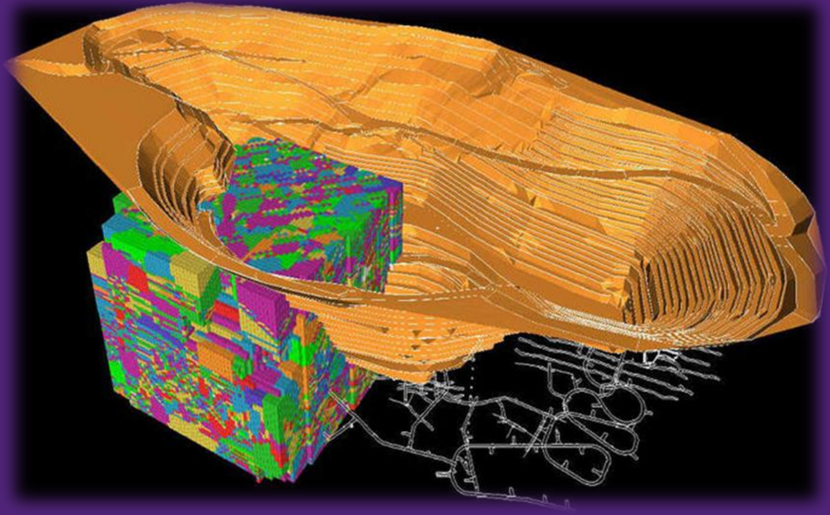
Applications of geometallurgy for waste characterisation and management across the mining value chain

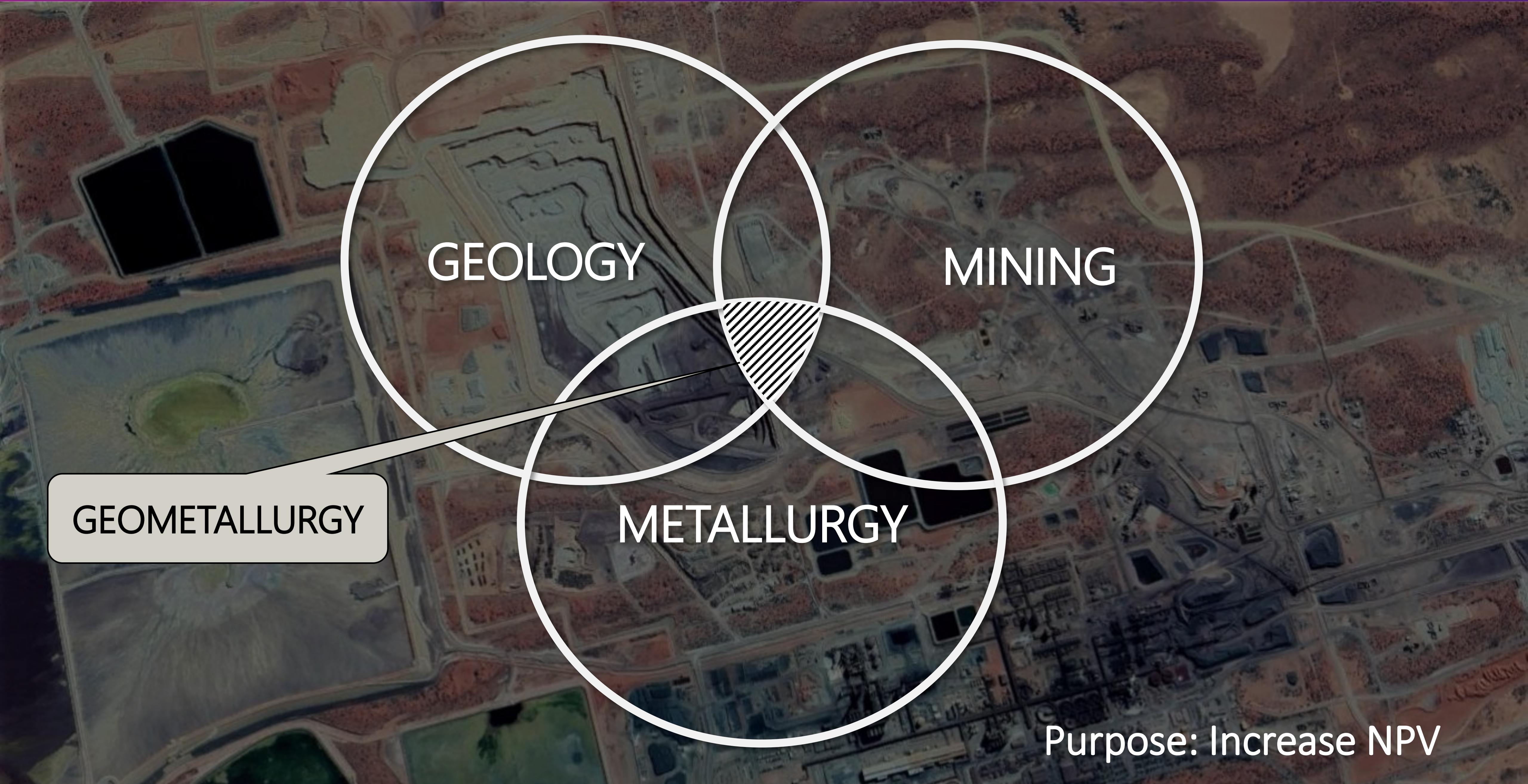
Dr Anita Parbhakar-Fox

Senior Research Fellow

WH Bryan Mining and Geology Research Centre, SMI, UQ



What is 'geometallurgy'?



Purpose: Increase NPV

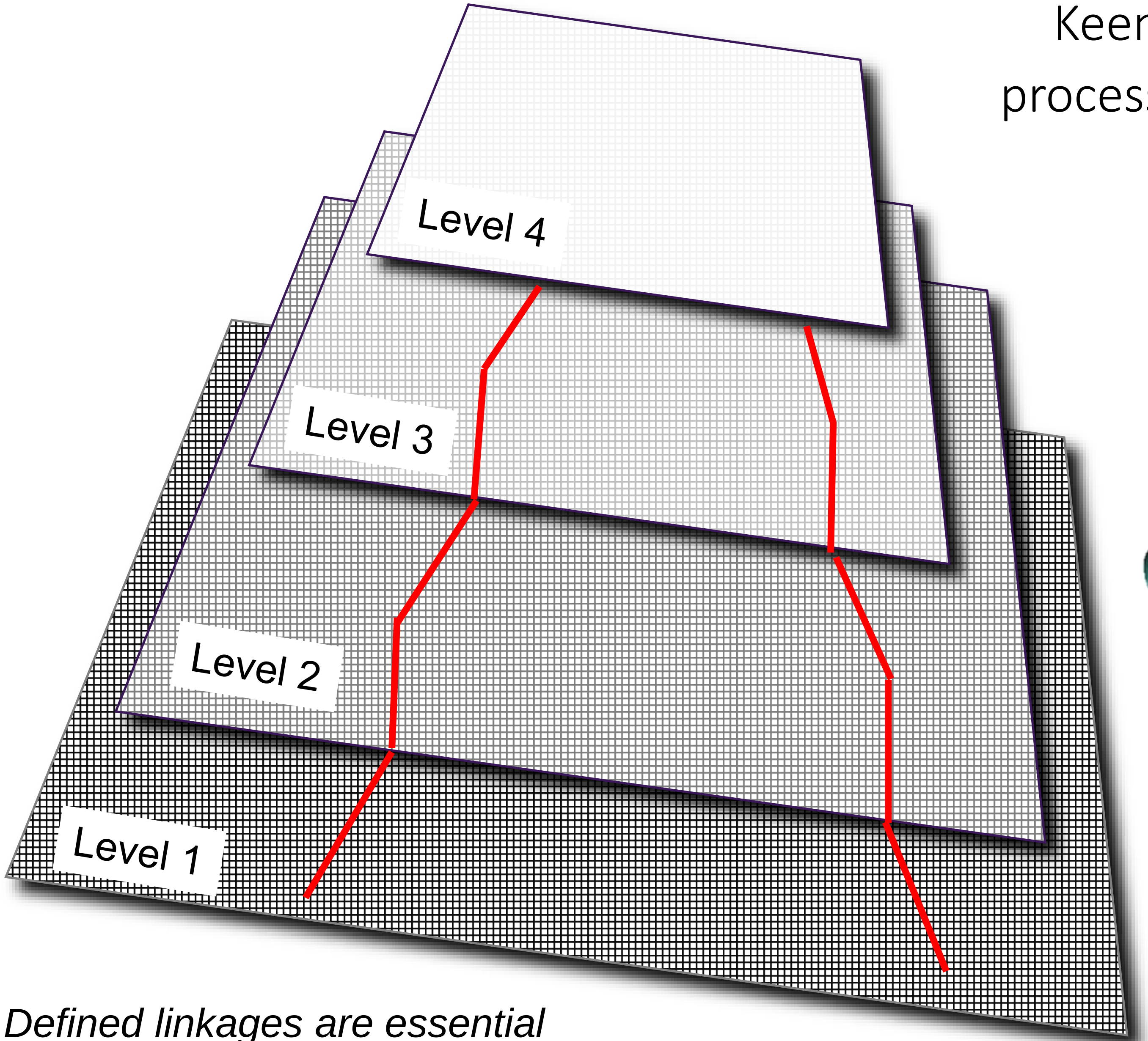
What is ‘geometallurgy’?




- Through an integrated approach geometallurgy establishes 3D models which enable NPV optimisation and effective orebody management, while minimising technical and operational risk to ultimately provide more resilient operations
- Critically, through spatial identification of variability, it allows the development of strategies to mitigate the risks related to variability (e.g., collect additional data, revise the mine plan, adapt or change the process strategy, or engineer flexibility into the system)
- To achieve these goals, development of innovative technologies and approaches along the entire mine value chain are being established
- Geometallurgy has been shown to intensify collaboration among operational stakeholders, creating an environment for sharing orebody knowledge, leading to the integration of such data and knowledge into mine planning and scheduling
- Companies that embrace the geometallurgical approach will benefit from increased net present value and shareholder value

Dominy et al. (2018)

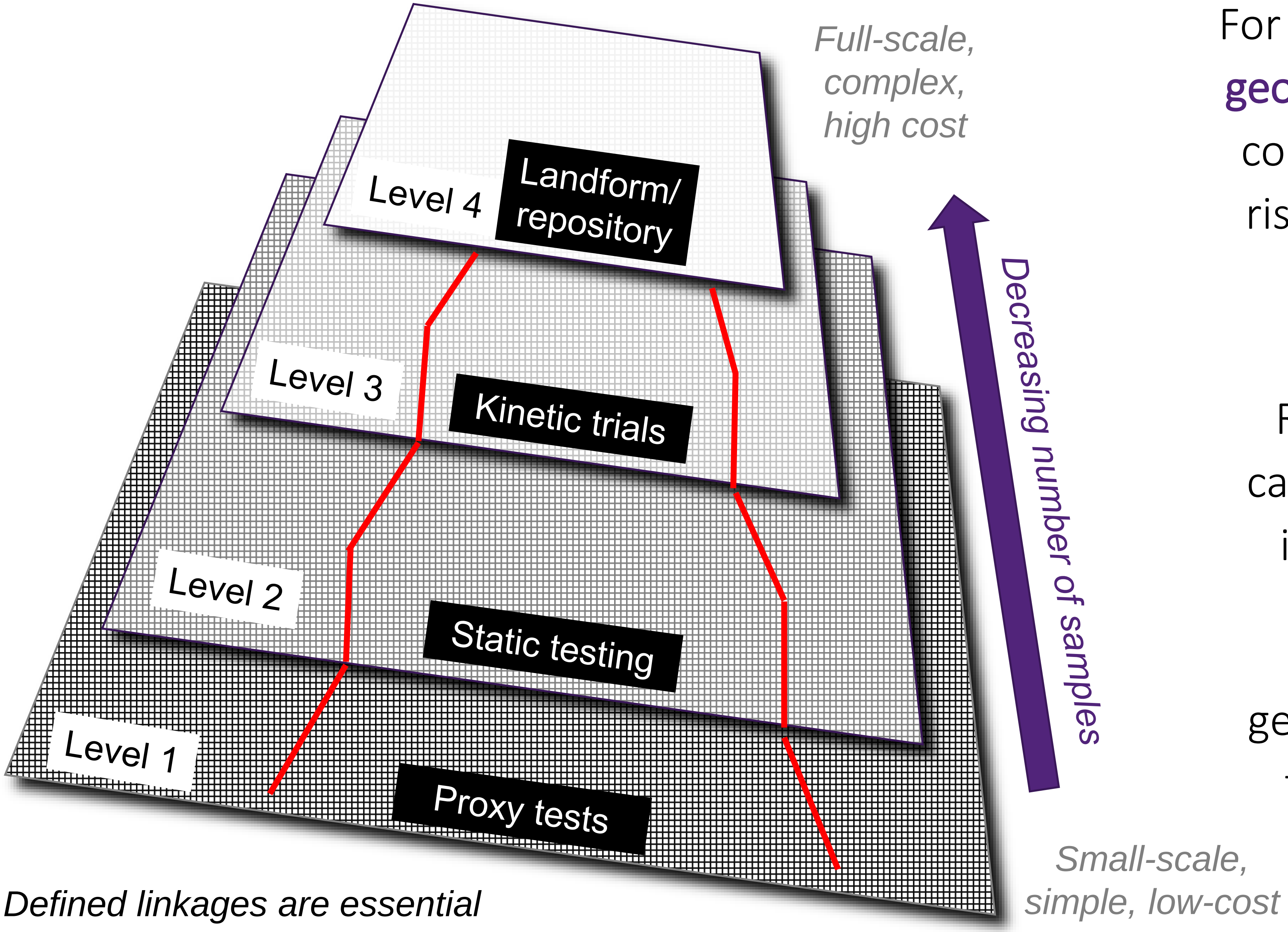
Geometallurgy Matrix concept



Keeney (2008): Aim is to propagate measured processing attributes (i.e. A*b, BMWI) down in the matrix to Level 2 and Level 1

Defined linkages are essential

Geometallurgy Matrix concept



Defined linkages are essential

For mine waste characterisation a **geometallurgical matrix approach** could be readily adopted to de-risk projects and improve long-term financial outcomes

Representative sampling and capturing heterogeneity is a key issue- this helps overcome it

Requires the embedding of geoenvironmental proxy tests at the earliest LOM stages (i.e., exploration/prefeasibility)

The (enviro)geometallurgy tool kit

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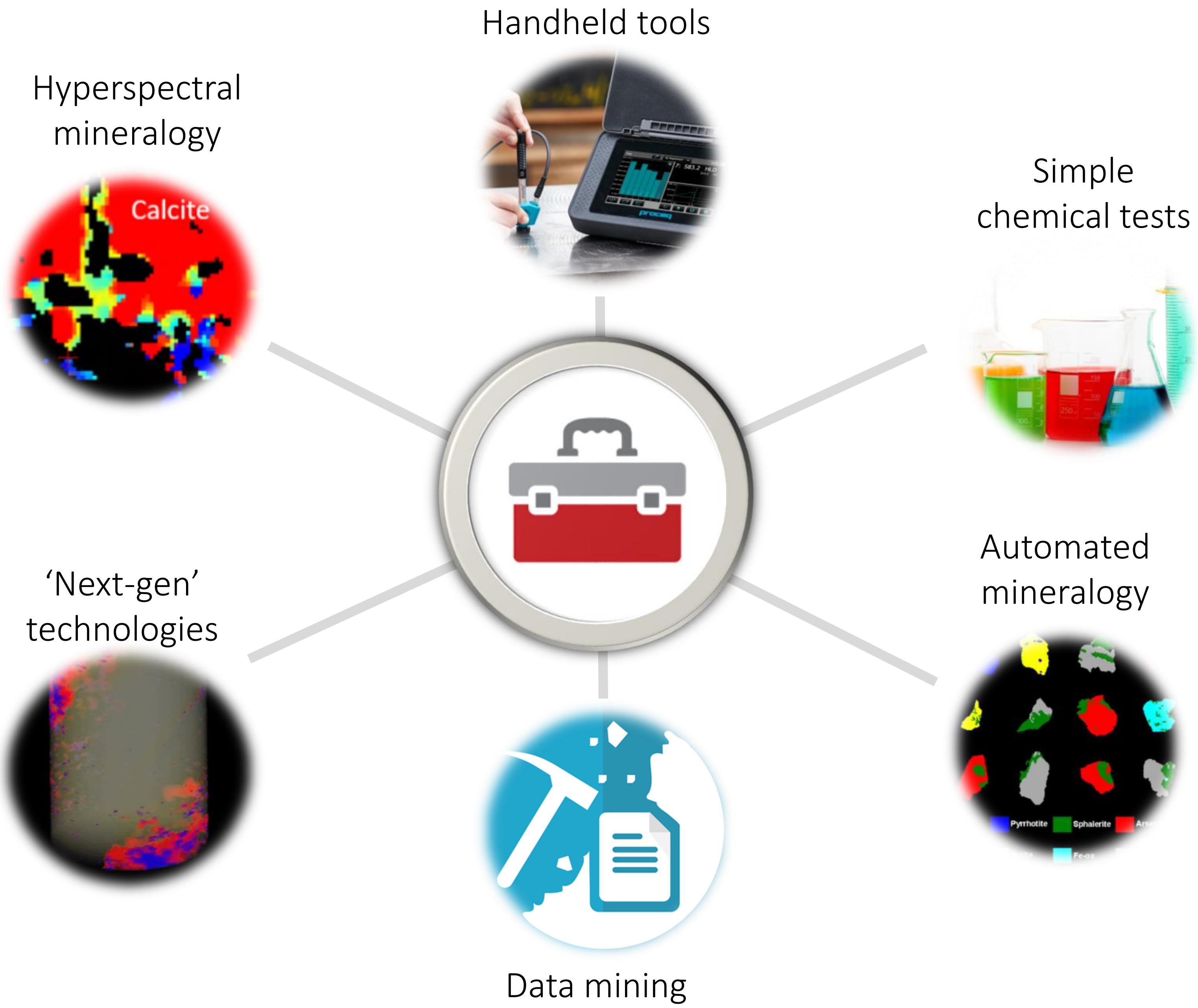

Hyperspectral mineralogy

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AUSTRALIA

- Challenges encountered when collecting ‘representative’ geoenvironmental samples at early life-of-mine stages
- Increasing ore deposit knowledge will assist with static and kinetic testing sample selection
- Hyperspectral data measuring VNIR and SWIR active minerals (e.g., Corescan) and TIR (e.g., HyLogger)
- Corescan: ~2,000 m can be collected per day
- Value-add opportunity by perform geoenvironmental domaining to support waste forecasting
- Identify potentially acid forming, non-acid forming and neutralising domains to enable waste management through early forecasting of geoenvironmental characteristics

Hyperspectral mineralogy

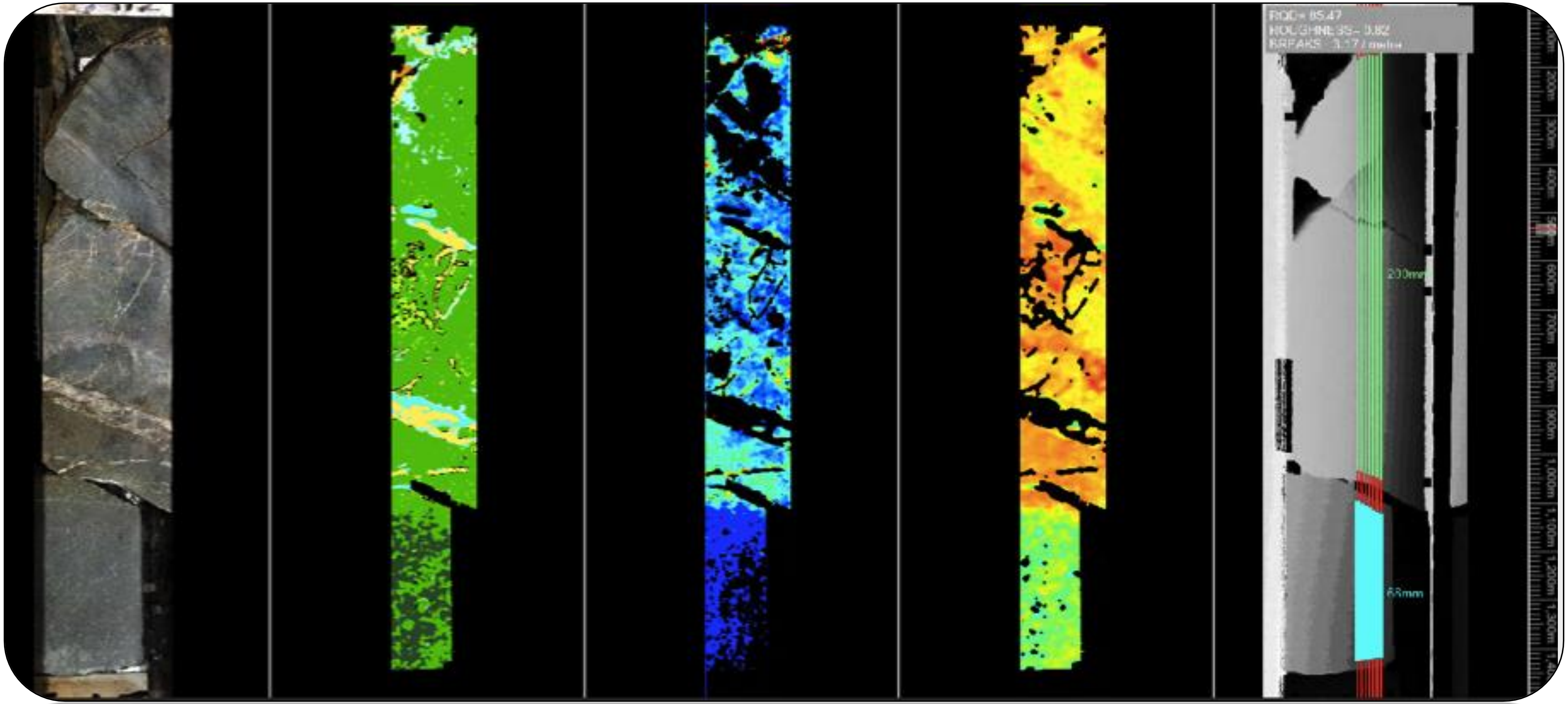
The University of Queensland Australia

Type	Silicate Structure	Mineral Group	Example	VNIR Response	SWIR Response	TIR Response
Silicates	Inosilicates	Amphibole	Actinolite	Non-diagnostic	Good	Good
		Pyroxene	Diopside	Good	Moderate	Good
	Cyclosilicates	Tourmaline	Dravite	Non-diagnostic	Good	Moderate
	Neosilicates	Garnet	Grossular	Moderate	Non-diagnostic	Good
		Olivine	Foresterite	Good	Non-diagnostic	Good
	Sorosilicates	Epidote	Clinozoisite	Non-diagnostic	Good	Good
	Phyllosilicates	Mica	Muscovite	Non-diagnostic	Good	Moderate
		Chlorite	Chlinochlore	Non-diagnostic	Good	Moderate
		Clay minerals	Illite	Non-diagnostic	Good	Moderate
			Kaolinite	Non-diagnostic	Good	Moderate
	Tectosilicates	Feldspar	Orthoclase	Non-diagnostic	Non-diagnostic	Good
			Albite	Non-diagnostic	Non-diagnostic	Good
		Silica	Quartz	Non-diagnostic	Non-diagnostic	Good
Non-silicates	Carbonates	Calcite	Calcite	Non-diagnostic	Good	Good
		Dolomite	Dolomite	Non-diagnostic	Good	Good
	Hydroxides		Gibbsite	Non-diagnostic	Good	Moderate
	Sulfates	Alunite	Alunite	Moderate	Good	Moderate
			Gypsum	Non-diagnostic	Good	Good
	Borates		Borax	Non-diagnostic	Good	Uncertain
	Halides	Chlorides	Halite	Non-diagnostic	Moderate	Uncertain
	Phosphates	Apatite	Apatite	Moderate	Moderate	Good
	Oxides	Hematite	Hematite	Good	Non-diagnostic	Non-diagnostic
		Spinel	Chromite	Non-diagnostic	Non-diagnostic	Non-diagnostic
	Sulfides		Pyrite	Non-diagnostic	Non-diagnostic	Non-diagnostic

Linton et al. (2018)

Hyperspectral mineralogy

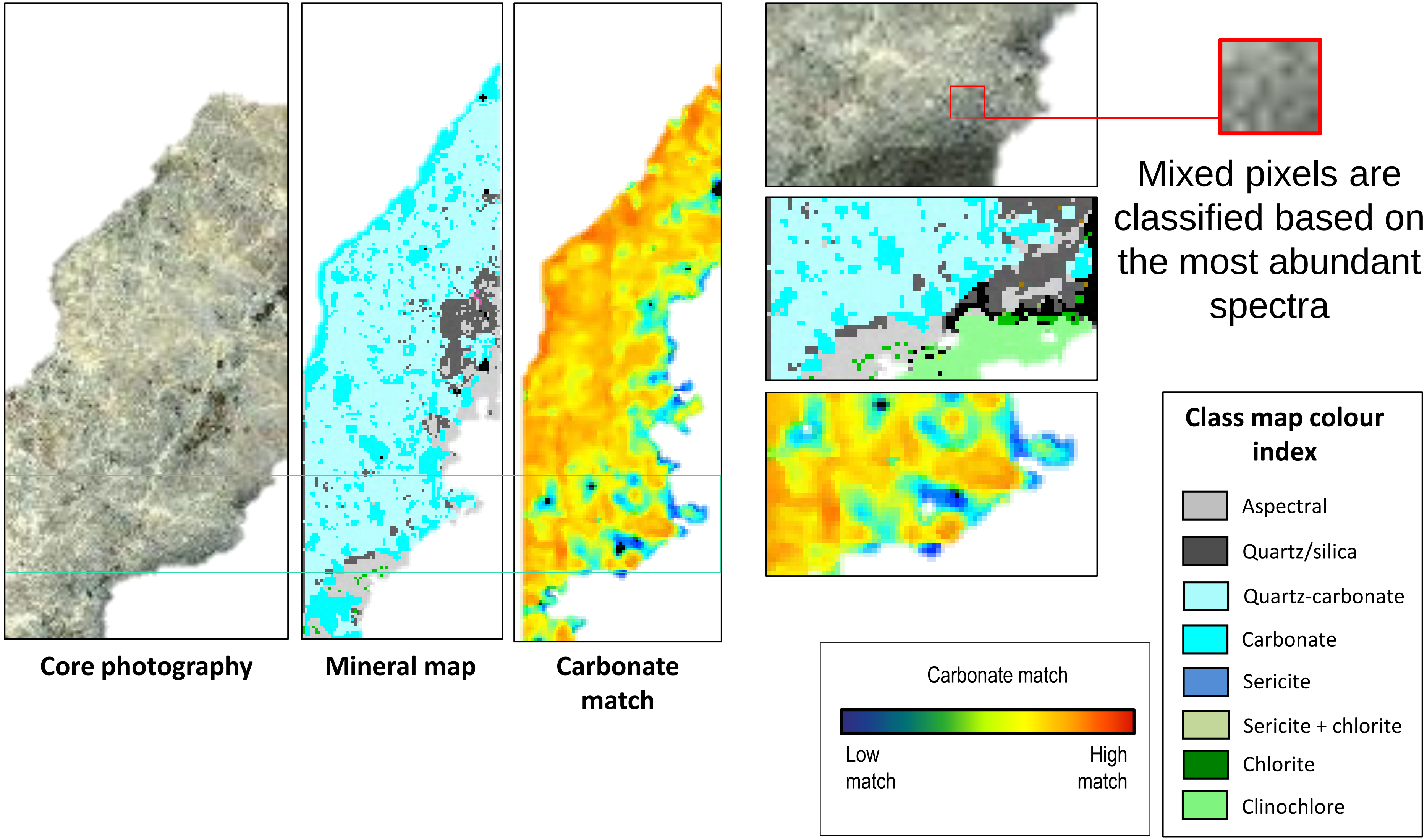
The University of Queensland
Australia



Core photography | Mineral Class map | Chlorite wavelength position | Chlorite match intensity | Geotechnical parameters

corescan

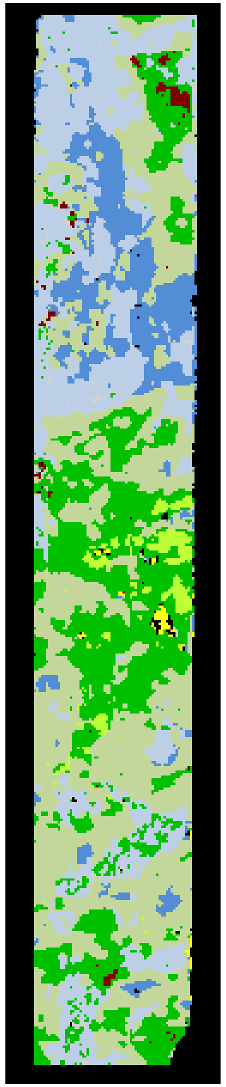
Hyperspectral mineralogy



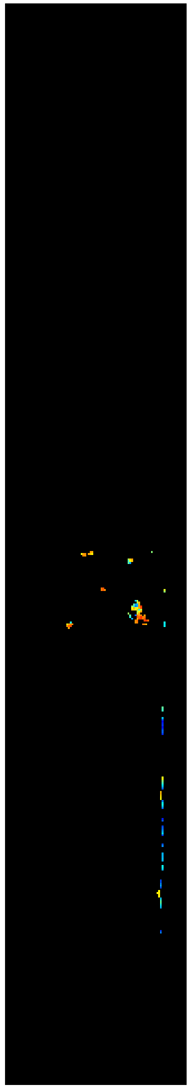
Hyperspectral mineralogy

Core photography

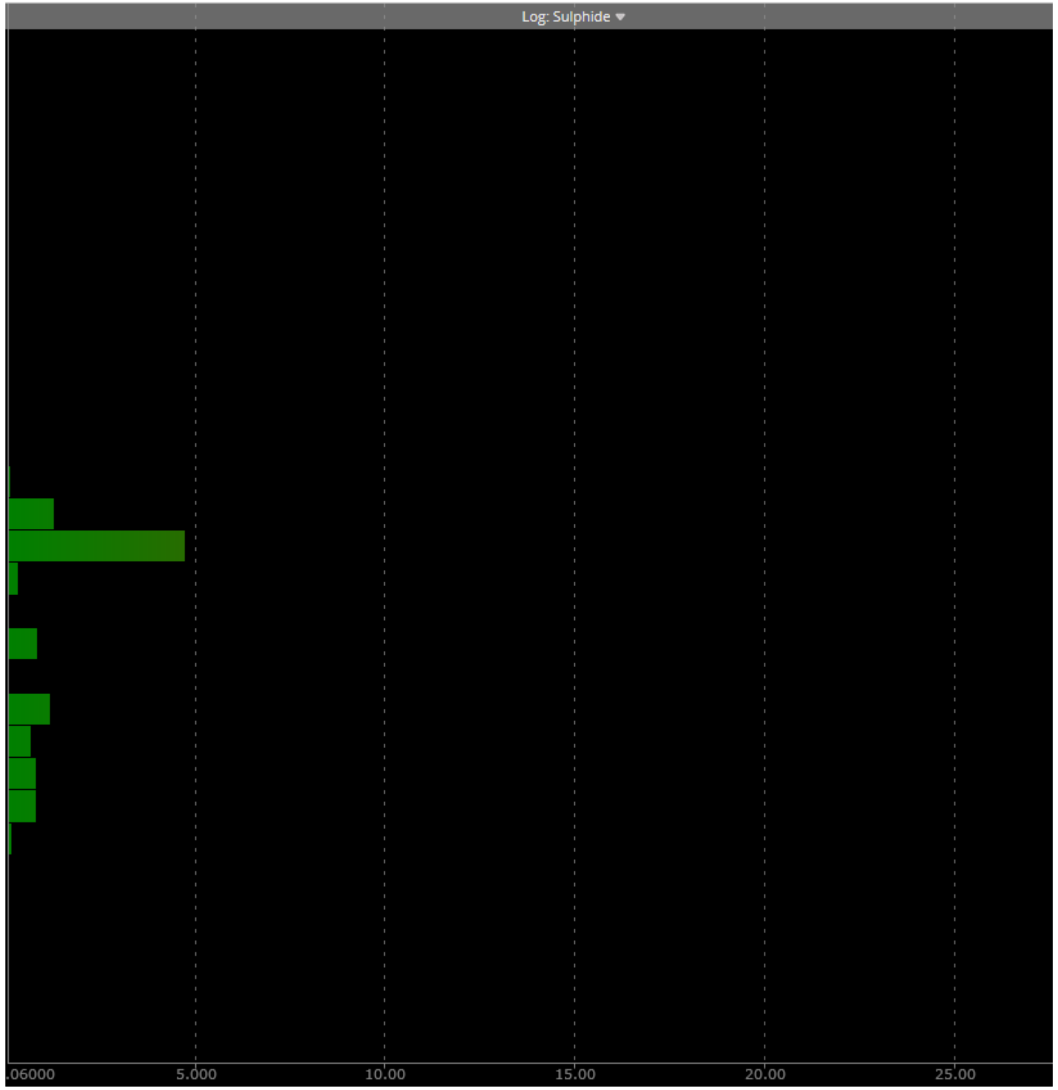
Mineral class map



Sulfide distribution



Log Sulfide distribution



Hyperspectral mineralogy

Hyperspectral data

Core images

Mineral maps

Geoenvironmental Domaining Index (GDI)

Calculated Mineral abundance * **Scaled Neutralising Potential/ Acid Potential values** * **Relative reactivity values**

(Jambor et al., 2007; Parbhakar-Fox and Lottermoser, 2014)

(Sverdrup, 1990)

Example

Chlorite: 60 %	* 0.006	* 0.02	= 0.00012
Carbonate: 30 %	* 1	* 1	= 30
Quartz: 10 %	* 0	* 0.004	= 0

Pixel GDI = ~30

Jackson et al. (2018)

Hyperspectral mineralogy

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First pass GDI (V2) value risk assessment with sulfides identified defines 5 risk grade classification fields

GDI value	GDI risk grade	Description of geoenvironmental characteristics
- 35,000 to -900	Extreme risk	Dominance of acid forming minerals. Sulfides identified as first mineral > 75 %. No primary neutralisers (AP >>NP).
-900 to 0	High risk	Sulfides common. Sulfides identified as 2nd and 3rd mineral < 75 %. No primary neutralisers (AP >NP).
0 to 10,000	Potential risk	Dominated by silica/quartz, sericite, chlorite. Few sulfides present, minor primary neutralisers (AP≠NP). Some gypsum present.
10,000 to 40,000	Low risk	Carbonate abundance < 50 % (AP<NP).
40,000 to 100,000	Very low risk	Carbonate dominates as first Corescan mineral > 50 %. Long term acid neutralising capacity likely (AP<<NP).

Jackson et al. (2018)

corescan

Hyperspectral mineralogy

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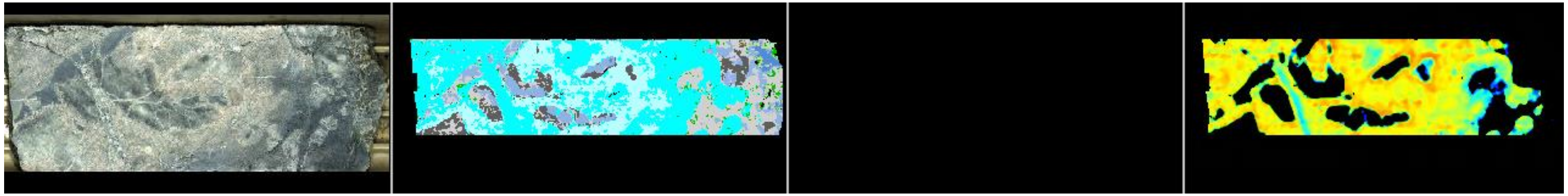
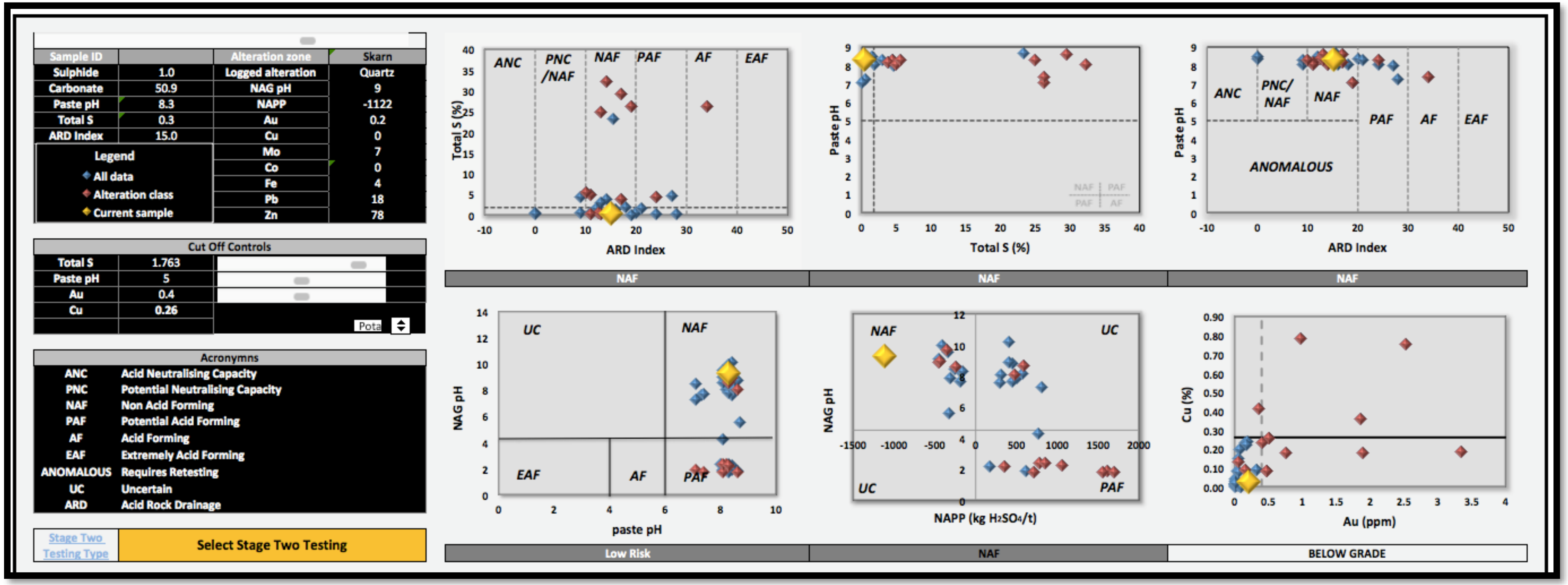
Sample A: Skarn

Core photography | Classified mineral map | Sulfide recognition | Carbonate identification



GDI V2:
34,370
Low risk



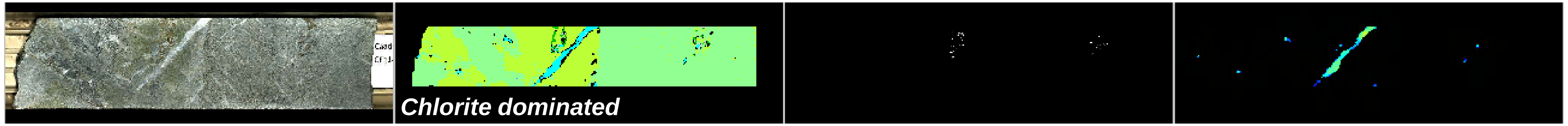
Static testing=
NAF
(High ANC)

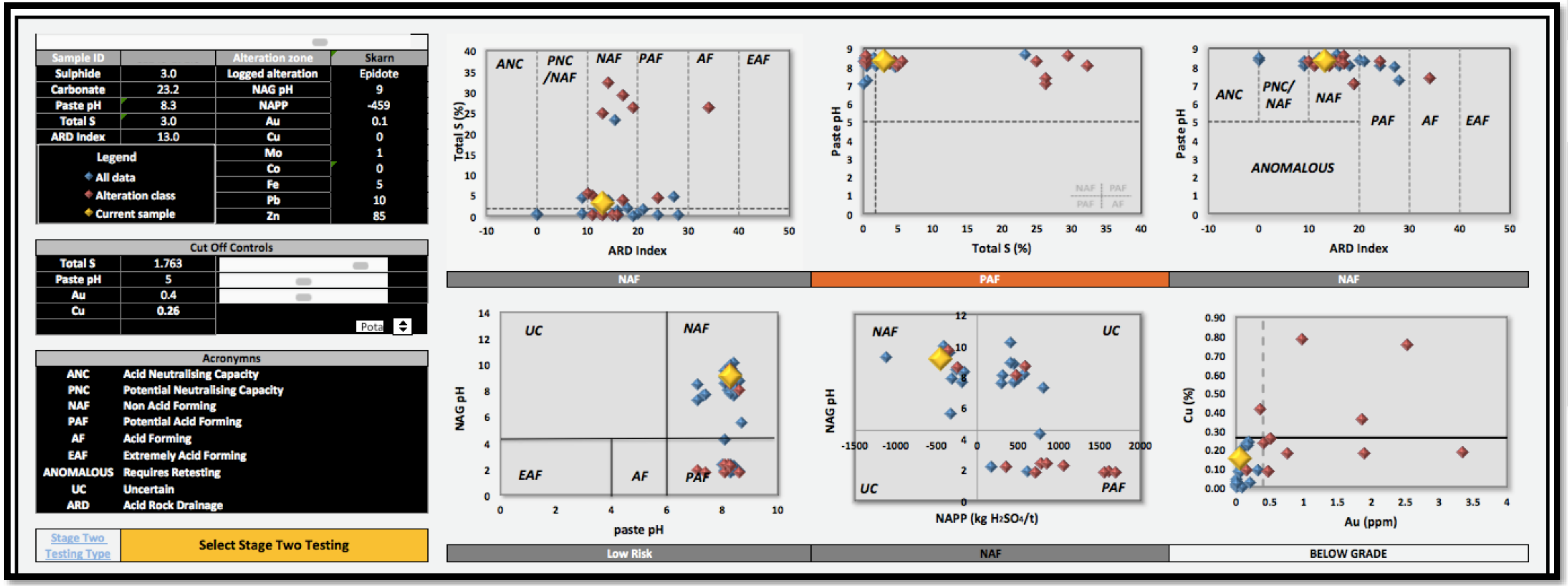
Jackson et al. (2018)

corescan

Hyperspectral mineralogy

Sample B: Skarn





Sample ID		Alteration zone	Skarn
Sulphide	3.0	Logged alteration	Epidote
Carbonate	23.2	NAG pH	9
Paste pH	8.3	NAPP	-459
Total S	3.0	Au	0.1
ARD Index	13.0	Cu	0
		Mo	1
		Co	0
		Fe	5
		Pb	10
		Zn	85

Legend
- All data
- Alteration class
- Current sample

Cut Off Controls	
Total S	1.763
Paste pH	5
Au	0.4
Cu	0.26

Acronymns	
ANC	Acid Neutralising Capacity
PNC	Potential Neutralising Capacity
NAF	Non Acid Forming
PAF	Potential Acid Forming
AF	Acid Forming
EAF	Extremely Acid Forming
ANOMALOUS	Requires Retesting
UC	Uncertain
ARD	Acid Rock Drainage

GDI V2:
1910
Potential risk

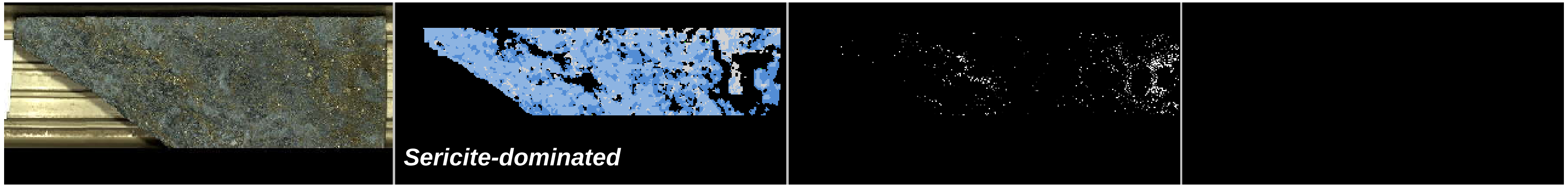
Static testing=
NAF (3% sulfide-sulfur; 23% calcite)

Jackson et al. (2018)

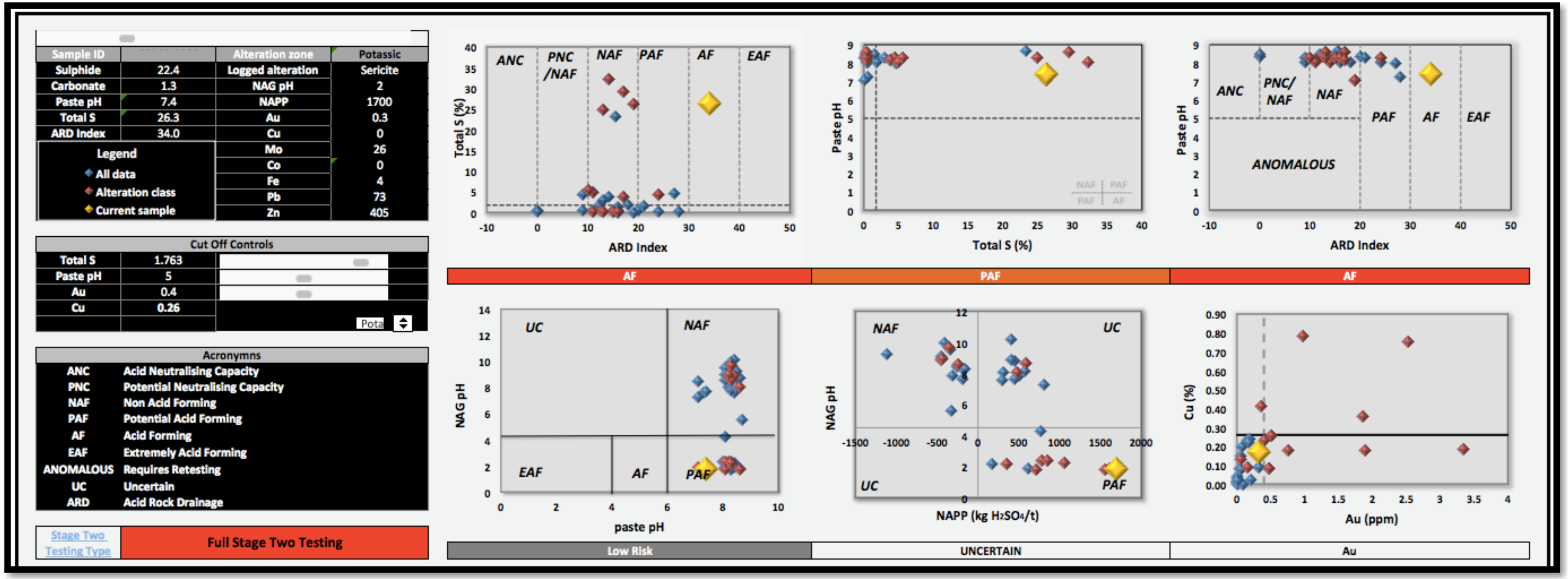
Hyperspectral mineralogy

Sample C: Potassic Zone

Core photography | Classified mineral map | Sulfide recognition | Carbonate identification



GDI V2:
-140=
High risk



Sample ID		Alteration zone	Potassic
Sulphide	22.4	Logged alteration	Sericite
Carbonate	1.3	NAG pH	2
Paste pH	7.4	NAPP	1700
Total S	26.3	Au	0.3
ARD Index	34.0	Cu	0
Legend		Mo	26
All data		Co	0
Alteration class		Fe	4
Current sample		Pb	73
		Zn	405

Cut Off Controls	
Total S	1.763
Paste pH	5
Au	0.4
Cu	0.26

Acronyms	
ANC	Acid Neutralising Capacity
PNC	Potential Neutralising Capacity
NAF	Non Acid Forming
PAF	Potential Acid Forming
AF	Acid Forming
EAF	Extremely Acid Forming
ANOMALOUS	Requires Retesting
UC	Uncertain
ARD	Acid Rock Drainage

Stage Two Testing Type	Full Stage Two Testing

Static testing=
PAF/AF

Jackson et al. (2018)

Hyperspectral mineralogy

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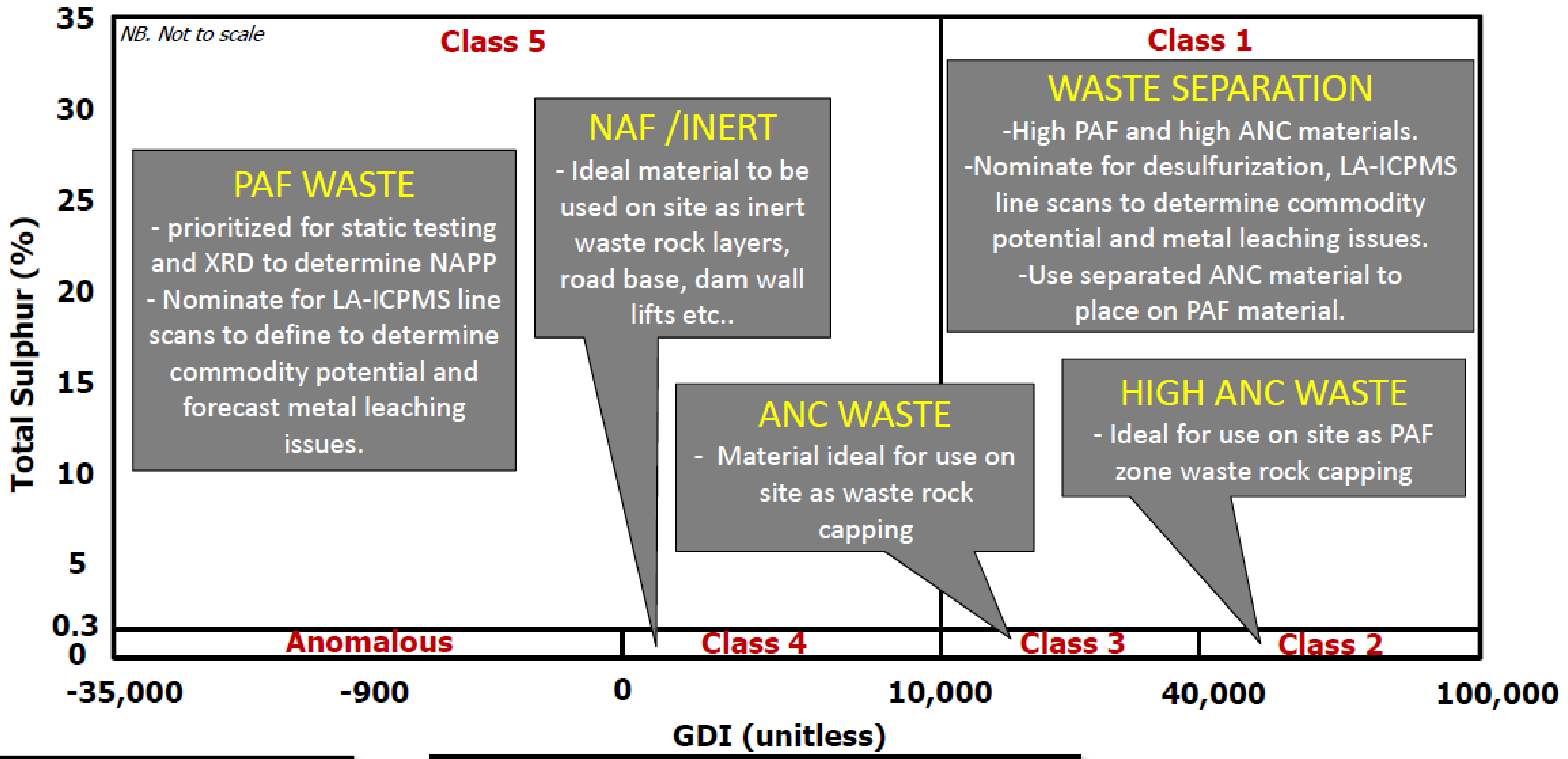


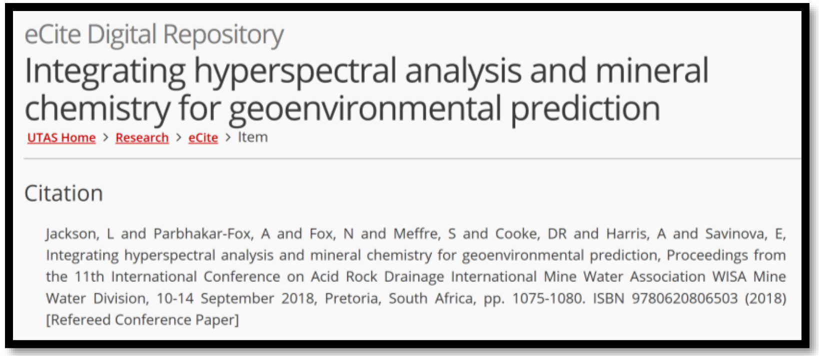
minerals MDPI

Article

Forecasting Geoenvironmental Risks: Integrated Applications of Mineralogical and Chemical Data

Anita Parbhakar-Fox [1,*], Nathan Fox [2], Laura Jackson [1] and Rebekah Cornelius [1]

1 ARC Transforming the Mining Value Chain Industrial Transforming Research Hub, University of Tasmania, Private Bag 79, Hobart, Tasmania 7001, Australia; lauraj0@utas.edu.au (L.J.); rebekah.k.cornelius@gmail.com (R.C.)
2 CRC for Optimising Resource Extraction, University of Tasmania, Private Bag 79, Hobart, Tasmania 7001, Australia; nathan.fox@utas.edu.au
* Correspondence: anitap1@utas.edu.au; Tel.: +61-4-00850831



eCite Digital Repository

Integrating hyperspectral analysis and mineral chemistry for geoenvironmental prediction

UTAS Home > Research > eCite > Item

Citation

Jackson, L and Parbhakar-Fox, A and Fox, N and Meffre, S and Cooke, DR and Harris, A and Savinova, E, Integrating hyperspectral analysis and mineral chemistry for geoenvironmental prediction, Proceedings from the 11th International Conference on Acid Rock Drainage International Mine Water Association WISA Mine Water Division, 10-14 September 2018, Pretoria, South Africa, pp. 1075-1080. ISBN 9780620806503 (2018) [Refereed Conference Paper]

Additional applications when scanning column feed materials prior to kinetic testing – results to be published later in 2019

Handheld tools and chemical tests

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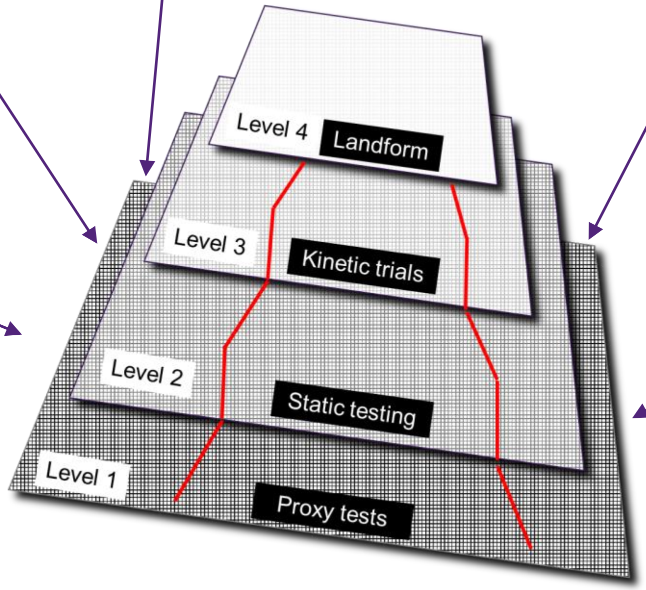
Environmental Logging

Chemical Staining

Hardness measurements

pXRF



Field chemical tests

Not all are new, but not routinely applied for geoenvironmental characterisation

Integration of results provides the best quality information to feed into the geometallurgical matrix

Acid Rock Drainage Index (ARDI)

- Sulphide content: *(0 to 10)*
- Sulphide alteration: *(0 to 10)*
- Sulphide morphology : *(0 to 10)*
- Carbonate content : *(-5 to 10)*
- Mineral association : *(-5 to 10)*

Extremely acid forming

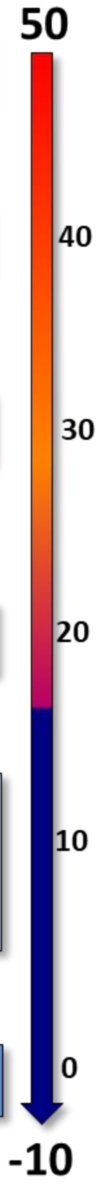
Acid forming

Potentially acid forming

Non-acid forming

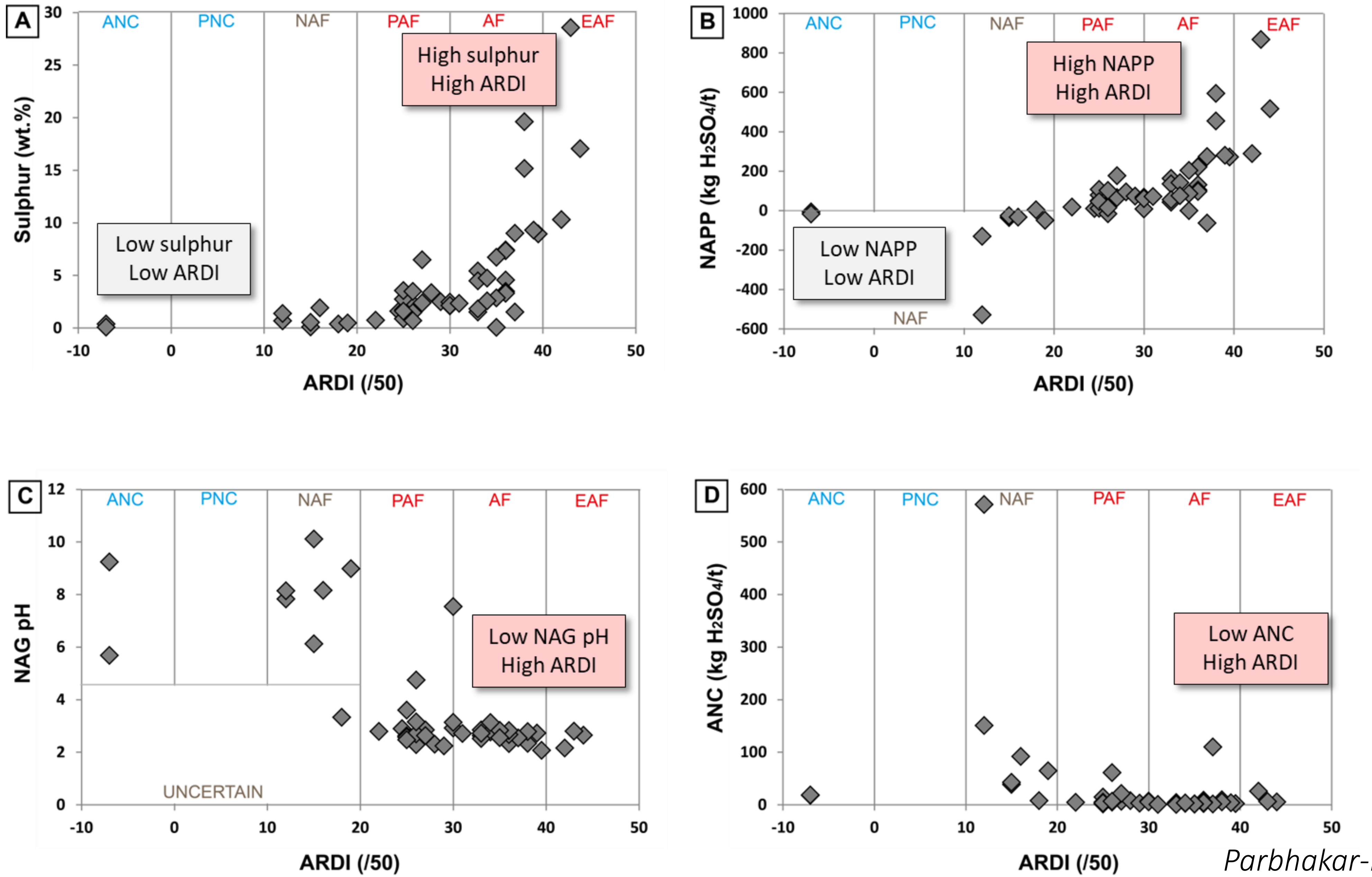
Non-acid forming/ potential neutralising capacity

Acid neutralising capacity



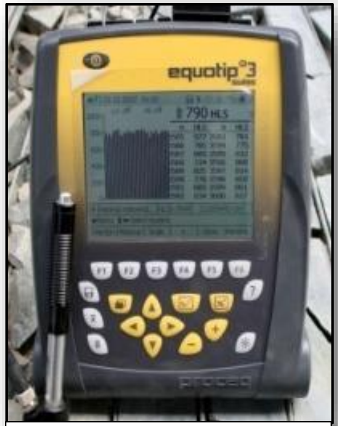
Parbhakar-Fox et al. (2011; 2018)

Handheld tools and chemical tests



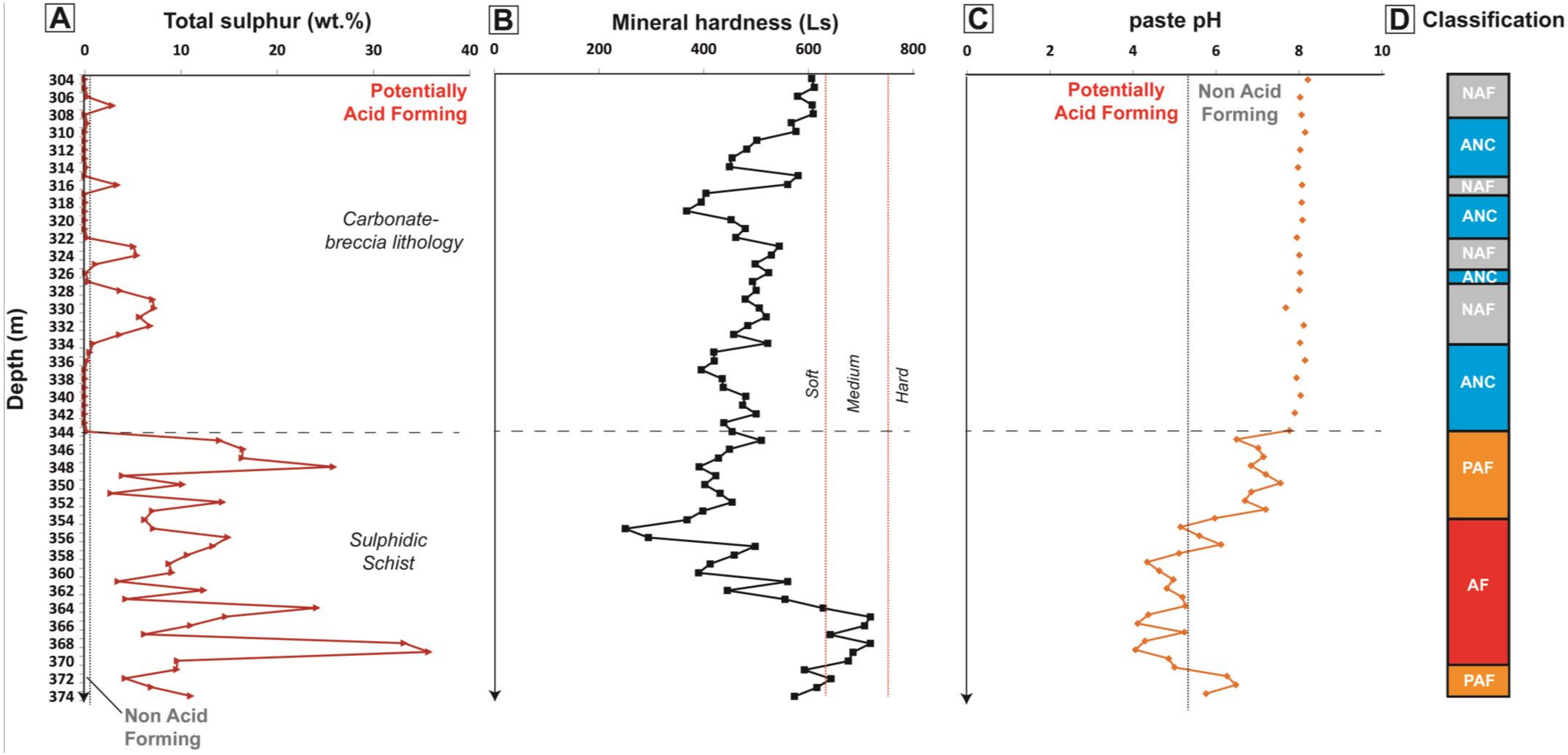
Parbhakar-Fox et al. (2015)

Handheld tools and chemical tests



EQUOtip

Mineral hardness to determine rate of weathering and predict elution of acid/ neutralisation



Parbhakar-Fox et al. (2015)

Handheld tools and chemical tests

Alizarin Red-S (2g) + Potassium Ferricyanide (2g)

↓

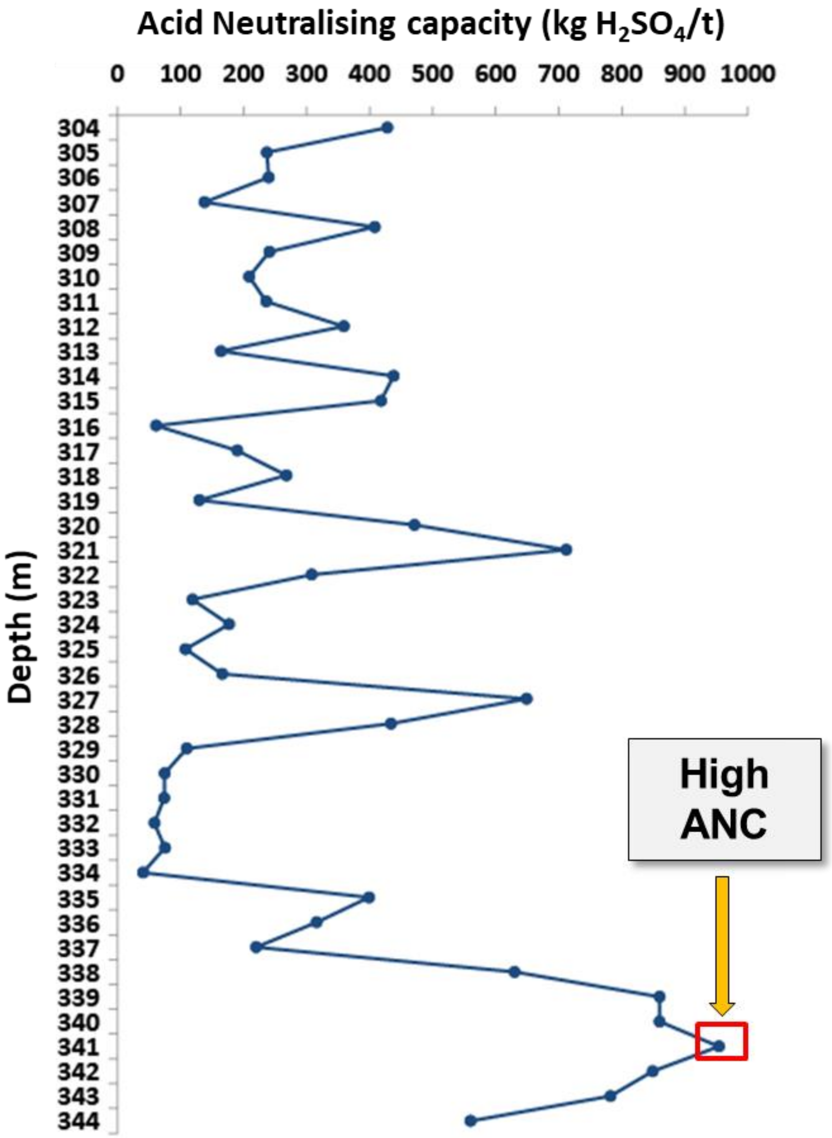
250 ml HCl (2%)

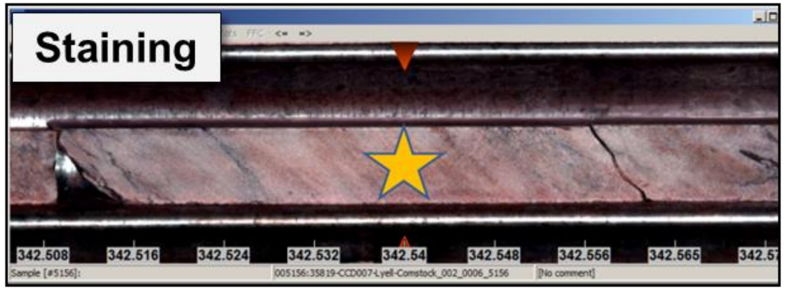
↓

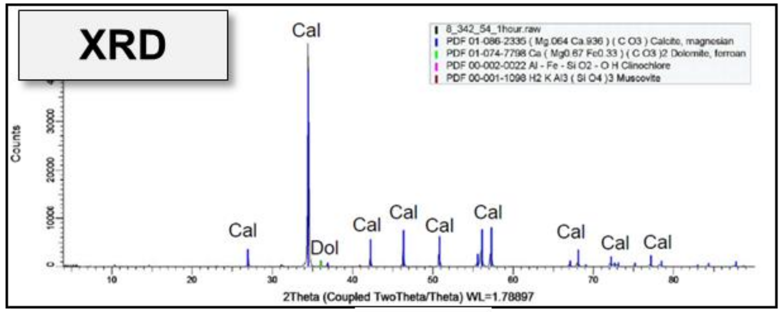
Apply several coats of stain

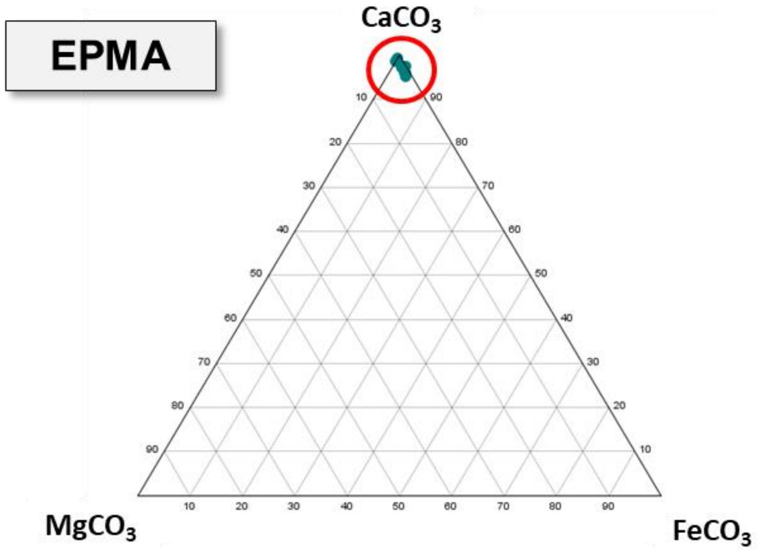
↓ calcite: red

↓ ferroan dolomite: blue





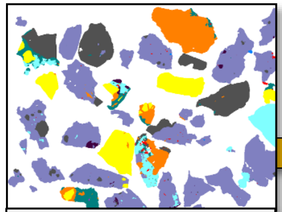




Parbhakar-Fox et al. (2015)

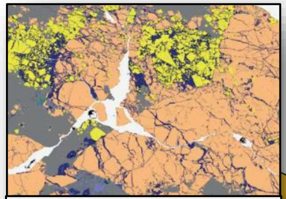
Automated mineralogy

Mineral Liberation Analyser

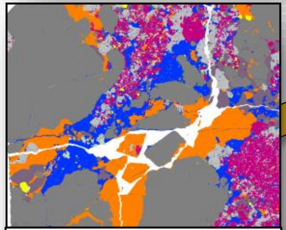


SPL Lite

→ Target sulphide phases & characterise grain properties → *Hours* → **Buckwalter-Davis (2013)** Six tailings samples New Caloumet mine, Canada



XBSE



GXMAP

→ Characterise grain properties for mineral of interest and examine associations → *Hours* →

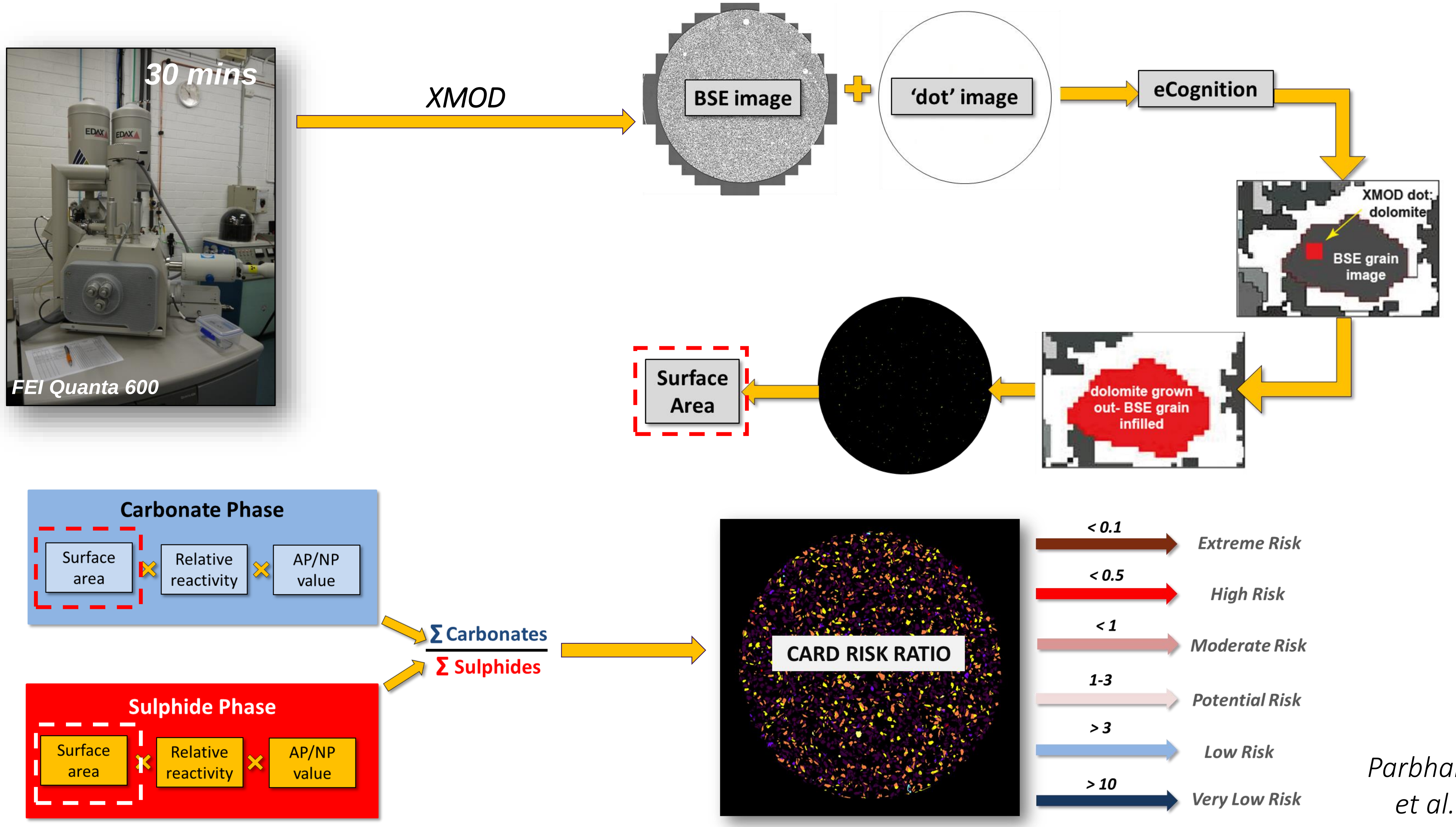
Aranta (2010): 4 waste rock samples, Antamina Mine, Peru
Parbhakar-Fox (2012): 10 waste rock samples, Lode-Au mine, 9 IOCG samples, Australia
Edraki et al. (2014): Cu-Au porphyry tailings

Current practice:
Application in predictive ARD characterisation testwork and tailings characterisation

Commonly used techniques do not allow for low-cost high volume analysis- can XMOD be used?

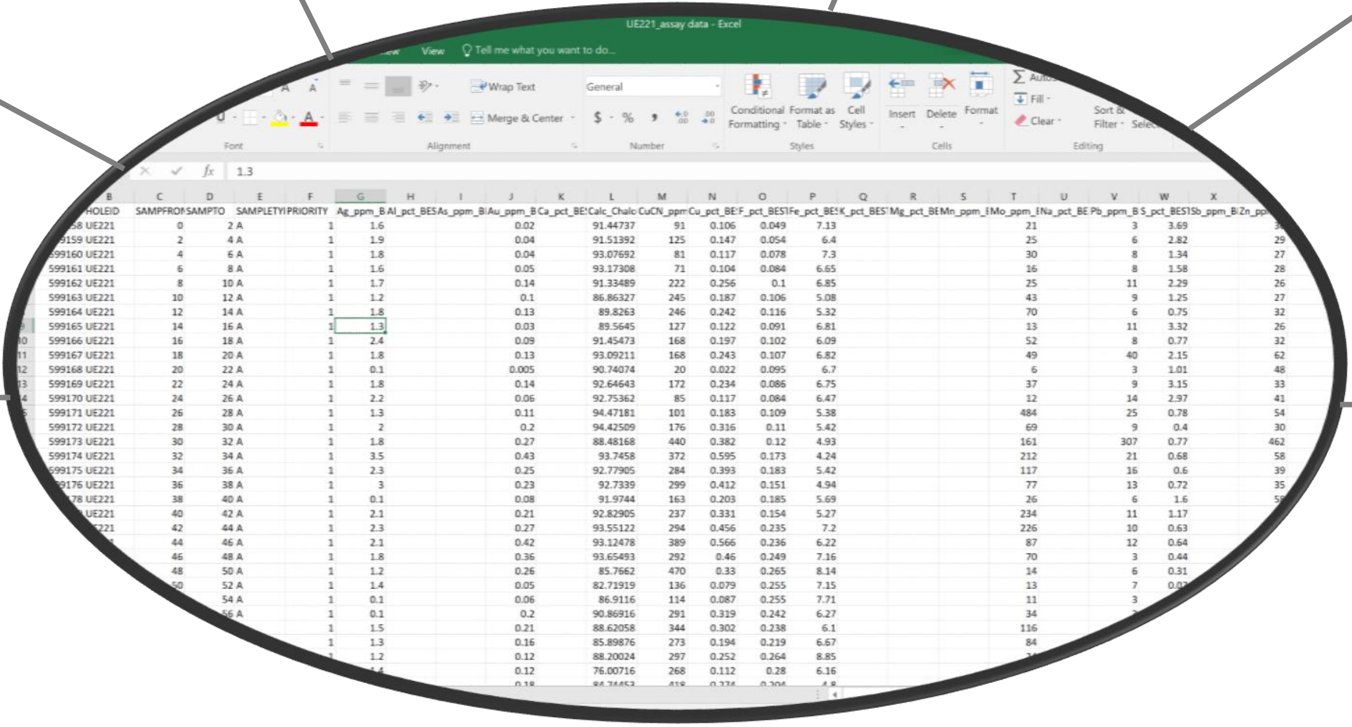
Automated mineralogy

The University Of Queensland
AUSTRALIA



Parbhakar-Fox et al. (2017)

Data mining and machine learning



Matlab

SQL

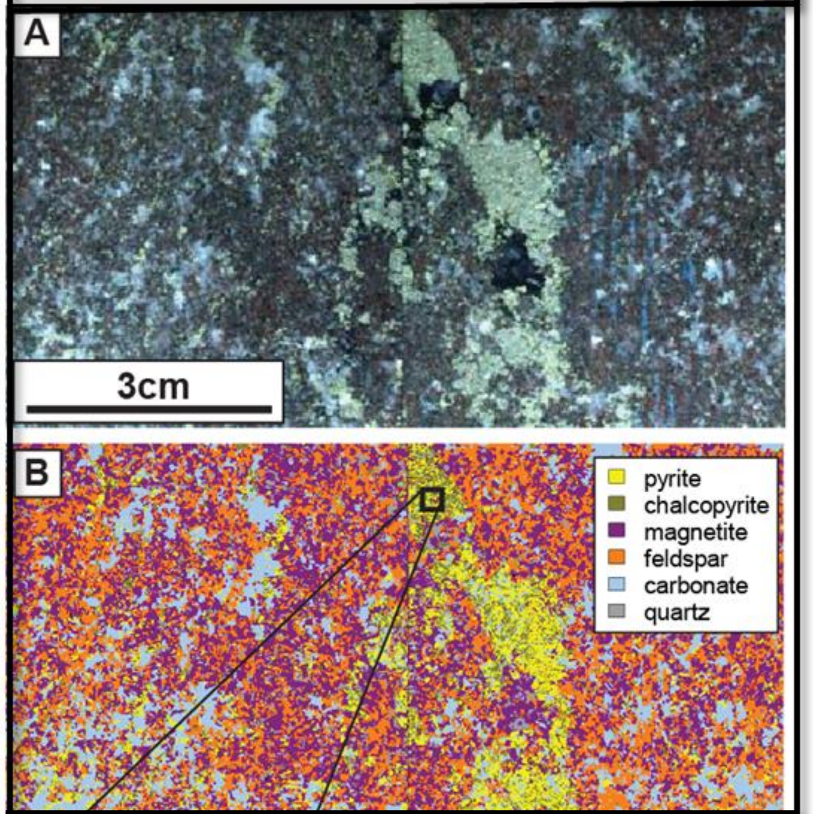
Opportunity to enhance waste domaining e.g., using Ca and Mg from assay (Jackson et al., 2019)

Extract more information from existing data sets e.g., mineralogy and texture (Cracknell et al., 2018)

Calculate mineralogy using assay data (e.g., Berry et al., 2015; Beavis et al. 2017; Howard et al., 2019)

Data mining and machine learning

High-res drill core image

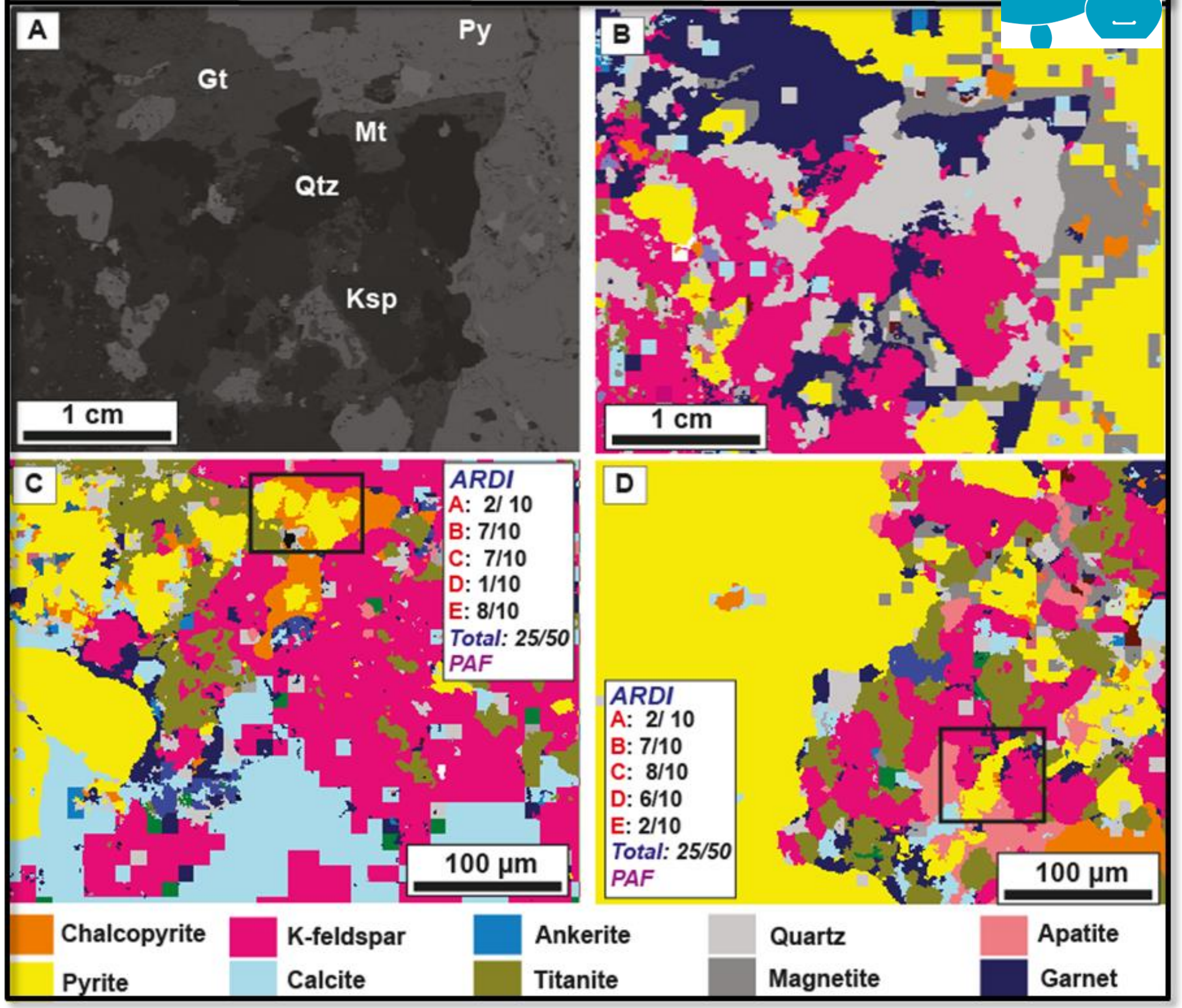


minerals
MDPI
Article

Automated Acid Rock Drainage Indexing from Drill Core Imagery

Matthew J. Cracknell [1,2,*], Anita Parbhakar-Fox [1], Laura Jackson [1,2] and Ekaterina Savinova [3]
1 Transforming the Mining Value Chain, ARC Industrial Transformation Hub, University of Tasmania, Private Bag 79, Hobart, TAS 7001, Australia; anita.parbhakar@utas.edu.au (A.P.-F.); lauraj0@utas.edu.au (L.J.)
2 Centre for Ore Deposit and Exploration Science (CODES), University of Tasmania, Private Bag 79, Hobart, TAS 7001, Australia
3 Corescan Pty Ltd., 1/127 Grandstand Road, Ascot, WA 6104, Australia; katerina.savinova@corescan.com.au

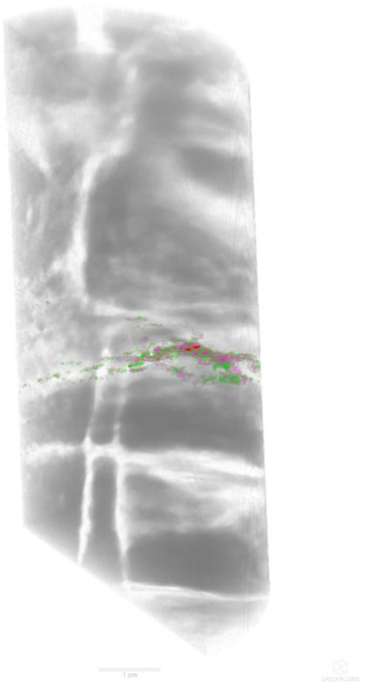
MLA GXMAP image



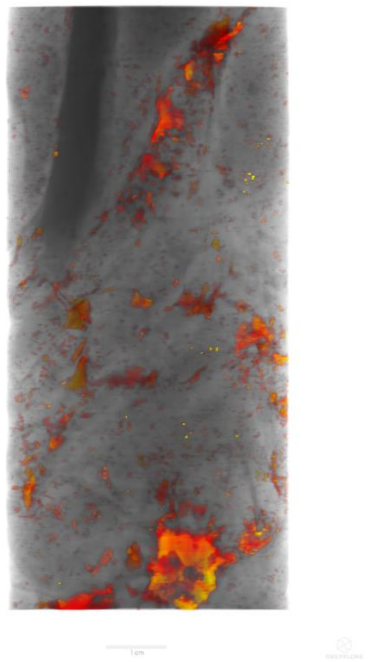
‘Next gen’ technologies

X-ray tomography + XRF

Orexplore core scanning – structural features, ore and gangue phase morphology
(200 µm voxel resolution)



Sulphide distribution - Sunrise Dam



Pyrite – Rio Blanco tourmaline breccia Cu deposit

3D A-ARDI assessments

Mine waste: Ore bodies of the future

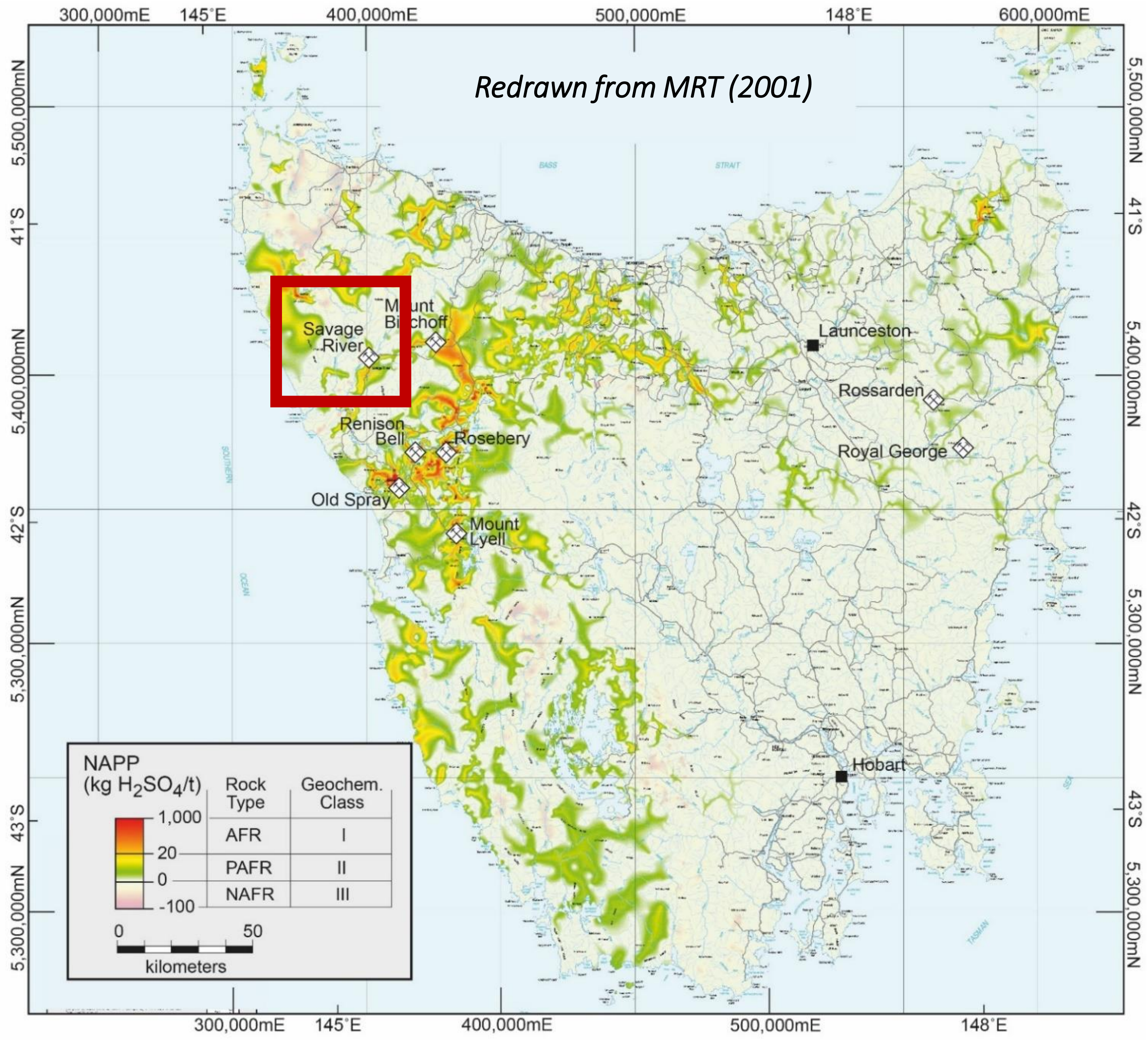
The University Of Queensland
AUSTRALIA

New cobalt resources

Tin and gold from historic tailings

Zinc from slag

New indium resources?



MMG

GRANGE RESOURCES

METALS X LIMITED

vedanta transforming elements

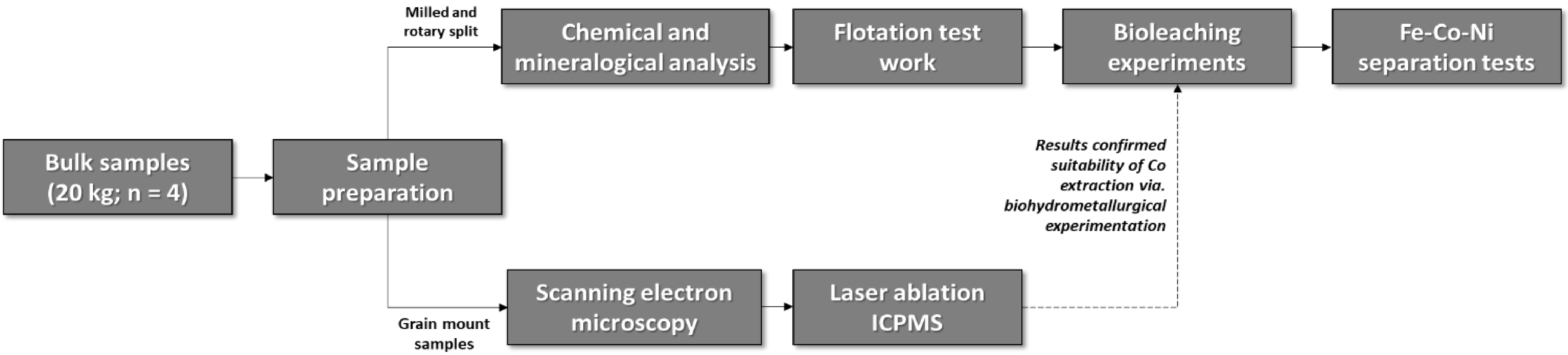
ELEMENTOS LIMITED

nq minerals

TARTANA RESOURCES LIMITED

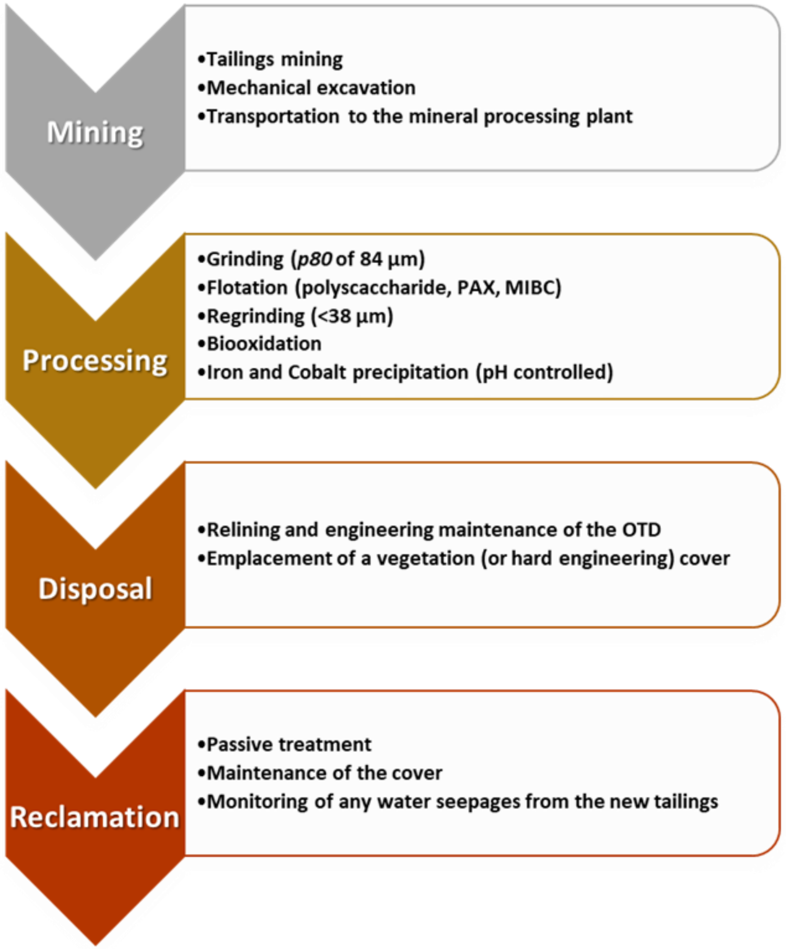
Mine waste: Ore bodies of the future

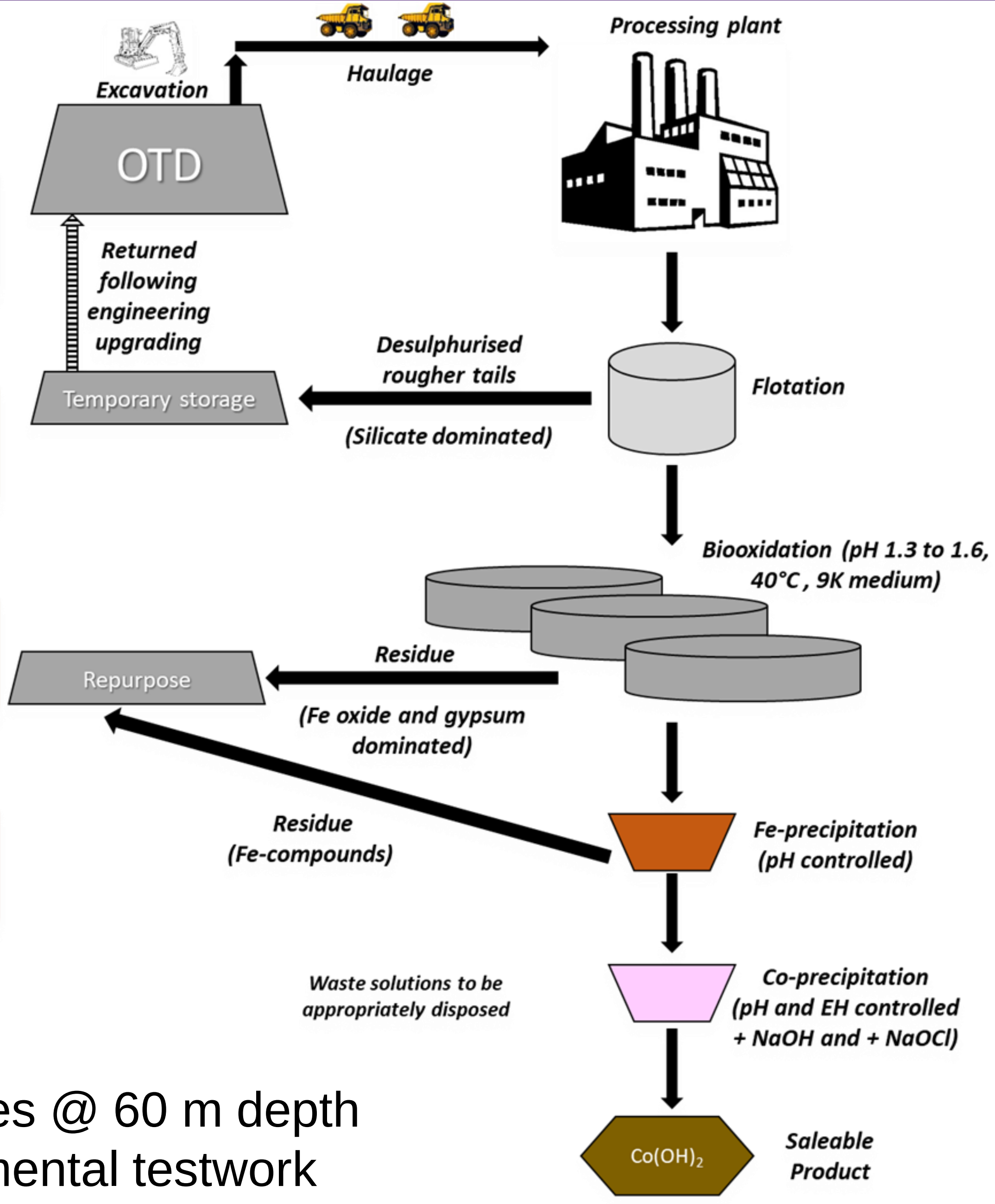
The University Of Queensland
Australia



Parbhakar-Fox et al. (2018): https://www.mdpi.com/2075-163X/8/10/454

Mine waste: Ore bodies of the future





Planning to return and drill up to 5 drill holes @ 60 m depth perform geometallurgical and geoenvironmental testwork

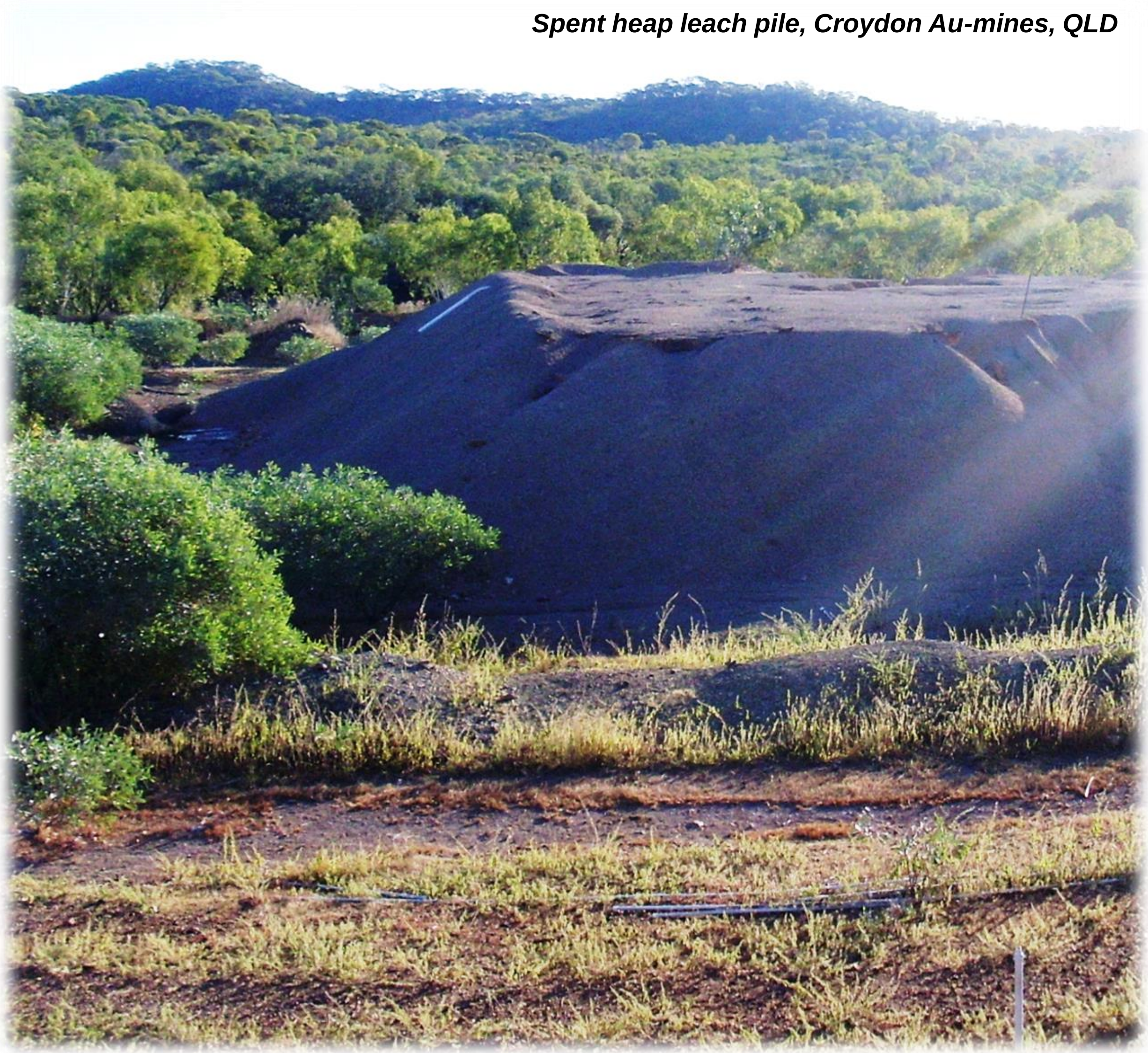
Additional uses of geometallurgy data and tools

Forecast the potential for future mine wastes to fix atmospheric CO_2 (using TIR data): Develop GHG consumption index

Identify 'soft' zones based on classified mineralogy: Predictive dust characterisation protocol

Spent heap leach materials: identify and characterise post-leach mineralogy (e.g., alunite-group)

Spent heap leach pile, Croydon Au-mines, QLD



‘Enviro’ opportunities in geometallurgy

The University of Queensland
Australia

“Transform how explorers and miners plan and predict mining and environmental activities, by providing new tools to guide these activities from the initial discovery through to end of mine life”

Mineralogical & chemical data analysis to predict AMD characteristics

‘Next gen’ technologies and new chemical testing

Sensor-based waste assessments during operational stages

Tailings ‘fingerprinting’ during deposition

Characterisation of historic mine sites and waste to determine reuse

New assessment tools and processing approaches

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Thank you

Sustainable Minerals Institute
University Experimental Mine
40 Isles Road, Indooroopilly, QLD 4068

T +61 7 3365 5977 M +61 400 850831
E a.parbhakarfox@uq.edu.au