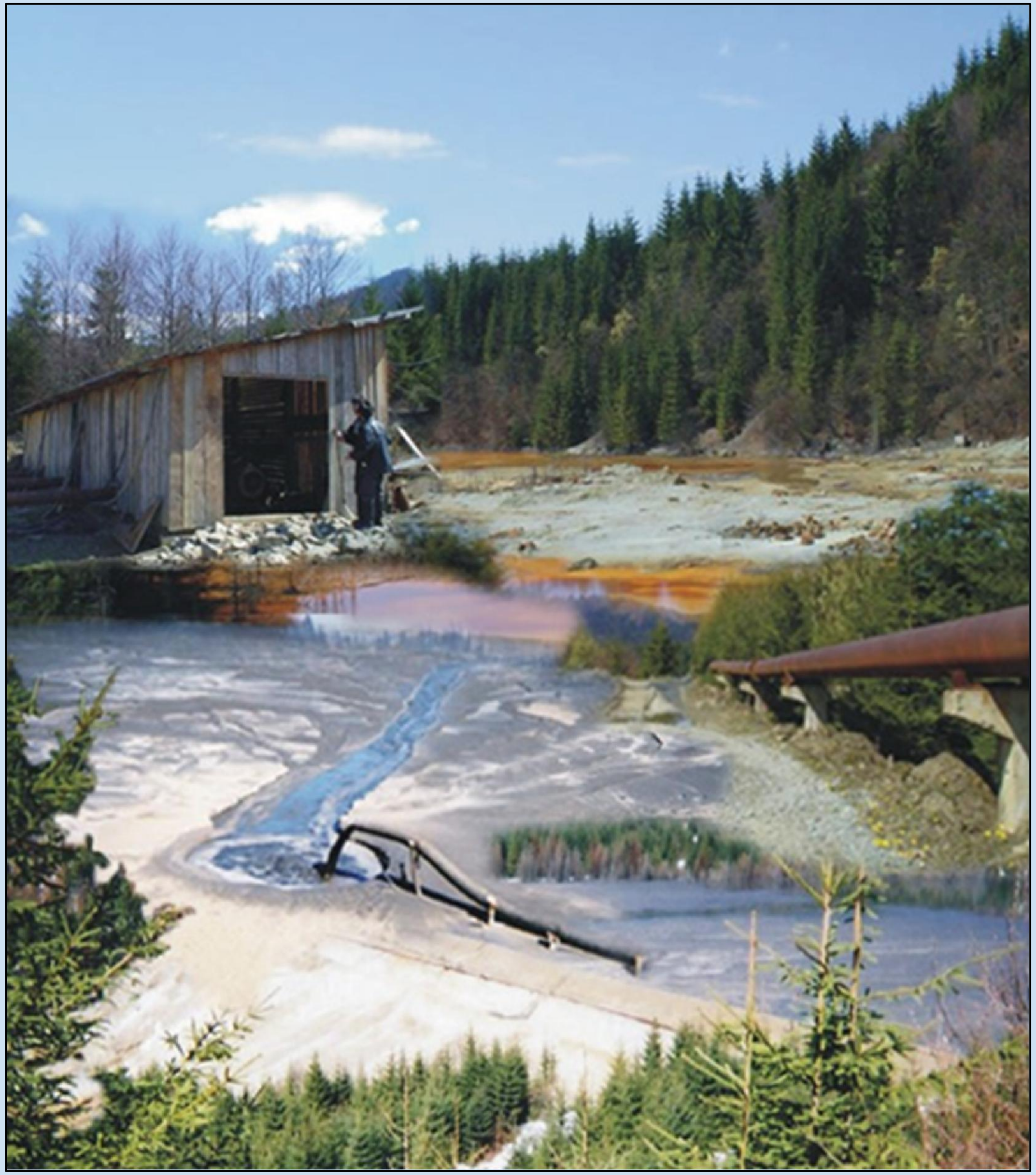
The role geology plays in the sustainable management of mine tailings

A presentation by Nick Watson to the West Midlands Regional Group of GSL, 10 March 2020

TSF = PROCESSING + OPERATION + CONSTRUCTION	
16km access road	10.3km slurry pipeline
1.4km diversion tunnel	7.9km pipeline tunnel
4 dams	4 pump stations



The outside world	View from within
‘prospective students are put off by the perceived association of geologists with dirty industries, energy resources and environmental damage’	‘geoscientists and their skill sets are a vital part of the solution, not the cause’
‘few youngsters are interested in studying a subject that has played a central role in damaging our planet’	‘geoscience has a crucial part to play in fixing these issues and creating a pathway to sustainable development’

- Geology is perceived by students to be supporting dirty industries and damaging the planet
- Authors of the articles felt the opposite: geology was part of the solution and not the problem
- Oil and mining? Tailings dams failures make the news and give the mining industry a bad reputation
- The talk explores the link between geology and sustainability when it comes to the properties of tailings

Geoscientist, September 2019

CONTENTS

Data

1. Gold and base metal mines, REE
2. Unverified internet references
3. Test results taken from project work

Sustainability and mining

Sustainability		Mining
Meeting the needs of the present without compromising the ability of future generations to meet their needs[1]		Equator principles – financial due diligence, adherence to good international environmental and social standards
Public health and workplace safety Community involvement	**People**	Designers and operators responsibility for H&S Social licence to operate concept
Promote reuse, recycling, waste minimisation etc • 2 billion smartphones upgraded every 11 months…….<10% recycled[2]	**Planet**	Mines are high tonnage – low grade operations and generate a lot of waste • A smartphone may use up to 62 metals[3] • iPhone 6 weighs 129gm = 34kg of process waste[4]
Use natural resources conservatively and wisely	**Profit**	Mine life cycle and mine life spiral Resources and reserves & WIP Ore bodies are unique

1. www.investopedia.com/terms/s/sustainability.asp
2. www.bbc.com/future/article/20161017
3. www.acs.org/content/dam/acsorg/education/resources
4. www.vice.com/en_us/article/433wyqhttps:

Material properties

Ore genesis – the start of the process

Some examples

Mineralisation	Setting
Cu-Fe-Au	Massive sulphide mineralised breccia, volcanic arc/carbonate platform
Fe	Skarns, volcanic/carbonate shear zone complex
Zn-Pb-Cu-Ag	Volcanic massive sulphides, sea floor hydrothermal activity
Pb-Zn	Carbonate hosted massive sulphide sedimentary exhalative deposit
Au	Epithermal mineralisation, structurally controlled
REE minerals	Shear zone emplaced ore in peralkaline igneous complex (nepheline syenite), igneous differentiation

Examples of useful mineral, gangue and process additives

Ore	Useful mineral	Gangue
Copper	Chalcopyrite, gold	Magnetite, pyrrhotite, siderite, anthophyllite, K-feldspar, dolomite
Iron	Magnetite	Garnet, pyroxene, calcite, gypsum, chalcopyrite, sphalerite, pyrite, scapolite
Poly-metallic	Chalcopyrite, galena, sphalerite, silver	Pyrite, arsenopyrite, quartz, calcite, feldspar
Lead-zinc	Galena, sphalerite	Dolomite, pyrite, quartz, calcite
Gold	Gold	Quartz, mica, dolomite
REE	Eudialyte and catapleiite	Aegirine, albite, anorthoclase, microcline, nepheline, zeolite

+

Process additive
Flotation reagents
Solvent, e.g. cyanide
Complex process, gypsum sludge and brine by product

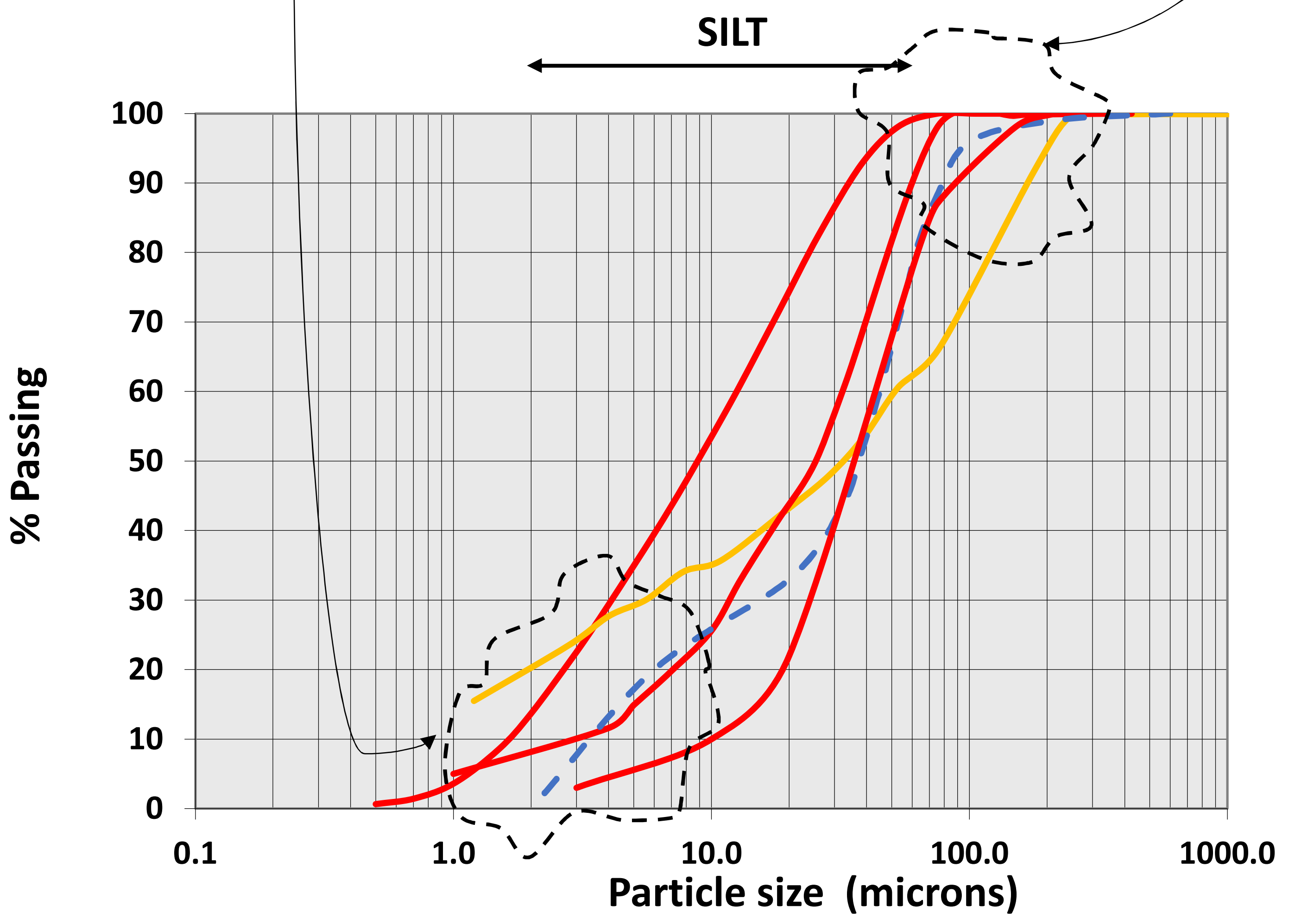
← **TAILINGS** →

(plus unrecovered useful mineral)

Processing

Reflects grind size and original mineralogy and grain size, possibly also residual process chemicals

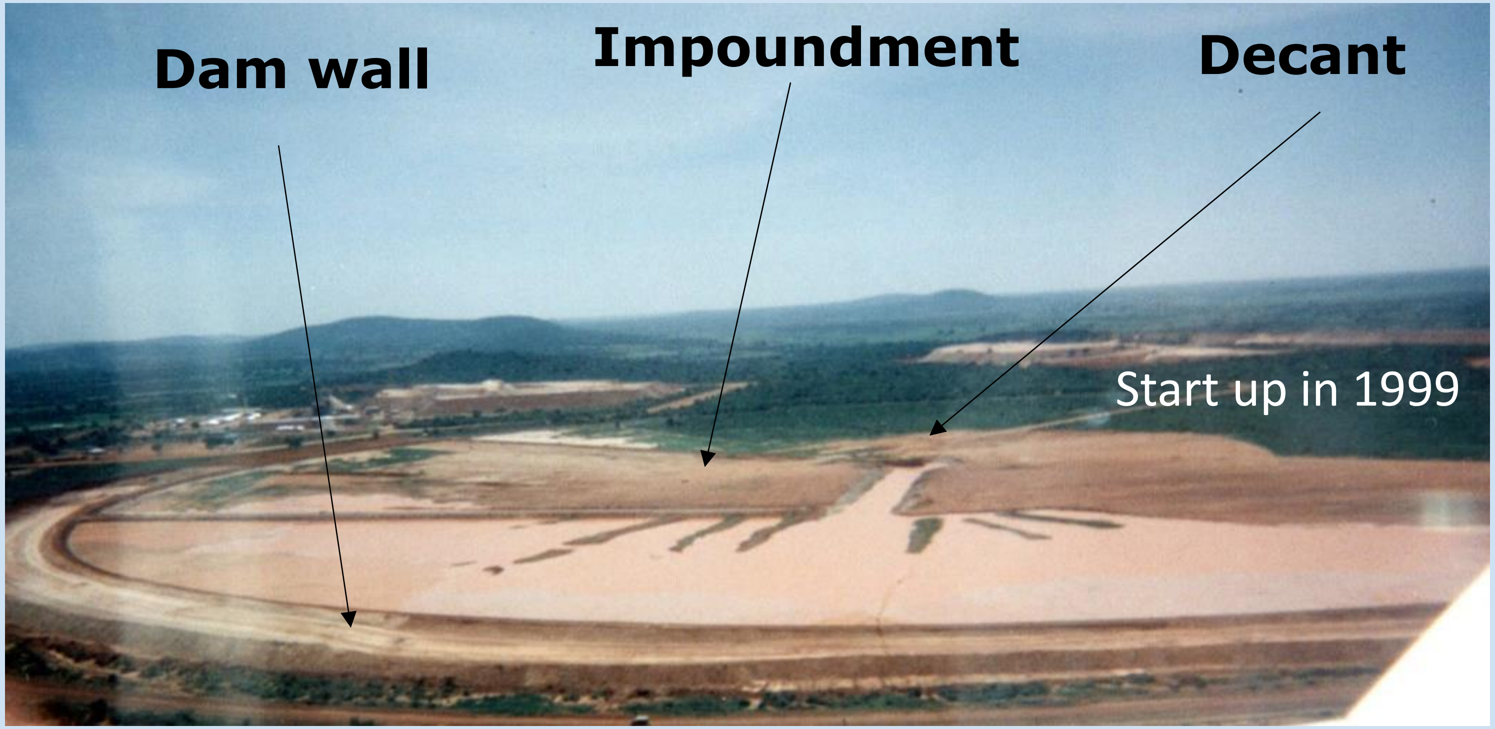
Defined by processing – grind size



Examples of particle size distribution curves

Tailings	
Base metal	
Gold	
REE (approx.)	

Operation and construction

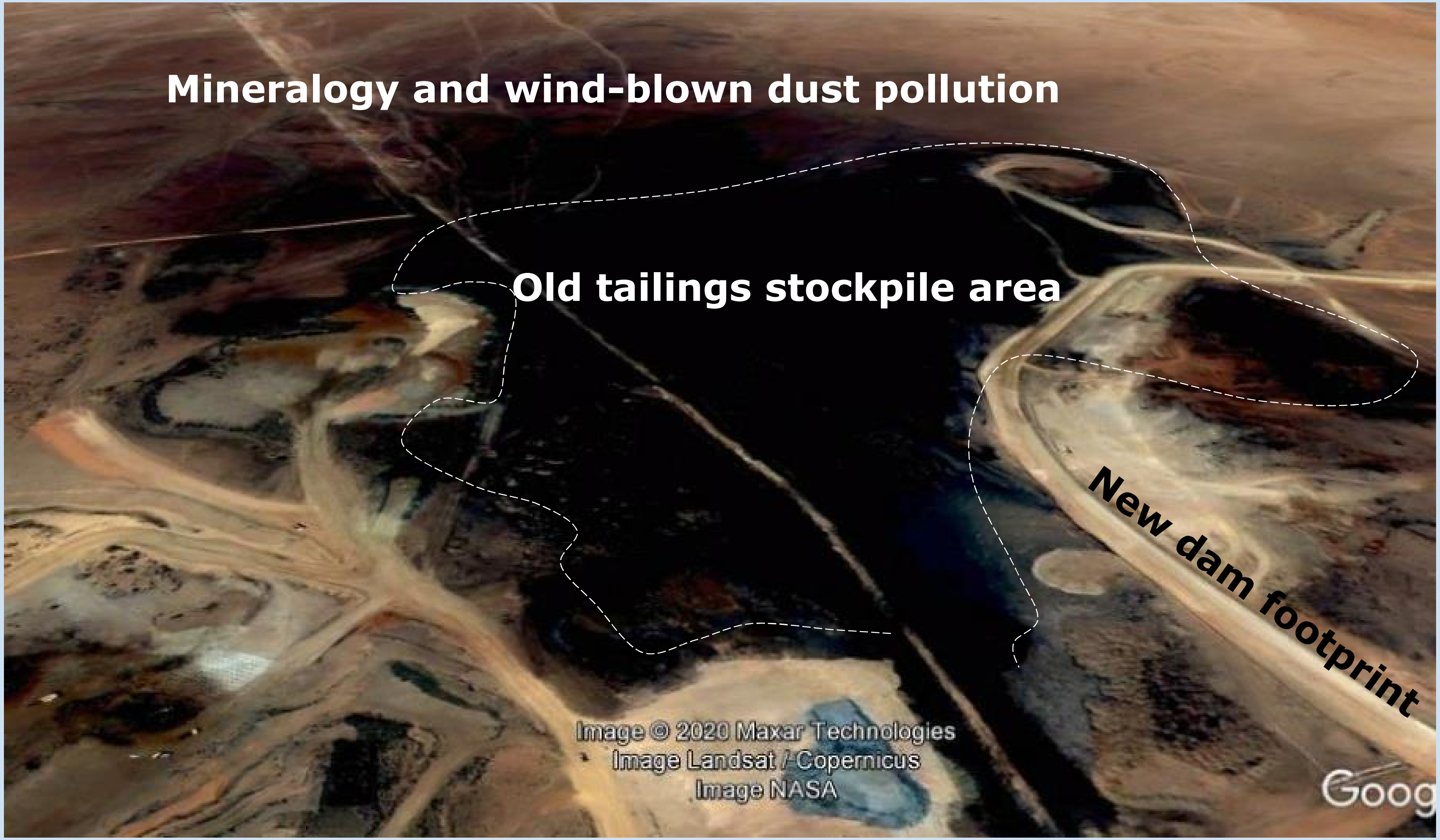


- **Containment** – during operation and closure stages
- **Operation** – multiple discharge points helps beaching and water reclaim, more bang for your buck
- **Size** – better management of tailings deposition
- **Embankment raises** – staged construction to suite mine production, allows for progressive closure

Tailings-related geohazards and sustainability

TSF	Engineering geology	Impact	Sustainability
Processing	Mass properties	Workplace or public health **Air born dust**	People
Operation	Situation	Chemical changes **ARD and metal leaching**	Planet
Construction	Engineering performance	Physical changes **Density and strength**	Profit

MATERIAL PROPERTY ✚ MASS FABRIC ➞ **MASS PROPERTIES**



Legacy from past mining

Wind blown dust from old end-tipped stockpiles of black magnetite-rich tailings formed by dry processing of oxide ore

Wind blown dust

Old black magnetite tailings

Historical mining operation

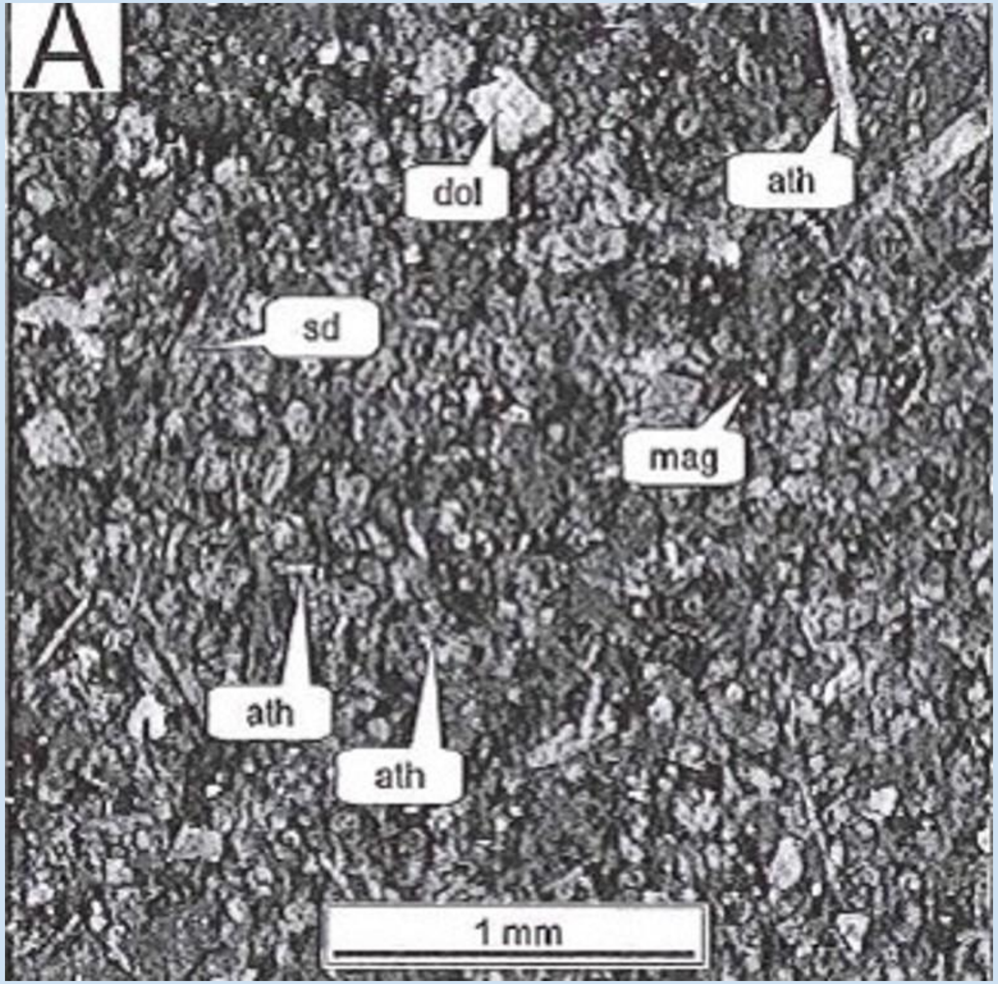
- No attempt at containment

New gold tailings storage cell with wind blown sand

New mining operation

- Sulphide ore contains anthophyllite – a fibrous amphibole
- Development of fibrous minerals management plan for workplace protection

Mineralogy



Photomicrograph of tailings sample

- Fibrous amphiboles – 10%vol anthophyllite
- Av 300 micron length, range <40 microns to 1mm
- Known carcinogen
- Fibres <10 microns in length, & 3 microns or less in width, are most likely to remain in the lungs
- Arid climate, wind blown dust
- Risk management procedures enforced
- Dust suppression and control, PPE, monitoring

Workplace hazard

- Direct link between mineralogy and workplace safety
- Significant wind blown dust not detected visually or by monitoring at the tailings beach
- Slurry discharged at a solids content of 60-70%, thin layer deposition
- Arid climate, wet layers rapidly desiccate and become weakly cemented due to carbonate content, a positive benefit of slurry deposition?

Pollution linkage – source treatment

Role of slurry water in stabilising beach?

Slurry at deposition point

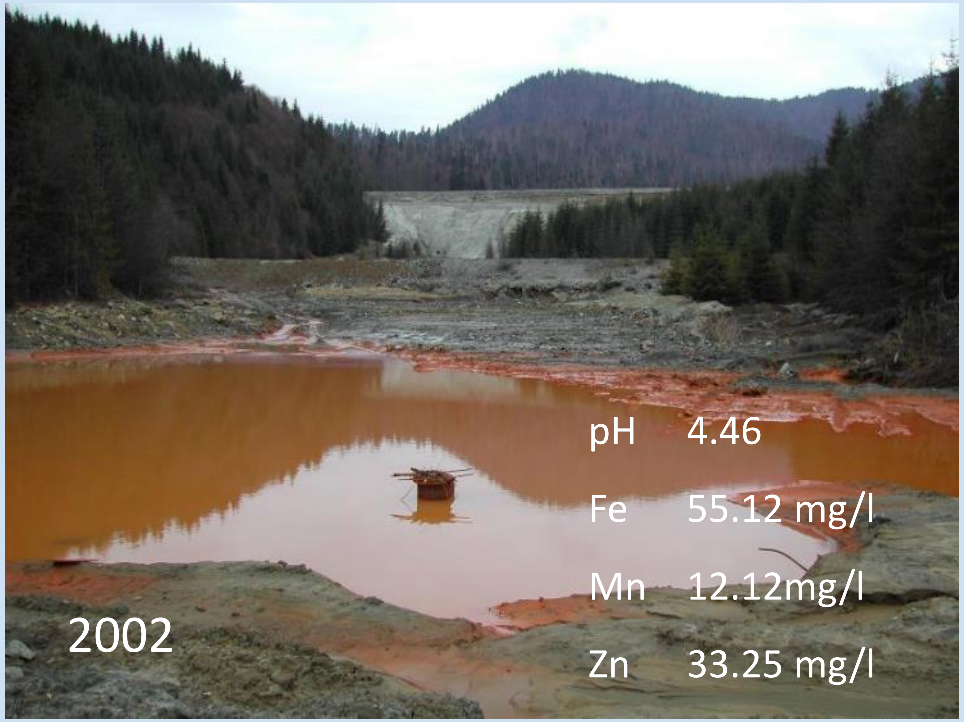
Wet beach – dry beach

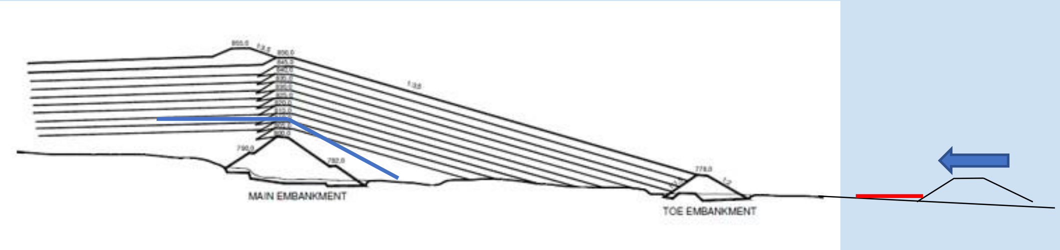
Desiccation and cementation

Removal

- Rework old tailings for magnetite
- Mining used as a reclamation tool
- Breaks pollution linkage at source

MASS PROPERTIES ✚ ENVIRONMENT → SITUATION





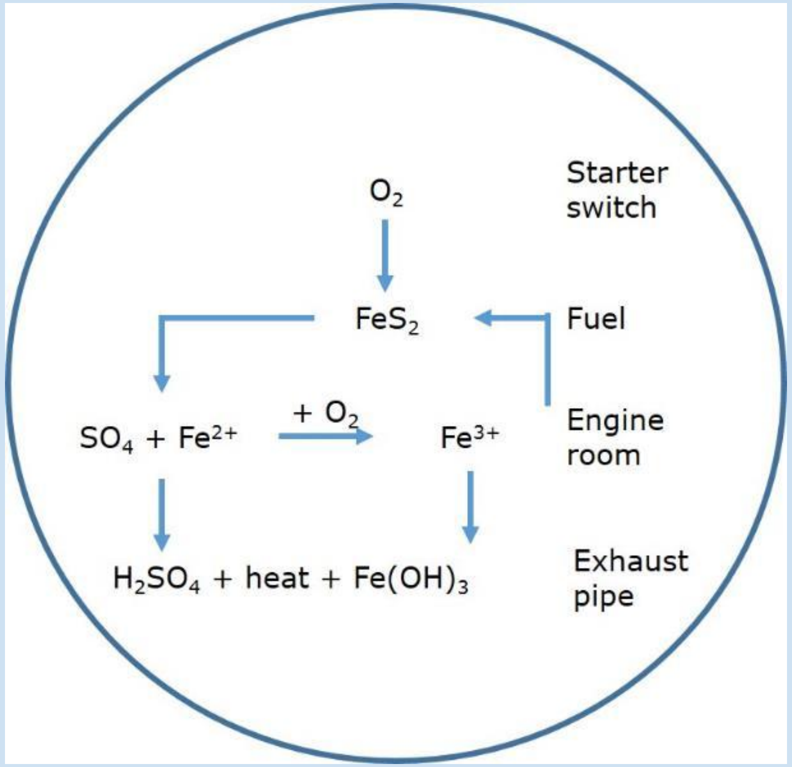
Designer’s intentions

ENVIRONMENTAL IMPACT

- Sulphide ore body
- Acid rock drainage and metal leaching
- Containment in seepage pond
- Intercept the pathway, no source treatment

Complex reaction kinetics and hydrochemical transport mechanisms

Acid generation



- Sulphide mineral species
- Oxidant – oxygen, ferric iron

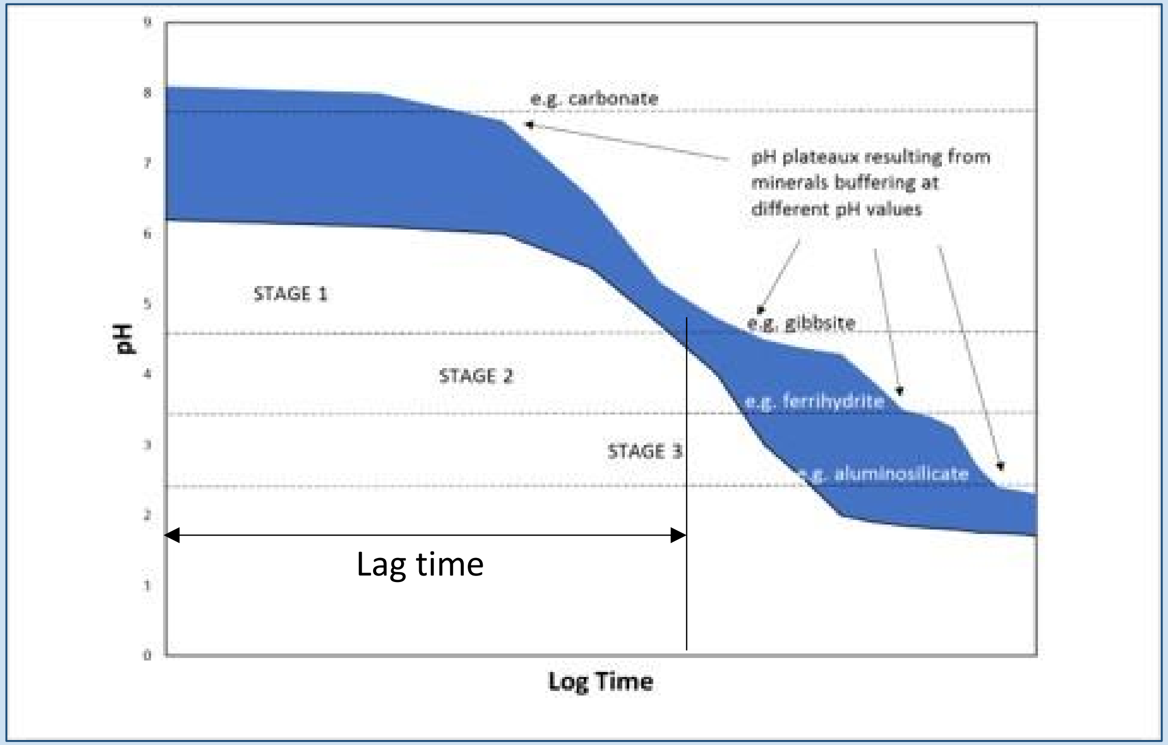
Reaction products: acidity, sulphur species, total dissolved solids, iron hydroxide, metals

Neutralisation

Consumption of acid by dissolution of carbonate and silicate minerals provides buffering capacity

Acid rock drainage

Over time, pH decreases along a series of plateaux governed by the buffering of a range of mineral assemblages



http://www.gardguide.com

Acid Base Accounting – (rapid)

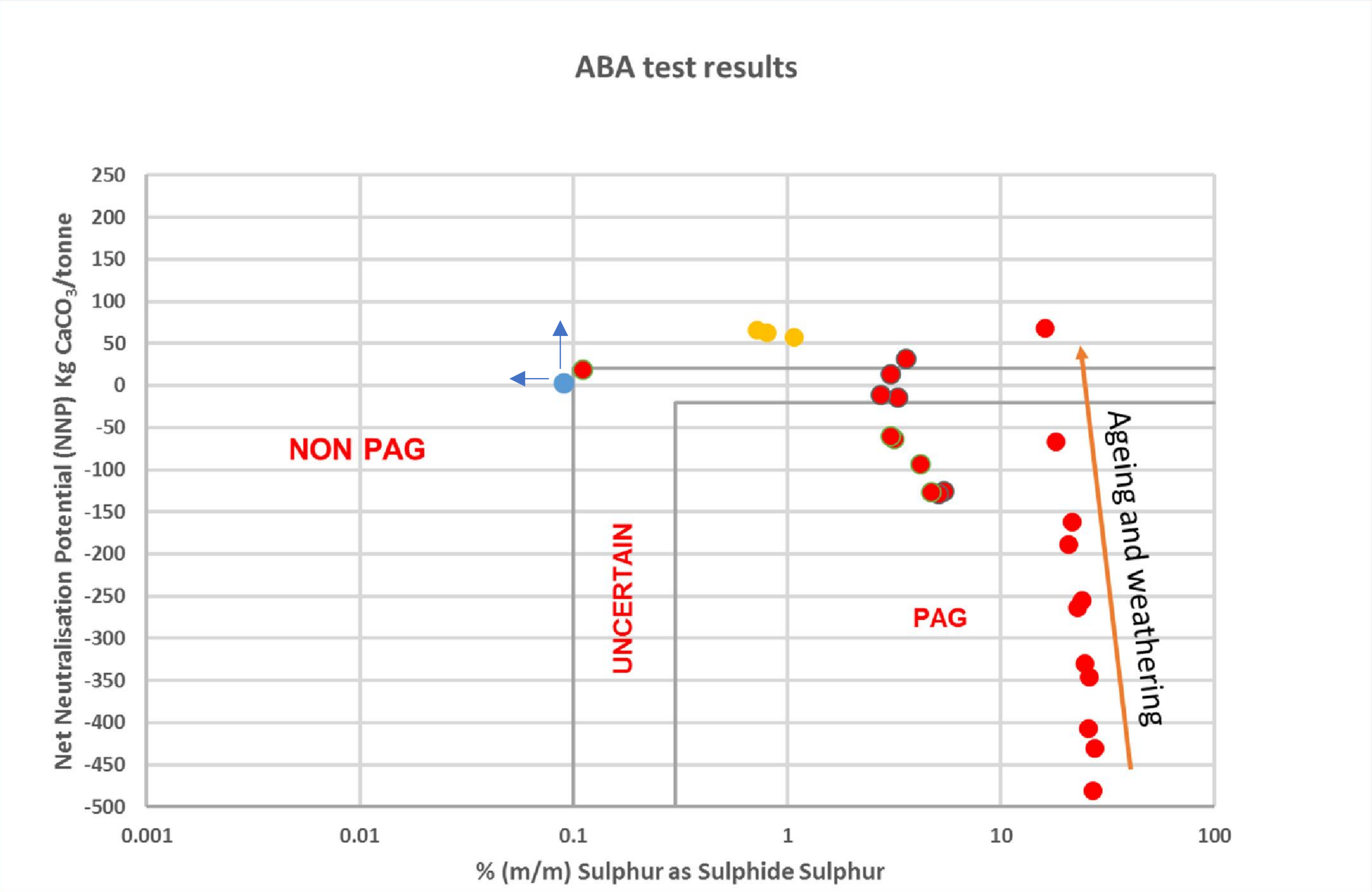
- A static test to determine if a material has potential to produce acid seepage
- Sulphur/sulphide analysis and titration to determine neutralization potential

Humidity cell testing – (lengthy)

- A kinetic procedure: a sample is subjected to cyclic conditions of dry air permeation followed by humid air permeation then water washing and leachate analysis.
- Accelerated weathering to identify if the material will form acid drainage with consequent effects on metal seepage.
- A direct measurement of acid generation and consumption rates under fully oxygenated conditions such as the immediate exposed surface of a tailings deposit.
- Not a simulation of leaching conditions in wastes which may be partially or fully saturated and oxygen-deprived.

Laboratory testwork

Static testing

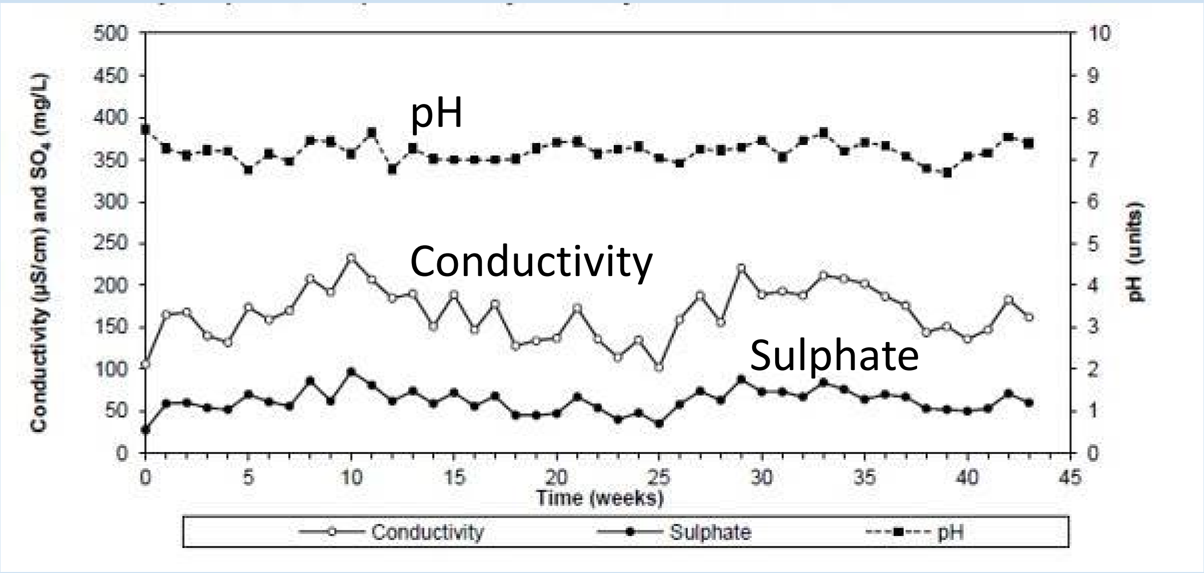


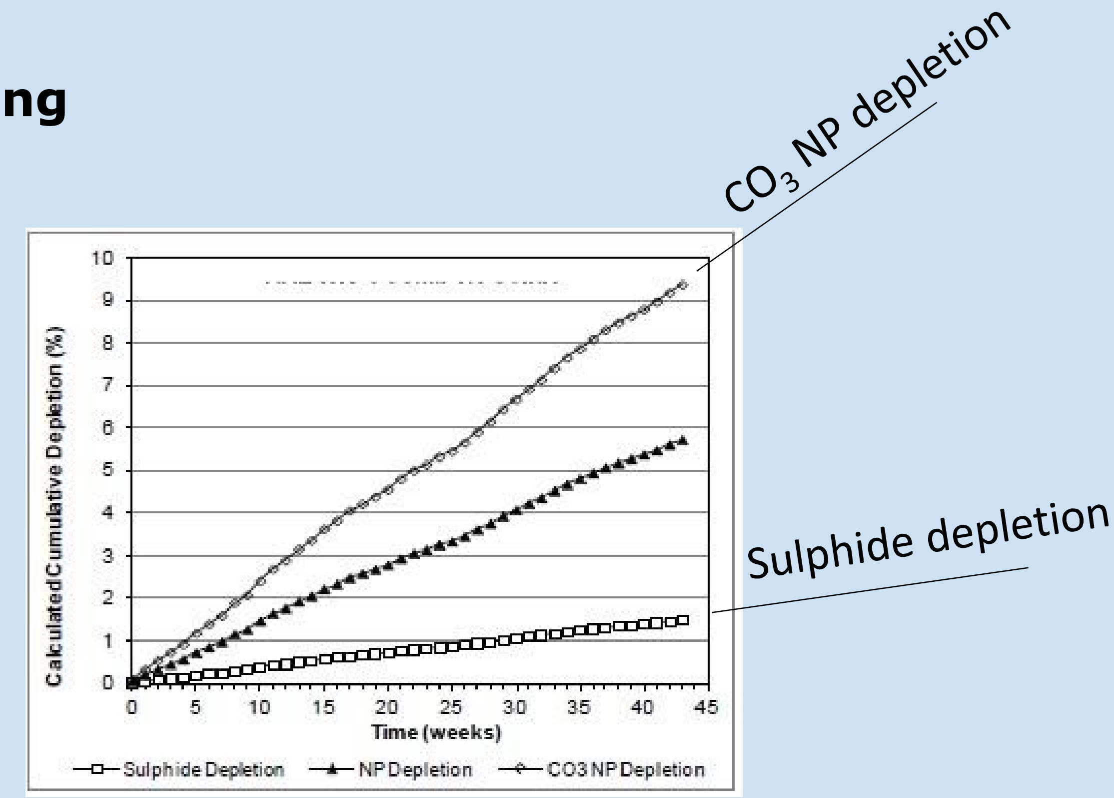
Tailings	
Base metal	● (red)
Gold	● (yellow)
REE	● (blue)

- Examples of testing from different orebodies
- NNP – potential to neutralise acidity
- PAG – potentially acid generating
- REE and gold tailings contain trace sulphide
- Sulphide tailings tests show effect of ageing or weathering

Bernd Lottermoser, Mine Wastes: Characterization, Treatment and Environmental Impacts

Kinetic Testing





- An example of test results for a sulphide ore
- 43 weeks of weathering – kinetic – testwork
- Neutralising potential of these samples is expected to be exhausted prior to the samples respective sulphide contents

ARD prevention at source

Operation
Water cover and subaqueous deposition of tailings used to inhibit ARD reactions.

Downstream embankment raises with internal filters and drains needed to accommodate tailings production.

Operation
Kinetic test results used to justify subaerial deposition methods and upstream raises

Closure
Progressive restoration possible. Wet cover maintained by rockfill capping system, land returned to agricultural usage.

SITUATION ✚ ENGINEERING CHANGE → ENGINEERING BEHAVIOUR

Natural hazards – landslip

Extreme events – overtopping

Engineering defects – internal erosion

Loss of containment; other factors to consider besides tailings properties

Density and Specific Gravity

DESIGN AND COSTING

Process Engineering

- Mass balance and process flow diagram
- Equivalent volumes for storage – weight – volume relationship

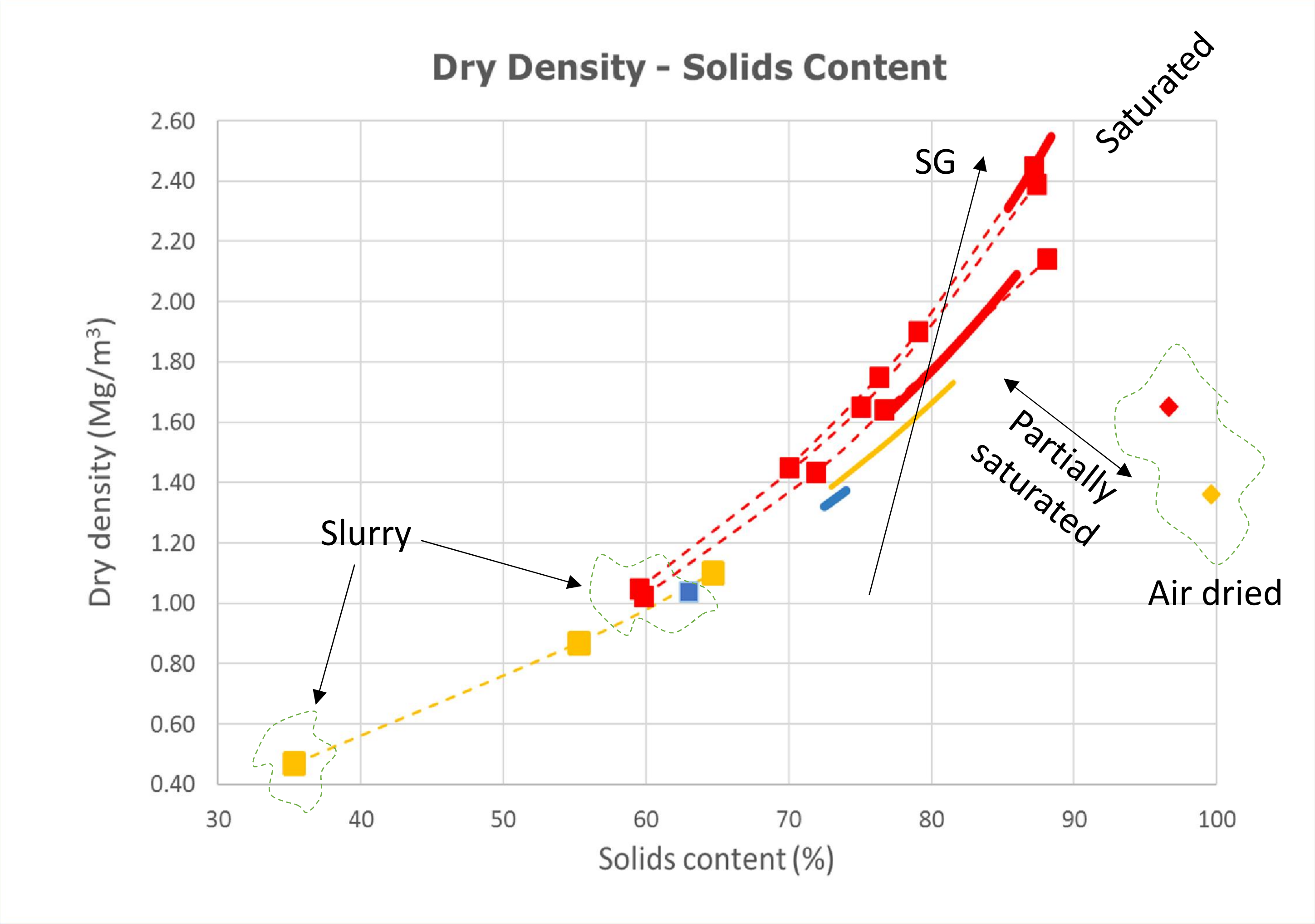
Specific Gravity

- Ratio of the weight of the mineral to that of an equal volume of water
- 2.6 – 2.8 generally sparry non metallic minerals
- About 5 metallic-looking elements

dry unit weight γ_d

$$\gamma_d = \frac{W_s}{V_t} = \frac{G_s \gamma_w (1-n)}{1-n+n} = G_s \gamma_w (1-n)$$

Settlement and consolidation



Tailings	
Base metal	
Gold	
REE	

Saturated tailings

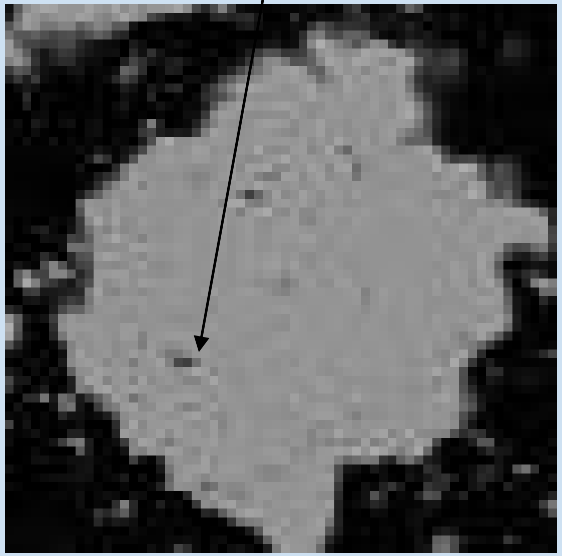
- Un-thickened – thickened slurry
- Settlement/drainage testwork on slurry
- Oedometer consolidation
- Effect of SG on results

Partially saturated (beaching – desiccation)

- Air dried testing

Tailings particles

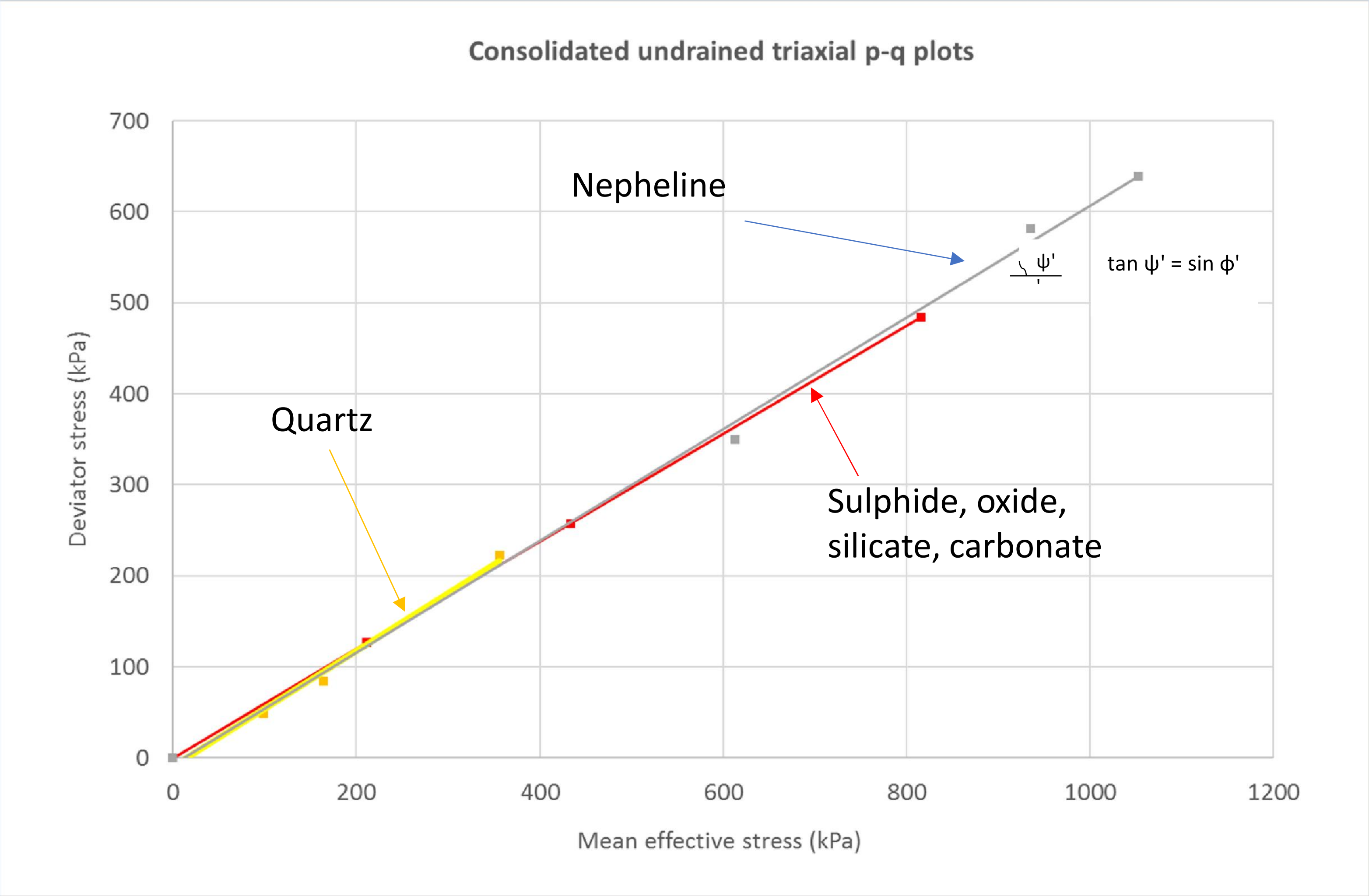
50 micron



50 micron

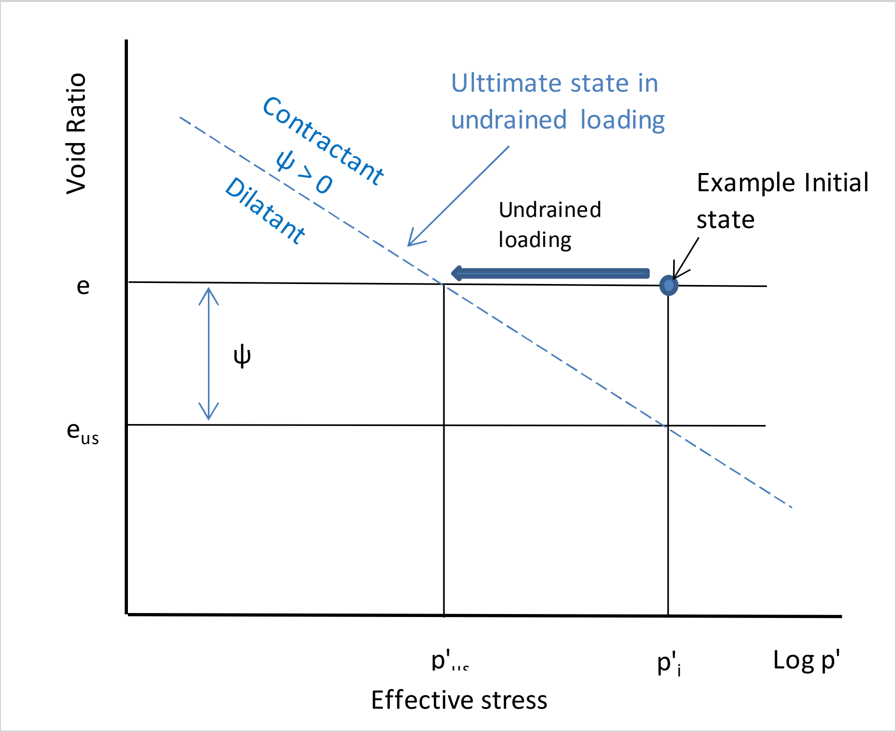
- Size ordered false colour and backscattered electron microscope images
- Angular granular particles formed by crushing
- Dense compacted material with good frictional properties

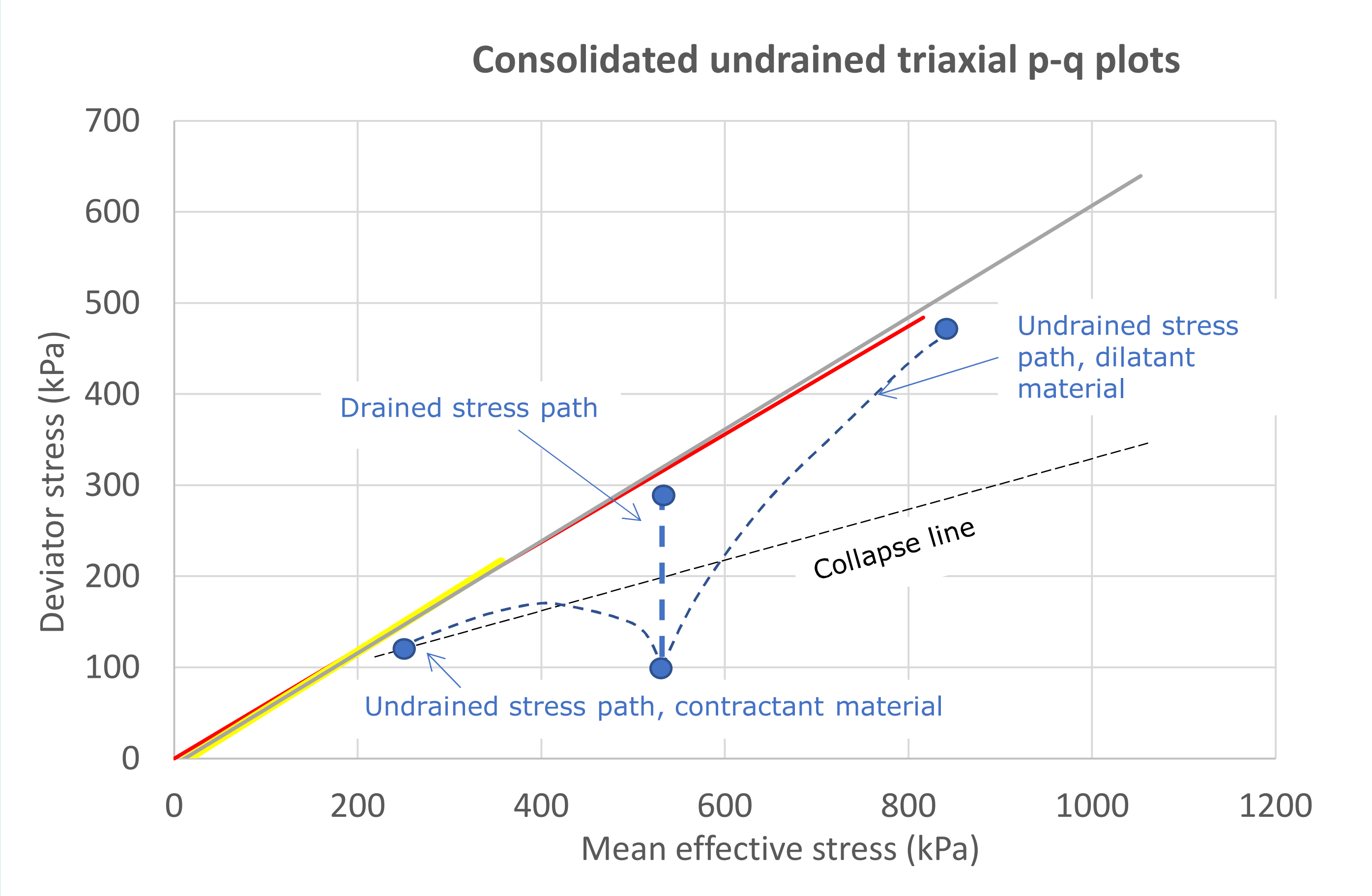
Consolidated undrained triaxial testing



- No relation between mineralogy and angle of internal friction for these examples
- Assumption that drained analysis is always appropriate for granular soils is incorrect
- Slurry tailings are susceptible to undrained failure

Static liquefaction failure





Undrained triggers in contractant material leading to liquefaction

- Increase in piezometric surface
- Rapid embankment raise
- Removal of toe support whne static shear stress exceeds collapse surface
- Ditto for foundation movement

'Static liquefaction of tailings – some fundamentals and case histories', Davies et al, Proceedings, Tailings Dams 2002, ASDSO

Failure modes are not linked back to gangue geology

Drained

- Cracks in steep slope c45^{O} formed in tailings
- Evaporative drying and desiccation, tailings dilatant?
- Drained analysis using frictional strengths with hydrostatic pore pressures suggest F < 1.0
- Slope stands 'by habit' not design
- Suction forces maintain limiting equilibrium under drained conditions
- Containment maintained, no failure, no clean up cost

Undrained

Aznalcollar
http://www.davidjackson.info

- Static liquefaction of contractant tailings following foundation spreading in brittle foundation soils
- Release of 5.5 million cubic metres of acidic, metal-rich water and approximately 1.3 to 1.9 million cubic metres of toxic tailings [1]
- Andalusian Government and the Spanish Environmental Ministry … have spent more than Pesetas 40,000 million (Euro 240 million / US$ 210 million) for the clean-up of the spill. (El País Nov. 21, 2001) [2]

[1] Kristina Thygesen
https://www.grida.no/resources/11433
[2] http://www.wise-uranium.org/mdaflf.html

Summary

- Tailings materials are gangue minerals – mineralogy has an impact on safe storage
- Ore deposits are unique and variable – geological knowledge and understanding of the orebody are needed for sustainable management of tailings
- Other factors can become more important than geology – seek specialist advice
- Advantages of source treatment – to avoid a problem don't create it in the first place
- Waste characterisation & performance monitoring – best practice