Surfactant foams:
The development of a powerful and polyvalent tool for site and soil treatment

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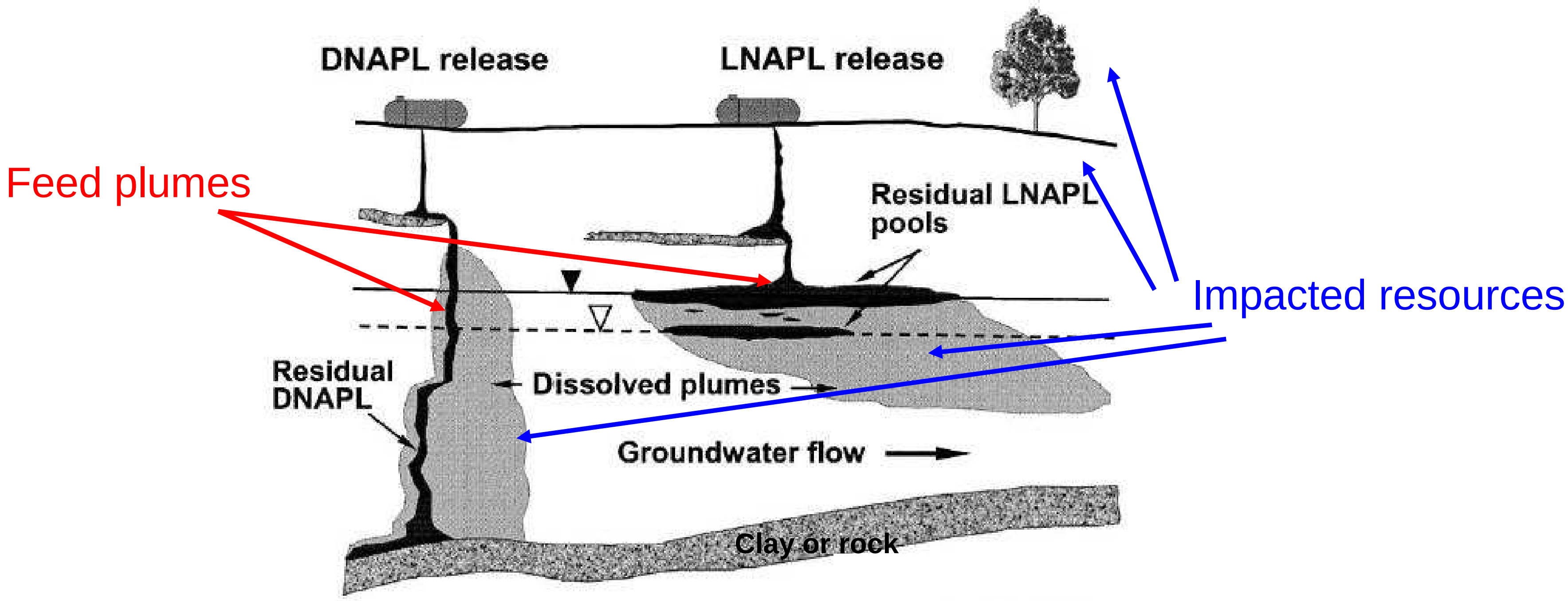
Context : In Situ Treatment of Residual NAPLs of Recalcitrant SVOCs



Remediation steps in source zone:

1- pump and treat the pure phase,

2- remove the residual: **SVOCs/NVOCs require chemicals**

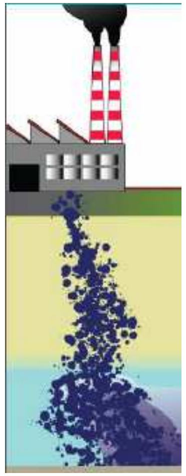
3- let biorem. achieve the work

Context : Many difficulties for In Situ Treatments

How to warrant homogeneous treatments for :

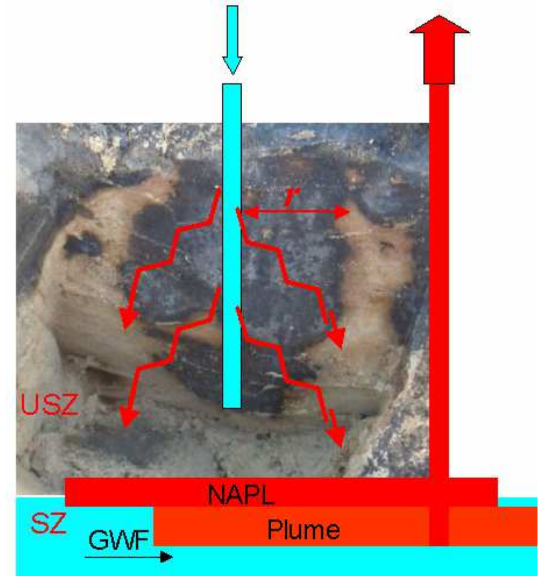
- Heterogeneous subsoils or underground structures ?

$$U = \frac{k}{\eta}\nabla P$$



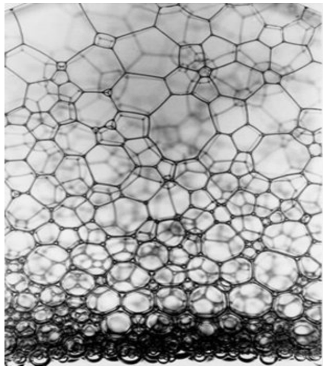
- Hydrophobic zones - What injectability ?

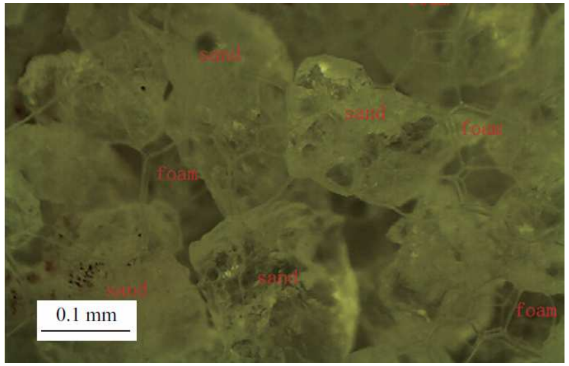
r = f(gravity, capillarity, viscosity, permeability)



Properties of surfactant foams

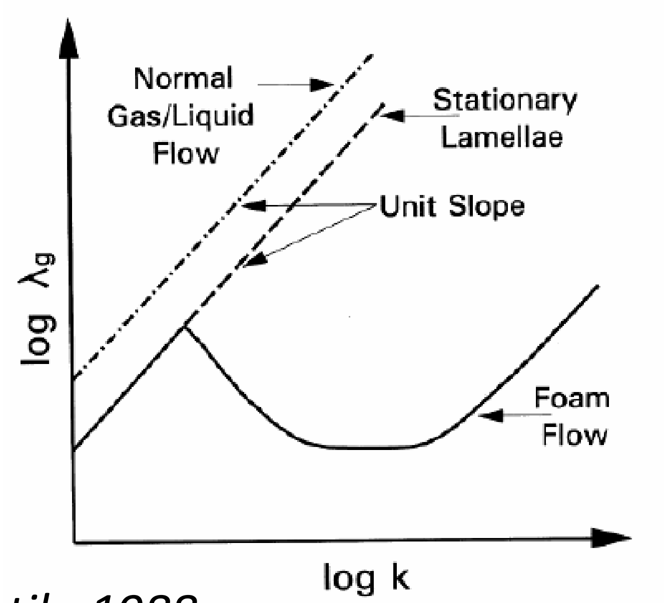
Low bulk density ($1 m^3/l$), high specific area ($200\ m^2/l$)





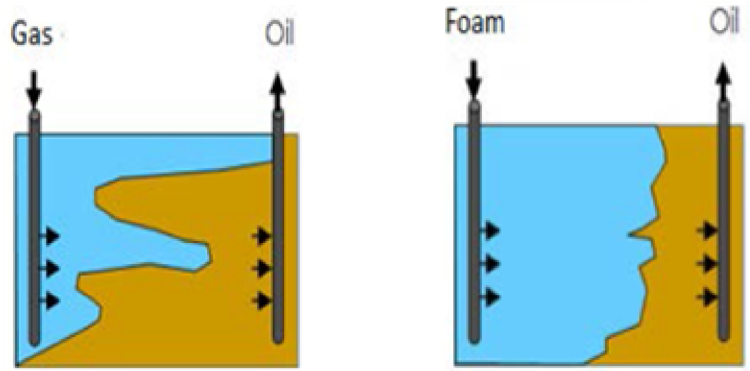
Viscous fluids with treshold flow

Mobility vs. permeability



Khatib, 1988

Use for **EOR**

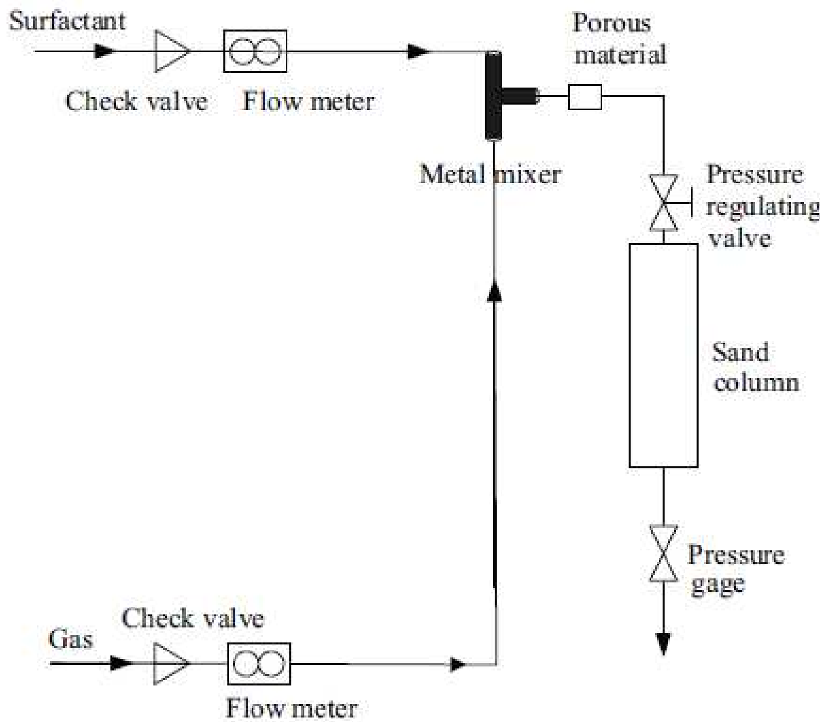


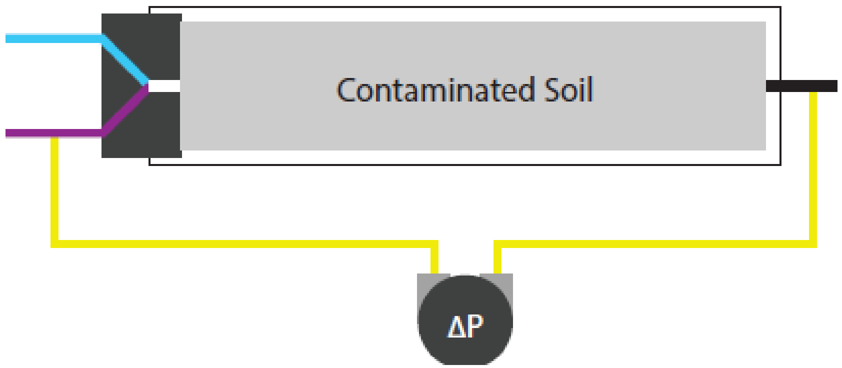
ISER

Lower depths and residual conc.

Modes for injection

Ex situ (ES), in situ (co-injection or SAG) → Different behaviors

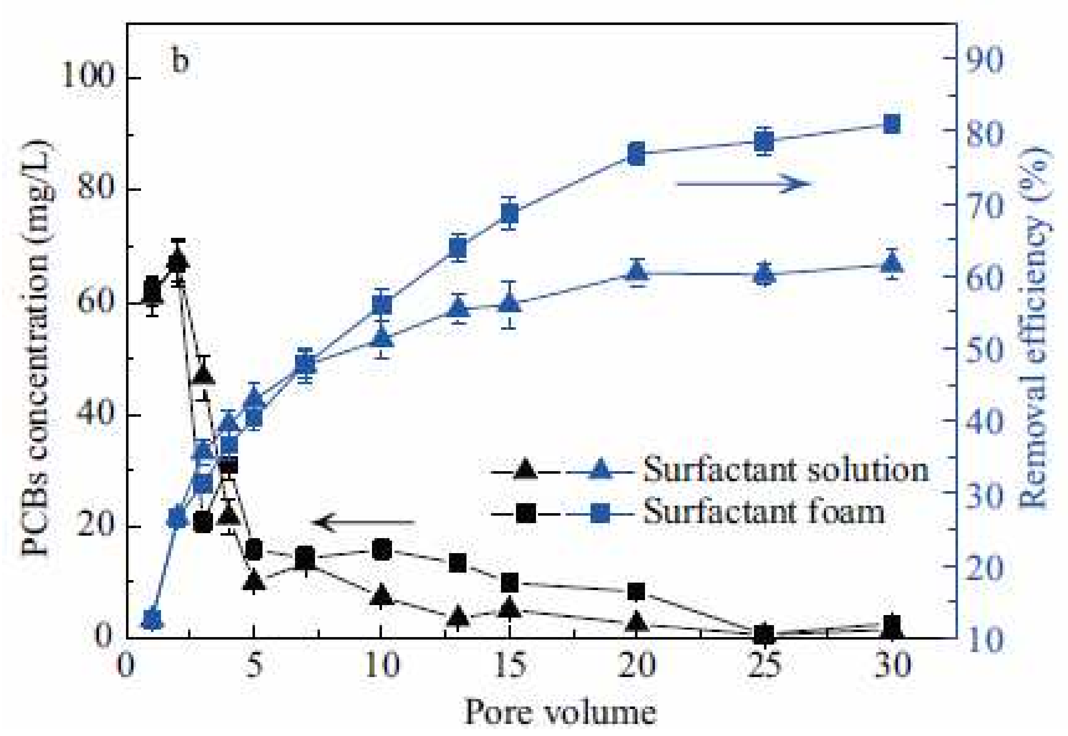




Higher drop pressures

Longer to make foams

Sweeping efficiency improvement for contaminant desorption



	Fine sand (15 D)	Coarse sand (120 D)
S. solution	0.71	0.84
S. foam	0.93	0.98

Wang & Chen, JES, 2012

Results : Surfact. foams in flushing operation for ads. PAHs removal

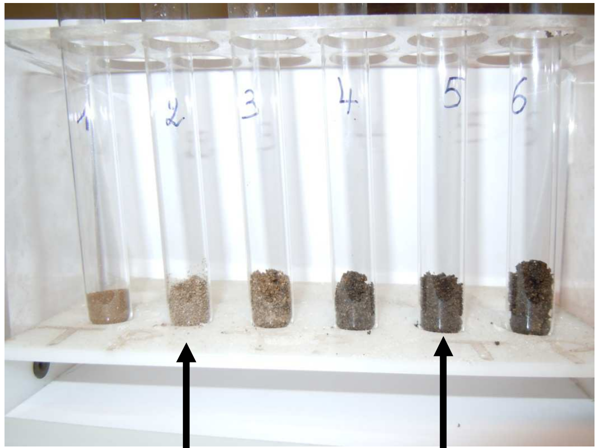
Unsaturated creosote-contaminated soils

Fine sand (4 D)

TPH 3-10 g/kg

PAH: 2-8 g/Kg

Treatment with ES foams



After Before

$$\eta^{Foam}(\%) = \eta^{L}(\%) + \eta^{G}(\%)$$

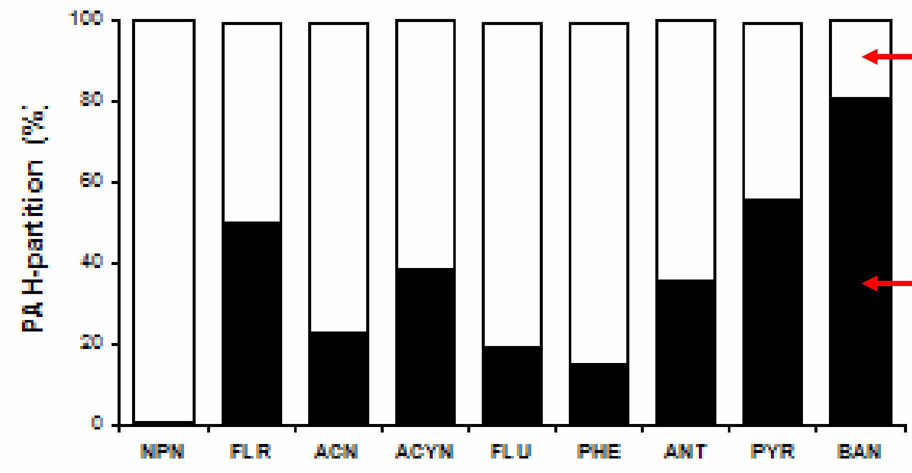
S (2%w)	PV_{inj}	$\eta^L(\%)$	$\eta_{tot}(\%)$	$\eta^G(\%)$	η^G/η^L	$\eta^{tot}(\%)$ +10 PV water
CB	19	21	95	74	3.5	97.5
CHS	30	21	94	78	3.5	98.0
LB	53	20	95	79	3.8	99.7
SDS	57	23	94	76	3.1	99.6

TPH (C10-40) mainly extracted in the gas-phase

timbre

Results : Surfactant foams in flushing operation for PAHs removal

Mass balance on PAHs



Extracted in the vapor phase of foams

Extracted in the liquid phase

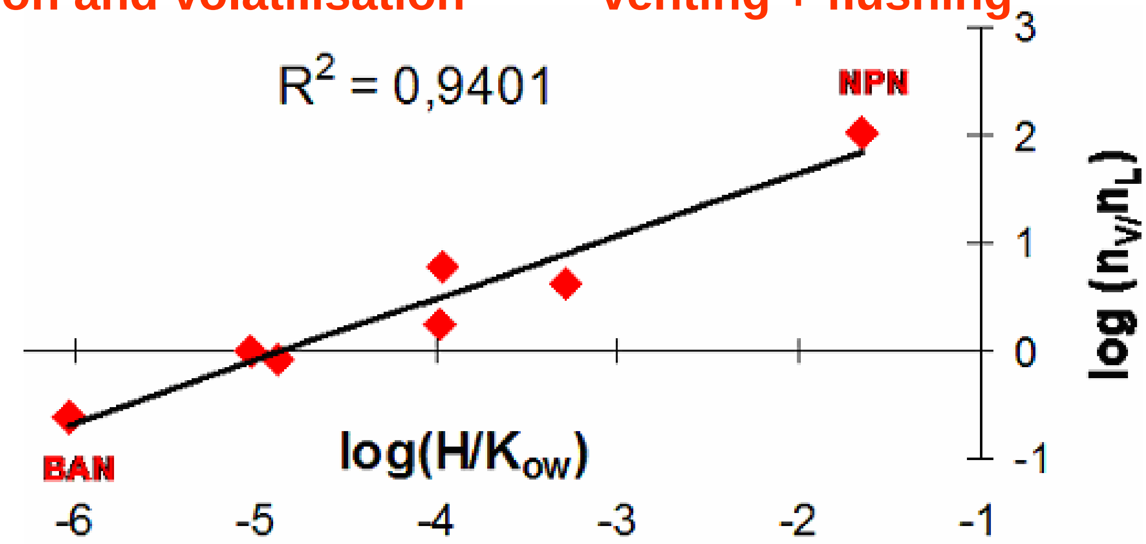
Competition between solubilisation and volatilisation $\longrightarrow$ venting + flushing

$$\frac{n_{i,V}}{n_{i,L}} \propto \frac{H_i}{1 + K_{m,i} \times (C_S - CMC)}$$

$$K_{m,i} \times (C_S - CMC) \gg 1$$

$$\boxed{\log K_{m,i} \propto \log K_{OW,i}}$$

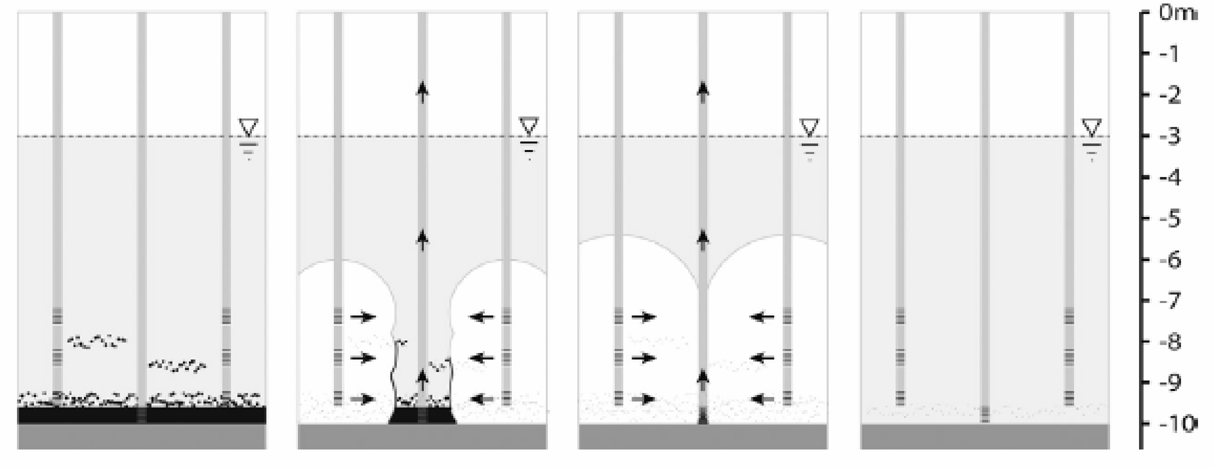
Valsaraj & Thibodeaux Wat Res, 1989



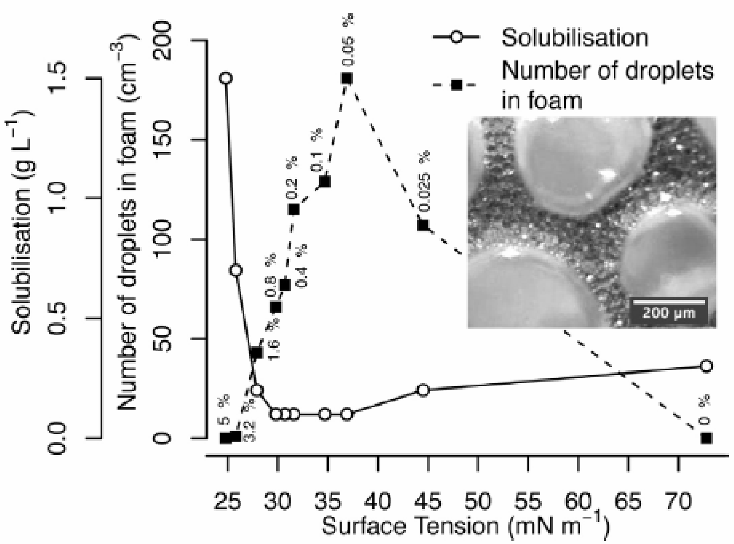
timbre

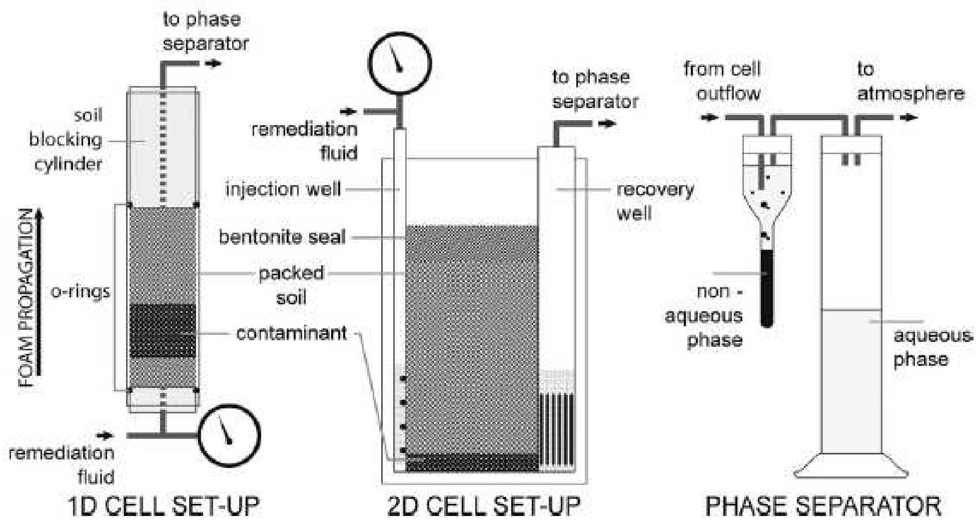
Results : Surfactant foams for pure phase extraction of COHs in SZ

Goal: recovery of DNAPL-residual with minimal dissolution



Soil 20 D

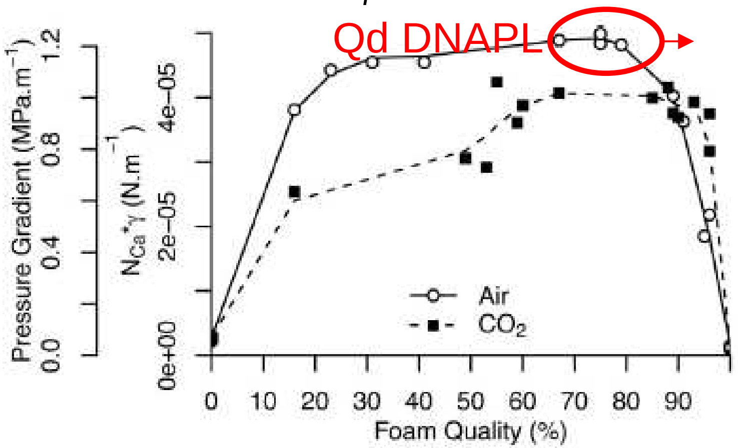


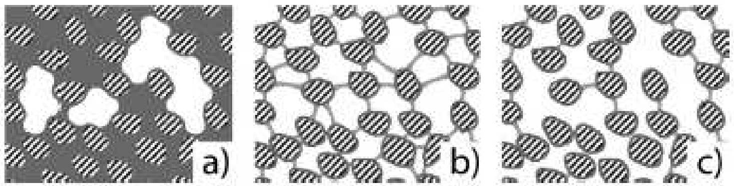


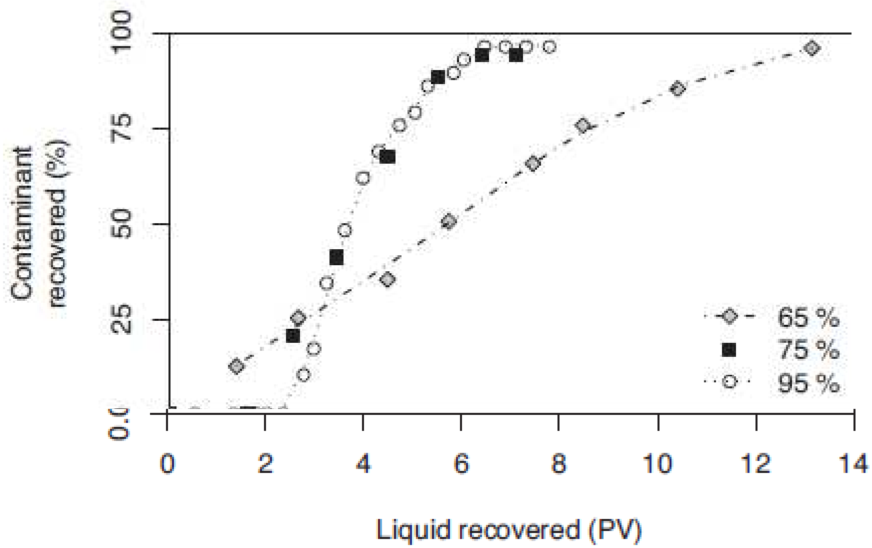
Maire et al.,J Haz Mater 2015

Results : Surfactant foams for pure phase extraction of COHs in SZ

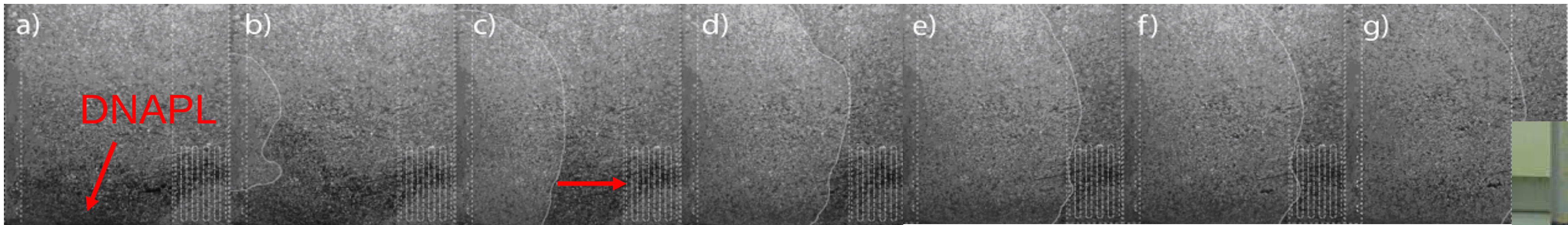
ES foams $F_q = \frac{V_{gas}}{V_{foam}}$ $N_{Ca} = \frac{\eta}{\gamma_{ow}} U$







Improved extraction of the DNAPL and residual



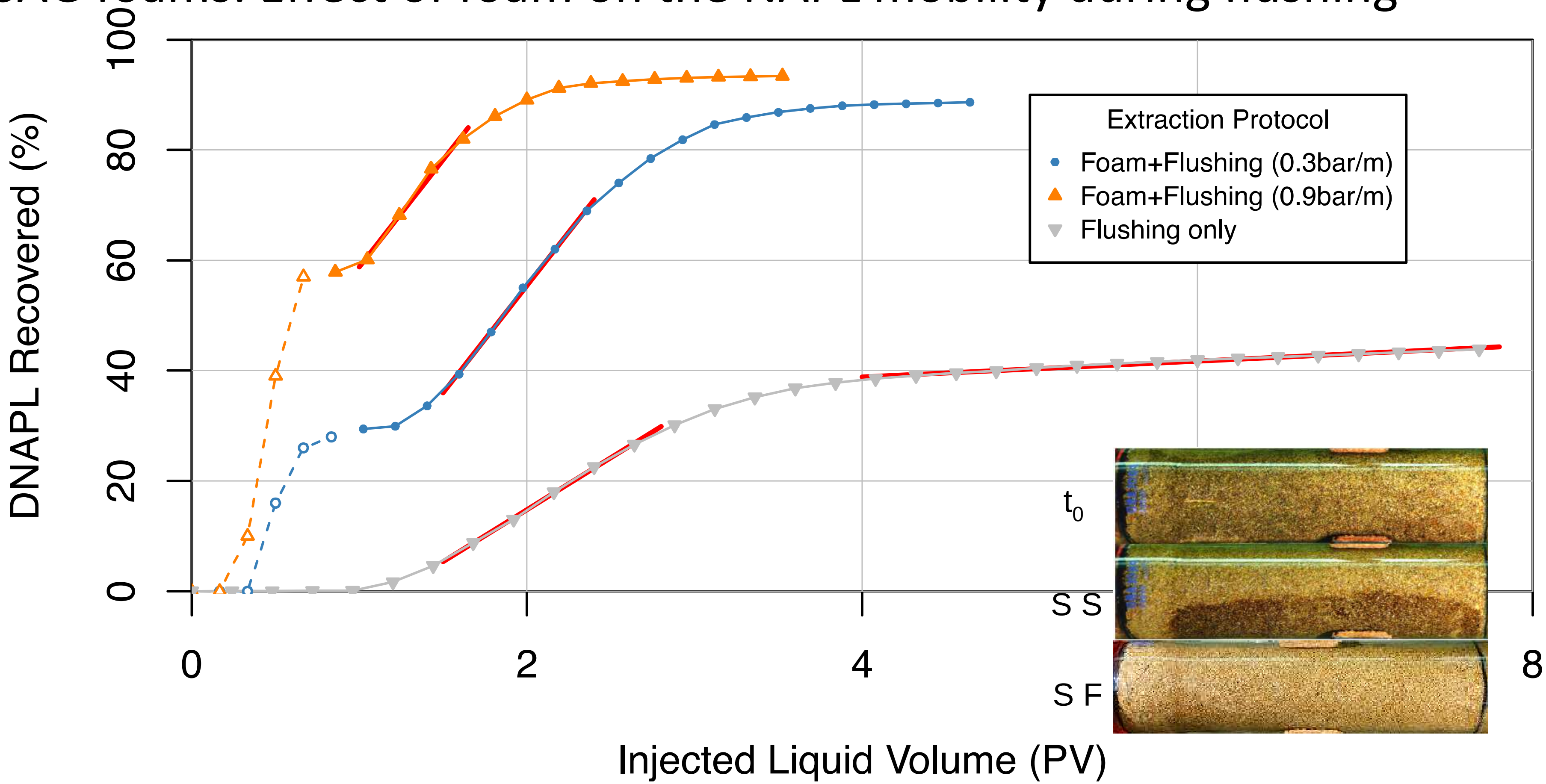
Extraction **without solubilization** - surfactant: **3g/kg** of recovered DNAPL

Y ~ 80-90%, but ∇P too high for ISER

Maire et al.,J Haz Mater 2015

Results : Surfactant foams for pure phase extraction of COHs in SZ

SAG foams: Effect of foam on the NAPL mobility during flushing



	∇P (bar/m)	S/NAPL (kg/kg)	Y_{pure_phase} (%)	Y_{tot} (%)
S. solution	0.3	~ 14	-	~ 90
S. foam	0.3	1.46	30	89
	0.9	1.04	60	95

Silphes

Results : Surfactant foams for pure phase extraction of COHs in SZ

SAG foams: Effect of ∇P on the COHs recovery

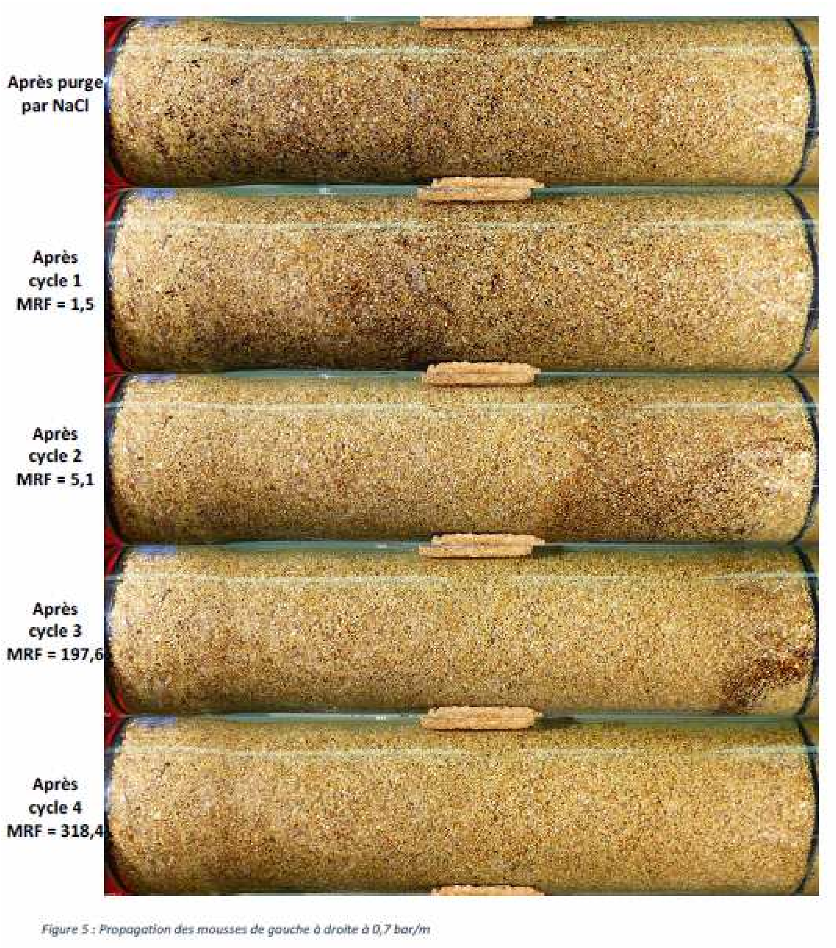
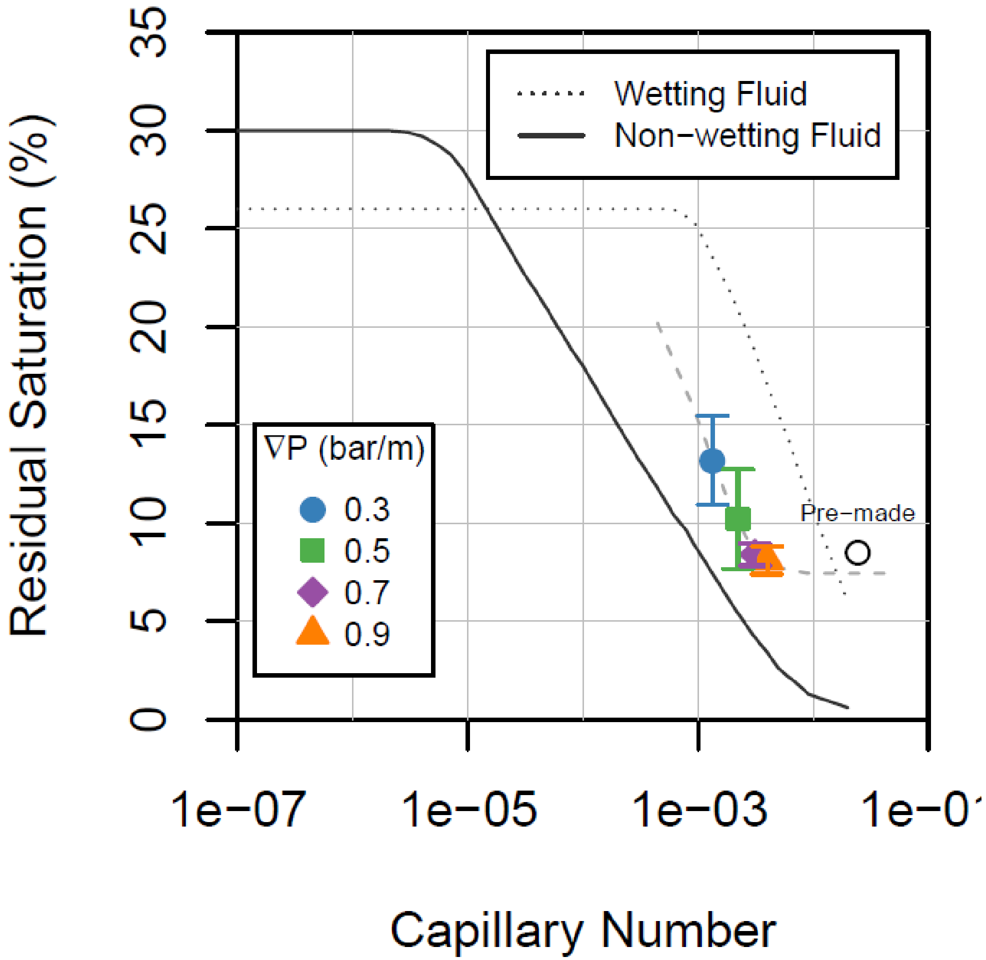


Figure 5 : Propagation des mousses de gauche à droite à 0,7 bar/m

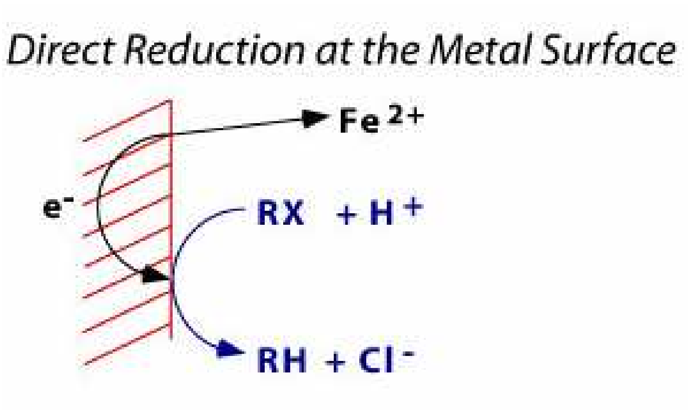


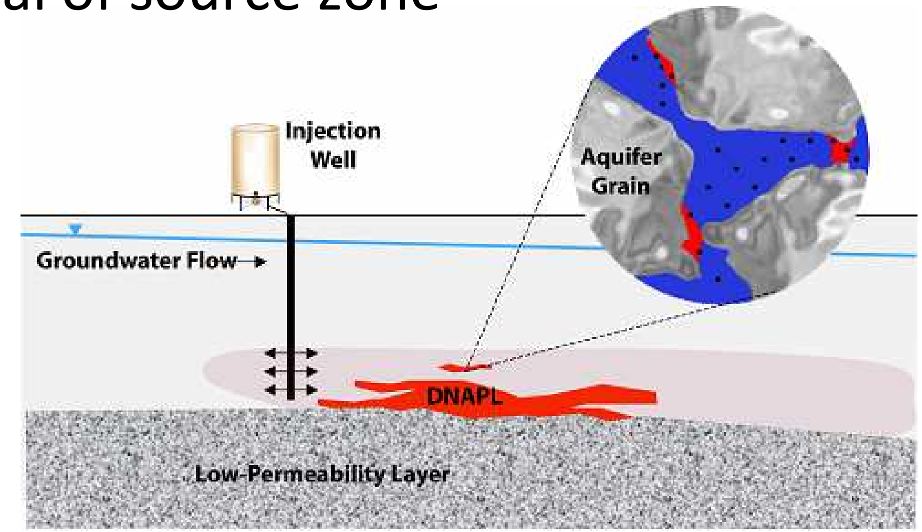
Lake, EOR, 1989

Silphes

Results : Surfactant foams for the degradation of COHs in SZ

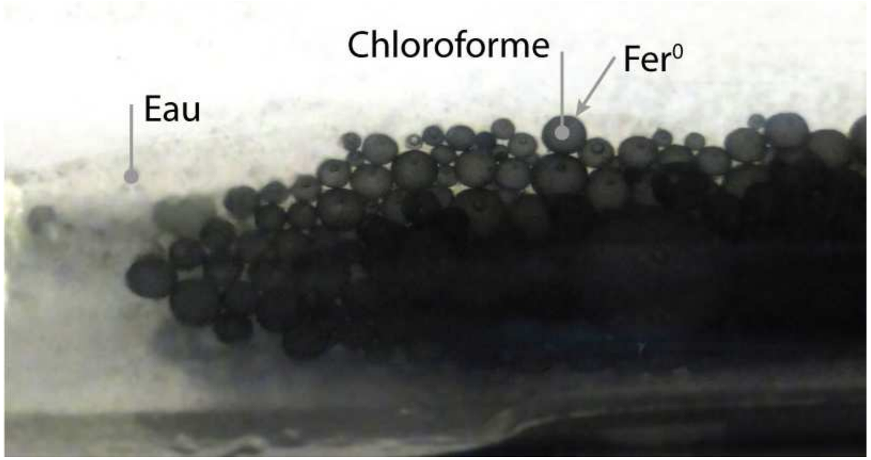
ES foams for ZVI (2-10g/l) in residual of source zone



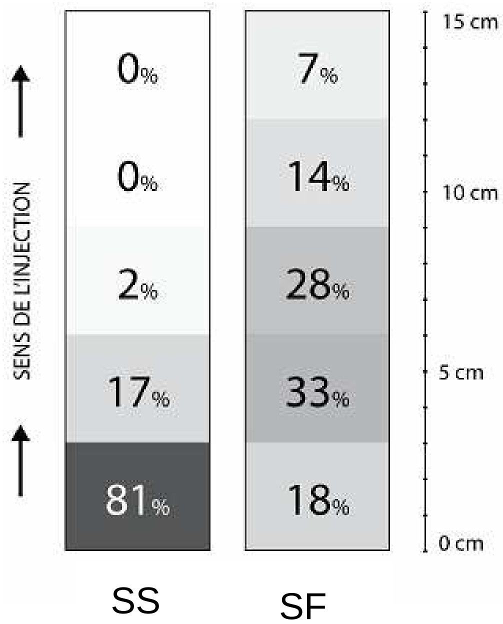


Polymer coated 20-µm Fe(0),

Controlled sorption at the water/DNAPL interface



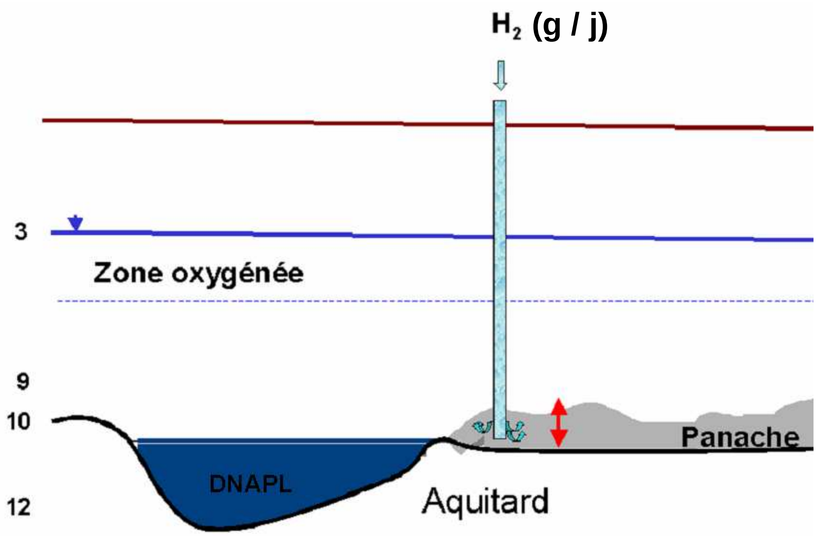
Fe distribution



Soil 20 D

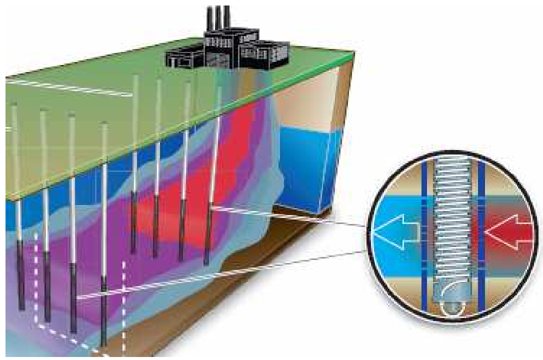
Results : Surfactant foams for the red. degradation of COHs in plume

ES foams for H_2 stabilization in plume: enhanced and remanent delivery



Loss, risk, costs

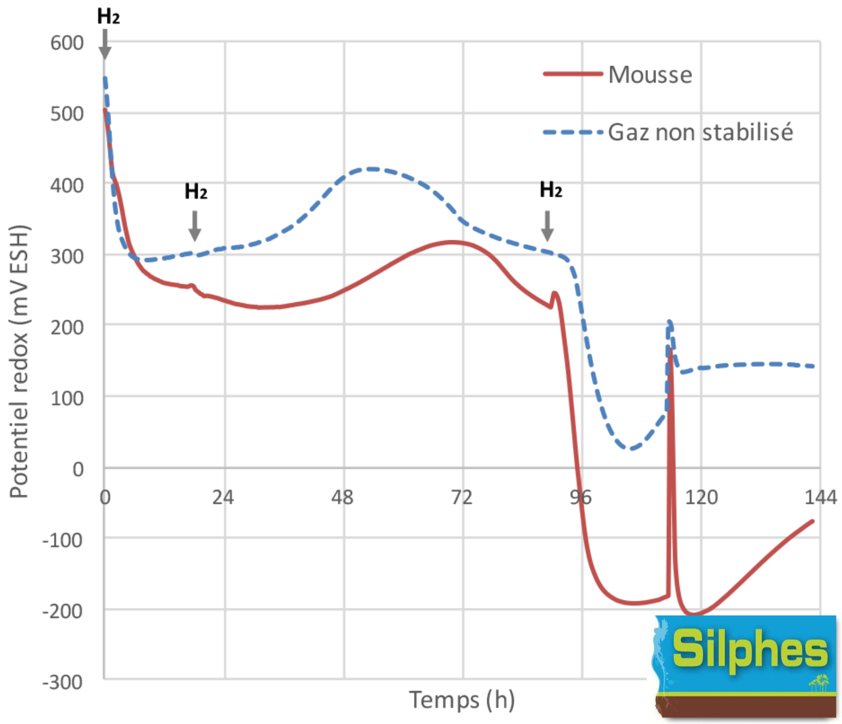
unstabilized H_2



Usual eqip. for H_2 dissolution

Low stability foam

high stability foam

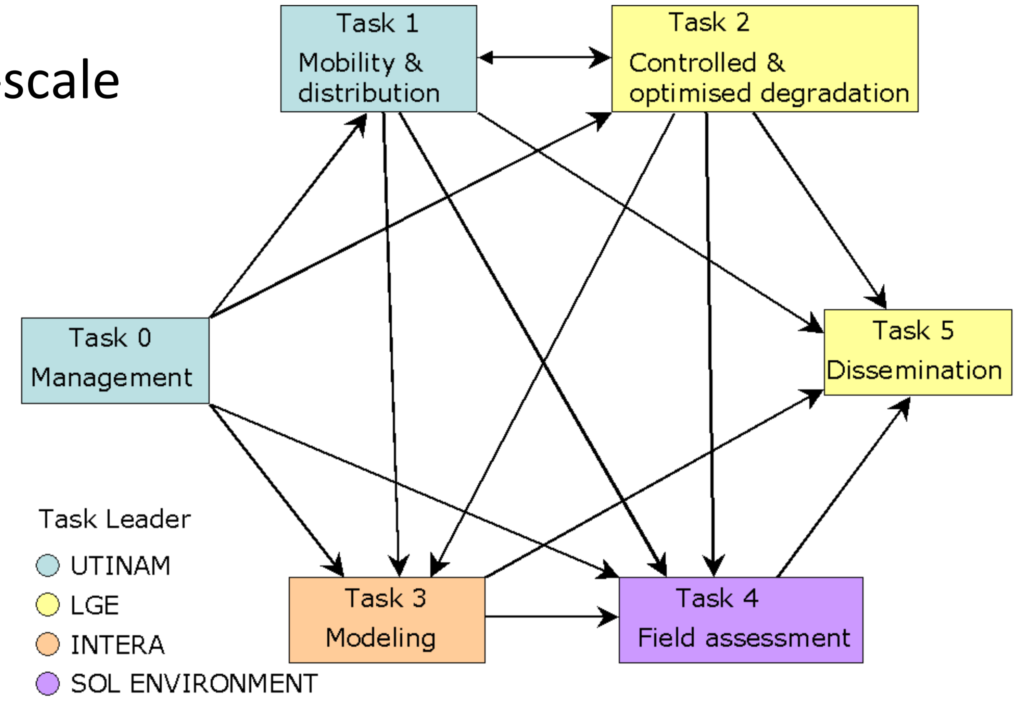


Silphes

MOUSTIC project

Foams for the enhanced and remanent Ox/Bio-delivery in USZ for PAHs deg.

- Better understand effects of soil heterogeneity on foam behavior
- Selective and synergistic PAHs degradation
- Modeling reactant transport and degradation kinetics
- Implementation at field-scale



ANR 2015
Website (Moustic-anr.org)

THANK YOU