EARTH'S RESOURCES & THE ENVIRONMENTS

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CHAPTER Four

DEPOSITION & EXTRACTION

DRILLING EXPLORATION

- **Most expensive part of exploration (> 200$/m)**
- **Types of Drilling:** Hummer (old, shallow), Rotary
- **Components of Drilling Rig:**
  1. Platform (superstructure)
  2. Drill pipes (segments screwed together)
  3. Motor to rotate drill pipes
  4. Pumps, & Drill bit (diamond chips)
  5. Cooling system (air, water, & drilling mud)
- **Rotary Drilling samples:** Core, & Cuttings
- **Rotary Drilling types:**
  1. **Normal (vertical) & Horizontal Drilling**
  2. **Directed Drilling:** Use of wedges & motors to drill in the desired directions
- **Why We use directed & horizontal drilling?**
  1. **Geological reasons**
  2. **Technical & economic reasons**

OFFSHORE EXPLORATION

- **Offshore Exploration:** is an exploration in the sea-bed, & done using drilling ship or platform
- Maximum water depth 2,400m

Type of Platforms	Depth [ft]
Fixed Platform (FP)	1500
Compliant Tower (CT)	1500-3000
Sea star (S-Star)	500-3500
Floating Production System(FPS)	1500-6000
Tension Leg Platform (TLP)	1500-7000
Subsea System (SS)	up to 7000
SPAR Platform (SP)	2000-10000

RESERVES ESTIMATION

- **Ore**: is a geological material (mineral or a rock) from which a metal can be extracted or utilized at a profit
- **Ore Grade**: concentration of ore in a sample [wt%, ppm]
- **Acts of Reserve Estimation**:
  1. Drilling holes in a regular grid
  2. Determination of ore Thickness (T, km), area (A, km²), specific gravity (G ,ton/km³), & grade (wt%)
  3. Calculation of grade as average in all drill holes
  4. Ore reserve calculation: $R_{ton} = AxTxGxwt\%$
  5. Deposit Classification: proven, inferred, &measured
- **Characterization**: determination physical & chemical property of ore (purity, weight, grain size, homogeneity)
  - ➢ Is a stage that starts after the discovery of the mineral deposits & continue until the extraction

FEASIBILITY ANALYSIS

- **Feasibility Analysis:** is the determination if the mineral deposit is an ore deposit or not
- **Steps of feasibility analysis:**
  1. **Calculation total costs** (TC): determination costs of Extraction, Administration, Transportation, Reclamation, Processing, Environmental monitoring
  2. **Determination of future price of commodity** (FC)
  3. **Determine future profitability:** Compare TC with FC, If TC < FC ore is feasible & extraction starts

MINERALS MINING

- **Mineral Extraction or Mineral Mining**: is the removal of rocks & minerals from the ground
- As mine depth increases difficulties & costs increase
- Labor wages dictates mining costs

Types of Mines

Surface

- **Mining Depth**: Deposits <100m
- 50% of world mines, 90% of Europe
- **Limits**:
  1. Maximum depth 100m up to 200m
  2. ore handling, costs, & rock falls
  3. mine-walls collapse
  4. Movement of equipment inside the mine
- **Overburden**: unwanted material covers deposit
- **Stripping ratio:** thickness of overburden materials per thickness of ore (**< 5,** up to 10)
- **Shape of Surface Mines:** Step (benches), Low slope, Wider opening than the bottom

Under-ground

- **Mining Depth:** deposit>100m deep
- **Difficulties:**
  1. Maximum depth: 2250 (up to 3466 for Au)
  2. Geothermal gradient & Groundwater
  3. Maximum cable length in shaft
  4. Presence of weak or fractured rocks

Shaft	Vertical tunnel
Adit	Horizontal tunnel
Drift	Ore extraction tunnel
Stope	Ore extraction hole

Types of Mining

Bulk	Called mixed mining, & are open pit mines
Selective	Used when the ore occurs in specific zones **Types**: Open pit (less) & underground (more)

Methods of Surface Mining	
Strip	Shallow, & flat-laying bodies, restore land
Open Pit	Shallow ore bodies, lenses with no lateral extension, & looks like a hole
Contour	Follow contour lines, in high overburden & thin ore
Dredging	High inflow of water cant be pumped, & ore is unconsolidated for placers
Hydraulic	Water jet to disaggregate rock & wash it
Solution (Frasch, for sulfur)	Pumping of hot water via a pipe to melt the sulfur, & Compressed air into a deposits via 2nd pipe that forces sulfur to surface via 3rd pipe

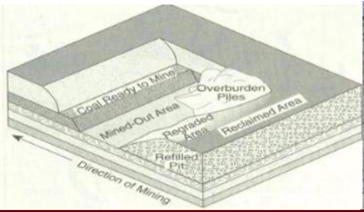
Methods of Under-ground Mining (Classified into 2 type)

1. **Continuous:** Tabular & flat-laying ore (room,pillar)
2. **Selective:** for steep-dipping ore, include Cut & Fill stoping & Bulk Mining (Sub-level & block caving)

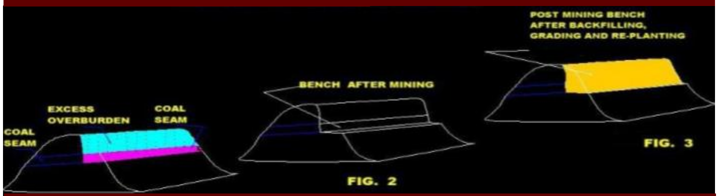
Room & Pillar	Ore removed as a long room with pillars or walls between leaves a large amount of ore behind
Cut & fill stoping	All ores are removes & space is filled with waste material by underground &surface processing good in placing waste material back underground but expensive (so used for valuable ores)
Block caving	Ore blasted from drillholes below, no attempt is made to control hanging wall of ore which drawn down from below via draw points, as waste fills muck pile, draw points exhausted

Shrinkage stoping (sub-level)	Ore is blasted & broken, with drilling of new ore taking place from top of broken ore pile, When blasting complete ore is drawn out from below via draw points. Mined area may be left as open stope or partially filled, No roof support needed

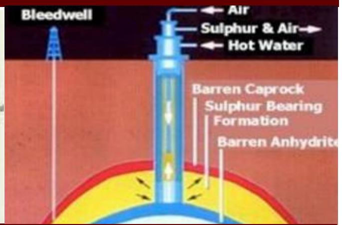
Methods of Surface Mining



Strip Mining | **Open Pit Mining**



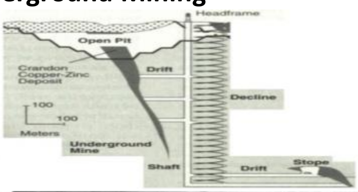
Contour Mining

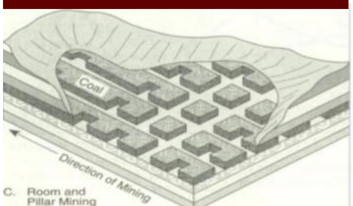


Contour Mining | **Solution Mining**

Methods of Underground Mining

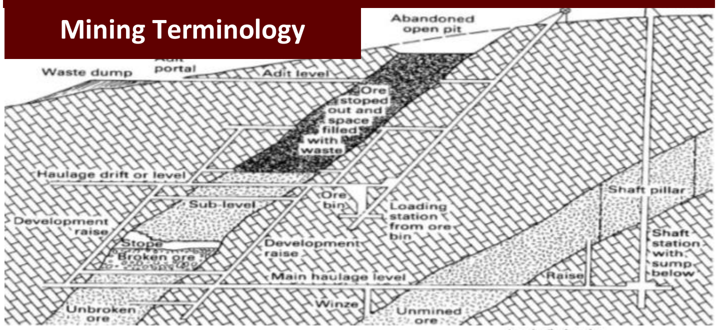
Ore is taken to surface by trains, conveyors, & lifted by skip

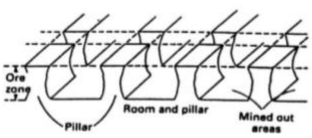


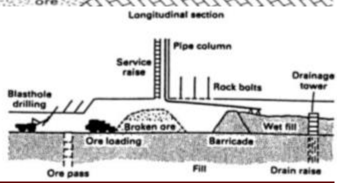


Continuous Mining

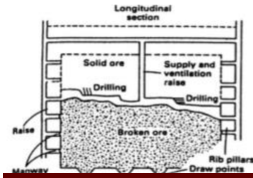
Mining Terminology

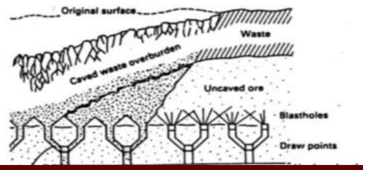






Room & Pillar | **Cut & Fill Stoping**



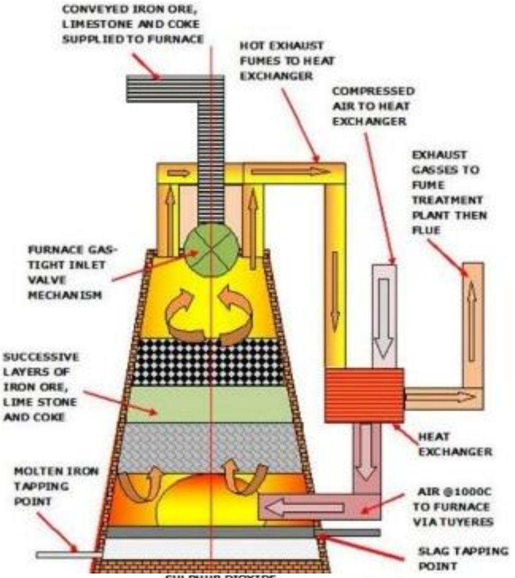


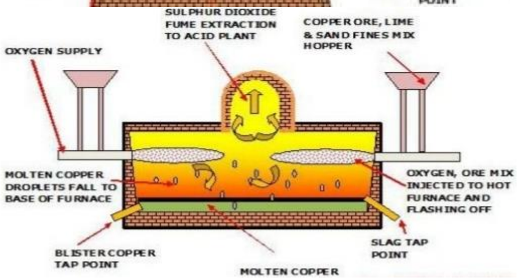
Shrinkage Stoping | **Block Caving**

- **Mineral deposits Processing**: method of concentrating wanted (target) mineral ores & dispose gangue minerals

Mineral Processing Techniques	
Crushing & Grinding	The size reduction of solid materials to liberate target from gangue
Pulverizing	Powdered
Screening	Handpicking
Separation	Magnetic & Density differences Separation
Froth Floatation	Separation using hydrophobic organic liquid, Target mineral attach to air bubbles & float
Separation of Metals	**Smelting**: separation of metals to immiscible phases using pyro metallurgy inside smelters (Heavier liquid target sink, solid waste slag)

- **Cu- smelting reactions:**





Iron-Smelting Reaction
Hematite → Pig iron
$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$

Cu-Smelting Reaction
Chalcopyrite → matte
$SuFeS_2 + O_2 \rightarrow CuFeS + SO_2$
$SuFeS + O_2 + SiO_2 \rightarrow Cu + FeSiO_2 + SO_2$

- **Grade**: ore concentration in ore-body (%, ppm)

$$GG = \frac{\textbf{weight of target in sample}}{\textbf{total weight of sample}} x100\%$$

- **Assaying**: determination of concentration
- **Cut-off grade (COG):** Lowest grade that can be produced to meet the approved standard specifications
- **Assay limit**: Boundary of ore-body
- **Head grade:** Concentration of the ore before processing

$$\text{Yield} = \frac{\textbf{end product weight}}{\textbf{head sample weight}} \text{x}100\%$$

- **Recovery (R)**: percentage of ore that can be recovered

$$R = \frac{\textbf{target mineral produced weight}}{\textbf{head sample target mineral weight}} \text{x}100\%$$

Environmental Impacts of Extraction

- **Environmental Impacts (EI) result from** the extraction of resources, the use of resources, & the disposal of resource products (e.g. The production & use of Plastics)
- **Environmental Impacts (EI):** result of & related to mining, mineral processing, & metal extraction operations, that have impacts on the Earth systems (atmosphere, lithosphere, hydrosphere & biosphere)

Environmental Impacts of Extraction

On Atmosphere

- **Blasting** in quarrying & mining operations
  1. **Dust** (200t explosive→ 20M m^3 dust): dust inhalation cases disease (e.g. silicosis, asbestosis, mesothelioma)
  2. **Gas** (NH_3,NO_2): 1ton explosive → 40-50m^3
- **High Intensity Noise**: hazardous human health
- **Escaping Gases**: Waste products, Rocks, Exhausts of machinery, Smelters
  1. **Coal mines**: Methane CH_4
  2. **Smelters & led to acid rain:** SO_2, & CO_2
  3. **Rock waste tip (acid rain):** H_2S,SO_2, CO, NO_2
- **Mitigation of EI involves continuous monitoring of air to determine the following**
  1. Discharge, content & precipitation of dust
  2. Type & Con. of heavy metal (Cd, Pb…)
  3. Concentration (Con.) & types of gases

On Lithosphere

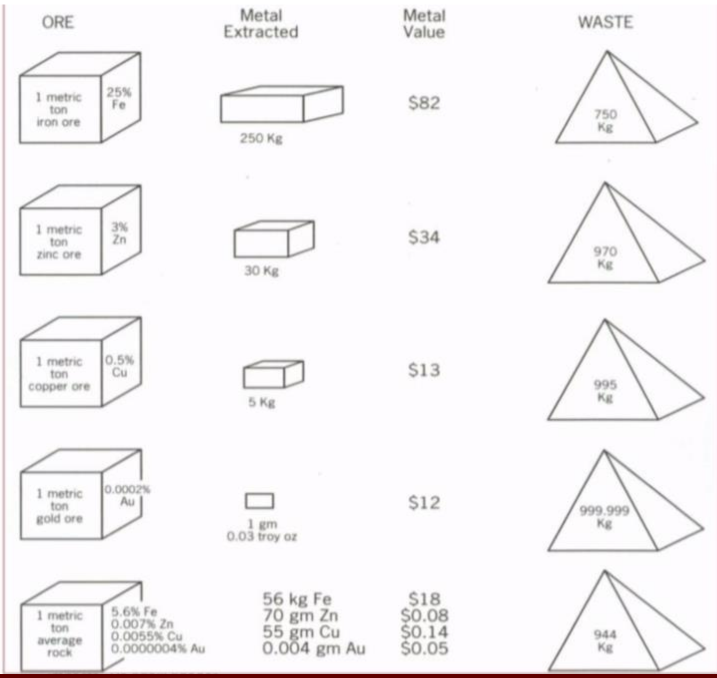
- **Surface subsidence, mine collapse, & sinkhole formation**: disturbance in run-off, formation of water-filled depressions, & flooding
- **Mass-wasting**: include landslide, rock, mudflow
- **Damage to land, change in landscape & land use**: due to excavation & waste dump
- **Loss of soil cover**

On The Hydrosphere

- **Acid mine drainage to rivers or lakes**
  $2FeS_2 + 15O_2 + 2H_2O \rightarrow 2Fe(SO_4) + 2H_2\,SO_4$
- **Change in drainage patterns are due to**
  1. Discharge of slurry & sludge to the water
  2. Toxic substances by mine water or heaps
- **Toxic substances such as**:
  1. Highly toxic (soluble form): Cd, Hg, As, & Sb
  2. Highly toxic (less soluble form): Pb
  3. Cyanide by gold extraction(Co,Mn,Ni,Pb,Zn)
- **Groundwater water**
  - Lowering of water table & water pressure → cone of depression → hydraulic head reduction (dewatering)
  - Water seepage to groundwater affect its quality, & Water can be pumped into the ground during extraction (for sulfur)

On Biosphere

- **Loss of farming land**
- **Degradation & damage of the ecosystems**
- **Effecting microclimate**: disappearance of local forests
- **Health & safety of workers & near by residents**
- **Effecting plant photosynthesis**



Amounts of metal extracted & waste disposal

- **EI Statement:** Governments ask companies working in exploration, mining or processing of mineral deposits to prepare the environmental impacts statement (EIS)
- **Aspects should EI cover**: Vegetation, Climate, Air quality, Noise, Groundwater, Surface water
  - Proposed methods of reclamation
  - A bound is deposited to assure that reclamation dose take place
  - Records of the condition of the environments in the Proposed area. Carried out while exploration

Mercury Pollution (Hg)

- **Hg Pollution in artisanal gold mining:** Extracted from river sediments, 6-8 kg Hg used for amalgamation to extract 1kg A, & 1.5 kg Hg are irrecoverable (lost)
- **Effects of Hg:** Bacteria convert Hg to methyl mercury (toxic form) that concentrated in fish tissues & transported to human (effect the lungs, kidneys & brain)
- **Hg enter human body through:**
  1. Inhalation
  2. Ingestion of food & water
  3. Transfer through skin
  - FAO/WHO permissible level 0.3mg/week

CHAPTER FIVE

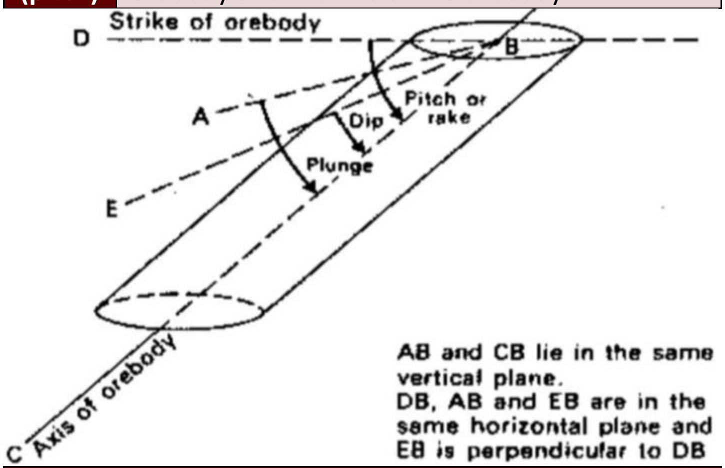
ORE DEPOSIT MORPHOLOGY, PARAGENESIS, & ZONING

- Morphology, Paragenesis, & Zoning are critical to economic geology (in exploration for deposits)

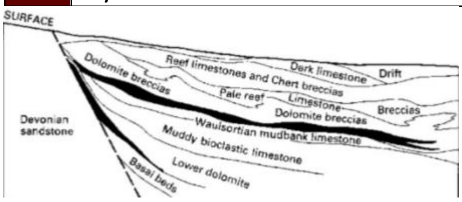
Morphology of Ore Deposits

- **Morphology:** is a shape of ore deposits, & is critical to develop models for how we explore

Morphology of Ore Deposits	
Strike	Long axis of an orebody in plan view
Dip	Inclination of orebody perpendicular to strike
Axis	The longest dimension of the orebody
Plunge	The dip of the orebody relative to a flat horizontal surface & the plane containing its axis
Rake (pitch)	Angle of dip between the strike plane of the orebody and the axis of the orebody

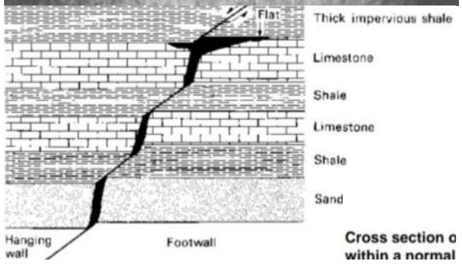


Morphology of Ore Deposits	
Tabular Orebodies	• extensive in 2D, but have a restricted development in the 3D **Stratiform deposits**: forms a layer that coextensive with sedimentary, metamorphic, or igneous layers **Vein (or lode) deposits:** forms a layer cuts across beds or layers of rock or through a massive rock **Pipe (chimney) deposits:** Vertically or subvertically oriented tubular deposits
Irregular Orebodies	**Disseminated deposits:** the ore minerals occur as disseminated grains throughout a mass of rock; (may occur in more than one rock type) **Stockwork deposits:** Many disseminated deposits consist of thin veinlets which cut the rock and could be more properly Termed stockwork deposits **Replacement deposits:** formed by replacement of preexisiting rocks (e.g. skarn deposits formed by reaction of carbonate rocks with moderate to high T hydrothermal solutions to form calc-silicates)

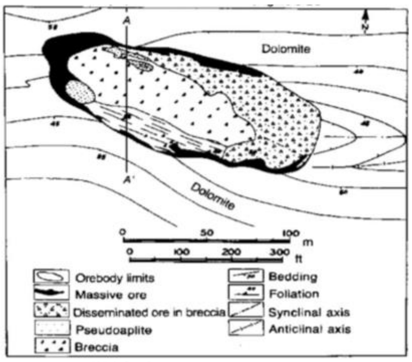


Stratiform deposit
Zn-Pb-Ag deposit
Ore zone parallel to bedding in limestone

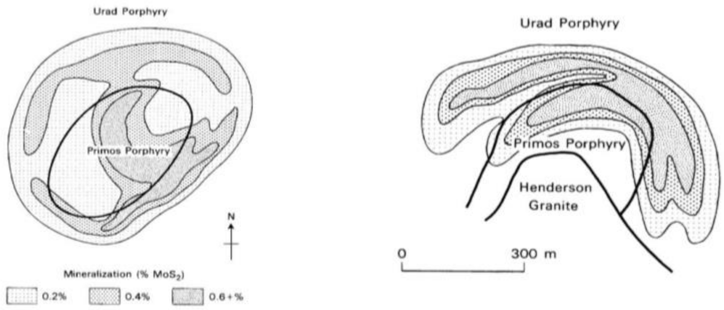
Stratiform deposit
Chromitite layer (dark) in anorthosite
Chromitite is parallel to igneous layering (i.e. Forms a bed)



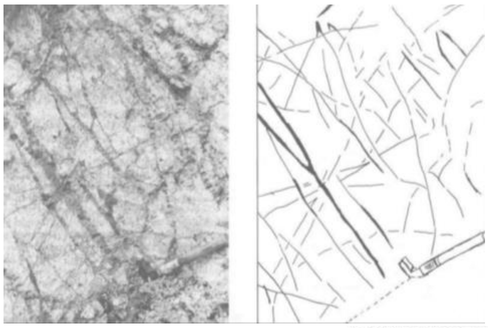
Vein(lode) deposit
Cross section of vein within a normal fault



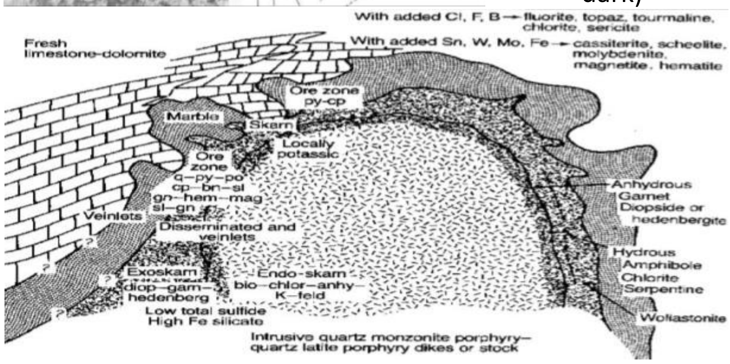
Pipe (chimney) deposits
Plan view of Tsumeb Cu-Zn-Pb-Ge pipe (above) from the 26th level, cross section of Pipe



Disseminated deposits: Henderson Mo deposit, Colorado which consists of an Inverted cup shaped zone containing abundant veinlets & Disseminations of molybdenite



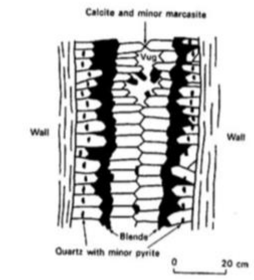
Stockwork
porphyry Cu deposits
Qz-orthoclas-chalcopyrite vein Stockwork being cut by Qz -pyrite veins (large & dark)



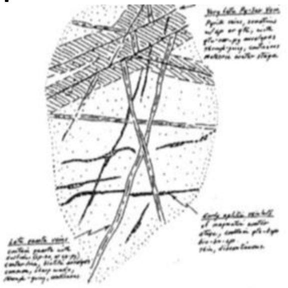
Replacement deposits
Cross-section of Skarn deposit showing irregular ore shape

Paragenesis

- **Paragenesis:** is a mineral assemblage (minerals semblages such as ore & gangue minerals formed at the same time & normally in equilibrium)
- **Paragenetic Sequence:** changes in mineral assemblages with time, used for determining chemical environment of ore deposits (chronological order of mineral deposit)
- Paragenetic sequence is determined from textures:
  1. **successive mineral overgrowths**
  2. **cross-cutting relationships**

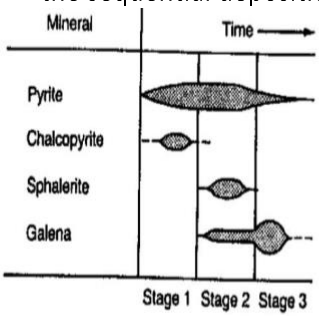


Section across a crustiform vein. Paragenesis is 1) quartz + pyrite; 2) blende (sphalerite); 3) calcite + marcasite. (from Evans, 1993, p. 41).



Sketch of a rock slab from the Yerington porphyry copper deposit, NV. Paragenesis is: 1) early aplitic veins (qtz-biot-ksp-bn-cp) cut by; 2) quartz veins with cp-bn or cp-py cut by; 3) late py-sericite veins with wide qtz-ser-py envelopes (from Einaudi, unpub)

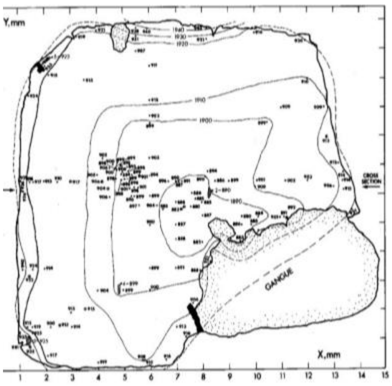
- **Means of Depicting Paragenetic Sequences:** Paragenetic sequence diagram (fish diagram) displays the sequential deposition of minerals



"Fish diagram" showing changes ins sulfide mineral assemblages through time. Early pyrite + chalcopyrite (stage 1) to pyrite + sphalerite + galena (stage 2) to galena + pyrite (stage 3). The thickness of the lines gives a schematic indication of relative amounts of each mineral present. (from Guilbert and Park, 1986, p. 21(

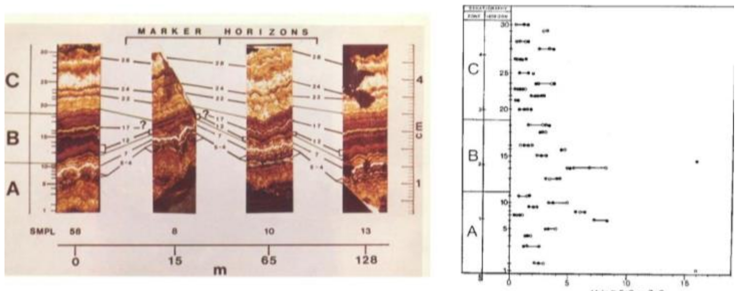
Zoning

- **Zoning:** is a spatial change in paragenesis, help guide us toward an ore deposit within a zone of alteration
  - ➢ Changes in fluid chemistry in an evolving ore fluid produce changes in ore & gangue mineralogy (paragenesis) along courses of deposition
  - ➢ Zoning may occur from the scale of individual minerals to entire mineral districts or regions
  - ➢ Zoning occurs within minerals as changes in the concentration of trace elements or in the amount of particular isotope of an element included in mineral
- Zoning in epithermal deposits is very obvious & sharply defined, & in sedimentary deposits broad & gradational



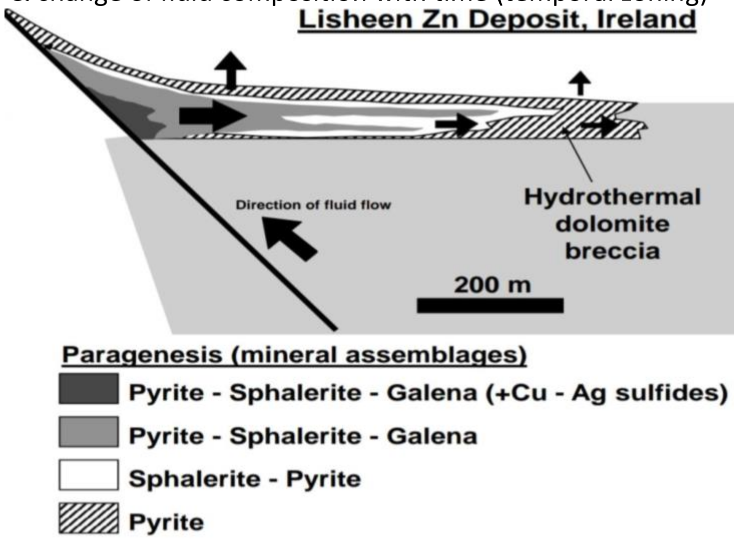
Map of an individual galena crystal

MO is individual ion microprobe $^{208}Pb/^{206}Pb$ These have then been contoured, shows zoning of lead isotopes within the individual crystal



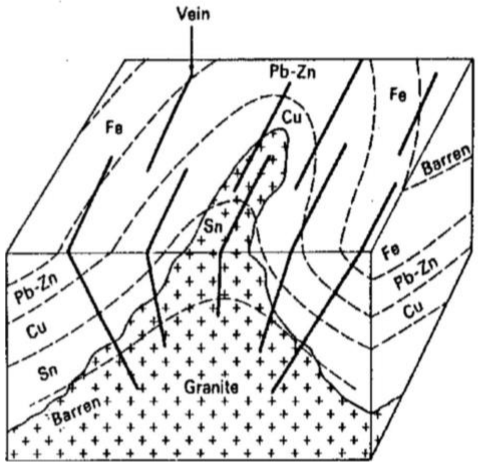
Sphalerite from the Upper Mississippi Valley district (Wisconsin) displaying color differences (zoning)

The color differences are caused by differing amounts of Fe in sphalerite (graph of trace Fe content determined by microprobe), The color bands traced throughout individual orebodies, & between orebodies indicating a consistent "sphalerite stratigraphy" this suggest widespread fluid flow & change of fluid composition with time (temporal zoning)



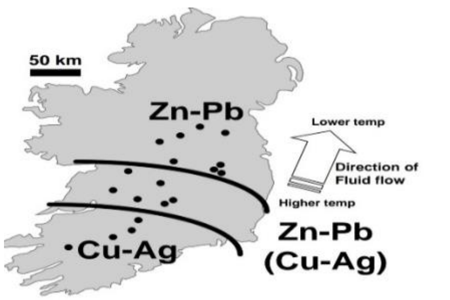
Zoning – Deposit-scale (Lisheen, Ireland)

Zoning occurs within individual mineral deposits as variations of mineral assemblages (paragenesis) & element abundances (critical in discussion of grade "difference between ore and waste")



Zoning – District-scale (Cornish Tin District)

Zoning occurs within mineral as element abundance variations District zoning is important in helping to define the pathways of mineralization



Zoning – District-scale (Ireland)

Zoning occurs within mineral districts as variations of element abundance or characteristic mineral assemblages

CHAPTER SIX

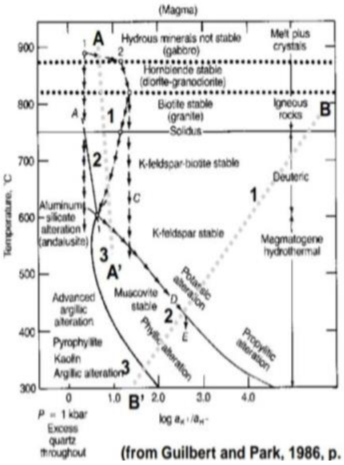
HYDROTHERMAL ALTERATION

- **Alteration:** mineral changes due to chemical process
- **Ways of alteration:** *Diagenesis* (in sediments), *Metamorphism* (regional), *Cooling* (Post magmatic or volcanic processes), & *Mineralization*
- **Hydrothermal alteration (HA):** a type of metamorphism involving the recrystallization of a parent rock to new minerals more stable under the new conditions
- **Importance of the study of hydrothermal alteration:**
  1. HA is one of the key features in mineral exploration
  2. Understanding the conditions of HA allows us to better understand conditions of mineral deposition
  3. HA can be confused with other alteration phenomena (by not trained to spot differences)
- **The assemblage *epidote-chlorite-Mg/Fe/Ca carbonate ± albite* can be formed by the following process**
  1) Cooling of a basalt-andesite-dacite sequence
  2) Regional metamorphism of mafic-intermediate ign.
  3) HA peripheral to intrusive-related orebodies
  ➢ The difference between these types of alteration is discerned by textural & contextural relationships
- **The volume of hydrothermal alteration is termed:**
  1. **alteration selvage**: small, generally around a veinlet
  2. **alteration envelope or alteration halo**
  3. **alteration zone**: large, may be district scale
- HA may be prominent as in high sulfidation epithermal deposits (e.g. Summitville, & CO) where several Km² converted to clays with Fe-oxides (bleached rock with rusty zones) or totally inconspicuous as in dolomitization of limestone adjacent to some Mississippi Valley-type deposits (little change in texture or color)
- **Importance of HA:** halos around many ore deposits are more widespread & easier to locate than the orebodies within them (e.g. Morenci, AZ porphyry copper deposit)
- **The hydrothermal alteration products are depend on:**
  1. The character of the wall rock
  2. The character of the hydrothermal fluid
  3. The T-P at which the reactions take place
- Guilbert & Park state "*hydrothermal alteration is most important in epigenetic igneous ore deposits*" but this is not true, HA in these deposits is more evident (& better studied) than in other deposits, it is equally important in ore deposits where it is difficult to see (cryptic)

Types of Hydrothermal Alteration (HA)	
Hydrolysis	Most common type, introduction of hydrogen ion $3KAlSi_3O_8 + 2H^+ \rightarrow KAl_3Si_3O_{10}(OH)_2 + 6SiO_2 + 2K^+$
Hydration	Addition of water (H_2O) from a fluid into a mineral $2Mg_2SiO_4 + 2H_2O + 2H^+ \rightarrow Mg_3Si_2O_5(OH)_4 + Mg^{2+}$
Dehydration	Removal of water from a mineral (as P-T increase) $Al_2Si_2O_5(OH)_4 + 2SiO_2 \rightarrow Al_2Si_4O_{10}(OH)_2 + H_2O$
Alkali metasomatism	Addition of an alkali metal to a mineral $KAlSi_3O_8 + 6.5Mg^{+2} + 10H_2O \rightarrow$ $Mg_{6.5}(Si_3Al)O_{10}(OH)_8 + K^+ + 12H^+$
Decarbonation	Remove CO_2 from carbonates to form silicates (skarn) $CaMg(CO_3)_2 + SiO_2 \rightarrow (CaMg)Si_2O_6 + 2CO_2$
Silicification	Addition of silica (Prograde skarn) • **Jasperoid**: $2CaCO_3 + SiO_2 \rightarrow 2Ca^{+2} + 2CO_2 + H_2O$ • **Prograde skarn**: $CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2$
Desilicification	Removal of silica (Retrograde skarn) $Ca_3Fe_2(SiO_4)_3 \rightarrow 3CaCO_3 + Fe_2O_3 + 3SiO_2$
Sulfidation	Addition of sulfur
Oxidation-Reduction	Called REDX reaction, the changing of oxidation state of elements (Fe & S are the most important)

Alteration Assemblages

- **Mineral assemblages**: is observing what minerals are stable together & which replace other once
- **The mineral assemblage's importance:**
  1. Deduce the chemical composition of the fluids which were stable with the mineral assemblages
  2. Gain idea of how the physiochemical conditions changed with time during alteration/mineralization
  3. Deduce the chemistry of HF & how they changed over time (By combining of ore mineral deposits & alteration mineral assemblages "paragenesis")



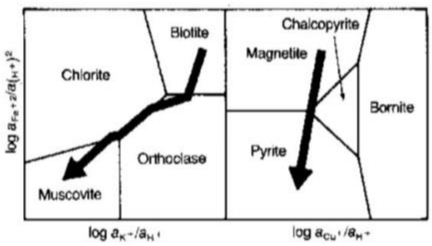
Plot of mineral stabilities at variable temperature And activity of K+ and H+ at 1 kbar pressure (approximately 3-4 km depth). Using K and H we are able to look at the stability of potassium-bearing minerals such as hornblende, biotite, potassium feldspar, and muscovite. The arrowed lines show the connection between magmatic fluid chemistry at high (magmatic) temperatures and hydrothermal fluid chemistry at lower temperatures.

What mineral assemblages are stable along line A-A' and B-B' at points 1, 2, 3?

Answer:
A-A': 1- biotite; 2-andalusite; 3-pyrophyllite-kaolin
B-B': 1-K-feldspar-biotite; 2- muscovite; 3- pyrophyllite-kaolin

(from Guilbert and Park, 1986, p. 176)

- **We can interrelated chemistry of the alteration:** for example, As K-Fs altered to muscovite, H⁺ are consumed which decrease pH, degree of dissociation of H-complexes, & the solubility of metals in solution (Fe-Cu) & Thus alteration cause mineralization
- **H-containing complexes:** affects association degree of NaCl, KCl, & metal-chlorine complexes



Activity-activity diagrams for Iron over hydrogen ion vs. potassium over hydrogen ion (a) and copper over hydrogen ion (b). These diagrams, which are relevant to porphyry copper Deposits relate silicate minerals and sulfide minerals.

- **Importance of Activity-Activity (phase) diagram**:
  1. Determine the physical & chemical parameters responsible for sulfide-assemblages
  2. (Petrographic lab & field work) Establish the equilibrium assemblages in a mineral deposit & how changed through time (because diagram indicate changes in physical & chemical parameters that were operative when assemblages precipitated)
  3. As sulfide data combined with physical & chemical data of alteration assemblages, we able to constrain physical & chemical env. of ore deposition (better prepared to predict where additional ore located)