U3A

Environmental impacts in mining

Introduction

- Unsatisfactory practices in mining operations can have deleterious effects on people and the environment
- pollution problems caused by mining operations include acid mine drainage, heavy metal contamination, chemical contamination and sedimentation
- various programs are rigorously implemented nowadays to both mitigate and remediate the impact of mining

Environmental effects of mining operations

- Mining operations can badly affect the quality of air, land and water in and around the operation
- in recent decades mining practices have been forced to change to mitigate the environmental impact of mining

(1) *Air quality*

- Removal of vegetation → exposes soil to wind erosion → particulates become airborne due to wind
- particulate materials can include toxic metals e.g. As, Cd and Pb or dangerous minerals e.g. asbestos

Environmental effects of mining operations

(2) Land degradation

- Mining can cause physical disturbances to the landscape e.g. collapse into voids created by underground mining activity
- waste rock piles can create eyesores and affect biota in an area
- deforestation and habitat destruction

Mining shaft collapse

St Stephens, Cornwall, UK

Types of water pollution from mining

(3) Water pollution

There are four types of mining impact on water quality:

- Acid mine drainage (AMD) - forms when sulphide minerals in rocks react with water to produce iron hydroxide and sulphuric acid
- Heavy metal contamination - occurs when heavy metals (As, Co, Cd, Pb, Ag and Zn) contained in ore, interact with acid mine water
- Processing chemical contamination - occurs when chemical agents (e.g. Hg, CN, H_2SO_4) spill or are leached from a mine site
- Erosion and sedimentation – mining may disturb rock or soil and produce substantial amounts of sediment → can clog rivers and affect the ecosystem if not contained

pH

- Measure of the acidity/alkalinity of an aqueous solution
- water molecules may dissociate into H^+ and OH^- ions

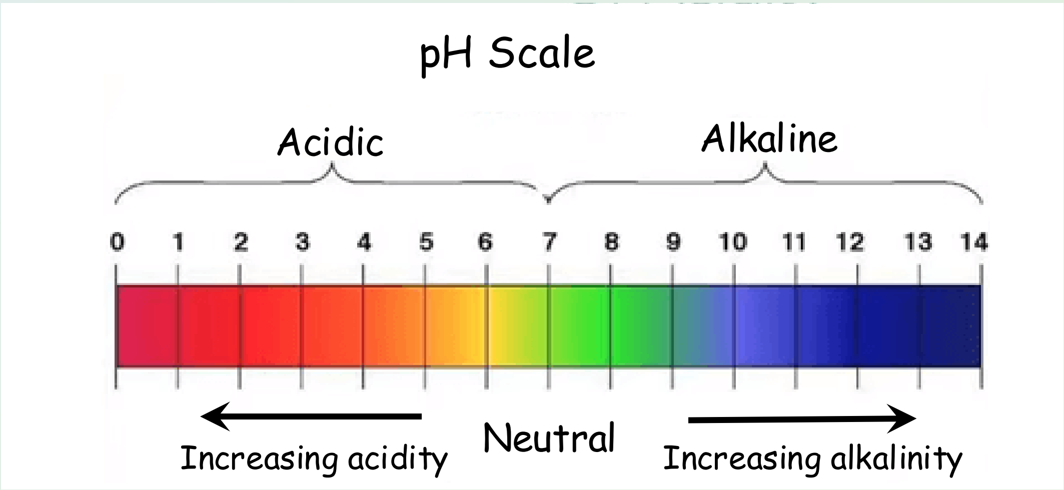
$$H_2O \rightarrow H^+ + OH^-$$

Acids also dissociate: $HCl \rightarrow H^+ + Cl^-$

- pH is a function of the concentration of H^+ ions in solution

→ the higher the concentration of H^+ ions → lower the pH

- scale is logarithmic → pH 1 is a million times more acidic than pH 7



Acid mine drainage

- Acid mine drainage → low pH, high metal and high sulphate -bearing waters
- leaching of sulphides from mine waste on mullock heaps and tailings produces acid drainage and heavy metal contamination of streams
- major pollution problem because of its ability to transport heavy metals and total dissolved salts (TDS)
- many acid mine waters contain elevated levels of toxic metals e.g. Cu, Ni, Pb, As, Zn, Cd and Mn

Acid mine drainage (AMD)

- Oxidation of Fe-sulphides in old mine workings and mine dumps causes widespread pollution in the form of acid mine drainage (AMD)

- AMD occurs mainly where sulphide minerals (mainly pyrite/marcasite) react with air and water, produce Fe-hydroxide and sulphuric acid

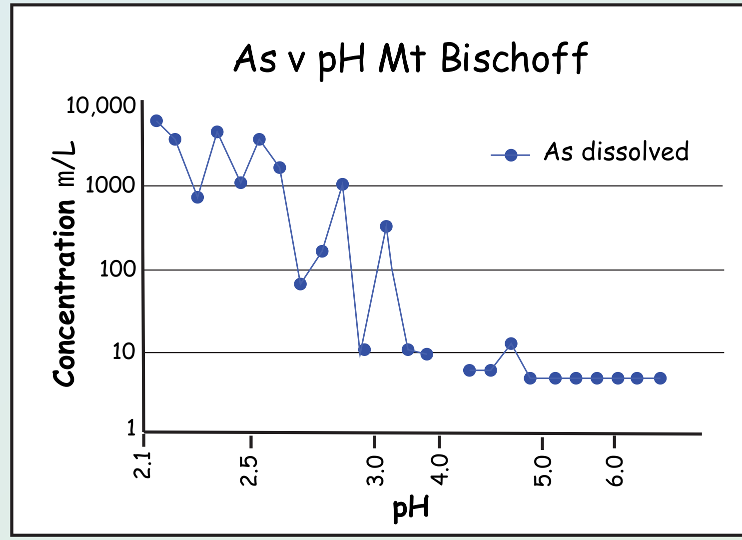
$$\underset{\text{pyrite/marcasite}}{4FeS_2} + 14H_2O + 15O_2 \leftrightarrow \underset{\text{iron hydroxide}}{4Fe(OH)_3} + \underset{\text{sulphuric acid}}{8H_2SO_4}$$

- this reaction is catalysed by Fe and S-oxidising micro-organisms

- when AMD occurs → sulphuric acid pollutes the water, lowers the pH and reddish orange sludges cover the bottom of streams

- other harmful metals such as Pb, Cd, As or Hg may also be leached from the rocks

Acid mine drainage



AMD at Mt Bischoff mine Tasmania

AMD, Yukon ,Canada

Environmental effects of AMD

- Drinking water, streams and groundwater can be polluted
- acid waters kill aquatic life in most acidic streams, only specialised bacteria survive
- acid waters attack man-made structures e.g. concrete bridges, container walls, concrete pipes and well casings
- in nature metal leaching by acid drainage occurs at rates >100 faster in the presence of the bacterium *Thiobacillus Ferrooxidans*
- not all mines that contain sulphides produce AMD. Deposits that contain limestone or extensive carbonate alteration may avoid AMD
- extensive carbonate alteration occurs in rocks hosting Au at the Morning Star mine at Woods Point, Vic. Mine water → pH = 7.2 – 7.5

AMD mitigation

(1) Adding lime or other alkaline substance to neutralise acidity

(2) Reduce infiltration of water into contaminated material

(3) Direct contaminated water through treatment plants where metals are removed

(4) Fill in mine workings with materials that will prevent formation of AMD e.g. water removes oxygen, alkaline materials neutralize acid

(5) Use bacteriocides to kill bacteria that speed up formation of AMD

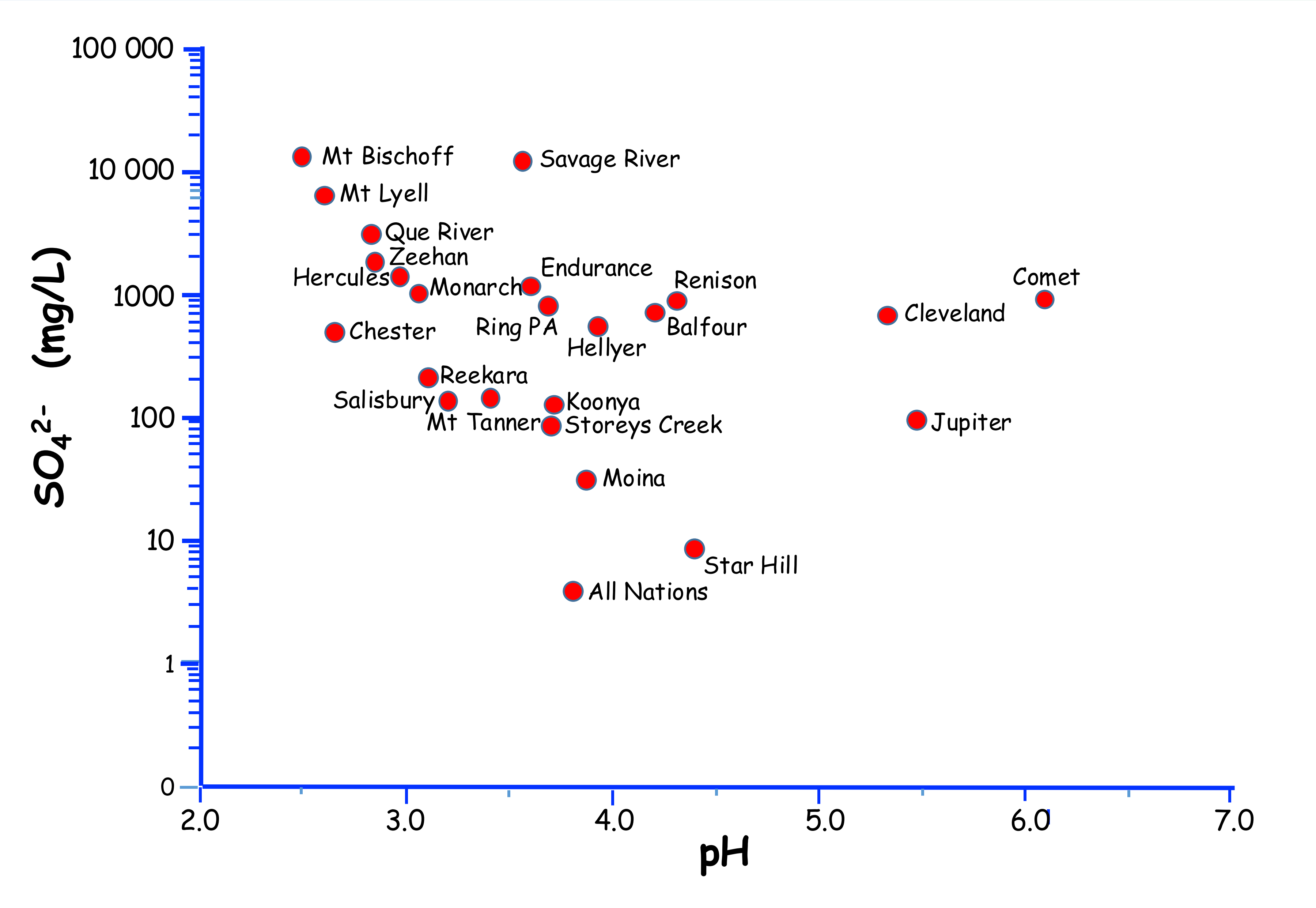
(6) Disposing of mine waste underground → prevent exposure to oxygen

(7) Construct wetlands with plants e.g. Cattails, Sphagnum moss that survive in acid water and remove toxic dissolved metals

Average surface water quality in Tasmanian catchments impacted by abandoned mines (Gurung 2005)

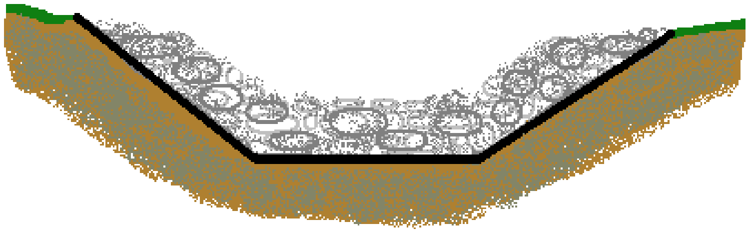
Parameter	No. of samples	Minimum	Maximum	Mean	ANZECC standard
pH	850	2.0	9.0	5.45	6.5 – 9.0
SO_4^{2-} (mg/L)	776	0.02	13,900	557	400
Al (mg/L)	532	0.0001	880	12.4	0.01
As (mg/L)	448	0.001	43.91	0.41	0.05
Cd (mg/L)	606	0.001	3.71	0.03	0.002
Cu (mg/L)	654	0.001	180	2.52	0.005
Fe (mg/L)	631	0.001	2,230	34.5	1.0
Mn (mg/L)	604	0.001	274	4.4	
Pb (mg/L)	650	0.001	27.4	0.21	0.005
Zn (mg/L)	672	0.001	728	7.45	0.01

Selected site characterisation by SO_4^{2-} levels in water



Use of limestone

- Limestone is commonly used to raise pH and precipitate metals in AMD
- low cost, safe method → however, problems due to low solubility and tendency to be coated by ferric oxide {$Fe(OH)_3$} and Fe-carbonate ($FeCO_3$)
- open limestone channels provide passive treatment
- high flow velocity and turbulence → keep precipitates in suspension
  → reduces armouring of limestones



Cross section of an open limestone channel

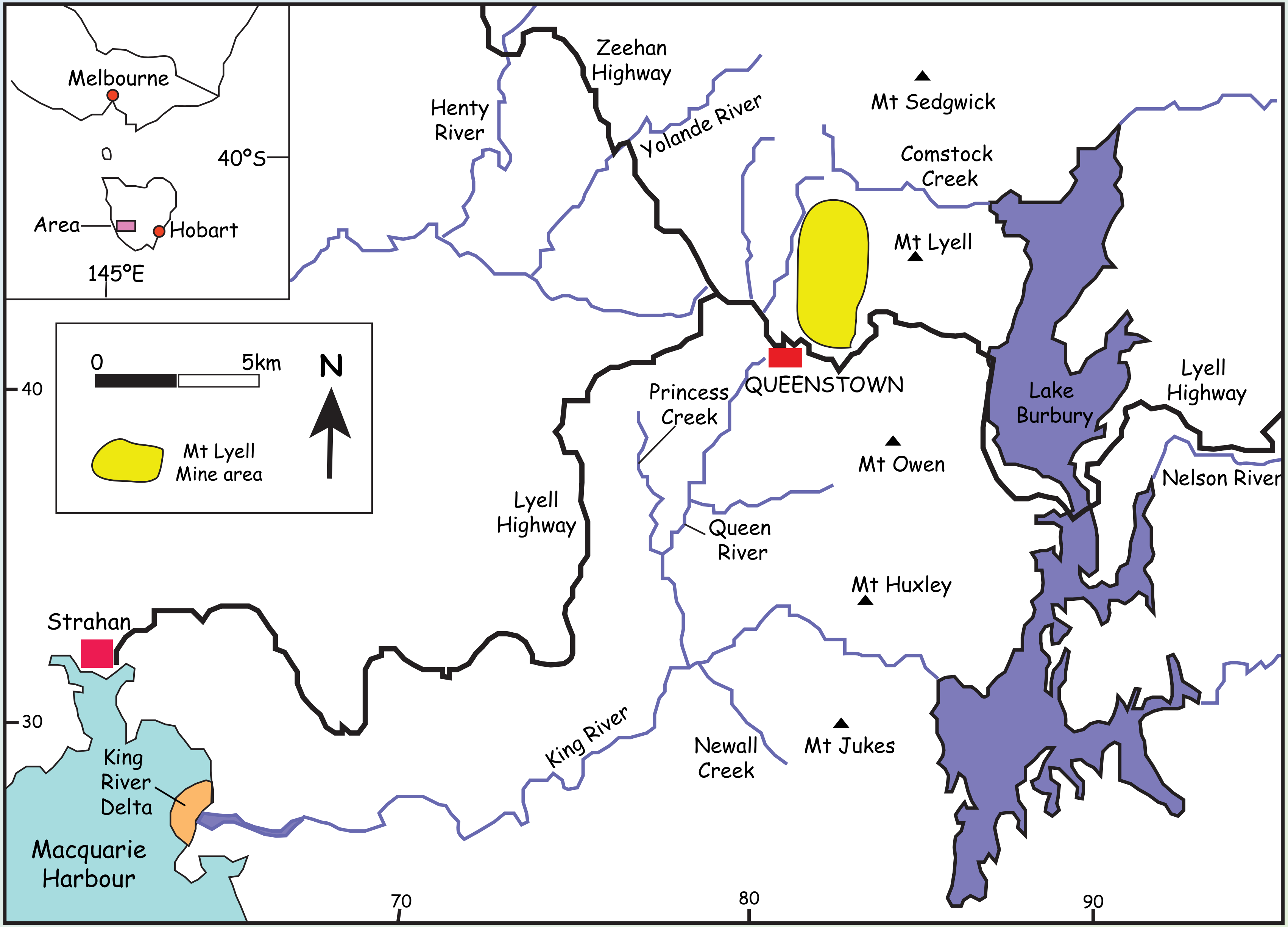
Effects of limestone on AMD

- Neutralisation process → increases pH
- removes heavy metals → solubility of heavy metals → dependent on pH → the higher the pH → the lower the solubility of heavy metals
- Ferrous iron (associated with AMD) oxidises at faster rate at higher pH
- the effect of limestone depends on its purity → high percentages of Mg and Si reduce its effectiveness.

Queen River Tasmania

- The Queen River is part of the King River Catchment in Western Tasmania that empties into Macquarie Harbour
- sourced by runoffs from the peaks of Mt Lyell and Mt Owen
- the river is heavily polluted by AMD originating from mine waste at the Mt Lyell Cu-Au mine with huge amounts of tailings entering the river
- an estimated 100million tonnes of acid waste have been leached into the river over the history of mining at Mt Lyell
- river's entire ecosystem → severely polluted killing all aquatic life and ancient Huon and King William pines that once grew on banks
- orange colour of river is due to iron sludge

Western Tasmania



Queen-King Rivers remediation

- Although addition of mine waste into the King River catchment has ceased, the catchment continues to be the source of heavy metals
- pollution due to acid rock drainage and remobilisation of waste in river banks, river bed and delta
- attempts are being made to reverse the damage and remove, neutralise or contain contaminated waters
- mine closure does not solve the problem because of high rainfall, large volume of sulphide rocks and extensive underground workings
- only solution to treat the acid drainage effluent from Mt Lyell is by extracting metals or neutralising the acid

Queen River, Queenstown, Tas.

Acid drainage from Mt Lyell mine workings

AMD in Queen and King Rivers

Pollution at confluence of Queen and King rivers

King River delta in Macquarie Harbour

Heavy metal contamination

- Mine waters are commonly contaminated with heavy metals and pose a threat to the health of people, animals and vegetation
- heavy metals most commonly associated with poisoning of humans are Pb, Hg, As and Cd all of which can occur in mine waters
- emissions of heavy metals from mine tailings lead to soil contamination → become resident in food chains
- heavy metals are refractory and do not undergo microbial or chemical degradation

Mechanisms for mitigation of heavy metal pollution

(1) Precipitation

A variety of alkaline chemical reagents used to neutralize AMD in order to increase pH and precipitate and recover metals, they include limestone ($CaCO_3$), caustic soda (NaOH), quicklime (CaO), slaked lime Ca(OH) and magnesium hydroxide {$Mg(OH)_2$}

Metal ion	pH	Metal ion	pH
Al^{3+}	4.1	Pb^{2+}	6.0
Fe^{3+}	3.5	Zn^{2+}	7.0
Mn^{2+}	8.5	Cd^{2+}	6.7
Cr^{3+}	5.3	Fe^{2+}	5.5
Hg^{2+}	7.3	Cu^{2+}	5.3
Na^{+}	6.7		

pH at which metals in AMD precipitate

Mechanisms for mitigation of heavy metal pollution

(2) Adsorption

- Adsorption occurs when an absorbate adheres to the surface of an absorbent
- only feasible for low concentration solutions → at high concentrations, adsorbent becomes saturated with absorbate
- not viable in large scale metal remediation

(3) Ion exchange

- Ion exchange → exchange of ions of like charge between an insoluble solid and ions in solution surrounding the solid
- high cation exchange capacity clay, zeolites and resins are commonly used for the uptake of metals from aqueous solutions

Mechanisms for mitigation of heavy metal pollution

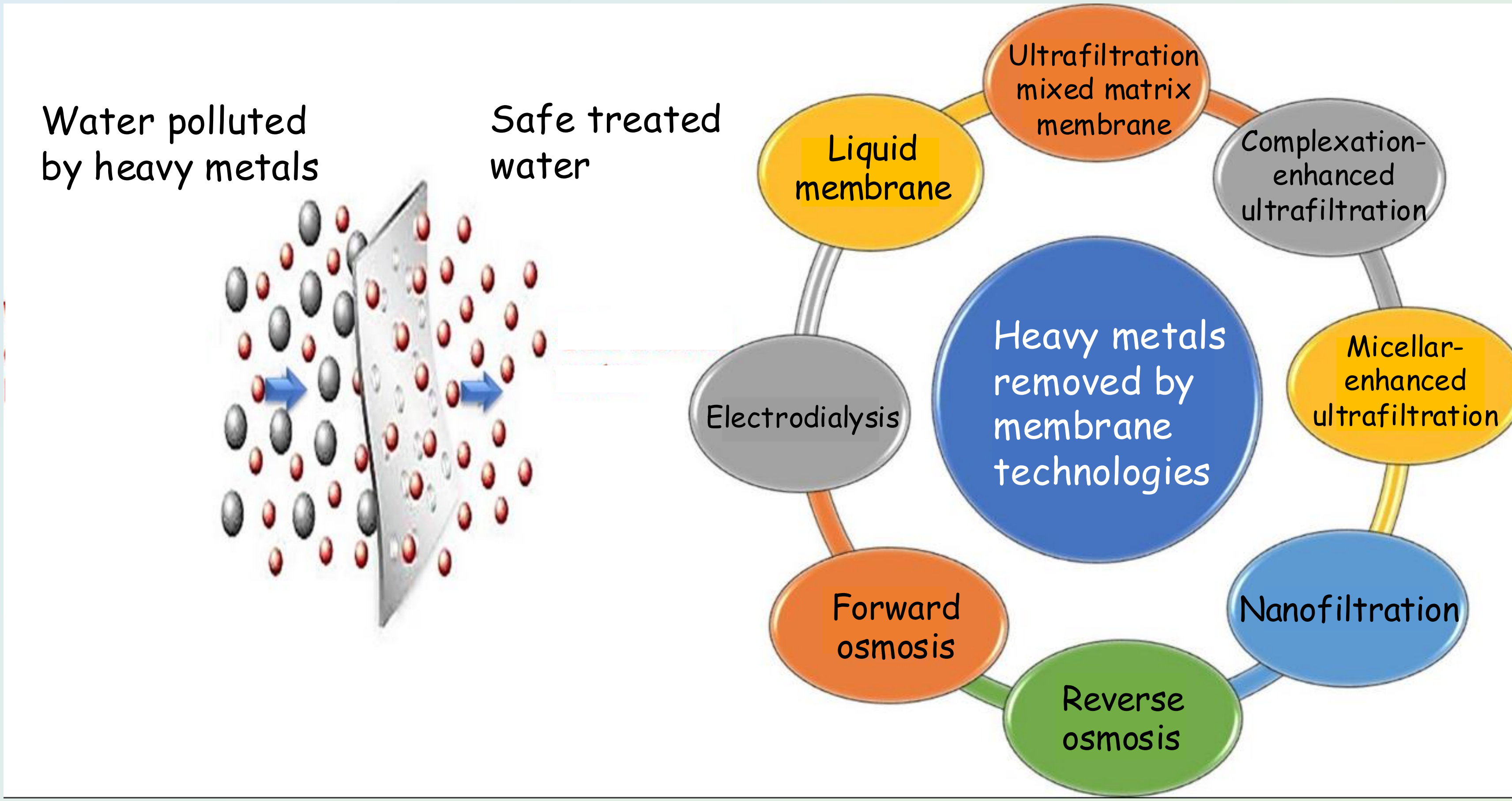
(4) Biosorption

- removal of pollutants from water systems using biological material
- wetland plants e.g. *Sphagnum* (peat moss), *Typha latifolia* (cattail) and *Phragmitis australis* (common reed)

(5) Membrane technologies

- use of membrane technologies → very effective
- different types of membranes used to treat mine water → ultrafiltration, nano-filtration, reverse osmosis, microfiltration, particle filtration

Membrane technologies



Mine water treatment Ballarat East Gold Mine

- Underground mine workings below the water table require constant dewatering
- mine water from underground workings → pumped out of mine → passes through water treatment circuit
- mine water slightly saline and contains metals (e.g. Fe, Mn, As, Cd, Pb) leached from rocks exposed in mine workings
- water is treated in pond and wetland system → removes metals to accepted safe levels
- treated water used for mining/processing of ore or discharged to environment under strict EPA discharge conditions

Mine water treatment circuit

Water tower	→	Ponds 1 & 2	→	Pond 3	→	

Series of mesh grids
→ water droplets
→ Fe^{3+} precipitation

Plastic lined,
aerated
sulphate added
→ metal precip.

Plastic lined,
aerated
water plants
→ biosorption

Wetlands,
vegetated
→ biosorption

Ballarat gold mine wetlands

Chemical pollutants produced in mining practices

Mercury

- Highly toxic metal → contaminates air, water and soil
- widely used from 1850s to 1980s to extract gold from milled ore
- gold and mercury combine → form amalgam
- mercury recovered by retorting amalgam for further use
- certain bacteria convert mercury to even more toxic methylmercur

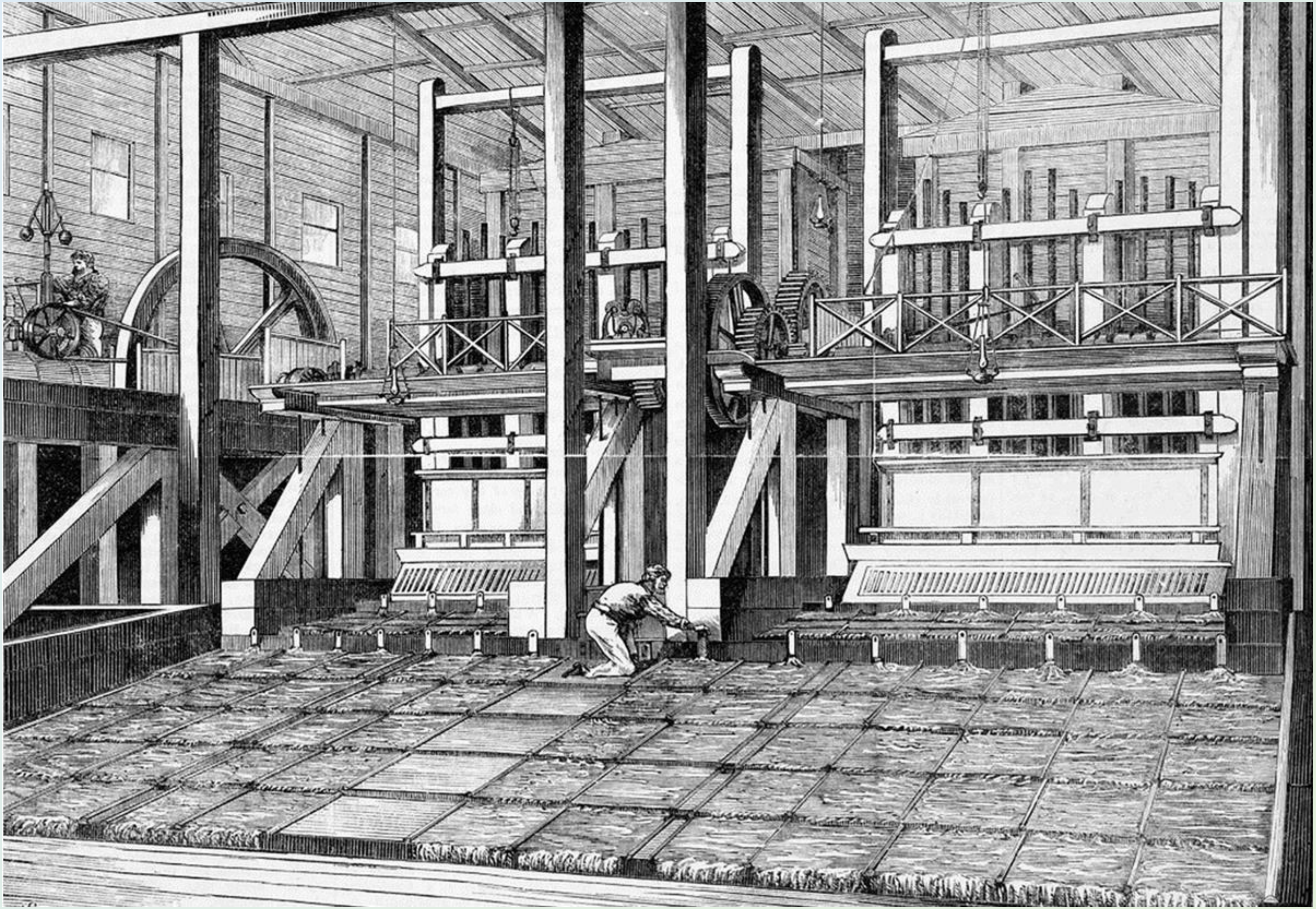
Glass retort

Mercury being used to extract gold from fine sediment, Brazil

Mercury pollution in Victoria

- Historic data on Hg used in Victorian goldfields 1868-1888 → 131 tonnes of mercury discharged into environment as mine tailings
- sediments analysed by Monash University chemists near the battery outlet at the A-1 mine, Gaffneys Creek, central Victoria commonly contained 50-150ppm Hg with a high of 1900ppm Hg
- elevated levels of Hg (1-10ppm) were present in sediments downstream in Raspberry Creek and the Goulburn River
- EPA accepted level in drinking water → 2ppb
- beads of Hg often observed in gold panning

Gold recovery using amalgamation



Chemical pollutants produced in mining practices

Cyanide

- Cyanide salts are used to extract gold from finely crushed ore
- common method is heap leaching → spraying ore on a heap with dilute cyanide solution → leach gold → collect extract

$$4Au + 8NaCN + O_2 + 2H_2O \rightarrow 4NaAu(CN)_2 + 4NaOH$$

- cyanide biodegradable, safe if used carefully
- potential dangers due to large scale spillages of concentrated cyanide and Na-cyanide pellets that may release CN into streams

Heap leaching

Baia Mare cyanide spill, Romania, 2000

- In 2000, cyanide spilled from a containment dam failure, flowing over farmland before entering the Somes River near Baia Mare, Romania
- polluted waters entered the Danube killing large numbers of fish in Romania, Serbia and Hungary
- pollution from the spill affected 5 countries: Romania, Hungary, Serbia, Bulgaria and the Ukraine
- cyanide concentration reached 7.8mg/L in the Somes River and still measured 0.2mg/L by the time it reached the Danube
- hypochlorite that was added to the Danube to neutralise the cyanide was responsible for many of the fish dying

Erosion and sedimentation

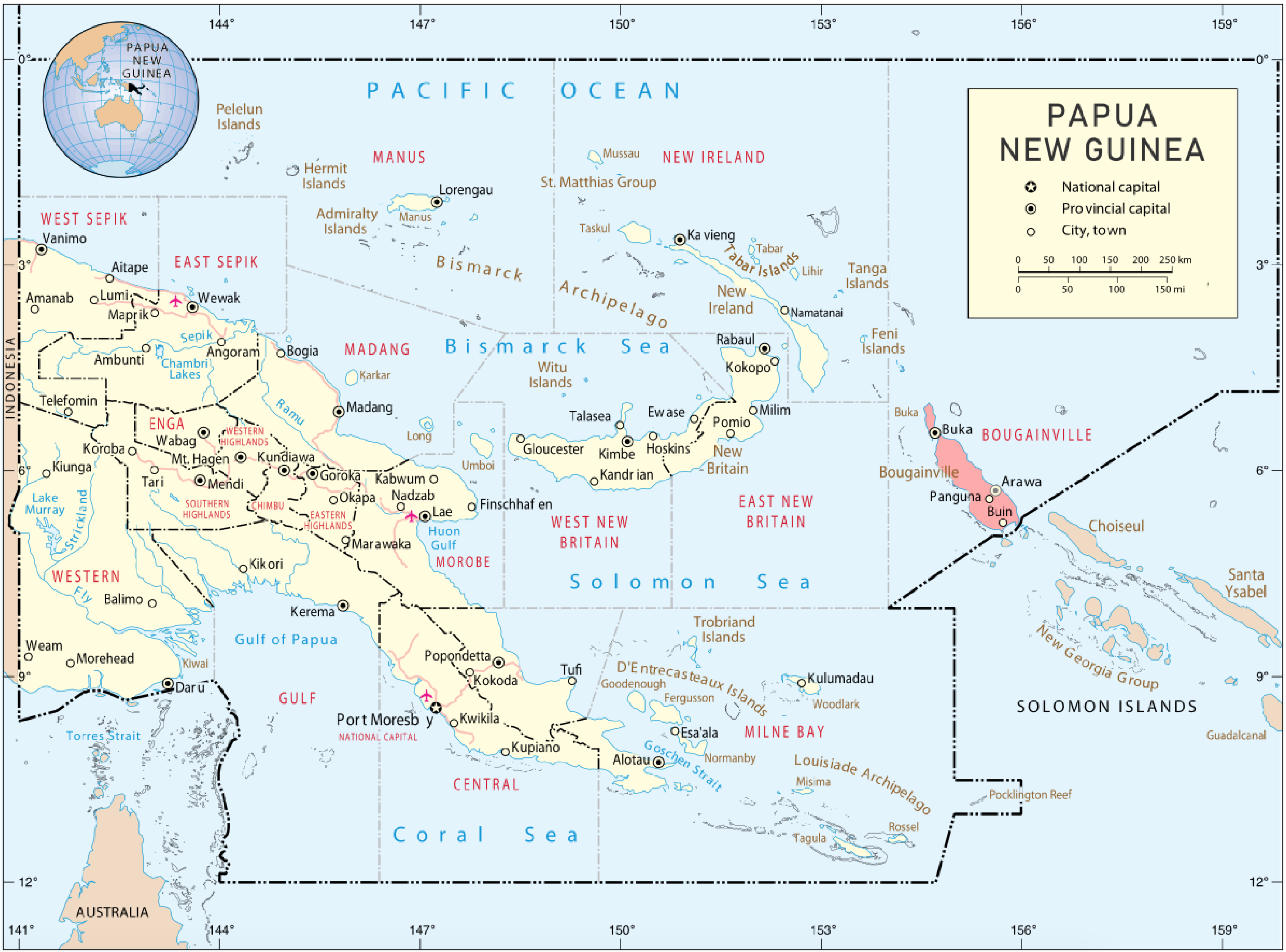
- Excess sedimentation can damage the health of waterways
- sediments may accumulate in areas of slow-flow → smother bottom-dwelling organisms and their habitats
- increased fine sediment in suspension → turbidity → reduces light penetration (inhibits algal photosynthesis), clogs fish gills
- nutrients in fine sediments promote algal blooms
- mining operations are required to take necessary actions → sediment traps and settling ponds used to mitigate excess sedimentation

Panguna Cu mine, Bougainville, PNG

- Cu exports dominate the economy of PNG
- Panguna Cu-Au mine in Bougainville PNG → one of the largest Cu reserves in PNG → estimated 1billion tonnes of Cu ore, 12Moz of Au
- Rio Tinto operated the mine from 1972-1989 when landowners angered by pollution sparked a war that closed the mine
- during its 17 years of operation → mine generated $US1.44 billion

PNG Govt.	61.5%
Local landowners	1.4%

Bougainville



Panguna Cu mine, Bougainville, PNG

Open cut mine, Panguna

Mining pollution from the Panguna Mine, Bougainville, PNG

- Cu mining in Bougainville resulted in serious pollution of the tropical environment → rivers choked with sediment, large areas of rain forest destroyed → sea contaminated with heavy metals
- at height of mining, 150-300,000 tonnes of waste rock and tailings were discharged daily from mine into Kawerong – Jaba river system
- buildup of mine tailings in streams caused widespread flooding
- levy banks built to contain flooding → breached by floodwaters → river polluted by acid leached from mine waste now floods large areas
- Rio Tinto divested interest in mine in 2016 without remediation
- PNG government considering reopening mine to fund a cleanup of site

Polluted drainage at Bougainville

Cu-Fe sulphates in mine drainage, Panguna mine

Asbestos pollution

- Asbestos pollution in the air → cause of mesothelioma
- Wittenoom area of WA affected by asbestos contamination from mining activity at three mine sites
- mines operated from 1930s to 1966 → produced tailings containing varying amounts of blue asbestos (riebeckite)
- stockpiles of tailings → eroded → dispersed by wind and water → now extend several kilometres from mining sites

Asbestos mine mullock heap, Wittenoom, WA

It is not all bad news

- Since 1980s → strict regulations introduced to mitigate impact of mining and remediate historic mining sites
- OH&S and environmental regulations in the mining industry are the strictest of any industry in the country
- strict regulations on tree felling and weed control e.g. blackberry, English Broom
- mining companies are aware that if they do not conform with these regulations, they will be closed down
- mining companies take mitigation very seriously and commonly employ environmental scientists on their staff

Land rehabilitation post mining