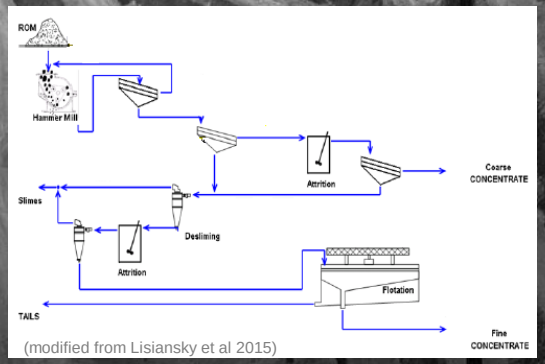
CRU Phosphates 2017

Optimising processing costs through the assessment of geological and mining cut-off grades



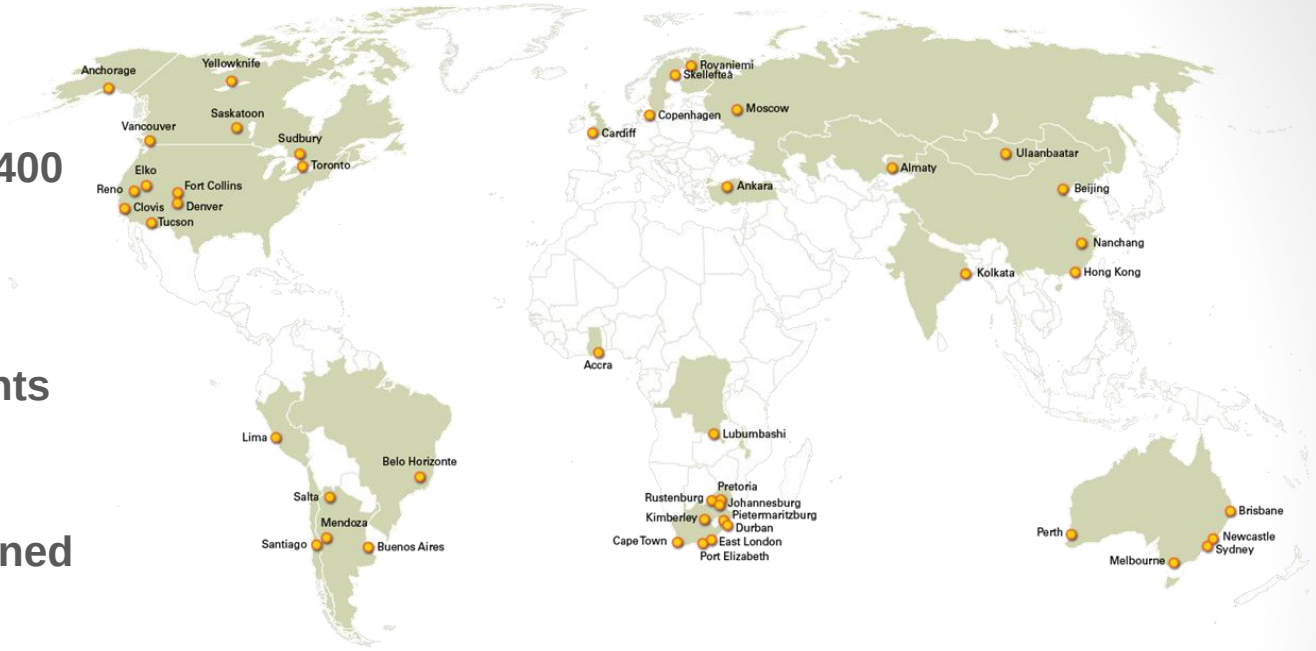
(modified from Lisiansky et al 2015)

Presenter: **Tim Lucks**
Anna Fardell, Fillip Orzechowski and Mark Campodonic

Location: CRU Phosphates 2017, Tampa, Florida ,USA

Strong Track record in the Phosphate Industry

- **Mining industry consultancy**
- **Established in 1974**
- **Globally employ over 1400 staff**
- **45 Offices,**
- **22 countries, 6 continents**
- **Multi-national Staff**
- **Independent - 100% owned by employees**



- Exploration, Geology and Mineral Resource
- Geotechnical Engineering,
- Mining and Mineral/Ore Reserves
- Mineral Processing
- Infrastructure and Logistics

- Water Management
- Tailings and Mine Waste Disposal
- Environmental and Social Impact Assessment
- Mine Closure Planning

Strong Track Record in the Phosphate Industry

Chaketma PFS
Inc. JORC Mineral Resource & Reserve estimates (in progress)

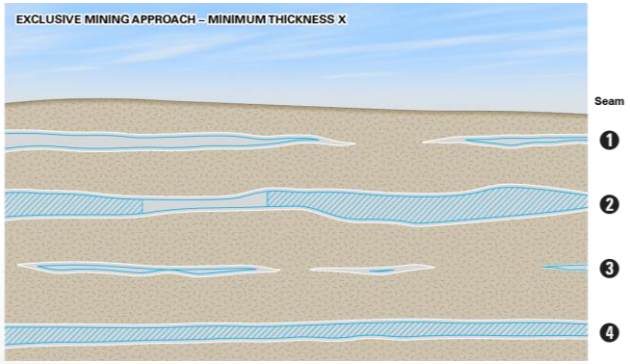
Hinda Phosphate DFS
Inc. JORC Mineral Reserve estimate

Wa'ad Al Shamal BFS
Inc. JORC Mineral Resource & Reserve estimates

Scoping, Pre-Feasibility & Feasibility Studies, ESIAs, Acquisition/Vendor Due Diligence, Independent Engineers Reports, CPRs , 43-101 Technical Reports, Mineral Asset Valuations

Introduction

- Processing cost is typically highly dependent on the RoM feed grade
- The cut-off grade for the geological model and mining studies are often selected at an early stage in the Project (and fixed) based on grade statistics and a target feed grade to the plant
  - Economic operating cut-off grade is often below what is required to produce a saleable product (based on current market prices)
- Advanced studies and operational experience tells us that manipulating the RoM grade to be more selective in terms of particularly the deleterious components, can significantly optimise/reduce the processing cost



Selectivity Vs Simplicity

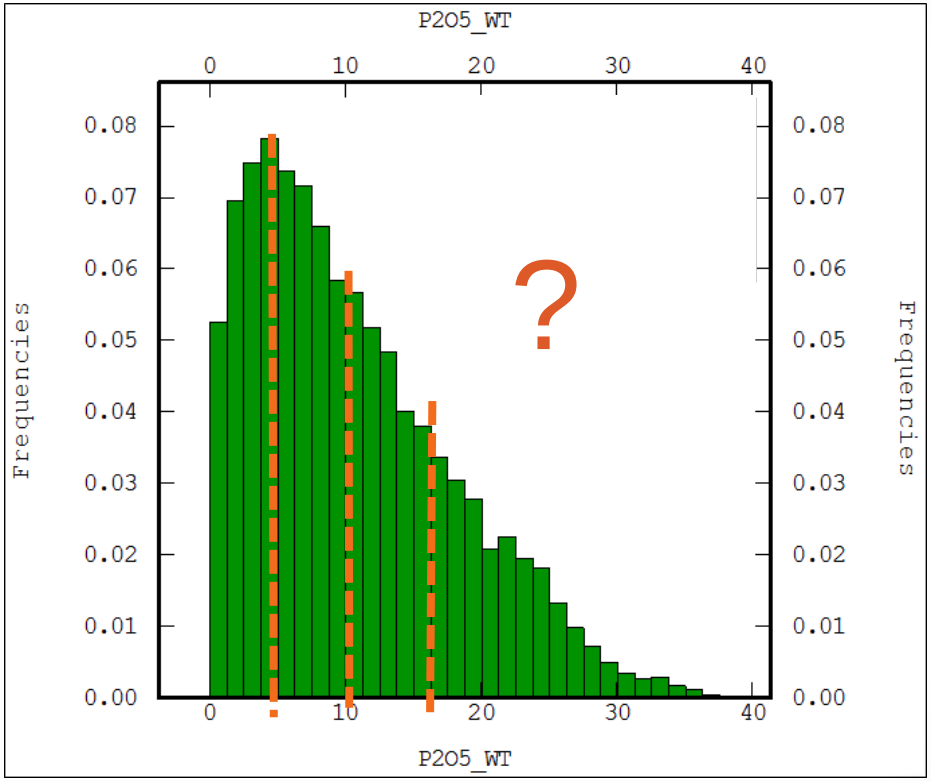
By fixing the geological modelling cut-off grade at an early point in the project cycle it is possible to miss some key questions:

- How continuous is the deposit at different P_2O_5 cut off grades?
  - Continuity of individual seams
  - What is the tonnage impact
- How sensitive is the deposit to certain deleterious element components?
  - SiO_2, MgO
  - Minor element - U, Cd
- What is the impact of mining on the plant feed grade?
- Are all seams economically viable under the proposed mining conditions?

Issues Faced

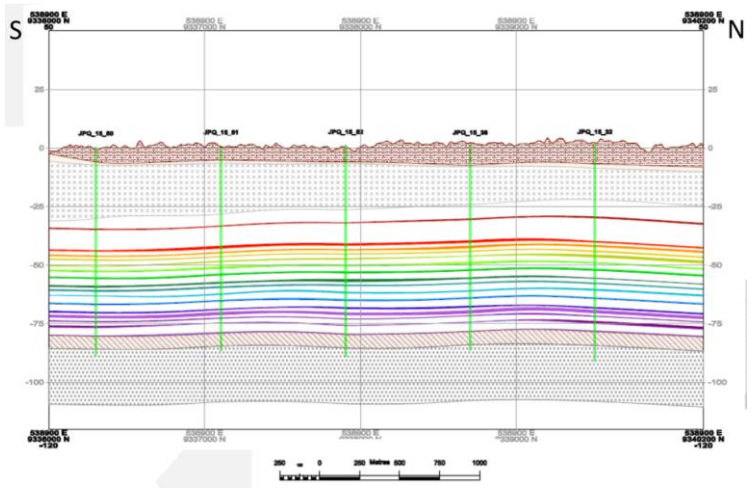
- There is often no natural cut-off grade

- Example grade profile for a single typical phosphate seam
- No clear mineralised / unmineralised distinction
- Where to apply the modelling cut-off grade?

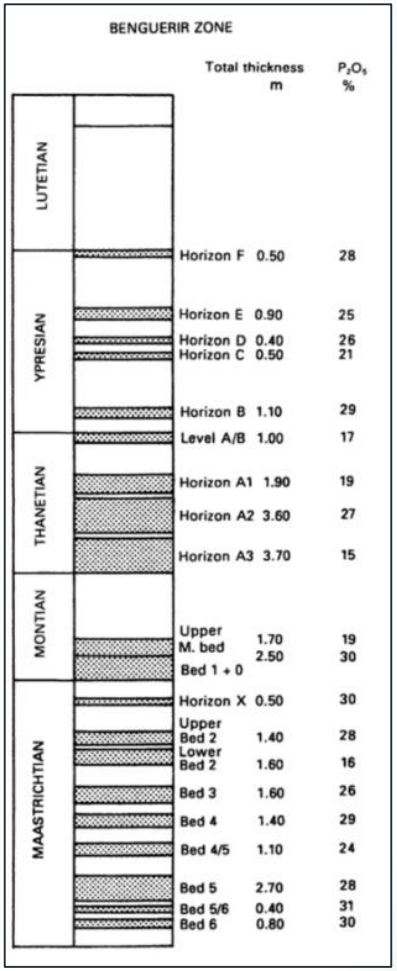


Issues Faced

- We are often considering multiple seams with different attributes
  - Many of the sedimentary phosphate regions of the world occur as multiple seam deposits
  - Individual seams can have different grade distributions and profiles (vertically and horizontally)



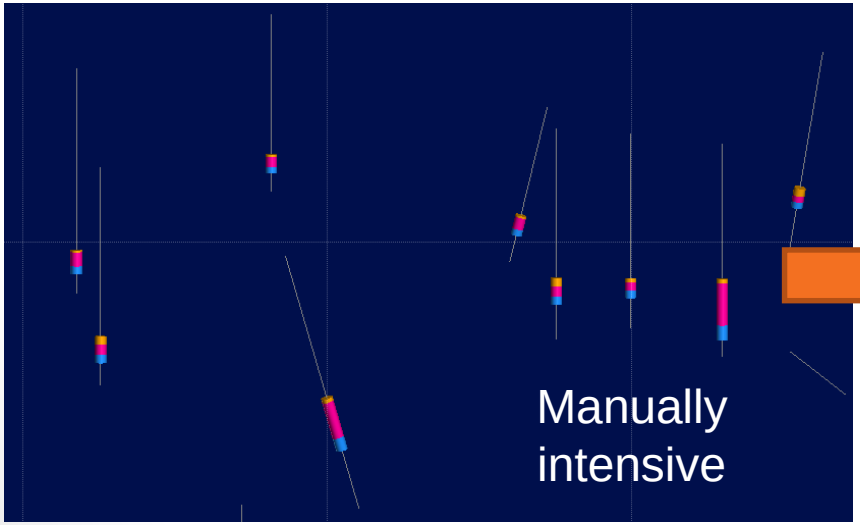
Bayovar – Source: Focus Ventures

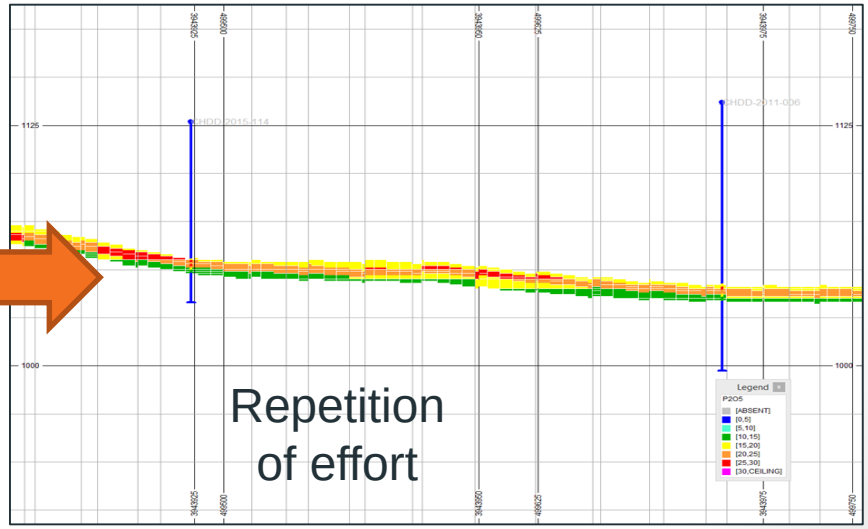


Source: Phosphate Deposits of the World: A. J. G. Notholt, R. P. Sheldon, D. F. Davidson

Issues Faced

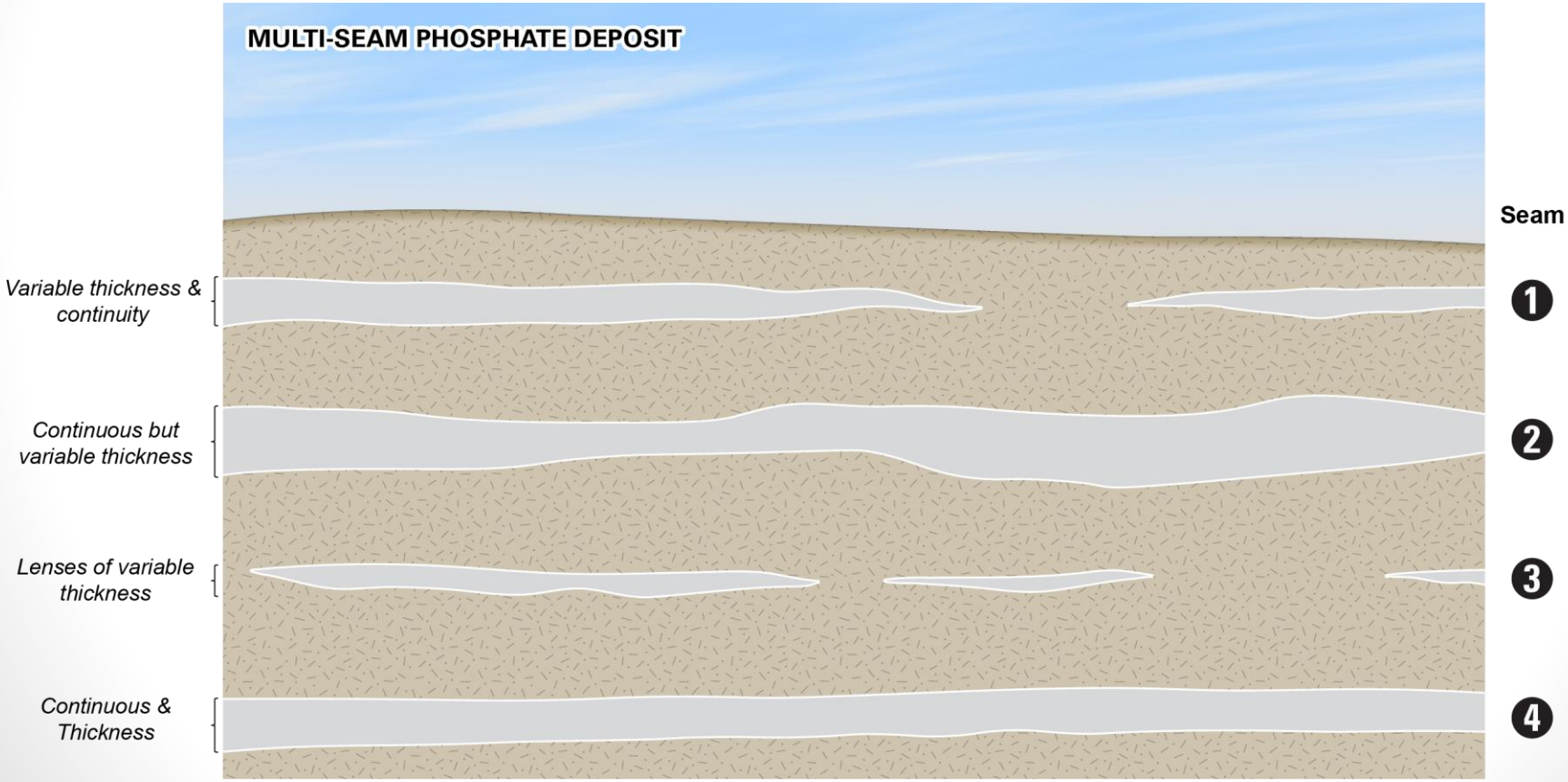
- Fixing the geological modelling cut-off grade at an early point in the project cycle can restrict the project outcomes
- Revisiting the geological modelling cut-off grade has historically required significant effort – time and cost
  - Manually coding the drillhole intercepts (ore and waste)
  - Remodelling, re-estimating….
  - Simplistic approaches do not consider factors such as geological continuity





The SRK Concept

- Ability to test multiple scenarios in a cost and time effective manner
  - Cut-off grade – P_2O_5, SiO_2, MgO, Cd etc.
  - Impacts of mining dilution and recovery
  - Viability of each seam in the context of waste stripping



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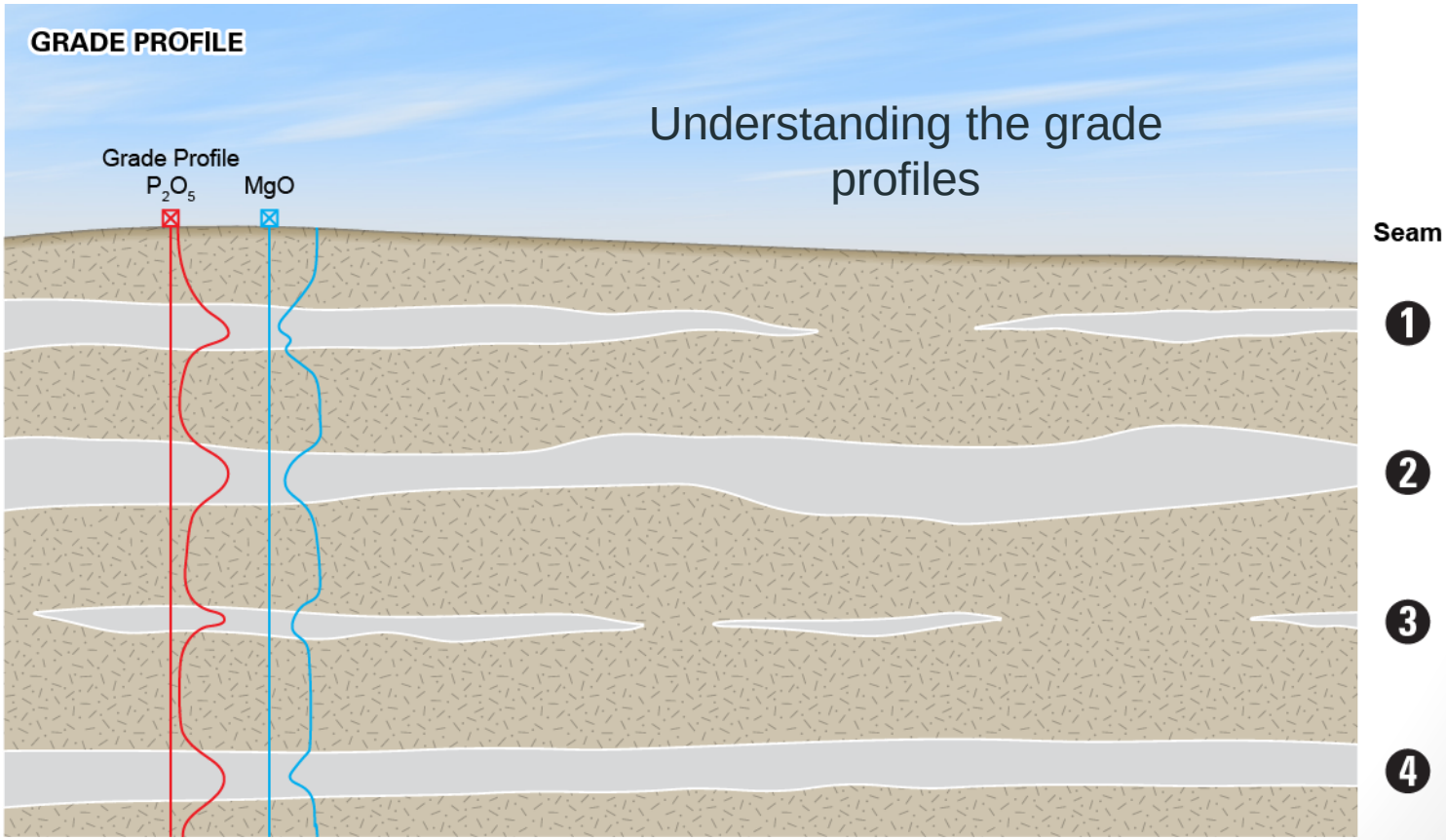

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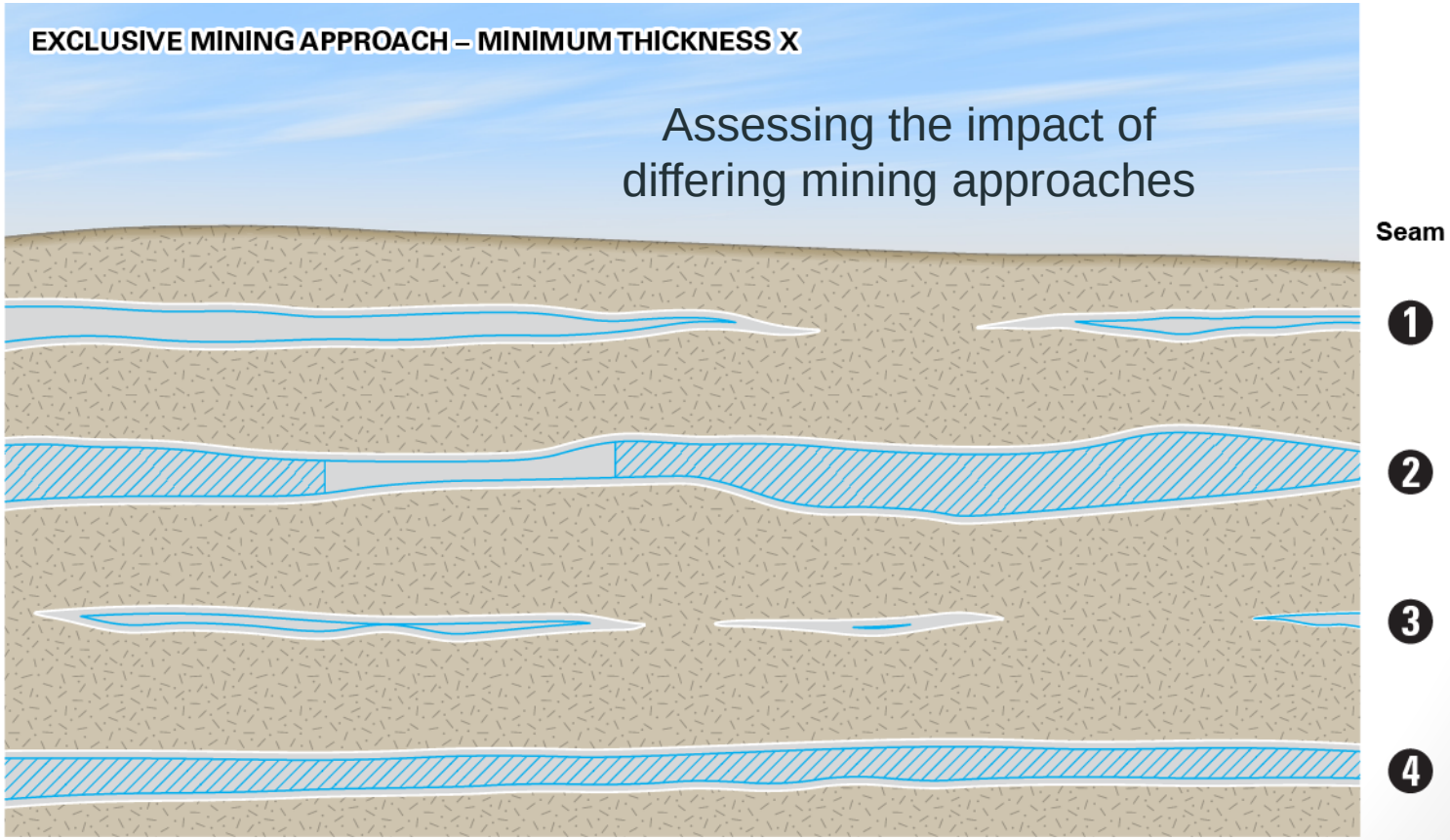

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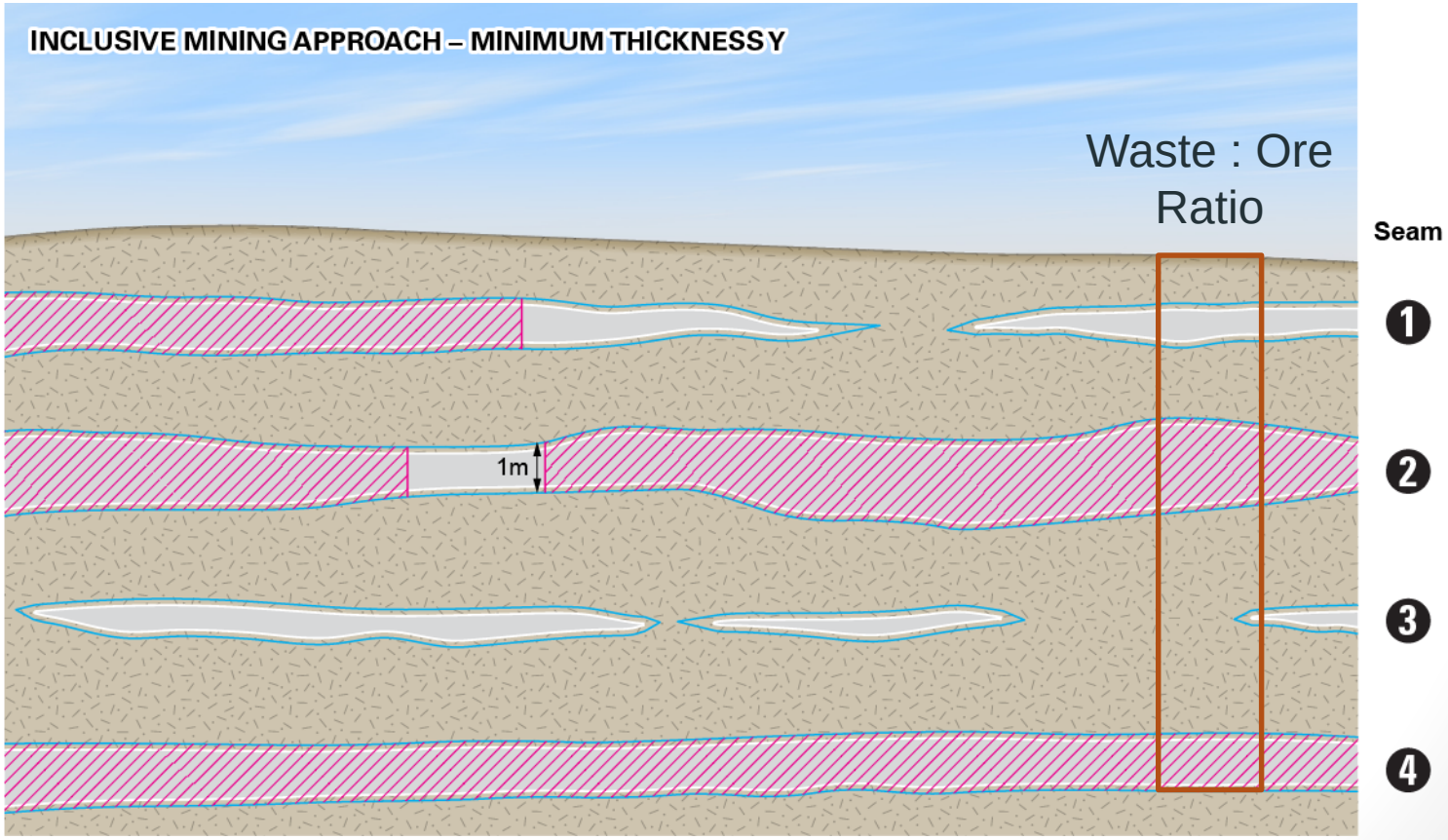


- Workflow / Approach:
  - Seam coding
  - Application of dilution and recovery
  - Margin Ranking

- Output:
  - Sensitivity matrix – tonnage and grade
  - Seam continuity ratio
  - Margin ranking results – relative value

Process of running multiple scenario models

Compositing samples according to different grade and thickness parameters

- **Minimum Grade**
- **Minimum Mineralisation Thickness**
- **Maximum thickness of internal waste**

Automated Coding to Sequence Mineralisation (using scripts)

Define Horizon Sequence: eg:

- **H2**
- **H4**
- **H6**
- **H8 etc.**

Multi-horizon, Multi-variable Grid Modelling for each scenario

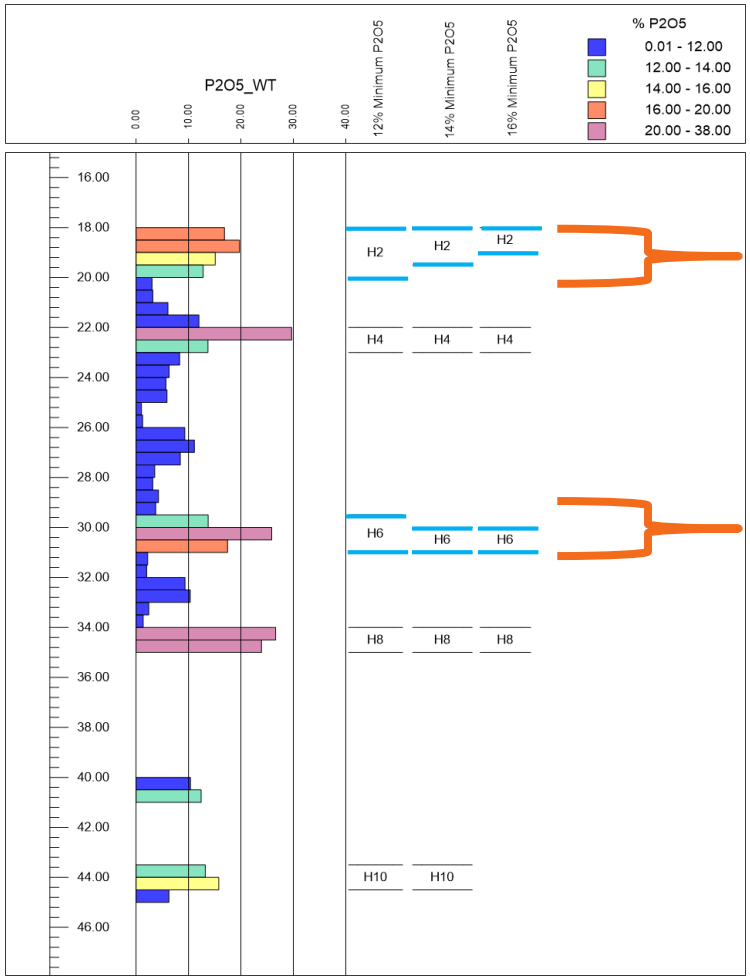
Produce a set of Grade and Structural Grids for each scenario. E.g.

- **P_2O_5 > 12% & 1m thick**
- **P_2O_5 > 14% & 1m thick**
- **P_2O_5 > 16% & 1m thick**

Example - Sensitivity of Phosphate Mineralisation to Cut-off grade

Automated Coding – applying P_2O_5 cut-off 12%, 14% and 16%

Increasing P_2O_5

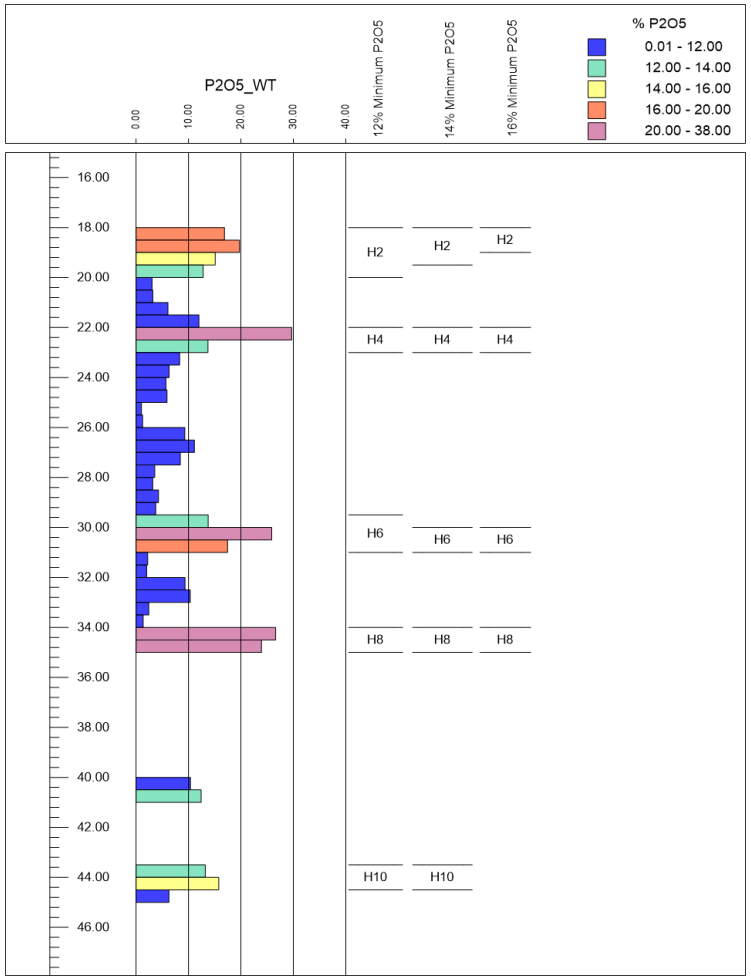


Reduction in seam thickness with increasing cut-off grade

Reduction in seam thickness with increasing cut-off grade

Example - Sensitivity of Phosphate Mineralisation cut-offs

Automated Coding – applying P_2O_5 cut-off 12%, 14% and 16%



Grade changes on Example Drillhole

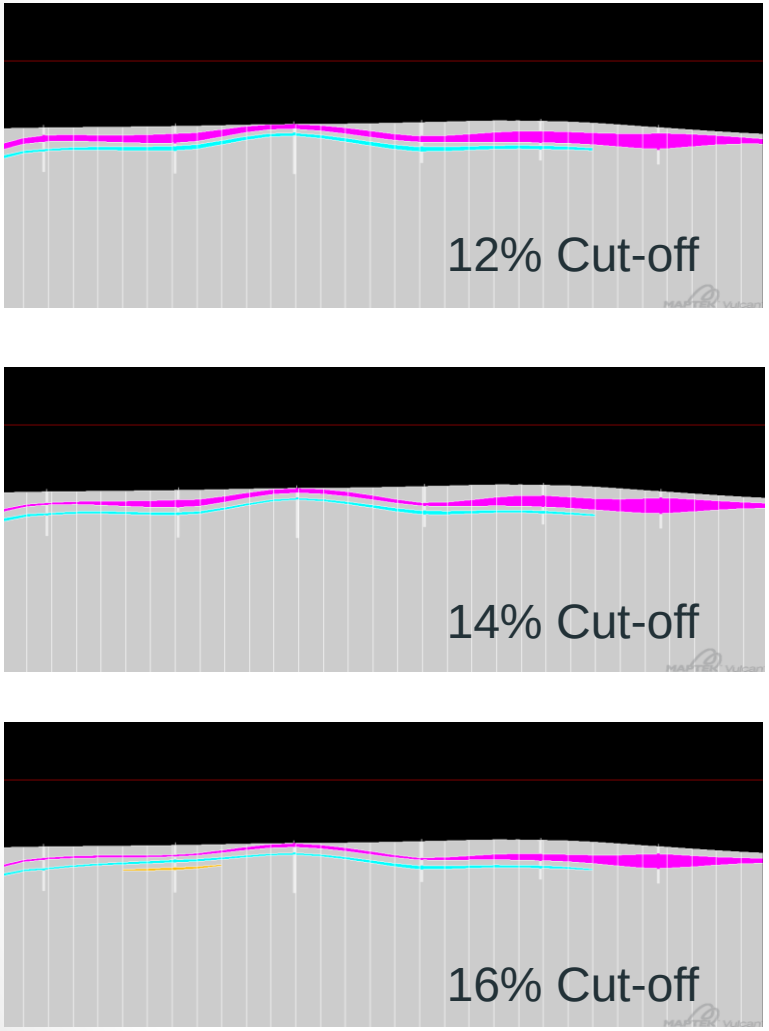
Variable	Unit	P_2O_5 12%	P_2O_5 14%	P_2O_5 16%
P_2O_5	%	18.8	19.8	21.7
SiO_2	%	9.2	8.0	3.1
MgO	%	0.13	0.13	0.14
Phosphate Thickness	m	6.5	5.5	4.0
Overburden thickness	m	18	18	18
Interburden thickness	m	20	21	13
Maximum depth	m	45	45	35
Overall Vertical Strip Ratio	m:m	5.8	7.1	7.8

- Expected impact on P_2O_5 grade
- MgO insensitive to change in P_2O_5 cut-off
- Significant potential to realise benefits in SiO_2 reduction
- Decease in average thickness
- Lowest seam drops out at higher grades

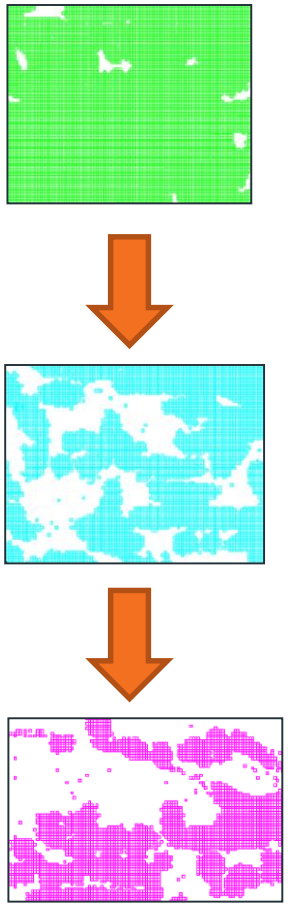
Example - Assessing Geological Continuity

Seam Continuity Ratio

Horizon Continuity



Seam H2 Plan Coverage



% Coverage Vs Base Case

100%

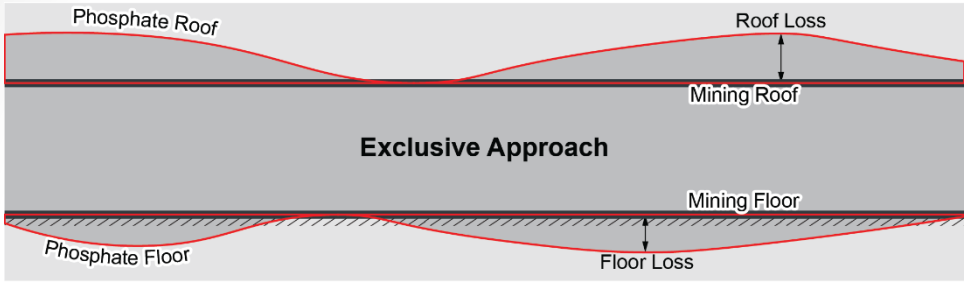
60%

40%

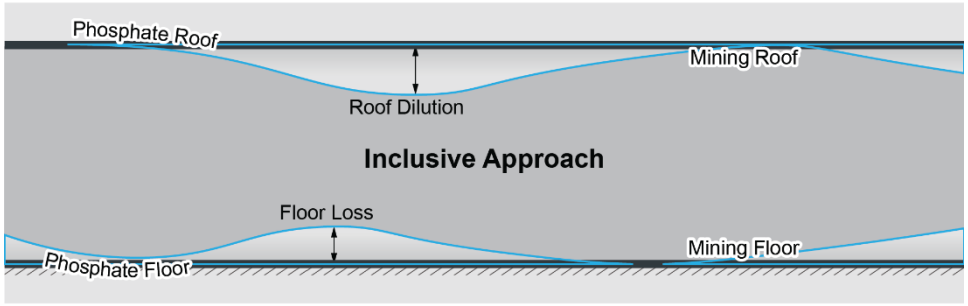
In process of developing pixel analysis of different block size ranges to feed into continuity assessment

Application of Mining Factors

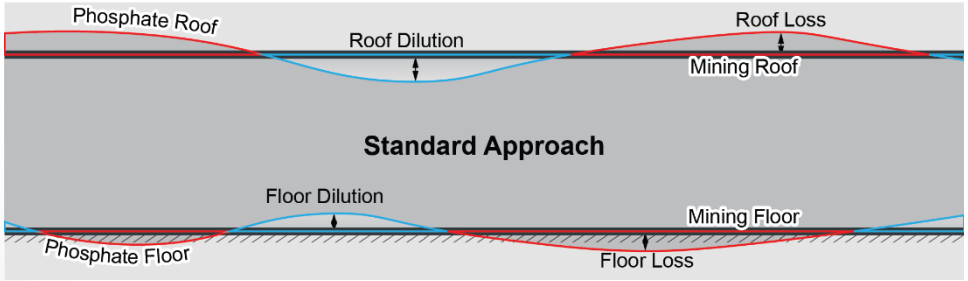
Various approaches are available - need to understand which is most suitable and adequate to the situation/deposit



No dilution, only losses
Losing part of Mineral Resource
Maintaining in situ qualities



Dilution, no losses
Adding material to Mineral Resource
Decrease in quality



Dilution and losses
Adding and losing material to/from Mineral Resource
Some decrease in quality

Thicknesses should be based on the ability to identify the contacts and potential mining equipment tolerances

Example – Grade and Tonnage Sensitivity

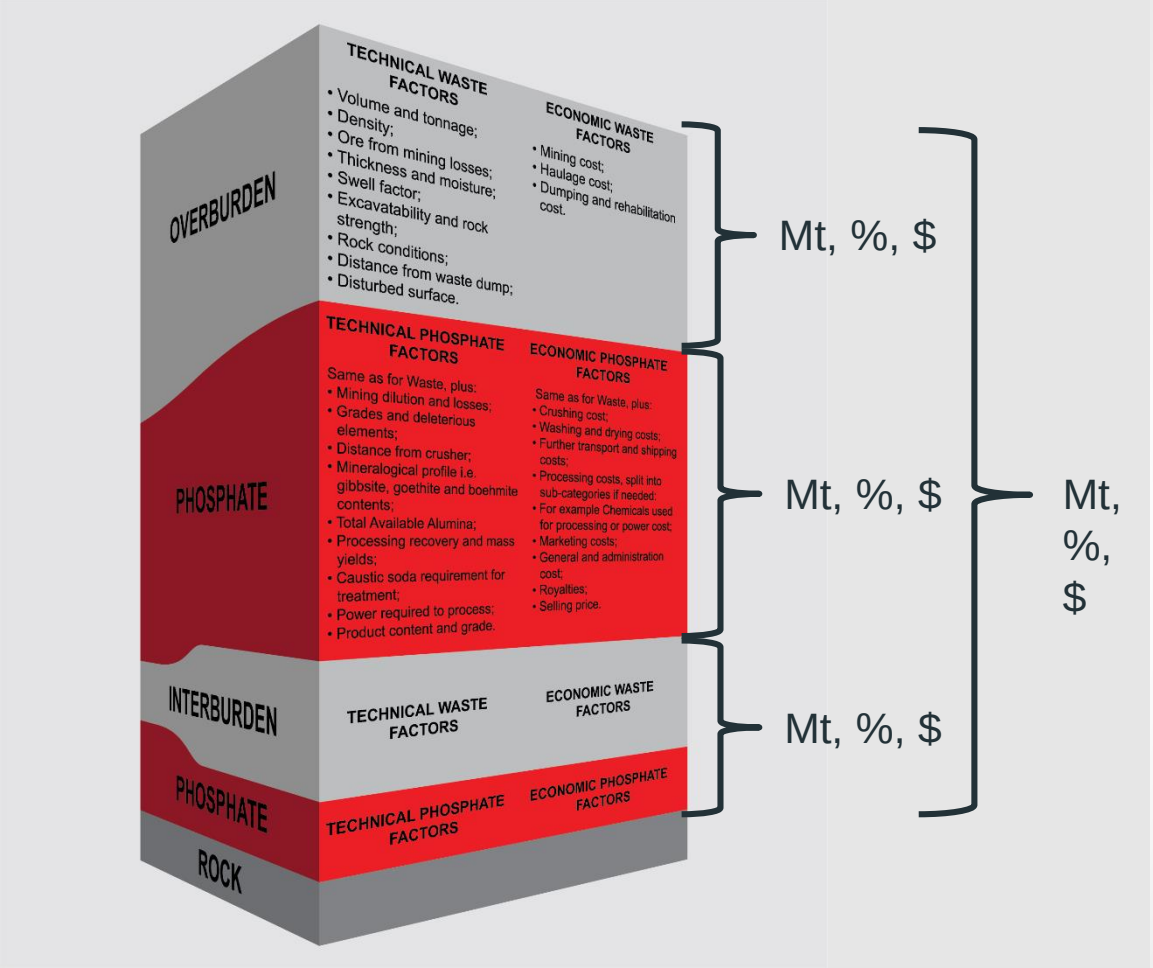
	Thickness Cut-off	In-Situ	1.0m minimum			1.25m minimum			1.5m minimum		
			Inclusive	Standard	Exclusive	Inclusive	Standard	Exclusive	Inclusive	Standard	Exclusive
H2	Mt	506	611	506	401	598	497	396	555	465	376
	P_2O_5	16.1	14.0	15.1	16.1						
	MgO										

	Cut-off Grade	In-Situ	16% P_2O_5			17% P_2O_5			18% P_2O_5		
			Inclusive	Standard	Exclusive	Inclusive	Standard	Exclusive	Inclusive	Standard	Exclusive
H4	Mt	506	49	129	199	16	45	104	0	16	43
H2	P_2O_5										
	MgO										
	CaO										
	SiO_2	8.7	7.4	6.8	5.5						
H4	Mt	362	179	236	229	123	168	197	65	115	147
	P_2O_5										
	MgO										
	CaO										
	SiO_2										

- Tonnage sensitivity to mining approach
- Sensitivity of different seams to different cut-off grades
- Impact of mining approach on deleterious element
- Sensitivity assessment can be run on multiple scenarios individually or in combination - P_2O_5, SiO_2, MgO, Cd etc.

Margin Ranking – Assessing Relative Value

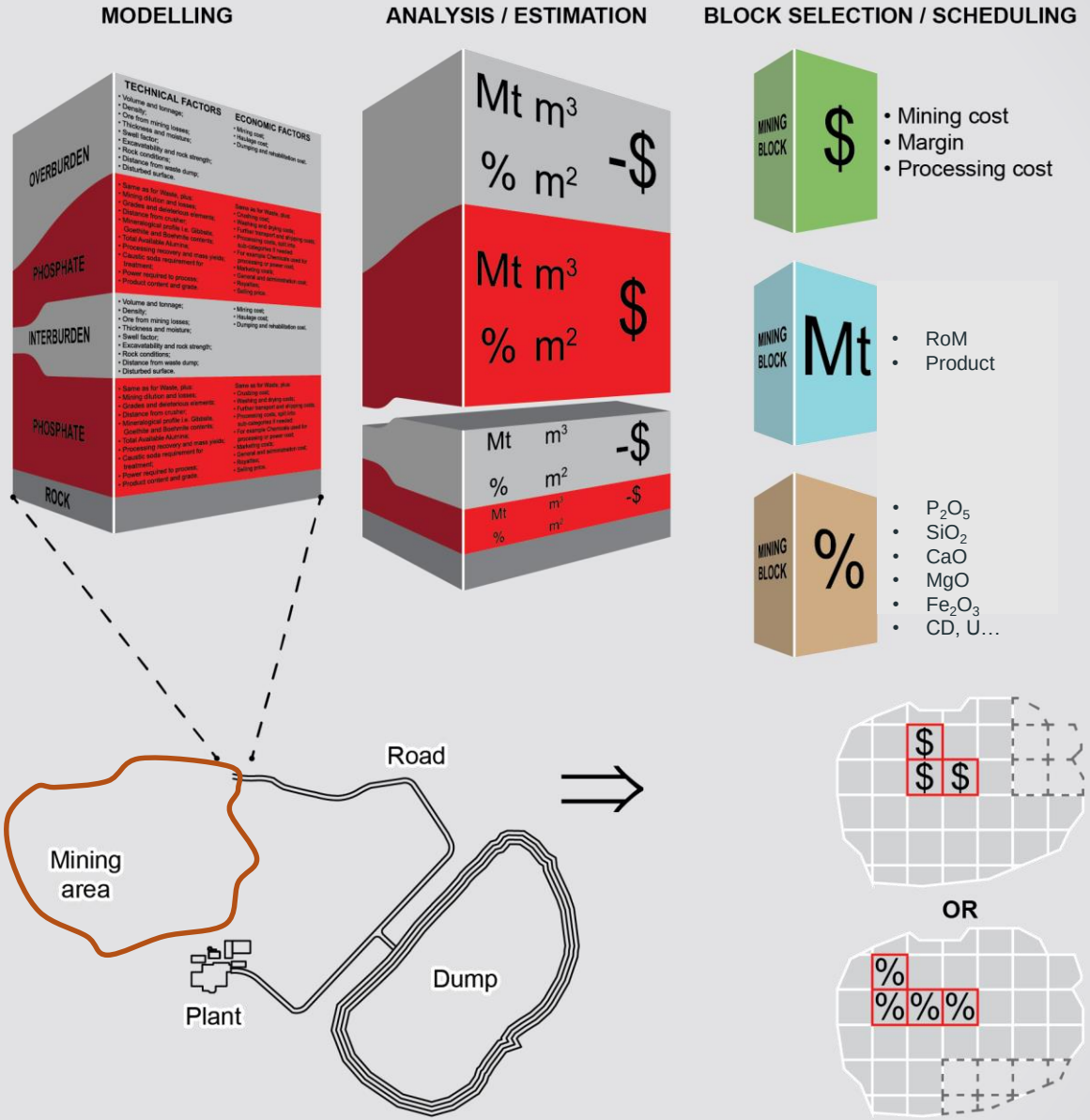
- A similar concept to conventional pit optimisation
- Except that an economic value is calculated for the entire vertical mining column
- Includes influencing technical and economic factors
- Aim of margin ranking is to define which mining blocks are economic



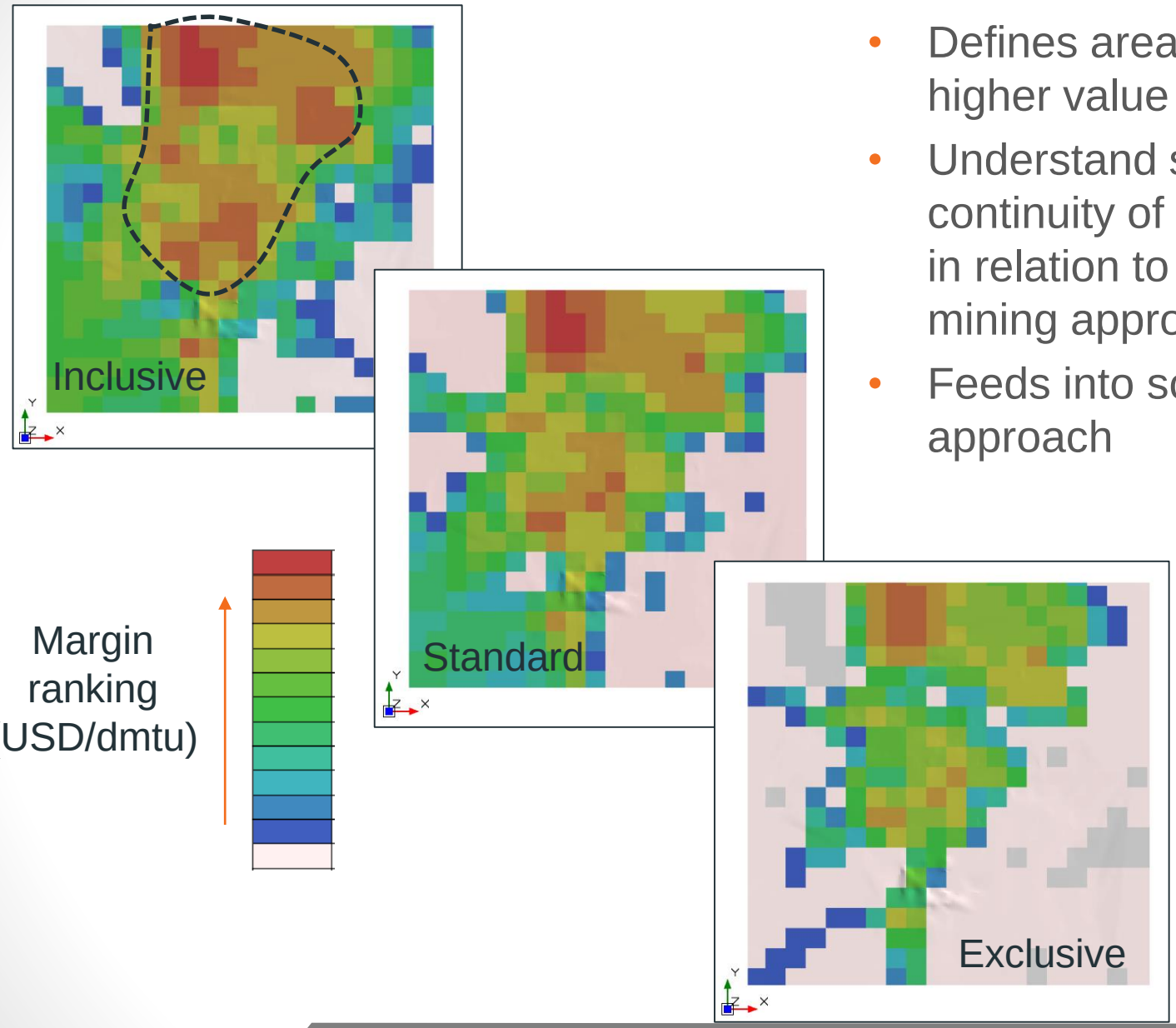
Mine Planning

Method

1. Application of the technical and economical factors
2. Assessment of seam viability vs stripping
3. Margin Ranking applied to the entire deposit block by block
4. Identifying uneconomic or unsalable blocks and removing them from the LoM plan

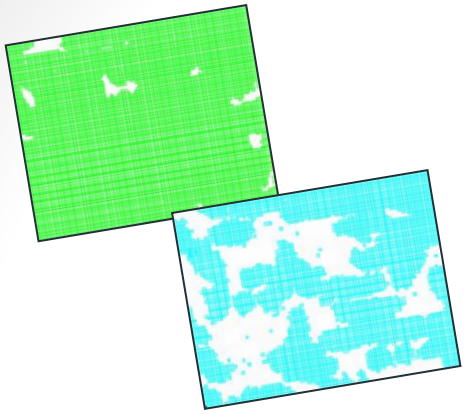


Example - Margin Ranking Results



- Defines area(s) of relatively higher value
- Understand spatial continuity of mining blocks in relation to different mining approaches
- Feeds into scheduling approach

Results Summary

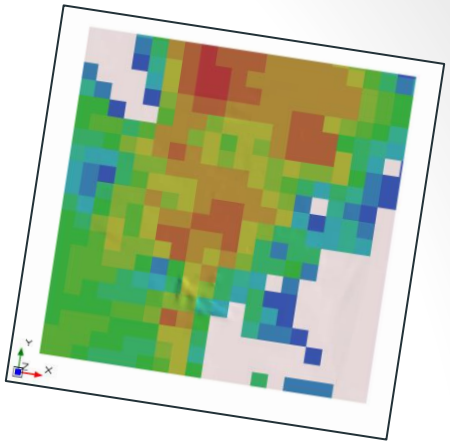


Assessment of geological continuity Areas of high impurities

	Cut-off Grade	In-Situ	16% P_2O_5			17% P_2O_5			18% P_2O_5		
			Inclusive	Standard	Exclusive	Inclusive	Standard	Exclusive	Inclusive	Standard	Exclusive
H2	Mt	506	49	129	199	16	45	104	0	16	43
	P_2O_5										
	MgO										
	CaO										
	SiO_2	8.7	7.4	6.8	5.5						
H4	Mt	362	179	236	229	123	168	197	65	115	147
	P_2O_5										
	MgO										
	CaO										
	SiO_2										

Grade and tonnage sensitivity Analysis

Considering different mining approaches



Economic assessment of seam and deposit viability

Sensitivity Analysis

Ability to make an informed decision on:

Cut-off grade

Impacts of differing mining approaches

Viability of the individual and consolidated seams

Processing implications

- Potential to simplify beneficiation circuit:
  - E.g. removal of excess stages in the flotation circuit
- Identify seams or areas of the deposit which are potentially higher in impurities and contribute to increased reagent consumption
- Improve phosphate rock quality:
  - E.g. manage MgO content and therefore additional costs in the phosphoric acid plant
  - Exclusion of seams or areas of the deposit with high minor element content which could have a negative impact on saleable product quality
- Assess the potential to adopt / accommodate more inclusive mining approach within the beneficiation flow sheet – i.e. slightly higher SiO_2 or MgO content – resulting in a simplified mining method

Summary

- SRK has developed an approach which allows the user to assess the sensitivity of a phosphate deposit to:
  - Cut-off grade - for all relevant elements
  - Mining approach
  - Technical and economic parameters (relative value)

- The process is designed to remove manual input and therefore can efficiently investigate multiple variables providing value, without incurring significant time and cost

- The approach is applicable throughout the project life cycle:
  - In development projects, from maiden MRE to FS level
  - In operations where there is the potential to optimise costs

- Ability to make an informed decisions which could save repetition of work further down the line, and is easily repeated as situations change

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