Hashemite University
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Economic Geology (111201491)

Part5: Ore deposits Exploration

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Ore: any naturally occurring material from which a mineral or aggregate of value can be extracted at a profit.

Gangue minerals: Usually worthless, non metallic minerals of a deposit

Grade: The concentration of an element in a mineral deposit is termed grade usually expressed as % or in ppm

Types of Ore Deposits

1. **Magmatic**

Pt, Cr, Fe, Ni, Ti, Diamond

2. **Pegmatite**

Li, Be, U, Rare Earths, Feldspar, Mica, Gems

3. **Hydrothermal**

600 C: W, Sn

400 C: Au, U, Ag, Co, Mo

200 C: Cu, Zn, Cd, Pb

Cool: Hg, As

4. **Sedimentary Rocks**

- Fe, Cu, U, Mn, Mg

5. **Weathering**

a. Secondary Enrichment:

  - Cu, Ni

b. Soils

  - Al, Ni

c. Placer

- Pt, Au, Sn, Ti, W, Th, Rare Earths U (Fossil), Gems

Residual Deposits

- Bauxite is an oxisol

- Nickel laterites in tropical countries
  - Ni substitutes for Mg
  - Very enriched in ultramafic rocks
  - Concentrates at water table

Placer Ores

- Gold (Sierra Nevada, Piedmont)
- Platinum (Russia)
- Tin(Malaysia)
- Uranium Placer Deposits
- Heavy Beach Sands (Australia, Africa)
  - Zircon, Ilmenite, Monazite, Tungsten

Metamorphic Minerals

- Ornamental stone: marble, slate, migmatite
- Specific metamorphic minerals
  - Kyanite, wollastonite for refractories
  - Garnet for abrasives
- Skarn Deposits

Natural resources

1. Building
    1. Stone, Sand, Gravel, Limestone
2. Non-metallic Minerals

   Sulfur, Gypsum, Coal, Barite, Salt, Clay, Feldspar, Gem Minerals, Abrasives, Borax, Lime, Magnesia, Potash, Phosphates, Silica, Fluorite, Asbestos, Mica
3. Metallic Minerals

   a. Ferrous: Iron and Steel, Cobalt, Nickel

b. Non-ferrous: Copper, Zinc, Tin, Lead, Aluminum, Titanium, Manganese, Magnesium, Mercury, Vanadium, Molybdenum, Tungsten, Silver, Gold, Platinum

4. Energy Resources: Coal, Oil, Natural Gas

5. Radioactive materials

Metal Prices: Nov. 9, 2011

US Dollars / Troy Ounce (Oz)(=31.1 gm)

- Gold 1,798.40
- Silver 35.137
- Palladium 677.15
- Platinum 1,670.60
- Iron Ore (62% Fe) $130/ton

Metal Prices: Nov. 9, 2011

US Dollars / Lb. (1 kilogram is equal to 2.20 lb)

- Aluminum .9494
- Copper 3.5473
- Lead .9051
- Nickel 8.4210
- Tin 10.0698
- Zinc .8859
- Molybdenum 14.1748
- Cobalt 13.3810

Concentration Factors and Economics

- Natural abundance and distribution
- Geologic Processes to Concentrate Element
- Intrinsic Value of Material
- Cost of Extraction from Earth

Ore Exploration

is the activities related to establishing a mineral deposit through geological, geophysical, and geochemical methods, it is carried out to:

- to find a new deposits as commodity
- to replace deposits presently being mined
- to increase the ore reserves

Principal steps in the exploration ore deposits (life cycle):

1. Mineral exploration: to discover a mineral deposit.

This process begin with study phase that includes:

choice of potential target, study of demand, supply, commodity price trends, available markets, exploration cost, draw up budget.

2. Feasibility study: to prove its commercial viability.

3. Mine development: establishment of the entire infrastructure.

4. Mining: extraction of ore from the ground.

5. Ore processing:

a. milling of the ore,

b. separation of ore minerals from gangue material,

c. separation of the ore minerals into concentrates

d. smelting: recovering metals from the mineral concentrates.

6. **Refining**: purifying the metal

(floating, upgrading, and beneficiation)

8. Marketing: shipping the product

9. Closure: before a mine has reached the end of its life, there has to be a closure management plan.

Exploration Methods and Techniques

A. **Geological methods**:

- Drilling
- trenching
- Pitting

B. **Geophysical methods**:

- Magnetic
- Gravity
- electrical
- seismic (Reflection – Detailed but Expensive and Refraction – Cheap but Not Detailed)
- Subsurface / borehole methods

C. Geochemical Sampling

D. Electrical Sounding

Ground-Penetrating Radar

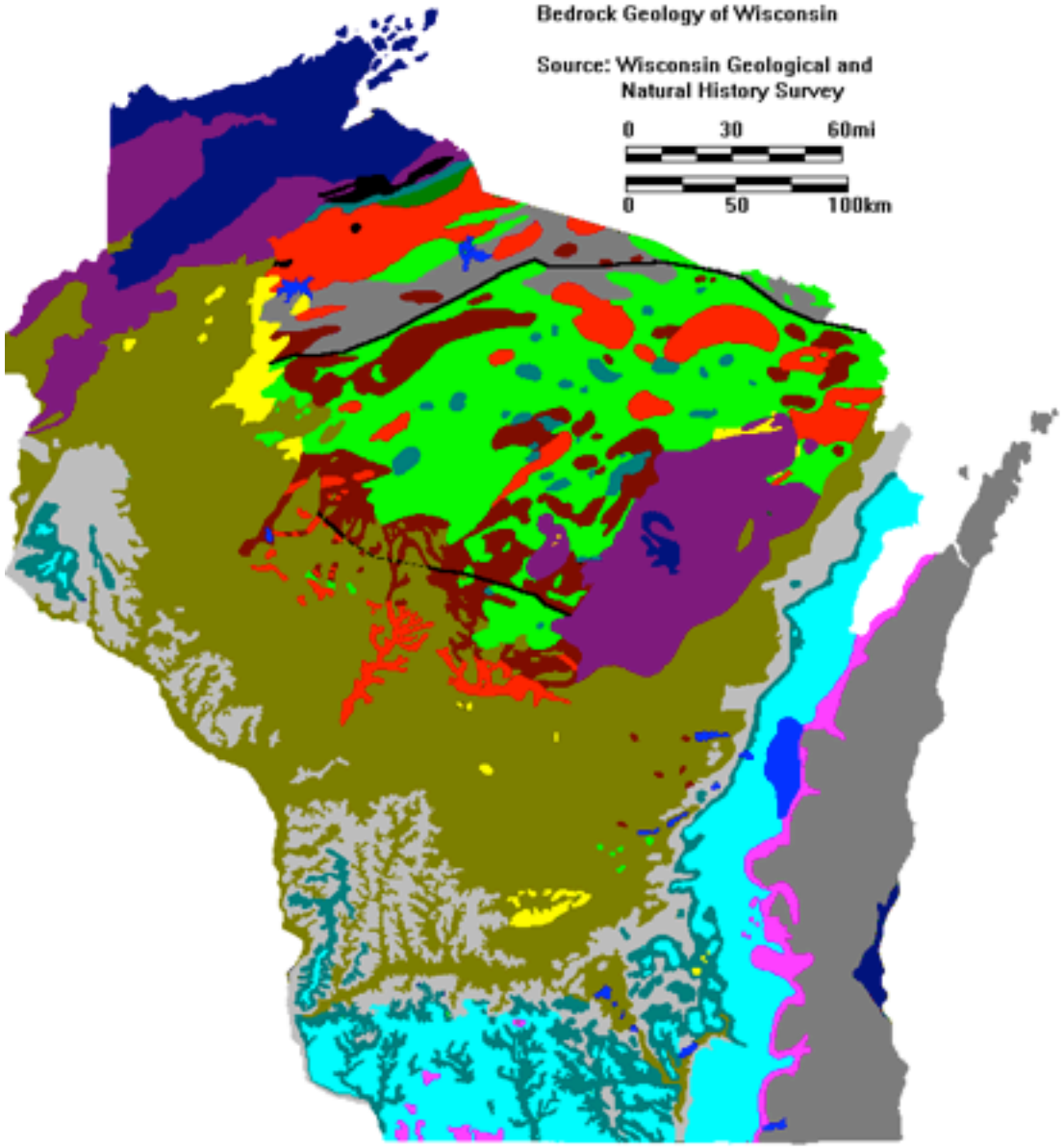
E. Core Sampling and Well Logging

Mapping production

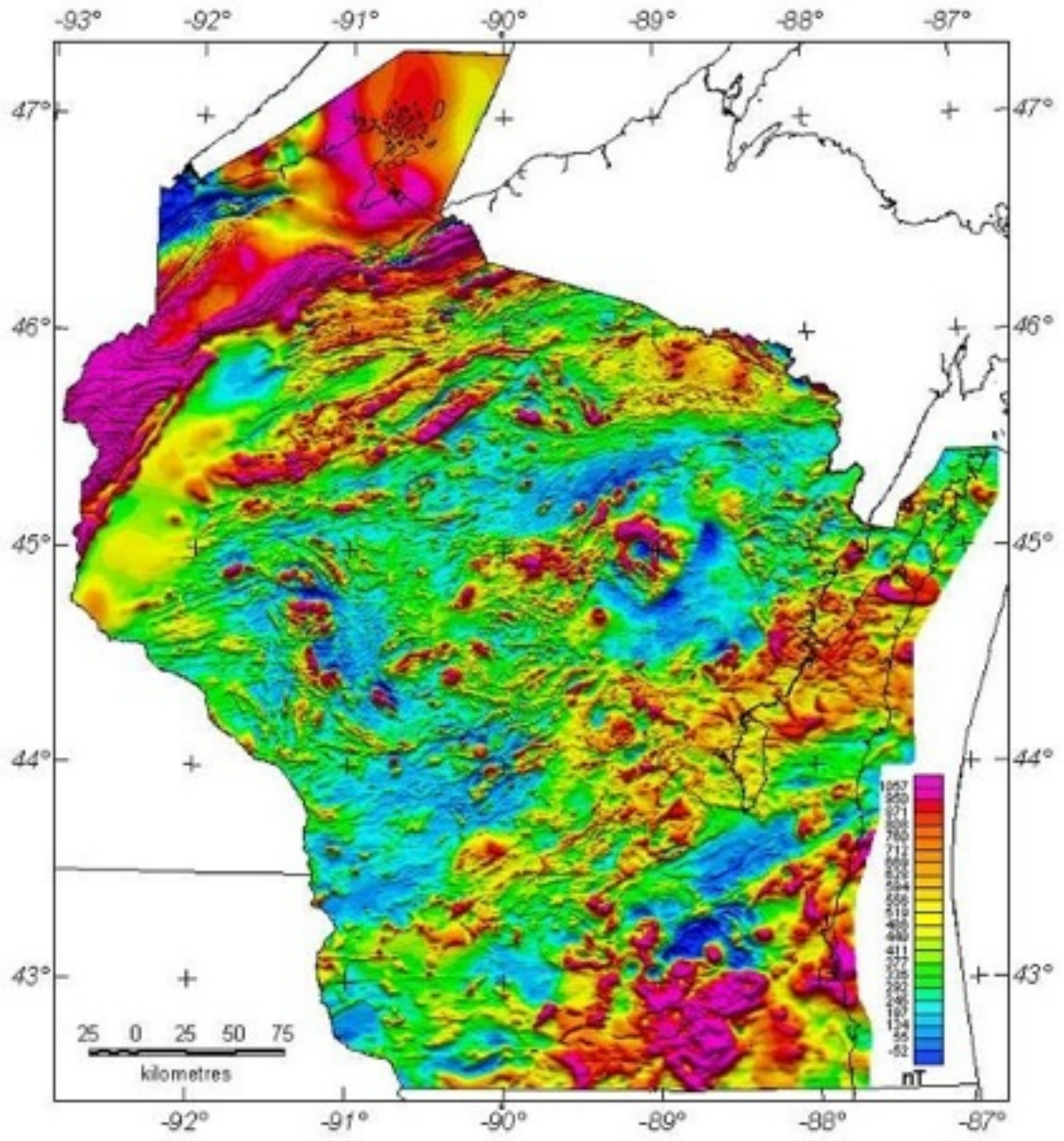
- Satellite and Aerial Photography
- Remote Sensing
- Geological Mapping
- Magnetic Mapping
- Gravity Mapping
- Radioactivity Mapping

Satellite Image of

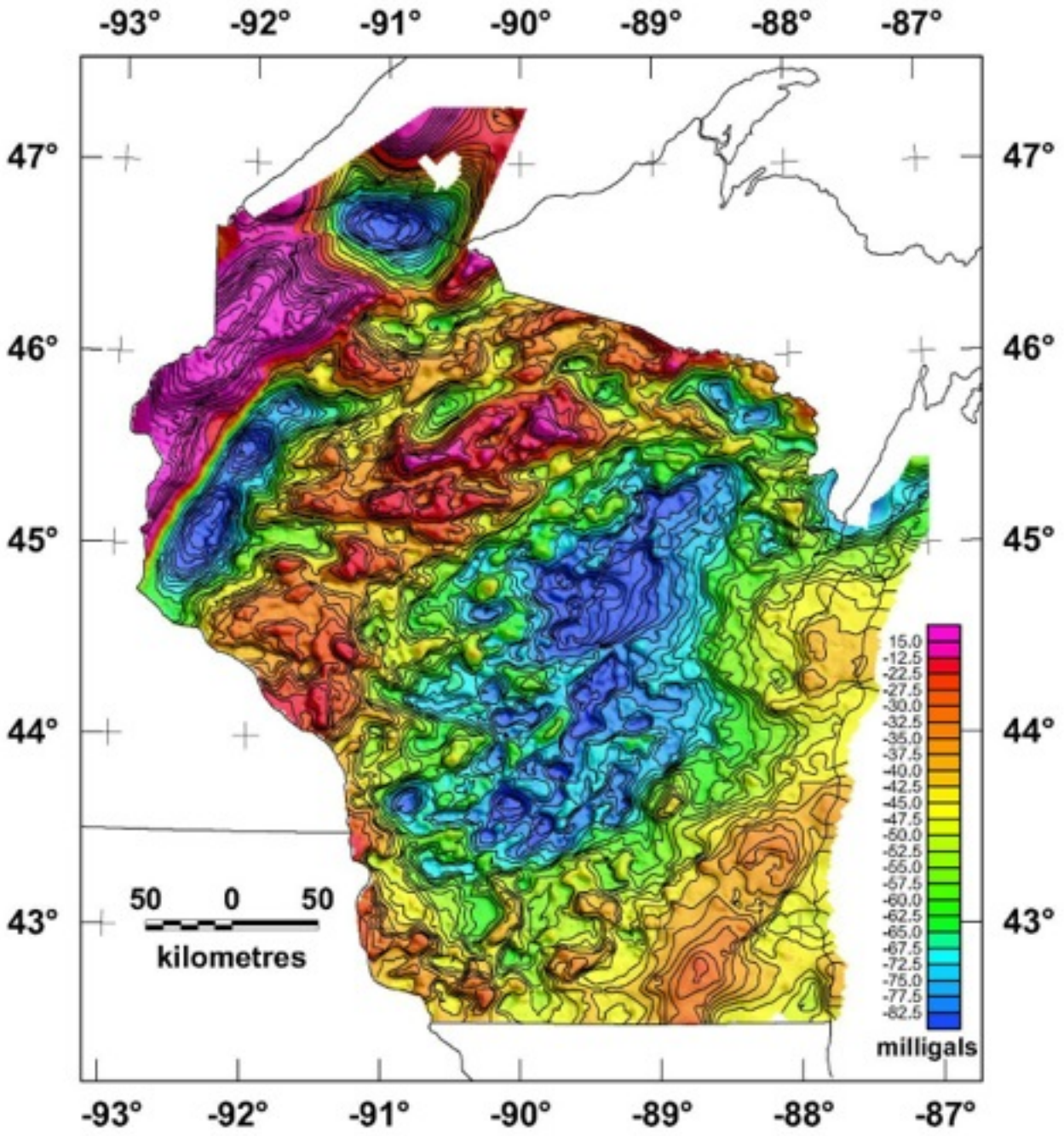
Geologic Map



Magnetic Map



Gravity Map


-93°
-92°
-91°
-90°
-89°
-88°
-87°
47°
46°
45°
44°
43°
50 0 50
kilometres
15.0
-12.5
-22.5
-27.5
-30.0
-32.5
-35.0
-37.5
-40.0
-42.5
-45.0
-47.5
-50.0
-52.5
-55.0
-57.5
-60.0
-62.5
-65.0
-67.5
-72.5
-75.0
-77.5
-82.5
milligals

Life Cycle of a Mine

- Development
- Active Mining
  - Excavation
  - Crushing, Milling, Flotation, Chemical Separation
  - Smelting and Refining
  - Disposal of Waste
- Shut-down

Economic Factors in Mining

- Richness of Ore
- Quantity of Ore
- Cost of Initial Development
- Equipment, Excavation, Purchase of Rights
- Operating Costs: Wages, Taxes, Maintenance
- Price of the Product
- Will Price Go up or down?

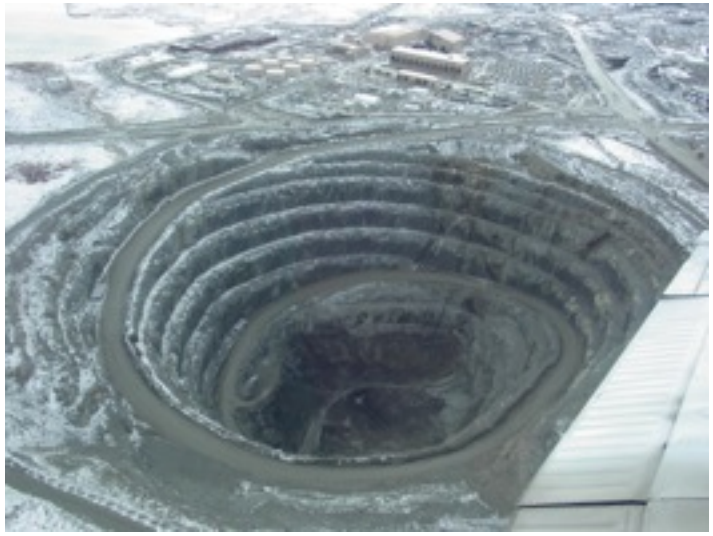
Mining Type

1. **Surface mining** – shallow deposits

a. Open pit mines
   - Where large 3D ore body lies close to the surface
   - Leaves a large exposed hole on the surface

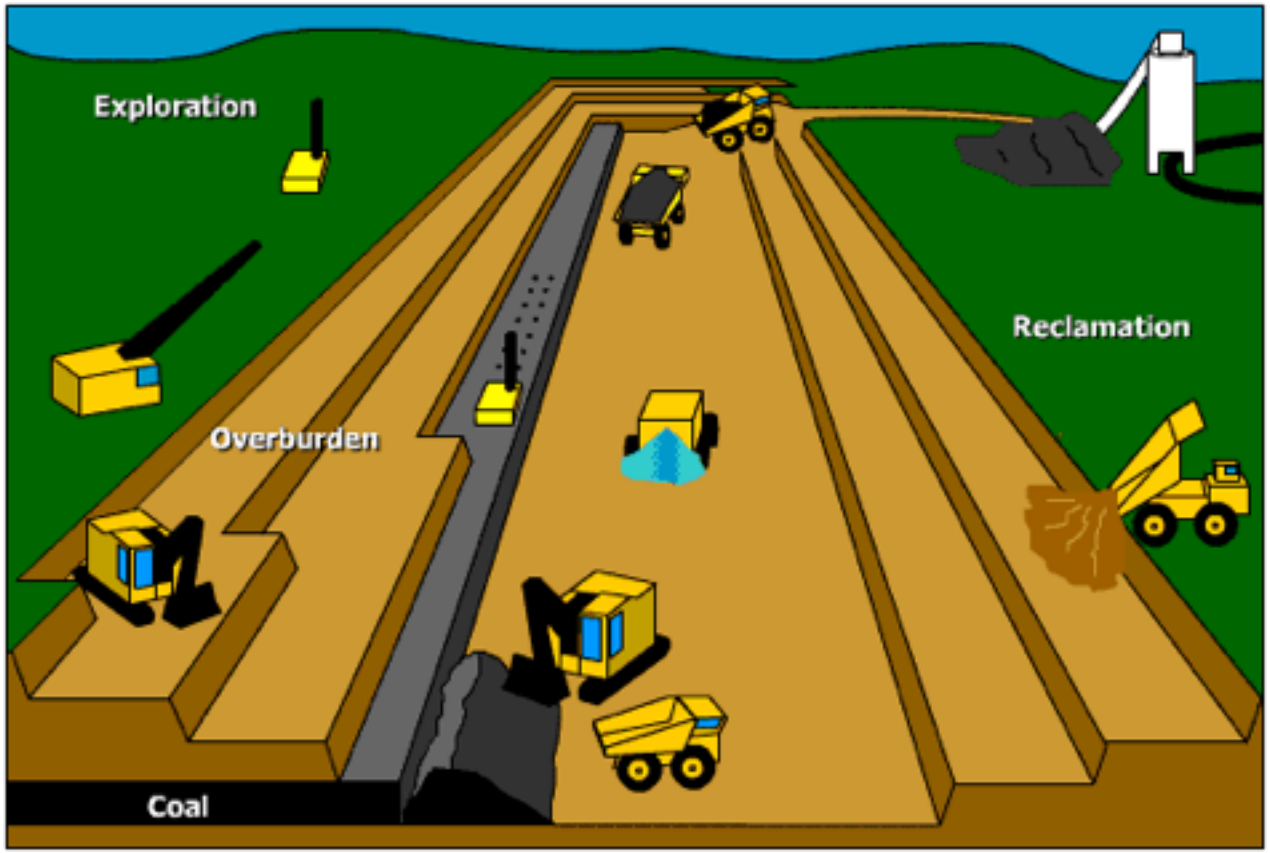
b. Strip mines
   - Mostly for coal where minerals occur in layers paralleling the surface

Open Pit



Strip Mining

Strip Mining



Very efficient for high level flat lying ore bodies.
Overburden and top soil can be replaced minimizing environmental damage

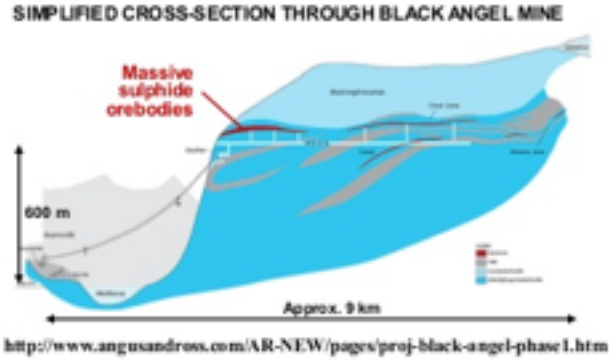
2. **Subsurface mining** - deposits that are too deep for surface mining

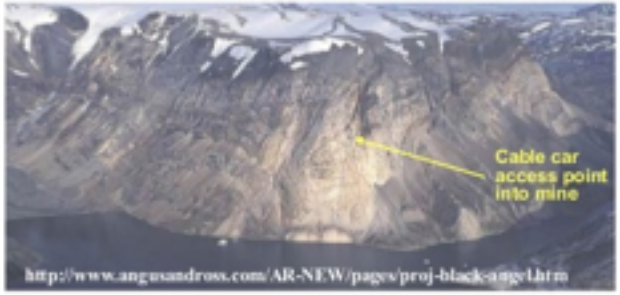
- Disturbs less
- produces less waste
- but also less effective and dangerous.

Types of Ore

a. **Massive**: e.g.Cu, Ni, Zn

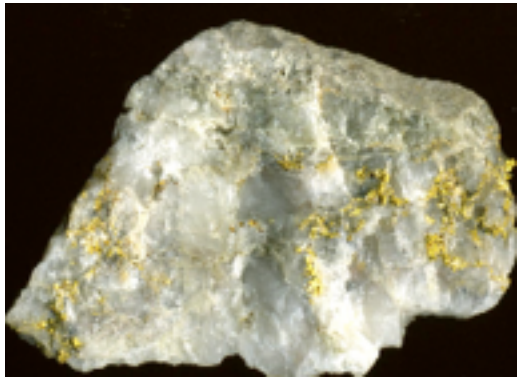
the valuable minerals occur in almost solid form with very little waste mineral.





b. **Disseminated**: e.g. gold

Ore carrying small particles of valuable minerals, spread more or less uniformly through the gangue matter



c. Bedded Ore bodies

flat layer extensively

Mineral Resources Evaluation

In case mineralisation is found, orebodies are defined, and mines are made.

The questions now:

- How does a volume of mineralized rock become designated as a resource ?
- by what process is this resource selected to become an ore reserve?

Value Of Mineralisation

"Value" is a financial concept and is related to the several issues:

1. **Technical issues** such as determination of the ore reserves, selection of appropriate mining and processing methods, financial, social, environmental, and reclamation aspects of the project.

2- **Business issues**, such as the project's ownership structure, permitting, marketing, and government relations and their interactions.

3. **Mine life and production rate**

The greater the tonnage of mineable mineralisation the longer the mine life. It follows that:

$$\text{Mine life in years} = \frac{\text{total ore reserve}}{\text{average annual production}}$$

Factors relating to mine life include the following:

1. Legal limitations:

Exploitation of the mineralisation may be under the constraints of a lease granted by its former owner such as the government of the state concerned.

If the lease has an expiry date then the probability of obtaining an extension has to be seriously considered.

2. Market forecast

What will be the future demand and value for the minerals produced?

3. Political forecast

The local government how long is this government likely to remain in power? Will a new government wish to either cancel or modify this agreement?

4. Financial return

The development of a mine is a form of capital investment.

The main concern is for this investment to produce a suitable level of return that will probably decide the number of years of production.

As a very general rule the minimum life of a mine should be 7-10 years.

5. Production rate

A commonly used guide for the Average Annual Production Rate (AAPR) is:

$$\mathrm{AAPR} = \frac{(\text{ore reserve})^{0.75}}{6.5}$$

example, for ore reserves of 20 Mt, the AAPR is 1.5 Mt a^{-1}, and for 10 Mt it is 0.9 Mt a^{-1}

4. **Quality of mineralisation**

The Grade , mineralogy and grain size determine the quality of ore.

Concentration plants vary from low cost (separating sand from gravel) to high cost, complex plants as in the separation of lead and zinc sulfides.

5. **Location of the mineralisation**

Local availability of power, water supply, and skilled labor must be considered, and local housing, educational and recreational facilities for the workforce.

6. Market conditions

a. income

The sale of minerals extracted from a mine is usually its only income.

b. Pay cost to:

develop the mine,

production and processing,

transport of the product to market, and

local and national taxes

In any particular mineral project:

Cash flow

= cash into the project (revenue) minus cash leaving the project (cost)

= (revenue) − (mining cost + ore beneficiation costs + transport cost + sales cost + capital costs + interest payments + taxes)

is calculated on a yearly basis over either a 10–year period or the expected life of the mine

From the results of an order of magnitude feasibility study on an occurrence of sphalerite and galena mineralisation, the first 3 years of a 10-year cash flow are given below. The plan is to mine the mineralisation underground and produce galena and sphalerite concentrates at the main site. These would be sold to a lead and zinc smelter for metal production.

Calculations are for year end; interest payments on borrowed capital to build the project are excluded. Units are $US1000 and 1000 tonnes.

(a) Total initial capital (CAPEX) to establish the mine is $140,600. Construction will take 2 years: years –1 and –2.

(b) Ore production is 2400 t yr^{-1} but only 1600 t yr^{-1} in the first year of production (year 1). Ore grade is 9.3% zinc and 2.0% lead.

(c) Ore treatment is as in Fig. 11.3.

(d) Revenue: the selling price of zinc is taken as $0.43 lb^{-1} and for lead as $0.21 lb^{-1}. Translating this value to ore gives a revenue of $46.6 per tonne.

(e) Operating costs per tonne:

Mining	$7.25
Mineral processing	8.10
Overheads	4.35
	$19.70 per tonne ore

The cost includes transporting the sphalerite and galena concentrates to a local port, and loading charges. The concentrates are sold to the smelter at the port and it is then the smelter company's responsibility to ship the concentrates to their plant.

(f) There is a royalty payment to the previous mineral owners of 4.5% of gross revenue less production cost.

(g) Calculation f is made before the payment of tax.

Can the product be sold and at what price?

There has to be a reasonable assessment of **future demand and price over the life of the mine**, or at least its first 10 years.

The product price is the most variable is difficult to predict

Market principles suggest that:

– during a period of low prices, production costs should be minimized to extract the maximum possible tonnage of easily accessible mineralisation at the highest grade

– during periods of higher price, lower grade material could be extracted.

Present day mineral and metal prices are available in publications such as the Mining Journal, Engineering and Mining Journal, and Industrial Minerals, and websites which summarize average weekly and monthly commodity prices, as well as providing annual reviews.

7. **Economic climate**

During the life of the mine we interested by :

- The prediction of general business sentiment,
- The demand for products, and
- Inflation and
- Exchange rates

8. Political stability of host country

The government of the host country may have a different order of priorities, such as continuity of employment, social objectives, and taxes to central government for national social policies

9. Sustainable development, health and safety factors

10. Government controls: any potential mine will have to operate within a national mining law and a fiscal policy.