HOKKAIDO UNIVERSITY

Groundwater flow and chemistry around the tailings dam of a closed mine and countermeasures for the leachate

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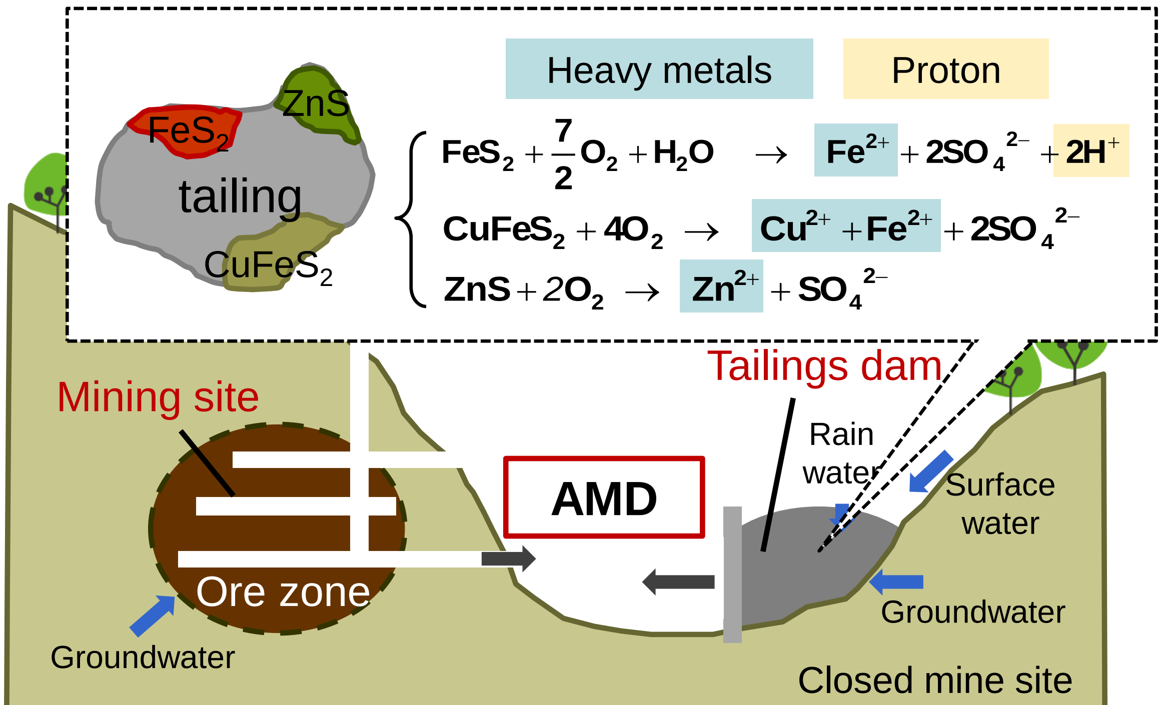
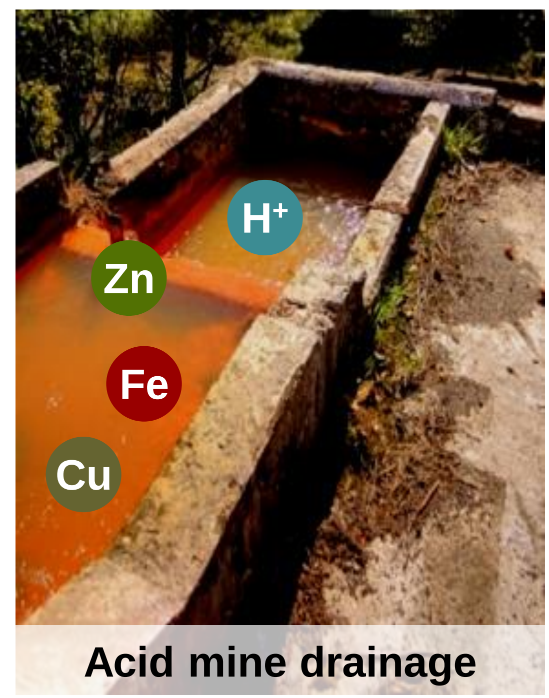
Introduction

- Acid mine drainage (AMD) is a serious environmental problem in many abandoned mine sites all over the world including Japan.

- In general, AMD is very acidic and contains toxic heavy metals.

General mechanism of AMD generation

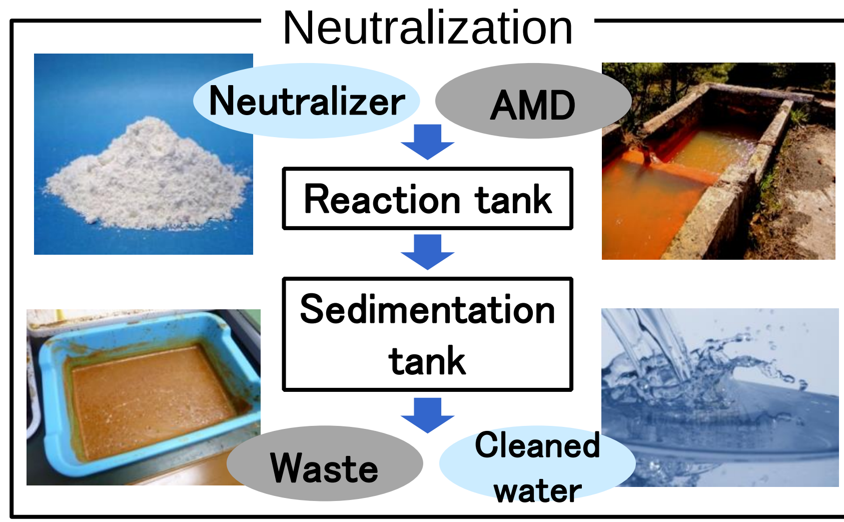




Introduction

▸ Management practice of AMD

To prevent environmental pollutions…



AMD flows out to the environment…

Environmental pollutions

▸ **Disadvantages of neutralization…**

- We need to continue neutralization until AMD production stops.
- The cost is enormous in the long term.

We need to look for more sustainable alternatives.

Introduction

- Objectives of our study…

- To characterize the leachate from the tailings dams
- To design and evaluate an alternative countermeasure to reduce AMD production or its associated load of heavy metals

- To achieve these objectives, we need to answer the following questions;

  - Where is the AMD coming from?
  - Which heavy metals are leached out from the tailings dam?
  - How long will the tailings continue to generate AMD?
  - How will the concentrations of heavy metals in AMD change with time?
  - What kinds of countermeasures are effective?

Introduction

- Objectives of our study…

> - To characterize the leachate from the tailings dams
> - To design and evaluate an alternative countermeasure to reduce AMD production or its associated load of heavy metals

- To achieve these objectives, we need to answer the following questions;

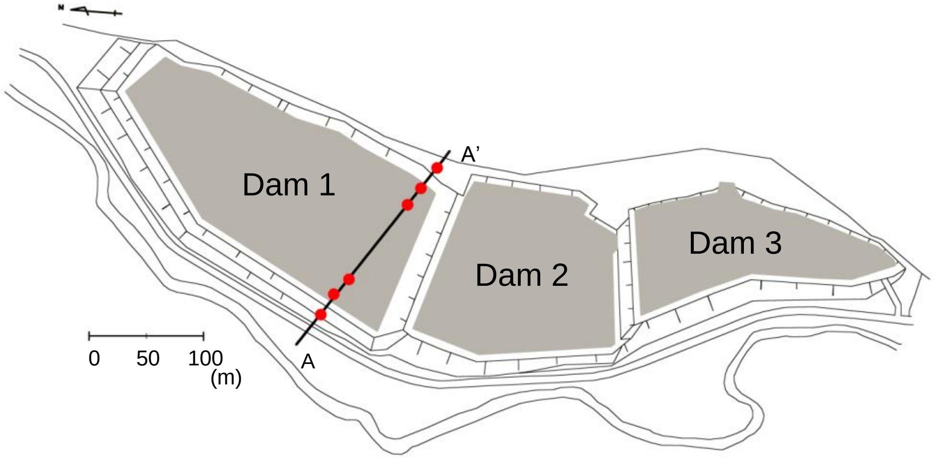
  - Where is the AMD coming from?
  - Which heavy metals are leached out from the tailings dam?

To answer these questions batch experiments and numerical simulation were conducted in this study.

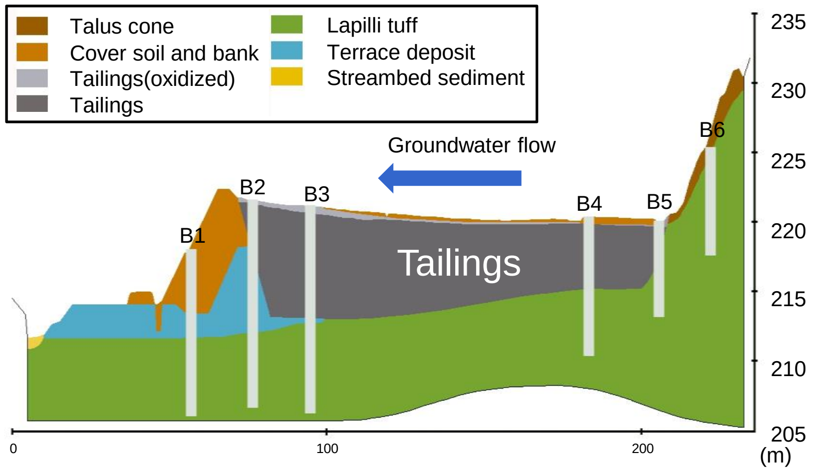
  - How will the concentrations of heavy metals in AMD change with time?
  - What kinds of countermeasures are effective?

Site description

- This study focused on a tailings dam of a closed mine site containing Cu, Zn and FeS_2.
- AMD has been generated in this site for more than 40 years and neutralization has been conducted for AMD management.
- Tailings, rock and soil samples were taken from bore holes B1 to B6.



Plain view of the tailings dams



Cross sectional view of AA’

Methods

- Experimental part

(1) Batch leaching experiments

→To investigate the concentrations and leaching behaviors of heavy metals

(2) Sequential extraction

→To investigate the solid phase partitioning of heavy metals in the tailings

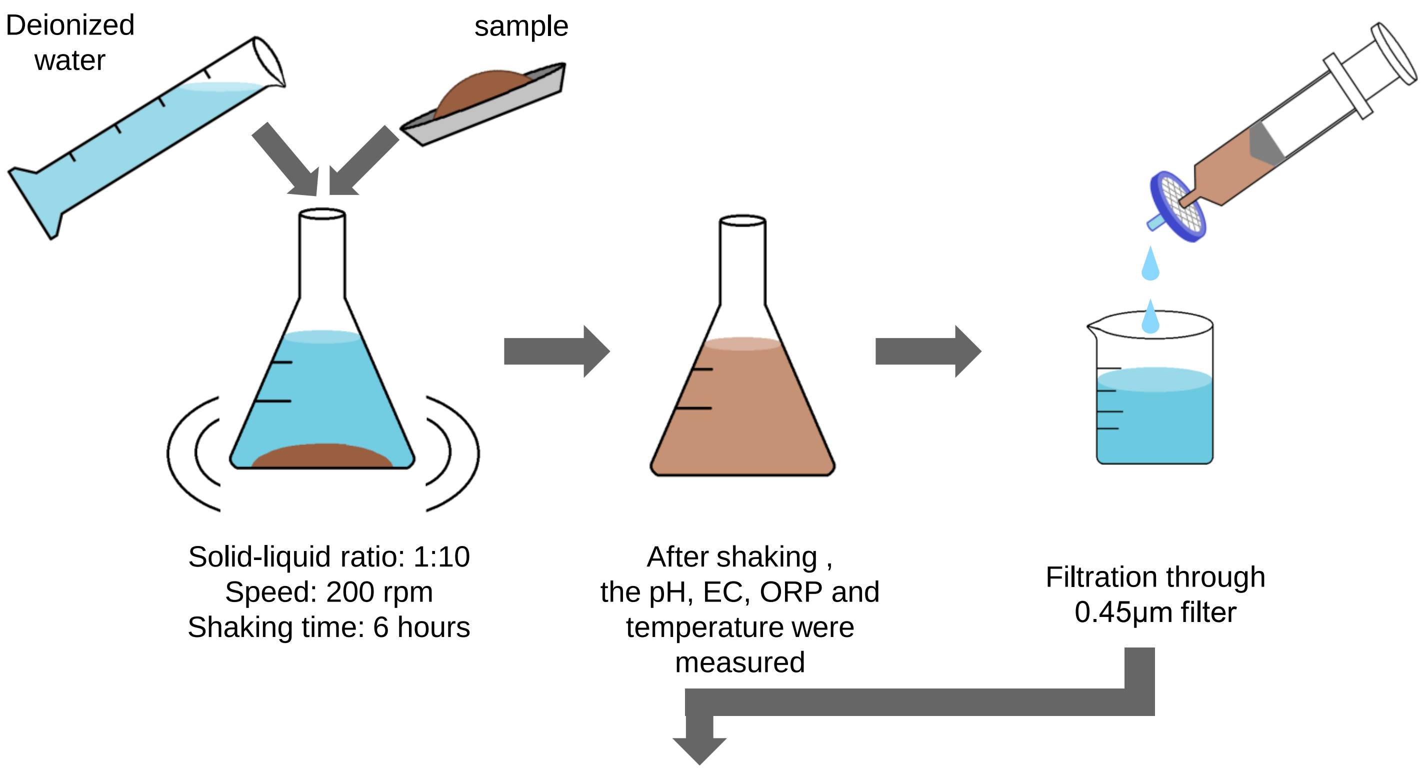
- Simulation part

(3) Numerical simulation using MODFLOW

→To investigate how long the tailings would continue to generate AMD

→To evaluate the effectiveness of the countermeasure.

▸ Batch leaching experiment



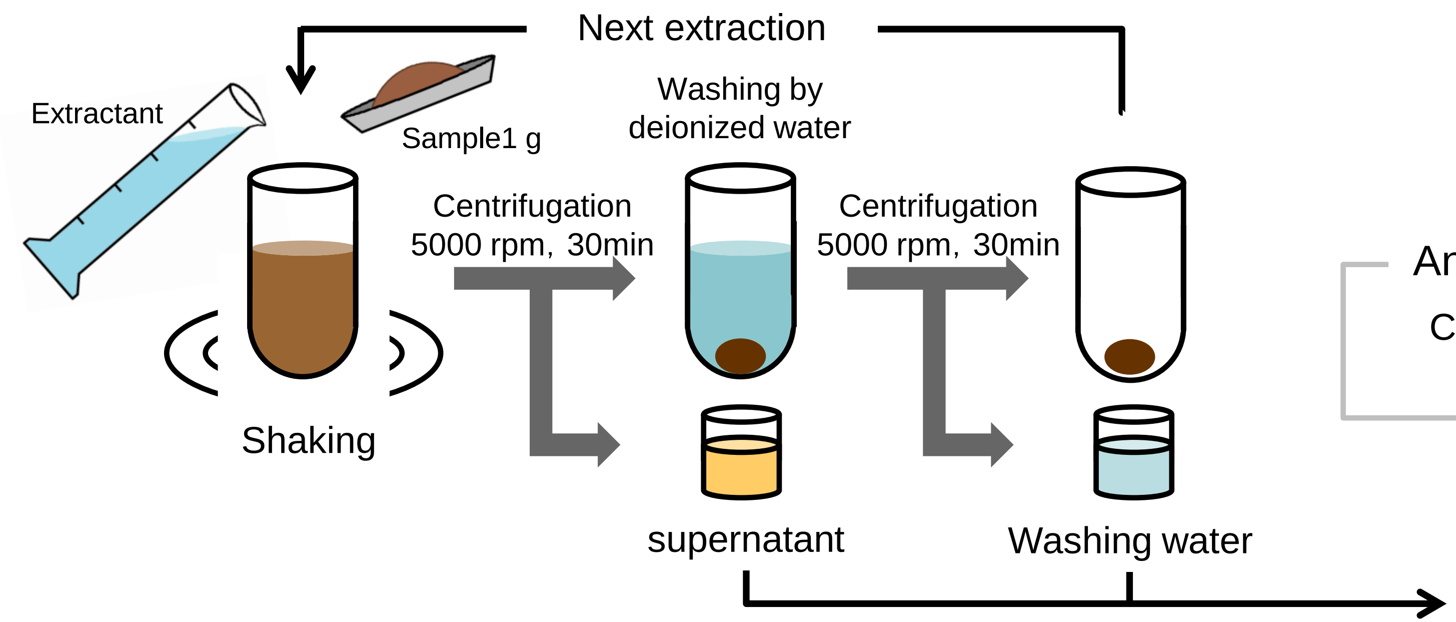
Analyzed elements

Al, Ca, Cd, Cu, Fe, K, Mg, Na, Pb, Zn, Si (ICP-AES)

SO_4^{2-} (Anion chromatography)

Experimental part

▸ Sequential extraction



Analyzed elements

Cd，Cu，Fe，Pb，Zn
(ICP-AES)

(1) Exchangeables

Extractant
1 M $MgCl_2$

Shaking time
1 hour

Temperature
25℃

(2) Carbonates

Extractant
1 M CH_3COONa+ CH_3COOH

Shaking time
5 hours

Temperature
25℃

(3) Iron and Mn oxides

Extractant
0.04 M $HONH_3Cl$ + 25 %CH_3COOH

Shaking time
5 hours

Temperature
50℃

(4) Sulfide and Organic

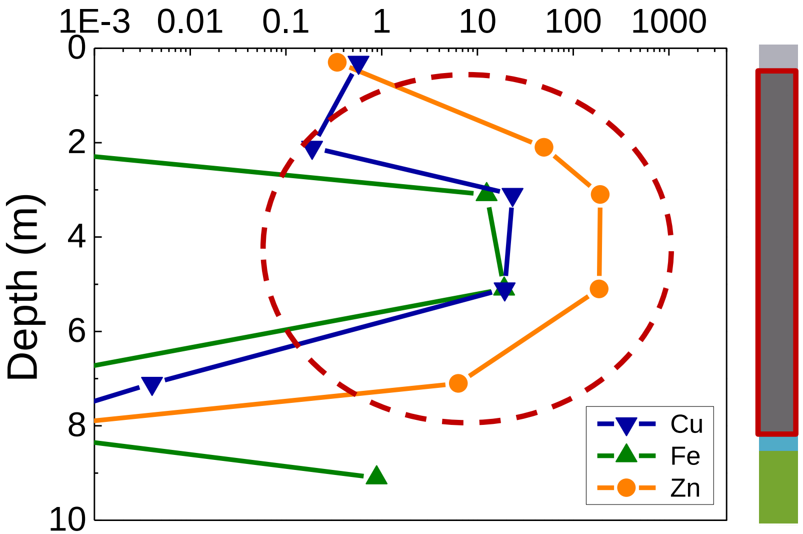
Extractants
0.04 M $HONH_3Cl$+ 25 %CH_3COOH
0.02 M HNO_3
30 %H_2O_2

Shaking time
5.5 hours,

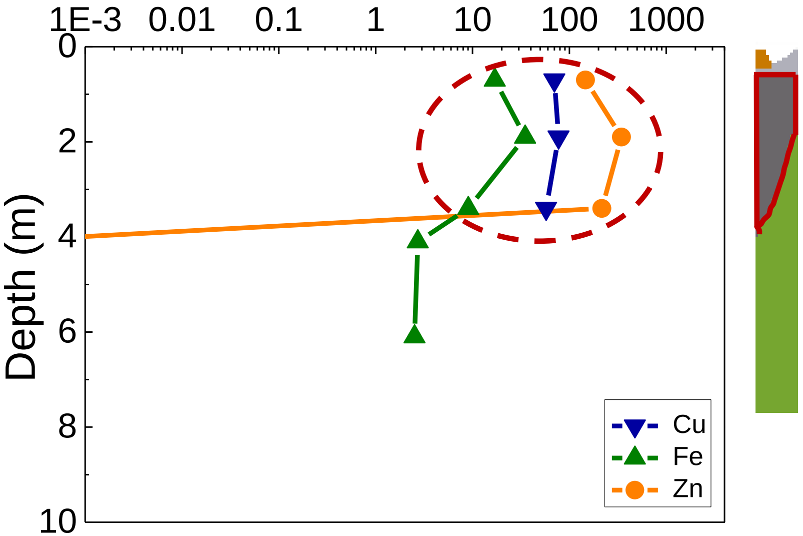
temperature
50℃

(5) Residual: This corresponds to heavy metals that remained in the sample after extraction

- Batch leaching experiment

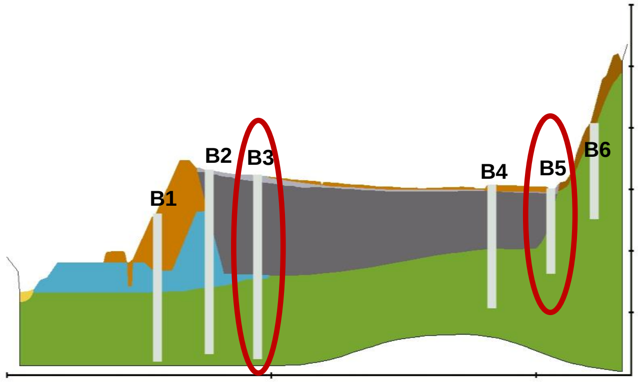


Depth vs. concentrations of Cu, Fe and Zn in B3

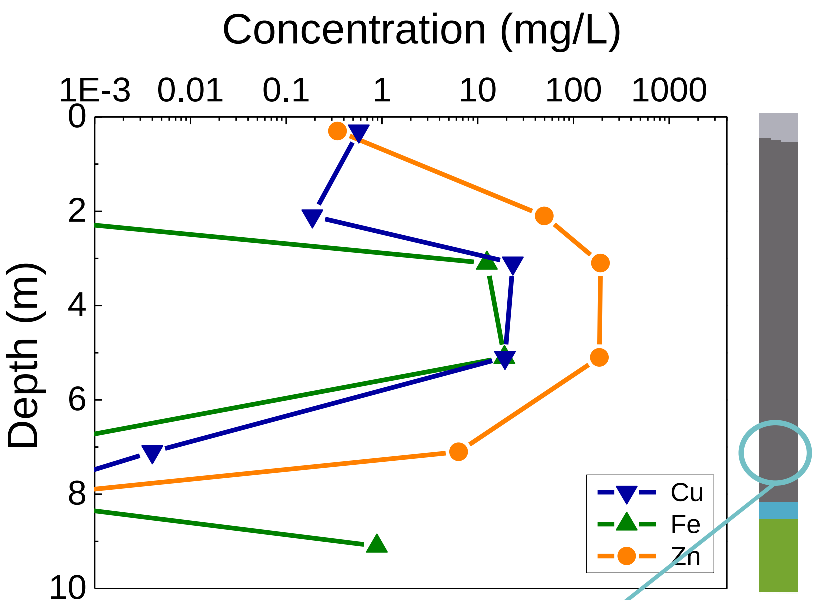


Depth vs. concentrations of Cu, Fe and Zn in B5

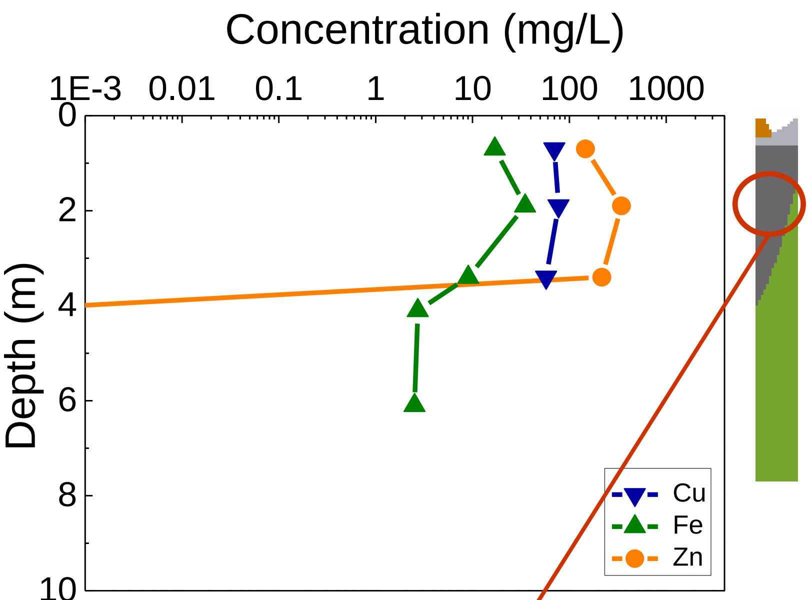
- Heavy metal concentrations were higher in the tailings zone than in the other zones.
  → Heavy metal source is tailings.
- Heavy metal concentrations leached from the tailings differed with depth.



Batch leaching experiment



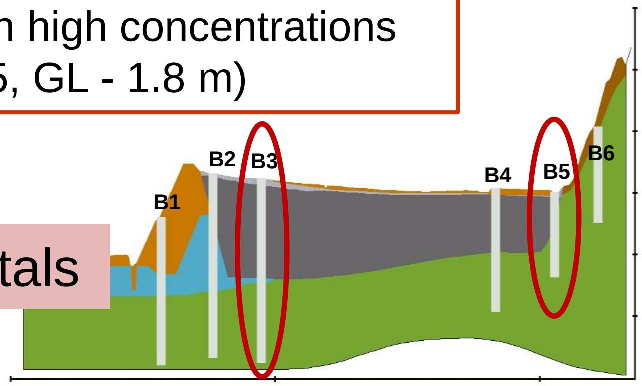
Depth vs. concentrations of Cu, Fe and Zn in B3



Depth vs. concentrations of Cu, Fe and Zn in B5

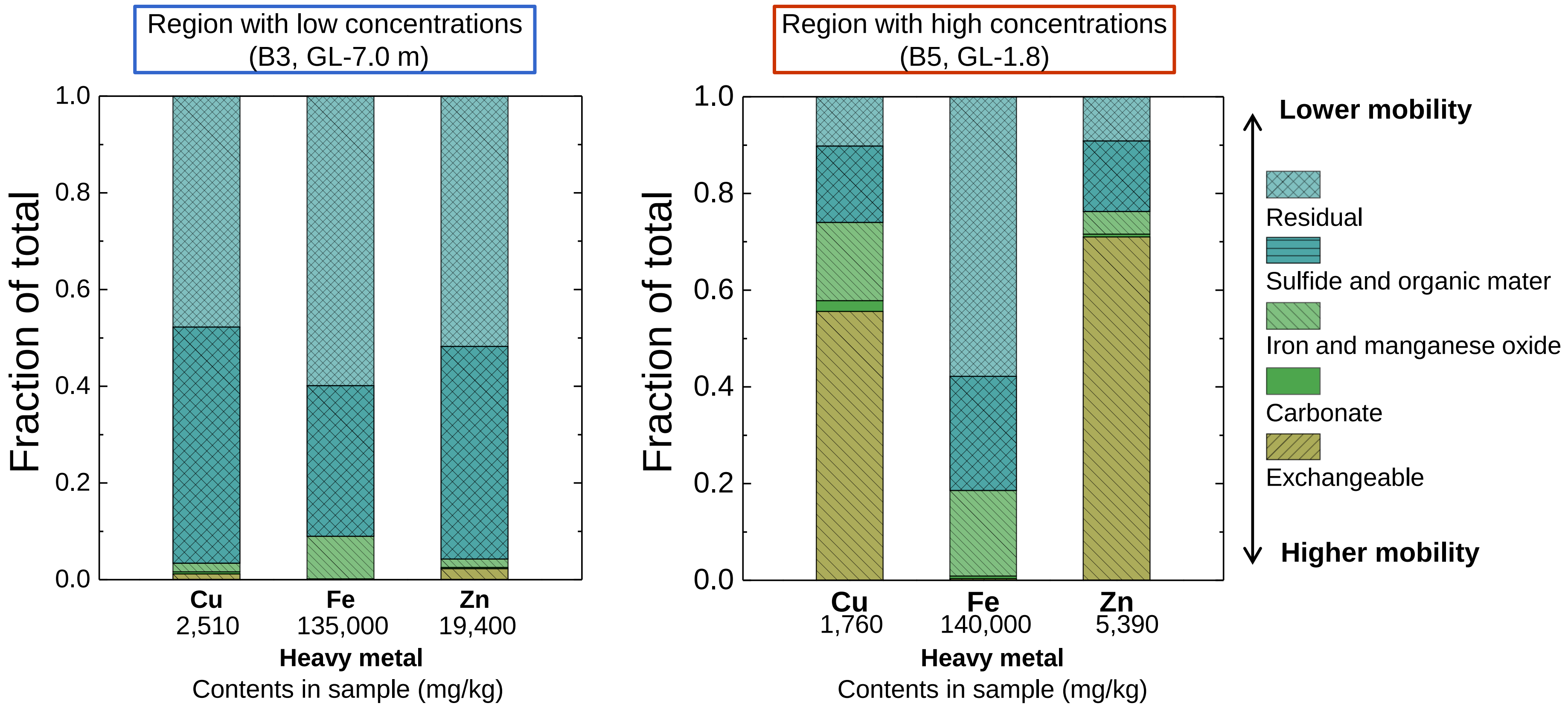
Region with low concentrations
(B3, GL – 7.0 m)

Region with high concentrations
(B5, GL - 1.8 m)



Compare the solid phase partitioning of heavy metals

▶ Sequential extraction



Solid phase partitioning and contents of the heavy metals are different at each point.

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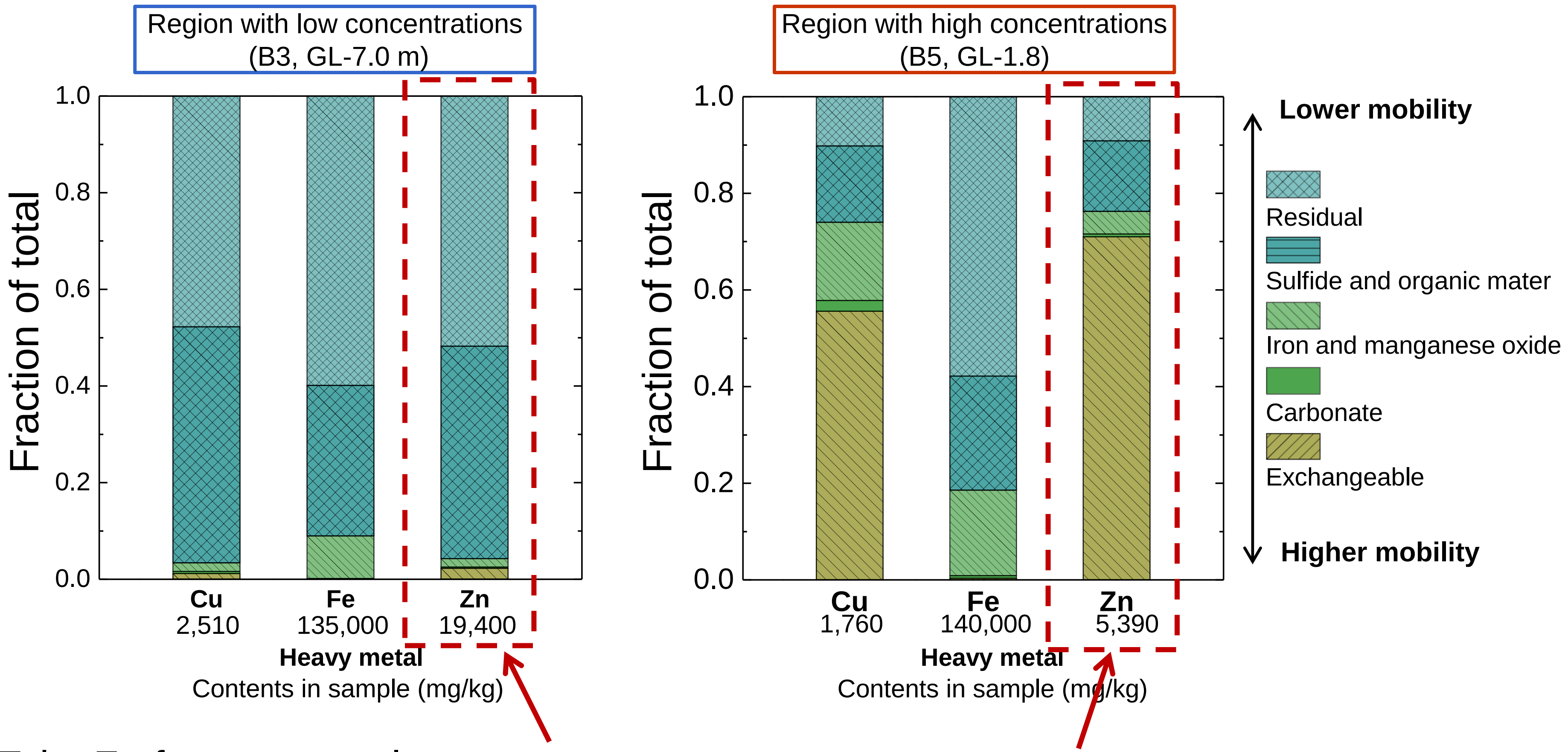
The solid phase partitioning and the contents of heavy metals may affect the leaching concentration.

▸ Sequential extraction



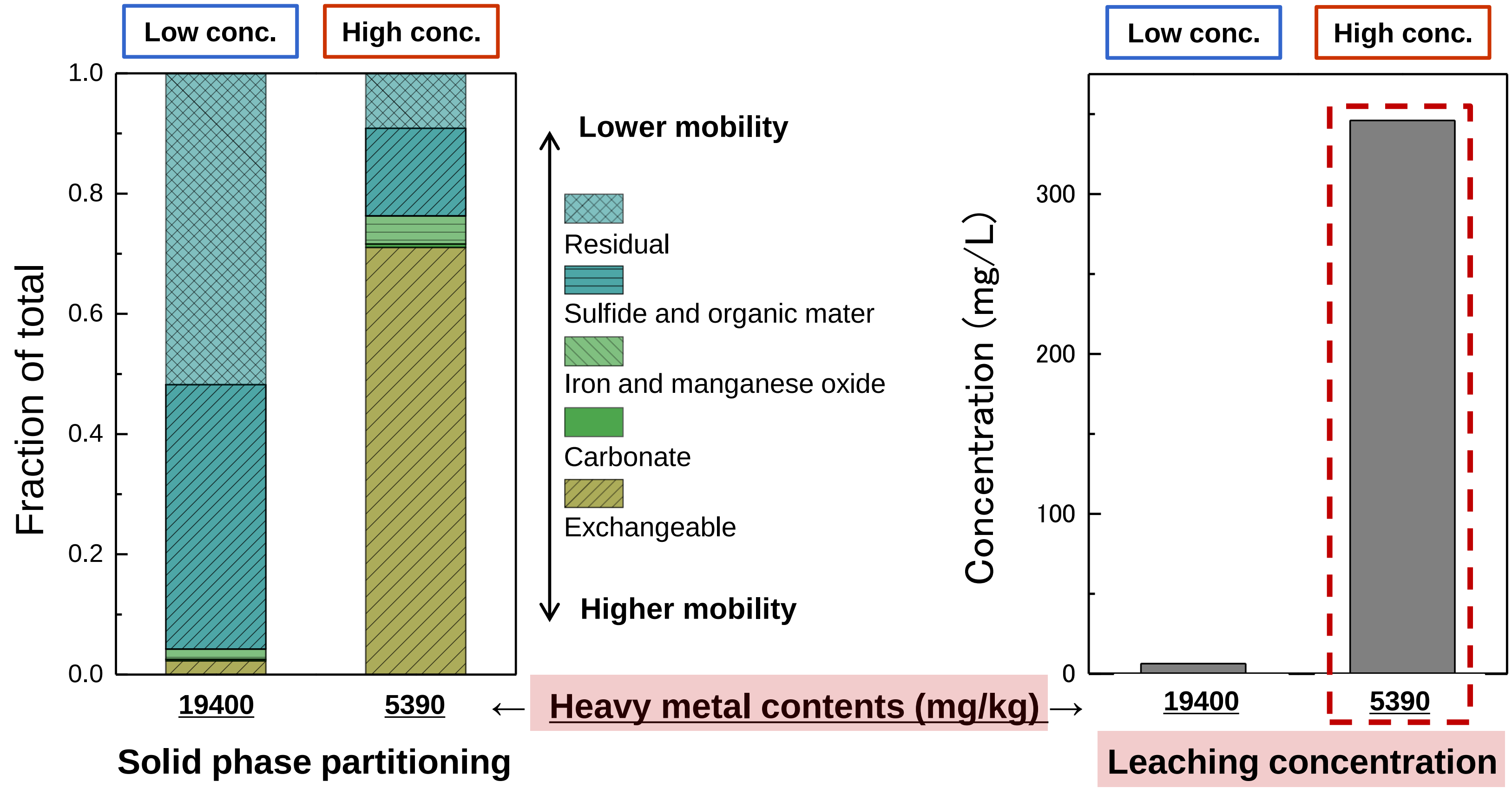
Take Zn for an example,

let's investigate the relationship between its solid phase partitioning and contents of heavy metals and leaching concentration.

Experimental part

- Results & Discussion -

▶ Relationship between solid phase partitioning and leaching concentration



The sample with lower heavy metal contents has higher leaching concentration.

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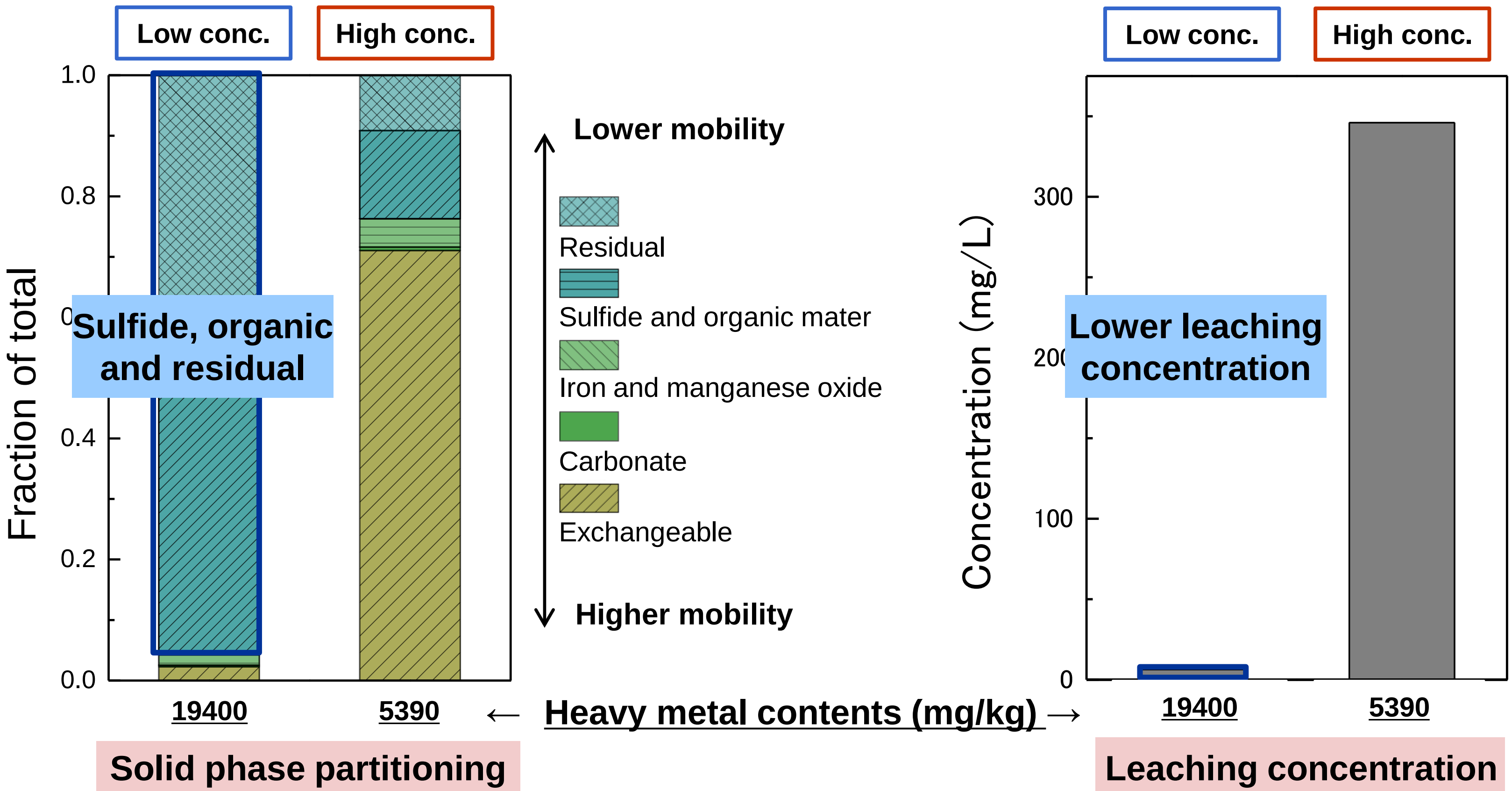
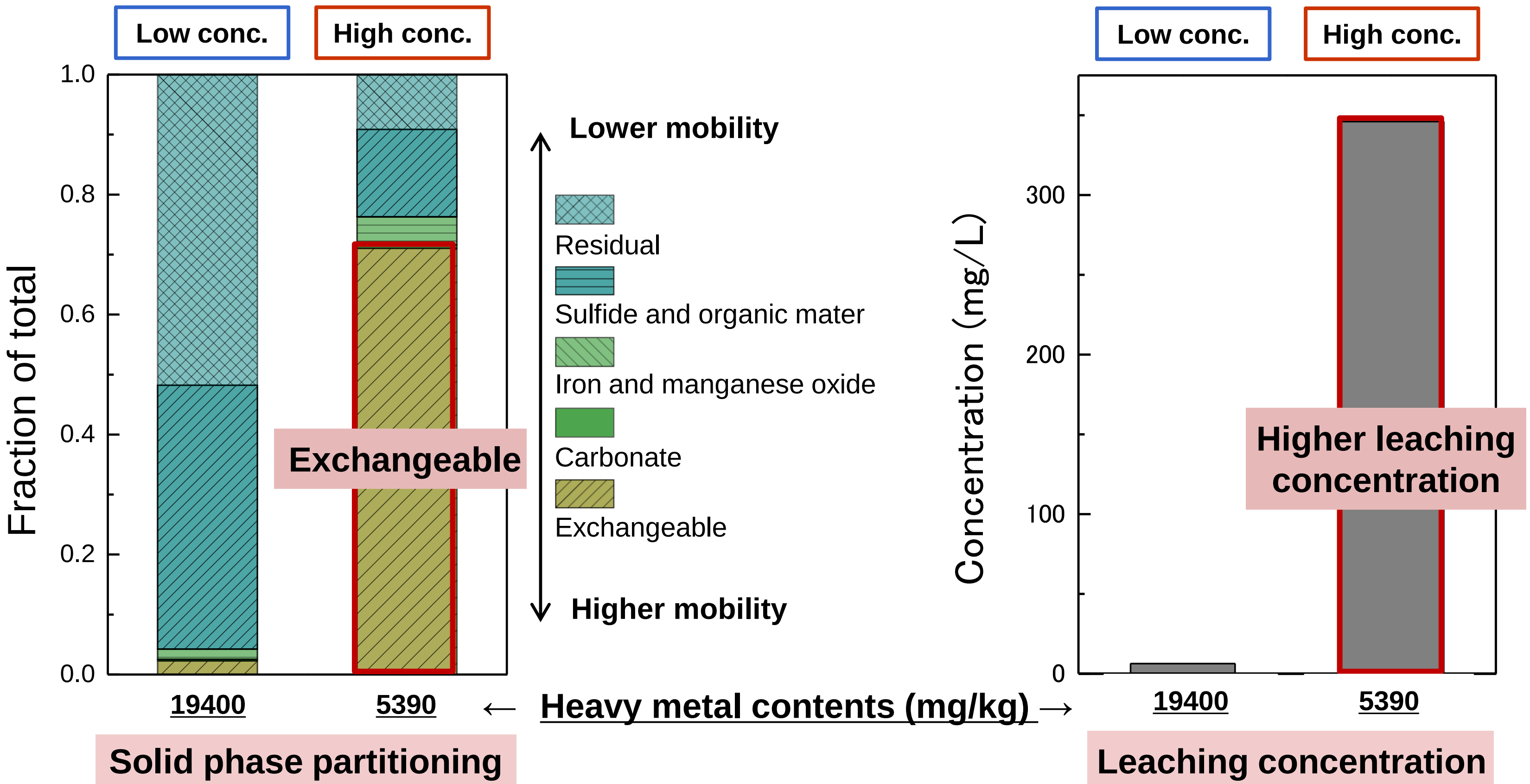
Higher heavy metal contents do not always correspond to higher leaching concentrations.

▶ Relationship between solid phase partitioning and leaching concentration



The site with high sulfide, organic and residual fraction has lower leaching concentration.

▶ Relationship between solid phase partitioning and leaching concentration



The site with high exchangeable fraction has high leaching concentration.

↓

The solid phase partitioning, especially the exchangeable phase, has a stronger effect on the leaching of heavy metals than the total heavy metal contents.

Methods

- Experimental part

(1) Batch leaching experiments

→To investigate the concentrations and leaching behaviors of the heavy metals

(2) Sequential extraction

→To investigate the solid phase partitioning of heavy metals in the tailings

- Simulation part

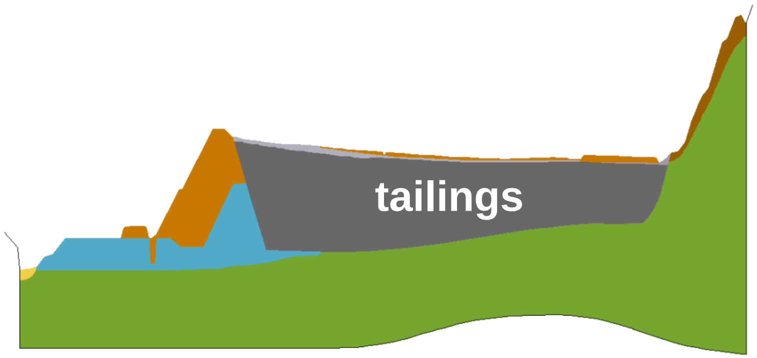
(3) Numerical simulation using MODFLOW

→To investigate how long the tailings would continue to generate AMD

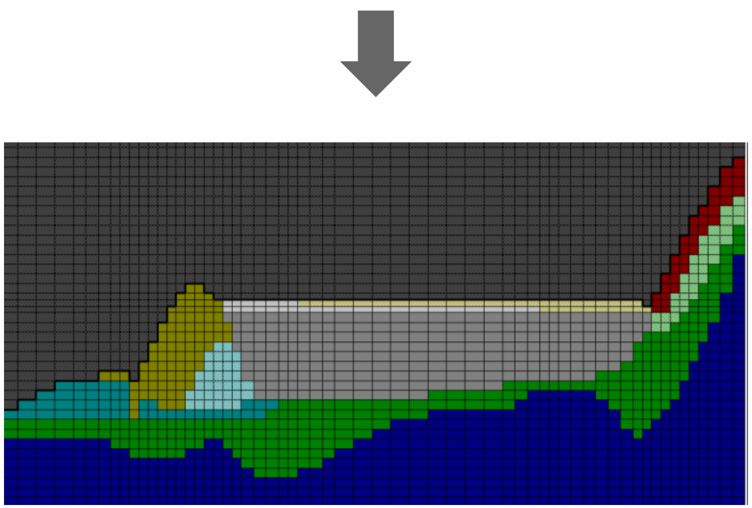
→To evaluate the effectiveness of the countermeasure.

Simulation part

- Simulation was conducted by using MODFLOW that can simulate groundwater flow and solute migration.



Cross sectional view of tailings dam



Model of tailings dam

The model included:

- Groundwater flow simulation
  - Steady-state condition
- Heavy metal migration
  - Unsteady-state condition

Simulation part

- Methodology-

- Conditions of simulation

<u>Boundary conditions</u>

Right and bottom→impermeable / Upper→ recharge(300mm/yr)

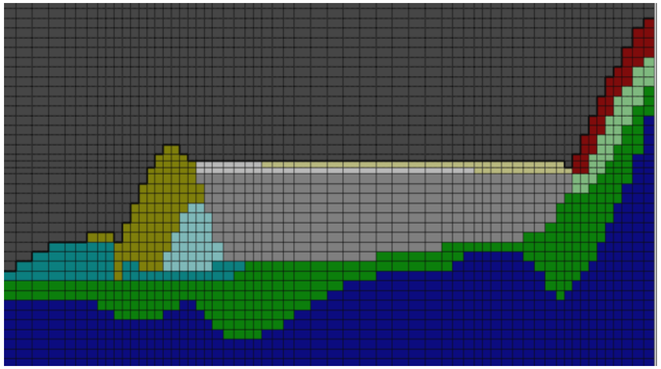
Left→ river

<u>Initial condition for Zn migration</u>

Initial concentration(40 mg/L) was set only in the region with tailings.

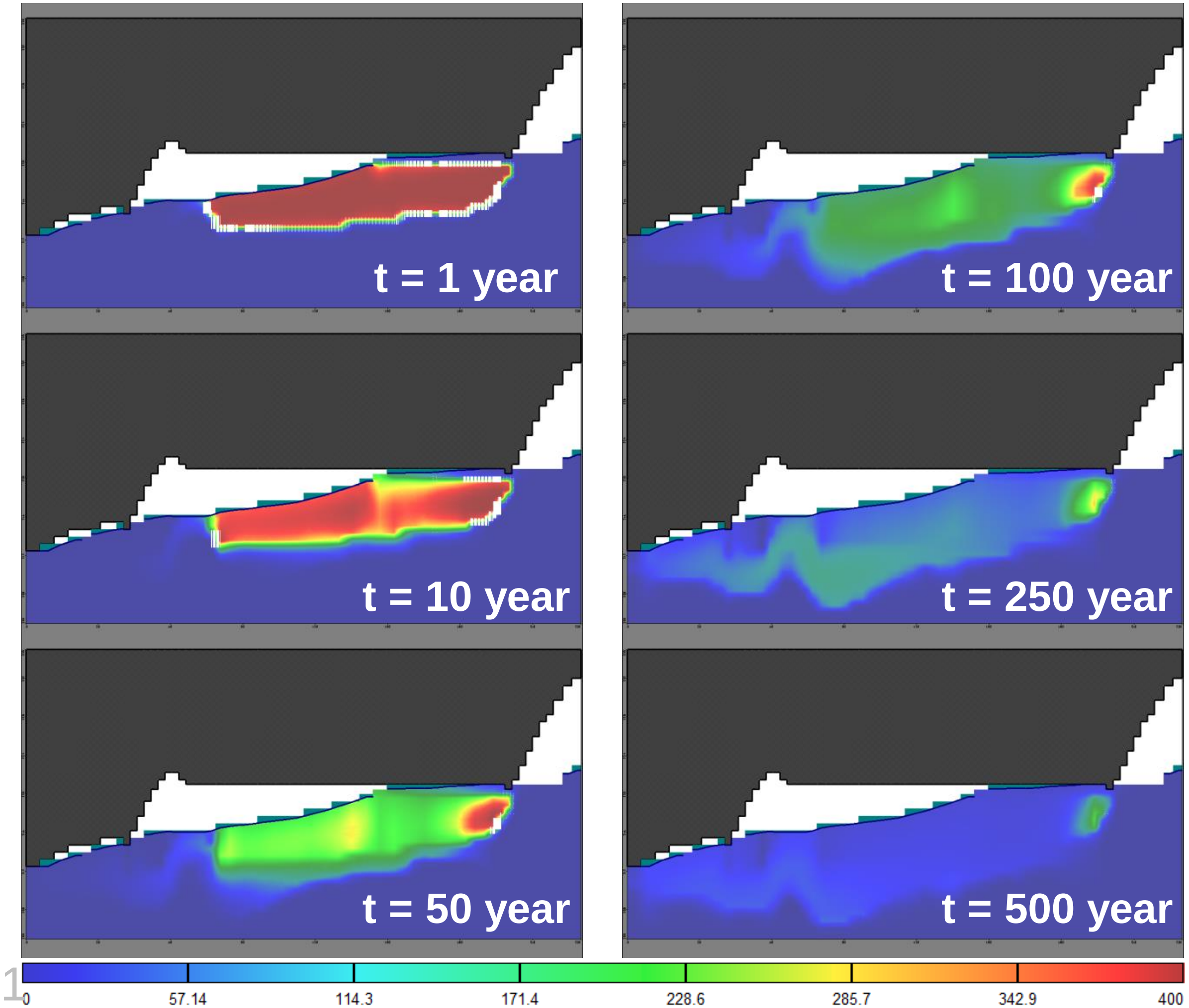
Hydraulic conductivity(*K*) and distribution coefficient (K_d) are as follows.

	Geological settings	*K* (m/s)	K_d(L/mg)
	Lapilli tuff (weakly weathered)	5×10^{-8}	10^{-5}
	Lapilli tuff (weathered)	10^{-5}	10^{-5}
	Lapilli tuff (strongly weathered)	5×10^{-4}	10^{-5}
	Terrace deposit (low conductivity)	5×10^{-6}	10^{-5}
	Terrace deposit (high conductivity)	10^{-4}	10^{-6}
	Bulk	10^{-7}	10^{-5}
	Cover soil	10^{-5}	10^{-5}
	Tailings (oxidized)	10^{-4}	10^{-5}
	Tailings	10^{-7}	5×10^{-6}
	Talus cone	10^{-3}	10^{-5}



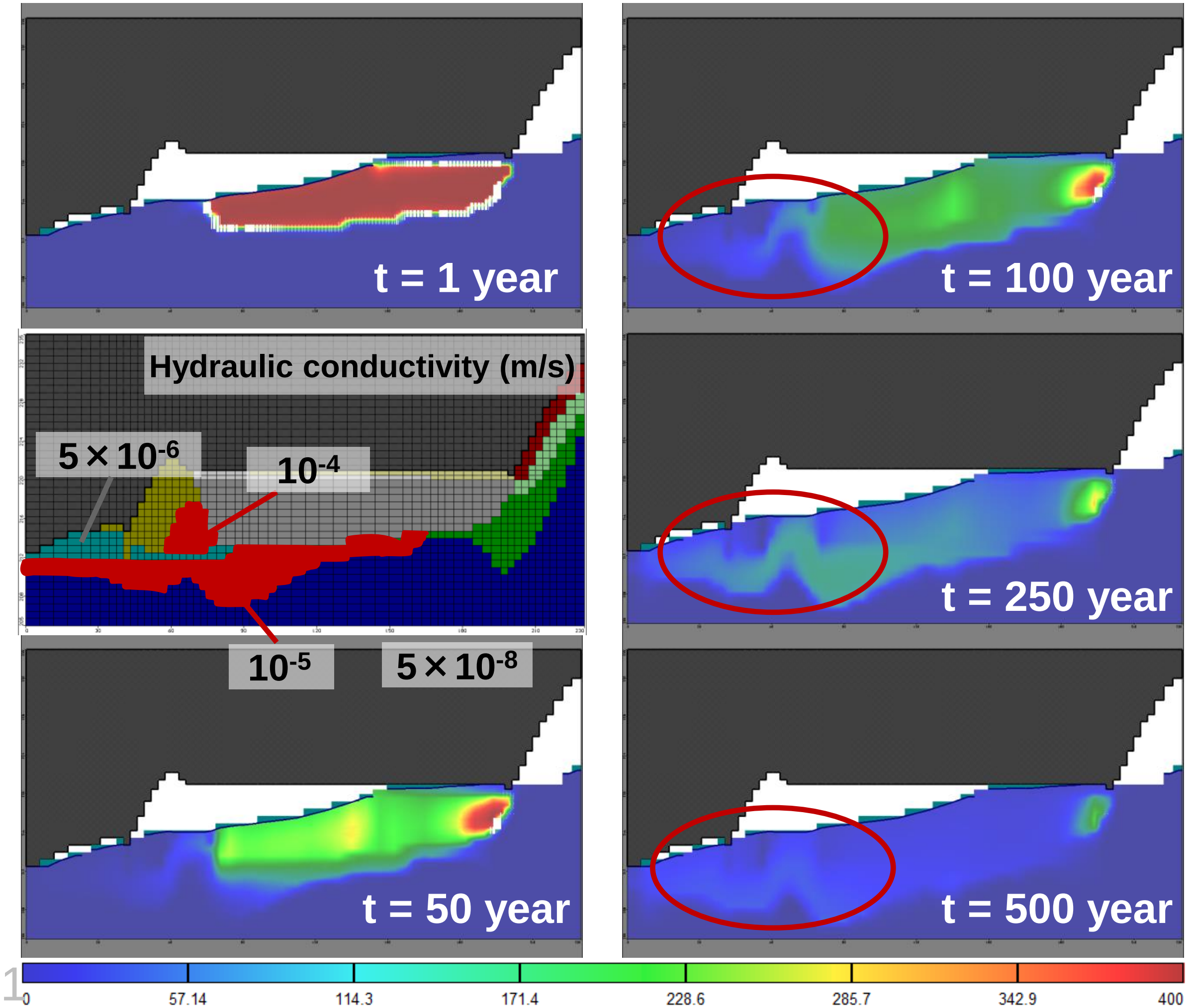
(*K* and K_d values were based on in situ measurements and experiments, respectively.)

- Migration of Zn in the tailings dam (without countermeasures)



Zn migrated downward with time.

▸ Migration of Zn in the tailings dam (without countermeasures)



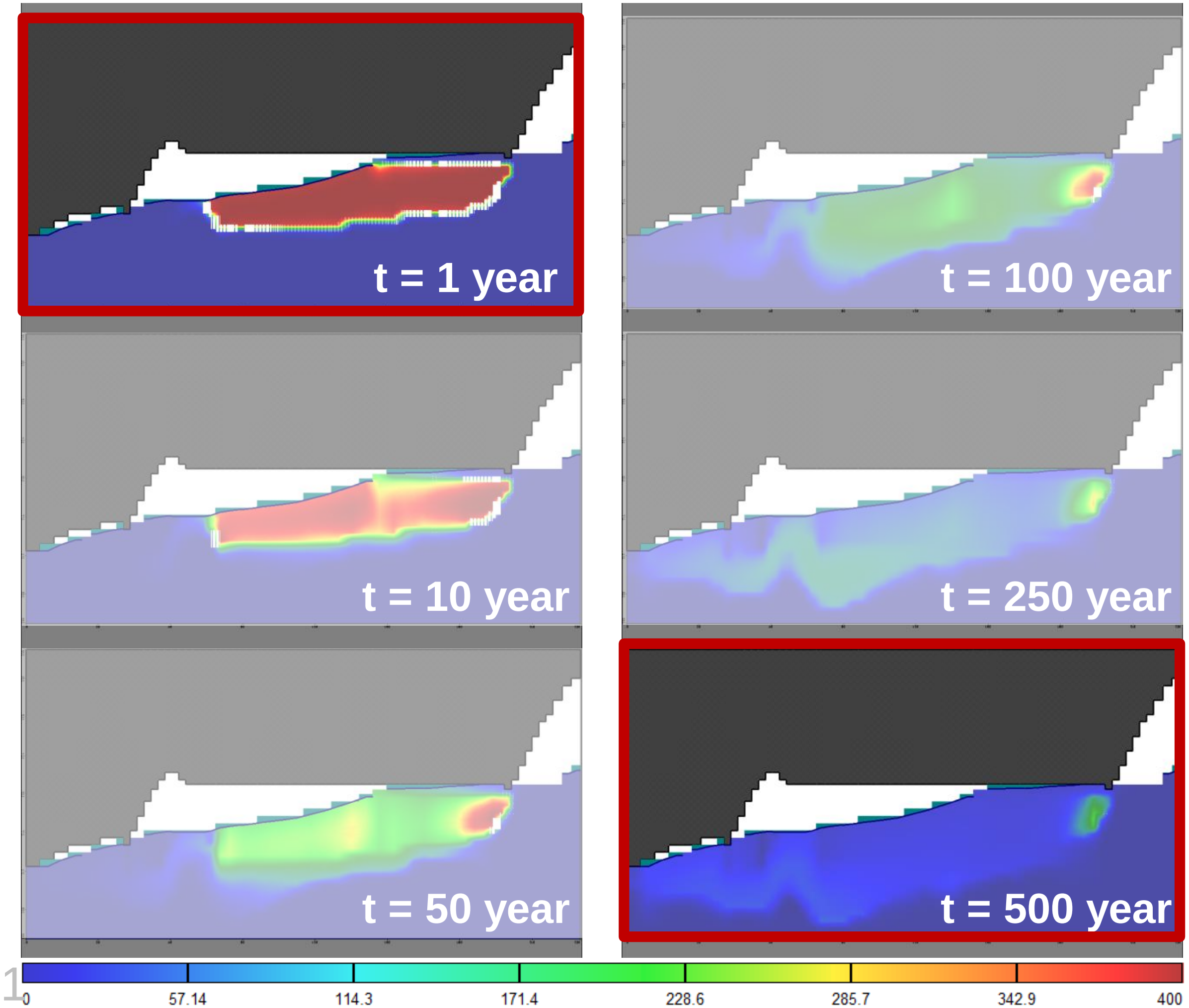
Zn migrated downward with time.

Zn passes through zones with high permeability.

Simulation part

- Results & Discussion -

▸ Migration of Zn in the tailings dam (without countermeasures)



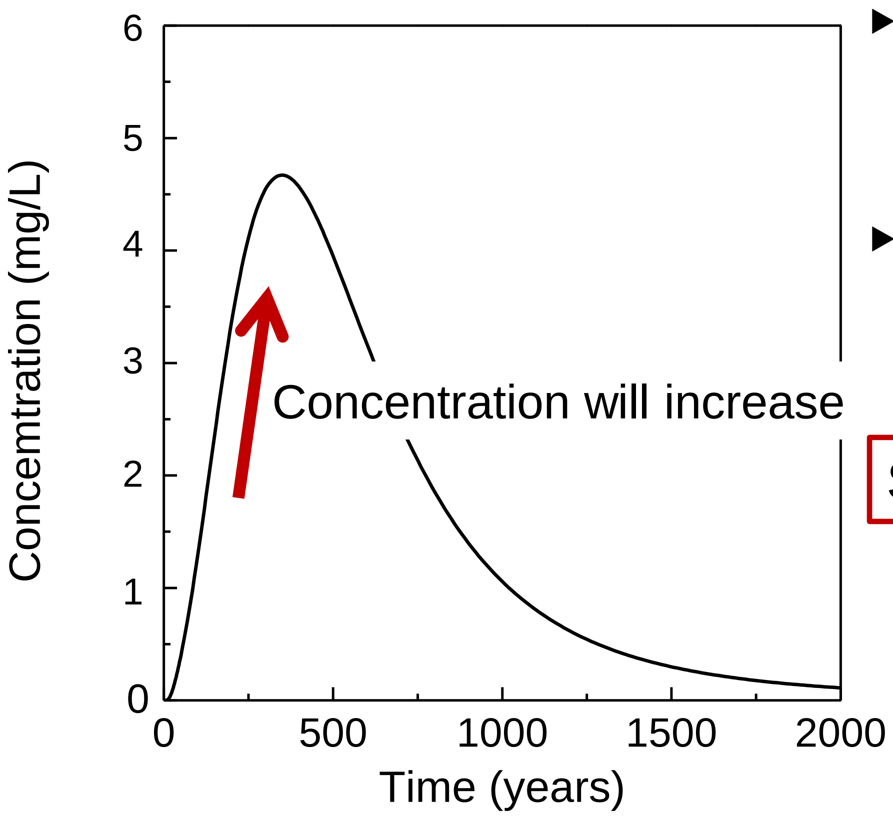
Zn migrates downward with time.

Zn passes through zones with high permeability.

Zn concentrations after 500 years decreased by 90%.

We can see the distribution changes of Zn concentration in tailings dam with time from the simulation.

- Zn concentration in leachate



Change of concentration in seepage

- The result shows that the tailings will continue to generate seepage with high concentration of Zn for a long time.
- The concentration of Zn in the seepage will increase in the future.

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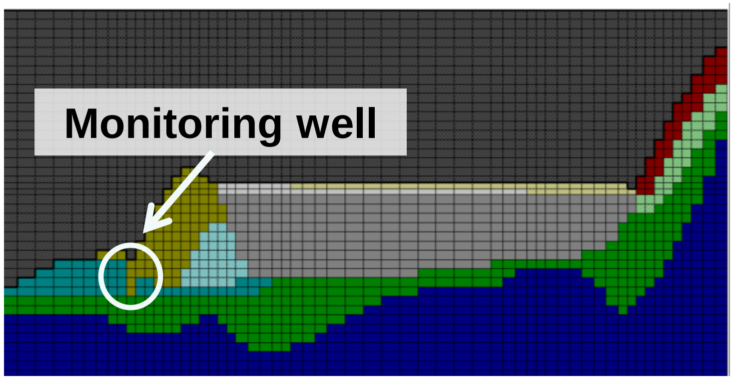
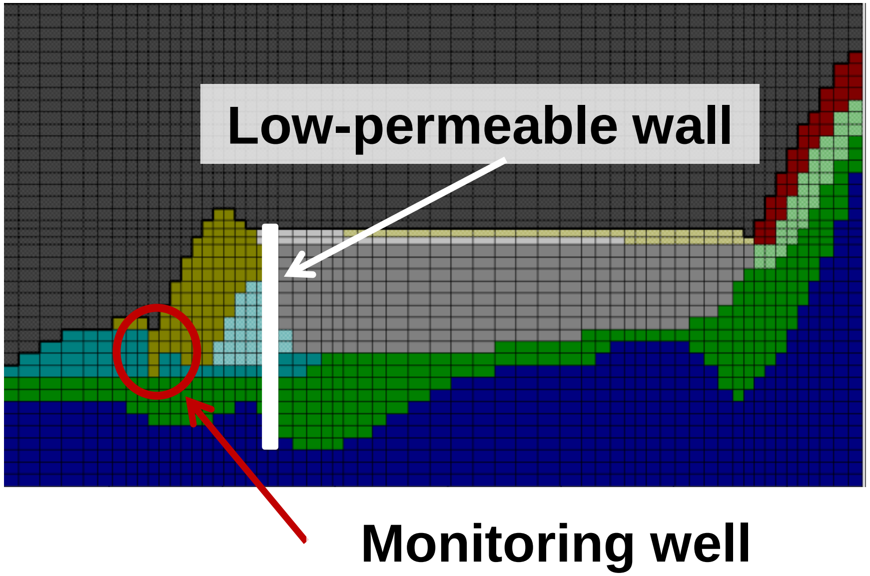
Some countermeasures should be taken!



- One of the countermeasures to decrease the heavy metal burden of the AMD from the tailings dam is to:

Constructing a low-permeable wall downstream of the tailings dam



Setting an observation point to monitor the concentration of heavy metal and water quantity from the tailings dam.

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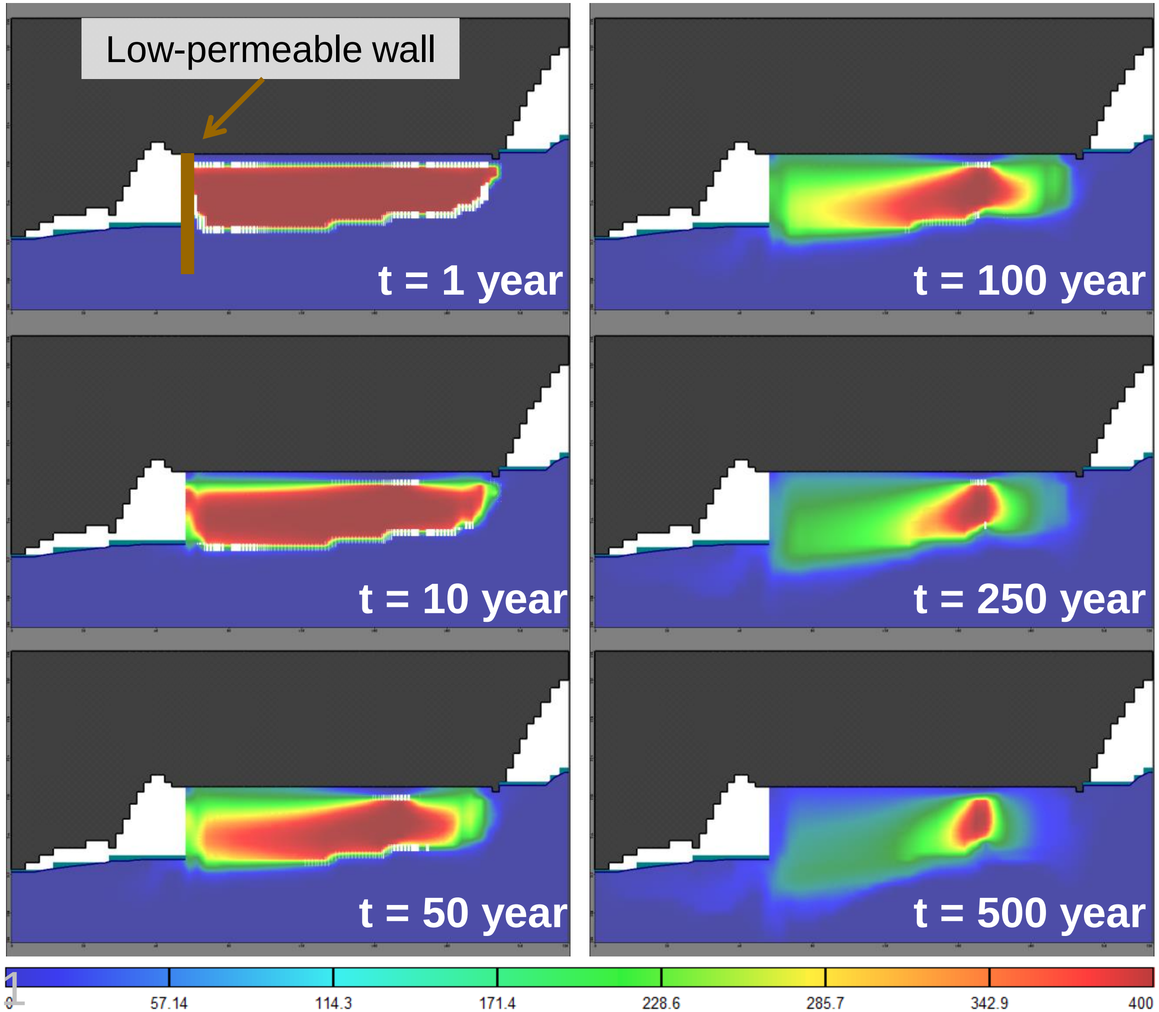
To evaluate the effectiveness of the countermeasure, we compared the result without countermeasure and with the low-permeable wall.

- Migration of Zn in the tailings dam
  (A low-permeable wall is constructed downstream of the tailings dam)

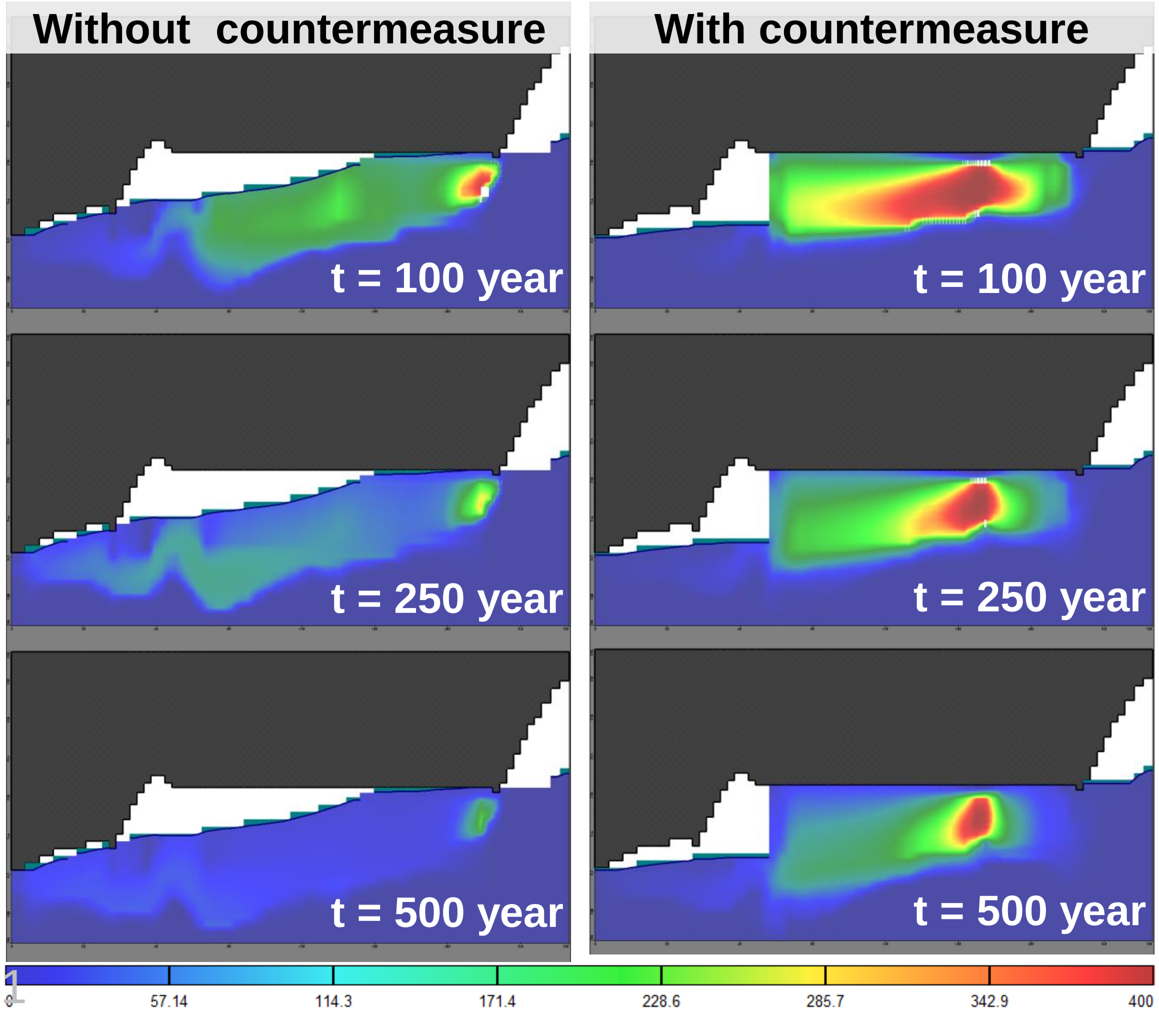


A low-permeable wall prevented Zn transport out of the tailings dam.

Simulation part

▶ Migration of Zn in the tailings dam

(A low-permeable wall is constructed downstream of the tailings dam)



A low-permeable wall prevented Zn transport out of the tailings dam.

Migration of Zn out of the tailings dam was delayed.

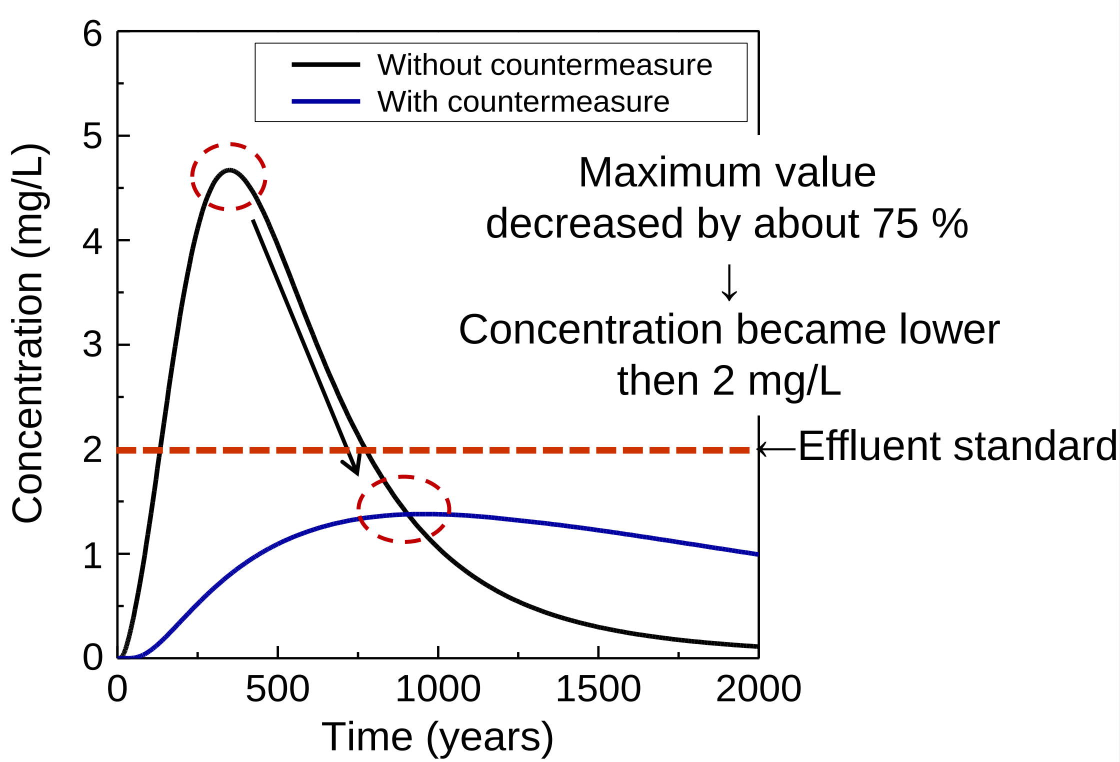
Low-permeable wall minimized groundwater flow and raised groundwater level.

↓

Adsorption sites increased so that more Zn could be adsorbed and immobilized in the tailings .

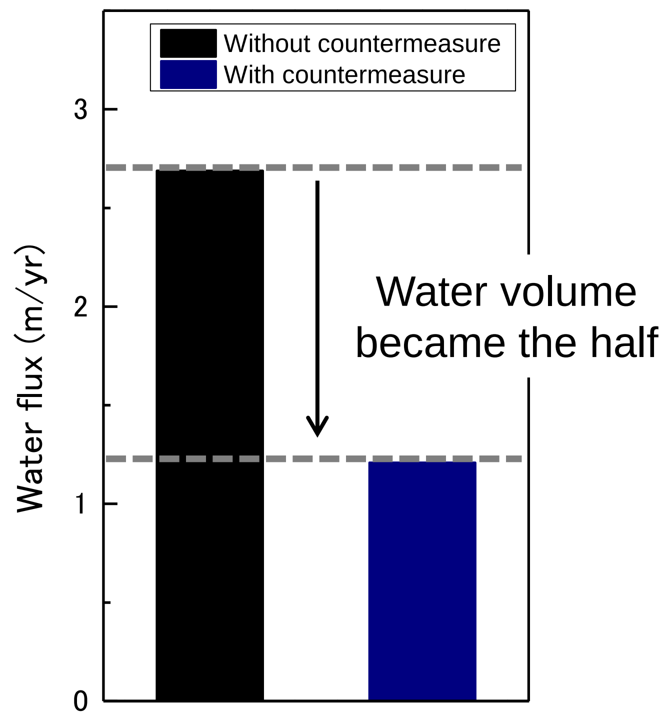
- Effectiveness of countermeasure

Water quality



Change of concentration in seepage

Water volume



Comparison of flux of seepage

We can improve the water quality and decrease the volume of seepage by constructing a low-permeable wall downstream of the tailings dam.

Overall conclusions

- Tailings have higher leaching concentration than the other zones because of its high heavy metal contents and the partitioning of the heavy metals in labile phase.
- The tailings with higher heavy metals partitioned in the exchangeable fraction have higher leaching concentration than the those with lower exchangeable fraction.
- Leaching of the heavy metal from the tailings dam will continue because of the high exchangeable and sulfide phases in the tailings.
- It is effective to construct a low-permeable wall downstream of the tailings dam to improve the quality of the seepage from the tailings dam and to decrease the quantity of AMD.

Closed mine sites in Japan

- There are more than 5,000 closed mine sites in Japan.
- Some countermeasures for AMD are conducted in about 100 closed mine sites in Japan.
- Neutralization is taken place in 80 sites.

Locations of closed mine sites
with some countermeasures

Contents of elements and minerals in samples

The contents of each element in the tailings

	SiO_2 (wt%)	Al_2O_3 (wt%)	Fe_2O_3 (wt%)	S (mg/kg)	As (mg/kg)	Pb (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	LOI (wt%)
Tailings	**45.8**	**12.6**	**20.6**	**54880**	**42.1**	**47**	**2170**	**6720**	**6.8**
Tailings (Oxidized)	**62.5**	**10.3**	**5.49**	**6678**	**20.5**	**24.6**	**271**	**362**	**4.03**

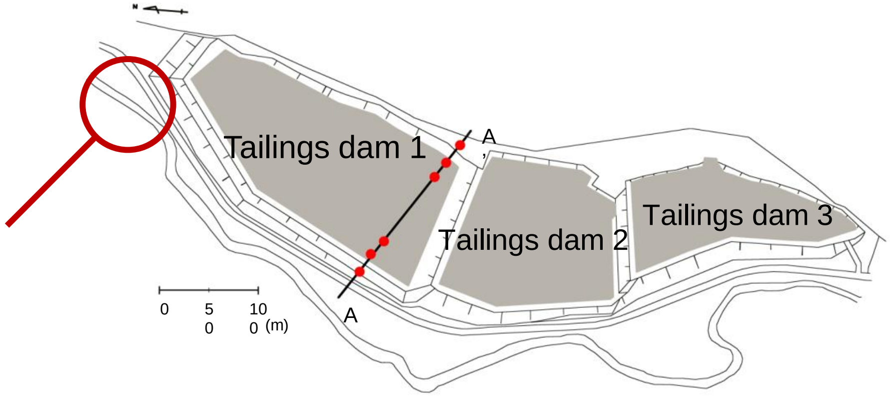
The minerals in the tailings

Geology	Minerals
Tailings	**Chlorite, Pyrite, Quartz**
Tailings(Oxidized)	**Jianshuiite, Quartz**

Water quality of seepage from tailings dams

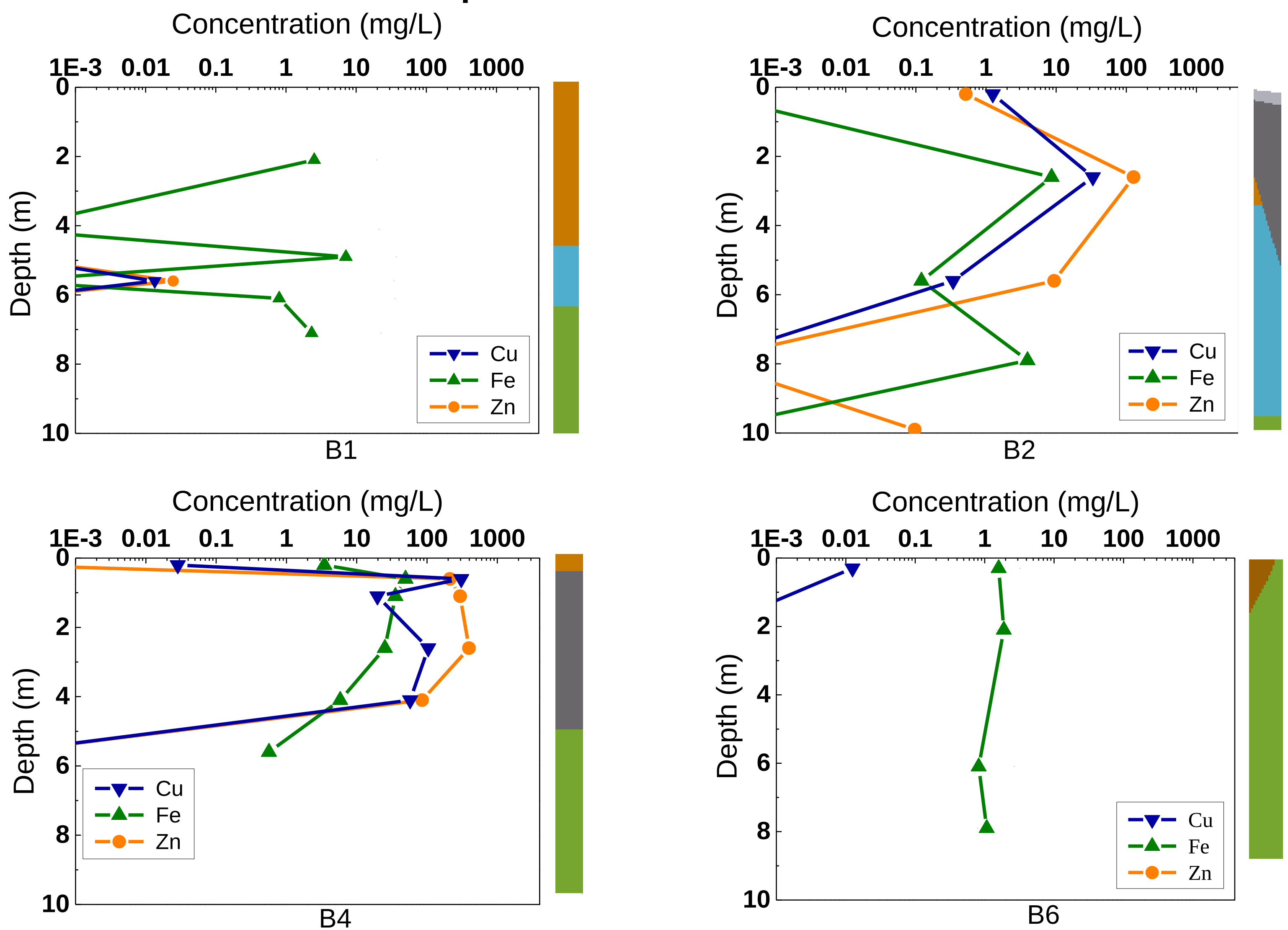
	pH	volume (m^3/min)	Concentration of heavy metals(mg/L)		
			Cu	Fe	Zn
Effluent standard	5.8～8.6	-	≦3	≦10	≦5
Before treatment (2002)	3.33	0.068	0.89	55.4	5.50
After treatment (2002)	6.86	-	0.08	0.75	0.74
Before treatment (2010)	3.52	0.041	0.62	71.4	8.57
After treatment (2010)	7.61	-	0.025	0.124	0.488

These values of before treatment were measured in here.



The results of batch leaching experiment

- Concentration vs. depth



The results of batch leaching experiment

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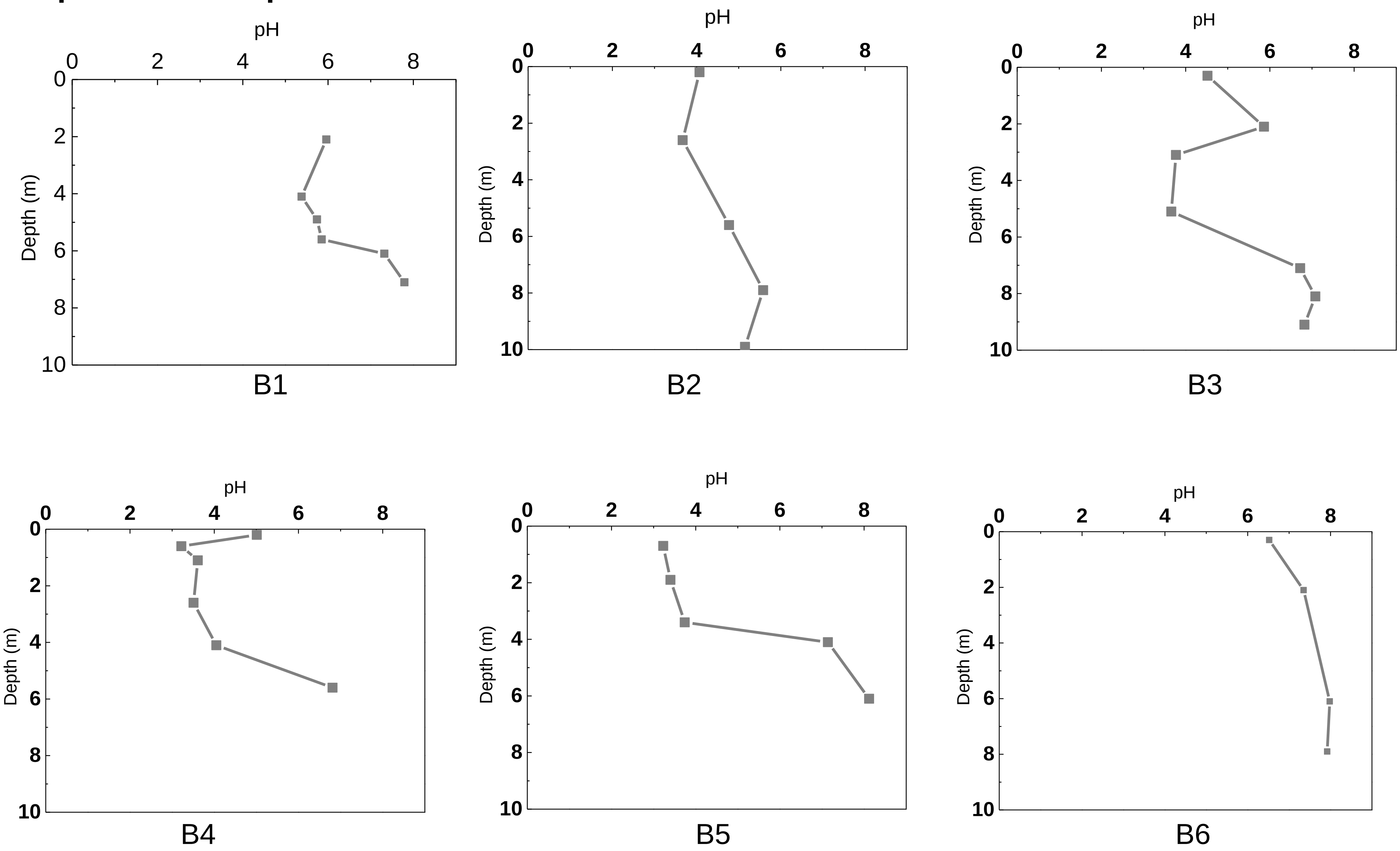


Relationship between leaching concentration and solid phase partitioning

Contents and leaching concentrations of heavy metals

		B5-2	B3-5
Contents of heavy metals (mg/kg)	Cu	1760	2510
	Fe	140000	135000
	Zn	5390	19400
The results of batch leaching experiment (mg/L)	Cu	95.4	0.0587
	Fe	67	0
	Zn	365	36.8

Fraction of exchangeable

	B5-2	B3-5
Cu (%)	55.6	1.19
Fe (%)	0.303	0.0408
Zn (%)	71	2.26

Contents in 10g samples and leaching concentrations of heavy metals from 10g samples

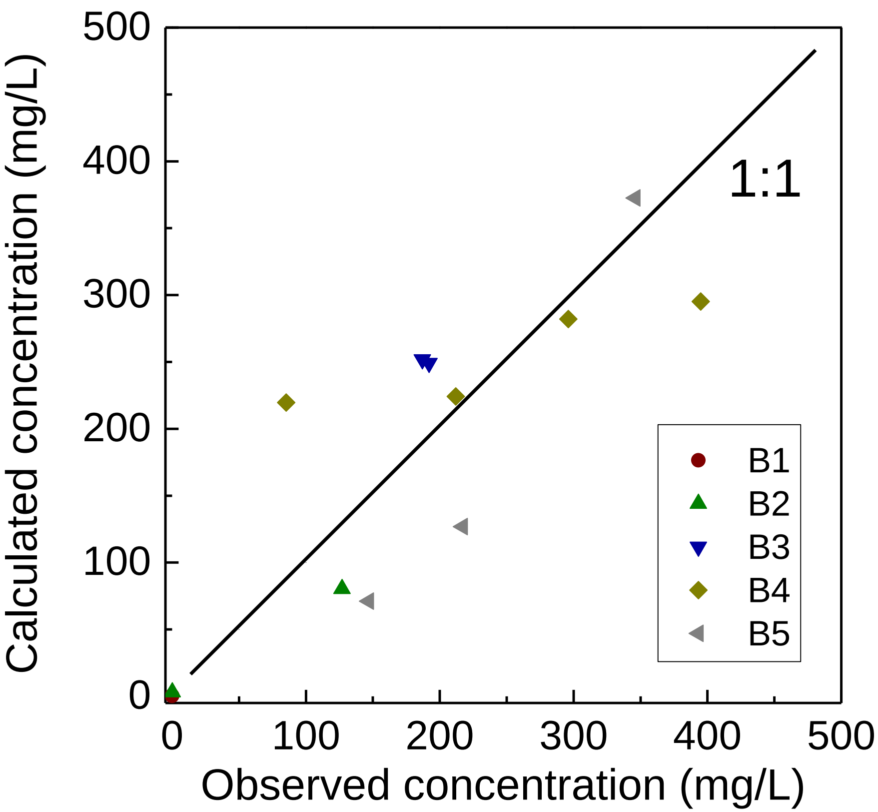
		B5-2	B3-5
The contents of exchangeables (mg)	Cu	9.79	0.299
	Fe	4.24	0.00551
	Zn	38.3	4.38
The amount of leaching heavy metals (mg)	Cu	9.54	0.00587
	Fe	6.7	0
	Zn	36.5	3.68

Conditions of numerical simulation

- Parameters
  - Porosity : 0.4
  - Density : tailings 2.8 g/cm^3 the other :2.65 g/cm^3
  - Dispersivity : 10 m

- Initial condition
  - Initial head : 220 m

Validation of the simulated results



Comparison of calculated and observed concentrations

Comparing concentrations (after 40 years) calculated in the simulation with those observed in batch leaching experiments, because this tailings dam was constructed 40 years ago.

Calculated concentrations are close to the observed concentrations.

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This model adequately predicted groundwater flow and Zn migration.