Biogeochemistry as a tool for mine water treatment

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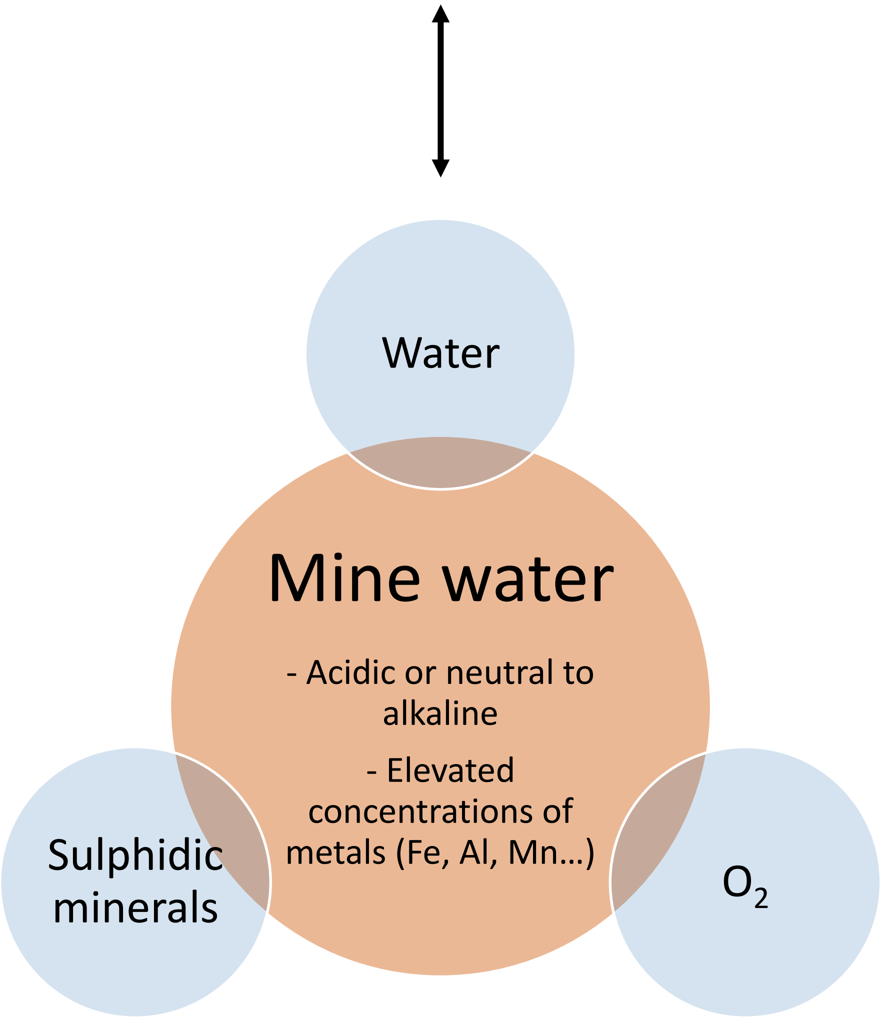
Team: Biogeochemistry at the Antropocene of Elements and Emerging Contaminants

Congrès des Doctorants (CDD) – March 2024 in Paris

Communicating biogeochemistry in the context of mine water treatment

Biogeochemistry : biology, geosciences and chemistry.



Environmental challenges associated with the mining industry:

- long-term pollution.
- impact on water resources.

Oxygenation cascade – Messeix treatment plant (France)

Treatment plants:

- subject to environmental regulations.
- based on biogeochemical mechanisms.

(D.B. Johnson, K.B. Hallberg / *Science of the Total Environment* 338 (2005) 3–14)

Mine water: which solutions?

1/ Prevention of mine water formation

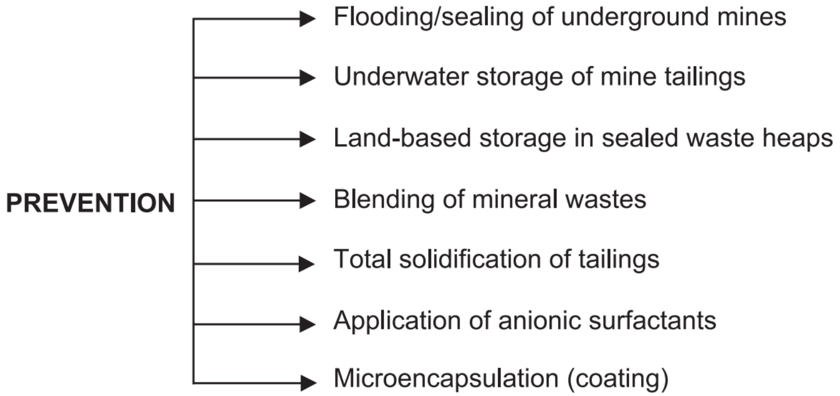


Figure 1 – Various approaches that have been evaluated to prevent or minimise the generation of mine drainage waters (taken from D.B. Johnson, K.B. Hallberg / *Science of the Total Environment* 338 (2005) 3–14)

2/ Treatment of mine water

<u>Non-exhaustive list of treatment systems:</u>

Active

- Addition of chemical-neutralising agent
- Addition of flocculating agent

Passive

- Aerobic wetlands
- Bioreactors
- Anoxic Limestone Drains

Aerobic wetland – Destival treatment plant (France)

Treatment systems

Table 1 – Importance of long-term management, cost-effectiveness and environmental sustainability of passive versus active treatment technologies.

Type	Passive	Active
Energy	Natural source energy (gravity, microbial metabolism, photosynthesis, geochemical reaction)	High consumption
Maintenance	Lower requirements	Continuous chemical dosage
Cost	Lower	Higher

→ when the **physico-chemical conditions** of mine water and the **design criteria** are compatible and viable

Main removal mechanisms

The main idea is to reduce contaminant concentrations through precipitation processes by increasing dissolved O_2 concentration and pH value.

- Oxidation/precipitation

$$4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O$$

$$4Fe^{3+} + 12H_2O \rightarrow 4Fe(OH)_3 + 12H^+$$

- Sedimentation
- Filtration
- Sorption

How can biogeochemistry help mine water treatment?

Aerobic wetland – Destival treatment plant (France)

The example of manganese (Mn)

Common contaminant in mine water.

Toxicity issues for ecosystems.

In 2021, the WHO has set a guideline value of **0.08 mg.L^{-1}** of Mn in drinking water, based on health considerations.
(World Health Organization (2021) Manganese in drinking water: background document for development of WHO Guidelines for drinking-water quality)

The discharge threshold in France is set at **1 mg.L^{-1} or less** (prefectoral decrees).

Table 2 – Typical concentrations of manganese in mine water and observed removal efficiency associated with a specific passive treatment system.

Initial [Mn] (mg.L^{-1})	**Type of passive treatment system**	**Removal efficiency (%)**	**References**
1.6 – 2	Aerobic wetland	0 - 100	Moorhouse-Parry et *al*., *IMWA Conf*. (2023)
6 - 30	Pyrolusite system	10 - 100	Rose, Arthur W., et *al*., *ASMR* (2003) pp 1059 – 1078
3.6	Dispersive Alkaline Substrate	3	Orden, Salud, et *al*., *Journal of environmental management* 280 (2021): 111699
0,29 – 70	Oxic limestone bed	44.3 – 98.4	Fubo Luan et *al*., *Mine water and the Environment* (2019): 130-135
1.1 – 1.5	Biofilters	34 - 97	Jacob Jérôme et *al*., Water 14 (2022): 1963
3.1 – 4.6	Aerobic wetland	43 - 92	This study
1.4 – 1.6	Aerobic wetland + biofilters	100	This study

Manganese removal

Dissolved form

Mn^{++}

Oxidation / Precipitation

Mineral

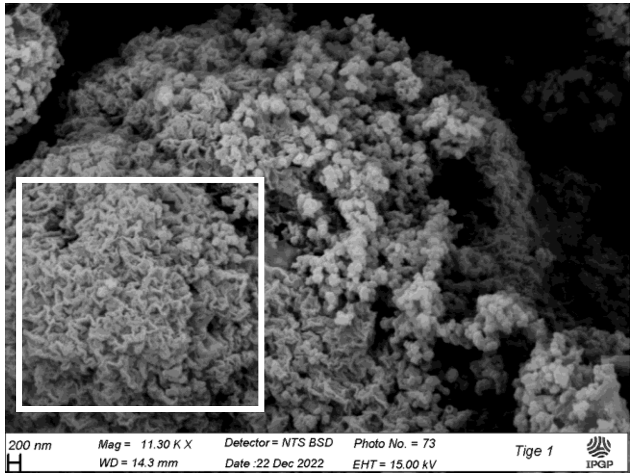
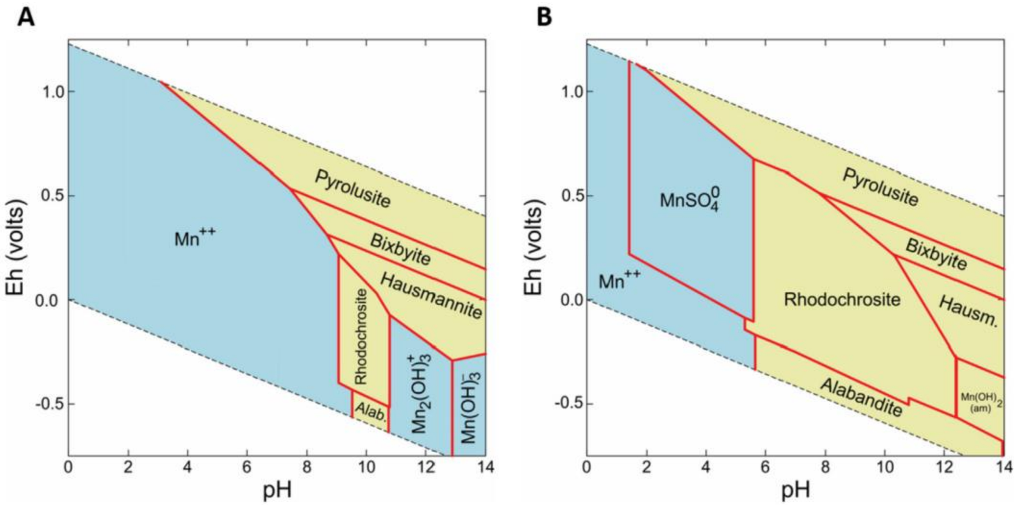


Figure 2 – SEM image of Mn(III/IV) oxide minerals sampled at the passive treatment of Alès (France)

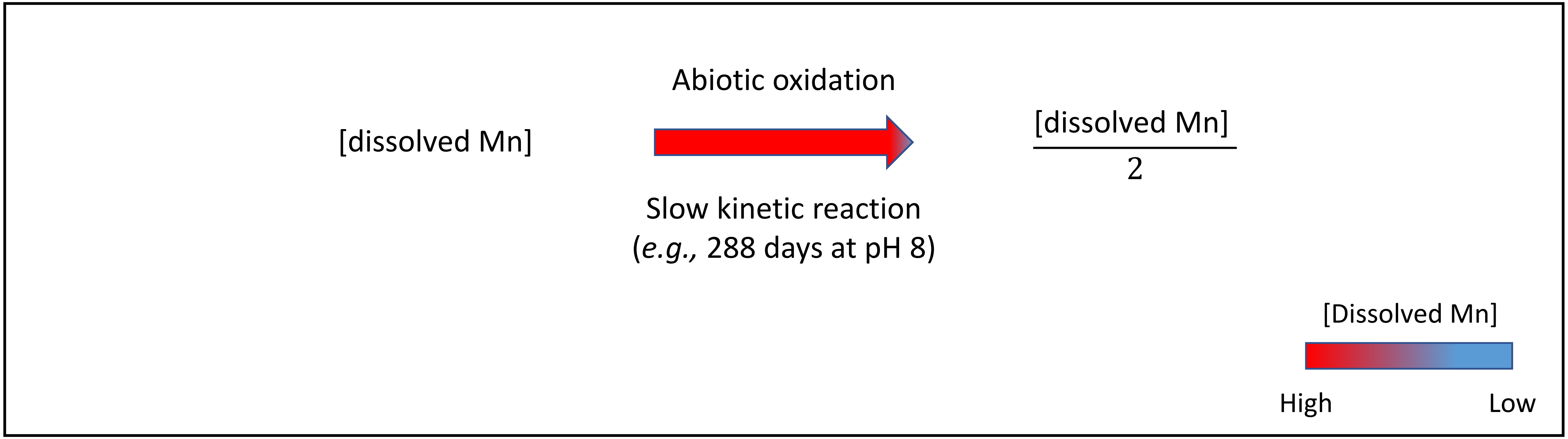


→ Precipitation depends on physico-chemical conditions

Figure 3 – Eh-pH diagram for Mn from C.M. Neculita, E. Rosa / *Chemosphere* 214 (2019) 491-510.
A) Fresh water condition and B) in mine water condition with high concentrations of SO_4^{2-} and HCO_3^-.

Manganese removal limitation

In acidic or neutral pH and well-aerated waters conditions



(C.M. Neculita, E. Rosa / *Chemosphere* 214 (2019) 491-510)

→ Dissolved Mn removal rate too slow for passive treatment plant design criteria

Management significance:

"**Additional** and more **expensive** treatments would be required to abate Mn below the regulated values" (S. Orden et al. / *Journal of Environmental Management* 280 (2021) 111699)

Importance of biogeochemical processes

In acidic or neutral pH and well-aerated waters conditions

Abiotic oxidation	+	Biotic oxidation	=	Abiotic and biotic oxidation
Autocatalytic oxidation (*e.g.,* 29 days at pH 8)		Direct or indirect processes		

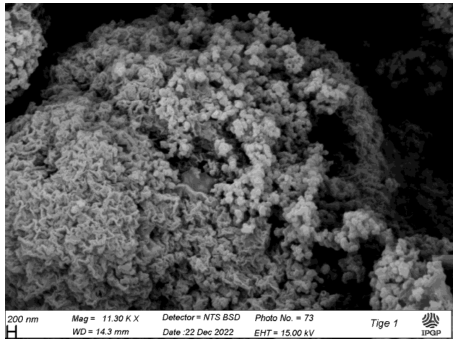


Figure 4 – SEM image of Mn oxide minerals sampled at the passive treatment of Alès (France)

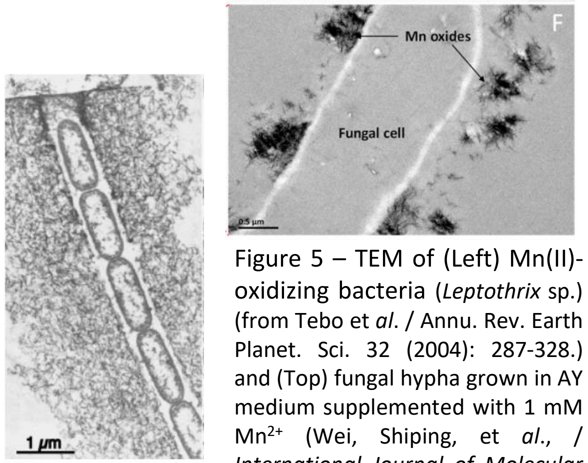


Figure 5 – TEM of (Left) Mn(II)-oxidizing bacteria (*Leptothrix* sp.) (from Tebo et *al.* / Annu. Rev. Earth Planet. Sci. 32 (2004): 287-328.) and (Top) fungal hypha grown in AY medium supplemented with 1 mM Mn^{2+} (Wei, Shiping, et *al.*, / *International Journal of Molecular Sciences* 24.23 (2023): 17093).

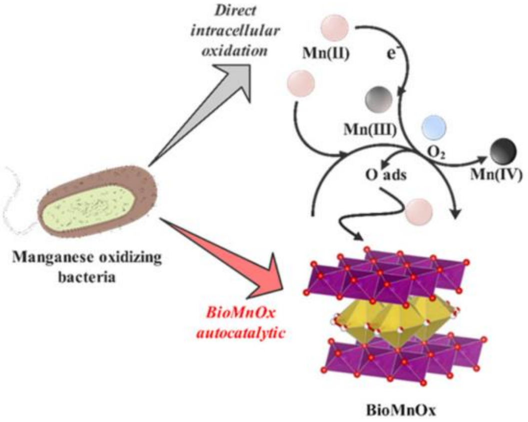


Figure 6 – Schematic drawing of bio-mediated Mn removal by biogenic manganese oxides (BioMnOx) in the sand filtration process *(from Yang, Haiyang, et al. / Environmental Science: Water Research & Technology 9.10 (2023): 2631-2642.)*

[Dissolved Mn]

High — Low

→ **Catalytic processes for the removal of dissolved Mn.**

(C.M. Neculita, E. Rosa / *Chemosphere* 214 (2019) 491-510)

Mine water remediation gaps

Mn elimination processes are based on biogeochemical mechanisms.

But:

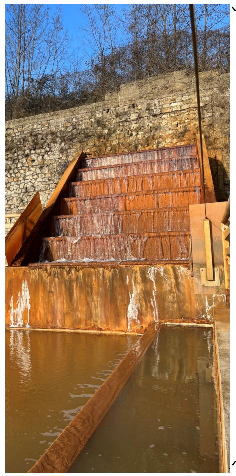
- Evaluate the importance of chemical and biological processes contributing to manganese removal in mine water treatment plants.

- Characterization of the factors involved in the removal rate of Mn.

→ Developing efficient long-term treatment plants

Messeix treatment plant (France)

Field observation to identify limiting parameters

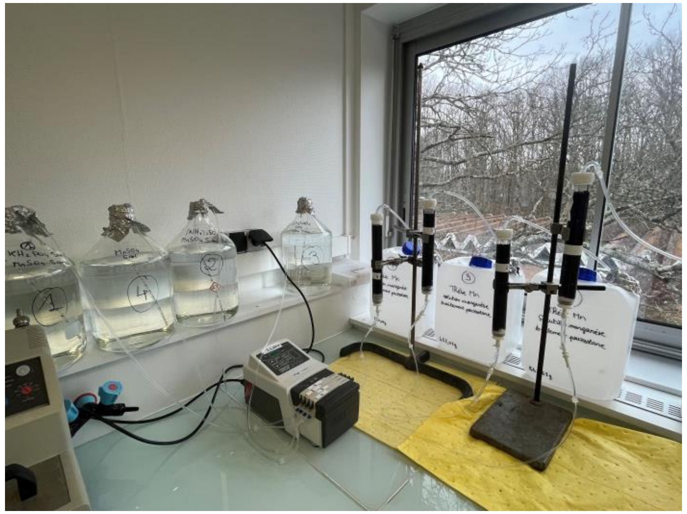


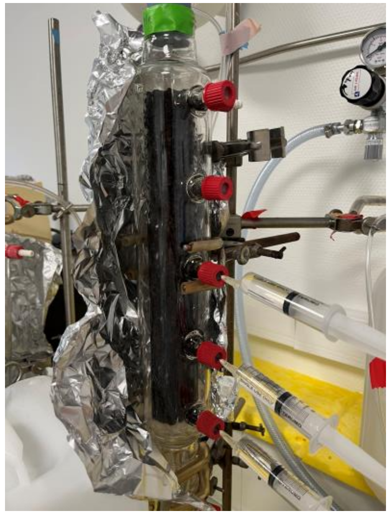
Water composition: ICPOES ; IC ; TOC

Physico-chemical parameters: probes and µ-probes

Microorganisms: DNA sequencing

Bioreactors





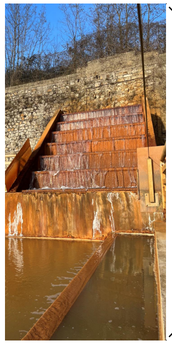
Test of various parameters:

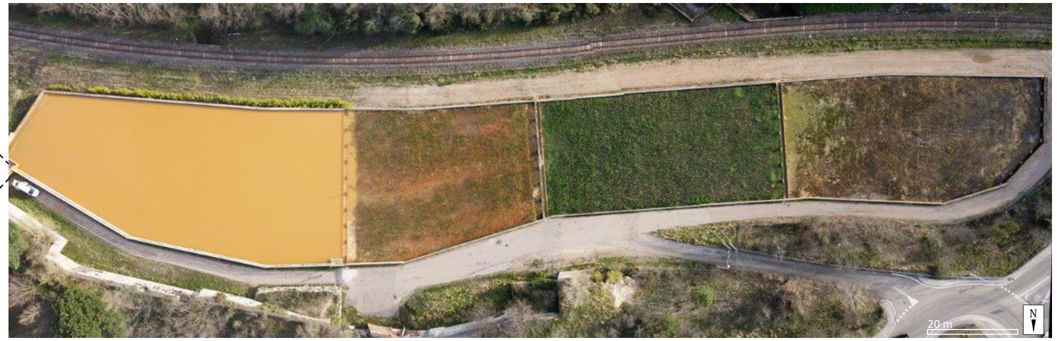
→ Addition of nutrients

→ Low or high [Fe]

→ Temperature

Field observation to identify limiting parameters





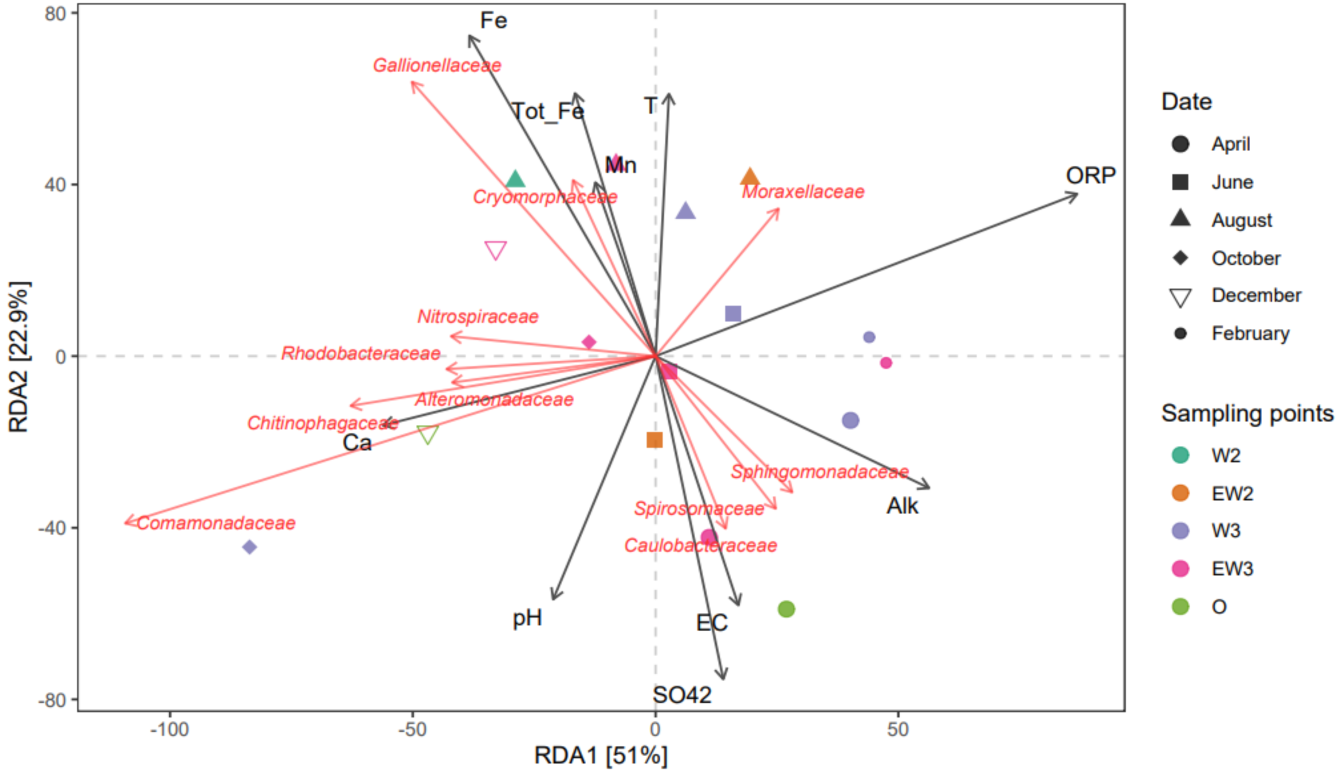


Figure 7 – Redundance analysis (RDA) of the 10 principal taxa at the family level

- Presence of *Alteromonadaceae* and *Comamonadaceae*
- Precipitation of rhodochrosite and Mn oxides ($Mn(II)CO_3$ and δ-$Mn(III/IV)O_2$ confirmed by XAS analysis)

Bioreactors

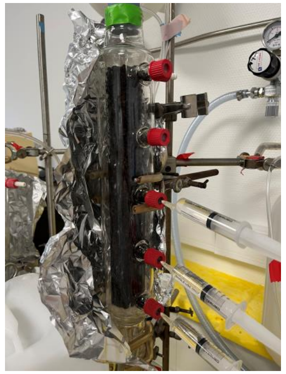
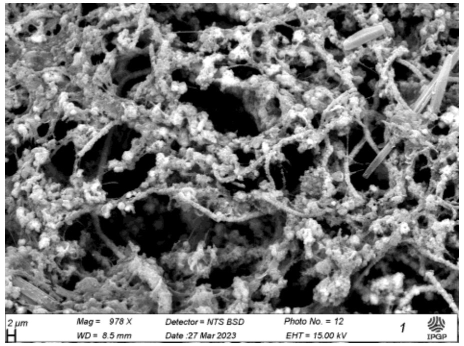
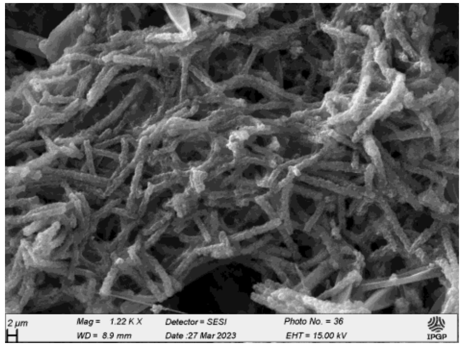
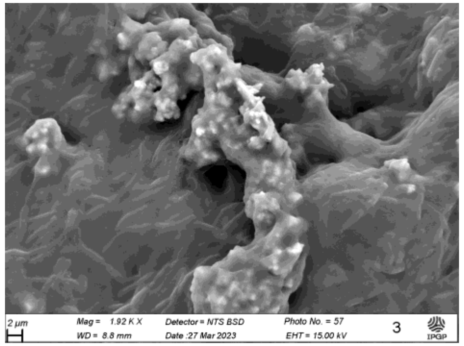
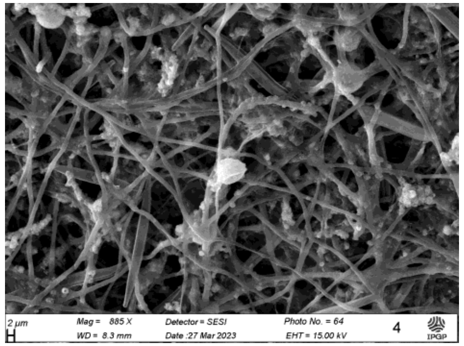


Table 3 – Bioreactor experimental conditions.

N° column	**1)**	**2)**	**3)**	**4)**
Conditions*	1mg/L Mn 0,01 mmol/L **P + Mn**	1 mg/L Mn 0,2 mmol/L **N + Mn**	1 mg/L Mn 1 mmol/L **C + Mn**	1 mg/L **Mn**
SEM images of minerals in each bioreactor, from left to right: P ; N ; C ; only Mn.				
Removal efficiency (%)	100	60 - 100	0	100

*Flow rate 0,7 – 0,75 mL/min

Conclusion: Biogeochemistry as a tool for mine water treatment

- Mine water can have a adverse effect on water bodies: elevated metals concentration and low pH value.
- Biogeochemical mechanisms are essential to mine water treatment.
- For design and management purposes, biogeochemical mechanisms need to be better understood.

Let's get humans, plants and micro-organisms working together for a better water quality !

Thank you for your attention