Enhanced Mineral Weathering as a Marine Geo-engineering Approach

Processes, potential and problems

Francesc Montserrat, Phil Renforth, Pol Knops and Filip Meysman

Vrije Universiteit Brussel

Enhanced (Mineral) Weathering

- Mineral dissolution by carbonic acid (CO_2)
- Geological (abiotic) bulk CO_2 uptake
- Natural global climate control (Raymo & Ruddiman, 1992)

- **Olivine (Mg_2SiO_4)**
  - fast-weathering
  - widely abundant

Papakolea “Green Beach”
Hawai'i (USA)

Enhanced Olivine Weathering

$$CO_2 + H_2O \rightarrow H^+ + HCO_3^-$$

$$Mg_2SiO_4 + 4H^+ \rightarrow 2Mg^{2+} + H_4SiO_4$$

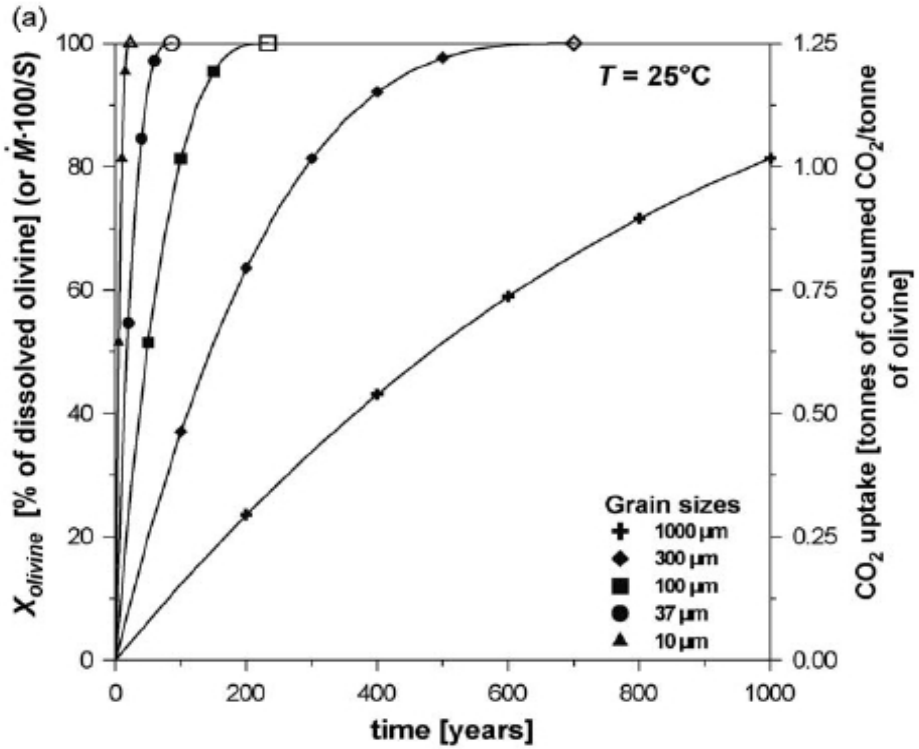
$$=$$

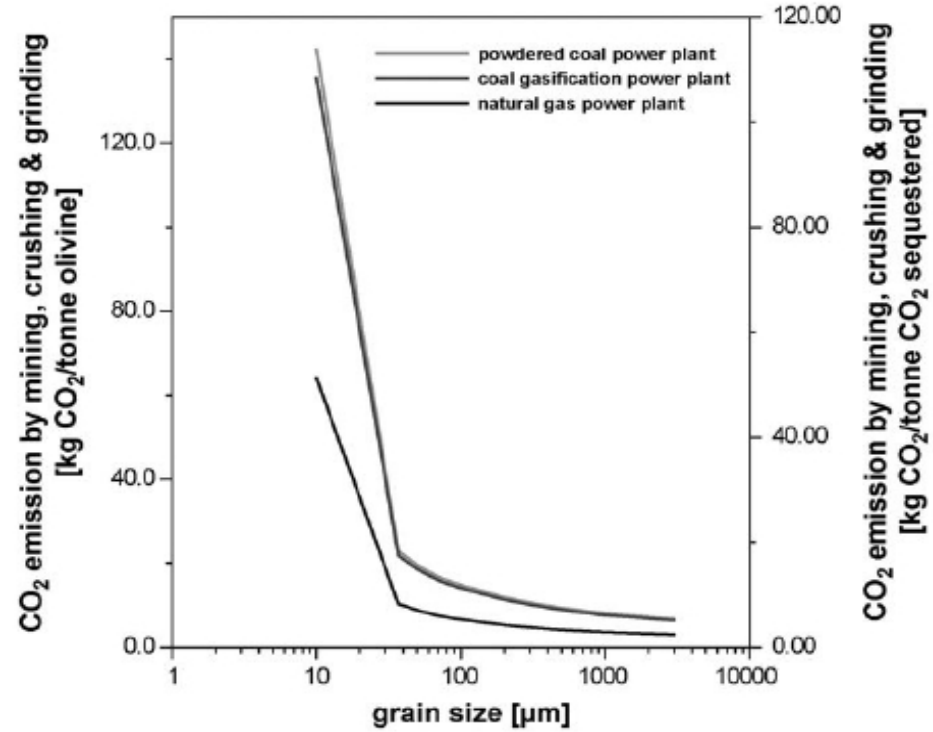
$$Mg_2SiO_4 + 4CO_2 + 4H_2O \rightarrow 2Mg^{2+} + 4HCO_3^- + H_4SiO_4$$

$$Mg^{2+} + CO_3^{2-} \rightarrow MgCO_3\ (s)$$

- vs. Ocean Acidification
- Oceanic CO_2 sink
- Dependent on: Temp, pH, contact surface area
- "...Enhanced..." → mining, grinding & spreading

Carbon Costs

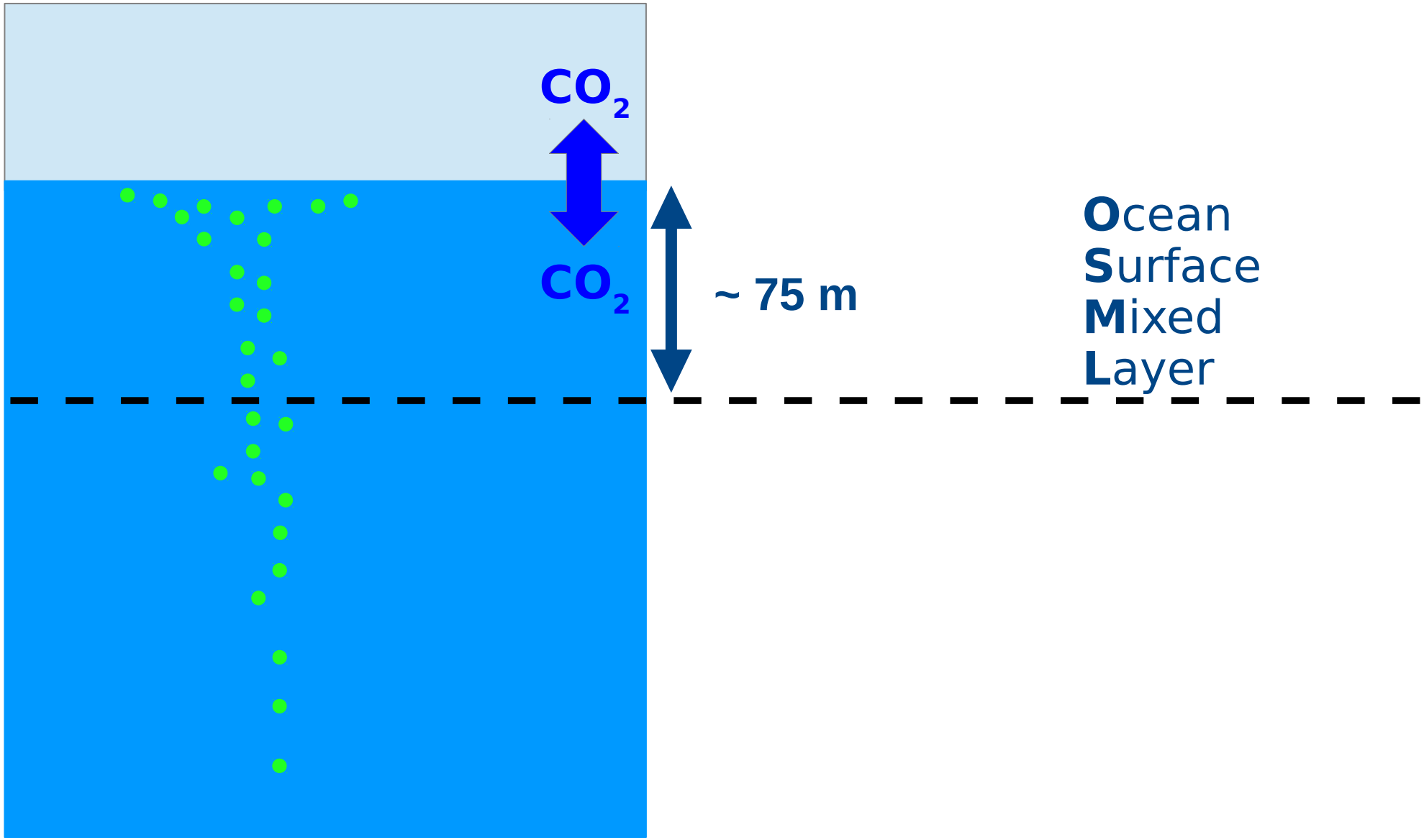




Hangx & Spiers, 2009

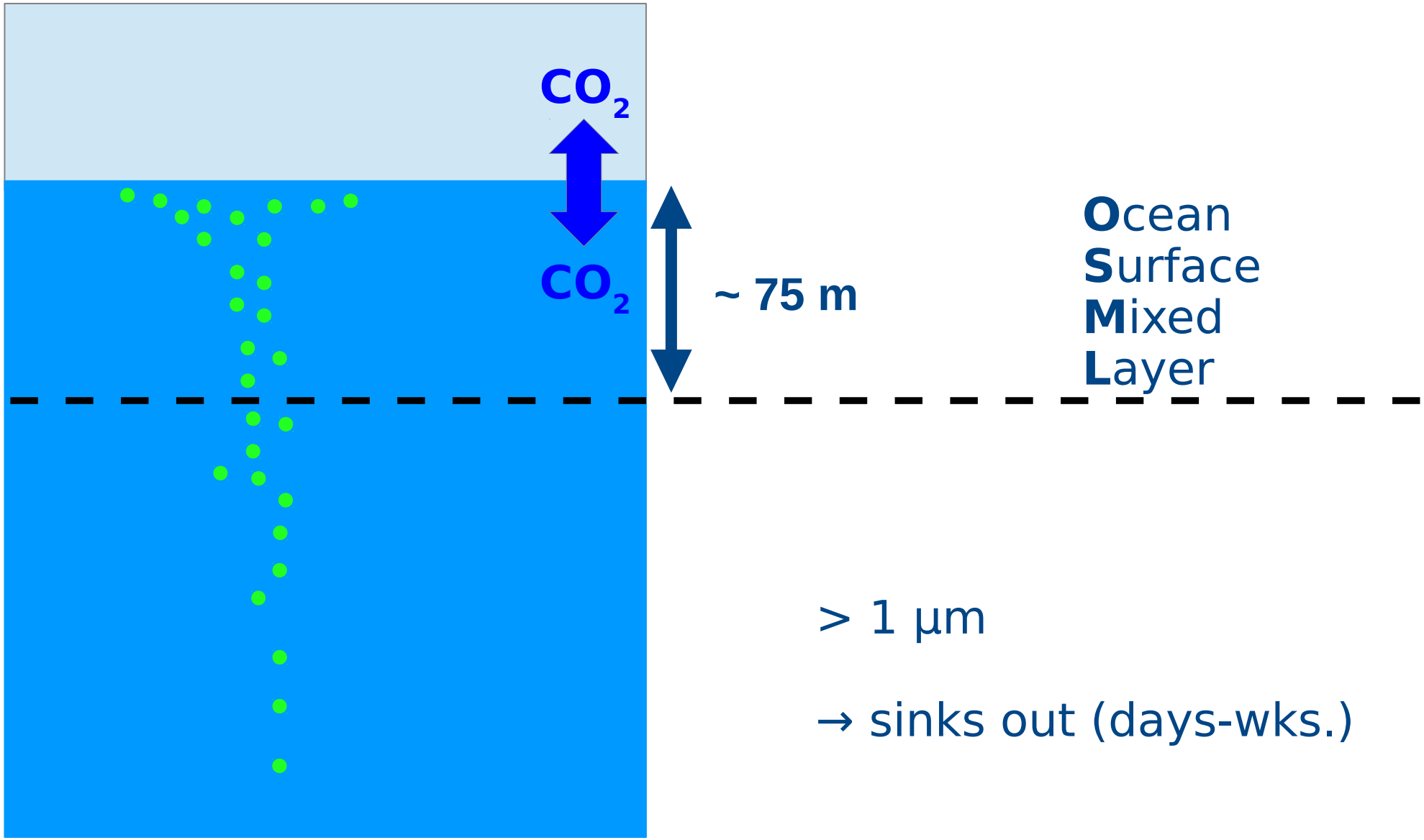
- Dissolution grainsize dependent → grinding
- Drastic efficiency loss below ~35 µm

Olivine in the open ocean



Köhler et al.,2013

Olivine in the open ocean

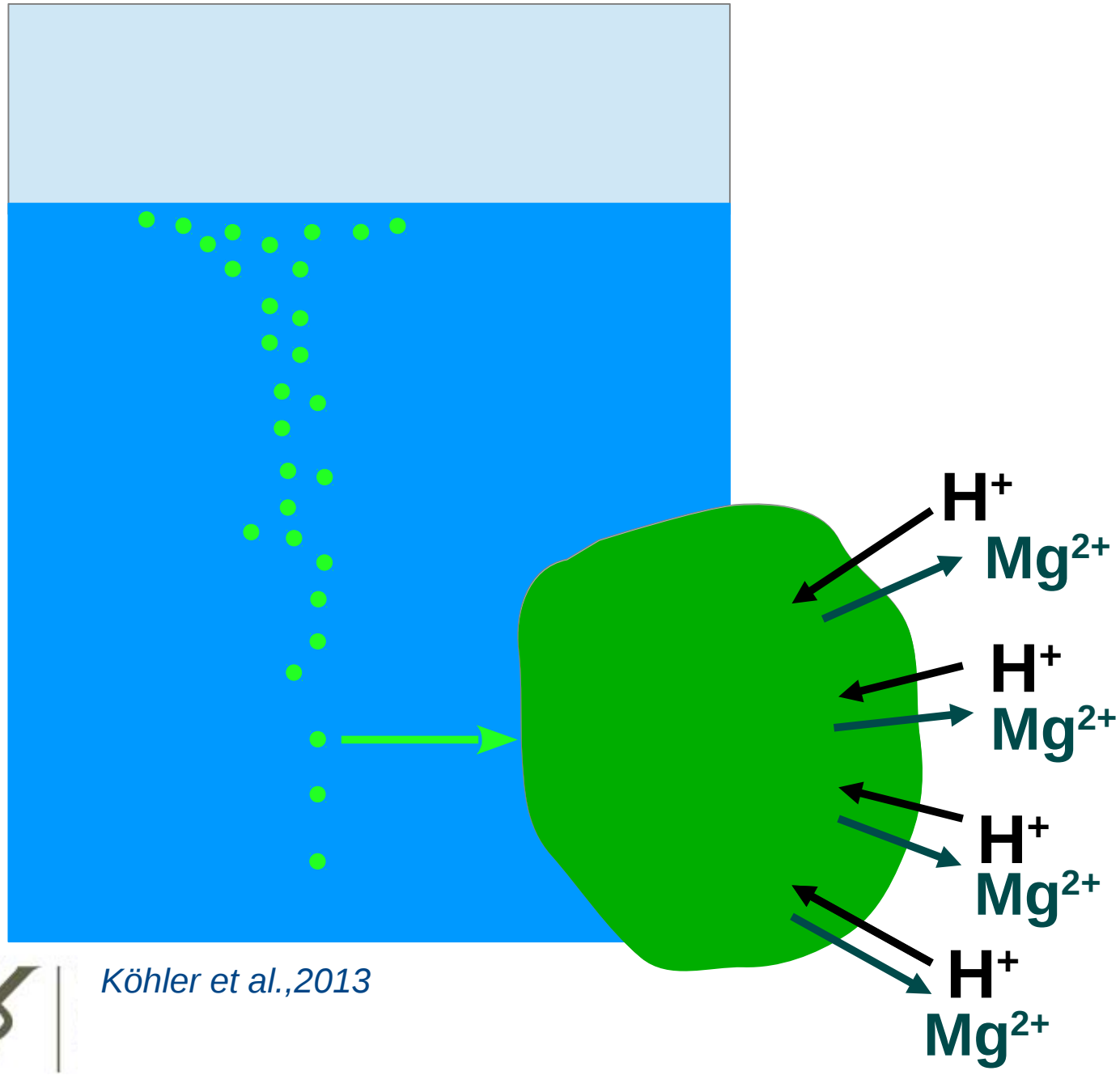


> 1 µm

→ sinks out (days-wks.)

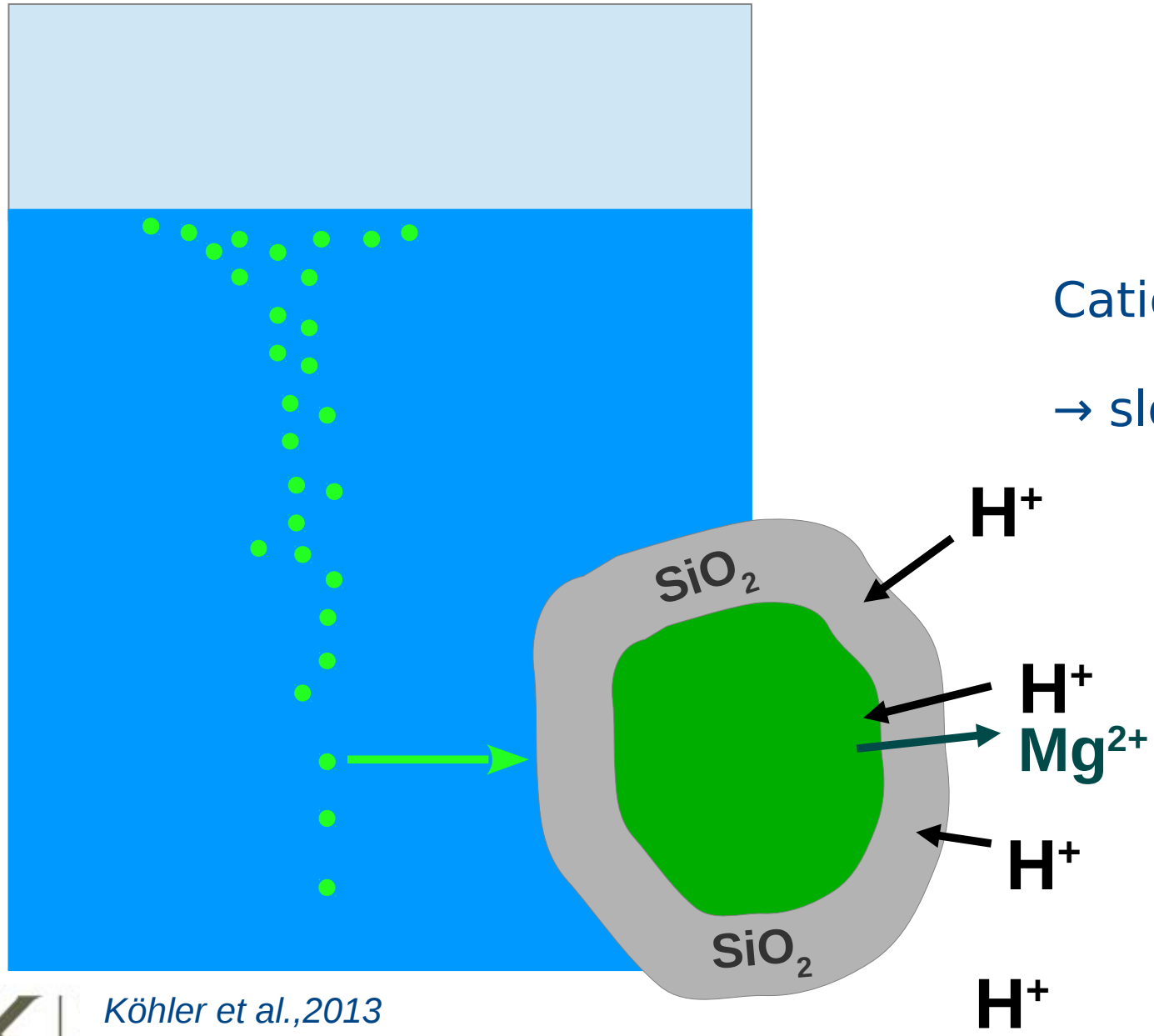
Köhler et al.,2013

Olivine in the open ocean



Köhler et al.,2013

Olivine in the open ocean

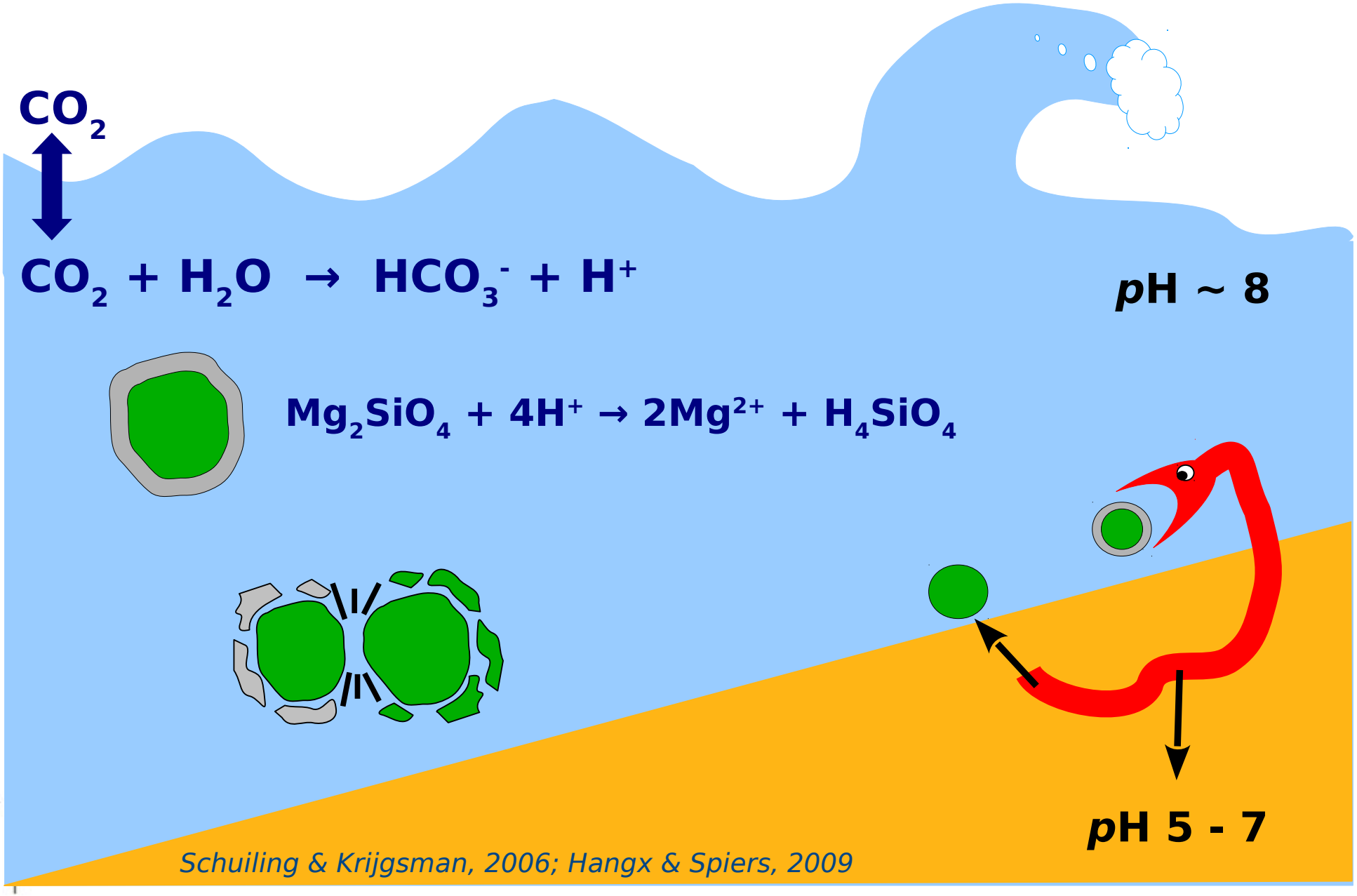


Cation-depleted layer

→ slows dissolution

Köhler et al.,2013

Coastal processes enhancing dissolution ?



Schuiling & Krijgsman, 2006; Hangx & Spiers, 2009

Olivine marine geo-engineering ?

!!! No experimental evidence !!!

- Olivine in **tap**water → pH ~ 9
  (*Schuiling & de Boer, 2011, Earth Syst. Dyn. Disc.*)

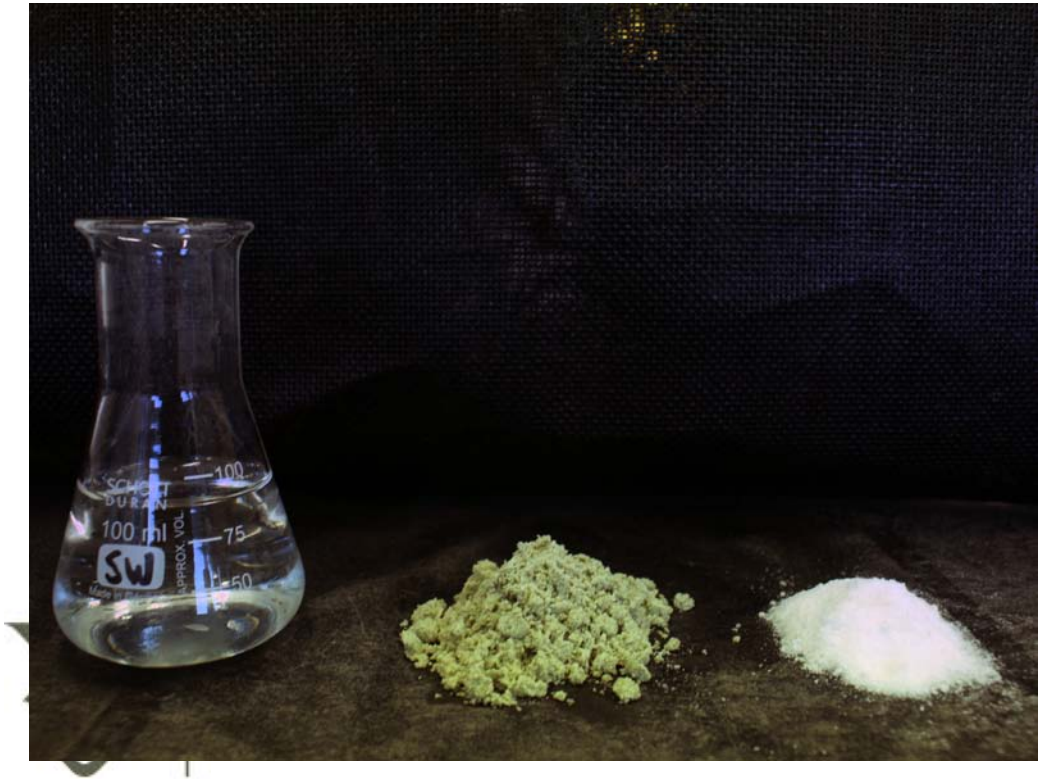
→ Earth surface conditions ?

→ Seawater chemistry ?

→ Proxies ?

Olivine dissolution process

- Physical mixing in coastal environment
- Simplify: Bottles on rotating table
- Filtered / artificial seawater
- Olivine (Mg_2SiO_4), Quartz (SiO_2), seawater only

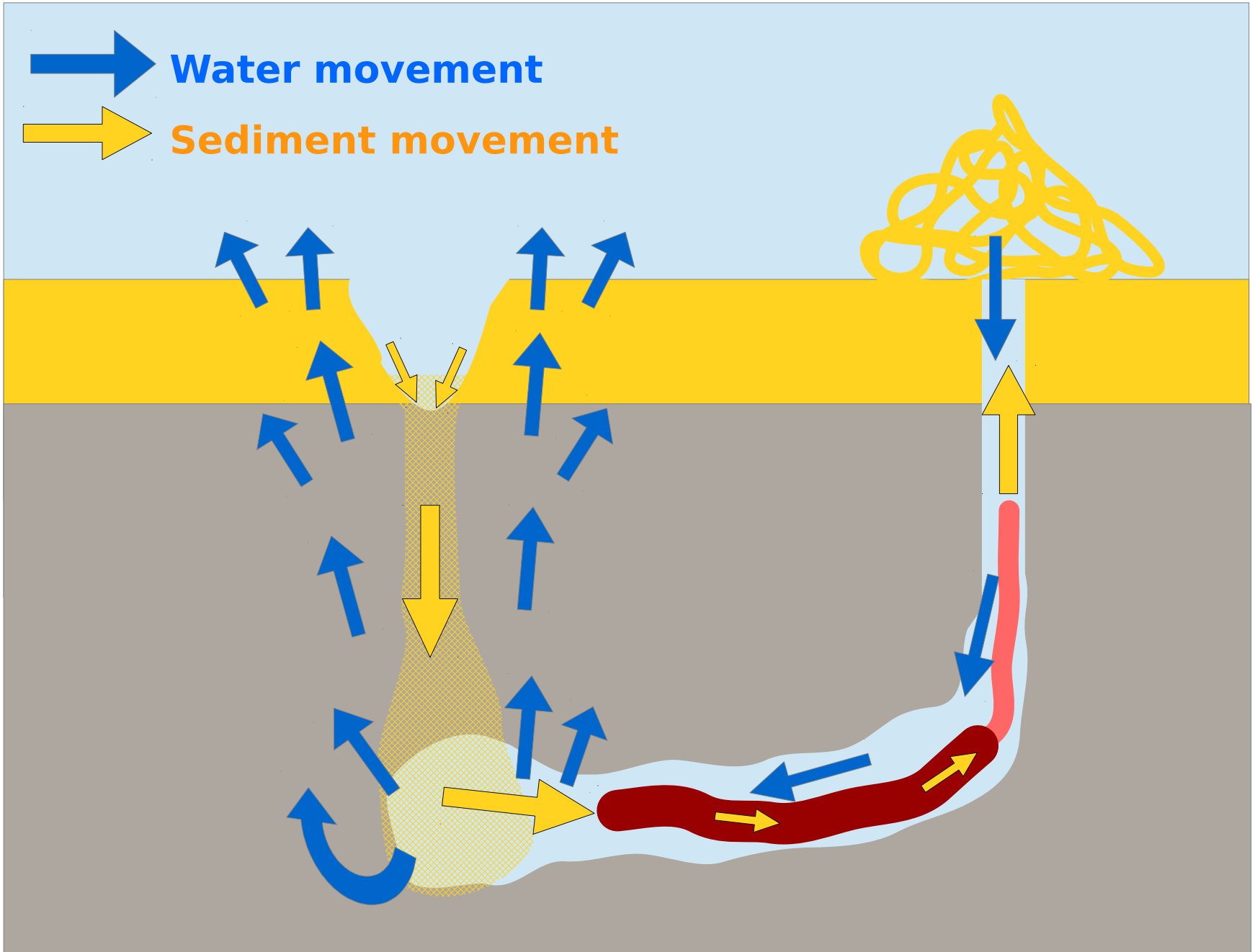


Into the Wild…

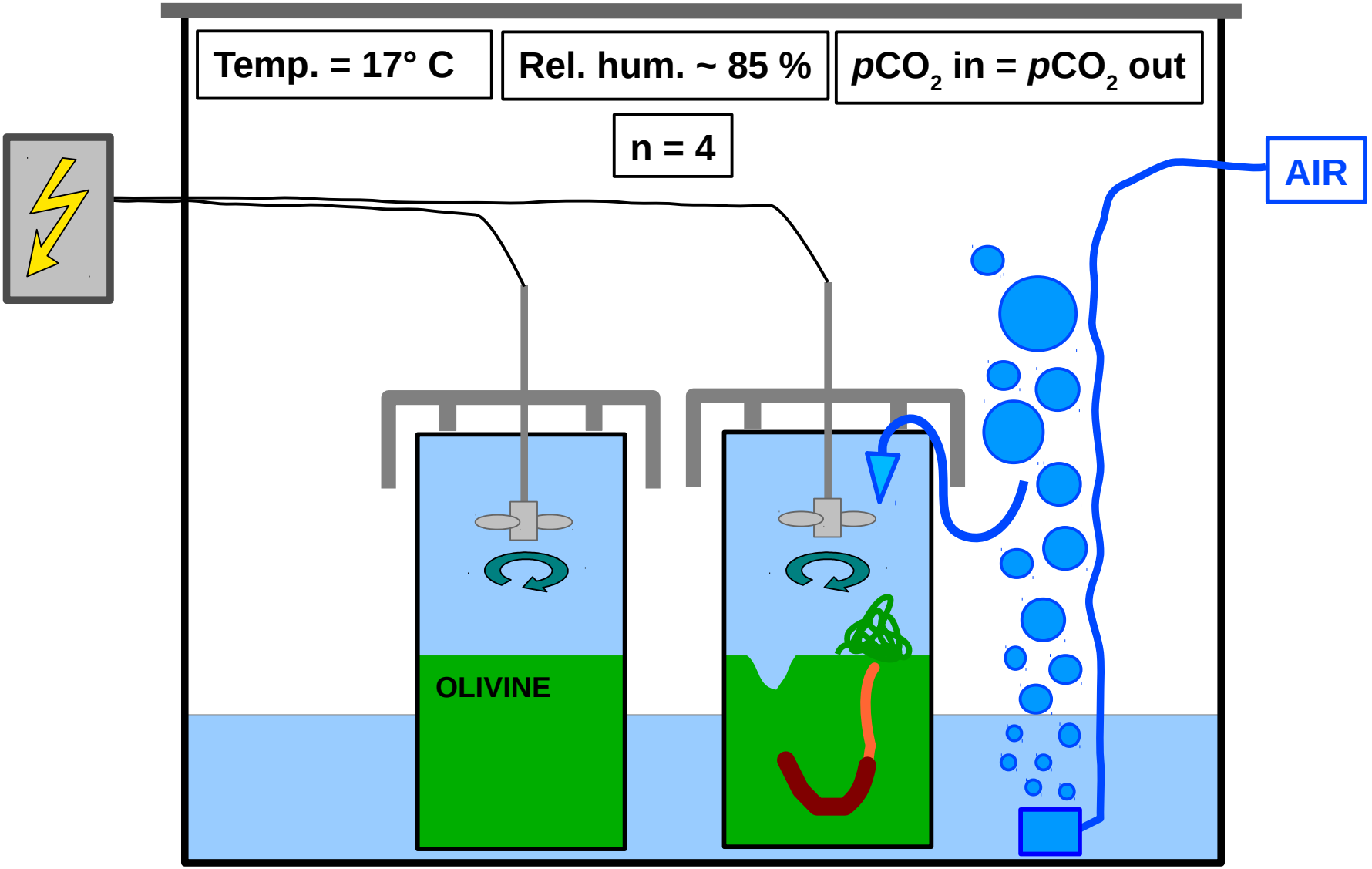
- Bottom fauna process sediment **→ bioturbation**
- Top 10 cm passes through in 1 year !
- Worms' intestine pH 5.5 - 7 (seawater pH ~ 8.1)

Lugworm: *Arenicola* sp.

Bioturbation & Bio-irrigation



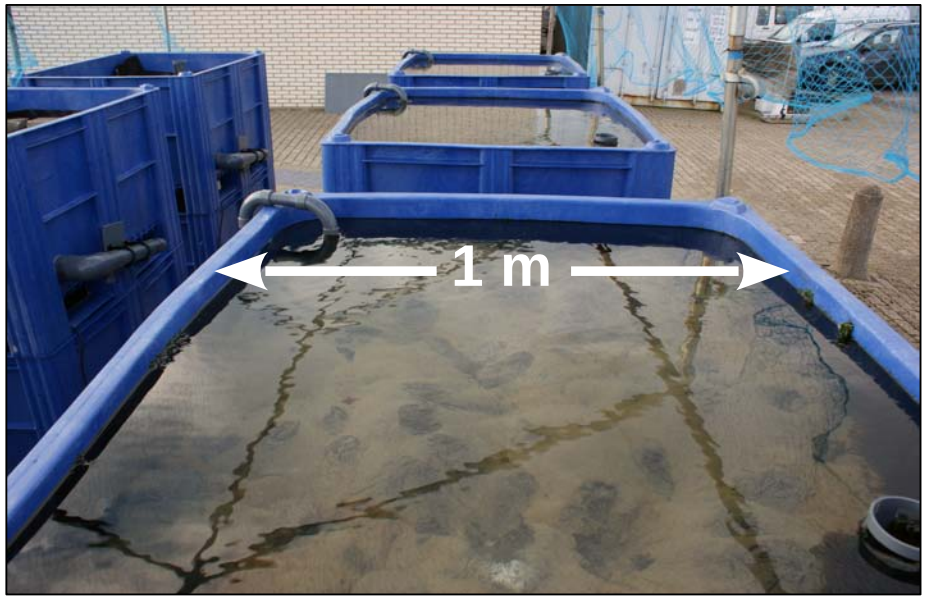
Bioturbation effects experiment



Montserrat et al., *in prep.*

Natural Sediment

- Olivine + real sediment → more complex !
- Mesocosm experiments
- Upscaling: 1 m^2 – 100 m^2 – 10.000 m^2



Coastal Applications

Marine infra

Aquaculture

Conservation

Ecosystem Effects

- Alkalinity ("acid buffering capacity")
  - Reef builders → corals, shellfish

- H_4SiO_4 (Silicate)
  - Diatoms → primary production
  - Sponges → species competition

- Turbidity !!!
- Ni (Nickel)
  - Ecotoxicity ?
  - Bio-accumulation / -magnification ?

Summary

- Olivine dissolution in seawater

  → seawater **alkalinisation**

  → dissolution rates within proposed range

  → stoichiometry affected by Ca/Mg precipitation ?

- Strong dissolution effect bioturbators

→ elemental composition solid phases (SEM-EDX)

→ work in progress...

- Far from realistic environmental conditions

Are we there yet ?!!

- Geochemistry ?
- Particle ?
- Ecosystem ?

→ Modelling, Empirical

- No silver bullet...but very promising !
- Local cure for global condition ?

- Efficiency analysis ***sensu*** Moosdorf et al. (2014)

- Multi / interdisciplinary approach !!!

Thank you for your attention !

Questions ?

Remarks ?

francesc.montserrat @ nioz.nl

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