Prediction of Water Quality Downstream of Mines

West Coast and Southland, New Zealand

J. Pope & D. Craw

Mine Drainage Framework

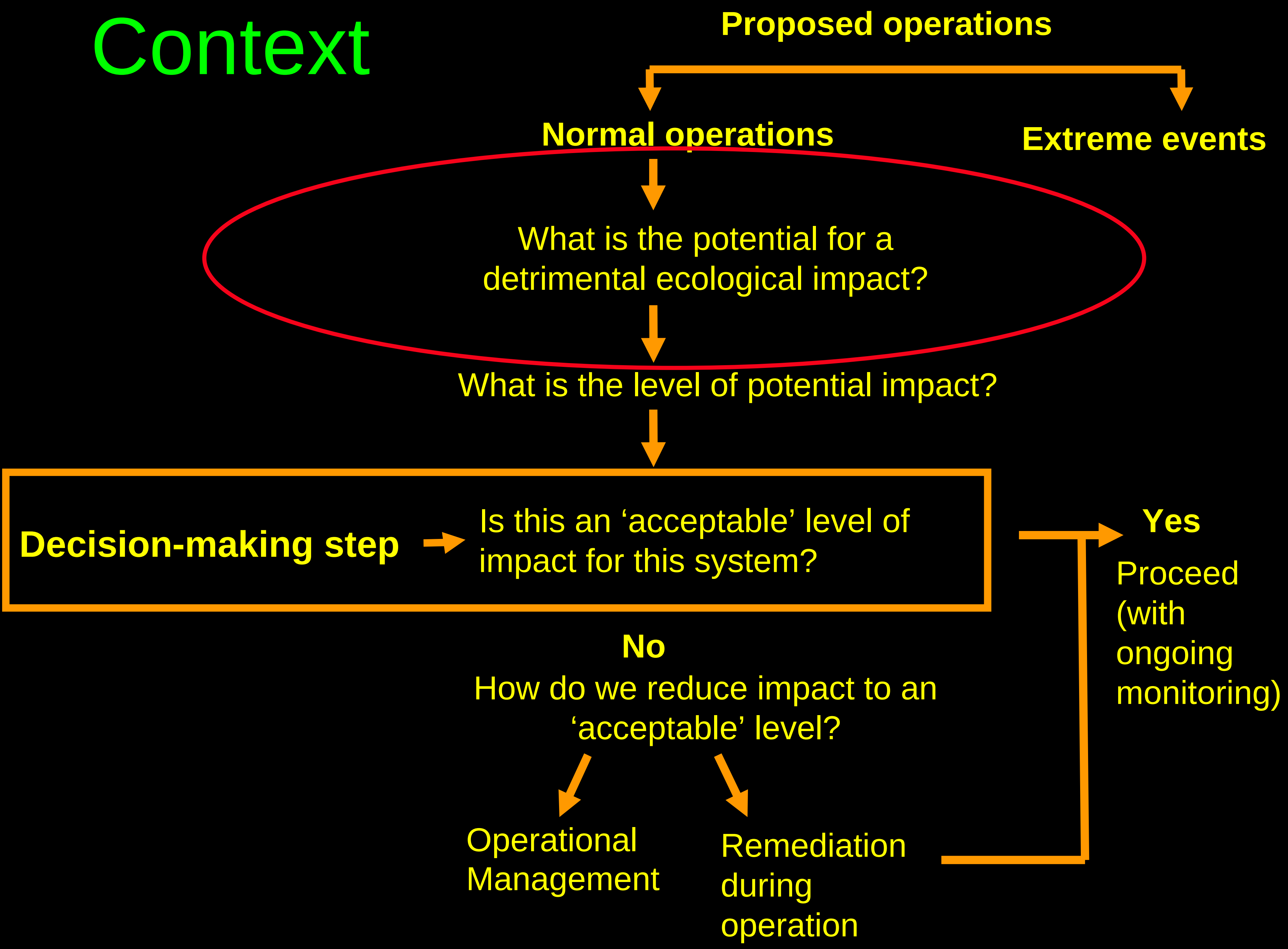
Manaaki Whenua Landcare Research

University of Otago
Te Whare Wānanga o Otāgo

CRL Energy Ltd

UC University of Canterbury
Te Whare Wānanga o Waitaha
Christchurch New Zealand

Context



Proposed operations

Normal operations

Extreme events

What is the potential for a detrimental ecological impact?

What is the level of potential impact?

Decision-making step

Is this an ‘acceptable’ level of impact for this system?

Yes

Proceed (with ongoing monitoring)

No

How do we reduce impact to an ‘acceptable’ level?

Operational Management

Remediation during operation

Contents

1. Introduction - objectives

2. What information do we need?
   - Regional and background information
   - Rock analysis
   - Integration of site specific information

3. How does the Framework Document help?
   - Case study – coal & potentially acid forming

4. Summary – take home messages

5. Where too from here?

1 Objectives of Framework: Geochemistry

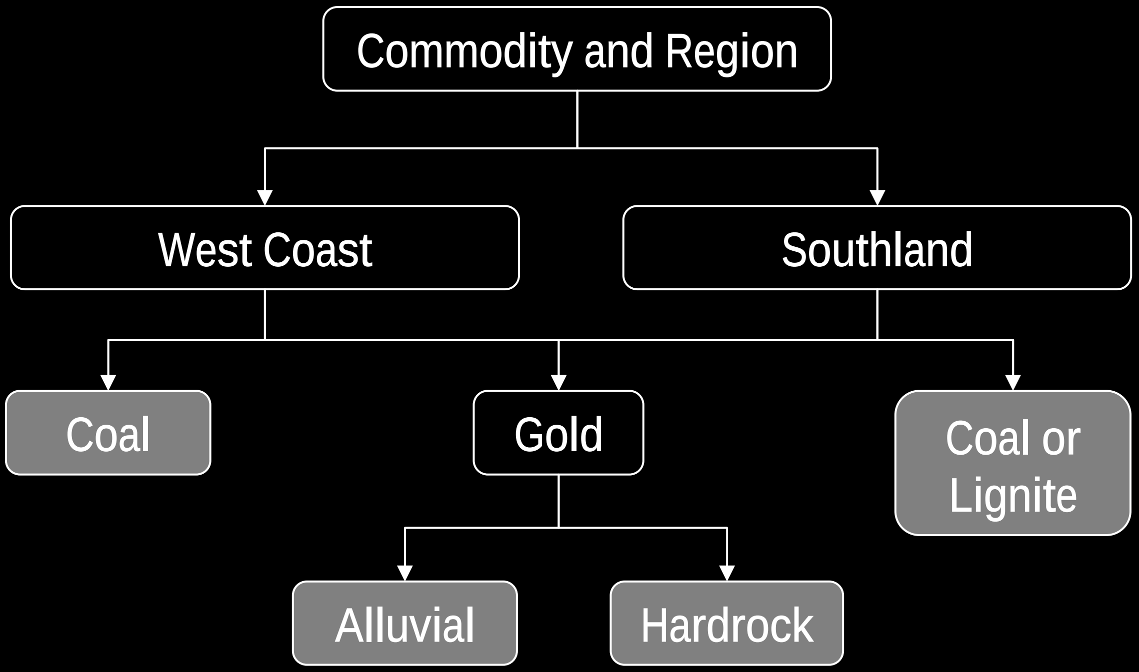
- What do we really want from the Framework?
  - Identify areas with potential for acidity or trace element issues before we have them

    - Identify relevant (and irrelevant) data sources
    - Determine appropriate methods
    - Determine appropriate quantity of information
    - Predict water quality
  - Relate data to access and consent process

2 What information do we need?

2.1 Background information

- Commodity and region



Commodity and Region

West Coast

Southland

Coal

Gold

Coal or Lignite

Alluvial

Hardrock

- Geological Formation

Geological Formation

- What is a geological formation?
  - Eg Paparoa Coal Measures

- Why are they useful?
  - Predictable characteristics including geochemistry

- What can I find out about them?
  - More than you ever want to know!
  - Importantly – location and extent

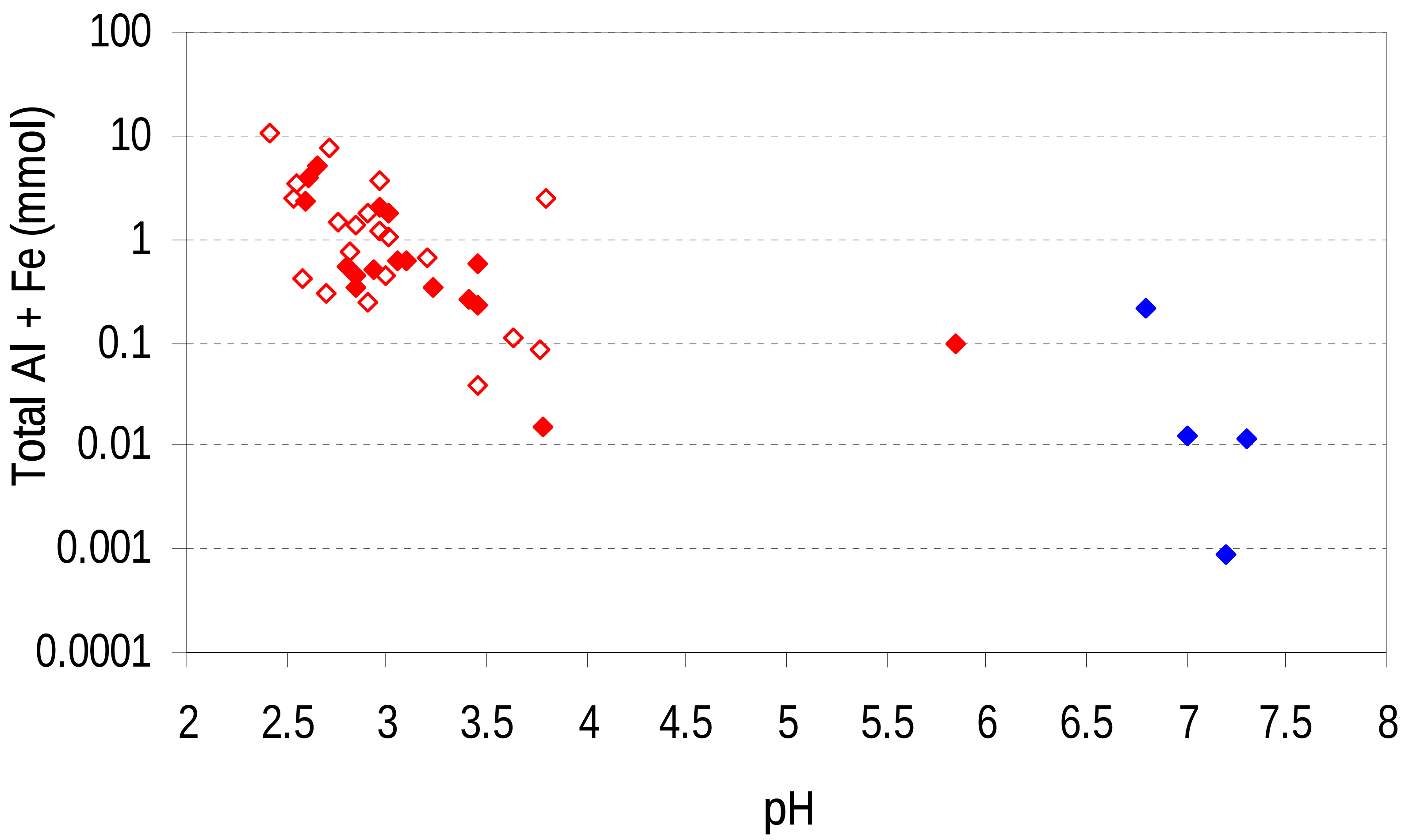
- Some data with mine drainage implications
  - PAF, NAF and trace elements

Geological Formation

- In summary – what can we get from background information

- Indicative information on mine drainage chemistry based on geological interpretations and previous published results

Paparoa and Brunner Mine Drainage



2.2 Rock Analyses - Sampling

- Strategy
  - Initial quantification of acid production potential or trace element content
    - Sample representative rock types
    - Sample rocks with implications for mine drainage chemistry
      - Sulphide or carbonate rich
    - Samples must be ‘fresh’ preferably drill core

- Quantity of samples
  - Initial quantification of acid production potential or trace element content
    - 5-10 replicate samples of each rock type
    - Repeat every 500m x 500m of disturbance

Brunner Coal Measures Drill Core

Rock analysis

- Geological description of sample
    - Rocktype and importatnt minerals sulphides, carbonates and others

- Acid production or neutralisation tests

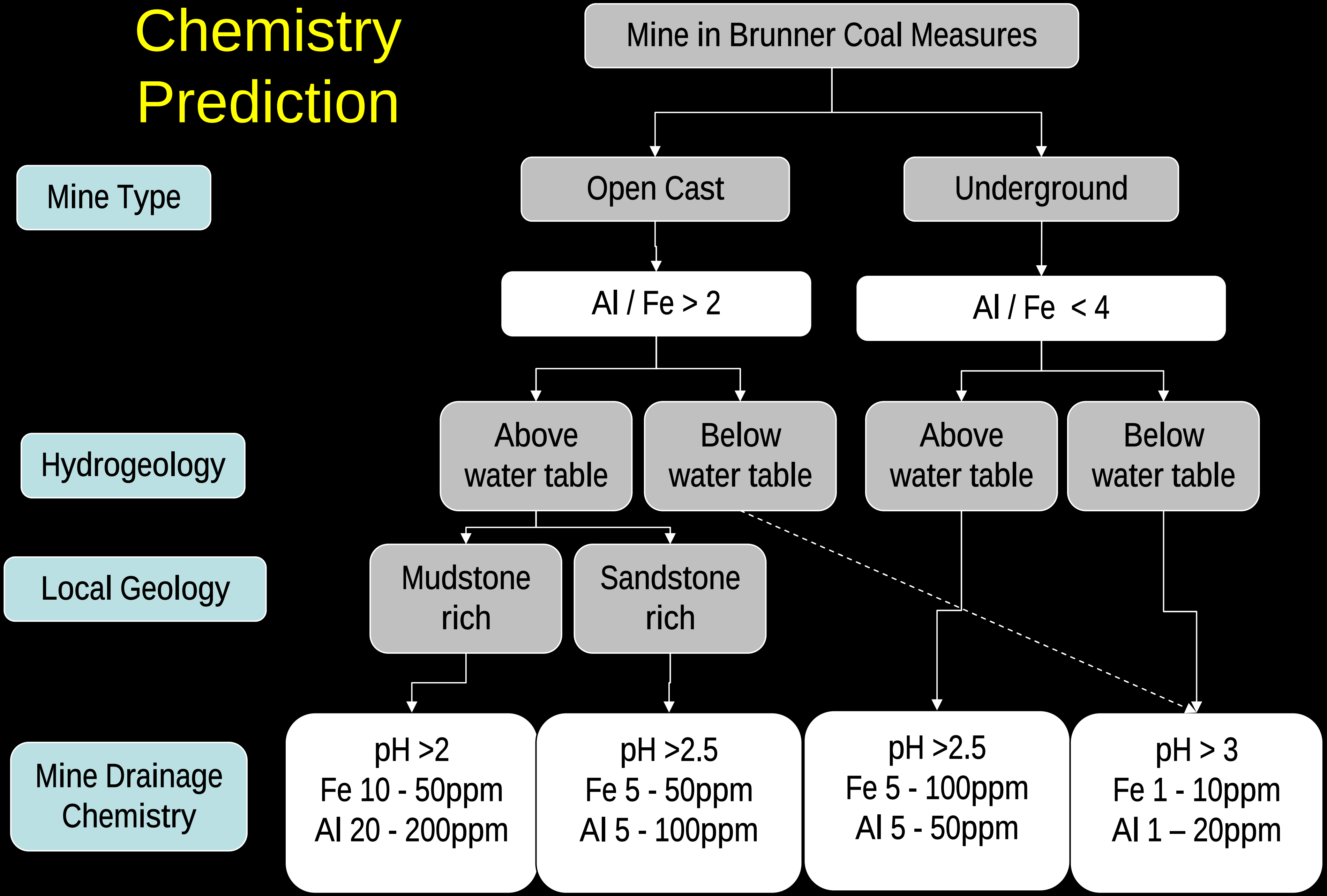
- Trace

- Rock

Acid – Base Accounting

- Maximum potential acidity (MPA)
    - Sulphur speciation
- Acid Neutralising Capacity (ANC)
- Net acid production potential (NAPP)
    - NAPP = MPA – ANC
- Net acid generation (NAG)
    - Organic material

Mine Drainage Chemistry Prediction



Mine in Brunner Coal Measures

Mine Type

Open Cast

Underground

Al / Fe > 2

Al / Fe < 4

Hydrogeology

Above water table

Below water table

Above water table

Below water table

Local Geology

Mudstone rich

Sandstone rich

Mine Drainage Chemistry

pH >2
Fe 10 - 50ppm
Al 20 - 200ppm

pH >2.5
Fe 5 - 50ppm
Al 5 - 100ppm

pH >2.5
Fe 5 - 100ppm
Al 5 - 50ppm

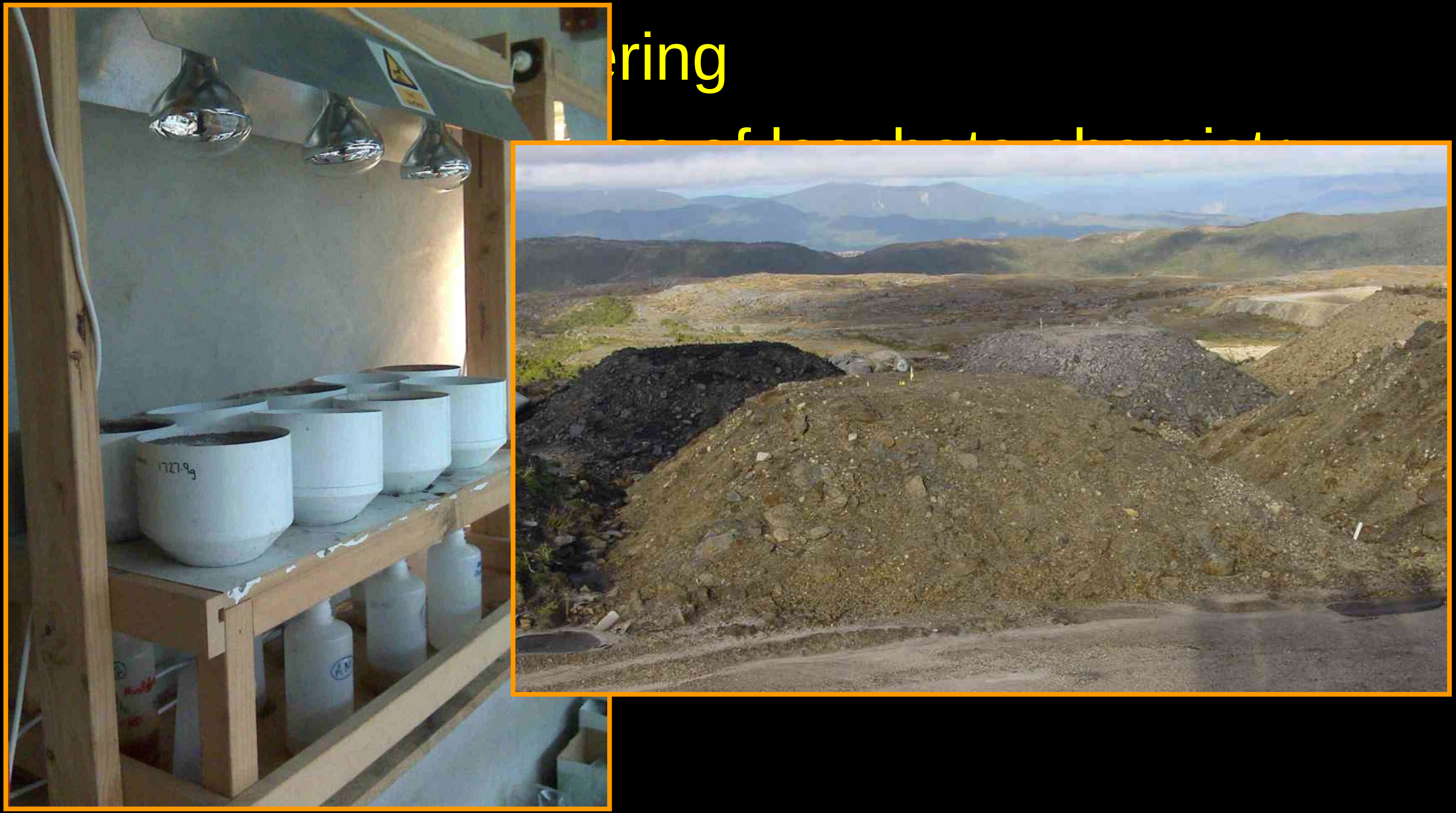
pH > 3
Fe 1 - 10ppm
Al 1 – 20ppm

Rock reactivity tests

- Simulate weathering
- Detailed prediction of leachate chemistry

Rock reactivity tests

ering



2.3 Site specific information

- Background water chemistry
    - Natural upstream water quality
    - Historic mine drainages
    - Natural acid rock drainage

- Surface hydrology
    - Surface flows
    - Seasonal variations

- Groundwater flows if necessary

Mixing mine drainage and other surface water

High Alkalinity

Mixing Zone
Alkalinity consumed
pH increase

$Al(OH)_3$
precipitation
pH decrease

Low pH, high Al

3 How does the framework document assist?

- Provides current background information

- Guidance on appropriate analyses
  - Purpose of analysis
  - Number of analyses
  - Pitfalls

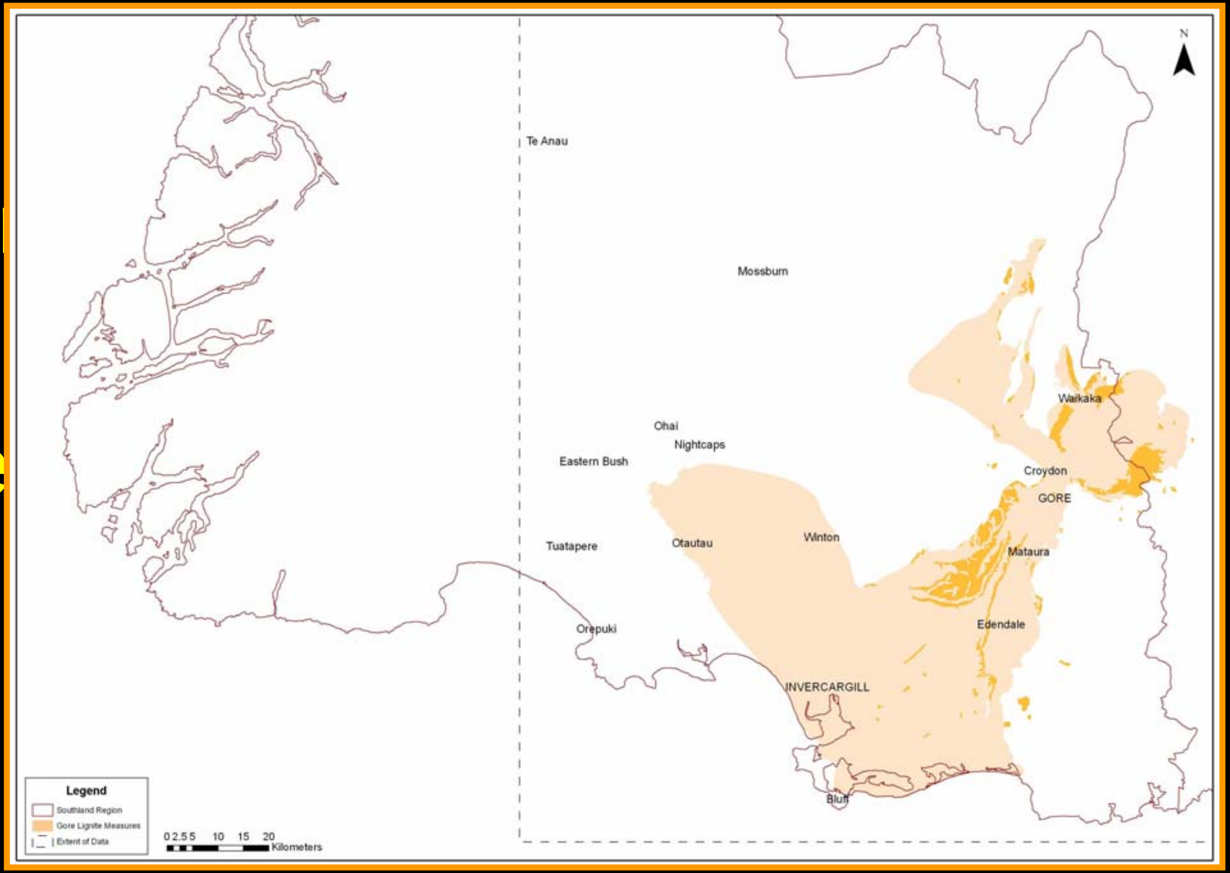
- Information on site specific hydrology requirements
  - Key parameters
  - Methods

Geological formations in the framework

- Geological Summary
- Map
- Mine Drainage Implications – indicative only
- References - geological and mine drainage related

Geological formations in the framework

- Geological Summary
- Map
- Mine Drai
  only
- Reference
  draiange r



Geological formations in the framework

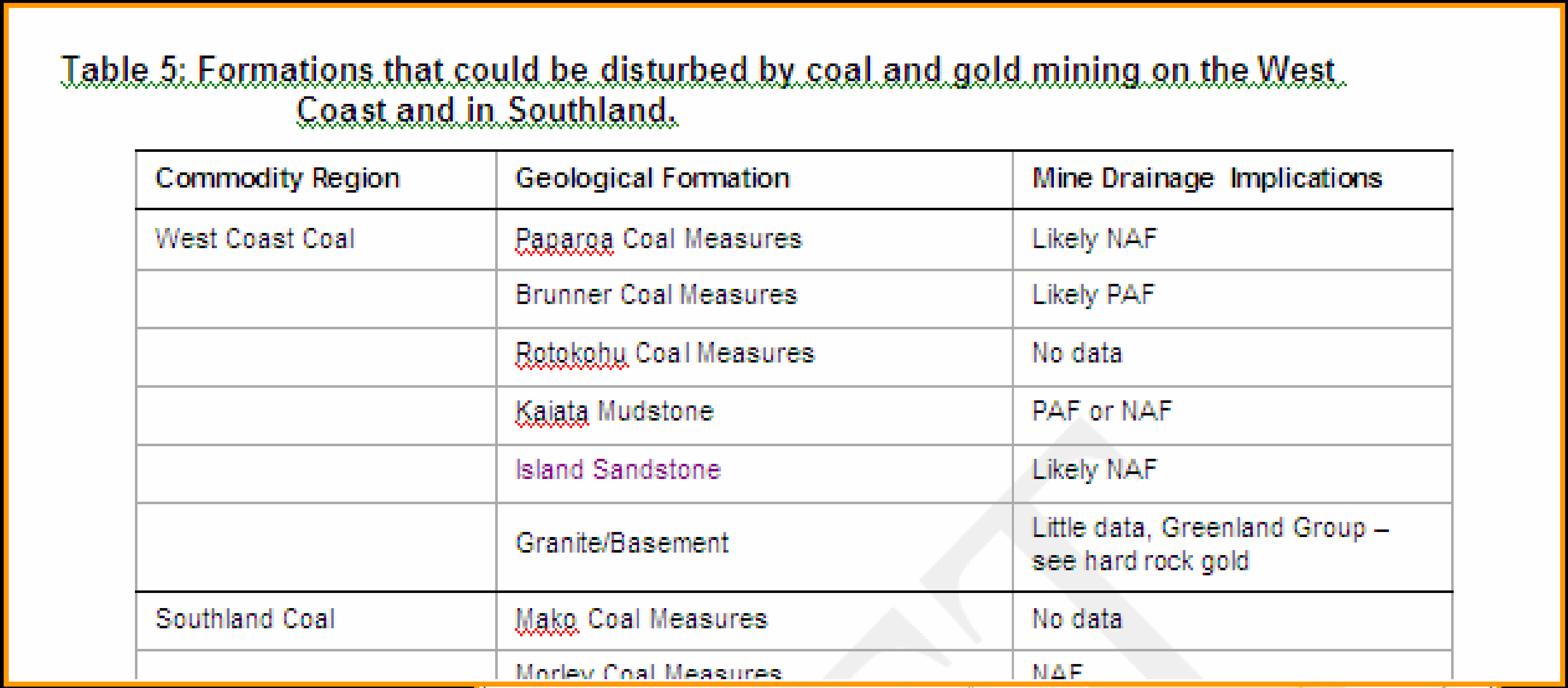
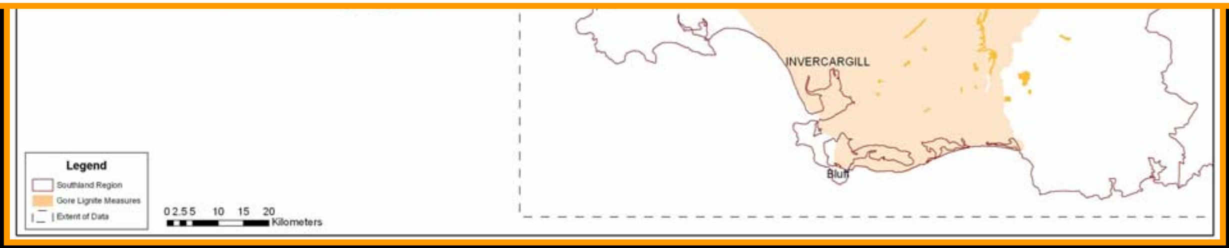


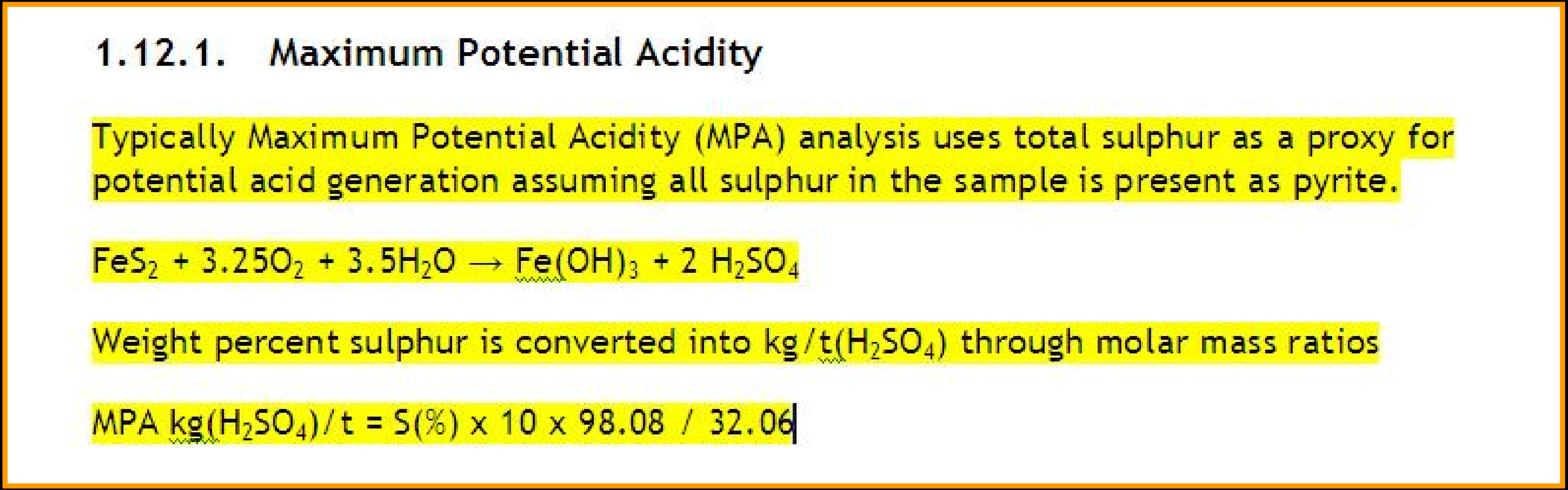
Table 5: Formations that could be disturbed by coal and gold mining on the West Coast and in Southland.

Commodity Region	Geological Formation	Mine Drainage Implications
West Coast Coal	Paparoa Coal Measures	Likely NAF
	Brunner Coal Measures	Likely PAF
	Rotokohu Coal Measures	No data
	Kaiata Mudstone	PAF or NAF
	Island Sandstone	Likely NAF
	Granite/Basement	Little data, Greenland Group – see hard rock gold
Southland Coal	Mako Coal Measures	No data
	Morley Coal Measures	NAF



Rock analyses

- Framework provides
  - Sampling strategy and quantity
  - Description of methods
  - Notes on interpretation
  - Analytical information
  - Limitations or defficiencies in methods



1.12.1. Maximum Potential Acidity

Typically Maximum Potential Acidity (MPA) analysis uses total sulphur as a proxy for potential acid generation assuming all sulphur in the sample is present as pyrite.

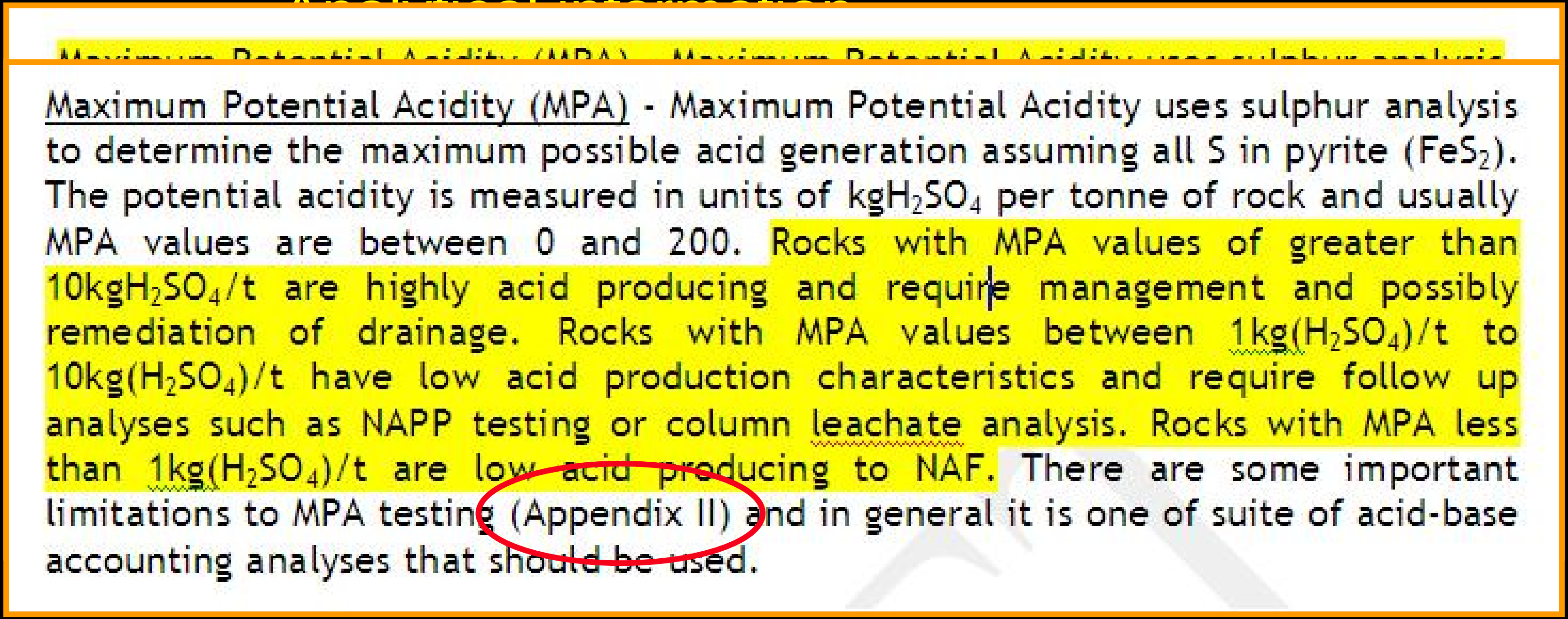
$FeS_2 + 3.25O_2 + 3.5H_2O \rightarrow Fe(OH)_3 + 2\ H_2SO_4$

Weight percent sulphur is converted into kg/t(H_2SO_4) through molar mass ratios

MPA kg(H_2SO_4)/t = S(%) x 10 x 98.08 / 32.06

Rock analyses

- Framework provides
  - Sampling strategy and quantity
  - Description of methods
  - Notes on interpretation
  - Analytical information

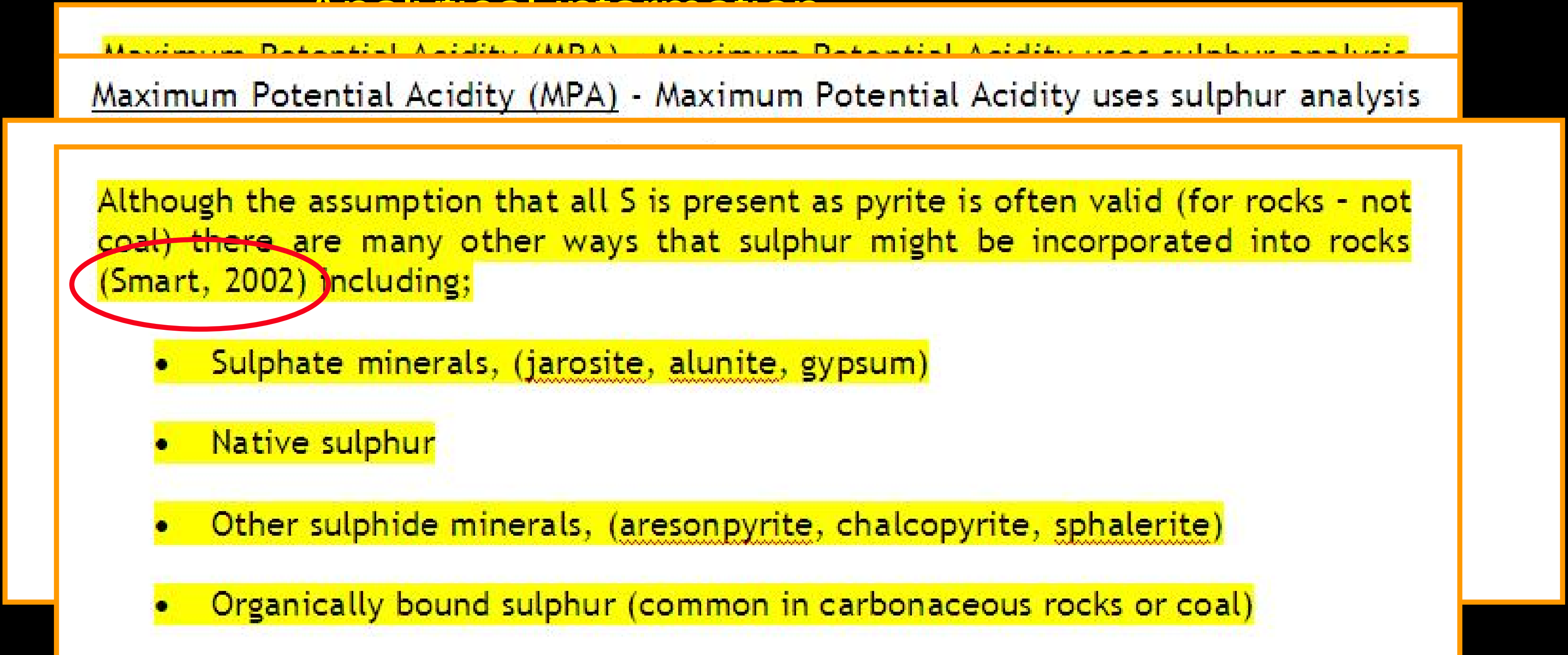


Maximum Potential Acidity (MPA) - Maximum Potential Acidity uses sulphur analysis

Maximum Potential Acidity (MPA) - Maximum Potential Acidity uses sulphur analysis to determine the maximum possible acid generation assuming all S in pyrite (FeS_2). The potential acidity is measured in units of kgH_2SO_4 per tonne of rock and usually MPA values are between 0 and 200. Rocks with MPA values of greater than $10kgH_2SO_4/t$ are highly acid producing and require management and possibly remediation of drainage. Rocks with MPA values between $1kg(H_2SO_4)/t$ to $10kg(H_2SO_4)/t$ have low acid production characteristics and require follow up analyses such as NAPP testing or column leachate analysis. Rocks with MPA less than $1kg(H_2SO_4)/t$ are low acid producing to NAF. There are some important limitations to MPA testing (Appendix II) and in general it is one of suite of acid-base accounting analyses that should be used.

Rock analyses

- Framework provides
  - Sampling strategy and quantity
  - Description of methods
  - Notes on interpretation
  - Analytical information

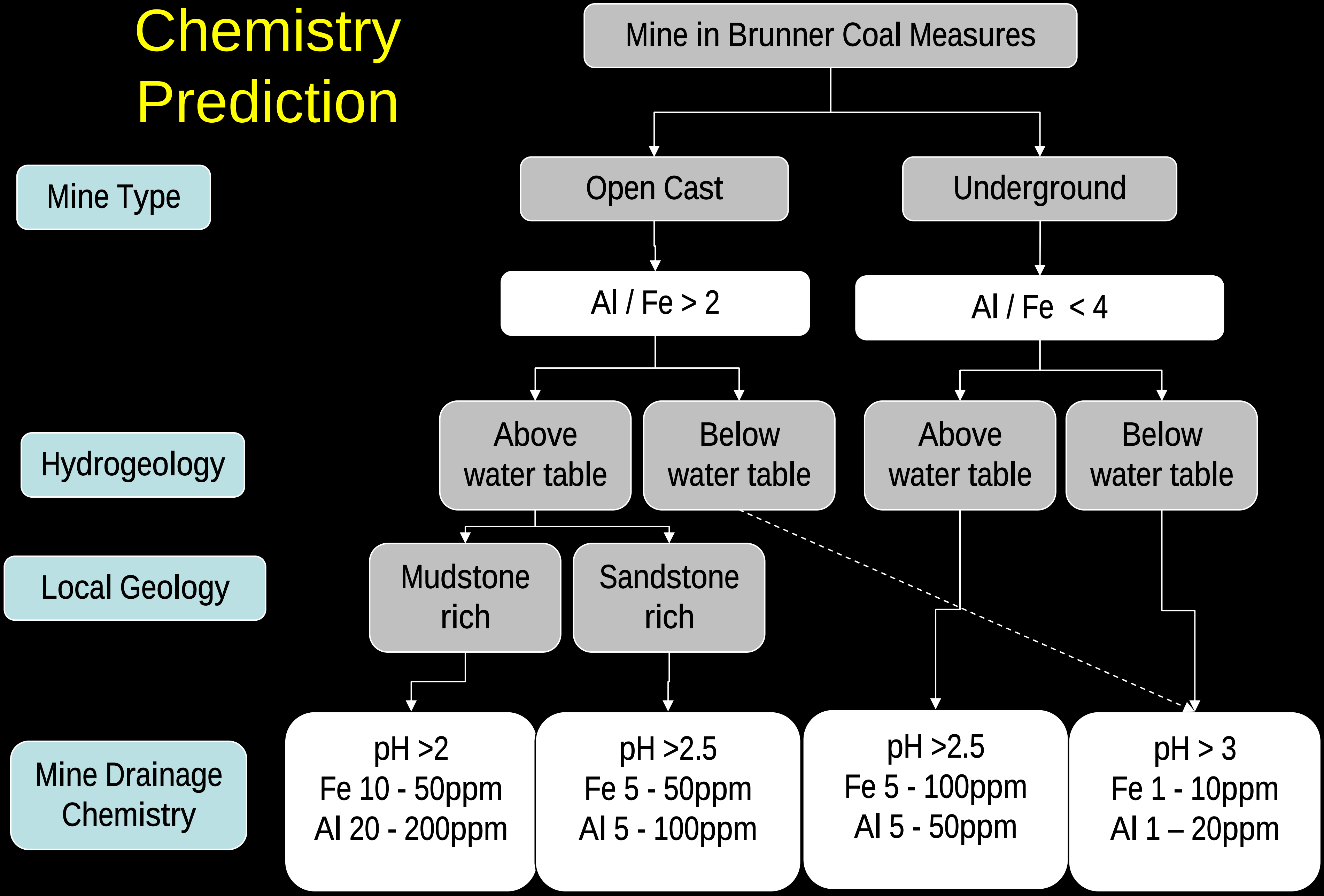


Maximum Potential Acidity (MPA) - Maximum Potential Acidity uses sulphur analysis

Although the assumption that all S is present as pyrite is often valid (for rocks - not coal) there are many other ways that sulphur might be incorporated into rocks (Smart, 2002) including;

- Sulphate minerals, (jarosite, alunite, gypsum)
- Native sulphur
- Other sulphide minerals, (aresonpyrite, chalcopyrite, sphalerite)
- Organically bound sulphur (common in carbonaceous rocks or coal)

Mine Drainage Chemistry Prediction



Mine in Brunner Coal Measures

Mine Type

Open Cast

Underground

Al / Fe > 2

Al / Fe < 4

Hydrogeology

Above water table

Below water table

Above water table

Below water table

Local Geology

Mudstone rich

Sandstone rich

Mine Drainage Chemistry

pH >2
Fe 10 - 50ppm
Al 20 - 200ppm

pH >2.5
Fe 5 - 50ppm
Al 5 - 100ppm

pH >2.5
Fe 5 - 100ppm
Al 5 - 50ppm

pH > 3
Fe 1 - 10ppm
Al 1 – 20ppm

Site specific information

- Why is it important?
    - Mine drainage chemistry vs consent point chemistry

- What sampling protocols should be followed?
    - Filtered samples
        - Dissolved target analytes – Fe, Al, some trace elements
    - Unfiltered samples
        - Particulate target analytes - As
    - Acidified samples
        - Target species that precipitate – Fe, Al
    - Non-acidified samples
        - Target analytes react with acid – alkalinity, suspended solids

Site specific information

- What analytes are important?
    - Coal mine – pH, Fe, Al, selection of trace eleemnts

- Suggestions for flow measurements
    - Stream junctions
    - Flow measurements coincident with samples
    - Substitution with conservative elements
    - Variability
    - Changes in chemistry with flow, flush vs dilution

Consent point water chemistry

- Merge AMD chemistry and site specific information with a reactive transport model

- More detailed chemical data available through leach testing

- Detailed data probably more useful post consent and during site manangment

4 Take Home Messages

1. Types of information that help predict mine drainage chemistry
    - Indicative mine drainage information from Geological Data
    - Require analyses to confirm and predict

2. The number of samples required

3. Site specific data to predict consent point chemistry

4. Some of the complexity and pitfalls prediction process

5. The type of information and level of detail that will be in the Frameword document we’re preparing

5 Where to from here?

- Predict Ecological Impact….

Predicting water quality from gold mines

Dave Craw, Laura Haffert and James Pope

Mine Drainage Framework

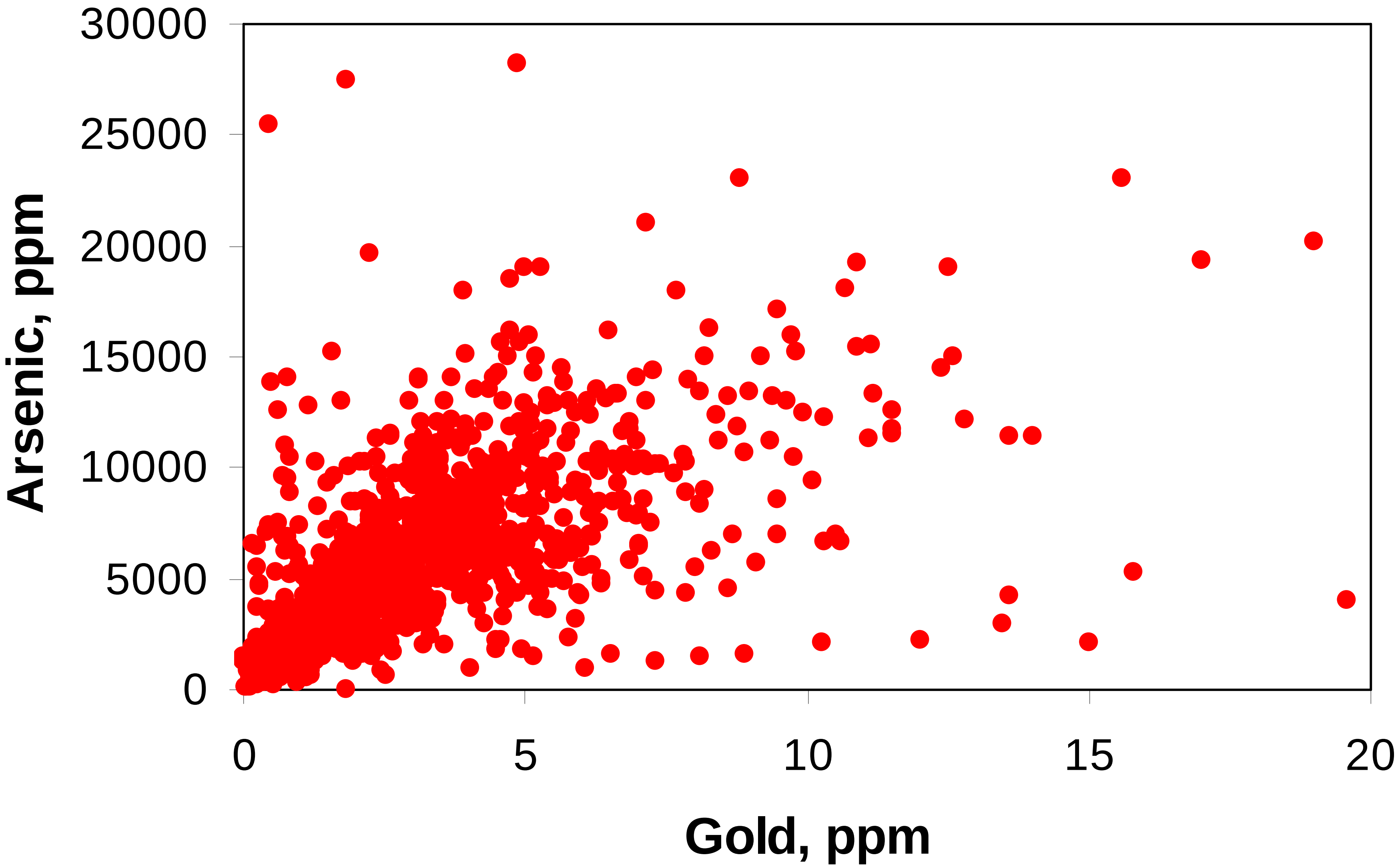
Manaaki Whenua
Landcare Research

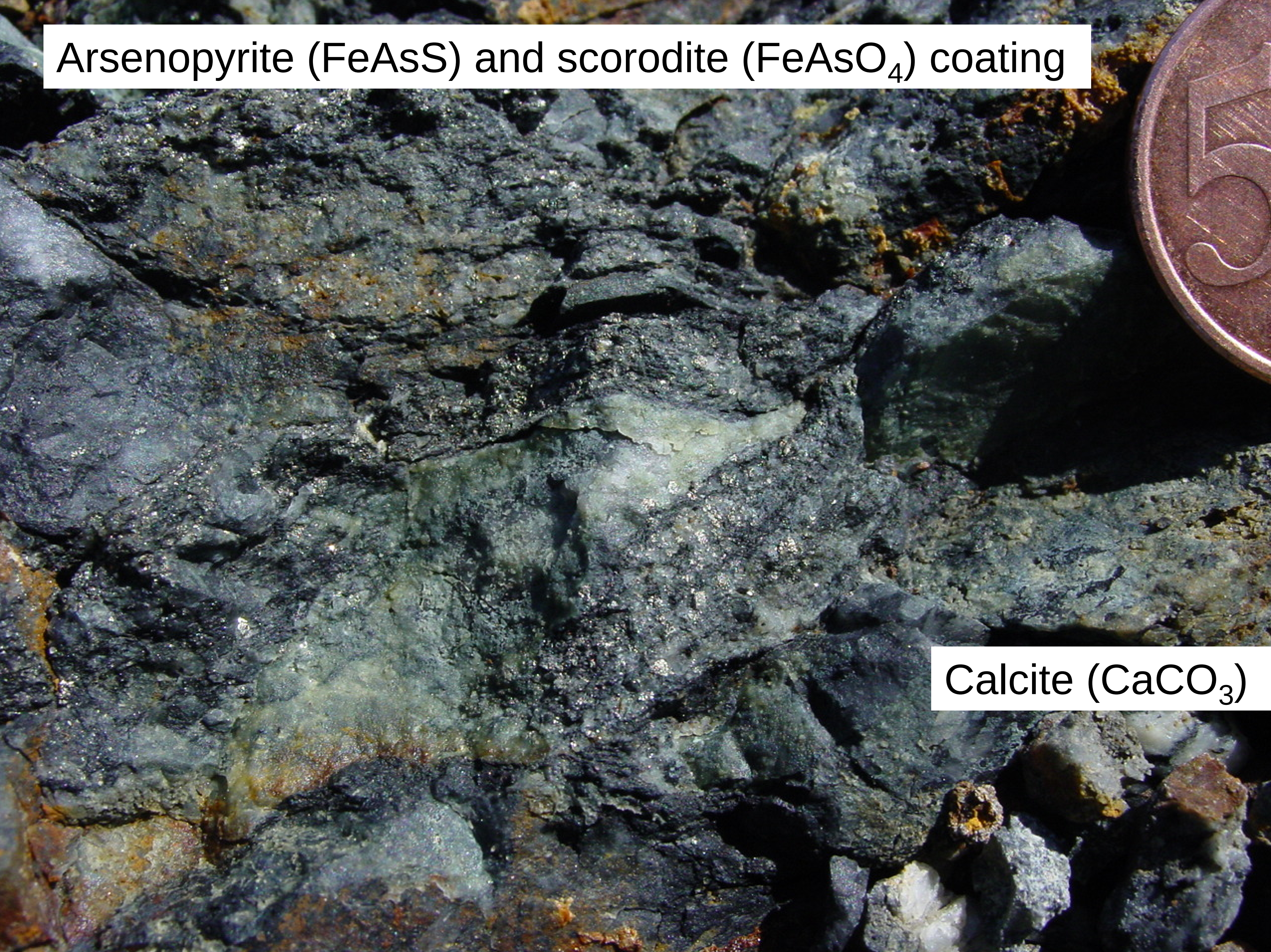
University of Otago
Te Whare Wānanga o Otāgo

CRL Energy Ltd

UC
University of Canterbury
Te Whare Wānanga o Waitaha
Christchurch New Zealand

Greenland Group greywacke/schist, Westland

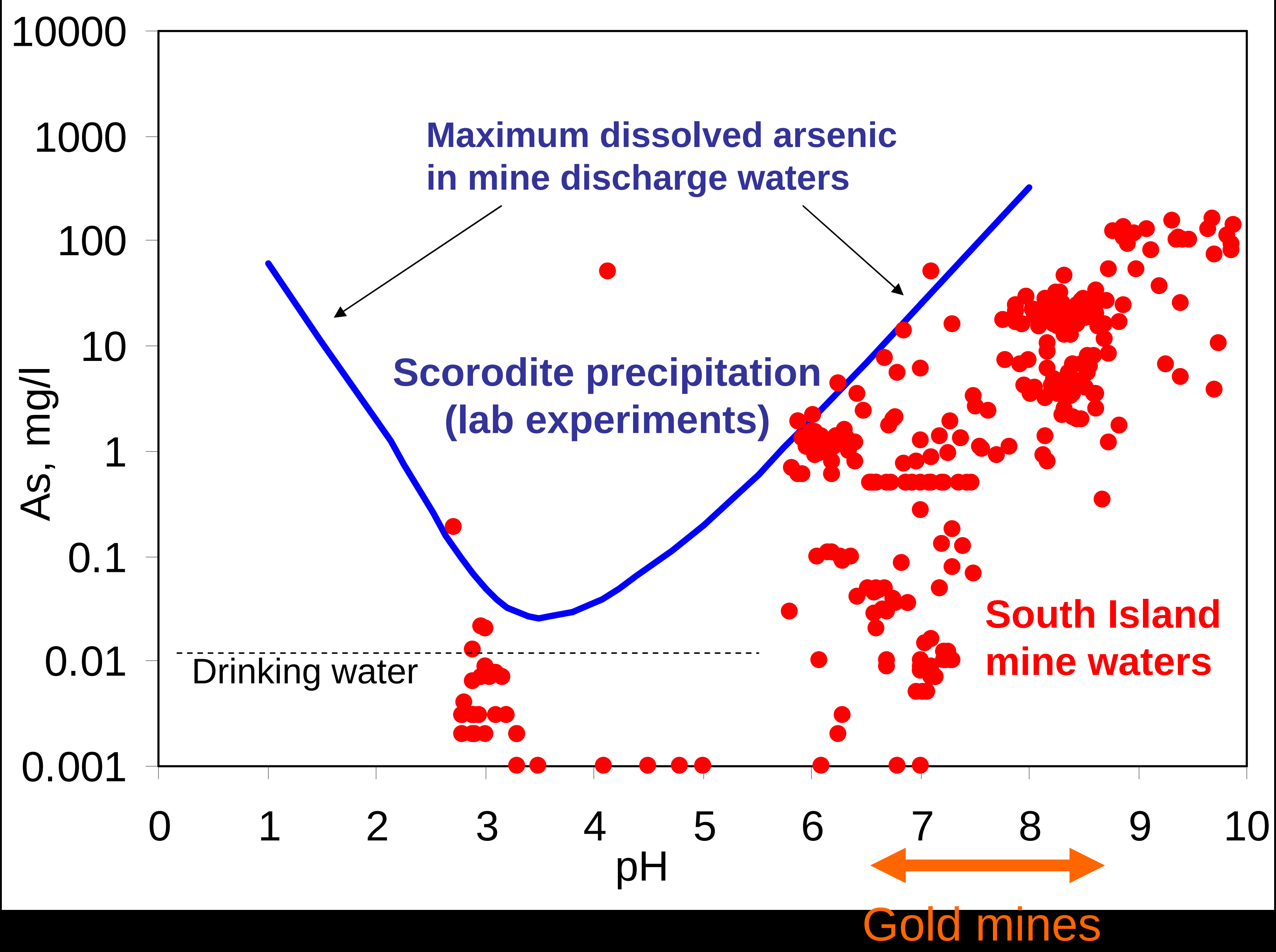




Arsenopyrite (FeAsS) and scorodite ($FeAsO_4$) coating

Calcite ($CaCO_3$)

Arsenic is extremely soluble at the high pH of gold mines



Gold mines

Mine excavation:
ore contains As minerals
As dissolves in runoff

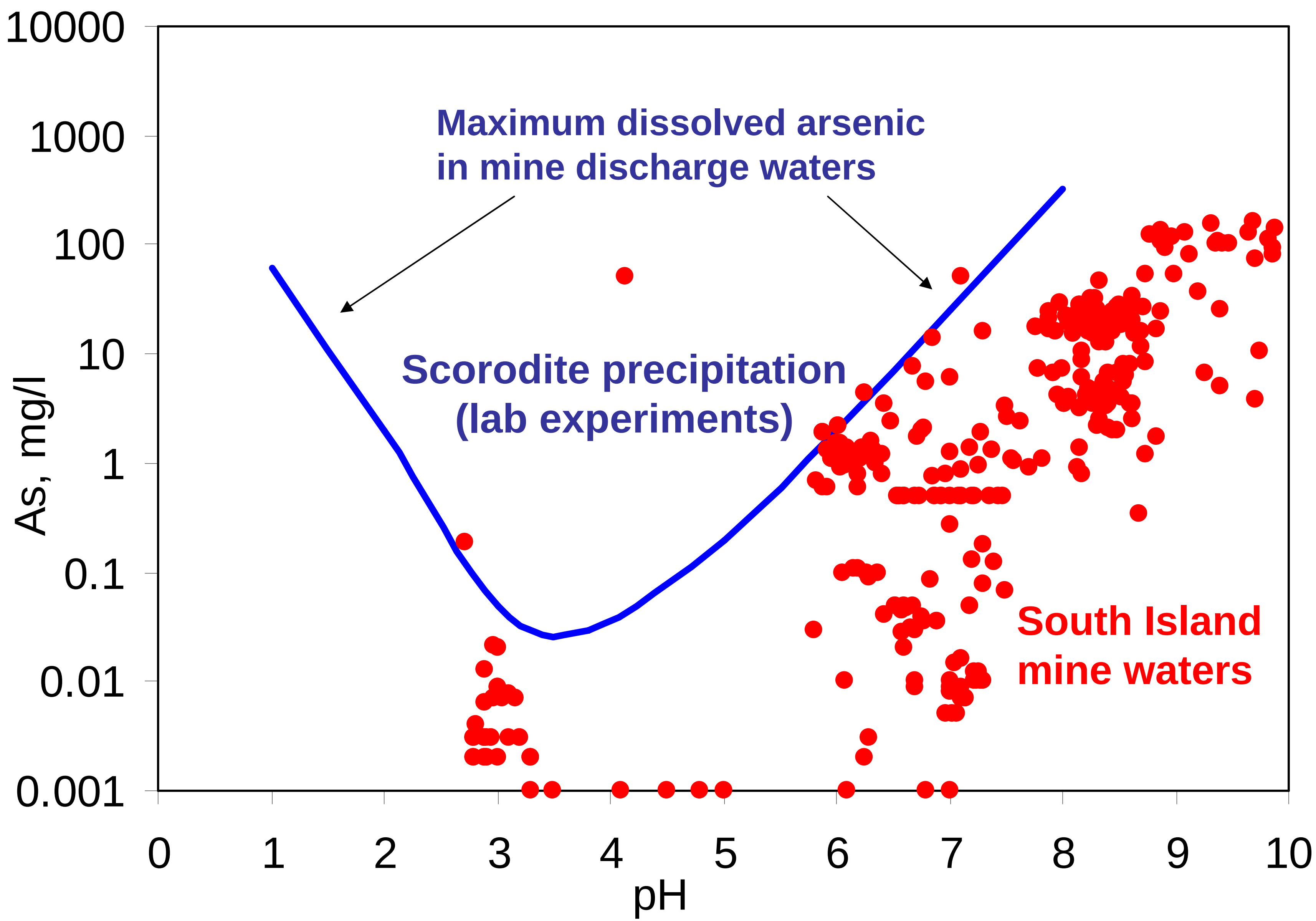
Waste rock:
little or no As
runoff has minor As

Processing plant:
slurry contains As minerals
As dissolves

Tailings dam:
may contain As minerals;
water has dissolved As

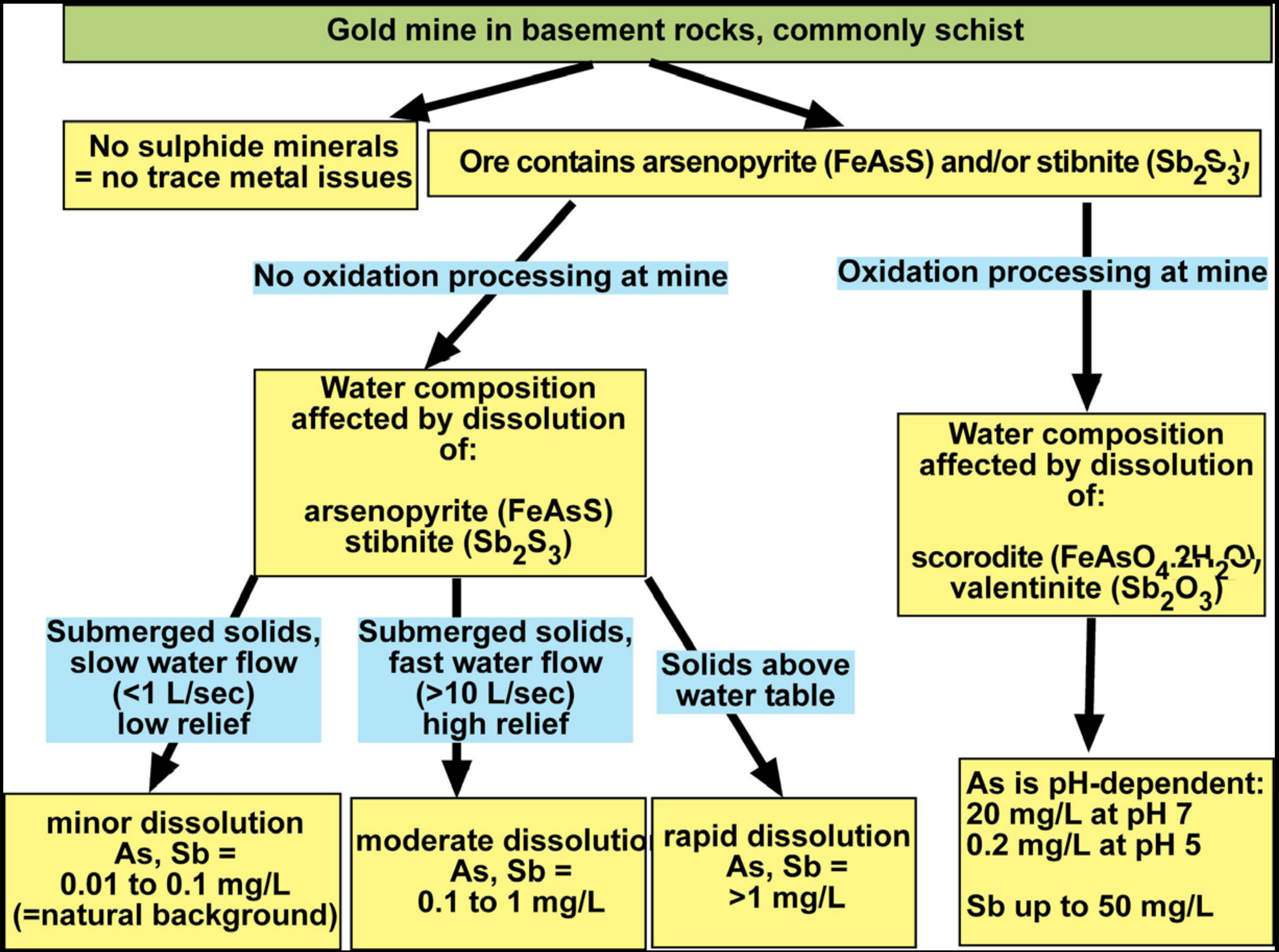
Processing plant:
waste waters with As;
As removed before discharge

Minor acidification is an advantage for arsenic suppression



No addition of lime in site management

Framework predictions of water quality



Gold mine in basement rocks, commonly schist

No sulphide minerals
= no trace metal issues

Ore contains arsenopyrite (FeAsS) and/or stibnite (Sb_2S_3),

No oxidation processing at mine

Water composition
affected by dissolution
of:

arsenopyrite (FeAsS)
stibnite (Sb_2S_3)

Submerged solids,
slow water flow
(<1 L/sec)
low relief

minor dissolution
As, Sb =
0.01 to 0.1 mg/L
(=natural background)

Submerged solids,
fast water flow
(>10 L/sec)
high relief

moderate dissolutio
As, Sb =
0.1 to 1 mg/L

Solids above
water table

rapid dissolution
As, Sb =
>1 mg/L

Oxidation processing at mine

Water composition
affected by dissolution
of:

scorodite ($FeAsO_4.2H_2O$),
valentinite (Sb_2O_3)

As is pH-dependent:
20 mg/L at pH 7
0.2 mg/L at pH 5

Sb up to 50 mg/L

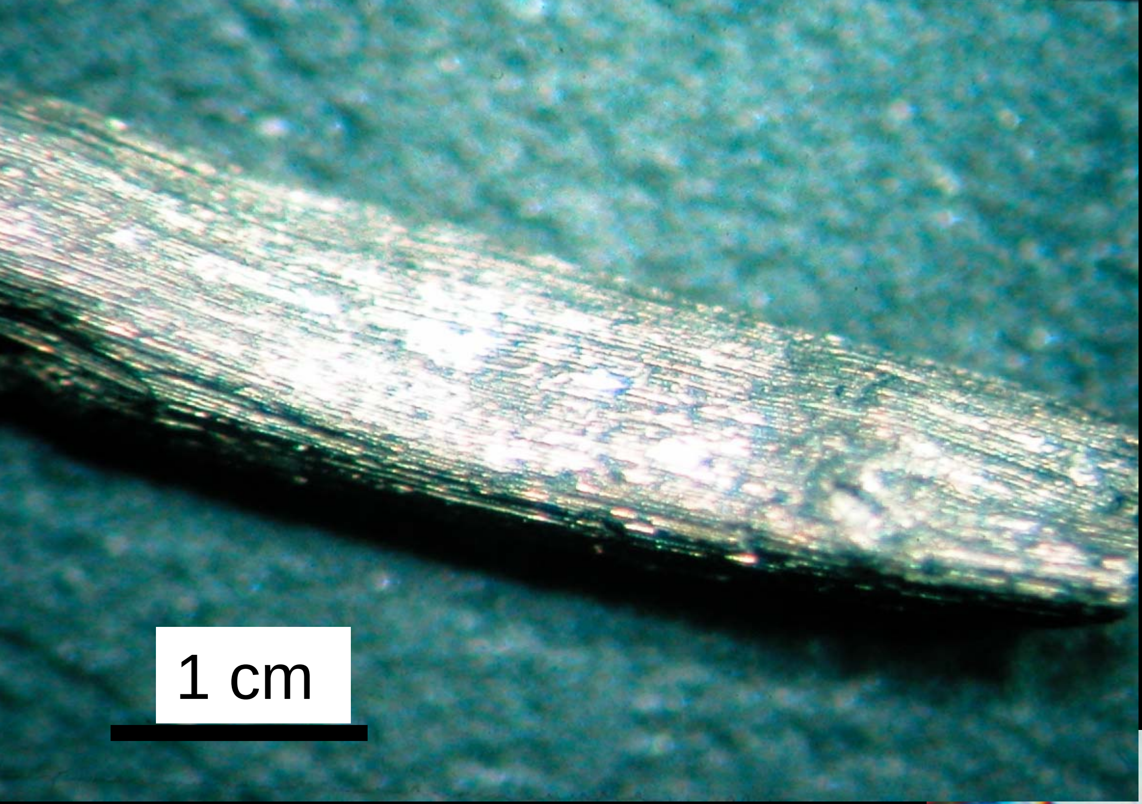
Alluvial mines and AMD

- Most alluvial gold mines have no AMD
- Some Southland sedimentary rocks have pyrite or marcasite (both FeS_2)
- Sulphides occur with woody material below the water table
- Sulphides were added to rock by groundwater AFTER rock deposition,

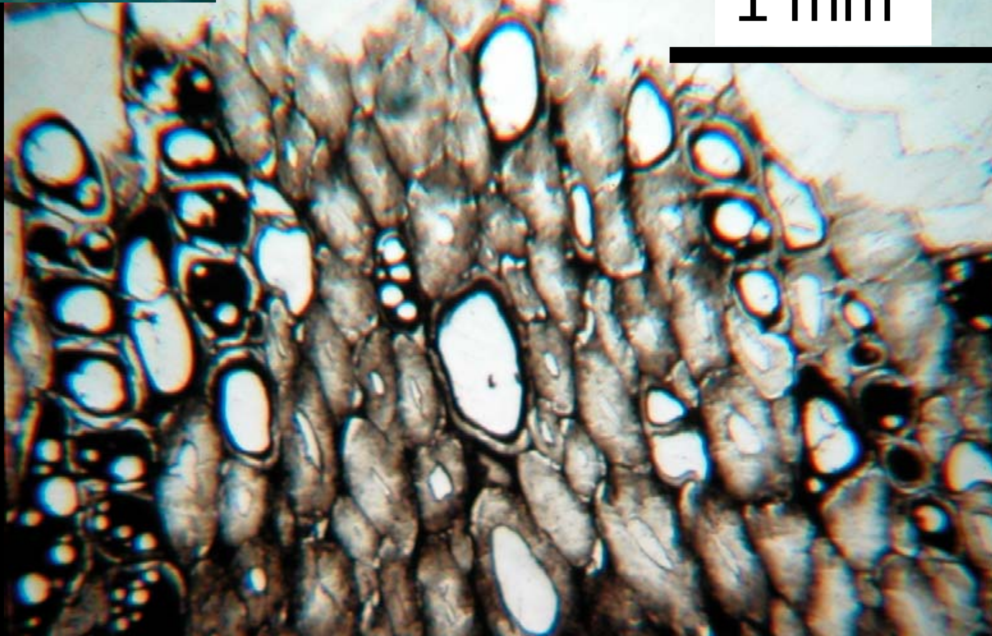
Glenore Au mine,
Milton, South Otago

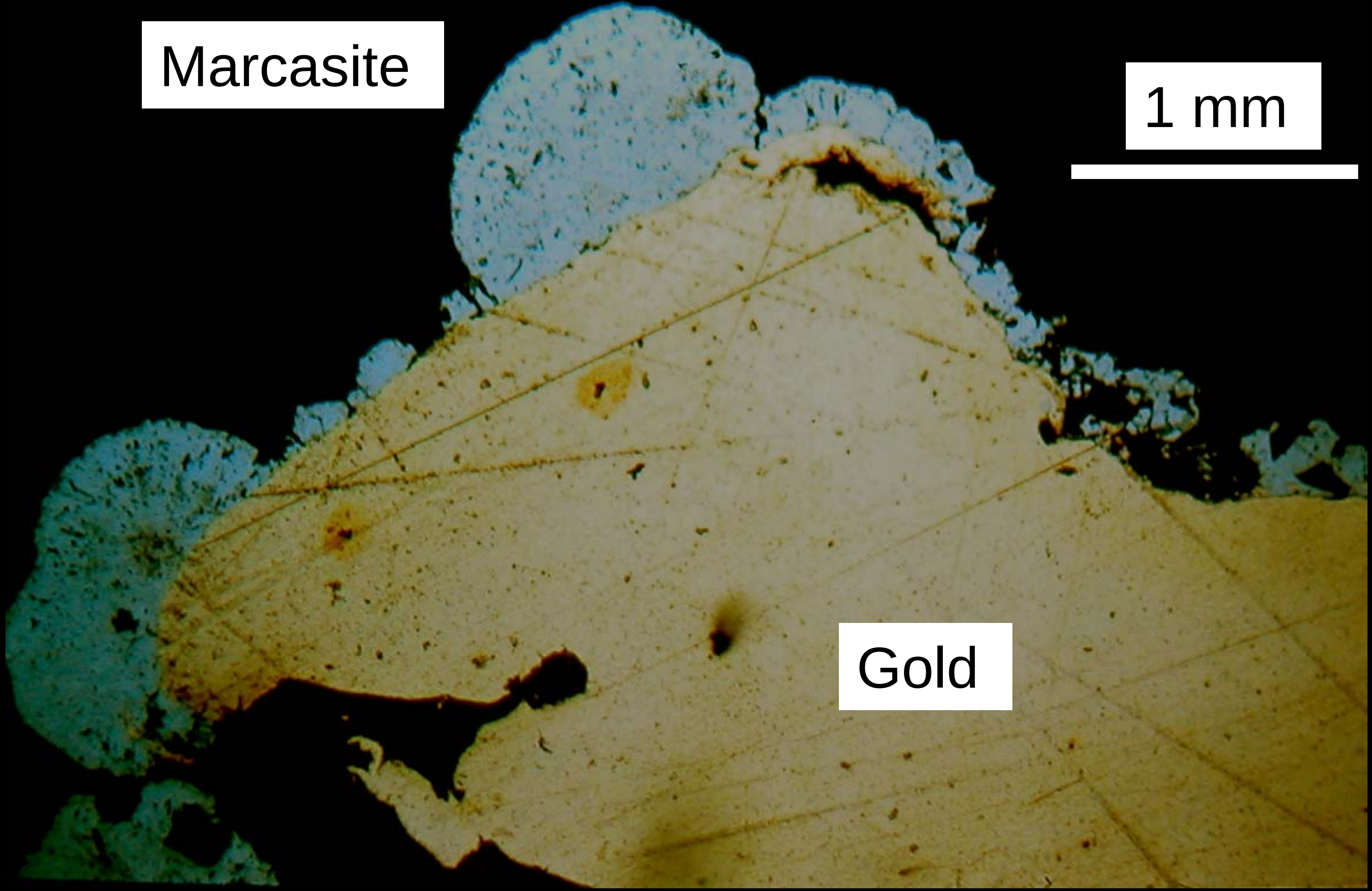
Pyrite in dark layer,
associated with wood

Belle-Brook, Southland
Au deposit



Marcasite (FeS_2)
replaces wood




Marcasite
1 mm
Gold

Alluvial mines and AMD

- Most alluvial gold mines have no AMD
- Local sulphides can lead to AMD, as for coal, with the same predictions for water quality
- Sulphide distribution is difficult to predict: different from marginal marine coal
- Sampling for ABA has to be done on rock from below the water table