UBC Investigation of the Mineralogical, Hydrological and Biogeochemical Controls on Drainage from Waste Rock at the Antamina Mine, Peru

ANTAMINA WASTE ROCK STUDY

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Project goals

Provide Antamina a knowledge base to support waste-rock management and decision making

- Operational criteria
- Closure planning

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Site description - Antamina

- Located at 4300-4800 MASL
- Alpine climate with bimodal precipitation
- Cu-Zn skarn deposit
- Mills 130 kt/day
- 340 kt/day waste rock
- Waste rock produces drainage with circum-neutral pH
- Metals of concern include As, Cu, Zn and Mo

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Antamina site

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East waste-rock pile

East waste-rock pile

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Antamina site

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Tucush waste-rock pile

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Multi-scale investigation

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Project components

1. Field cells.
2. Experimental waste-rock piles.
3. Cover experiments.
4. Classification / diagnostic leaching.
5. Real time and instantaneous gas monitoring.
6. Mineralogical characterization.
7. Microbiology.
8. Data integration and interpretation with process-based models.

Site waste-rock classification

Type A – reactive, high potential for leaching

Type B – moderate potential for leaching

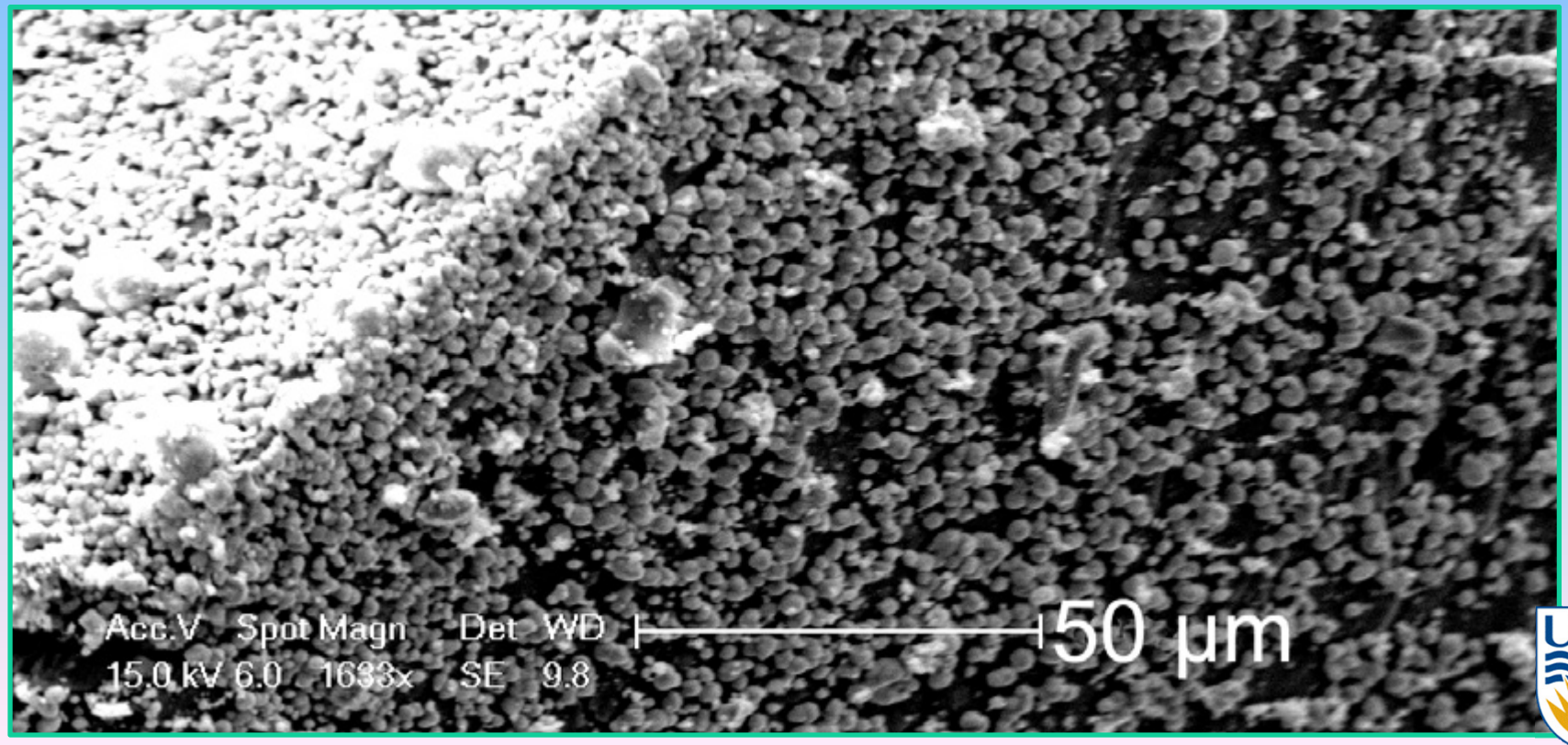
Type C – low potential for leaching (Clean)

Elements of Concern: Mo, Zn, Cu, As

Molybdenum attenuation

- Attenuated in two mineral phases:
  - Powellite ($CaMoO_4$)
  - Wulfenite ($PbMoO_4$)

Powellite crystals



Field cells

- End member drainage compositions from individual rock types
- Attenuation processes

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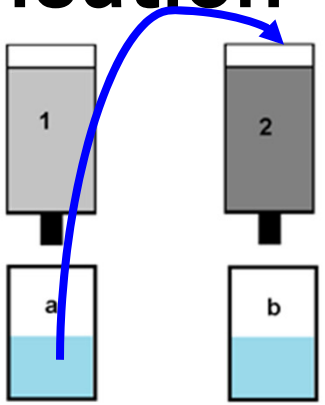
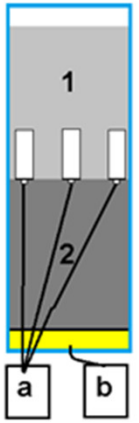
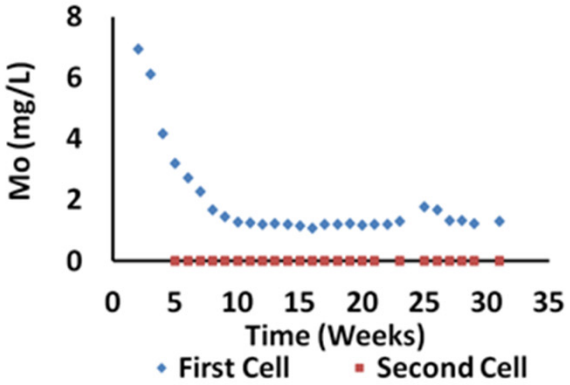
Mo attenuation

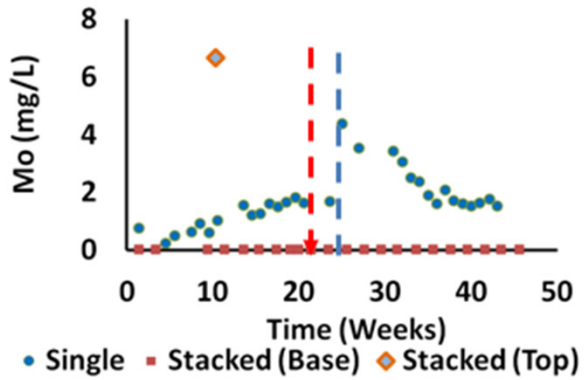
Intrusive

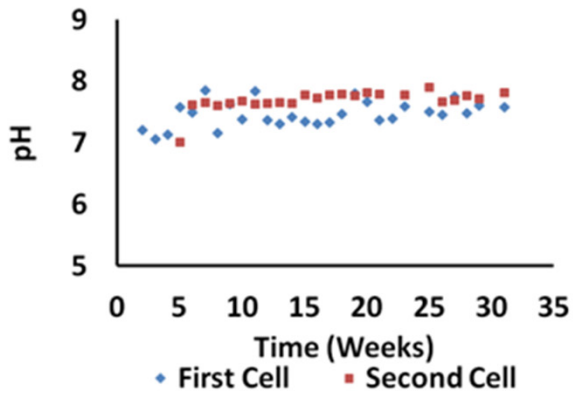
Black Marble

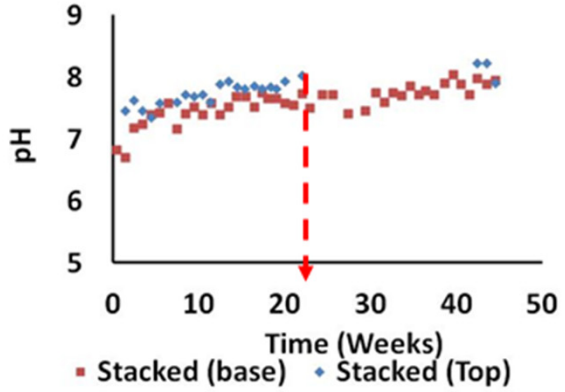












Pile experiments

30,000 tons, 36 x 36 m x 10 m high

End-dumped in 3 stages

Pile 1 – Class B + “A” marble and hornfels

Pile 2 – Class A intrusive

Pile 3 – Class A exo/endoskarn

Pile 4 – Class C hornfels + B marble mixture

Pile 5 – Class C hornfels + A intrusive, exoskarn

Mixing

Protective cover and sublysimeters

Pile experiments

Flow Through Cell (EC, Temp, sampling)

Tipping buckets

Flow splitter

Data loggers

Pile experiments

Temperature

Volumetric Water Content

Gas Sample

Matrix Water Sample

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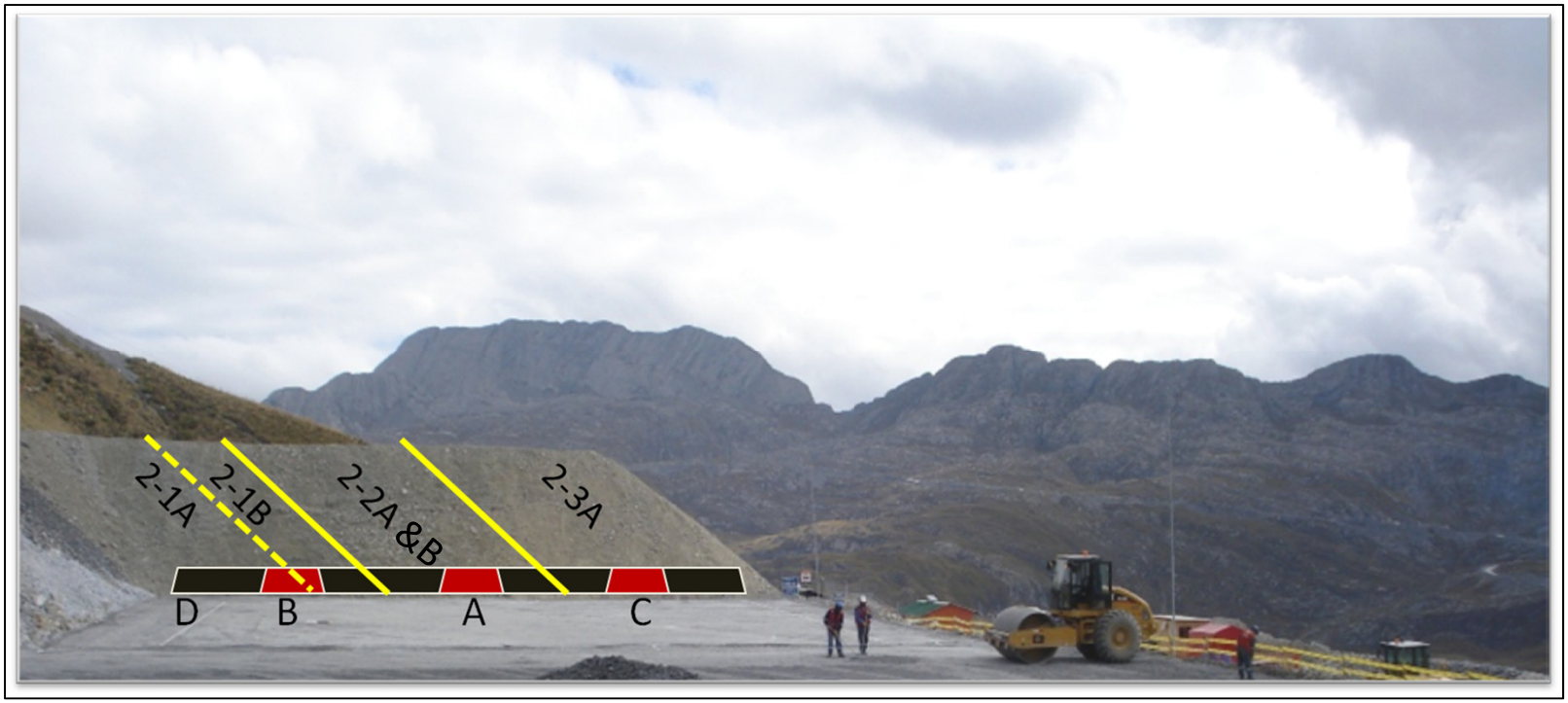
Overview: Rapid geochemical transition

- During a two-month period:
  - pH dropped
    - pH 7.7 → pH 6.4
  - Cu increased
    - 0.01 mg/L → 67.0 mg/L
  - Zn increased
    - 5.9 mg/L → 41.9 mg/L
  - Accumulation of predominantly amorphous precipitate

ANTAMINA WASTE ROCK STUDY

Project Description: Pile 2

Field Cell ID	Tipping Phase	Associated Lysimeter	NP/ MPA	S (%)	C (%)	As (ppm)	Cu (ppm)	Mo (ppm)	Zn (ppm)
Range			0.06 - 1.90	0.2 - 4.26	0.05-0.17	21-228	612-7140	265-429	33-439
Average			0.80	1.46	0.11	108	3096	340	231



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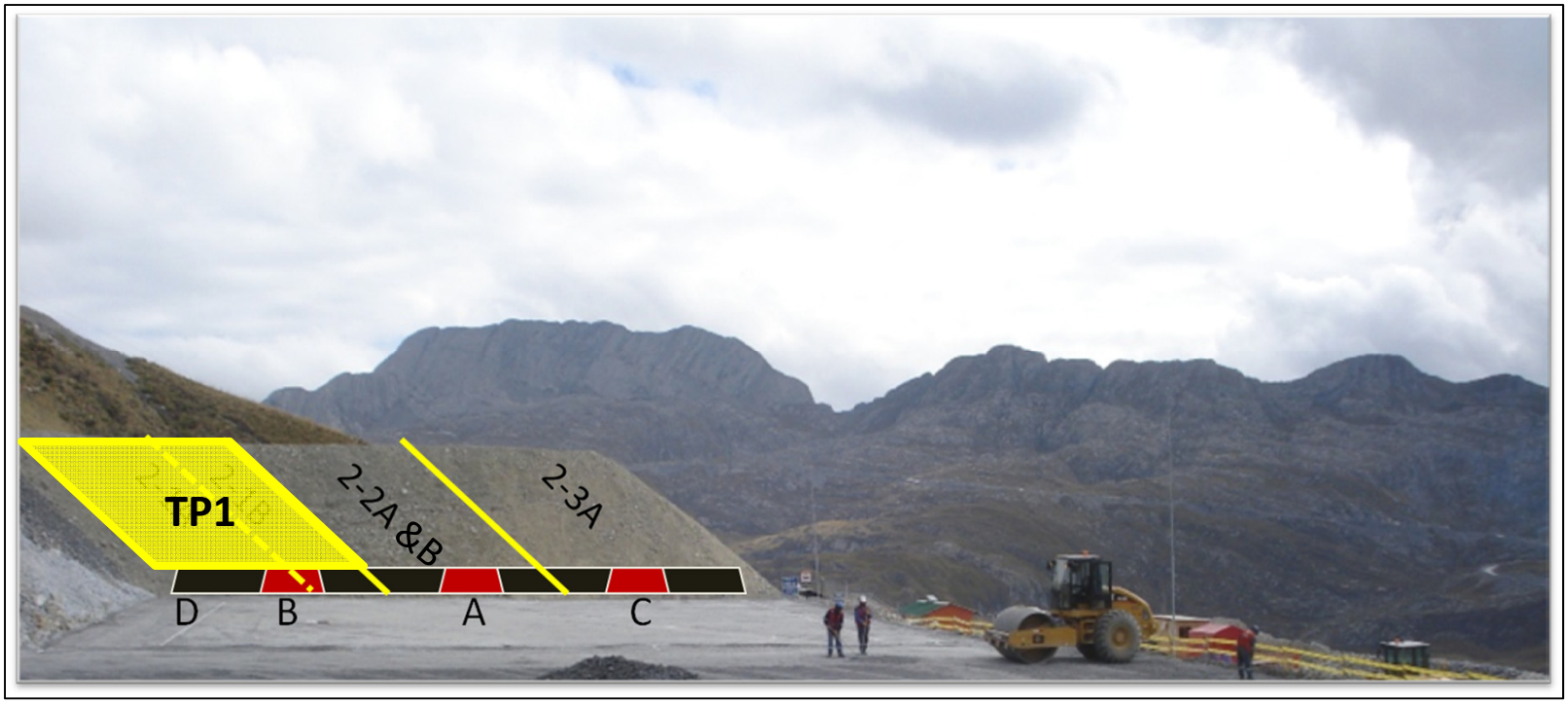

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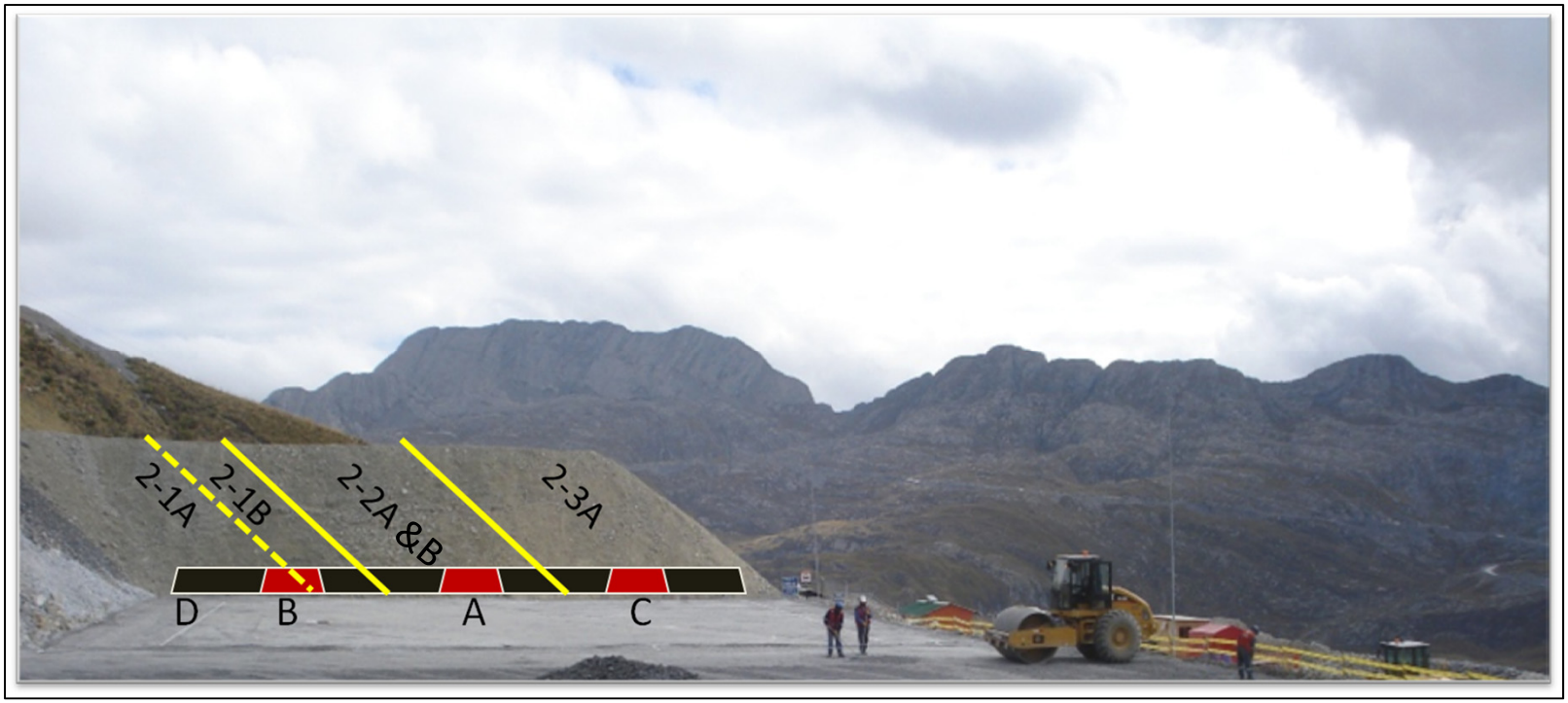

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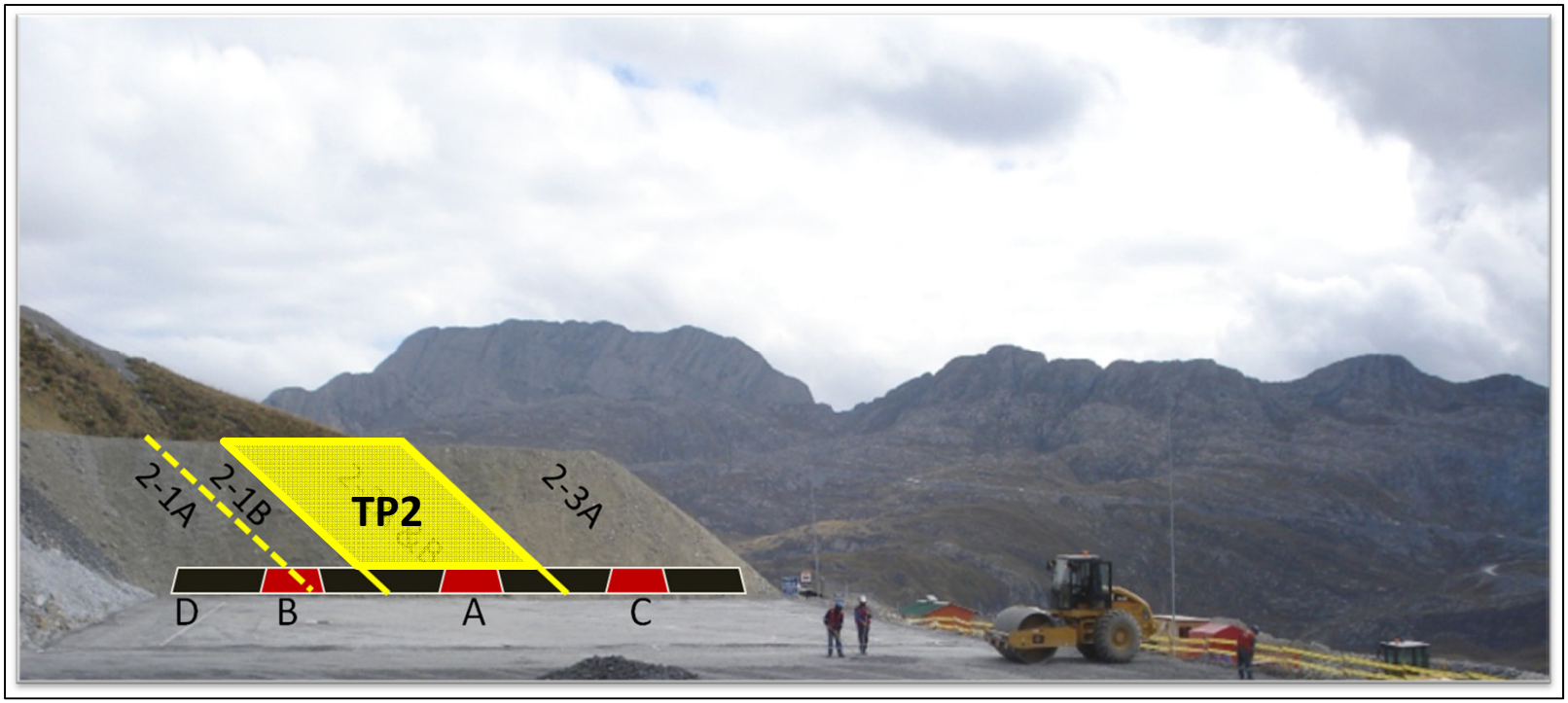

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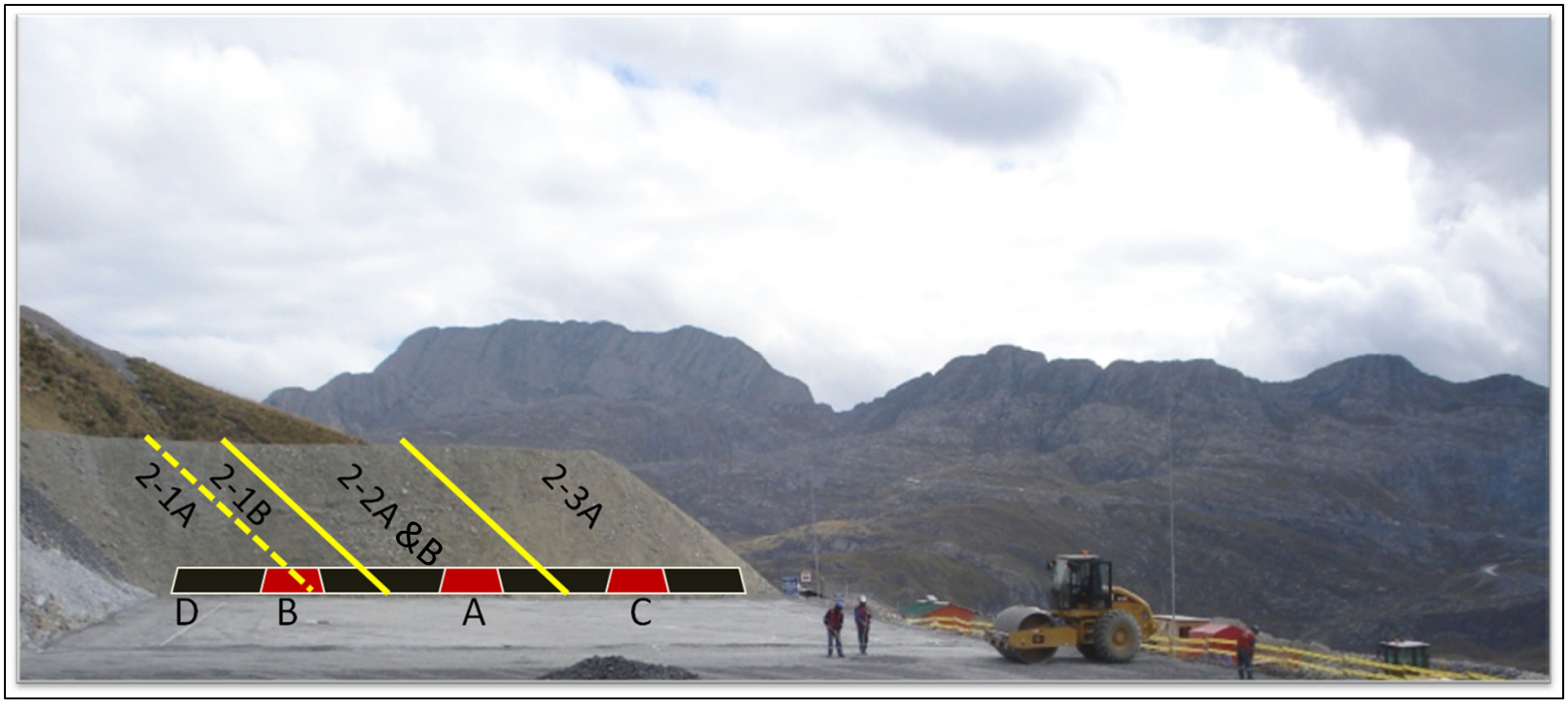

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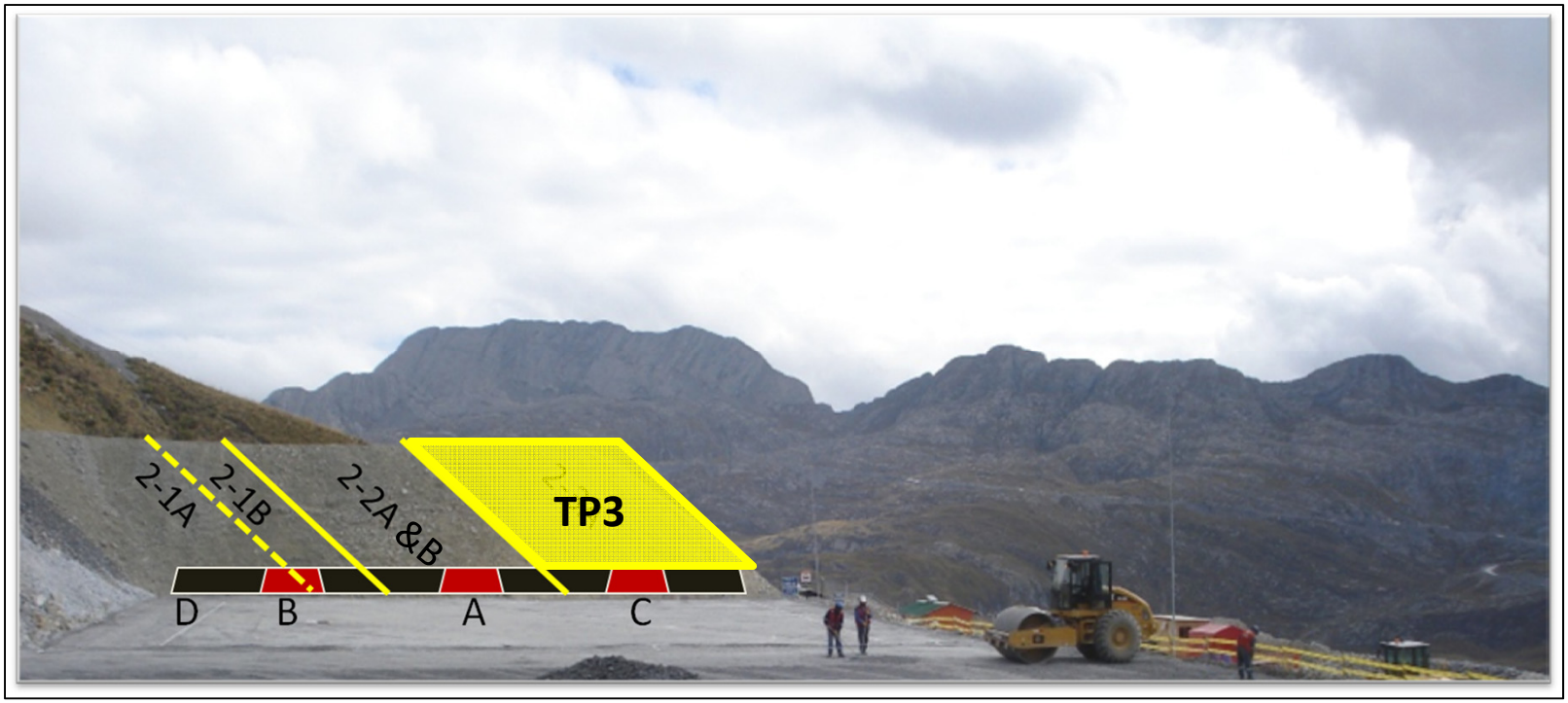

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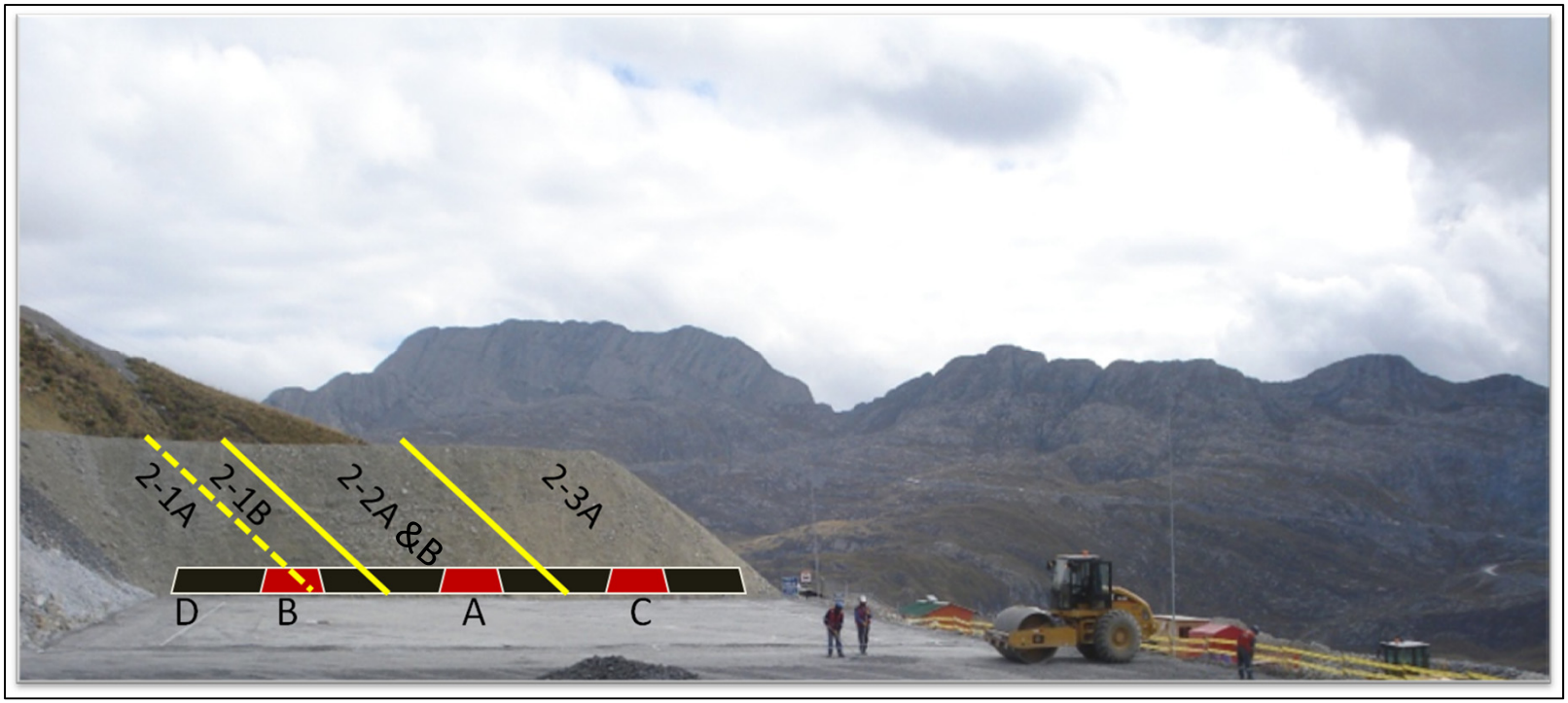

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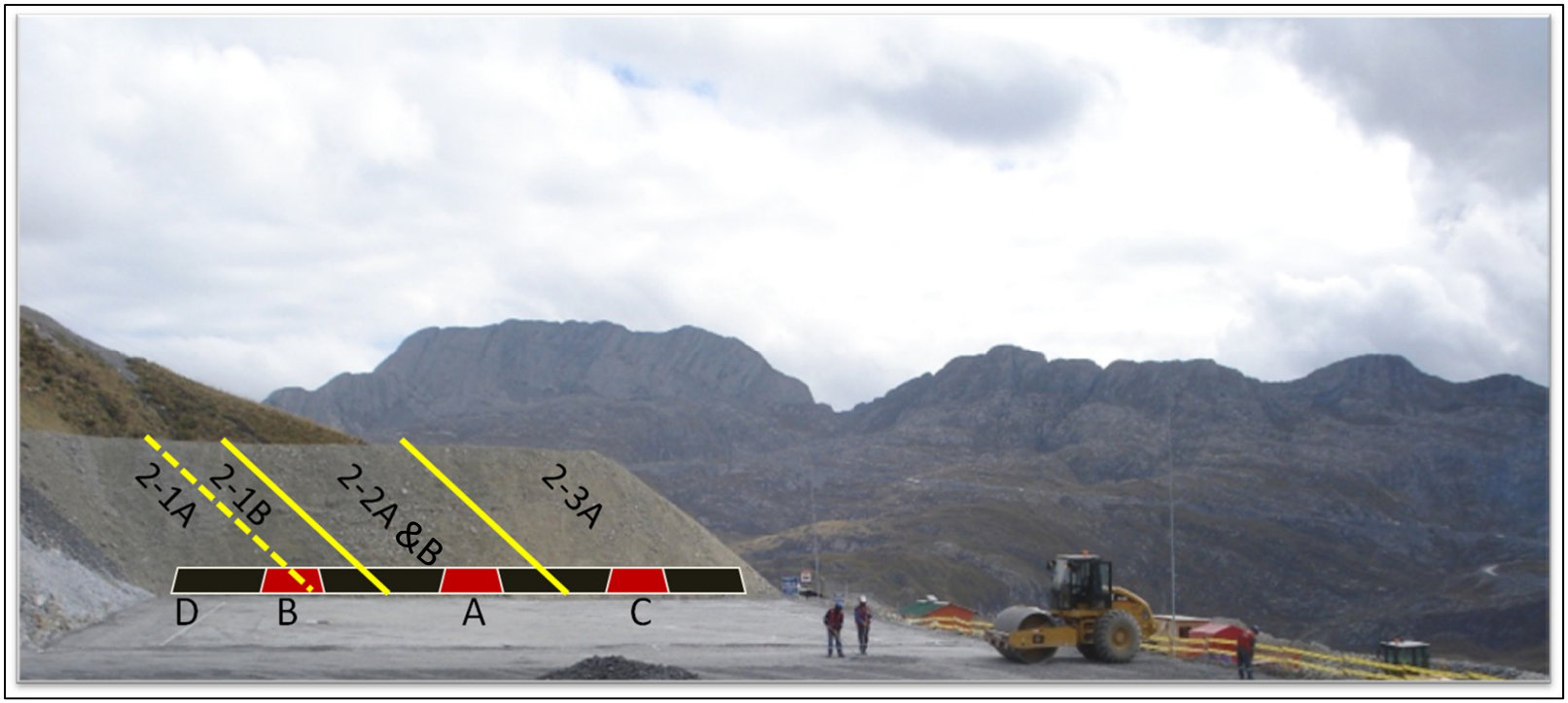

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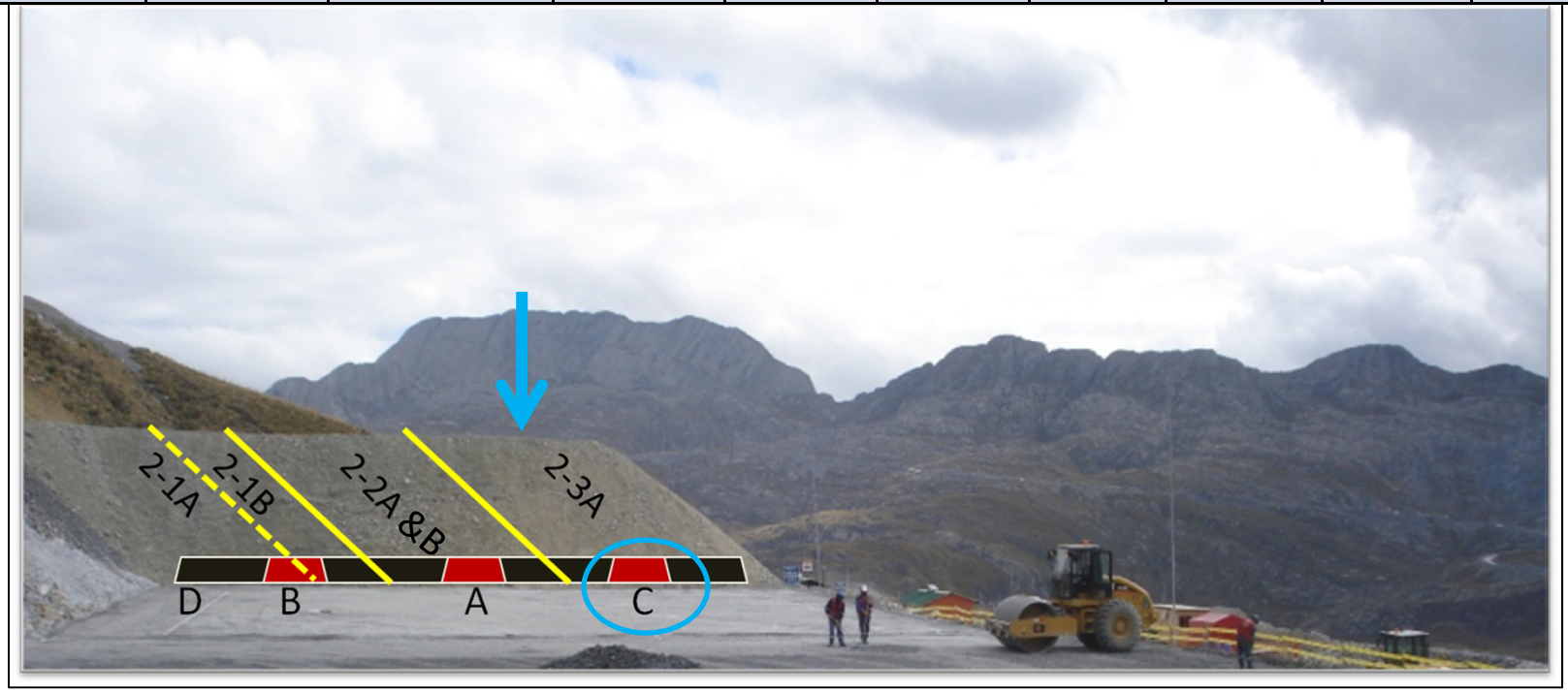

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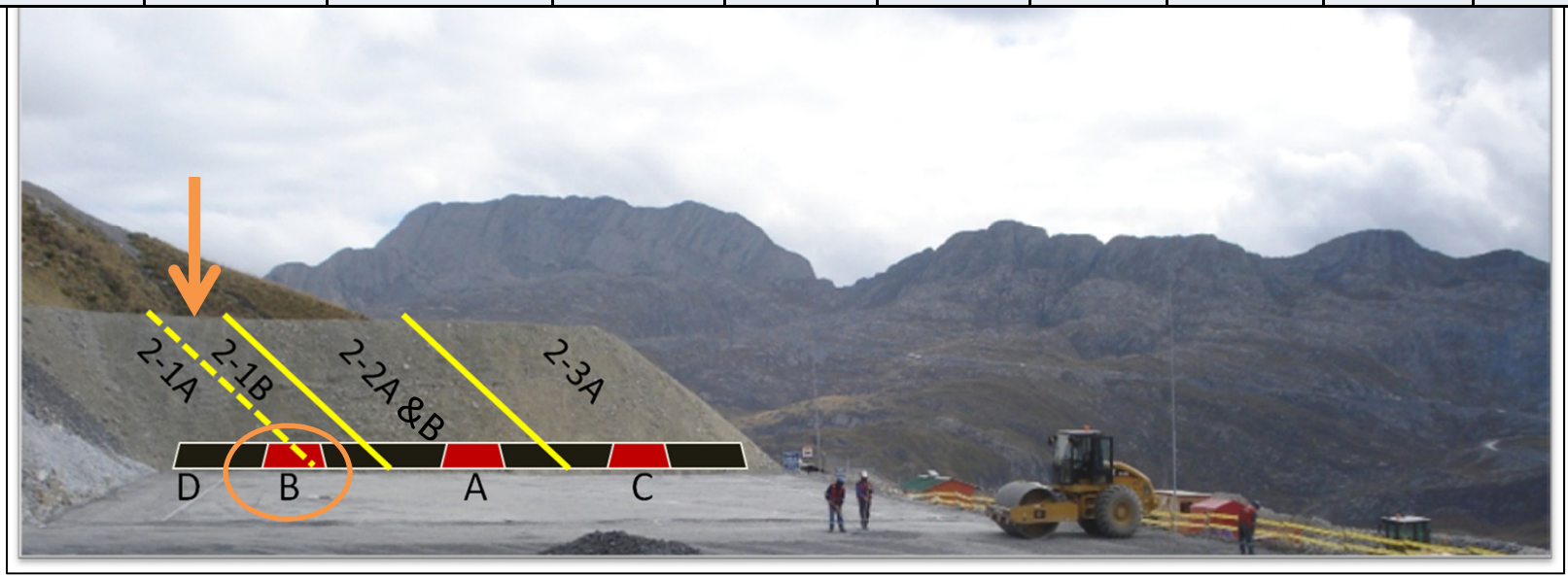
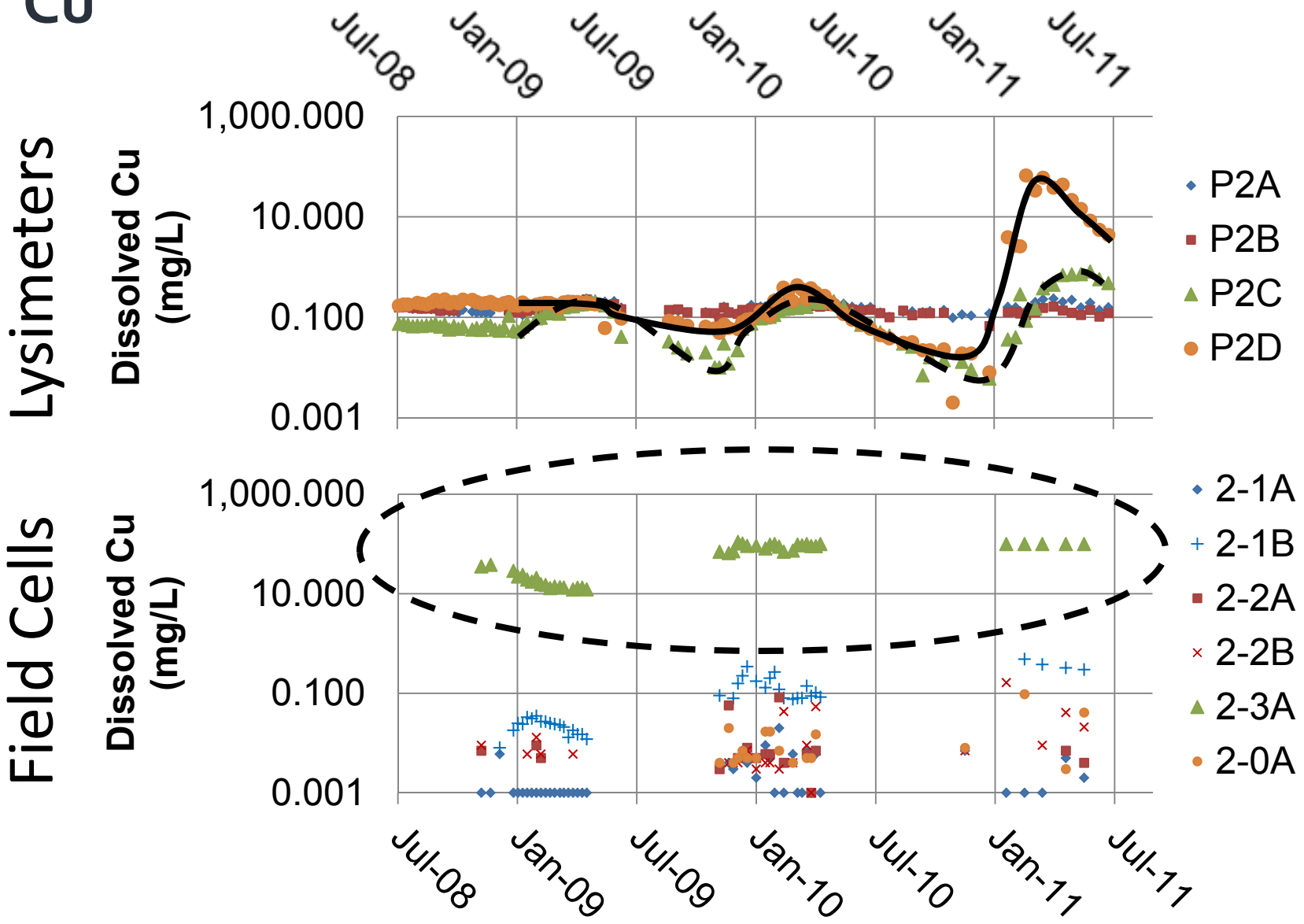
2-3A	Tipping phase 3	P2C	0.14	1.56	0.05	228	7140	282	310
2-1B	Tipping phase 1	P2B	0.06	4.26	0.09	21	1710	329	439



Lysimeter & Field Cell Chemistry: Cu



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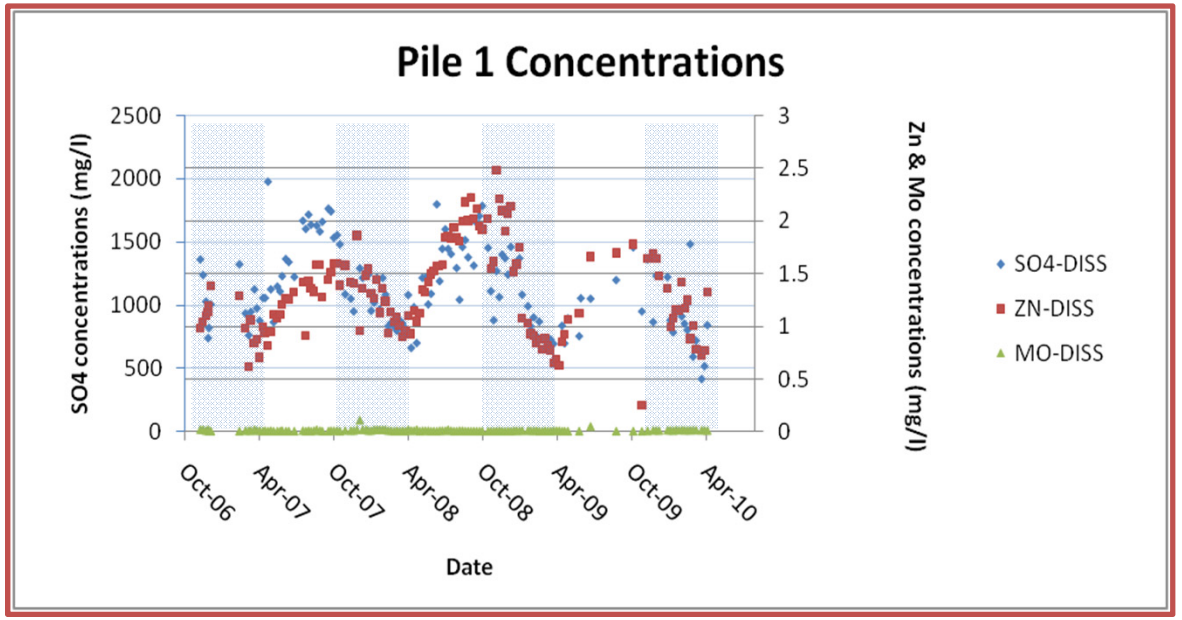
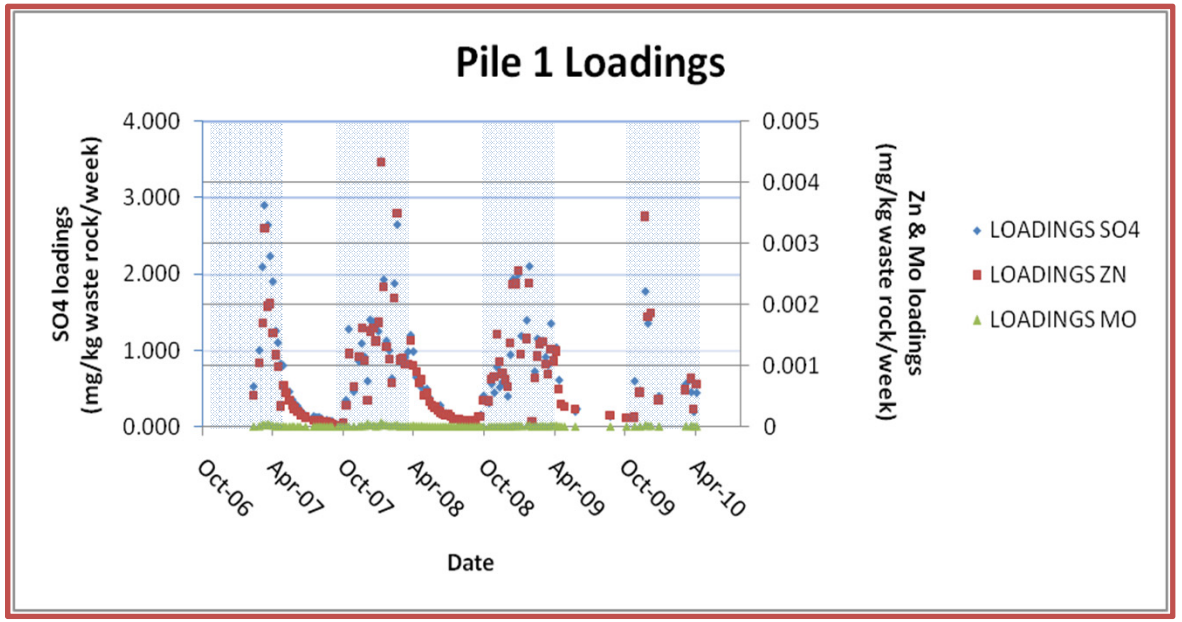
Pile chemistry

- Concentrations peak end of dry season
- Loadings peak mid-wet season





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Scale effect: Zn loading (mg/kg/week)

Location	Wet season	Wet Season Ratio
Pile 1	$3.3x10^{-03}$	2.5
Field Cells	$8.1x10^{-03}$	
Pile 2	$1.0x10^{-01}$	3.7
Field Cells	$3.7x10^{-01}$	
Pile 3	$6.1x10^{-02}$	2.6
Field Cells	$1.6x10^{-01}$	
Pile 4	$4.6x10^{-04}$	
Field Cells: B	$1.6x10^{-03}$	3.6
Field Cells: C	$5.8x10^{-04}$	1.3
Pile 5	$2.6x10^{-04}$	
Field Cells: A	$1.0x10^{-03}$	3.9
Field Cells: C	$8.3x10^{-04}$	3.2

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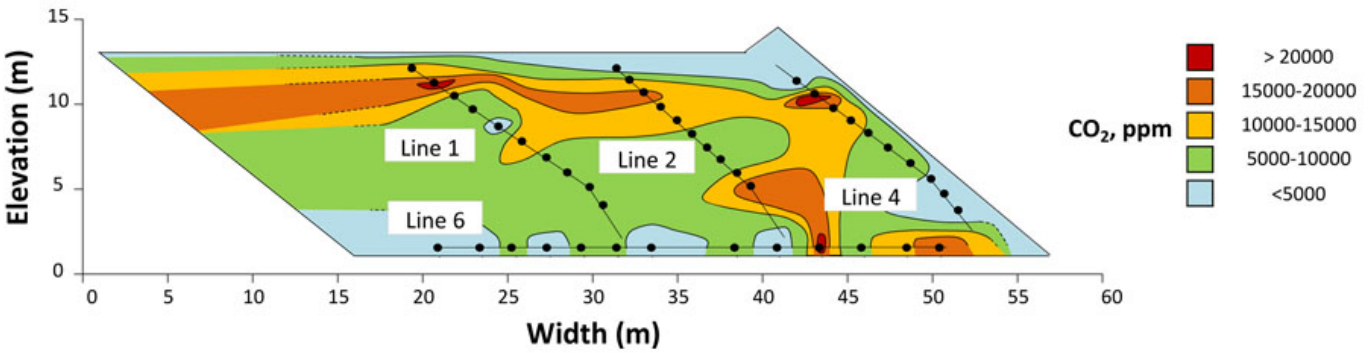
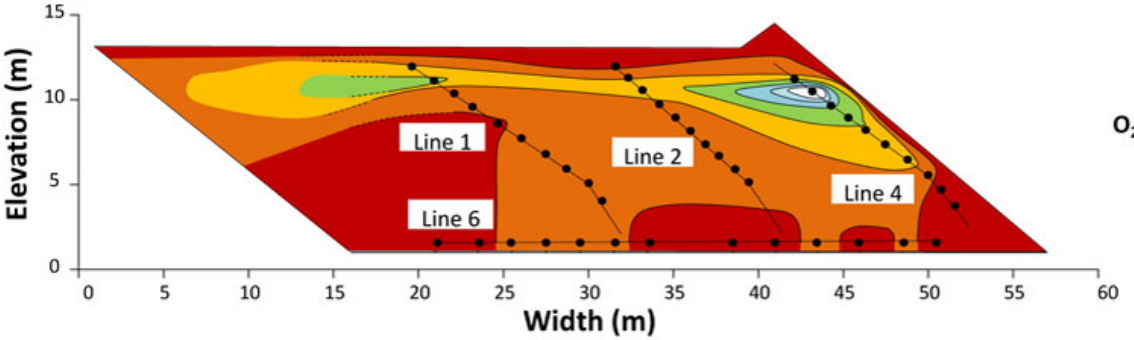
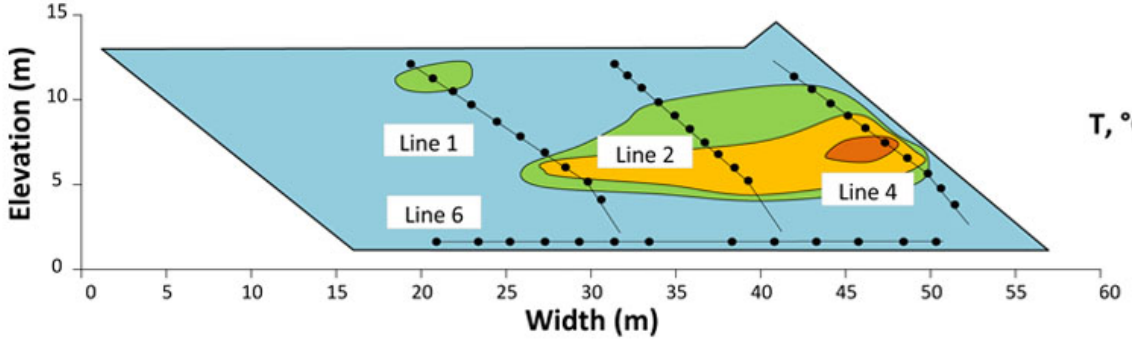
Pile 2

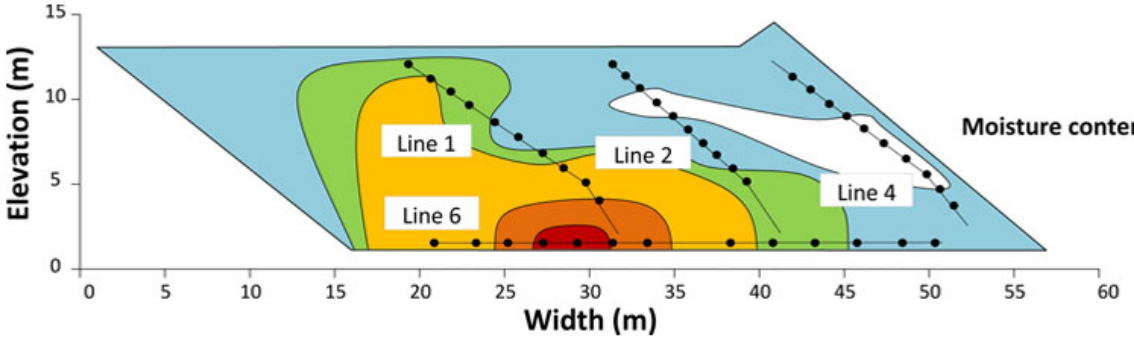
Oxygen depletion

Heat & CO_2 production









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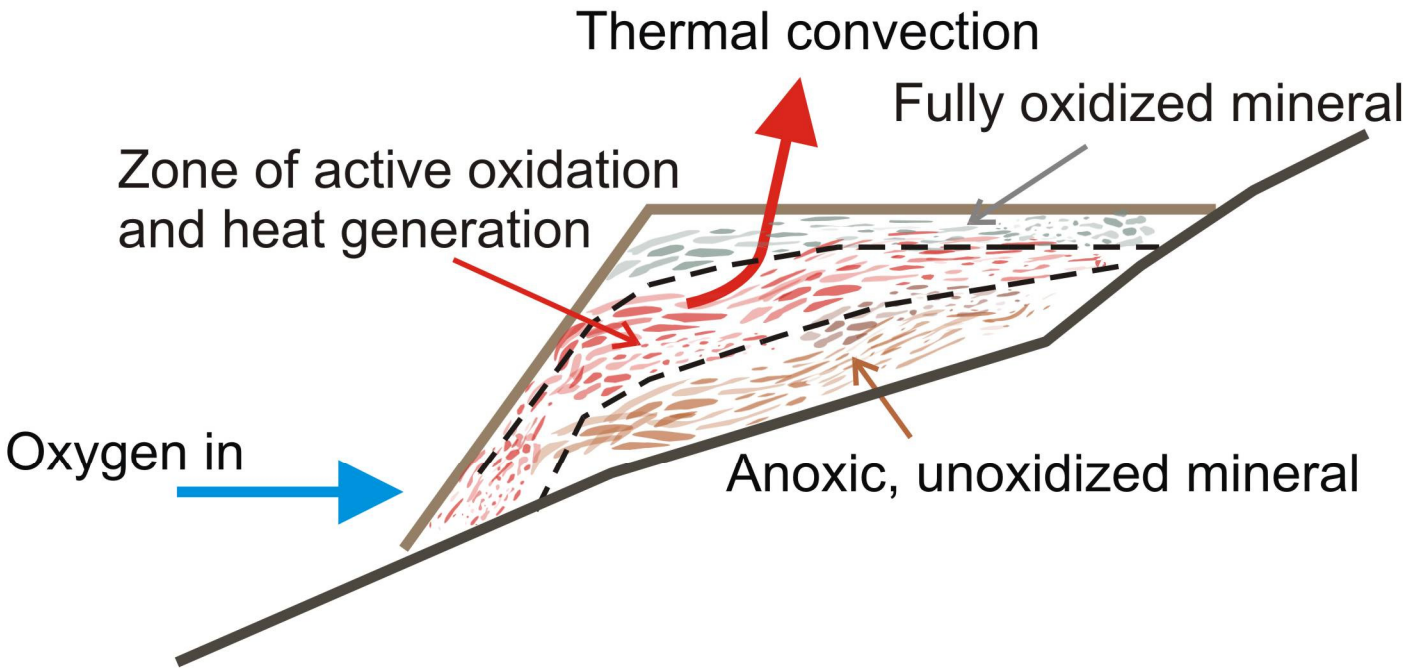
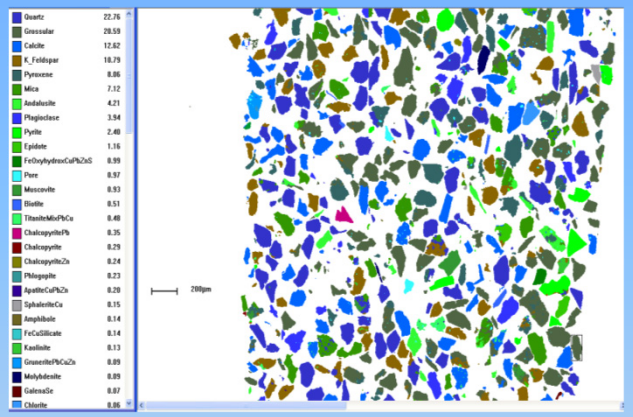
Conceptual model: Oxygen transport effects



Less oxidation than under fully aerobic conditions

Integration using mechanistic models



$$\phi_f R_f \frac{\partial c_f}{\partial t} = \nabla \cdot (\mathbf{D}_f \cdot \nabla c_f) - \mathbf{q} \cdot \nabla c_f - F_m$$

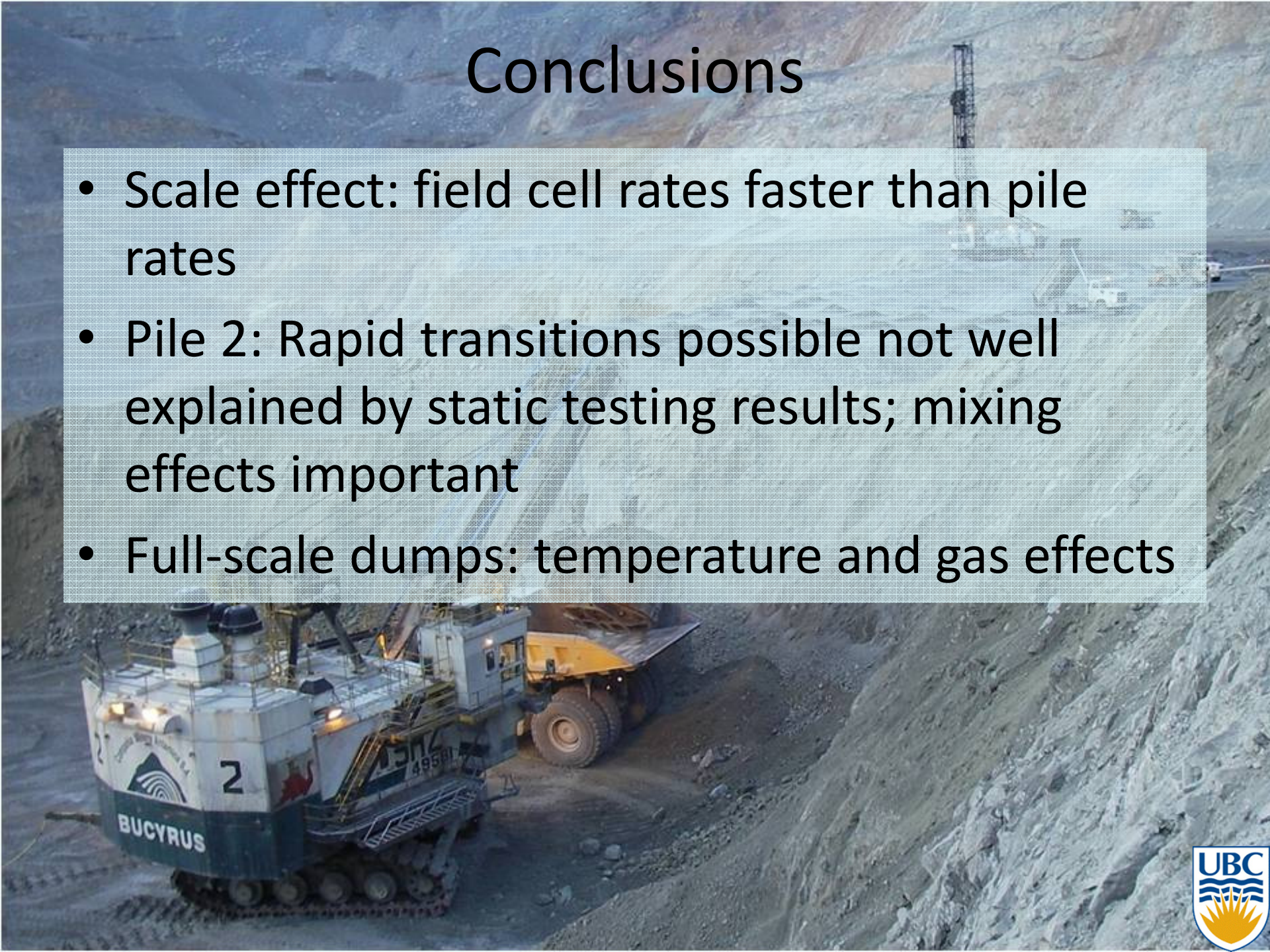
$$\frac{\partial \theta_w}{\partial t} = \nabla \cdot \left[K(\psi) \left(\nabla \psi + \nabla z \right) \right],$$

$$\theta_w = \theta_w(\psi).$$

Quantitative modeling

Conclusions

- Scale effect: field cell rates faster than pile rates
- Pile 2: Rapid transitions possible not well explained by static testing results; mixing effects important
- Full-scale dumps: temperature and gas effects



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Thank-you!

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