Tutor instructions: Course split into three 1.5 hour sessions. Each involves a lecture follow by a practical session.

Structure and rough timings for part 2.
Lecture (slides 1 to 29): 30-40minutes
Break: 5minutes
Introduce practical (slides 29 to 36): 5-10minutes
Completion of practical questions by participants: 30minutes
Wrap up and group discussion of summary practical questions (slide 37 to 38): 10 minutes

Tutor introduction

Dr. Luke Bridgestock

- MSci Geology and PhD in Isotope Geochemistry, Imperial College London
- Postdoctoral Research Associate, University of Oxford (2015 to 2020)
- Leverhulme Early Career Research Fellow, University of Cambridge (May, 2020 to present)
- Research interests in metal cycling in the environment
- More details at https://www.earth.ox.ac.uk/people/luke-bridgestock/

Heavy metal pollution from mining activities

TIDE

Part 2: Mining activities as sources of heavy metal pollution to rivers

Luke Bridgestock
Department of Earth Sciences,
University of Oxford

UNIVERSITY OF OXFORD

In this part of the course we are going to consider the sources of heavy metals to the environment, with of focus on those related to mining operations.

Activity Outline

This activity will focus on the exposure of local populations to heavy metal pollution from mining operations

Part 1; the impact of heavy metal pollution from mines on water quality and the health of local populations

Part 2; the release of heavy metals to surface waters (rivers and lakes) from mining activities

Part 3; remediation techniques for acid mine drainage

Practical; a case study to assess the exposure routes of local people to heavy metals and the sources of heavy metals to a river system impacted by mine pollution.

Just as a reminder of the structure of this course.

We have covered how people are exposed to heavy metals, and how to assess and identify populations of people how are at risk of developing chronic metal toxicity problems in part 1. As mentioned we will now seek to understand how metals are released to the environment by mining processes and in the practical on this part of the course you will think about the role of mining activities in the hypothetical case study for causing chronic toxicity risks you identified using HQs in part 1.

In part 3 we will build directly on some of the knowledge presented in this lecture to learn about some remediation techniques for acid mine drainage, a key mining process for metal pollution,

Introduction

Exposure to high amounts of certain heavy metals can be toxic to humans and wildlife.

Human activities have released large amounts of these elements into the environment, increasing the risk of metal toxicity.

However, exposure to toxic amounts of heavy metals can also occur due to natural processes

To be able to develop successful strategies to protect the public from heavy metal toxicity problems, it is important to understand the sources (both human and natural) of these elements in the environment.

As mentioned in the last lecture, understanding the sources of heavy metals in the environment, and their transport pathways to the point of human exposure is key to being able to develop strategies that protect the public from metal toxicity problems.

Heavy metals can be mobilized and transported in the environment to points of human exposure by natural processes, but human activities have greatly accelerated to the mobilization and transport of many metals in the environment.

Processes related to mining operations are among the most important human activities for releasing metals to the environment, and so this is the focus of this section of the course

Part 2; Key learning objectives

1. What are the main processes that release heavy metals to the environment from mining operations?
2. What is acid mine drainage and how is it produced?
3. What is the mercury amalgamation technique?

For this part of the course the key learning objectives are to be able to answer these 3 questions

1. What are the main processes that release heavy metals to the environment from mining operations?
2. What is acid mine drainage and how is it produced?
3. What is the mercury amalgamation technique?

Again will we revisit these at the end of this lecture and hopefully you'll all be able to answer these questions

Human sources of heavy metals to the environment

Human activities have resulted in the release of large quantities of metals into the environment. This has increased the risk of toxic effects to living organisms due to exposure to high amounts of these metal elements

Important human activities for releasing metals to the environment are;

Mining

- **Acid mine drainage; mercury amalgam; smelting**

Atmospheric emissions

- Burning of fuels and waste materials

Discharge of industrial, agricultural and domestic waste waters

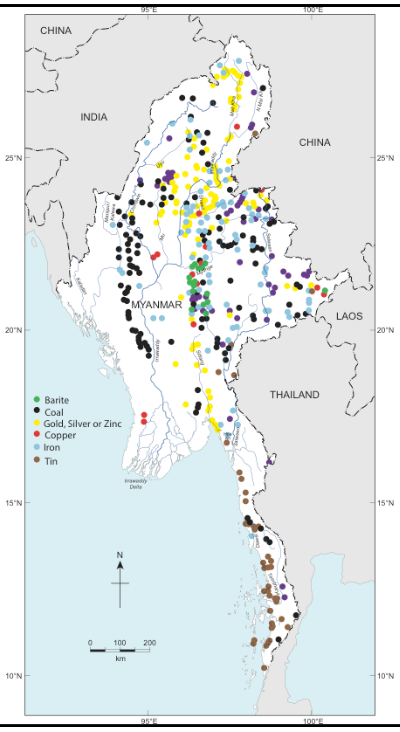
- Chemicals used in industry; fertilizers and pesticides; sewage

It is important to note than mining operations are not the only human activities that release metals to the environment.

Other important processes include;
burning fuels and waste materials during which volatile metals (have a low boiling point) are vaporized and emitted to the atmosphere. Upon cooling metals condense onto very small particles (less than 1 micron in size) that can remain suspended in the atmosphere and undergo long-range transport by the wind, before being ultimately deposited to soils and water bodies.

Metals can also be directly discharged to soils and water bodies at 'point sources' (i.e. individual locations). Industries can directly release waste containing high metal concentrations, fertilizers and in particular certain pesticides used in agriculture can contain certain metals, as can sewage discharged into rivers. Additionally, technological products such as batteries can contain large amounts of certain toxic metals which if improperly disposed of can leach metals into the surrounding environment.

Mining related processes however are a dominant source of many metals to the environment



Mining in Myanmar

Abundant tin, gold, copper, lead and coal mines

Mining operations are often 'small scale' or 'artisanal'

Artisanal/Small Scale mining

Local people mining independently of mining companies, with little to no specialist equipment - *low level of technology*

This type of mining operation is very difficult to monitor and regulate, but can be an important source of income for local communities

Myanmar has an abundance of active mining operations and a lot of mineral resources, with scope for further expansion of the mining sector which could be an important driver for the economic development of Myanmar in the future.

Understanding issues surrounding metal pollution from mines is therefore a particularly important environmental topic to focus on.

Many of the mining operations in Myanmar are classified as small scale or artisanal. This does not refer to the size of these mining operations, many of which can be extensive, but instead refers to the level of technology used. Small scale/artisanal mining involves little of no specialist equipment and often operate illegally with out being properly monitored and regulated by governing bodies.

For these reasons, these types of mining operation can present particularly high risks in terms of metal pollution. Lack of technology and regulation can lead to practices that do not seek minimize metal pollution.

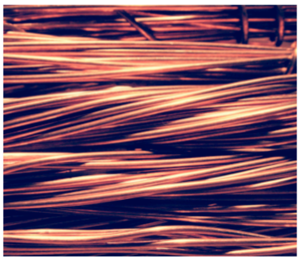
Mining

Mining is very important to the economy but can have harmful effects on the environment

Metals are mined from ore deposits – rocks that contain high concentrations of certain metal elements

Metal ores are extracted from the ground and processed to produce the raw metals

Large amounts of waste material known as 'mine tailings' are also produced



Photos; pexels.com

Mining is essential to the economy and modern society, an activity that we cannot do without, despite the potentially harmful impacts on the environment and health of local populations. Instead we must seek to minimize the negative environmental impacts of mining.

Some very brief background on mining operations relevant to understanding how metals can be released as pollution (for those of you without geology backgrounds).

Metals are mined from ore deposits – essentially rocks that contain very high concentrations of certain metals. Once these rocks have been extracted from the ground they are processed to extract the metal. In doing so a large amount of waste material (mine tailings) are also produced.

The release of metals to the environment as pollution can occur during different stages of this general process – either directly from the metal rich primary rock material, during the processes of the ore, or from the mine tailings.

Metal pollution from mining

Mining activities can result in the release of large amounts of heavy metals into water bodies (rivers, lakes and groundwater) during ore processing and from the waste materials (tailings).

Important processes are;

1. **Acid mine drainage**; metals released from ore material and waste material (mine tailings)
2. **Smelting;** ore processing technique that results in metal emission to the atmosphere
3. **Mercury amalgamation**; technique to process gold ore that results in mercury (Hg) pollution

The important processes for releasing metals to the environment, that we will consider in more detail in the remainder of this lecture are:

1. Acid mine drainage − globally the dominate process for generating metal pollution from mine, involving the release of metals from mine tailings and ore material
2. Smelting − an ore processing technique resulting in metal emission to the atmosphere. The atmospheric budgets of numerous metals are currently dominated by this process
3. Mercury amalgamation − a technique used to process gold ore, that results in the release of mercury (Hg) to the environment. This process has been largely phased out of use, but is still widely used by artisanal gold mining operations, including in Myanmar, and represents a potentially important but un-studied environmental issue for Myanmar.

Summary
True or false?

1. Mining is important to the economy but can have negative impacts on the environment

2. Myanmar has a lot of mining operations many of which are artisanal/small scale mines

3. Metals can be released from mining operations to the environment due to acid mine drainage

Tutor instruction: Ask them to read through these statements and decide, based on the material presented so far, if they think they are true or false. Give them 3-5mins to to this and discuss among themselves. Then ask them to shout out what they think, before revealing the answers on the next page.

Summary
True or false?

1. Mining is important to the economy but can have negative impacts on the environment **TRUE✔**

2. Myanmar has a lot of mining operations many of which are artisanal/small scale mines **TRUE ✔**

3. Metals can be released from mining operations to the environment due to acid mine drainage **TRUE ✔**

Tutor instruction: Spend a moment to briefly explain any incorrect answers.

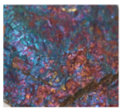
Acid mine drainage

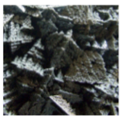
Acid mine drainage is the discharge of acidic (low pH) water with high concentrations of metals from mining areas.

It is produced by the chemical reaction of metal sulfide minerals with oxygen and water at Earth's surface

Metal ore deposits (and coal deposits) contain a lot of metal sulfide minerals.

<u>Common metal sulfide minerals in ore deposits</u>

Pyrite FeS_2  Chalcopyrite CuFeS 

Galena PbS  Sphalerite ZnS 

Photos; pexels.com

A major pathway for metal release from mines to rivers and groundwater is due to acid mine drainage.

Acid mine drainage is the discharge of acidic waters (low pH) that contain very high metal concentrations from mining areas. It is produced by the chemical reaction of metal sulfide minerals with oxygen and water at the surface of the Earth.

Ore deposits typically contain abundant metal sulfide minerals. Most ore minerals mined to produced metals are sulfides; e.g. PbS is mined to produce lead (Pb), ZnS is mined to produce zinc (Zn) and cadmium (Cd), and CuFeS is mined to produce copper (Cu). Pyrite (FeS2) is by far the most common sulfide mineral and is found throughout different metal ore deposits, although is not itself an ore mineral. Arsenic can also commonly occur in sulfide minerals in these deposits as arsenopyrite (FeAsS)

Coal deposits also typically contain lots of pyrite (and arsenopyrite) which can also generate significant amounts of acid mine drainage

Acid mine drainage

TIDE

When metal sulfide minerals are exposed at the Earth's surface they react with oxygen and water producing acidic fluids with very high concentrations of metals

For example, pyrite (FeS_2) will undergo the following chemical reaction;

$$2FeS_2 + 7O_2 + 2H_2O \longrightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$$

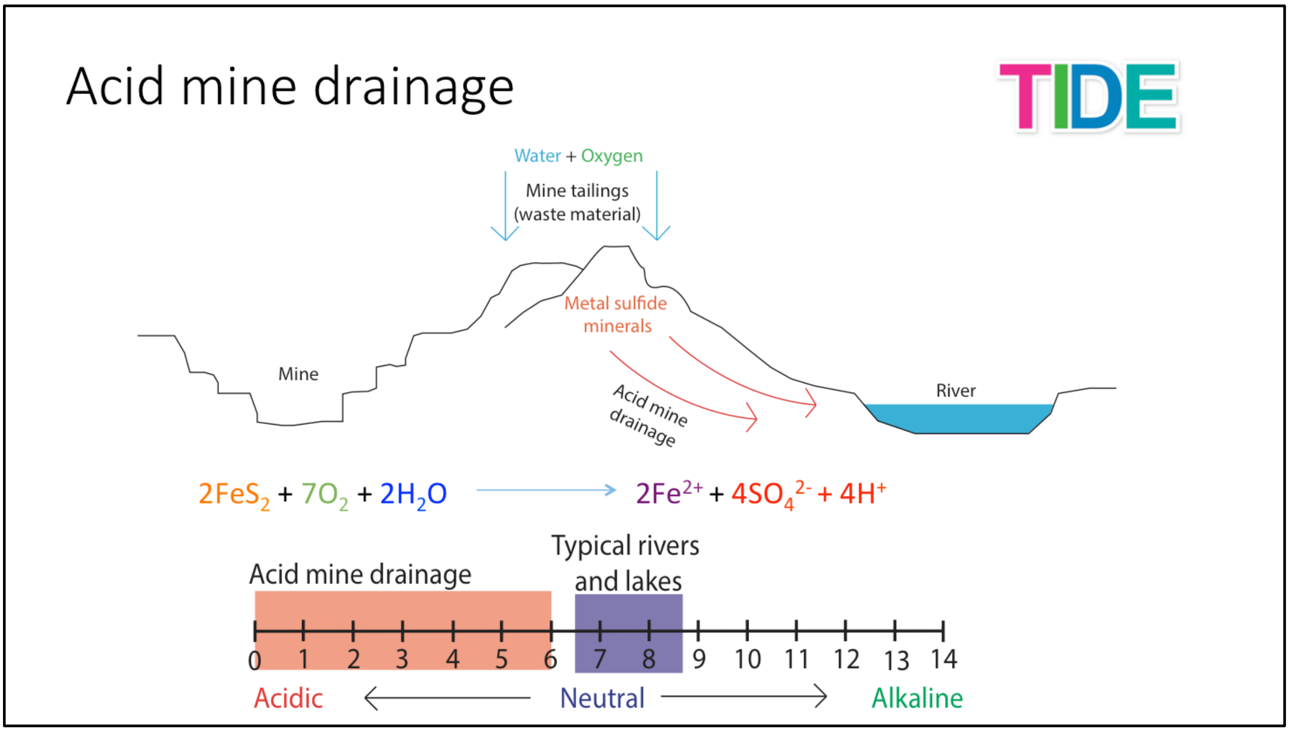
 + oxygen + water ⟶ Dissolved iron + sulfuric acid

Since pyrite is the most abundant metal sulfide mineral in most ore deposits, its reaction with water and oxygen is considered the main chemical reaction responsible for generating acid mine drainage, however oxidation reactions of other metal sulfides (e.g. FeAsS2, CeFeS2, PbS etc), can also be important depending on the mineralogy on the ore deposit and mine waste material.

This reaction can occur by different pathways, and microbes can often be important for mediating/speeding up this reaction and generating acid mine drainage. Understanding the reaction pathway and role of microbes is key to understanding the kinetics of this reaction, and hence the rate at which acid mine drainage is produced

The product of this reaction is Fe released to dissolved form (in its 2+ oxidation state) and sulfuric acid, collectively producing acidic water full of dissolved metals (i.e. acid mine drainage).

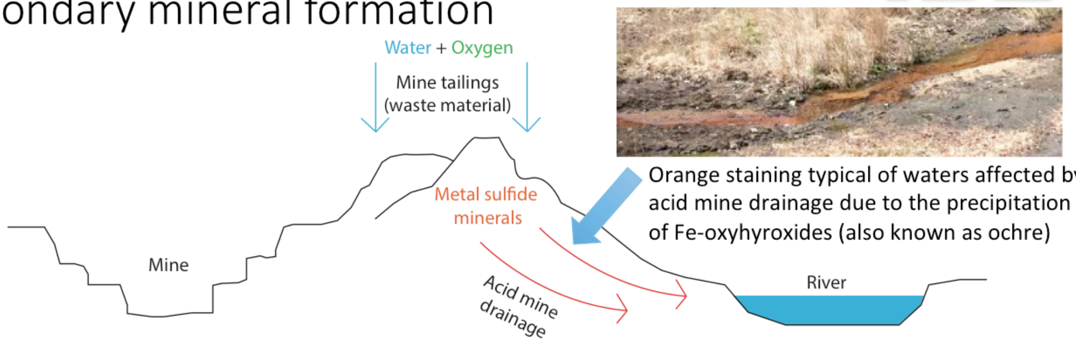
Similar chemical reactions involving other metal sulfide minerals (e.g. PbS) result in the release of a wide range of toxic heavy metals into dissolved form.



This chemical reaction occurs where metal sulfide minerals are exposed to water and oxygen. Mine tailings, crushed rock removed from underground and brought to the surface, typically contains abundant metal sulfides and create favorable environments for this reaction to take place, as due areas where overlying rock has been excavated to expose ore bearing rocks at the surface.

Fluids close to the source of acid mine drainage are characterized by low pH and high concentrations of sulfate (SO4) due to the generation sulfuric acid. The typical pH of surface waters (lakes and rivers) are around 7 to 8, but acid mine drainage can greatly reduce this, all the way to pH 0 in extreme cases. In addition to their high metal concentrations the low pH of these waters are toxic to both aquatic life and humans

Acid mine drainage;
Secondary mineral formation



Orange staining typical of waters affected by acid mine drainage due to the precipitation of Fe-oxyhyroxides (also known as ochre)

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$$

Acid mine drainage can be neutralized due to dissolution of surrounding rocks and soils (notably carbonate minerals; i.e. limestone)

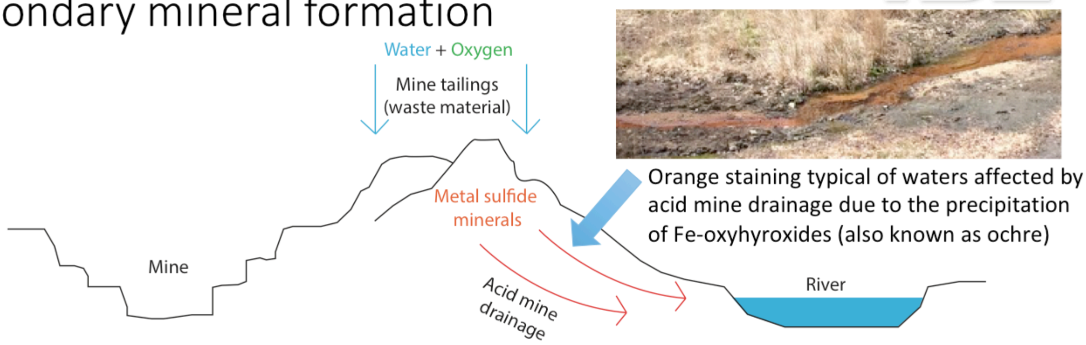
This increase in pH can cause the precipitation of secondary mineral phases

As waters flow always from the source of acid mine generation (i.e. areas with exposed sulfide minerals), secondary chemical reactions occur that act to modify pH of the solution and reduce the dissolved metal concentrations.

These secondary chemical reactions therefore play a key role in controlling the transport of dissolved metals into the wider environment.

Sulfate concentrations in contrast are better maintained and so can provide a useful ‘fingerprint’ of acid mine drainage in locations more distal from their sources.

Acid mine drainage;
Secondary mineral formation



$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$$

A common and important secondary mineral precipitation is of Fe-oxyhydroxides - $Fe(OH)_3$

$$4Fe^{3+} + 12H_2O \rightarrow 4Fe(OH)_3 + 12H^+$$

Precipitation of these minerals can remove toxic metals from the water, trapping them in soils

A ubiquitous secondary reaction is the precipitation of Fe-oxyhydroxide minerals, in which Fe2+ is first oxidized to Fe3+, which then reacts with water to form Fe-oxhydroxide minerals. In addition to reducing the dissolved Fe concentrations of these waters, other toxic metals can be removed by adsorption to the surfaces of these minerals.

Fe-oxyhydroxide precipitation leads to the orange staining of soils in the surrounding area, which is a prominent visual characteristic of areas impacted by acid mine drainage.

The pH of these fluids is also typically increased as fluids flow away from the source due to the the dissolution of CaCO3 minerals from rocks and soils, and through biological processes that generate alkalinity, neutralizing acidity.

As we will learn in part 3, these secondary reactions form the basis of a number of different remediation options for addressing acid mine drainage

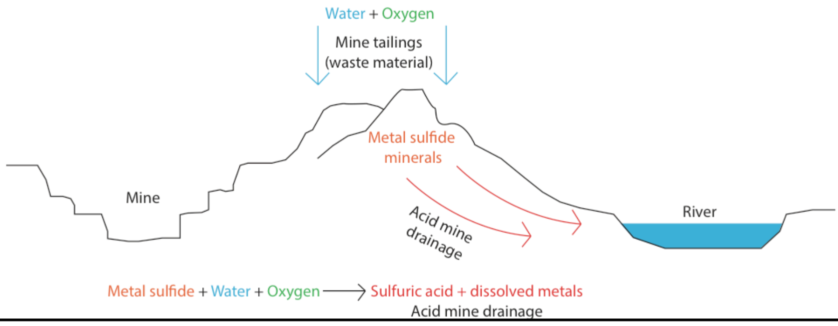
Acid mine drainage

Metal sulfide minerals in ore deposits react with oxygen and water producing acidic fluids with very high concentrations of metals

This chemical reaction happens naturally when rocks containing metal sulfide minerals are exposed at the surface of the Earth by erosion.

However, mining greatly exaggerates this process, by actively digging up material containing metal sulfide minerals, and crushing it into small pieces.

This allows oxygen and water to react with metal sulfides much faster.



It is important to note that acid mine drainage can occur naturally.

The natural exhumation of rocks containing metal sulfides by uplift and erosion, will bring metal sulfides into contact with water and oxygen at the surface of the earth, and drive the generation of acid mine drainage.

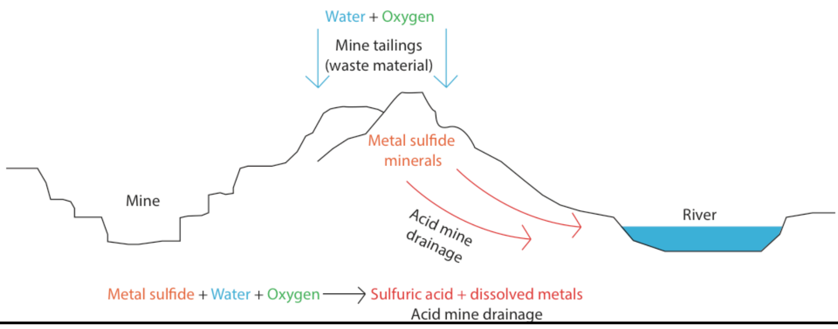
However mining has hugely accelerated this process by digging up sulfide rich rocks that would otherwise remain buried underground and crushing them into fine powder, greatly increasing the surface area of metal sulfide minerals that come into contact with water and oxygen at the surface of the earth.

Acid mine drainage

Metal sulfide minerals in ore deposits react with oxygen and water producing acidic fluids with very high concentrations of metals

The problem of acid mine drainage is very difficult to control.

Acid mine drainage will continue to be produced for many years (decades and even centuries) after the mine has closed.



Acid mine drainage is a major environmental issue in all regions that have a history of mining sulfide containing rocks.

It is an issue that is very difficult to control both because of the scale of the material that is involved, and because acid mine drainage is continued to be generated from mining areas for many decades to centuries after mining operations have ceased. This is because metal sulfide rich material remains at the earth surface and continues to react with water and oxygen for a very long time. Simply shutting down mining operations does not solve acid mine drainage issues, and in many cases can actually result in an increase in acid mine drainage generation, as mines flood when groundwater is no longer pumped out of them.

In part 3 we will focus on these issues in more detail and learn about some of the remediate techniques applied to try and address acid mine drainage issues.

Summary
True or false?

1. Acid mine drainage is acidic water with very high concentrations of heavy metals
2. Acid mine drainage is produced by the reaction of metal sulfide minerals with oxygen and water
3. Acid mine drainage does not occur naturally
4. Acid mine drainage is only a problem when mines are active

Tutor instruction: Ask them to read through these statements and decide, based on the material presented so far, if they think they are true or false. Give them 3-5mins to to this and discuss among themselves. Then ask them to shout out what they think, before revealing the answers on the next page.

Summary
True or false?

1. Acid mine drainage is acidic water with very high concentrations of heavy metals **TRUE ✔**
2. Acid mine drainage is produced by the reaction of metal sulfide minerals with oxygen and water **TRUE✔**
3. Acid mine drainage does not occur naturally **FALSE ✗** Acid mine drainage can occur any time metal sulfide minerals are exposed to water and oxygen at Earth's surface, including due to natural erosion
4. Acid mine drainage is only a problem when mines are active **FALSE ✗** Acid mine drainage remains a persistent problem long after (decades to centuries) a mine has closed

Tutor instruction: Spend a moment to briefly explain any incorrect answers.

Ore processing techniques and metal release to the environment

Once mined, ore material is processed to produce the raw metals

Metal Smelting

An important technique used to process metal ore

Involves heating the ore to very high temperatures

Metals can be vaporized in the process and emitted to the atmosphere

These metals can then be deposited into soils and surface waters (rivers and lakes)

Photos; pexels.com

Another major mining related process that releases large amounts of metals to the environment is smelting, which is a technique used to process ore material to produce raw metal.

It involves heating ore material to high temperatures, which exceed the boiling points of many volatile metals. These metals are emitted to the atmosphere as a vapor, and upon cooling condense onto very small particles, less than 1 micron in size, that can remain suspended in the atmosphere for days to weeks. During this time they can undergo long-range transport and be dispersed very widely, often being transported across entire continents and oceans to other regions of the world entirely. Eventually they are deposited to soils and water bodies, where they can release the metals into dissolved form. Not only are metal emissions from smelting concern to populations living close to these facilities (via exposure through inhalation and ingestion, after metal deposition and uptake into food/water resources), but they are also responsible for enriching metal abundances in environments that are very remote from human populations. For example, Antarctic snow/ice contains enrichments of certain metals (e.g. Pb) due to smelting emissions and long-range atmospheric transport. Emissions from metal smelting are currently considered to be the most important atmospheric source of numerous heavy metals, including cadmium, zinc, and copper, and are major atmospheric sources for others (like Pb).

Gold Mining; Mercury Amalgam

Mercury (Hg) amalgamation is a technique used for separating gold from ore deposits

It can result in the release of mercury (Hg), a very toxic heavy metal, to the environment

It is used widely by small scale and artisanal miners

Photos from; Esdaile & Chalker, 2018, *Chem. Eur. J.*

The final mining related process we will learn about here that release metals to the environment is the use of the mercury amalgamation technique. This is a technique used to separate gold, from ore material, by artisanal gold miners. Historically it was also an important ore processing technique used by non-artisanal mining operations, but it has been phased out of use in this sector in favor of less damaging techniques, since the harmful impacts of this technique have been recognized.

It currently represents the most important economic use of mercury (Hg) globally (i.e. most Hg commercially mined and sold is used in this process)

The release of mercury to the environment due to the use of this technique currently represents the biggest source mercury pollution globally. This is largely because other processes that release Hg to the environment have been phased out in a global effort to reduce Hg pollution. Because artisanal gold mines are by their nature unregulated by governing bodies, the use of the Hg amalgamation technique continues in this sector. Also for artisanal gold miners that do not have access to more expensive high-tech ore processing options, the use of the Hg amalgamation technique represents their only viable option to process the ore material they mine into gold that they can sell.

Gold Mining; Mercury Amalgam

The mercury amalgamation technique;

1. Liquid mercury is mixed with the ore material
2. Gold in the ore binds with the liquid mercury (forming a mercury amalgam) which is separated from the waste materials
3. The gold is separated from the mercury amalgam by evaporating the mercury

Photos from; Esdaile & Chalker, 2018, *Chem. Eur. J.*

How does this technique work?

1. Miners mix liquid mercury (sliver liquid in the photos), with crushed up ore material
2. Gold in the ore partitions into the mercury, forming a mercury amalgam, which can then be filtered to separate the liquid Hg (now containing gold) from the waste material
3. Finally the Hg amalgam is heated causing the Hg to evaporate, leaving a residue of purified gold (see photo on right)

Gold Mining; Mercury Amalgam

The evaporation of mercury (Hg) releases large amounts of this toxic metal to the atmosphere

Mercury is also released into waters from the waste material

Artisanal/small scale gold mining is often conducted in and close to rivers, so much of this mercury enters rivers

Photos from; Esdaile & Chalker, 2018, *Chem. Eur. J.*

Large amounts of Hg are released into the environment via 2 routes in this process.

1. Evaporation of Hg leads to its emission to the atmosphere as a vapor, where it can they be dispersed widely by the winds before being deposited to the land surface
2. The waste material, left behind after filtering the Hg amalgam, contains high concentrations of Hg due to inefficient separation by this process. Hg can then be leached from this waste material into the wider environment. Many artisanal gold mining operations are located close to rivers (as they often mine the river sediment), and this waste material can often be deposed of in the rivers, leading to Hg contamination in these water sources. An additional issue can also be the release of cyanide (a toxic organic contaminant). Cyanide can be sued to aid the recovery of gold from the ore material.

Gold Mining; Mercury Amalgam

The workers conducting this procedure are at very high risk of being exposed to high levels of mercury, by inhalation of the mercury fumes, and by dermal exposure if handling the mercury without protection

High levels of mercury in fish from rivers in areas where this technique is used are common due to biomagnification. Local populations who eat these fish are at risk of developing mercury toxicity problems.

Photos from; Esdaile & Chalker, 2018, *Chem. Eur. J.*

The workers conducting this procedure are at very high risk of being exposed to high levels of mercury, by inhalation of the mercury fumes during the evaporation of the Hg, and by dermal exposure if handling the mercury without protection. This process is often carried out in close proximity to the mine workers families, and the wider local community putting them at high risk of Hg exposure as well. These risks can be reduced by the use of protective equipment, gloves to protect against dermal exposure and a retort, a device that captures and re-condenses Hg vapor emitted during the evaporation step. The use of a retort is also advantageous in that it reduces the emission of Hg to the wider environment and allows the Hg to be reused by the miners. However these relatively inexpensive protective equipment are often not used.

The wider population living in regions surrounding these artisanal gold mining operations are at risk of developing Hg toxicity issues to the the consumption of fish. Fish can accumulate very high concentrations of Hg in these regions due to biomagnification as we discussed in part 1 of this course

Summary
True or false?

1. Smelting is an important technique for processing ore material into metals
2. Metals emitted to the atmosphere by smelting only impact localized regions
3. The mercury amalgamation technique is widely used in small scale and artisanal gold mining operations in Myanmar
4. The use of the mercury amalgam technique can be an important source of this toxic metal to rivers

Tutor instruction: Ask them to read through these statements and decide, based on the material presented so far, if they think they are true or false. Give them 3-5mins to to this and discuss among themselves. Then ask them to shout out what they think, before revealing the answers on the next page.

Summary
True or false?

1. Smelting is an important technique for processing ore material into metals **TRUE ✔**
2. Metals emitted to the atmosphere by smelting only impact localized regions **FALSE ✗** Metals emitted into the atmosphere by smelting are dispersed over very wide regions by the winds, often at a continental scale spanning international boarders
3. The mercury amalgamation technique is widely used in small scale and artisanal gold mining operations in Myanmar **TRUE ✔**
4. The use of the mercury amalgam technique can be an important source of this toxic metal to rivers **TRUE ✔**

Tutor instruction: Spend a moment to briefly explain any incorrect answers.

Key learning objectives- Summary

TIDE

1. What are the main processes that release heavy metals to the environment from mining operations?
   - *Acid mine drainage, atmospheric emissions from metal smelting and mercury release from the mercury amalgamation technique*

2. What is acid mine drainage and how is it produced?
   - *Acidic water (low pH) with very high concentrations of heavy metals. It is produced by the reaction of metal sulfide minerals with oxygen and water at the Earth's surface. Metal sulfide minerals are abundant in metal ore deposits, so the generation of such fluids is common in mining areas.*

3. What is the mercury amalgamation technique?
   - *A technique commonly used in artisanal/small scale gold mining operations to extract gold from the ore material. It results in the release of large amounts of mercury into the environment*

This brings us to the end of this 2nd lecture, where we will review the 3 key learning objectives, being:

1. 1. What are the main processes that release heavy metals to the environment from mining operations?

   Acid mine drainage, atmospheric emissions from metal smelting and mercury release from the mercury amalgamation technique

2. What is acid mine drainage and how is it produced?

   Acidic water (low pH) with very high concentrations of heavy metals. It is produced by the reaction of metal sulfide minerals with oxygen and water at the Earth's surface. Metal sulfide minerals are abundant in metal ore deposits, so the generation of such fluids is common in mining areas.

3. What is the mercury amalgamation technique?

   A technique commonly used in artisanal/small scale gold mining operations to extract gold from the ore material. It results in the release of large amounts of mercury into the environment

Heavy metal pollution from mining activities

TIDE

Practical 2: Assessing the role of mining activities for causing the identified toxicity problems

Luke Bridgestock
Department of Earth Sciences,
University of Oxford

Tutor instruction: Depending on time availability it is good to pause for a 5 minute break at this point to give the participants to discuss the lecture materials among themselves. It is also a chance for participants to ask the tutor questions about the lecture material individually (i.e. not in front of the whole class), which they are often more confortable/willing to do.

Natural or mine pollution?

Metal pollution from mines can contaminate water bodies (rivers, lakes and groundwater) in the surrounding regions

Metal concentrations in these waters can also vary due to natural processes

How can we tell if metals in water bodies are from mining pollution or natural sources?

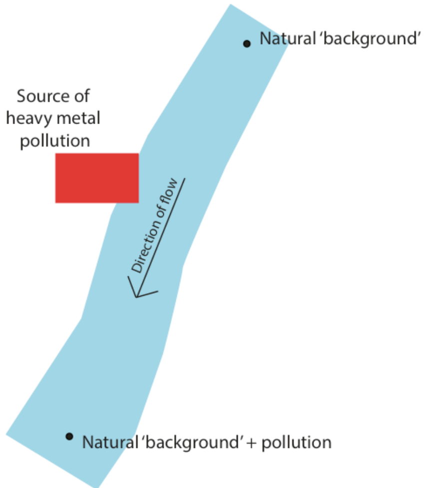
We have learnt how metals are released from mining processes into the environment, representing important transport pathways to points of human exposure (i.e. drinking water and food sources). However, given that metal concentrations in water sources and food can vary significantly due to natural metal mobilization in the environment, a key question is how can we tell if metals in the wider environment are from natural or human sources such as mining?

This is crucial to answer to be able to properly address identified chronic metal toxicity risks. Correctly identifying the processes responsible for releasing these metals to these points of human exposure (for example acid mine drainage), then allows the implementation of appropriate remediation strategies. On the other hand, incorrect identification of these processes will lead to implementation of remediation strategies that are not effective in reducing these toxicity risks.

Comparison to natural 'background' values

Assuming that there are no other sources of pollution, heavy metal concentrations upstream from a mine should represent natural concentrations.

Downstream from the mine the heavy metal concentrations are likely to represent both the natural 'background' and heavy metals from pollution.



One method to assess the importance of mining pollution versus natural metal sources to water is, to compare metal concentrations of water suspected of being polluted to those thought to represent the natural 'background' for that river or area.

Choosing appropriate water samples to represent the natural 'background' is very important. Ideally variability of these natural 'background' metal concentrations over seasonal to inter-annual timescales should be characterized using a large amount of time-series measurements.
Comparing metal concentrations of river water upstream and downstream of a point source of metal pollution, for example a mining region with acid mine drainage. Upstream metal concentrations should represent natural 'background' values, while downstream metal concentrations may be elevated due to the addition of metals from the pollution source. Note it is not necessarily clear that these background values truly represent natural concentrations as they may be impacted by pollution input further upstream or via dispersed atmospheric deposition. However they should provide a decent reference value to asses how much metal is added by the point source.

Comparison to natural 'background' values

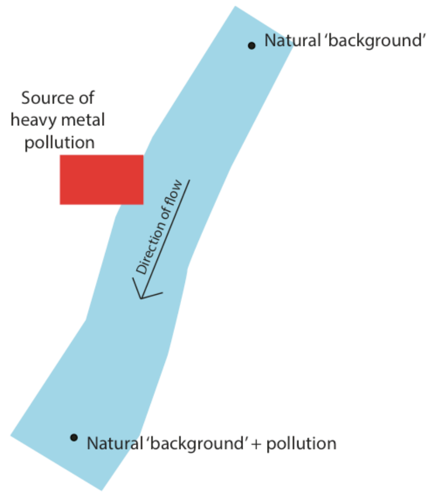
TIDE

We can calculate the amount of heavy metal from pollution versus natural sources using;

Total concentration = pollution + natural
(downstream of mine)

Pollution = Total − natural
= downstream − upstream

Percent pollution = (Pollution ÷ Total) × 100



We can calculate the amount of heavy metal from pollution versus natural sources using, by taking the difference between the measured metal concentration (total) and the 'background' reference value, which we can then use to calculate the fraction of metal in the sample that is from the pollution source

(as shown in the stated equations)

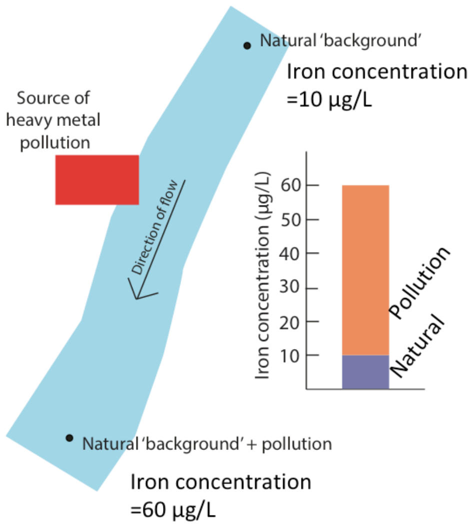
Comparison to natural ‘background’ values

For example;

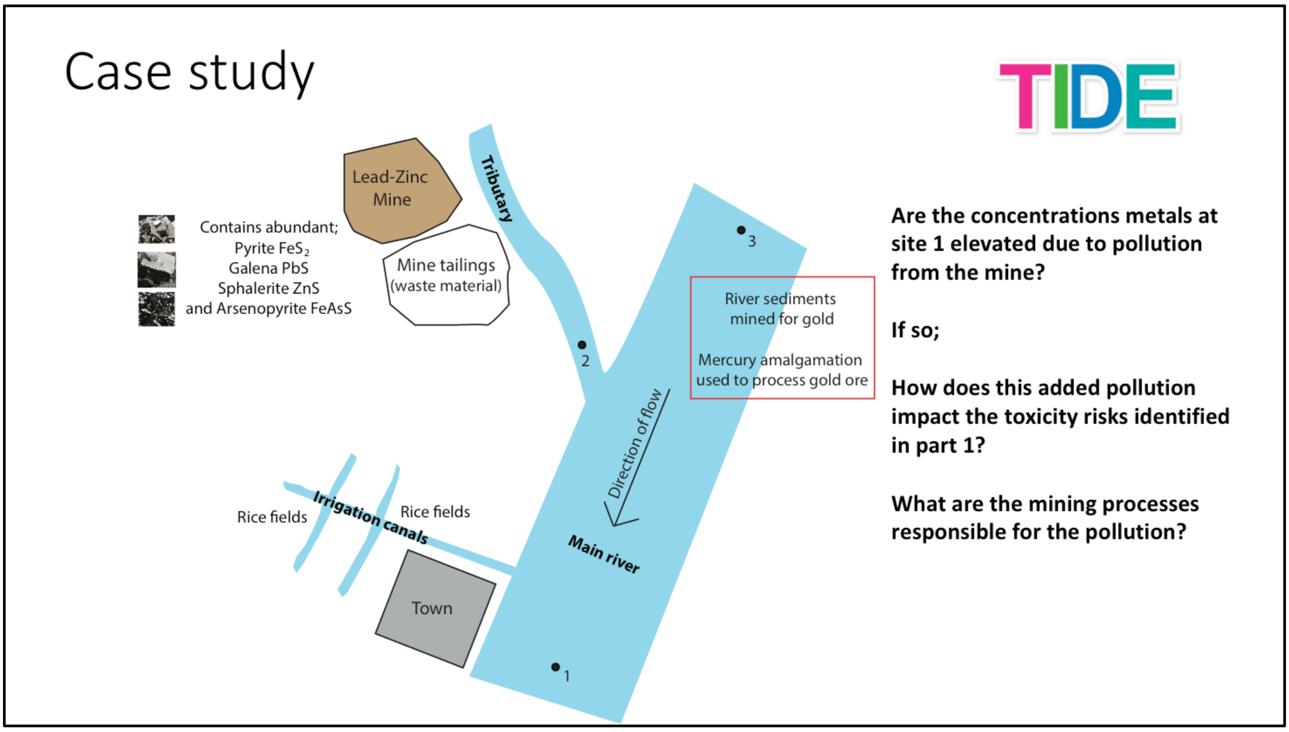
If iron concentrations are 10 µg/L upstream of the mine, and 60 µg/L downstream of the mine, then;

Pollution = Total − natural
= downstream − upstream
= 60 − 10 = 50 µg/L

And,
Percent pollution = (Pollution ÷ Total) × 100
= (50 ÷ 60) × 100
= 83%



For example, upstream from a point source of metal pollution, dissolved Fe concentrations in the river are 10ug/L, and downstream this increases to 6o ug/L. This suggests that 50ug/L are added by the pollution point source, representing 83% of the total metal at the downstream site.



In the practical you will use this simple logic to answer the following important questions about the hypothetical case study from part 1.

Are the concentrations of metals in the river close to the town (site 1) elevated due to pollution from the mining activities upstream, or due they represent natural values?
If so, how does this added metal pollution impact the chronic toxicity risks you identified in part 1?
And, what are the mining processes responsible for releasing this pollution?

For example, acid mine drainage vs smelting vs Hg amalgam. Answering this final question is key to developing appropriate remediation strategies.

To address these questions environmental scientists have collected water samples for 3 locations; site 1, downstream from mining activities next to the town, site 2, the tributary draining the area near the Pb-Zn mine, and site 3, upstream from the mining activities.

Work through questions 1 to 4, and then think about answers to the 3 group summary questions. We will then discuss these as a group in the final 10 minutes of this session.

Summary – Answers

TIDE

1. Site 2 >> Site 1 > Site 3

2. Site 2; low pH, water is an orange colour, and heavy metal concentrations are very high. This sample is from the tributary draining the lead-zinc mine, which features waste material with abundant metal sulfides.

Tutor instruction: After allowing 30minutes for the participants to work through the practical questions, quickly run through these answer on this and the following slide and check that they understand them

Summary – Answers

3.

	Natural 'background' concentration from Site 3	**Total** heavy metal concentration Site 1	Heavy metal concentration from **pollution** *Total - Background*	Percentage of pollution derived heavy metal *(Pollution/Total) × 100*
Iron	10 µg/L	60 µg/L	50 µg/L	83%
Lead	0.5 µg/L	12 µg/L	**11.5 µg/L**	**96%**
Arsenic	5 µg/L	30 µg/L	**25 µg/L**	**83%**
Copper	1 µg/L	2 µg/L	**1 µg/L**	**50%**
Cadmium	0.05 µg/L	2 µg/L	**1.95 µg/L**	**98%**
Mercury	0.005 µg/L	0.01 µg/L	**0.005 µg/L**	**50%**

4. ADI = 0.014
HQ = 0.1
Much lower than 1. This suggests that pollution from the mining activities is to blame for the chronic toxicity threats posed by lead in the drinking water.

Group discussion

TIDE

1. What are the important mining related processes (acid mine drainage, smelting and Hg amalgamation) for contaminating the river with different metals?

2. Would closing the lead-zinc mine result in a decrease in heavy metal pollution?

3. Would stopping the artisanal gold mining result in a decrease in heavy metal pollution, and if so which metal(s)?

Tutor instruction: In the final 5-10minutes go though these 3 summary questions together as a group. Ask the participants to volunteer to share their answers with the rest of the class and fill in any gaps/miss-understandings where needed.

Question 1: For Pb, As, Cu, Cd and Fe, the metal pollution (elevated over background values of site 3) is derived from acid mine drainage generated from the Pb-Zn mine. Evidence being that they are highly concentrated in the tributary draining this area (site 2), which has a low pH and an orange colour, both of which are characteristics of waters impacted by acid mine drainage. The latter due to the precipitation of secondary Fe-oxyhydroxide minerals. For Hg, the metal pollution at site 1 is instead derived from the use of the mercury amalgamation technique in the artisanal gold mining area upstream of the town on the main river channel. Hg is not significantly added from acid mine drainage from the Pb-Zn mine, because waters from site 2 are not enriched in Hg.

Group discussion

1. What are the important mining related processes (acid mine drainage, smelting and Hg amalgamation) for contaminating the river with different metals?

2. Would closing the lead-zinc mine result in a decrease in heavy metal pollution?

3. Would stopping the artisanal gold mining result in a decrease in heavy metal pollution, and if so which metal(s)?

Question 2; Closing the Pb-Zn mine would not result in a decrease in metal pollution. As established this pollution is derived from acid mine drainage, which will be continued to be generated even once this mine is closed. This is because metal sulfide rich mine tailings will continue to react with water and oxygen for many decades to centuries. Reducing the metal pollution derived from acid mine drainage will require implementation of remediation techniques − as we will learn about in part 3

Question 3: Stopping the artisanal gold mining on the other hand should result in a decrease in Hg pollution, due to the cessation of the Hg amalgamation technique in these area.