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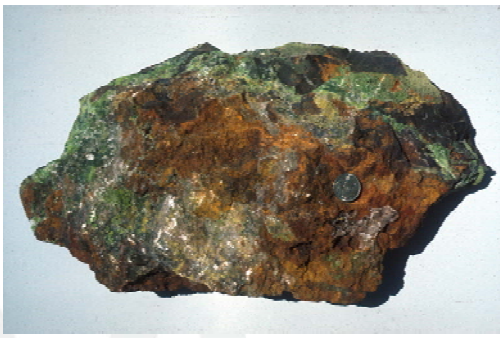
Title Slide

Terminology

- Ore mineral
- Gangue minerals
- Ore
- Ore grade
- Deposit
- Resource



Gossan of nickel-sulphide ore Otter Shoot, Kambalda, WA by R Hill. CSIRO Science Image

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Ore mineral: a mineral from which one or more metals can be extracted.

Gangue minerals: minerals that accompany ore minerals but are of little or no worth.

Ore: a body of rock containing one or more ore minerals and is economically viable to mine.

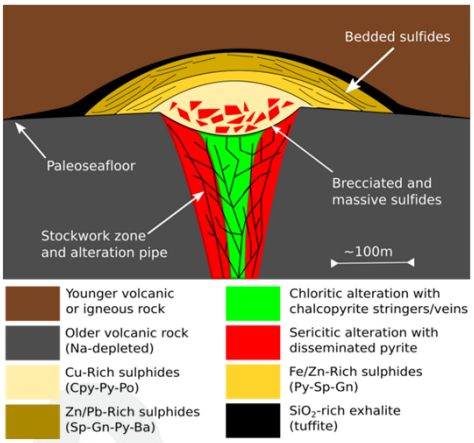
Ore grade: total metal content of the ore.

Deposit: an area where a known ore mineral/s exist- does not necessarily indicate viability.

Resource: the total of all known and unknown supplies of a commodity. Includes renewable and non-renewable as well as metallic and non-metallic.

Ore Formation

- Igneous
  - Intrusive
  - Exhalative
- Hydrothermal
- Weathering = leaching
- Complex combinations



Cross-section of a typical volcanogenic massive sulphide ore deposit. (RockingGeo 2019 Wikimedia Creative Commons)

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There are many different processes that can concentrate an ore mineral into a particular area.

There are intrusive igneous processes like fractional crystallisation and gravitational settling. Extrusive processes include black smokers and VMS deposits (shown in diagram).

Hydrothermal fluids can also concentrate metals.

Ore minerals can also be concentrated by weathering processes, such as leaching. The movement of rainwater/groundwater through the soil profile and upper bedrock can cause these minerals to concentrate in regions, for example with lateritic nickel or bauxite (aluminium).

In truth ore formation is often a complex mix of processes varying from deposit to deposit.

Exploration Techniques

- Gathering information

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The first step in exploration is to gather as much information already available about the area as possible. Sources may include:

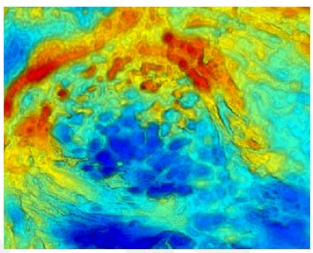
- Data from the local geological survey (this may include geophysical data)
- Core samples for previous exploration in the area
- Historical information about the area (perhaps past gold rushes?)
- Models for ore deposits
- A walk over by a geologist – looking for gossans, weathered ore, quartz veins etc.

Mining companies increasingly use public data from sources such as Google Earth, which features geophysical data such as gravity surveys.

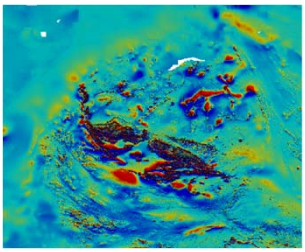
Exploration Techniques

- Gathering information
- Geophysical surveys
  - Magnetic
  - Gravity
  - Radiometric

Gravity Map



Magnetic Anomaly Map



From Geoview
https://geoview.dmp.wa.gov.au/geoview/?Viewer=GeoView
accessed 15 April 2020

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Depending on the resources being explored for geophysical surveys may be a next step. These airborne surveys can give further detail for an area.

- Magnetic survey: will give a magnetic signature of rocks in an area. E.g. strong magnetic response of ultramafic rocks which may be a nickel host
- Gravity survey: measures density differences in rocks, again can identify ultramafic rocks.
- Radiometric survey: measures the relative proportions of natural radioactive elements like potassium, uranium and thorium in rocks. This technique may assist with identification of large granite bodies or mineral sands.

Exploration Techniques

- Gathering information
- Geophysical surveys
  - Magnetic
  - Gravity
  - Radiometric
- Field work
  - Chip samples
  - Stream sediment sampling
  - Soil sampling
  - Drilling (reverse circulation, diamond)

A core sample for the Woodlawn mine near Goulburn, NSW (CSIRO Science Image)

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- Chip samples can be taken at regular intervals over a large area and then tested. This process is being replaced by some companies with XRF (x-ray fluorescence) machines. These hand-held devices can be calibrated to calculate the percentage of a range of elements in outcrops in just seconds.
- Sediments from samples can be collected and tested. This may lead back to an ore body (many early finds were in steams/rivers where eroded material had been deposited, gold rush)
- Geochemical sampling of soil may reveal what lies beneath. Sometimes this may not be by identifying the desired mineral but through an associated mineral or element.
- Drilling is undertaken once an area with a high potential has been identified, as this process is very expensive. Two commonly used types of drilling are:
  - Reverse circulation = brings up chip samples and is a fast and relatively cheap technique. Not economical for very hard rock or where this is a lot of water, also not as precise in the information it delivers as diamond drilling.
  - Diamond drilling = brings up solid cylindrical cores of rocks providing a

detailed picture of what lies below. As the drill is tipped with diamonds it can penetrate hard rocks but it is slow and costly.

Mining

- Open cut
  - Ore deposit relatively close to surface
  - Dug downwards in intervals (= benches)

Open cut mining at Paddington Gold Mine near Kalgoorlie (1998, CSIRO Science Image)

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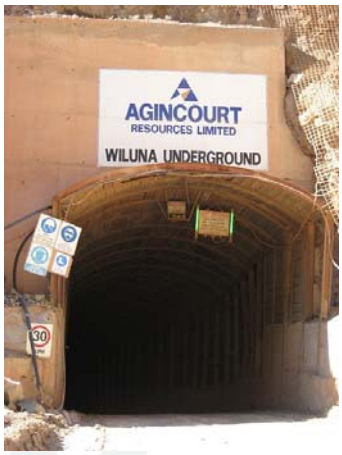
Open cut mining is often used for ore deposits that are close to the surface, as whilst the overburden (non-ore material) above is being removed, the operation will not be making any profit. In fact, they run at a large loss at this stage.
The pit is dug in intervals called benches and the walls are angled to prevent collapse

Mining

- Open cut
  - Ore deposit relatively close to surface
  - Dug downwards in intervals (= benches)
- Underground
  - Ore deep underground (often in pockets)
  - Accessed through tunnels and shafts



Entry to Wiluna Underground Gold Mine, Wiluna WA (2009, Wikimedia Creative Commons)

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Another method is underground mining. This method is used if the ore is deep and/or is in pockets. This is not a preferred method, as it is more expensive and can pose more risks than open cut mining.
A series of tunnels and shafts are used to access the ore – this is all carefully mapped out prior to and during mining.

Processing

- Crushing and grinding

Ball mill at Cadia mine, NSW (2012, S Filan)

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Once collected, the ore must be processed to extract the desired metals.

The following is a generalised set of steps. Depending on the type of ore, more steps may be involved and some of these may be omitted.

Generally, the first step is crushing and grinding the ore to a size suitable for processing. A ball mill (shown) tumbles ore with steel balls to crush it.

Processing

- Crushing and grinding
- Magnetic/Gravity separation

Multi Gravity Separator manufactured by Gravity Mining Ltd, England (2008, Wikimedia Creative Commons)

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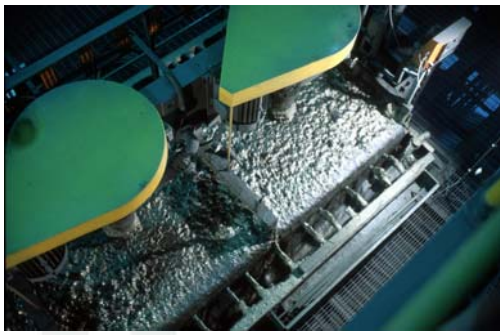
If the ore mineral is magnetic or particularly dense, it may be run past magnets or into cyclones during the processing.

Processing

- Crushing and grinding
- Magnetic/Gravity separation
- Froth flotation



Flotation mill at Woodlawn mine, NSW (CSIRO Science Image)

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Many ores are concentrated by froth floatation. During this process the ore is mixed with a set of chemicals and then agitated to produce bobbles. As the bubbles rise, they collect the ore minerals on the way through. This produces a concentrate at the top where it can be collected.

Processing

- Crushing and grinding
- Magnetic/Gravity separation
- Froth flotation
- Carbon in leach (pulp)

Sunrise Dam Gold Mine (WA) carbon in leach tanks (2009, Wikimedia Creative Commons)

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Gold may be collected using the carbon in leach (or pulp) process. The concentrated slurry is placed through a series of tanks with activated carbon which collects the gold.

Processing

- Crushing and grinding
- Magnetic/Gravity separation
- Froth flotation
- Carbon in leach (pulp)
- Elution
- Electrowinning

Copper cathodes at the Inspiration Consolidated Copper Company's electrowinning refining plant (Arizona, USA) (CM Keyes 1972, National Archives and Records Administration public domain)

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In elution, the 'loaded' carbon is pumped into an elution circuit where the gold is washed from the carbon using a series of chemicals.
The gold can then be removed from solution using a charge circuit – electrowinning.
Electrowinning is also used for copper and aluminium extraction.

Processing

- Crushing and grinding
- Magnetic/Gravity separation
- Froth flotation
- Carbon in leach (pulp)
- Elution
- Electrowinning
- Smelting

Liquid gold that has been smelted in an arc furnace is removed to pour (demonstration in South Africa) (D Brown 2006, Wikimedia Creative Commons)

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By this point the metal (e.g. gold) can then be smelted – melted and cast.

Rehabilitation

- Backfilling and contouring

The former Jackpile-Paguate uranium Mine in New Mexico USA has been backfilled and contoured. (M Gant, National Institute of Environmental Health Sciences 2013, Public Domain)

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Many processes can be undertaken during rehabilitation. These are some common ones. Where possible holes and trenches are filled and the land is contoured to give a natural slope and to reduce erosion.
Sometimes a void is used for landfill, as part of the backfilling process.

Rehabilitation

- Backfilling and contouring
- Ripping
- Top soil return

The Polkemmet coal mine in North Lanarkshire Great Britain is being landscaped. (R Webb 2009, Wikimedia Creative Commons)

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If the area has been backfilled with overburden, it is then 'ripped' to break through compacted soil and rock, allowing tree roots to penetrate.
Top soil that has been stored is returned during rehabilitation and spread over the contoured and filled site.

Rehabilitation

- Backfilling and contouring
- Ripping
- Top soil return
- Seeding
- Weeding
- Monitoring

Megathyruss maximus (Petrie Green Panic) ispasture grass sown in mine rehabilitation sites in the Hunter region of NSW (H Rose 2016, Wikimedia Creative Commons)

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Seeds of endemic (locally native) plants or desirable pasture species are spread in the area. Seedlings may also be planted.
The area is monitored to keep weeds and introduced animals out.
Monitoring of flora and fauna continues with mitigation of issues where possible.

Environmental Hazards

- Noise
- Dust
- Chemical Contaminants
- Others

Soil pollution at the Brukunga Pyrites Mine in the Mt Lofty Ranges, SA. (J Coppi 1992, CSIRO Science Image)

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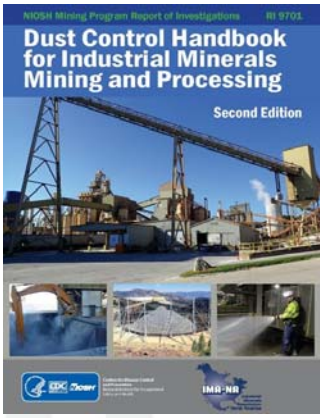
Noise from mining and blasting is regulated by the local regulations and dust control must be carried out regularly.
Sulfide ores may produce acid drainage, like that shown contaminating soil in the photo, so require adequate containment.

Reducing Environmental Impacts

- Environmental approvals at all stages
- Securing drill sites
- Backfilling trenches
- Dust suppression



Dust control handbook from the National Institute for Occupational Safety and Health (USA). (NIOSH 2019, Public Domain)

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Prior to any work, including exploration, approval must be obtained. This approval may require site studies, detailed environmental plans and a commitment to ongoing monitoring. A bond is also required.
Drill holes must be capped to stop local fauna from falling down them.
Trenches dug for exploration or to support mine logistics re backfilled and rehabilitated.
Dust is a major issue on most mine sites. Many dust suppression measures may be undertaken including, the wetting down of access roads by water carts and also as ore is being loaded into trucks. Large barriers may also be placed between populated areas and mines to protect them from dust. Blasts may also be cancelled due to strong winds and/or winds blowing towards populated areas.

Reducing Environmental Impacts

- Environmental approvals at all stages
- Securing drill sites
- Backfilling trenches
- Dust suppression
- Lining tailings ponds
- Pollution control methods
- Ongoing monitoring

Black Cloud Mine tailings pond in Colorado USA. (J Holm 2008, Wikimedia Creative Commons)

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Tailings (the waste materials of processing the ore) need to be handled carefully to ensure that chemicals don't make their way into the water table. Some preventative measures include, creating bunds (piles of earth) around transport pipes to contain any spillages, also to line tailings ponds to prevent seepage.

Pollution control methods may include things like placing scrubbers in chimneys of roasters to collect potentially harmful particulates before they are released into the atmosphere, reducing the amount of chemicals used in the processing plant and continuously monitoring the levels of harmful gases on site enacting shut down procedures for breaches.

Ongoing monitoring of gas levels, the local water table, dust levels and local flora and fauna. This is coupled with action to mitigate issues identified.

Social and Heritage Issues

- Social issues may include
  - Health impacts
  - Supporting family life
  - Land use competition
- Heritage issues may include
  - Sites of cultural significance
  - Native title
  - Land use competition

Old head frame of underground workings at Whim Creek Mine, WA (2008, Public Domain)

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Social issues of mining may include

- Health issues – related to dust and release of chemicals for both workers and the local community
- Supporting family life – particularly for fly in fly out workers
- Land use competition – particularly where economic resources are identified in populated areas or areas already in use for agriculture

Heritage issues of mining may include

- Sites of cultural significance - including those with historically artefacts like rock art
- Native title – land ownership issues may be an issue
- Again land use competition – land of cultural significance may be required for important ceremonies or other uses

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