2019 Workshop

26th Annual BC MEND Metal Leaching/Acid Rock Drainage Workshop

Vancouver, BC. December 4-5, 2019

Equity Mine, photo courtesy of M Aziz

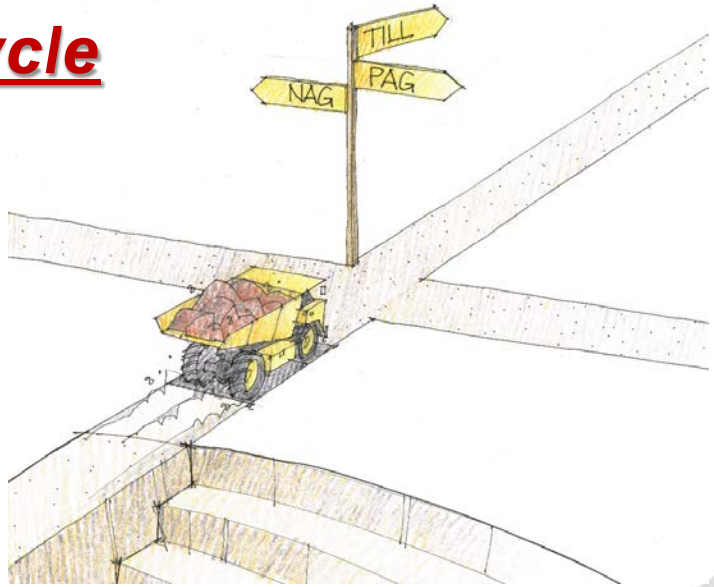
A Review of Potential Improvements to Mine Rock Stockpile Construction Methods

O'Kane, M.[1], Taylor, J.[2], Robertson, J.[1], Pape, S.[2], Tremblay, G.[3], Kelley, B.[3]
1: Okane Consultants, 2: Earth Systems, 3: INAP

BC MEND ML/ARD Annual Workshop
December 4-5, 2019

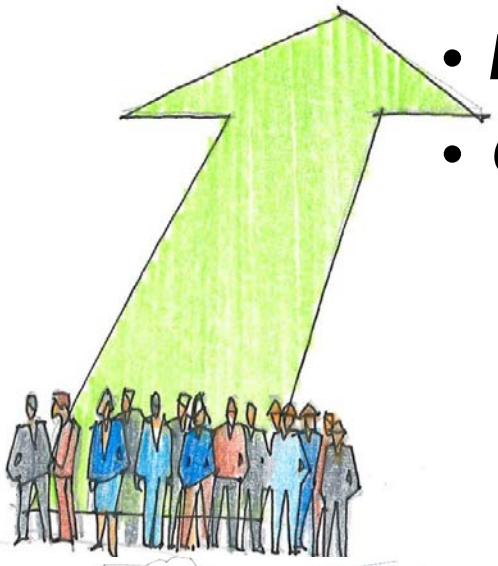
Essence of Project Proposal to INAP

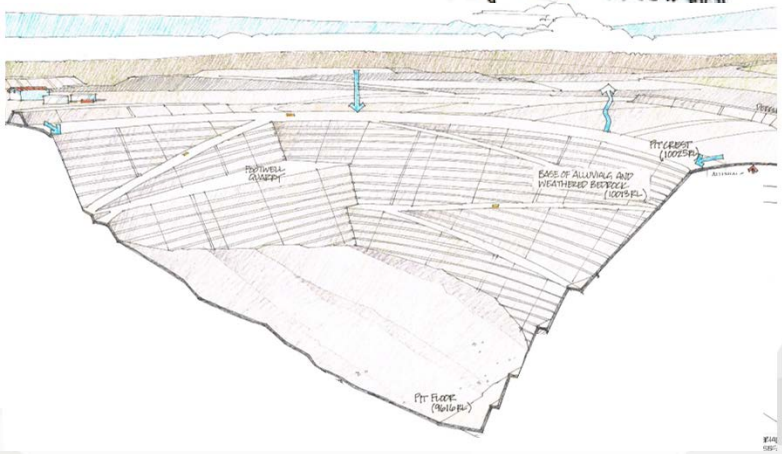
*"… **Essence** of the proposed project is to determine, through **strategic MRS construction** methodologies, whether there is a **mine-life-cycle cost benefit** to **reducing risk** associated with MRS **geochemical stability**, by changing MRS construction methods, for a minimal incremental cost, **during life-of-mine** …"*



Session Discussion Themes

- ***Project Timeline***
- ***Project Scope (within 9 tasks)***
- ***Opportunities***





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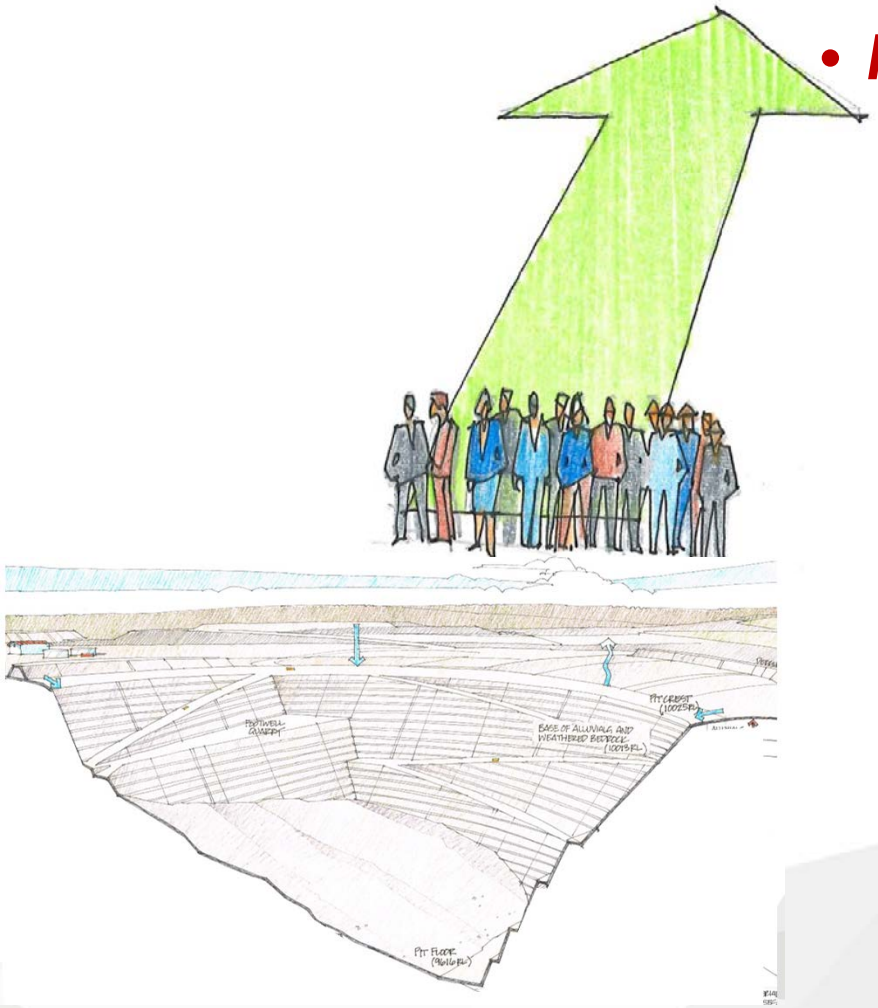


- *Project Timeline*
- ***Project Scope (within 9 tasks)***
  1. ***Framework for Communicating Risk***
  2. ***ML-ARD…***
     Why Focus on Mine Rock Stockpiles?
  3. ***Conceptualization / Evaluation of:***
     - *Conventional MRS Performance*
     - *Alternative MRS Construction Approaches*
  4. ***Communicating Opportunity using Risk-Based Approach Supported by…***
     - *Literature Review and Case Studies*
     - *Semi-Quantitative Assessment thermal / gas / water, and acidity generation modelling*
- *Opportunities*

Project Timeline(s)

- ***May 2018 Discussion***
  - *Four (4) phases discussed*
- ***December 2018 Proposal***
  - *Phase 1: Review and Summary of Methodologies / Technologies*
- ***April 2019 draft Report***
- ***November 2019 final Report***
  - *Minor edits / changes final version to be available very soon at:*

www.inap.com.au

Framework for Communicating Risk

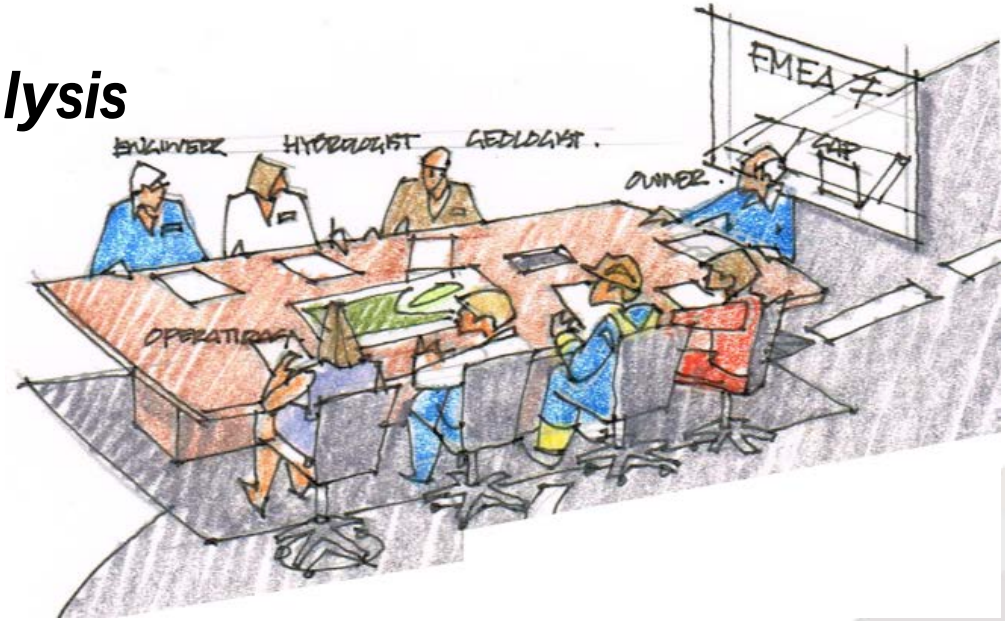
Project used the

Failure Modes and Effects Analysis (FMEA)

as a tool

to inform on, and communicate,

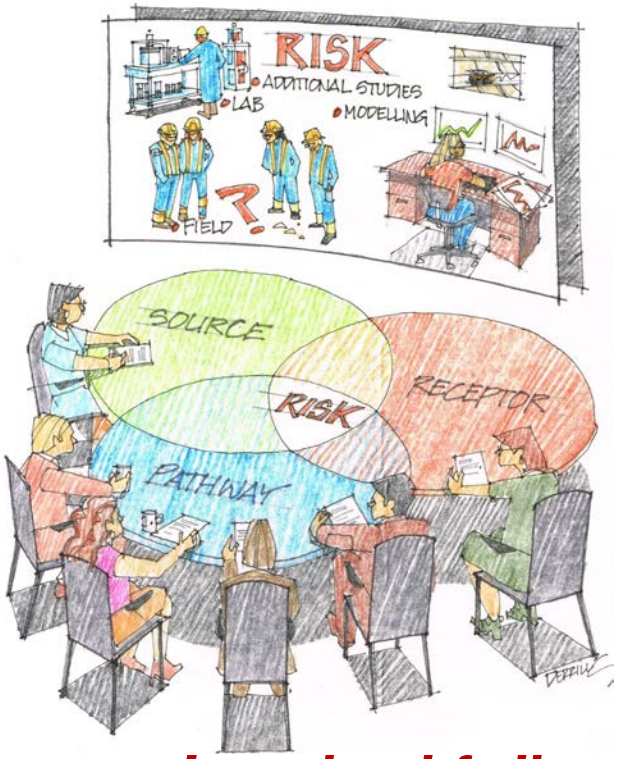
Incremental Benefit…



…Alternative to Alternative

Framework for Communicating Risk

FMEA Evaluating Question:



*"... What conditions could lead to the **geochemical failure** of the applied MRS construction method, whereby "failure" refers to **inadequate** spatial extent of **suboxia** conditions and/or **increased treatment** requirements?..."*

Framework for Communicating Risk

FMEA Evaluating Timeframe:

Immediate-Term:

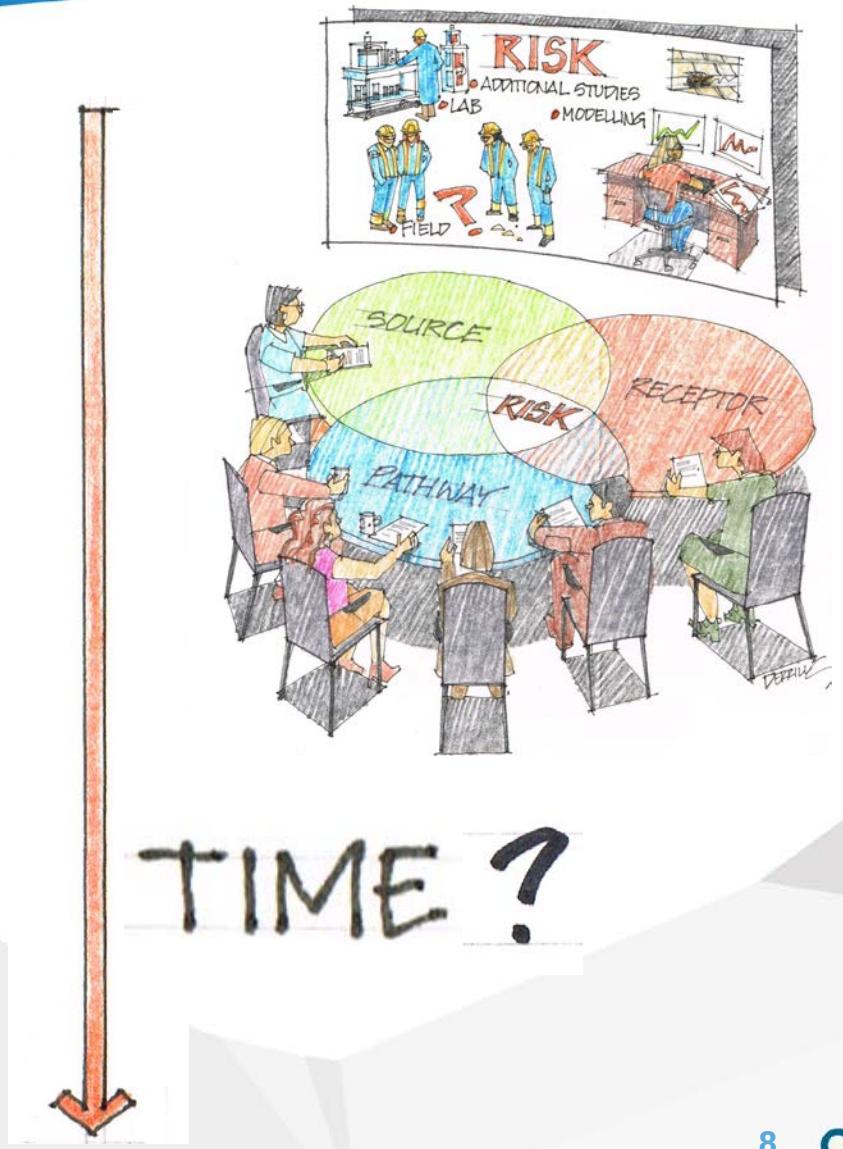
- *Permitting, planning, design, construction and the operation years (assumed **10 years** of rock placement)*

Short-Term:

- *Closure Period >10 years*

Long-Term:

- *Post-Closure Period >100 years*



Framework for Communicating Risk

FMEA
Evaluating Timeframe:

Failure Mode	Effects and Pathways	Likelihood	Consequence Category				Risk Ranking
			#1	#2	#3	#4	

We developed several (~20) 'high-level' Potential Failure Modes

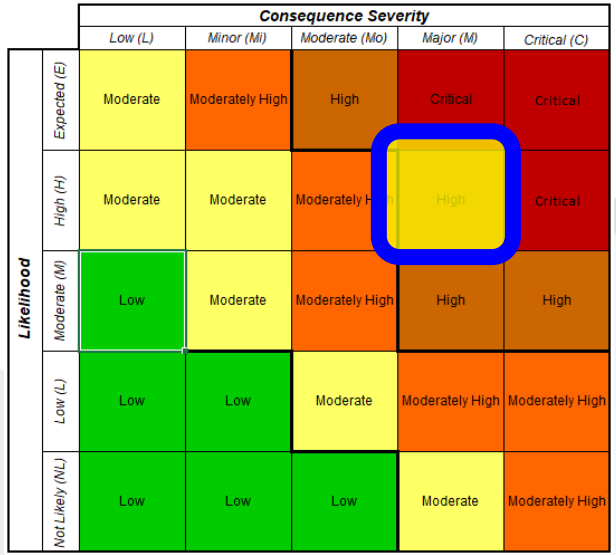
Likelihood	Consequence Severity: Low (L)	Minor (Mi)	Moderate (Mo)	Major (M)	Critical (C)
Expected (E)	Moderate	Moderately High	High	Critical	Critical
High (H)	Moderate	Moderate	Moderately High	High	Critical
Moderate (M)	Low	Moderate	Moderately High	High	High
Low (L)	Low	Low	Moderate	Moderately High	Moderately High
Not Likely (NL)	Low	Low	Low	Moderate	Moderately High

okane

Framework for Communicating Risk

FMEA
Evaluating Timeframe:

	Failure Mode	Effects and Pathways	Likelihood	Consequence Category				Risk Ranking
				#1	#2	#3	#4	
I-T	FM #1	EP #1-1	High	Minor	Major	Low	Low	High



Framework for Communicating Risk

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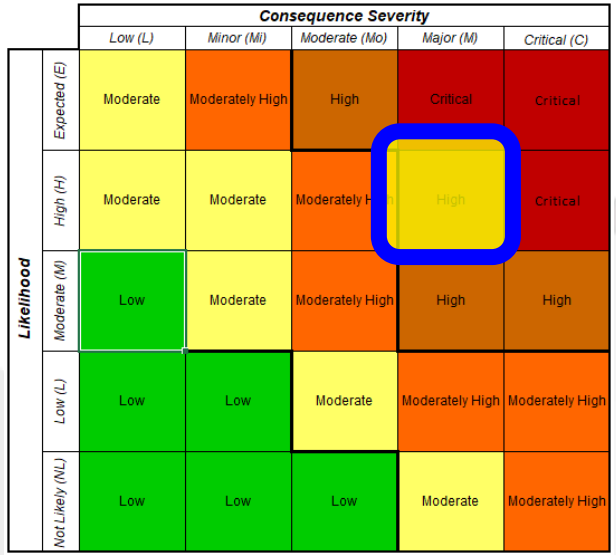
	Failure Mode	Effects and Pathways	Likelihood	Consequence Category				Risk Ranking
				#1	#2	#3	#4	
I-T	FM #1	EP #1-1	High	Minor	Major	Low	Low	High
S-T	FM #1	EP #1-1	Mod	Minor	Mod	Low	Low	Mod-High
L-T	FM #1	EP #1-1	Low	Minor	Mod	Low	Low	Medium

Example, for:

Immediate-Term to Short-Term

- *Application of an Alternative MRS Methodology*



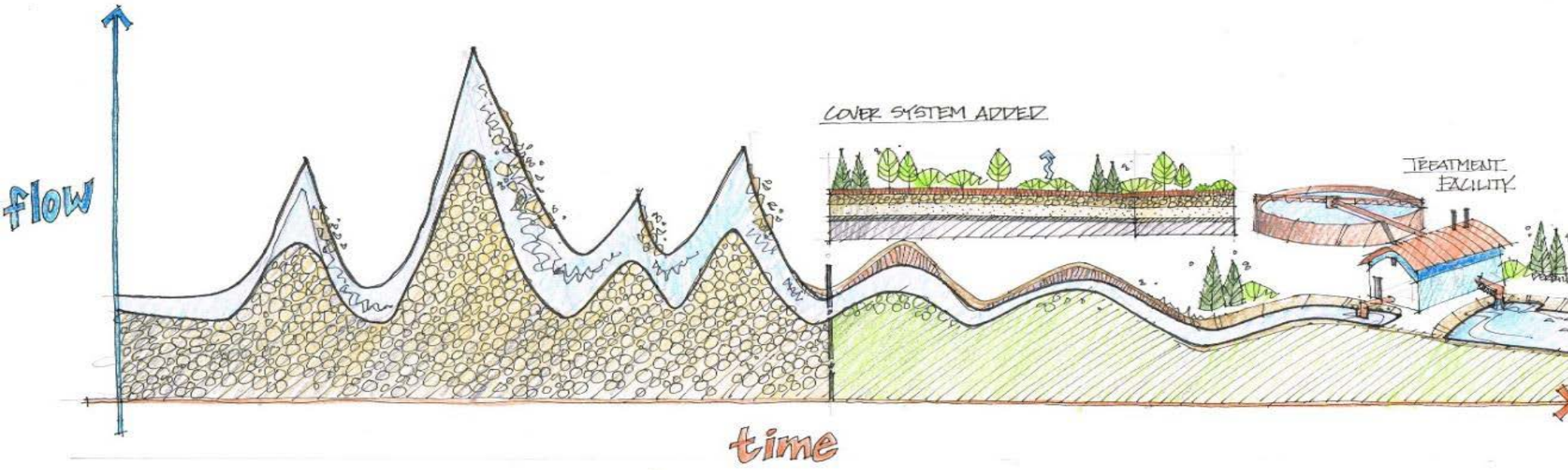
O'Kane et al, 2019: Improving MRS Construction Methods
BC MEND ML/ARD Annual Workshop
December 4, 2019

ML/ARD: …Focus on Mine Rock Stockpiles?

- ***Over the wide range of climate conditions possible…***
- ***Mine Rock Stockpiles (MRSs) typically contribute 75%, or more, of the acidity load at mine site, and***

ML/ARD: …Focus on Mine Rock Stockpiles?

- ***Over the wide range of climate conditions possible…***
- ***Mine Rock Stockpiles (MRSs) typically contribute 75%, or more, of the acidity load at mine site, and…***
- ***The mining industry typically manage this risk…***



Improved MRS Construction Methods

- ***Six "Improved" Construction Methods Identified for Assessment***
  - *Four (4) "geotechnically-focused" methods*
  - *Two (2) "geochemically-focused" methods (geochemical engineering)*
- ***Geotechnically-Focused Methods:***

  Manage Vertical and/or Lateral Gas Transport Capacity

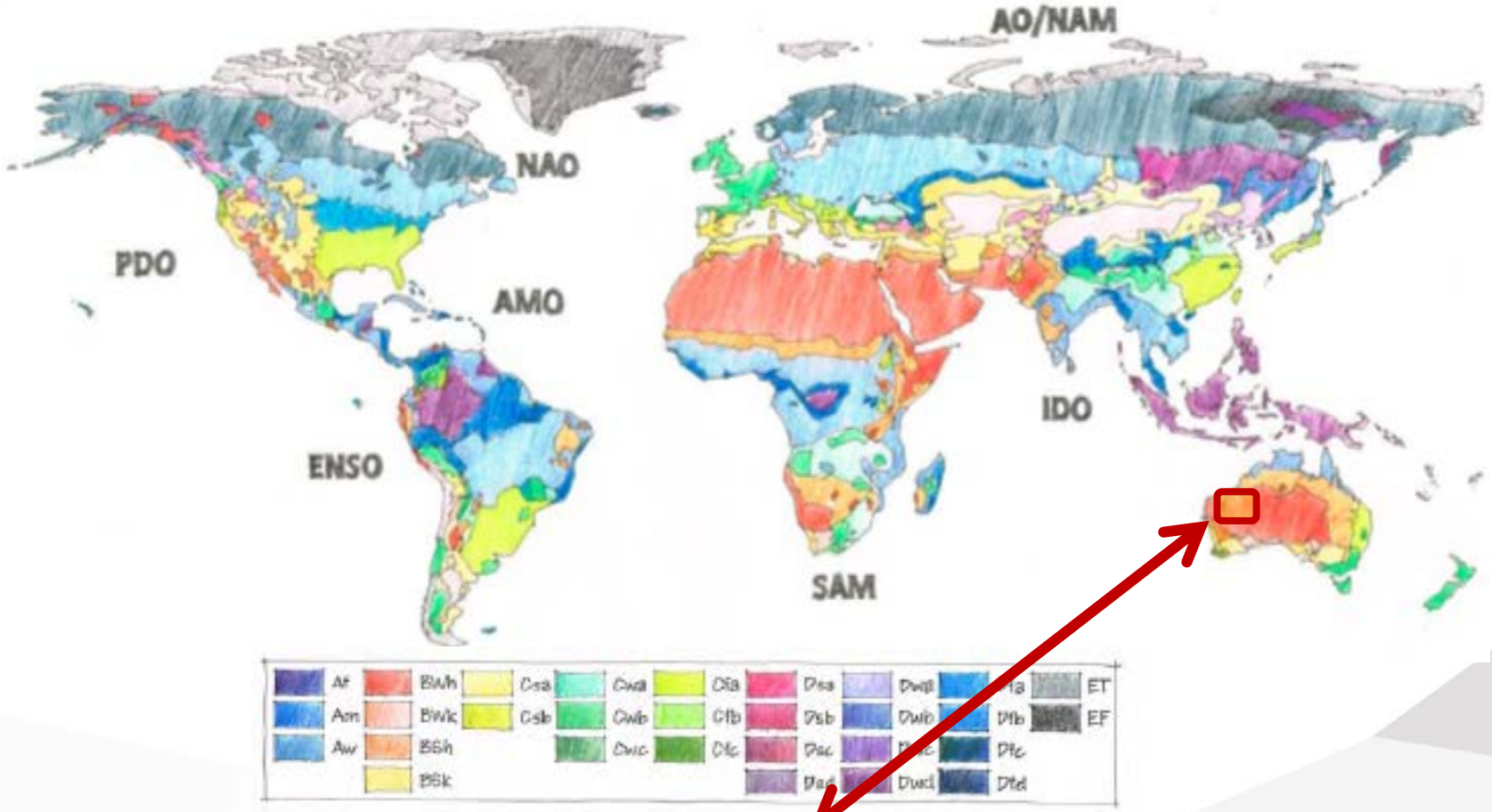
- ***Geochemically-focused methods:***
  1. *Oxygen consuming materials*
  2. *Sulfide passivation*

Additional (evolving) methods also identified in report

Case Study…
Vertical Gas Management

Mining and Storage of Reactive Shale at BHPBilliton's Mt Whaleback Mine

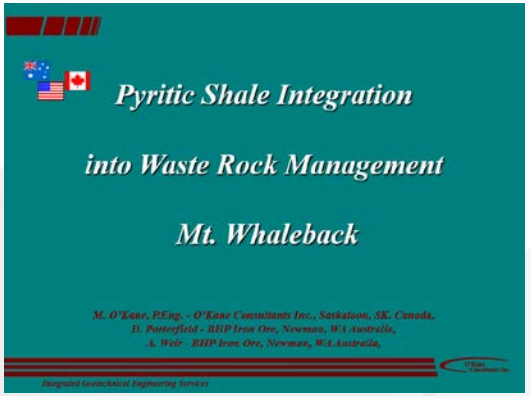
P Waters[1] and M O'Kane[2]

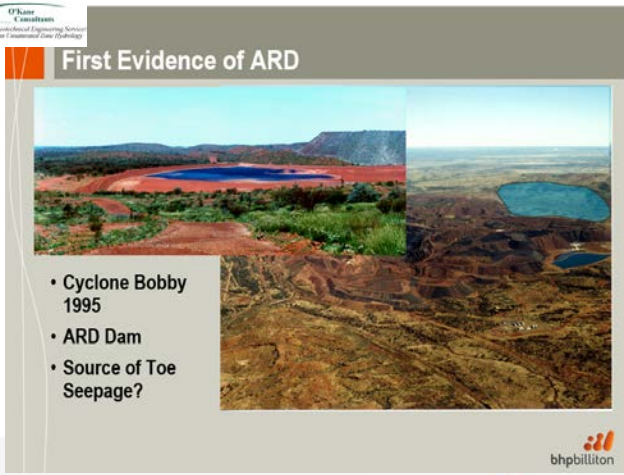


- ***Köppen-Geiger Climate Classification***
  - ***Bwh – Hot Desert***

Case Study…
Vertical Gas Management

- ***Open Pit – Highly reactive pyritic / carbonaceous shale***





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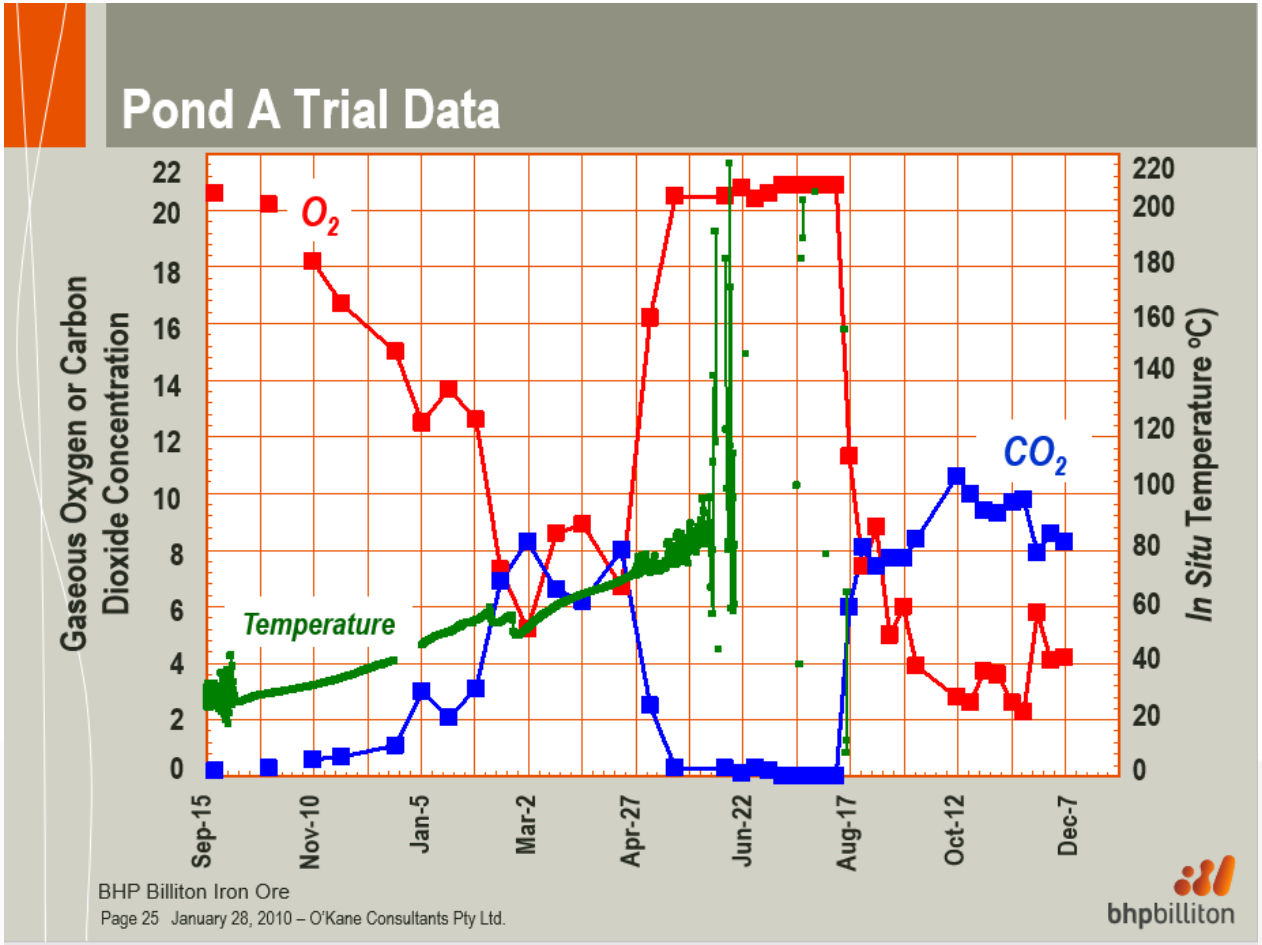

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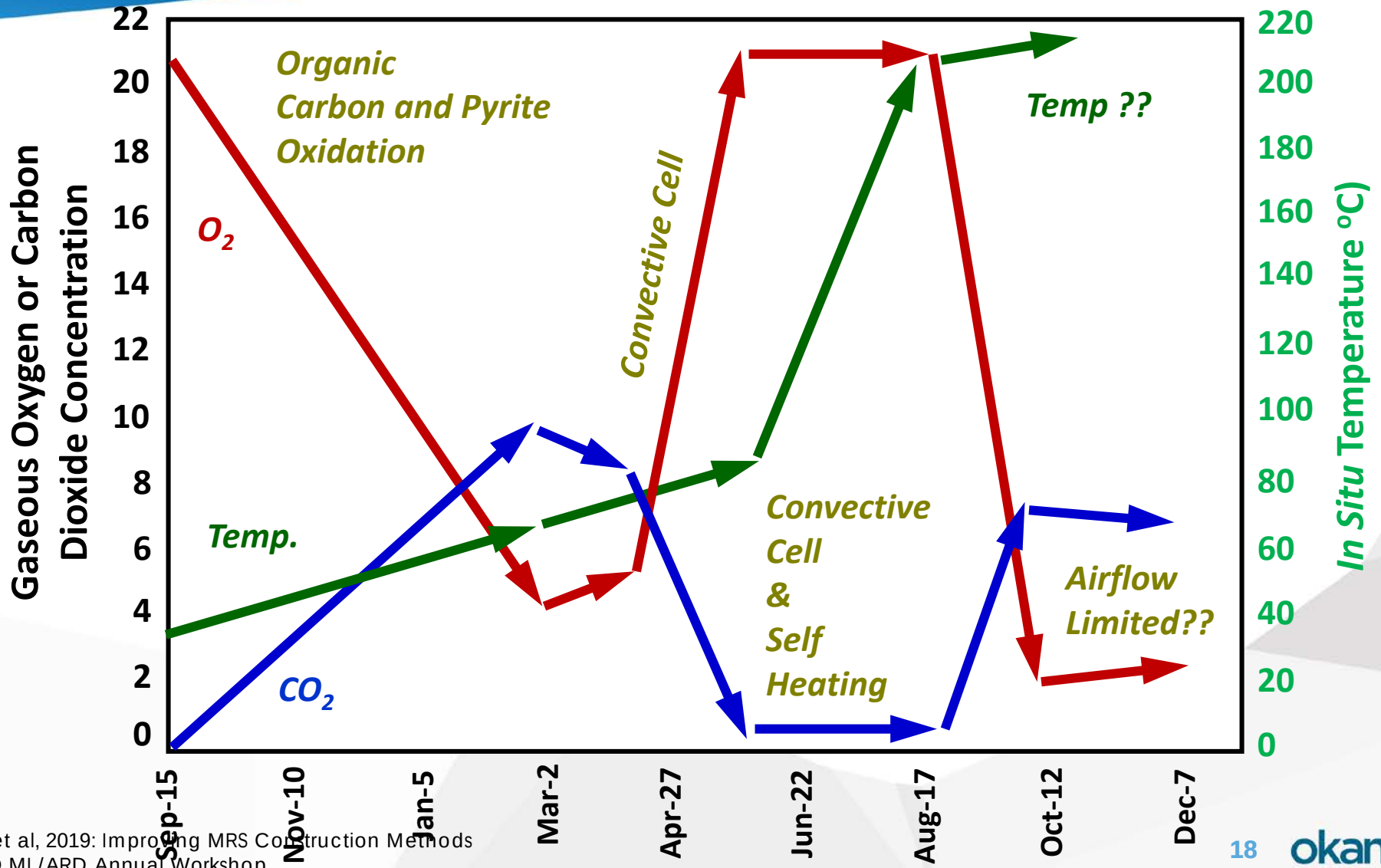

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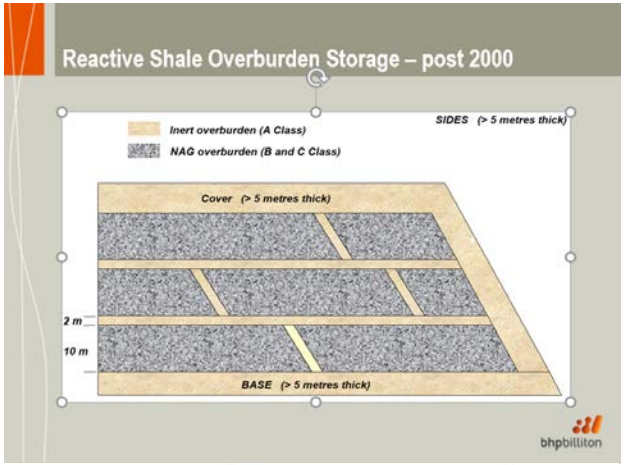
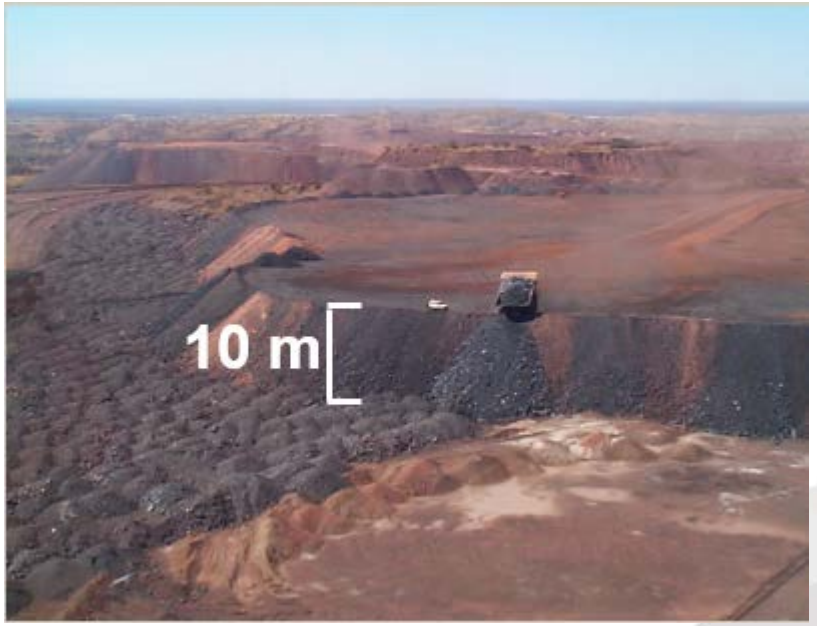
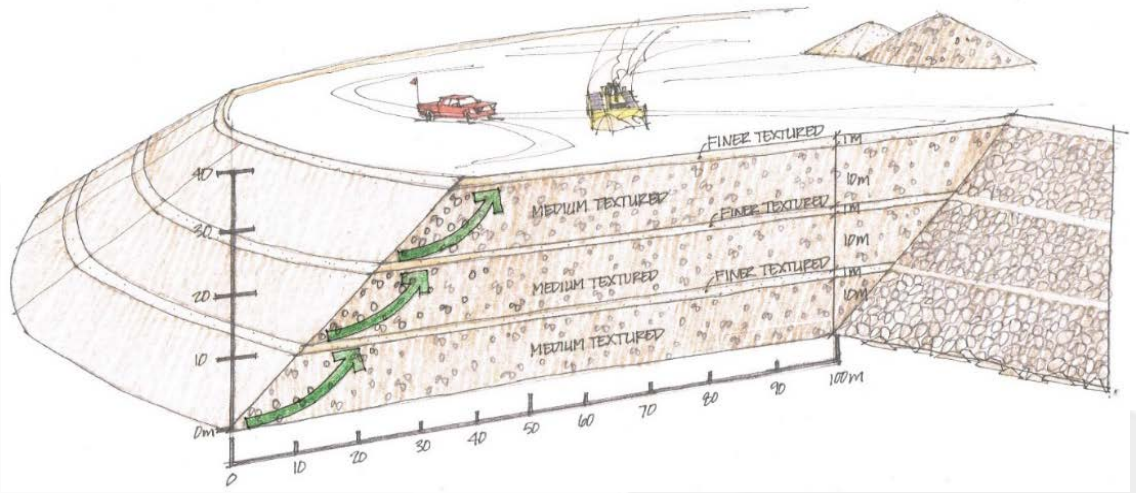
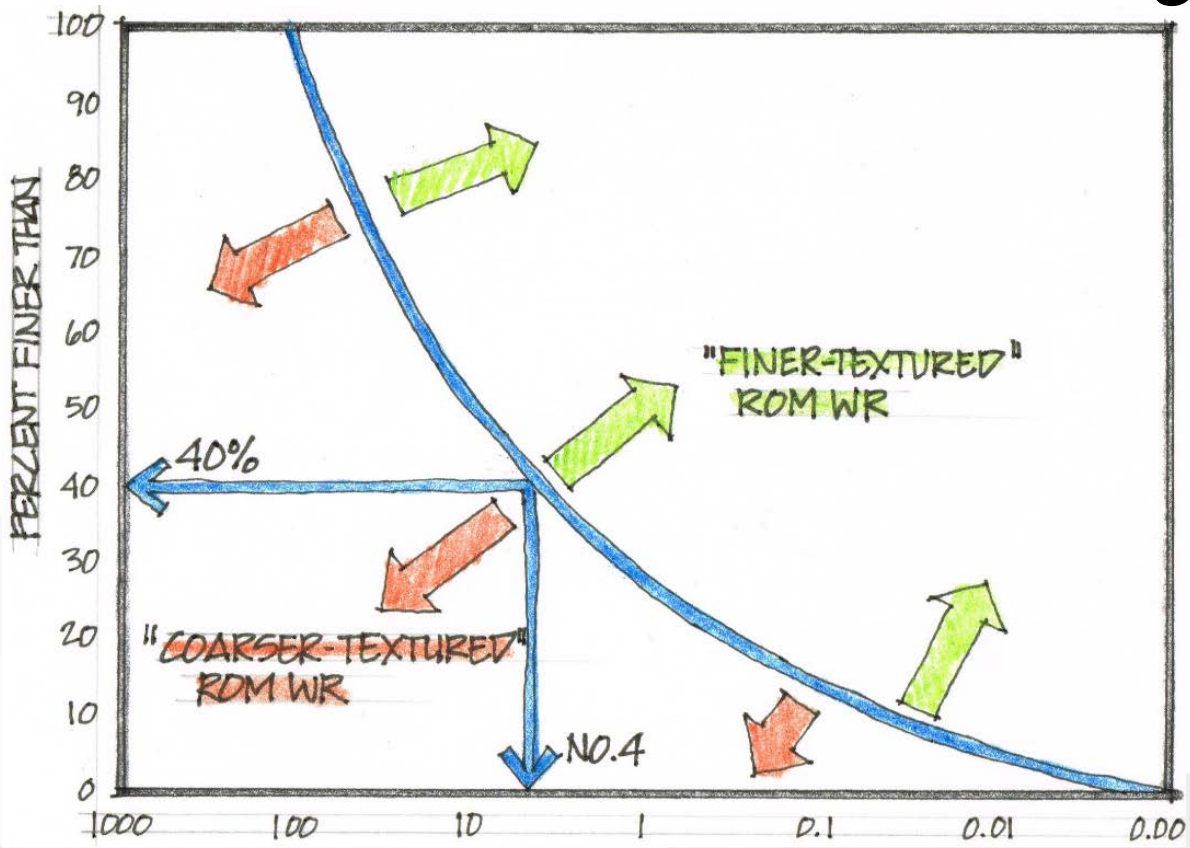






Finer- and Coarser-Textured Mine Rock

- ***Conceptualization… Finer-Textured Mine Rock***
  vs.
  Coarser-Textured Mine Rock



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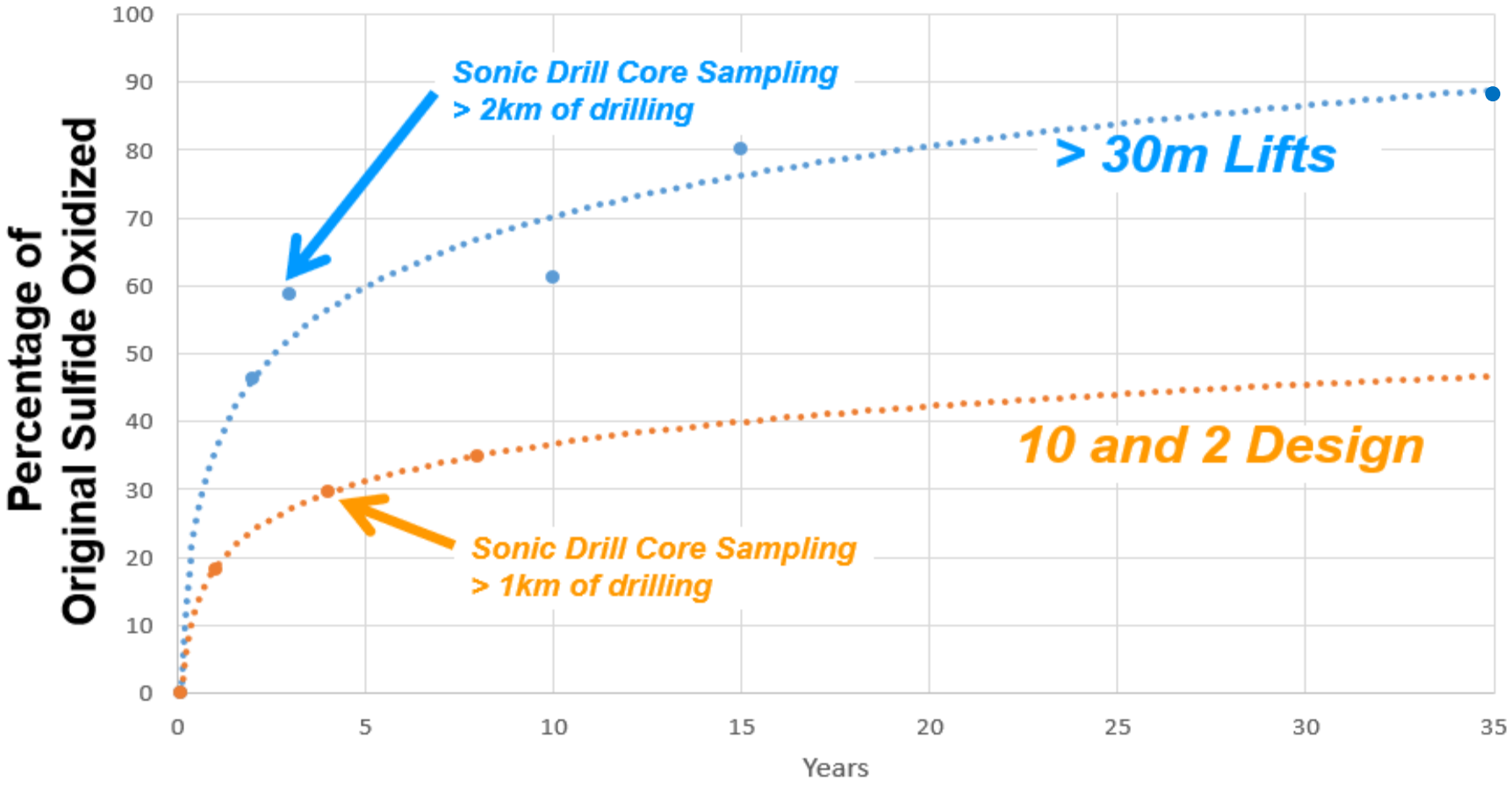
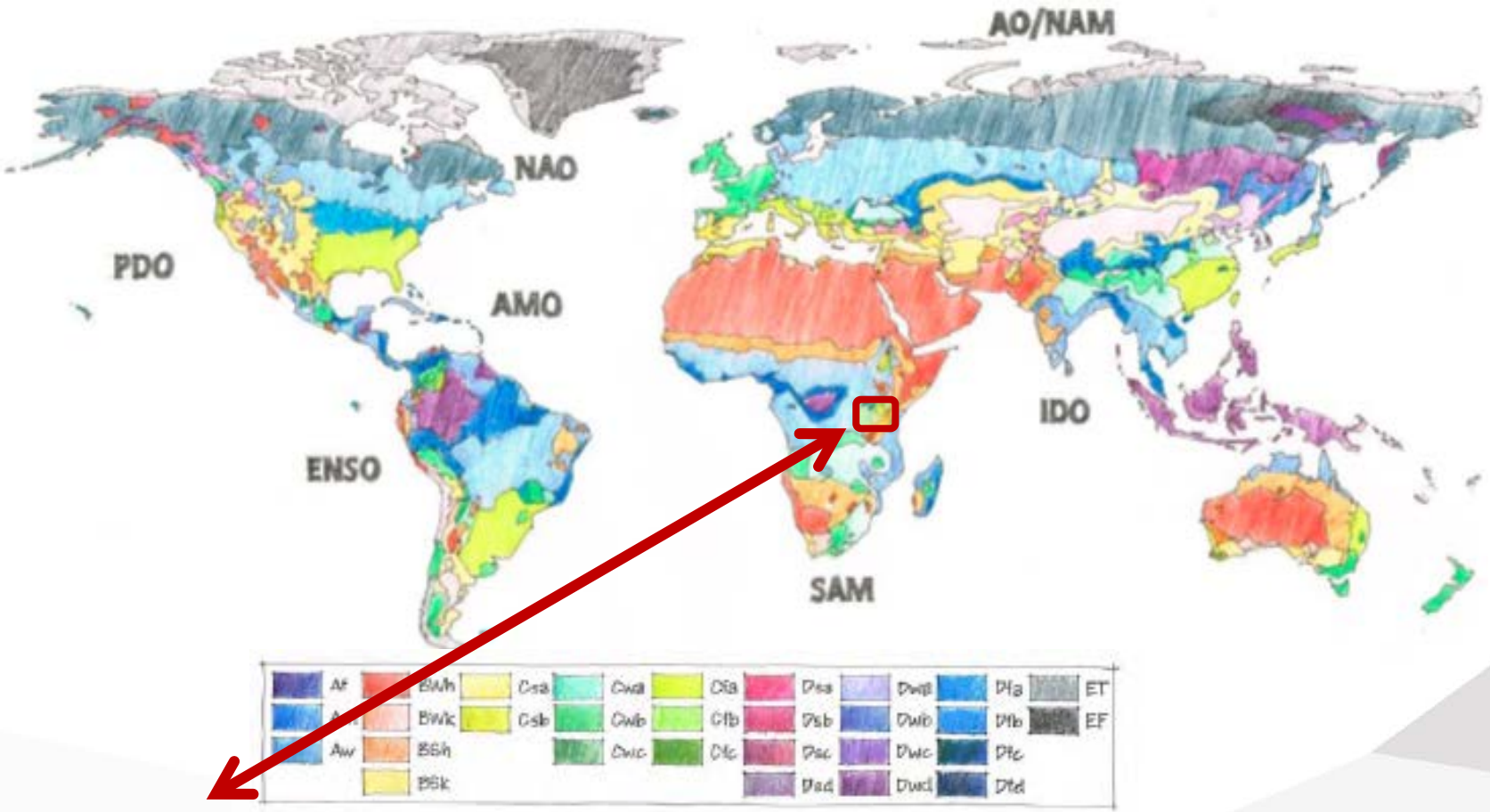


Case Study… ‘True’ Encapsulation

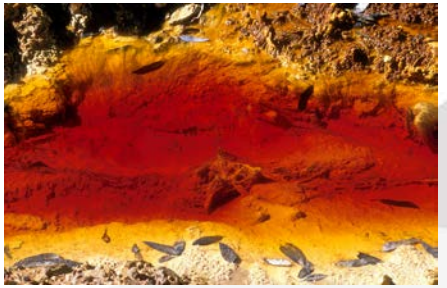


- ***Köppen-Geiger Climate Classification***
  - ***Aw/As – Tropical Savannah***

Case Study… ‘True’ Encapsulation

- ***Mine Rock…***
  - ***S% ave. ~ 3%***
  - ***~40% PAF (PAG)***
- ***We should observe…***
  - ***“Typical ML-ARD”***

…. but we don’t



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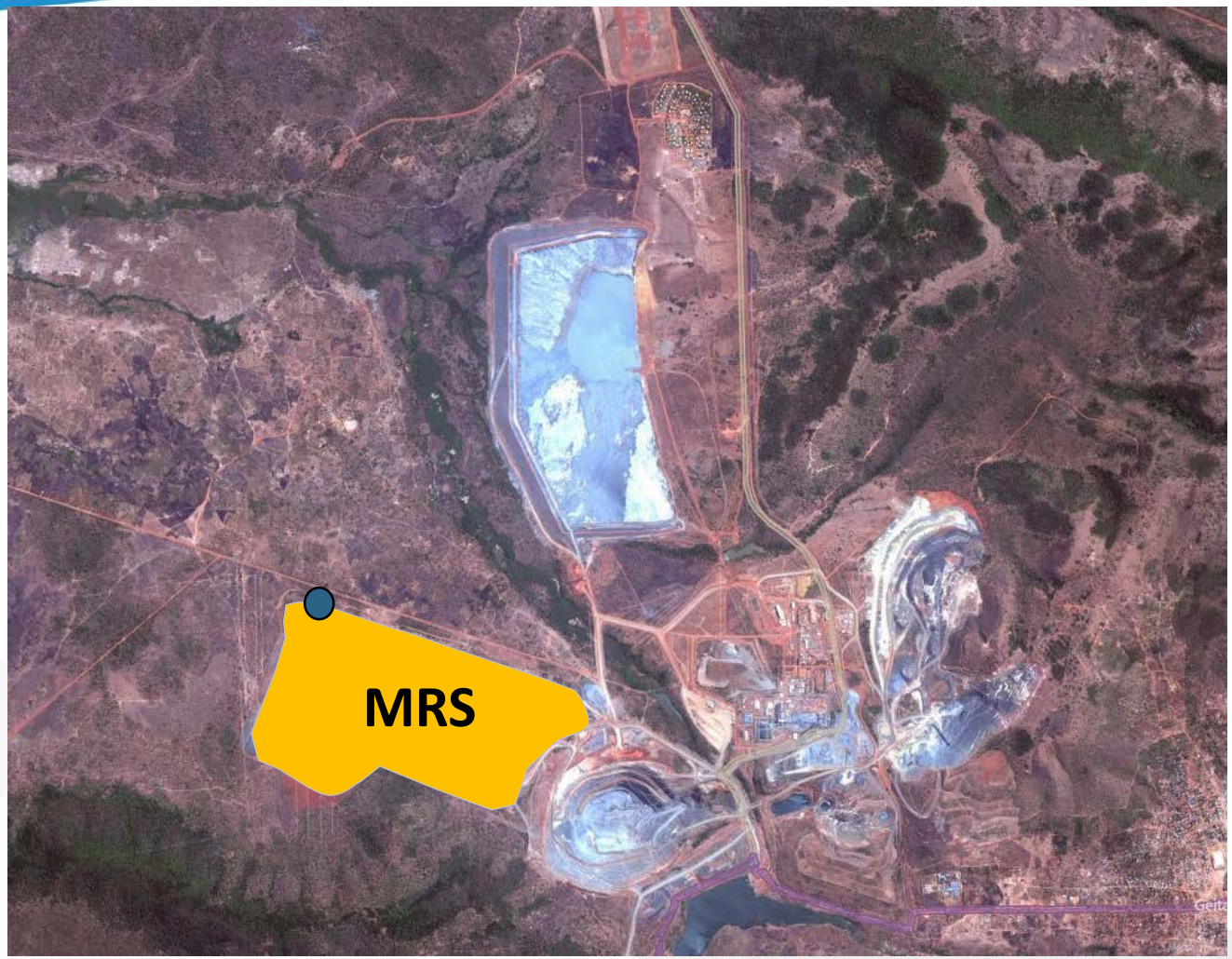


- ***Why Not…?***
  - ***For a ~100m high x 1km wide x 2km long MRS…***
  - ***After > 10 years … only one seep with water quality issues of any significance (SO_4 only)***

Case Study… ‘True’ Encapsulation

- ***Why Not…?***
  - ***Oxygen availability during rock placement***
  - ***Acidity generation is <u>not</u> “defined” by “all sulfides” oxidizing***

Case Study… 'True' Encapsulation

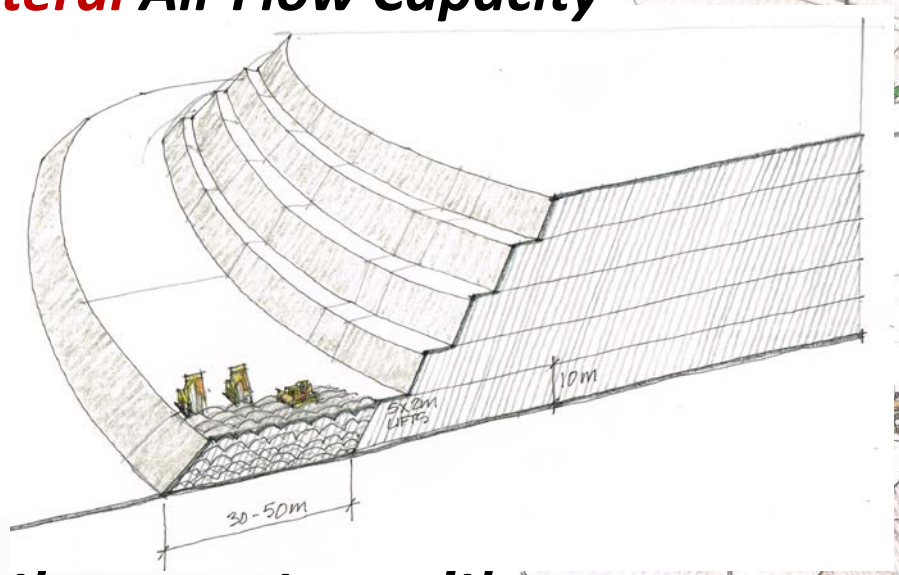
- ***Why Not…?***
  - ***Oxygen availability during rock placement***
  - ***Acidity generation is not "defined" by "all sulfides" oxidizing***
  - ***~0.3m clay layer for truck tire damage***
  - ***Limits Vertical Advective Gas Transport Capacity***

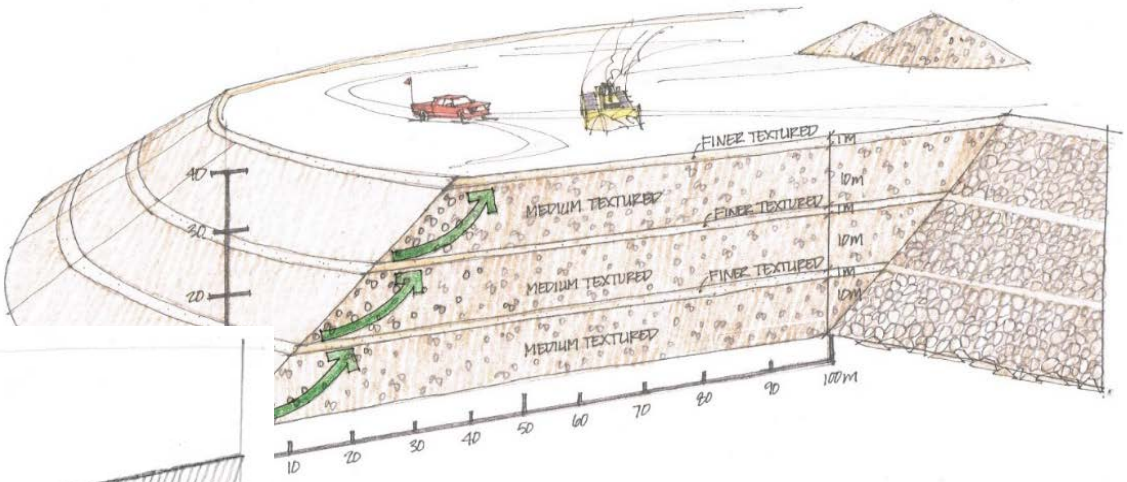
Case Study… 'True' Encapsulation

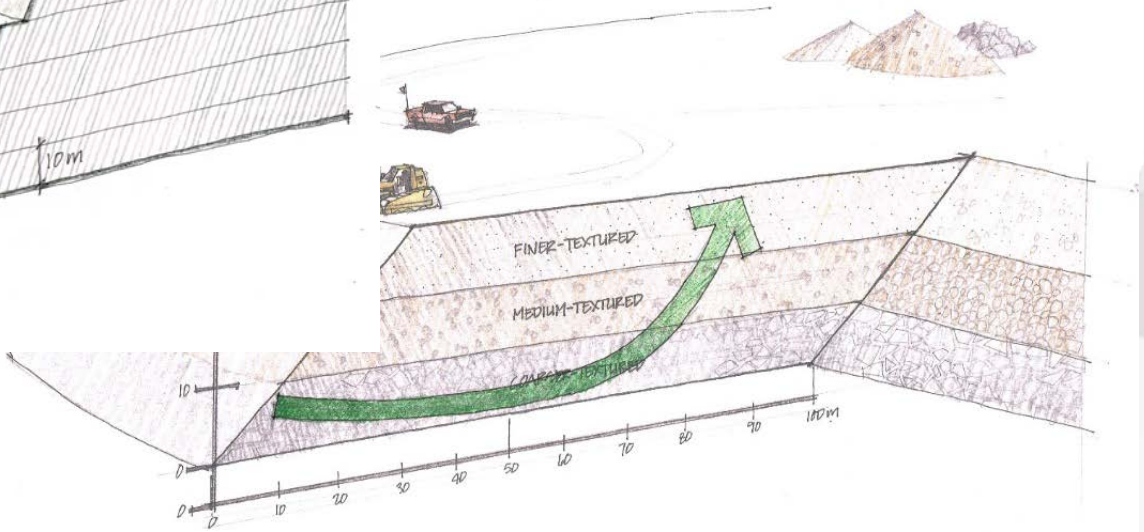
- ***Why Not…?***
  - ***Oxygen availability during rock placement***
  - ***Acidity generation is not "defined" by "all sulfides" oxidizing***
  - ***~0.3m clay layer for truck tire damage***
  - ***Limits Vertical Advective Gas Transport Capacity***
  - ***Base up, thin lift***
  - ***Limits Lateral Advective Gas Transport***

Case Study… ‘True’ Encapsulation

- ***A system was created with***
  Low Vertical Air Flow Capacity
  and
- ***Low Lateral Air Flow Capacity***



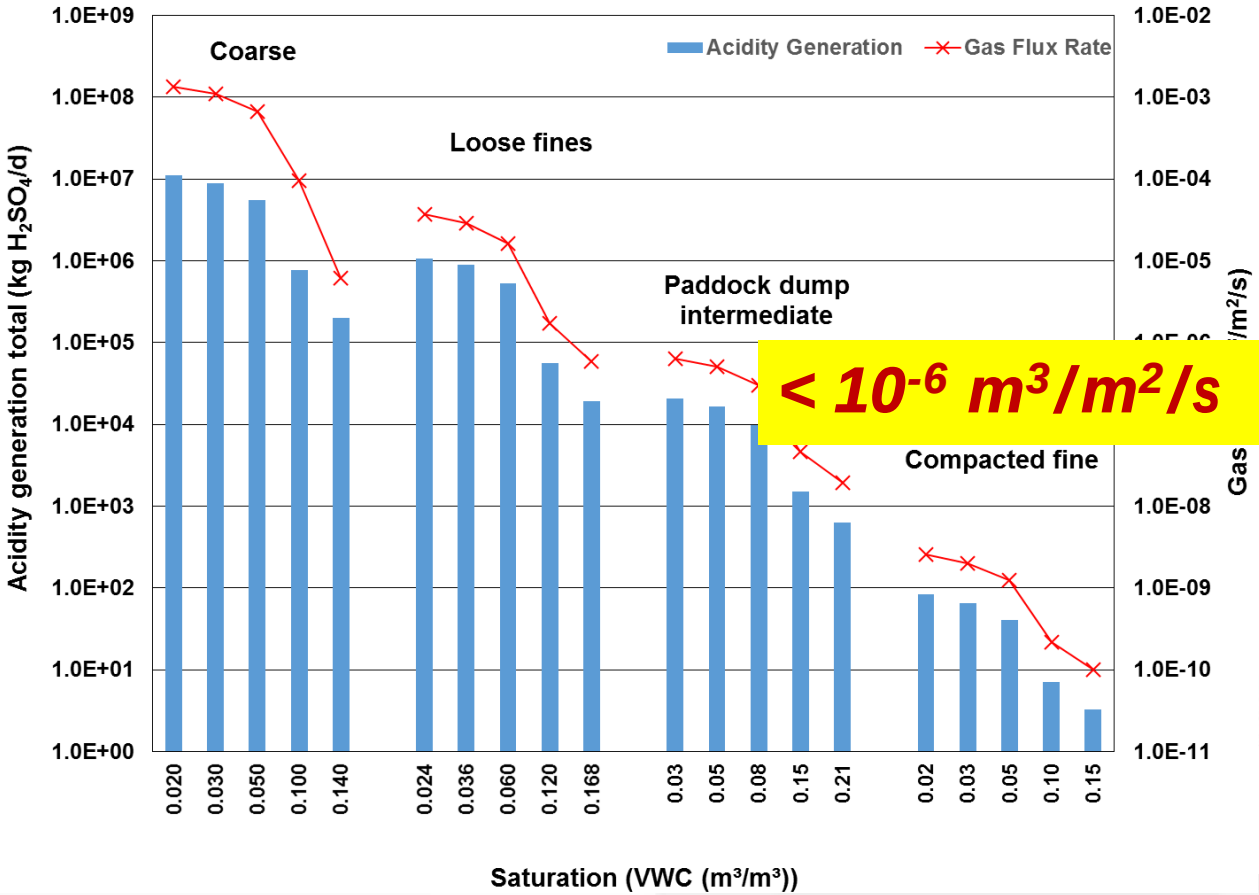




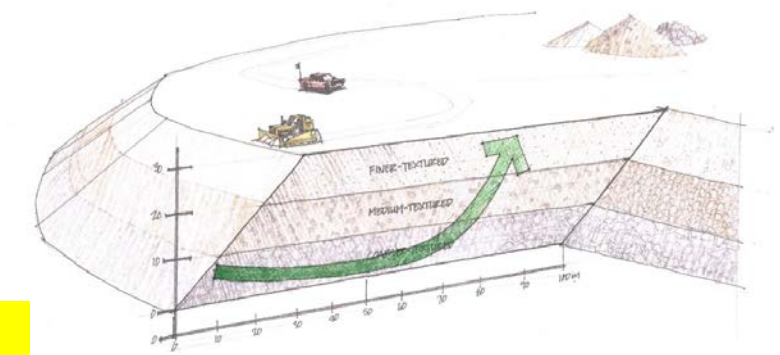
- ***Rather than a system with***
  High Air Flow Capacity

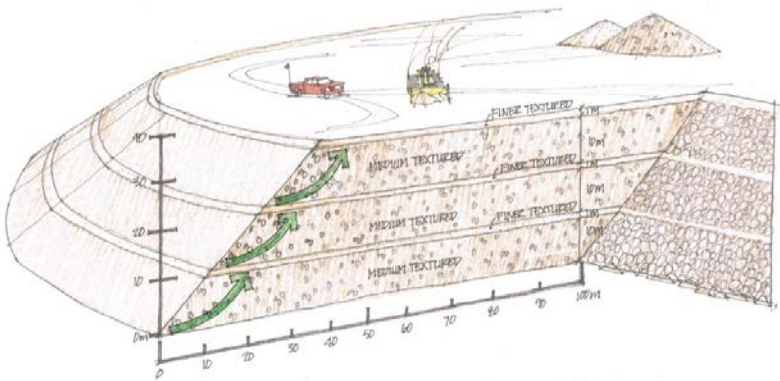
Case Study… 'True' Encapsulation

- ***Conceptual / Numerical… Low vs. High Gas Transport Capacity***

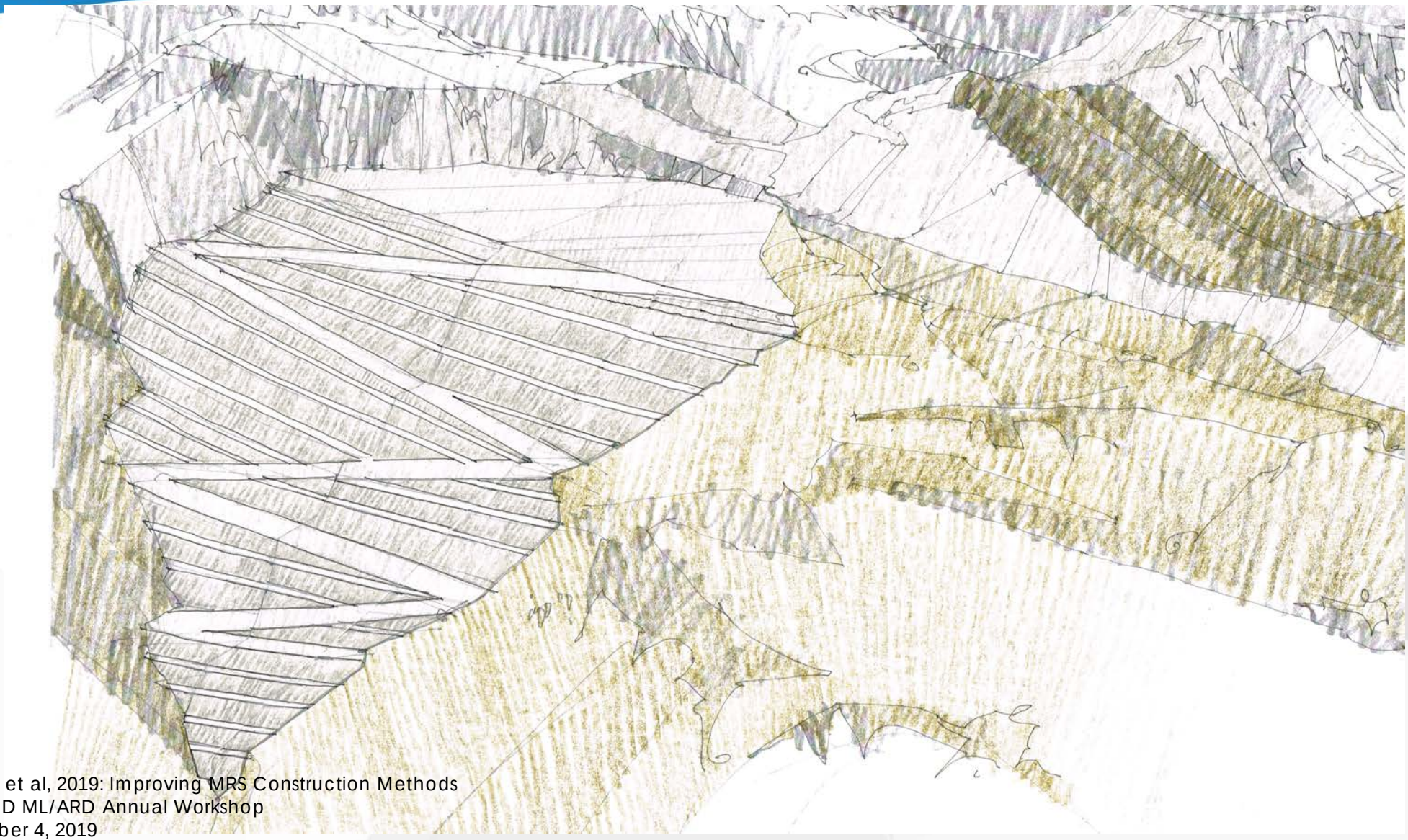


$< 10^{-6}$ $m^3/m^2/s$



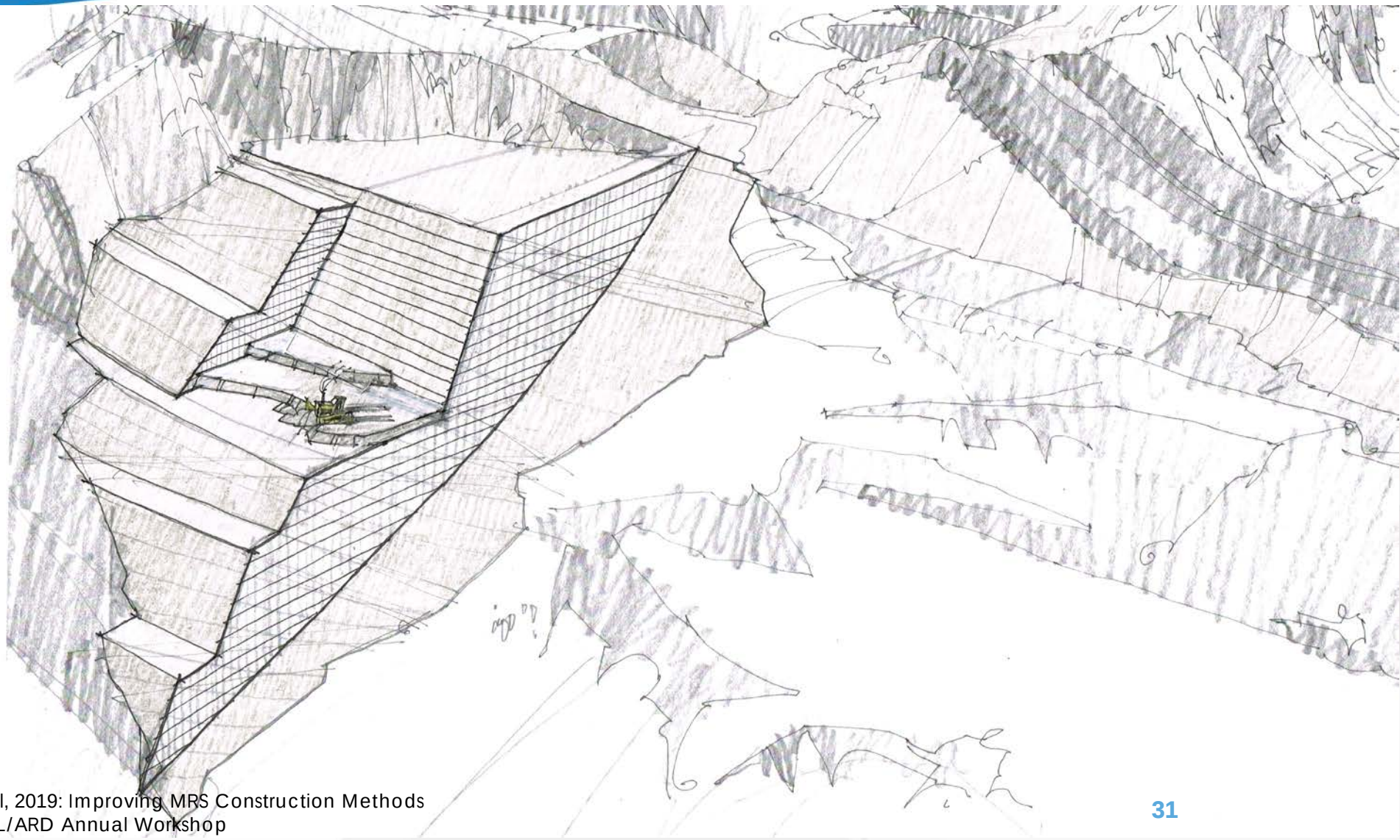


Let's Evaluate a Valley Fill MRS...



Let's Evaluate a Valley Fill MRS...

"Moderately Reactive Mine Rock Material"



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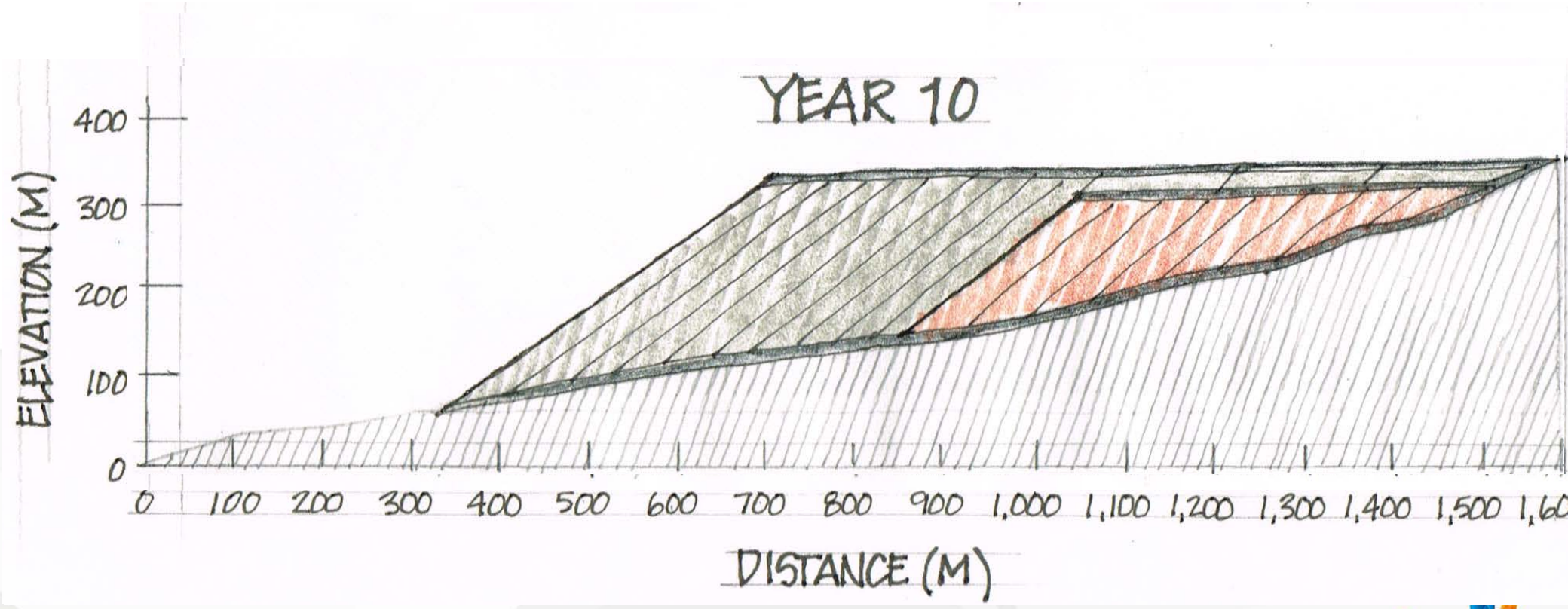
"Moderately Reactive Mine Rock Material"

Two Approaches

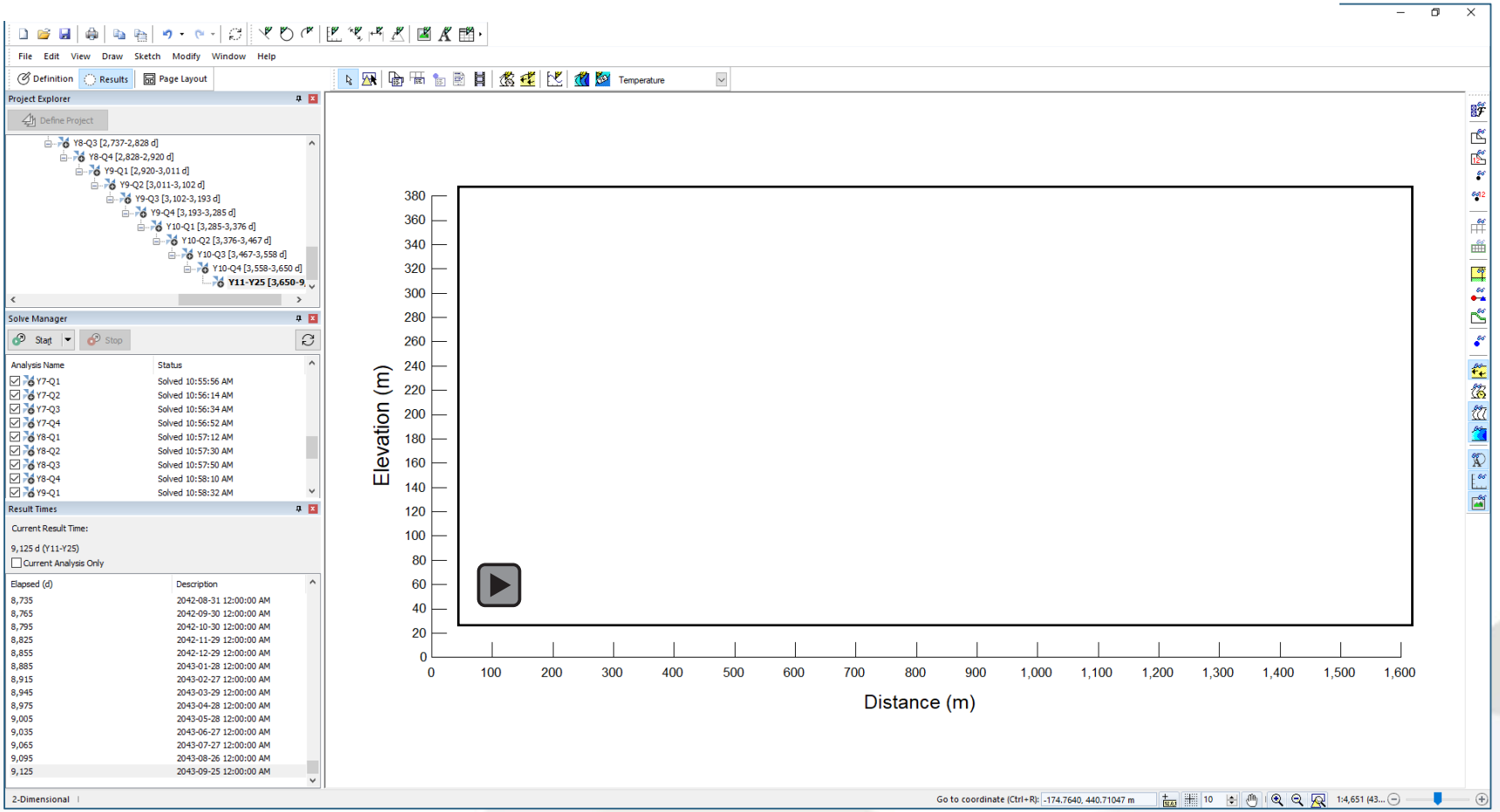
1. "Conventional"… Ridgeline End-Dumping 'high tip-head'



Let's Evaluate a Valley Fill MRS…

"Conventional"… Ridgeline End-Dumping 'high tip-head'

- ***Advective and Diffusive Air Flow – Coupling of Water, Heat, Gas***

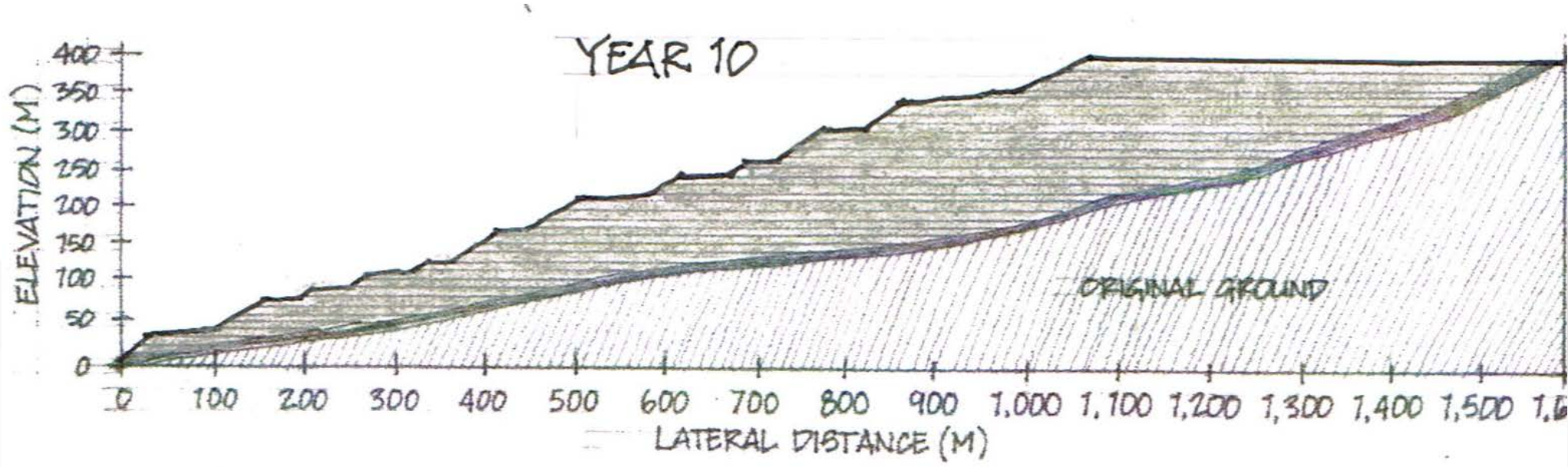


Let's Evaluate a Valley Fill MRS…

"Moderately Reactive Mine Rock Material"

Two Approaches

1. ***"Conventional"… Ridgeline End-Dumping 'high tip-head'***
2. ***"Alternative"… Bottom Up End-Dumping 'short tip-head'***



Let's Evaluate a Valley Fill MRS

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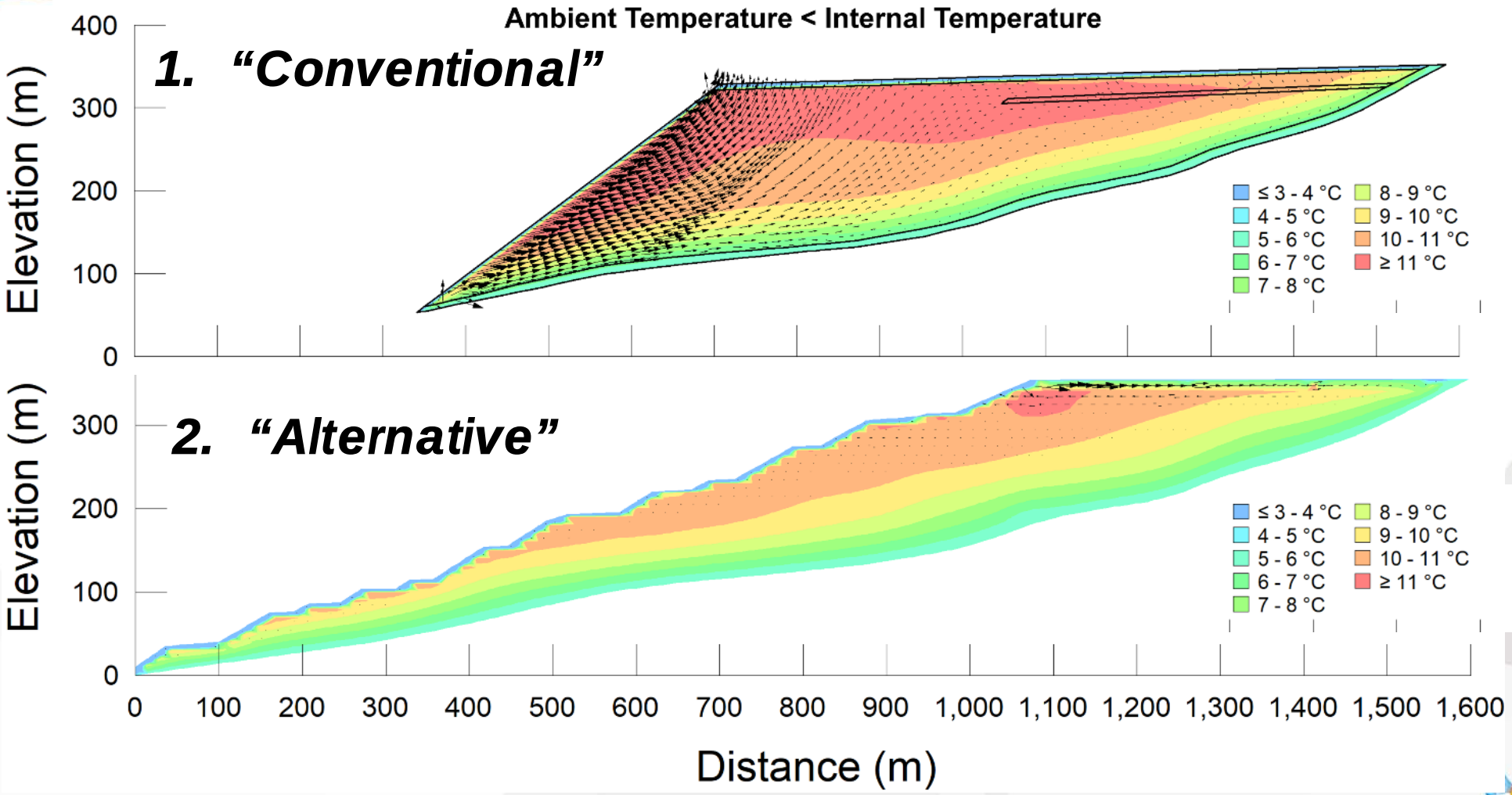

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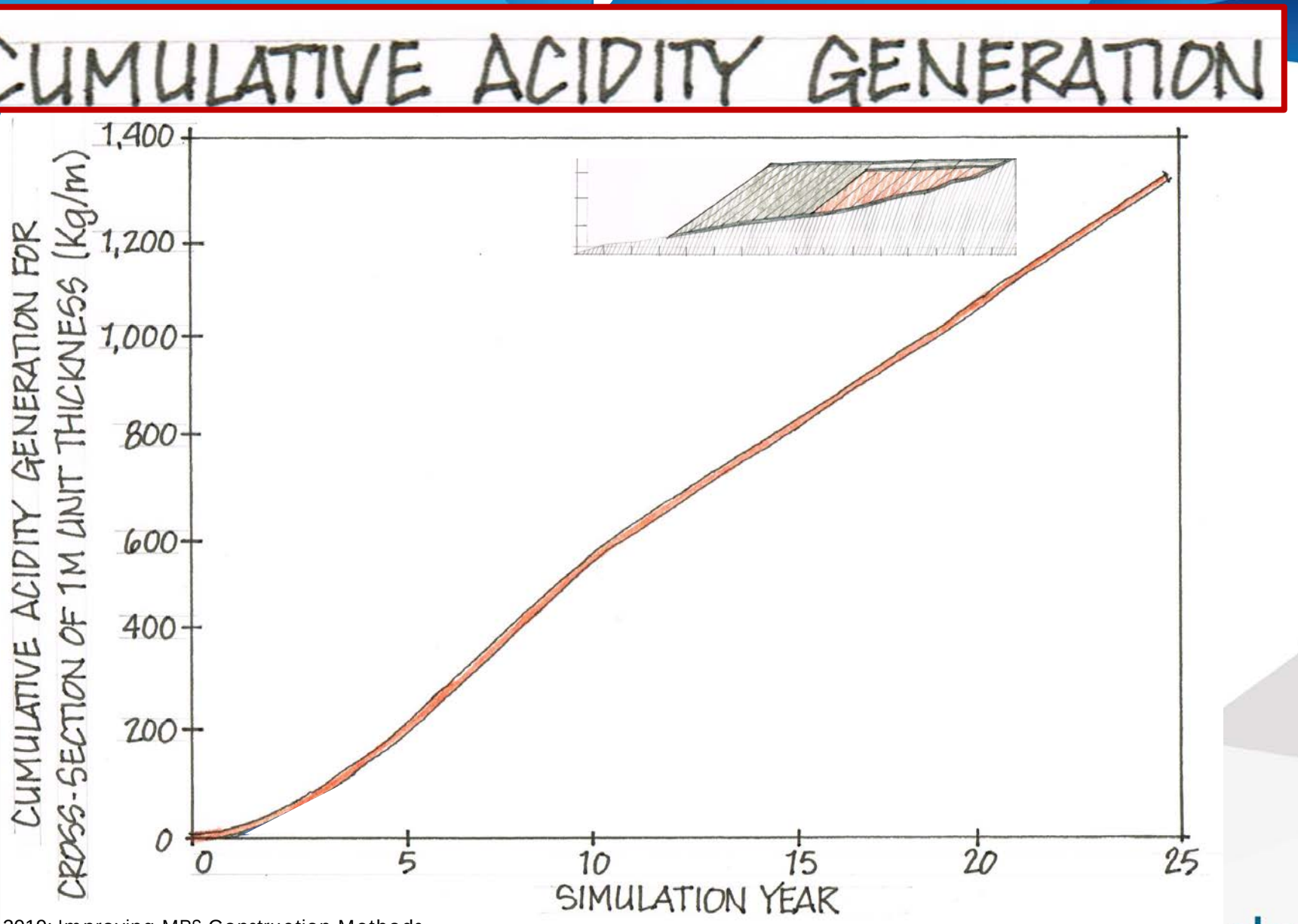

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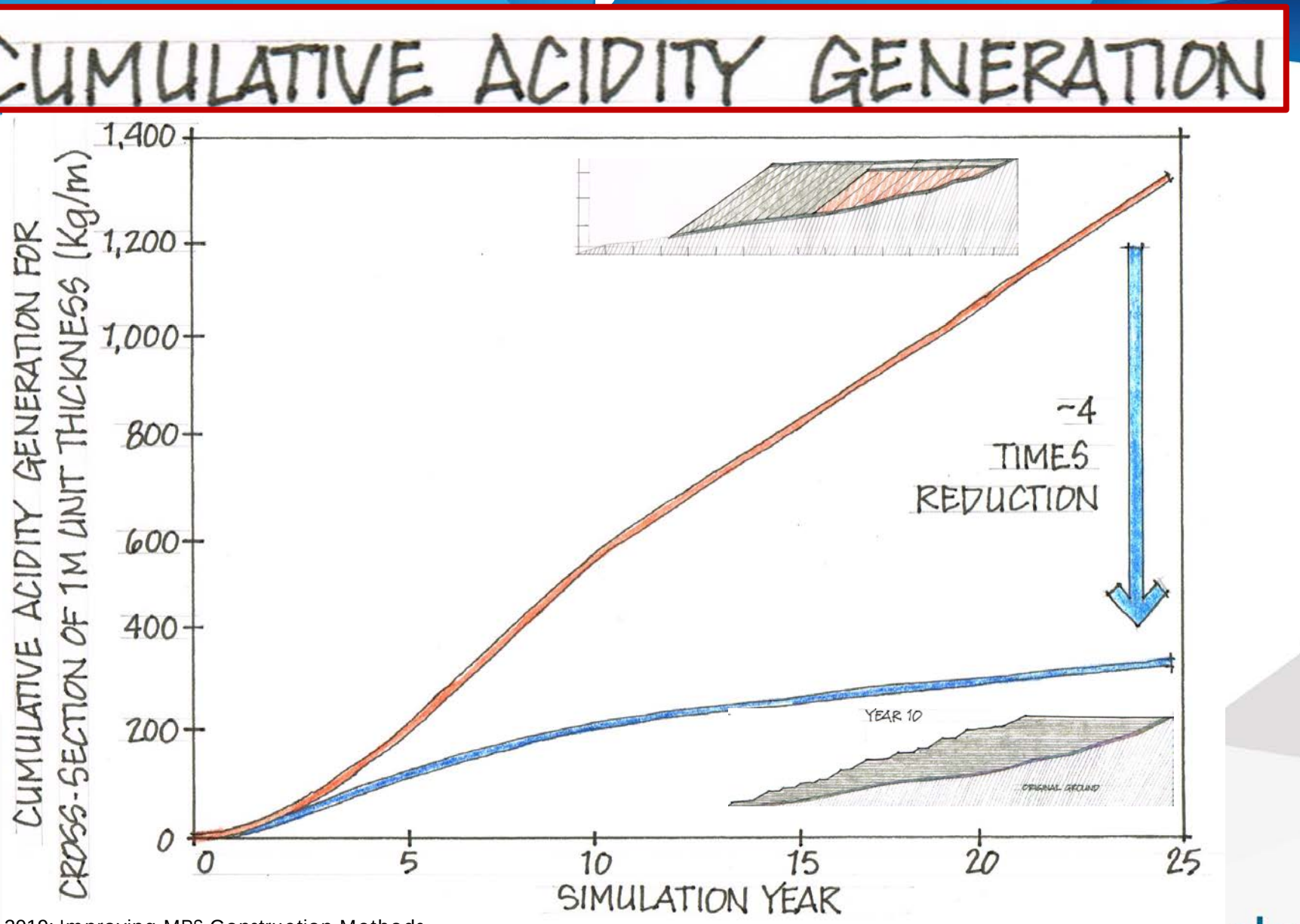

Session Discussion Themes?

- *Project Timeline*
- *Project Scope (within 9 tasks)*
  1. *Framework for Communicating Risk*
  2. *ML-ARD…*
     Why Focus on Mine Rock Stockpiles?
  3. *Conceptualization / Evaluation of:*
     - *Conventional MRS Performance*
     - *Alternative MRS Construction Approaches*
  4. ***Communicating Opportunity using Risk-Based Approach Supported by…***
     - *Literature Review and Case Studies*
     - *Semi-Quantitative Assessment thermal / gas / water, and acidity generation modelling*
- *Opportunities*

Communicating Risk and Opportunity

Failure Mode ID	Failure Mode Description	Timeframe	Likelihood	Consequences						Level of Confidence	Highest Risk Rating
				Environment Effects		Consequence Cost		Regulatory Approval			
12	MRS design does not meet performance expectations due to inadequate (i.e., not enough) static geochemical characterization and therefore AMD risk classification in mine block model, leading to the Question	Immediate-Term	H	Mi	M	Mi	M	Mi	M	M	M
12		Short-Term	H	Mi	M	Mo	H	Mi	M	M	H
12		Long-Term	VH	Mi	M	C	VH	Mi	M	H	VH

- Unexpectedly high amounts of PAF would increase acidity generation (high likelihood)
- Environmental effects are assumed to be minor because we will treat the water
- Requirement of water treatment incurs higher consequence cost
  - Long-term: Catastrophic consequence cost due to treatment in perpetuity and construction of additional treatment plants (> $100 M)
- High confidence – there are many sites in this situation
- Very high risk rating – a key driver for this project

Communicating Risk and Opportunity

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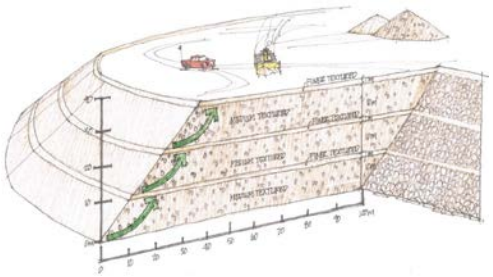
12		Long-Term	L	Mi	L	Mo	M	Mi	L	L	M

- Even if there is more PAF material than expected, the construction methods result in ~80% of the MRS remaining suboxic (no re-supply of oxygen)
- The likelihood of the failure mode causing 'the question' is decreased
- I-T: Potential need for water treatment because suboxia does not occur immediately
- Short- and Long-Term: Suboxia established; the risk of the failure mode can be mitigated
- Low confidence in risk ranking – Generational Change; we require more full-scale data from Purposeful MRS construction
- Moderate risk rating – decreased from a 'Very high' risk rating

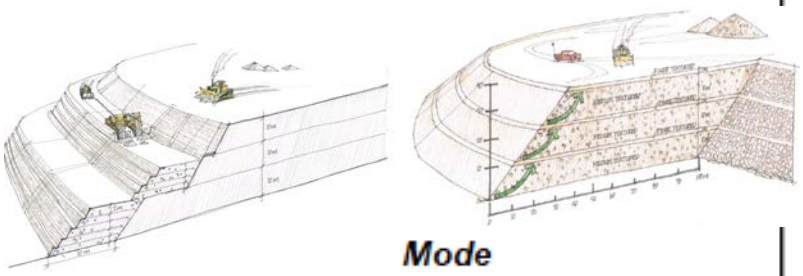
Communicating Risk and Opportunity

Failure Mode ID	Failure Mode Description	Timeframe	Likelihood	Consequences						Level of Confidence	Highest Risk Rating
				Environment Effects		Consequence Cost		Regulatory Approval			
16	 Engineered layers at top of lifts to manage vertical gas transport do not meet performance expectations due to insufficient material availability, leading to the Question	Immediate-Term	M	Mi	M	Mo	M	Mi	M	M	M
16		Short-Term	M	Mi	M	Mo	M	Mi	M	M	M
16		Long-Term	M	Mi	M	Ma	H	Mo	M	M	H

- Engineered layers are a key facet to controlling air flow capacity; site-specific designs are required
- There is a risk of increased costs if the material on site cannot meet performance expectations
- Costs include making the material on site, shipping material to site, or treating water
- Can the other improved MRS construction methods mitigate these risks?

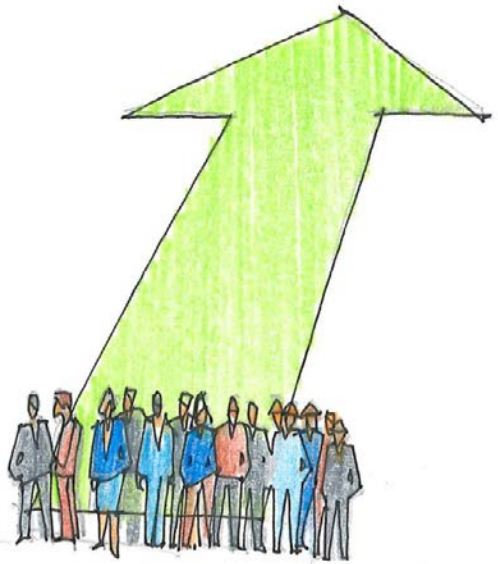
Communicating Risk and Opportunity

Failure Mode ID	Mode Description	Timeframe	Likelihood	Consequences						Level of Confidence	Highest Risk Rating
				Environment Effects		Consequence Cost		Regulatory Approval			
16	Engineered layers at top of lifts to manage vertical gas transport do not meet performance expectations due to insufficient material availability, leading to the Question	Immediate-Term	L	Mi	L	Mo	M	Mi	L	M	M
16		Short-Term	L	Mi	L	Mo	M	Mi	L	M	M
16		Long-Term	L	Mi	L	Mo	M	Mi	L	M	M



- **Adding 'true' encapsulation (lateral gas transport),** oxygen consuming layers, and sulfide passivation
  - Strategic placement of NAF material around PAF material
  - Placement of alkalinity released materials of top of MRS
- If there was insufficient material for the engineered layers, it is unlikely that water treatment needs would increase
- The risks are further mitigated by the presence of additional construction methods

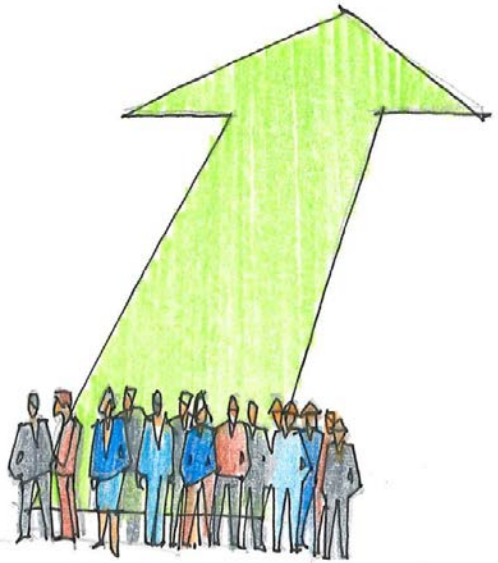
Session Discussion Themes?

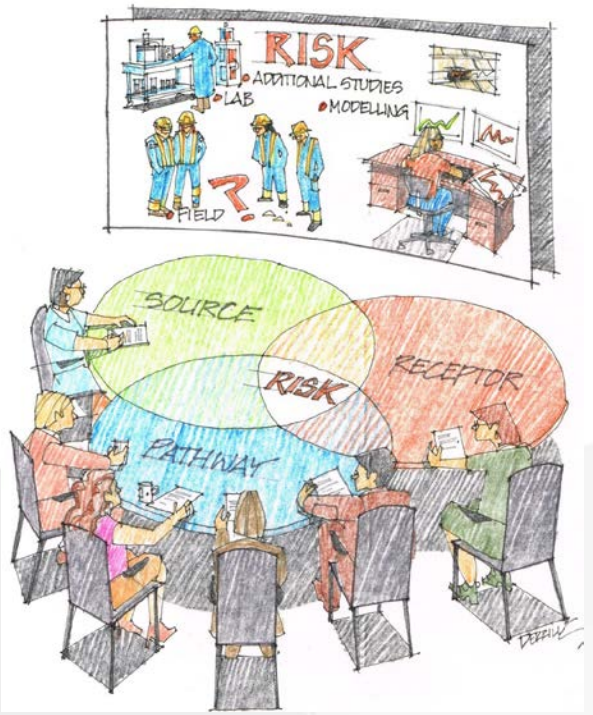


- ***Project Timeline***
- ***Project Scope (within 9 tasks)***
  1. ***Framework for Communicating Risk***
  2. ***ML-ARD… Why Focus on Mine Rock Stockpiles?***
  3. ***Conceptualization / Evaluation of:***
     - *Conventional MRS Performance*
     - *Alternative MRS Construction Approaches*
  4. ***Communicating Opportunity using Risk-Based Approach Supported by…***
     - *Literature Review and Case Studies*
     - *Semi-Quantitative Assessment thermal / gas / water, and acidity generation modelling*
- ***Opportunities***

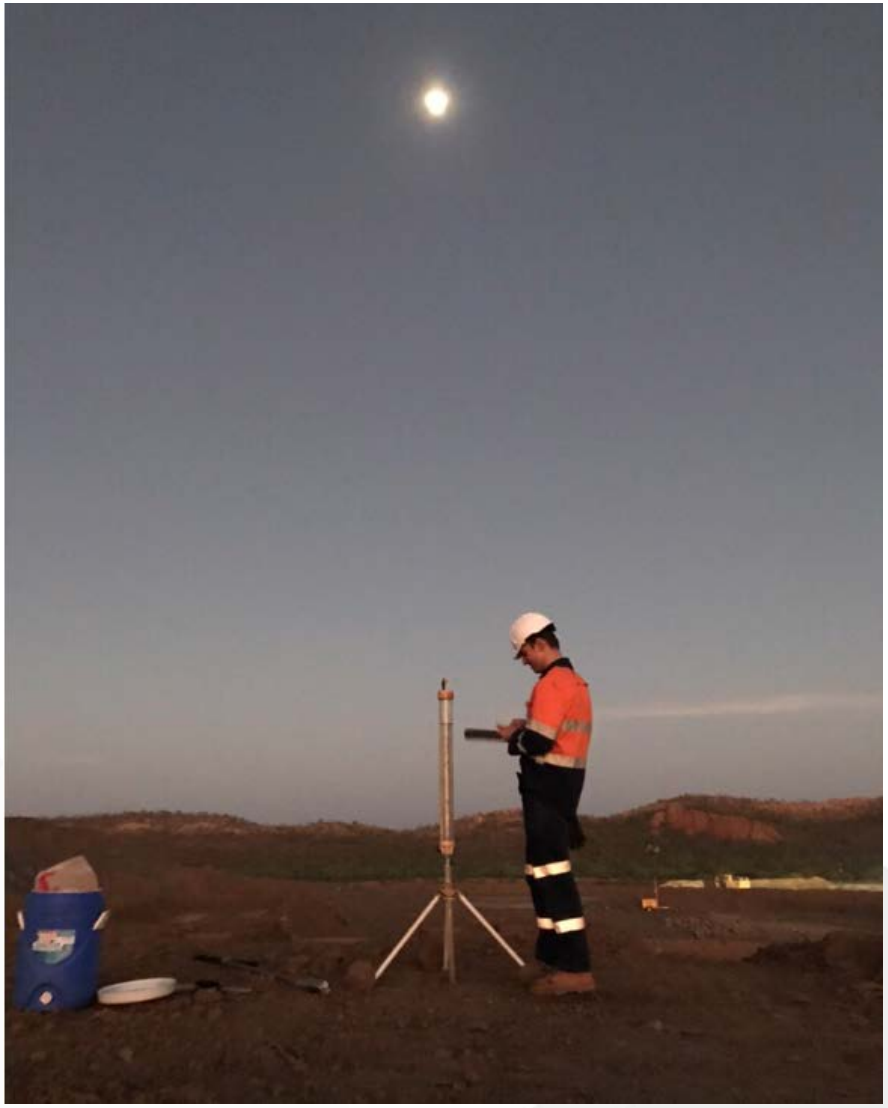
Opportunities

- ***Incorporating Mine-Life-Cycle costing into Life of Mine Planning***
- ***Evaluating existing MRSs***
- ***Field-Scale Evaluations***
  - *Setting Expectations… Spatial and Temporal Influences!*





Thank You!



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Let's Evaluate a Valley Fill MRS…

"Alternative"… Bottom Up End-Dumping 'short tip-head'

Spoil Pile Oxidation – Convective Air Flow - Coupling of Water, Heat, Gas