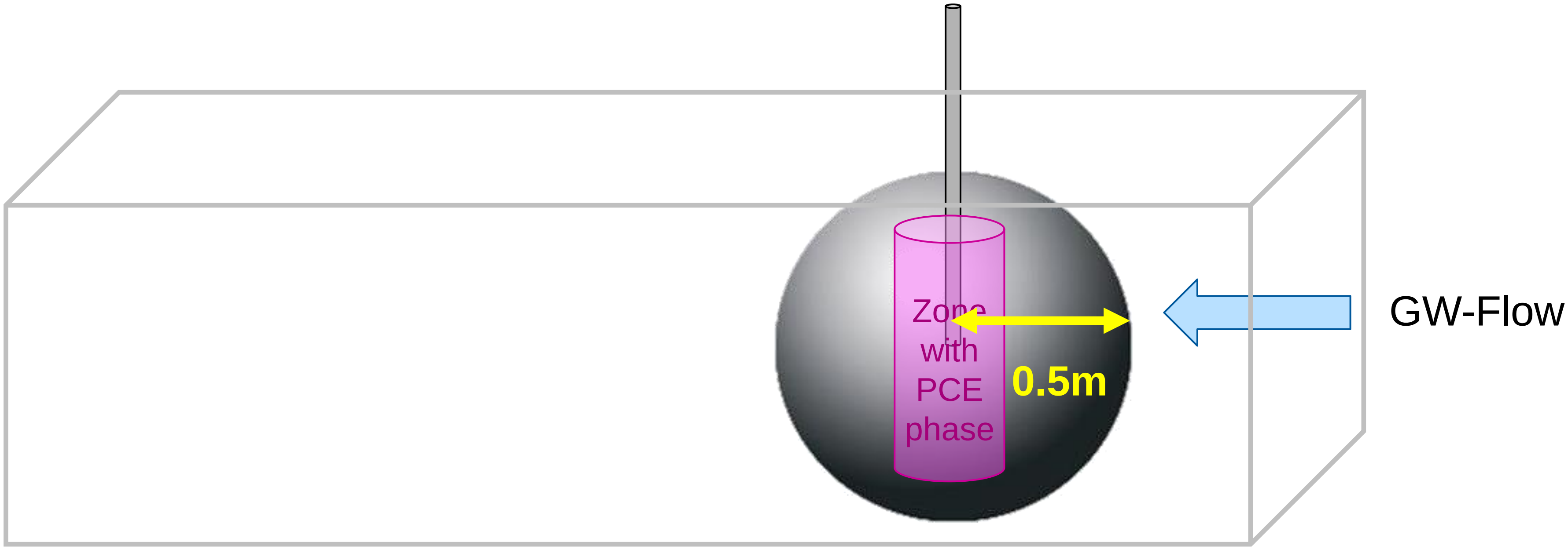
Flume experiment at Uni Stuttgart (VEGAS)



Challenge

- Place 20 kg Carbo-Iron within a radius of 0.5 m around source
- high suspension concentration
- Avoid blockage, daylighting but also particle “escape“ from the 0.5-m-zone

high suspension stability but fast deposition needed

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Flume experiment at Uni Stuttgart (VEGAS)

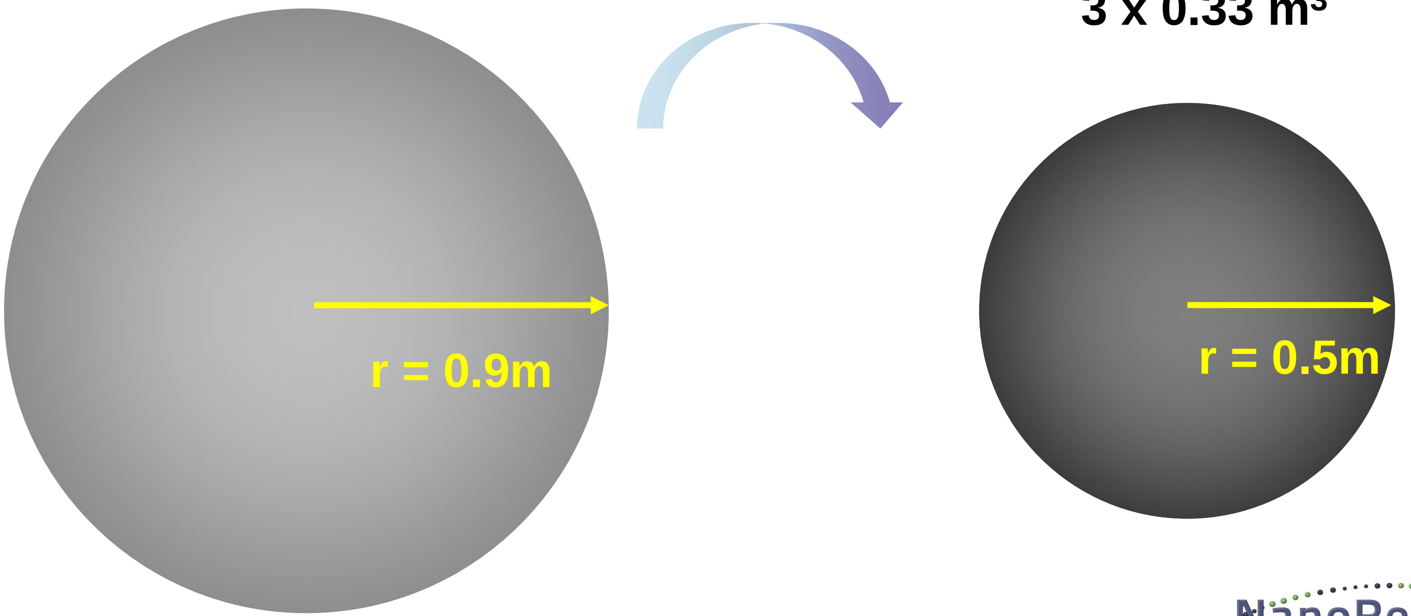
Decision aid by column experiments

20 kg Carbo-Iron with 20 g/L = 1 m^3 Injection suspension

Injection of 1 m^3

Injection of

3 x 0.33 m^3



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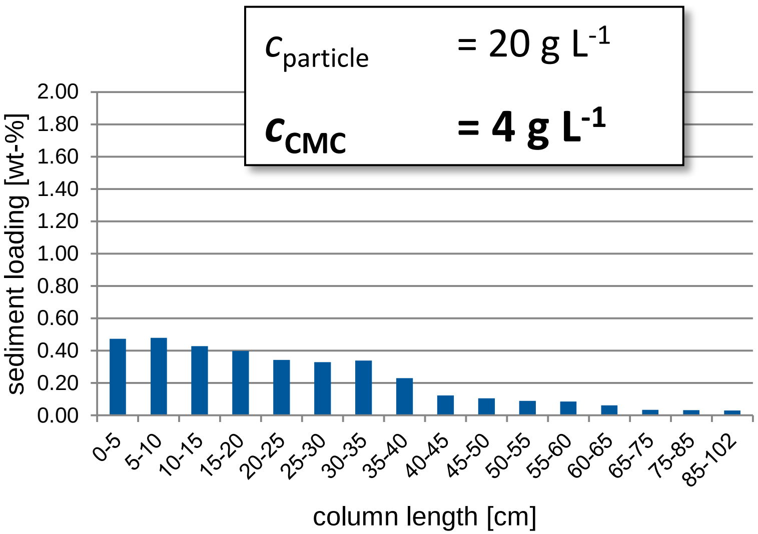
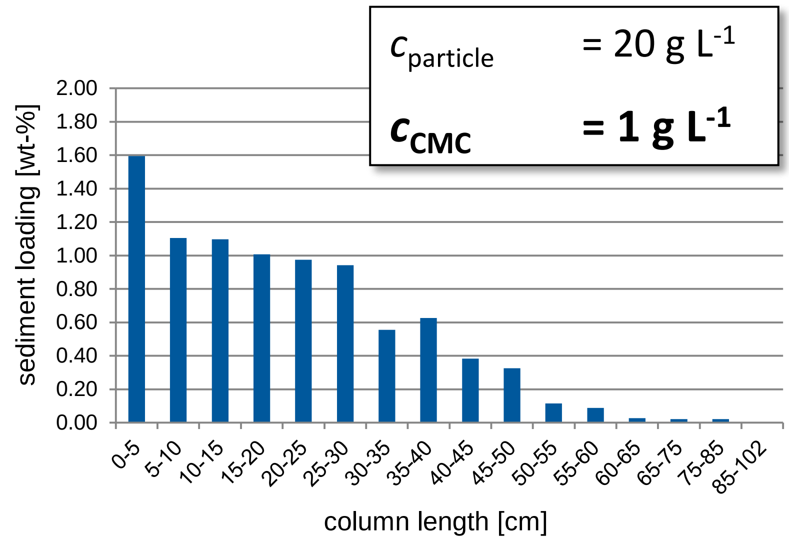
Column experiment to optimize particle placement

How to control Carbo-Iron mobility and particle mass loading?

Influence of suspension stabilizer on **sedimentation profile** and colloid mobility



$L_{T,99.9}$ = 12 m



$L_{T,99.9}$ = 1.2 m

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Suspension composition determines particle mobility

no CMC

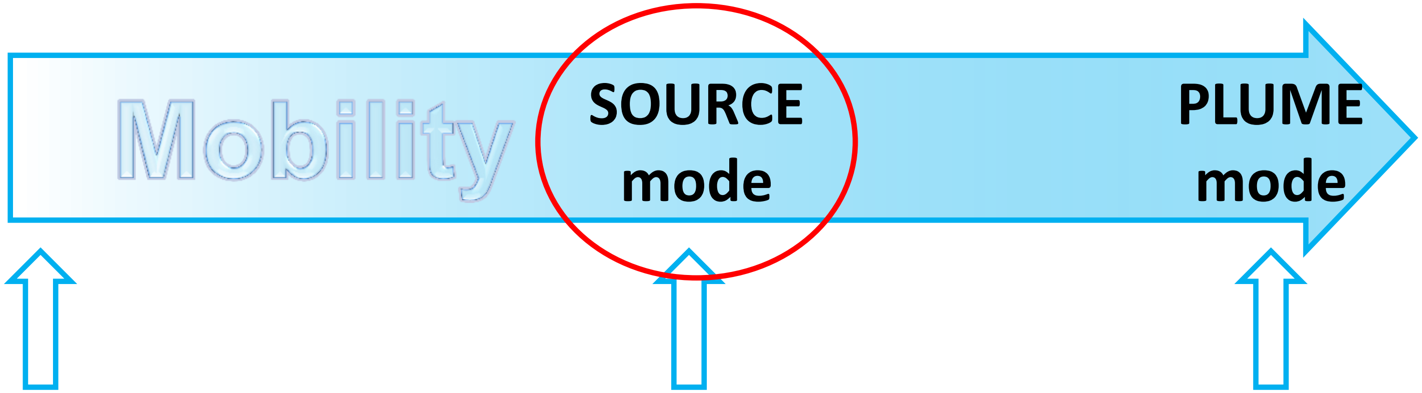
suspension unstable

5 wt-% CMC
(ref. to particle mess)

suspension semi-stable

20 wt-% CMC
(ref. to particle mess)

long-term suspension stability



no transport
→ blockage expected

moderate mobility
($L_{T,50} \approx 0.3 \ldots 0.5$
$L_{T,99} \approx 0.8 \ldots 1.3$ m)
→ particle placement

highest mobility
($L_{T,50} \approx 1.1 \ldots 2$ m
$L_{T,99} \approx 10 \ldots 12$ m)
→ broad reactive zone

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Testing of reactivity - source

Conditions:

Sediment: Dorsilit

Dyed Organic phase: PCE

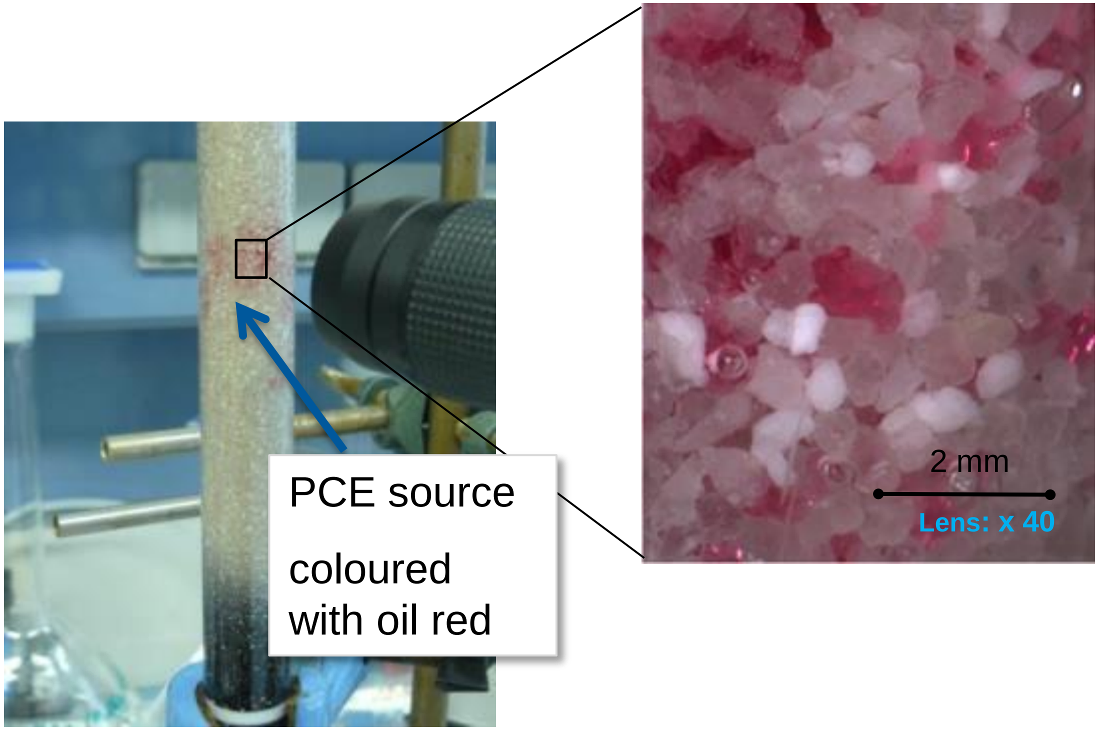
fluid: medium hard water

Injection flow: 10 m/d

$c_{particle}$: **20 g L^{-1}**

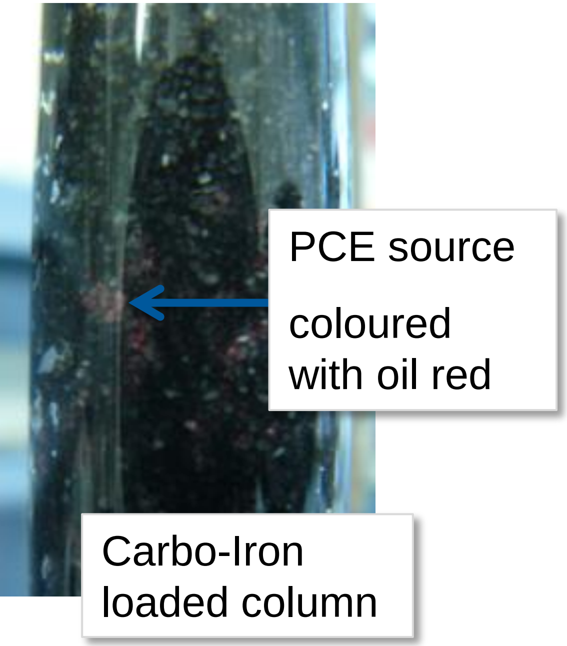
c_{CMC}: **1 g L^{-1}**

Emplaced PCE droplets

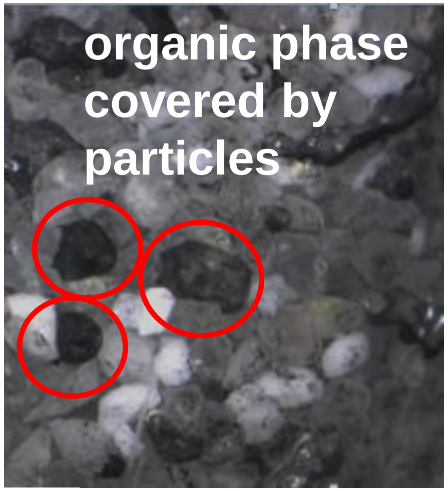


Visualization by digital microscope

Testing of reactivity - source



Initial Carbo-Iron injection phase



Remaining particles on organic surfaces after flushing with de-ionized water

Outcome so far:

- non-selective particle deposition on contminant under injection conditions
- Decrease of ionic strength usually leads to remobilisation of particles from grain surface, Carbo-Iron remains at organics interphase

To do: Quantification of product formation

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Thank you for your attention!

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