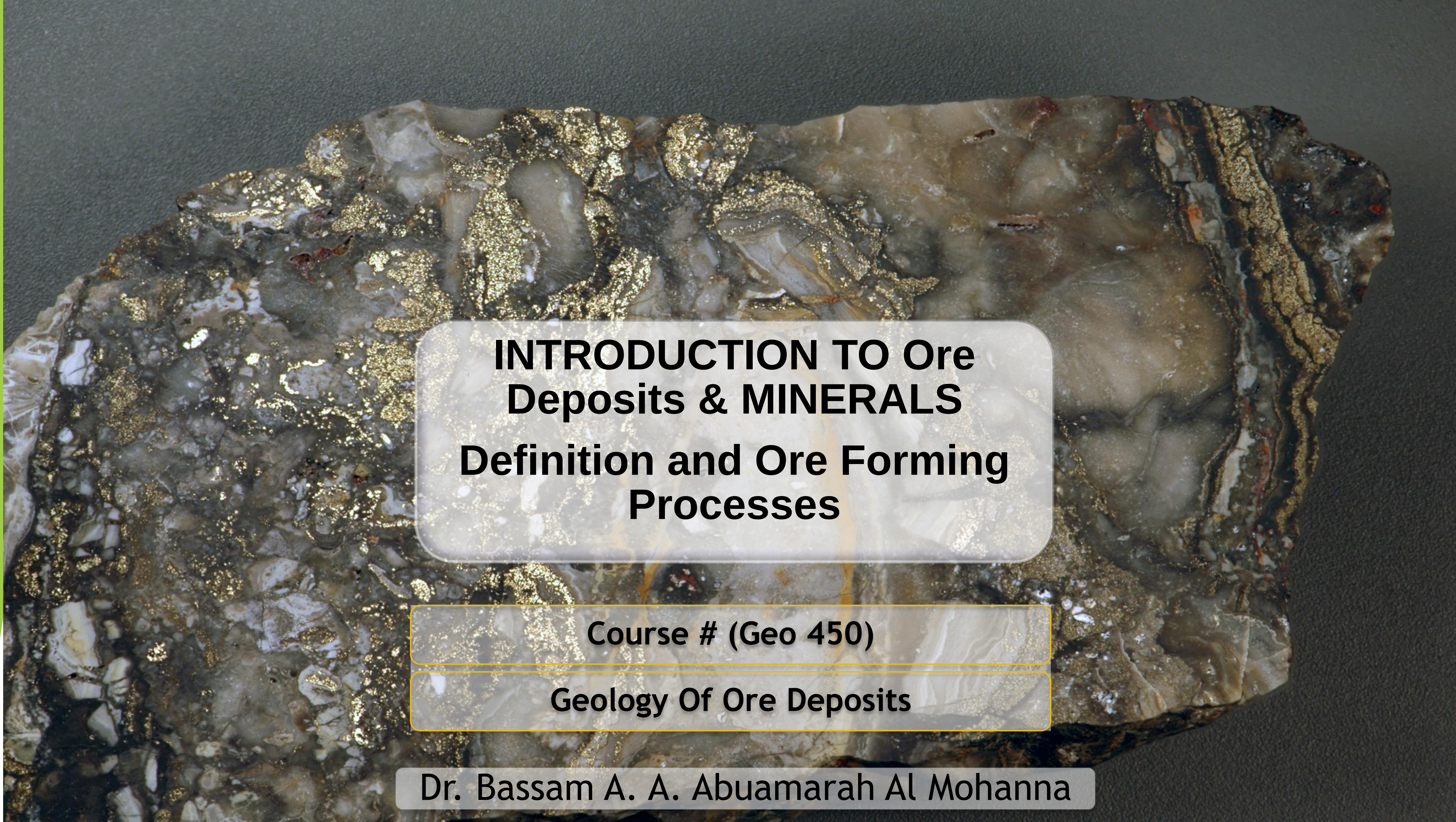
INTRODUCTION TO Ore Deposits & MINERALS
Definition and Ore Forming Processes
Course # (Geo 450)
Geology Of Ore Deposits
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Lectures Objectives; Basic Concepts:

- Ore Deposits Terminology & Definations.
- Mechanisms of Ore Forming Processing & Concentration.

Economic Ore Deposits geology.

To know:

How, why, and where minerals are concentrated in specific rocks, facies of those rocks, structures, and tectonic settings within the earth's crust.

To know:

How to search for and find these concentrations.

To do:

Extract the concentrations in a safe, environmental way for societies benefit and for the maintenance and expansion of our civilization.

Introduction

- To know: How, why, and where minerals are concentrated in specific rocks, facies of those rocks, structures, and tectonic settings within the earth's crust.
- To know how to search for and find these concentrations
- To do: Extract the concentrations in a safe, environmental way for societies benefit and for the maintenance and expansion of our civilization.

- ✓ **A concentration of minerals, can be mined and sold at a profit. This is an economic, a business definition and not a geological one.**
- ✓ **Concentration is defining ore as a solid, natural occurring mineral, its concentration useable as mined or from which one or more valuable constituents may be economically recovered.**

Introduction

- The geological processes of ore concentration formation; **that's is to say** a 10 million ton massive sulfide deposit of 10% zinc, 1% copper, and 1% lead may be identical to an occurrence of 200,000 tons of 5% zinc, 0.5% copper and no lead.

Thus,

- The **concentration based on tonnage and grade one is an ore deposit and the other is not.**
- **Geologists will be concerned with processes of formation and concentration of Ore deposits** with emphasis on formation environments, host rocks and facies of host rocks, tectonic setting, structures,

Introduction

- Thus, the mineral concentration can be defined and classified and leads to exploration.
- **Finding** these concentrations lead to economic geology formation areas or field, such as:

    a) Volcanology

    b) Structural geology

    c) Igneous-sed-met petrology

    d) Geochemistry

    e) Geophysics

    f) Hydrogeology

Introduction

- Geomorphology
- Environmental Geology
- From all the above then we will approach economic geology and this course by:

1. Looking at and learning what the most important ore, gangue, and alteration minerals are for a given ore deposit types-Lab .
2. Looking at and learning about the geological and geochemical characteristics of a wide variety of ore deposits as well as something about their environment of formation and genesis-lecture and lab.

3. Exploration criteria for searching for these concentrations.

Introduction

- The making of a mineable ore deposit involves much more than just finding it, and development of an ore deposit the following are of importance:
  - Study Phase: Mineral exploration program, finding ore deposit. to select areas to explore:
    - Decide how the exploration will be carried out,
    - Quick field checks,
    - followed by the reconnaissance phase which involves field mapping, geochemical sampling, geophysical surveys, economic petrological studies, channel sampling, relogging of any core, and data compilation.

Introduction

2. **Feasibility studies: economically viable.**

   This depends on many factors including size, tonnage, grade, price, and demand. This stage takes detailed drilling, assaying, and pilot mill tests.

   For industrial minerals this stage involves such things as homogeneity, size, chemical purity, and color. At this stage also need to consider the effect on the environment (flora, fauna, air, water) and cost of cleanup and environmental protection

3) **Mine development:** the establishment of infrastructure, which includes site clearing, roads, power, mill, disposal areas, mine buildings, and shaft sinking (if underground) or pit design.

Introduction

4) **Mining:** extracting the ore from the ground-open pit or underground, disposal and/or storage of waste rock; the ore goes to the mill

5) **Ore Processing:** this involves milling (crushing, separation of ore minerals from gangue, separation of ore minerals into separate concentrates-ie. sphalerite and chalcopyrite from pyrite-quartz-chlorite gangue, followed by separation of zinc from copper. Gangue to tailings disposal and concentrate shipped to smelter.

6) **Closure** and clean-up-waste rock, tailings, mine site, etc.

7) **Smelting** to get metal(s) out of concentrate.

8) **Marketing**

Introduction

To find or to explore an ore deposits, we have to :

- Understanding the kind of deposit host rocks, alteration, environments of formation, ore genesis, structure, etc.
- Geological mapping-from recon to detailed facies-alteration, economic petrology studies(thin sections, x-ray, SEM, microprobe, polished sections, etc.),
- Reconnaissance stage will use geochemistry , Geophysical surveys to support, drilling holes to finally identify, quantify and outline of ore deposits.

- All above used to delineate areas of potential for the kind of ore deposit being explored

Introduction

- Ore deposits geology deals with the materials of mineral that's man his necessities of life and comfort.
- He started to discover new lands.
- It tends to be commercial or political supremacy , or has caused strife (Conflict) and war.

Thus, the demand

It acquired man to have the knowledge of their distribution, character, occurrence, and this knowledge has led to theories concerning their origin.

Thus,

The minerals deposits educated developed as was as used to be one phase of mining in early mining schools.

Introduction

- Accordingly, a greater attention was paid to the rocks hosting or enclosed to the Ore deposits, and to the land forms developed upon the rocks , the boarder science of Geology.
- Today; the Ore deposits geology is considered as a separate branch of GEOLOGY.

Consequently

- This, alarming and leading to the consumption rate of mineral resources and the exhaustion (Consumption) of known reserve;
- Means a new supply and Areas should be explored to replace it in industry to cover the human demand and needs.

What is the Ore?

- ore is a naturally occurring as solid material containing a useful commodity that can be extracted at a profit.
- By “useful commodity” we mean any substance that is useful or essential to society, such as metals, or energy sources, or minerals with distinctive properties.

What Is an Ore Deposit?

- An ore deposit is an accumulation of ore. This is distinct from a mineral resource as defined by the mineral resource classification criteria.
- An ore deposit is one occurrence of a particular ore type.
- Most ore deposits are named according to their location.

Introduction

- The Study and the scope of Ore deposits geology will involve :
  1. Metallic Ore Deposits.
  2. But, also include the field of Nonmetallic (earthy substance), bearing in mind that the term of "ORE" does not applied on such substance (Nonmetallic).
  3. Another important subdivision of Nonmetallic ore deposits geology is **Petroleum geology** (by studying, by specifying its location, occurrence, migration, and origin of Petroleum & Gas).

Introduction

- To Study the ore-forming processes to reach the precious natural resources.

and

- To provide a better understanding on the nature and the origin of mineral resources and how they fit into the earth's system.

Thus

- The Ore deposits form should be found in a sufficient concentration to be considered as a useful commodity as to be an accessible part of the Earth's crust ,

So

-It can be profitably extracted.

Introduction

- The metal concentration is the main factors that will characteriz the metal formation of ore deposit types.

- Some of the strategic important metals such as Fe, Al, Mg, Ti and Mn: are abundantly distributed in the earth crust (i.e. between 0.5 to 10% and require a relative small degree of enrichment) in order to make it a viable (Feasible) deposits.

By contrast, the base metal such as Cu, Zn, and Ni are much sparsely distributed and abundance in a range of 55 – 75 ppm,

- These metal have to be economically dictate needs to be concentrated by factors in hundred in order to be potentially economics

Introduction

Metal	Average crustal abundance	Typical exploitable grade	Approximate concentration factor
Al	8.2 %	36%	X4
Fe	5.6%	50%	X9
Cu	55 ppm	1%	X180
Ni	75 ppm	1%	X130
Zn	70 ppm	5%	X700
Sn	2 ppm	0.5%	X2500
Au	4 ppb	5g t^{-1}	X1250
Pt	5 ppb	5g t^{-1}	x1000

Note: l ppm is the same as 1 g t^{-1}

Introduction

- Pure metals are very rarely found in nature, they are always associated chemically with other elements to form compounds known as ores.
- Minerals are elements combined with sulphur, chlorine or oxygen to form Sulphides, silicates, chlorides or oxides.
  - For instance; Copper carbonates ($CuCO_3$) are bright green (malachite) or blue (azurite), or a strong red color (cuprite, Cu_2O). They are clearly visible if exposed on the surface.
- Despite; their concentrations as natural metals are occasionally found in relatively small areas of the earth's crust,
  - For examples being gold, silver, copper, and metals in the platinum group

Introduction

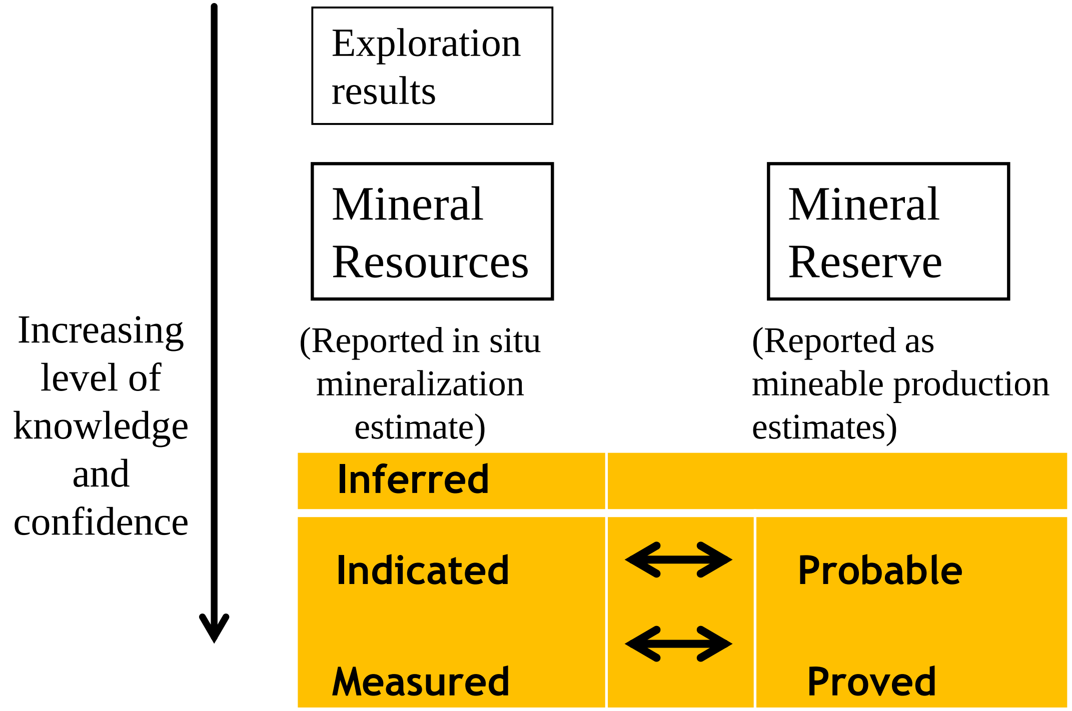
- Thus, it is clear that the nature, origin, and distribution of the worlds minerals deposits remains one of the strategic topic.
- There are an increase demand for the production of the nature resources.
- The economic geology should covers all aspect relating the understanding of mineral resources.
- The correction of economic geology and particularly in the field of Metallurgy (the study of the Ore Deposits genesis) remains critical to teach.

- **Metallurgy** **is the a metal extraction from ores, via refining, extracting, and preparing them for use.**
- The process consists an altering of the chemical minerals nature in order to separate the metal from its Sulphurous compounds, oxides, silicates or carbonates.
- These **methods depend very much on the type of vein formation and its chemical composition**.
- In some cases, **it is a mechanical process, in which gold is recovered from its core by pulverizing (meshing) it and then washing it in water.**

reserves

- A *mineral resource* : it is an occurrence of essential economic interest exists in such form and quantity that there are reasonable prospects for its eventual exploitation.
- **Resource can only be referred to as an ore reserve if it is part of an economically extractable measured or indicated mineral resource.**
- The term "Ore deposit" has no significant in the professional description of a mineral occurrence and is best to use it as a simple descriptive or generic term

As shown in the following diagram



Mining, metallurgical, economic, marketing, legal, environmental, social, and governmental factors

(Factors that contribute to the successful exploitation (Utilization) of a deposit)

Figure Simplified and illustrating the conceptual difference between mineral resources and ore reserves as applied to mineral occurrences.

It is the basis for the professional description of ore deposits as defined by the Australian and South African Institutes of Mining and Metallurgy.

Cont'd: General Definition

There are several terms will be used throughout the course , where the definition is either useful or necessary.

The following definitions are consistent with Bates and Jackson, 1987 and the Encyclopedia of the solid earth sciences (Kearey, 1993):

- ✓ **Ore:** a solid, natural occurring mineral concentration useable as mined, or from which one or more valuable constituents may be economically recovered
- ✓ **Ore Deposit:** defined as an accumulation of a useful commodity that is present in high-enough concentration and in sufficient quantity to be extractable at a profit.
- ✓ **Syngenetic:** refers to ore deposits that form at the same time as their host rocks.

Cont'd: General Definition

- **Hypogene:** refers to mineralization caused by descending hydrothermal solution.
- **Supergene:** refers to mineralization caused by descending solution. Generally refers to the enrichment processes accompanying by the weathering and Oxidation of sulfide and oxide ores at near or above the surface.
- **Polymetallic:** Refers to an ore deposit that is the source of more than one metal suitable for recovery.
- **Gangue:** the commercially worthless minerals associated with economically valuable metallic minerals in an ore deposit.

Cont'd: General Definition

- **Hanging Wall:**

  The rocks stratigraphically and/or structurally above an ore deposit

- **Wallrock:**

  Non-mineralized rocks adjacent to an ore deposit.

- **Syngenetic:**

  Ore deposits that form at the same time, or close to it, as their host rocks.

- **Epigenetic:**

  Ore deposits that form later than their host rocks.

- **Hypogene:**

  Primary minerals in an ore deposit that formed from ascending hydrothermal solutions.

Cont'd: General Definition

- **Supergene:**

  Refers to mineralization caused by descending surface waters. Common useage signifies the enrichment process accompanying the weathering and oxidation of a sulfide and/ore oxide ore deposit at or near the surface.

- **Mesozonal:**

  Orogenic, hydrothermal ore deposits formed at depths of 5 to 10 km and temperatures of 300-475^{0}C.

- ***Mesothermal*:**

  hydrothermal ore deposits formed at intermediate depths (1500 – 4500 meters) and temperatures (200 – 400 °C).

Cont'd: General Definition

- ***Hypothermal*:**

  hydrothermal ore deposits formed at substantial depths (greater than 4500 meters) and elevated temperatures (400 – 600 °C).

- **Epizonal:**

  Orogenic, hydrothermal ore deposits that formed at depths of less than 6km and temperatures of 150 to 300 °C.

- **Hypozonal:**

  Orogenic, hydrothermal ore deposits formed at depths >10km and temperatures between 400 and 600°C.

- **A mineral occurrence:**

  is any locality where a useful mineral or material is found.

Cont'd: General Definition

- ✓ **Metallogeny:**

  The study of the genesis of mineral deposits, with emphasis on their relationships in space and time to geological features of the Earth's crust.

- ✓ **Metallogenic Province**:

  An area of the earth's crust characterized by a particular assemblage of ore deposit types.

- ✓ **Gossan**
  - Is a rusty, surficial weathering zone which is caused by the oxidation of pyrite to produce secondary iron oxide minerals. Since pyrite is often associated with ore deposits, gossans can be a guide to ore.

Cont'd: General Definition

- ✓ **Metallogenic Epoch**:

  A period of geological time favorablre for the deposition of ore depositds characterized by specific deposit types.

- ✓ **Reserves:**

  A mineral deposit that can be economically and legally extracted or produced at the time of the reserve determination.

Cont'd: Some General Definition

- ✓ **mineral prospect:**

  is any occurrence that has been developed by underground or by above ground techniques, or by subsurface drilling to determine the extent of mineralization.

- ✓ **The terms mineral occurrence and mineral prospect do not have any resource or economic implications.**

Variation among Mineral and Ore deposits and Ore

- ✓ **A mineral deposit is any occurrence of a valuable commodity or mineral that is of sufficient size and grade (concentration) that has potential for economic development under past, present, or future favorable conditions.**

- ✓ **An ore deposit is a well-defined mineral deposit that has been tested and found to be of sufficient size, grade, and accessibility to be extracted (i.e. mined) and processed at a profit at a specific time. Thus, the size and grade of an ore deposit changes as the economic conditions change.**

- ✓ **Ore: refers to an industrial minerals as well as metals.**

Some General Definition

- ✓ **Generally,** the industrial minerals are any types of rocks, mineral, or naturally occurring as substance or closely related man-made material of economic value (Tiles, Granite, marble.. Etc. , generally excluding metals, fuels, and gemstones.

  "Without a market, an industrial mineral deposit is simply a geological curiosity"

- ✓ Demand feeds back from the end-user market, to the end product, to the intermediate end product, and finally back to the mineral supplier.

- ✓ Customer specifications will include its physical and chemical and some other criteria

ORE GRADE for SELECTED ELEMENTS

Clarke: the average abundance of an element in the earth's crust

Clarke of Concentration:
the concentration of an element in a rock compared with its average concentration in the earth's crust.

Ore Grade, or the Clarke of Concentration changes over time and is affected by:

1. **The availability of minerals with high concentrations if the element . (e.g. Cu_2S, PbS, etc.**
   REEs, for example, lack such minerals)
2. **The difficulty and expense of recovering the metal from its ore (e.g. Aluminum, Titanium)**
3. **Advances in mining and refining technology**
4. **Changes in the value that society places upon the metal (e.g. Gold, REE, Lead, Tin).**

In general, the larger the Clarke of Concentration, the smaller the typical orebody becomes:

Metal	Clarke (in percent)	Ore Grade (in percent)	Clarke of Concentration for Ore Grade
Aluminum	5.13	30	4
Iron - Fe	5.00	60	12
Titanium	**0.66**	**15**	**23**
Copper	0.0055	0.25	45
Rare Earths	**0.019**	**1.6**	**84**
Nickel	0.0075	1.5	200
Gold - Au	0.0000005	0.00023	460
Manganese	0.10	35	350
Uranium	0.0002	0.1	500
Zinc	0.007	4.0	600
Lead – Pb	0.0013	4.0	3000
Chromium	0.01	30	3000
Tin – Sn	0.0002	1.0	5000
Silver – Ag	0.00001	0.05	5000

IMPORTANT TERMS

✓**MINERAL RESOURCE:**

- any naturally occurring non-living substance that is, has been,
- or may be useful to human beings

✓**RESOURCE BASE:**

- The volume of rock in a given area that contains more than the **Clarke**,
- or average concentration of that mineral in the Earth's crust.

✓INFERRED RESOURCES:

- volumes of mineralization above the minimum grade that are known to exist,
- or volumes are hypothesized on geological grounds to exist, for a given area, but have not been measured. May be orders of magnitude (size) less than resource base and greater than the quantities of known ore.

✓INDICATED RESOURCES:

- mineral occurrences that have been sampled to a point where an estimate has been made, at a reasonable level of confidence, of their contained metal, grade, tonnage, shape, densities, physical characteristics.
- Generally orders of **magnitude less than inferred resources in same area**.

- ✓**LEAD:** an area in which there are specific indications of valuable mineralization.

- ✓**GRADE:** the percentage of the rock composed of valuable material. E.g. 62% Fe, 1% Cu,

Or

Grade is the concentration of each ore metal in a rock sample, usually given as weight percent. If concentrations are extremely low, as with Au, Ag, Pt and others, the concentration may be given in grams per tonne (g/t). The average grade of an ore deposit is calculated, often employing very sophisticated statistical procedures, as an average of the grades of a very large number of samples collected from throughout the deposit.

- ✓**ORE GRADE:** any grade above the lowest grade that can be mined at a profit. Varies with time and deposit.

✓Cut-off

The cut-off grade is the randomly defined as the lowest grade which will be mined from an ore ore deposit, and usually defines the boundary of the deposit. For example, if the average grade of a porphyry deposit is 0.5% Cu, the cut-off might be 0.2% Cu. any rock with a grade below 0.2% Cu would be waste.

✓**PROSPECT:**

an area in which there are sufficient indications of the presence of ore to carry out a serious evaluation campaign (drilling, test mining). (It takes 10 – 100 LEADS to find 1 PROSPECT)

✓**DEPOSIT:**

A defined or partially defined body of mineralization, which may or may not be ore, depending on economic conditions. (It takes 10 - 100 PROSPECTS to develop 1 DEPOSIT)

Ore Forming Processes and Fluids

Ore deposits form in a great variety of different geological different processes work toward elements and minerals concentrating them 10-1000 or more times thus turning them into viable mineral deposits.

Some of **the geological processes for forming ore deposits are**:

1. **Evaporation of seawater**: salt, potash, borax **($Na_2B_4O_7 \cdot 10H_2O$ or $Na_2[B_4O_5(OH)_4] \cdot 8H_2O$).**
2. **Melting glaciers:** sand and gravel.
3. **Alluvial:** concentration of dense, durable minerals like gold, tin, platinum, and diamonds.
4. **Weathering:** nickel laterites, bauxite (aluminum).
5. **Sedimentary precipitation:** iron ore .

Ore Forming Processes and Fluids

6. **Digenesis and extraction of connate brines: MVT deposits(highly valuable concentrationof Lead and Zinc sulfide Ores hosted within Carbonate (Limestone, marl, dolomite)formation share commongenetic origin), and sedimentary exhalative deposits.**
7. **Metamorphism-Sapphires, Rubies and metamorphic fluids: orogenic gold.**
8. **Magmatic differentiation plus magma mixing: chromium, magnetite, lithium, REEs.**
9. **Liquid Immiscibility: nickel, copper, platinum, palladium .**
10. **Hydrothermal: copper, zinc, lead, mercury, arsenic, gold, silver, bismuth, antimony**

- **The most common processes that form most kinds of Ore deposits, are via hydrothermal and magmatic processes along with precipitation from seawater.**

Ore forming fluids can be subdivided into:

I. Magmatic .
II. Magmatic Hydrothermal.
III. Seawater-meteoric water-connate water,
IV. Mixing of 2 and 3.
V. Metamorphic fluids

I. Magmatic Fluids and Ore Forming Processes:

- Ore deposits formed by magmatic processes are typically orthomagmatic, its minerals are crystallized and concentrated in a magma chamber .
- These minerals concentrated by such a process are :
  1. nickel, chromium, copper, titanium, vanadium, PGEs, and iron.
  2. Its common minerals are pentlandite, chromite, chalcopyrite, ilmenite, platinum, palladium, magnetite, apatite, rutile.

Ore Forming Processes and Fluids

Thus,

Processes that lead to concentrate these elements and minerals are:

a) Fractional crystallization:

- Layered igneous rocks result from the gravitational settling or rising of minerals that precipitate out of a cooling silicate (mafic-ultrmafic) magma, settling of minerals occur due to density differences between crystals and melt, in order to get chromite or magnetite only layers in mafic-ultramafic intrusions.
- In addition; 1) mixing of a new magma with the cooling and crystallizing intrusion, and 2) changes in the partial pressure of oxygen in the magma chamber, or 3) increase in the total pressure in part of the chamber.

Thus,

- **Increase in fugacity (partial pressure) of oxygen at high temperatures and pressures promotes chromite stability and may allow only chromite to precipitate out of the melt.**

Ore Forming Processes and Fluids

i.e. **The Oxygen pressure can be altered by devolitizing of the magma. And a sudden increase in the total pressure, especially at the top of the chamber due to vesiculation, can shift phase boundaries and allow chromite and/or magnetite to precipitate until normal pressure brought back.**

b) Liquid Immiscibility:

- It is the segregation of 2 coexisting liquid fractions from an originally homogeneous silicate magma.
- Immiscibility is best seen in the extrusive rocks where rapid quenching prevents the segregated products from being rehomoginized.
  - ✓ in basalts 2 distinctly different glasses interstitial to the crystalline minerals, these glasses have the composition of rhyolite and a magnetite-ilmenite-apatite-pyroxene mix
  - ✓ In Kilauea basalt directly observed that a sulfide melt separated from a cooling basaltic magma
- These occurrences provide further evidence that both sulfide and iron-titanium-phosphorus immiscible fractions separated from magma.

Cont'd: Ore Forming Processes and Fluids

The There are 2 types of Liquid Immiscibility

1- Oxygen immiscibility:

- **Occurred by two immiscible liquids, one magnetite-apatite and the other having the general composition of synodiorite,**
- **In a wide range of rock compositions under conditions of high oxygen fugacity can lead to formation of an immiscible iron oxide melt.**

2) Sulfide immiscibility:

- **As a common feature of magma crystallization.**
- **silicate and sulfide liquids can coexist over a large volume of the FeS-FeO-SiO2 system.**
- **the amount of sulfide dissolved and its saturation will vary as the magma crystallizes.**
- **at any point where saturation does occur sulfide droplets form.**
- **Sulfide saturation can be achieved as T ^{o}C decrease, and increase Oxygen fugacity and due to decrease in ferrous iron, and due to external sulfur, or magma mixing.**

Cont'd: Ore Forming Processes and Fluids

So,

Factors that stimulate sulfide immiscibility are:

a) **Externally derived sulfur**: komatiite lavas flowing over shale or iron formation; by intruding to and assimilating sulfur rich rocks, , Or due to melting of crustal rocks due to a meteor impact.
b) **Injection of new magma** and magma mixing-

Hydrothermal Fluids :

- **These fluid occur at temps and pressures that range from those of shallow crustal levels to those deep in the crust,**
- **These fluid can be found in both igneous, sedimentary, and metamorphic environments.**
- **These fluids are referred as hydrothermal and the deposits they form as hydrothermal mineral deposits.**

Cont'd: Ore Forming Processes and Fluids

- These (hydrothermal) fluids are common, and active in volcanic terrains. This conclusion comes from:
  1. Presence of hot springs and numerous subaerial geothermal systems.
  2. Fluid inclusions in minerals.
  3. Alteration of rocks.
  4. Hot mine waters.
  5. *Heat studies show the oceanic crust at spreading ridges* is cooled by large volumes of seawater moving through it.
     - It is *estimated as heat loss from the crust*, that sea water circulate through young oceanic crust.
     - It is react with the oceanic crust crystallizing them and modifying their chemistry.

  This heated water eventually exits (comes out to the Earth's Surface) as warm or hot springs.

Cont'd: Ore Forming Processes and Fluids

and

- **Hydrothermal fluids are often parts of geothermal systems.**
- **A geothermal system is one in which fluids circulate.**
- **These form where a combination of favorable structures and rocks occur together in areas of high heat flow.**
- ***In general, the Hydrothermal conditions will include:***

a) An aquifer zone to contain the heated water, naturly permeable units.

b) A cap-rock:

- It may be naturally impermeable or become impermeable by a process called self-sealing,
- it will precipitate within permeable units due to the decrease of temperature and pressure, or due to oversaturation.

that is to say

- Warm water is buoyant, it rises up; cooling slightly and attached with a slight pressure decrease, causes some precipitation, particularly of quartz and carbonate.

Cont’d: Ore Forming Processes and Fluids

c) Recharge channels:

- Recharge channels represent areas where fresh water enters an aquifer.

d) and discharge channels affected through the cap rock and send heated water to the surface.

d) The heat source is typically start to COOLING, near surface of magma body, often a subvolcanic intrusion.

Consequentlt,

- A hydrothermal system with recharge and discharge channels is referred to as open system, ones with only discharge channels are called closed systems.
- The difference is based on the reactivity of seawater magnesium during reactions with basalt. all the magnesium is extracted (removed from seawater) during the reactions (low ratios), or (high ratios), i.e. hydrothermal water -rock dominated (water to rock ratio <40/1).

Cont'd: Ore Forming Processes and Fluids

- There are 4 sources for the water in the hydrothermal systems:
  i. Seawater.
  ii. Connate water (water trapped in sediments and breccias at time of formation).
  iii. Metamorphic water-especially common at transition from Greenschist to amphibolite grade due to dehydration reactions.
  iv. Magmatic

- Source of metals in hydrothermal fluids have 3 origins:
  1. Rocks or sediments through which fluids pass and interact.
  2. Magmas.
  3. Combination of 2-mixing in geothermal systems

Cont'd: Ore Forming Processes and Fluids

II. *Magmatic Hydrothermal Fluids, it occurs*

- At either, the earlier or later felsic magma crystallization history,
  - It becomes water saturated resulting in the Exsolution of an aqueous fluid which **forms** chemical distict **phase of silicate melt** (This **process call WATER-SATURATION**, it is refered to as **either "boiling" or "vapour-saturation"**)

- Magmatic Hydrothermal fluids originated **from magmas**, as they cool and recrystallize at various level of the earth's crust.
- It is responsible for forming:
  - for a wide-range of Porphyry Deposits (Copper Cu, Molybdenum Mo, Tin, Gold, Au, Tungsten … Etc.),
  - Epithermal Gold Deposits, Volcanic Massive Sulfide deposits,
  - Skarn, and elements such as Mercury, Arsenic, Bismuth.. Etc.

Cont'd: Ore Forming Processes and Fluids

- This aqueous phase , at depth up to few Km's, the water will be the major constituent, although the fluid may contains CO2, SO2, H2S, NaCl, FeCl, CaCl, HCl, HF, and a wide variety of metals.
- This phase can exist as a LIQUID or VAPOR used for Magmatic-hydrothermal phases, this is aprocesse of water-saturation can be achieved :
  - ✓ Either by progressive crystallization of the magma
  - ✓ Or by decreasing the pressure of the magama system.

❖ The term"First Boiling" is used when water-saturation occurs by advantage of decreasing pressure (usually due to upward emplacement of magma).

❖ The Term "Second boiling" refers to the achievement of water saturation by progressive crystallization of dominantly anhydrous minerals under isobaric condition. This is apply to the deep seated magmas and occur late in their crytstallization history.

Cont'd: Ore Forming Processes and Fluids

- Immiscipility in these system can occur at low pressure where the equeous fluid actually separated into 2 phases:
    1. A dense, very Saline brine, and
    2. A low salinity aqueous solution.

Thus,

- The felsic magma can exsolve a lot of water ; a consideration of typical magma viscosity; bubble size compared to Silicate melt leads:
    1. Either to exsolve water or
    2. vapor or multiphases form;

  Both will rise very rapidly to be collected in the highest part of the magma chamber.

The following Observation strongly supporting this

Cont’d: Ore Forming Processes and Fluids

- Ore Deposits commonly occur around cuplas (Dome,roof) within or adjacent to the intrusive bodies.

1. Initial volcanoc eruptions are dominantly gas rich and expolsive, and the explosives decreasing as the eruption progresses.
2. Analysis of the lava lakes flow show gas content decrease with depth.
3. Hydrous minerals (Biotite, Hornblende) in felsic intrusion tell us about water Exsolution i.e. to crstallized those mineral magma needs to have 2 -5 %water.

Therefore

- The appearance of an EXSOLVED aqueous fluid within MAGMA is acompiened by a release of MECHANICAL ENEREGY .
- Since the Volume /unit mass of silicate melt + low density aqueous fluid is much greater than the equivalent MASS OF WATER SATURATED MAGMA

Cont'd: Ore Forming Processes and Fluids

So,

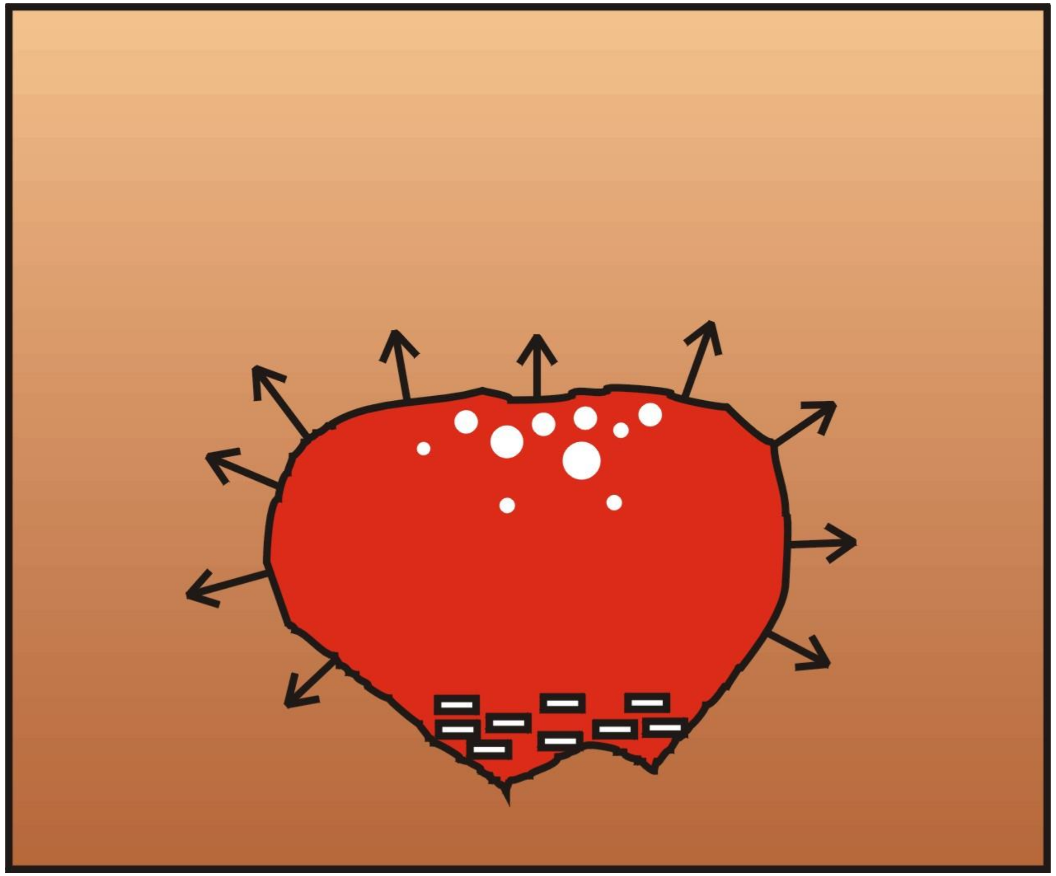
At shallow level of the crust:

- Volume change accompanying an aqueous fluid separated from a melt may be about 30%
  - This causing an over pressure within the chamber interior and to adjacent wall and can LEADS TO Brittle Fracturing' (Hydro-Fracturing) in hanging rocks or in the hos rocks around intrusion.

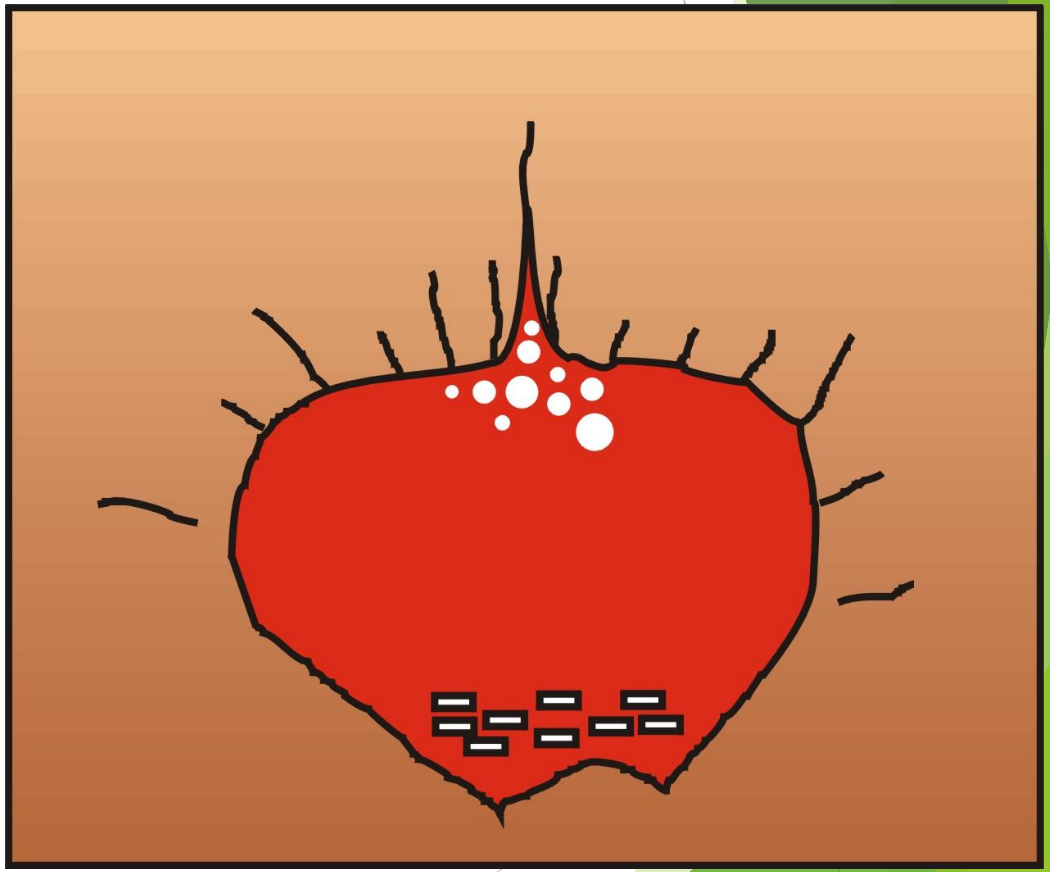
- This hydro-fracture is also leading to formations of cracks with steep dips.
- These fractures will circulate and propagate into the country rocks and becomes CONDUITS for EXSOLVING FLUID PHASE

The Closed Magma Chamber

Cooling and crystallisation causes the exsolution of volatiles

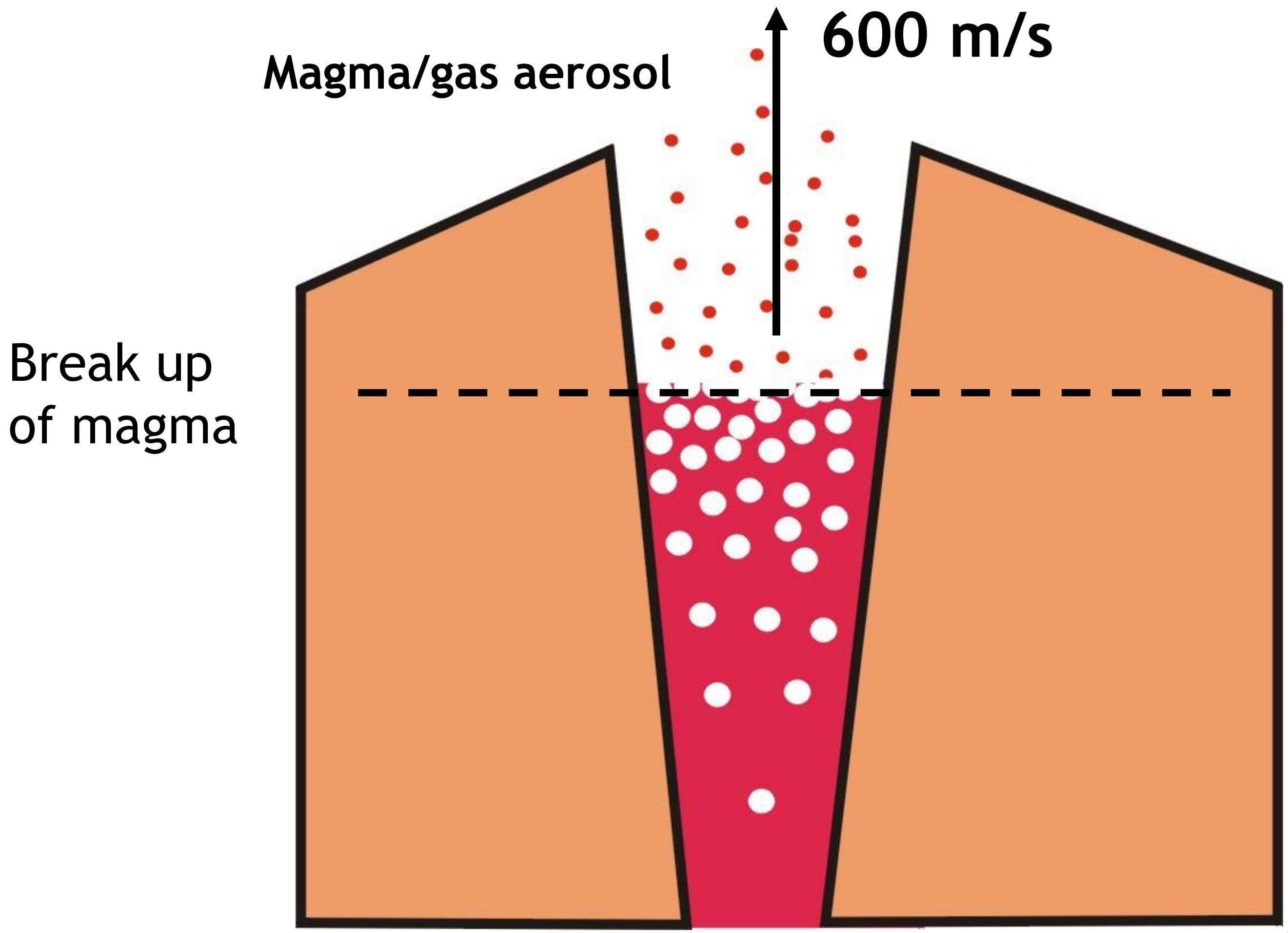


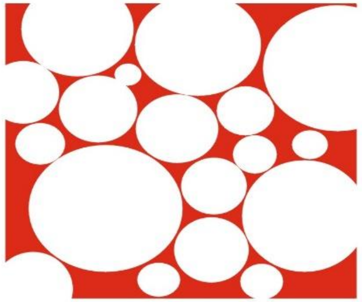
Expansion of the magma chamber causes tensile failure of country



An Open Conduit

Exsolution of volatiles due to decreasing pressure





Foam reaches
77 vol% vesicles

Cont'd: Ore Forming Processes and Fluids

So, Once the EXSOLVE fluid rising

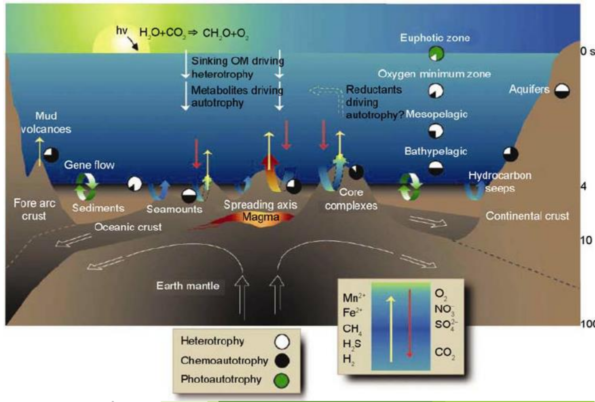
1. It can move directly into near the surface environment with little interaction with geothermal water, **these fluids** remains SALINE and ACIDIC.
2. Or mixed with geothermal waters, so these waters will lose most of its characteristics and take it into GEOTHERMAL SYSTEM adding its dissolved coponents to the circulted waters.

These two paths lead to

Ore Deposits with different geological characters

Cont’d: Ore Forming Processes and Fluids

III. Sea Water:



- It is extensively circulated through the oceanic crust as part of large scale of GEOTHERMAL SYSTEM, causing a widespread alterations and metal redistribution when sea water losing Mg and Ca and GAINING Fe and METAL.
- When seawater drawdown into faulted and fractures in the ocean crust , it will be heated up , chemically interacted with Basalt & Gabbro and Diabase.
- Subsequently, come back from EXHALATIVE vent

This is Leading to

a major Oceanographic discovery helped to Understanding of Volcanic massive Sulfide (VMS) Deposits formation.

In addition, this is confirmed the possibility of SEAWATER to be as Hydrothermal ore-forming fluid source

Cont’d: Ore Forming Processes and Fluids

➢ ***Factors causing the metal concentration*** and transportation in SEAWATER are and/depends on:

1. Temperature which determines iron oxide (FeO) or Iron Sulfide accumulation versus accumulation of Zinc, Cupper, Lead, Silver and /or Gold,
2. The degree in mixing with magmatic hydro thermal fluids.

Cont'd: Ore Forming Processes and Fluids

IV. Meteoric Water:

They are rain, river, ground and / or lakes waters that has been able to:

1- Percolate relatively to the deep level in the crust,

2- and then circulated within/in the crustal regime

It is responsible for forming hydrothermal Ore Depositsespecially those with low Temperature of transport and precipitate (URANIUM ORES and NATIVE COPPER)

Cont'd: Ore Forming Processes and Fluids

V. Connate Water:

- This water found in interstitial pore space in the sediment as it is deposited, or within breccia deposits (Debris flows).
- Initially, it either METEORIC OR SEAWATER, it will be modified as the sediments or breccia is Buried, compacted, and lithified, Called (Water-rich sediment) to lithify the rock,

- It is produces aqeous fluids that evolved with time and depth.

- Thes fluid move upwards via stratigraphic sequences ca be involved in formation of Ore Deposits.

Cont’d: Ore Forming Processes and Fluids

VI. Metamorphic Water:

- As the rocks progressively buried and Temperature exceed 300 °C the process of diagenesis evolves into metamorphism.

- The importancy of metmorphism to ORE forming processes is where HYDROUS and CARBONATE minerals breakdown to anhydrous mineral exsovling water, **transition** → from greenshist to amphibolite

Cont'd: Ore Forming Processes and Fluids

Con'd: Connate Water:

1. **Progressive burial** of sediments to depth 300 m **or** more "T" & "P" increased (Gradient) ***results*** ***rapid reduction in pore space and initial large volume of water formed***

2. The **Connate water** is also **increasing in SALINITY** due to interaction with evaporate prospect, Density increases due to "P"

Connate 10-30wt% Nacl brines (low T (100 to 150 °C) and Ph 4.5 to 5 in hosted rocks are in **forming MVT (Mississippi Valley Type deposits) and Sedimentary –Exhalative Deposits**

Cont'd: Ore Forming Processes and Fluids

VII. Metamorphic Water:

- As the rocks *progressively buried and Temperature exceed 300 ºC the process of diagenesis evolves into metamorphism*

- The importancy of metmorphism to ORE forming processes is where HYDROUS and CARBONATE minerals breakdown to anhydrous mineral exsolving water, to transition from greenshist to amphibolite grade.

- At about **300 ºC** It begins at **Kaoline to Phyrophyllite, Koaline contains more water than phyrophyllite**

and,

- At about **400 ºC** cholorite changes to biotite, and even hugher grades Hornblende to Pyroxene

Therefore,

Metamorphic reactions and waters are important in Orogenic GOLD Deposits

TYPES OF MINERAL DEPOSITS

Epigenetic mineral deposit

formed much later than the rocks which enclose it

Syngenetic mineral deposit

formed at the same time as the rocks that enclose it

Why do we classify mineral deposits?

Why do we classify mineral deposits?

- geological conditions of formation
- how they formed
- where they formed
- exploration

Simple classification

- magmatic
- sedimentary
- supergene
- metamorphic

Deposit Groups

- Organic
- Residual/surficial
- Palcer
- Continental sediments and volcanics
- Sediment-hosted
- Chemical sediment
- Marine volcanic association
- Epithermal
- Vein, breccia and stockwork

- Manto
- Skarn
- porphyry
- Ultrmafic/mafic
- Carbonatites
- Pegmatites
- Metamorphic-hosted
- Gems, semi-precious stones
- Industrial rocks
- other

Lithology

- Unconsolidated deposits
- Sedimentary rocks
- Volcanic rocks
- Intrusive rocks
- Regionally metamorphosed rocks

Classification of industrial minerals

- End-use and genesis (Bates, 1960)
- By unit price and bulk (Burnett, 1962)
- Unit value, place value, representative value (Fisher, 1969)
- Chemical and physical properties (Kline, 1970)
- Geologic occurrence and end-use (Dunn, 1973)
- Geology of origin (Harben and Bates, 1984)
- Alphabetical (Harben and Bates, 1990, Carr, 1994)

COMMODITIES OUTLINE

- Introduction (definition)
- Uses (properties)
- Production
- Geologic descriptions and distribution
- Processing, marketing