Appendix 4-HH

Waste Rock Management Meeting - October 2019

NWP Coal Canada Ltd.

October 9, 2019
Dump Layering

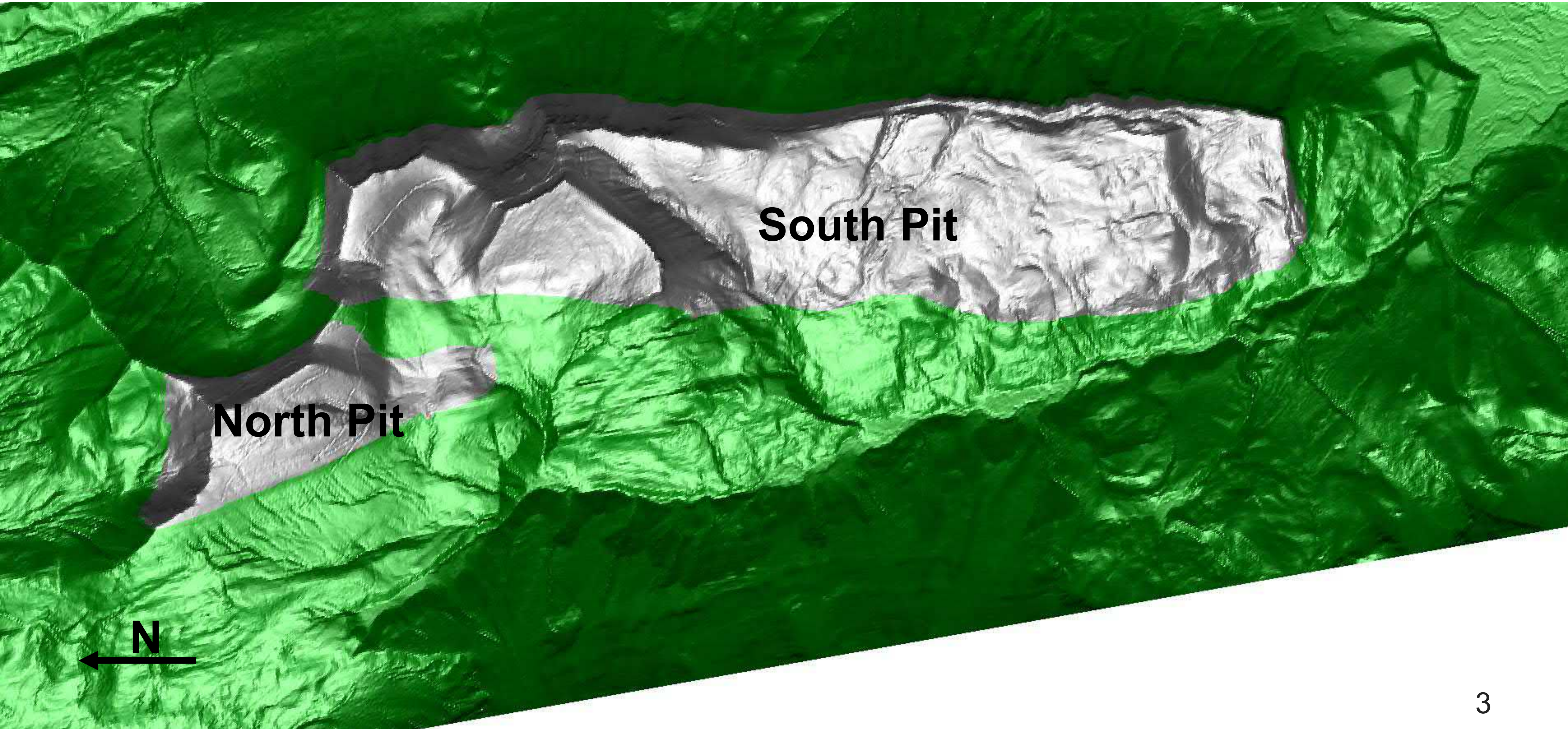
Sean Ennis, P. Eng.

Stantec

Overview

- The purpose of this presentation is to demonstrate the feasibility of layering tailings/CCR within the dump.
- Utilize dump construction practices which allow for construction of stable structures which meet short and long-term geotechnical stability criteria.
- Development of multiple platforms for concurrent mine rock dumping and plant rejects placement can be carried out while mitigating potential hazards due to rock roll-out and slope instability.
- *The production quantities and dump configurations shown in this presentation are representative of the "in-progress" mine plan and may be modified as part of the final feasibility level design*.

Site Overview – Pit Limits



Material Quantities Release Schedule - LOM

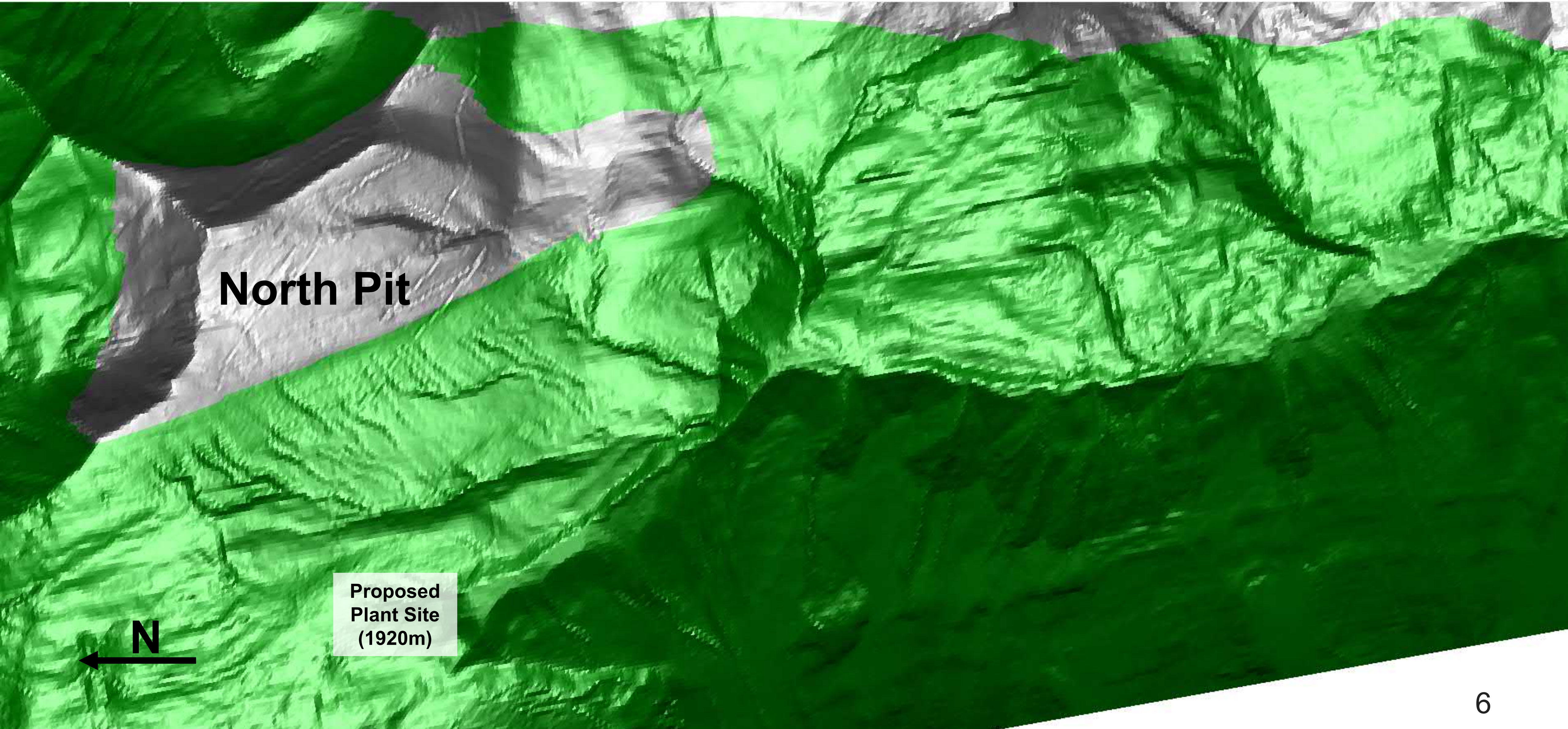
	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10
Clean Coal (t)	2.1	2.2	2.4	2.0	1.9	1.9	1.9	1.9	1.9	1.9
Waste Rock (Placed Mm^3*)	14.4	22.0	21.7	23.2	24.3	21.3	20.2	23.0	23.1	34.5
Rejects (Placed Mm^3**)	0.7	0.9	1.0	1.0	1.3	1.4	1.3	1.4	1.4	1.4
Ratio WR:Rejects	21	25	22	23	18	15	16	16	16	25

	Y11	Y12	Y13	Y14	Y15	Y16	Y17	Y18	Y19	Total
Clean Coal (t)	1.8	1.9	1.9	1.9	1.7	1.5	1.7	1.2	1.4	35.2
Waste Rock (Placed Mm^3*)	41.7	41.6	41.9	42.0	41.7	42.8	41.6	25.8	14.9	562.0
Rejects (Placed Mm^3**)	1.3	1.4	1.4	1.2	1.3	1.0	1.1	0.7	1.1	22.2
Ratio WR:Rejects	31	31	31	36	32	42	38	39	13	25

* assumed 30% swell

** assumed placed density of $1.4t/m^3$

Pre-mining Topography

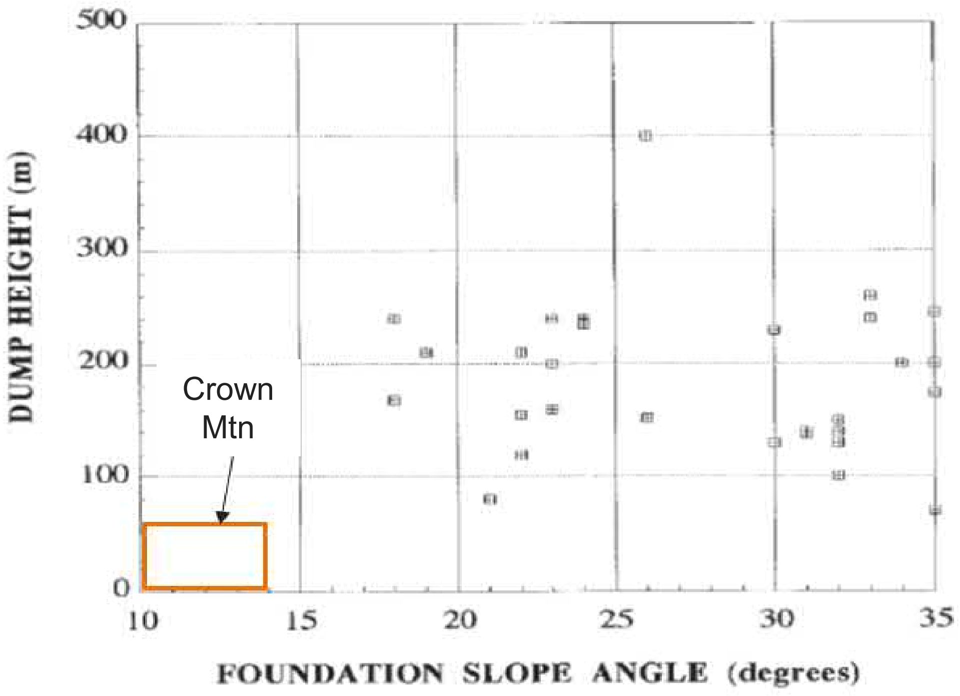


Development of Stable Dumps

Construction of stable dumps is based on:

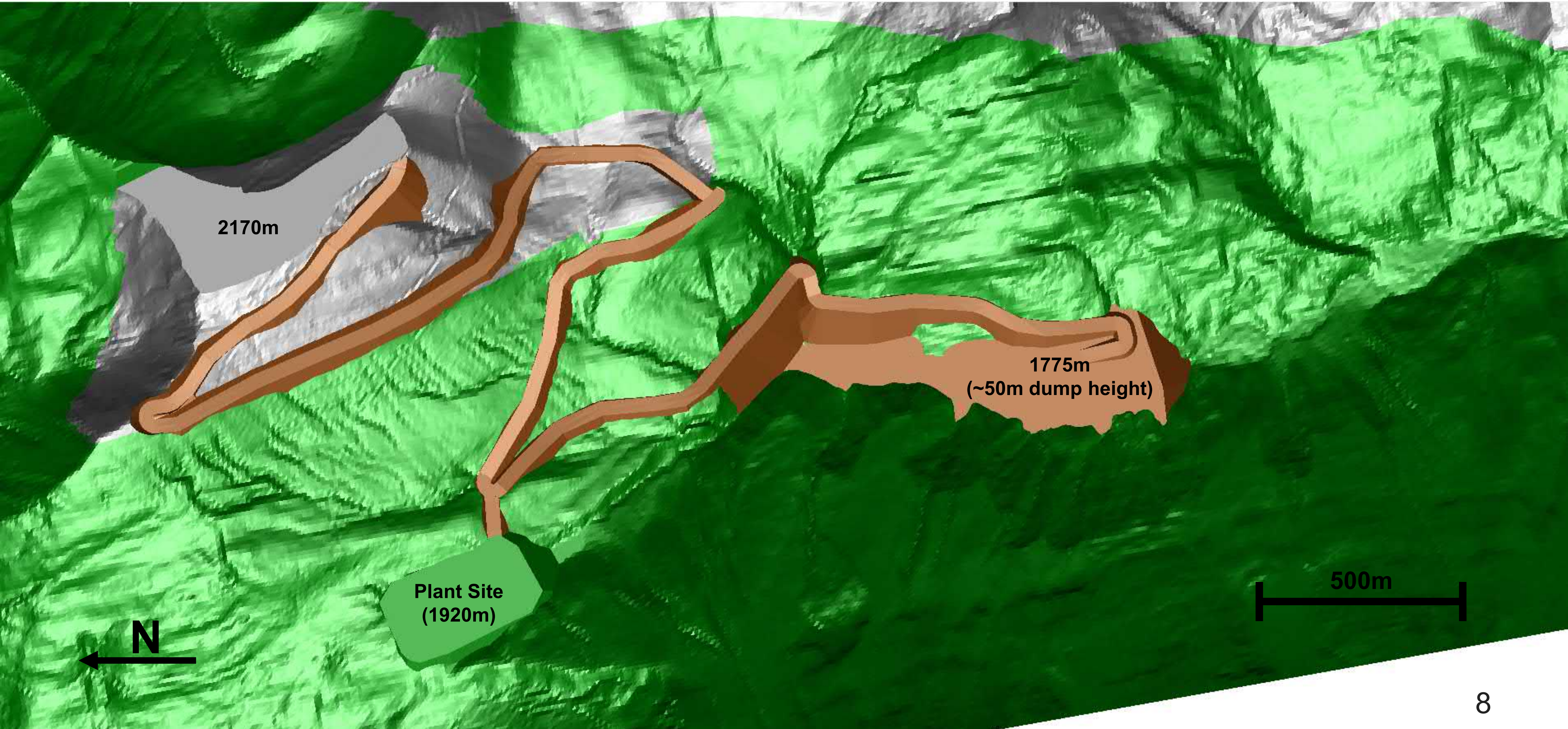
- Bottom-up development sequence
- Controlled lift heights (50m or less)
- Overall outer slopes 2H : 1V or shallower

Crown Mountain's dump development construction will begin with the development of ramps constructed of waste rock at angle-of-repose of up to a maximum height of 50m. The sequence is designed to limit the height of the ramps/lifts to reduce the potential for runout hazards.

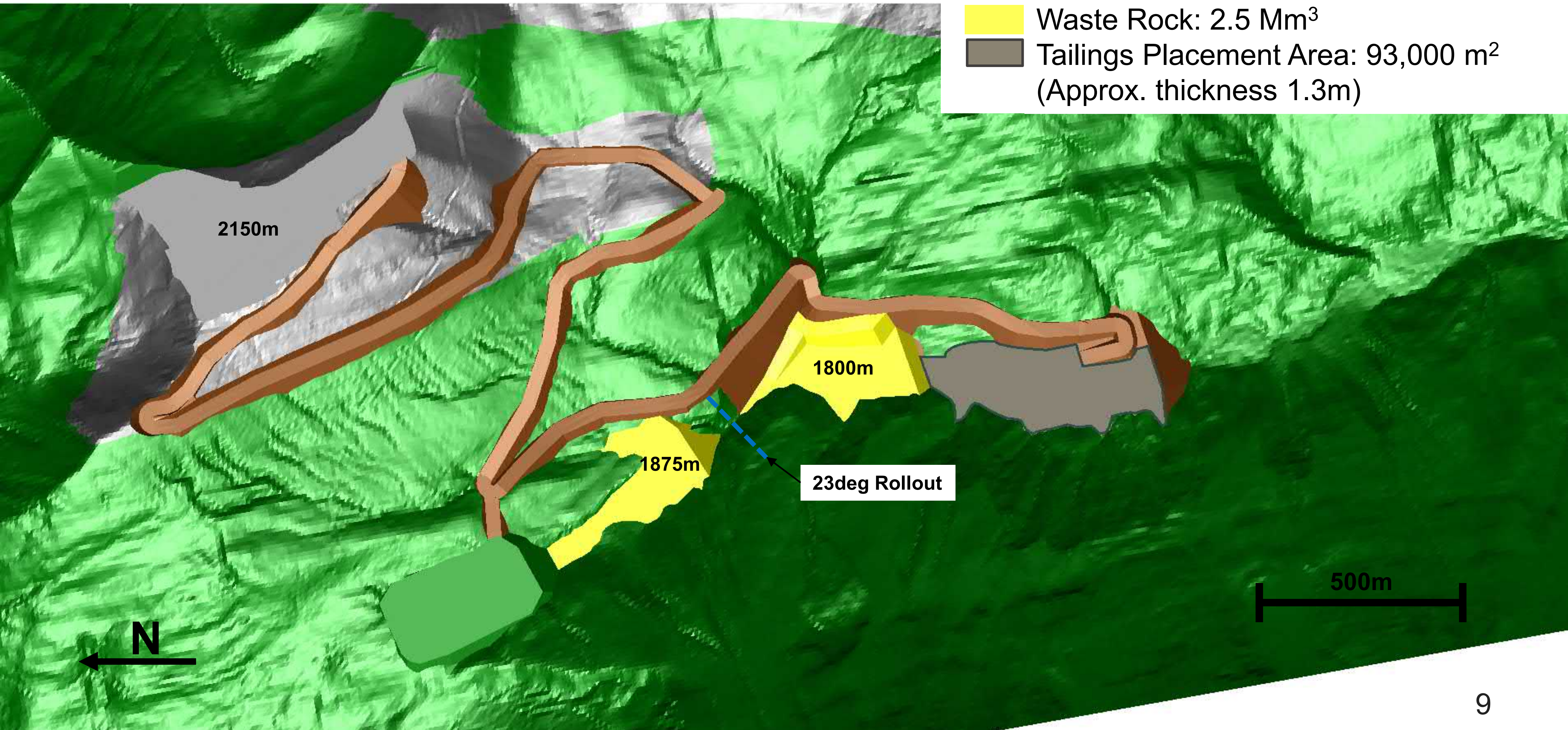


Dump Height vs. Foundation Slope Angle for High Runout Waste Dump Flowslides (Dawson et al, 1998)

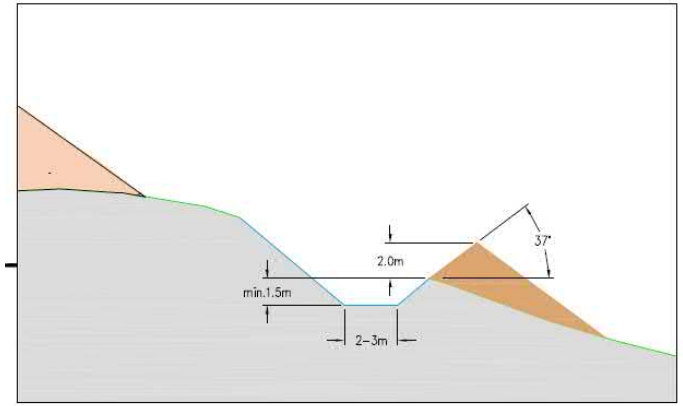
Pit and dump configuration prior to Plant Rejects Placement – Year 0



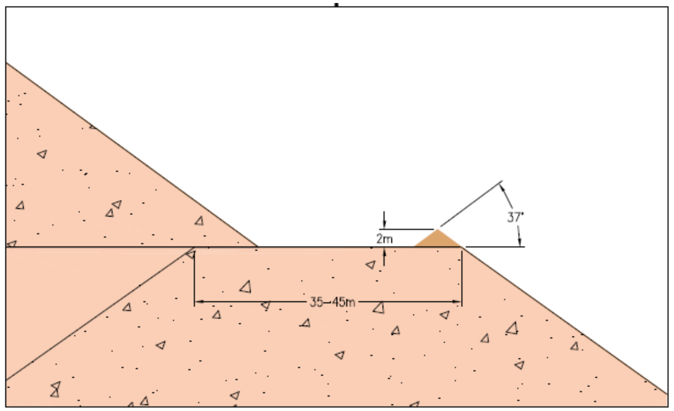
Waste Rock / Reject Progression ~Y1Q1



Rock Roll-out Hazard Mitigations



2 BERM DETAIL ABOVE HAULROAD
Scale: 1:200

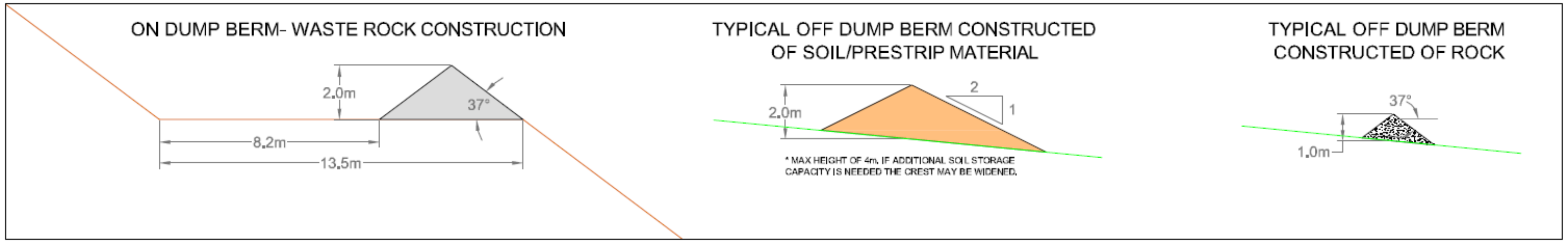


3 BERM DETAIL ON DUMP BENCH
Scale: 1:400

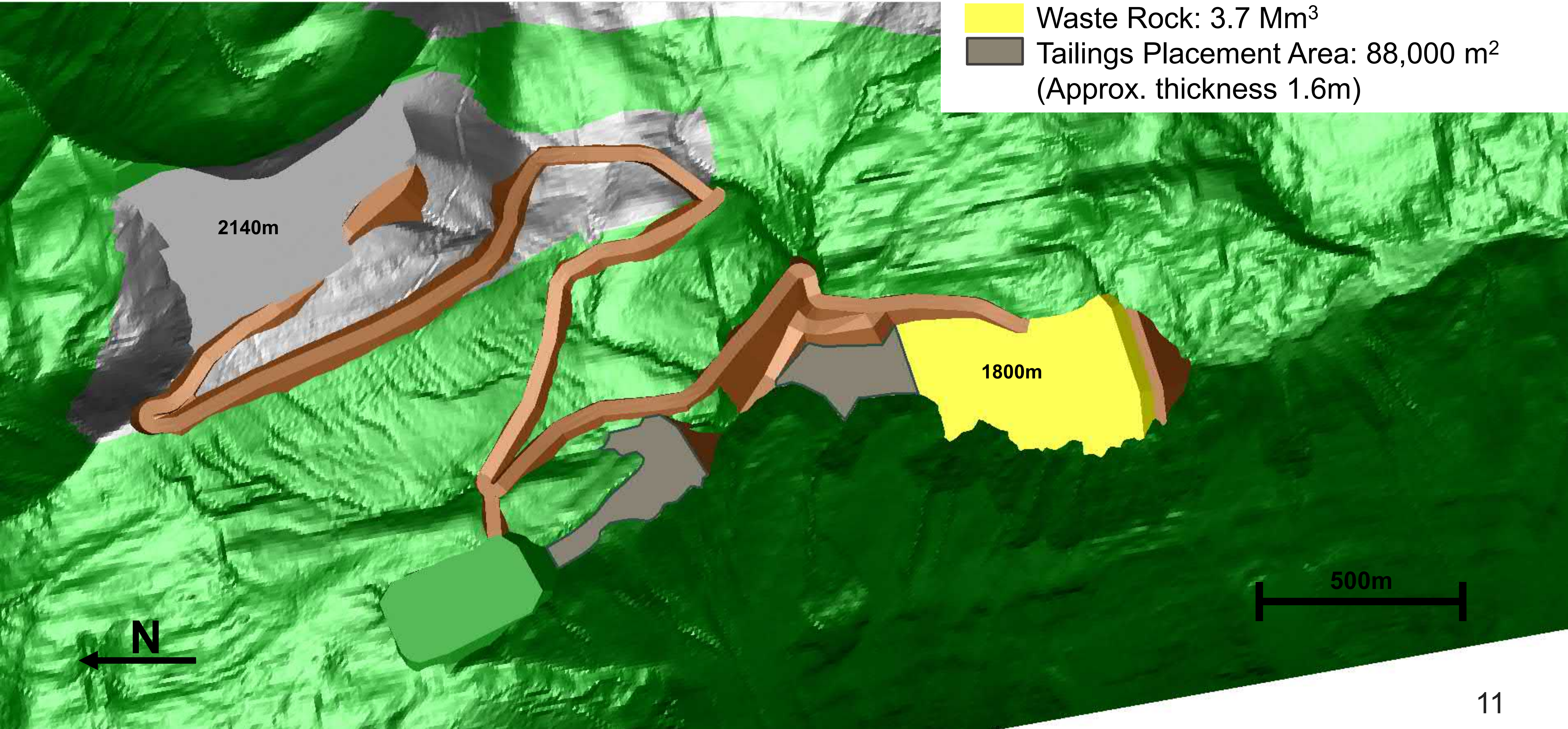
A shadow angle for boulder roll-out of 23° (considered lower-bound based on case histories) is used to estimate the extents of boulder roll-out hazards at different construction stages.

<u>Mitigation controls</u>:

- Minimum 10m wide catch benches with 2m high catch berms.
- Plan dumping and plant rejects placement construction sequence to reduce hazard potential and exposure to downslope areas (i.e., using barrier lifts, limit ramp/lift height).

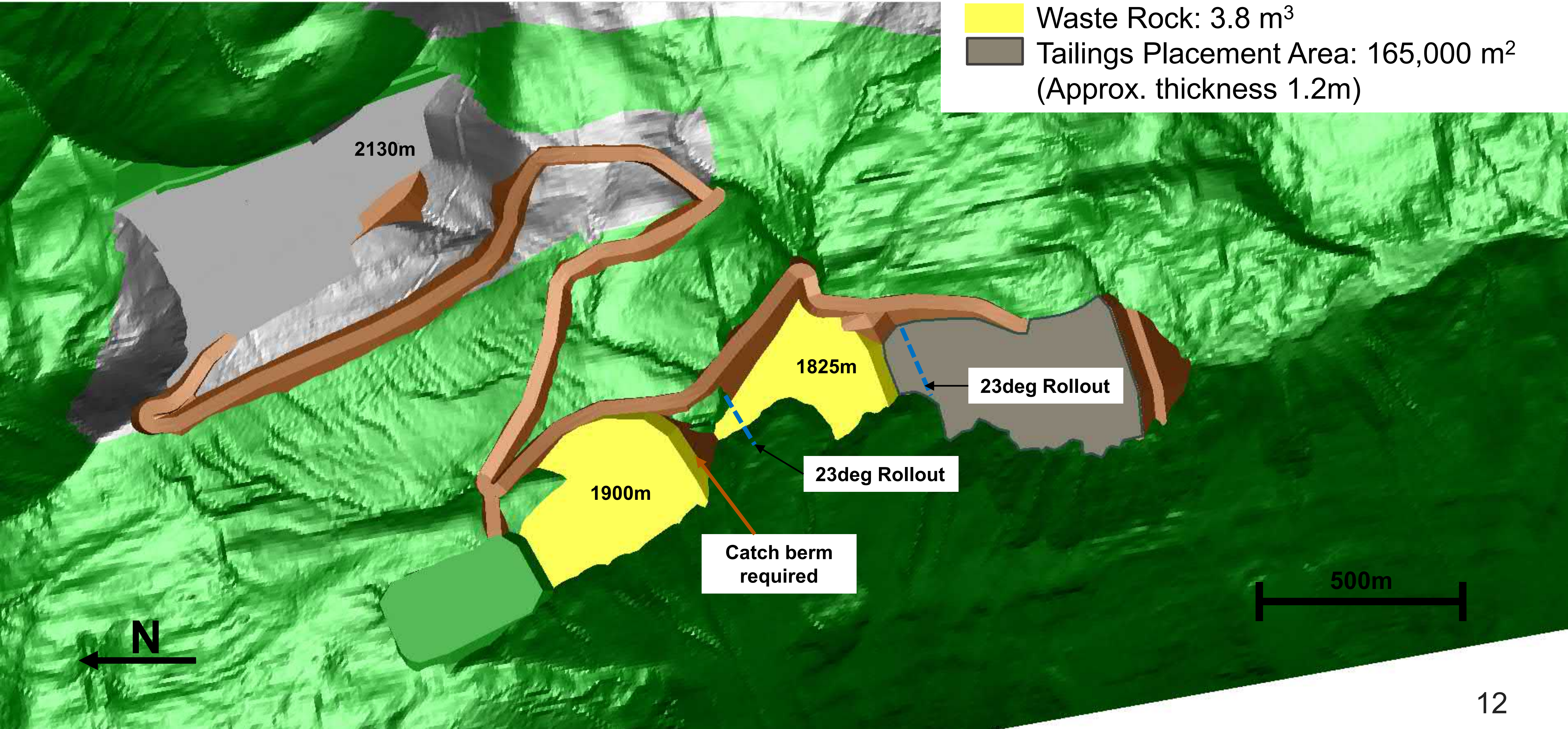


Waste Rock / Reject Progression ~Y1Q2

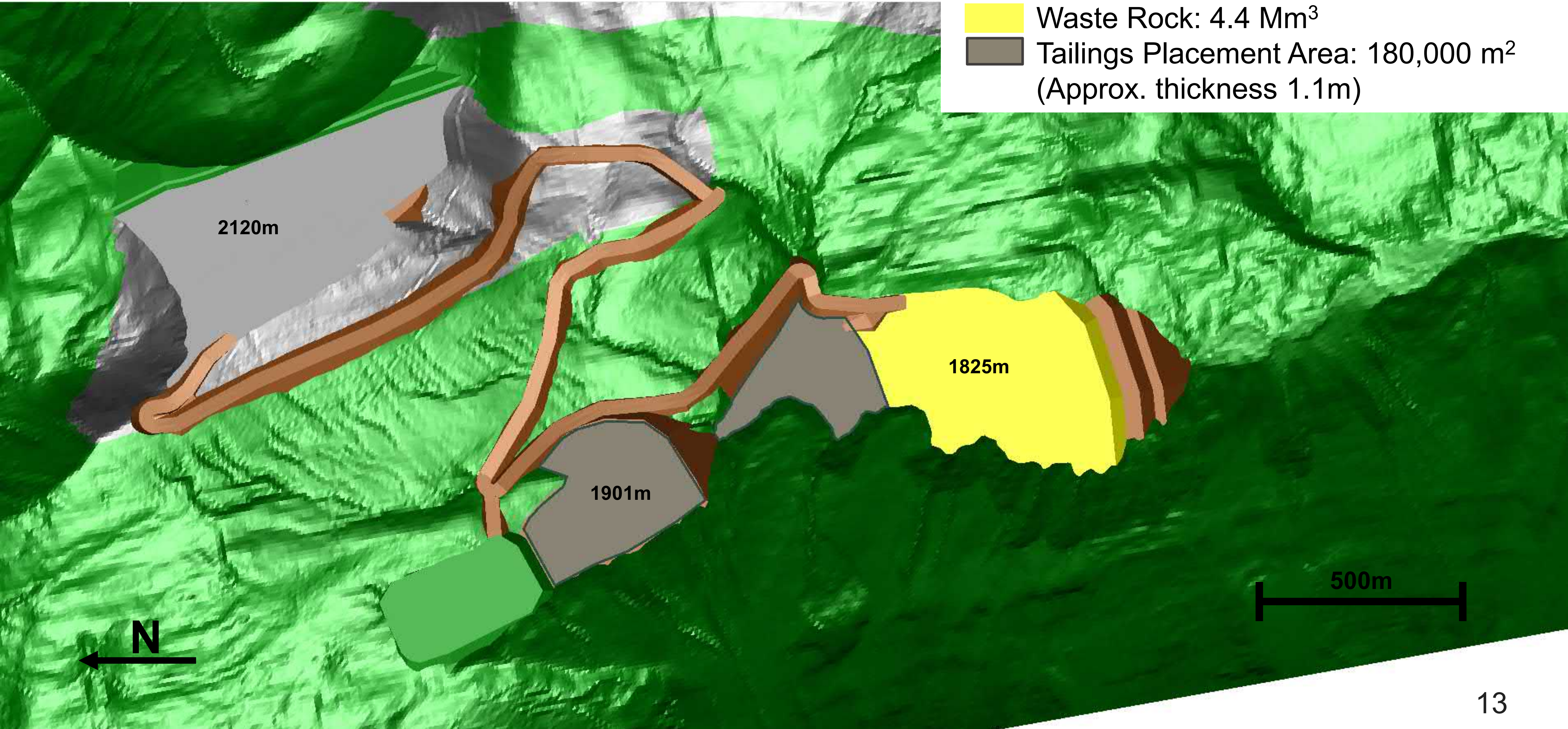


Waste Rock / Reject Progression ~Y1Q3

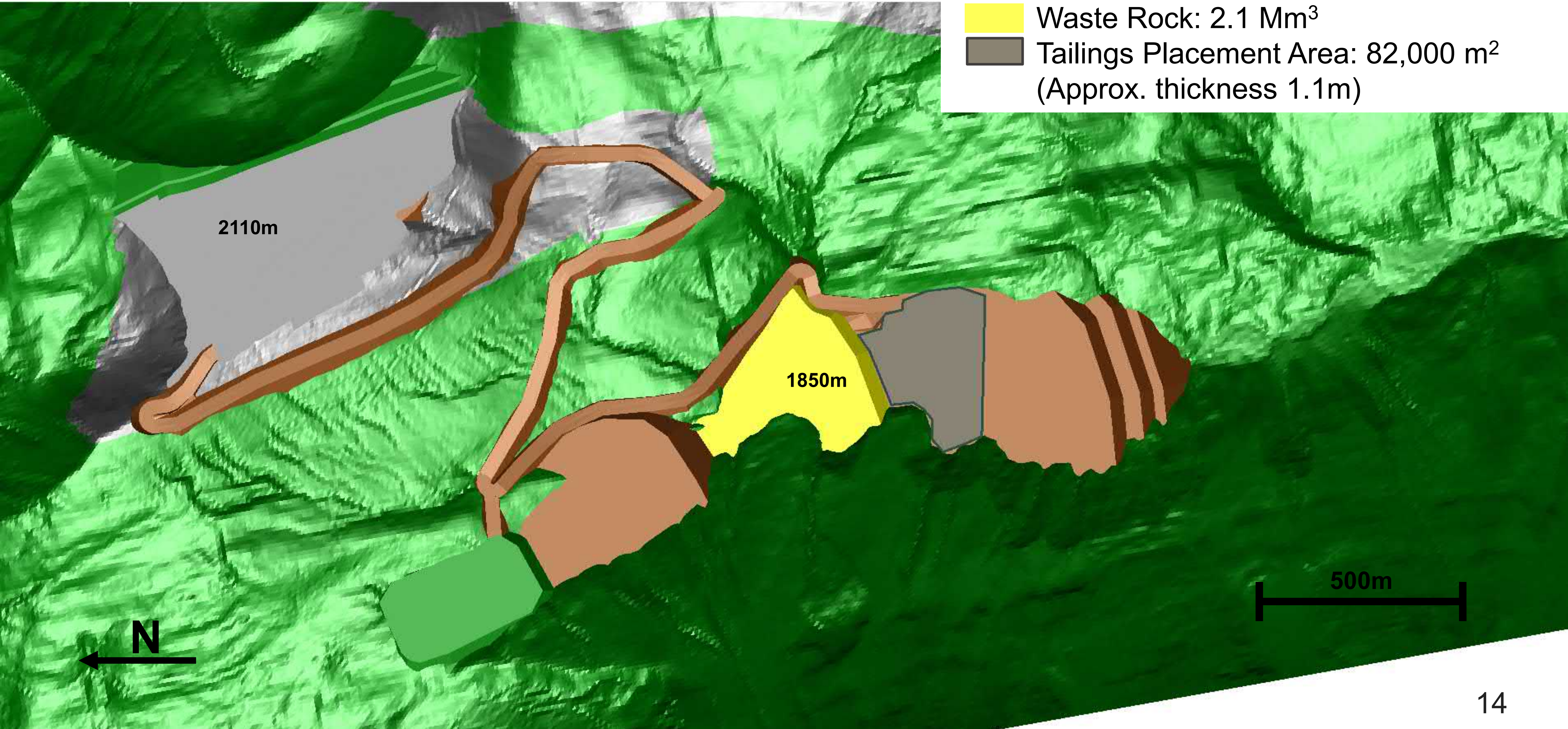
Waste Rock: 3.8 m^3
Tailings Placement Area: 165,000 m^2
(Approx. thickness 1.2m)



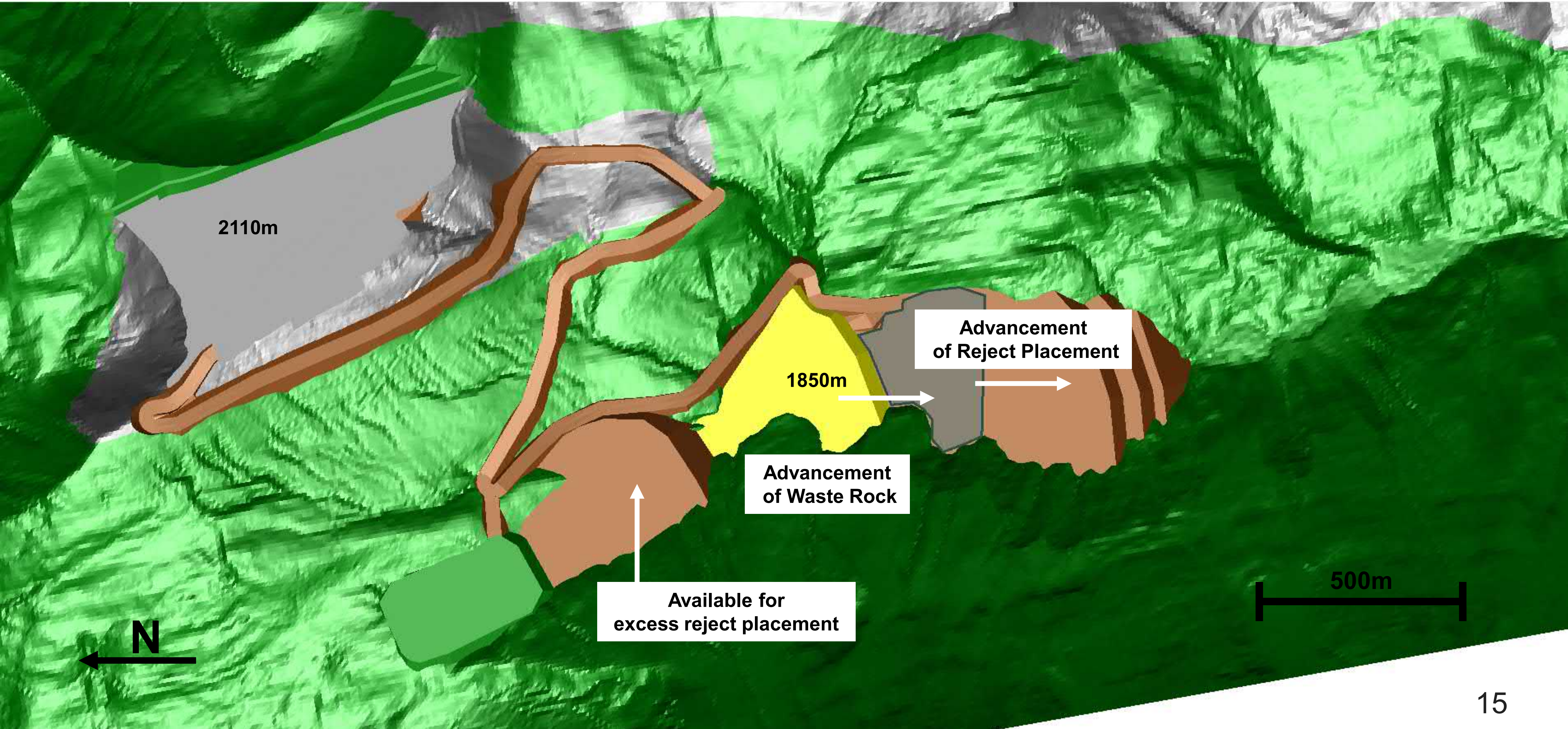
Waste Rock / Reject Progression ~Y1Q4



Waste Rock / Reject Progression - Mid Y2Q1



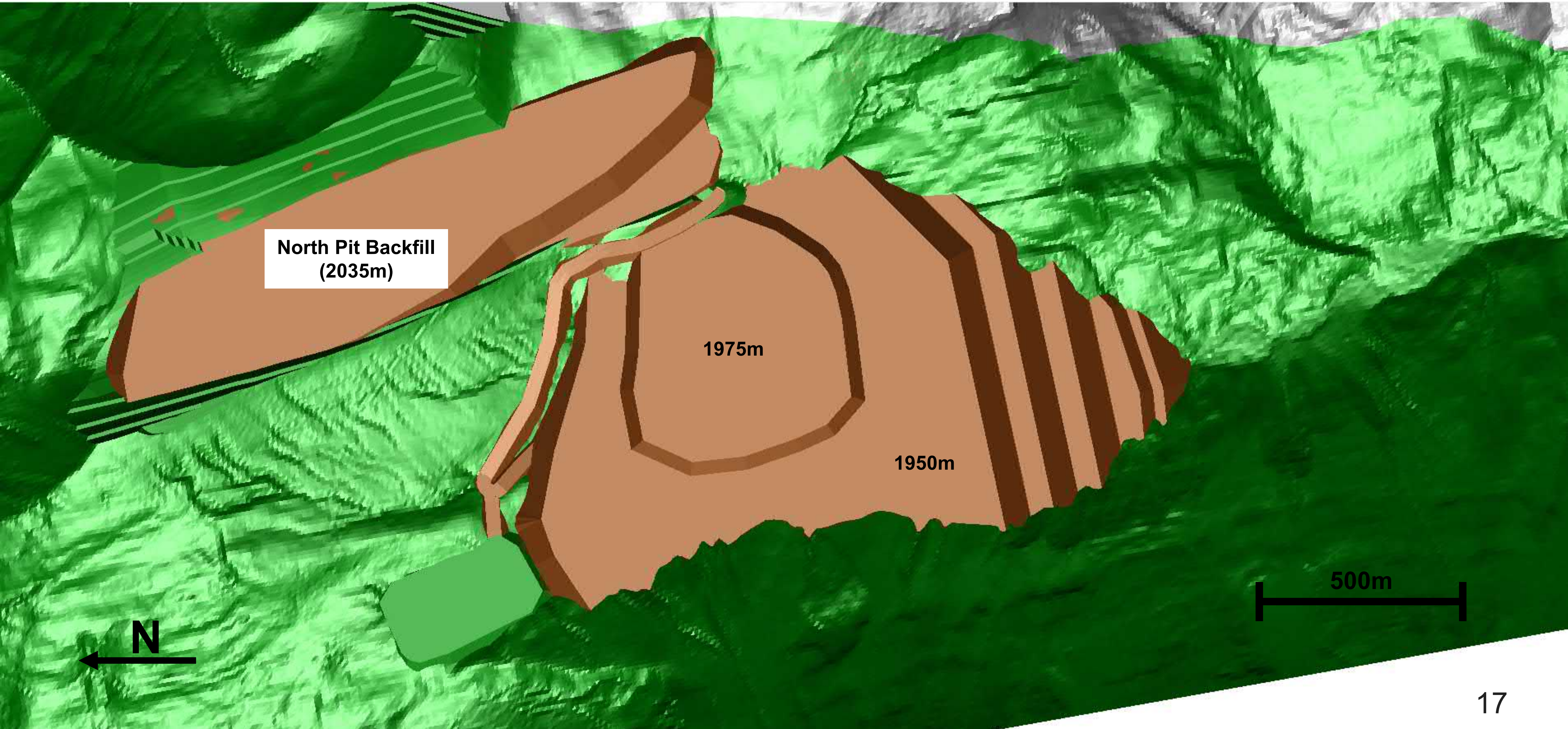
Waste Rock / Reject Progression - Mid Y2Q1



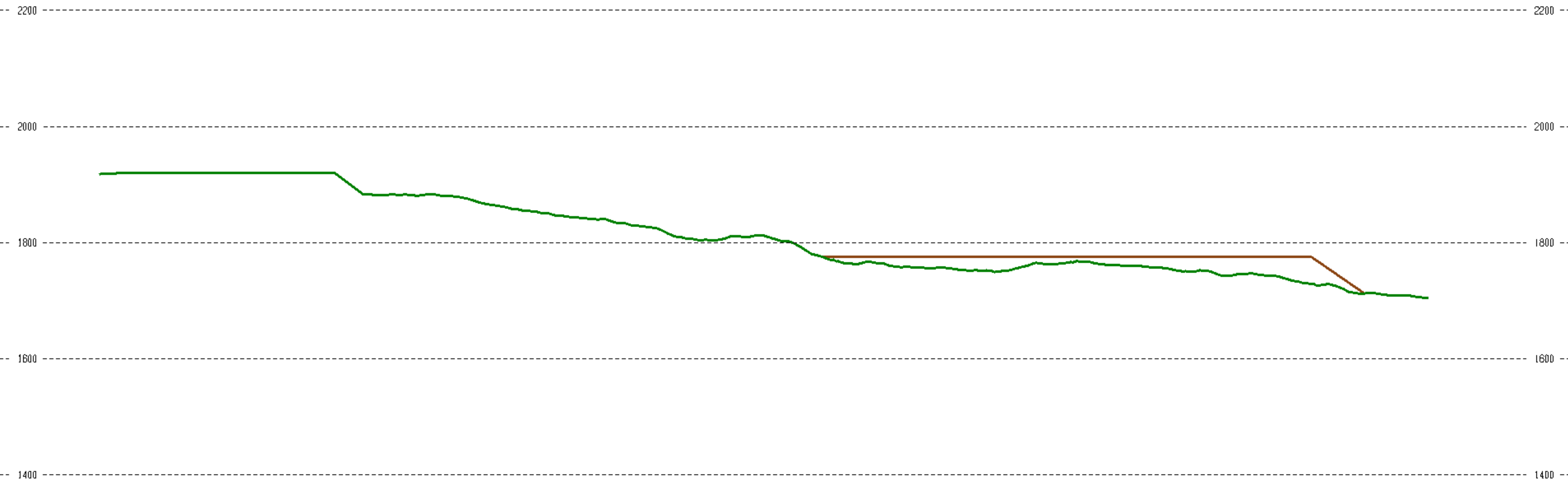
First Five Years of Mining

- Initial mine dump development occurs in the northern portion of the West Alexander valley using mine rock from the North Pit.
- As North Pit is mined out (during Year 4), backfilling of the pit void with mine rock can occur.
- In-pit backfilling allows for a period of observation and monitoring of the external mine rock dump.

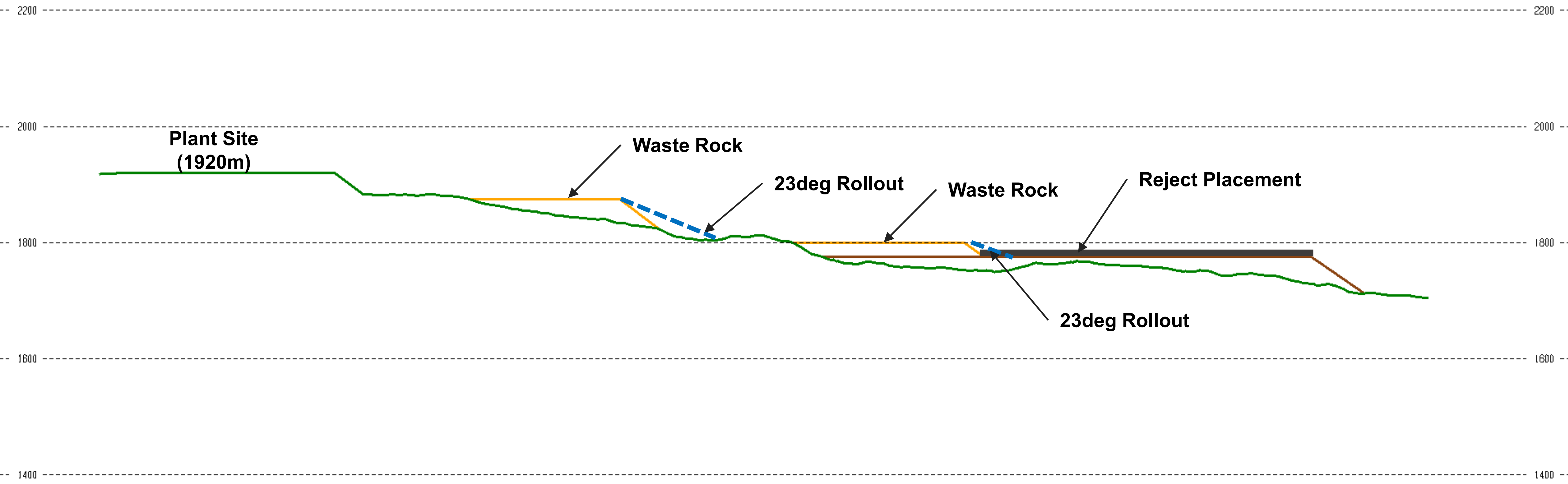
North Pit Backfill (~Y5)



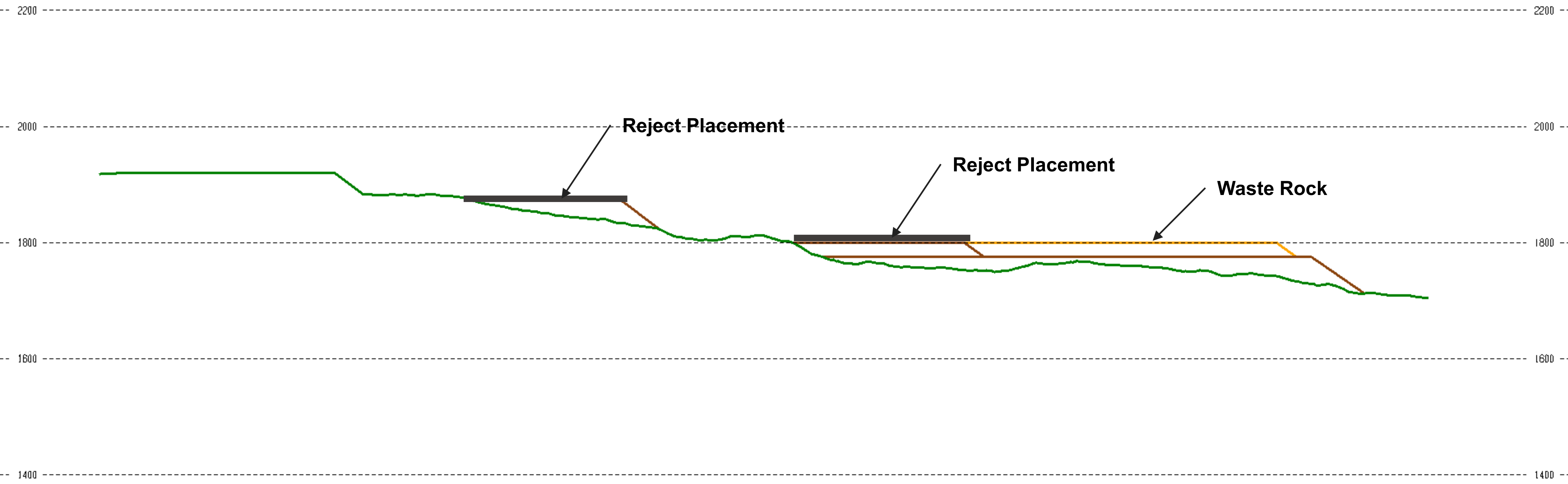
Dump configuration prior to Plant Rejects Placement – Y0



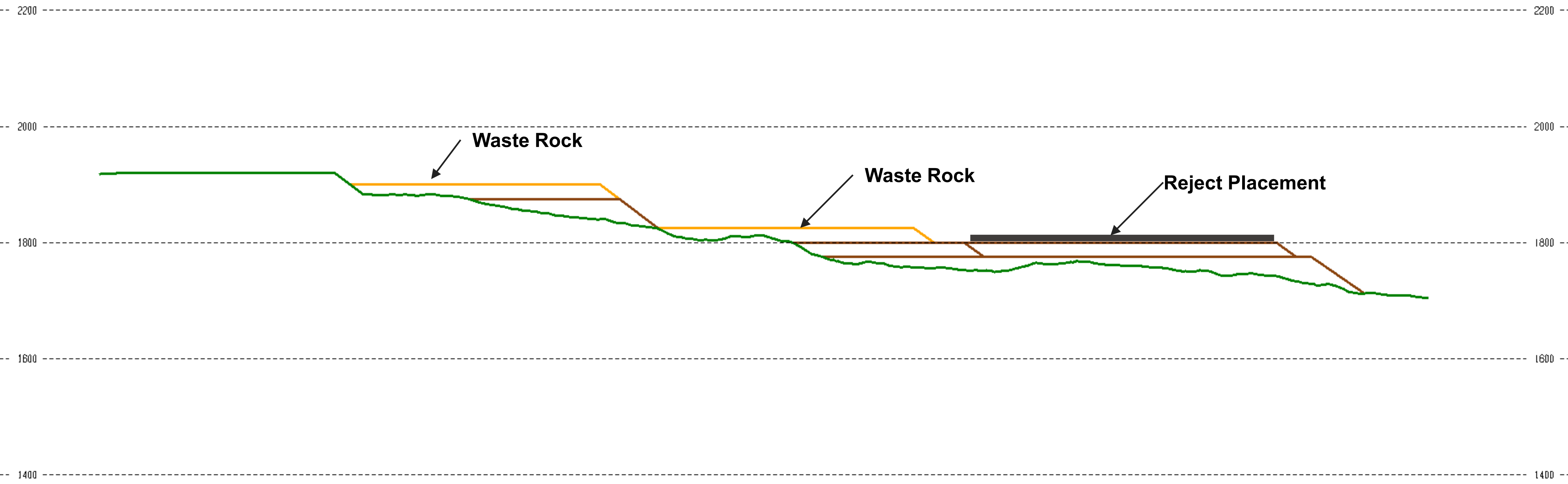
Waste Rock / Reject Progression ~Y1Q1



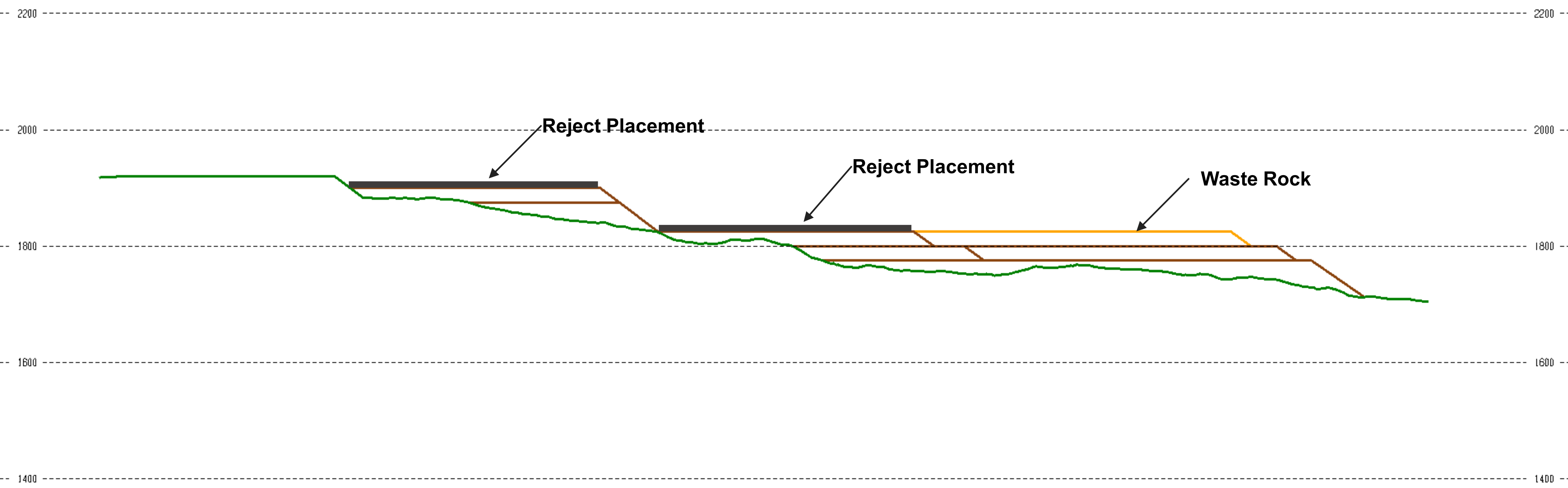
Waste Rock / Reject Progression ~Y1Q2



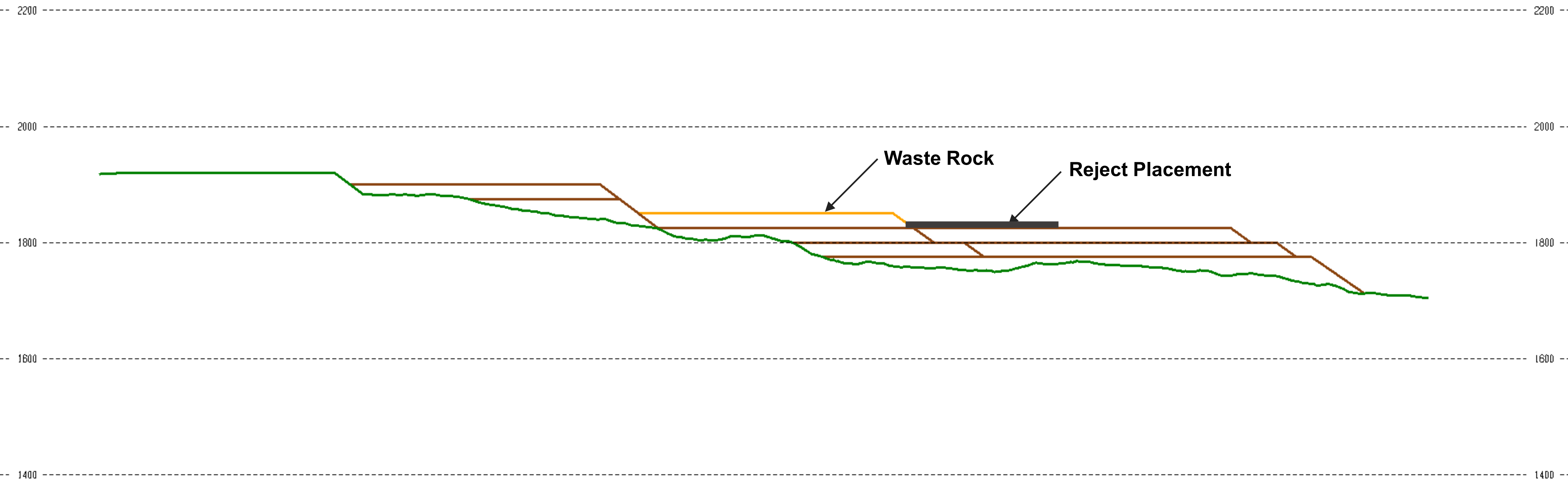
Waste Rock / Reject Progression ~Y1Q3



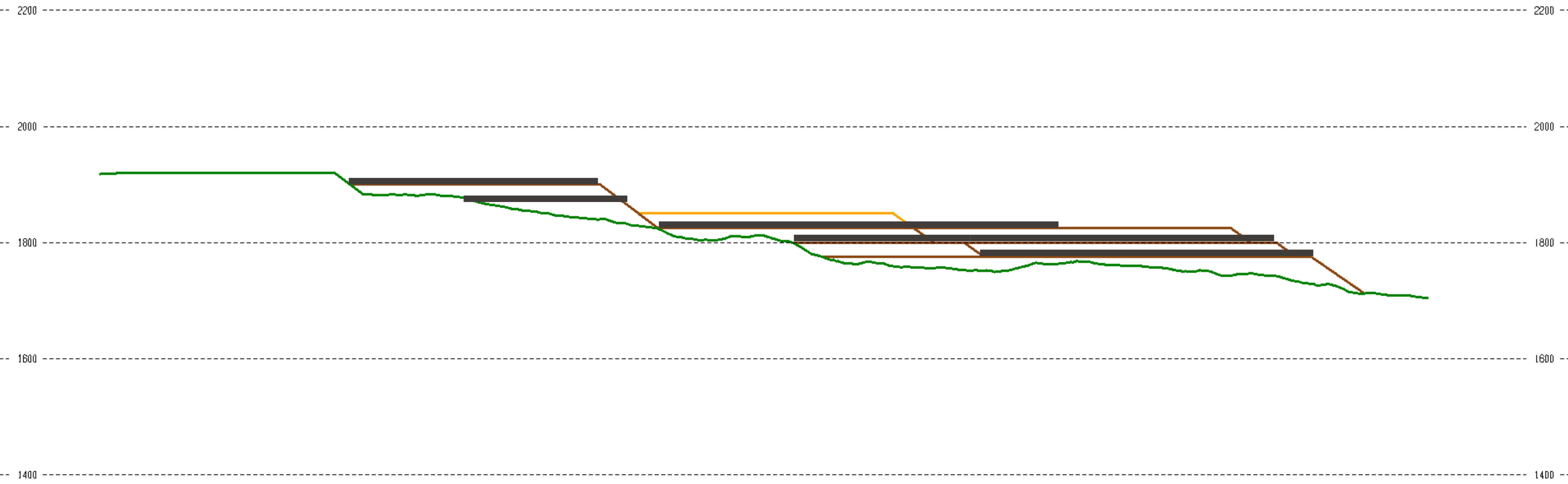
Waste Rock / Reject Progression ~Y1Q4



Waste Rock / Reject Progression - Mid Y2Q1



End of Year 2 - All Reject Layer Locations



On-going Work

- Finalizing laboratory testing of plant rejects blends for strength, grainsize and compaction characteristics
- Preparing life of mine rock pile configuration followed by stability analyses
- Providing surface area quantities for geochemical modeling as sequence is finalized

Crown Mountain Waste Rock Design Update on Waste Geochemistry and Modelling of Layering Concept

October 9, 2019

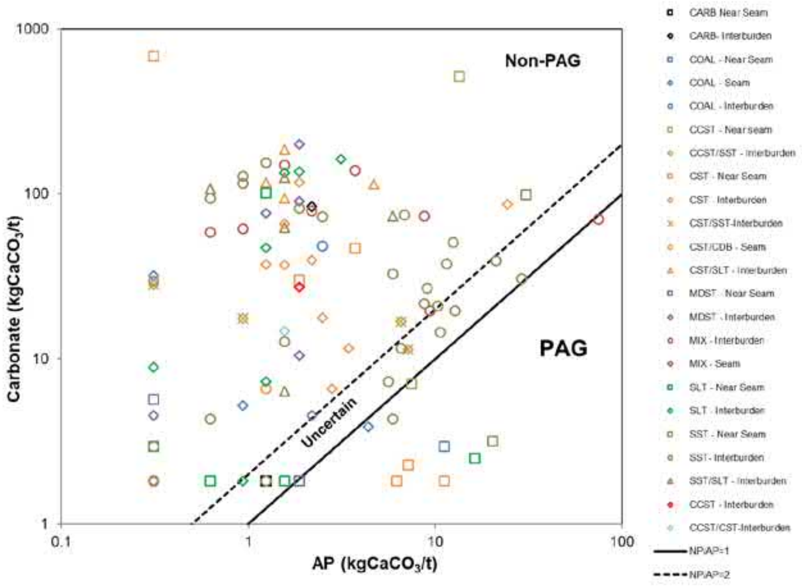
Outline

- Geochemical characterization.
- Update on modelling the layered spoil concept.

Geochemical Characterization

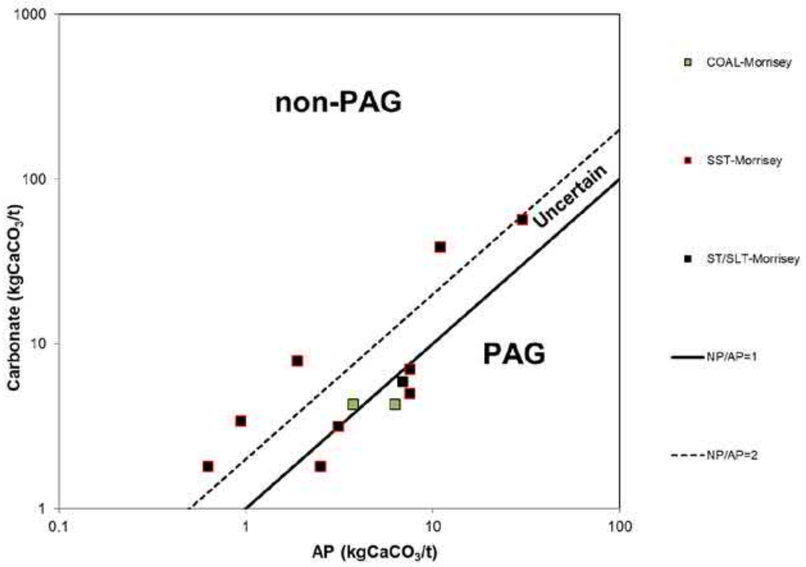
- Acid-base accounting
  - 235 rock samples tested from Mist Mountain Formation, Morrissey Formation and Fernie Formation
  - Continuous sampling cores at several locations in the proposed pits.
  - Augmented with test pit samples.
- Kinetic tests
  - 12 rock samples (20 weeks of testing completed)

Geochemical Characterization - Results



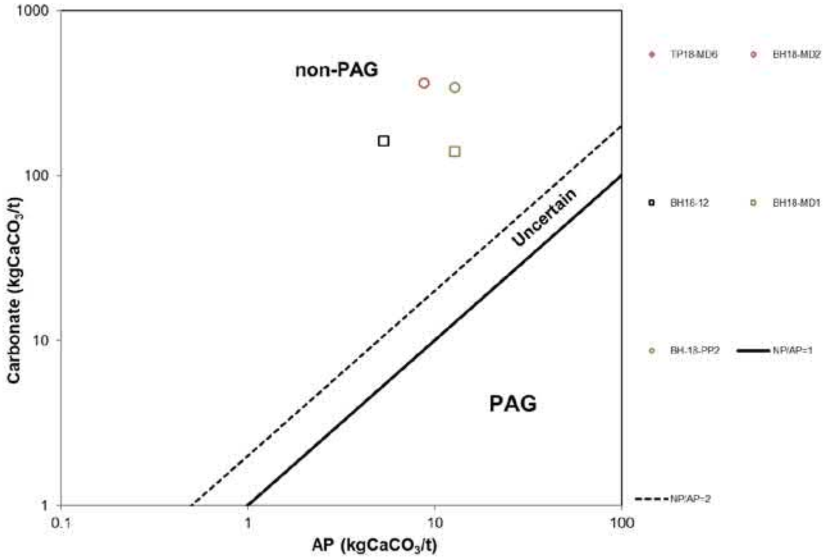
- Mist Mountain Formation is similar to elsewhere in the Elk Valley
  - Dominant formation is bulk of waste rock.
  - Mostly non-PAG except locally very near seams.
  - Selenium concentrations less than 5 mg/kg (one exception).

Geochemical Characterization - Results



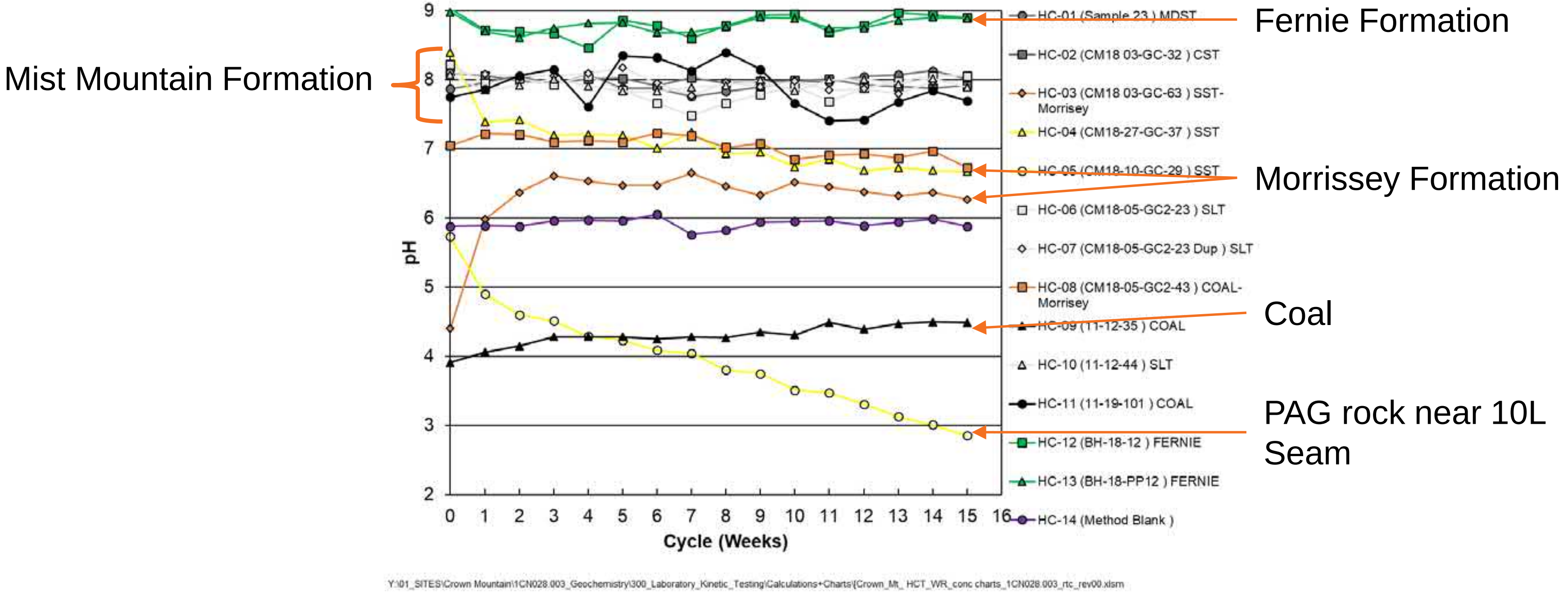
- Morrissey Formation
  - Footwall of MMF mined locally at Crown Mountain for pit wall stability
  - Non-PAG to weakly PAG.

Geochemical Characterization - Results



- Fernie Formation
  - Thrust over MMF.
  - Mined outside pit for infrastructure development.
  - Consistent with elsewhere in the Elk Valley
    - Non-PAG, carbonate-rich.

Geochemical Characterization – HCT Results



Current Observations

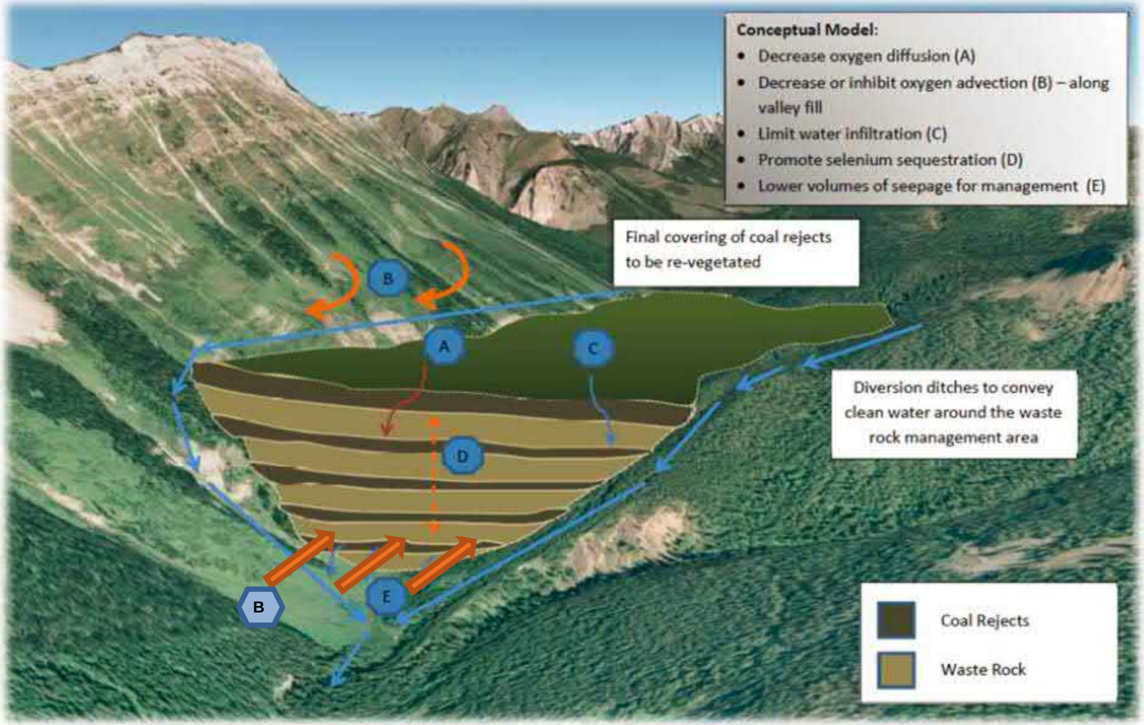
- Geochemical characteristics are very similar to elsewhere in the Elk Valley.
- Bulk of waste rock is non-PAG and is expected to show similar leaching to waste rock elsewhere in the Elk Valley.
- Controlled management by blending of Morrissey Formation for localized PAG characteristics.

Update on Modelling the Layered Spoil Concept

Project Team

- SRK
  - Hydrological Modelling
    - Michel Noel, PEng, MASc, Principal Consultant
    - Ryan Williams, BEng, Senior Consultant
  - Geochemical Modelling
    - Andrew Garvie, PhD, Principal Consultant
  - Project Review
    - Stephen Day, PGeo, Corporate Consultant
- Enviromin
  - Biogeochemistry
    - Lisa Kirk, PhD, Principal
    - Seth Dimperio, PhD, Senior Microbiologist

Waste Rock Management: Layered Approach



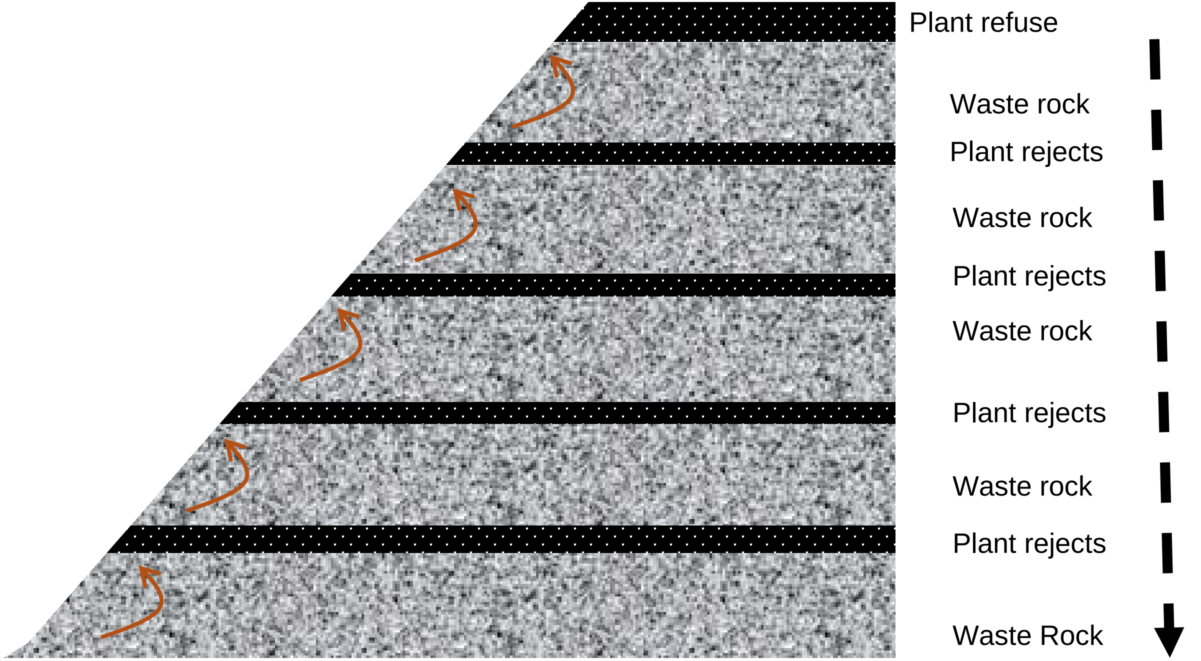
Conceptual Model For Se and NO_3 Attenuation in the Layered Spoil

Expected role of plant refuse layers:

- Retain moisture retarding oxygen transport.
- Generate dissolved organic carbon.
- Provide sub-oxic zones where reductive processes could occur.

Oxygen movement internally by diffusion not advection.

Convection in exposed faces.



Reductive Processes

O_2 decreasing

<u>When DO<0.5 mg/L:</u>

$NO_3^- \rightarrow N_2$
$SeO_4^{2-} \rightarrow Se^0$

srk consulting

Difference Between O_2 Movement by Diffusion and Convection

- Diffusion
  - O_2 moves from higher concentrations to lower concentrations due to the constant random motion of gas particles.
  - Presence of moisture decreases connection between gas in pore spaces and requires O_2 movement through water which is inherently slower than in air.
- Advection can be driven by pressure and density gradients. Pressure gradients can arise by:
  - Wind over a pile
  - Temperature gradients induced by heat released due to oxidation
  - Density gradients induced by the removal of oxygen by oxidation
- Convection is the term often used for advection caused by temperature and density gradients

Conceptual Model For Se and NO3 Attenuation in the Layered Spoil

- The layers are conceptualized to force O_2 to move slowly by diffusion with convection limited to side slopes.
- Native organic carbon and sulphide in the plant reject and waste rock consumes O_2 by oxidation
- When sufficient O_2 is consumed, Se and NO_3 can be converted to less mobile selenite and elemental selenium, and nitrogen gas by oxidation of organic carbon.
- All processes are microbially-mediated.

NWP Suboxic
Waste Rock Management
Column & Respirometry Studies

Enviromin, Inc.

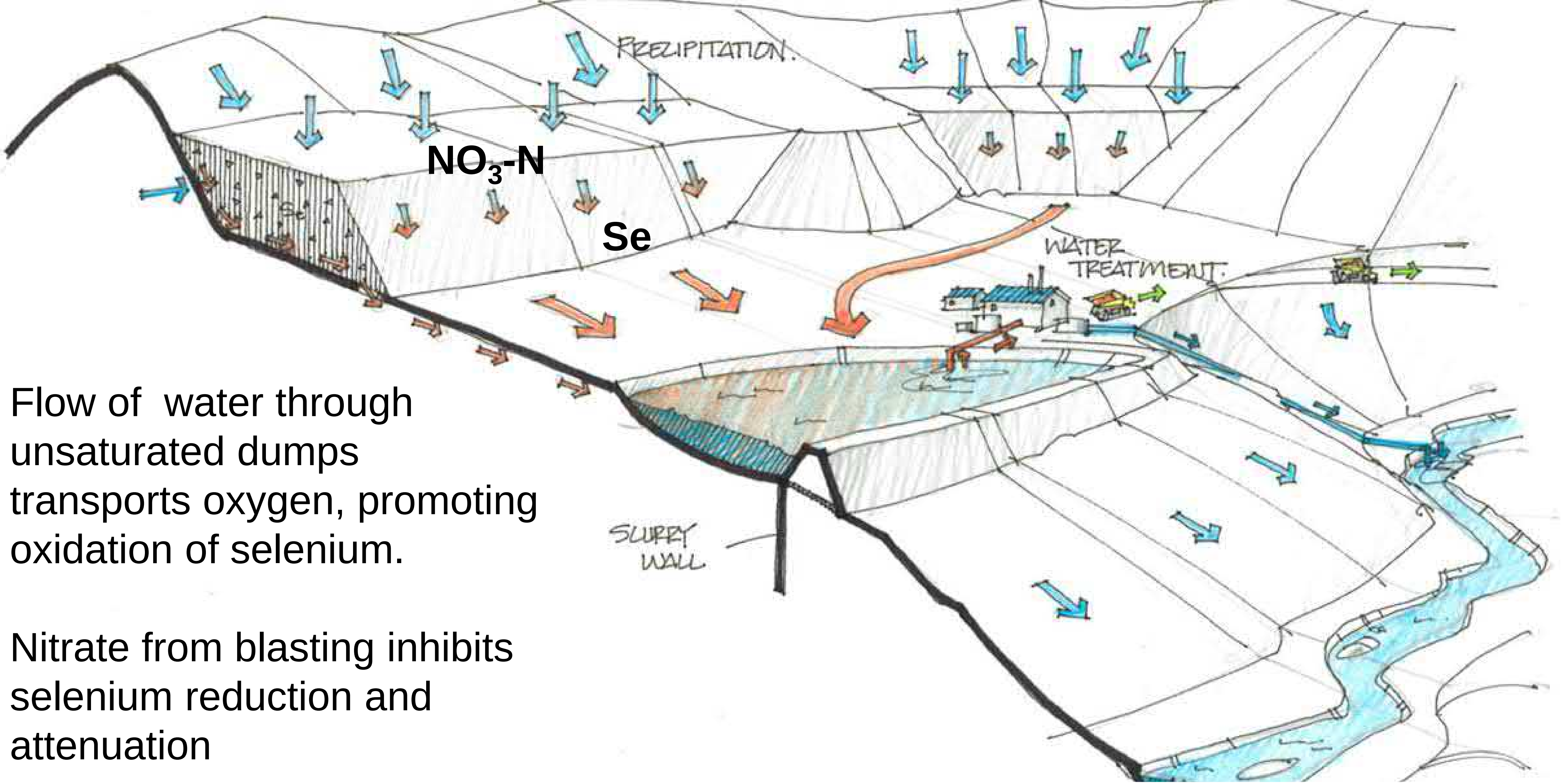
October 9, 2019

Enviromin

Selenium Mitigation

- Waste rock dump or backfill design to reduce NO_3 and Se loading
- *In situ* microbial source control
  - Control oxygen, moisture, lithology (carbon) to affect reduction
  - Integrate controls into mine design
  - Saturated fills with management of flow, carbon and nutrients
  - Interbedded Coal Reject/tails with waste rock

SAPSM, 2010



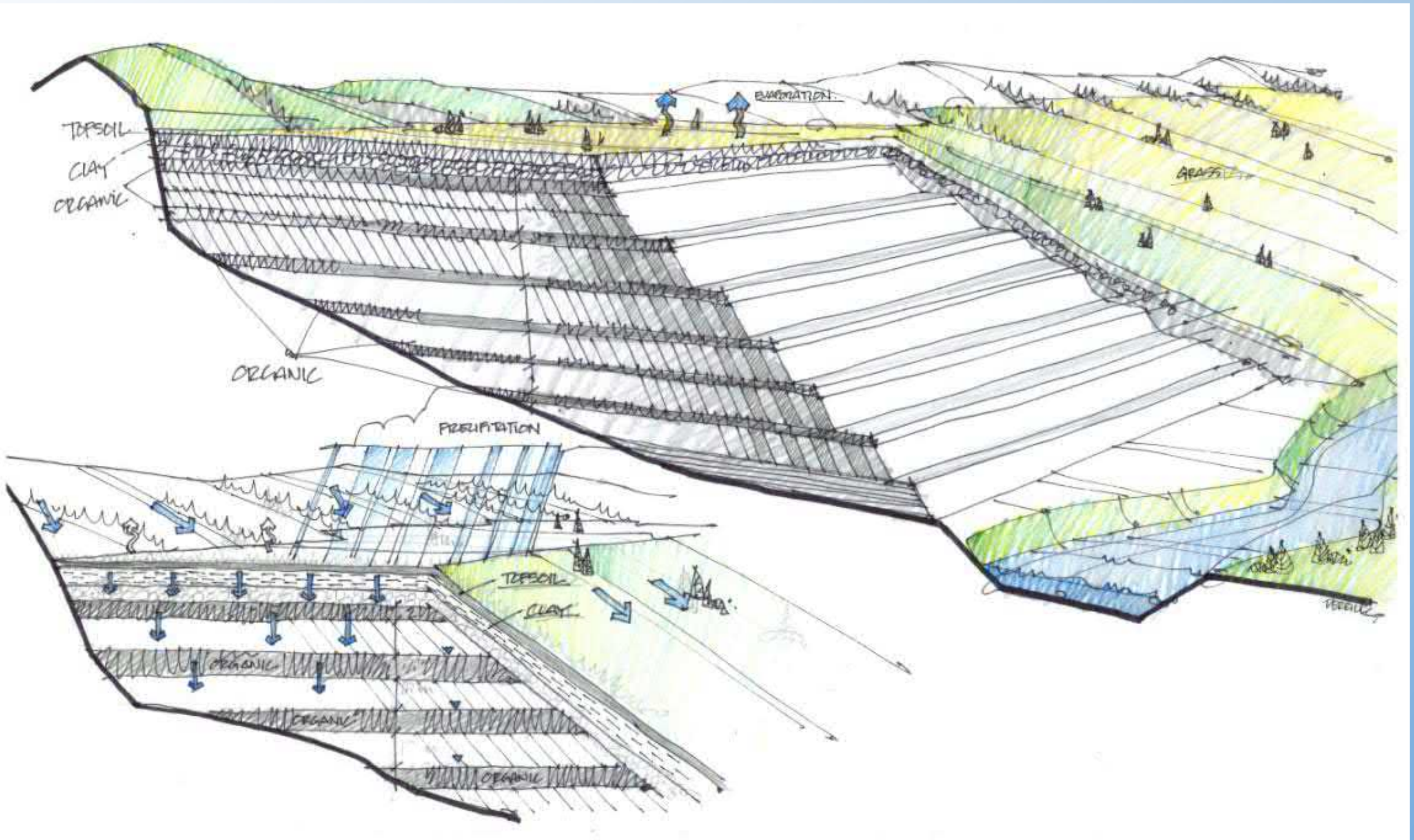
Flow of water through unsaturated dumps transports oxygen, promoting oxidation of selenium.

Nitrate from blasting inhibits selenium reduction and attenuation

SAPSM, 2010

Suboxic Waste Rock Dump Design

Attenuation (biotic and abiotic) >> Release (oxidation/desorption)



Redox Biogeochemistry

- Electron exchange during oxidation or reduction from
  - Reduced carbon (DOC, e.g. methanol, acetate, etc.) Oxidation – electrons lost
  - Fe^{2+} to Fe^{3+} (1 e- removed)
- Reduction – electrons gained
  - Fe^{3+} to Fe^{2+} (1 e- gained)
- Elemental cycling
  - Fe^{3+} to Fe^{2+} to Fe^{3+} to Fe^{2+} , etc.
- In mined materials, native microbes biochemically oxidize or reduce nutrients (e.g., NO3-), various metals/metalloids (e.g., Se, Fe), and S –
  - To make energy
  - To detoxify their own environments
- Microbes drive rates of reactions between minerals and water (kinetics)
  - Oxidation (e.g., FeS2 to ARD)
  - Reduction (formation sulphide or insoluble Se minerals)

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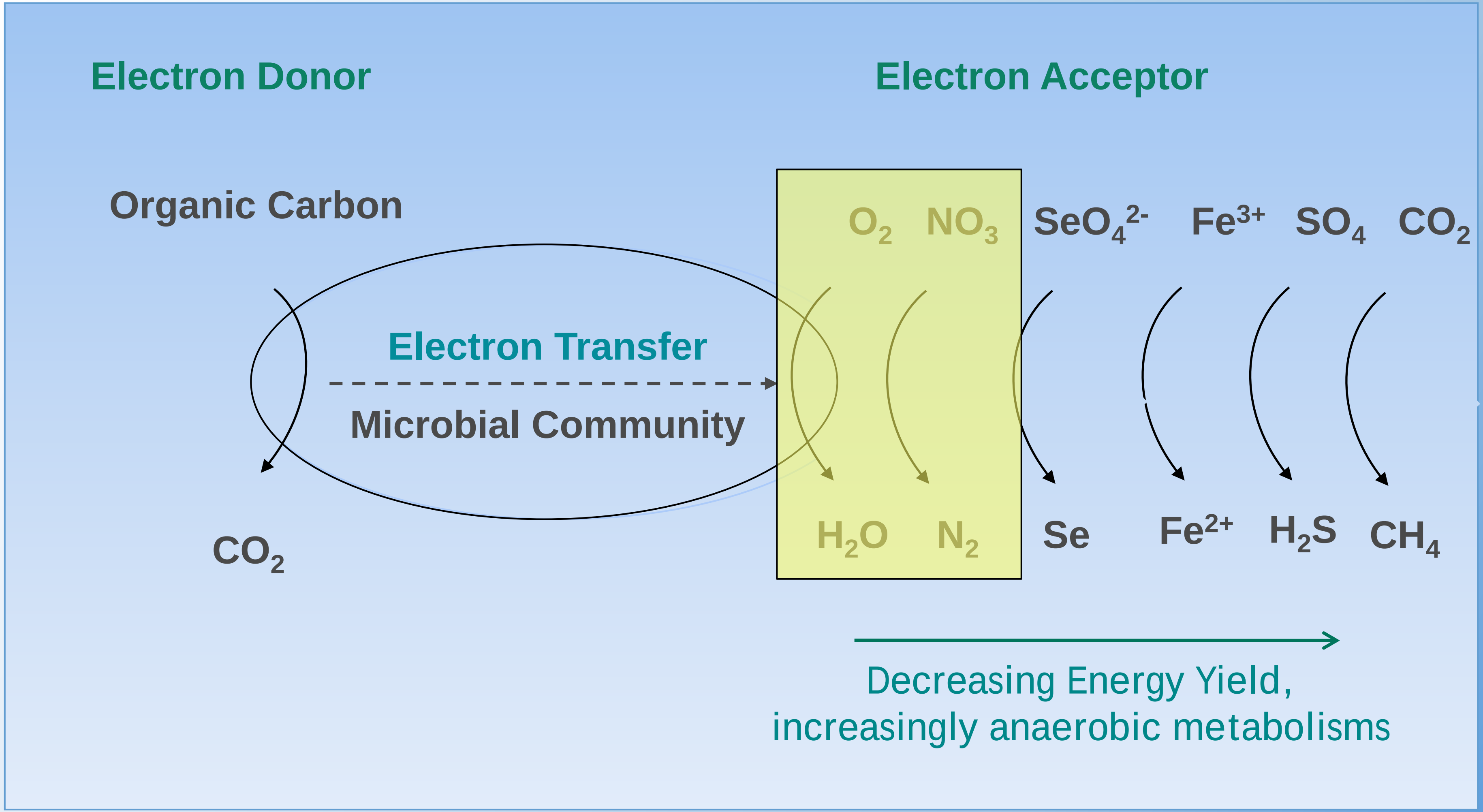
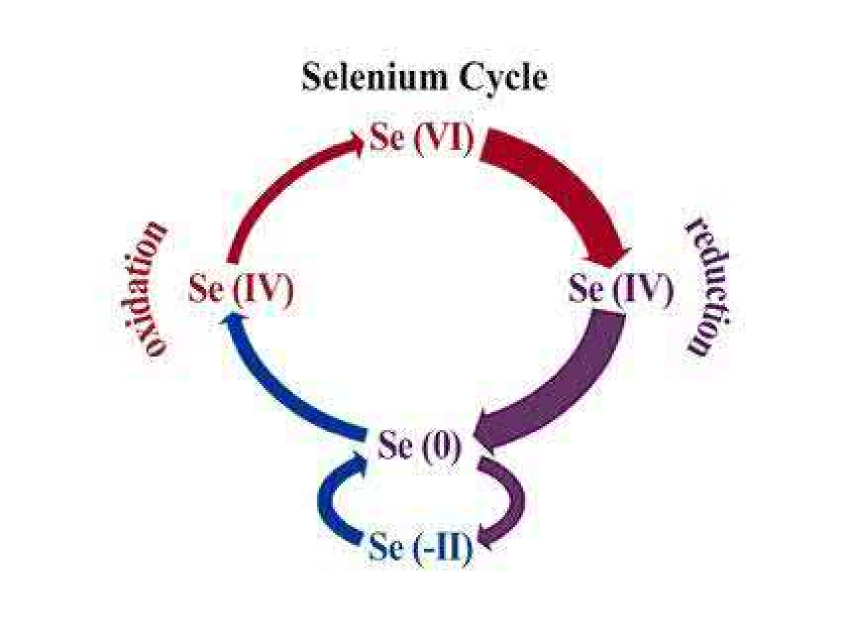
Microbial Metabolism



Selenium

- Redox-sensitive metalloid
  - Mobile under oxidizing, alkaline conditions
  - Immobile under reducing, moderately acidic conditions
- Four valence states: +VI,+IV, 0, -II
  - $Se^{+VI}O_4^{2-}$ selenate
  - $Se^{+IV}O_3^{2-}$ selenite
  - Se^{o} elemental selenium
  - H_2Se^{-II} selenide gas, metal selenide
- Attenuation Mechanisms
  - Sorption – selenite to iron oxides, clays, calcite
  - Mineral precipitation – selenite/selenate salts ($BaSO_4(SeO_3).2H_2O$, metal selenide minerals, elemental selenium
  - Degassing as H_2Se or methylated Se



Se Cycling – Abiotic and Biotic

- Abiotic oxidation, release, mobility

$$Se^{o} + 3/2O_2 = SeO_3^{2-} + 1/2O_2 = SeO_4^{2-}$$

- Biotic selenate reduction

$$4CH_2COO- + 3SeO_4^{2-} = 3Se^{o} + 8CO_2 + 4H_2O$$

  – Kinetic constraints for selenate reduction
  – Non specific/detox – nitrate reductase enzymes
  – Growth – selenate reductase enzymes

- Selenite and elemental selenium can be further reduced via biotic or abiotic pathways

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Abiotic $Se^{VI}O_4$ Reduction

- Abiotic reduction of $Se^{VI}O_4$ to $Se^{IV}O_3$ occurs very slowly except
  - Green rust (Fe^{II}-Fe^{III} hydroxysulfate) Myneni et al, 1997

- Abiotic reduction of $Se^{IV}O_3$ to Se^{o} more common Chakraborty, 2010
  - FAST (24 hrs) siderite, mackinawite, magnetite
  - SLOW (weeks) pyrite, troilite, green rust , Fe(II)-adsorbed montmorillonite, and zerovalent iron Fe(II) sorbed on or coprecipitated with calcite
  - reduction products can differ with a variety of elemental Se (red, gray) and iron selenides (e.g., FeSe)
    .

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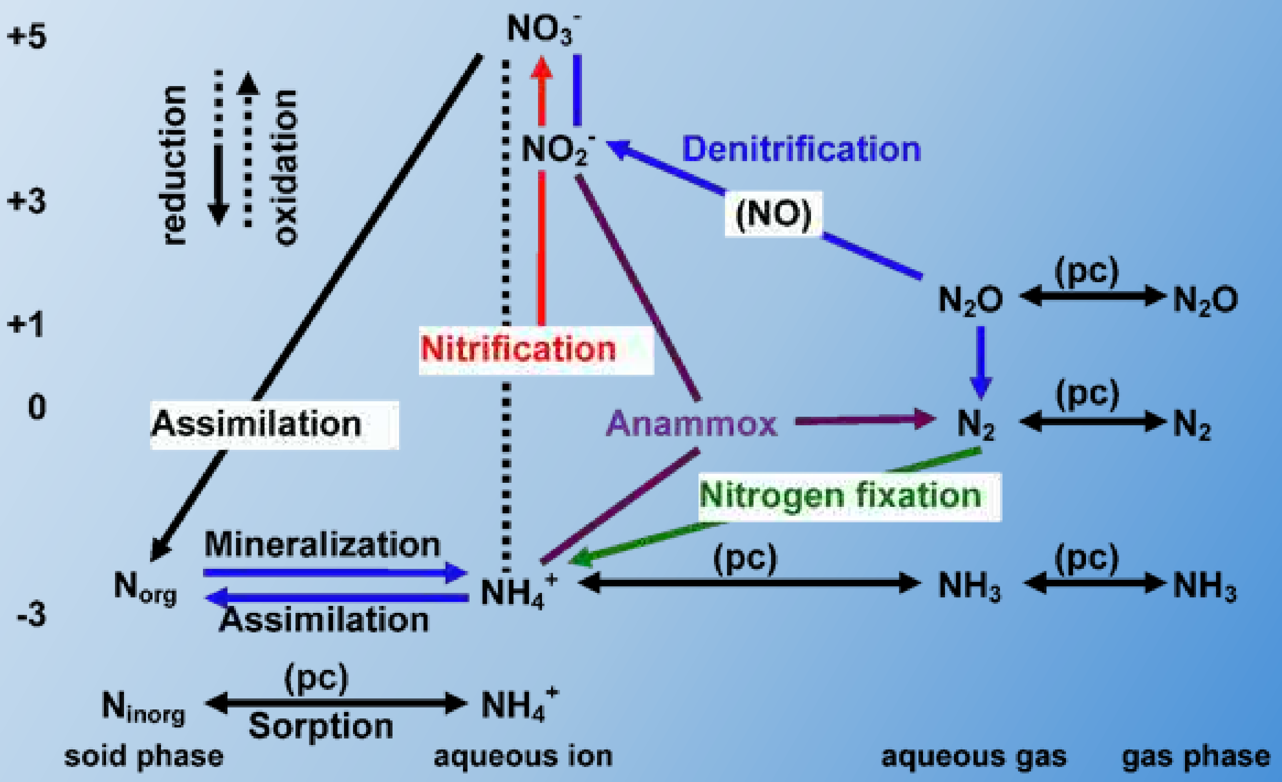
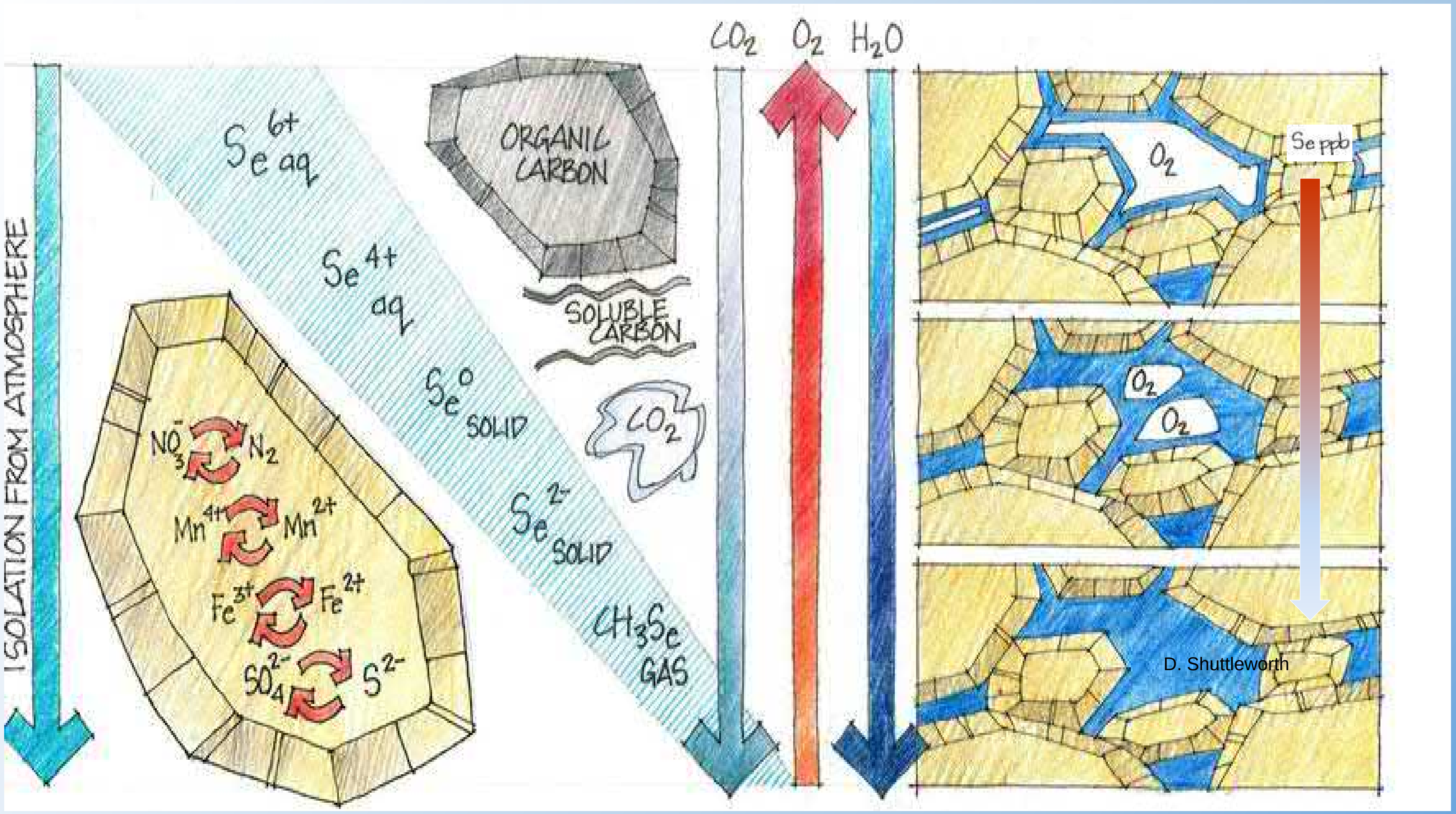
Nitrate

- Released during blasting
- Nitrogen has 5 redox states
- Like Se, N redox biogeochemistry is complex.
- Key inhibitor of selenate reduction
  - –Competition for nitrate reductase enzyme substrate
- Readily reduced biologically to nitrite and nitrogen gas under suboxic conditions



Concurrent biological nitrate and selenate reduction is possible via multiple enzyme substrates in mixed microbial community

Conceptual Selenium Biogeochemistry



- SeO_4^{2-} is released during sulphide oxidation
- Reduced SeO_3^{2-}, Se^0, & Se^{2-} are less soluble than SeO_4^{2-}

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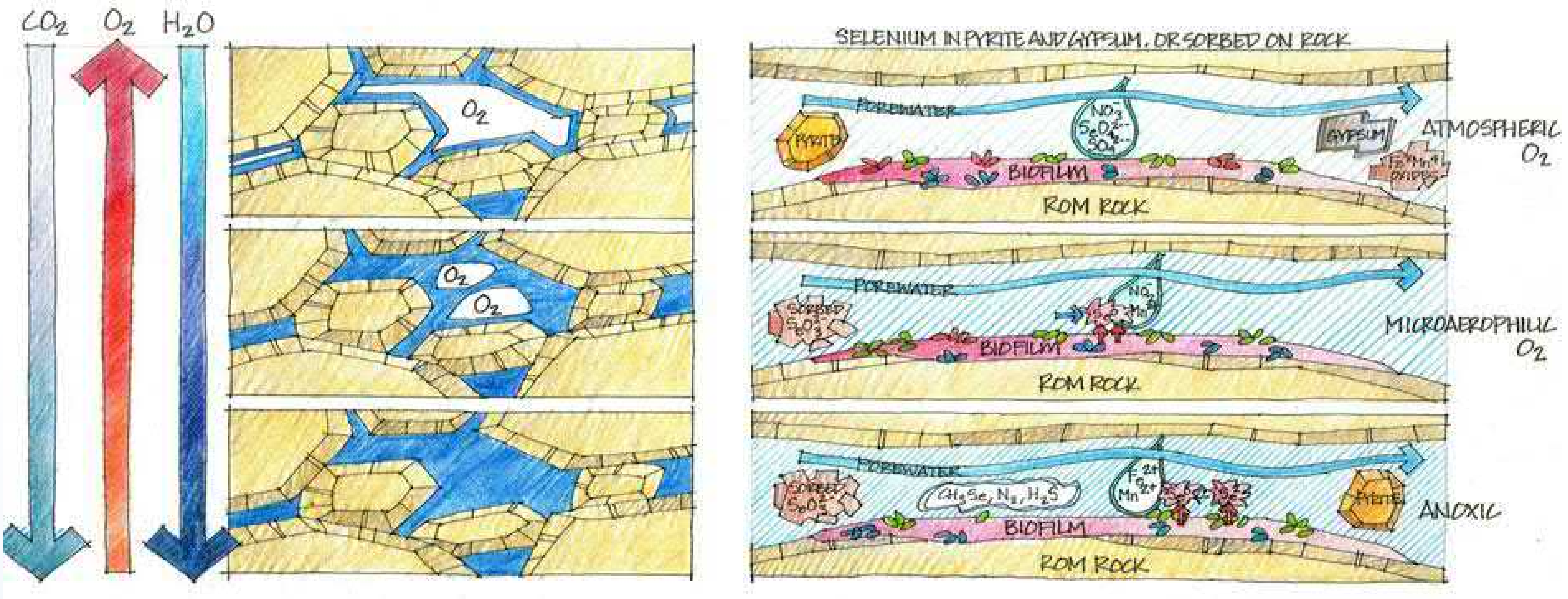
Selenium Biogeochemical Model



KIRK, 2015

- Soluble SeO_4^{2-} is associated with O_2 , NO_3^-, & SO_4^{2-}
- Microbial community changes with O_2 availability
- O_2 & NO_3^- consuming microbes also promote Se reduction

NWP Column & Respirometry Studies

Case Study in an Unsaturated System

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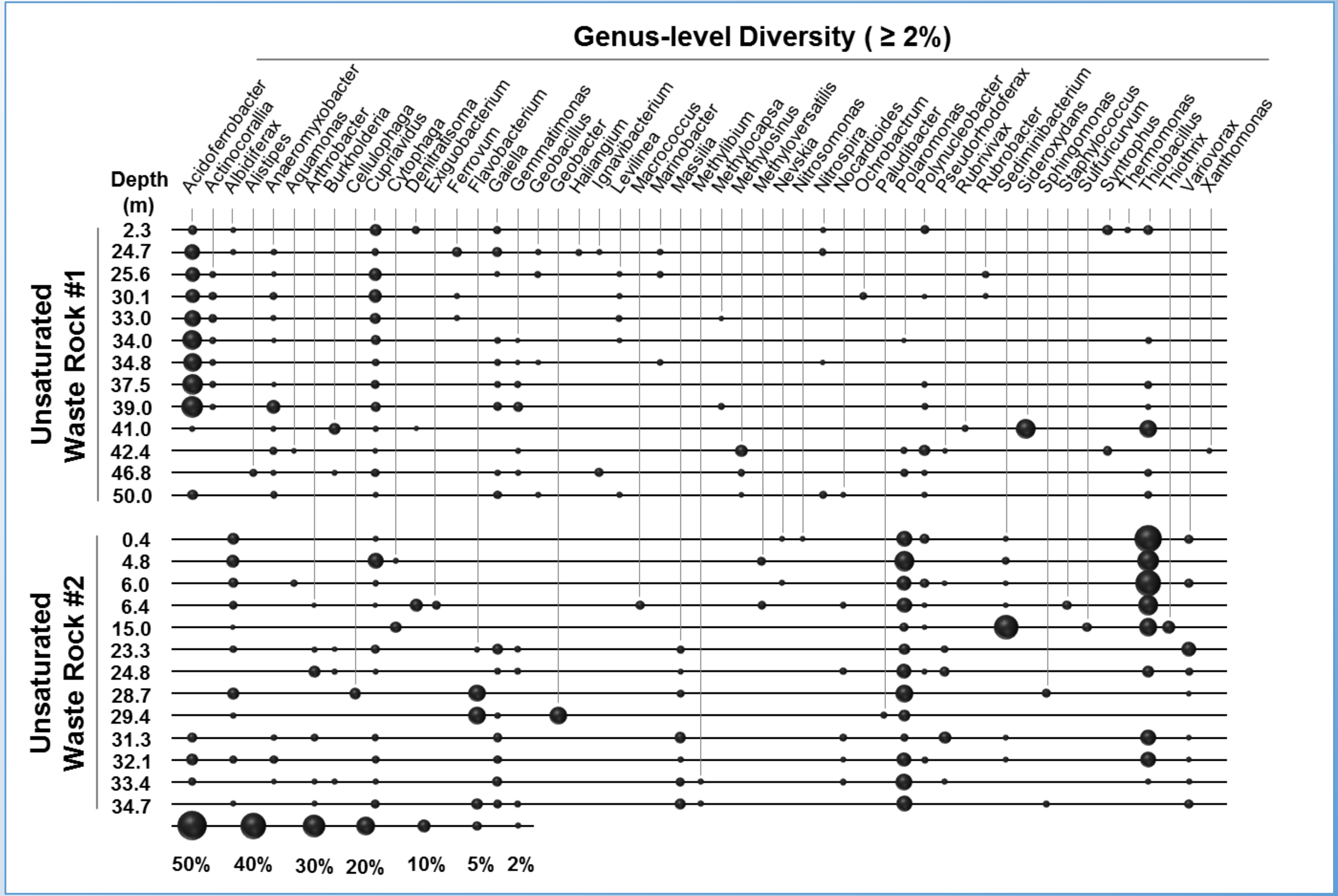
Elk Valley Microbial Community Structure and Function

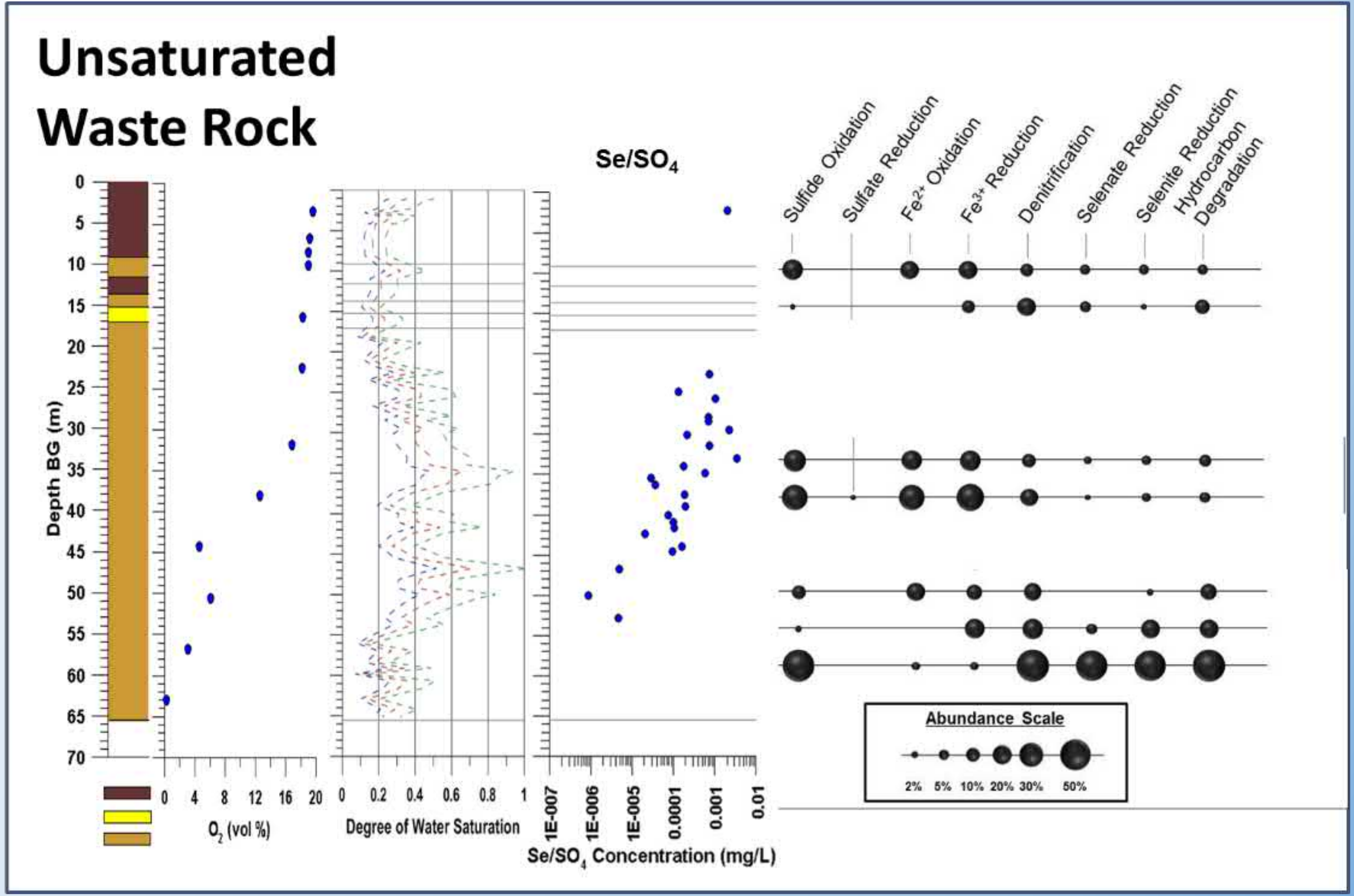
Mine waste with Se release

Microbial community changes with depth

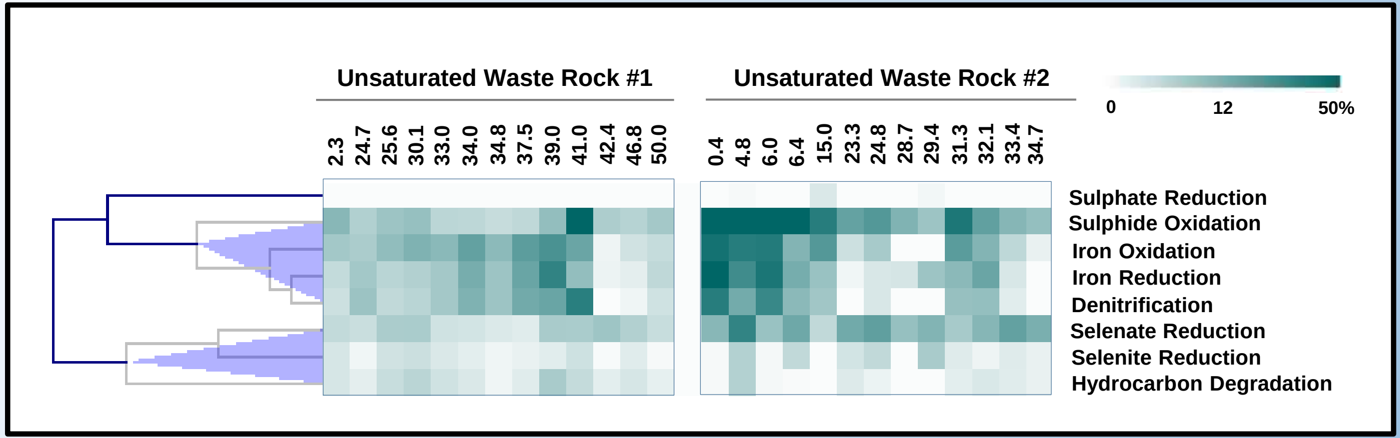
Geochemistry plays an important role in community structure



Community Analysis Supports Geochemical Evidence



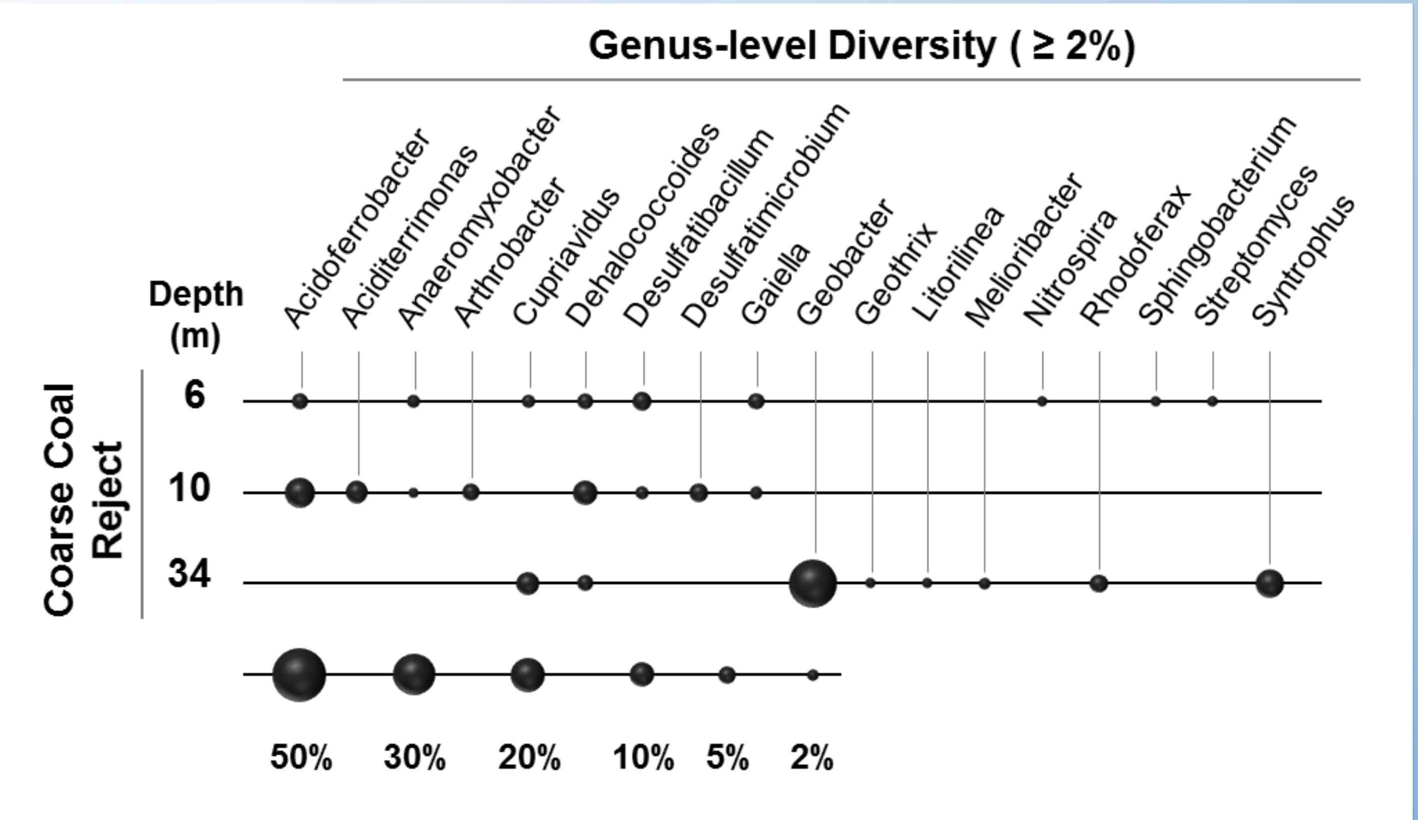
Microbial Characterization: Signatures



Metabolic potential changes spatially

- *Few SO_4^{2-} reducers*
- *S-/Fe-oxidizers and denitrifiers:*
  - *#1: Abundant ≤ 41 m*
  - *#2: Abundant in shallow and mid-depth waste rock*
- *SeO_4^{2-} and SeO_3^{2-} - reducers*
  - *#1 & #2: SeO_4^{2-}-reducers are common, not so for SeO_3^{2-}*
- *Hydrocarbon degraders: abundance tracks most closely with Se*

Microbial Community – Coal Reject



- Anaerobic community in the processed waste
- *Geobacter* is rare in other waste, but dominant in the deep CCR
- Is an obligate anaerobe with strong capacity for metal reduction, including Se

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Scope of Work

HERE

1. Proof of Concept

- Assemble existing data
  - Material and water balance
  - Published oxygen consumption rates
- Conceptual design model
- Analytical model of oxygen consumption potential

2. Quantitative Evaluation- Lab

- Sampling
  - Groundwater
  - Waste Rock
  - Coal Reject
- Characterize material properties
- Test oxygen consumption rates
- Test denitrification and selenium reduction rates under controlled oxygen exposure, T=10ºC, unsaturated flow in columns

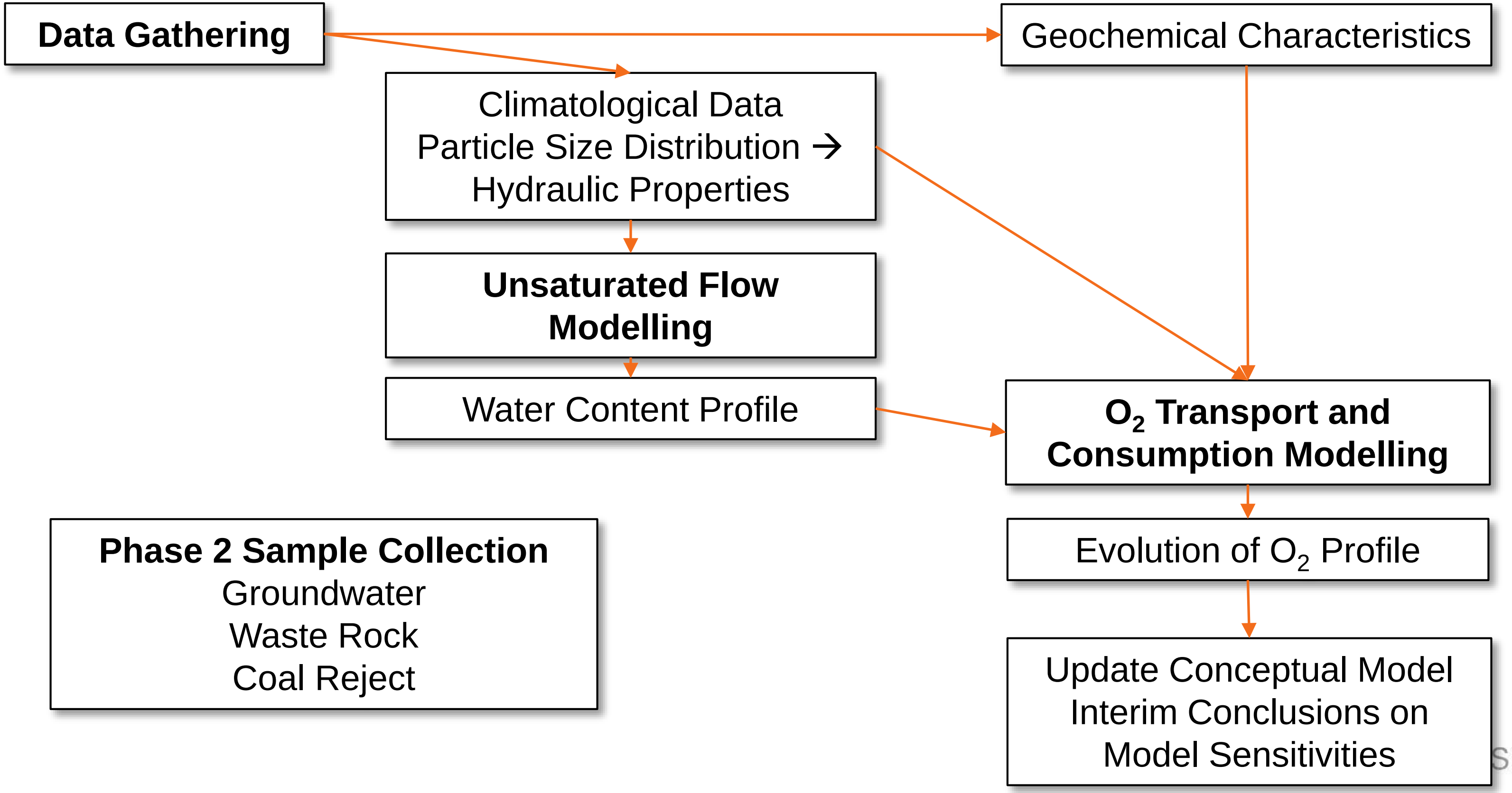
3. Revise Designs for Demonstration

- Numerical Modeling of Phase 2 results
  - Revise oxygen predictions
  - Calculate Se and NO_3 reduction
  - Predict Water Quality
- Update Conceptual design model
- Develop field scale demonstration design

4. Demonstration

- Site Waste Characterization
- Pilot Scale test demonstration
  - Facility design
  - Monitoring
  - Assessment

Phase 1 – Methods and Results



Findings from Phase 1

- Modelling of layering concept using data gathered from other sites and literature.
- Confident with proof of concept where there is not advection
  - Diffusive transport of O_2
  - Compaction of plant refuse needed to retain moisture and reduce O_2 transport and allow it to be consumed.
  - Would take a few years to remove O_2 from pore gases and allow selenium and nitrate reactions to proceed.

Phase 2 Modelling – Method

- Similar to Phase 1.
- Site climatic data were used to estimate the moisture content profile in the layered spoil.
  - The moisture content determines how fast O_2 diffuses into the spoil.
- The rate at which O_2 is delivered was compared to how fast it is consumed by modelling.
  - Determines how long to deplete O_2 in the pore spaces and how far oxygen diffuses below the surface at a given time.
- The rates of Se and NO_3 attenuation are then evaluated in the context of pore water residence time in the O_2-depleted pore spaces.

Phase 2 Modelling – Inputs

- Inputs are now site-specific:
  - The plant refuse used in the testwork was obtained from process testing of Crown Mountain raw coal.
  - O_2, Se and NO_3 removal rates have been obtained by laboratory testing (Enviromin).

srk consulting

Lab Project Objectives

- **Generate oxygen, nitrate, and selenium reduction rates for use in facility design**

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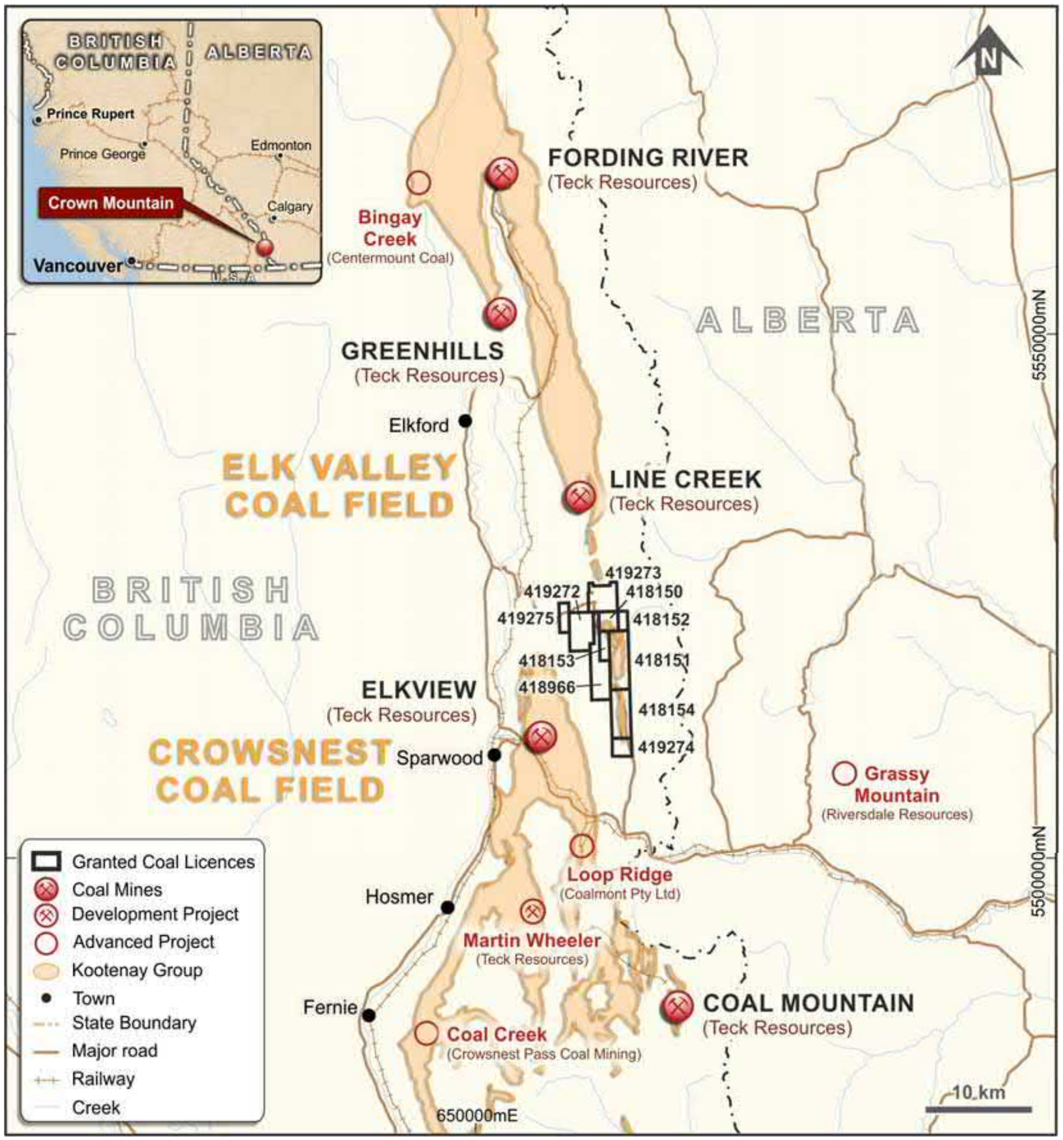


BRITISH COLUMBIA
ALBERTA
Prince Rupert
Prince George
Edmonton
Calgary
Crown Mountain
Vancouver
U.S.A.
N
FORDING RIVER
(Teck Resources)
Bingay Creek
(Centermount Coal)
GREENHILLS
(Teck Resources)
ALBERTA
Elkford
ELK VALLEY COAL FIELD
LINE CREEK
(Teck Resources)
BRITISH COLUMBIA
419273
419272
418150
419275
418152
418153
418151
418966
ELKVIEW
(Teck Resources)
418154
419274
CROWSNEST COAL FIELD
Sparwood
Grassy Mountain
(Riversdale Resources)
Loop Ridge
(Coalmont Pty Ltd)
Hosmer
Martin Wheeler
(Teck Resources)
Fernie
COAL MOUNTAIN
(Teck Resources)
Coal Creek
(Crowsnest Pass Coal Mining)
5550000mN
5500000mN
650000mE
10 km
Granted Coal Licences
Coal Mines
Development Project
Advanced Project
Kootenay Group
Town
State Boundary
Major road
Railway
Creek

Respirometry Testing

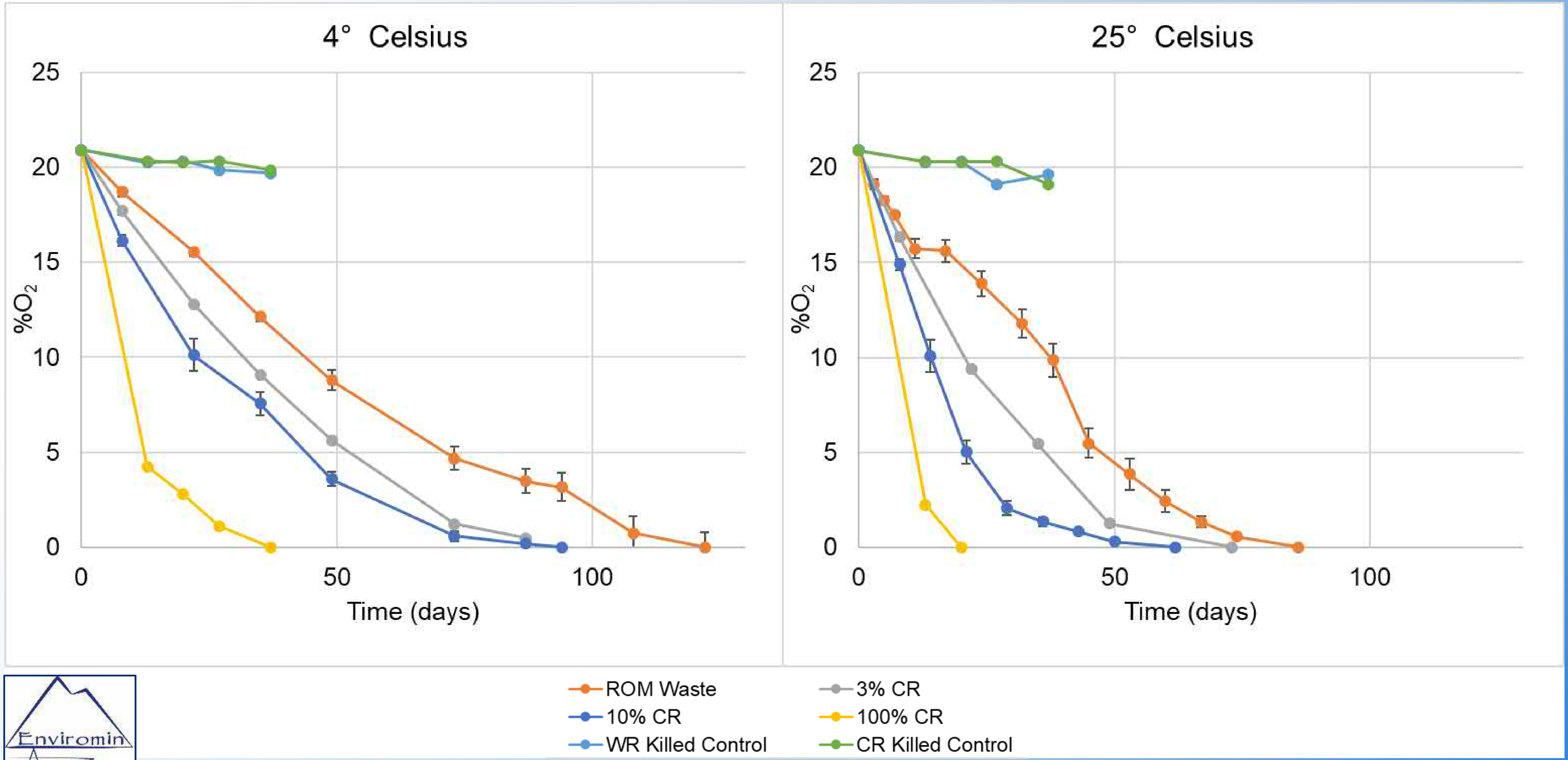
Objective:

- Characterize progressive consumption of oxygen by biotic and abiotic activity
- Create suboxic conditions needed for nitrate and selenium reduction

Parameters Tested	
ROM Waste	At 4°C, 10°C, 25°C
3% Coal Reject	
10% Coal Reject	
100% Coal Reject	
CR Control	
WR Control	

Enviromin

Respirometry Results



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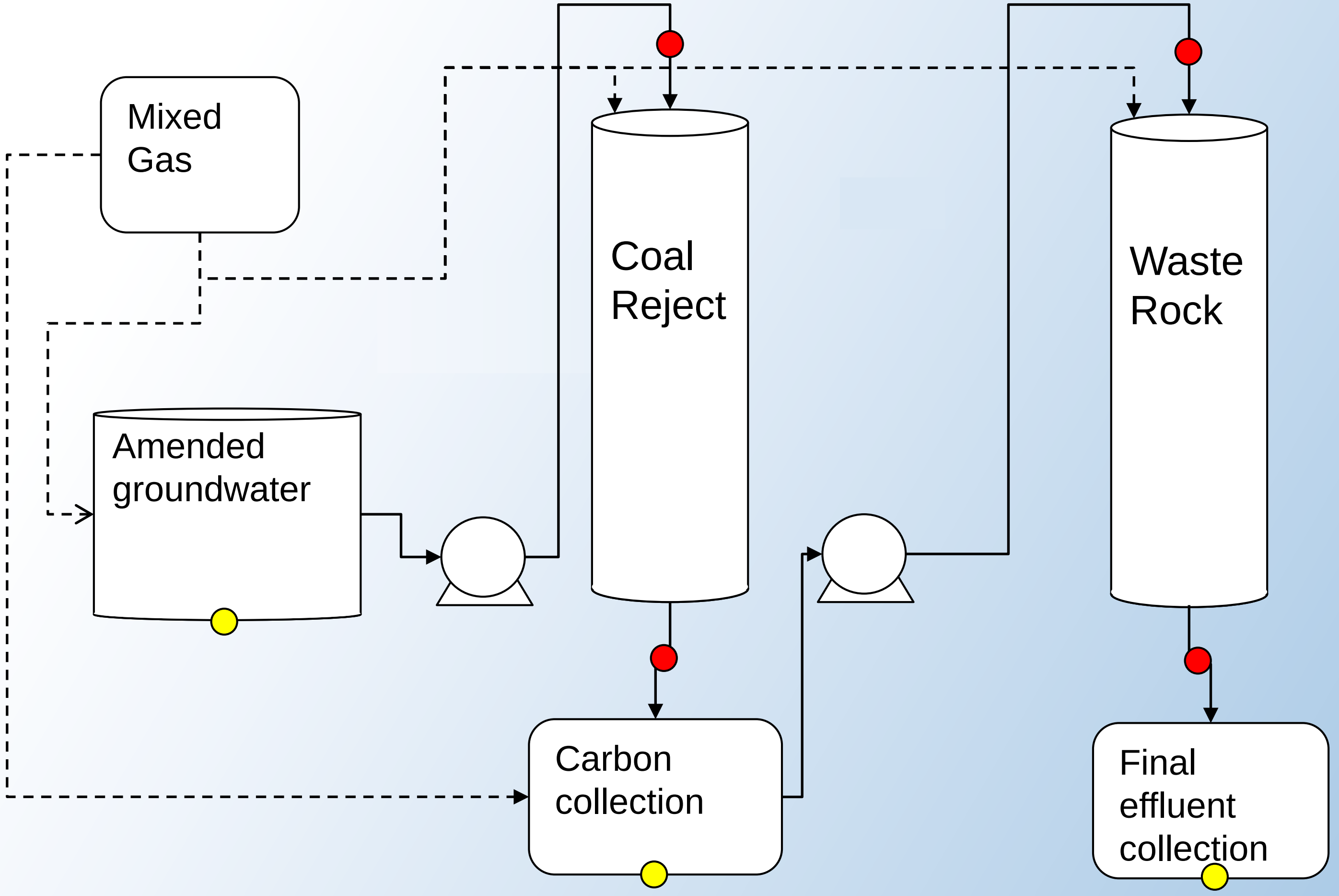
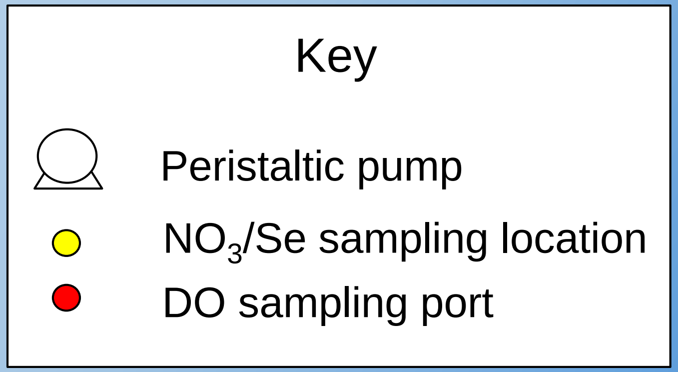
Column Experiments

Objective:

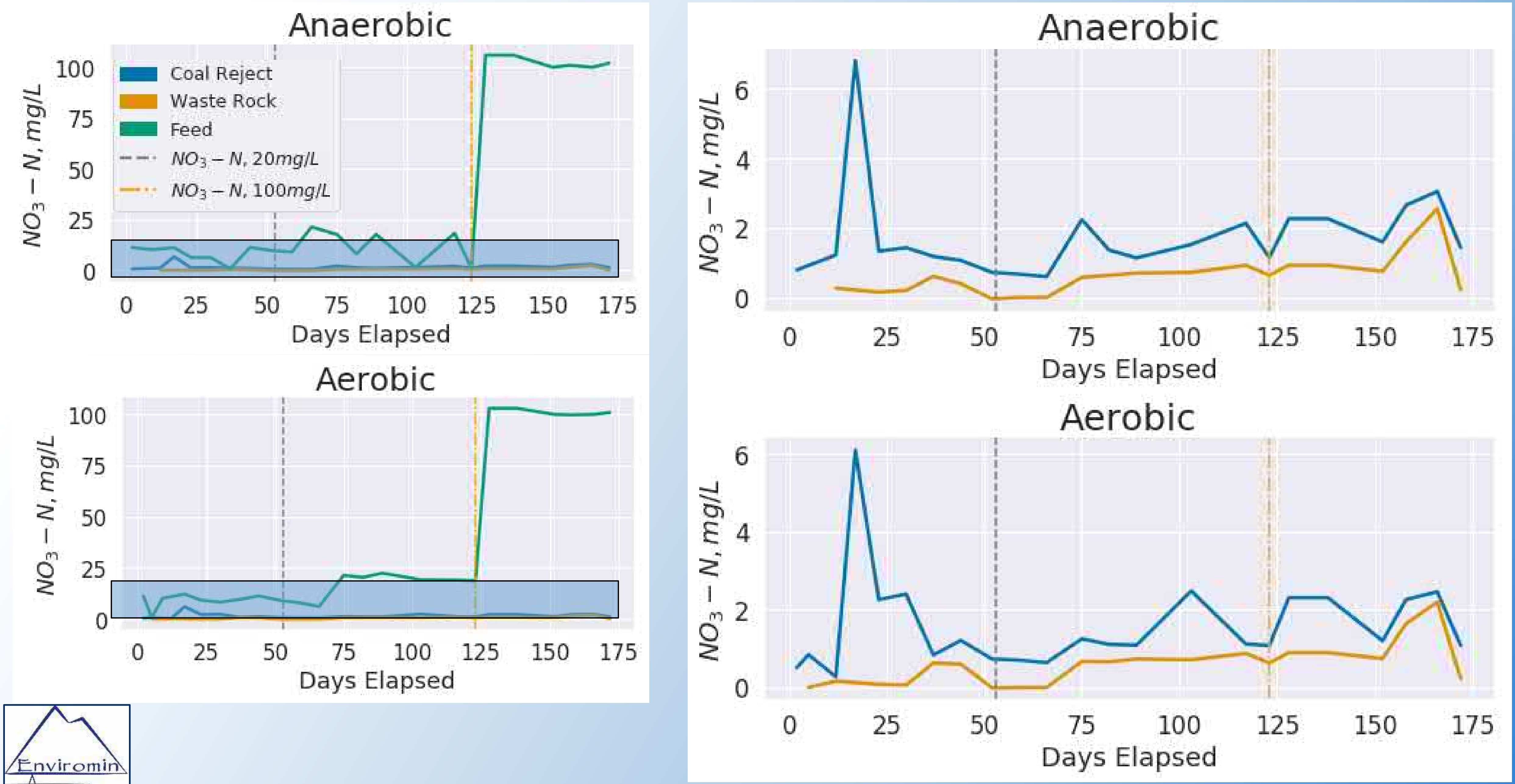
- Determine residence times
- Determine oxygen, nitrate, and selenium removal rates
- Verify hydraulic parameters





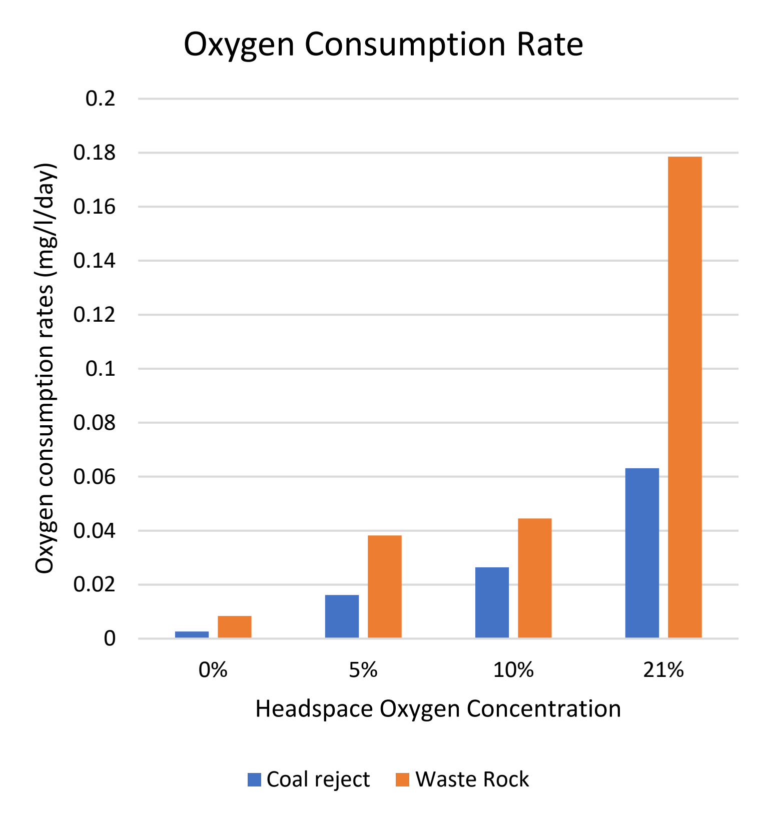
Enviromin

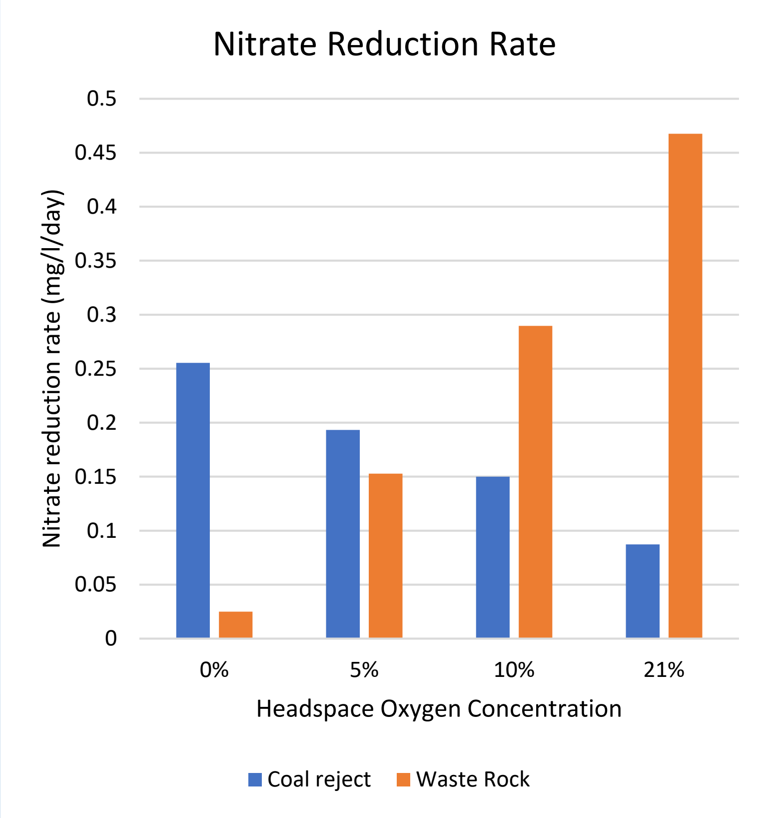
Nitrate

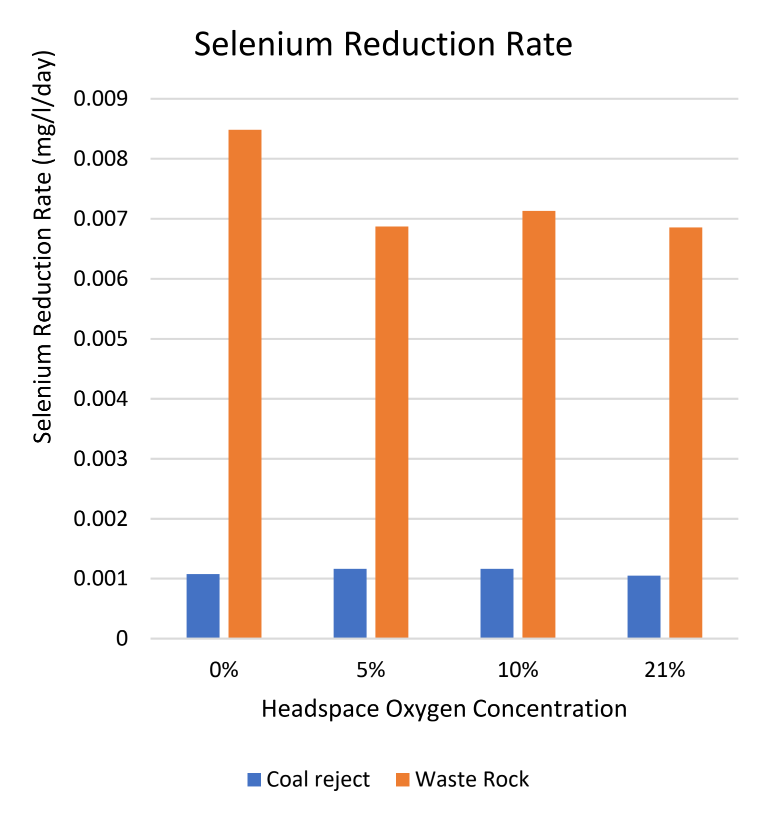


Enviromin

Oxygen, Nitrate, and Selenium Reduction Rates







Rates of oxygen, nitrate, and selenium removal higher than initially modeled
10% oxygen in headspace causes shift in nitrate reduction to waste rock

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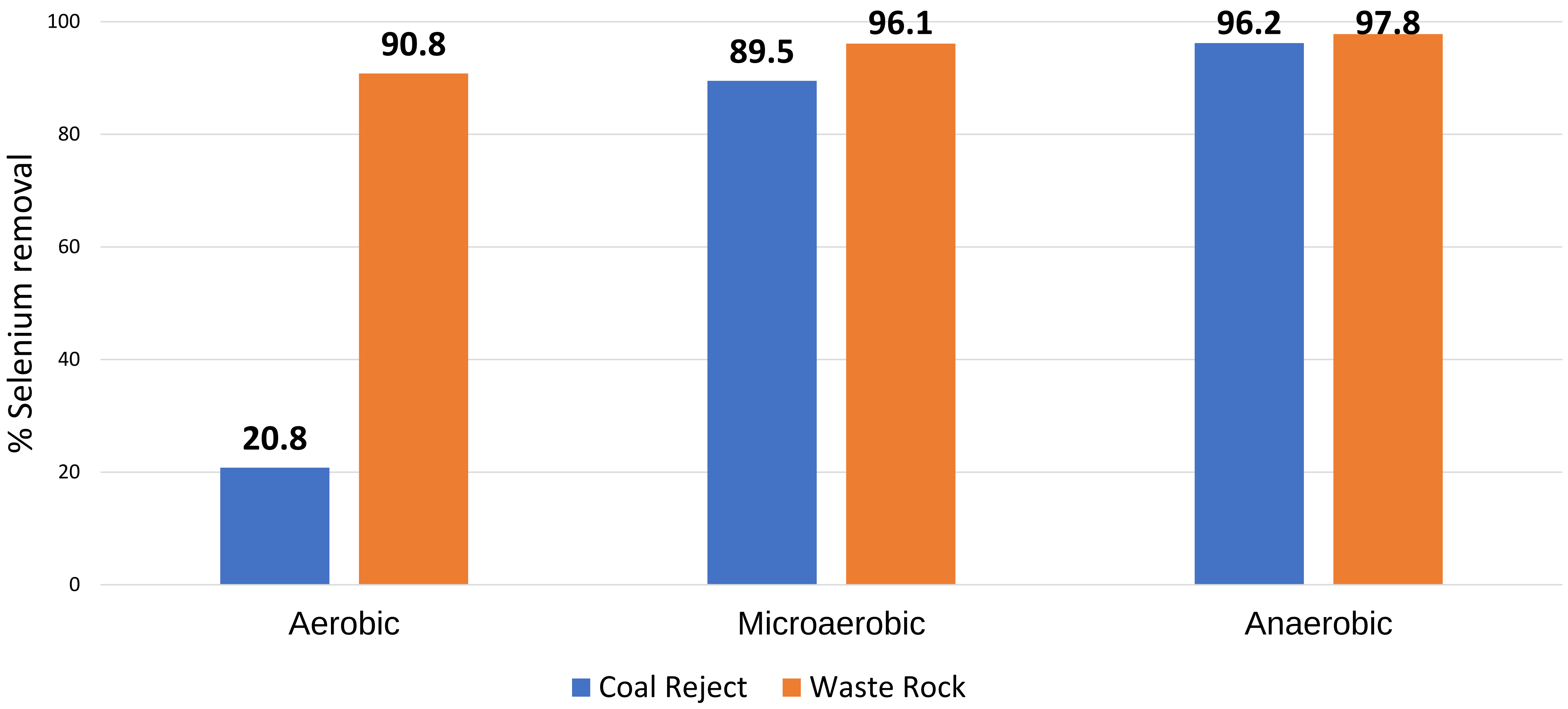
Selenium Removal



Conclusions

- Microbes in coal reject and waste material are capable of nitrate and selenium removal
- Oxygen concentration affects rates and extent of denitrification and selenium reduction.
- Oxygen consumption rates are much higher than previously reported, based on abiotic sulfide oxidation
- O_2, nitrate, and selenium reduction rates can be applied to pilot and full-scale dump design for full-scale testing.
- Updated modeling results support pilot testing – reduced time to develop suboxic conditions from years to months.

Phase 2 Modelling – Inputs

- The testwork continues to use Sukunka Project waste rock:
  - Important to use spoil rather than core.
  - Geochemically, Sukunka and Crown Mountain interburden are sufficiently similar (mineralogical, sulphur content, organic carbon).
  - This is not considered to be a significant limitation.

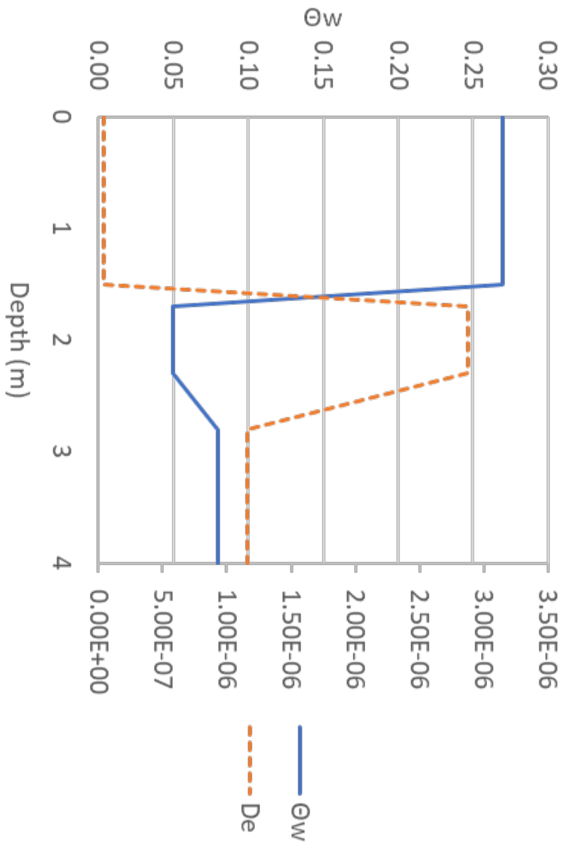
Sensitivities Evaluated

- Infiltration 25% and 50% of total annual precipitation.
- Compaction vs non-compaction of plant rejects.
- 30 m vs 50 m waste rock lifts.
- Breaker reject included or not included as a capillary break.

Phase 2 Modelling – High Level Outcomes

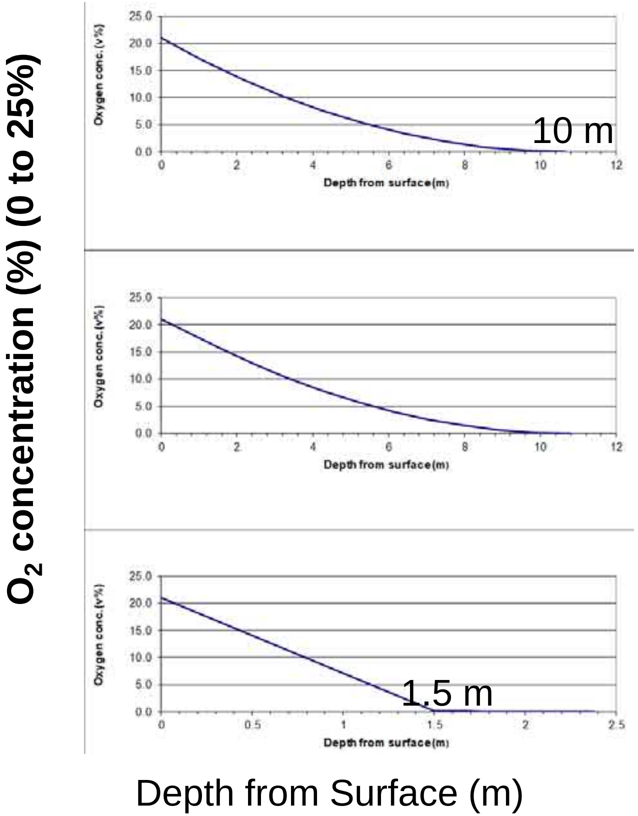
- Proof of concept was reinforced by the Phase 2 modelling.
- O_2-depleted conditions are expected to develop within a year of placement of the spoil.
  - Improvement over the Phase 1 modelling.
- NO_3 removal from pore water expected to take 2.5 years.
  - Compared to expected average ~13 year residence time of pore water.
- Se removal is much more rapid (<2 months).
- Conclusions are robust
  - Sensitivity shows that compaction of plant reject is required.

Phase 2 Modelling – Examples of Ouputs



- Modelling moisture content (Θ_w) and effective diffusion coefficient (D_e) in a 1.5 m plant reject layer overlying waste rock.
- Reject layer achieves about 75% saturation (100% would be fully saturated).

Phase 2 Modelling – Examples of Outputs



- Modelling of O_2 penetration after O_2 is depleted at depth.
- Investigation of the sensitivity of oxygen penetration to oxygen diffusion coefficient in the top 1.5 m of waste rock (top and middle).
- Investigation of the benefit of a 1.5 m thick layer of oxygen consuming coal reject with low diffusion coefficient (bottom)

Conclusions

- SRK/Enviromin concluded based on Phase 1 and 2 modelling:
  - Layering of compacted refuse with waste rock is expected to create sub-oxic conditions in the spoil under unsaturated conditions.
  - Sub-oxic conditions provide an environment under which selenium and nitrate can be removed from existing and arriving pore water.
  - Removal of oxygen also decreases the volume of spoil contributing to loadings of other parameters leached from waste rock (e.g. SO_4, Cd, Co, Zn).
  - The effects of sub-oxic conditions are expected to be observed internally a year after waste rock is placed.

Gaps/Uncertainties

- The main uncertainty relates to the ability of the plant rejects and waste rock to deliver the organic carbon needed to remove nitrate.
  - Rate of delivery.
  - Sufficient organic carbon to outlast nitrate.
  - Differences between Sukunka and Crown Mountain waste rock.
- Role of convective movement in delivering oxygen at the edges of the spoil and resulting significance of loadings to water quality.

Recommendations

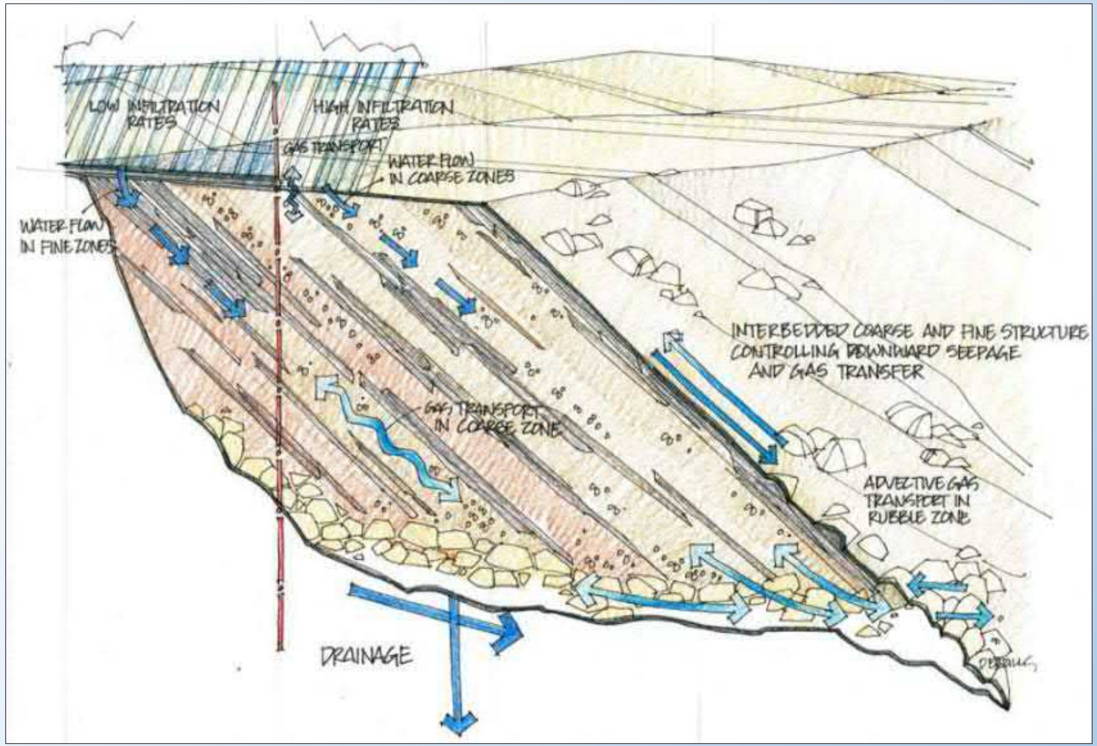
- Controlled construction of instrumented full-scale test facility at the beginning of the mine life.
  - Current mine design includes first 2 years of construction to achieve this objective.
- Explosives management measures to limit availability of nitrate in pore waters.
  - All blast holes will have liners.
- No further O_2 modelling
  - Current modelling is focusing on the progression in water quality.
  - Modelling will evaluate parallel cases where the layering approach is successful and unsuccessful in developing O_2-depleted conditions.

In Progress

- Geochemical kinetic testing.
- Water quality modelling.
- Iterative refinement of mine plan in response to water quality modelling.

Additional Supporting Materials

Water Flow in Waste Rock

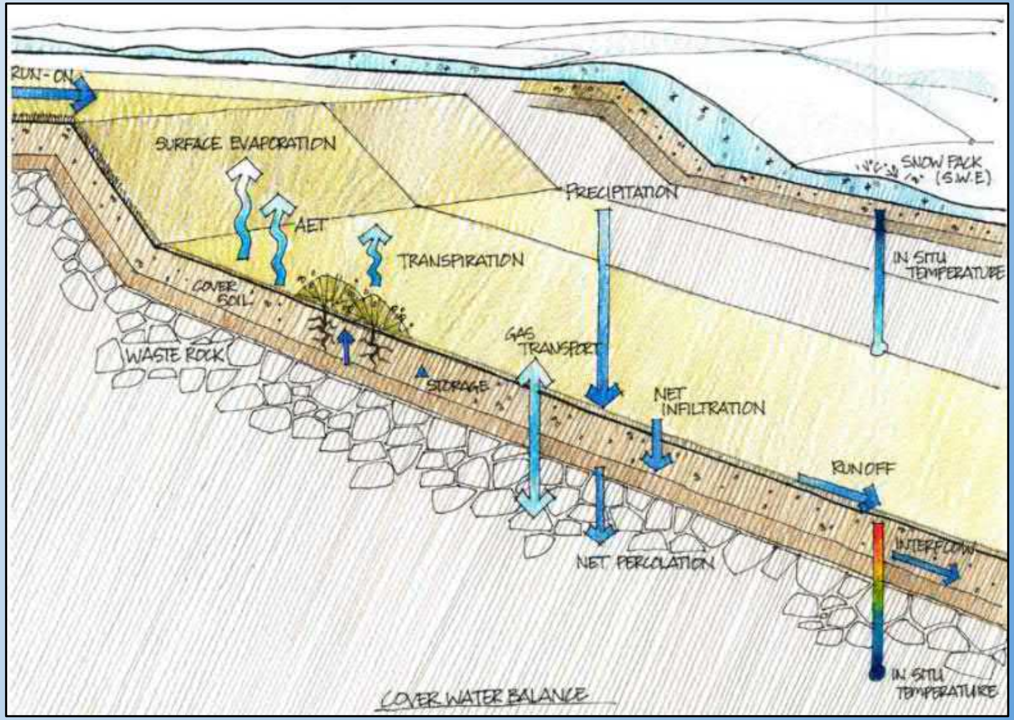


- Infiltration into the dump from rainfall, surface water and snowmelt
- Hydrologic behavior can be complex
- Physical characteristics such as stratification, segregation, particle size and construction method all affect the waste dump permeability and hydrologic behavior

Source: MEND Cold Regions Cover System Design Technical Guide (2012)

Hydrodynamics for Mine Waste Covers

- Unsaturated flow behavior
- Water balance can be complex
- Key inputs: precipitation, actual evapotranspiration, soil hydraulic parameters (e.g. van Genuchten)
- Design of covers – or overall dump?



Source: MEND Cold Regions Cover System Design Technical Guide (2012)

Oxygen Movement in Waste Rock

- Advection
  - Thermally driven
  - Facility scale
  - Can be limited by saturation with water or by creating flow discontinuities with textural breaks, caps, etc.

- Diffusion
  - Gradient driven
  - Small scale
  - Can be limited by saturation of pores with water

Gas Flow by Advection – Simple Terms

Gas flows upward and out the top surfaces of stockpiles when it is lighter than the surrounding air

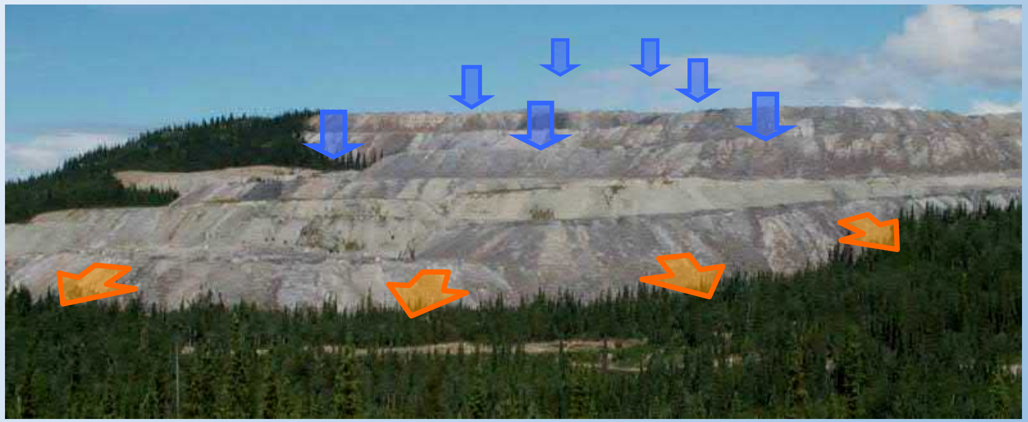
- Less O_2, more H_2O_{vapour}, lower T_{air}

From O'Kane Consultants

Dawson et al, 2009
Phillip et al, 2009
Lahmira et al 2009
Hockley et al 2009

Gas Flow – Simple Terms

- Gas flows downward and out the toe of stockpiles when it is heavier than the surrounding air
  - Increase in CO_2, higher T_{air}



From O'Kane Consultants

Dawson et al, 2009
Phillip et al, 2009
Lahmira et al 2009
Hockley et al 2009

Relationship between Gas Transport and Reactant Consumption

- Convection/advection is driven by total gas pressure differences
- Diffusion is driven by oxygen concentration gradients
- Reactant consumption rate is determined by the material characteristics and a range of parameters. E.g. temperature, oxygen concentration
- Intrinsic permeability - the material parameter that controls the rate of convection/advection of gas
- Oxygen diffusion coefficient – the material parameter that controls the rate of oxygen diffusion
- Construction of dump – compaction to reduce convection/advection & increase water content to reduce the diffusion supply of oxygen

Mathematical Relationship allows Calculation

$$\frac{\partial \rho}{\partial t} + \nabla \bullet (\rho \omega_i \boldsymbol{v} - D_i \nabla (\rho \omega_i)) = IOR$$

Change in O2 density over time

Convection term

Diffusion of oxygen

Consumption rate of reactant e.g. pyrite

Velocity of gas flow

intrinsic permeability

$$\boldsymbol{v} = \frac{-K k_g(\varepsilon_g)}{\mu \varepsilon_g} (\nabla P + \rho g \nabla z)$$

IOR is the reactant oxidation rate
V = gas velocity
∇P = gas pressure gradient
$\rho g \nabla z$ = gas density * acceleration due to gravity * height difference
ω_i = concentration of oxygen

Can dumps be designed to support *in situ* microbial reduction?

- What are the moisture and gas flux requirements for native microbial reduction in Crown Mountain spoil piles?

O_2 availability (rate) =

$[O_{2\ placed} + O_{2\ advect} + O_{2\ diffus}(T, S, \Theta, \varphi, D_G^s)] - [O_{2\ BOD\ (C,\ moisture,\ nutrients)} - O_{2\ COD\ (temp,\ surface\ area,\ mineralogy)}]$

Where T, temp

S, saturation

Θ , moisture content

Φ, gas filled porosity

D_G^s , effective diffusivity

BOD, biological oxygen demand respiration

COC, chemical oxygen demand (oxidation C and S)

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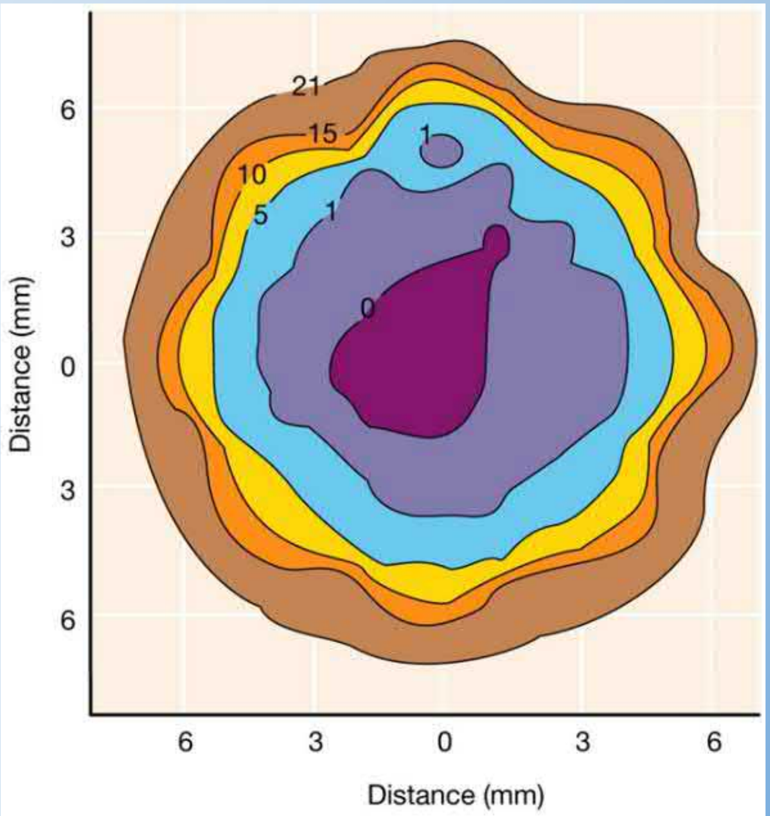
Pore Scale Oxygen

Goal is to prevent convection, limit oxygen flux to diffusion via partial saturation, and consume the remaining oxygen via microbial activity



Can microaerobic conditions be created in a dump?

- Evidence Sullivan
  - Phillip, Hockley, 2009
  - Low oxygen conditions were successfully developed
  - Hazard associated with discharge of carbon dioxide enriched, oxygen depleted gas within confined space
- Evidence Teck Coal
  - F2 and B5
  - GHO Area A CCR
  - LCO, LC3
- Evidence SE Idaho
  - Dry Valley
    - Saturated low, field capacity above, <0.3 mg/L at 15 ft
  - Enoch Valley, Luxor
    - Unsaturated, <0.3 wt % at 30 feet.

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Thank you.

Meeting Notes

Subject: Crown Mountain Coking Coal Project Waste Rock Management Meeting – Meeting Notes

Location: Teleconference/1st Floor Boardroom, BC Environmental Assessment Office, 836 Yates Street, Victoria, BC

Overview of Meeting Notes

Please find below notes from our October 9, 2019 waste rock management meeting and responses to each of the questions and comments. We thank you for your feedback on the Crown Mountain waste rock management update and look forward to discussing any comments or questions on the information presented below. If you would like to have a follow-up discussion, please contact Lucy Harrison at lucy.harrison2@canada.ca and Alex Denis at Alex.Denis@gov.bc.ca.

No.	Question/Comment	Proponent Response
Crown Mountain Geochemistry – Stephen Day		
1	Are the results presented for all 253 samples?	Yes, the results are for all 253 samples.
2	Humidity tests have been going for 20 weeks, but there are only 16 weeks illustrated on the charts. Where are the remaining?	The remaining samples are still ongoing and will come in soon. An update will be provided in the next water quality meeting.
3	The organic carbon is leachable – when is it going to release and what is the number of that finite resource? What happens when it is gone?	We observe that it is immediately leachable. We expect that it will leach at a steady rate and that the reservoir of available carbon far exceeds the demand for removal of nitrate and oxygen.
4	Alexander Creek is important to the Ktunaxa Nation Council – is this the first valley bottom fill in West Alexander?	The fill would be in West Alexander. It would be the first fill in this drainage.
5	What is the role of the microbes in this diagram?	The role of microbes is illustrated throughout the entire diagram. From the coal rejects, the microbes will deplete the oxygen (reduce oxygen to water) and contribute to denitrification (microbes will move on to nitrate once oxygen is removed). We do not need to remove all the nitrate to get to the selenium.
6	What it the timeframe to get to anoxic condition?	The answer is coming - will be determined via additional modelling. A timeframe will be provided in the next water quality meeting.
7	How do you address the variability of grain size?	Grain size is not variable in the coal rejects as it is controlled in the process. This is different from the waste rock material, which is highly variable. However, the process will be relying on the coal reject layers to provide the barrier to create anoxic conditions so the variability of the waste rock is much less important.

No.	Question/Comment	Proponent Response
8	Would the effects along the edges of the waste rock area be different considering the shape of the mountain?	Yes. Diffusion and advection processes will be considered, but concentrating on the outer edge with atmospheric conditions.
9	What about the sides against the mountain – will they affect advection processes?	This is not expected to be a substantial process. Oxygen is not expected to be able to move down valley walls into the waste rock piles by gas advection.
10	Why is the toe of the waste rock pile open (i.e., not covered with coal refuse)?	There will always be an open active face – cannot actively cover with refuse. Toe would be addressed as part of reclamation activities.
Selenium Lab Studies – Lisa Kirk		
11	The overall objective is to reduce the chemical states of the parameters. Does the reaction also generate heat?	Yes, the biogeochemical reactions generate some heat. Enviromin imposed field relevant conditions of 10°C during the column tests. The microbial contribution did not affect measured temperatures. We will evaluate the effect of temperature by modelling.
12	Nitrate was converted to nitrogen gas - was ammonium or nitrous oxide also produced?	The presence of these compounds could not be monitored due to limited effluent volume.
13	Selenate reduction – is it reversible?	Selenate was removed from all columns, with differing levels of efficiency controlled by oxygen exposure. No remobilization of selenium was observed in the experiments. Under anaerobic conditions, some soluble iron was detected, which suggests that iron oxide minerals were dissolved to produce Fe^{2+}. If selenite had been sorbed to these minerals, it is possible that it was released, but if that were true, it was apparently further reduced to elemental selenium as the dissolved concentration of selenium under these conditions was very low.
14	What are the conditions of the methylation of selenium?	Due to limited effluent volume, it was not possible to monitor for methylated compounds.
15	Have you considered if the temperature might drop below zero within some of the layers of the waste rock pile?	Yes. Possibly in the shallow zones, but the heat capacity of the rocks keeps the overall temperature satisfactory. We do not believe this would challenge the design at depth.
16	What are the assumptions regarding the depths of coal rejects used in the column tests?	No assumptions were made for the column testing.
17	How did you determine the amount of selenium removal?	We measured inputs to and outputs from the columns. Selenium was added to groundwater.
Water Quality Modelling and Spoil Pile Design Considerations – Stephen Day and Lisa Kirk		
18	Is the thickness of coal rejects used in the modelling?	Yes, it is used as a variable in the modelling.

No.	Question/Comment	Proponent Response
19	In existing waste rock piles, we see nitrate move from the piles almost immediately. What does this mean for the receiving environment?	As soon as waste rock is placed, we would expect to have some leaching of nitrate, but the quantity of material would be small; therefore the amount moving to the receiving environment would also be low. The next round of modelling will look at this in more detail.
20	Is there the intention to do a field study?	Yes. During initial production, waste rock placed following this design will be monitored to demonstrate its efficacy.
21	The timeframe does not start until a layer has been capped.	That is true – the timeframe does not start until a layer has been completed. Additional modelling needs to be completed.
22	Will sulphate treatment be needed?	We are not sure yet, this still needs to be modelled. An update will be provided in the next water quality meeting.
23	Is there a concern with biofouling in the pile?	We did not see any biofouling within the columns. We expect that they will be oligotrophic (low abundance) biofilms so do not believe biofouling will be an issue.
Spoil Pile Construction and Geotechnical Considerations – Sean Ennis		
24	Are the assumptions on the thickness made for the coarse reject layer?	We never reach a point where we have 50 meters of layer; we always make sure we have enough plant material to layer. The maximum is 42 meters in year 16 (slide 4).
25	For the open toe design, could you not close the toe of the layer to prevent oxygen entering the pile?	We can look into opportunities to close the toe of the pile.
26	Are the spoil piles fires resilient? Fires are becoming more common and a big concern for the KNC.	The team will look into the pile design from a fire resilience perspective. This will be a consideration in the cover design.
27	Is there a need for temporary stock piling?	The team will look into potential needs. It is expected that we will need to put some materials aside for use in specific years or at the end of the mine life.