Performance of natural and residual materials for mine water treatment and mine sites rehabilitation

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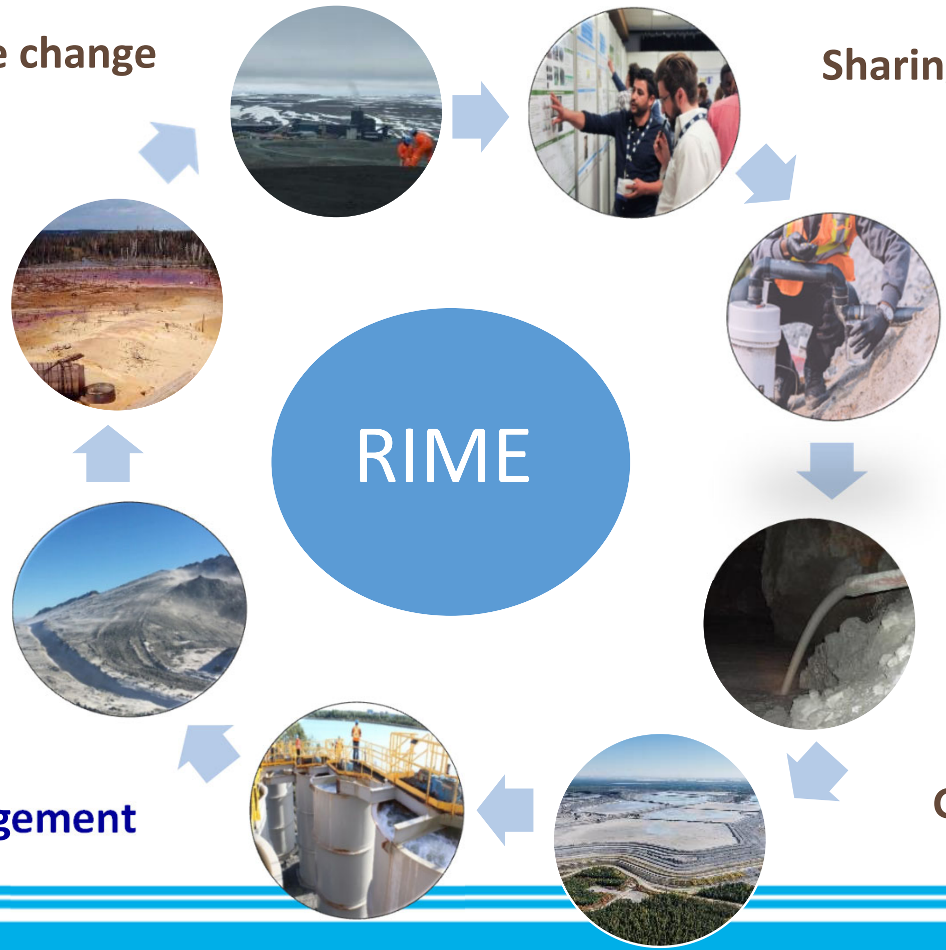
Morgantown, WV, April 22, 2024

Research topics



Arctic conditions and climate change

Sharing knowledge with communities

Geology, geoenvironmental characterisation
Prediction of mining effluents quality

Integrated management of mine waste
Valorisation of mine waste

Geotechnical stability of tailings impoundments

Water treatment and management

Contaminants transport in the environment

Site reclamation and revitalisation

Industrial partners mine sites









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Introduction: Mines and water contamination

Contaminants	**Mine drainage** (runoff water)		**N-based compounds** (mine effluents)	
	AMD (acid mine drainage)	NMD (neutral mine drainage)	CN^-, SCN^-	Ammonia (NH_3-N)
Sources	Metal sulfides + O_2 + water		Au, Ag extraction + blasting agents (ANFO)	
Characteristics	**pH < 3; high [] metals (Fe >1g/L), sulfates**	**Metal [] > criteria**	Ore dependent, **but [] > criteria**	
Why prevent or treat?	Regulation, environmental and social impacts			
Challenges	**Several contaminants**	**High contaminant mobility**	**Complexity (toxicity, costs, flowrates)**	
Treatment issues	Sludge management (quantity, stability)	Limited knowledge	Low kinetics of N oxidation	
Research work (RIME)	**Use of natural and residual materials (raw vs modified) for prevention and control of mine water contamination, and mine sites rehabilitation**			

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Natural and residual materials for mine water treatment and sites rehabilitation

Case study	AMD/NMD prevention	Passive treatment
I: East-Sullivan mine site	Residual organics cover	Constructed wetlands + water pumping through the organic cover
II: Manitou mine site	Desulfurized non-acid generating tailings cover	(To be designed and constructed)
III: Wood-Cadillac mine site	Inert sand-based cover	Wood-based biofilter
IV: Lorraine mine site	CCBE (cover with capillary barrier effect) – multi-layer	Anoxic dolomite drains + tri-unit biochemical train

V: New materials	Modification / Improvement	Use
Charred dolomite	Enhanced specific surface and porosity, increased pH and alkalinity generation	Synthetic NMD treatment
Modified wood ash		Real NMD treatment
Activated biochar	Porosity arrangement	Real AMD treatment
N-rich residuals	N/A	Non-acid generating tailings revegetation

- **Ongoing research**
- **Concluding remarks**

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Location of East-Sullivan and Manitou mine sites

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I East-Sullivan mine site: operation, abandonment, rehabilitation

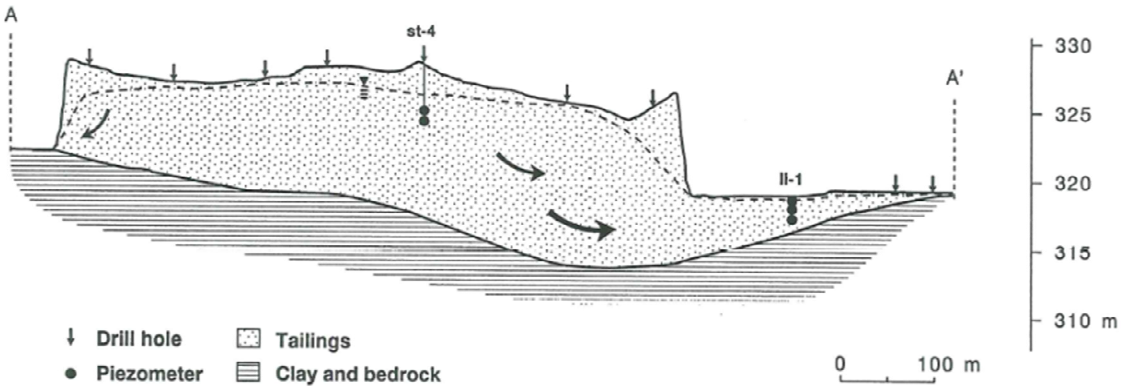

Figure 2. Cross-section A-A' through the East-Sullivan tailings impoundment. Arrows indicate locations of drill holes to the bedrock or clay basement. Dots represent piezometer locations for water sampling.

- **Low pore-water quality in 1992**
  - pH ≈ 2
  - Fe (Fe^{2+}): up to 17 g/L
  - SO_4^{2-}: up to 37 g/L
  - Cu, Pb, Zn : 0.1-1 g/L

➡ **High strength AMD**

Long-term treatment OR prevention and temporary polishing?

(http://sebastienlavoie.com/maitrise/photos.html; http://www.mrn.gouv.qc.ca/mines/restauration/restauration-sites-east-sullivan.jsp; https://www.oiseauxduquebec.org)

East-Sullivan organic cover: mine site rehabilitation

- **1984: Organic waste (residual wood and biosolids) cover instalment for AMD prevention and [temporary] treatment**
- **1990:** Seepage collection system
- **1992-1996:** Confining dike (6 km) + water polishing in constructed wetlands
- **1998-2005:** Collected AMD in constructed wetlands pumping through the organic cover
- **2019-2020:** Wood cover completion

  ⇒ **Some effluents were still acidic**

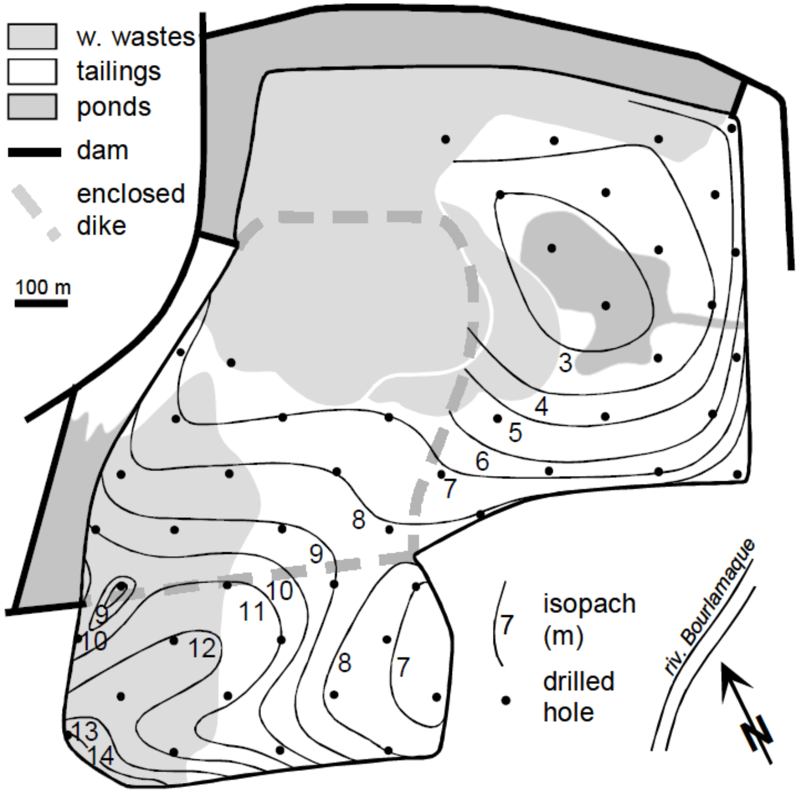

Figure 1. Map of the East Sullivan tailings impoundment in 1994

(Germain et al., 2009)

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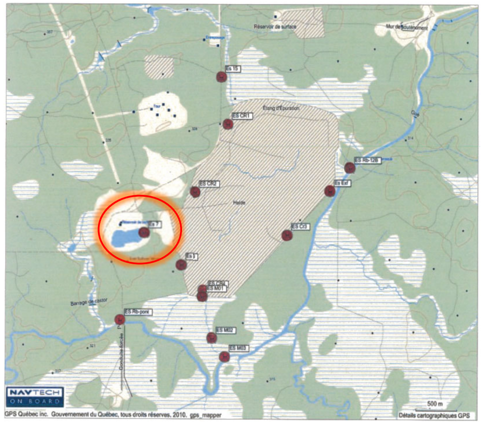
East-Sullivan organic cover: mine site monitoring

- **Network of sampling points**
  - over 20-year data
- **Parameters analyzed**
  - pH, Fe, Cu, Zn (+ Al, Mn, Pb, SO_4^{2-})
- **Compliance, <u>except for the last covered tailings</u>**

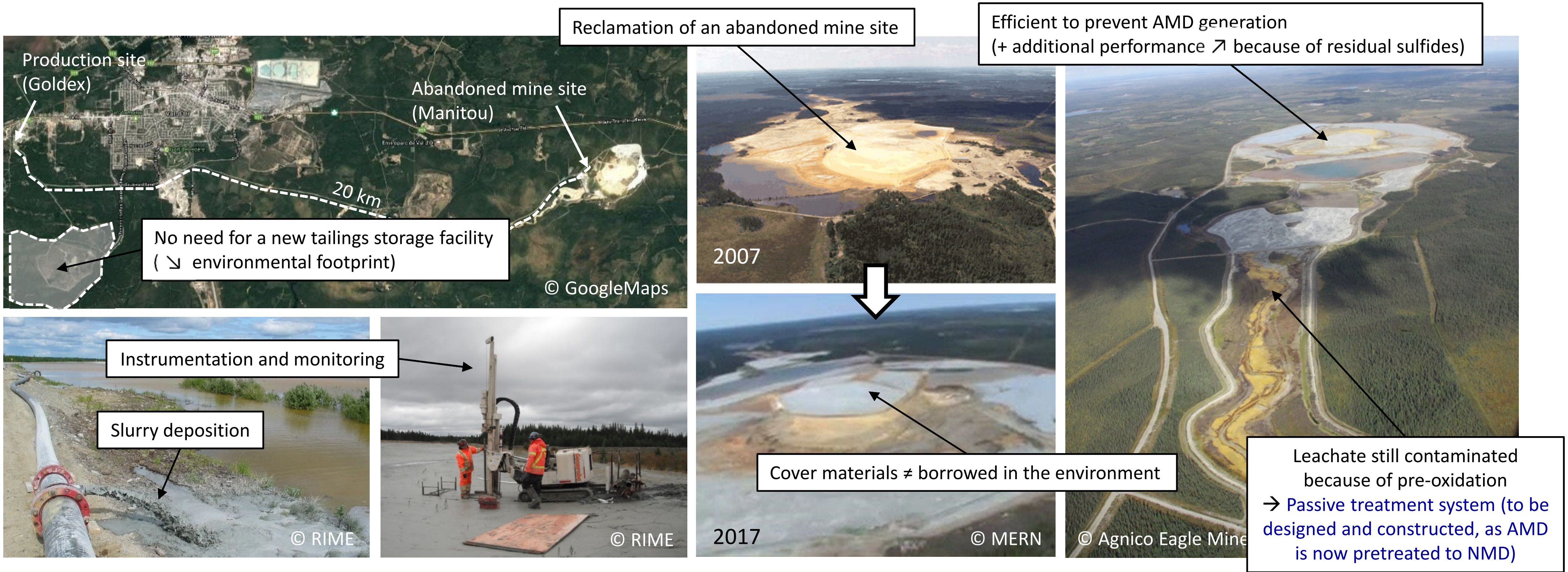


- Covered tailings and constructed wetlands: **blooming vegetation** and **birds' refugee** (> 190 species listed)

(Rakotonimaro et al., 2015; Malki & Roy, 2024; https://www.google.ca/flickr.com)

Desulfurized tailings cover: Manitou mine

- Prevention and pretreatment of AMD (pH: 2-3; 10-12 g/L Fe; 0.6-1 g/L Zn; 0.1-1 g/L Cu; 30-40 g/L SO_4^{2-})



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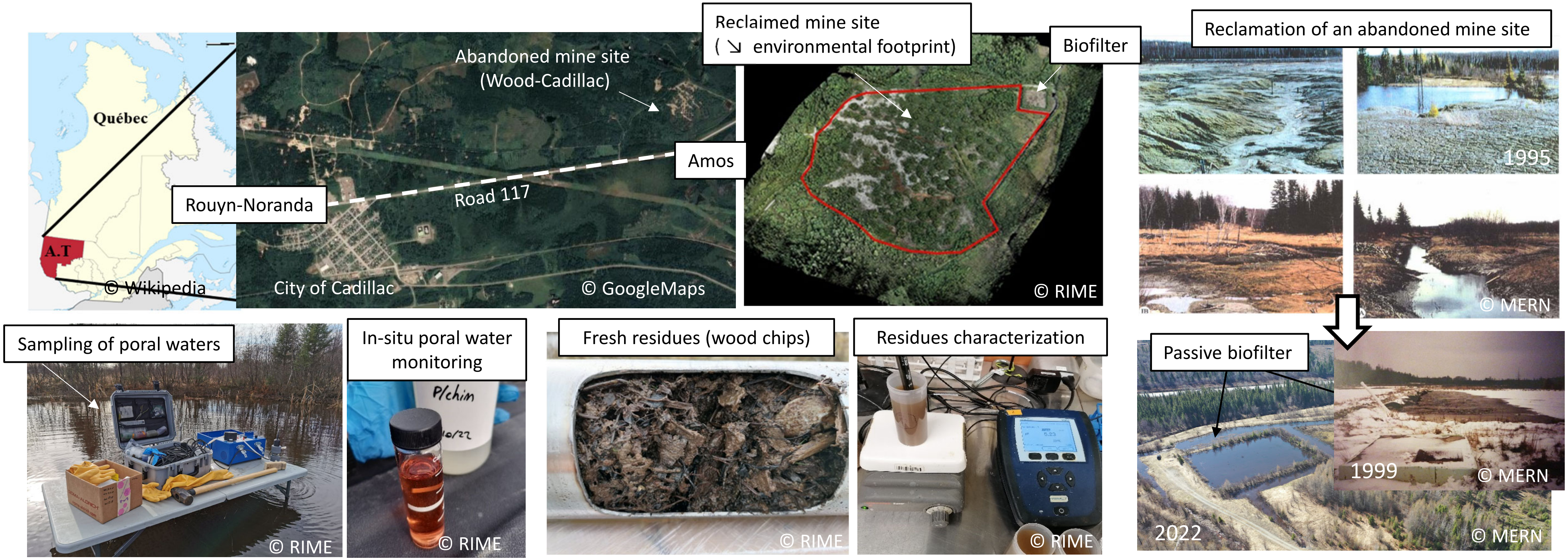
Sand cover + wood-based biofilter: Wood-Cadillac mine site

- Efficient passive treatment of As-NMD: removal of As & metals; decrease of SO_4^{2-} [] to < 200 mg/L



(Germain & Cyr, 2003; Libéro, 2007; Mehdaoui et al., 2024; Thevenot et al., 2024)

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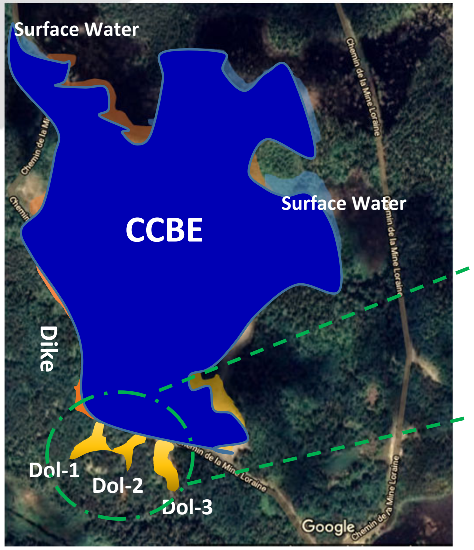
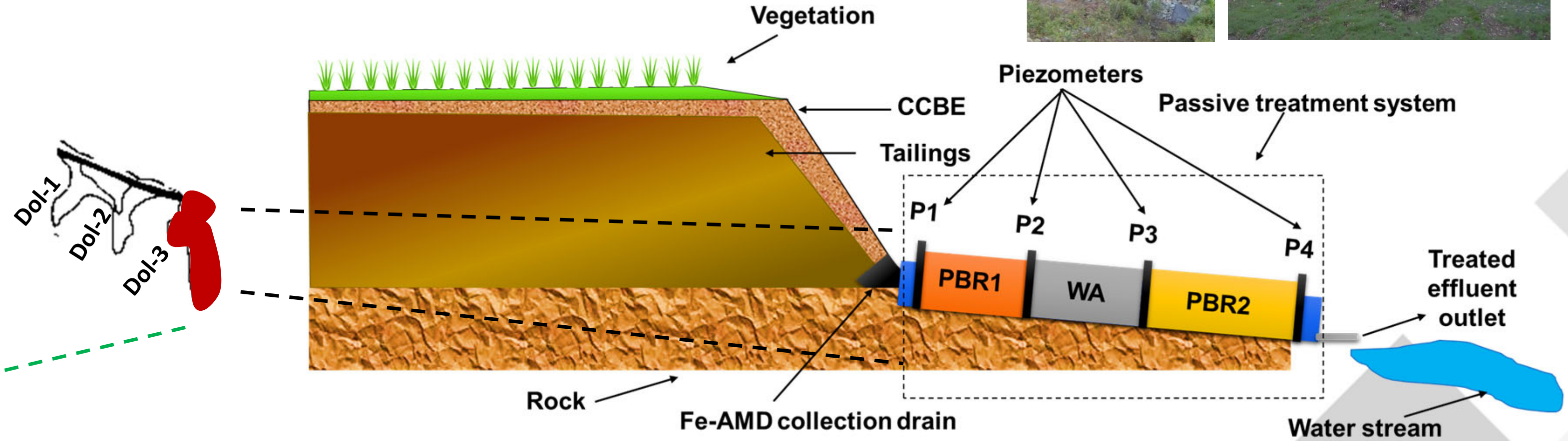
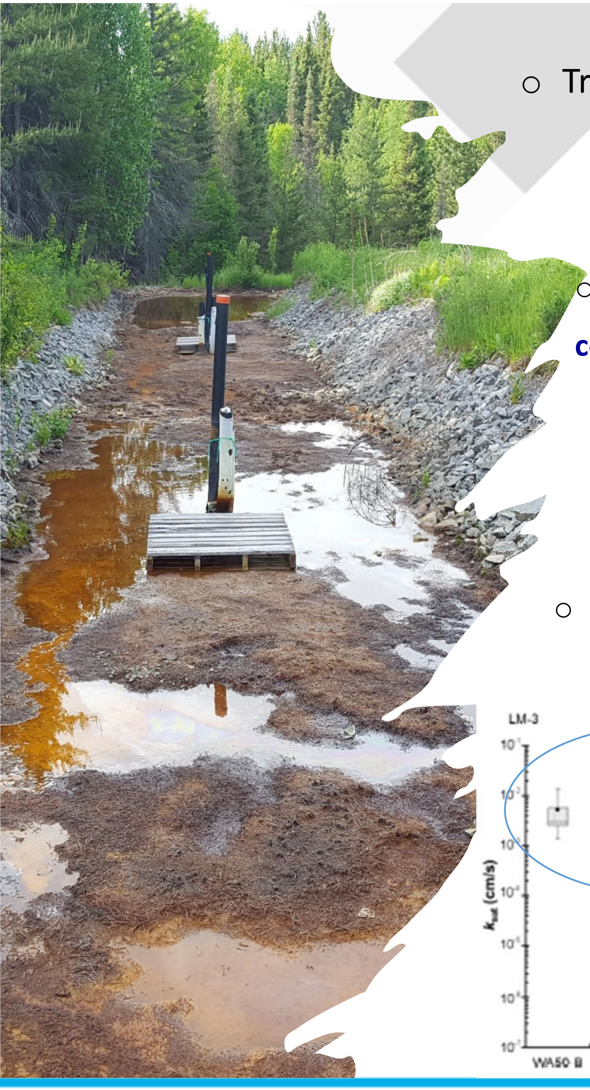
CCBE + passive treatment: Lorraine mine site





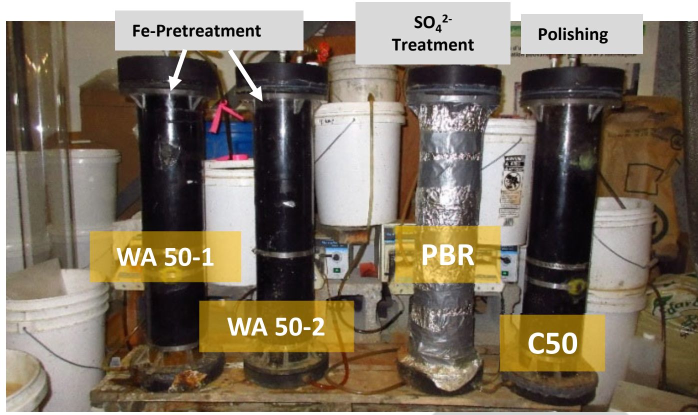
- **1964-1968:** Extraction of **Cu, Au, Ag, and Ni**
  - Acid generating tailings: 15.5 ha (up to 6 m)
  - AMD: pH=3.6, 7 g/L Fe and 15 g/L sulfates
- **In 1998: Mine site reclamation**
  - Multi-layer dry cover with capillary barrier effect (**CCBE**): O_2 prevention
  - **AMD treatment: 3 anoxic dolomite drains** (Dol-1 to Dol-3)
- **In 2011: Dol-3 clogged**, replaced by **tri-unit system: PBR1-WA-PBR2**
  (AMD: pH < 4, 3g/L Fe)
  - **PBR1**: 40% organics, 60% inorganics (**pH ↗, sulfate removal)**
  - **WA**: 100 % wood ash (**Fe treatment**)
  - **PBR2**: 77% organics, 23 % inorganics (**polishing**)



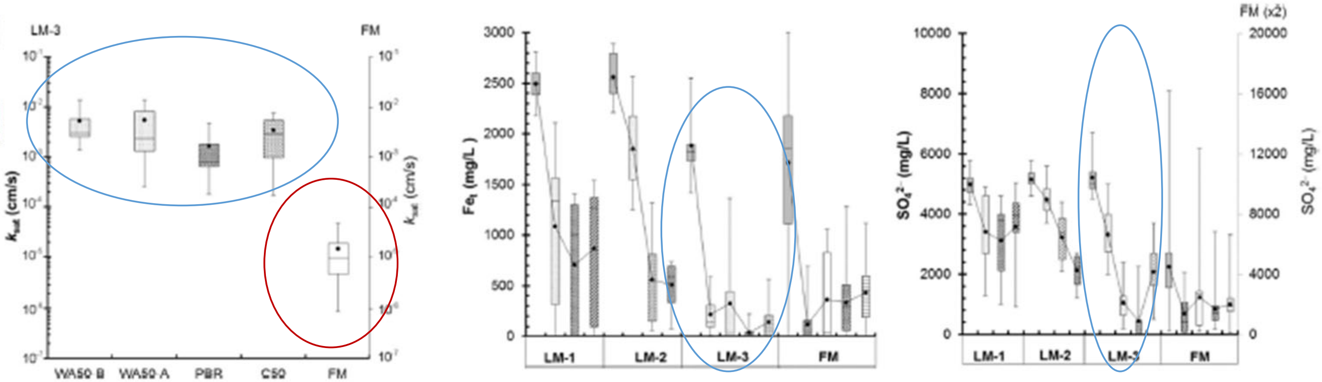
- Tri-unit system **progressive loss of efficiency**: PBR1-WA-PBR2
  - **Porosity clogging** by Fe minerals
  - **Preferential flow** and partial water **bypassing** the system

→ **New multi-step system ?**

- Multi-step system **calcite-/dolomite-DAS (dispersed alkaline substrate: coarse material + neutralizing agents)** & **passive biochemical reactors**
  - 2 Fe pretreatment units (50% wood chips + 50% wood ash)
  - 1 SO_4^{2-} treatment unit (70% organic + 30% inorganic matter)
  - 1 polishing unit (50% calcite + 50% wood chips)



- **Correction factor** of **0.2–0.8** for **Q and Fe removal** + factor **1/100** for k_{sat} (measured in laboratory)



(Rakotonimaro et al., 2018)

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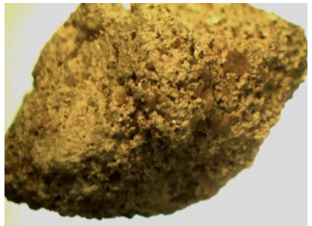
Va New materials: Sources and modification procedures

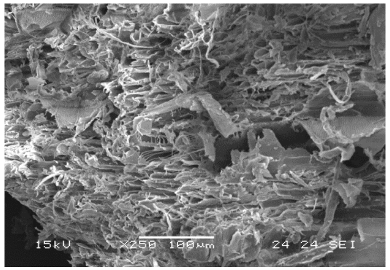


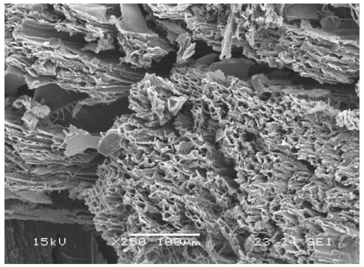
Material	Parameter		Composition (%)		
	pH_{paste}	Porosity	Dolomite [$CaMg(CO_3)_2$]	Calcite [$CaCO_3$]	Magnesia [MgO]
Raw dolomite	7.9	0.44	**87.1**	BDL	BDL
Half-charred dolomite	**11.6**	**0.56**	**7.2**	**53.7**	**19.9**

- **Half-charred dolomite: dolomite** content **decreased, two new minerals** were **created**

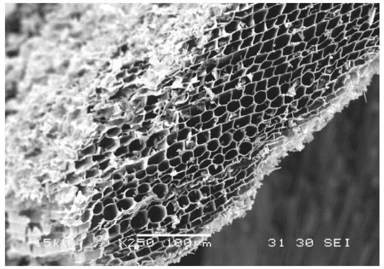
Parameter	Ash B	**Ash B modified**	Ash W	**Ash W modified**
pH_{paste}	13.8	12.6	9.3	12.8
CEC, meq /100g dry	138	322	66	311

- **Wood ash: modification generated high CEC and paste pH new materials**





Step 2: Activation (chemically: KOH, H_3PO_4 or physically: steam, CO_2)



- **Activated biochar: arranged porosity**

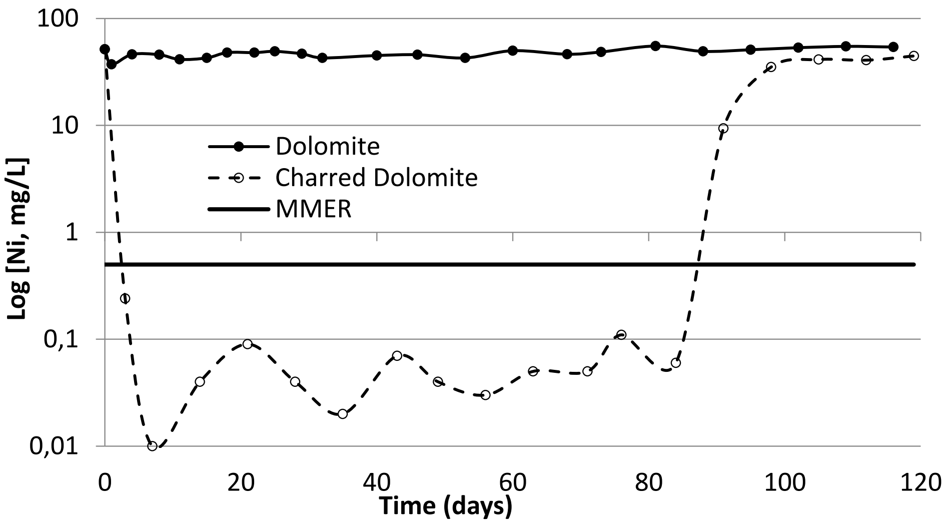
Step 1: Torrefaction, slow to flash pyrolysis, or gasification under different operating conditions

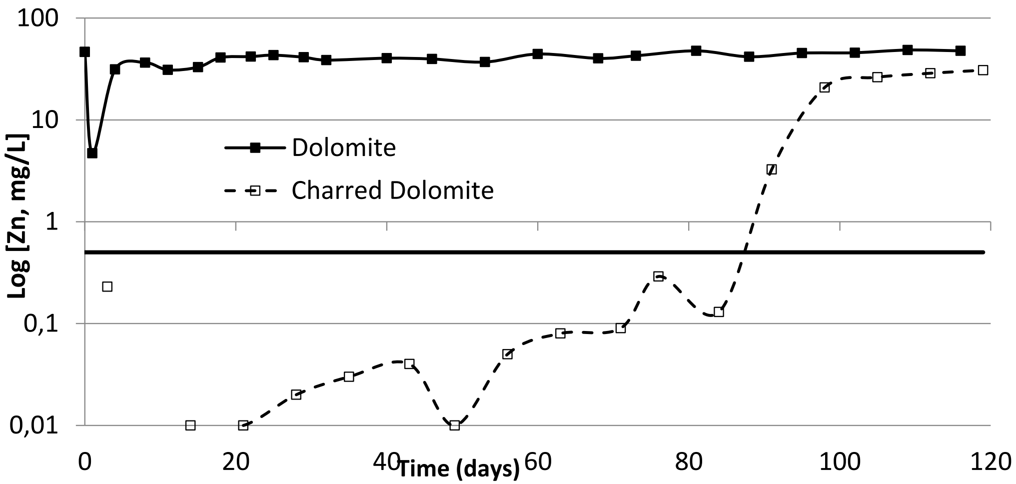
(Calugaru et al., 2016-2020; Braghiroli et al., 2018)

Va

Raw vs modified dolomite: Ni, Zn removal in synthetic NMD

- **Significantly better efficiency of charred dolomite for Ni and Zn removal** (50 mg/L each)

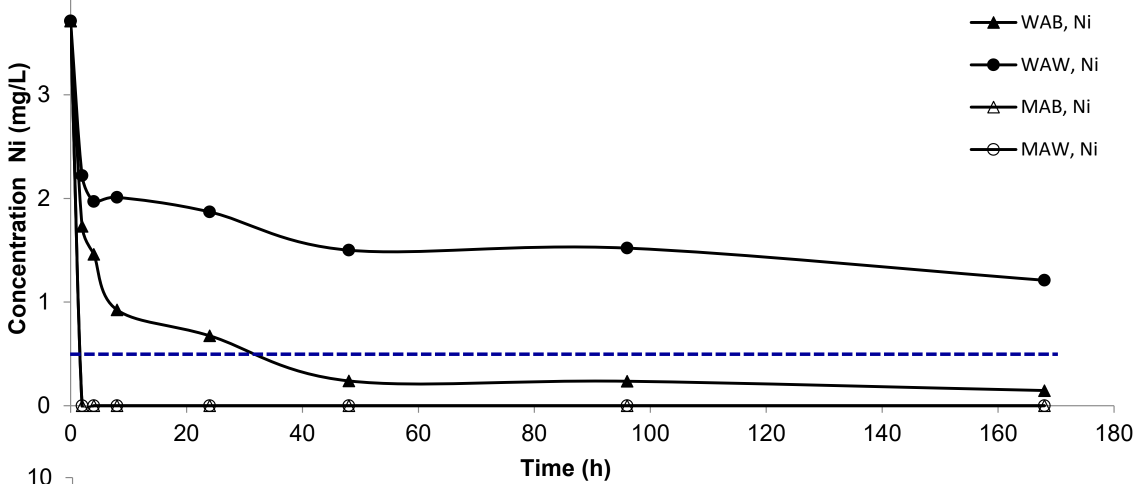




Criteria

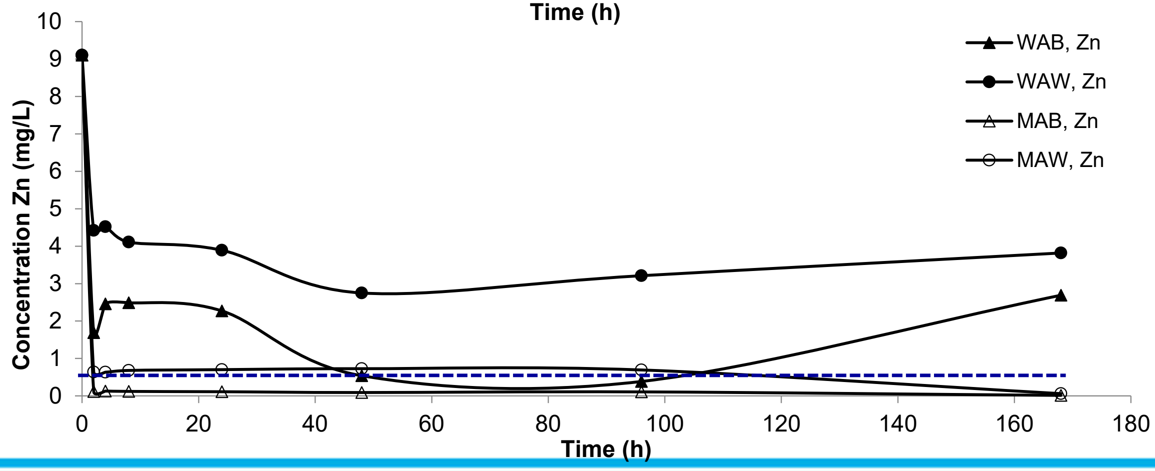
(Calugaru et al., 2019)

Raw vs modified wood ash: Ni, Zn removal in real NMD



Effluent #1 (pH 7.89, 3.71 mg/L Ni)

- Ni removal (<0.5 mg/L)
  - 2h for both modified ash (MAB & MAW)



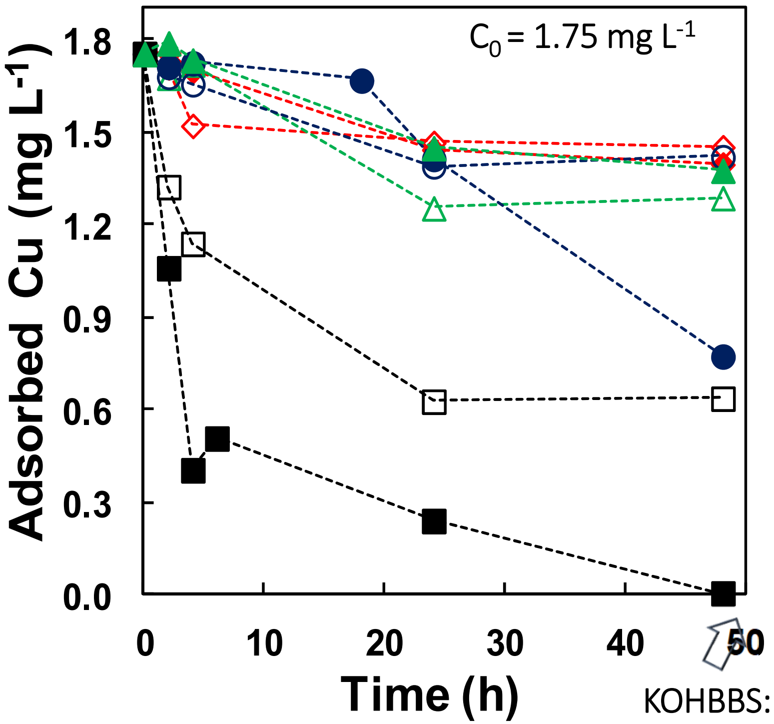
Effluent #2 (pH 6.85, 9.1 mg/L Zn)

- Zn removal (<0.5 mg/L)
  - 2h for MAB
  - 7 days for MAW (93% within 2h), but 2h for Mn removal (99% of 4.2 mg/L)

Va Activated biochar: Cu removal in real AMD

- **KOHBBS:** Efficient for Cu removal in **real** effluents

  S_{BET} = 1700 m²/g; 100% de micropores; 22.4% oxygenated groups



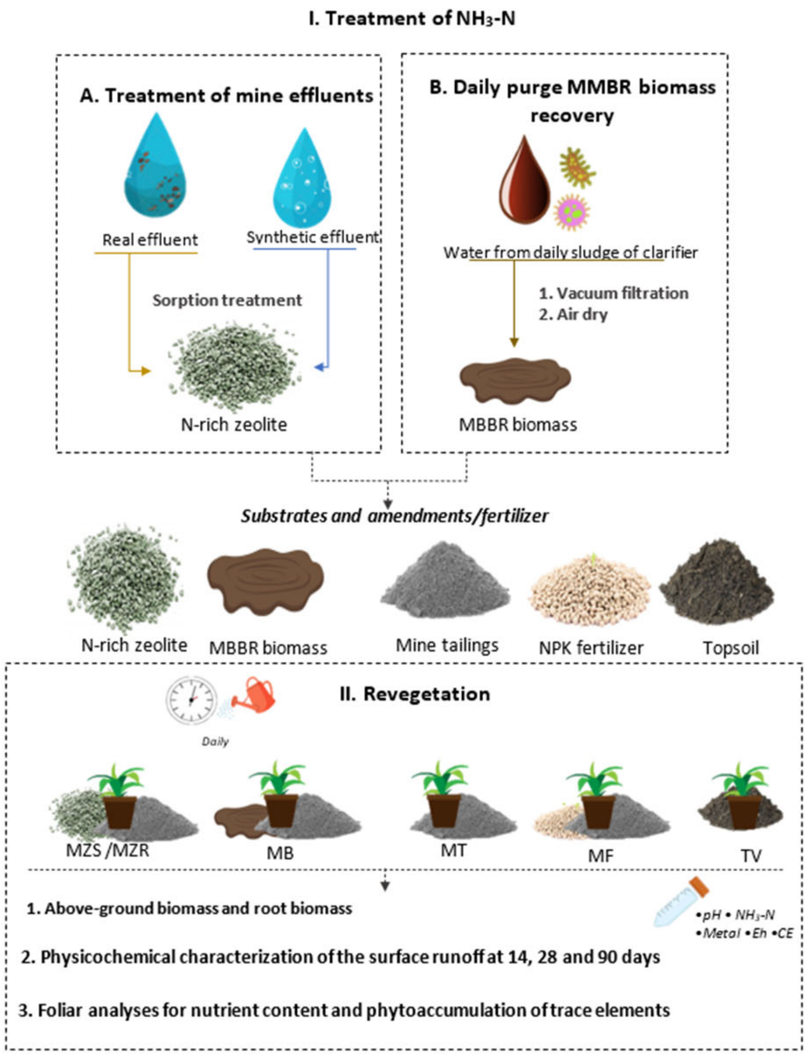
KOHBBS: C_t = 0.0055 mg/L

Parameter	Real AMD (mg/L)	After adsorption (KOHBBS) (mg/L)	Efficiency (%)
Co	9.4	0.5	95 ↓
Cu	**1.75**	**0.006**	**~ 100 ↓**
Fe	468	405	13 ↓
Mn	10.9	9.7	11 ↓
Pb	0.14	0.08	43 ↓
Zn	4.9	4.6	6 ↓

(Braghiroli et al., 2019)

N-rich residuals use in tailings revegetalization

Vb



Summary of main findings

N-rich zeolite **vs** MBBR Biomass

N-rich zeolite	MBBR Biomass
○ Plant biomasses like tailings alone	○ Plant biomasses like fertilized tailings and topsoil
○ Foliar Na concentrations 6-9 times higher than in other treatments	○ High Se concentrations in leaves
	Better performance

○ Foliar N concentrations and root biomasses failed to discriminate between the two tested types of amendment

(Saint-Aimé et al., 2023)

Ongoing research

Scientific knowledge for informed new practical applications

- **Organic cover**: is elevated water table required? Is water pumping through the cover necessary?
- **Low-sulfides no-acid generating tailings cover**: evolution and fate of potential contaminants under oxic vs anoxic and abiotic vs biotic conditions
- **Passive NMD treatment in residual organics-based biofilters**: contaminants removal mechanisms and residues stability*
- **Raw vs half-charred dolomite**: prevention of AMD generation from pyrrhotite-rich tailings and passive polishing
- **N-rich residuals from mine water treatment**: potential of surrounding environment contamination (uptake by vegetation, runoff)

*Some findings to be presented during ICARD 2024 (Mehdaoui et al., 2024; Thevenot et al., 2024)

Concluding remarks

- **Successful rehabilitation approach** for oxidized tailings on mine sites (precious and base metals) **must combine prevention** (tailings covering) and **passive treatment**
- **Residual materials valorization** (already available on or in the proximity) limits disposal concerns, environmental footprint, and mine sites rehabilitation costs
- **Materials** (natural and residual): efficient in **mine tailings covers** for AMD prevention or **transformed**, with promising results in contaminated mine water treatment
- Metal recovery, whenever feasible, **could decrease water treatment costs**
- Pilot scale production and testing of modified materials is limited
- Metal recovery, sorbent and treated water reuse, are rarely addressed

Selected references

1. Braghiroli, F.L., Bouafif, H., Neculita, C.M., Koubaa, A., 2019. Performance of physically and chemically activated biochars in copper removal from contaminated mine effluents. Water Air Soil Pollut 230: 178.
2. Braghiroli, F., Bouafif, H., Neculita, C.M., Koubaa, A., 2018. Activated biochar as an efficient sorbent for organic and inorganic contaminants in water. Water Air Soil Pollut 229(7): 230.
3. Calugaru, I.L., Genty, T., Neculita, C.M., 2021. Treatment of manganese, in the presence or absence of iron, in acid and neutral mine drainage using raw vs half-calcined dolomite. Miner Eng 160: 106666.
4. Calugaru, I.L., Neculita, C.M., Genty, T., Zagury, G.J., 2020. Removal and recovery of Ni and Zn from neutral mine drainage by thermally activated dolomite and hydrothermally activated wood ash. Water Air Soil Pollut 231: 226.
5. Calugaru, I.L., Neculita, C.M., Genty, T., Zagury, G.J., 2018. Metals and metalloids treatment in contaminated neutral effluents using modified materials. J Environ Manage 212: 142-159.
6. Calugaru, I.L., Neculita, C.M., Genty, T., Bussière B., Potvin, R., 2017. Removal of Ni and Zn in contaminated neutral drainage by raw and modified wood ash. J Environ Sci Health 52(2): 117-126.
7. Calugaru, I.L., Neculita, C.M., Genty, T., Bussière B., Potvin, R., 2016. Performance of thermally activated dolomite for the treatment of Ni and Zn in contaminated neutral drainage. J Hazard Mater 310, 48-55.
8. Germain, D., Tassé, N., Cyr, J. (2009) The East-Sullivan mine site: Merging prevention and treatment of acid mine drainage. BC MEND ML/ARD Annual Workshop, 15p.
9. Neculita, C.M., Pabst, T., 2020. Circular economy applied to mining reclamation. 7th Int Symp Mine Reclamation, MIRECO, November 5-6, 2020.
10. Nordstrom, K., Blowes, D.W., Ptacek, C.J., 2015. Hydrogeochemistry and microbiology of mine drainage: An update. Appl Geochem 57: 3–16.
11. Rakotonimaro, T., Roy, T., Lacroix, R., Trudel, S., Neculita, C.M., 2015. East Sullivan mine site restoration: Current success and perspective. Goldschmidt, Prague, Czech Republic, August 16-21.
12. St-Aimé, R., Guittonny, M., Neculita, C.M., 2023. Valorization potential of ammonium-rich zeolite and MBBR biosolids in the revegetation of non-acid-generating gold mine tailings. Sci Total Environ 891: 164279.

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Thank you!

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Merci!

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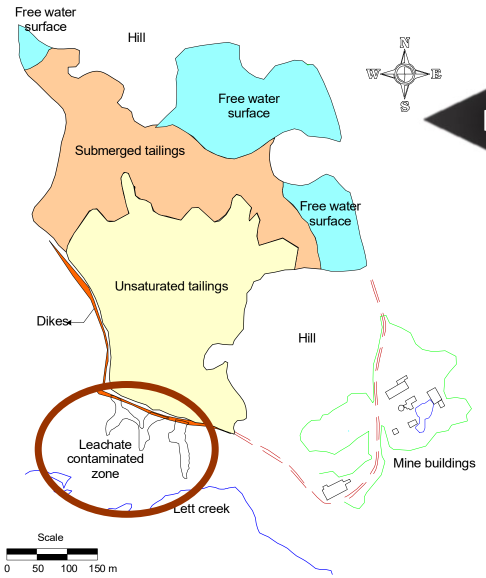


IV

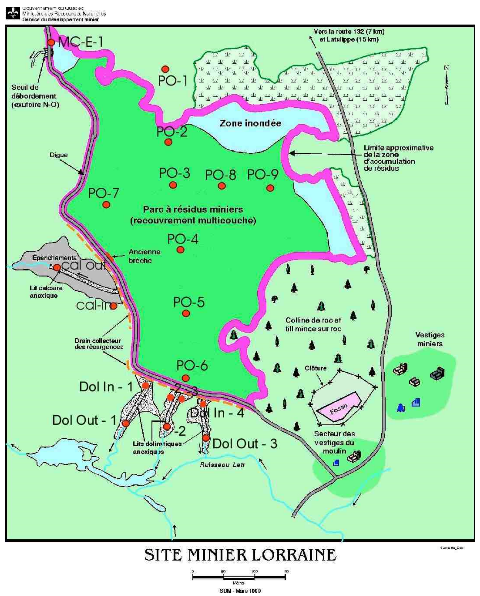
CCBE + passive treatment: Lorraine mine site

1964-1968 : extraction of Cu, Au, Ag, Ni

acid-generating tailings: 15.5 ha (up to 6 m)

AMD: pH 3.6, 7 g/L Fe, 15 g/L sulfate

2000: CCBE + 3 dolomitic drains



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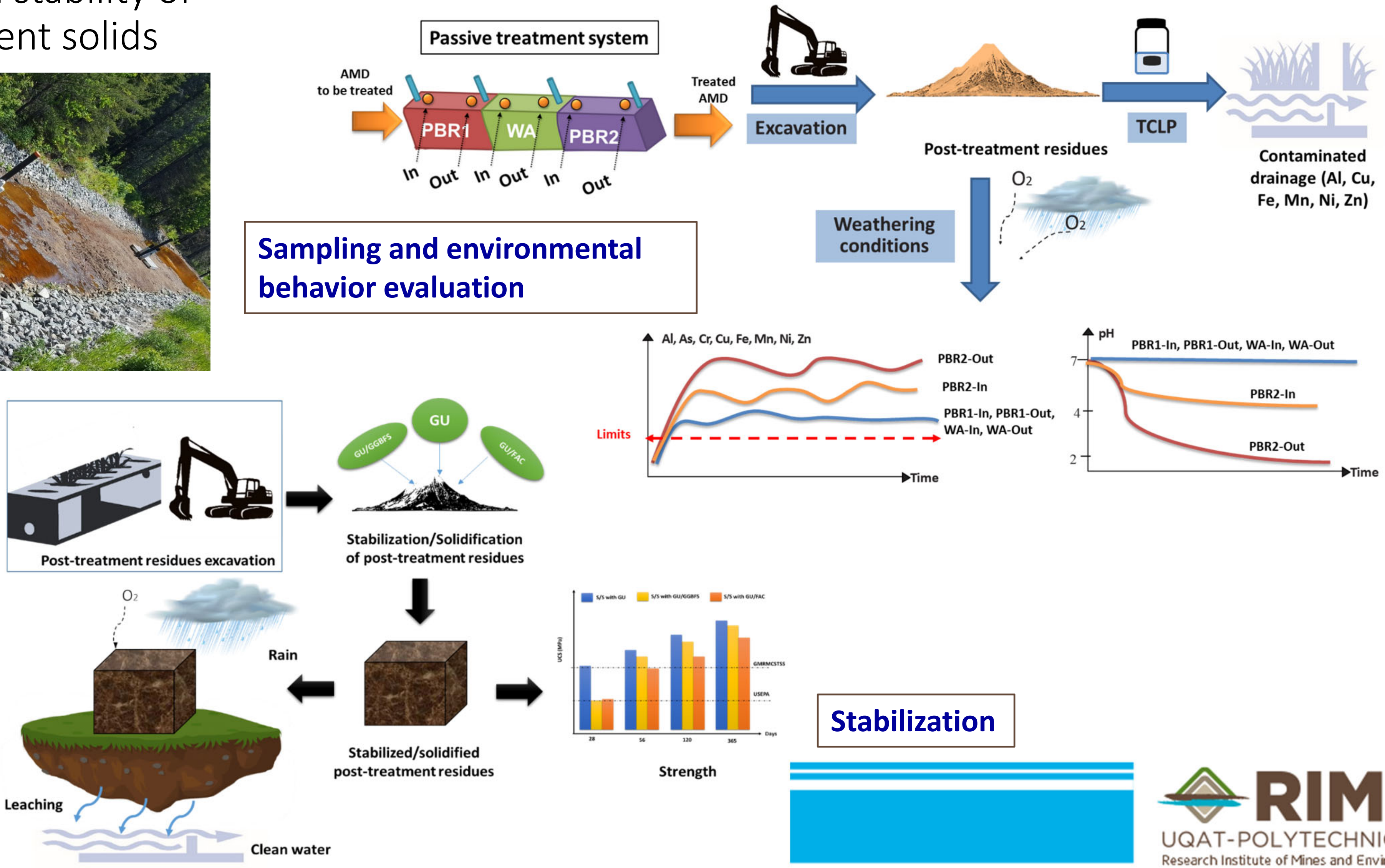
Geochemical stability of AMD treatment solids



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Plant material and growing conditions