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Incorporating wall washing data sets into closure planning: Insights from Brucejack Mine

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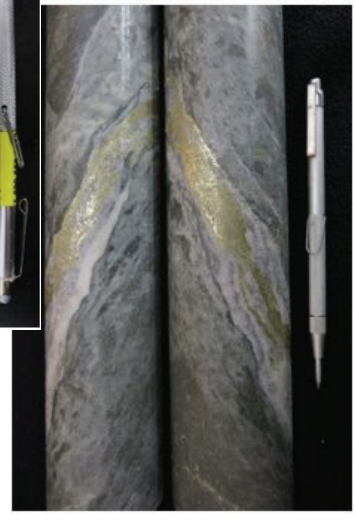
Introduce presentation

While we have this photo up – for those that don't know, here is Brucejack Mine. Located in NW BC as shown on the inset map on the left. Brucejack is located in the Golden Triangle and is a high-grade underground gold and silver mine, in operations since 2017.

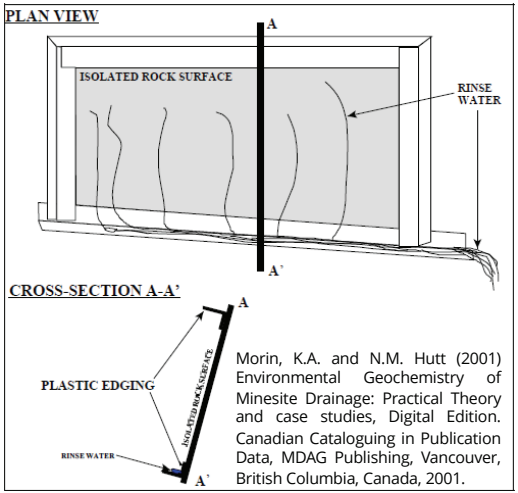
Brucejack Mine

- High grade gold and silver underground mine
- Volcanic arc-related epithermal vein deposit
- Waste rock has been well characterized:
  - Static tests (>500 samples)
  - Humidity cells (81, 22 ongoing)
  - Saturated columns (35, 24 ongoing)
  - Field Bins (14)
  - Wall washing stations (7)
- Waste rock managed as PAG, but significant carbonate present so onset to ARD is on the order of decades.
- Comprehensive water quality monitoring ongoing (Sumps, Seeps, Stopes, Mine Water)

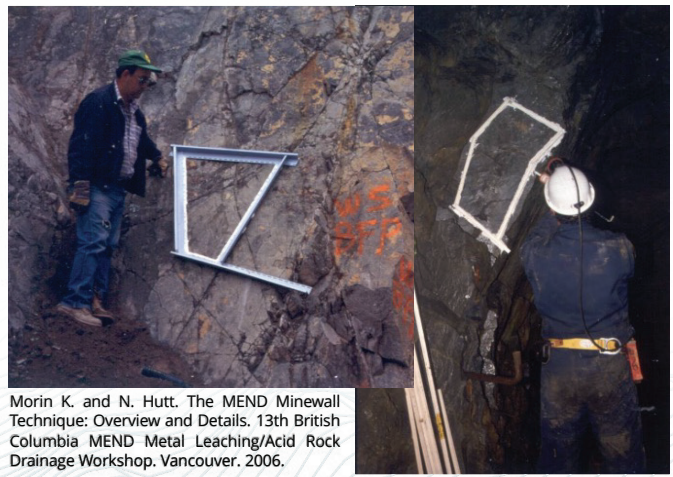


As mentioned, Brucejack is a high-grade gold and silver underground mine. It is a volcanic arc-related epithermal vein deposit. The waste rock at site has been well characterized (reference testing) with the majority of these samples indicating that the waste rock is PAG. However, as you can see on the right, the ore is often hosted within carbonate-quartz vein systems, which provides significant buffering capacity, making the timeline to ARD onset on the order of decades. In addition to various static and kinetic tests, a comprehensive water quality monitoring program is ongoing as part of the operation to understand the evolution of water quality within the mine through time and development.

Wall Washing Stations – Program Design



Morin, K.A. and N.M. Hutt (2001) Environmental Geochemistry of Minesite Drainage: Practical Theory and case studies, Digital Edition. Canadian Cataloguing in Publication Data, MDAG Publishing, Vancouver, British Columbia, Canada, 2001.



Morin K. and N. Hutt. The MEND Minewall Technique: Overview and Details. 13th British Columbia MEND Metal Leaching/Acid Rock Drainage Workshop. Vancouver. 2006.

So – what is Wall Washing and where does it fit into Brucejack's operation?

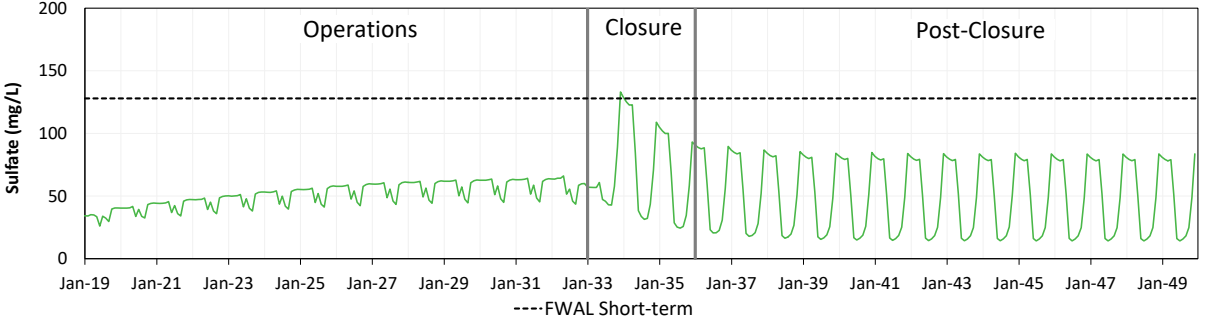
Morin and Hutt helped to develop workflows around Mine Wall Washing and provided the fundamentals that this approach is based on. Morin and Hutt have used the Mine Wall methodology to look at mine site drainage incorporation the entire water balance, whereas at Brucejack we are focusing in on mine closure and wall flushing specifically to inform closure planning.

Above are some schematics and images pulled from various publications and presentations that show station design and real-life application.

Brucejack Mine

WATER QUALITY PREDICTIONS

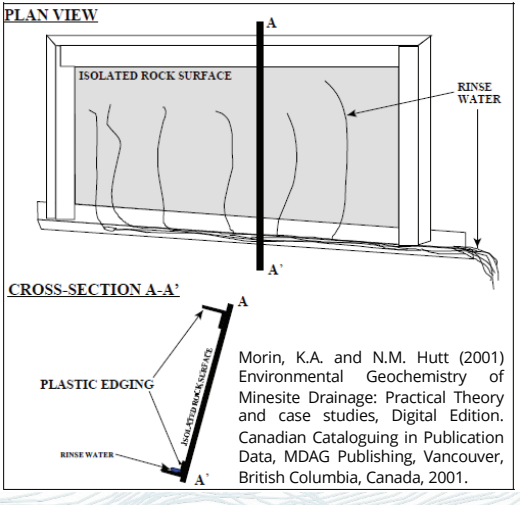
- Water quality model predicts discharge concentration peaks associated with mine flooding (mine wall flushing) at closure



2020 5-YR update model predictions

When we look towards the closure of the Brucejack Mine, current water quality modeling predicts that there could be concentration peaks for various parameters at discharge during the closure period as the mine is flooded and loads are flushed from the exposed surfaces underground.

Wall Washing Stations – Program Design



Morin, K.A. and N.M. Hutt (2001) Environmental Geochemistry of Minesite Drainage: Practical Theory and case studies, Digital Edition. Canadian Cataloguing in Publication Data, MDAG Publishing, Vancouver, British Columbia, Canada, 2001.

As shown previously, Morin and Hutt provide example station designs, which we have largely adopted for Brucejack. We attempt to create 1m^2 sections on the mine wall, with all four borders providing protection. The upper border stops water dripping or flowing down the mine wall from entering the station. The lower border acts as the rinsate collection trough for sampling. The side borders stop water from flowing into the station area laterally and allow for a cover to be affixed more solidly.

Wall Washing Stations – Site Selection

Key considerations for station selection:

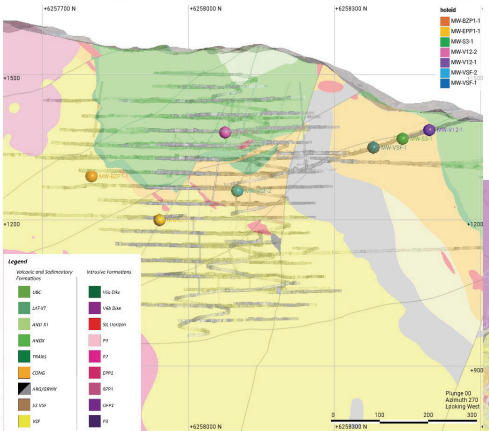
1. represent current and future lithologies
2. in areas that will allow long-term monitoring (no future development in area)
3. on flat walls that allow ease of construction (seals and sampling)
4. on faces without large fractures that could take water

In practice, we start by looking at the mine plan and determining the lithologies that we will be mining through (presently and into the future) and the associated exposed volume to prioritize installation of stations within our dominant mined lithologies. From there you look for a relatively flat piece of mine wall that is unlikely to be altered or destroyed through subsequent development (exploration drifts, vent raises, storage areas, etc).

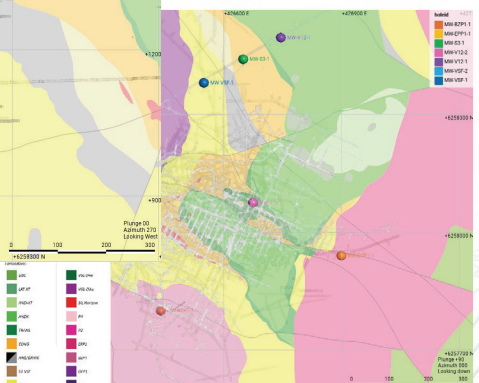
Once you have zeroed in on lithologies and safe areas, you look for mine walls within those areas that are largely flat for two reasons:
1) You don't want to have irregular mine walls that will make it difficult to create a competent seal of the station to the wall,
2) You want to be able to easily capture all the rinse water applied, overhanging walls or irregular walls can lead to drips leaving the station area or incomplete capture.
For similar reasons, you want to avoid walls that are heavily fractured that could allow for rinse water infiltration into the mine wall face.
Also – avoid areas with markings/impacts (image shown above was started, but after inspection we realized we couldn't completely remove the blue spraypaint, the ground support could drip onto the station, and a slight overhang could lead to non-ideal sample conditions.

Challenges of setting stations up in an operating mine that doesn't interfere with operations – had one station that was destroyed. Not only challenges in selecting, but also maintaining and ensuring it can be sampled regularly

Brucejack Wall Washing Stations



Section view – looking west



Plan view – north up

2017 Stations

- Two stations in volcanic sedimentary facies unit
- Two stations in Fragmental volcanic unit
- One station in conglomerate unit

2024 Stations

- Two stations in Porphyry units

Brucejack now has a total of seven wall wash stations – two of which were just installed this September. They cover the main mined lithologies and location choice was guided by the existing geochemical dataset to ensure stations were installed in representative areas (avoid irregular veining or other features that stray from the typical unit character)

Wall Washing Stations - Construction

Key steps for station construction:

1. Drill pilot holes based on mapped station extents
2. Affix rubber stripping loosely to wall with concrete anchors/rock bolts
3. Apply sealant/caulking to rubber stripping and tighten anchors/bolts
4. Confirm station is sealed and add more sealant if necessary, covering anchors
5. Cut and affix poly sheeting/cover

Once you have chosen a section for mine wall installation, mark out the area that the station will cover and…discuss above steps

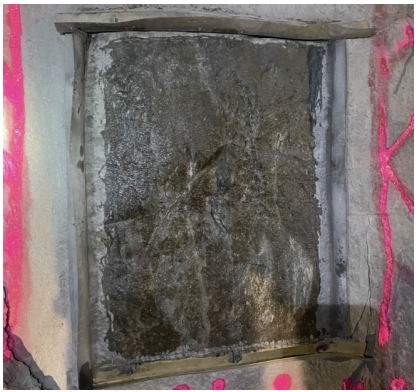
Wall Washing Stations – Monitoring Program

Muck sampling: assessment of material to be rinsed

Precipitate sampling: assessment of solubility controls on metals/metalloids

Muck samples and precipitate samples are collected from each station annually. Muck samples are used to assess the material to the rinsed, while precipitate samples help to assess the solubility controls on metals/metalloids

Wall Washing Stations – Monitoring Program



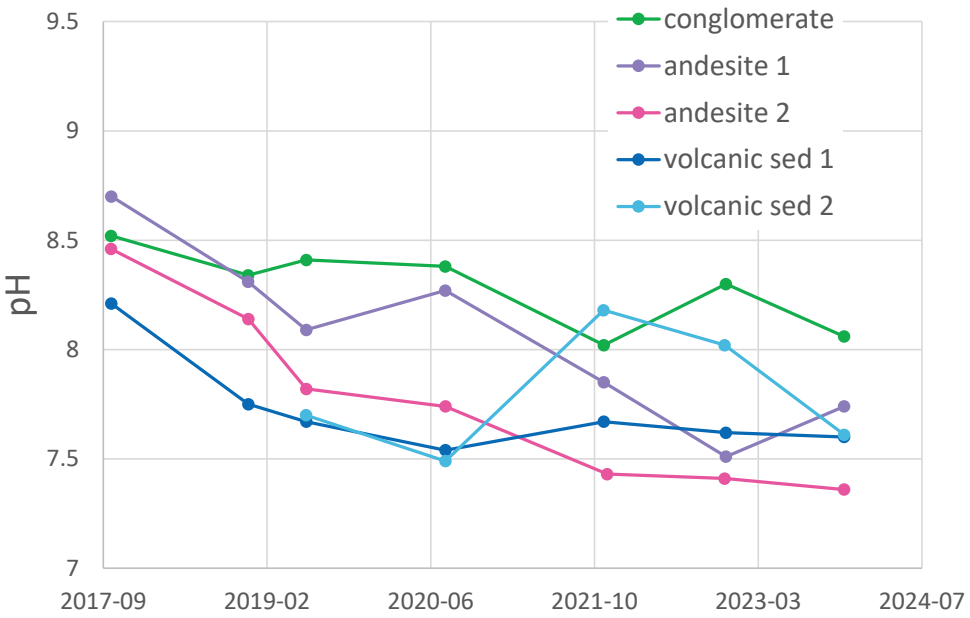
1. Remove cover from station and ensure no station defects (ideally check stations prior to sampling)
2. Apply 500 mL of DI-water evenly to wet entire surface of the wall station (~1m^2)
3. Collect rinsate from trough for general chemistry, nutrients and dissolved metals

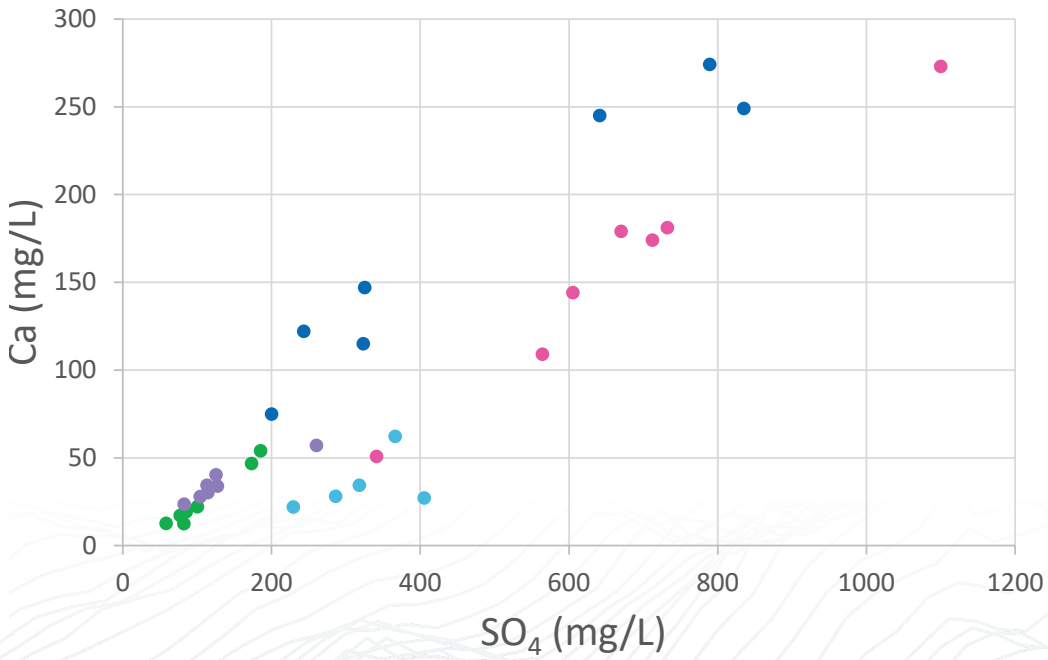
Wall washing water quality samples are also collected annually. Follow above steps. Morin and Hutt recommend at least 200 mL, but as little water as possible - we have found 500 mL to be an adequate amount to wet the entire face and allow for required sample volumes. Rinsate is collected in a 1L beaker, as shown, with samples and field parameters collected from this composite.

At sampling completion, the entire surface area of the station should be wetted.

Wall Washing Station Program Results: ARD

2017-2024

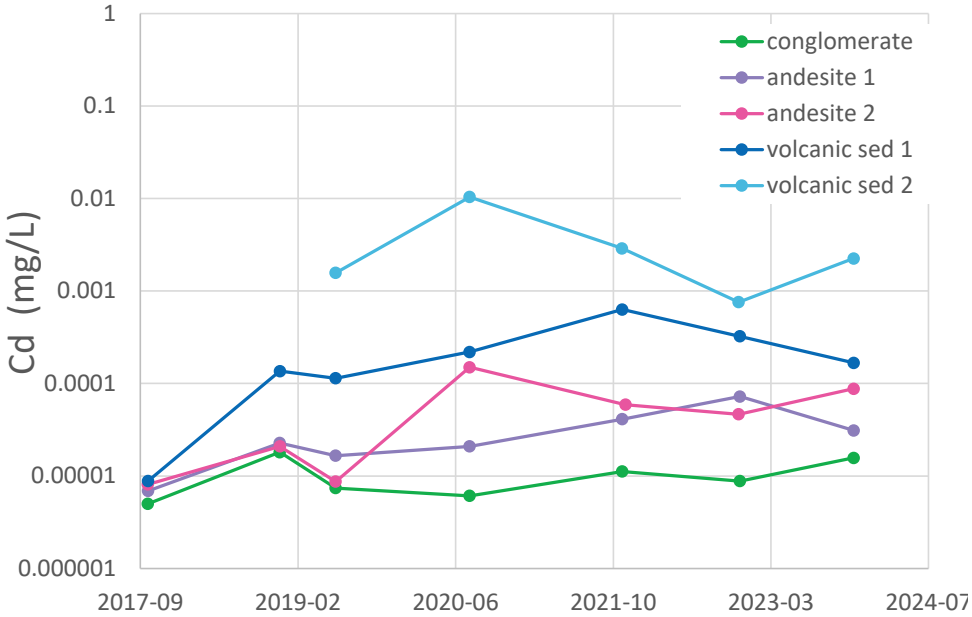


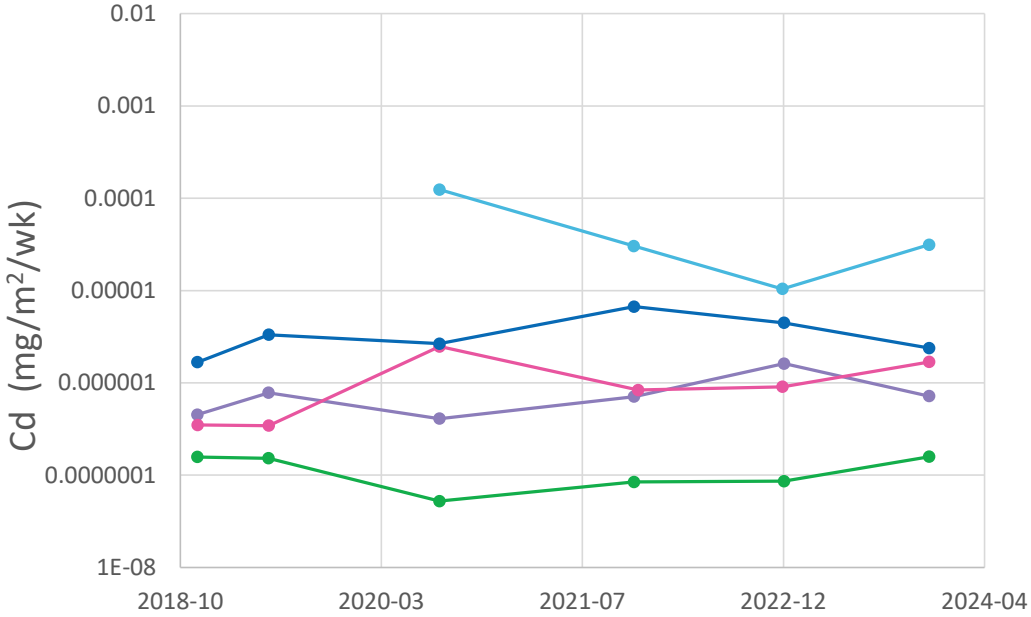


- Slight decrease in pH observed, but still in neutral range – consistent with ARD onset calculations
- Evidence for sulfide oxidation and carbonate buffering

Wall Washing Station Program Results: Cd

2017-2024

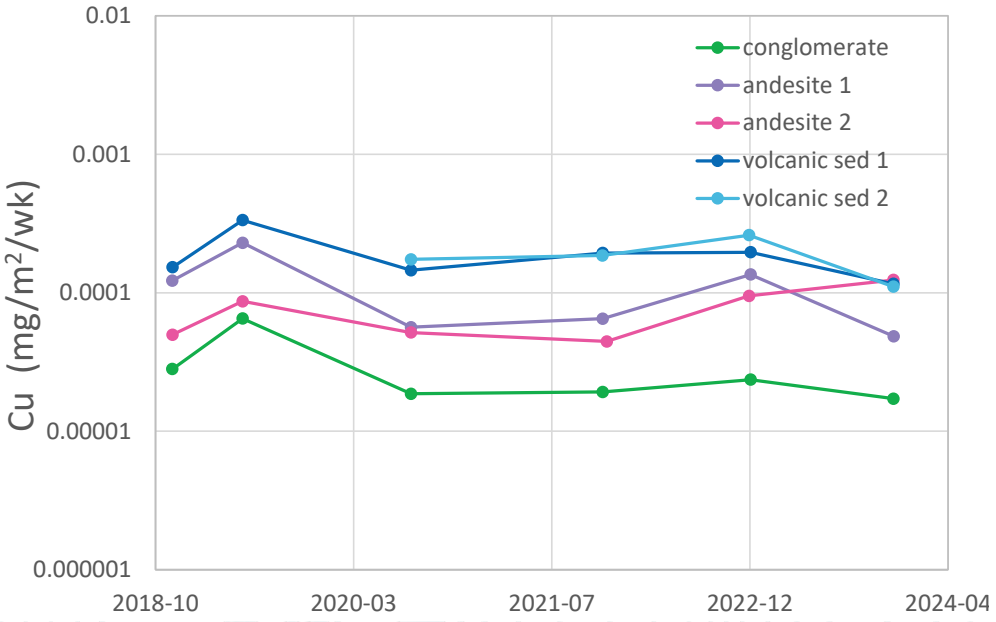


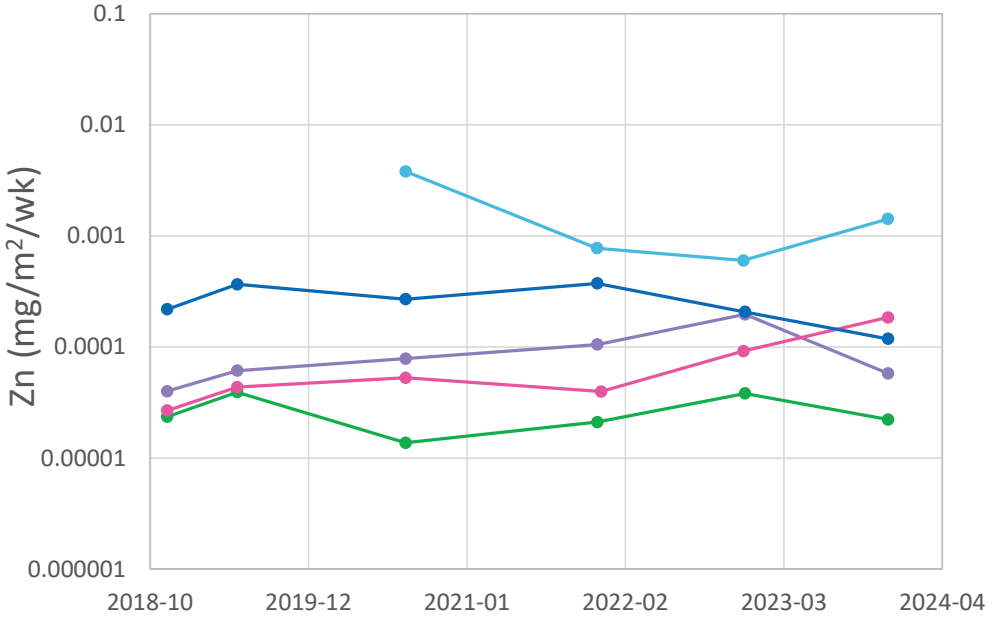


- Cd concentrations show minor increases or relatively stable levels, as expected for neutral pH
- Concentrations converted to area-based loadings – normalizes for variable areas and timing of sampling

Wall Washing Station Program Results: Cu and Zn

2017-2024

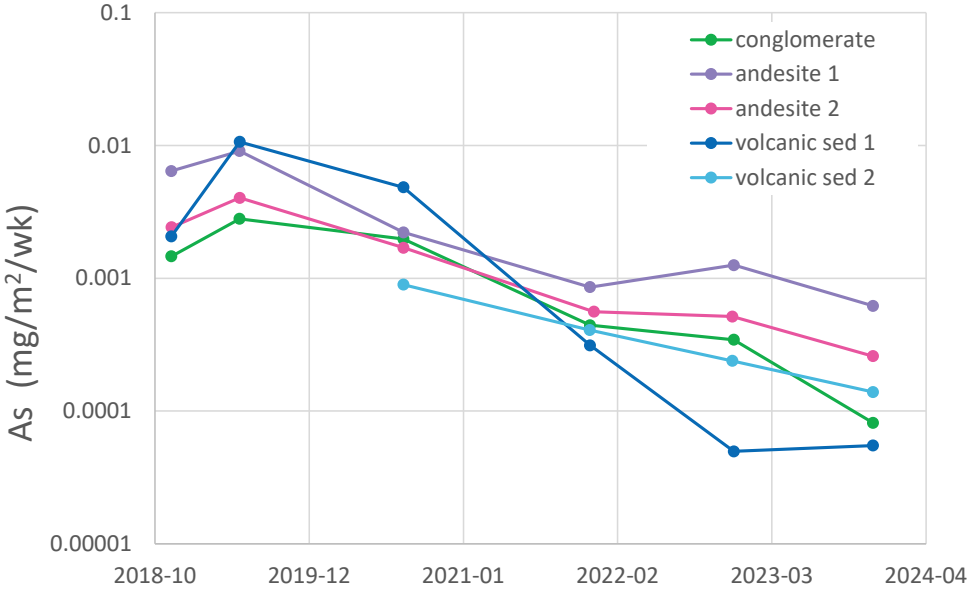


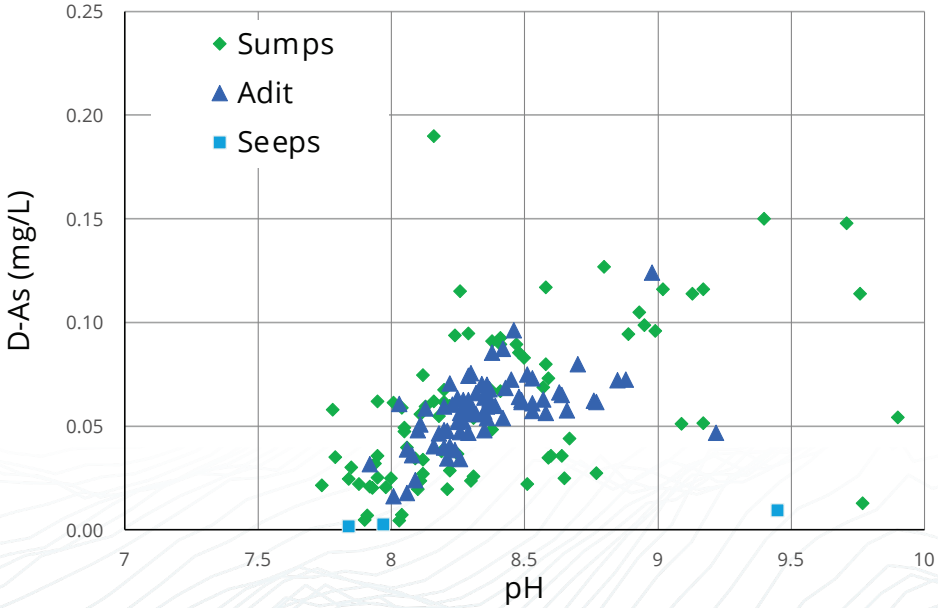


- Cu and Zn also show relatively stable release rates, as expected for neutral pH

Wall Washing Station Program Results: As

2017-2024





- Decrease in As is consistent with expected solubility behaviour for As as pH declines, and site-specific monitoring.

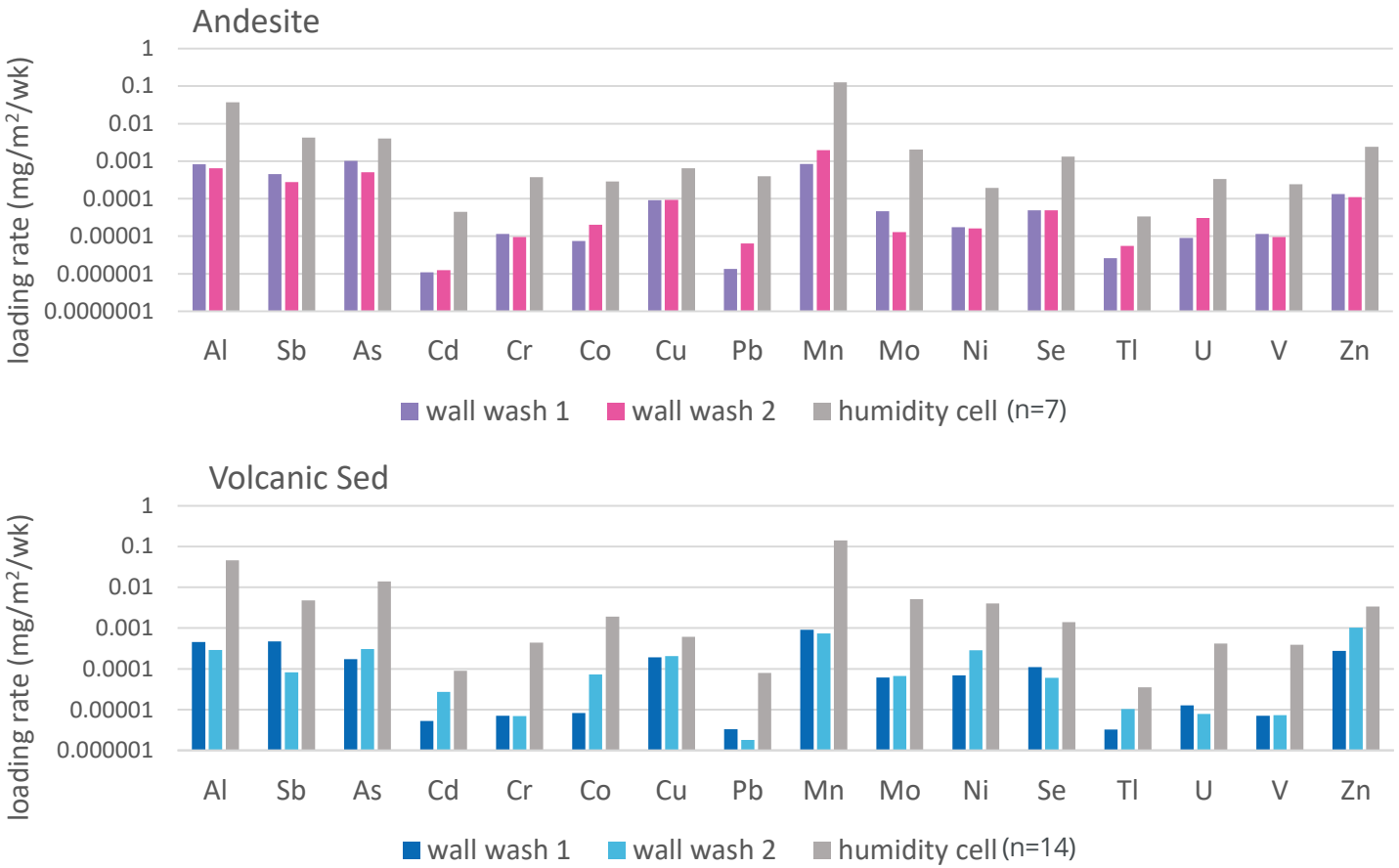
Calculating flushing loads

PREDICTING CLOSURE WATER QUALITY

Method	Benefits - Challenges	Utility at Brucejack Mine
Extrapolation of historic flooding data	Direct in-situ measurements – dependent on exposure time and lithologies exposed, represents only a snapshot.	Indication of **water quality** but magnitude of concentration peaks uncertain.
Wall washing loading rates	Direct in-situ measurements capturing evolving geochemistry - logistical challenges in operating mines.	Direct assessment of **in-situ loading rates** (neutral conditions, and potentially onset of ARD).
Scaled humidity cell test (HCT) loading rates	Controlled lab experiment - conversion to area-based terms, scaling factors.	Assessment of loading rates for a potential **future ARD condition**.

Comparison of wall washing vs. neutral HCT loading rates

WEEKLY LOADING RATES



Humidity cell rates are significantly higher since the experiments induce an accelerated weathering rate:

- higher T
- dry/humid cycle
- periodic leaching

Wall washing rates are more representative of actual loads and can provide insight on applicable HCT scaling factors.

Conclusions

WALL WASHING DATA SETS

Summary

- Track in-situ evolution of mine wall geochemistry and confirm time to ARD onset
- Provide *direct* in-situ measurements of loading rates as compared to HCT where scaling is needed.
- Provide estimates of applicable scaling factors for HCT.

Assessment

- Wall washing monitoring programs are an effective means of predicting flushing loads that will be released during mine flooding.
- These data, along with site-specific water quality monitoring data sets, provide insight to water quality and water treatment/management needs at closure.

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